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Human Transportation System (HTS) Study

Final Report

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List of Acronyms

ACC	Advanced Carbon Carbon
ACR	Architecture Cost Risk
ACRC	Assured Crew Return Capability
ACRV	Assured Crew Return Vehicle
AET	Architecture Evaluation Tool
ALS	Advanced Launch System
ALV	Air Launch Vehicle
AMLS	Advanced Manned Launch System
AMSC	Advanced Military Spaceflight Capability
AOA	Abort Once Around
APU	Auxiliary Power Unit
ASE	Airborne Support Equipment
ASRM	Advanced Solid Rocket Motors
ATF	Available Time Fraction
ATO	Abort-to-Orbit
ATPS	Advanced Thermal Protection System
C of F	Construction of Facilities
CALV	Cargo Air Launch Vehicle
CBM	Common Berthing Mechanism
CCAFS	Cape Canaveral Air Force Station
CDR	Critical Design Review
CEM	Crew Escape Module
CF	Correlation Factor
CIF	Cargo Integration Facility
CLV	Crew and Logistics Vehicle
CNDB	Civil Needs Data Base
CPF	Centaur Processing Facility
CPF	Cost Per Flight
CRV	Cargo Return Vehicle
CTF	Cargo Transfer Function
CTV	Cargo Transfer Vehicle
DAT	Delta, Atlas, and Titan
DDT&E	Design, Development, Test, and Evaluation
DOD	Department of Defense
DOF	Degree-of-Freedom
ECC	Expanded Crew Capability
EDO	Extended Duration Orbiter
ELV	Expendable Launch Vehicle
EMA	Electromechanical Actuator
EOS	Earth Observing System
ET	External Tank

ETO	Earth-to-Orbit
ETR	Eastern Test Range
EVA	Extravehicular Activity
FOM	Figure of Merit
FPM	Forward Propulsion Module
FSE	Flight Support Equipment
GDSS	General Dynamics Space Systems
GEM	Graphite-Epoxy Motor
GEO	Geosynchronous Earth Orbit
GH_2	Gaseous Hydrogen
GLOW	Gross Lift-Off Weight
GO_2	Gaseous Oxygen
GOA	Ground Operability Attribute
GOX	Gaseous Oxygen
GPS	Global Positioning System
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GTO	Geosynchronous Transfer Orbit
HLLV	Heavy Lift Launch Vehicle
HPF	Horizontal Processing Facility
HR	Human Rated
HRB	Hybrid Rocket Boosters
HST	Hubble Space Telescope
HTP	High Thermal Performance
HTS	Human Transportation System
I/T	Intertank Area
ICBM	Intercontinental Ballistic Missile
IMU	Inertial Measurement Unit
IOC	Initial Operational Capability
IOP	Integrate on Pad
IR&D	Independent, Research and Development
ISF	Industrial Space Facility
ITL	Integrate/Transfer/Launch
IUS	Inertial Upper Stage
JP	Jet Propellant
JSC	Johnson Space Center
KSC	Kennedy Space Center

LaRC	Langley Research Center
LC-17	Launch-Complex 17
LCC	Life Cyle Cost
LDO	Long-Duration Orbiter
LEO	Low Earth Orbit
LES	Launch Escape System
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LRB	Liquid Rocket Booster
LRU	Line Replaceable Unit
LRV	Logistics Return Vehicle
LSC	Launch Schedule Confidence
LV	Launch Vehicle
LWET	Light-Weight External Tank
LWO	Light-Weight Orbiter
MECO	Main Engine Cut-off
MLP	Mobile Launch Platform
MLS	Manned Launch System
MLS-HL	MLS Heavy Lift
MLSUS	MLS-HL Upper Stage
MLV	Medium Launch Vehicle
MPLM	Mini-Pressurized Logistics Module
MSFC	Marshall Space Flight Center
MST	Mobile Servicing Tower
MTBF	Mean-Time-Between-Failure
MTBM	Mean-Time-Between Maintenance
NASP	National Aerospace Plane
NIT	NASA-Industry Team
NLP	National Launch Policy
NLS	National Launch System
NMTS	Next Manned Transportation System
NS	Number of New Systems
NTO	Nitrogen Tetroxide
NUS	No Upper Stage
NWODB	New Ways of Doing Business
OMB	Office of Management and Budget
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
OV	Orbital Vehicle
P^3I	Pre-planned Product Improvement
P_A	Probability of Abort

PALV	Personnel Air Launch Vehicle
PCS	Payload Containment System
P_d	Probability of Death
PI	Program Immaturity
P_L	Probability of Loss
PLF	Payload Fairing
PLM	Pressurized Logistics Module
PLS	Personnel Launch System
PMC	Permanently Manned Capability
PMS	Probability of Mission Success
P_S	Probability of Survival
PYF	Peak Year Funding
QFD	Quality Functional Deployment
RCS	Reaction Control Subsystem
RCV	Reusable Cargo Vehicle
RPC	Reusable Personnel Carrier
RSRM	Redesigned Solid Rocket Motors
RT	Response Time
RTLS	Return to Launch Site
RTmax	Longest Response Time
RTmin	Shortest Response Time
RUPC	Reusable Ultralight Personnel Carrier
SDI	Strategic Defense Initiative
SEI	Space Exploration Initiative
SLC-2w	Space Launch Complex 2 West
SRB	Solid Rocket Booster
SRD	Systems Requirements Documents
SRM	Solid Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SSF	Space Station Freedom
SSME	Space Shuttle Main Engine
SSTO	Single-Stage-to-Orbit
STAS	Space Transportation Architecture Study
STIS	Space Transportation Infrastructure Study
STME	Space Transportation Main Engine
TAA	Trans-Atlantic Abort
TAC	Total Architecture Cost
TC	Technical Challenge
TDRS	Tracking and Data Relay Satellite

TFU	Theoretical First Unit
TPS	Thermal Protection System
TRANSIT	Transportation Systems Integration Tool
TSTO	Two-Stage-to-Orbit
UMA	Unscheduled Maintenance Action
UTF	Unavailable Time Fraction
VAFB	Vandenberg Air Force Base
VHM	Vehicle Health Monitoring
VIC	Vehicle Isolation Cell
VIF	Vehicle Integration Facility
VMF	Vehicle Maintenance Facility
VMC	Vehicle Maintenance Cell
VTOHL	Vertical Take-Off and Horizontal Landing
WBS	Work Breakdown Structure
WTR	Western Test Range

SECTION 1
INTRODUCTION

For the nation to embark on a robust space program which includes the deployment and operation of the Space Station Freedom (SSF), the human transportation function to and from low Earth orbit (LEO) over the next several decades will have to be accomplished routinely, affordably, reliably, and safely. Currently, the United States relies on the Space Shuttle to provide its human transportation needs, as well as the bulk of its cargo transportation needs. However, over the past several years, there have been numerous system concept development efforts investigating what the next human transportation system *might* be. Some of these alternative transportation architectures take as their underlying premise the replacement of the Space Shuttle orbiters at the end of some useful lifetime. Other alternative scenarios assume that it is more expedient to evolve the Space Shuttle, recommending modifications that range anywhere from minor to substantial. Still other alternative scenarios assume the eventual replacement of the Space Shuttle with other concepts which rely extensively on the use of advanced technology. Yet other scenarios have been constructed which involve augmenting the Space Shuttle with another independent transportation system to achieve "assured access."

As could be expected, these divergent, underlying, initial assumptions about the fundamental purpose of a new vehicle have given rise to widely disparate system concepts for the next human transportation system. For example, the NASA Langley Research Center is currently studying the characteristics of a horizontal lifting body vehicle, designated the HL-20, as a personnel carrier. Its primary mission is to support crew rotation to and from the SSF. The Johnson Space Center (JSC) also investigated personnel carriers for this same reference mission, focusing primarily on biconic shapes. These concepts only address the transportation of the crew and do not include any provision for the transportation of cargo. Other concepts, such as the Crew and Logistics Vehicle (CLV), have been developed which include a small amount of cargo on the personnel carrier. Several system concepts have also been proposed that are based on evolving the Space Shuttle by incorporating increased safety and performance features, while retaining the ability to carry cargo. The Advanced Manned Launch System (AMLS), Single-Stage-to-Orbit (SSTO), and the National Aerospace Plane (NASP) are concepts which have been developed by those who believe that technological advances may offer significant savings in operations costs by routinely achieving high flight rates. In addition, conventional approaches such as launching small personnel carriers on top of an expendable launch vehicle and more unconventional approaches where the personnel carriers are mated to an air-launched booster, have also been considered. Many of these system concepts could be used to provide alternate access to the Space Shuttle.

Recognizing that limited resources will be available to accomplish the activities required for missions to and from Planet Earth, the JSC, as the agency's lead for piloted vehicles, initiated this study under the sponsorship of NASA Headquarters, Advanced Program Development Division. The purpose of this study was to address the need and urgency for any next human transportation system, and develop the decision materials to determine what the next human transportation system *should* be. A large portion of the data for this study came from the abundant, available technical information about various, alternative concepts that have been developed in recent study and design efforts across the country.

1.1 Study Background

A fundamental tenet of the Human Transportation System (HTS) study was that products and recommendations should be based on consistent and applicable mission models, requirements, and attributes. Although several architecture studies have been conducted over the past 7 years, they have not produced a clear consensus on the results, for precisely this reason. These previous studies were the Space Transportation Architecture Study (STAS), the Space Transportation Infrastructure Study (STIS), and the Next Manned Transportation System Study (NMTS).

The STAS study was a combined effort of both NASA and the Department of Defense (DOD). Many of its recommendations led to the beginning of the Advanced Launch System (ALS) and the National Launch System (NLS) programs. However, the STAS study had mission models that showed much larger traffic models than are shown in the current NASA Civil Needs Database (CNDB). In some of the mission models, this was a reflection of the expected payload size, weight, and flight rate requirements for the Strategic Defense Initiative (SDI) at the time of the study (1985). The study also used cost as the only quantitative measurement of comparisons between systems. For example, safety of the crew was assumed to not be a discriminator, and therefore, was not a measured criterion. Since crew safety is always of primary concern, it should be considered quantitatively when comparing and defining transportation architectures.

The NMTS study was conducted without NASA funding but with industry participation. The study did produce some enlightening data, however, since the industry participants used their own funding, each study had its own process and its own recommendations. There were no unified conclusions or recommendations.

The STIS study has been used effectively for performing specific trade studies on a few possible transportation architectures. It can, for example, provide insight into the effect on the cost of using NLS to off-load the Space Shuttle, or assess the impacts of Earth-to-orbit (ETO) cargo carriers and transportation nodes on ETO transportation in support of various Space Exploration Initiative (SEI) scenarios. It does, however, have a narrow focus (based on the number of ETO architectures compared to each other) and is not trying to evaluate all the impacts of architecture differences (safety, cost risk, reliability, etc.) that may be needed to truly judge (in the customer's eyes) one architecture relative to another.

While these studies did produce useful information, they did not develop rigorous and measurable evaluation criteria (attributes) to compare differing transportation architecture options. Moreover, many of the study assumptions (e.g., overly optimistic traffic models) made them untimely for answering questions currently being asked within the agency regarding future transportation strategies. To focus the agency's human transportation efforts and to achieve the desired products, this study was conceived with an objective to address the significant top-level architectural considerations prior to conducting additional individual system concept definition efforts. The HTS study approach examined the transportation needs of the country, defined those transportation system attributes desired by the customer, and evaluated various transportation architecture options against those needs and attributes. The study horizon was from the present to the year 2020.

SECTION 2
STUDY APPROACH AND GROUND RULES

From the beginning of the study, it was recognized that if some of the top-level architectural considerations were to be answered, it was essential to have access to the best data from previous concept design efforts. Also, since there was interest in determining just what convergence existed in the data, it was decided that the study approach should involve the best minds in the business, both in and out of the government. It was determined that a partnership between NASA and industry was essential, and hence the NASA-Industry Team (NIT) concept was formed. This approach involved six major aerospace firms working together with NASA to provide technical data to address the architectural considerations. These six firms were selected by competitive process through an agency-wide evaluation to participate in the NIT. These included Boeing, General Dynamics, Martin Marietta, Rockwell, Lockheed, and McDonnell Douglas. NASA centers working together to complete the NIT included JSC, Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC), as well as NASA Headquarters. The industry team members conducted their study efforts under contracts of $425K each, for a total of $2550K.

2.1 STUDY APPROACH

The study was divided into four tasks. The first two tasks involved determining the transportation needs and transportation attributes. This essentially formed the input requirements for the study. The third task was to evaluate the candidate architectures. The fourth task was an evaluation of NASA's current business practices which may be hindering, to some degree, the ability to develop, procure, and operate any next human transportation system. These four tasks are described in more detail in the following paragraphs.

2.1.1 Task 1: Transportation Needs

From the outset, it was felt that the mission of any next human transportation system must be understood in terms of the transportation jobs that it must accomplish. These jobs are the requirements which define what payloads need to be transported and when. This indicated a needs-based study approach, as opposed to a capabilities-based approach. Furthermore, the best solution for human transportation can not be developed without taking into consideration the transportation of cargo since optimization of the transportation attributes may require the use of commonality between the personnel and cargo transportation systems. In addition, addressing current national questions as to whether any new system was required as a replacement for the Space Shuttle, or whether a new system was required to operate in conjunction with the Space Shuttle to assure human access to space, could only be answered by a needs-based approach. Finally, by taking a parametric look at the transportation needs as function of the major space activities, the study approach was able to accommodate the large uncertainty in the space agenda that the nation might eventually embark upon. Figure 2.1.1-1 illustrates how eight potential mission types were assembled into five levels of space activity to comprise the components of the parametric transportation needs model. This is the HTS "mission model."

2.1.2 Task 2: Customer-Desired Transportation Attributes

Attributes reflect what the customer considers important in the next human transportation system. These attributes are determined by placing ourselves in the customer's shoes, and asking what factors would be considered in the decision-making process. These attributes are typically related to cost, safety, reliability, risk, etc. To be useful in a rigorous study, the definitions and measurements of these attributes had to be precisely established. Also, to quantitatively define the contribution of each individual attribute to the customer, utility functions, describing how important the value of each attribute was to the customer, were defined.

The customer for the next human transportation system was determined to be that individual most responsible for (a) ensuring that the transportation needs are accomplished, (b) resolving what the total (human-tended and untended) transportation architecture should be, (c) determining how that architecture is implemented and operated, and (d) deciding how the total architecture is funded. It was the consensus of the study team that the NASA Administrator best fit this description.

2.1.3 Task 3: Architecture Evaluation

The results from Tasks 1 and 2 were used as inputs for Task 3. The ultimate objective of this task was to develop the system-level requirements on any indicated next transportation system. This was accomplished by first addressing the inevitable architectural considerations concerning how the next human transportation system relates to the other existing and planned programs which now provide some degree of the transportation function. The requirements that resulted from this task address the need and urgency for any next system(s), and provide "marks" for the safety, reliability, cost, etc. values that the next system should possess to be architecturally competitive. Addressing these requirements was best accomplished by defining a list of *considerations* to be investigated. These considerations included:

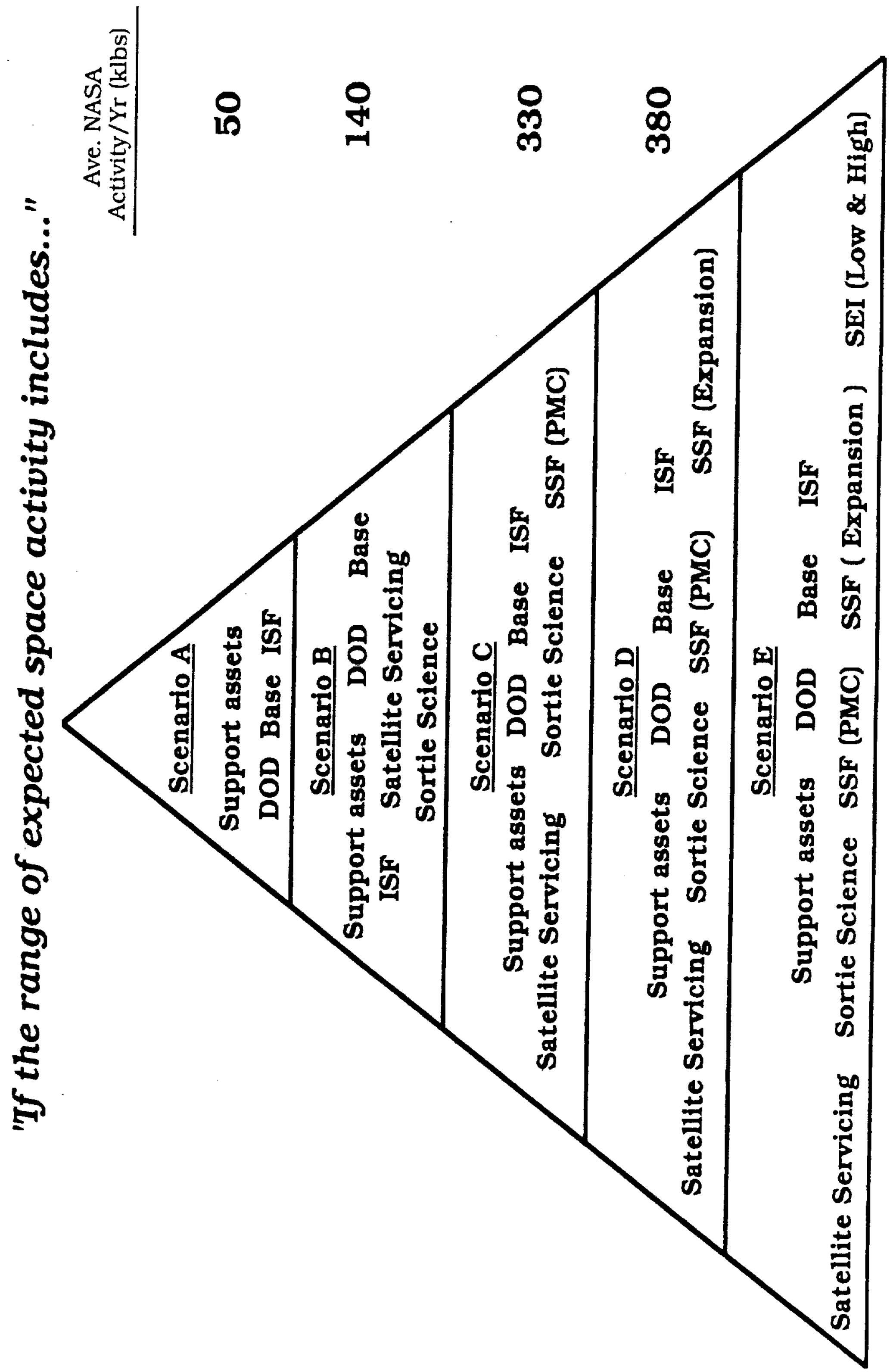


Figure 2.1.1-1.– Transportation needs "If" scenarios.

- the degree of separation of people and cargo

- the role of any new transportation system in relation to that of the Space Shuttle

- assessing the cost-to-benefit of alternate access, that is having two methods to deliver and/or return people and cargo

- commonality with or influence on the ACRV

- evolution of current systems

- the size and features of an expendable booster developed specifically from the outset with human transportation in mind

- the benefit that could be realized by using transportation systems employing advanced technology approaches.

To address these considerations, a set of approximately 20 architectures was constructed. An architecture is that set of transportation systems that accomplishes the transportation needs over some specified time frame. To be unique, an architecture must include the introduction dates of new systems and retirement dates of old systems, numbers of expendable vehicles, fleet size for reusable vehicles, and the supporting ground infrastructure supporting the flight systems. Evaluation of the attribute values for these architectures as they perform the different levels of space activity provides valuable target values for future systems to achieve if they are to accomplish improvements over the current systems they are replacing.

It was recognized early in the study that an automated decision support tool would be required to manipulate the large volume of data generated in support of the evaluation process. In addition, the use of an automated tool would allow sensitivity analyses on the relative weights of the attributes and their associated utility functions to be conducted. Finally, an automated tool would allow the architecture performance assessment across six levels of space activity to be confined to the last months of the study, thereby allowing maximum time for the development and collection of quality data from the team members. An automated tool would also facilitate updating the results of the study in subsequent years, should that be required.

2.1.4 Task 4: New Ways of Doing Business Better

The way transportation system elements are procured, managed, designed, and operated has a significant bearing on their ability to provide routine, affordable, reliable, and safe transportation. The objective of this task was to identify any new ways of doing the future transportation business that would result in more favorable values of the transportation attributes. Most of the effort associated with this task was directed at reducing the costs of ownership. The ultimate intent of this activity was to identify current barriers to lower ownership costs so that management could develop subsequent plans for their removal and so that the most significant of these findings could be implemented at the conclusion of the study. The data from this activity was developed by interviewing top program and project managers within industry and government, who were requested to provide their insight into those organization, management, policy and procedures, and funding and budget practices that, if done differently, would result in the largest improvement in transportation system costs.

Figure 2.1.4 shows the study schedule. The team members were in residence at JSC for the entire first month of the study. One benefit of being together for the entire month was that the team better understood the strengths that each member brought to the study, both organizationally as well as personally. During that time, the team defined the detailed study approach jointly with the government so that all team members had ownership not only of the study intent, but also of the process by which the study was to be conducted. The team then spent the remainder of that first month in concentrated work sessions, developing both the transportation needs, i.e., what had to be transported to and from space and when, and the important attributes of the transportation architecture. Three week-long meetings where held over the next 5 months to define systems, architectures, and associated manifesting philosophy, to refine the study flow as needed, and to divide the work activities according to the strengths of the team. An additional month-long working session was then conducted at JSC to assemble the final system and architecture data, and to obtain team approval of this data prior to its being loaded into an automated Architecture Evaluation Tool (AET). One final review was held at the conclusion of the study to evaluate the final results, perform any required sensitivity analysis to gain a better understanding of what the results meant, and obtain consensus on the single, final report.

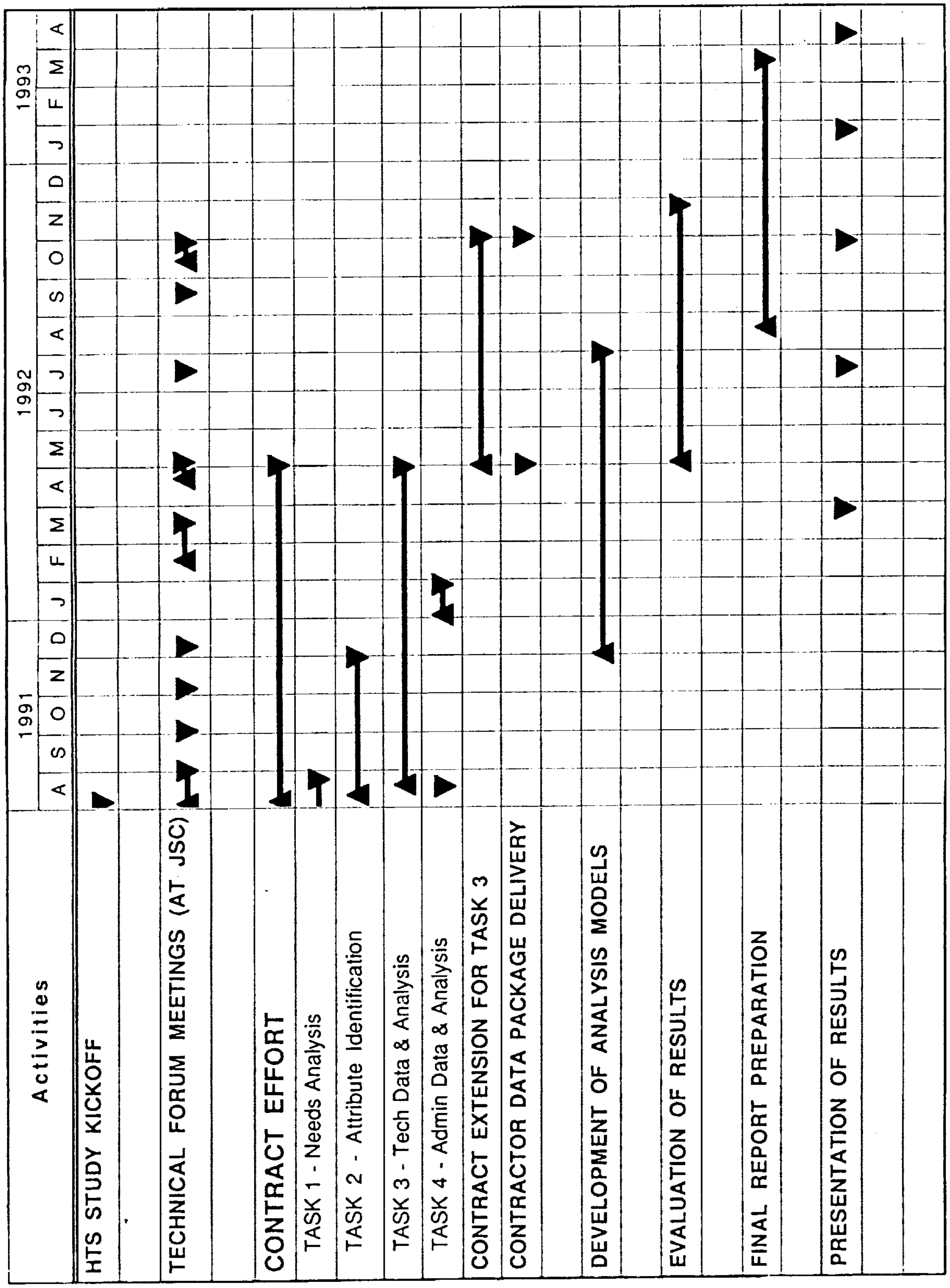


Figure 2.1.4.– HTS study schedule.

2.2 ARCHITECTURE CONSIDERATIONS FOR THE HTS STUDY

The principal considerations assessed in the study were:

- Separation of people and cargo. This consideration addressed whether it is better to physically separate people and cargo onto different launch vehicles if the people and cargo have a common destination. There is a perception that crew safety or other factors can be enhanced through this separation. In other words, what impact does carrying cargo have on crew safety and mission success?

- Alternate access. This consideration addressed the impact of having an alternative way to deliver and return both people and cargo. The principal advantage of having alternate access is that there is a greater probability that a required mission or payload can be accomplished. The principal disadvantage is the cost of simultaneously operating multiple systems to do the same job. Note that the term "assured access" is not used, since it was felt early-on by the study team that there was no way to assure access or to measure whether, through systems design, it could be achieved.

- Commonality with or influence on the ACRV. This addressed the impact of either having an ACRV and its effect on the resultant system choices that would be made in a transportation architecture, or identifying whether other systems could perform the emergency crew return function instead of a separate ACRV vehicle.

- Which booster to use for human launch applications. This addressed the relative advantages and disadvantages of using a new versus an existing expendable launch vehicle for delivery of astronaut crews to low Earth orbit.

- Role of advanced technology (new concepts). This consideration addressed the degree to which new or advanced technology enhanced the cost, safety, etc. of a transportation architecture. For this study, this included only new technology systems, rather than technology advances at the subsystem or component level.

- Evolution of current systems. This addressed the relative advantages and disadvantages of evolving the current mixed fleet of launch vehicles, compared with development of completely new systems.

- Effect of return cargo requirements. This consideration quantified the impact of return cargo requirements on the transportation architecture. Having a return cargo requirement is a principal systems consideration in an architecture, as it requires a distinct vehicle (either expendable or reusable) to return a payload. In most cases, this would preclude delivery of the payload on an ELV.

Other considerations were not addressed in this study. Although these other considerations may be important in and of themselves, they were judged by the study team to be of lesser importance, or significantly more difficult to quantify, compared with the above considerations. Also, since the team believed that it would encounter resource limitations and difficulty in getting valid data to make comparisons of options which would address these considerations, it decided to defer an assessment of these for this study. However, the team felt that all of these warranted additional study. These are summarized below:

- Influence of total SEI transportation requirements. Because transportation requirements for SEI would be of such a magnitude greater than Earth-to-Orbit requirements, and given the uncertainty of these requirements, the study team chose only to include the impact of crew delivery to support SEI missions on the ETO transportation systems.

- Use of foreign assets. This would address the use on non-U.S. transportation assets for delivery or return of people or cargo. Though the study team felt this was an important consideration, it was not able to get the pertinent data (launch vehicle cost, reliability, etc.) from foreign sources within the required study time frame.

- Reusable versus expendable personnel carriers. This referred specifically to the trade of reusable versus expendable personnel launch system (PLS) concepts. This was deemed to be a lower level effect than the architecture-level focus of the study would indicate.

- The extent of evolution for the Space Shuttle. This addressed the idea that, given that evolution is the "right" answer, what level of evolution makes the most sense. Again, this was deemed to be a trade-study to be done at a level lower than the architecture-level focus of this study.

- The degree to which technology should be "pushed" to meet an early need. This would explore the relationship between funding and technology readiness, i.e., if a certain technology was required, what level of near-term expenditures would be required to meet a specific program schedule. The study team felt it did not have sufficient information to assess this effect.

2.3 GROUND RULES AND ASSUMPTIONS

In the real world, initial constraints often exist that will constrain the trade space to be explored in an architecture study. These extremely top-level requirements or groundrules, called "stone tablet" requirements, are not tradeable and must be met by all architectures without exception. These requirements were developed by the NIT consensus, and represent the best estimation of what types of groundrules would be considered inviolate by senior agency management. Some are based less on engineering trade studies than on perception or policy. One way to see these requirements is to think of the customer asking the following question: "I don't care what the architecture looks like, as long as it does the following: ________".

On August 16, 1991 the NIT held a brainstorming session to develop a list of stone tablet requirements. The inputs were subsequently grouped into different types of ideas:

- Space Policy
- Minimum Attribute Values
- Operational Constraints
- Baselined Architecture Solutions

At this point, debate on each suggestion ensued until consensus was reached on which items should survive as stone tablets. Both the six items that survived and the list of rejected items are presented here, in no particular order, along with some elaboration on the decision to accept or reject the idea.

2.3.1 MTS Stone Tablet Requirements

- *There can be no reliance on foreign countries to* *__develop__* *elements.*– The proper role of existing foreign elements within an architecture is left as a trade or sensitivity to be explored through alternative architectures (see section 3.3). In deference to those who consider space hardware development as much a contribution to national prestige, knowledge, and future competitiveness as it is to science, no architectural scenario will *require* the development of any element for its successful implementation. In addition, the United States would have little control over the development schedule of an element for which it did not have any budget authority. An example would be a fully operational Hermes in support of the SSF permanently manned capability (PMC) which represents a schedule risk that is not within NASA's purview and also aids and abets the technological prowess of a competitor. This did not preclude use of existing foreign assets.

- *SSF will be assembled with the Space Shuttle up to PMC.*– The design of the SSF, which could theoretically be changed, was deemed mature enough to assume that the station elements are designed in a way that can only be deployed or assembled by a Space Shuttle Orbiter. To avoid the concern that this reinforcing logic could perpetuate the Space Shuttle beyond a date where it may be undesirable for other reasons, it was decided that SSF activities after PMC could be supported by some other transportation element(s). This implies, for example, that growth modules could be redesigned for launch on an ELV.

- *The SSF design through PMC is fixed.*– The design of the SSF and its experiments, which could theoretically be changed to better match the capabilities of a given architecture, was deemed mature enough to assume that the station elements' mass and volume are already set. To avoid the concern that this reinforcing logic could perpetuate the Space Shuttle beyond a date where it may be undesirable for other reasons, it was decided that SSF activities after PMC could be supported by some other transportation element(s). This implies, for example, that logistics modules and/or their constituent cargo could be significantly redesigned, including exploring expendability options.

- *The operational requirements, procedures, and constraints of the SSF and other on-orbit assets are fixed.*– Although the approach to transporting payloads and people may vary, the operational rules associated with SSF and certain on-orbit assets must be adhered to. For example, the rendezvous and docking procedures for the SSF imply the element must have the capability of controlling the velocity vectors within the SSF-specified levels.

- *Mixed fleet manifest will be used to define the architecture through 1996.*– Although it may be shown that certain elements may be phased out as soon as possible in the best interests of the architecture, it was assumed that the planning and procurement of transportation elements, and the flight and facilities manifesting that goes with them, has already commenced and is unlikely to be altered until after 1996.

- *No international treaties will be violated.*– It has been, and remains, the stated policy of the United States to cooperate with other nations so that the benefits of space reach all humankind. This cooperation takes the form of joint efforts, international contracts, and compliance with international law and treaties. In some cases, the generated architectures have no relationship to these treaties; when the specifics of operations are explored, there may be some consideration due to these international agreements. The following treaties and conventions have been ratified by the United States and are in effect.

  - "Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Underwater," in force October 10, 1963. Context is self-explanatory; impact to this study precludes the manifesting of any DOD flights that would include nuclear weapons.

  - "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," in force October 10, 1967. This so-called "Outer Space Treaty" establishes celestial bodies as open to all scientific investigation by any state and precludes any nation from claiming sovereignty, or from placing weapons of mass destruction on those celestial bodies, or in space. Similar to the Antarctica Treaties, there still is some question as to how commercialization and/or resource utilization would be handled. To achieve compliance, within the scope of the architectures (extending to 2020), exploration should be limited to a national program, such as SEI, and commercial ventures (such as the Lunar Hilton) should be omitted.

- "Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space", in force December 3, 1968. The spirit of this treaty ensures the return of astronauts who land in foreign terrain or on the high seas. The implication is that emergency/abort to a signatory state is acceptable. Performance capabilities to reach the continental United States in any contingency, for example, should not be a requirement.

- "Convention on International Liability for Damage Caused by Space Objects", in force October 9, 1973. This is a complex treaty that basically states that liability is assessed to the state from which the object was launched. For example, the United States is liable for damages that a spent stage might cause to another country after a launch of a commercial launch vehicle.

There are several other conventions, such as the "Convention of the Registration of Objects Launched Into Outer Space," the International Telecommunications Convention (frequency allocations), and patent law, that are assumed to be met by all candidate elements. The legal policies for space environment (pollution) and jurisdiction are still evolving. For a transportation system, legal jurisdiction is governed by the launching countries' rules from the time the hatch is closed on the launch pad to the time the payload is delivered to orbit.

2.3.2 Rejected Stone Tablet Requirement Ideas

- *National Security is a top priority.*– Historically, the DOD has provided for its own launch facilities and vehicles. It is conceivable, however, that future architectures may include a more integrated use of transportation assets. In the event of a crisis situation where access to space is considered a national imperative, civilian manifesting could be altered to accommodate the DOD. It was the opinion of the majority of the NIT that accounting for this possibility would require a level of modelling sophistication that may not be justified, since it would be unreasonable to expect full manifest resiliency in the event of a major national crisis.

- *No use of foreign launch services is permitted.*– The argument against using foreign launch services is based on a heritage that found it advantageous to use U.S. assets exclusively for reasons of national security, internal economic growth, less scheduling risk, and national prestige. The next 30 years promise to be significantly different, with international ventures and contracts increasingly more commonplace. In the area of launch vehicles, technology transfer is becoming less of an issue as several nations have mature systems. In general, the United States is opposed to protectionist policies, and seems to be moving toward accepting the legality of allowing the user to select their preferred launch service provider. The proper role of foreign assets will be explored in the architecture options (see section 3.3).

- *Must be consistent with National Launch Policy (NLP).*– Existing national policy enables governmental leadership to plan space development efforts within an accepted framework. A goal of the HTS study is to quantify the impact of the NLP on an architecture over time. For example, there are no current plans to build any more Space Shuttle Orbiters; what would be the impact if two more were added to the fleet? Rather than limit the study to options that are wholly consistent with national policy, other possibilities will be explored to document the effect of alternative "policies".

- *Must ensure dual access.*– Dual access is defined here as the ability to do all the "jobs" two separate ways. While this seductive possibility would virtually eliminate issues of dependability, availability, resiliency, and loss of prestige associated with a major failure, it could be very expensive. The requirement for dual access was thought by some to be a reaction to a series of failures in the mid-1980's, and not a rational groundrule for all future operations. Dual access may be addressed in the architecture options.

- *New ways of doing business must be included in candidate architectures.*– Some of the most fertile areas for realizing future improvements in cost and operability involve the successful implementation of new methods of doing business and/or operations (see section 3.4). It is not a forgone conclusion, in the opinion of this group, that the customer would chose to implement these suggestions for all elements, especially existing ones. To that extent, it was decided that the best place to explore the benefits of these ideas would be in "Task 4: New Ways of Doing Business" (see section 2.1.4).

- *New elements must advance the state-of-the-art.*– In the past, it was a foregone conclusion that each new element would and should advance the nation's scientific and engineering knowledge. Within the context of a perceived shift in priorities that places more budgetary emphasis on the payload and less on the transportation system itself, the NIT consensus was that, in many cases, the dictate to use new technology is often incompatible with the stated transportation goals of low cost and high safety and should, therefore, not be a requirement. This would not preclude NASA from pursuing new technology, but would distinguish operational systems (used to meet the transportation needs defined in this study) from developmental systems.

- *The government is not the developer nor the operator of the human-tended transportation elements.*– This concept is similar to the fifth item. Again, while this requirement may be an excellent idea, it was thought that it could best be explored in section 2.1.4.

- *No new system will achieve Initial Operational Capability (IOC) before 1999.*– Given the typical development and manufacturing cycle of new aerospace hardware, this constraint is probably a realistic one. It was decided, however, that there is no reason to preclude the possibility of an aggressive, new program that could come into use sooner than 1999, leaving it instead as an architectural option that would be accounted for in terms of cost and risk.

- *The Industrial Space Facility (ISF) will be deployed by the Space Shuttle.*– As currently envisioned, the ISF is designed to be deployed by the Space Shuttle. It is conceivable, given that the ISF hardware has yet to be produced, that it could be designed to be launched on another vehicle, in which case this requirement was viewed as an unnecessary constraint.

- *Use only Western Test Range (WTR) and Eastern Test Range (ETR) launch sites.*– Developing new launch sites is an expensive proposition. National security may also require a limitation on the number and location of launch sites. Also, by only specifying these two launch sites, any cost estimations (including operations, facilities, range safety, etc.) would reflect a high degree of confidence in the data. If properly accounted for, a new launch site could be included in an architecture. This proposed requirement will not be considered because of the absence of any quantifiable data on the undesirability of another launch site.

- *No west coast launch sites.*– This proposed requirement is similar to the above item. In this case as well, the requirement will be dropped from further consideration, in the absence of specific measures of merit for limiting launch sites.

- *SSF and all "Big Science" type payloads will be prevented from falling from orbit at all costs.*– The consequences of a premature entry of complex, large, orbital payloads can be considerable in terms of cost (hardware, lost data, etc.), prestige, and impact hazards. There is a strong impetus, therefore, to make the establishment of procedures, hardware elements, and scheduling to prevent the entry of these large payloads a priority. As was the case in some other suggested requirements, the NIT felt that it would be difficult to credibly predict when a crisis would occur; since a crisis would be dealt with at that time with available resources, it would not, therefore, be a separate requirement.

- *Current systems are restricted by current range-safety constraints.*– Over the years of operating launch vehicles, NASA and the DOD have developed very clear and effective range safety procedures that have resulted in superior safety records. The proposed requirement seeks to limit current systems to using those proven features and constraints. The NIT concluded this policy should result from careful range safety studies for new and existing systems, not from a mandated requirement.

- *Provide 2 days additional loiter time to achieve additional landing opportunities.*– Additional on-orbit loiter time enables a low energy phasing to occur that would result in more landing opportunities in the event that the planned landing has been waved off. It was the group's feeling that whether the capability is 2 days, x orbits, or whatever, it should be determined as a system trade, not a levied requirement.

- *Minimize extravehicular activity (EVA).*– This is an activity that is both a risky and expensive aspect of spaceflight, and should be minimized. It was felt that this idea would be more appropriate as a design guideline, than as a stone tablet, in that it would be impossible to define what an acceptable minimum level of EVA would be.

- *All new elements are to be largely reusable.*– There is a widely-held perception that reusability is a desirable system feature. Recurring and manufacturing costs can be reduced. Expendability, however, also has a place in an architecture, especially in cases where only a few flights are needed. It was decided to defer this issue to an architectural option, rather than legislating an unsubstantiated assertion as a requirement.

- *Human systems will accommodate "average" deconditioned humans.*– The trend in human spaceflight has been away from the test pilot astronaut and towards the scientist/mission specialist astronaut. These latter individuals tend to come from a more average physical population than the extraordinary physiological capabilities exhibited by a test pilot population. Future systems must account for the decrease in average tolerance to g-levels, dexterity, etc. While there was no dispute with the statement, the group felt that this policy requirement is superfluous in the context of discriminating between candidate architectures.

- *The average system downtime after a major failure will be TBD months.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *Personnel vehicles must have on-board intervention capability.*– The ability of on-board personnel to have input to the events that occur during flight has been debated for 30 years. The proposed requirement reflects policy and philosophy, rather than a technical decision. We could not hope to conclusively resolve this issue in this study; it was determined that this represents a level of design detail that won't be considered in the elements anyway, and is therefore unnecessary as a top-level requirement.

- *Personnel vehicles must be "piloted".*– The role of a human "pilot" has also been a subject of recent debate both in the spacecraft and aircraft communities. Technically, the nation has reached a level of technological sophistication where flight vehicles can be safely flown with no trained pilot onboard. When it will be permitted for human-tended vehicles to be operated in this fashion is unknown. The NIT declined to include this requirement, based on previous studies that showed the gross technical differences in the elements of weight, cost, etc. for piloted and non-piloted versions were insignificant to the architecture as a whole.

- *All the "jobs" must be done on time.*– To enable an exact comparison between architectures, it would be necessary to demand that each candidate completes the delivery of all payloads and completes all other mission types before 2021. This requirement could, however, mandate excessive resiliency or excess capacity when accounting for random, worst-case scenarios. The NIT decided that as long as the proposed architecture has the basic capacity to complete all the jobs in the absence of major schedule disruptions, it will be acceptable.

- *The architecture can survive a catastrophic loss.*– In the event of a catastrophic loss involving one or more major elements, there is always the possibility that national leadership could decide to cancel programs or elements, rather than proceeding with a recovery plan. While it was acknowledged that such a possibility could occur, the NIT decided against declaring whether or not an architecture will always return to it's original element mix.

- *Probability of launching priority payloads is greater than TBD.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *Reliability is greater than TBD.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *Dependability of 95 percent within 2 weeks of scheduled launch.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *All systems must be at least as safe as TBD.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *Total Life Cycle Cost (LCC) is less than TBD.*– This proposed requirement falls under the category of minimum attribute values. To that end, the NIT decided that this idea is not a stone tablet requirement, but will be addressed in the attribute discussion (section 3.2).

- *The transportation system should be environmentally "friendly".*– Recently, a large amount of attention has been given to our impact on the environment, including space launch activities. As stated, the requirement lacks an acceptable threshold. It was decided to treat environmental impact as an attribute, which could reflect the continuum of relative impact a given architecture might exhibit.

- *Humans must remain in the launch decision process.*– In the advent of automated procedures and vehicle health monitoring technologies, it is possible to fully automate the launch decision process to account for all measurable data. There will continue to be value in the role of a human to make a judgement, based on the data presented. Even accounting for human error, it was considered unacceptable that a computer could commit to the launch of a personnel vehicle. While there was no dispute with the statement, the group felt that this policy requirement is superfluous in the context of discriminating between candidate architectures.

- *Abort must be provided for in all flight phases.*– There has been much scrutiny (especially post-Challenger) of the ability of a vehicle to safely abort at all times during its flight. The time periods where no escape exists in the event of a catastrophic failure are typically short, but the loss of personnel is unacceptable, regardless of when it occurs. The inclusion of abort capability can impose significant performance penalties. The consensus of the group was that, while a worthy goal, the proposed requirement was better served by trade studies that adequately account for costs of providing and costs of not providing (cost of failure) an all-aspect abort system.

SECTION 3
STUDY TASKS

3.1 TASK 1 - HTS NEEDS ANALYSIS

3.1.1 Introduction

To facilitate identification of the requirements and potential options for the next HTS, a needs analysis was performed from which space transportation architectures were created and analyzed. This analysis identified the number, mass, type, and destination of human and untended payloads to space. The payloads were then broken into several categories based on a common mission or theme.

The needs model is based on the NASA Mixed Fleet Manifest and the CNDB FY90 version with Space Station restructure modifications and an additional representative DOD mission model. Upper-stage weights for those payloads going beyond LEO and required support equipment were not included. This was, however, accounted for when flight manifests were generated for the transportation architectures. Payloads were categorized as "Untended" or "Human Receipt at Destination." The only missions requiring a human categorization were for SSF and SEI crew delivery. All other missions were classified as "Human Receipt." All mission payload crew sizes were four persons, although extra persons might be required to support and operate the human vehicle.

Needs-Based versus Capability-Based Approaches

To compare architectures on an even basis each architecture must meet the same set of requirements. This needs-based approach was accomplished by establishing a common model of the space transportation needs. The architectures could then be compared because each was performing the same set of missions.

The alternative is to compare architectures by the capabilities of the space transportation elements that comprise them. The underlying assumption is that the user community will make use of any vehicle that is available (i.e., let the transportation system drive the payload design and operational requirements as a higher priority to the mission). Although there may be some realism to this philosophy with respect to how new systems are sold to Congress, there is a danger in developing a launch system that does not meet user requirements or that requires extensive modifications to payloads or their carrying vehicles. In addition, it becomes difficult to compare these architectures or systems to each other. For instance, larger payload capability does not necessarily mean cost efficiency because some flights may only be partially filled. Also, minimum cost architectures may not meet the flight rate or performance requirements of the users.

Previous Studies

One of the more notable studies performed on the future of space transportation was the STAS, which was performed in the mid-1980's. At this time, the budget for space activities was expected to grow significantly over the coming years. The mission models developed for that study, which were later to become the CNDB were extremely optimistic, greatly exceeding anything that could reasonably be expected today. These missions included the SDI in its largest scale, aggressive Lunar and Mars Initiatives, human missions to Geosynchronous Earth Orbit (GEO), and extensive ETO and in-LEO infrastructures. The smallest STAS mission model (Constrained Model) is equivalent to the largest mission model currently developed for this study.

Since the STAS, several other architecture-level analyses have been performed. Many of these studies were performed within the scope of a specific vehicle development program (e.g., NASP-derived vehicle (NDV) Task 11, ALS, etc.). The purpose of these studies usually focused on assessing the role of a specific transportation system within the national space architecture. The mission models developed were often modified to enhance the characteristics of the system being studied.

The Next Manned Transportation System (NMTS) study was performed in 1989 to assess future human transportation requirements. The needs model for this study was primarily based on the CNDB with a series of additional groundrules.

More recently, the STIS at MSFC has been analyzing architectural impacts of various systems, missions, and operations. The STIS has taken a similar approach to the HTS Study in the needs analysis area. The difference between STIS and HTS lies less in the needs model area and more in the choice of architectures selected for study and the evaluation process used.

3.1.2 The CNDB

Background/Description

The CNDB was established in 1985 by NASA Headquarters to project future, civil-space payload requirements. These requirements are developed in the various NASA Headquarters Codes and are then integrated and released by the Office of Spaceflight Development. The payload types range from Space Station build-up and logistics support, to Spacelab missions, to Tracking and Data Relay Satellite (TDRS) deployment, to small experiments such as growth of frog eggs and fruit flies. Each payload in the database has a description of the mass and volume requirements, return payload requirements, whether the payload requires human interaction, the date of first launch, the number of required launches, and programmatic points of contact.

Analysis of the CNDB

For the HTS study, the standard RBASE version of the CNDB was converted for use on the Macintosh using the Acius 4th Dimension database management program. The payloads of the CNDB were then divided into seven distinct mission types: SSF, Satellite Servicing, Support Assets, Industrial Space Facility, Sortie Science, Base, and SEI. In addition, a DOD mission model was incorporated into the study. These mission types are described in detail later.

One of the most interesting results found in reviewing the CNDB is that the proposed mass to be sent to orbit during the next 15 years is seven times greater than that sent to orbit during the past 15 years (see Figure 3.1.2-1). This reflects the expectation of increased space flight activity (e.g., SSF). Nearly two-thirds of all non-SEI, non-DOD mass that will be delivered until 2020, is to build and support SSF. Also, 43 percent (by mass) of payloads *require* crews to be aboard the launch vehicle. Finally, one quarter of all mass sent to space is to be returned; the majority of that is the return of Space Station logistics modules. Two-thirds of the payloads (by number) weigh less than 1000 pounds and 80 percent weigh less than 10 000 pounds (see Figure 3.1.2-2). For the return payloads, 83 percent of these payloads weigh less than 1000 pounds, and 94 percent weigh less than 10 000 pounds (see Figure 3.1.2-3).

Shortcomings of the CNDB

There were several difficulties in using the CNDB for the HTS study. Some of these were compensated for by simplifying assumptions in the HTS Needs Model. Others could not be handled, and their inclusion in future versions of the CNDB would enhance results obtained in future space transportation architecture analyses.

First, many payload requirements are based on the current transportation architecture. Examples include requiring payloads to be returned based on Space Shuttle flight-return capability rather than a true need for the returned payload, and requiring SSF payloads to be serviced at each crew rotation opportunity. It is recommended that hard payload requirements should drive the systems which comprise the space transportation architecture, not the reverse.

Second, a large number of payloads in the CNDB claim to require human interaction with the payload (e.g., Advanced X-Ray Astronomy Facility (AXAF)). Many of these payloads could be placed on cargo vehicles or could simply require personnel at the destination, such as for SSF payloads. Similarly, many payloads have a return requirement, the necessity of which should also be carefully considered.

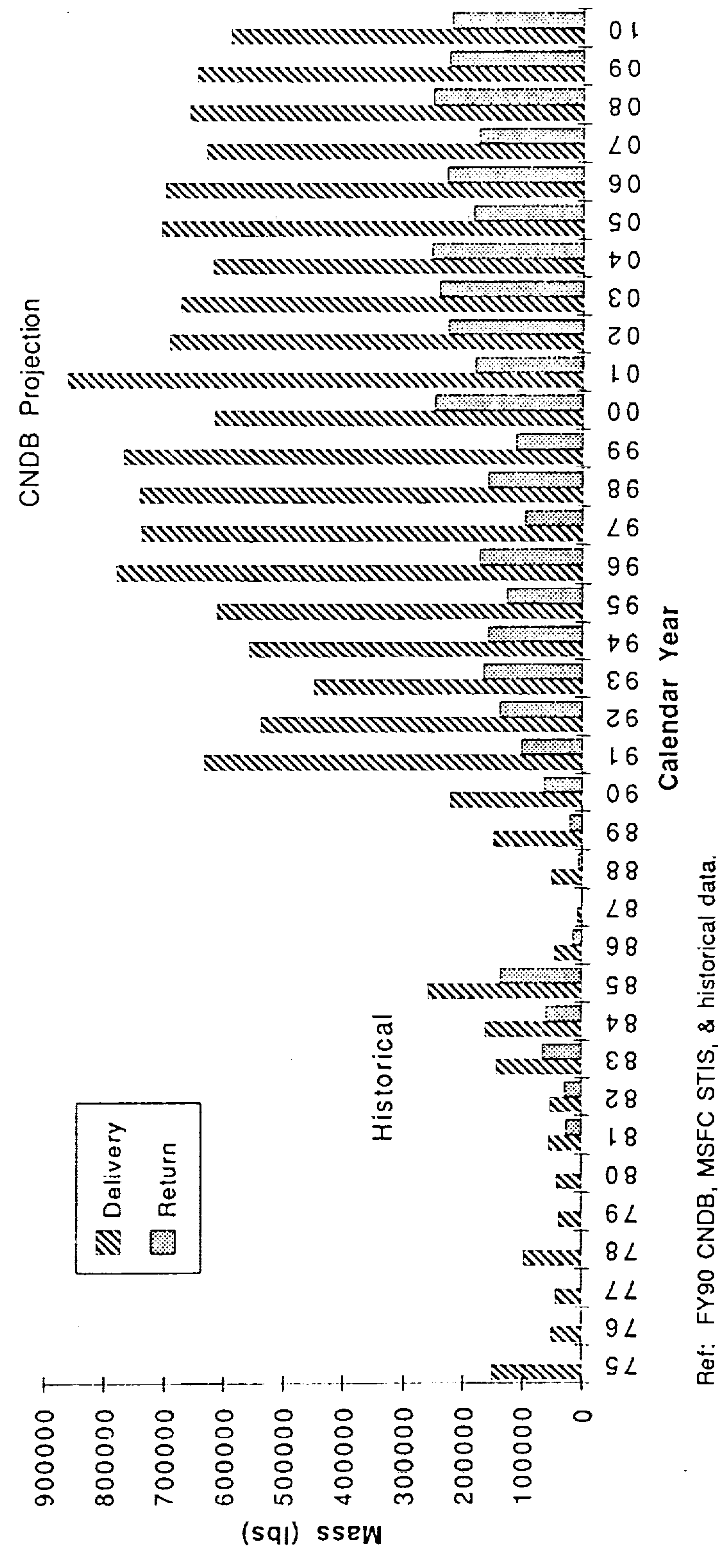


Figure 3.1.2-1.– Total payload mass delivery and return – ETO (civil and available) DOD, no SEI or SSF expansion).

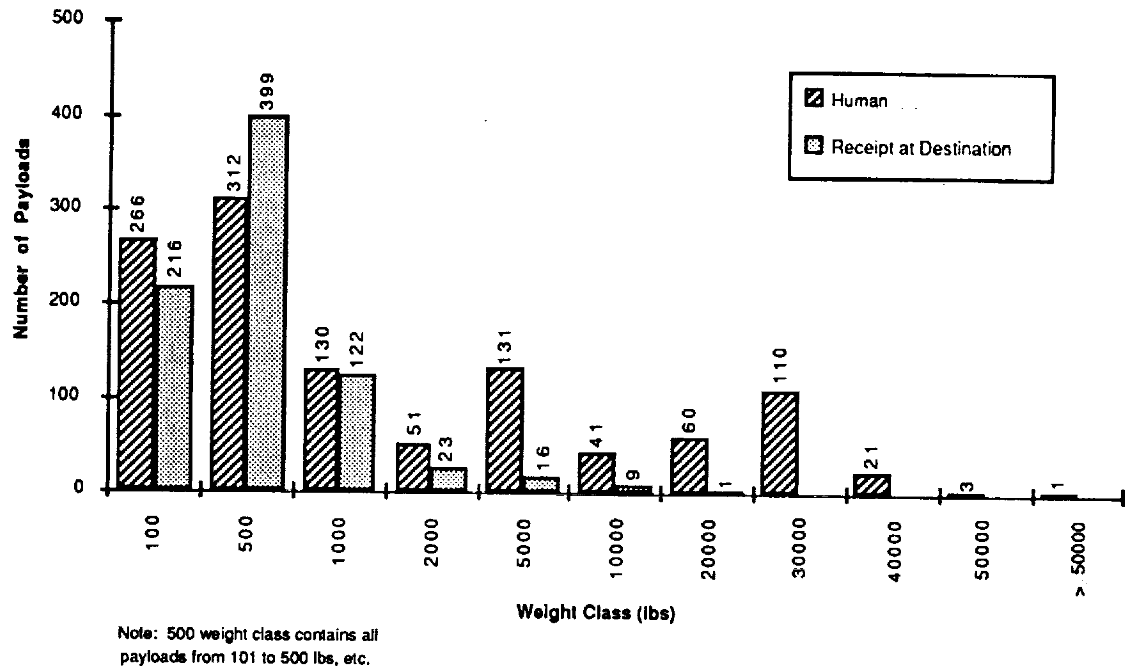


Figure 3.1.2-2.– Payloads-up by weight class (FY90 CNDB base model - no SEI).

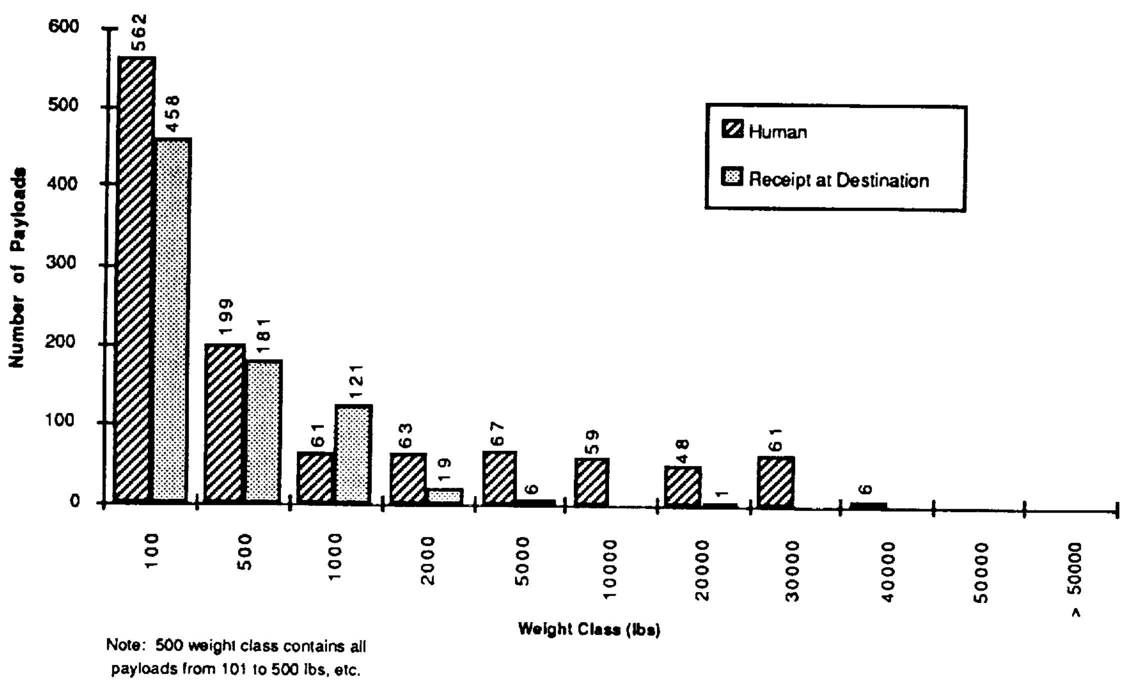


Figure 3.1.2-3.– Payloads-down by weight class. (FY90 CNDB base model - no SEI).

Third, one of the problems in analyzing payloads from the CNDB is that there is no sense of the urgency or criticality for launching a particular payload at a particular point in time. An attempt to avoid this has been made by defining mission types which have roughly the same level of need. If a mission type is included within a transportation architecture scenario, all missions within that type will be flown. Some payloads may require a very specific launch window (e.g., a Pluto fly-by or Mars Observer) which might make that payload much more critical in terms of on-time launching than perhaps an LEO Great Observatory. To this end, NASA should develop a way to assess or rank a payload based on its criticality. These criticality levels should appear with the payload descriptions in the CNDB. This could be done in four levels:

- Loss of life or major infrastructure component (e.g., SSF reboost)
- Loss of mission opportunity window (e.g., Mars flight)
- Loss of minor infrastructure component or mission (e.g., Hubble Space Telescope (HST), Long-Duration Exposure Facility retrieval)
- Little or no impact of delays to mission success (e.g., Spacelab Simulator-1, Gamma Ray Observatory (GRO) deployment).

Finally, there are at least two ways of skeptically viewing the payload model credibility of the CNDB. The first view claims there are many more payloads in the data base than will be flown. While it is true there are many placeholders in the data base, and that future payload projections are much higher than the nation has launched into space in recent history, it is also true that the space program is proposing much more ambitious endeavors in space by building a permanent space station, attempting to return to the Moon, and going to Mars. The second view states there are many more payloads "out there" than have been incorporated into the data base and/or if the transportation infrastructure had enhanced capabilities at reduced cost, there would be many more payload requirements.

As a result, some believe that because the CNDB does have shortcomings, it should not be used or that a mission model approach is not appropriate. Shortcomings should not invalidate the use of mission models, rather their presence demands greater rigor in developing hard payload requirements.

3.1.3 HTS Needs Model

3.1.3.1 Modifications to the Needs Model

A principal implication of using the CNDB in an unmodified form would be to require an architecture that includes a system with Space Shuttle-like characteristics. Because of the "Human" requirement specified by many of the payloads in the CNDB, the systems that carry crew and cargo on the same vehicle are the only ones that would correctly capture these missions (i.e., Space Shuttle). In addition, because of the identified delivery and return payload sizes, at the least a Space Shuttle-like capability would be required to perform certain delivery and return missions.

Payload Requirements

Due to the difficulty in understanding what true human requirements were, all "human" and "Space Shuttle" requirements were changed to "Human Receipt at Destination". This means that instead of requiring that personnel fly with the payload or that a payload must fly on the Space Shuttle, a payload was only required to have human interaction with the payload while on orbit. This allowed transportation architectures which would separate people and cargo. While it was highly likely that a Spacelab mission would be flown aboard the Space Shuttle, it was not required.

Smoothing

Because the near-term (before 2000) space transportation needs are easier to predict than the longer term (after 2000), the CNDB exhibits a "bow wave effect", that is, payload requirements in the next few years greatly exceed the out-year requirements. Many believe that this requirements bow wave will continue to exist at any point in time because of the emphasis on near term mission planning. Designing an architecture to meet this type of time-phased effect would be shortsighted. To effectively assess the architectural impacts through 2020 and the life cycle cost of various systems, the HTS study needed a mission model that accurately reflected the most probable space missions through this time period. Therefore, the study team chose to perform a *smoothing* on the mission types that would otherwise dwindle to near zero in the out-years. Figure 3.1.3.1 illustrates the idea of smoothing on the level of mission type flight activity. Five of the mission types were subsequently smoothed in this fashion.

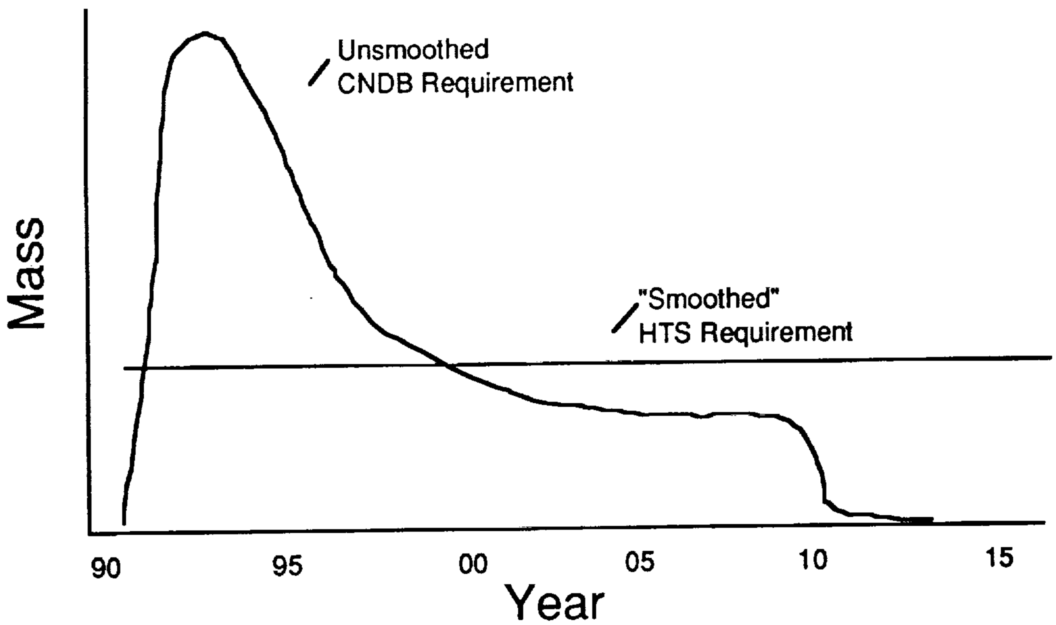


Figure 3.1.3.1.– Mission type payload "smoothing".

3.1.3.2 Mission Types

The payloads in the HTS Needs Model were divided into eight mission types or groups of activity that had similar characteristics. These mission types are described below. Appendix A (see Volume II) provides a summary of the mission model payload requirements by mission type and year. Commercial payload requirements were not included, since these would have little or no cost impacts to any proposed transportation architecture.

<u>DOD</u>

This category includes piloted and unpiloted DOD missions. Though not a part of the CNDB, the NASA-Industry team believed it was important to include DOD requirements, since their Expendable Launch Vehicle (ELV) and human flight requirements, as well as ground-processing facility requirements, would have a synergistic effect on the costs of a particular transportation architecture to NASA, and because they resulted in government expenditures whereas commercial missions did not. The unpiloted data for this category was obtained from the MSFC Space Transportation Infrastructure Study and is expressed in terms of vehicle class launch rates, rather than specific missions or payloads. This is a capability-based (number of expected flights) model due to the classified nature of the needs.

To select the DOD piloted mission requirement, 10 of the 45 Space Shuttle flights since 1981, have been dedicated to DOD, an average of about one per year. (In the

NASA Mixed Fleet Manifest, there is an additional flight in 1992, with no additional flights forecasted or manifested after this.) Based on this information, DOD will continue with a human mission requirement of one per year. It is also assumed that the DOD piloted missions will require some cargo, but not necessarily on the same flight or vehicle. This is a reduction from the requirement used in the NMTS study in 1989 which identified a piloted mission requirement for future DOD missions of three flights per year.

Base

This category is comprised of basic science and technology development payloads which have low return requirements. Example payloads are GRO, Earth Observation System (EOS), Cassini, and the Combined Release and Radiation Effects Satellite (CRRES). It also includes the middeck-size payloads flown aboard the Space Shuttle. All payloads in this category have a return requirement of less than 1000 pounds. This category should not be confused with the CNDB Base Model.

The Base mission type is comprised of the EOS , Planetary, LEO-Large (11 000 lbs.), LEO-Small, and LEO-Human Receipt payloads. Each of these smoothed payloads are flown once a year for an annual mass to orbit of 65 000 pounds. The LEO-Human Receipt has the only return requirement.

Supports Assets

This category constitutes high-priority, space-based infrastructure satellites for communications, tracking, and data relay. The nine payloads in this mission type reflect operational versus scientific or developmental systems, and would have a very high launch priority compared to other science or exploration missions. Example payloads are TDRS, GN&C Orbital Environment Simulation, and the International Maritime Satellite (INMARSAT). There are no human requirements in this category, although a few of these payloads will be carried aboard the Space Shuttle.

The Support Asset mission type is smoothed by destination. It includes GEO-large, Sun-synchronous, GEO-small, and mid-inclination payloads. The average mass delivered per year is 5000 pounds.

Industrial Space Facility

This category includes those payloads which comprise the Industrial Space Facility (ISF). For the HTS study, a reduced-scale ISF payload model was used based partially on recommendations from the MSFC STIS. All payloads in this mission type have a common destination.

Sortie Science

This category includes larger, "Spacelab-type" missions which have return requirements greater than 1000 pounds. Example payloads are Space Life Sciences, the Astronomy Ultraviolet Telescope (ASTRO), and the International Microgravity Laboratory. Payloads requirements in this mission type strongly reflect Space Shuttle-based transportation architecture.

The Sortie Science mission type is categorized by four different types of payload mixes being flown once a year from 1998 to 2020 (total of 69 000 lbs. per year). These include Office of Space Science and Applications Cargo, Material Sciences, Earth/ Astronomy Observation, and other pressurized cargo. It is assumed all delivered mass is returned.

Satellite Servicing

This category includes satellite servicing missions for repair, reboost, maintenance, retrieval, and upgrade of LEO satellite systems. It does not include servicing missions for SSF or SEI.

The Satellite Servicing mission type was smoothed from 2011 to 2020 to reflect alternating requirements for large and small servicing flights for a total of 19 000 pounds per year. The Large Deployable Reflector and HTS servicing missions are included prior to 2010 (8600 lbs.).

SSF

This category includes those payloads which comprise SSF. This includes assembly, utilization, logistics, crew rotation, and expansion flights modified to the latest SSF design configuration restructure. However, the actual user payloads were the same as those of the FY90 version of the CNDB. Even though the restructure activity will greatly impact non-core, SSF-related payloads, developing a new payload model with a reasonable degree of confidence would have been very difficult for this study. Since these payloads represented only a fraction of the core station weight, it was assumed that the overall mass of these payloads would not change significantly from the FY90 CNDB. This assumption must be revisited, since it is likely that after the restructure, payload requirements far exceed available capability. Therefore, data for all non-core, SSF-related payloads came from the FY90 CNDB. However, all first flights for the payloads were shifted later by 2 years to reflect the changes in the station design and schedule due to restructure.

The SSF mission type was further broken down into a PMC model which included assembly, operations, and support of the PMC configuration, and an expansion model which included any non-SEI expansion to the PMC configuration (e.g., Eight-Man Crew Capability (EMCC)). All payloads in the SSF mission type have a common destination.

In the SSF mission type, the SSF logistics and utilization flights were smoothed to reflect a continuation of the PMC support requirements through 2020. Similarly, "If" scenario D was smoothed to continue the EMCC support requirements.

Since no official SSF crew rotation policy exists, the following assumptions were made for the study so that the number of flights required to support SSF crew rotation could be established.

- The entire four-person crew during the PMC phase will be rotated every 90 days. (After some certification, the crew would probably be rotated every other flight for longer duration tours of duty.)
- During an eight-crew phase, only four crew members can be rotated during a human flight. This implies a 180-day tour of duty.
- All Space Shuttle flights to the SSF have a crew of seven. Other personnel vehicles have crew sizes ranging from four to seven.

SEI

The model for SEI in the HTS study is based on a high-and-low traffic requirement for crew-to-LEO to support human missions to the Moon and Mars. This requirement was established based on recommendations of possible SEI activity levels from the NASA 90-day Study and the Synthesis Group report. The manifesting considered only delivery missions, since it was assumed crew return would be handled by direct return or rendezvous with SSF. Lunar and Mars cargo requirements were not considered since these requirements are still emerging and the proposed scope of activities would mean large differences in the payload requirements. Also, since it is likely that a heavy-lift launch vehicle would be required and that this vehicle would be oversized for crew transportation requirements, there would be little synergism between this vehicle and one required for transporting crew to LEO. This assumption will be revisited in future studies.

3.1.4 HTS Data Base Summary

Once the above modifications had been incorporated, the resultant needs set was renamed the HTS Data Base. Table 3.1.4 shows the total mass delivery and return requirements by mission type for the study data base over the study time frame. Note again that the overall delivery mass in the HTS data base excludes the SEI cargo requirements. Individual mission type requirements are somewhat higher than the CNDB requirements since (smoothed) payloads have been added in the out-years to account for ongoing support requirements. Appendix A (see Volume II) provides a summary of the mission model by mission type and year.

TABLE 3.1.4.– SUMMARY OF HTS MISSION MODEL PAYLOADS BY MISSION TYPE (1991-2020)

Mission Type	Total Mass Up (klbs)	Total Mass Down (klbs)
SSF (incl science)	7405	4487
Sortie Science	2531	2565
Support Assets	212	0
ISF	107	13
Sat Serv (no SEI or SSF)	259	214
Base	1463	182
SEI	-	-
DOD	-	-
TOTAL	11 977	7461

Finally, the eight mission types were combined into five levels of possible future space activity. These levels are called "If" scenarios, i.e., "If the range of expected space activity includes..." These levels are additive and represent increasing levels of requirements, not only in terms of payload to and from space but also additional vehicle capabilities (RMS systems, on-orbit stay times, etc.) Dividing proposed space activity into different levels gives the customer insight into the effect of various payload requirements on the space transportation architecture.

The five activity scenarios are shown in Figure 3.1.4-1. "If" scenario A represents what would likely be the minimum level of space activity the nation would pursue. "If" scenario B represents the current level of space activity. "If" scenarios C and D represent the addition of SSF and its proposed expansion. Finally, "If" scenario E represents the inclusion of the SEI crew missions. These "If" scenarios are then used to manifest the system concepts of interest across the range of transportation architectures to be studied. Figures 3.1.4-2 and 3.1.4-3 show the Human Receipt mass required to be delivered and returned per year for the various activity levels.

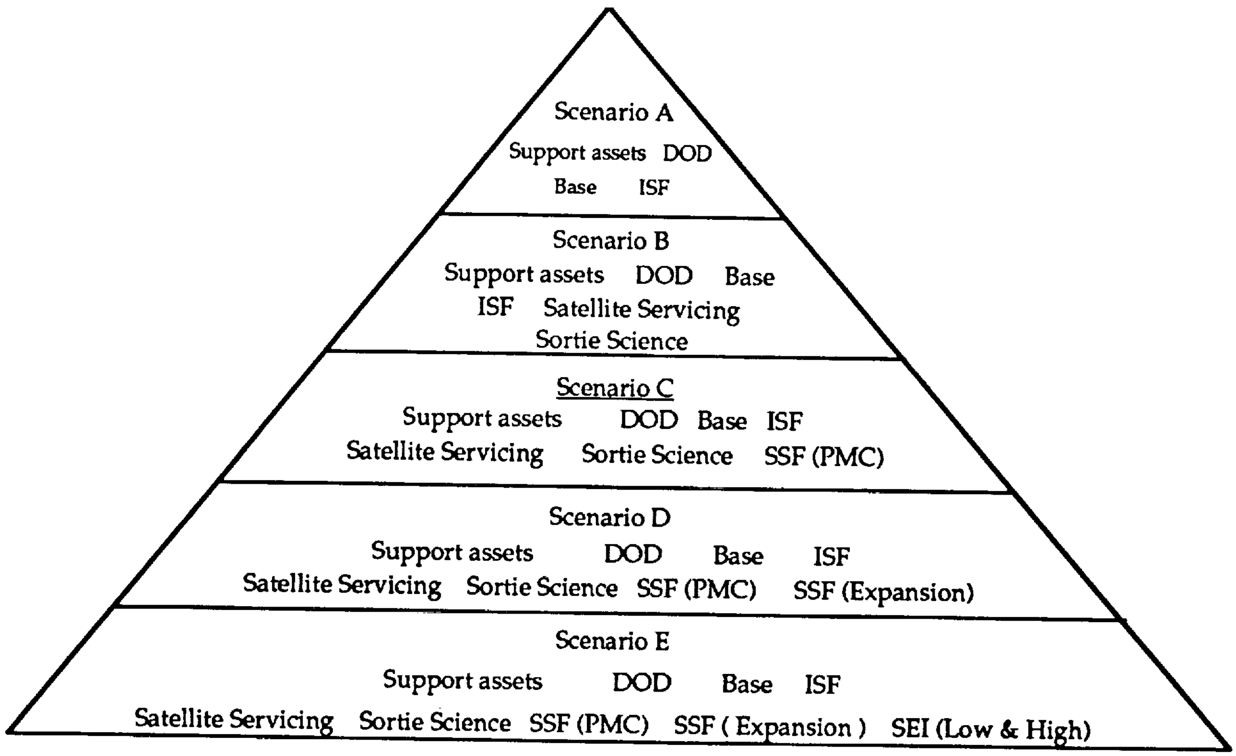


Figure 3.1.4-1.– HTS "If" scenarios, "If the range of expected space activity includes...".

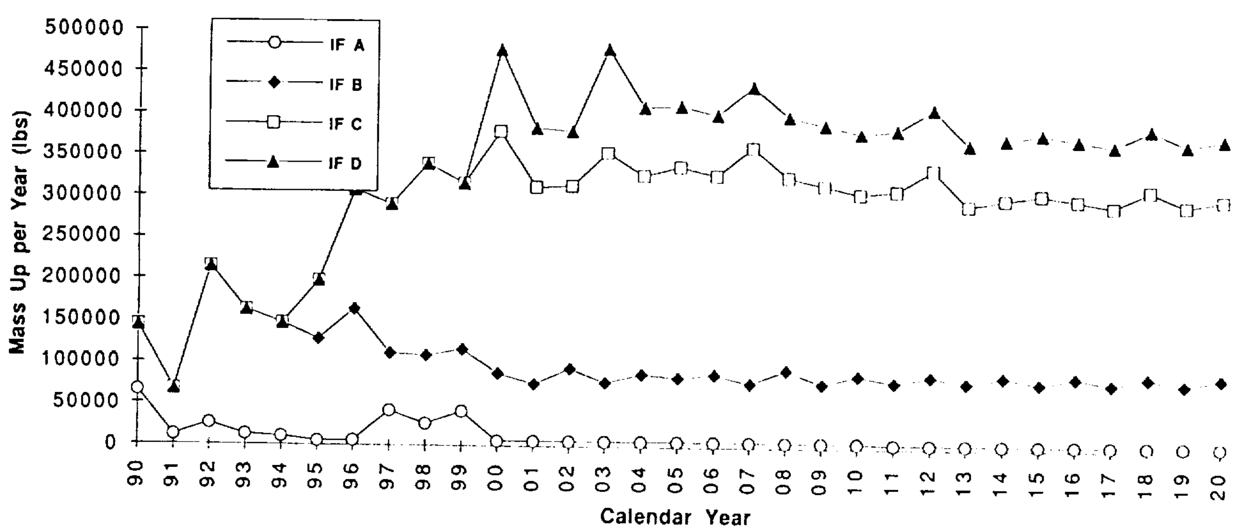


Figure 3.1.4-2.– Human receipt mass up per year for each "If" scenario.

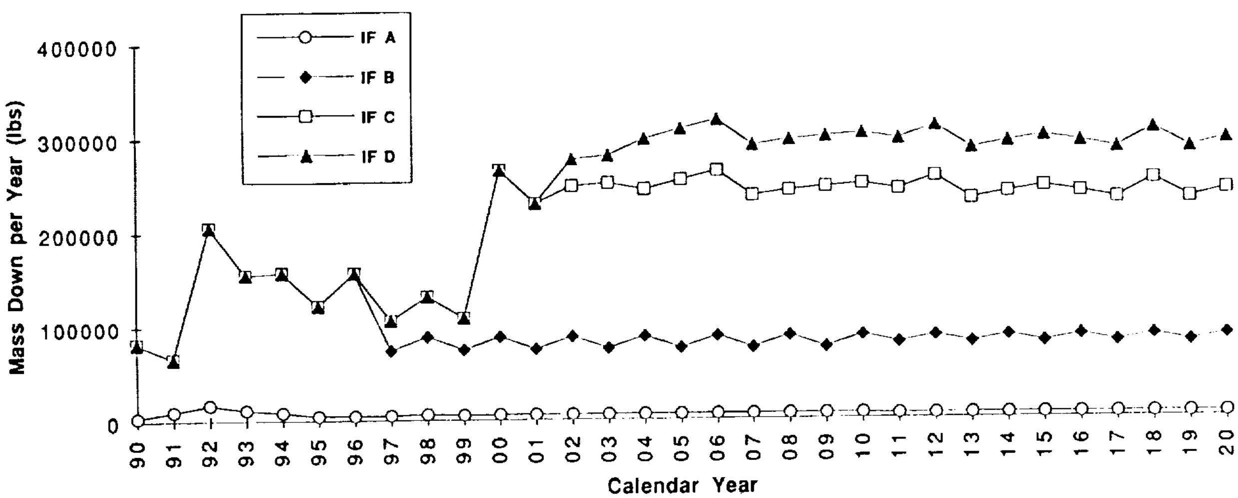


Figure 3.1.4-3.– Human receipt mass down per year for each "If" scenario.

3.2 TASK 2 - IDENTIFICATION OF SIGNIFICANT ATTRIBUTES

The HTS Study was initiated to gather data to determine the *right* transportation system architecture(s) needed for human access to space. To determine this set, a method for comparing the candidate systems had to be defined. Attributes are the means that the HTS study team used to make those comparisons. Attributes allow comparison of elements that meet the requirements and the *needs* (mission model). This section discusses the need for and definition of attributes, as well as the process used to determine them.

3.2.1 Approach

One of the first tasks that the HTS team set out to address was the definition of the attributes that would be used in the HTS study. The attributes chosen and the measurement techniques used determined what information would be needed about each of the concepts being investigated. The attributes ultimately chosen by the HTS team were derived from a list of nearly 130 attributes that were initially proposed. Certain techniques used in Quality Functional Deployments (QFD) were used to arrive at consensus on the final list.

The attributes defined in detail for this study are: Funding Profile, Probability of Mission Success (PMS), Human Safety, Architecture Cost Risk (ACR), Launch Schedule Confidence (LSC), Environment, Dependability, Availability, Resiliency, Alternate Access, and Mission Growth Potential. Each of these is listed below along with its definition.

Midway through the study it became apparent that some of the lower-weighted attributes were taking a large percentage of the available study time to calculate. It was also felt by the HTS team that the measurements needed for two of the attributes in particular (Dependability and Availability) were difficult to generate and more difficult to justify. Therefore, the calculation of these five attributes was deferred to a follow-on phase. These attributes include: Dependability, Availability, Resiliency, Alternate Access, and Mission Growth Potential. While the Environment attribute was judged to be less important than the other five, its calculations were essentially completed, and so the HTS team decided to continue to use it and observe its effect on the architecture decisions. Its relative importance, however, was not increased above those that had been deleted. Given that the three operations-related attributes; Dependability, Availability, and Resiliency, were eliminated in this phase, the group felt that some indication of an architecture's ability to meet launch schedules should be included. Therefore, the LSC attribute was defined. It is simpler to calculate than the others, but unfortunately is also a less accurate indicator of an architecture's ability to meet schedules.

3.2.1.1 Definition of an Attribute

Attributes are the means by which an architecture's "goodness" is determined in order that it may be compared with other architecture options. Attributes must have certain characteristics in order to be useful in performing this comparison function. Many of these characteristics have been effectively described by Dr. Deming in the context of how important measurement is in improving the quality of any system. These important characteristics of attributes are listed below.

a. To be useful in comparison, the attribute must be defined and be measurable.

> "An operational definition puts communicable meaning into a concept. Adjectives like good, reliable, uniform, round, tired, safe, unsafe, unemployed have no communicable meaning until they are expressed in operational terms of sampling, test, and criterion."[1]

b. The measurements must be repeatable, which in turn means that the calculations are well understood and the assumptions are clear and used consistently across each architecture.

> "An operational definition... must be communicable, with the same meaning to vendor as to purchaser, same meaning yesterday and today... Without an operational definition, investigations of a problem will be costly and ineffective, almost certain to lead to endless bickering and controversy."[1]

c. A level of detail and accuracy of the measurements needs to be agreed upon. There are no absolute right or wrong values for any measurement.

> "Any physical measurement is the result of applying a given procedure. Likewise with the count of people in an area. It is to be expected that two procedures for measurement or for counting will give different results. Neither of the two figures is right and the other wrong. The experts in the subject matter may have a preference, however."[1]

d. Also, no new system will have the detail or empirical data that the Space Shuttle system has until the system is built and flown for over 50 flights. However, the agency cannot afford to build every option and fly it before it makes a decision. Therefore a preferred procedure specifying the level of detail and accuracy adequate to make decisions at the chosen level must be defined.

"A preferred procedure is distinguished by the fact that it supposedly gives or would give results nearest to what are needed for a particular end... "[1]

e. The weighting of each attribute relative to the other attributes must be determined. It is the combination of all the weighted attribute scores that determines the *best* answer. Weighting is important to understand, because every customer does it in the process of making decisions, whether he does it consciously or unconsciously. The magnifying of one attribute, by expending resources and placing emphasis on it solely, misses the fact that few decisions are made based on a single criterion.

3.2.1.2 QFD Process for Determining Study Attributes

To determine the attributes, it was important to do two things. The first step involved getting a large cross-section of the aerospace community's views, opinions, and ideas about what important characteristics (attributes) the next HTS should have. The second step required getting a consensus from this group as to what the *most* important of these characteristics (attributes) would be. These would be the attributes used in the HTS study. The first objective was met by creating the HTS team, as described in section 2.1.1. Members of the team included representatives of the major aerospace corporations, as well as the major NASA centers. A forum was set up to accomplish the second objective. The forum was comprised of representatives from each of the HTS team centers or contractors. Rules for discussion (some derived from QFD techniques) were established in order to facilitate the meeting of the objective. The HTS forum began by using three 8-hour sessions. At the end of these three sessions, the name and definition of the major attributes had been agreed to. During the next three months, detailed measurement techniques for the attributes were developed and later agreed to by the forum in follow-up meetings. The major rules of the forum were as follows.

a. Keep the forum to a controllable size. This allows adequate time for each member to participate. The HTS forum was limited to 12 people. If other persons in a representatives group wanted to add something, they would funnel it through the forum representative of that group.

b. Keep the membership of the forum consistent and make attendance mandatory. If the people on the forum are constantly changing, much time is lost educating the new members on the previous work of the forum.

c. Use a facilitator. The facilitator should be knowledgeable on the subject being discussed and be able to focus the group and keep it on track without controlling the discussion.

d. Allow each member to discuss their position without being interrupted.

e. The time allotted for the forum must be adequate for the group to reach consensus.

The forum proceeded using the following process. First, an agreement on who the customer for the next transportation system would be. The forum began by defining the responsibilities of the person who was likely to be the customer. Those responsibilities included (a) ensuring that the transportation needs are accomplished, (b) resolving what the total (human and untended) transportation architecture should be, (c) determining how that architecture is implemented and operated, and (d) deciding how the total architecture is funded. After much discussion, the HTS forum agreed that the NASA administrator best fit this description.

The forum then proceeded to brainstorm on what attributes the customer would consider important. Over 100 separate attributes were suggested. Then similar attributes were grouped and definitions were refined. The first gathering of attributes is shown in Table 3.2.1.1-1 (no prioritization is implied).

TABLE 3.2.1.1-1.– FIRST GROUP OF ATTRIBUTES

<u>Schedule/Risk Group</u> Cost Risk Technical Risk Schedule Risk Launch-On-Demand Schedule Assurance <u>Cost Group</u> Production Cost Fixed Cost Marginal Cost Non-recurring Cost Procurement Cost Discounted LCC $/Flight Operations Costs Unreliability Costs Peak Year Funding Affordable Cost Less $/lb Lowest LCC Opportunity loss to grounded fleet	<u>Assured Access Group</u> 'Assured' Access Dual Access Alternate Access <u>Reliability Group</u> Dependability Supportability Routine Robustness Reliability <u>Availability Group</u> Availability Maintainability Operability Resiliency <u>'Other' Group</u> Facilities Complexity MTBF Capability STS Complimentary Ops Support of STS Phaseout IOC date Flight Rate Responsiveness	<u>Enabling Group</u> Longer Duration Excess Payload Capability Servicing Missions High Inclination Orbits Growth Potential Enhanced Capabilities Supply-Side Capability <u>Safety Group</u> Robust Abort Capability Number of Cat. Failure Modes Abort in All Phases Abort Capability Minimize Crew Losses No gaps in crew escape Landing Opportunities Complexity Crew can survive cat. loss Crew Impairment <u>Public Perception Group</u> National Prestige Confidence Politically Acceptable Spinoffs Broad Constituency

TABLE 3.2.1.1-1.– FIRST GROUP OF ATTRIBUTES (CONCLUDED)

Flexibility Group	'Other' Group - Concluded	Public Perception Group - Concl.
Operational Versatility	New Technology	Environmentally Friendly
Landing Opportunities	New Elements push SOTA	Excitement
Level of Autonomy	Uninterrupted Flt. Ops	Aesthetics
International Capability	Number of Failure Modes	Early Results
ACRV Functionality BIT	Must do all jobs on time	
All Inclination Launch	Fewer Problems	
	Ease of System Upgrades (Modularity)	

The next attempt at consensus resulted in a reduced list of attributes (again, in no particular order). These discussions involved critically evaluating each attribute, removing requirements, and removing unmeasurable items. The reduced attribute set is shown in Table 3.2.1.1-2.

TABLE 3.2.1.1-2.– REDUCED LIST OF ATTRIBUTES

Flexibility	Maintainability	Producibility
Safety	Fixed Cost	Dependability
DDT&E Cost	Robustness	Enabling
LCC	Reliability	Marginal Cost
Availability	Funding Profile	Operability
Cost of Failure	Resiliency	Assured Access
Supportability	Margins	Routine
Schedule Risk	Technical Risk	Cost Risk
Job Complete	Operations Costs	Alternate Access
Procurement Costs	Other (perception)	
Operational Versatility	PMS	

Further debate and voting ensued to reduce the list to its final form. The votes taken were not to enforce majority rule, but to limit the list to the attributes the group thought most important. If, for instance, a member of the forum was the only member to think a particular attribute was highly weighted, it was not automatically eliminated. A discussion ensued where the defender of the attribute would propose why he felt the attribute was important. This allowed the group to see each others point of view. Many of the disagreements concerning the final list were handled this way. Table 3.2.1.1-3 shows the final list at this point in the process.

TABLE 3.2.1.1-3.– FINAL LIST OF ATTRIBUTES

Safety	Availability
Mission Growth Potential	Program Risk
Funding Profile	Resiliency
PMS	Dependability
Environment	Alternate Access

The rationale for excluding certain previously suggested attributes is also important as it may provide insight into the NIT group psychology. The following terms attempt to capture the primary reasoning behind the exclusion of certain attributes.

- *Producibility* - Producibility will show its effect under cost. However, its effect is small compared to the other cost drivers.

- *Supportability* - The effect of supportability should show its effect as part of availability. A concept with poor supportability will lengthen its own average turnaround time.

- *Assured Access* - The factors that contribute to assured access include reliability, dependability, and PMS; which are attributes in themselves. Additionally, alternate access will be one of the architectural considerations, and comparison of competing architectures should reveal the benefits and costs associated with assured access. The group felt that alternate access was a better attribute because of the implied certainty of assured access.

- *Job Complete* - It was resolved that the HTS study would manifest all jobs to be competed by the year 2021 and therefore, no system or architecture would have done less than the complete list of jobs.

- *Cost of Failure* - Cost of failure is accounted for in cost attribute.

- *Marginal Cost* - Marginal cost was included in the calculation of architecture cost.

- *Routineness* - Routineness was thought to be similar to dependability.

- *Margins* - Margins would be reflected in values for safety, risk, reliability, etc.

- *Maintainability* - Maintainability was considered part of the availability and/or dependability attributes.

- *Flexibility* - Flexibility was be rolled up into the dependability and availability attributes.

- *Cost Risk, Technical Risk, and Schedule Risk* - These were assembled into a larger risk attribute.

- *Operability* - The group was at first divided on whether this would be included in cost or dependability. Since those are covered as attributes, operability did not need to stand as a separate attribute.

- *Procurement Cost* - The study will provide all costs at a top level breakdown. The customer can break out procurement cost separately, but it was felt there was no need to distinguish it as a distinct attribute.

- *Technology Advancement* - Technology should be viewed as a means to an end for the transportation job. Only if the technology helped to reduce cost or maximize the value of any important attribute, would it be used.

- *Reliability* - Reliability will be incorporated as an element of PMS or some similar attribute.

- *Operations Costs, DDT&E Costs, LCC, Fixed Costs, etc.* - All costs will be rolled up into a funding profile attribute. All these line items should be apparent in the HTS data, but it was determined that one group could not meaningfully (as the customer might) weight these various elements of cost.

3.2.1.3 Determination of Attribute Weights and Utility Curves

The HTS team decided to develop an analytical/mathematical process, whereby the attribute scores could be combined and the *ranking* of the architectures could be determined. The HTS team understands, however, that the results of this process can not, in and of itself, be accepted as the final answer. Careful attention must be paid to the impact of the analytical/mathematical process itself on the answer. The process used by the HTS team did, however, provide valuable insight into the major trends and drivers that affect an architectures ranking.

Two analytical/mathematical processes were proposed in the HTS study. The first method, called the direct method, begins by converting the attribute value, dollars for cost, crew loss events for safety, etc., into a non-dimensional value. Utility curves can be used for this purpose. This technique requires that the HTS team determine the shape and boundaries of the utility curve. The group determined that since there was no minimum or maximum acceptable value for any attribute (otherwise it would be a requirement), the utility curves should range linearly from the *best* attribute score in each "If" (activity scenario) being normalized to 1.0, to the *worst* attribute score being normalized to 0.0 (see Figure 3.2.1.3-1). A linear utility curve relationship was chosen as a simplifying assumption, since a more complex mathematical relationship could not be justified. In Figure 3.2.1.3-1, the cost values of roughly $50 billion and $150 billion are examples of the best and worst funding profile attribute values for all the architectures in a particular "If" scenario. The weighting of one attribute versus another must also be determined. The HTS members assigned each attribute a weight. The weights of the individual attributes must add up to 100. The results of this scoring were shown to and commented on by high-level representatives of the customer (i.e., JSC Center Director). This was essential, since if the weightings are not consistent with the customers views, the conclusions could be inaccurate. Weights for the initial set of attributes as well as the weights for the final set of attributes are shown in Table 3.2.1.3-1.

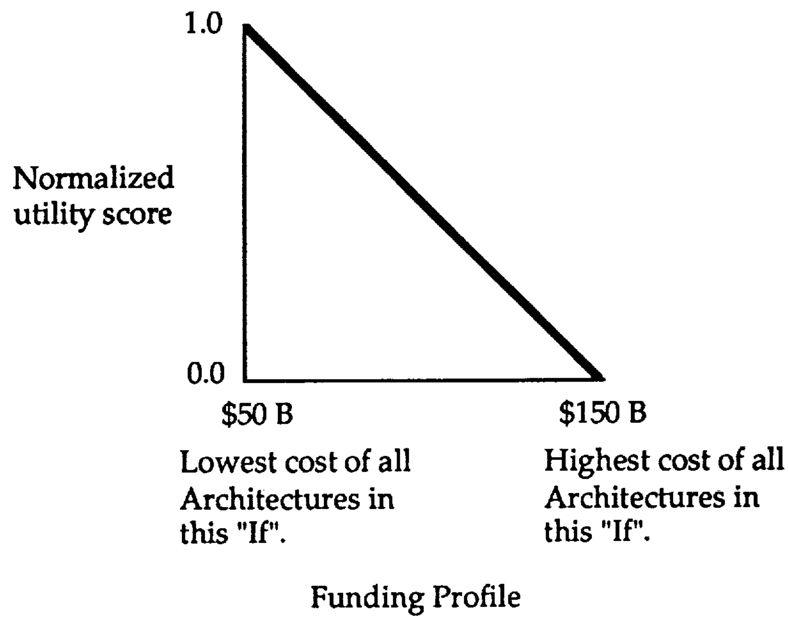


Figure 3.2.1.3-1.– Example attribute utility curve.

TABLE 3.2.1.3-1.– BASELINE ATTRIBUTE WEIGHTINGS

Attribute	Complete Set Weight	Abbreviated Set Weight
Funding Profile	22	27
Human Safety	18	29
PMS	16	19
Architecture Cost Risk	13	13
Dependability	9	
Mission Growth Potential	6	
Alternate Access	5	
Resiliency	4	
Availability	4	
Environment	3	4
Launch Schedule Confidence		8
Total, %	100	100

The second method, called the trade-off method, involves comparing attribute scores directly, one to one with each other, and determining the relative weightings. The intent of the trade-off method is to find a set of equally preferred outcomes such that the decision-maker is indifferent between them. An example is shown below in Figure 3.2.1.3-2 for the trade-off between the two attributes of funding profile (cost) and crew loss events (safety). The decision-maker is initially offered the choice between A (the best outcome on safety paired with the worst outcome on cost) and B (the worst outcome on safety paired with the best outcome on cost). The decision-maker's choice will depend on the two considerations. First, which attribute is more important to the decision-maker. Second, what is the range (difference between the worst and best outcomes) for each attribute. In this example, the decision-maker chose B and continued to prefer the B choices until the best outcome on the cost axis was diminished to B'''. At that point, the decision-maker was indifferent between A (the best outcome on safety paired with the worst outcome on cost) and B''' (the worst outcome on safety and a cost defined by B''').

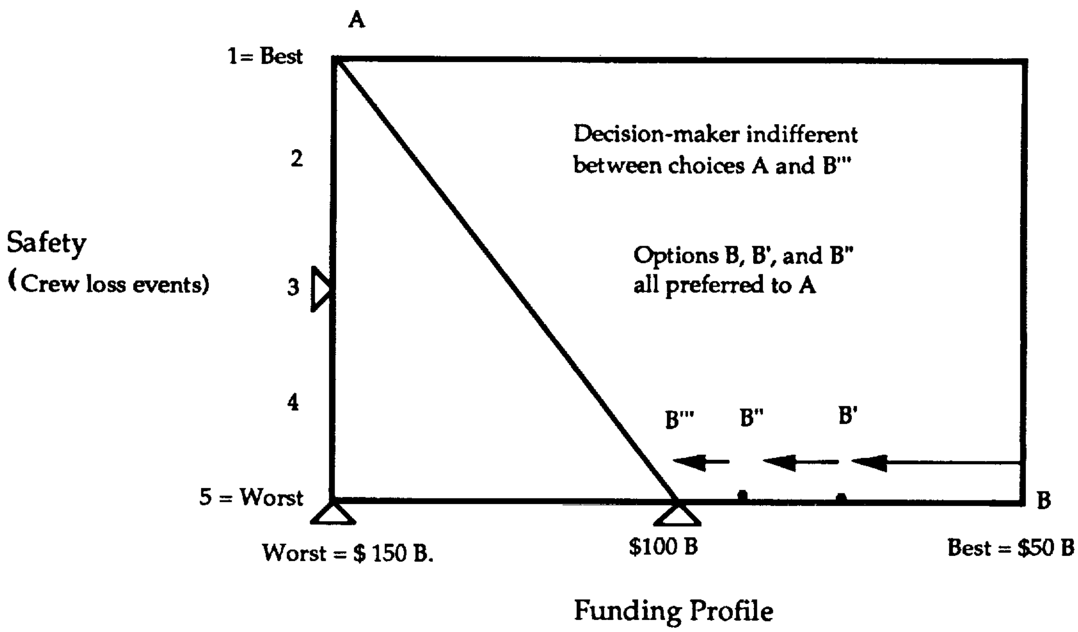


Figure 3.2.1.3-2.– Example attribute trade-off curve.

Since the decision-maker is indifferent between these two pairs of outcomes, the sum of their weighted utilities must be equal since,

(cost wt)*(utility of A cost) + (safety wt)*(utility of A safety)
= (cost wt)*(utility of B''' cost) + (safety wt)*(utility of B''' safety).

This indifference equation can be solved for the relative weights between cost and safety by setting all the worst outcome scores for each attribute equal to zero and the best outcome scores equal to one. Since the decision-maker is interested in the relative desirability of the various choices (architectures), a relative scoring method with a zero-one convention for the worst and best outcomes simplifies the analysis. The utility curve between these two points can assume any shape. Typically, when the outcomes are certain and the Government is the decision-maker, the most practical utility for the intermediate outcomes is linear. A linear utility curve means that each additional dollar spent or the next crew loss is just as undesirable as the previous one.

The utility scores for the above outcomes are substituted in the above equation. For the worst cost outcome (utility of A cost) and the worst safety outcome (utility of B''' safety), the utilities are both 0. For the best safety outcome (utility A safety), the utility is 1. If the utility scores for cost between worst and best is linear, then the utility for B''', which is halfway between the worst and best, is .5. The above equation reduces to the following:

$$(\text{cost wt}) * 0 + (\text{safety wt}) * 1 = (\text{cost wt}) * .5 + (\text{safety wt}) * 0$$

$$(\text{safety wt})/(\text{cost wt}) = .5$$

This trade-off relationship indicates that the safety attribute is one-half as important as the cost attribute, given these specific ranges for each attribute.

Thus, the tradeoff assessment between pairs of attribute outcomes reveals their relative weights. The rationale for the weights is based on specific preferences for different sets of attribute outcomes. The trade-offs and the reasons for them are based on the decision-maker's inherent preferences for specific combinations of outcomes. Both the preferences and rationale can be communicated and discussed, and the audit trail of the decision-makers thinking is preserved for future reference.

The number of tradeoff assessments required, of the type shown in Figure 3.2.1.3-2, to compute the relative weights between N attributes is N-1 tradeoff pairs. Typically, one attribute is selected as the reference attribute and the tradeoff relationship is found between it and all the others. The most important attribute is generally used as the reference, and for many evaluation studies of this type the most important attribute is often cost. As a consistency check, other attributes were used as the reference in the tradeoff as a partial consistency check.

A comparison of weightings resulting from this method and the direct method is given in Table 3.2.1.3-2. Notice that, except for the slight lowering of the PMS weighting, the results are very similar. The basis of this study uses the direct method. These weightings are a good measure of the relative importance of the major attributes that should be used in judging human launch systems.

In the final analysis, the only attribute weightings that matter are those that the NASA administrators chooses (the customer). The process he uses to combine the attributes will also affect his choice of the next human transportation system. Therefore, while the HTS team believed that the analytical/mathematical method it developed was useful in identifying trends and drivers affecting the architecture rankings, the results of this method are not reported in the findings section (3.3.12). What will be reported are the major attribute values and key drivers effecting those values that the HTS team believes will affect a customers decision.

TABLE 3.2.1.3-2.– COMPARISON OF ATTRIBUTE WEIGHTING METHODS

Attribute	Direct Method	Trade-off Method
Funding Profile	27	30
Human Safety	29	33
PMS	19	11
Architecture Cost Risk	13	11
Launch Schedule Confidence	8	8
Environment	4	7
Total, %	100	100

3.2.2 Funding Profile

This section contains the definitions of the Funding Profile attribute and its measures, a discussion of the process by which the architecture cost estimates were generated, the HTS cost analysis groundrules and assumptions, and a discussion of the utility curves for this attribute.

3.2.2.1 Definition

The Funding Profile attribute is evaluated through the consideration of two subattributes, Total Architecture Cost (TAC) and Peak Year Funding (PYF). The definition of Funding Profile adopted by the NIT is:

> The sum of the system costs of an architecture, by year, incurred over the time period of study interest (1992-2020), to deliver all missions flown from 1998 through 2020. The costs per year include the non-recurring and recurring element/system costs associated with providing the capability to satisfy the mission model as defined in the particular 'If' scenario of interest.

The subattributes of TAC and PYF are defined as:

> The TAC is the total architecture cost over the life of the study, including the cost of unreliability. The PYF is the dollar amount in the year of peak (maximum) costs.

3.2.2.2 Measurement of Attribute

The following describes the methodology used to develop the cost data used for the funding profile of each architecture.

3.2.2.2.1 Cost analysis data flow.– The cost analysis was carried out as an integrated process, requiring key inputs supplied by each of several different NIT groups developing and measuring different architecture attributes. Resulting architecture cost estimates were passed to the AET for final processing and inclusion in the overall architecture scoring process. Figure 3.2.2-1 outlines the Funding Profile attribute data flow.

The manifesting lead supplied yearly flight rates and system IOC dates for each system. The operations lead defined architecture asset requirements, including

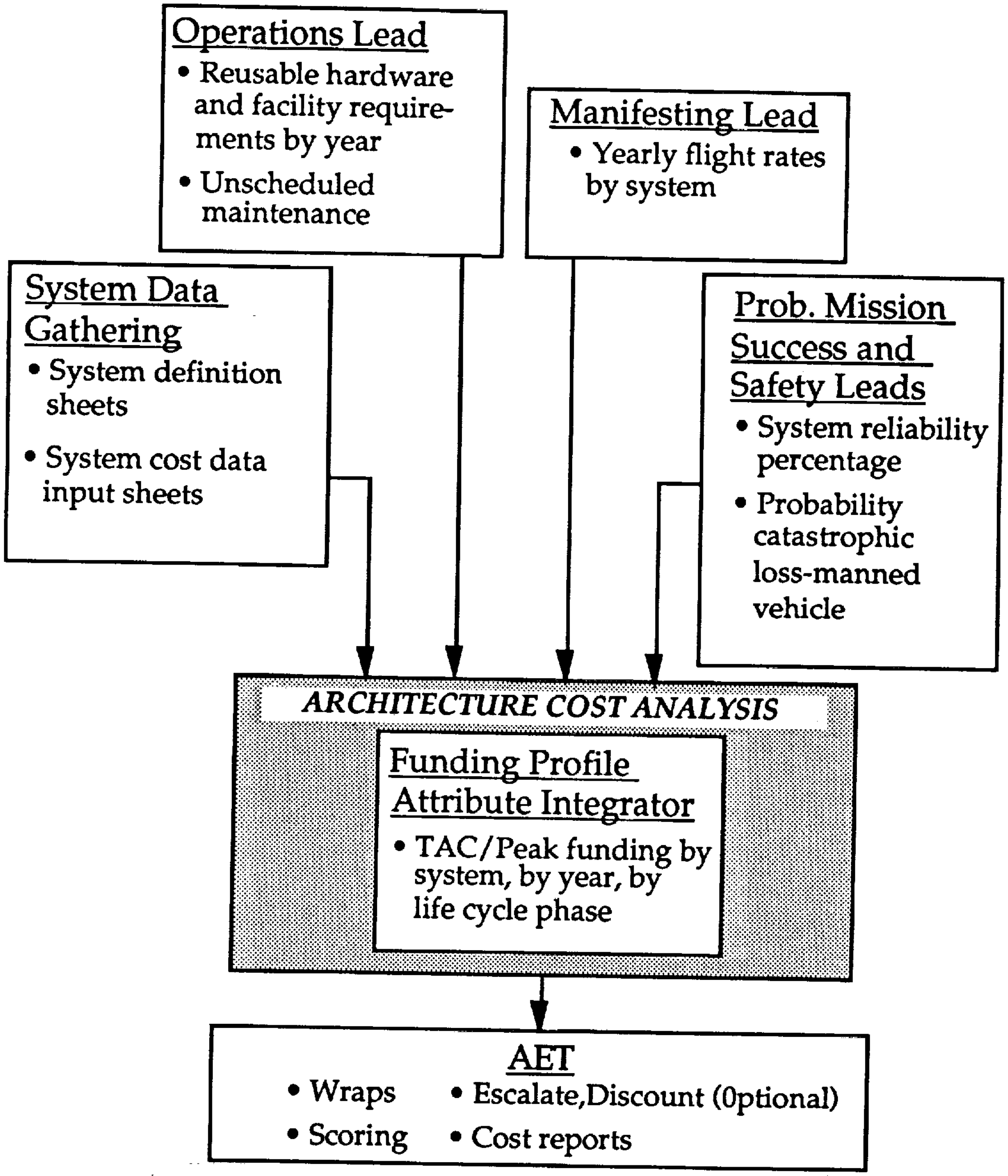


Figure 3.2.2-1.– Funding profile attribute architecture cost analysis data flow.

ground facilities and reusable hardware production quantities (if hardware quantities were driven by ground processing times instead of flight rates). The system data leads provided system cost input data for each system, including the non-recurring costs for DDT&E and facilities, as well as flight-rate-sensitive recurring production and operations cost inputs. These were in the form of Theoretical First Unit (TFU) costs plus learning and rate curves, and/or fixed per year and variable per flight costs. As part of their inputs, system data leads also provided year-by-year spread factors for each cost element to reflect the year in which costs were incurred.

The architecture cost "model" utilized to generate the architecture level cost estimates was a series of electronically linked Excel computer spreadsheets, each calculating some portion of TAC. A separate model of linked spreadsheets was developed for each architecture, modifying the spreadsheets to tailor them to reflect the specific systems included in each unique architecture. Figure 3.2.2-2 illustrates the general input-process-output connections within the cost model.

3.2.2.2.2 Cost analysis definitions.– The TAC of an architecture includes the total cost of all transportation systems in the architecture, where total system life cycle cost is the sum of non-recurring, recurring, and transportation system failure costs as defined below

The TAC for each architecture system includes all applicable Work Breakdown Structure (WBS) systems and subsystems for the following phases of the system's life cycle:

- Non-Recurring - Design, Development, Test, and Evaluation (DDT&E), Non-Recurring Production, Facilities, Pre-Planned Productivity Improvement (P3I)

- Recurring - Recurring Production, Operations

- Transportation system failures

The WBS used is shown in Table 3.2.2-1.

DDT&E includes the cost of the following for each applicable WBS item for new vehicle development and existing vehicle modifications consistent with a Full Scale Development program:

- Hardware (Ground and Flight) - design, prototype manufacturing and assembly, test and evaluation, integration of all vehicle and ground support equipment (GSE)/peculiar support equipment (PSE) WBS items to next higher assembly through system level integration, systems engineering, program management

- Software (Ground and Flight) - systems analysis (design), coding, test and debug, system integration, validation and verification, and program management

Facilities costs include architecture and engineering, construction of facilities (C of F or "brick & mortar"), Real Property Installed Equipment, and site activation for any new, additional, or modified production, launch, flight, or associated facilities.

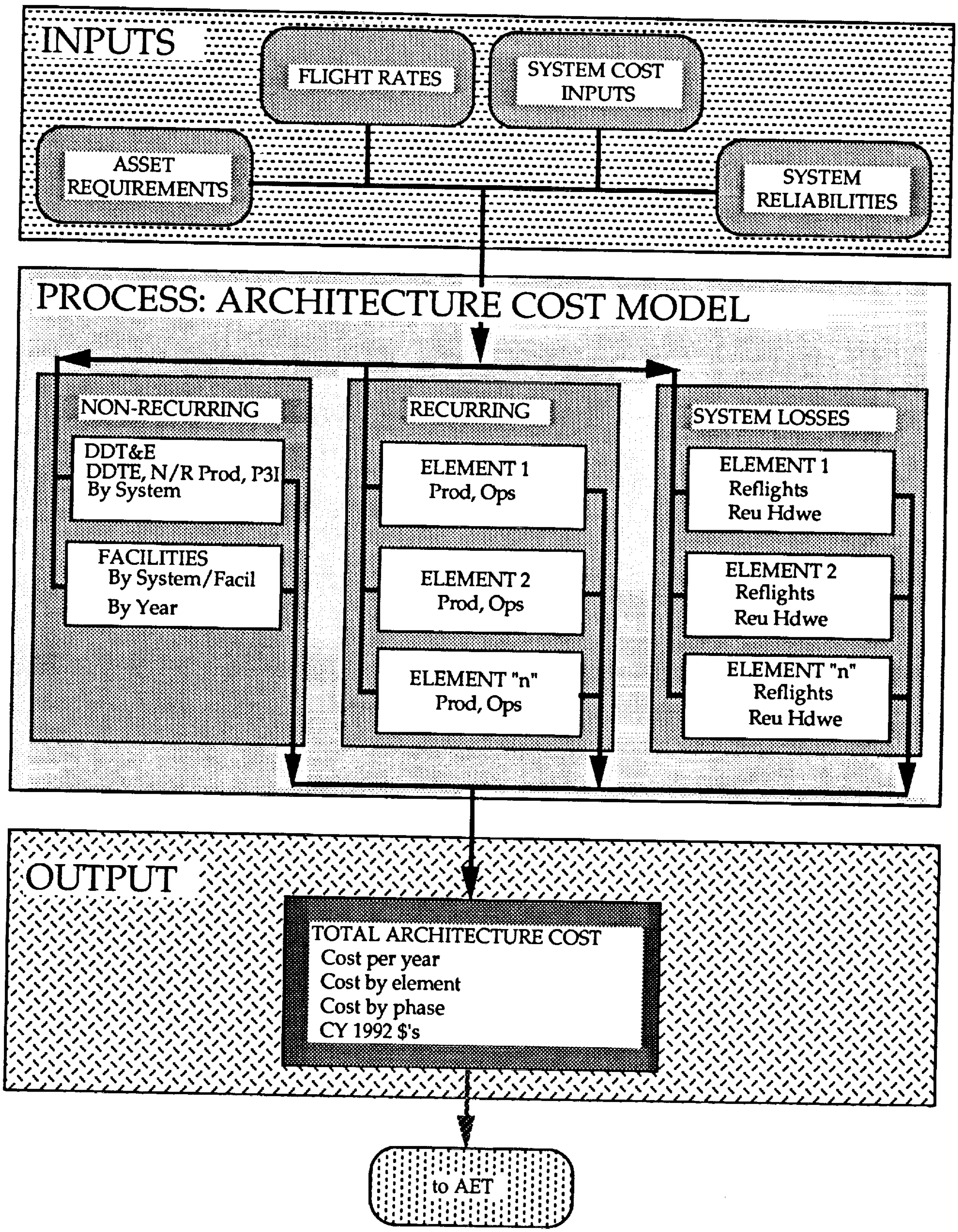


Figure 3.2.2-2.– Architecture cost modeling process.

TABLE 3.2.2.-1.– HTS WBS

LEVEL: 0 LABEL: Architecture	I System	II Segment	III Element	IV Subsystem	V Subsystem Definitions (As Applicable - Items Listed = Examples Only)
n.0 ARCHITECTURES 1 TO 18					
	1.0 TRANSPORTATION SYSTEM - COMMON SYSTEMS				For elements common between systems in an architecture
		1.1 *PROGRAM SEGMENT*			
			1.1.1 Program Management & Support		
			1.1.2 Systems Engineering & Integration		
		1.2 *VEHICLE SEGMENT*			
			1.2.1 to 1.2.6 ELEMENTS (1 thru 6)		All stages, plus shrouds, crew modules, reusable cargo carriers
				1.2.1.1 IAT	Element integration, assembly, & test
				1.2.1.2 Structures	Tanks, Adapters, Skirts, Wings, Empennage, Fuselage
				1.2.1.3 Separation Sys	Separation systems, Ordnance, Disconnects
				1.2.1.4 Recovery & Landing Sys	Parachutes, Landing Gear
				1.2.1.5 Thermal Protection	Tiles, Blankets, MLI, Carbon/Carbon, SOFI
				1.2.1.6 Main Engine Prop	Liquid engines, Solid motors
				1.2.1.7 Auxiliary Propulsion	TVC, RCS, OMS
				1.2.1.8 Propulsion Feed Sys	Feed lines, Fill & drain, Propellant Utilization, Pressurization
				1.2.1.9 Power Gen & Distrib	Batteries, Fuel Cells, Cables & harnesses, Power Distrib Units
				1.2.1.10 Control System	Hydraulics, EMAs
				1.2.1.11 Avionics	GN&C, Comm & Track, Data Process, Instrumentation, Telemetry Range Safety, Active thermal control
				1.2.1.12 Envir Ctl & Life Supt	Atmosphere Ctl, Consumables & waste mgt, Airlock
				1.2.1.13 Tooling	Design, manufacture, and maintenance of production rate tooling
				1.2.1.14 Support Equipment	System-peculiar (or common for 1.0) ground support equipment (GSE)
				1.2.1.15 Spares & Repair Parts	Sum of all element subsystem spares
				1.2.1.16 Major Overhauls	Major overhaul of entire element, including all subsystems
		1.3 *GROUND SEGMENT*			
			1.3.1 FACILITIES & EQUIPMENT		
				1.3.1.1 Launch Pad	For all facilities: Non-Recurring = Architecture & Engineering
				1.3.1.2 Vertical Process Facil	(A&E), Construction of Facility (C of F), Site Activation (SA);
				1.3.1.3 Horizontal Proc Facil	Recurring = Facility maintenance
				1.3.1.4 Launch Ctl Cntr	*
				1.3.1.5 Mission Control Ctr	*
				1.3.1.6 Comm Network	*
				1.3.1.7 Test Facilities	*
				1.3.1.8 Manufacturing Facil	* Government Owned/Contractor Operated (GOCO) only
				1.3.1.n Other Facilities	Whatever other facilities apply to specific system
		1.4 *TEST & OPERATIONS SEGMENT*			
			1.4.1 SYSTEM TEST & EVALUATION		

LEVEL: 0 LABEL: Architecture	I System	II Segment	III Element	IV Subsystem	V Subsystem Definitions (As Applicable - Items Listed = Examples Only)
				1.4.1.1 Development Tests	Subsystems - aerothermal, acoustic shock & vibration, fluids
				1.4.1.2 Operational Tests	Integrated system ground, flight
			1.4.2 SYSTEM OPERATIONS & SUPPORT		
				1.4.2.1 Training	Start-up training program for personnel associated with operations, recurring crew and flight controller training
				1.4.2.2 Launch Operations	Vehicle launch processing, Cargo integration, Flight-to-flight refurbishment, Base ops support, Liquid propellants, Landing & recovery ops, Unscheduled maintenance
				1.4.2.3 Flight Operations	Flight planning & design, Real-time mission control, Analytical payload integration, Crew operations
		1.5 *SOFTWARE SEGMENT*			
			1.5.1 FLIGHT SOFTWARE		
				1.5.2.1 Operating System	For all software: Non-Recurring = System design, coding, test &
				1.5.2.2 Guidance, Nav, & Ctl	debug, Independent Verification & Validation;
				1.5.2.3 Subsystems Mgt	Recurring = Software maintenance, Flight-to-flight reconfiguration
				1.5.2.4 Comm/Telemetry	
				1.5.2.5 Other	
			1.5.2 GROUND SOFTWARE		
				1.5.3.1 GSE Operations	
				1.5.3.2 Pre Launch Ops	
				1.5.3.3 Launch Management	
				1.5.3.4 Post Launch Ops	
				1.5.3.5 Other	
	2.0 to n.0 TRANSPORTATION SYSTEM - INDIVIDUAL SYSTEMS				For each individual system in an architecture

Non-Recurring Production includes the cost of the following for each applicable WBS item:

- Tooling - design and manufacture of production-rate tooling.
- Initial Training - start-up training for all personnel associated with recurring phase activities, such as production manufacturing personnel, ground operations technicians, and flight controllers.
- Initial Spares - initial lay-in of vehicle spares and repair parts.
- Prototype Refurbishment - cost associated with refurbishing a development prototype unit for production use.
- Support Equipment Acquisition - fabrication, assembly, and initial lay-in of spares and repair parts of GSE, including common and peculiar equipment.

Preplanned Productivity Improvement includes continuing modification and upgrade programs. For example, for Space Shuttle, these would include: an interface monitoring unit (IMU), general purpose computer, and auxiliary power unit (APU) upgrades, Extended Duration Orbiter (EDO), and Space Shuttle main engine (SSME) turbopump redesign.

Recurring Production includes:

- Hardware - procurement, fabrication, assembly, integration and checkout of all reusable and expendable vehicle flight hardware, program management and manufacturing support activities (tooling and plant maintenance, scheduling, quality assurance, etc.), transportation to launch site, major off-line overhauls of reusable vehicles, and vehicle spares and repair parts.

Recurring Operations includes:

- Launch - hands-on launch vehicle processing and integration, payload-to-vehicle cargo integration, flight-to-flight refurbishment and checkout (reusables), launch processing support activities (ground software maintenance, launch facility and GSE maintenance/recurring spares, base operations support, and program management), liquid propellants, landing and recovery ops, and unscheduled maintenance operations and support.
- Flight - flight planning and design, flight-to-flight mission software development and reconfiguration, flight software simulation and test, crew and flight controller recurring training, real-time mission control, analytical payload integration, systems engineering and integration, program management, crew operations, base operations support, and communications network support.

- On-Orbit - on-orbit space transportation operations and support activities.

Transportation System Failure costs include the cost of vehicle replacement and reflight. The number of failures was determined by multiplying the individual element or system total flights in the architecture by one minus the element or system's PMS. This number was used to determine the number of reflights to be included in the cost of unreliability. This cost was estimated using the variable portion of operations cost. In the case of expendable systems, this cost also included the cost of an additional vehicle. The production cost of the additional expendable vehicles were costed at an average or nominal production rate for the architecture. In the case of reusable vehicles, the number of crew loss events per element or system per architecture was used to determine the number of replacements of reusable vehicles which was added to the variable operations cost. Cost *did not* include lost payloads, accident investigation and resolution, added cost during backlog recovery, or cost of lost opportunities.

3.2.2.2.3 Cost analysis groundrules and assumptions.– All costs are reported in constant 1992 dollars. Data normalization to 1992 dollars and any HTS program requirements to provide escalations of architecture funding profiles to inflation-adjusted, then-year dollars is accomplished using the Code BA NASA New Start Inflation Index escalation rates published May 13, 1991, shown in Table 3.2.2-2.

Present value discounting can be accomplished using the AET. The discount rates are used on yearly funding streams of escalated (using the above yearly rates), then-year dollars. (The study team chose to look only at the constant dollar costs for analysis and comparison of architectures.)

The TAC assessment time horizon for all architectures is 1992 through 2020, considering the non-recurring and recurring cost to support all missions flown from 1998 through 2020. The costs for missions flown from 1992 through 1997 are *not* considered part of TAC. As an exception, in the event architecture assets, including ground facilities or new reusable hardware elements (e.g., launch pad or Space Shuttle Orbiter) are required to support flights from 1992 through 1997, and are also required subsequently to support post-1997 flights, the cost to provide those assets is recognized in the years appropriate to support the pre-1998 flights.

Cost wraps - with the exception of existing systems, whose costs were assumed to inherently include wraps, all architecture estimates provided to the architecture evaluation tool did *not* include wrap factors for contractor fee, government support, and contingency. The wrap factors are applied to the cost estimates within the AET. Agreed upon baseline wrap factors are contained in Table 3.2.2-3.

Transportation system cost data inputs were supplied to the funding profile attribute integrator using standard format cost data input sheets (see Table 3.2.2-4).

TABLE 3.2.2-2.– CODE BA NASA NEW START INFLATION INDEX

	1991	1992	1993	1994	1995	1996	1997	1998	5/23/91 1999	2000	2001	2002	2003	2004	2005	
	4.0%	5.0%	4.9%	5.2%	5.3%	5.0%	5.2%	5.2%	5.4%	5.6%	5.0%	5.0%	5.0%	5.0%	5.0%	
	1.040	1.050	1.049	1.052	1.053	1.050	1.052	1.052	1.054	1.056	1.050	1.050	1.050	1.050	1.050	
FROM 1959	6.531	6.857	7.193	7.567	7.968	8.367	8.802	9.260	9.760	10.306	10.822	11.363	11.931	12.527	13.154	1959
FROM 1960	6.262	6.575	6.897	7.255	7.640	8.022	8.439	8.878	9.357	9.881	10.375	10.894	11.439	12.011	12.611	1960
FROM 1961	6.067	6.371	6.683	7.030	7.403	7.773	8.177	8.603	9.067	9.575	10.054	10.556	11.084	11.638	12.220	1961
FROM 1962	5.834	6.126	6.426	6.760	7.118	7.474	7.863	8.272	8.718	9.207	9.667	10.150	10.658	11.191	11.750	1962
FROM 1963	5.637	5.919	6.209	6.531	6.878	7.221	7.597	7.992	8.424	8.895	9.340	9.807	10.297	10.812	11.353	1963
FROM 1964	5.394	5.664	5.941	6.250	6.581	6.911	7.270	7.648	8.061	8.512	8.938	9.385	9.854	10.347	10.664	1964
FROM 1965	5.217	5.477	5.746	6.045	6.365	6.683	7.031	7.396	7.796	8.232	8.644	9.076	9.530	10.007	10.507	1965
FROM 1966	4.921	5.167	5.421	5.703	6.005	6.305	6.633	6.978	7.355	7.766	8.155	8.562	8.991	9.440	9.912	1966
FROM 1967	4.691	4.926	5.167	5.436	5.724	6.010	6.323	6.652	7.011	7.404	7.774	8.162	8.571	8.999	9.449	1967
FROM 1968	4.451	4.674	4.903	5.158	5.431	5.703	5.999	6.311	6.652	7.024	7.376	7.744	8.132	8.535	8.965	1968
FROM 1969	4.211	4.422	4.638	4.879	5.138	5.395	5.676	5.971	6.293	6.646	6.978	7.327	7.693	8.078	8.482	1969
FROM 1970	3.939	4.136	4.339	4.565	4.806	5.047	5.309	5.585	5.887	6.217	6.527	6.854	7.196	7.556	7.934	1970
FROM 1971	3.706	3.891	4.082	4.294	4.522	4.748	4.995	5.254	5.538	5.848	6.141	6.448	6.770	7.108	7.464	1971
FROM 1972	3.506	3.681	3.862	4.062	4.278	4.492	4.725	4.971	5.239	5.533	5.809	6.100	6.405	6.725	7.061	1972
FROM 1973	3.317	3.483	3.653	3.843	4.047	4.249	4.470	4.703	4.957	5.234	5.496	5.771	6.059	6.362	6.681	1973
FROM 1974	3.094	3.249	3.408	3.585	3.775	3.964	4.170	4.387	4.624	4.883	5.127	5.383	5.652	5.935	6.232	1974
FROM 1975	2.793	2.932	3.076	3.236	3.407	3.578	3.764	3.959	4.173	4.407	4.627	4.859	5.102	5.357	5.624	1975
FROM 1976	2.562	2.690	2.822	2.969	3.126	3.282	3.453	3.632	3.829	4.043	4.245	4.457	4.680	4.914	5.160	1976
FROM 10	2.509	2.635	2.764	2.908	3.062	3.215	3.382	3.558	3.750	3.960	4.158	4.366	4.584	4.813	5.054	10
FROM 1977	2.313	2.428	2.547	2.680	2.822	2.963	3.117	3.279	3.456	3.650	3.832	4.024	4.225	4.436	4.658	1977
FROM 1978	2.145	2.253	2.363	2.486	2.618	2.749	2.891	3.042	3.206	3.386	3.555	3.733	3.919	4.115	4.321	1978
FROM 1979	1.959	2.057	2.158	2.270	2.391	2.510	2.641	2.778	2.928	3.092	3.246	3.409	3.579	3.758	3.946	1979
FROM 1980	1.770	1.858	1.949	2.051	2.159	2.267	2.385	2.509	2.645	2.793	2.933	3.079	3.233	3.395	3.565	1980
FROM 1981	1.607	1.688	1.771	1.863	1.961	2.059	2.167	2.279	2.402	2.537	2.664	2.797	2.937	3.083	3.238	1981
FROM 1982	1.491	1.566	1.642	1.728	1.819	1.910	2.010	2.114	2.228	2.353	2.471	2.594	2.724	2.860	3.003	1982
FROM 1983	1.401	1.472	1.544	1.624	1.710	1.796	1.889	1.987	2.094	2.212	2.322	2.438	2.560	2.688	2.823	1983
FROM 1984	1.330	1.396	1.465	1.541	1.622	1.704	1.792	1.885	1.987	2.098	2.203	2.313	2.429	2.551	2.678	1984
FROM 1985	1.286	1.350	1.416	1.490	1.569	1.648	1.733	1.823	1.922	2.029	2.131	2.237	2.349	2.467	2.590	1985
FROM 1986	1.249	1.311	1.375	1.447	1.523	1.600	1.683	1.770	1.866	1.970	2.069	2.172	2.281	2.395	2.515	1986
FROM 1987	1.199	1.259	1.321	1.390	1.463	1.537	1.616	1.700	1.792	1.893	1.987	2.087	2.191	2.301	2.416	1987
FROM 1988	1.139	1.196	1.255	1.320	1.390	1.459	1.535	1.615	1.702	1.797	1.887	1.982	2.081	2.185	2.294	1988
FROM 1989	1.087	1.141	1.197	1.259	1.326	1.392	1.465	1.541	1.624	1.715	1.801	1.891	1.985	2.085	2.189	1989
FROM 1990	1.040	1.092	1.146	1.205	1.269	1.332	1.402	1.475	1.554	1.641	1.723	1.809	1.900	1.995	2.095	1990
FROM 1991	1	1.050	1.101	1.159	1.220	1.281	1.348	1.418	1.494	1.578	1.657	1.740	1.827	1.918	2.014	1991
FROM 1992		1	1.049	1.104	1.162	1.220	1.284	1.350	1.423	1.503	1.578	1.657	1.740	1.827	1.918	1992
FROM 1993			1	1.052	1.108	1.163	1.224	1.287	1.357	1.433	1.504	1.580	1.659	1.742	1.829	1993
FROM 1994				1	1.053	1.106	1.163	1.224	1.290	1.362	1.430	1.502	1.577	1.655	1.738	1994
FROM 1995					1	1.050	1.105	1.162	1.225	1.293	1.358	1.426	1.497	1.572	1.651	1995
FROM 1996						1	1.052	1.107	1.166	1.232	1.293	1.358	1.426	1.497	1.572	1996
FROM 1997							1	1.052	1.109	1.171	1.229	1.291	1.355	1.423	1.494	1997
FROM 1998								1	1.054	1.113	1.169	1.227	1.288	1.353	1.421	1998
FROM 1999									1	1.056	1.109	1.164	1.222	1.284	1.348	1999
FROM 2000										1	1.050	1.103	1.158	1.216	1.276	2000
FROM 2001											1.000	1.050	1.103	1.158	1.216	2001
FROM 2002												1.000	1.050	1.103	1.158	2002
FROM 2003													1.000	1.050	1.103	2003
FROM 2004														1.000	1.050	2004
FROM 2005															1.000	2005

TABLE 3.2.2-3.– BASELINE WRAP FACTORS

Element	Non-Recurring Costs	Recurring Costs
Fee *	10%	10%
Program Support **	20%	10%/15% #
Reserves ***	35%	20%
HQ Taxes ****	2%	2%
Combined Total Wrap Factor	**80.4%**	**47.4%/54.0% #**

Notes:

* Percentage shown is of Prime Cost.

** Percentage shown is of Total Prime Cost with Fee. Includes management and integration.

*** Percentage shown is of Total Prime Cost with Fee + Program Support.

**** Percentage shown is of Total Prime Cost with Fee.

With No Primary Engines/With Primary Engines

The Vehicle Cost Inputs Summary sheets were used as the cost data input to the architecture cost model. It was the minimum system data required to conduct an architecture cost analysis. It included top level non-recurring cost estimates for DDT&E, Non-Recurring Production, P^3I, and Facilities, as well as recurring element estimates in a flight-rate sensitive format for TFU and learning and rate curves, and/or fixed cost per year and variable cost per flight.

It also included per year cost-spread factors for each element, and other pertinent information such as elements common with other systems, critical technologies, facility dwell times, and reusable hardware useful life.

TABLE 3.2.2-4.–VEHICLE COST DATA INPUT SUMMARY SHEET - SAMPLE

SHUTTLE

NON-RECURRING	TOTAL COST	SPREAD FACTORS -8	-7	-6	-5	-4	-3	-2	-1	EARLIEST IOC	DWELL TIME	MAX FPY/FAC*	NUM FAC
RDT&E	$0												
N/R PROD	$0												
P3I	$1,000	100%	100%	100%	100%	100%	100%	100%	100%				
FACILITIES:													
Pad	$973					15%	40%	40%	5%		28	10.7	2
VAB-1 Hi Bay	$252					15%	40%	40%	5%		41	7.3	2
OPF - 1 Lo Bay	$268					25%	30%	30%	15%		60	5.0	3
LCC - 1 Fr Room	$54						40%	45%	15%				3
MLP	$116						35%	45%	20%		64	4.7	3
Production													

* 300 workdays/yr

RECURRING	QTY/ VEHICLE	UNIT COST: TFU	LC%	RC%	VAR CPF	FIXED CPY	SPREAD FACTORS -5	-4	-3	-2	-1	YEAR OF FLIGHT	COMMON-ALITY
PRODUCTION													
• Reusable •													
Orbiter (New)		$1,637	100%	100%				25%	30%	30%	15%		
SSME (New)		$96	90%	90%					25%	60%	15%		
Flight to Flight •													
ET					$12	$352			23%	36%	40%	1%	
SRB (S/Set)					$23	$358				1%	58%	41%	
SSME (Refurb)					$5	$75			16%	26%	26%	32%	
Orbiter/CE					$10	$229						100%	
LAUNCH OPS					$5	$598						100%	
FLIGHT OPS					$7	$666				1%	7%	92%	
R & PM/SUPT					$0	$327						100%	

CRITICAL ITEMS:

RECURRING CPF (without reusable hardware production)

Flts/Yr	2	4	6	8	10	12
CPF	$1,366	$714	$497	$389	$324	$280

Vehicle-specific assumptions of the following parameter values were provided by system leads on a system-by-system basis:

- Design-useful life and flights per major overhaul (reusables).
- Ground and flight test program definition (number of prototypes, etc.).
- Schedules - IOC's, development and production schedules.
- Operations and personnel shifting assumptions.

The following costs are *not* included in architecture TAC estimates:

- Technology development not conducted directly as part of a system's Phase C/D (FSD) program.
- Phase A/B concept design and demonstration and validation activities.
- Payload acquisition and launch preparation cost (except for transportation-related payloads).
- Previous sunk costs for existing programs.
- SSF Acquisition and Operations cost, except for additional cost which might be incurred to support transportation missions.
- Advanced solid rocket motor (ASRM) development.

The results of the Funding Profile Attribute cost analyses were passed to the AET, where top level wrap factors for government support, contractor fee, and contingency were applied. An example of the summary Funding Profile data available from the AET is shown in Figure 3.2.2-3. The wrapped values of TAC and PYF, expressed in constant 1992 dollars, were used within the AET to generate the overall Funding Profile attribute score.

3.2.2.3 Funding Profile Utility Curves

Linear utility curves were developed for use in the AET to score the various architectures with respect to their costs. Each architecture was examined, by HTS Mission Model "If" scenario to determine the minimum and maximum values of both TAC and PYF within the given "If". For each subattribute, the architecture(s) with the maximum values of TAC or PYF were assigned a score of zero for that subattribute. Conversely, the architecture(s) with the minimum values of TAC or PYF were assigned a score of one. The subattribute scores for all other architectures in the "If" were determined through linear interpolation, based on their values of TAC and PYF relative to the minimum and maximum values.

The final architecture score was obtained by combining the equally weighted scores for TAC and PYF (essentially averaging the two scores) to obtain a single score between zero and one. Since it was unlikely that a single architecture would have both the lowest or highest score in both TAC and PYF, the range of combined scores would most likely be greater than zero and less than one. For this reason, the combined scores were then forced into a range from zero to one through a similar linear interpolation process to that used for the subattribute scores. Again, the highest combined score was given a one, and the lowest a zero. This then assured that at least one architecture in each "If" scored a one or a zero.

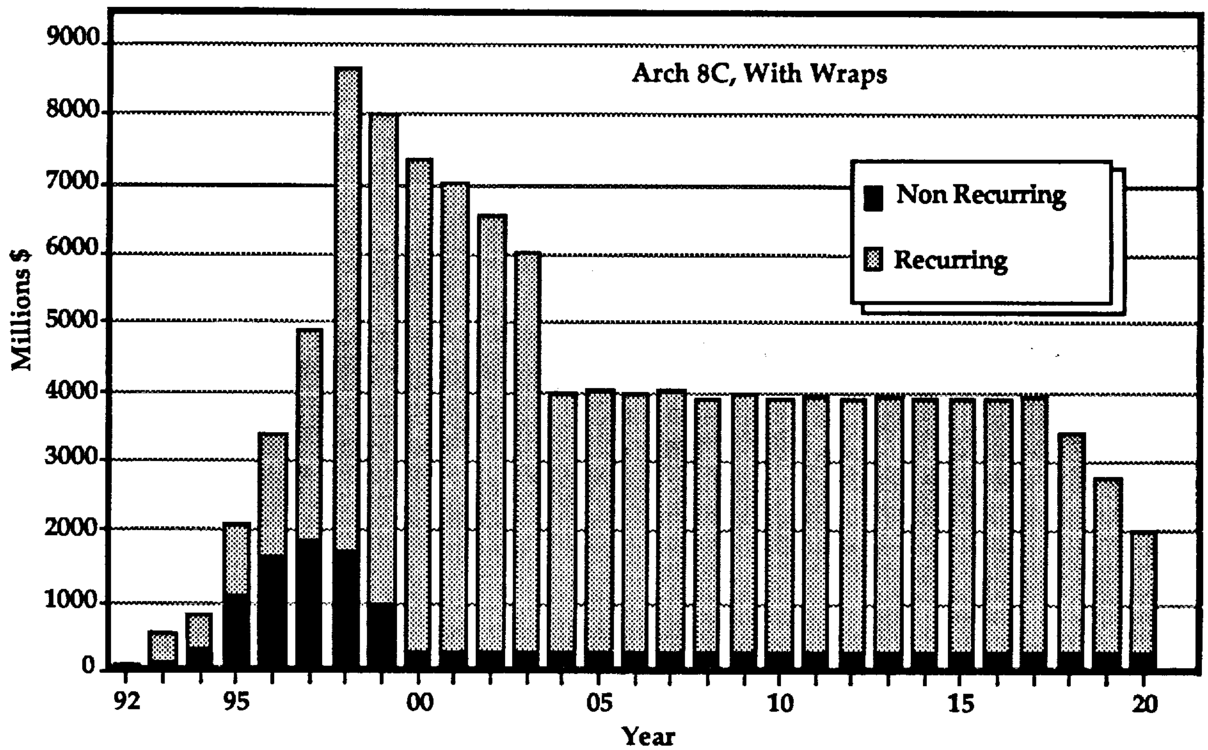


Figure 3.2.2-3.– Example of the funding profile data.

3.2.3 Human Safety

The inclusion of safety as a comparative system attribute was based on the perception that adequately providing for the well being of humans associated with space flight endeavors has been, and will remain, an important consideration to the customer (as well as the general public). Not only should a system exhibit an acceptable level of safety as a moral and legal obligation, but as a means of sustaining public confidence and hence congressional support. From the outset, it is acknowledged that, from a systems engineering perspective, system safety could be measured in terms of cost; the impact of a major mishap or loss has significant program cost (hardware replacement and repair, schedule slides, insurance, etc.) as well as more indirect costs associated with loss of prestige, public confidence, and credibility.

3.2.3.1 Definition

The definitions of the term *safety* vary depending on the scope of the boundaries of a system. In the broadest sense, the definition might best be:

> Safety is freedom from risk to people
> and property both public and private.

This represents the ultimate goal of safety; however, the best that can ever be done is to reduce that risk (through design, testing, and operational procedures) to some agreed upon acceptable level, as risk can never be truly eliminated from any endeavor. It is unlikely that an architecture will be rejected solely on the basis of safety. It is possible that less than an optimum level of safety will be deemed acceptable because of superior mission or cost performance (the Space Shuttle is a typical example). This is acceptable as long as it done from a position of informed consent and a clear understanding exists of the potential effects resulting from the additional risk.

For the purposes of this study, the NIT consensus was to limit the scope of safety to reflect the fact that some of the costs of a failure are covered under other attributes. Based on group discussions, the HTS definition of safety is as follows.

> Safety is the measure of risk in terms of
> human loss caused by the elements and/or
> operations associated with a given architecture.

Human loss is defined as death (or incapacitating injury) of flight personnel. No attempt was made to determine loss of the general populace that would be associated with a catastrophic event involving a major population center (such as a crash in Orlando or a major chemical spill). This definition is also meant to exclude the impact on property.

The exclusion of ground personnel from the definition of safety was a point of much discussion. Basically, it was thought that it would be extremely difficult to measure losses of ground personnel, requiring Monte Carlo type simulations of ground operations for systems which in some cases are strictly hypothetical. Assuming the losses could be calculated, the question remains, "What is the impact of ground personnel losses as compared to flight personnel (astronauts) losses?" While it is probably true that flight crew losses result in larger cost and schedule impacts, can or should a differentiation be made? The approach was not to consider ground personnel and to assert that any endeavor or industrial activity involves accidents and losses, not just activities related to spaceflight. To check this assertion, recent accident rates for space launch operations personnel and typical aerospace industry were compared. For KSC, (contractor and government personnel) an average of 0.89 cases and 13.0 lost days per 100 workers is typical. The corresponding figures for the aerospace industry were 4.5 cases and 114.7 lost and restricted days.

The establishment of the level of necessary and acceptable risk is a formidable task, and is one not to be determined in this study. In other aerospace systems, a Military Specification or Federal Aviation Administration Federal Airworthiness Regulation would be used as a basis for identifying acceptable risk. For space systems, the nation still seems a long way from such guidelines. Even the man-rating standards now in development seem unlikely to assuage the public in the event of the loss of the astronauts. In any case, once a level of acceptable risk has been defined, all systems can be simply evaluated - either they conform or they do not conform. There is no such thing as "safe, safer, and safest", only safe or unsafe.

3.2.3.2 Measurement of the Attribute

The approach taken to compare safety was to calculate a risk index for each proposed element. Each architecture, in turn, would sum the indices for the elements it uses to arrive at a total probable number of flight personnel losses over the duration of the architecture.

Inflight emergencies can be caused by any number of failures and often involve complex system interactions; some of these emergencies will require contingency procedures. Because it was impractical to model all the possible failure modes and effects, six major groupings of typical failures were evaluated for each flight phase for each system. These categories are meant to define the *primary* cause of the flight emergency – in many historical cases, the failures often involved elements from several categories. For example, the primary cause of the Challenger accident could be used as a structural failure of the aft solid rocket booster (SRB)/external tank (ET) attachment; subsequent rupture of the ET lead to aerodynamic breakup, loss of control, and some degree of explosion. The six categories considered in this study were defined as follows:

- Explosion - a rapid, violent release of energy that is characterized by large change in pressure and temperature. Hazards to crew members result from overpressure to structures and human tissues, flash heating, and shrapnel impacts.

- Fire - an energy release characterized by elevated temperatures. In the process of burning, oxygen available to the crew can be consumed, while at the same time, hot gases, often toxic to humans, are generated.

- Loss of Control - failure to maintain attitude and/or velocity that could place the crew at risk. Hazards to the crew would occur because of overstress of structure (aerodynamic or aerothermodynamic), acceleration or rotation rates in excess of human tolerance, or placement in an unrecoverable locale (high orbit or Arctic waters).

- Damaged Vehicle - failure induced by external sources that compromise the integrity and functionality of the vehicle.

- Benign Failure - a degradation in system performance that is characterized as presenting no immediate life-threatening situation. Any failure that will ultimately necessitate some contingency procedure represents an increase in overall risk. This category includes all failures that do not fit in one of the other five categories.

- Hazardous Environment - a failure that creates a detriment to human health within the crew enclosure. Hazards include toxic substances, loss of pressure, or temperature extremes.

The method used to calculate risk involves a high-level reliability assessment and a statistical (or postulated in new systems) grouping of the major types and effects of failures. The reliability assessment uses the output from the PMS attribute; that is, a reliability value for each distinct and significant flight phase. When a failure event occurs (Probability of Failure = 1- PMS), there is a chance that any crew can survive the short term effects immediately attributable to the failure condition. This Probability of Survival (P_S) is determined for each of six major failure categories through analogy to historical systems and through assessment by a group of safety experts. Subsequently, for the cases where the crew has survived the failure, it is assumed some abort or contingency procedures would be initiated. It is assumed that throughout this attribute that the entire crew realizes the same fate – there is no accounting of partial crew losses. Depending on the system design, flight regime, and the nature of the failure, there will be some probability of a successful abort – defined as the point where the crew has arrived on land alive and with no incapacitating injuries. This Probability of Abort (P_A) is also determined for each of six major failure categories by historical analogy and assessment by a group of safety experts.

To determine the probability of a crew loss event, the probabilities of unsuccessfully surviving and aborting are multiplied together with the relative percentage of occurrence (F, in %) of the major failure category, and then summed to produce a single risk index (called P_D) for each flight phase. Mathematically:

$$P_D = 1 - \sum_{i=1}^{6} \{ (F / 100) * (P_S)_i * (P_A)_i \}$$

where "i" is the failure category.

An example of how a *benign* failure can effect safety is found in the case where an ET fails to separate from the Space Shuttle orbiter. There will be no immediate impact to the mission or to the safety of the crew; however, some contingency procedure will need to be executed to successfully reenter the orbiter, and that procedure may not be wholly successful, resulting in crew loss.

Figure 3.2.3.2-1 is a sample worksheet of how the P_D value is derived; all the worksheets can be found in Appendix B. Another way to look at the value of P_D is to use it as a ratio of loss events over the total failure events. The values for P_D are, in general, conservative; however, since all the elements were developed with the same thinking and the same experts, the *relative* comparison should be valid.

For the entire mission, the P_D by phase is multiplied by the value of unreliability of that phase, and multiplied across all phases to arrive at a net Probability of Loss (P_L) defined as:

$$P_L = 1 - [\prod_{j=1}^{k} \{ P_{MSj} + (1 - P_{Dj}) * (1 - P_{MSj}) \}]$$

where k is the total number of flight phases.

The value of P_D takes into account (qualitatively) the duration of the flight phase (exposure to risk), the flight environment (altitude, q, temperature, ambient pressure, etc.), and the abort modes or contingencies available at that point in the mission profile. Thus a value of P_D of 0.05 is not simply ten times worse than a value of 0.005; multiplication with (1 - PMS) amounts to an adjustment based on the likelihood of failure.

Although typically the riskiest part of any space mission, the ascent phase is only part of the total exposure to hazards for the crew. Should the safety attribute quantify the risks during the rest of the mission? To test the premise that ascent alone would represent all significant losses to be incurred for any given system, a typical flight phase representation for on-orbit operations and descent and landing operations was evaluated. The values of P_D during on-orbit operations are well below the level of descent and landing, which are typically an order of magnitude below the ascent phase. As the on-orbit operations values are so low, and given the high degree of variability that might be encountered from mission to mission, it was

Element: HR Titan IV/PLS
Flight Phase: Stage 1 (Core) Ignition

Emergency	Probable Cause	% of Failures	P Survivable	P Abort
Explosion	Propellant leak, turbopump failure	19	0.5	0.8
Fire	Propellant leak, APU, fuel cells	15	0.3	0.7
Loss of Control	Actuator failure, GN&C failure	20	0.07	0.6
Damaged Vehicle	Shock interactions, transient loads	5	0.5	0.8
Benign Failure	Software, failure of non-critical system	40	0.9	0.97
Hazardous Environment	ECLSS failure, leak in pressure shell	1	0.97	0.9
		100		

PD = 0.1311

Figure 3.2.3.2-1.– Sample safety worksheet.

decided not to include on-orbit operations or descent and landing in the calculation of the safety attribute at this level of study.

3.2.3.3 System Results

Although the most significant safety comparisons are made at the architectural level (multiple systems with variable flight rates), it is informative to examine the relative loss rates of different human systems used in this study. Figure 3.2.3.3-1 depicts the average number of flights between crew loss events for the thirteen

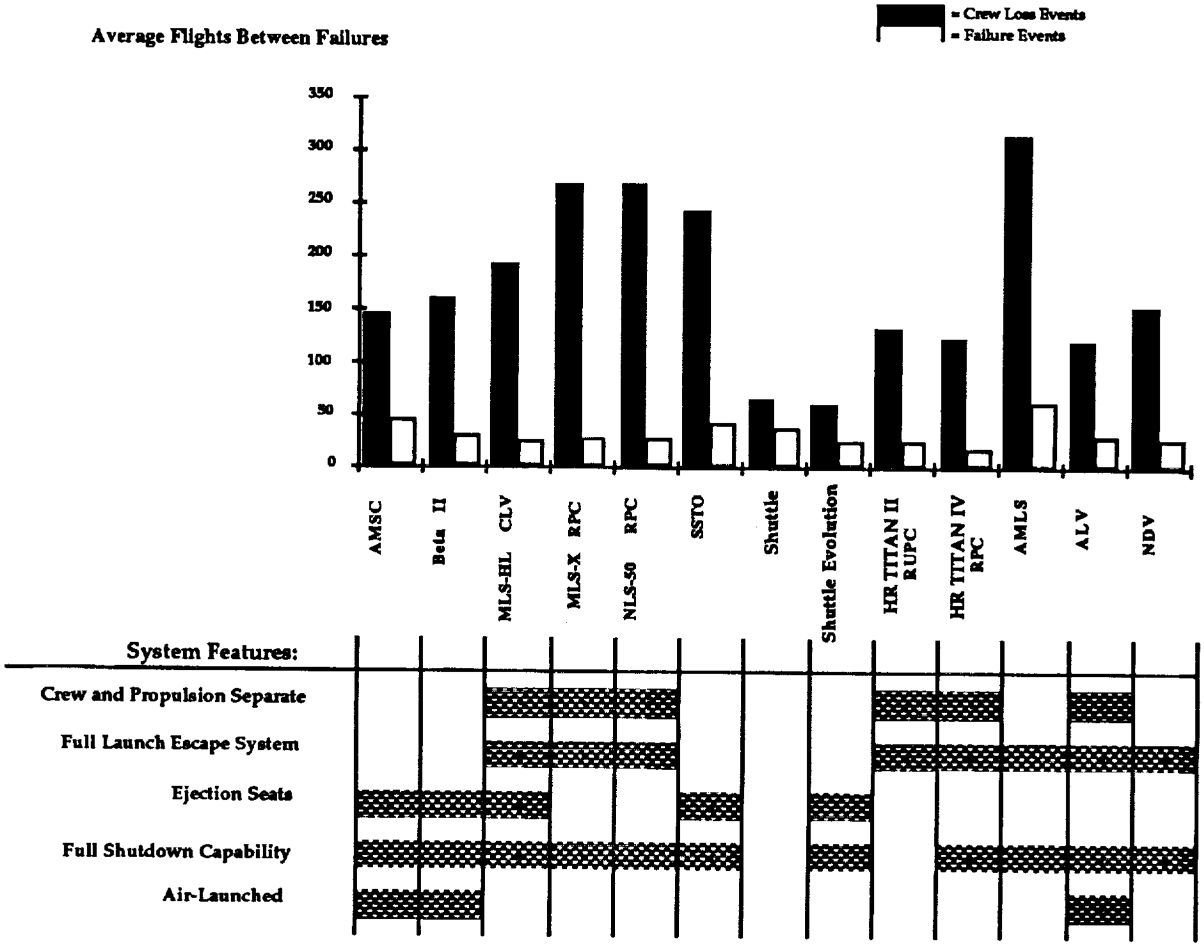


Figure 3.2.3.3-1.– Relative loss rates for human systems.

human systems. The table directly below points out some major features related to safety that help in understanding the relative loss rates.

3.2.3.4 Utility Curves

Development of the utility curve for the safety attribute involved two areas of significant discussion within the NIT: the nature of human loss which was to be measured and the shape of the curve itself. Discussing human losses, especially as it relates to the highly visible astronaut corps, is an emotional argument. To arrive at the utility curve, some basic questions that the NIT debated at length were:

a. What would the nation be more concerned with, 3 failures of a human system in the next 25 years, or a loss of 12 people in the next 25 years?

b. Is the loss of one vehicle carrying six people the same as the loss of three vehicles, each carrying two persons?

c. Is the rate or timing of loss events important? For example, do two loss events (before the year 2020) 2 years apart have the same score as two loss events, 10 years apart? Can this effect be responsibly modeled within this study?

d. Should loss calculations be rounded off? While only integers are valid to count actual losses, can rounding up lead to erroneous conclusions? For example, is a calculated value of 2.006 losses equal to two or three loss events?

Within the limitations of this study, the consensus of the group was to base the utility curve on the number of total loss events (non-integer) over the duration of the architecture.

The shape of the utility curve was debated at the NIT forum and the choices narrowed to two general types of functions. One school of thought within the NIT was that each loss event represents a serious blow to the credibility of the human space program and the score would geometrically decrease by one-half for each additional loss (refer to curve (a) on Figure 3.2.3.4-1). Another group within the NIT felt that a trend similar to curve (b) of Figure 3.2.3.4-1 would reflect the customers limited tolerance for system failures. Public opinion may or may not be driven by each failure, but the logic behind curve (b) was that the customer, the decision maker, had the perspective that: past investment in the system(s) was substantial, failures do happen despite the best efforts and are not necessarily symptomatic of a generic flaw in the transportation approach, and the costs (fiscal and political) of moving to a new system may be unacceptably high. Ultimately, curve (c) was selected as an average representation.

The final version of the utility curve is depicted in Figure 3.2.3.4-1 as curve (c). The range of values for the losses, where the utility score decreases from one to zero, is determined by the minimum to maximum range of losses across all architectures within a given "If".

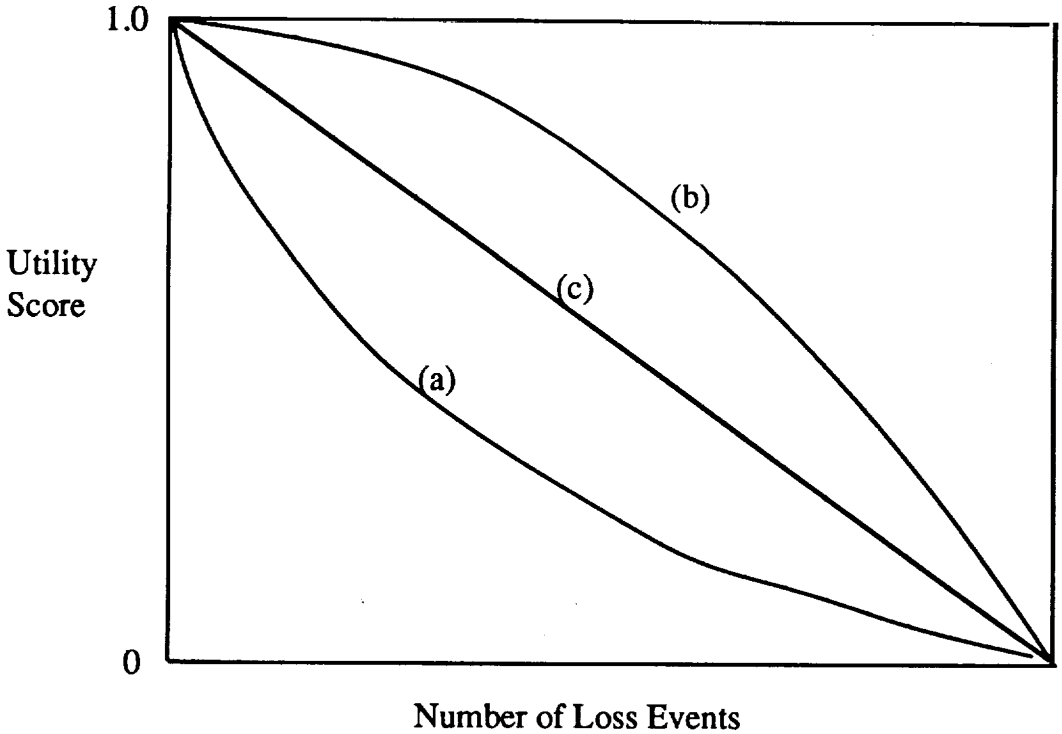


Figure 3.2.3.4-1.– Candidate utility curves for the Human Safety attribute.

3.2.4 Probability of Mission Success

3.2.4.1 Definition

The PMS is the number of successful missions, including transportation elements, but not payload, divided by the total number of missions, including reflights, to work off the effects of failure. Successful missions are defined as accomplishing the jobs described in the mission model, not necessarily returning the reusable hardware or flight crew safely.

3.2.4.2 Measurements

Calculating the PMS begins with describing the phases of flight for each system and constructing a system success tree. Equations are then defined to determine the probability of success of each flight phase. The input values for each variable in the equations are determined for each system and the final PMS is calculated. The architecture value is obtained by flight rate averaging the value for each system and then combining all of the system scores in that architecture.

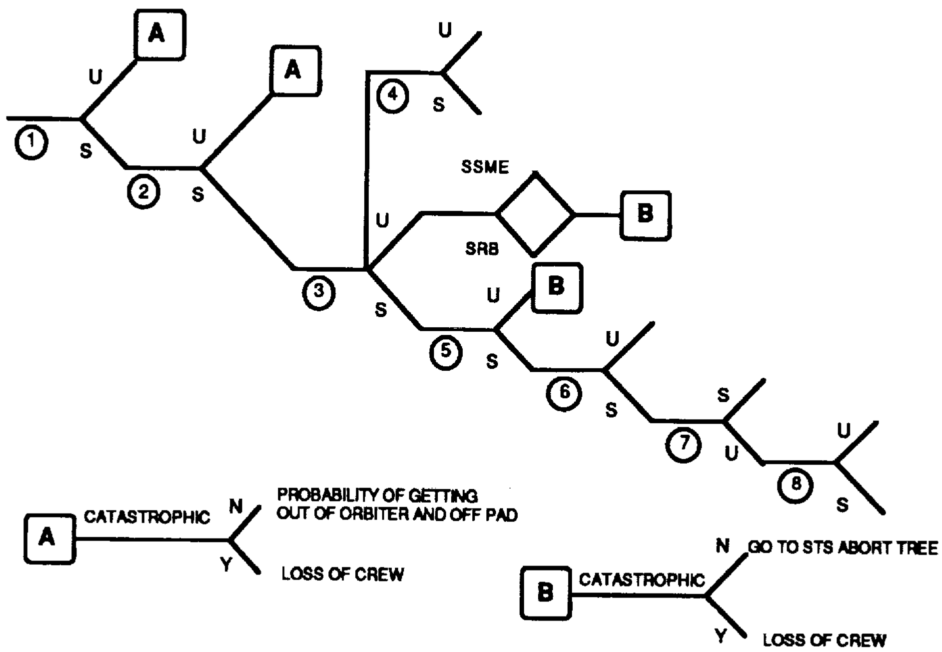
System Success Trees

The foundation for quantifying PMS is the system success tree. The tree developed for the Space Shuttle (Figure 3.2.4.2) is used here to explain its development. A full complement of system success trees can be found in the section B.1.9.2 of the Technical Appendix.

Initially, the mission profile was divided into three parts: ascent, orbit, and descent. Each part was then subdivided into phases based on distinct flight events. These phases represent distinct launch vehicle reliability and/or safety changes. For the Space Shuttle, there are four different propulsive modes during ascent: SSME ignition and thrust buildup (Phase 1), SRB ignition through burnout (Phase 2), SSME operation from SRB jettison through main engine cut-off (MECO) (Phase 4), and orbit circularization (Phase 8). Two staging events; SRB and ET jettison, occur during ascent. SRB jettison (Phase 3) separates Phases 2 and 4. The ET is jettisoned (Phase 3) shortly after MECO. In addition, there is a coast period (Phase 7) between ET jettison and orbit circularization.

Orbit success trees were developed for six distinct mission types: space station crew exchange (internal, or pressurized), servicing, external servicing, sortie science, deployment, and retrieval. Twelve different activities have been identified for on-orbit operations. A job can employ any number of operations, but they all begin

SHUTTLE ASCENT SUCCESS TREE



PHASE	DESCRIPTION	COMMENTS
1	SSME IGNITION	IGNITION AND THRUST BUILDUP
2	SRB IGNITION	IGNITION AND LIFTOFF
3	SSME/SRB BURN TIME	PARALLEL BURN TIME TO SRB TAILOFF
4	SRB SEPARATION	
5	SSME BURN TIME	THROUGH MECO
6	ET JETTISON	
7	COAST	
8	OMS CIRCULARIZATION	INCLUDES IGNITION, BURN & CUTOFF.

Figure 3.2.4.2.– Space Shuttle ascent success tree.

and end with an orbit change. Each system flight can perform multiple jobs and more than one of each job. These on-orbit trees are generic and apply to any system.

Descent trees are also generic. They are comprised of six different operations, beginning with the deorbit burn. Vehicle alignment for entry (Phase 2) is crucial for successful return. Phase 3 extends from entry interface to the point where aerodynamic surfaces can be used. Terminal area energy management defines Phase 4. The use of propulsive hardware during the return phase is covered by Phase 5 (this applies to rocket engines or air-breathing engines). Landing and roll out are included in Phase 6, which begins just prior to landing gear deployment. On-orbit and descent phases were common across all systems and, therefore, did not contribute to mission success comparisons between systems. For this reason the ascent phase was the only part of the mission trees that was modeled for reliability analysis.

Modeling System Reliability

A review of space launch attempts shows that failures can be grouped into three categories: engine failures, propulsion system failures (tanks, lines, etc.) and other failures (avionics, electronics, etc.). The equations used in this study account for the number of engines, stages, and their associated reliabilities. If a system has three engines on one stage, the reliability is cubed. If a particular event (e.g., SSME burn) occurs across several phases, the reliability for that functioning hardware is raised to a power of one over the number of phases in which it operates. A cumulative reliability for a candidate system is the product of the reliability of each phase.

As an example, the following equations were developed for the first five phases of the Space Shuttle ascent.

RS1 = Stage 1 Propulsion Hardware
AR = Avionics Reliability
RL = Liquid Engine Reliability
RSS = Segmented Solids Reliability

Phase 1 - SSME ignition and thrust buildup

$$R_{p1} = RS1^{1/4} * AR^{1/8} * (RL^3)^{1/4}$$

Phase 2 - SRB ignition

$$R_{p2} = RS1^{1/4} * AR^{1/8} * (RL^3)^{1/4} * (RSS^2)^{1/2}$$

Phase 3 - SSME and SRB burn

$$R_{p3} = RS1^{1/4} * AR^{1/8} * (RL^3)^{1/4} * (RSS^2)^{1/2}$$

Phase 4 - SRB Separation

$$R_{p4} = AR^{1/8} * 0.9999$$

Phase 5 - SSME burn to cut-off

$$R_{p5} = RS1^{1/4} * AR^{1/8} * (RL^3)^{1/4}$$

A complete list of system equations can be found in the Volume 2 Technical Appendices, section B.1.9.3.

Deriving System Engine, Stage, and Avionics Reliabilities

Two methods of calculating reliability values for launch vehicle hardware were investigated. They were calculating mean-time-between-failure (MTBF) values and calculating probabilities of success for hardware groups.

The first method was an attempt to develop a MTBF value for each hardware component to take into account the effect of operating time on hardware reliabilities. This method proved difficult for two reasons. The first reason was that a credible method of estimating MTBF's for future launch systems could not be found. The second reason this method was not used was that using MTBF data would have caused an increase in the number of failures with an increased burn time. Analysis of launch histories indicates that nearly as many failures are cycle-dependant and occur early in a launch as are time-dependant and occur after extended flight time. The spread of launch vehicle failures over time has been confirmed by other reliability studies[2].

The second method, deriving a probability of success for hardware groups, was the method that was chosen for this study. A database of Delta, Atlas, Titan, Saturn, and Space Shuttle flight history was used to establish a reference reliability of the three types of hardware system – engines, propulsion systems, avionics. The history of each hardware type was researched to determine the number of flights the hardware type was flown and the number of failures that have occurred. Flights were accumulated based on the number of flights an item was flown (e.g., one Space Shuttle launch is five flights of a liquid propulsion engine, three SSME's, and two Orbital Maneuvering Systems (OMS)). The probability of success for a hardware type was calculated using the following formula:

Reliability (component) = 1 - (# FAILURES / # FLIGHTS)

Because the number of engines is not equal to the number of stage propulsion hardware systems, the failures for this hardware were broken into two groups. Failures occurring in pressurization systems, tanks, lines, and valves were used in the calculation for the stage propulsion hardware reliability. Failures occurring in the engine (i.e., combustion chamber, nozzle cooling system, and gas generators) were used in the engine-reliability calculation. The following are some examples of failures that were attributed to stage propulsion hardware:

DATE	VEHICLE	CAUSE
8/7/66	ATLAS	Centaur propellant leak
8/9/84	ATLAS	LOX leak created lateral thrust
9/1/64	TITAN	Transtage lost helium pressure
10/21/71	DELTA	Oxidizer vent valve lost

For those systems which could lose an engine during ascent and still achieve the proper orbit, the following equation was used to account for the increase in PMS:

$$R_{n \text{ engines with engine out}} = RL^{n} + (n * RL^{n-1} * (1 - RL))$$

The more engines a launch system relies on, the lower its reliability. The SSTO system has the most engines of any system in the HTS study. Because it has engine-out capability, only 11 of the 12 engines need to work. Its statistical probability of success, therefore, is enhanced greatly by engine-out capability.

A sensitivity study was done to determine the need for including a parameter to measure the effect of an engine failure causing catastrophic damage to the other engines on the vehicle (engine correlation factors (CF)). A CF could expose the down side to engine out, since the additional engines could have an increased chance of failing catastrophically and damaging other engines. The SSTO was used as the test for this trade as it has the most engines and has engine-out capability. Using a CF of 0.2, meaning that 20 percent of engine failures propagate beyond the initial failed engine and, therefore, cause mission loss, the difference in PMS was decreased by only 0.005. With the SSTO flying 330 flights, this increased the number of mission failures by only 1.65. It was decided that the effect was not large enough to add value to the study results.

3.2.4.3 System Results

The final calculated PMS values for the systems used in this study are presented in Table 3.2.4.3-1. It is important to note that the purpose of this analysis was to provide a way of comparing relative reliabilities of different launch systems and not to develop a point reliability value. In addition, since the avionics reliability value was a single multiplier used on all systems and did not contribute any comparative information, it was eliminated from the final score. The effect of eliminating the avionics reliability was to increase the predicted system reliabilities by 1.6 percent.

Also, by using a single value based on all launch history since 1964 for a hardware type (such as liquid engines), some existing individual launch vehicles have lower combined reliabilities than their present launch history indicates. An example of this is the Titan IV. If a PMS was calculated for this system according to its recent flight history it would be 0.958. Using the study model yields a PMS for the Titan IV of 0.9307. This bias, however, is applied across all systems and, therefore, does not detract from the validity of its intended purpose as a tool for relative comparison.

Figure 3.2.4.3-2 depicts the results of the study along with indications of the major features that effect the PMS values: number and type of engines, engine-out capability, and number of stages.

3.2.4.4 Utility Curves

The utility curve for PMS is based on assigning a value of 1.0 to the architecture with the highest PMS and a value of 0.0 to the architecture with the lowest PMS for a given "If" scenario. By graphing the results with a straight line connecting these two points, some value between 1.0 and 0.0 can be assigned to each vehicle analyzed. It is important to note that the values of 1.0 and 0.0 are used only as starting and ending points and do not indicate any judgment as to the value of a particular vehicle configuration. These numbers are used only as a starting point for comparison purposes.

TABLE 3.2.4.3-1.– PMS RESULTS

SYSTEM	PMS	STAGES	ENGINES	ENGINE OUT?
AMSC	.9577	2	5	N
ATLAS IIAS	.9326	3	7L,4MS	N
ATLAS EV	.9369	3	5L,4MS	N
BETA II	.9652	2	3	Y
DELTA	.9319	3	3L,10MS	N
MLS-X (CTV)	.9455	3	10	Y
MLS-X (RPC)	.9544	3	12	Y
MLS-X (non SSF)	.9842	1	6	Y
MLS-HL (NUS)	.9691	2	9	Y
MLS-HL (CTV)	.9455	3	11	Y
MLS-HL (RPC/LRV, CRV,CLV)	.9543	3	12	Y
NLS-20 (AUS)	.9435	3	5	N
NLS-50 (CTV)	.9455	3	10	Y
NLS-50 (RPC)	.9544	3	12	Y
NLS-50 (NUS)	.9842	1	6	Y
NLS-50 (AUS)	.9455	3	10	Y

TABLE 3.2.4.3-1.– PMS RESULTS (CONCLUDED)

NLS-HL (CTV)	.9308	3	8L,2SS	Y
NLS-HL (CRV)	.9308	3	8L,2SS	Y
NLS-HL (AUS)	.9308	3	8L,2SS	Y
SSTO	.9691	2	14	Y
Space Shuttle	.9431	2	5L,2SS	N
Shuttle evolution	.9290	4	13	Y
RCV	.9290	4	13	Y
TITAN II	.9626	2	3	N
MR TITAN II (RUPC)	.9323	3	7L,10MS	Y
TITAN III	.9307	3	4L,2SS	N
TITANev	.9519	2	5L,2SS	Y
TITANev/CENT	.9166	4	7L,2SS	Y
TITAN IV (NUS)	.9307	3	4L,2SS	N

L - Liquid Engines
SS - Segmented Solids
MS - Monolithic Solids

Y - Yes
N - No

System Features	AMSC	ATLAS IIAS	BETA II	DELTA	MLS-X (CTV)	MLS-X (RPC)	MLS-X (NON SSF)	MLS-HL (NUS)	MLS-HL (CTV)	MLS-HL (RPC/LRV/CRV)	NLS-20	NLS-50 (CTV)	NLS-50 (RPC)	NLS-50 (NUS)	NLS-50 (AUS)	NLS-HL (CTV)	NLS-HL (CRV)	NLS-HL (AUS)	SSTO	Shuttle	Shuttle EVOLUTION	TITAN EVOLUTION	HR TITAN II (RUPC)	TITAN IV (CTF/LRV)	TITAN IV (NUS)	TITAN IV (CENTAUR)	HR TITAN IV (RPC)
Liquid Fuel Engines	5	7	3	3	10	12	6	9	11	12	5	10	12	6	10	8	8	8	14	5	13	5	7	7	4	7	18
Solid Fuel Engines (M- monolithic, S- segmented)		4 M		10 M												2 S	2 S	2 S		2 S			10 MS	2 S	2 S	2 S	
Propulsion Systems	2	3	2	3	3	3	1	2	3	3	3	3	3	1	3	3	3	3	2	2	4	2	3	3	3	4	5
Engine Out	N	N	N	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	N	Y

Figure 3.2.4.3-2.– System features and PMS.

3.2.5 Architecture Cost Risk (ACR)

This section contains the definitions of the ACR attribute, its measurements, and a discussion of the process by which the architecture cost risk estimates were generated.

3.2.5.1 Definition

After much deliberation, described in subsequent paragraphs, the NIT defined ACR as the risk, or expression of uncertainty, in developing, producing, and operating all systems in an architecture at their stated costs, based upon their present level of definition. Although the expressions of risk approximate the relative cost risk between architectures, the reader is cautioned against using the results obtained from this methodology to predict uncertainity in absolute dollar amounts of the estimates, or to estimate required levels of program reserves.

3.2.5.1.1 Architecture Cost Risk modeling.– The NIT reviewed and discussed several methods for evaluating the risk attribute of space transportation system candidates in the selected HTS architectures. These were used to form a consensus on the most appropriate method of measuring the cumulative risk of any given architecture. It was decided that the NIT should pick a modeling technique which could handle all of the primary risk elements associated with human space transportation programs. The selected uncertainty model should provide a "standardized" framework, with common formats and scaling levels for all the architecture elements (space system projects) to be analyzed.

The traditional program risk areas of Schedule, Management, Technical, and Cost could be addressed in a cost risk model. The political and social risk areas were not chosen to be addressed in the risk evaluations, since their associated-probability-level selections would be hard to quantify and defend. Several cost risk modeling methods and tools were considered. The two principal methods considered are described below.

The @RISK Cost Modeling System

The @RISK modeling application software is a commercially-available, analytical, assessment product for risk evaluation. The model is basically a mathematical probability and statistical analysis tool. It can be used for evaluating the risk ranges of variable cost estimates or reliability estimates.

The @RISK model applies user-selected distribution curves to the program elements being analyzed. The curve selections can be varied from beta (skewed, unimodal) distributions, standard distributions, histogram distributions (square, "step" curves), or even to the application of triangular distributions. The tool is available to all potential customers with a personal computer and enough computer memory capability to operate the program.

The @RISK modeling tool was not selected because of the required setup and background detail to properly document the risk evaluation inputs. The model was viewed by many members of the NIT as more appropriate for an "in-depth" analysis of the candidate architecture elements. This model could be used after lower detail description levels are obtained for the system hardware projects to be analyzed (with better test requirements and hardware characteristics definitions).

<u>The Boeing Ranger Cost Uncertainty Model</u>

The Ranger Cost Uncertainty Model was developed for internal cost risk evaluations by Boeing Aerospace Company (now called Boeing Defense and Space Group) in 1985. This proprietary model was developed for acquisition cost estimate evaluation. Acquisition estimates include cost elements for the development and production phases of an aerospace program. Ranger is used at Boeing to evaluate risk with parametrically-derived or preliminary planning cost estimates (where a minimal amount of program definition data is available to the analyst).

The Ranger model utilizes inputs of the program estimate by subsystem and task elements. The program item estimates must exclude program contingency and management reserve factors. The Ranger high value estimate outputs can be compared later to the user-selected management reserve or contingency factors to judge whether the factor levels are too high, too low, or just about right to cover the modeled uncertainty environment. The model also uses a standardized uncertainty factor selection scale, shown in Figure 3.2.5.1.1-1.

The preferred method for using the Ranger factors scale is to gather separate risk factor inputs in the four risk categories for each estimated line item from design, system engineering, management, manufacturing, and estimating personnel. A consensus (using "Delphi" methods) interview is conducted with each functional design or management area representative by an experienced cost analyst. A successful interview requires the following information: a credible program master planning schedule; the reference estimate inputs; the factor selection scale; and system hardware or task descriptions at the subsystem level for each phase evaluated.

System operation and support cost estimates are not addressed because the Ranger model was not developed initially to evaluate "ownership" cost estimates. The Boeing Ranger Uncertainty Model uses an "expert opinion" lookup table to set range limits in the four acquisition risk areas. These limits were established by Boeing senior managers and engineers in interviews concerning past space and missile program development and production cost variance environments.

	1	2	3	4	5	6	7	8	9	10
SCHEDULE DRIVERS										
• Length	Appropriate Contingency		Reasonable				Too Long or Short		Too Short	
• Synch with Interfaces	Time to Test Interface			Serial Loading			Parallel Load		Out of Sync	
• Dev/Prod Overlap	No Overlap			Minimal Overlap			Some Overlap		Much Overlap	
PROGRAM DEFINITION										
• Requirements	Clear			Minimal Ambiguity			Ambiguous		None	
• Organization	Clear Command and Well Staffed			Well Staffed			Inadequate Staffing			Conflict
• Funding	Adequate with Reserves				Adequate and Steady			Irregular		Poor
• Communication	Effective Conprehensive			Comprehensive			Incomplete		Dysfunctional	
• Management	Experienced Effective				Experienced			Inexperienced		Disruptive
TECHNICAL CHALLENGE										
• State of Technology	OTS		State of the Art			Some Advance		Much Advance		New Tech
• Experience	Same Product			Similar Product			New Line Same Tech		New Tech	
• Technical Approach	Standard		New Processes			Need Inovation			Complete New Approach	
• State of Specs	Available		Some New		All New				No Standard	
ESTIMATING APPROACH										
• Accuracy of Tools	Extension of Actuals		Firm Quotes		Good Parametrics			Educated Guesses		
• Estimator Experience	Familiar with Product			Familiar with Similar Product			No Familiarity		Minimal Experience	
• Support from Program	Good Inputs			Uncertain Clear Inputs			Sloppy Inputs Minimal Staffing			
• Reviews	Regular			Ad Hoc				None		

Figure 3.2.5.1.1-1.– Boeing Ranger Cost Uncertainty Model selection scale.

3.2.5.1.2 Ranger evaluation results.– Preliminary evaluations were accomplished for most of the new system hardware elements in the 18 architectures. The elements which were not evaluated either had only one summary cost estimate number (with no subsystem detail information submitted), lacked a well-documented program master schedule for reference, or had major information voids present in all process inputs. The Ranger method was eventually not considered useful in the initial HTS architecture evaluation process for the following reasons:

- Some system estimates did not contain sufficient definition to run the Ranger model at the proper technology application risk evaluation level (the Ranger-desired program cost estimate breakout inputs of structure, propulsion, avionics, flight controls, software, and crew systems of personnel vehicles was not consistent for all systems).

- The risk factor selection inputs for some system production theoretical first unit (TFU) estimates were inconsistent due to interviewee differences in levels of manufacturing experience. Manufacturing and engineering personnel were not always available for the interviews. Experience in using the Ranger model has shown that lack of a mix of disciplines in a production estimate interview seems to unfairly bias the outputs for both low ("marketeer" optimism) and high (fabrication and delivery failures pessimism) values.

- In some cases, a complete program master schedule with hardware and task category development breakouts for each estimated line item was not available for reference in the interview process. Many preliminary system master schedules had no first unit production flows shown for the interviewees to use as reference material for selection of uncertainty factors.

- The Ranger outputs showed little "high" to "reference estimate" ratio sensitivity. This resulted in the *clustering* of upper stage and *scattering* of booster risk values. The clustering of vehicle risk factor results did not provide the desired or expected differentiation to break ties between competing systems.

- Ranger is not applicable for addressing operations and support cost estimates, so the total life cycle cost uncertainty could not be evaluated.

- The Ranger model is considered a company proprietary tool.

3.2.5.1.3 NIT consensus methodology.– Since each of the risk models identified were either deficient or too detailed for the level of information available, the NIT set out to determine its own relative measure of risk using the most significant contributing factors to architecture cost risk. Using a "nominal group technique", the architecture cost risk was determined to be a function of three primarily parameters, or subattributes:

- *Technical Challenge (TC).*– The TC represents the degree to which a transportation system's technology deviates from current technology. The technologies of the candidate systems ranged from being essentially off-the-shelf to entirely new technologies. The TC of transportation systems can be determined – independent of how a system is used in any architecture.

- *Program Immaturity (PI).*– The PI represents the current actual state of definition of a system, based primarily upon a current drawing count. The PI of transportation systems can be determined – independent of how a system is used in any architecture.

- *Number of New Systems (NS).*– The NS is simply the count of the number of new systems in the candidate architecture, with credit acknowledged for families of systems where vehicles which use significant common hardware with other vehicles in that architecture are recognized as not being entirely new developments. The NS is a direct architecture-level measurement.

Consensus weightings for the contribution of each subattribute to the overall architecture cost risk was determined by the NIT to be as follows:

Technical Challenge	45%
Program Immaturity	30%
Number of new Systems	25%

3.2.5.2 Measurement of the Attribute

The following section describes the methodology used to develop the relative architecture cost risk.

3.2.5.2.1 Technical challenge.– The relative technical challenge of each system comprising the architectures was assessed by the HTS team. This was accomplished by determining the technical challenge of each of the phases in the life cycle of each system: the development, or non-recurring phase (which includes DDT&E, non-recurring production, facilities, and pre-planned product improvement); the production phase; and operations phase, and then cost-weighting the TC of each phase by the cost of that phase. The relative assessment of TC for each phase was made by having each NIT member assess an integer value from 1 (least technical challenge) to 10 (most technical challenge) to each phase of each system. A consensus value was then selected to represent the assessment of the NIT. Table 3.2.5-1 provides the consensus results of this phase-level assessment, along with the range of inputs received during the process.

TABLE 3.2.5-1.– PHASE-LEVEL TECHNICAL CHALLENGE FOR TRANSPORTATION SYSTEMS

System	Non-Rec TC	R	Prod TC	R	Ops TC	R
AMLS	7	5-7	6	4-7	6	4-7
AMSC	6	3-7	4	3-7	6	5-9
ACRV	3	2-4	2	1-4	3	2-5
Atlas	1	1	1	1	1	1
Atlas Evolution	2	2-3	1	1-2	1	1-2
Atlas/Delta/Titan CTF	4	2-7	2	1-4	3	1-7
Beta II	8	7-10	7	5-9	8	6-9
CLV	5	2-6	3	1-5	3	1-5
CRV	4	2-5	3	1-5	3	1-5
CTV	4	2-5	3	1-5	3	1-5
Delta	1	1	1	1	1	1
LRV	3	2-5	3	1-5	2	1-5
MLS	4	3-5	4	3-5	3	3-4
HR Titan	3	2-5	2	1-2	3	2-4
NASP Derived Vehicle	10	10	10	10	9	9-10
NLS -1	4	3-6	4	3-5	3	3-4
NLS - 2	4	3-6	4	3-5	3	3-4
NLS - 3	4	3-6	4	3-5	3	3-4
RCV	3	2-4	2	1-3	3	2-3
RPC	5	2-5	3	1-5	3	3-7
RUPC	8	5-9	6	5-7	3	3-8
Space Shuttle	1	1	1	1	1	1
Shuttle Evolution	3	2-4	2	1-2	3	2-4
SSTO (Rocket)	9	5-10	6	4-10	9	6-9
Titan II	1	1	1	1	1	1
Titan IV	1	1	1	1	1	1
Titan IV Evolution	3	2-4	2	1-4	2	1-2
HR Titan IIS	3	2-4	2	1-4	2	1-2

NonRec = Non Recurring; Prod = Production; Ops = Operations; R = Range

3.2.5.2.2 Program immaturity.– The relative program immaturity of each system was assessed by the HTS team. The relative assessment was made by having each NIT member assess an integer value from 1 (least program immaturity) to 10 (most program immaturity) based upon an estimate of the percentage completion of applicable drawings. The HTS program immaturity scale, with the explanation of the program immaturity levels, is provided in Table 3.2.5-2, and is based upon a subset of the NASA-JSC Advanced Missions Cost Model.

TABLE 3.2.5-2.– HTS PROGRAM IMMATURITY SCALE

Rank	Explanation
1	Virtually 100 percent of the drawings exist and need not be renumbered; the continuation of an existing product.
2	Predominant number of drawings exist; drawings may have been renumbered.
3	Majority of drawings exist; minor resizing of hardware is possible.
4	Roughly half of the drawings exist; significant resizing of hardware is possible.
5	Only a minority of drawings exist; however, existing drawings are based on a familiar product line.
6	Drawings are essentially new; however, a design point-of-departure is known to exist.
7	Drawings are new, the mission of the design are, in part, unfamiliar.
8	Drawings are new, either mission or design concept is unfamiliar.
9	Drawings are new, both mission and design concepts are unfamiliar.
10	Drawings are new, and the design concepts transcend the state-of-the-art.

A consensus value was then selected to represent the assessment of the NIT. Table 3.2.5-3 provides the consensus results of this assessment, along with the range of inputs received during the process.

3.2.5.2.3 Number of New Systems.– The number of new systems comprising the architectures was assessed by the HTS team. The relative assessment was made by a count of the number of new systems in each architecture. Families of systems in an architecture were evaluated for the number of distinctly new systems represented by that family; in other words, a family was given credit for commonality. A consensus value was then selected to represent the assessment of the NIT. Table 3.2.5-4 provides the consensus results of this assessment, along with the range of inputs received during the process.

3.2.5.2.4 Total Architecture Cost Risk.– To make the relative linear assessment of TC and PI more closely approximate the impact of TC and PI on the cost risk experienced in real programs, an algorithm was developed to spread the consensus input TC values

TABLE 3.2.5-3.– SYSTEM LEVEL PROGRAM IMMATURITY FOR TRANSPORTATION SYSTEMS

System	Program Immaturity	Range
Element List		
AMLS	8	6-9
AMSC	7	6-9
ACRV	5	4-7
Atlas	1	1
Atlas Evolution	3	2-4
Atlas/Delta/Titan CTF	6	4-8
Beta II	10	9-10
CLV	7	6-8
CRV	7	6-8
CTV	6	5-8
Delta	1	1
LRV	7	6-8
MLS-HL, MLS-X	6	5-7
HR Titan	4	3-6
NASP Derived Vehicle	10	10
NLS -1	6	4-7
NLS - 2	6	4-7
NLS - 3	6	4-7
RCV	4	3-4
RPC	6	4-7
RUPC	7	6-8
Space Shuttle	1	1
Shuttle Evolution	4	3-4
SSTO (Rocket)	8	7-10
Titan II	1	1
Titan IV	1	1
Titan IV Evolution	4	3-4
HR Titan IIS	3	2-4

TABLE 3.2.5-3.– SYSTEM LEVEL PROGRAM IMMATURITY FOR TRANSPORTATION SYSTEMS (CONCLUDED)

System	Program Immaturity	Range
System List		
Atlas/Delta CTF	6	-
CLV/MLS-HL	7	-
CRV/MLS	7	-
CTV/NLS-1	6	-
LRV/NLS-1	7	-
RPC/MLS-X	6	-
RPC/HR Titan IV	6	-
RPC/NLS-2	6	-
RPC/LRV/MLS-HL	7	-
Titan IIS/RUPC	7	-

TABLE 3.2.5-4.– NUMBER OF NEW SYSTEMS

System	Number of New Systems	Range
ACRV	1.0	0.8-1.0
AMSC	1.0	1.0-1.2
Atlas Evolution	0.2	0.1-0.3
Atlas/Delta CTF	1.0	0.7-1.0
Beta II	1.7	1.0-2.0
CRV	1.0	1.0
CRV	1.0	1.0
CTV	1.0	1.0
LRV	1.0	1.0
MLS-X + RPC, MLS-HL	2.8	2.2-3.0
MLS-X and MLS-HL/CLV	2.7	2.0-3.0
MLS-X, MLS-HL + CLV	2.7	2.0-3.0
HR Titan II + RUPC	1.4	1.2-1.5
HR Titan IV + RPC	1.4	1.2-1.7
NLS-1,2 (w/AUS)	1.6	1.2-2.5
NLS-1,2 + RPC	2.5	2.2-2.6
NLS-1,2,3 (w/AUS),	2.5	2.2-4.0

TABLE 3.2.5-4.– NUMBER OF NEW SYSTEMS (CONCLUDED)

System	Number of New Systems	Range
NLS-1,2 + RPC	2.5	2.2-2.6
NLS-1,2,3 (w/AUS),	2.5	2.2-4.0
NLS-1,2,3 + RPC	3.4	3.3-3.5
SSTO	1.0	1.0
Shuttle Evolution + RCV	1.0	0.5-1.1
Titan CTF	1.0	0.9-1.0
Titan Evolution	0.5	0.1-0.8

prior to developing the final relative architecture cost risk. That algorithm was then applied to spread the TC for each phase of each system and the PI for each system. The algorithm developed for the spread value of TC and PI was

$$sv = (1.6681)^{(n-1)}$$

where n is the linear number assigned to TC or PI.

The TC or PI spread function is plotted in Figure 3.2.5-1.

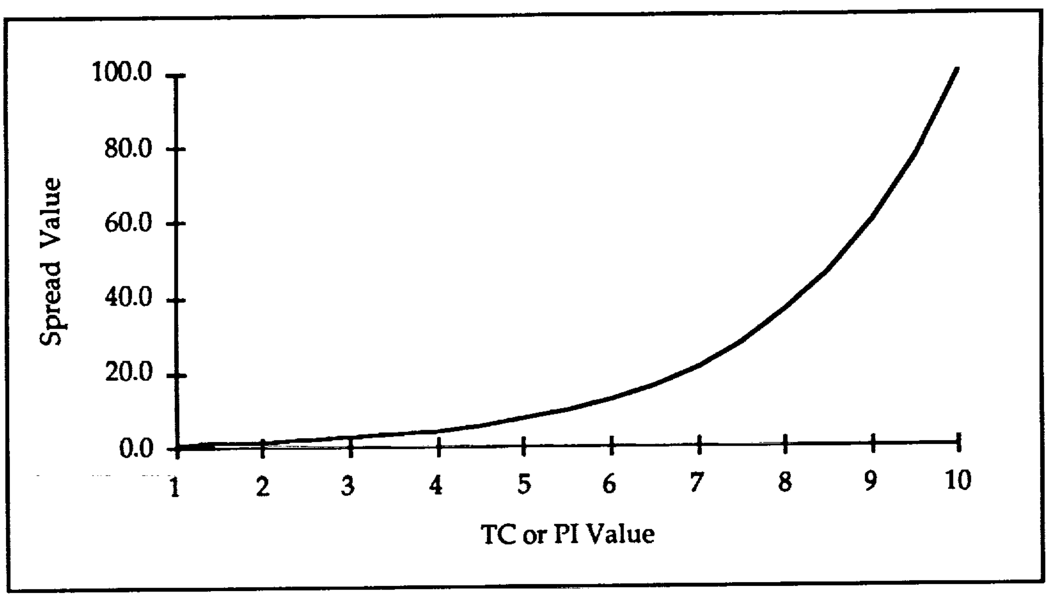


Figure 3.2.5-1.– TC and PI spread function.

This function more closely approximates the experience reflected in more sophisticated cost uncertainty models, which show that "beating" the midrange or nominal estimate for TC and PI does not appreciably mitigate the risk, while underestimating the TC and PI results in a substantial cost risk.

The TC for each system was then derived by cost-weighting the exponentially spread values of TC for each phase by the total cost of that phase. The total architecture TC is the sum of the cost-weighted TC for each system in that architecture. The PI for the entire architecture was derived by weighting the exponentially spread values of PI for each system by the flight rate of that system in that architecture to account for the impact of the relative usage rate of the individual systems. The NS for the entire architecture was derived by adding the number of new systems in that architecture using the values from Table 3.2.5-4. These final TC, PI and NS values were then used as input to the utility functions in the HTS AET to aid in a relative evaluation of the architectures.

3.2.6 Launch Schedule Confidence (LSC)

3.2.6.1 Definition

- *Launch Schedule Confidence* provides an indication of an architecture's ability to meet its launch schedules. It is determined by the measurement of three subattributes– schedule compression, schedule margin, and percentage of flights with delays.

- *Schedule compression* provides insight into the ability of a system's ground processing flow to absorb unscheduled or unplanned activities while still remaining on schedule.

- *Schedule margin* compares the utilization rate of a system's ground processing facilities associated with meeting the required annual flight rate relative to the maximum annual throughput capability of those facilities.

- *The percentage of flights with delays* is an estimate of a system's likelihood to have a launch delay based on unscheduled maintenance items occurring at critical times in the flow.

3.2.6.2 Measurement of Attribute

This attribute has three parts to its measurement, as described above. Each will be measured separately and then combined. The architecture value is obtained from a flight-rate-weighted average of the individual system's values.

The first two subattributes utilize data associated with the ground processing flow for each element or system. To facilitate these first two measurements, summary level, ground-processing-flow schematics were prepared for each element or system. An example, representing the current Atlas launch vehicle, is shown in Figure 3.2.6-1. Pertinent information contained in the schematic includes the identification of the major components of the system, the unique facilities and their number used in the processing flow, and the processing time (in work days) and shift information associated with the flow's critical path. Similar schematics for all the elements and systems can be found in the Appendix B.

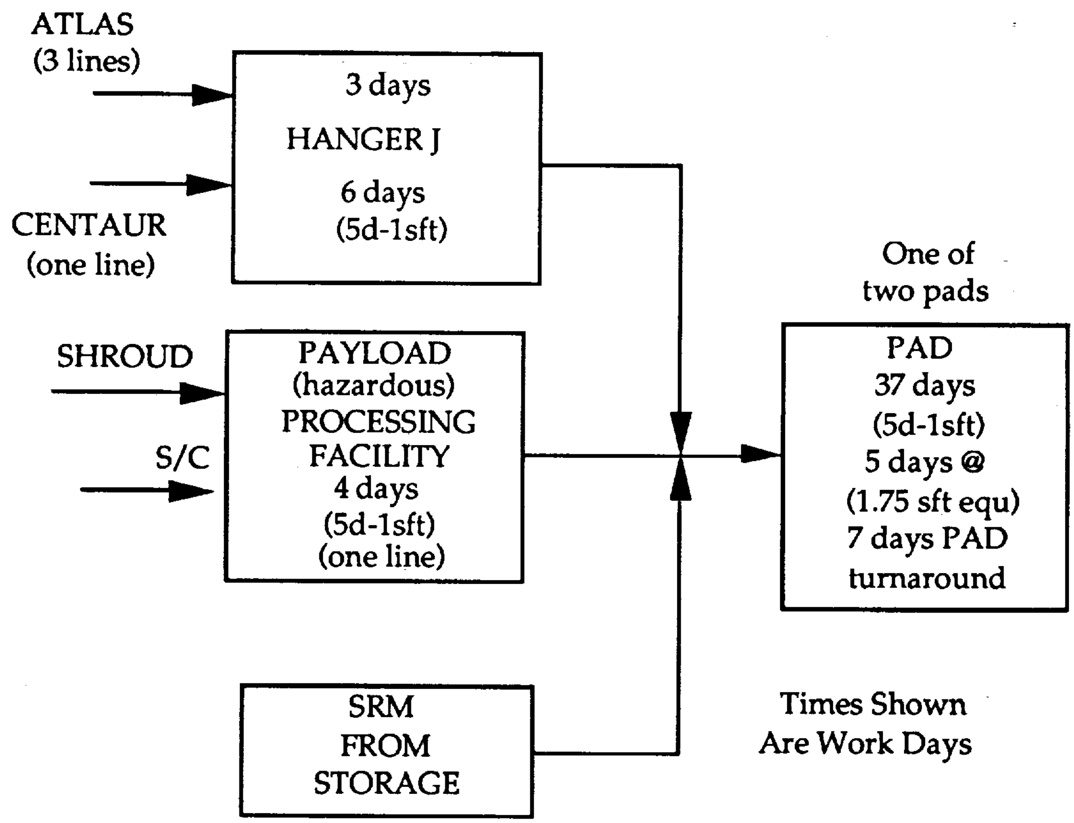


Figure 3.2.6-1.– Atlas processing.

Schedule compression.– This is a measure of a system's ability to make up schedule slips by extending shifts and adding work on weekends to the processing flow. Those parts of the ground operations flow that are in the critical path are boosted to 7-day-per week operation along with increasing the shift size by 50 percent. For example, if the nominal processing flow has one 8-hour shift, the compressed flow would have 1.5 shifts, or 12 hours. In cases where two 8-hour shift operation is the norm, the compressed flow would have two 12-hour shifts, or round-the-clock operations. This assumes that new crews are not hired, but that existing crews work overtime.

The compressed flow is expressed in consecutive days. This is compared to the total number of calendar days required in the nominal flow. In the sample flow shown above, the total calendar days in the nominal flow along the critical path is 66 days. The compressed flow time is 34 days. For the last five days on the pad, no compression is possible since the single crew is already working above the 50 percent shift time extension. The difference between this compressed flow time and the nominal flow time, 32 days (66 - 34), is divided by the nominal processing time (66 days) to show how long the compressed time is relative to the normal process flow (32/66 = 0.485). This number is independent of flight rate and is a constant for a given element or system. The schedule compression for an architecture is the total system flight averaged schedule compression for all the systems manifested in that architecture. This calculation is performed within the Architecture Evaluation Tool.

Schedule margin.– This is a measure of a system's ability to make up schedule or launch slips by using facilities and personnel that are not working at full capacity since, for any particular year, there are fewer flights than those for which the system's ground facilities are designed. This calculation is made using the most process-time-limiting facility in the critical path. This is usually the facility requiring the most time for throughput, however, this is not the case where there are duplicate facilities for portions of the flow. The difference between the required flight rate in a given year and the design (maximum) flight rate is converted to a number of days. This is divided by the nominal processing time to give a ratio of the added time relative to the normal process flow.

In the above Atlas example, the pads represent the "bottleneck" in the processing flow. The total time a pad is tied up in the processing flow is 67 calendar days, including 9 calendar days of pad turn-around time. Assuming a flight rate of six per year, the pads are in use for 402 (67 x 6) days. With two pads, there are 730 (365 x 2) days of available pad time. Therefore, the schedule margin for that year, or any year with 6 flights, is 328 (730 - 402) days. The schedule margin for an architecture is the sum of the annual flight rate averaged schedule margins for all the systems manifested in that architecture. This calculation is also performed within the AET.

Percentage of flights with delays.– This measurement is based on a statistical correlation using MTBF values developed for existing launch vehicles, space systems, and military aircraft. This measurement predicts the number of delays which occur in the final portion of the launch processing, i.e., the time during which the vehicle and its systems are powered up just prior to launch. This measurement does not, however, attempt to measure the length of the delays. The mass, complexity, and mission duration of each system is used to calculate a number of unscheduled maintenance action (UMA) items that the system would be expected to experience. Judgments, based on Space Shuttle experience and sensitivities of airline-type operations to delays, are used to determine how many of those unscheduled actions appear during the flight countdown, and how many of those actually cause a delay.

Using the Atlas expendable launch vehicle as an example, and starting with the predicted average MTBF for the Atlas avionics during the launch phase of 23.76 hours, a value for MTBF during the ground checkout was derived. This calculation was based on the observation that, on the average, the MTBF during ground checkout is eight times greater than during the launch phase. This yields a MTBF of 190.08 (23.76 x 8) hours. This ground checkout MTBF was then converted to a Mean Time Between Maintenance (MTBM) based on the observation that, on average, there are 2.04 unscheduled maintenance actions for every failure. This leads to a MTBM value of 93.176 (190.08/2.04) hours. Dividing the Atlas' ground checkout time (35 hours) by this value yields 0.376 (35/93.176) UMA's or 0.1074 UMA's per hour. Assuming any UMA occurring in the final five hours before launch would cause a launch delay due to insufficient time to repair, predicts 0.0537 (0.01074 x 5) UMA's or delays per launch attempt. In other words, 5.37 percent of scheduled launches will be delayed. Similar calculations were made for the Delta and Titan launch vehicles using their respective MTBF's and checkout times. The Titan MTBF value, the highest of the three, was used in the calculations for the new expendable launch vehicles. It was assumed that new vehicles would be at least as good as Titan, so this was considered a threshold value for purposes of comparison.

The same basic procedure was used for calculating delays for the reusable vehicles. It is reasonable to further assume that refurbished, reusable vehicles arrive at the pad with undiscovered UMA's and failures resulting from previous flights. These previously undiscovered UMA's and failures are detected during the prelaunch checkout and are added to the UMA's and failures expected to occur during the checkout. From contemporary military aircraft experience (F-16, F-15, FB-111, B-1B, C-5, B-52, and C-141) on the average, about 8 percent of all unscheduled maintenance needs are discovered just prior to flight (during preflight inspection and during engine and system checks). Twenty-eight percent of those UMA's discovered result in flight delay or ground abort. The situation is not quite the same for launch vehicles since some systems (e.g., SRB's and other thrust-related equipment) cannot be completely tested prior to liftoff. As a result, only about 40 percent of any existing UMA's and failures can be discovered during prelaunch testing (prior to engine ignition) on the pad. The remaining UMA's and failures become apparent following liquid engine ignition, but prior to liftoff. These clearly result in launch delay. "Percent of flights delayed" values, along with the governing input values and assumptions, and intermediate calculated values are given in Table 3.2.6-1 for all the element or systems in this study. The element and system values are rolled up into architecture "percent of flights delayed" scores within the AET by flight-weighting the individual scores.

3.2.6.3 System Results

Launch Schedule Confidence results for the systems in all architectures are not presented here, as they are flight-rate (of "If" scenario) dependent. Architecture values can be found in the Appendix.

3.2.6.4 Utility Curves

Utility scores, between zero and one for each subattribute, were obtained assuming a linear distribution of the rolled up architecture scores for each subattribute. Within an "If" scenario, the architecture with the best score received a one, the worst a zero.

The final architecture score for LSC was obtained by combining the equally weighted utility scores for the three subattributes, essentially averaging the three scores, to obtain a single score between zero and one. Since it was unlikely that a single architecture would be the lowest or highest in all three subattributes for a given "If", the range of combined scores would most likely be greater than zero and less than one. For this reason, the combined scores were then forced into a range from zero to one through a similar linear interpolation process to that used for the subattribute scores. Again, the highest combined score was given a one, and the lowest a zero. This assured that at least one architecture in each "If" scored a one or a zero.

TABLE 3.2.6-1.– PERCENT OF FLIGHT DELAYED

VEHICLE	EMPTY WEIGHT (LBS)	PRELNCH CHECKOUT (HRS)	MISSION DURATION (HRS)	MTBM	MTBR	MTTR	POS	UMA'S/ MISSION	UMA'S/HR (PAD)	UMA'S (T-5 HRS)	RMVL'S/ MISSION	AIRLINE MTCE FACTOR	% FLIGHTS DELAYED
ACRV (180 DAYS)	13121	—	4320	204.355	700.937	3.000	0.90	21.1397	—	—	6.1632	1.00	0.04
AMLS BOOSTER	127475	35	0.24	0.015	0.057	2.500	0.90	15.9300	0.0181	0.0504	4.1900	1.20	5.04
AMLS ORBITER	180680	35	168	0.991	4.950	2.500	0.90	169.5257	0.0452	0.2259	33.9394	1.20	22.59
AMSC	160000	35	24	0.414	1.398	3.000	0.90	57.9710	0.0197	0.0985	17.1625	1.00	9.85
ATLAS	0	35	EXPEND	93.176	202.193	3.000	0.90	0.3756	0.0107	0.0537	0.1731	1.00	5.37
B-747	350000	—	2	0.600	2.100	3.000	0.90	3.3333	—	—	0.9524	1.00	5.40
BETA BOOSTER	360500	35	0.25	0.005	0.020	3.000	0.90	47.1334	0.0172	0.0861	12.4035	1.00	8.61
BETA ORBITER	61444	35	168	2.914	14.556	3.000	0.90	57.6508	0.0196	0.0981	11.5418	1.00	9.81
BETA II BOOSTER	181667	35	0.25	0.011	0.040	3.000	0.90	23.7520	0.0119	0.0594	6.2505	1.00	5.94
BETA II ORBITER	52948	35	168	3.382	16.891	3.000	0.90	49.6793	0.0178	0.0890	9.9459	1.00	8.90
CLV	55000	—	168	1.730	5.830	3.000	0.90	97.1098	—	—	28.8165	1.00	11.36
CRV	34479	35	168	3.772	12.958	3.000	0.90	44.5421	0.0319	0.1595	12.9653	1.00	15.95
DELTA	0	35	EXPEND	65.882	142.965	3.000	0.90	0.5313	0.0152	0.0759	0.2448	1.00	7.59
LRV	11810	35	168	8.040	27.120	3.000	0.90	20.8955	0.0112	0.0561	6.1947	1.00	5.61
MLS-HL	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.0139	1.00	3.22
MLS-X	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.0139	1.00	3.22
NASP	93980	35	168	2.660	9.130	3.000	0.90	63.1579	0.0209	0.1044	18.4124	1.00	10.44
NLS-20	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.0139	1.00	3.22
NLS-50	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.0139	1.00	3.22

TABLE 3.2.6-1.– PERCENT OF FLIGHT DELAYED (CONCLUDED)

VEHICLE	EMPTY WEIGHT (LBS)	PRELNCH CHECKOUT (HRS)	MISSION DURATION (HRS)	MTBM	MTBR	MTTR	POS	UMA'S/ MISSION	UMA'S/HR (PAD)	UMA'S (T-5 HRS)	RMVL'S/ MISSION	AIRLINE MTCE FACTOR	% FLIGHTS DELAYED
NLS-HL	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.0139	1.00	3.22
RPC (7 DAYS)	20975	35	168	8.200	21.300	2.500	0.90	27.0968	0.0126	0.0632	7.8999	1.20	6.32
RPC (180 DAYS)	20975	35	4320	127.835	438.474	2.500	0.90	33.7935	0.0142	0.0708	9.8523	1.20	7.08
RUPC	18000	35	168	7.225	24.821	3.000	0.90	23.2526	0.0118	0.0588	6.7685	1.00	5.88
SHUTTLE	603000	35	168	0.900	3.040	3.000	0.90	186.6667	0.0481	0.2455	55.2622	1.00	24.55
SHUTTLE EVOLUTION	588000	35	168	0.923	3.118	3.000	0.90	182.0232	0.0480	0.2402	53.8685	1.00	24.02
SSTO	81352	35	168	2.970	10.190	3.000	0.90	56.5657	0.0194	0.0969	16.4914	1.00	9.69
TITAN II	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.1039	1.00	3.22
HR TITAN II	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.1039	1.00	3.22
TITAN III	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.1039	1.00	3.22
TITAN IV	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.1039	1.00	3.22
HR TITAN IV	0	35	EXPEND	155.255	336.903	3.000	0.90	0.2254	0.0064	0.0322	0.1039	1.00	3.22

3.2.7 Environment

3.2.7.1 Definition

The NIT's definition of the Environment attribute is:

> "The degree to which a given architecture has a long term effect on the Earth's environment during the course of nominal operations."

Note that this definition is meant to exclude manufacturing processes and materials, also excluded are abort situations where the immediate preservation of human life is assumed to take precedence over any potential environmental damage.

Effects on the environment can result from several distinct mechanisms. The major groupings are discussed in the following paragraphs and include launch vehicle effluents through the atmosphere, facilities associated with operations, power required for ground operations, and space debris.

a. Environmental Effect of Launch Vehicle Effluents Through the Atmosphere.– The exhaust products from chemical propulsion may produce local and global effects that can be detrimental to life. In addition to the direct impact of acids, halogens, trace heavy metals, etc., in the effluent, a number of secondary effects and reactions are known to occur.

   The work performed under the auspices of an American Institute of Aeronautics and Astronautics (AIAA) workshop entitled "Atmospheric Effects of Chemical Rocket Propulsion", held in Sacramento on June 28-29, 1991,[3] formed the basis for much of the numeric data used in the HTS study. The limitations of this work should be noted; in particular, the exit plane, equilibrium chemistry that was modelled fails to account for the fact that much of the important chemistry (with regards to detrimental effluent species) occurs before and after the exit plane. Also, insufficient time exists for all but the fastest reactions before the exit plane – this tends to be insignificant for propulsion calculations, but not for precise exhaust chemistry characterization.

   Environmental effects also vary as the vehicle flies through different zones in the atmosphere. For example, HC_l deposition is a major concern at high altitude where ozone depletion is the issue; at low altitude, heavy metal particulate deposition would be a concern. Ideally, the measurement of environmental impact in a future study would account for the exhaust products versus altitude.

b. Environmental Impact Resulting from Operations Facilities.– Attempts to quantify environmental impact as related to facilities is divided into three categories. The first is a grouping of construction of facilities sites (primarily buildings) exclusive of launch and landing sites that are characterized by a large human presence for significant periods (power/water/sewer utilization and parking facilities). The second grouping is related to the actual launch site, arbitrarily defined as the area bounded by a security fence, where there are areas of biodisplacement and habitat loss, soil contamination (propellants, burning, and runoff from noise attenuation systems), and periods of high energy exposure (heat, noise, etc.). The third grouping is associated with land landing and recovery facilities involving large areas of biodisplacement or habitat loss and runoff pattern alteration.

c. Environmental Impact Resulting from Power Required for Ground Processes.– If the boundary of the space transportation system encompasses the entire range of activities related to its operations, consideration must be given to the potential impact that is related to the production of electrical power needed to support all phases of activities. Specifically, production of propellants involves large power requirements that may require additional generation capability above and beyond what the regular social infrastructure would dictate. For the time frame covered in this study, power generation will continue to be dominated by thermodynamic conversion technologies (coal, oil, or fission) that produce significant quantities of effluents that can contribute to smog, acid rain, etc.

d. Space Debris.– Most new programs, such as NLS, are making an early, concerted effort to minimize either the amount of hardware that stays on orbit and/or the degree of fragmentation and degradation that can be expected during space operations.

3.2.7.2 Measurement of the Attribute

A full simulation of environmental impacts related to launch vehicles is significantly beyond the scope of this study. A simple, consistent, and traceable set of metrics was developed to quantify differences between elements or architectures. These measurements are described by impact category as discussed previously.

a. Environmental Effect of Launch Vehicle Effluents Through the Atmosphere.– An attempt was made to derive a weighted score for each exhaust product based on a perceived environmental impact. This net vehicle score implies a higher value is 'worse' than a lower one. In this simplistic approach, five key types of environmental concern were simultaneously considered:

- Ozone depletion - destruction of the Earth's protective ozone can be hastened by the introduction of species that break down O_3 into O_2. Most significantly, HC_l from solid rockets acts as a catalyst.

- Acid rain - one of the largest contributors to acid rain is rocket exhaust and the production of NO_X. In this case, N_2, normally considered benign as the largest constituent of the Earth's atmosphere, is artificially weighted higher to reflect NO_X production.

- Cloud nucleation - studies of high altitude aircraft contrails has shown a correlation between cloud cover and surface temperature and light levels (and subsequent oceanic biology levels). Water, OH, H, and H_2 molecules, as well as dust (trace elements in exhaust), can contribute to cloud nucleation.

- Greenhouse gases - there are a multitude of anthropogenic sources of greenhouse gases. Rockets that burn hydrocarbon fuels will add these gases directly to the atmosphere.

- Particulates - heavy particles can alter soil chemistry and biology (particularly at the launch site) and can adversely affect marine life. Solid rocket exhaust contains several heavy metal compounds.

For the purposes of this study, the impact factors used in developing a weighted score (see System Results) considered the above effects.

Exhaust Product	Impact Factor	Rationale
CO	1.7	greenhouse gas
CO_2	1.5	greenhouse, many sources
H_2	0.1	secondary effects
H_20	0.3	cloud nucleation
HCl	5.0	O_3 depletion, acid rain
N_2	0.3	acid rain (NO_X)
OH	0.1	secondary effects
H	0.1	secondary effects
Al_2O_3	3.0	particulates

A more rigorous approach to developing these impact factors would almost certainly change the weighted results. Any conclusions related to planning transportation elements based on an environmental attribute must be viewed as preliminary.

b. Environmental Impact Resulting from Operational Facilities.– In looking for a correlation between facilities and space transportation size or type, a survey of historical and existing systems was conducted. It was quickly apparent that, even for similar type systems, simple relationships do not exist. Factors such as local topography, operational philosophy, and time period seem to have a more significant effect than, say, gross liftoff mass. Given the large uncertainty that would accompany any prediction of future systems' facilities, it was deemed inappropriate to use any simple method for comparing a given architecture's environmental impact as it would relate to the facilities employed.

c. Environmental Impact Resulting from Power Required for Ground Processes.– As was the case in trying to correlate facilities with environmental impact, attempts to relate the power required for a given element with its size, payload, or other feature proved inconclusive. Based on these cursory investigations, it was decided to exclude "power required" as a factor in determining environmental impact.

d. Space Debris.– Given the trend towards design practices which should limit the degree of additional debris caused by the launch of any new system, it is difficult to predict with any certainty what any random mission will contribute to the orbital debris environment. For the purposes of this study, specific characterization of debris contribution was dropped from further consideration.

3.2.7.3 System Results

The environment attribute scores by element are shown in Table 3.2.7.3-1. The effluent masses are in klbs. The bottom line "score" is derived by multiplying each effluent specie mass per launch by the impact factor, as discussed previously, and summing the number of flights to arrive at the architecture-level value.

TABLE 3.2.7.3-1.– ENVIRONMENT DATA BY ELEMENT

Exhaust Product	Space Shuttle	Shuttle Evol.	Atlas E	Atlas I	Atlas II	Atlas IIAS	Delta II	NLS-20	NLS-50	NLS-HL	Beta II
CO	574.6	625.5	81.5	100.1	112.8	128.8	125.2	0.0	0.0	542.6	0.0
CO2	84.2	518.8	67.7	83.1	93.8	95.8	76.6	0.0	0.0	48.2	377.5
H2	102.8	90.6	4.8	5.9	6.6	8.2	6.6	11.8	58.2	108.8	11.0
H2O	1735.4	2286.7	101.1	124.1	140.0	146.2	70.4	331.2	1628.2	1813.9	481.9
HCl	502.6	0.0	0.0	0.0	0.0	14.0	31.4	0.0	0.0	479.9	0.0
N2	208.8	0.0	0.0	0.0	0.0	5.6	17.8	0.0	0.0	197.8	0.0
OH	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0
H	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0
Al2O3	720.0	0.0	0.0	0.0	0.0	20.0	450	0.0	0.0	851.3	0.0
Total Mass per Flight (klbs)	3930.0	3521.6	255.1	313.2	353.2	418.6	373	343	1686.4	4049.7	870.4
Score	6023	2079	254	308	347	510	633	34	169	6203	616

TABLE 3.2.7.3-1.- ENVIRONMENT DATA BY ELEMENT (CONCLUDED)

Exhaust Product	Titan II	Titan II + GEM	Titan III	Titan IV SRM	Titan IV SRMU	Titan IV 14' core	Titan IV LRB	MLS-X	MLS-HL	SSTO	AMSC
CO	11.3	51.7	220.7	284.2	326.3	342.7	624	0.0	0.0	125.2	0.0
CO2	30.5	60.0	92.0	111.0	117.2	174.2	217.2	0.0	0.0	76.6	0.0
H2	15.9	5.1	20.7	26.6	30.4	32.6	8.4	58.2	58.2	6.6	8.0
H2O	146.4	120.3	200.2	243.6	260.1	370.6	421.2	1628.2	1628.2	70.4	223.2
HCl	0.0	31.5	229.2	230.6	267.5	267.5	0.0	0.0	0.0	31.4	0.0
N2	114.9	148.5	177.6	276.8	292.4	433.3	537.0	0.0	0.0	17.8	0.0
OH	0.0	0.1	0.3	0.3	0.4	0.4	0.0	0.0	0.0	0.0	0.0
H	0.0	0.1	0.3	0.3	0.4	0.4	0.0	0.0	0.0	0.0	0.0
Al2O3	0.0	45.0	254.1	330.0	382.8	382.8	0.0	0.0	0.0	45.0	0.0
Total Mass per Flight (klbs)	319.0	462.3	1195.1	1503.4	1677.5	2004.5	1807.8	1686.4	1686.4	373.0	231.2
Score	116	528	2497	2903	3334	3500	1591	169	169	633	23

3.2.7.4 Utility Curve

The lowest environmental score within an "If" has a utility value of 1.0 and the highest environmental score within the same "If" has a utility value of 0.0.

3.2.8 Availability

3.2.8.1 Definition

Availability defines a system's ability to meet launch schedules for planned and unplanned missions. Different communities have evolved different approaches to defining and measuring equipment availability. Some define it as readiness for planned use, some for random or on-demand use. This is a crucial distinction – the measurements are quite different – and it led us to define and measure availability as the average of both. Therefore, Availability has two subattributes: Available Time Fraction (ATF) and Response Time.

a. The ATF defines the ability of a system (booster plus spacecraft, but not payload) to meet planned mission schedules. It counts the normal mission preparation activities as Available Time, then estimates, as Unavailable Time, the delays in these activities due to five factors: (1) unscheduled maintenance, (2) facility delays, (3) logistics delays, (4) major modifications, and (5) fleet standdowns or groundings. It is essentially a measurement of ground- processing reliability. It is not dependent on the length of ground-processing time, only the probability that this time will be exceeded.

b. Response Time is defined as the nominal time to prepare a system to launch an unplanned payload. It gives credit to a system with a short ground-processing time.

3.2.8.2 Measurement

a. ATF

System Measurement.– The data needed to measure this subattribute consists, first, of the duration of each part of the normal processing flow summed (taking into account parallel activities) to total Available Time. Then an accurate estimate is needed, for each of the five factors listed above, of the probability of its occurrence and the average duration of each occurrence. The product of probability times duration gives an average number of days per mission that the vehicle would be unavailable due to that delay factor. The sum of these five times is Unavailable Time for that vehicle.

The ATF for a single system is then calculated as Available Time/(Available Time + Unavailable Time).

Architecture Calculations.– First, the increase in ATF due to the presence of multiple systems (e.g., four Space Shuttles) is calculated:

(1) The Unavailable Time Fraction (UTF) is calculated as 1-ATF

(2) Architecture UTF = System UTF/the square root of the number of Systems

(3) Architecture ATF = 1-Architecture UTF

Finally, the ATF's for multiple systems in an Architecture are combined as above.

b. Response Time

System Measurement.– The normal processing flow times, as used in ATF, are used to measure Response Time. For a single system, the longest Response Time (RTmax) is the total processing time (the vehicle is assumed to be in flight when needed for an unplanned mission.) The shortest Response Time (RTmin) assumes that the system has completed preflight preparation up to the time of payload integration; only integration and prelaunch processing times are counted. System Response Time (RT) is the average of these two times.

Architecture Calculations.– With multiple systems in an architecture, the response time for which a 50-50 probability exists decreases from the average toward the minimum. This can be expressed by the equation: Architecture Response Time = RTmin + (RTmax - RTmin)/n+1, where n = the number of systems. Since the number of systems may vary from year to year, the value must be calculated annually and averaged.

3.2.8.3 Utility Curves

The preliminary approach was to rank the architectures relative to one another. For each subattribute, its score was converted to a value between 0 and 1 by the equation: (Score-Lowest Score)/(Highest Score-Lowest Score). The architecture final score was the average of the two subattribute scores. Since some insight is lost by this averaging, the raw scores for each system were to be provided as well.

This attribute was dropped due to the complexity of estimating all the unavailable times for new systems with no historical data.

3.2.9 Mission Growth Potential

3.2.9.1 Definition

Mission Growth Potential is the ability of an architecture to enable specific new desirable mission types which are not currently baselined.

This attribute rose out of the observation that the HTS mission model had no human missions to inclinations other than 28.5°, of durations longer than 7 days, to altitudes higher than 220 nautical miles, or with room onboard for "passengers." It was felt that some of these mission types were perceived as desirable by the customer, even though none are absolute requirements. The capability of each system and architecture was measured to enable these missions.

3.2.9.2 Measurement

The Mission Growth Potential score is the sum of three subattribute scores, measured for each system:

a. Inclination

The largest inclination change from 28.5° that can be reached is determined. A score is assigned based on a linear formula which yields 0 for 28.5° and 1 for 110° (Sun-synchronous).

That score is then multiplied by factors which express the system's payload and altitude capability at this highest inclination. The upper limits for which these multipliers give credit were determined by consensus as robust, but achievable. The multipliers are: a multiplier for payload capability -1 for no payload, 2 for 30 000 lbs. A multiplier for maximum altitude achievable -1 for 150 n.m., 2 for 400 n.m. A third linear multiplier is used for the number of years the system is available in this architecture: 1 for 1 year and 2 for 20 years. Twenty years was chosen because the first new human system IOC is scheduled for 2000; the Space Shuttle is not given credit for being in use prior to that year.

Example: Space Shuttle in Option 1 can reach 57°, carries 19 000 pounds to that inclination, can reach 324 NM, is available more than 20 years;
score = 0.5*1.63*1.7*2 = 2.77.

b. Duration

The number of days this vehicle can remain in a standard orbit with a standard payload and crew is determined. A score is assigned which yields 0 for 7 days and 1 for 30 days. A multiplier is used for the number of years the system is available in this architecture, as above.

Example: Space Shuttle duration now is 16 days; score = 0.4*2 = 0.8.

c. Passengers

The number of people that can be carried in excess of (four + vehicle crew) is determined. A score is assigned which yields 0 for 0 extra people, 1 for 4. A multiplier is used for the number of years the system is available in this architecture, as above.

Example: Space Shuttle carries vehicle crew of 3 + 4 payload crew; score = 0*2 = 0.

Separate scores for Inclination, Duration and Passengers are calculated as above for each human system in the architecture. For each subattribute, the highest system score is selected. The three are summed for the raw architecture score.

In the above example, Space Shuttle is the only human system in Option 1; its raw score is 2.77+0.8+0 = 3.57.

3.2.9.3 Utility Curves

A utility curve divisor was to be used to reduce the raw scores to a fraction between 0 and 1. The probable divisor was the highest architecture raw score.

This attribute was deferred because of its low ranking. If it was ranked higher, there might have been a tendency to overdesign new systems to score well here, with a corresponding impact on the other attributes.

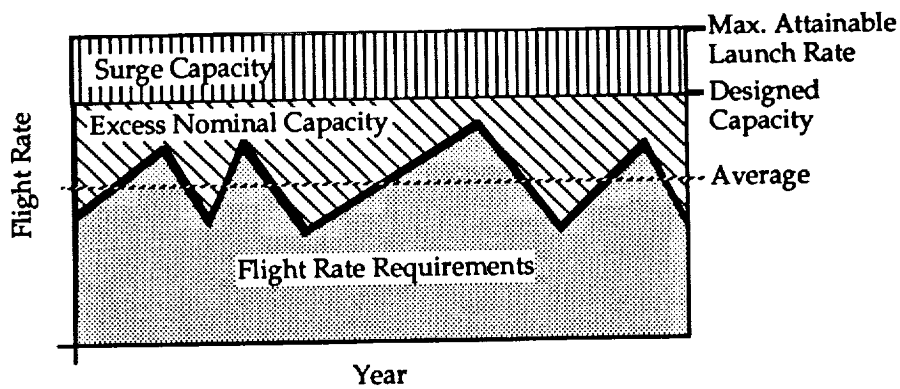
3.2.10 Resiliency

3.2.10.1 Definition

Resiliency is the ability of an architecture to exceed the flight rate requirements of a given architecture to work off the backlog resulting from a standdown. This attribute does not explicitly consider the resiliency benefits which result from an architecture with alternate access (i.e., where another system can perform the missions of a grounded system) because traditionally, launch systems are not interchangeable.

3.2.10.2 Measurement

One difficulty in measuring a system's resiliency is determination of the standdown times induced by various failures and simulating the occurrence of these failures throughout a mission capture analysis. This would require a complex Monte Carlo simulation and detailed Failure Mode and Effects Analysis of the vehicles subsystems. A more deterministic methodology was sought to measure resiliency based upon the ground-processing system's margin. The selected methodology involves measurement of the nondimensional recovery launch rate factor (S). It is a measure of the excess nominal capacity plus allowable surge of the systems ground segment (see Figure 3.2.10-1). The excess nominal capacity is the remaining capability of a system after it has performed the required missions. The surge capacity is the difference between the maximum attainable launch rate and the designed capacity of the system.



Calculation:
S = (Surge Availability + Flight Rate Requirement)/Flight Rate Requirement

Where:
Surge Availability = Excess Nominal Capacity + (0.2) (Surge Capacity)

Figure 3.2.10-1.– Recovery launch rate factor measurement.

The recovery launch rate factor represents the ability of an architecture to exceed nominal operations without constructing new processing or launch facilities. It does not prohibit temporary manpower increases (e.g., second and third shifts or extended work days or weeks), however, it does limit surge operations to an average of 20 percent of total available work time (deemed to be a reasonable ground crew workload).[4] The assumption is that new employees will not be used to meet surge requirements because of the unpredictability of standdowns and the long training time required for new employees.

Since architectures are to be comprised of multiple systems, the total resiliency is the flight rate-weighted average of each systems measure, based upon its share of the total mission capture. This methodology allows for the time phased increase or decrease in resiliency resulting from the ramping in and out of different systems.

3.2.10.3 Utility Curves

One suggestion for a resiliency utility curve would give a score of 1.0 for a system that has a recovery launch rate factor greater than or equal to 1.5. This means a system can increase its flight rate capacity by 50 percent while in a surge mode (i.e., it can work off the backlog created by a standdown in twice the duration of the standdown).

Another method would give an architecture with the greatest resiliency a score of 1.0 and the least, a score of 0.0. All other architectures would be linearly separated based upon their relative score. This would make all resiliency measures relative to each other and not absolute.

Establishing a minimum value of S for a resilient architecture or system is difficult because these requirements can only be determined by considering the availability and reliability of the systems in each architecture. In other words, a system with low reliability will need a higher resiliency so that it can work off backlogs induced by the standdowns during failure analyses and resolution. On the other hand, a system with a high reliability will not need a high resiliency because the likelihood of a failure requiring a standdown will be less.

As a final note, systems with a large share of their missions dedicated to commercial flights may have an artificially high measure of resiliency (e.g., Atlas). This has resulted from not including the commercial missions in the "If" Scenarios. However, if you assume that the government can expropriate (take control of) all space launch operations in the event of a crisis, then resiliencies may be compared equally.

The NIT determined that this attribute was not a discriminator relative to other highly weighted attributes such as cost, safety, and probability of mission success. In order to dedicate more effort to the other attributes and analyses, this attribute was deferred to follow-on activities. Therefore, a utility curve was not selected at this time.

3.2.11 Dependability

3.2.11.1 Definition

The ability of an architecture to meet its own launch schedules.

3.2.11.2 Measurement of Attribute

There are three subattributes, each involving specific launch-time criteria:

(1) "Annual": probability of achieving at least N_{peak} launches per year, where N_{peak} is the greatest number of launches required in a single year for this launch system in the architecture and "If" is being evaluated

P_N = Probability of $\geq N_{peak}$ launches per year

(2) "Launch Day": probability per launch of ≤3 days slip after a launch date is specified

P_D = Probability of ≤3 days slip per launch after date set (T-1 week)

(3) "Window": probability of launching within 10 minutes of planned launch time

P_M = Probability of ≤10 minutes (after T-24 hours) slip per launch

The major factors affecting dependability are weather, fleet sizes and processing facilities, and complexity and reliability. The Dependability Attribute for an architecture will be improved by increasing the number and duration of *built-in* holds that are incorporated into processing schedules and countdowns; by increasing the reliability of GSE and obtaining back-up GSE, by providing margins in vehicle equipment and on-board redundancy in excess of that *required* for launch, and by planning for adequate staffing of support personnel and working normal shifts (i.e., overtime is also a margin that may be invoked for meeting schedules).

The calculation of the foregoing probabilities was assigned to the AET, using extensive databases of site-specific weather and vehicle-specific systems data. In order to determine probability of launch susceptibility to weather and hardware delays, the following were input to the AET:

p_D(weather) = probability of acceptable weather at time launch window opens – considering all aspects, including pad, abort sites, and winds aloft

p_D(hardware) = probability of no launch scrub on day of launch due to hardware – including GSE, flight equipment, com net, facilities, etc.

p_M(hardware) = probability of no scrub during 10-minute launch window

The AET then calculates the following:

$pD = pD(weather) * pD(hardware)$ = probability of launching on a given day

$P_D(D \leq 3 \text{ days}) = 1 - (1-p_D)^3$

Note: exponent reflects three successive day criterion. This formulation assumes slips are one day at a time, and that two or more day slips are so infrequent as to be insignificant. Historical distributions should be used when available.

P_M (M≤10 minutes) = p_M

Note: weather effects are totally reflected within P_D, and do not affect P_M.

Using the peak number of launches, N_{peak}, of the relevant human system in a single year needed to support the given "If" in the architecture under evaluation, $P_N(\geq N)$ values are determined and inserted into a table in the AET data base, for N = 1 through 20.

P_N (≥N) can be established from actual experience, or it may be calculated based upon the following idealized model:

P_N (≥N) = f [number of days available per year/ (number of days per launch x number of launches)]

Minimum possible launch rate per single-string system:
$P_N = 1$, when $N_{min} \leq (365 - T_w - T_{p/l})/(T_p+3\partial)$

Maximum possible launch rate per single-string system:
$P_N = 0$, when $N_{max} > (365 - T_w - T_{p/l})/(T_u+T_p + \partial - T_m)$

Where:

N = number of launches/yr

T_p = minimum number of days between consecutive launches (pre-flight processing time + mate to booster + pad time + countdown + avg. flight time + post-flight processing)

∂ = standard deviation of T_p

T_u = unscheduled lost time (unplanned maintenance; equipment down time)

T_m = margin per launch that can be captured through increased use of resources (cost, overtime, special equipment, etc.)

T_w = number of days per year with unacceptable weather = 365 * q_D(weather)

$T_{p/l}$ = number of days lost per year due to P/L or other non-t transportation delays (including strikes, continuing resolutions, holidays, etc.)

Other values of P_N must be computed by statistical procedures, using a probability model for types of interruptions requiring use of margin times (T_m), fleet size, bottleneck facilities, etc. At the point at which work on this Attribute was discontinued it had not been decided whether an exact formulation, a Monte Carlo approach, or a curve approximated from engineering judgment would be employed for accomplishing this. These probabilities are also to be multiplied by the number of duplicated facilities when taken through the critical path.

Finally, the AET calculates $P(N \geq N_{peak})$ from its $P_N(\geq N)$ look-up table and the value of N_{peak}.

3.2.11.3 Utility Curves

There are no explicit utility curves associated with the Dependability Attribute. Rather, the subutility components of the final attribute value are calculated by the AET, weighted, and summed internally, as indicated in the following steps. Using input values of subutility relative-weighting factors (w_N, w_D, and w_M – see below), and AET-calculated subutilities from curve fits of Utility vs. Probability, an overall utility value for each launch system is calculated.

The overall Utility is thus the weighted sum of the three subutilities:
Utility of Launch System = $U_x = (w_N U_N + w_D U_D + w_M U_M)/(w_N + w_D + w_M)$

In the process, each launch system is categorized as to whether it is human-tended, untended-critical, or untended-noncritical. The AET then calculates an overall Utility for the architecture under consideration using the utilities for each separate launch system and additional weighting factors that take into account the relative importance of human *vs.* untended, critical payloads, etc. These weighting factors were consensually established at the following values:

f_m = weighting factor for human systems = 10

$f_{c,u}$ = weighting factor for critical, untended payloads (e.g., because of a need to make a certain launch window, or to resupply logistics to SSF) = 4

$f_{n,u}$ = weighting factor for non-critical untended payloads (no launch urgency) = 1

Ultimately, the aggregate Utility is the weighted sums of the utilities, expressed as follows:

$$\text{Utility of Dependability} = (f_m U_m + f_{c,u} U_{c,u} + f_{n,u} U_{n,u})/(f_m + f_{c,u} + f_{n,u})$$

3.2.11.4 Status

Dependability was one of the attributes dropped at the mid-point of the HTS Study. The effort involved in calculation of the attribute values was deemed excessive within the funding constraints of the overall study relative to other, more significant, attributes. The foregoing discussion describes the planned treatment of the Dependability Attribute at the time work was discontinued on it.

3.2.12 Alternate Access

The "Augustine Committee Report"[5] in its Recommendation #11, advised that "NASA initiate design activity so that human activity in the Space Station could be supported in the absence of the Space Shuttle ..." The HTS study addressed the concept in two ways. The first was as one of the 10 original attributes, discussed herein; the second was via the preparation of architectures contrasting with respect to the presence or absence of such a capability to continue personnel SSF operations in the absence of the Space Shuttle (see section 3.3.7).

3.2.12.1 Definition

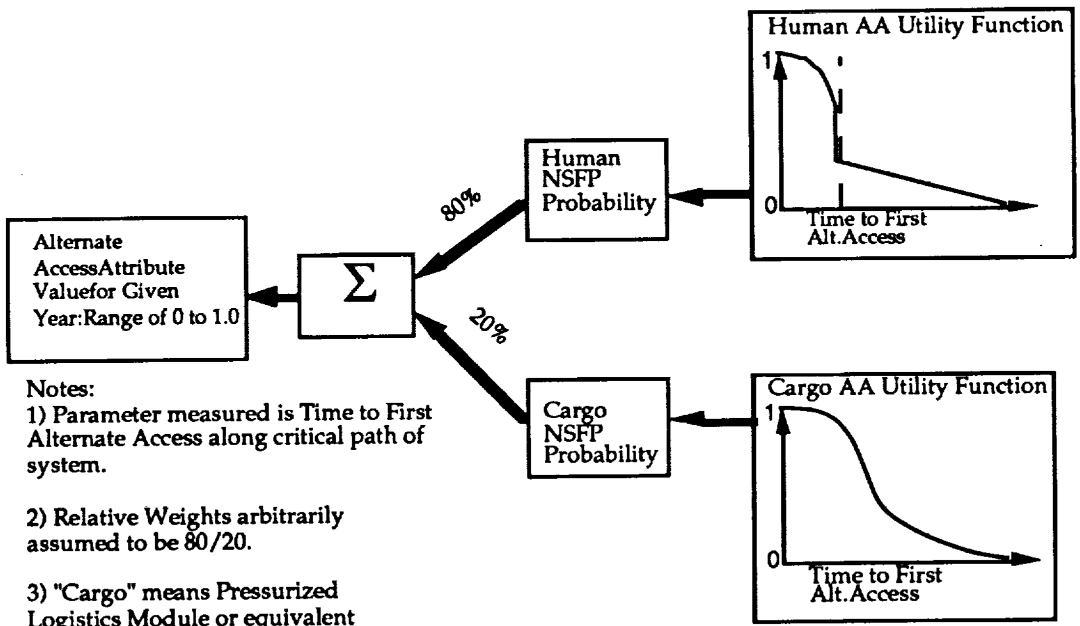
The definition of Alternate Access is the ability of an architecture to continue or resume personnel and/or cargo flights in a timely manner to SSF in the absence of the primary system for such flights.

3.2.12.2 Measurement of Attribute

Quantification of Alternate Access was in terms of *the number of days* required from the unexpected termination of primary system availability until the appropriate alternate personnel or cargo system was projected to be ready to launch.

3.2.12.3 Utility Curves

Piecewise continuous utility curves for both personnel and cargo Alternate Access were developed (Figure 3.2.12.3-1). Each of these decreased slowly until the delay in regaining access via the alternate method became so long as to (a) require use of an ACRV for crew evacuation in the human situation, or (b) result in degradation of SSF attitude control capability due to propellant depletion in the cargo situation. For greater time delays, the utility curves yielded smaller values going to zero at an 18-month delay. The discontinuity in the *human* curve reflected study estimates of the programmatic impact, and national and NASA "loss of face" from a forced crew evacuation. The 18-month cut-off was based upon the estimation that any prime system standdown was unlikely to last more than two years. As delays in resuming operations via the Alternate Access system approached that time value, there would be progressively less benefit from and pressure to use it.



Notes:

1) Parameter measured is Time to First Alternate Access along critical path of system.

2) Relative Weights arbitrarily assumed to be 80/20.

3) "Cargo" means Pressurized Logistics Module or equivalent and includes reboost propellant.

4) NSFP Probability is the probability that failure of an element will NOT be common to both the primary and alternate access systems concurrently. It equals:

$$\left(1 - \frac{\Sigma \text{ (Major failure rates of common elements)}}{\Sigma \text{ (Major failure rates of all elements of primary system)}} \right)$$

Figure 3.2.12.3-1.– Alternate access (composite).

The resulting personnel and cargo utility values were then "derated" individually by a factor involving the failure rates of any elements *common to both* the primary and alternate systems, divided by the overall failure rate of the primary system. The derated personnel and cargo functions were then arbitrarily weighted 80/20, respectively, and summed on a yearly basis.

3.2.12.4 Status

Alternate Access was one of the attributes dropped at the mid-point of the HTS Study. Lacking the means for and a consensus to conduct a Monte Carlo (or similar) simulation of launch vehicle failures, there was no way that the benefits of providing Alternate Access within an architecture could be quantified. The attribute itself was assigned a relatively low weight by the NIT. When combined with the heavily weighted Cost Attribute, Alternate Access was overshadowed by the increased cost of providing it. Consequently, Alternate Access was dropped as an attribute, but remained as a feature for the subjective comparison of some architectures.

3.3 TASK 3 - ARCHITECTURE ANALYSIS AND EVALUATION

3.3.1 Task Approach

To understand whether a particular vehicle design option should be built, it must be viewed in the context of the other elements which will be used to provide the total transportation capability. This grouping of transportation elements is called an architecture. Because an evaluation of a design option's characteristics and attributes can only be evaluated in the context of what mission requirements it meets and which vehicles are available to carry a required payload, it is impossible to evaluate, for example, a PLS without an architectural context.

An architecture is defined as the total group of elements (launch vehicles, boosters, capsules, etc.), with their associated capabilities and infrastructure, which are providing transportation access to space over some defined period of time. As will be described below, this architecture set was constructed by selecting a series of considerations important to the customer, and then selecting the group of elements which, in conjunction, provide a set of launch capabilities. The elements in the architecture were then manifested to meet the HTS Needs Model, and attribute values (cost, safety, risk, etc.) for each architecture were calculated to provide a quantitative assessment of how potential concepts fared relative to one another.

Figure 3.3.1-1 is a flow chart to show how data was used in the study and the relationships between data input and output in the process of an architecture's evaluation.

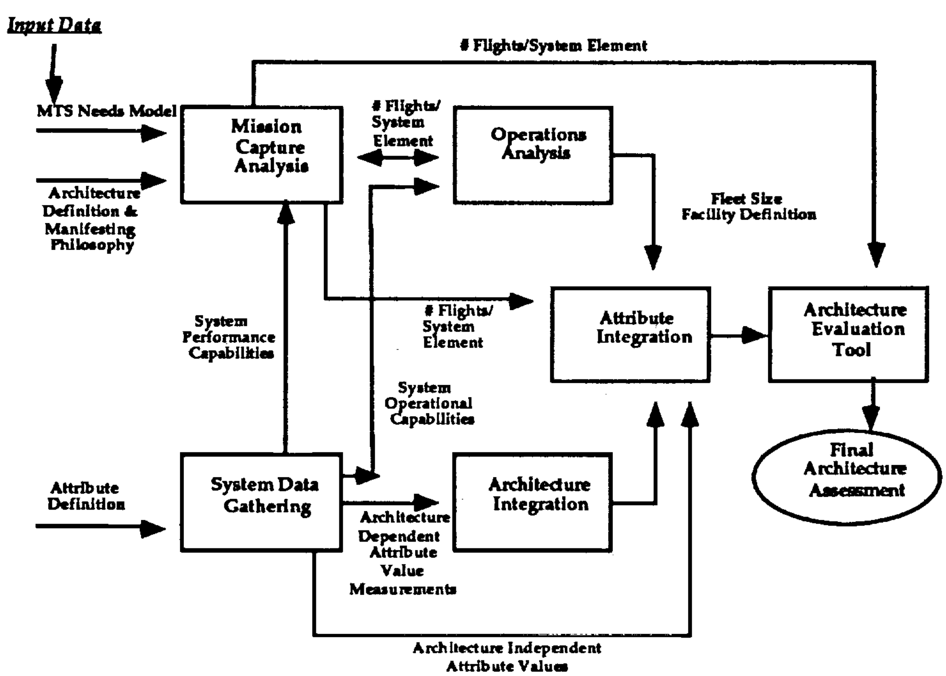


Figure 3.3.1-1.– Study data flow.

3.3.2 Architecture Options Development

3.3.2.1 Development Methodology

The architecture set for the HTS study was developed to gain understanding into a set of considerations or issues which will affect the design of the next human space transportation vehicle. These considerations are described in section 2.2.3. The architectures were comprised of elements which provided crew and cargo delivery and return functions from the present to 2020.

To understand the impact of these considerations on future system options, a set of architectures was compared for each consideration. For example, to understand the separation of people and cargo, three architectures were constructed. The first kept people and cargo together by using the Space Shuttle or a miniature "Space Shuttle" for Human Receipt at Destination payloads. The second completely separated the two, with the crew going to orbit in a personnel carrier, and the cargo aboard a separate ELV. The two would then be required to rendezvous on orbit to complete the mission. The third separated people and cargo into distinct crew and cargo modules which were launched on the same launch vehicle. These three architectures were then manifested and their attributes were evaluated. A similar approach was taken for the other considerations.

Approximately 30 distinct architectures were identified for study, which was subsequently narrowed to 18 after review and consensus from the HTS Study Team. From this group, three were subsequently deferred due to the unavailability of data on the primary human elements of that architecture. For each architecture, elements were identified which would provide people up (delivery), people down (return), cargo up, and cargo down functions. Elements were phased in five-year increments from 2000 to 2015. This was a simplifying assumption since it was believed that a 1 or 2- year difference in vehicle IOC would have a small impact on the overall architecture cost, risk etc. No vehicles were phased in or out prior to 2000 since it was unlikely that NASA would introduce new systems prior to this date. Figure 3.3.2.1-1 shows an example of a template for a representative architecture and Figure 3.3.2.1-2 provides a summary of the architectures considered in the study. A detailed explanation of these architectures is provided in sections 3.3.5 to 3.3.11. Finally, for each architecture, a set of manifesting philosophies were developed which governed how an element would be used. This allowed the team to assign priority, consistent with the architecture intent, to different vehicles which could carry the same payload.

Function	2000	2005	2010	2015
People Up	• Space Shuttle	•Space Shuttle	• Space Shuttle	• Space Shuttle
People Down	• Space Shuttle • ACRV	• Space Shuttle • ACRV	• Space Shuttle • ACRV	• Space Shuttle • ACRV
Cargo Up	• Space Shuttle • Delta, Atlas Titan	•Space Shuttle •Delta, Atlas Titan	• Space Shuttle • Delta, Atlas Titan	• Space Shuttle • Delta, Atlas Titan
Cargo Down	• Space Shuttle	•Space Shuttle	• Space Shuttle	• Space Shuttle

Figure 3.3.2.1-1.– Example of an architecture template.

Architecture Variations to Answer Considerations*

- **Architecture Baseline** — Continued use of current systems; ACRV for SSF PMC (Arch #1)
- **Architecture Considerations**
  - Evolution — Evolve Current Systems (Arch #2)
  - Alternate Access
    - Cargo up only; use of domestic systems w/ NLS (Arch #3)
    - Crew & Cargo up only; use of domestic systems w/ MR Titan (Arch #14)
    - Crew & cargo; use domestic systems w/ personnel & cargo vehicles (Arch #4)
    - Crew & cargo; use of foreign-developed systems (Arch # 15) - Deferred due to lack of data
  - Separation of People and Cargo
    - Crew & cargo together using Crew & Logistics Vehicle (Arch #5)
    - Crew & cargo launched separately using personnel & cargo vehicles (Arch #6)
    - Crew & cargo launched together using attached personnel & cargo vehicles (Arch # 7)
  - Which Manned Booster?
    - Use of NLS (Arch #13)
    - Use of Man-rated Titan (Arch #14)
    - Use of medium-lift Manned Launch System (Arch #6)
    - Use of heavy-lift Manned Launch System (Arch #5)
  - ACRV Commonality
    - Don't build ACRV; develop personnel vehicle (Arch #11)
    - Build ACRV, but phase out after personnel vehicle IOC (Arch #12)
    - Build both ACRV and personnel vehicle together (Arch #13)
- **Other Options of Interest to Customer or of Potential Leverage**
  - Advanced Technology
    - Near-term, rocket- powered SSTO; Rockwell SDIO concept (Arch #8)
    - Far-term, rocket-powered TSTO; LaRC AMLS concept (Arch #9) - Deferred due to lack of data
    - Far-term, air-breathing SSTO; NASP JPO NDV (Arch #10) - Deferred due to lack of data
  - New Concepts
    - Air-launched personnel carrier; Rockwell AMSC concept (Arch #16)
    - Reusable ultralight personnel carrier; Martin Marietta concept (Arch #17)
    - Advanced TSTO; Wright Labs Beta II concept (Arch #18)

Figure 3.3.2.1-2.– Architecture summary.

In addition, other analyses, beyond the evaluation of the above considerations, were conducted. For example, to assess the impact of return cargo requirements, a group of architectures was selected and the needs model was modified by reducing return cargo requirements. The architectures were then remanifested and compared with the baseline results.

The HTS architecture set is broad enough to gain insight into other considerations. For example, comparison of the reference architecture (continued use of current systems) with the architecture that adds the NLS gives insight into how many payloads could be off-loaded from the Space Shuttle onto the new launch vehicle. One could also gain insight into the effect of Space Shuttle system phase-out dates by comparing architectures with early and late Space Shuttle phase-outs. One should use caution, however, in trying to get absolute answers from these architectures (e.g., how many more Space Shuttles NASA should buy), since the architectures and the subsequent attribute scores are better suited for comparative purposes. In other words, the study is better suited to understanding architectural implications of new system alternatives compared to continued use of current systems It is not intended to answer detailed issues within a given alternative. However, sufficient accuracy and depth has been covered to meet the objectives of the HTS study.

3.3.2.2 Architecture Manifesting Groundrules and Approach

At the onset of the study, the study team defined a set of top level groundrules and assumptions for the mission capture analysis. These groundrules and assumptions are applied across all architectures consistently. Architecture-specific assumptions were also necessary and were created and approved by the study team on an as-required basis. Tables 3.3.2.2-1 and 3.3.2.2-2 list the general groundrules and assumptions, respectively.

3.3.2.2.1 Mission capture and payload manifesting.– The General Dynamics TRANSIT (Transportation Systems Integration Tool) was used to perform the end-to-end mission model analysis, including system performance calculation, mission capture, and payload manifesting. Mission capture is the matching up of a certain mission or group of missions to the launch system while satisfying all mission constraints and vehicle constraints, including performance. Mission constraints include final destinations, payload mass and dimensions, or other operational considerations (e.g., multiple, identical payloads must be flown separately). Vehicle constraints include launch site, IOC, other availability limitations, cargo volume, performance to the destination orbit, etc. Only when the two sets of requirements are matched are missions "captured." When there is more than one vehicle that can capture a particular mission, other secondary criteria must be provided to help select between the candidate systems, such as cost-per-flight or system priority. For the study, the team selected the other criteria based on the intent of the architecture.

TABLE 3.3.2.2-1.– GENERAL MISSION CAPTURE GROUNDRULES

The mission models used for mission capture were the "If Scenarios" defined by the HTS Study Team.
Mission capture and payload manifesting used only those systems in the study-defined architectures.
The mission model period is 1992 to 2020. • The NASA Mixed Fleet Manifest (August 1991) was used for flight rates between 1992 and 1997, while the HTS Mission Model requirements were used for 1998 and beyond.
15 percent Airborne Support Equipment is added to all payloads, except for SSF logistics and ACRV.
Both payload mass and dimensions must be observed during manifesting; when dimensions are not available, payload mass must still be observed.
SSF logistics, Satellite Servicing and Science Sortie payloads can be resized to match new launch vehicle performance.
Payload delivery must be accomplished in the years specified by the mission models.
Human DOD missions were flown with the lowest cargo system capability available.
In the early years, "Unmanned" payloads are limited to untended systems until new reusable systems such as the SSTO or TSTO are available to fly them.
West coast Titan II total flights in any architecture will not exceed 55; 14 being refurbished by MMC, 41 still in storage by the U.S. Air Force. • This constraint is lifted in Architecture 17, when it was assumed more Titan II's are built for RUPC transport.
ACRV payload and launch information in HTS CNDB was not up-to-date. Therefore updated ACRV delivery mass to include FSE & ASE: 17,318 lbs; return mass is 16,188 lbs; dimensions are 15.67 ft length x 14.5 ft diameter. • Also, extend ACRV launch schedule from 2010 to 2020 with similar traffic pattern for manifesting purposes
SEI human flights in "If E" are dedicated flights.

TABLE 3.3.2.2-2.- GENERAL MISSION CAPTURE ASSUMPTIONS

Only east and west coast launch sites were considered.
For mission capture and payload manifesting purposes, system failures or standdowns were not accounted for , i.e., flight rate results exclude reflight consideration. Unreliability costs are accounted for in the life cycle cost analysis.
New systems phase out existing systems nominally over a 5-year period. Ramping was linear and based on maximum flight rate in architecture/ "If" scenario combination. It was not necessarily related to the system development or program schedule.
The EOS payloads of 30 000 lbs to sunsynchronous orbit may be split into smaller pieces to fit on the Titan IV flying out of the West Coast
Atlas E has only one vehicle left at this time; the remaining DOD Atlas E class payloads will go on either west coast Delta II, or new vehicles, e.g. NLS-20.
X-ray background survey explorer in HTS Needs Model is destined for 200 nmi, which is the only mission to this orbit; assume 220 nmi for manifesting purposes.
For those architectures having RPC replacing ACRV, one extra RPC flight is added in 2002 to enable transition from 4-to-8 crew SSF.
For additional planetary missions beyond the current planning horizon, assume: • Delivery mass is nominally 12 100 lbs • Average C3 requirement is 0 km^2/sec^2.

Payload manifesting, on the other hand, is the selection of additional payloads to fly on the flight of a given system once it has been chosen for the primary mission. Once the mission's and system's match-up has been determined, TRANSIT begins to manifest payloads together on the launch vehicles. The payload manifests for this analysis do not produce flight assignments such as those for the Space Shuttle, since (1) these are only projected payloads, and (2) payload compatibility, integration, and other issues have not been considered.

Some payloads were resized to fit onto new launch vehicles. These were

a. the SSF Pressurized Logistics Module (PLM),

b. the SSF Mini-PLM (MPLM),

c. the SSF unpressurized logistics module cargo, and

d. all smoothed Satellite Servicing and Science Sortie payloads.

These payloads were broken up to best fit in the new vehicle, accounting for total mass and launch schedule. For example, with the 29 748 lb PLM requiring three deliveries every year, three Space Shuttle flights are required, each with additional payloads to maximize payload efficiency. But for an SSTO (Rocket) launch vehicle which has only a 15 000 lb capability to the SSF, the PLM is broken up into two modules of
14 874 lb each, for a total of six flights per year. This was done to maximize launch efficiency while keeping the manifesting simple.

Figure 3.3.2.3 shows the general mission capture and payload manifesting steps. The figure shows five different payloads to be considered by the three candidate vehicles, depicted by their cargo bay and fairing. Based on the understanding of the mission objectives and requirements, the matching of mission and system determines which mission can potentially be captured by which system. Further tests by TRANSIT as to performance of the system to the mission destination, payload mass and dimensions, vehicle cargo volume, east and west coast launch constraints, system availability (year and maximum flight rate), etc., will determine if the system can capture the missions.

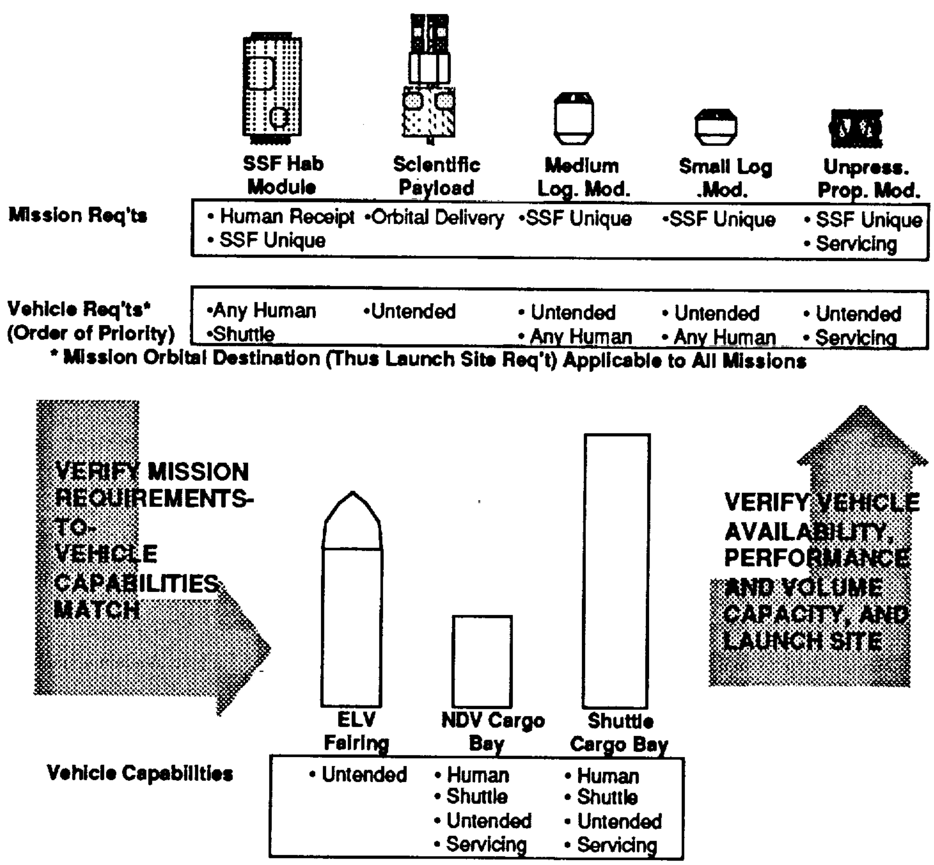


Figure 3.3.2.3.– Mission capture illustration.

Once the mission-to-system match-up is done, actual manifesting, i.e., putting payloads together with each other on the same flight, is done. Again, a series of tests are utilized to verify if the payloads can be put together on the same flight. Criteria for manifesting the tests include:

a. Payloads with higher priority are considered first; this ensures that critical missions are provided before annual launch rate constraints take effect.

b. Both the payload mass and dimensions must be within the system's capability (performance to destination orbit, cargo bay or fairing volume). If the launch mass efficiency is low because the payload size is large, the launch vehicle must still fly with low mass efficiency.

c. Payloads allowed together on the same flight must have the same vehicle requirements, i.e., they must require the same service from the system. Otherwise, a detailed operational analysis must be performed to ensure the vehicle can maneuver onorbit, change plane and/or altitude, etc., to satisfy different mission needs.

TRANSIT applies this generic mission capture algorithm to all architectures for each mission, vehicle system, and year in the mission model. At the completion of the run, the outputs are tabulated. They include mission-to-vehicle capture, listing of payloads on the same flight, manifesting efficiency, summary of flight results for each launch site, and number of required launch systems. This information is, in turn, used to determine the other flight-rate-weighted study attributes, including number of required launch vehicles, and their associated launch costs.

3.3.3 Transportation Elements and Systems

The process of populating the architectures with element or vehicle concepts was more difficult than developing the theme of the architectures themselves. A list of roughly 25 elements was identified which could be incor-porated into the architectures. Many of these elements were selected not only for their ability to fill a capability or function gap in some architecture set but also to incorporate concepts which are well known and have resources devoted to study them. For example, it was important to know how a PLS or an SDI SSTO vehicle fit into the spectrum of possible design and architecture concepts. In the end, most of the concepts which were of principal interest to the customer were incorporated.

Table 3.3.3 shows a summary of the elements used in the study. The table identifies in which architectures these elements appear, as well as their phase-in and phase-out dates. Small commercial vehicles (Pegasus, Taurus, Conestoga, etc.) and sounding rockets (Scout, Aires, etc.) were not considered in this study since it was believed that their use/flight rates would have a negligible impact on an architecture's attributes. Detailed descriptions of these elements are provided in subsequent paragraphs.

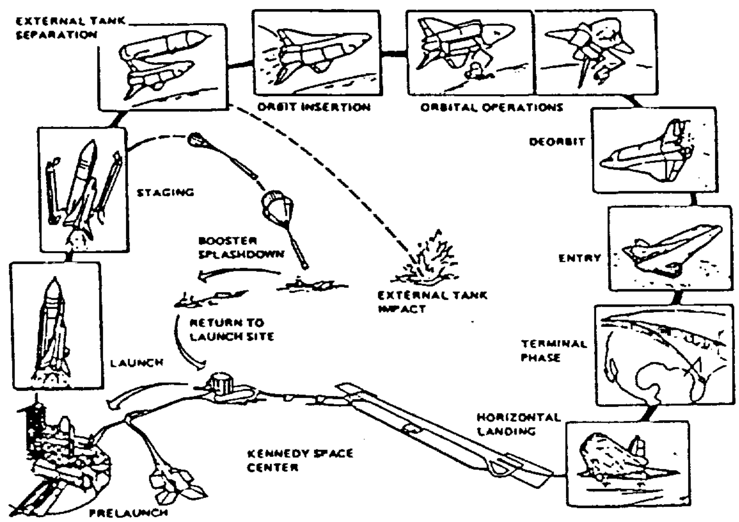
TABLE 3.3.3.– HTS ARCHITECTURE ELEMENTS AND OPERATION PHASES

Earth-to-Orbit Systems	Architecture Options																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	17	18
Atlas IIAS	92	92	92-10	92-10	92	92	92	92	92	92	92	92	92	92	92	92	92
Delta II	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Shuttle	92	92	92	92	92-05	92-05	92-05	92-05	92-10	92-15	92	92	92	92	92-10	92-05	92-10
Titan IV	92	91	92-05	92-05	92-05	92-05	92-05	91	91	91	92-05	92-05	92-05	92	92	92	92
ACRV	97	97	97	97				97	97	97		00-10	97	97	97	97	97
CTF/Delta II								00	00	00				00	00		00
CTF/Atlas IIAS								00	00	00				00	00		00
CTF/Titan IV								00	00	00				00	00	00	00
Shuttle Evol w/ LRB		00															
RCV W/ ASRB		00															
Atlas Evol.		00															
Titan Evol.		00															
RPC/HR Titan IV+														00			
RUPC/Titan II+ GEM																00	
RPC/NLS-2				00							00	05	00				
NLS-1			00	00							00	00	00				
NLS-2			00	00							00	00	00				
NLS-1 + AUS			00	00							00	00	00				
NLS-2 + AUS			00	00							00	00	00				
NLS-3 + AUS			05	05													
CTV/NLS-1			00	00							00	00	00				
CTV/NLS-2			00	00							00	00	00				
CRV/NLS-1				00													
RPC (CLV)/MLS-HL					00												
RPC/MLS-X						00											
RPC/LRV/MLS-HL							00										
MLS-HL					00	00	00										
MLS-X					00	00	00										
CRV/MLS-HL					00	00	00										
LRV/CTF/Titan IV															05	00	
SSTO (Rocket)								00									
SSTO (Air Breathing)										10							
TSTO LARC									05								
TSTO WL/FIMG (BETA II)																	05
AMSC															05		

3.3.3.1 Space Shuttle

System Description

The Space Shuttle is NASA's only human ETO system at this time (Figure 3.3.3.1-1). Performance specifications called for the ability to put 65 klb (18.2 mt) into a 100 nm (185 km) orbit inclined 28.5 degrees to the equator, 40 klb (18.2 mt) into a 100 nm orbit at a 90 degree inclination, and 25 klb (11.3 mt) into a 277 nm (513 km) orbit inclined 55 degrees to the equator. To meet abort requirements for polar launches, a 1500 nm (2780 km) cross-range capability was required. The current Space Shuttle system consists of a reusable orbiter, an expendable ET, and two recoverable SRB's.



Event	Time min:sec	Geodetic altitude mi (km) a		Inertial velocity mph (km/hr)		Inertial velocity mph (km/hr)	
SSME ignition	-00:03.46	184	(56) b	914	(1 471) c	0	(0)
SEB ignition	00:03	184	(56) b	914	(1 471) c	0	(0)
Begin pitchover	00:07	545	(166) b	917	(1 476)	0	(0)
Maximum dynamic pressure	01:09	8.3	(13.4)	1 654	(2 662)	4	(6.4)
SEB separation	02:04	29.4	(47.3)	3 438	(5 533)	23.7	(38.1)
Main engine cutoff	08:38	73	(117.5)	17 500	(28 163)	829.3	(1 335)
External Tank separation	08:50	73.5	(118.3)	17 498	(28 160)	886.6	(1 427)
OMS-1 ignition	10:39	78.3	(126)	17 479	(28 129)	1 380	(2 221)
OMS-1 cutoff	12:24	83.2	(133.9)	17 591	(28 309)	1 860	(2 993)
OMS-2 ignition	43.58	173.6	(279.4)	17 201	(27 682)	9 775	(15 731)
OMS-2 cutoff	45:34	174.2	(280.3)	17 321	(27 875)	10 269	(16 526)

a - Altitude reference to Orbiter center-of-gravity avove the geodetic representation of the Earth's surface.
b - in meters (feet)
c - Rotational velocity of Earth at KSC latitude of 28.5°N

Figure 3.3.3.1-1.– Space Shuttle mission profile.

Performance characteristics

At present, there are four operational orbiters: Columbia (OV Orbital Vehicle -102), Discovery (OV-103), Atlantis (OV-104), and Endeavor (OV-105). The Space Shuttle Orbiter has a design life of 100 missions. Its crew compartment accommodates up to 7 crew members and can handle 10 persons during emergency operations. The Orbiter's cargo bay is 60 ft long and 15 ft in diameter (18.5 x 4.5 m). It can carry payloads to and from orbits ranging from 100-600 nm (185-1100 km) in altitude (payload capacity as a function of inclination and altitude is given in Table 3.3.3.1-1). Upon completion of its orbital activities, the Orbiter lands horizontally, as a glider, at a speed of about 312 fps (95 mps) and a glide angle of 18 to 22 degrees.

TABLE 3.3.3.1-1.– SPACE SHUTTLE PERFORMANCE CHARACTERISTICS

INCLINATION (deg)	APOGEE X PERIGEE (nmi)	PAYLOAD (klbs)
28.5	160 x 160	54.0
28.5	220 x 220	46.0
28.5	300 x 300	37.0
57.0	160 x 160	38.0
57.0	324 x 324	19.0

The Space Shuttle's propulsion is provided by the three SSME's located in the aft fuselage and two SRB's. The SRB's operate during the first 212 seconds. After thrust tail-off, they are jettisoned into the ocean for retrieval and refurbishment operations. Fuel for the main engines is carried in the ET, which is jettisoned shortly after SSME cut-off, at about 98 percent orbital velocity. In orbit, the Space Shuttle is propelled by the OMS contained in two pods on the aft fuselage. The Reaction Control Subsystem (RCS) is contained in the two OMS pods and a module in the Orbiter's nose section. The RCS provides attitude control in space and during reentry and is used during rendezvous and docking maneuvers. The Orbiter is constructed primarily of aluminum and is protected from reentry heat by the Thermal Protection System (TPS). The principal substructures of the Orbiter are the crew module, forward fuselage, mid-fuselage, payload bay doors, aft fuselage, engine thrust structure, wings, and vertical tail.

During ascent, the Space Shuttle has four abort alternatives, depending on mission elapsed time when the failure occurs. They are: return to launch site (RTLS), trans-Atlantic abort (TAA), abort once-around (AOA), and abort-to-orbit (ATO).

Operational Facilities

Space Shuttle operations involve three key NASA Centers: JSC (lead center, Orbiter, mission operations), KSC (launch, landing and refurbishment), and MSFC (SRB's, SSME's, and ET). In addition, Space Shuttle uses the Air Force's Dryden Research Center as a primary and backup landing site. Test facilities at the Stennis Space Center are used for on-going SSME life cycle and development tests.

A typical Space Shuttle processing flow schematic, indicating facility dwell times, along with work day and shift information used in this study, is shown in Figure 3.3.3.1-2.

Attribute Values

System input data related to each attribute, as well as system specific attribute values are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level. These will be discussed following the presentation of the Space Shuttle system data.

a. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. A single design feature (the slide pole) of the Space Shuttle (added after flight 51L) allows for crew escape from the Orbiter. However, its use is restricted to level, unpowered flight at subsonic speeds, which occurs at the end of each abort mode (except ATO) and near the end of the landing phase. It provides no relief during powered ascent. On the other hand, several abort options (described earlier) exist and can be used in the event of a non-catastrophic SSME failure. If an abort-to-orbit is executed, it is possible that the mission will be a success. The Space Shuttle does not have a means of aborting the crew should there be an SRB catastrophic failure. Other salient features include having the crew module in the same element as the liquid engines, but over 70 feet ahead of their location, and having the crew module parallel to the propellant tank, as well as to the solid rocket boosters.

b. Funding Profile.– Cost information provided to the HTS study team included the cost of new facilities, new Orbiters, variable and fixed costs per flight for each flight element, launch and flight operations, and NASA's Research and Program Management support. In addition, spread factors for each cost item were provided, identifying how much of the total cost was spent in the years preceding the need for flight date. Table 3.3.3.1-2 presents a summary of this data.

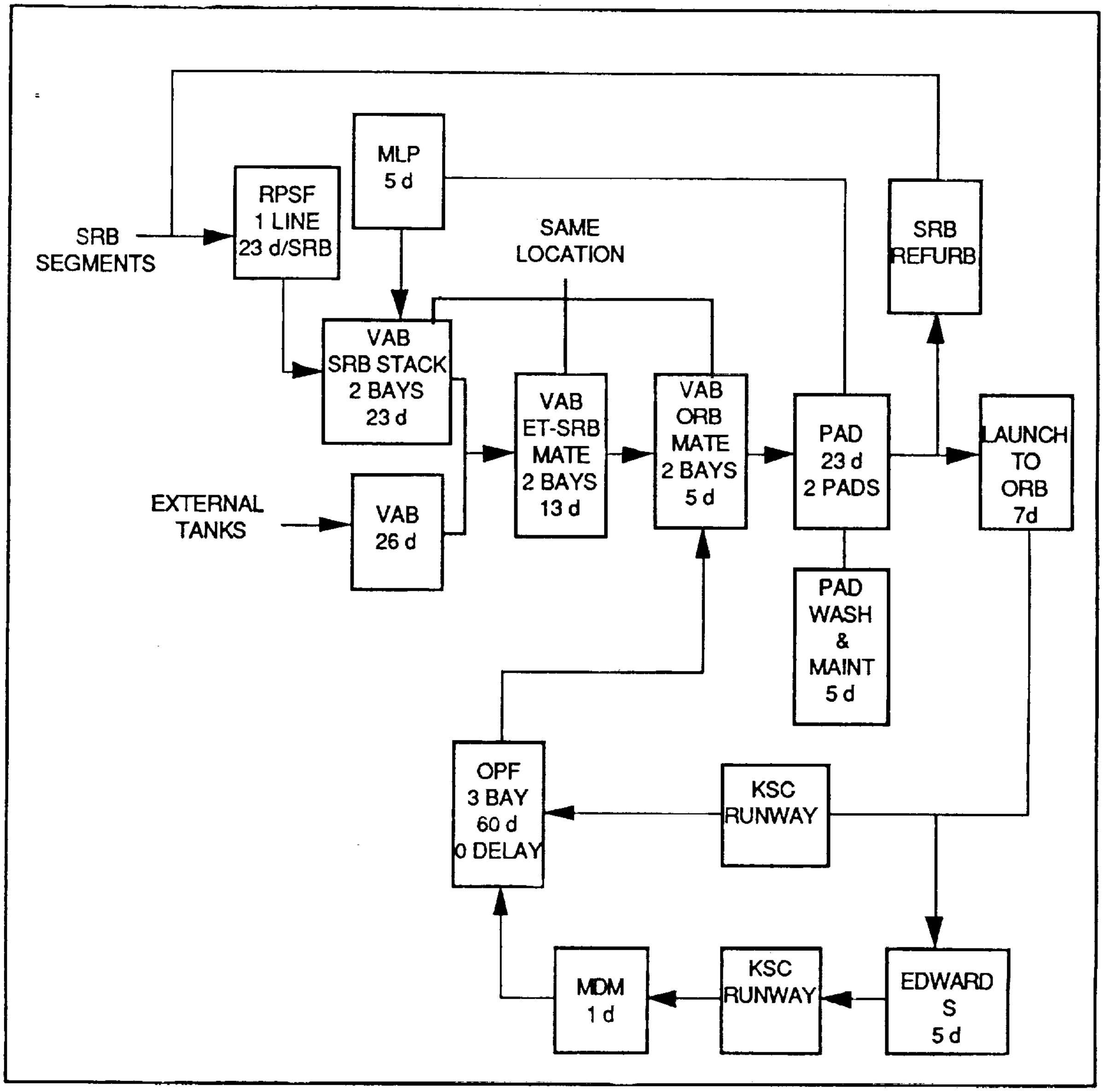


Figure 3.3.3.1-2.– Space Shuttle operations flow schematic.

TABLE 3.3.3.1-2.– SPACE SHUTTLE FUNDING PROFILE INPUT DATA

SPACE SHUTTLE COST BREAKDOWN CATEGORIES	TOTAL OR TFU COST ($M)	LEARN -ING CURVE (%)	RATE CURVE (%)	COST PER FLT ($M)	COST PER YEAR ($M)	Y -4 (%)	Y -3 (%)	Y -2 (%)	Y -1 (%)	FLT YR (%)
NON-RECURRING										
RDT&E	0									
PRODUCTION	0									
P3I	1000/YR									
LAUNCH PAD	973					15	40	40	5	
VERT ASSY BLDG BAY	252					15	40	40	5	
ORB PROC FACIL	268					15	40	40	5	
LAUNCH CONTROL CTR	54						40	45	15	
MOBILE LAUNCH PLTFRM							35	45	20	
RECURRING										
NEW										
ORBITER (new)	1637	100	100			25	30	30	15	
SSME (new)	96	90	90				25	60	15	
FLIGHT TO FLIGHT										
EXTERNAL TANK				12	352		23	36	40	1
SOLID ROCKET BOOSTERS				23	358			1	58	41
SSME (refurb)				5	75		16	26	26	32
ORBITER/CE				5	75					100
LAUNCH OPERATIONS				5	598					100
FLIGHT OPERATIONS				7	666			1	7	92
R & M/SUPPORT				0	327					100

c. Probability of Mission Success.– A system description and flight profile contains the required input information for this attribute. In summary, the Space Shuttle has one liquid propulsion stage, three liquid engines (with engine out capability per the abort descriptions), and two solid motors used during the initial boost period. A mission profile and sequence of events is shown as part of Figure 3.3.3.1-1.

d. Architecture Cost Risk (ACR).– Two of three subordinate attribute values for ACR are Technical Challenge and Program Immaturity. Since Space Shuttle is an operating system and is capable of meeting the needs without further development, it received the best rating (score of 1.0) on both scales. The third component, Number of New Systems, is an architecture-level value. Space Shuttle's contribution to architecture scores for this component of ACR is zero.

e. Launch Schedule Confidence (LSC).– As in ACR, there are three subordinate attribute values for LSC: Schedule Compression, Schedule Margin, and Delays due to unscheduled maintenance activities. Schedule Compression and Delays are architecture independent while Schedule Margin is architecture dependent since its values are a function of annual flight rates and available facilities and Orbiters. Space Shuttle's Schedule Compression values are: nominal cycle time - 129 days, compressed cycle time - 86 days, and compression ratio - 0.67. It is estimated that launch delays will occur in 24.5 percent of the flights.

f. Environmental Impact.– The Space Shuttle uses liquid hydrogen and liquid oxygen as propellants, as well as two solid strap-on boosters. Its propellant load includes: oxygen - 1361.936 klbm, hydrogen - 227.641 klbm, and solid propellant - 2216.0 klbm. Using the given propellant weights, major effluent constituents were determined and are shown in Table 3.3.3.1-3. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.1-3.– EFFLUENT DATA FOR SPACE SHUTTLE

Exhaust Product	Space Shuttle (klbm)
CO	574.6
CO_2	84.2
H_2	102.8
H_2O	1735.4
HCl	502.6
N_2	208.8
OH	0.8
H	0.8
Al_2O_3	720.0

3.3.3.2 Space Shuttle Evolution

System Description and Performance Characteristics

Space Shuttle Evolution looks like and has similar operations to the basic Space Shuttle System (section 3.3.3.1) except for specific system upgrades as identified by the HTS study team. These improvements include: liquid rocket boosters (LRB), electro-mechanical actuators (EMA), light-weight external tanks (LWET), advanced thermal protection system (ATPS), light-weight Orbiter (LWO), long-duration (90-day) Orbiter (LDO), single I-Load (SIL), SSME limit to 100 percent thrust (SSME 100 percent), crew ejection seats, and the addition of a reusable cargo vehicle (RCV). These 10 items were selected because they are currently being touted as enhancements to improve Space Shuttle safety, increase performance, reduce turnaround time, reduce operational costs, and reduce the number of human flights, while still maximizing the use of Space Shuttle's existing infrastructure and its associated fixed annual cost. Overall performance increase for the Space Shuttle Evolution Orbiter is 13 500 lbs to 160 nmi or 12 000 lbs to SSF. The RCV can place up to 80 000 lbs to SSF. A summary of performance for specific altitudes and inclinations is given in Table 3.3.3.2-1.

TABLE 3.3.3.2-1.– SPACE SHUTTLE EVOLUTION PERFORMANCE CHARACTERISTICS

INCLINATION (deg)	APOGEE X PERIGEE (nmi)	PAYLOAD (klbs)	
		ORBITER	RCV
28.5	160 x 160	65.6	88.5
28.5	220 x 220	57.5	82.0
28.5	300 x 300	48.5	72.0
57.0	160 x 160	50.1	83.4
57.0	324 x 324	30.5	70.0

a. LRB's.– The LRB's selected for this study are expendable and use four pump-fed LO_2/RP-1 engines per booster. Each booster has engine-out capability from lift-off. Switching from the original SRB's to these LRB's provides an additional 20 klb payload delivery capability. Supporting data for their design was obtained from the Martin-Marietta LRB study contract (NAS8-37136).

b. EMA's.– Converting the Orbiter's control surfaces from hydraulic to electro-mechanical actuation offers improved processing time, reduced operating costs, and increased payload performance. These improvements result from elimination of the hydrazine APU, APU servicing, and its GSE; hydraulic system and its GSE; "SCAPE" suit operations and *area clears* for actuator tests; and potential for hydraulic leaks. Payload performance gains of about 5000 lbs are a direct result of eliminating current on-board hardware. Full implementation of this improvement is likely only for new Orbiter builds. Candidate functions for EMA upgrades include aerosurface control, door actuation, wheel deployment, brake actuation, umbilical retraction, and engine gimbal.

c. LWET.– A series of candidate changes in the design of the ET are being considered in order to improve performance and reduce weight. The candidates include Super Lightweight Ablator substitution, tumble valve deletion, deletion of slosh baffle, ET range safety system revision, variable insulation spray pattern, margin optimization-LO_2; biaxial yield-LH_2 tank; reduced weld land width; margin optimization-LH_2; biaxial yield-LO_2 tank; TPS LO_2 aft dome; LO_2 aft dome reduction, reduction of LO_2 proof pressure, substitution of Al-Li for sheet in the intertank area (I/T), I/T margin optimization, machining of I/T TPS, two-stage GO_2 (Gaseous Oxygen) vent valve, and tolerance weight reduction. These changes would provide a cumulative weight savings of about 3000 pounds, providing nearly a 1-pound payload increase for each pound of weight reduced from the ET.

d. ATPS.– Five major changes in the TPS are incorporated to provide increased safety and reliability due to increased TPS strength and temperature limits and reduced operations cost due to decreased maintenance between flights. These changes include using Advanced Carbon-Carbon (ACC) for the nose and wing leading edges (five times the strength and eight times the modulus of current reinforced carbon-carbon), High Thermal Performance (HTP) tiles (higher strength, temperature capability, and improved impact resistance), Nextel insulation blankets (higher temperature capability than current Advanced Flexible Reusable Surface Insulation), using PBI instead of Nomex felt (200-300 °F higher temperature capability), and Nextel 312 gap fillers and thermal barriers (permit higher mission-use life due to higher temperature capability).

e. LWO.– This effort, which is also called the Lightweight Aerosurface Structures Program, improves reliability and safety, lowers operating costs, and increases the Space Shuttle capability by incorporating several modifications: use of lighter material (candidates are Al-Li, Graphite/Polyimide,Graphite/Bismaleimide, and ACC) for the primary structure and components such as control surfaces, application of developed technologies to additional components such as the drag chute structure, and integration of advanced materials into Orbiter production and retrofit (i.e., nose cap, chin panel and wing leading edge). Besides a reduction of 300-500 lbs per vehicle through retrofit, up to 6000 lbs can be eliminated from new orbiters.

f. LDO.– The Space Shuttle LDO significantly increases the man-tended SSF crew stay time up to a 90-day mission by adding eight tank set pallets containing H_2 and O_2, and using some SSF power. Orbiter mission durations of up to 44 days are achievable without any SSF provided power. Changes in the Orbiter design which will be required for the LDO include high density packing stowage approach, autolanding capability to ensure safe return, N_2 (storage required to meet the crew cabin makeup gas requirements, implementation of long life fuel cells, and a number of relatively minor modifications such as docking and thermal control.

g. Single I-Load.– A single season I-load that can be used any time during the year is another approach for reducing ascent design effort. The monthly and day-of-launch
I-loads are concerned with absorbing wind and subsystem variations for a given launch. These activities result in considerable launch support effort and cost. To reduce this effort and complexity, a single season I-Load approach is incorporated. This change affects first stage, flight control I-loads, requires specific structural modifications, reduces average performance, and significantly reduces launch operations costs by eliminating day-of-launch software updates.

h. SSME Limit to 100 Percent Thrust.– SSME reliability has been shown to be related to operational power level, with lower power levels offering greater reliability.[6] By limiting SSME operation to no more than 100 percent thrust level versus operating at 104 percent, it is estimated that its single engine reliability against mainstage shutdown would be increased from 0.9860 to 0.9947. These values compare with 0.9977 used in the HTS study analysis for all liquid rocket engines.

i. Ejection Seats.– The ejection seat system was developed as part of the Space Shuttle Evolution Phase II Crew Escape Study. The option used for this study is capable of ejecting up to eight crew members in about 5 seconds. The operational sequence is: (a) blow off the roof structure above the flight deck, (b) eject the three crew members seated behind the commander and pilot, (c) blow off the section of the flight deck floor, and (d) eject the three middeck crew members by pushing them up to and out of the flight deck, followed by the commander and pilot. Use of this ejection seat system would provide an alternative to the RTLS abort option and would only be used if an RTLS abort could not be performed.

j. RCV.– The RCV design is based on the Space Shuttle Orbiter, and, in fact, has the same outer mold line as the Orbiter. However, a small pressurized volume replaces the Orbiter's crew module. This module provides the environmental control for Space Shuttle avionics currently housed in the crew module. In addition, specific subsystem items have been relocated forward to improve vehicle center of gravity, and hence, return flight characteristics. Operationally, it uses all existing Space Shuttle infrastructure.

k. Abort Modes.– The abort modes for the Space Shuttle Evolution will be similar to the current Space Shuttle with the exception of the ability of the crew to use the ejection seats. This could occur anytime from the pad up to approximately the following limits: V=700 fps, H=10 kft, and t=28 seconds from lift off. Ejection is not possible between altitudes of 10 kft and 30 kft due to SSME plume heating effects with all three SSME's burning. However, there is a 16-second window, which opens at 30 kft altitude, where ejection is again possible (altitude range is 30 - 50 kft, velocity is between 1290 fps and Mach 1.86). If the number one SSME is shut down before ejection, then the crew escape option is a continuous window from the pad up to an altitude of 50 kft. During descent, the limits for using the ejection seats are: V =< Mach 1, and H = 50 000 ft to 300 ft minimum. This system can also be used after touchdown to provide an escape option for all eight crew members.

l. Implementation.– The IOC for Space Shuttle Evolution used in this study is 2000, although all items have a projected availability before the turn of the century (Table 3.3.3.2-2). Also, some enhancements would be applicable to all flights, while others (e.g., light-weight Orbiter, EMA's) would only be realized as new orbiters are built.

Attribute Values

System input data related to each attribute, as well as system specific attribute values, are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level. These will be discussed following the presentation of the Space Shuttle evolution data.

a. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. For Space Shuttle Evolution, these include replacement of the SRB's by LRB's with engine-out capability and the addition of ejection seats. The use of LRB's with engine out increases the mission success rate and allows the boosters to be shut down and expended during the first two minutes of flight. Ejection seats provide more coverage (see Abort Modes above) of the mission profile than the slide pole, described in section 3.3.3.1, and therefore decreases the probable rate of crew loss events. Abort options (described in Section 3.3.3.1) remain and can be used in the event of a non-catastrophic SSME or LRB engine failure. Other salient features include having the crew module in the same element as the liquid engines but over 70 feet ahead of their location, and having the crew module parallel to the propellant tank as well as to the liquid rocket boosters.

TABLE 3.3.3.2-2.– SPACE SHUTTLE EVOLUTION ENHANCEMENT PROJECTED AVAILABILITY DATES

SPACE SHUTTLE EVOLUTION ENHANCEMENT	AVAILABLE
SINGLE I-LOAD	1994
100% SSME MAX POWER LEVEL	1996
EJECTION SEATS	1997
LDO	1997
ATPS	1998
LWET	1998
EMA's	1999
LWO	1999
LRB'S	1999
RCV	1999

b. Funding Profile.– Cost information provided to the HTS included the same breakdown as for the Space Shuttle system. However, additional costs associated with Space Shuttle Evolution development and operations have been included. Table 3.3.3.2-3 presents a summary of this data.

c. Probability of Mission Success.– A system description and flight profile contains the required input information for this attribute. In summary, Space Shuttle Evolution, with either the Orbiter or RCV in the stack, has 4 liquid propulsion stages and 13 liquid engines: 3 SSME's, 4 LRB engines per booster, and 2 OMS engines. The system has engine-out capability on each of the LRB from lift off and for the Orbiter and RCV per the abort descriptions in section 3.3.3.1. Its mission profile and sequence of events is similar to that shown for Space Shuttle in Figure 3.3.3.1-1.

d. Architecture Cost Risk.– Two of three subordinate attribute values for ACR, Technical Challenge and Program Immaturity, are system dependent. These were determined by the NIT through consensus. Since Space Shuttle Evolution is a derivative of an operating system and requires development of one new flight element (LRB) out of three (SRB, ET, Orbiter), plus a modified version (RCV) of an Orbiter, it received relatively high ratings for Technical Challenge and Program Immaturity. Specifically, Space Shuttle Evolution was a given a 3 (Non-Recurring), 2 (Production) and 3 (Operations) as part of its Technical Challenge value. These scale ratings, out of a range from 1-10, translated into values of 2.78, 1.67, and 2.78, respectively (see ACR discussion in

TABLE 3.3.3.2-3.– SPACE SHUTTLE EVOLUTION FUNDING PROFILE INPUT DATA

SPACE SHUTTLE COST BREAKDOWN CATEGORIES	TOTAL OR TFU COST ($M)	LEARN CURVE (%)	RATE CURVE (%)	COST PER FLT ($M)	COST PER YEAR ($M)	Y -6 (%)	Y -5 (%)	Y -4 (%)	Y -3 (%)	Y -2 (%)	Y -1 (%)	FLT YR (%)
NON-RECURRING												
RDT&E	1966					5	10	25	25	25	10	
PRODUCTION	0											
P3I	1000/YR											
LAUNCH PAD	973							15	40	40	5	
VERT ASSY BLDG BAY	252							15	40	40	5	
ORB PROC FACIL	268							15	40	40	5	
LAUNCH CONTROL CTR	54								40	45	15	
MOBILE LAUNCH PLTFRM	116								35	45	20	
LRB FACILITY	1140					5	10	25	25	25	10	
RECURRING												
NEW												
ORBITER (new)	1756	100	100					25	30	30	15	
SSME (new)	96	90	90						25	60	15	
FLIGHT TO FLIGHT												
EXTERNAL TANK				12	352				23	36	40	1
LIQUID ROCKET BOOSTER	176	90	88							1	58	41
SSME (refurb)				3	44				16	26	26	32
ORBITER/CE				10	229							100
LAUNCH OPERATIONS				5	582							100
FLIGHT OPERATIONS				7	664					1	7	92
R & M/SUPPORT				0	327							100

Section 3.2.5). On a similar scale from 1-10 for Program Immaturity, Space Shuttle Evolution was given a 4, which is a value of 4.64. The third component, Number of New Systems, is an architecture-level value. Space Shuttle Evolution's contribution to architecture scores for this component of ACR is 0.93.

e. Launch Schedule Confidence.– As in ACR, there are three subordinate attribute values for LSC: Schedule Compression, Schedule Margin, and Delays due to unscheduled maintenance activities. Schedule Compression and Delays are architecture independent, while Schedule Margin is architecture dependent since its values are a function of annual flight rates and available facilities and Orbiters. Space Shuttle Evolution's Schedule Compression values are: nominal cycle time - 87 days, compressed cycle time - 62 days, and compression ratio - 0.73. It is estimated that 24 percent of Space Shuttle Evolution's flights, both human and RCV, will experience a launch delay.

f. Environmental Impact.– The Space Shuttle Evolution uses liquid hydrogen and liquid oxygen as its main propellants, as well as liquid oxygen and RP-1 in its two liquid rocket boosters. Its propellant load includes: oxygen - 2032.936 klbm, hydrogen - 227.641 klbm, and RP-1 - 268.700 klbm. Using the given propellant weights, major effluent constituents were determined and are shown in Table 3.3.3.2-4. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.2-4.– EFFLUENT DATA FOR SPACE SHUTTLE EVOLUTION

Exhaust Product	Space Shuttle (klbm)
CO	625.5
CO_2	518.8
H_2	90.6
H_2O	2286.7
HCl	0.0
N_2	0.0
OH	0.0
H	0.0
Al_2O_3	0.0

3.3.3.3 Assured Crew Return Vehicle (ACRV)

System Description

The ACRV is currently the subject of a Phase B competition. The material in this section is based on a candidate configuration, the Viking-SCRAM, developed in-house at JSC. Cost and weight data are data supplied by the ACRV Program.

As a result of the Space Shuttle stand-down following 51-L, the need for an alternate system for returning the SSF crew was identified. A number of studies were completed to identify requirements and possible solutions. The conclusion was that a dedicated, space-station-based vehicle is required to assure the safe return of the SSF crew. Three design reference missions for this system are defined as follows:

- SSF crew return in the event of prolonged Space Shuttle stand-down.
- Return of ill or injured SSF crew person when Space Shuttle is not available, e.g., between normally scheduled Space Shuttle missions to SSF.
- Emergency evacuation of SSF and subsequent return of crew to Earth.

These design reference missions define a requirement for an operational mission life of up to 24 hours. The crew capacity and the landing mode – vertical or horizontal, land or water – are the major open trades to be determined in the Phase B study.

One ACRV is to be delivered to SSF as a payload in the Space Shuttle cargo bay to support SSF PMC, and a second is required at EMCC. After berthing at SSF, the ACRV will remain on station in a quiescent mode unless called upon for a crew return mission. Each ACRV will be returned to Earth, as Space Shuttle cargo, at approximately 5-year intervals for refurbishment. Ground processing sites, including facilities for refurbishment and pre- and post-flight processing, are also to be determined.

Performance Characteristics

The Viking-SCRAM ACRV shown in Figure 3.3.3.3-1 is comprised of an 11-ft diameter cylindrical crew compartment on a 14.5 ft-diameter Viking heat shield. An 8-ft diameter service module mounted forward of the heat shield is jettisoned after the deboost burn. Berthing at SSF is enabled by a berthing adapter that flares to accommodate a small (~36) in ACRV hatch mating at a standard (80 in) SSF hatch. The mass summary for the flight segment, including flight support equipment (FSE) and airborne support equipment (ASE), is presented in Table 3.3.3.3-1. Note that, with an eight-man capacity, the ACRV cargo capacity is essentially nil.

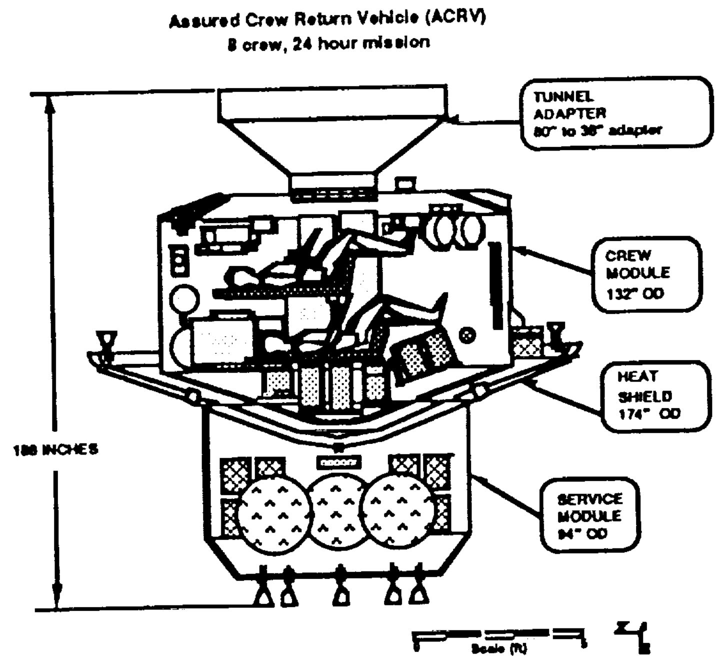


Figure 3.3.3.3-1.– Viking-SCRAM ACRV.

TABLE 3.3.3.3-1.– ACRV MASS STATEMENT

All Masses are in Pounds					
Functional Sub-System Code	Crew Module	Service Model	Berthing Adapter System	FSE & ASE	Meteoroid Debris Protect
1 Structure	1,552	475	544	1,600	523
2 Protection	1,216	71			
3 Propulsion	250	302			
4 Power	856	732			
5 Control	0				
6 Avionics	990	48			
7 Environment	1,817				
8 Other	989	52			
9 Growth	1,150	252	82	240	79
Dry Mass	8,820	1,932	625	1,840	602
10 Non-Cargo	1,820	56			
11 Cargo	120	0			
Inert Mass	10,760	1,988	625	1,840	602
12 Non-Propellant	373	0			
13 Propellant	264	866			
Gross Mass	11,397	2,854	625	1,840	602

Attributes Values

a. Program Costs and Funding Profiles.– ACRV development and acquisition costs in Table 3.3.3.3-2 and the ACRV development profile shown in Table 3.3.3.3-3 are based on data obtained from the NASA ACRV program office. A cost breakdown is available for the flight segment only, while development and acquisition costs are not available for either the ground segment or for the mission control segment. The only operations cost available is an estimate of $80M for the first 10 years of operation.

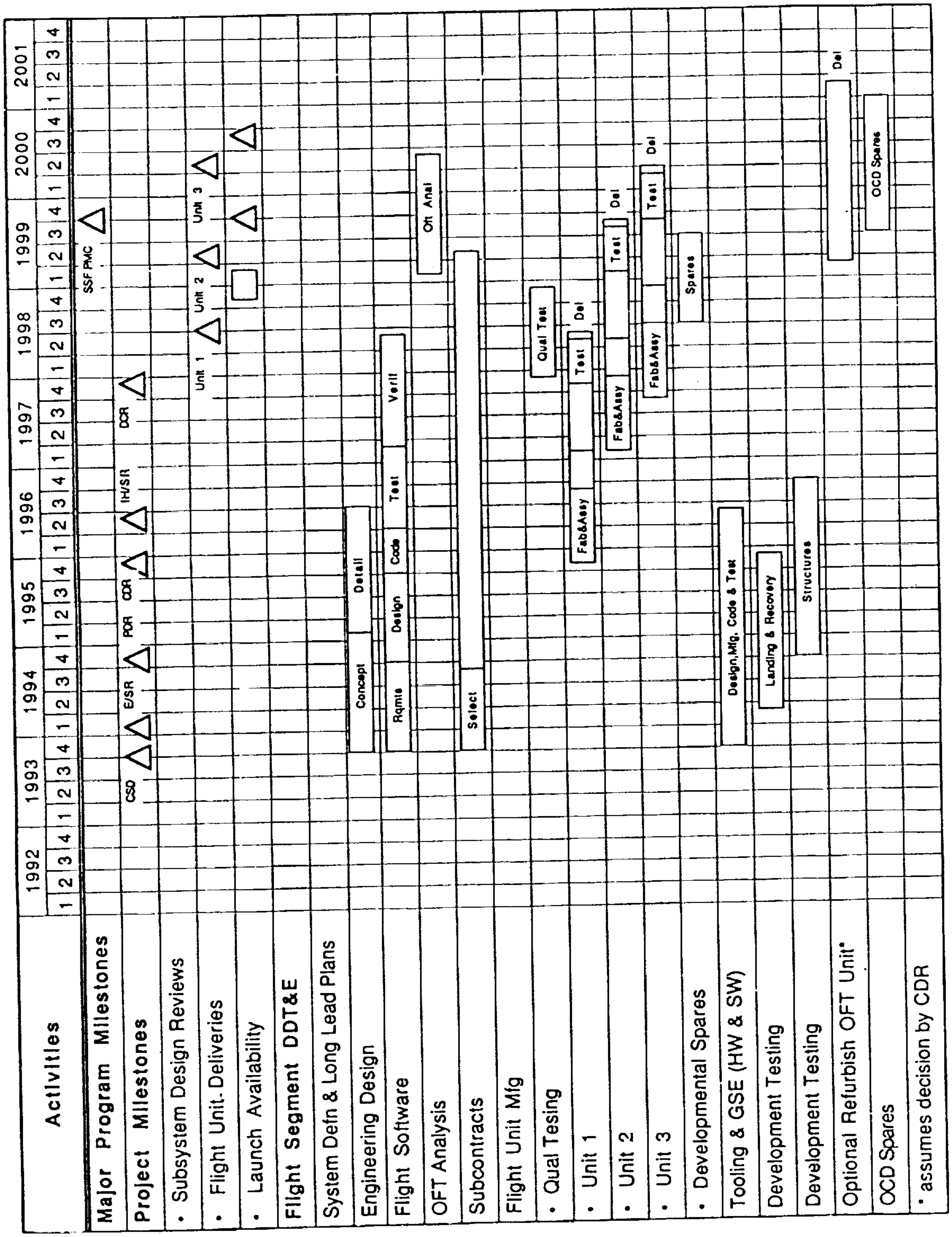
TABLE 3.3.3.3-2.– ACRV DEVELOPMENT AND ACQUISITION COSTS

FY92 DOLLARS IN MILLIONS	
INTEGRATION, ASSY, & C.O.	
STRUCT & MECHANISMS	171.9
RECOVERY & LANDING	41.6
THERMAL PROTECTION	37.3
PROPULSION	70.8
POWER (BATTERIES)	3.0
ELEC DIST & CONTROL	49.6
AVIONICS	193.2
ECLSS & PERS PROV	58.6
IACO TOTAL:	626.0
OFT VEHICLE	107.0
TOTAL NON-RECURRING	733.0
RECURRING PRODUCTION:	
TWO FLT UNITS @ 107.0	214.0
TOTAL DEVEL & ACQ:	947.0

b. Probability of Mission Success.– The ACRV is passive cargo in the Space Shuttle cargo bay for delivery to the SSF. The PMS for this phase is counted as Space Shuttle operations, and not as ACRV operations. The PMS for the ACRV crew return mission is defined as the probability that the ACRV will successfully complete the mission within the limits specified by the System Performance Requirements Document (JSC 34000). The availability and performance of the ground and mission support segments should not be considered except where support functions are necessary to accomplish a safe landing. The mission is successfully completed when splashdown or touchdown is within required impact acceleration limits (does not include initiation, rescue, or recovery functions). Because the ACRV is not manifested as distinct flights, its reliability does not contribute to the architecture's PMS score.

c. Architecture Cost Risk.– The ACRV is a low technology, moderately mature study.

TABLE 3.3.3.3-3.– ACRV FUNDING PROFILE



d. Operational Flow.– As noted previously, the ACRV is carried as a payload in the Space Shuttle cargo bay. The processing of this payload is an offline operation as far as Space Shuttle processing is concerned. The span available for ACRV ground processing (order of years) does not impact processing operations or LSC scores.

e. Environment.– Environmental contamination problems for launch systems are addressed in this study. The ACRV does not use any propulsion system within the sensible atmosphere, and as a result the only contaminants are those produced by a low-thrust-level reaction control system that may be used to provide attitude control during the descent phase.

3.3.3.4 Cargo Transfer Function (CTF)

System Description

a. History.– In some of the HTS architectures, cargo delivery to specific destinations is required. Using a low cost, expendable launch vehicle (ELV) is desirable; however, most ELV's are not equipped with the specific hardware and software features that would be required to perform a precision rendezvous. A cargo transfer function might be necessary if the cargo was, for example, a logistics element for the SSF. Depending on the ELV, the modifications to perform this cargo transfer can be minor or significant. The CTF is not so much a specific element as a common functionality which the ELV would incorporate in an architecture where precision delivery is needed.

b. Configuration.– The cargo transfer function represents an added capability (and cost) associated with precision rendezvous and delivery of untended payloads to destinations such as the SSF. Typically, all versions of CTF include features such as payload support and attachment structure, avionics, power, communications provisions, attitude control thrusters and tankage, and guidance software. In this study, the CTF is related to evolutionary versions of the Delta, Atlas, and Titan launch vehicles. The CTF will correspond to different designs depending on the launch vehicle, but all the concepts must conform to the following mission groundrules and operational requirements shown in Table 3.3.3.4-1.

c. Abort Modes.– The CTF is never used with human elements and has no specific abort modes.

d. Facilities.– The CTF facilities will be very similar to existing upper stage facilities at the U.S. Eastern Test Range sites. In many cases, only minor modifications may be required to use existing facilities for future operations at KSC or Cape Canaveral Air Force Station (CCAFS). Each carrier booster element section contains a description of the facilities requirement assumptions for the HTS study. Since most CTF designs use bipropellant OMS fuels and hydrazine RCS fuel, existing tank loading and settling facilities at CCAFS will need to be retained.

e. Operational Flow.– The operational flows are very similar to the NLS Cargo Transfer Vehicle and Advanced Upper Stage flows, except the flow time lengths may be different due to smaller vehicle size and different subsystem conceptual designs. The upper stage flow is considered parallel to the booster flow and doesn't result in any schedule drivers.

TABLE 3.3.3.4-1.– CTF GROUNDRULES, ASSUMPTIONS, AND TECHNICAL REQUIREMENTS

• SSF is in 220 nmi circular orbit
• CTF element(s) is (are) physically attached to payload, but supplies no services to the payload, nor does it receive services from SSF or other destination infrastructure
• Payload c.g. is on longitudinal centerline
• Active mission time is 25 hours
• 14 days on-orbit survival time
• MRMS (robotic arm) is the capture mechanism at SSF (two grapple fixtures on the CTF are required)
• No on-orbit maintenance of CTF
• CTF has sufficient GN&C capability to target payload to an envelop (typically 10 foot in diameter by 10 foot long volume) and stabilize attitude (nominally 0.05 deg/sec in x,y,z)
• Automated rendezvous
• Range rate and angle rate sensor
• GPS is used for navigation
• Person-in-the-loop proximity operations at SSF
• Ku band communications
• TV to SSF for final 3000 feet of approach
• Telemetry (32 Kbps) through TDRSS
• 6 DOF control

Performance Characteristics

The CTF itself has no performance capability, rather it is a feature that is added to a launch vehicle and is specific to that vehicle (see Figure 3.3.3.4-1 for Atlas example). Although there would be additional mass for the CTF, with a resulting reduction in payload capacity for a given launch vehicle, this effect was considered secondary.

Attribute Values

a. Funding Profile Summary.– The CTF estimates were developed by the three NIT member sources responsible for the parent launch system inputs. Each industry representative defined a new conceptual design and weight statement (no known current bus stages meet the requirements for this function) for cost estimating. Each NIT member assigned a CTF estimating task submitted a parametric cost estimate (in constant-year 1992 dollars excluding NASA program factors) for their respective CTF space flight element.

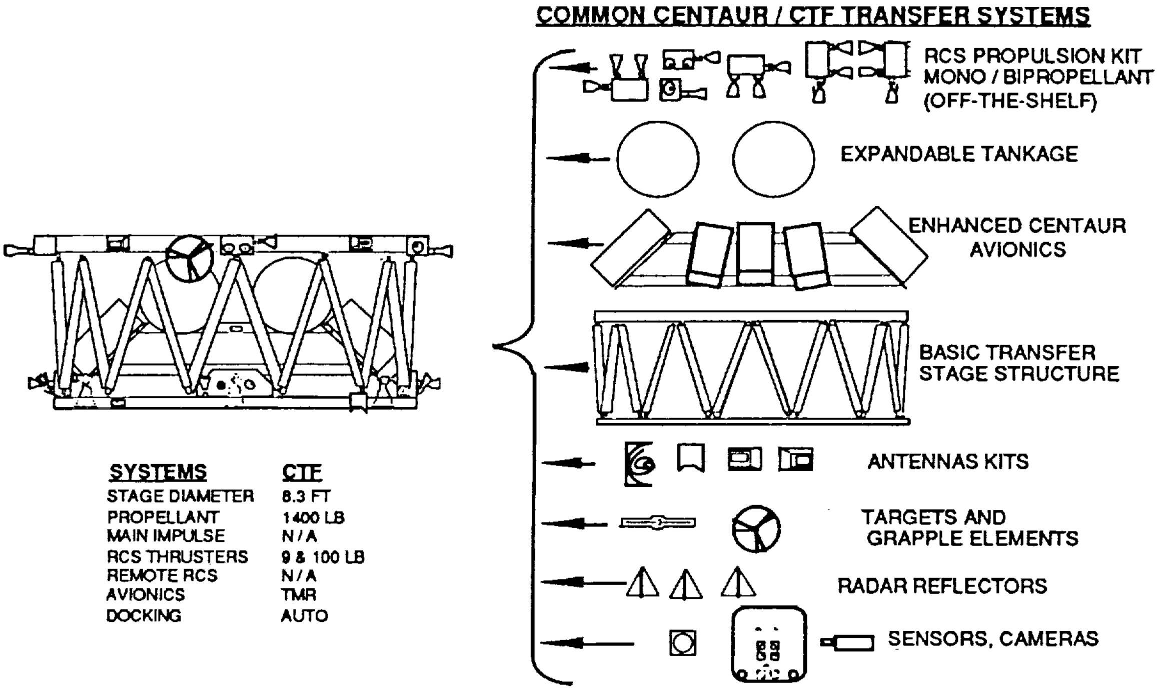


Figure 3.3.3.4-1.– Atlas example.

A summary of the cost estimates for CTF are shown in Table 3.3.3.4-3. Appendix 2.4 contains the cost estimate inputs sheets for each respective CTF conceptual design.

TABLE 3.3.3.4-2.– CTF COST SUMMARY

(1992 Dollars in Millions)			
	Atlas CTF Stage	Delta CTF Stage	Titan CTF Stage
Development:			
C/D Phase	$243	$243	$114
Facilities			
Total -	243	243	114
Production:			
Theo. 1st Unit	16	16	87
Supt./ Equip. Set	11	11	10
Oper. and Support:			
Variable Cost	XX	XX	XX
Fixed Annual	X	X	X

b. Probability of Mission Success.– The mission of the CTF begins after the CTF or payload has been inserted into orbit. By definition, mission success only considers flight phases up to orbital insertion. The CTF, therefore, has no contribution to the overall PMS as it is defined in this study.

c. Human Safety.– The CTF is used in conjunction with untended missions and therefore does not contribute to any safety score.

d. Architecture Cost Risk.– The CTF designs for the three versions were considered similar to the point where one set of risk scores were adequate. For the non-recurring portion of the Technical Challenge subattribute, a score of 4 reflects the NIT view that the CTF is within the state-of-the-art. A Production score of 2 and an Operations score of 3 are indicative of the small size and existing processes required to produce a CTF. The Program Immaturity factor was a 6, which reflects the lack of detail design at this point.

e. Launch Schedule Confidence.– The CTF operates in conjunction with other systems and does not have its own score for LSC.

f. Environment.– The CTF involves operation of elements outside the sensible atmosphere and does not contribute to the environment attribute score as it is defined in this study.

3.3.3.5 Delta II

System Description

a. History.– The Delta II is the newest, most powerful version of the Delta series of launch vehicles. Originally developed by and for NASA/Goddard Spaceflight Center, the Delta, using components from the USAF's Thor IRBM program and the Navy's Vanguard launch vehicle program, was first launched on May 13, 1960. Through mid-1992 there have been 196 successful launches out of 206 attempts, demonstrating a reliability of greater than 94 percent.

b. Configuration(s).– The current 7000 series booster configuration, the most advanced to date, was developed as the result of being selected by the USAF, during the Medium Launch Vehicle (MLV-1) competition, to launch the Global Positioning System (GPS). The first flight of this currently available Delta II occured on November 26, 1990. The characteristics of the Delta II launch vehicle are given in Table 3.3.3.5-1. Two-stage (7920) and three-stage (7925) versions are operational at this time. Two different payload fairing (PLF) sizes are offered, 9.5 and 10 ft diameter. The overall vehicle is shown with each of these PLF's in Figure 3.3.3.5-1 for the three stage configuration. The overall dimensions of the two stage are the same.

TABLE 3.3.3.5-1.– DELTA II VEHICLE CHARACTERISTICS

	Strap-On-Solids	First Stage	Second Stage	Third Stage
Length (ft)	42.5	85.6	19.6	6.7
Diameter (ft)	3.3	8	8	4.1
Total weight (lb)	28,618 ea (GL)* 28,800 ea (AL)**	224,239	15,394	4,721
Engine/motor	GEM	RS-27/C	AJ10-118K	Star-48B
Manufacture	Hercules	Rocketdyne	Aerojet	MTI
Quantity	6 (GL)* + 3 (AL)**	1	1	1
Propellants	Solid	LOX/RP-1	N_2O_4 /A-50	Solid
Propellant weight (lb)	25,800 ea	211,147	13,367	4,430
Thrust (lb) - SL	98,870 ea	201,000	-	-
- VAC	110,820 ea	237,000	9,645	15,100
Isp (sec) - SL	245.7	255.6	-	-
- VAC	273.8	301.8	319.4	292.6
Burn time (sec)	63	265.4	439.7***	87.1
Expansion ratio	10.65:1	12:1	65	54.8

*Ground lit
**Air lit
***Incl restarts

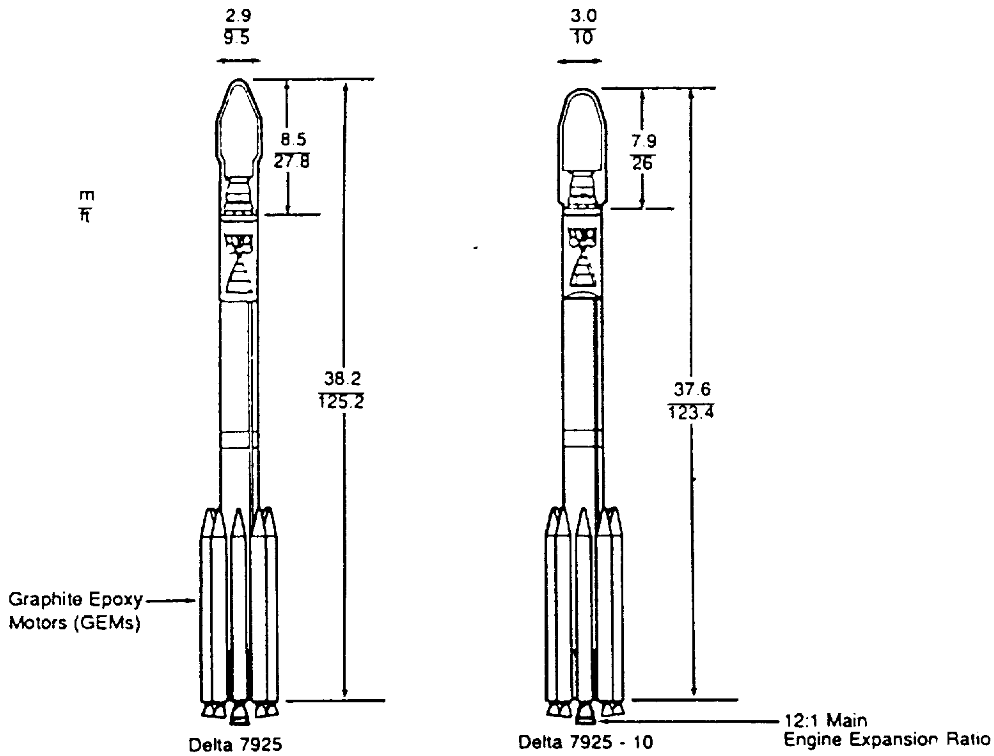


Figure 3.3.3.5-1.– Delta II 7925 configurations.

c. Operations.– Launch Operations: Delta vehicles are launched from Launch Complex 17 (LC-17) at CCAFS. LC-17 contains two active pads, 17A and 17B. The two pads can be used for simultaneous build up of two vehicles. The Delta launch site operations flow and typical (nominal) launch ops timeline are shown in Figure 3.3.3.5-2. Nominal operations can accommodate up to 12 launches per year from CCAFC.

West coast launches are from Space Launch Complex 2 West (SLC-2w) at Vandenberg Air force Base (VAFB). Vehicle and payload processing operations are performed at Building 836 in South Vandenberg and at the launch complex. The Delta launch vehicle elements are delivered to VAFB from Huntington Beach, California, where they have gone through the equivalent of the CCAFS Area 57 Delta Mission Checkout (DMCO). SLC-2w activities are similar to the LC-17 described in Figure 3.3.3.5-2.

Flight Operations.– Typical two- and three-stage mission profiles are shown in Figure 3.3.3.5-3. Details of a three-stage (7925) vehicle geosynchronous transfer orbit (GTO) mission profile are given in Figure 3.3.3.5-4.

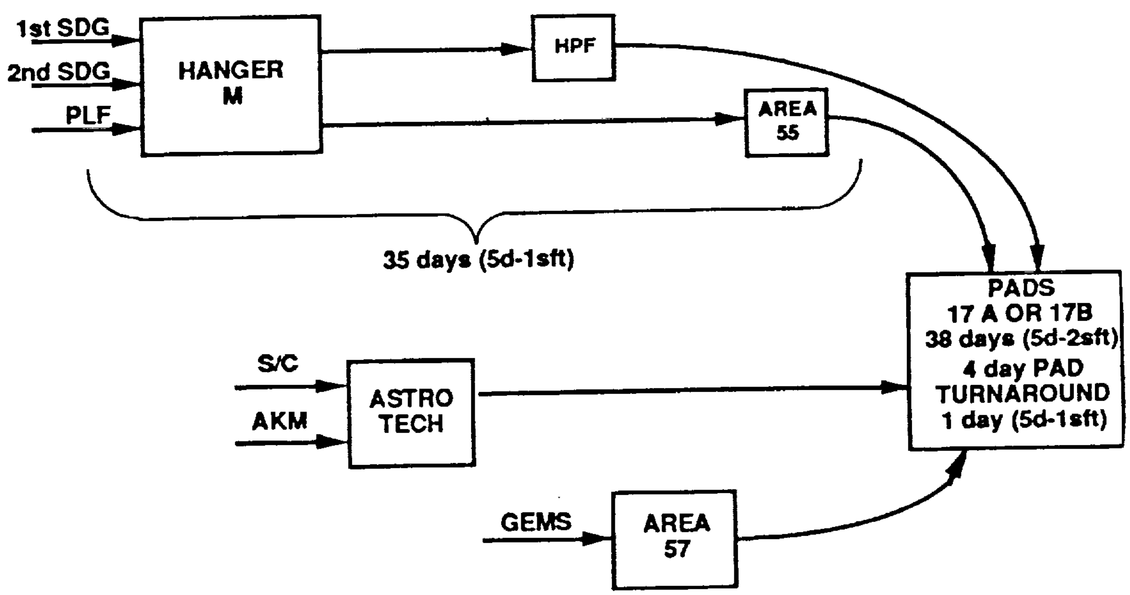


Figure 3.3.3.5-2.– Delta processing (ETR).

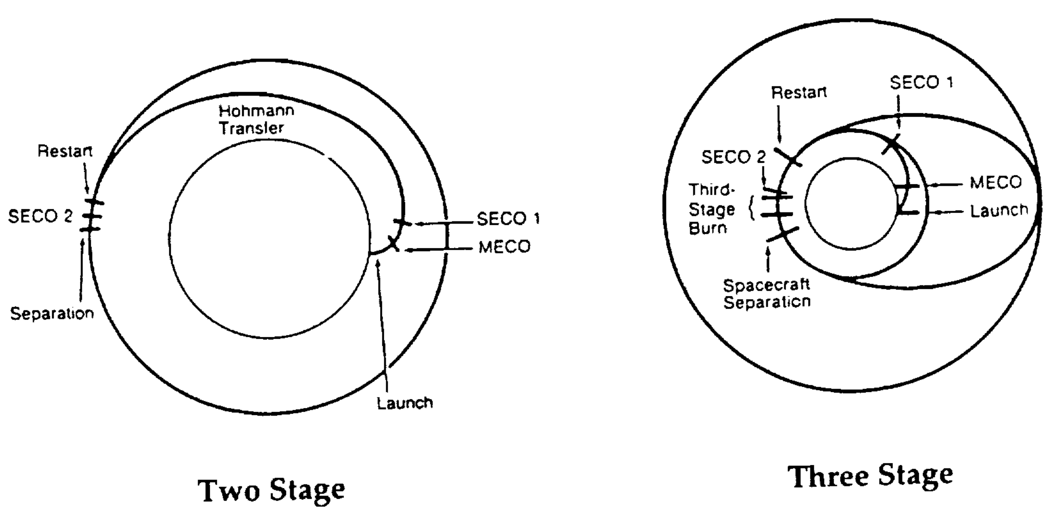
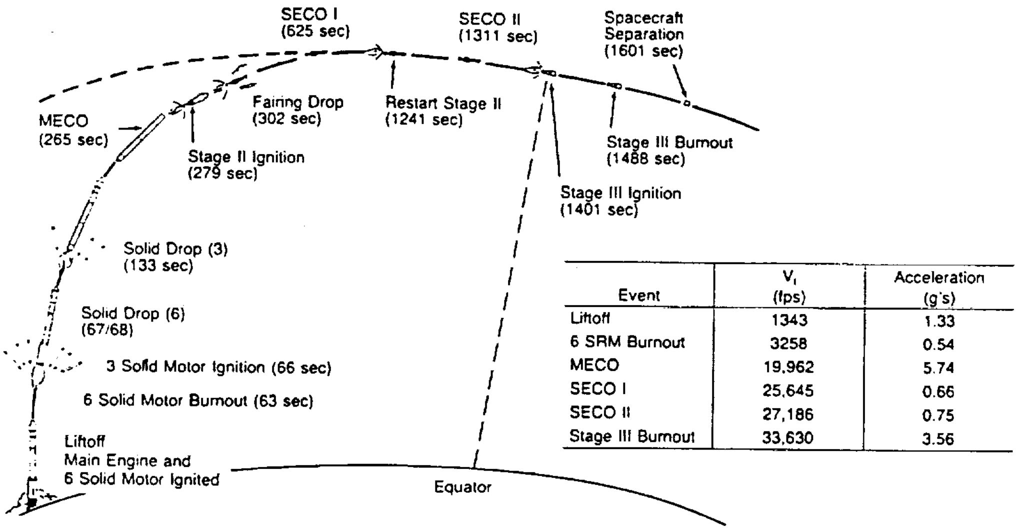


Figure 3.3.3.5-3.– Typical mission profiles.



Event	V_I (fps)	Acceleration (g's)
Liftoff	1343	1.33
6 SRM Burnout	3258	0.54
MECO	19,962	5.74
SECO I	25,645	0.66
SECO II	27,186	0.75
Stage III Burnout	33,630	3.56

Eastern launch site, flight azimuth 95 deg; maximum capability to 28.7-deg inclined GTO, 100-nmi perigee.

Figure 3.3.3.5-4.– Typical Delta II 7925 mission profile – GTO mission.

Performance Characteristics

a. GLOW.– The gross lift-off weight of the Delta II, not including payload, is given in Table 3.3.3.5-2 for both the two-stage (7920) and three-stage (7925) vehicles.

b. Cargo Envelope.– Details pertaining to the payload fairings and the available envelopes can be seen in Figure 3.3.3.5-5. Information for the two-stage and three-stage vehicles is shown for both the 9.5- and 10-ft diameter fairings.

c. Cargo Capacity.– The performance of the Delta II is shown in Table 3.3.3.5-3 as a function of orbital destination or orbital energy level, in the case of interplanetary missions.

TABLE 3.3.3.5-2.– VEHICLE GROSS WEIGHT
(DOES NOT INCLUDE PAYLOAD)

Segment:	Weight Lbs.	
Solids	2 Stg (7920)	3 Stg (7925)
6 Ground Lit		
2 Air Lit	171,696	171,696
First Stage	86,400	86,400
Second Stage	224,239	224,239
Third Stage	15,394	15,394
subtotal;	NA	4,721
Fairing(s)	497,729	502,450
	9.5 ft --------10 ft	9.5 ft ---------10 ft
Total(s):	1,850 2,200	1,850 2,200
	499,579 499,929	504,300 504,650

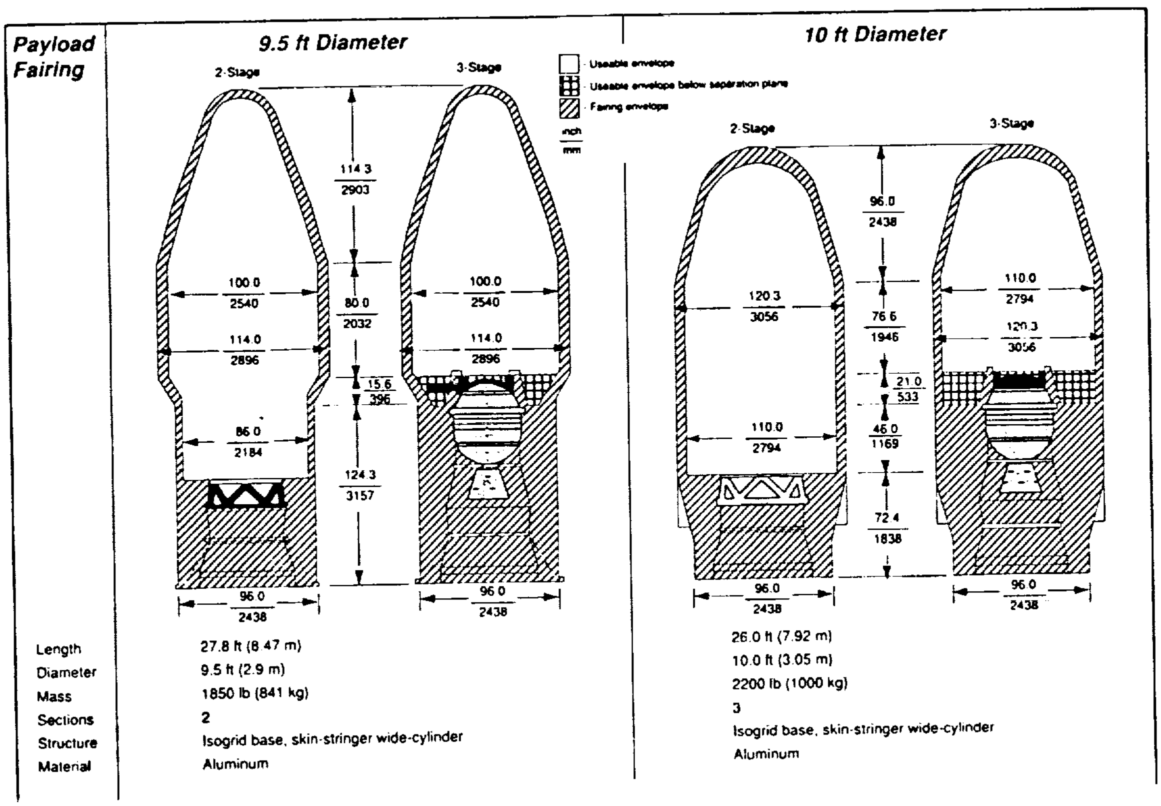


Figure 3.3.3.5-5.– Delta payload envelope.

TABLE 3.3.3.5-3.– DELTA II PERFORMANCE DATA

Mass to Orbit (lbs)		
28.5 degrees, 160 nm circular	10,900	2 stg
28.5 degrees, 220 nm circular	10,500	2 stg
57.0 degrees, 160 nm circular	8.800	2 stg
98.3 degrees, 450 nm circular *	7,000	2 stg
GTO	4,010	3 stg
Interplanetary (28.7 degree 100 nm perigee altitude) C3=0 Km^2/Sec^2 C3=25 " C3=50 "	 2,830 1,700 1,030	3 stg
* WTR launch, all others ETR		

Attribute Values

a. Funding Profile Summary.– The data in Table 3.3.3.5-4 was provided as input for the calculation of the funding profile attribute.

TABLE 3.3.3.5-4.– FUNDING PROFILE COST INPUTS (MILLIONS OF $)

NON-RECURRING:		RECURRING (Includes; Prod, Launch Ops, Flight Ops, Prog Mgt&Sup)				
		Fixed Cost/Flight $140			Fixed Cost/Flight $29	
RDT&E	$0		-3	-2	-1	Year of Flight
N/R	$0	Spread Factors	14%	48%	8%	32%
Production	$0					

b. Probability of Mission Success.– The flight profile shown previously in Figure 3.3.3.5-4 was used to derive the PMS reliability tree for the Delta vehicle. Vehicle characteristics used in the calculation included the use of 2 liquid rocket engines (first and second stages), 10 solid rocket motors (9 for thrust augmentation and 1 for third stage), and 3 liquid propulsion *stages* (first stage and the equivalent of 2 for second stage, due to restart of second stage). Because Delta is an existing vehicle with a launch history, the actual flight reliability of 94.1 percent (175 successes out of 186 attempts – 1964 through 1992) can be compared to the PMS calculated value of 93.2 percent.

c. Human Safety.– Not applicable.

d. Architecture Cost Risk.– Two of the three subattributes were based on system values, or scores. For the Delta vehicle, an existing vehicle, the NIT concensus scores for those subattributes, technical confidence, and program maturity, were both 1.0.

e. Launch Schedule Confidence.– As with ACR, two of the three subattributes were based on system values, or scores. One of these, schedule compression, was calculated based on the operations data given in section 3.3.3.5.1. The value of schedule compression was calculated to be 53 days saved from a nominal 101 day processing time, or 0.52. The other value, percent of flights with delays, was calculated to be 7.59 percent. Both of these calculated values, along with the schedule margin subattribute, were subsequently used with architecture-particular flight rate data to rollup the architecture schedule confidence attribute and value. Historically, six percent to nine percent of Delta flights have been delayed beyond the launch window due to hardware (six percent due to vehicle hardware and three percent due to support hardware).

f. Environment.– The Delta vehicle first stage has an RP-1/liquid oxygen (LOX) propellant load of 211 147 lbm, the second stage has 13 367 lbm of N_2O_4/A-50. In addition, nine solid strap-ons with 229 308 total lbm of propellant are used during the boost phase. Although the Delta utilizes a third stage on some flights, its use is outside the atmosphere and therefore does not contribute to the effluent total.

Using the given propellant weights, the major effluent constituents (in klbs) are shown in Table 3.3.3.5-5. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.5-5.– EFFLUENT DATA FOR DELTA II

Exhaust Product	Delta II Effluents
CO	125.2
CO_2	76.6
H_2	6.6
H_2O	70.4
HCl	31.4
N_2	17.8
OH	0.0
H	0.0
Al_2O_3	45.0

3.3.3.6 Atlas Launch Vehicle Family

System Description

a. History.– The current Atlas launch vehicle family has steadily evolved from the 1950's Atlas Intercontinental Ballistic Missile (ICBM) program. Since then over 500 Atlas launch vehicles have been flown in various configurations from both east and west coast launch sites. The current family uses the same basic 1.5 stage core vehicle as the early concepts, but also incorporates a state of the art cryogenic (LH_2/LOX) upper stage, Centaur.

b. Configurations.– Although various configurations of Atlas will be flown throughout the next several years, the Atlas IIAS configuration is being used as the representative vehicle in the mission capture analyses from 1998 to 2020 (the NASA Mixed Fleet Manifest is used from 1992 to 1997). Figure 3.3.3.6-1 shows the Atlas IIAS relative to the I, II, IIA, and two evolutionary options. An additional configuration, the Atlas E, has been flown frequently over the last several years (not shown in the figure). This configuration is not used in architectures beyond that specified in the Mixed Fleet Manifest (1997 and earlier).

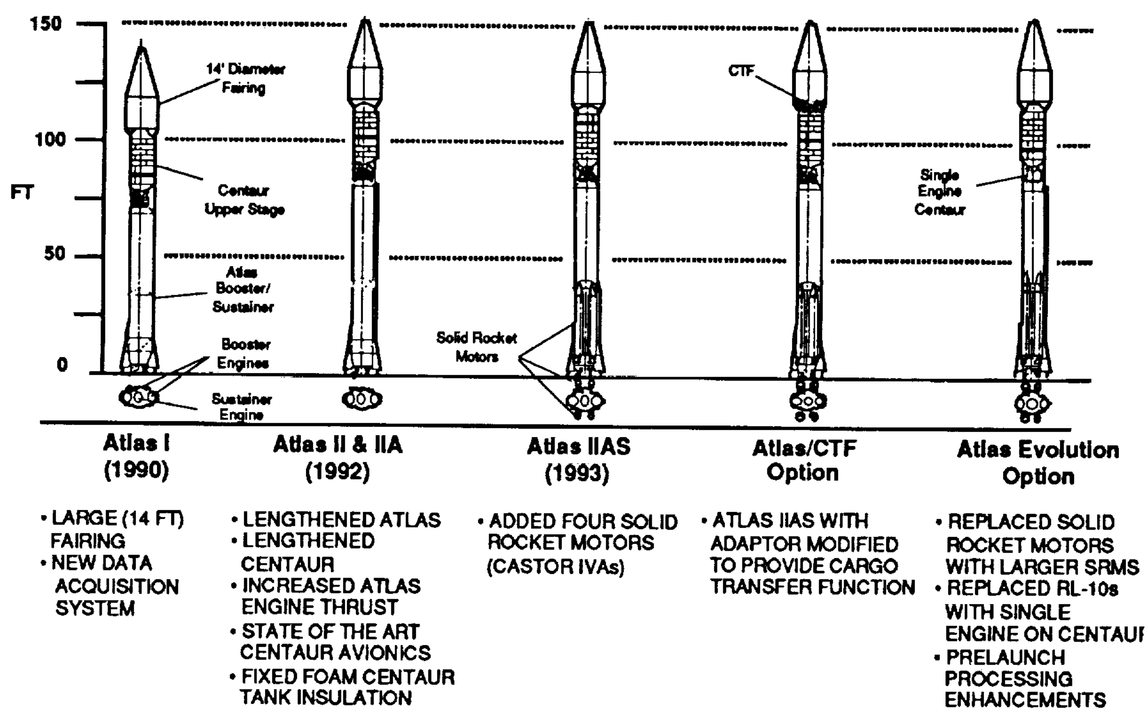


Figure 3.3.3.6-1.– Atlas launch vehicle family.

One evolutionary option of the Atlas IIAS includes a modification of the payload adaptor to provide the CTF. The CTF enables a system to perform rendezvous and proximity operations (including docking or berthing) with SSF or other LEO node destinations. The modifications to provide the CTF primarily consist of relocating some Centaur equipment (e.g. avionics) and the addition of off-the-shelf equipment needed for the proximity operations near SSF (e.g., sensors and thrusters). In addition, the Centaur will require some structural uprating to handle the larger LEO payloads. Figure 3.3.3.6-2 depicts the configuration and composition of the CTF.

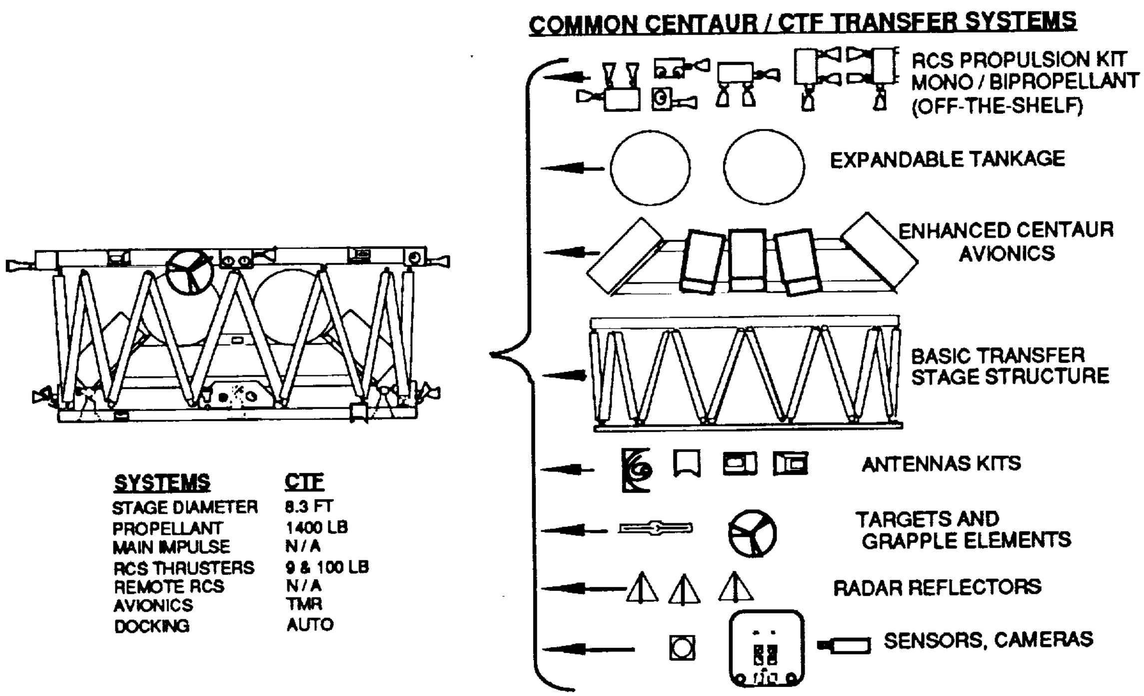


Figure 3.3.3.6-2.– Atlas/CTF configuration.

Another evolutionary option involves reliability, prelaunch processing, performance, and cost enhancements to the Atlas IIAS. As seen in Figure 3.3.3.6-1, this evolutionary option involves modification of the Centaur for a single upgraded RL-10, larger SRM's, a Centaur Processing Facility (CPF), and other enhancements to prelaunch processing.

c. Facilities.– The east coast facilities (CCAFS) used by the Atlas family primarily consist of a booster processing facility (Hangar J), SRM storage facilities, an off-line payload processing facility, and two launch pads (Pad 36A/B). A majority of the integration and checkout between the booster, upper stage, solids, and payload is done on the pad.

The west coast facilities are currently only equipped to handle Atlas E class vehicles (i.e., no Centaur). The mission capture analyses did not include any Atlas launches from the west coast beyond those specified in the NASA Mixed Fleet Manifest.

The Atlas with the CTF does not require construction of additional facilities, however, minimal modifications to the existing support equipment are anticipated and are included in the nonrecurring costs.

The Atlas evolution option includes the construction of a new CPF at the CCAFS for off-pad checkout. This additional facility, along with some other proposed or planned prelaunch processing enhancements, would reduce the time between consecutive launches to 38 days. The Titan evolution concept also benefits from the Centaur off-line processing.

d. Operational Flow.– The Atlas booster/sustainer and Centaur upper stage are delivered to the booster processing facility for inspection and pre-integration processing (3 and 6 days respectively). The Atlas is then transported to the pad and erected (2 days). Once the Çentaur has completed its receiving inspection and preliminary checkouts it is moved to the pad and mated on top of the Atlas (5 days). At this point a series of Atlas/Centaur/Ground System interface checks and system tests including SIMFLIGHT (electronics and software) and Wet Dress Rehearsal (fluids and cryogens) are performed (24 days). Next, the solids are mated to the stack (4 days). At this point the encapsulated payload is delivered to the pad and integrated onto the launch vehicle (2 days). A final certification is performed on the entire stack after which the launch preparations and countdown occur (5 days).

The processing flow for the Atlas IIAS is shown in Figure 3.3.3.6-3. The dwell times in each facility are also noted. The assumed shift schedule for Atlas processing is 5 days a week with one 8-hour shift. However, the last 5 days are around-the-clock operations at a 1.75 shift equivalent. With pad refurbishment and booster processing run in series, the minimum time between consecutive launches is 52 days. This allows a theoretical maximum launch rate of 14 flights per year (2*365/52) for 2 pads. Under nominal operating conditions (i.e. 365 days, less weekends and holidays) up to 10 launches per year are achievable.

Since most of the CTF subsystems are simply relocated from the Centaur to the payload adaptor, the processing flow for Atlas/CTF will be the same as the Atlas IIAS (Figure 3.3.3.6-3).

The processing flow for the Atlas evolution is shown in Figure 3.3.3.6-4. The CPF allows Centaur upper stages to be processed off-line for both Atlas and Titan missions. The booster on-pad operations are reduced through a number of planned and proposed enhancements to the vehicle and the ground segment. These include avionic and other vehicle subsystem upgrades, ground support equipment and launch control system enhancements, and optimization of manufacturing and launch operations.

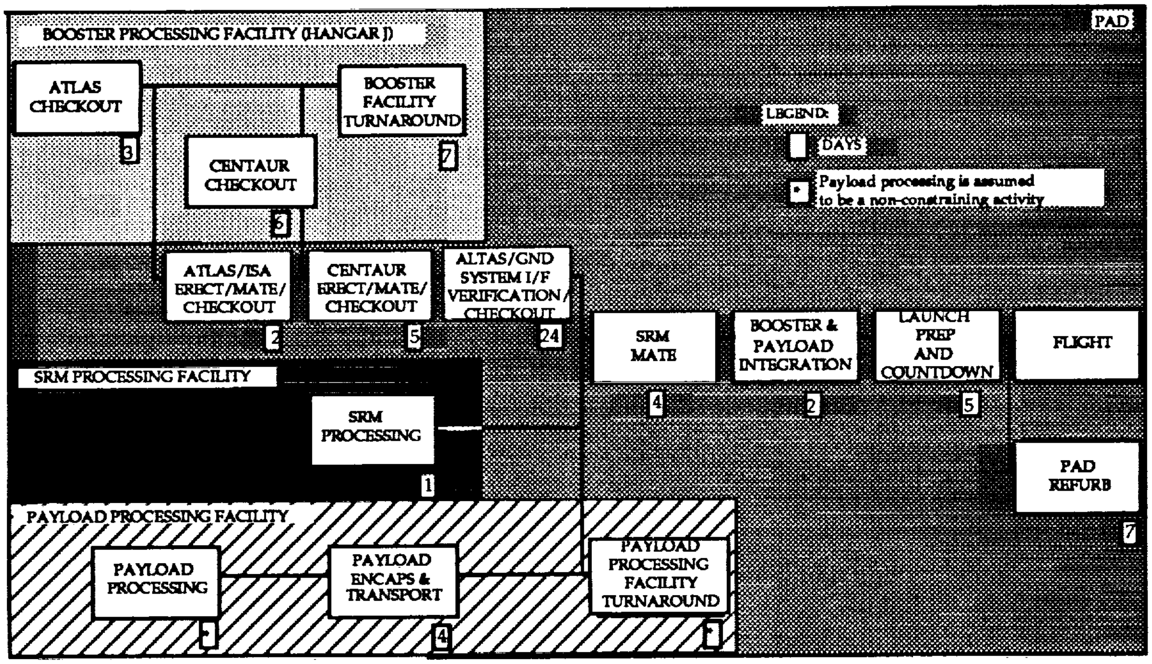


Figure 3.3.3.6-3.– Atlas IIAS processing flow.

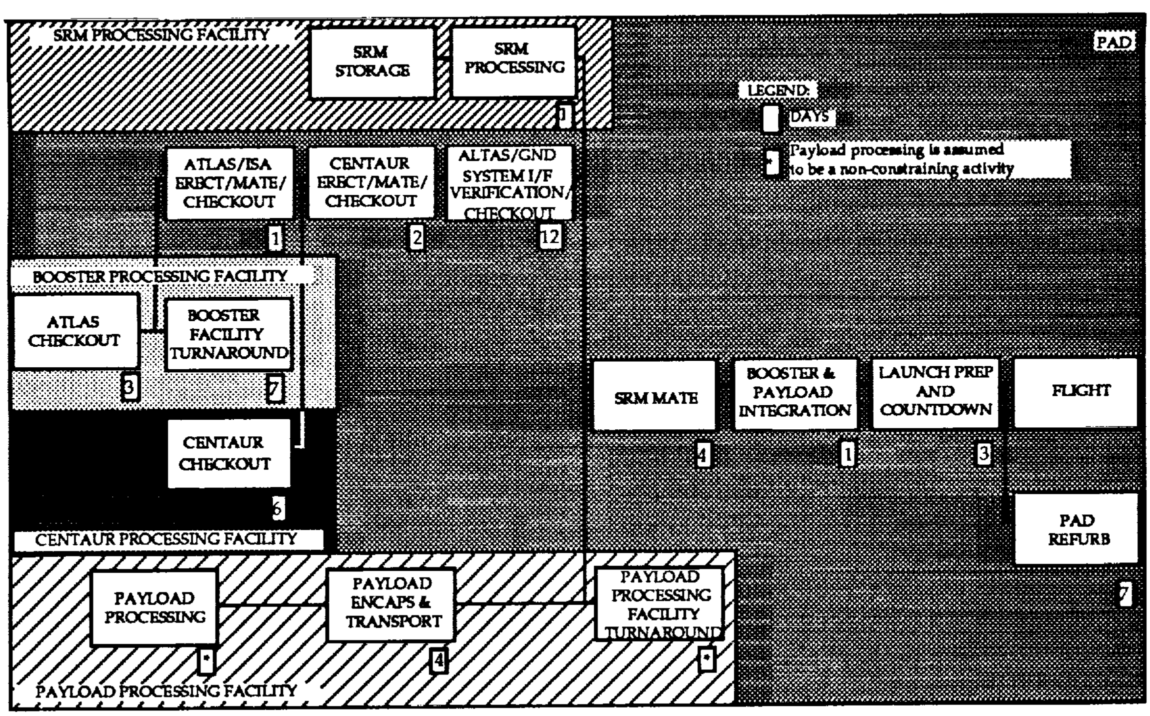


Figure 3.3.3.6-4.– Atlas evolution processing flow.

Performance Characteristics

The Atlas performance characteristics for the three configurations being used in this study are shown in Table 3.3.3.6-1. The Atlas/CTF is only used for SSF deliveries; therefore, the table only shows performance to 220x220 nmi, 28.5°. The Atlas evolution concept has been estimated at the same gross lift-off weight (GLOW) as the current vehicle because most enhancements are in the ground processing area, and those changes that result in mass differences tend to be offsetting (to the extent that they have been analyzed).

TABLE 3.3.3.6-1.– ATLAS LAUNCH VEHICLE PERFORMANCE

	Atlas IIAS	Atlas/CTF	Atlas Evol.
GLOW (lbs)	515,900	523,000	515,900
Press. Volume (ft3)	0	0	0
Cargo Envelop (lxd)	20x13.4	20x13.4	20x13.4
Cargo Capacity (lbs):			
160 nmi circ, 28.5°	17,600	n/a	
220 nmi circ, 28.5°		16,000	18,800
300 nmi circ, 28.5°	15,700	n/a	
30x220 nmi, 28.5°		n/a	22,000
GTO, 26°	7,700	n/a	10,000
Return Capacity (lbs)	0	0	0
Crew Capability (#)	0	0	0
Launch Site Limits	East Coast	East Coast	East Coast

Attribute Values

a. Funding Profile Summary.– The Atlas costs for the three configurations being used in this study are shown in Table 3.3.3.6-2. Because many of the cost numbers are architecture dependent, the following numbers have been calculated based upon several flight rates. The identified launch facility costs are incorporated only if required by the architecture and "If" Scenario (i.e. flight rates exceed capacity of current facilities). The CPF is only used in Architecture 2 and is used by both Titan/Centaur and Atlas/Centaur.

   The Atlas/CTF development schedule is shown in Figure 3.3.3.6-5 as a function of years from the start of Pre-Phase A studies of the system requirements. The program follows the standard development stages and ends with an initial operating capability in the seventh year.

TABLE 3.3.3.6-2.– ATLAS LAUNCH VEHICLE COSTS

All Values in M92$	Atlas IIAS	Atlas/CTF	Atlas Evol.
DDT&E	0	218	100
N/R Prod	0	24	0
P3I	0	0	0
Facilities (if required):			
Pad - ETR	381	381	381
SLC - WTR	476	476	476
Cent Proc Fac - ETR	0	0	150
CPF @: 2/yr	120	132	108
4/yr	93	101	86
6/yr	85	91	78
8/yr	80	85	74
10/yr	78	83	72
12/yr	76	80	71

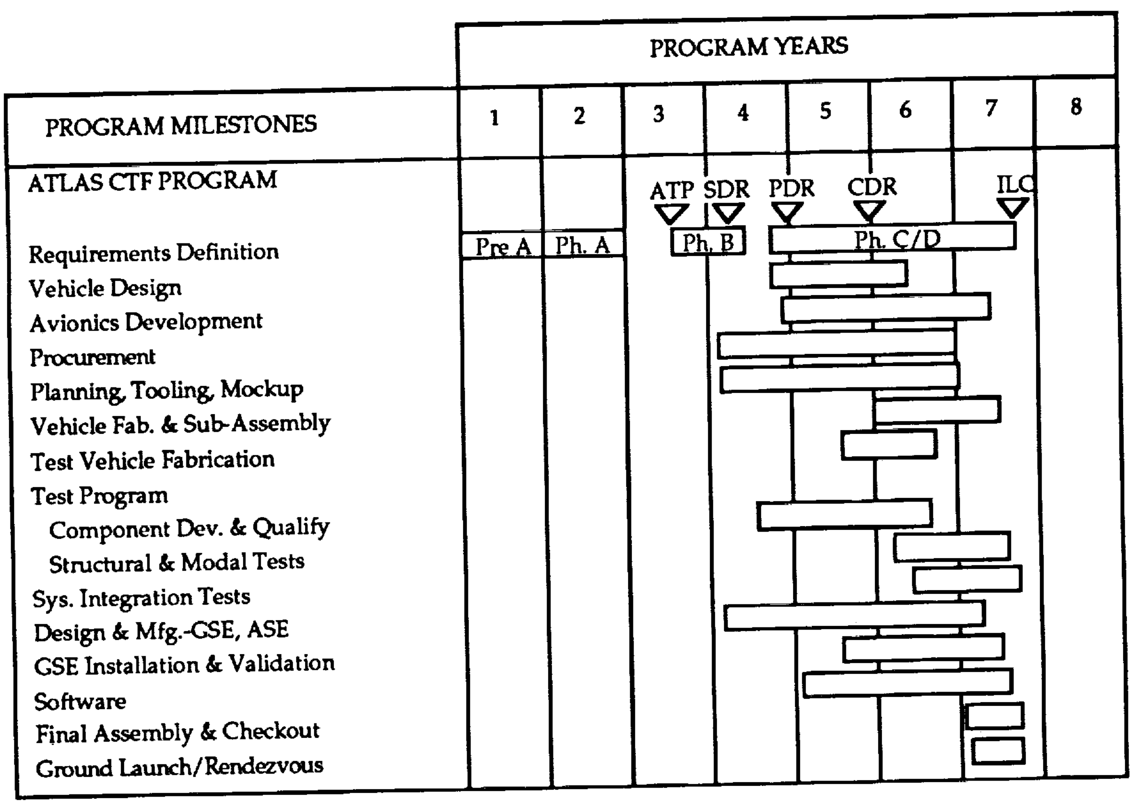


Figure 3.3.3.6-5.– Atlas/CTF development schedule.

b. Probability of Mission Success.– The PMS estimate for Atlas IIAS is based upon the use of a 3-liquid engine booster/sustainer, 2-engine/2-burn liquid upper stage, and four monolithic solids. The reliability tree for Atlas IIAS PMS is included in the Technical Appendix. This reliability tree, the basic configuration, and the historical reliability estimates for characterized subsystems results in an Atlas IIAS PMS of 0.9326. Refer to the PMS section of this report to further understand the measurement technique being applied (section 3.2.4).

For the Atlas/CTF, the CTF performs only on-orbit maneuvering, which is not being accounted for in the current definition of PMS. Thus the Atlas IIAS and Atlas/CTF have the same PMS value (0.9326).

The Atlas evolution concept employs a single-engine Centaur and therefore has a different upper stage impact upon the PMS attribute. The PMS measurement for Atlas evolution is 0.9369.

c. Human Safety.– The Atlas does not carry human vehicles in the architectures currently being examined in this study and therefore does not have a corresponding safety score.

d. Architecture Cost Risk.–The Atlas is an existing system which is currently performing missions and therefore has little to no risk. In the Technical Challenge subattribute the Atlas was judged with having no risk in all three program categories (i.e., nonrecurring, production, and operations). The Atlas was also judged to be a mature system and therefore warranting the lowest Program Immaturity score. The Atlas evolution was judged to have a small risk in the non-recurring development and to be less mature than the current flight configuration. The Atlas/CTF was judged to have a moderate amount of risk because it has yet to enter Pre-Phase A development. Table 3.3.3.6-3 presents the Atlas family contributions to the ACR.

TABLE 3.3.3.6-3.– ATLAS FAMILY RISK SCORES

Atlas Risk Attribute	Technical Challenge Sub-Attribute			Prgm. Immaturity Sub-Attribute
	Non-Recurring	Production	Operations	
Atlas	1	1	1	1
Atlas/CTF	4	2	3	6
Atlas Evolution	2	1	1	3

e. Launch Schedule Confidence.– As with ACR, two of the three subattributes for LSC were based on system values or scores. One of these, schedule compression, was calculated based on the operations data given previously in this section; its value represents the ratio of nominal processing time to the shortest processing time (maximum compression of the critical path). The nominal processing time is determined in calendar days (i.e., includes weekends). The other subattribute, percent of flights with delays, was calculated based upon UMA's for the system (see section 3.2.6). Table 3.3.3.14-4 shows the above two subattribute scores for the Atlas launch vehicle family. Both of the subattribute values were subsequently used with architecture-particular, flight-rate data to roll-up the architecture level values. The schedule margin subattribute score is architecture-specific and is described in Sections 3.3.5 through 3.3.11.

TABLE 3.3.3.6-4.– SCHEDULE CONFIDENCE SUBATTRIBUTE SCORES FOR THE ATLAS LAUNCH VEHICLE FAMILY

Atlas Schedule Confidence Attribute	Schedule Compression SubAttribute			% Flights With Delay SubAttribute
	Nominal Processing Time (Days)	Compressed Processing Time (Days)	Ratio: Nominal to Compressed	
Atlas	66	32	0.485	5.37
Atlas/CTF	66	32	0.485	5.37
Atlas Evolution	39	19	0.487	5.37

f. Environment.– The Atlas booster uses RP-1 and liquid oxygen as propellants. The IIAS has a sustainer/booster propellant load of 344.5 klbm, solid rocket motor propellant mass of 22.3 klbm, and an upper stage propellant load of 37 klbm (liquid hydrogen and liquid oxygen). However, the upper stage operates outside the sensible atmosphere and does not contribute to the environment score as defined in this study.

Using the given propellant weights, the major effluent constituents (in klbs) are shown in Table 3.3.3.6-5. These values (klbm) are from the October 1991 AIAA Workshop and Report on "Atmospheric Effects of Chemical Rocket Propulsion".[7] They are based upon equilibrium, non-afterburning calculations. Recognizing that this is a low-weighted attribute and that Atlas does not fly extensively in most architectures (most of its missions are commercial, which are not being considered in the current "If" Scenarios) it was assumed that Atlas/CTF and Atlas evolution effluents were the same as the Atlas IIAS. The environmental effects of larger solids for the Atlas evolution concept will be assessed in later efforts.

TABLE 3.3.3.6-5.– ATLAS IIAS EFFLUENTS PER LAUNCH

Exhaust Characteristics	Atlas IIAS	Atlas/CTF	Atlas Evol.
CO_2	128.8	128.8	128.8
CO_2	95.8	95.8	95.8
H_2	8.2	8.2	8.2
H_2O	146.2	146.2	146.2
HCl	14.0	14.0	14.0
N	5.6	5.6	5.6
OH	0.0	0.0	0.0
H	0.0	0.0	0.0
Al_2O_3	20.0	20.0	20.0

3.3.3.7 Titan Family

This family includes the Titan II, Titan III, and Titan IV basic launch vehicles, as well as various upgrades and improved versions postulated for future development.

System Description

All Titan launch vehicles currently utilize a 10-ft diameter core containing storable hypergolic propellants (Aerozine-50 and nitrogen tetroxide (NTO), with length stretched according to needed lift capability. Independent propellant tanks (oxidizer on top) are supported by aluminum monocoque construction. Two LR-87 gas generator cycle engines with a shared-feed system, but separate turbopumps, power the first stage. The second stage is of the same diameter and utilizes the same propellants, but employs one LR-91 engine (similar to the 1st-stage engines, but with lower thrust – 100 klb_f vs. about 500 klb_f), a higher expansion ratio nozzle, and higher vacuum specific impulse. Hydraulic systems are incorporated for core engine gimbaling. Power is obtained from Ag-Zn batteries; no APU's are required. Current versions of Titan allow for only one burn of the second stage. With the addition of a "start-kit", the second stage could be restarted, after a coast to apogee, for greater insertion into circular orbit capability (this option is not currently incorporated in any of the HTS architectures due to the reliability penalty assessed by the HTS methodology).

TABLE 3.3.3.7-1.– TITAN FAMILY CHARACTERISTICS

	No. and Type of Engines (# Engine Out)**			
	Stage 0	Stage 1	Stage 2	Stage 3
Cargo Only:				
Titan II G No Upper Stage (NUS)	–	2 L	1 L	–
Titan III/Cmrl Titan	2 S	2 L	1 L + RS	–
Titan IV (NUS)	2 S	2 L	1 L + RS	–
Titan IV (Centaur)	2 S	2 L	1 L	2 L + 2 RS
*Titan IV (CTF/LRV)	2 S	2 L	1 L	4 L
*Titan Evol (LDC)	–	2 L + 2 S	1 L	–
*Titan Evol/Centaur	–	2 L + 2 S	1 L	1 L + 2 RS
Crew Carriers:				
*HR Titan IIS (RUPC)	–	2 L + 10 GEM	1 L	4 L (1-out)
*HR Titan IV (RPC)	12 L (1-out)	2 L	1 L	3 L (1-out)

* Postulated designs (subject to change)
**Unless indicated, no engine-out capability
L=liquid engine; S=segmented solids (large); GEM=small monolithic solids; RS=Restart

Currently, the Titan III and IV have two large strap-on solid rocket motors; the Titan IIS includes 4 to 10 solid strap-ons. Whereas the solids on Titan II are small, monolithic grains, the two strap-ons for T-III and T-IV are segmented solid rocket motors – 5.5 segments for T-III, 7 segments for the currently operational T-IV, and the more advanced 3-segment composite case version known as the SRMU (solid rocket motor upgrade), planned to be available for the T-IV in 1993. For evolution (growth) of Titan, used in Architecture 2, additional vehicle development is required. The implementation schedule for this development is shown in Figure 3.3.3.7-1. The "Titan IV Evolution" launch vehicle defined for this study is a potential future development, featuring a large diameter core (14 ft) to achieve higher payload lift capability.

The human-rated (HR) version of the Titan II (HR Titan IIS) employs 10 of the small solids. The HR Titan IV concept incorporates the normal core, but with LRB's in place of solids, in order to provide the capability for emergency shut down. Each LRB is powered by six (or five) engines, with one engine-out and on-pad checkout capabilities.

Reusable personnel carrier (RPC) and reusable ultralight personnel carrier (RUPC) crew cabs are carried by the HR Titan IV and HR Titan IIS, respectively (see Architectures 14 and 17). The RPC and RUPC are self-contained vehicles with integral orbital propulsion stages, launch escape systems, and all necessary thermal systems to survive ascent heating without the benefit of a separate, external shroud, as is the norm for cargo-only payloads.

Performance Summary

Titan vehicle lift capabilities are given in Table 3.3.3.7-2. Payload shrouds vary, ranging from 10-ft diameter (by 20, 25, or 30-ft tall) for Titan II, 13-ft diameter (by 35-ft height) for Titan III, and up to 16.7-ft diameter (by 56 to 86-ft height) for Titan IV.

TABLE 3.3.3.7-2.– TITAN PERFORMANCE CAPABILITIES

Payload to Orbit (klb_m)					
Orbit Type	IIS	III	IV	IV Ev*	IV LRB*
1. Standard (80x95 @ 28.5°	14.4	31.6	45.3	64.3	-.-
2. Circ., 28.5°, 160 n. mi.	12.0	27.1	44.7	62.1	56.4
3. Circ., 28.5°, 220 n.mi.	10.1	25.5	43.5	60.0	55.6
4. Circ., 28.5° , 300 n.mi.	8.6	17.2	41.3	58.2	53.1
5. SSF Transfer (80x220)	12.0	31.0	47.0	62.0	49.0
6. Circ., 57° , 160 n.mi.	11.1	17.4	42.6	59.2	54.8
7. Circ., polar, 150 n.mi.	-.-	18.5	36.3	51.9	47.3
8. Circ., 98.7° , 445 n.mi.	-.-	2.8	7.0	9.5	8.9
9. GTO, (100x19330)	-.-	8.4	25.4+	35.3+	-.-

* Postulated designs (subject to change)
† Includes Centaur Class Upper stage (or Centaur Evol for T-IV Ev).

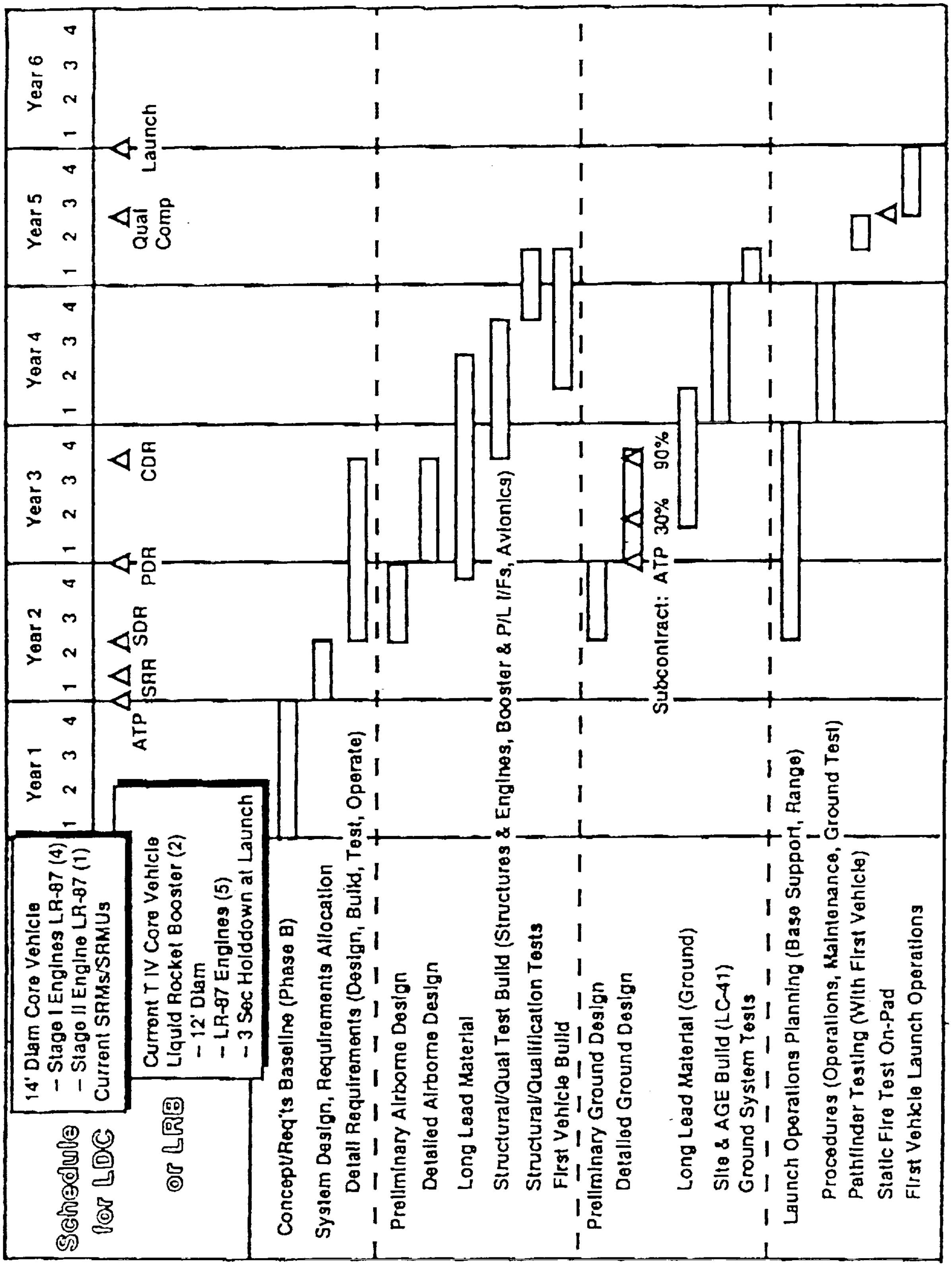


Figure 3.3.3.7-1.– Titan IV growth vehicle implementation schedule.

Attribute Values

Complete data on Attribute data for each of the Titan LV's in this family are provided in the Appendices. In the following sections, noteworthy characteristics or unique features of the Titan design are identified for each Attribute.

a. Funding Profile.– Titan system cost information used in the funding profile summary calculation is shown in Table 3.3.3.7-3.

TABLE 3.3.3.7-3.– TITAN SYSTEM COST INFORMATION

Millions of '92$ -- No Wraps								
	RUPC	T-IIS HR for RUPC	T-IV NUS ETR	T-IV w/ CTF	T-IV w/ CTF	T-IV NUS Evol'n	T-IV HR w/ RPC	T-IIG Refurb
DDTE	1,425	0	0	0	102	0	298	0
N/R Prod.	145	0	0	0	12	0	0	0
P^3I	--	518	0	0	0	403	518	0
Facilities:								
Pad-ETR	--	300	477	477	477	477	477	--
SLC-WTR	--	--	(596)	(596)	--	--	--	
VIB-Hi Bay	--	--	155	155	155	155	155	
SMAB	--	--	144	144	144	144	144	
RUPC Test	3	--	--	--	--			
Cost/Flight @								
2/yr	64	102	266	333	344	303	(1) 348	38
4/yr	51	82	213	266	275	243	(2) 279	30
6/yr	45	72	187	234	241	213	(3) 245	
8/yr	41	66	170	213	220	194	(4) 222	
10/yr	38	61	159	198	205	181	(5) 211	
12/yr	36	58	150	187	194	170	(6) 196	

Notes:
1. RUPC flight costs include refurb costs, and replacement after every 7th use.
2. All launches are from ETR except T-IIG (refurb), from WTR.
3. T-IV w/CTF if T-IV NUS + CTF.
4. HR T-IV w/RPC column is for T-IV only; RPC not included; number In parentheses is number of human flights out of year's total.
5. T-II w/RUPC column is for HR T-II only, RUPC not included.
6. RUPC cost/flight does not include T-II; total CPF for RUPC + T-II is the sum of figures in both columns.
7. Flight rate for each column is considered in isolation, except as noted above.

b. Probability of Mission Success.– The Titan reliability philosophy has been built upon design simplicity, robustness, extensive testing, design for enhancement of reliability, and the use of high-reliability components that have been thoroughly tested – rather than upon redundancy. This philosophy has resulted in a very high success rate and has been proven to be very cost effective. Engine gimbals are hydraulically actuated, with the engines providing the necessary pressurization. Titan engines are conservative in design; for example, operating at very modest chamber pressures (<860 psi). No igniters are needed because of the hypergolic nature of the propellant pair. High ullage pressures are not required, and autogenous pressurization systems are used in-flight to maintain positive expulsion flow rates (cold gas pressurization is an option for LRB's). There is no coast phase associated with staging, so that positive-g maintains propellant feed for subsequent stage ignition. The aluminum airframe is rugged: the vehicle can be supported either vertically or horizontally, without the need for propellant tank pressurization.

For human-rated vehicles the avionics equipment, engine actuators, and control paths would be made redundant. Hydraulic actuators would likely be replaced with electromechanical devices to gimbal the engines.

Titan reliabilities for engines and propulsion systems are at or above the average across many different LV systems ("generic" failure rates), as seen in the following table.

TABLE 3.3.3.7-4.– FAILURE RATES

	HTS	Titan
Reliability (per use)	Generic	Historical*
Liquid Engines	0.9977	0.9968
Liquid Propulsion Stages	0.9847	0.9929
Monolithic solids	0.9983	N/A
Segmented solids	0.9921	0.9866

* Based upon launch results since the development phase completion for Titan II (Dec. 1964), i.e., 2 engine failures out of 630 cases (210 flights of 3 engines each); 3 propulsion system failures out of 420 (2 propulsion stages per launch); 1 solid failure in 88 flights. Note: for basic LV, does *not* include upper stage failures (Transtage, Agena, Centaur).

The next table shows the calculated PMS, using both the HTS generic values and those obtained using Titan-specific, historically-based reliabilities. It should be noted that analytical reliabilities, based upon very detailed models, predict even higher reliability for the Titan family. Also, the redesign of historically anomalous components over the life of the program improves the reliability above those quoted in the table.

TABLE 3.3.3.7-5.– TITAN FAMILY PMS

	Reliability Basis**			
Vehicle	HTS Generic Rates & Model	Titan Historical Rates + HTS Model	Titan Program Analytic Reliab.	Titan Demonstrated Performance
Cargo Only:				
Titan IIG (NUS)	0.9626	0.968	N/A	1.000 (15/15)
Titan III/Cmrl Titan	0.9307	0.958	N/A	0.968 (150/155)
Titan IV (NUS)	0.9307	0.958	0.978	1.000 (5/5)
Titan IV/Centaur	0.9100	N/A	0.936	N/A
*Titan IV (CTF/LRV)	0.9242	0.937	N/A	N/A
same, but CTF1-		0.963		
eng out	0.9519	0.973	N/A	N/A
*Titan Evol (LDC)	0.9185	N/A	N/A	N/A
*Titan Evol/Centaur				
Crew Carriers:	0.9323	0.938	N/A	N/A
*HR Titan IIS (RUPC)	0.9189	0.967	N/A	N/A
*HR Titan IV (RPC)				

* Postulated designs (subject to change)
**First two columns use HTS failure model, but different failure rates (see Table 3.3.3.7-4). Third column contains Martin Marietta internal Titan Program estimates.

c. Human Safety.– The Titan vehicle has high reliability and safety performance as demonstrated by the flight history since initial development, including the perfect success in launching the human Gemini spacecraft.

Because the hydrazine-based fuels are intrinsically difficult to explode, the safety risk from a major breech of a propellant tank is considerably less than with other, more combustible fuels. When both fuel and oxidizer come into contact, the fire-like reaction tends to drive the two sources apart. Titan tanks are structurally independent, thereby minimizing this probability (except in the case of an induced destruct, which for untended missions purposely opens both tanks at their interface in order to facilitate burning and thereby reduce the amounts of raw propellants reaching the ground). For the same reason, fire propagates relatively slowly, allowing longer times for escape via a launch escape system (LES).

Both HR Titans will be safer for crews than the Titan cargo launch vehicle (LV), because (a) the HR T-IV has no solids and (b) each solid on HR T-IIS is small (only 2 percent of the amount of propellant of one Space Shuttle SRB) and located more than 50 ft from the crew capsule. Even failures involving larger solids, such as the 5.5 segment version, can allow sufficient time for escape if the LES is activated prior to the vehicle destruct system. In the 1988 T-34D failure, where the vehicle underwent on-board automatic destruct, more than 3 seconds were available from the time of burn-through until the fireball reached the payload area. Projectiles, apparently, only propagated outside a conical shadow zone, preventing the payload zone from suffering direct hits by debris.

d. Architecture Cost Risk.– For the HTS, the Titan Family is defined as a minimum set of readily-developed vehicle derivatives from the existing family of operational LV's. Evolved vehicles are achieved by solid rocket additions or improvement programs. As an example, the Titan IIS, incorporating strap-on graphite-epoxy motors (GEM's) (or Castors), is already in advanced study and being proposed for nearer-term applications, such as MLV-3, for next-phase GPS deployment. The most significant new development would be LRB's for the HR T-IV, involving a new core diameter and a cluster of multiple engines, with engine-out capability. Development risk is mitigated by using existing core engines and the same propellants.

   Human rating of Titan is not considered a development risk because of the good safety features of the LV and the personnel carriers being considered; the Gemini-Titan system and the Space Shuttle return-to-flight assessment heritages will aid the rating process.

e. Operational Flow.– At WTR, a two-pad Space Launch Complex is available for Titan launches. Titan IVs are launched from complex SLC-4E; Titan IIs from SLC-4W. A common Launch Operations Building also includes the launch control center, but each pad utilizes a separate mobile service tower and appropriate consumables facilities. Currently, the LV's are assembled on-pad, resulting in longer times between launches (appropriate to low launch rates), but future plans call for off-pad assembly concepts.

   At ETR, two Launch Complexes (LC-40 and LC-41) are now available for launching Titan III and IV. With minor pad modifications, Titan II could also be launched at these complexes, but studies underway address options for a dedicated Titan II complex using existing facility infrastructure. To support LC-40 and -41, a Vertical Integration Building has four cells. A new solid rocket processing facility provides stacking and checkout of the strap-ons. A planned Centaur processing facility will be available in 1994. Separate modular servicing tools (MST's) are provided for each pad. As at ETR, the required current launch rate for Titans is low and pad processing times are correspondingly long, but higher rates will be readily achievable in the future as they have been in the past.

   Typical current processing flows for Titan-family vehicles used in subsequent architectures are shown in Figures 3.3.3.7-2 through -5. For high traffic models,

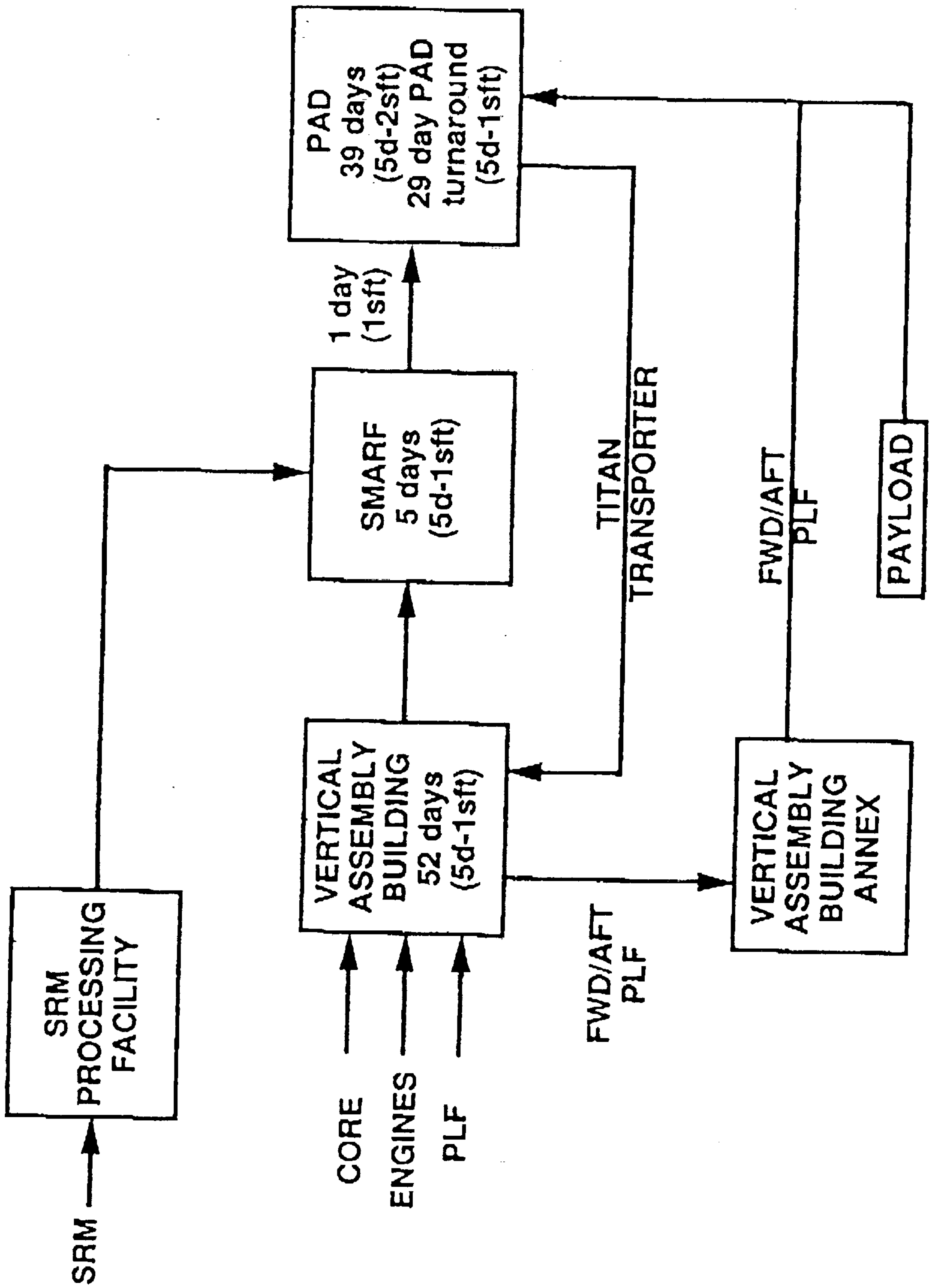


Figure 3.3.3.7-2.– Titan IV NUS processing (ETR).

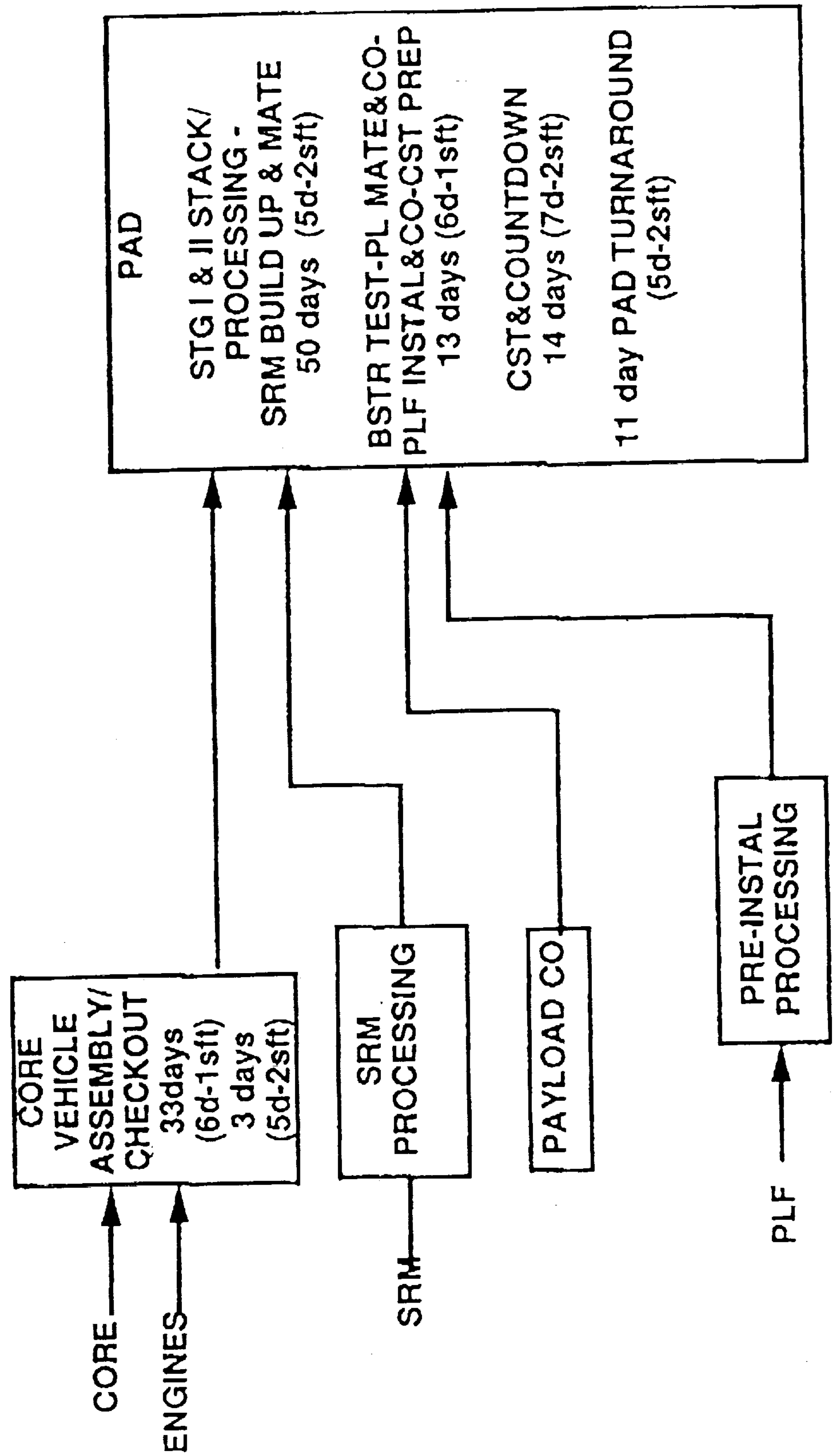


Figure 3.3.3.7-3.– Titan IV NUS processing (WTR).

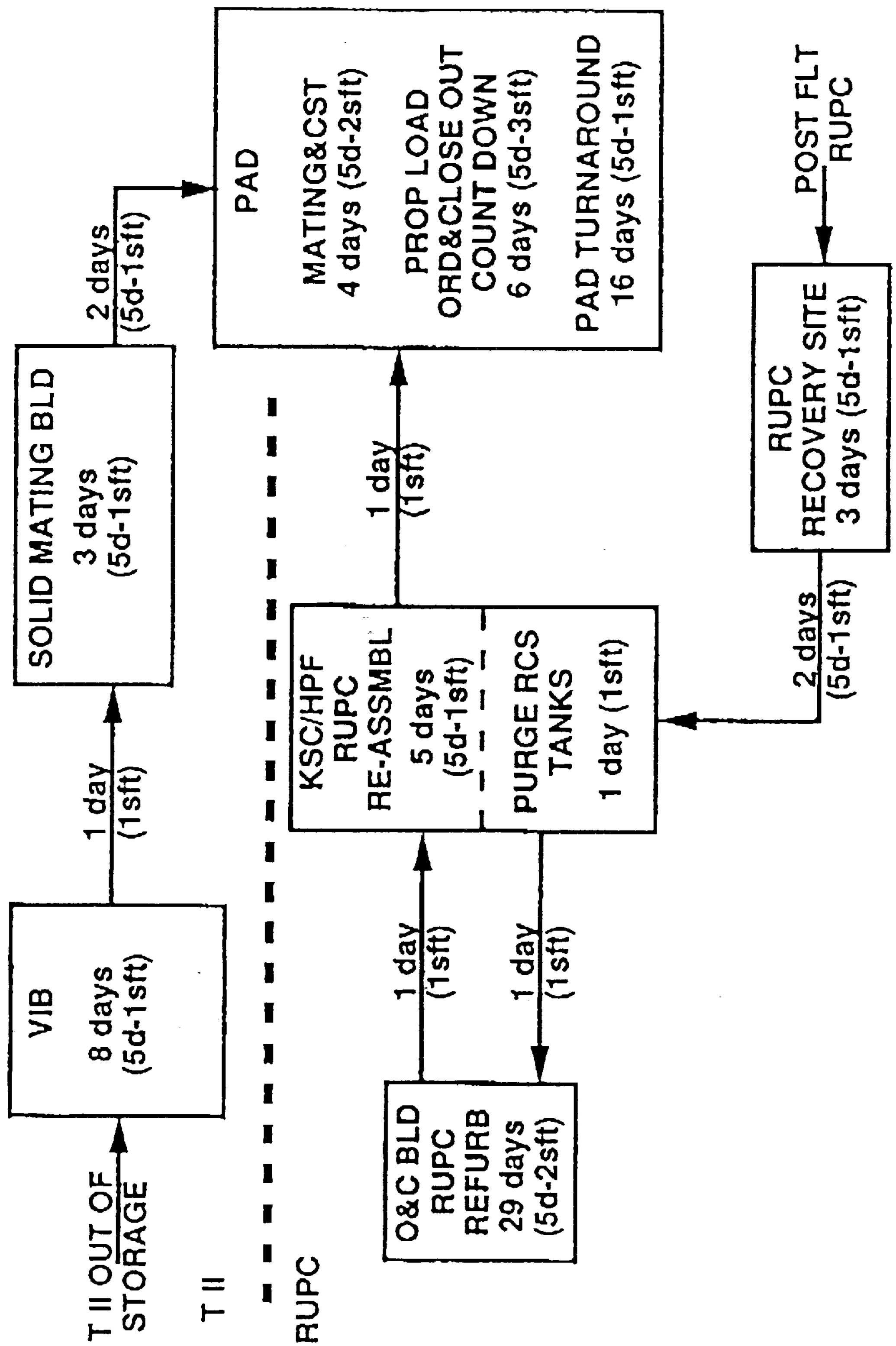


Figure 3.3.3.7-4.– Titan II/RUPC processing (ETR).

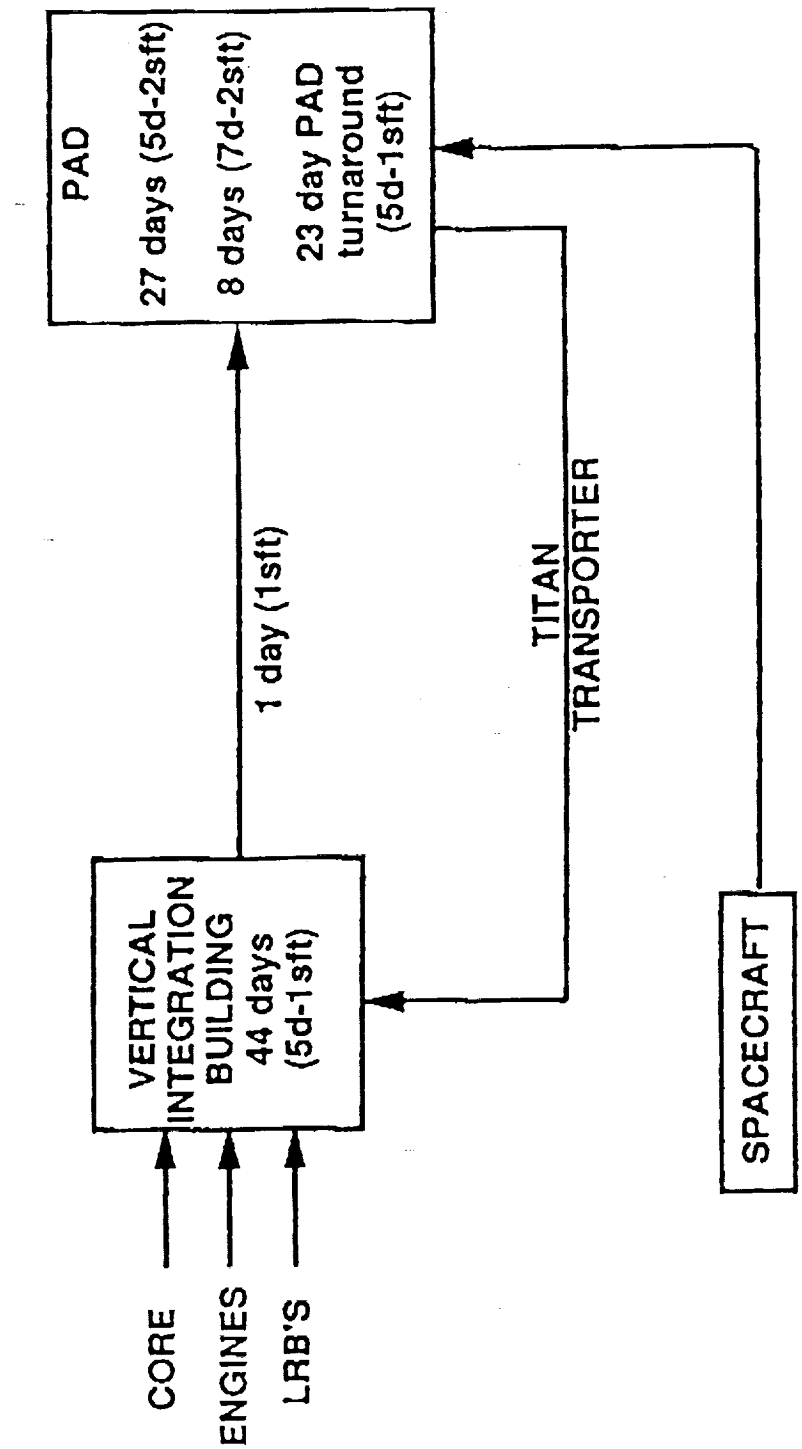


Figure 3.3.3.7-5.– Titan IV (human-rated) with LRB's processing (ETR).

the flow times can be reduced through the use of more integrated components, multiple shifts, and the addition of facilities.

f. Environment.– The only environmental impact considered significant enough for evaluation is the effluents from the solid rocket motors. In all cases, these emissions are considerably below the Space Shuttle launch emissions because of the small quantities of propellants, with the T-IIS solids being a factor of 20 less massive and the HR T-IV having no solids at all.

3.3.3.8 Cargo Transfer Vehicle (CTV)

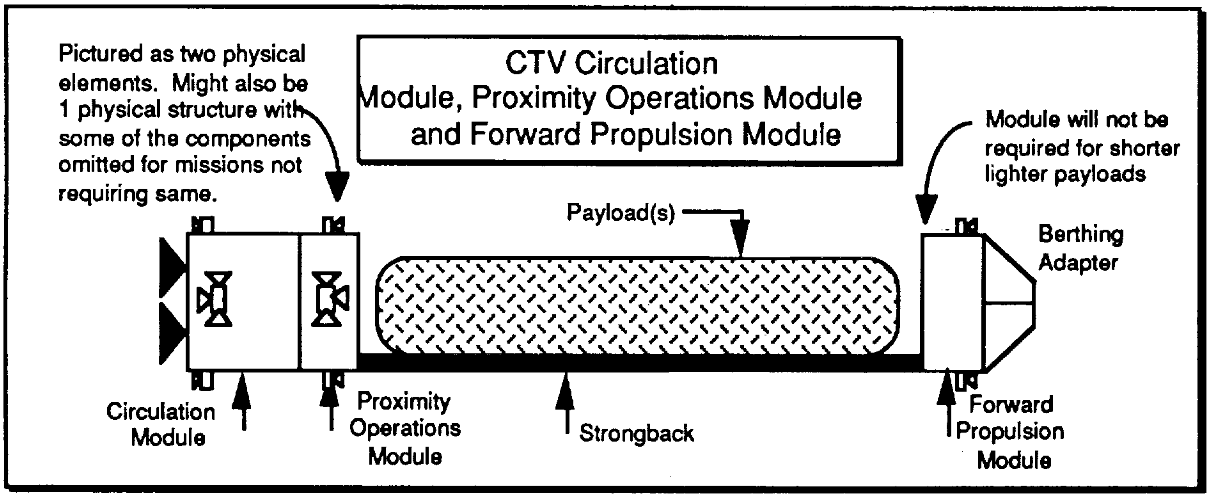
System Description

a. History.– The CTV is designed to deliver NLS 1 (the heavy lift launch vehicle (HLLV)) strongback and attached payload elements to SSF. To do this, it must be capable of raising the orbit perigee to a safe altitude, remaining in a phasing orbit until an appropriate time in order to rendezvous with the SSF, circularizing the orbit, conducting proximity operations, and hovering within reach of the Mobile Remote Manipulator System for capture and berthing to SSF.

b. Configuration.– Raising the perigee altitude and then circularizing the resulting orbit requires a propulsion system with sufficient thrust to accomplish these objectives over reasonably short burn arcs. In addition, the CTV must have structural and mechanical interfaces compatible with both the launch vehicle and payload and/or payload carrier. Maneuvering large payloads in the vicinity of the SSF requires six degree-of-freedom (6- degree-of-freedom (DOF) control capability and communication/command capability consistent with SSF requirements on free flyers operating in its command and control zone. Delivery of an 80 foot strongback and payload weights of 100 000 pounds will require a forward propulsion module (FPM) on the nose of the strongback which works in tandem with the CTV during proximity operations to assure full 6-DOF capability. Delivery of a single payload may be accomplished utilizing a shorter strongback (40, 50, 60 feet) and the CTV operating alone (no FPM) if the center of gravity is located within an acceptable performance envelope (e.g. 50 klb payload and c.g. of 25 feet).

   Operating in the SSF vicinity will require a high degree of reliability to insure crew safety and protect the SSF resource. Figure 3.3.3.8-1 shows a notional version of a CTV, FPM, and HLLV strongback. Weight summaries are given in Tables 3.3.3.8-1 and 2.

c. Operations.– The CTV is received from the manufacturer or from the recovery vehicle if the CTV is reusable. The CTV is refurbished and processed for the next flight in the CTV Processing Facility. The CTV Processing Facility consists of a receiving area, two clean room processing cells (class 100K), work areas, and a local control area. Activities occurring in these areas include inspection, cleaning, and purging; vehicle system test and checkout; and hypergolic propellant deservicing. Automated control and checkout operations are accomplished with local Launch Processing System (LPS II) stand-alone test equipment. Upon satisfactory completion of CTV checkout the vehicle is shipped to the payload encapsulation facility (PEF). The CTV processing flow is shown in relationship to the NLS processing in Figure 3.3.3.8-2.



Notes: (1) that the ACS and feeds are common with NLSUS. SSF requirements may drive the CTV ACS and feed system to more redundancy that needed for NLSUS' mission.
(2) that prox ops are conducted with mon-prop. This is an issue to be worked with SSF. Current plans are to utilize biprop for prox ops, just as the Orbiter does.
(3) that CTV will require "moderate avionics development. Avionics - Software development and validation in particular - are a significant part of the program.
(4) ILS 2001 @ KSC
* Note that the reference CTV is reusable. If trades indicate no payoff for a reusable system, the Shuttle-compatible fittings will not be needed. In addition, the CTV would not be driven by Orbiter requirements for saling of the propulsion system or by the structural design requirements for landing in the Orbiter.

Figure 3.3.3.8-1.– The CTV circulation module, proximity operations module, and forward propulsion module.

TABLE 3.3.3.8-1.– CTV WEIGHT SUMMARY (POUNDS)

AVIONICS		
Prime Power	0	
Space Shuttle/SSF Umbilical	80	
Cables	50	
GN&C	35	
Communications	0	
Data & Instrumentation	12	
Range Safety	150	
FPN Umbilical	30	
Subtotal		357
PROPULSION SYSTEM		
Propellant Tank	160	
Pressurant Tank	67	
RCS Thrusters (12-25 Lbt)	26	
Propellant Feed System	71	
Subtotal		324
STRUCTURES (Includes Thermal)		
Passive Berthing Mechanism	208	
Berthing Adaptor/Support Structure	292	
Forward Structure and Fittings	318	
Main Frame Structure & Keel Fittings	152	
Avionics Support Structure	50	
Aft Structure & Fittings	318	
Engine Support Structure	24	
Tanks Support Structure	65	
Grapple Fixture	25	
Subtotal		1452
CONTINGENCY (10%)		213
TOTAL DRY WEIGHT		2346
RESIDUALS &GN2		73
TOTAL (BURN-OUT WEIGHT)		2419
PROPELLANT LOADING		1043
TOTAL LAUNCH WEIGHT		3462

TABLE 3.3.3.8-2.– CTV WITH PROXIMITY OPERATIONS MODULES WEIGHT SUMMARY (POUNDS)

AVIONICS		
Prime Power	810	
Space Shuttle/SSF Umbilical	350	
Cables	900	
GN&C	478	
Communications	349	
Data & Instrumentation	536	
Range Safety	80	
FPN Umbilical	150	
Subtotal		3653
THERMAL CONTROL		400
PROPULSION SYSTEM		
Propellant Tank	1045	
Pressurant Tank	289	
RCS Thrusters (12-25 Lbt)	197	
Propellant Feed System	317	
Subtotal		2062
STRUCTURES (Includes Thermal)		
Passive Berthing Mechanism	208	
Berthing Adaptor/Support Structure	292	
Forward Structure and Fittings	864	
Main Frame Structure & Keel Fittings	904	
Avionics Support Structure	500	
Aft Structure & Fittings	864	
Engine Support Structure	48	
Tanks Support Structure	130	
Grapple Fixture	25	
Subtotal		3835
CONTINGENCY(10%)		995
TOTAL DRY WEIGHT		10945
RESIDUALS & GN2		609
TOTAL (BURN-OUT WEIGHT)		11554
PROPELLANT LOADING		10000
TOTAL LAUNCH WEIGHT		21554

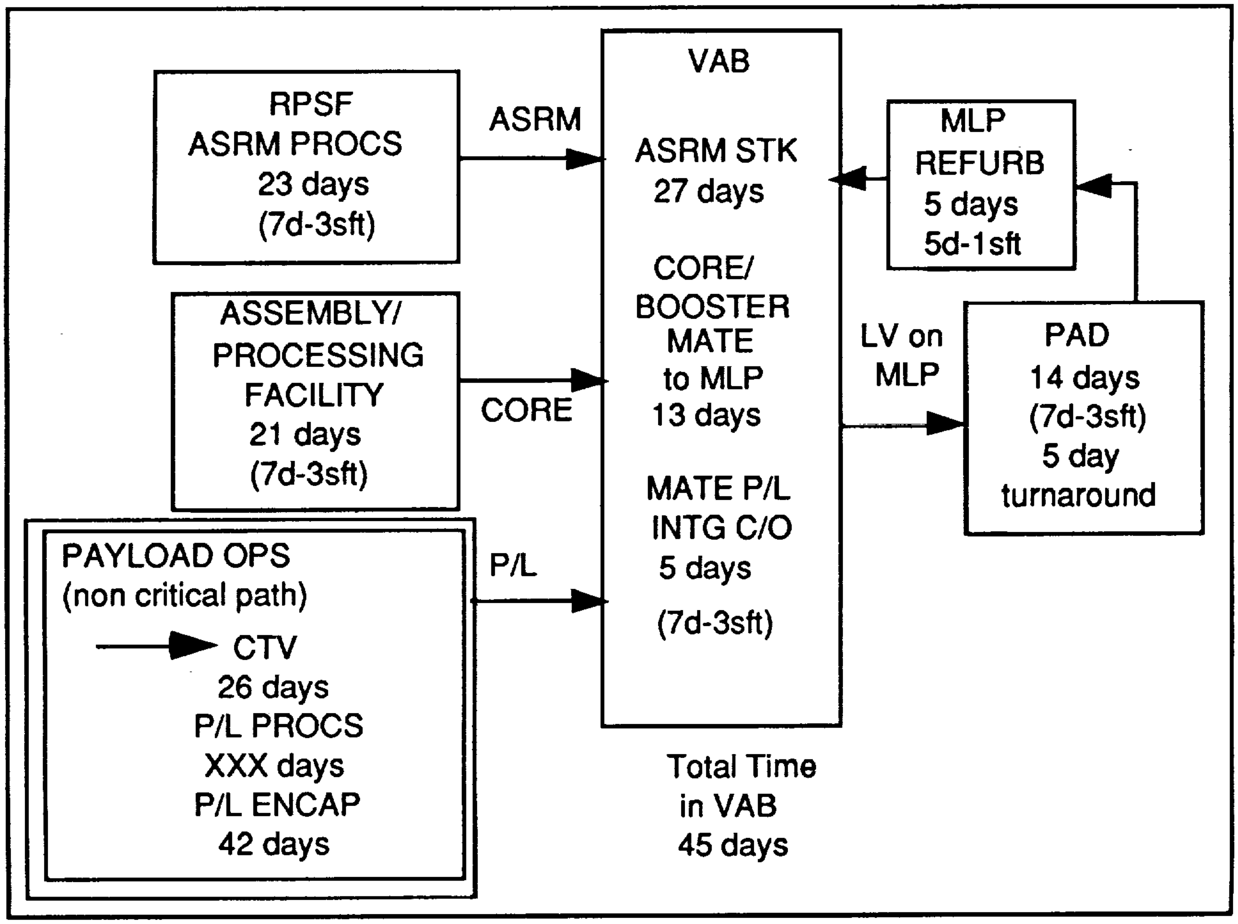


Figure 3.3.3.8-2.– NLS/CTV processing.

Performance

The performance characteristics of the CTV/NLS are given in Table 3.3.3.8-3.

TABLE 3.3.3.8-3.– CTV/NLS PERFORMANCE CHARACTERISTICS

Destination	SSF	Low LEO	
Orbit Alt	220 X 220	160 X 160	Cargo Vol
Inc/Element	28.5 Deg	28.5 Deg	Length X Dia
CTV/NLS 1	101 Klbs	105 Klbs	60 X 30
CTV/NLS 2	26 Klbs	30 Klbs	30 X 15

Attribute Values

a. Funding Profile Summary.– The data shown in Table 3.3.3.8-4 was used in calculating the CTV's contribution to the funding profile attribute in those architectures utilizing the CTV.

TABLE 3.3.3.8-4.– FUNDING PROFILE SUMMARY CARGO TRANSFER VEHICLE (MILLIONS OF $)

	Total Cost	TFU	LC%	RC%
DDT&E	$461			
Non-Rec. Facilities	$22			
Non-Rec. Production	$0			
Rec. Production				
Reusable Hardware*		$63	90%	100%
Expendable Hardware*		$16	90%	100%
Overhauls		$14	90%	100%
Launch Ops.		$25	90%	100%
Cost Per Flight	$25 Ave. For 79 Flights			

* Reusable Hardware = Kickstage + Prox Ops Module
** Expendable Hardware = Strongback + Forward Prop Module

b. Probability of Mission Success.– The PMS of the CTV was not separately calculated. The mission phases of the CTV were, however, included in the success trees of the NLS and used to determine the PMS of the CTV/NLS combination.

c. Human Safety.– Not applicable, not flown with human-tended vehicle.

d. Architecture Cost Risk.– Two of the three subattributes were based on system/element values or scores. For the CTV, the NIT consensus values for those subattributes, are shown in Table 3.3.3.8-5.

e. Launch Schedule Confidence.– Not applicable, not in critical path of NLS processing.

f. Environment.– Not applicable, only operates outside atmosphere.

TABLE 3.3.3.8-5.– CTV/NIO CONSENSUS VALUES

Technical Challenge	
Non-recurring	4
Recurring	3
Operations	3
Program Immaturity	6

3.3.3.9 National Launch System (NLS)

System Description

a. History.– The NLS is a new space launch system that is evolutionary in nature and is based upon the following engineering development and study activities: The Space Transportation Architecture Study in 1985-1986; the "clean sheet design approach" of the ALS studies in 1987 through 1989; the NASA Shuttle-derived cargo vehicle (Shuttle-C) studies conducted in 1985 through 1990; the Space Transportation Main Engine (STME) development starting in 1988 and continuing to the present; and the Advanced Launch Development Program system design and technology program in 1989 through to the present time.

A DOD Milestone Defense Acquisition Board, held in September 1988, validated the requirements for a new, untended space launch system for cargo transport in the late 1990's and beyond. This new family of vehicles is proposed to share space launch traffic demands with the Titan, Space Shuttle, Delta, and Atlas systems by providing increased launch capacity and availability at reduced cost. The Advisory Committee on the Future of the U.S. Space Program (i.e. the "Augustine Committee"), December 1990, recommended the following:

- Offload Space Shuttle in all but the initial phases of the SSF deployment,
- Provide an evolutionary vehicle potentially capable of fulfilling the SEI, SDI support, lunar base and Mars trip requirements,
- Incorporate advanced launch vehicle technologies where and when feasible,
- Reduce operational personnel requirements,
- Be capable of being human-rated.

A meeting with Vice-President Quayle, DOD, NASA and Office of Management and Budget (OMB) representatives on January 2, 1991 recommended that this new launch system program would be jointly funded and managed by the Air Force and NASA. The new program would:

- Provide a range of payload capabilities including heavy lift,
- Provide a human-rateable capability for some applications,
- Provide for an evolutionary near-term capability and a longer term capability that incorporates new technology,

- Achieve significant improvements in operations cost (particularly launch support manpower) and operational resilience compared to existing systems.

b. Configuration(s).– The following provides summary descriptions of the NLS vehicle family.

<u>NLS 1 - HLLV</u>

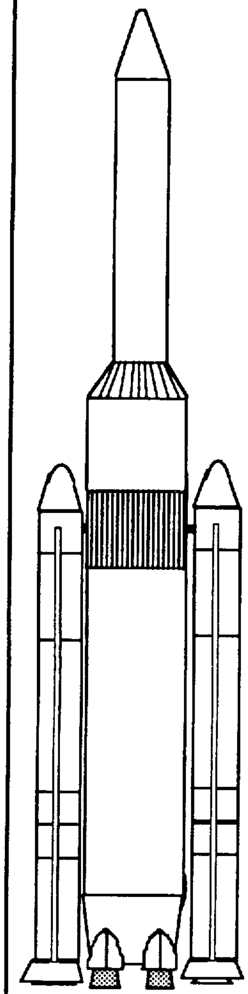
The 100 klb class vehicle has been designated as NLS 1 (HLLV). NLS 1 is comprised of a propulsion module, a version of the common core (with propellant tanks), two advanced solid rocket motors (ASRM's), a payload transition or adaptor section, and a payload carrier section consisting of a payload fairing. This fairing has a *strongback* to carry Space Shuttle payloads (in a similar manner as the Space Shuttle Orbiter). NLS 1 has the capability to add a CTV with an orbital propulsion and avionics system to deliver cargo to the SSF. All engines are pad ignited and the ASRM's burn to their pro-pellant depletion, at which time they are jettisoned and recovered from the ocean. The four STME engines burn to orbital insertion of a 30 x 200 nmi orbit and are shutdown by a guidance computer signal. If required to maintain a longitudinal acceleration limit, the STME's may be step- throttled down or two engines cut off prior to orbital insertion. The payload is separated from the payload adaptor and the remaining core is targeted for disposal with ocean impact.

The primary mission of NLS 1 is to deliver an 80 klb (net) payload to the SSF in a 220 nmi circular orbit. A configuration drawing is shown in Fig. 3.3.3.9-1.

<u>NLS 2 (Stage-and-One-Half 50 k Vehicle)</u>

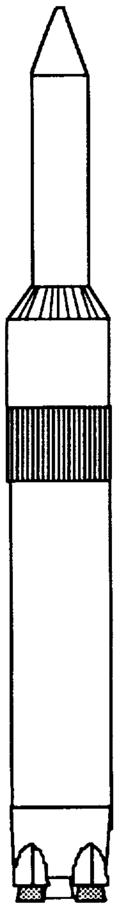
NLS 2 has been designated as a stage-and-one-half (1.5 stage) vehicle reflecting the engine burn profile. Six STME's are ground-ignited and burn until correct staging velocity, at which time four are shut down and jettisoned. The remaining two burn until orbit is achieved and are shutdown by a guidance computer signal.

NLS 2 is comprised of a propulsion module, propellant tanks ("common core"), a payload transition or adaptor section, and a Titan IV payload fairing. This configuration is to deliver a 50 klb payload to an 80 by 150 nmi orbit at an inclination of 28.5°. Any further orbital maneuvers will be performed by the payload, which may include an upper stage. A configuration drawing is shown in Fig. 3.3.3.9-2.



- ASRM Boosters
- Core Propulsion Module Located Under the Propellant Tanks
  - STME's (4)
    -- 583Klb Vac. Thrust (650K Jan 92
    -- 430.5 s Vac. Isp
    -- 45:1 Exp. Ratio
    -- 6:1 MR
    -- Step Throttleable (75%) Optional
  - Engine Out Capability
  - Propellant Feed System Commonality with NLS 2 (1.5 Stage) Propulsion Module
- ET Derived Core Tankage
  - Al 2219 Construction
  - 5 ft. Stretch in LH2 Tank (Wp ~ 1.69 Mlb)
  - Includes Structural Weight Penalty for Commonality with 1.5 Stage
- Titan IV Derived Payload Shroud with Space Shuttle Compatible Attachments
  - 15' x 80' Payload Envelope
- Kickstage / CTV for Circularization and SSF Rendezvous & Dock
- 1990 Technology Avionics with Moderate Development
- ILC ~ 2001 @ KSC

Figure 3.3.3.9-1.– NLS 1 HLLV.

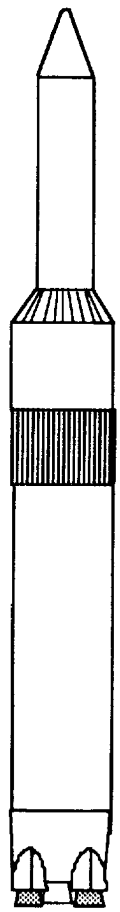


- Core Propulsion Module Located Under the Propellant Tanks
  - STME's (6 -- 4 Staged in Booster Module, 2 in Sustainer)
    - -- 583 Klb Vac. Thrust (650K Jan 92)
    - -- 430.5 s Vac. Isp
    - -- 45:1 Exp. Ratio
    - -- 6:1 MR
    - -- Step Throttleable (75%) Optional
  - Booster Module Initially Expendable
  - Engine Out To Orbit Capability
  - Propellant Feed System Common with Inline NLS 1 (HLLV) Propulsion Module
- ET Derived Core Tankage
  - Al 2219 Construction
  - 5 ft. Stretch in LH2 Tank (Wp ~ 1.69 Mlb)
  - Design for Commonality with Inline NLS 1
- Standard Titan IV Payload Shroud
  - 15' x 61.7' Payload Envelope
- 1990 Technology Avionics with Moderate Development
- ILC ~ 2001 @ KSC and 2002 @ CCAFS

Figure 3.3.3.9-2.–NLS 2 vehicle.

<u>NLS 2 with NLSUS (Two-and-One-Half Stage (2.5 Stage)) Vehicle</u>

The NLS 2 with NLSUS (2.5 stage) vehicle is so designated because it consists of the basic NLS 2 (1.5 stage), plus a new, high energy upper stage, NLSUS. The primary requirement for this vehicle is to deliver a 15 klb payload into geosynchronous orbits. Another possibility is an 80 klb (net) NASA resupply payload to SSF. A configuration drawing is shown in Figure 3.3.3.9-3.

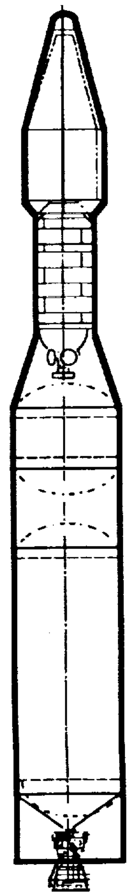


- Core Propulsion Module Located Under the Propellant Tanks
  - STME's (6 -- 4 Staged in Booster Module, 2 in Sustainer)
    - -- 583 Klb Vac. Thrust (650K Jan 92)
    - -- 430.5 s Vac. Isp
    - -- 45:1 Exp. Ratio
    - -- 6:1 MR
    - -- Step Throttleable (75%) Optional
  - Booster Module Initially Expendable
  - Engine Out To Orbit Capability
  - Propellant Feed System Common with Inline NLS 1 (HLLV) Propulsion Module
- ET Derived Core Tankage
  - Al 2219 Construction
  - 5 ft. Stretch in LH2 Tank (Wp ~ 1.69 Mlb)
  - Design for Commonality with Inline NLS 1
- Standard Titan IV Payload Shroud
  - 15' x 61.7' Payload Envelope
- 1990 Technology Avionics with Moderate Development
- ILC ~ 2001 @ KSC and 2002 @ CCAFS

Figure 3.3.3.9-3.– NLS 2 with NLSUS.

<u>NLS 3 (20 K Vehicle)</u>

NLS 3 consists of an 18 ft diameter first or booster stage with a single STME, a NLSUS second stage (common with the 2.5 stage vehicle), a payload adaptor, and an Atlas-derived payload fairing. NLSUS will be powered by a one or two RL-10A-4 derivative engine or equivalent. This vehicle satisfies user requirements for advanced MLV payloads in low-Earth orbits. Current studies will resolve what thrust level is needed in the booster STME (up to 640 k). A configuration drawing is given in Fig. 3.3.3.9-4.



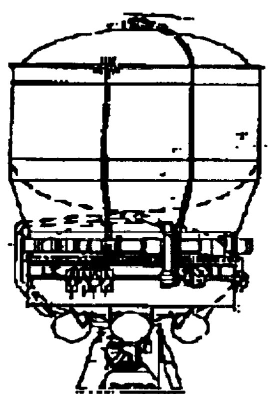
- Core Tanks are 18 feet in diameter
  - STME's (1 to 2)
    - -- 583 Klb Vac. Thrust (650K Jan 92)
    - -- 430.5 s Vac. Isp
    - -- 45:1 Exp. Ratio
    - -- 6:1 MR
    - -- Step Throttleable (75%) Optional
  - Booster Expendable
  - Propellant Feed System Components Piece-part Commonalty with Larger Propulsion Modules
- New Tankage Design
  - Al 2219 Construction (AL-LI is Optional)
  - (Wp ~ TBD Mlb)
  - Design for Ease of Growth.
- Upper Stage is the NLSUS
- Standard Atlas Payload Shroud
  - 10'x 21' Payload Envelope
- Advanced Technology Avionics
- IOC ~ 2004 @ CCAFS

Figure 3.3.3.9-4.– NLS 3 vehicle.

<u>NLS High Energy Upper Stage</u>

A high energy LOX/LH_2 powered top stage is required for the high orbits of the 2.5-stage missions and also for the 2-stage, 20 k payload LEO mission configuration. Tentatively, the NLSUS diameter is 15 ft., and contains about 47 000 lbs of useable propellant (exact quantity is TBD). One or two RL-10A-4 derivative engines of ~30 k vac thrust, or equivalent single engine, may be required. When utilized, NLSUS will incorporate the standard avionics suite developed for the family of vehicles. A configuration drawing is given in Fig. 3.3.3.9-5.

c. Operations.– The goal of the NLS ground operations program is to influence launch vehicle, facility, and equipment designs to the extent necessary to produce an operations flow free of complicated equipment and labor intensive activities, and which is characterized by rapid, dependable timelines.



STAGE CHARACTERISTICS

- New Cryogenic Top Stage
  - One or Two RL-10A-4 Equivalent Engines
  - 20-40Klb Vac. Thrust (30Klb Nominal) - 450-465 sec. Vac I_{sp} (455 sec Nominal)
  - 100:1/300:1 Exp. Ratio (110:1 Nominal)
  - 5.5:1/6.5:1 Mixture Ratio (6:1 Nominal) - Retracted Nozzle Optional
- Advanced Structure (AL/LI) w/Mass Fr. 0.88
- Wp~47Klb
- Stage Weight (Wet) ~ 54Klb
- Length ~ 30 Ft.
- Diameter ~ 15 Ft.
- ILC ~ 2001 @ KSC

Figure 3.3.3.9-5.– NLS high energy, upper stage vehicle.

Streamlined operational concepts will be designed to accomplish launch vehicle manufacturing, assembly, and checkout with as few facilities, tests, and labor intensive operations as possible. This goal will be met through proper application of existing and advanced technologies to satisfy the operability requirements set forth in the NLS Systems Requirements Documents (SRD).

NLS ground operations are based on the Integrate-Transfer-Launch (ITL) processing concept. Summary ground operations flows are shown in Figures 3.3.3.9-6 through 3.3.3.9-8. This process features the integration of the flight vehicles off-pad with subsequent transfer to the launch pad on a mobile platform. The process begins with the final assembly and/or checkout of large vehicle elements adjacent to the launch site. After each vehicle element is assembled and checked out, it is transferred to the Vehicle Integration Facility (or Vertical Assembly Building) where all elements are integrated into a single launch vehicle stack on a Mobile Launch Platform (MLP). The locations and inter-relationships of the NLS operations facilities are shown in Figure 3.3.3.9-9.

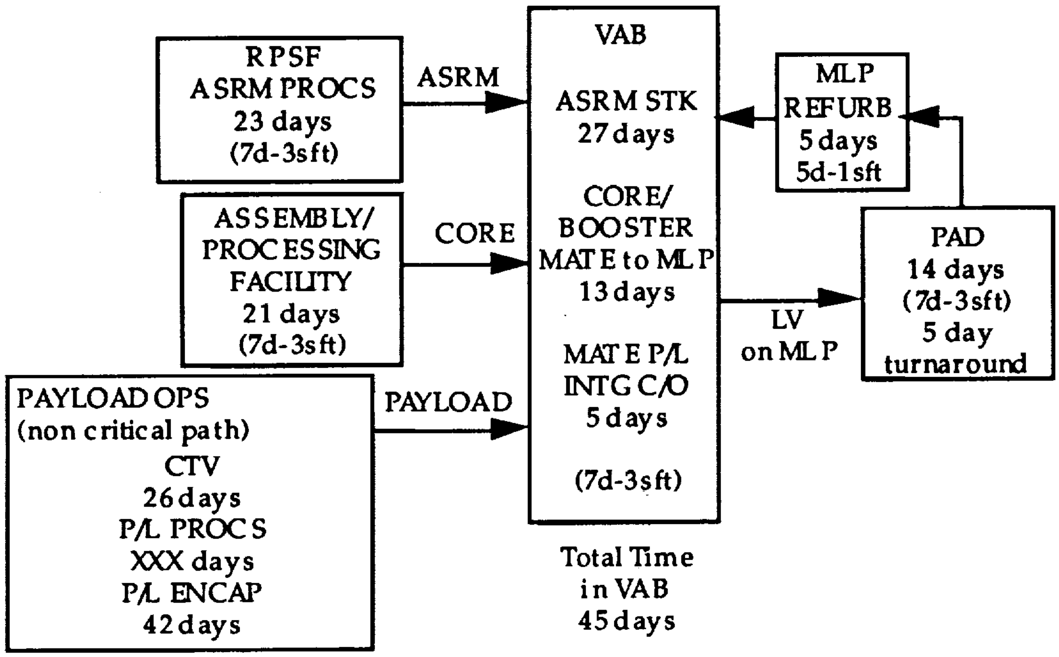


Figure 3.3.3.9-6.– NLS 1 processing (NLS HL).

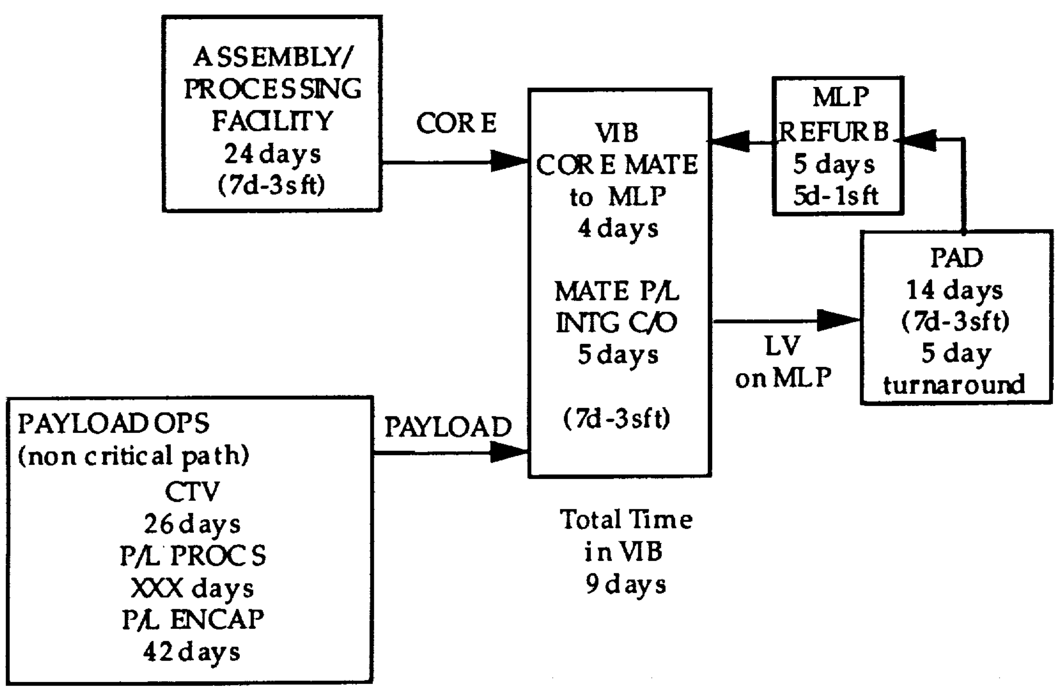


Figure 3.3.3.9-7.– NLS 2 processing (NLS 50).

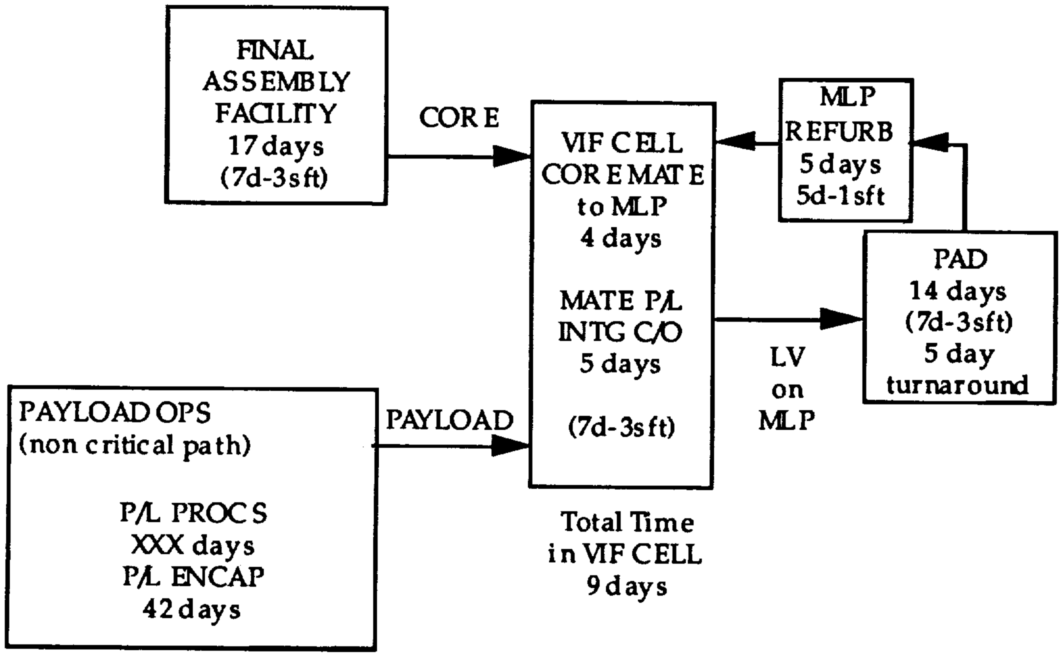


Figure 3.3.3.9-8.– NLS 3 processing (NLS 20).

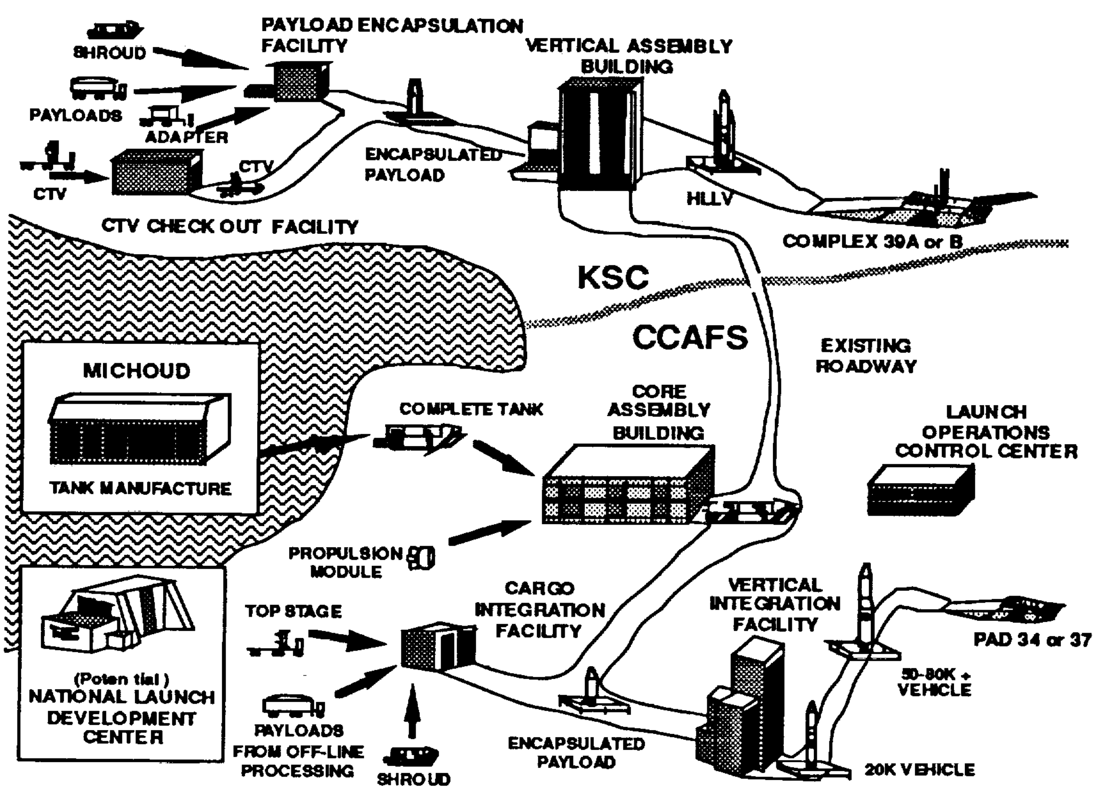


Figure 3.3.3.9-9.– NLS operations facilities.

Individual spacecraft and upper stages are processed in dedicated (non-NLS) facilities. When ready for integration, they are transported to the NLS Cargo Integration Facility (CIF) where upper stages are mounted to the NLS standard cargo adapter, and spacecraft are mounted either to the upper stages or to the cargo adapter as required. After cargo interfaces are validated, all cargo elements are serviced and NLS personnel assemble the fairing to encapsulate the cargo. The integrated cargo, encapsulated in the fairing, is brought to the Vehicle Integration Facility (VIF) and mounted on top of the stack. The cargo-to-vehicle interfaces are then validated and the MLP moves to the launch stand. The simplified interfaces between the MLP and the launch stand are mated and validated with a final systems test. After the systems test, cryogenic propellants are loaded and the vehicle is launched. Although there are no fixed towers or mobile gantries at the launch stand, the MLP does incorporate an umbilical mast to provide standard payload services.

The LCC supports prelaunch preparation and tests, launch and mission operations, and performs facility monitoring. This operations approach provides efficient planning and use of the launch stand(s), allows parallel processing, isolates the launch stand from the build-up area, and facilitates launch vehicle and payload changeout.

Recoverable vehicle elements (booster engines and possibly core propulsion and avionics) are recovered and processed through refurbishment facilities to ready them for their next flight.

Current siting concepts call for the eventual construction of launch operations facilities at KSC, CCAFS, and VAFB.

Performance Characteristics

The performance of the NLS family of launch vehicles, including performance with CTV, CTF, RPC, and CRV, is contained in Table 3.3.3.9-1.

Attribute Values

a. Funding Profile Summary.– The data in Tables 3.3.3.9.2 through 3.3.3.9-4 was used as input for the calculation of the funding profile attribute.

b. Probability of Mission Success.– The flight phases used for calculating PMS are based on the event trees for the NLS. These are described in the section describing the PMS attribute. Vehicle characteristics, which effect the calculation of PMS, follow.

TABLE 3.3.3.9-1.– NLS VEHICLE FAMILY PERFORMANCE
VEHICLES/PERFORMANCE (1,000 LB)

Orbit*	NLS 100	NLS 100 W/CTV	NLS 100 W/AUS	NLS 50	NLS 50 W/CTV	NLS 50 W/AUS	NLS 20 W/AUS
SSF 220X220 28.5°		101.0			26.0		
LEO 160X160 28.5°		105.0		49.7	30.0		
150X150 90°				31.0			4.0
445X445 98.7°				13.6			
SSF xfer 30x220 28.5°	45.0						
NLS xfer 80x150 28.5°	142.0			51.0			19.3
GTO			39.0			8.3	
GEO			19.5			4.2	
Usable Payload Vol (L x D in Ft.)	90 x 30	60 x 30	30 x 15	60 x 15	30 x 15	30 x 15	30 x 15

*Only orbits used in manifesting are shown

TABLE 3.3.3.9-2.– FUNDING PROFILE SUMMARY NLS 20 VEHICLE
(MILLIONS OF $)

	Total Cost	TFU	LC%	RC%
DDT&E	$218			
Non-Rec. Facilities				
Vert Proc Fac	$139			
Horiz Prod Fac	$154			
MLP	$62			
Non-Rec. Production	$0			
Rec. Production				
Core		$17	90%	87%
STME		$14	94%	94%
Shroud		$1	90%	100%
AUS		$22	90%	90%
Cost Per Flight	$64 Ave. For 64 Flights			

TABLE 3.3.3.9-3.– FUNDING PROFILE SUMMARY NLS 50 VEHICLE (MILLIONS OF $)

	Total Cost	TFU	LC%	RC%
DDT&E	$4,991			
Non-Rec. Facilities				
Pad	$278			
Vert Proc Fac	$248			
Horiz Prod Fac	$57			
MLP	$144			
Other	$789			
Non-Rec. Production	$83			
Rec. Production				
Core		$99	90%	87%
6 STME @		$14	94%	94%
Shroud		$8	100%	100%
AUS		$22	90%	90%
Cost Per Flight	$87 Ave. For 310 Flights			

TABLE 3.3.3.9-4.– FUNDING PROFILE SUMMARY NLS 100 VEHICLE (MILLIONS OF $)

	Total Cost	TFU	LC%	RC%
DDT&E	$120			
Non-Rec. Facilities				
Pad-Mods	$70			
Vert Proc Fac Mods	$4			
Cargo Prod Fac	$117			
MLP-Mods	$82			
Other	$104			
Non-Rec. Production	$0			
Rec. Production				
Core		$99	90%	87%
4 STME @		$14	94%	94%
Shroud		$18	100%	100%
AUS		$22	90%	90%
ASRM	$31 Rec Per Flight (2 Motors)			
Cost Per Flight	$127 Ave. For 146 Flights			

- All vehicles have hold-down capability.
- The NLS 50 and NLS HL have engine-out capability.
- The number and type of engines and stages are given in Figures 3.3.3.9-1 through 3.3.3.9-5 for each of the vehicles and/or elements.

The calculated values for PMS for each of the vehicles are as follows:

NLS 20	0.9435
NLS 50	0.9842
NLS 50/AUS	0.9455
NLS HL	0.9308

c. Human Safety.– The MLS safety is discussed as an integral element of safety for the RPC and CLV systems.

d. Architecture Cost Risk.– Two of the three subattributes were based on system values, or scores. For the NLS vehicles, the NIT consensus scores for the subattributes, technical confidence and program immaturity, for each of the vehicles are given below.

Vehicle	Technical Confidence	Program Immaturity
NLS 20	35.6	12.9
NLS 50	247.9	12.9
NLS HL	142.3	12.9

e. Launch Schedule Confidence.– As with ACR, two of the three subattributes were based on system values, or scores. One of these, schedule compression, was calculated to be zero for all NLS vehicles because the nominal flows for the NLS, shown previously in this section, are based on three shift, 7-day per week operations. The other, percent of flights with delays, was calculated to be 3.22 percent for all NLS vehicles. Both of these calculated values, along with the schedule margin subattribute, were subsequently used with architecture-particular flight rate data to roll-up the architecture LSC and value.

f. Environment.– The NLS 20 and 50 vehicles use all-LOX hydrogen propellants. The NLS HL uses solid boosters in addition to LOX hydrogen propellants.

Using the appropriate propellant weights for each NLS configuration, the major effluent constituents (in klbs) are shown in Table 3.3.3.9-5. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.9-5.– EFFLUENT DATA FOR NLS

Exhaust Product	NLS-20	NLS-50	NLS-HL
CO	0.0	0.0	542.6
CO_2	0.0	0.0	48.2
H_2	11.8	58.2	108.8
H_2O	331.2	1628.2	1813.9
HCI	0.0	0.0	479.9
N_2	0.0	0.0	197.8
OH	0.0	0.0	4.8
H	0.0	0.0	2.4
$A1_20_3$	0.0	0.0	851.3
Total Mass per Flight (klbs)	343	1686.4	4049.7
Score	34	169	6203

3.3.3.10 Manned Launch System (MLS)

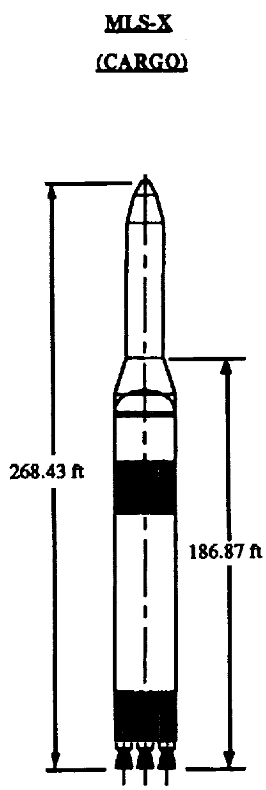
System Description

a. History.– One of the perceived objectives of any new human space transportation system will be to maximize crew safety. For architectures that include human elements boosted on an expendable (or partially reusable) launch vehicle, the safety of the entire system is limited by the characteristics of the booster. For the purposes of this study, we conceptualized a hypothetical launch vehicle with features that could significantly enhance crew safety (as opposed to a performance or cost-optimized design). This vehicle was dubbed the MLS.

b. Configuration.– To enhance the credibility of comparisons between similar architectures, it was decided to start with a booster design that was already included in this study and make minor changes to that design to arrive at an MLS. The NLS 50 k payload lift-capacity vehicle concept (or NLS-50, see section 3.3.3.9) is very close in performance to the requirement for a MLS. The NLS-50 also includes many of the features one would expect in a safety-driven booster design. Although the specifics of what human-rating implies are still subject to debate, certain booster attributes are desirable:

- Robust design – high factors of safety, weight margins.
- Integral Vehicle Health Monitoring (VHM) – sufficient sensors and processors to continuously evaluate system's health and to notify crew and/or abort system(s) in timely fashion.
- Engine-out capability – precludes the need to initiate abort procedures (which are risky) in a large percentage of failure modes (many failures have included propulsion hardware).
- Minimal correlated failure modes – maximize containment/isolation of critical subsystems.
- Eliminate rapid failure modes – abort systems and VHM are useless if there is insufficient reaction time (for example, some solid propellant boosters failures can be detected only milliseconds before a catastrophic detonation).

To encompass the range of missions for architectures using the MLS, a "family" of vehicles is required. The core stage MLS, known as the MLS-X, is sized to carry the RPC (see Section 3.3.3.11) with a small crew and no additional cargo to the SSF orbit. The MLS-X is a stage-and-one-half design featuring six STME's (four in expendable booster pods, and two sustainer engines) and a Shuttle External Tank-derived LOX/LH_2 fuel tank set. To carry larger cargo, or the human-tended CLV (see Section 3.3.3.12), a larger version of the MLS-X called the MLS Heavy Lift (MLS-HL) was conceived. The MLS-HL features a LOX/LH_2 upper stage in addition to the MLS-X core first stage. Figure 3.3.3.10-1 depicts the two MLS configurations with untended cargo fairings. Figure 3.3.3.10-2 shows the design of the upper stage.



- MLS-X same as MLS-HL except has new high energy upper stage
- Standard Titan IV payload shroud for cargo versions
  - 15 ft x 61.7 ft nominal payload envelope
- Core propulsion located under the propellant tanks
  - STME's: 6 (4 staged in booster module, 2 in sustainer)
    - -- 583 Klb vacuum thrust (650 Klb in January 92)
    - -- 430.5 seconds vacuum Isp
    - -- 45:1 Expansion Ratio
    - -- 6:1 Mixture Ratio
    - -- Step throttlability (75%) optional
  - Booster module initially expendable
  - Engine out to orbit capability
- ET derived core tankage
  - AL 2219 construction
  - 5 ft. stretch in LH2 tank (Wp - 1.69 Mlb)
- 1990 technology human rated avionics with moderate development

Weights for 80 X 220 nm Orbital Insertion Performance:

	MLS-X		MLS-HL
	RPC	Cargo	Cargo
Payload:	26,343	43,768	87,498
Margin:	13,615	-0-	-0-
Shroud:	2700	13,569	13,569
Launch Veh. (dry):	166,311	199,311	207,664
Propellant:	1,704,222	1,704,222	1,750,364
GLOW:	1,953,968	1,960,870	2,059,095

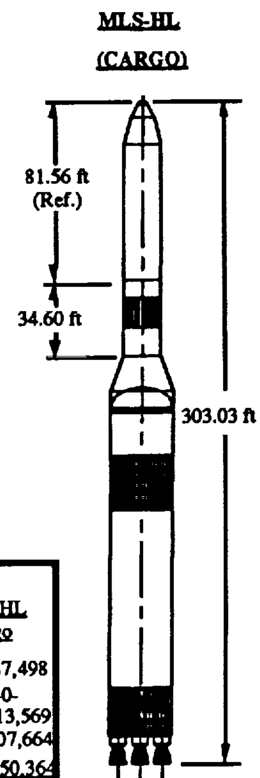


Figure 3.3.3.10-1.– MLS configurations.

Physically, the MLS differs little from the NLS configurations. There are additional sensors and a communications bus running forward to supply VHM data to the crew of a personnel capsule on top of the MLS. In both versions, the cross beam provisions found on the NLS-50 core stage for using strap-on boosters are absent.

c. Abort Modes.– In the event of an engine failure, the MLS can operate engine-out and complete the nominal ascent profile. In the event of any other major failure, the on board sensing system would warn the crew to initiate abort procedures. The LES motor would be ignited, the MLS main engines would be commanded to shut down, and the attachment fittings between the crew element and the MLS would be severed.

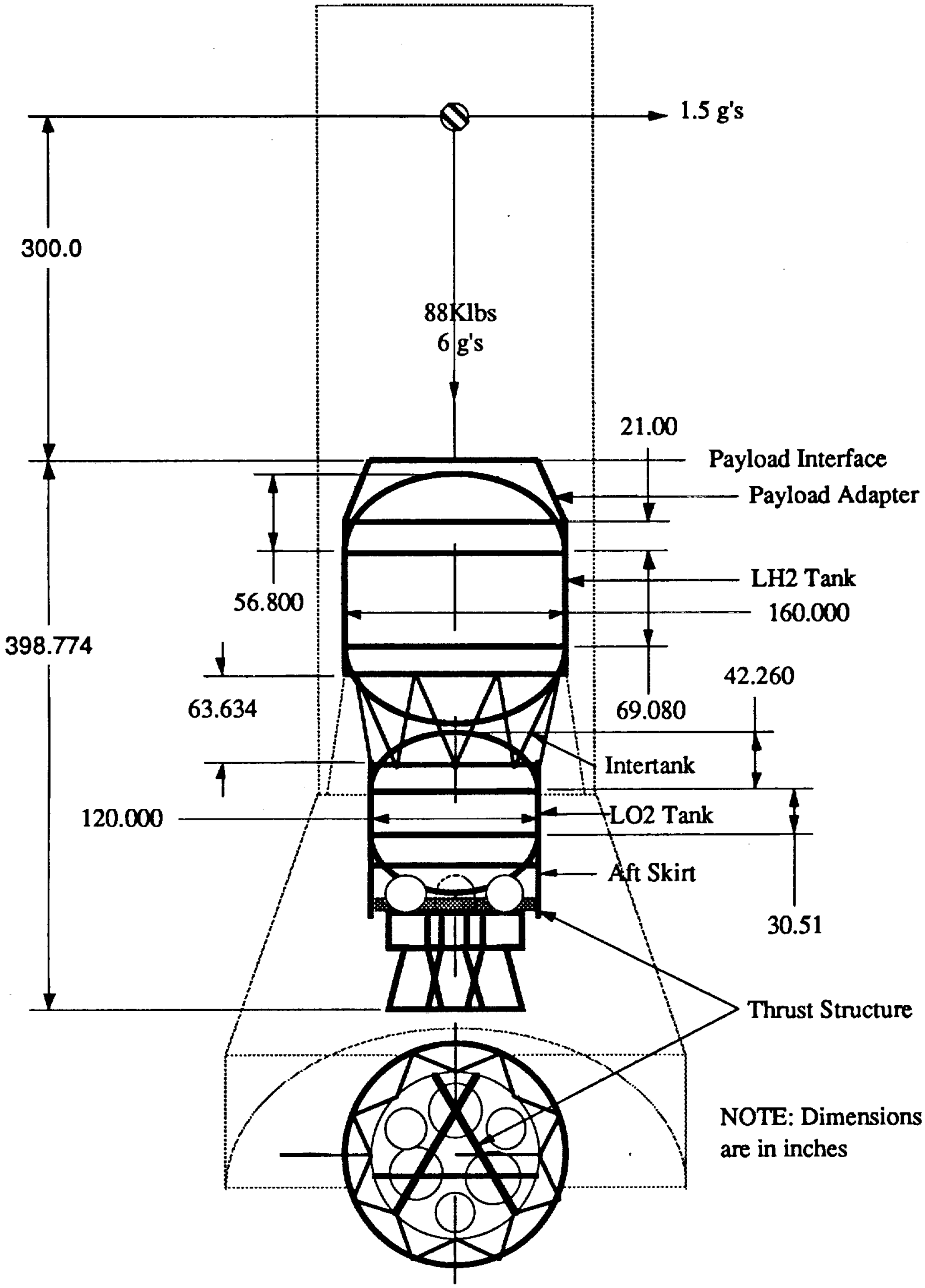


Figure 3.3.3.10-2.– MLS upper stage configuration.

d. Facilities.– The ground-processing facilities for the MLS are nearly identical to those described for NLS (section 3.3.3.9). There is no requirement for solid booster stacking or handling facilities, however. The launch pad will need to accommodate human access and safety provisions for both the MLS-X/RPC combination and the MLS-HL/CLV combination. The MLS launch pad definition includes the additional access tower and personnel preparation areas.

e. Operational Flow.– As is the case for facilities, the operational flow is basically the same as for the NLS (see Figure 3.3.3.9-9), with the exception that there are no solid boosters to assemble or integrate. The MLS upper stage will follow a launch operations processing flow similar to the NLS Advanced Upper Stage and CTV flows (also described in the NLS section).

Performance Characteristics

The baseline MLS performance is based on the system's ability to place a reference RPC into a SSF orbit. Accounting for the RPC's orbital maneuvering system capability, this translates to the needed MLS-X capability of 43 768 lbm to an 80x220 nmi (28.5°) orbit. Similarly, the MLS-HL performance is sized to put a CLV (87 498 lbm) into the same orbit.

Attribute Values

a. Funding Profile Summary.– The MLS-X and MLS-HL launch vehicles' family cost estimates developed for this study are summarized in Table 3.3.3.10-1. All estimates shown in the table are in constant-year 1992 dollars, at contractor cost (the estimates exclude contractor fees, management reserves, and government program support costs).

TABLE 3.3.3.10-1.– MLS FUNDING PROFILE SUMMARY

	(1992 Dollars in Millions)	
	MLS-X Core Stg.	MLS-HL Upper Stg.
Development:	$ 5,309	$ 631
C/D Phase	1,562	37 (mod.'s)
Facilities	6,871	668
Total -		
Production:	244	47
Theo. 1st Unit	15	
Supt. Equip. Set		
Oper. & Support:	34	6
Variable Cost	92	9
Fixed Annual		

- *Acquisition Phase Estimates.*– New development and production estimates were developed by Boeing for MLS-X hardware using the Boeing-proprietary Parametric Cost Model. New estimates for the MLS-HL Upper Stage (MLSUS) were developed by McDonnell Douglas Space Systems Company using their proprietary parametric cost model. The two MLS estimates were fully coordinated with the RPC and CLV program planning schedules for the architecture cost estimate inputs. The MLS-X estimate was also coordinated with the MSFC NLS estimate sources to ensure that the STME propulsion subsystem estimates and schedule matched the MLS master schedule used for the MLS development estimate definition.

- *Operation and Support Estimates.*– The operations' cost estimates data is shown for MLS elements only.

- *Funding Profile Attribute Cost Inputs.*– The data shown in Table 3.3.3.10-2 was estimated and evaluated for annual cost estimate spread factors using the Figure 3.3.3.10-3 MLS program master schedule. The summary included: percentage factors for cost spreads, cost improvement and realization curve factors for theoretical first unit, cost estimate extensions to develop total production fleet costs, and facility usage estimates. The MLS family cost estimate input forms are provided in Appendix B.

b. Probability of Mission Success.– The flight phases used for calculating PMS are the same as those for NLS (refer to the reliability tree of section 3.3.3.9). While some definitions of human-rating stress maximize reliability, it was felt that it would be unrealistic to claim any significant difference in component or system reliability from those used for NLS. The MLS-X PMS is thus equal to 0.9842 and the value for MLS-HL PMS is 0.9691.

c. Human Safety.– The MLS safety is discussed as an integral element of safety for the RPC and CLV systems.

d. Architecture Cost Risk.– The risk assessment of the MLS flight elements is based on preliminary program and design descriptions developed during the HTS study. The NIT average of the non-recurring portion of the Technical Challenge subattribute was a score of 4, reflecting the opinion that the MLS design is largely state-of-the-art technology. The production Technical Challenge subattribute score was also a 4 using similar reasoning. In the operations Technical Challenge subattribute, a score of 3 indicated that, since the MLS uses many existing facilities and procedures at KSC/ETR, there is a lower risk involved with operations cost estimation. The Program Imaturity score was a 6, which reflects the perceived level of design detail that exists at the time of this writing.

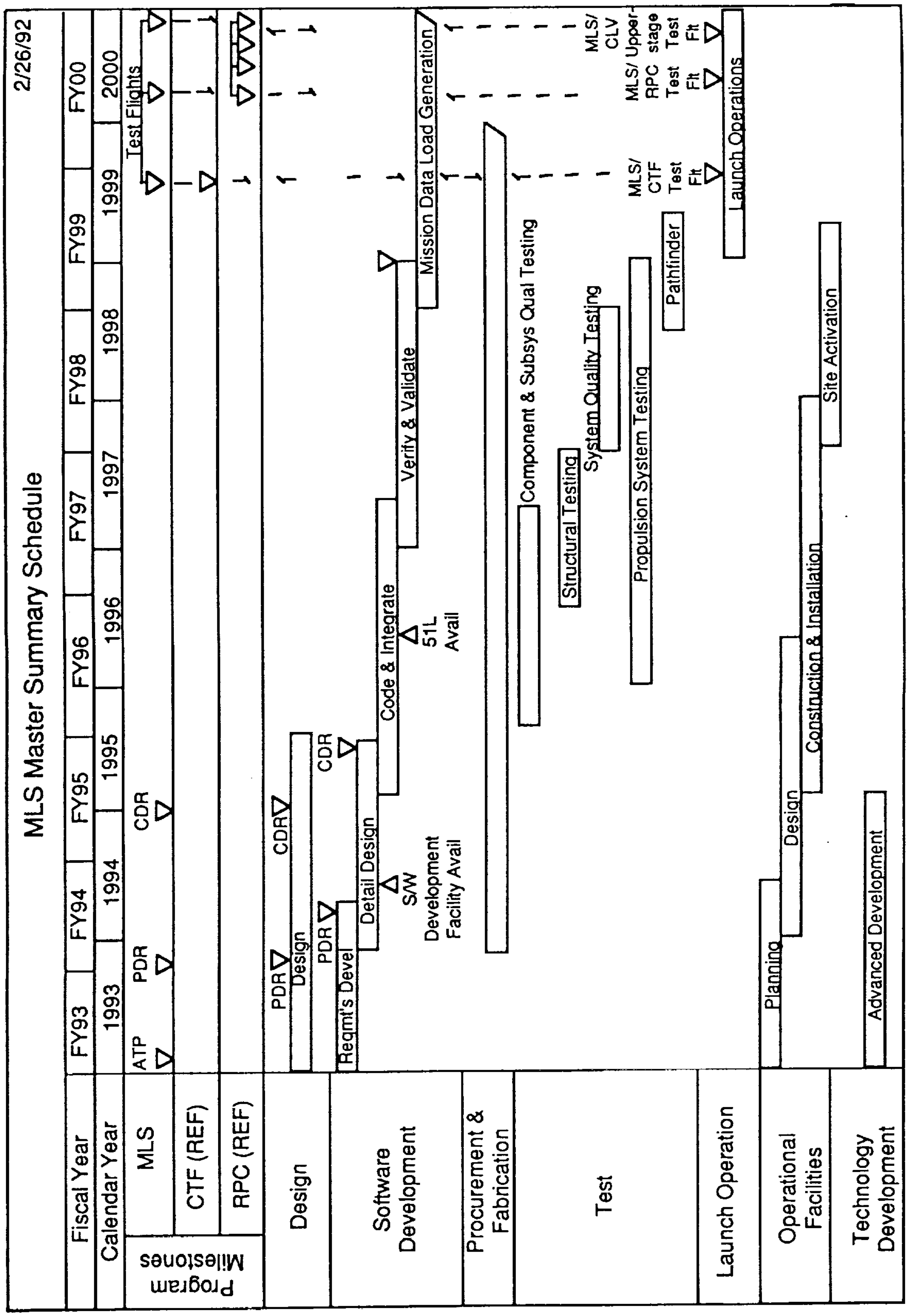


Figure 3.3.3.10-3.– Preliminary master schedule for LCC analysis.

e. Launch Schedule Confidence.– As with ACR, two of the three subattributes were based on system values, or scores. One of these, schedule compression, was calculated based on the MLS operations data; since compression is based on additional shift utilization and MLS processing around three shifts, 7 day-a-week operations, the compression is zero. The other, percent of flights with delays, was calculated to be 3.22 percent. Both of these calculated values were subsequently used with architecture-particular flight rate data to roll up the architecture subattribute value.

f. Environment.– The MLS booster uses liquid hydrogen and liquid oxygen as propellants. The MLS-X has a propellant load of 1,704,222 lbm which is identical to the first stage of the MLS-HL. Although the MLS-HL features an upper stage, this stages operates outside the sensible atmosphere and does not contribute to the environment score as defined in this study.

Using the given propellant weights, the major effluent constituents (in klbs) are shown in Table 3.3.3.10-2. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.10-2.– EFFLUENT DATA FOR MLS

Exhaust Product	MLS-X	MLS-HL
CO	0.0	0.0
CO_2	0.0	0.0
H_2	58.2	58.2
H_2O	1628.2	1628.2
HCl	0.0	0.0
N_2	0.0	0.0
OH	0.0	0.0
H	0.0	0.0
Al_2O_3	0.0	0.0

3.3.3.11 Reusable Personnel Carrier (RPC)

System Description

a. History.– Previous space transportation architecture studies have shown that a promising concept for human transportation involves a compact, reusable personnel carrier launched on an expendable launch vehicle that would carry no significant integral cargo. In recent years, several types of vehicles in this class have been studied, most notably the JSC/Boeing Biconic PLS and the LaRC/Rockwell HL-20 Lifting Body PLS. While the designs are different, their basic mission, size, and costs are very similar, and any one concept should serve as representative of the RPC and the architectures that feature it.

b. Configuration.– The design of the RPC is based on a moderate L/D capsule configuration that was explored in a JSC/Boeing PLS concept definition study.[8] The biconic capsule is launched atop an expendable launch vehicle; in the HTS study, launcher options include HR Titan IV, NLS-50, and the MLS-HL (discussed individually in subsequent paragraphs). Figure 3.3.3.11-1 depicts the fundamental vehicle features.

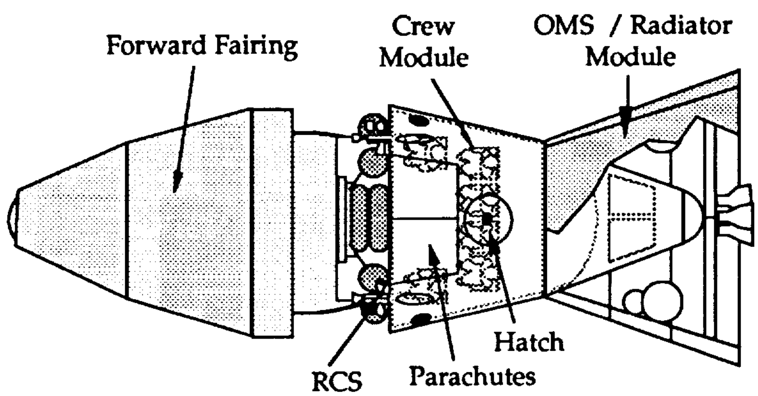


Figure 3.3.3.11-1.– RPC general arrangement.

The Boeing RPC biconic vehicle design includes both expendable and reusable hardware subsystems. The vehicle has sufficient room for personal provisions and perishable payloads on crew rotation missions to the SSF. In this design, the orbital maneuvering system and radiators are discarded during the time the reusable crew module section reenters the Earth's atmosphere. Other expendable RPC items are the LES and forward aerodynamic fairing (expended after initial ascent is accomplished) and most of the deployment landing parachutes (removed after landing.)

Kits for satellite servicing missions (not shown in the illustration) include a small manipulator arm (attached to the flat bulkhead); an additional EVA tunnel adapter for mission specialists' ingress and egress in space suits is also an option.

c. Abort Modes.– The LES for the RPC provides for a rapid removal of the crew module from the booster in the event of an emergency. This capability can be initiated anytime from prelaunch through orbital insertion. The RPC landing system includes redundant parafoils, which can be used just as effectively in the event of a water abort landing.

d. Facilities.– The RPC is treated as a special payload for the launch vehicle options. A separate processing facility (essentially a scaled-down version of the Space Shuttle Orbiter Processing Facility) is used to maintain and refurbish the RPC. Additional facilities include a mission and training facilities complex, administration facilities, and refurbishment support facilities.

e. Operational Flow.– The operations flow for the RPC is shown as Figure 3.3.3.11-2. The RPC design is considered sufficiently independent of the booster design such that the integration of the flow with the launch vehicle is a secondary effect.

Performance Characteristics

The RPC is a personnel vehicle and therefore has no payload capability to contribute to completing the cargo missions of the manifest. The vehicle is designed to carry up to six astronauts with sufficient on-orbit functionality to perform SSF crew rotation missions, orbital sortie missions and satellite servicing missions.

Attribute Values

a. Funding Profile Summary.– The cost estimates for the RPC program were developed on a JSC study contract in 1991 (NAS9-18255). The estimates were escalated from 1991 to 1992 dollars using a NASA inflation index.

   - Acquisition Phase Estimates. The Boeing PLS estimates used for the RPC inputs to the HTS architecture evaluation tool were developed with the Boeing-proprietary Parametric Cost Model, GE Price-S software cost model, and NASA Space Shuttle historical databases at KSC (facilities and equipment) and JSC (software, mission control, and training definition data). In addition, planning estimates for the OMS engines, LES engine (RS-27), and parafoil landing equipment was received from the source manufacturers of current equipments. The development schedule is shown as Figure 3.3.3.11-3.

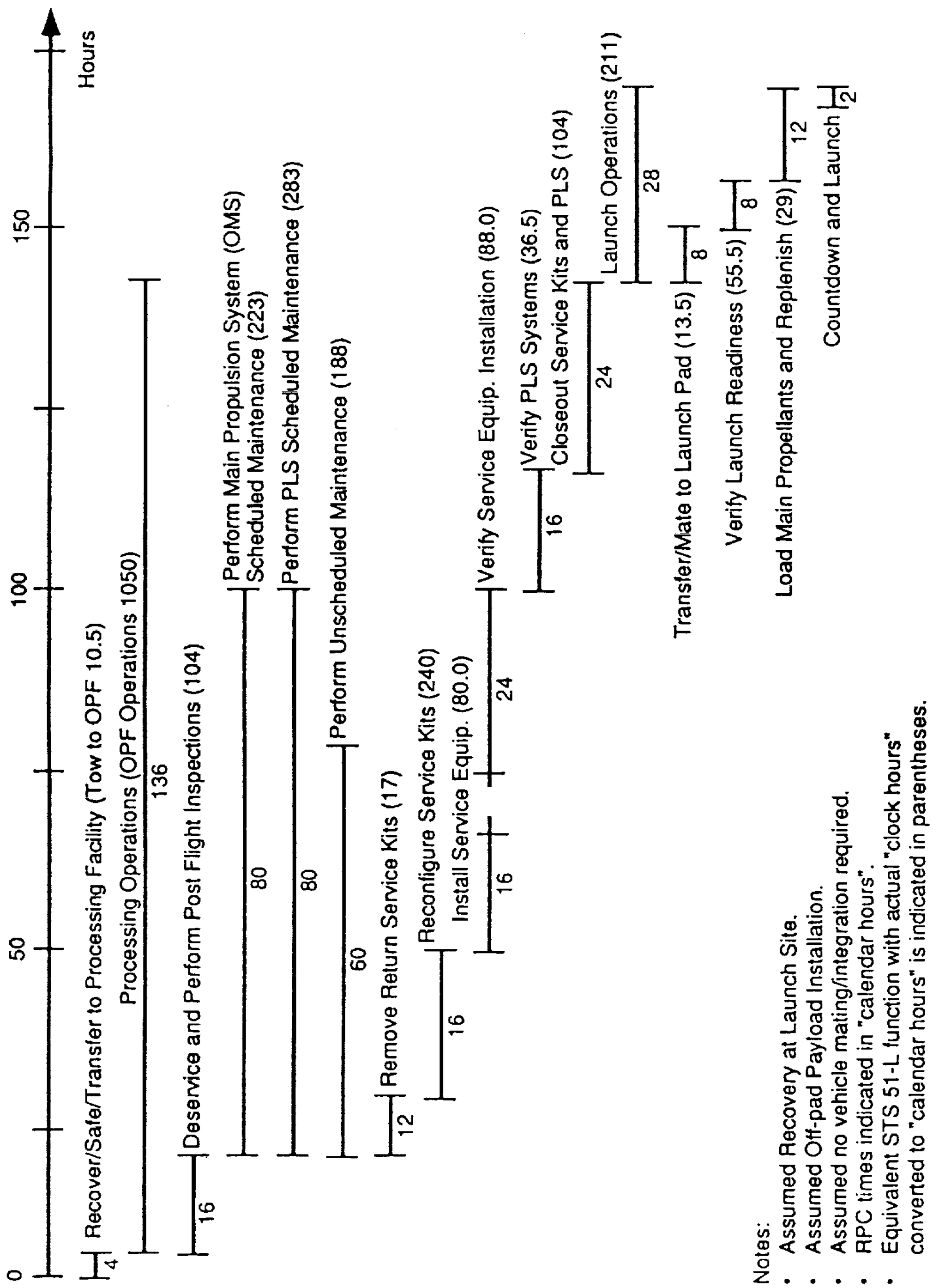


Figure 3.3.3.11-2.– Operational flow for the RPC.

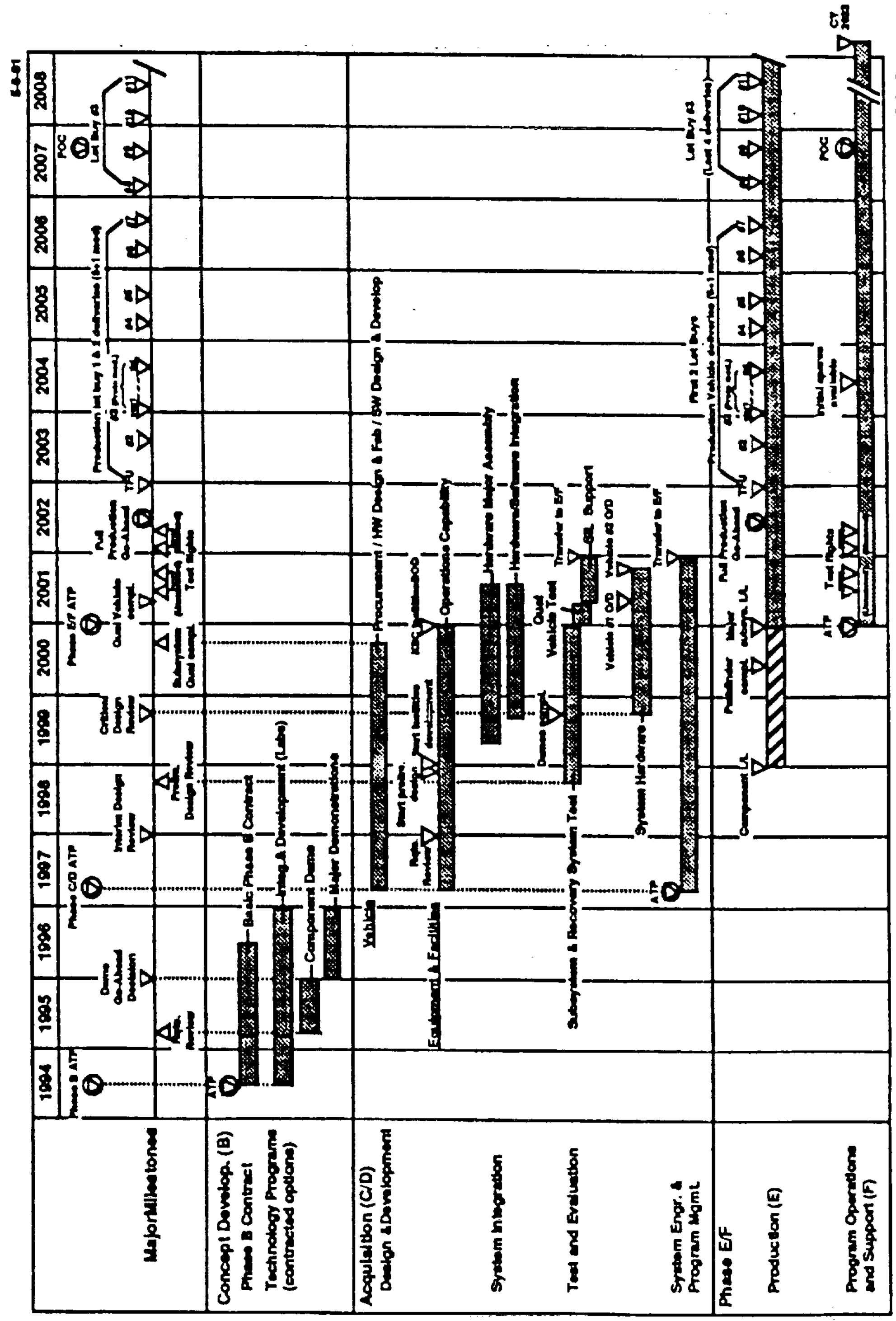


Figure 3.3.3.11-3.– RPC development schedule.

- Operation and Support Estimates. Operation and support functions were direct task human-load estimates and factor estimates.

- Funding Profile Attribute Cost Inputs. Table 3.3.3.11-1 contains the cost estimates summary for the RPC element.

TABLE 3.3.3.11-1.– RPC COST ESTIMATES SUMMARY

	(1992 Dollars in Millions) Reusable Personnel Carrier
Development:	
C/D Phase	$3,693
Facilities	434
Total:	$4,127
Production:	
Reusable TFU	257
Expendable TFU	65
Supt. Equip. Set	13
Oper. & Support:	
Variable Cost	28
Fixed Annual	125

b. Probability of Mission Success.– The contribution of the RPC to mission success is limited to its post-booster separation OMS burns and coast periods before its destination orbit is achieved (on-orbit operations, such as docking and descent phases are excluded from the current definition of mission success). Since these represent additional branches in the ascent reliability trees, as compared to untended launches using similar boosters, the PMS decreases slightly, as shown in Table 3.3.3.11-2. Note that in two cases, the booster option is never flown without the RPC.

TABLE 3.3.3.11-2.– RPC PMS

Booster	PMS w/o RPC	PMS w/ RPC
NLS-2	0.9842	0.9544
MLS-X	0.9842	0.9544
HR Titan IV	n/a	0.9188
MLS-HL w/LRV	n/a	0.9543

c. Human Safety.– The RPC design includes several features to enhance safety in the event of a launch vehicle failure. A launch escape system is carried throughout the entire thrusting ascent phase which would allow the crew to be pushed away from the launch vehicle. The parachute landing system can also be employed in the event of an unplanned water landing. Physical separation of the crew element and the launch vehicle is maximized by locating the RPC on top of the launch vehicle. The probability of loss, in the event of launch vehicle failure with the RPC design, is shown in Table 3.3.3.11-3.

TABLE 3.3.3.11-3.– RPC SAFETY (PROBABILITY OF LOSS)

Booster	P_L w/ RPC
NLS-2	0.00542
MLS-X	0.00543
HR Titan IV	0.01237
MLS-HL w/LRV	0.00641

d. Architecture Cost Risk.– The development of an RPC, reflected in the non-recurring portion of the Technical Challenge subattribute score, was set at a value of 5 by the NIT, indicating the design is largely existing technology with a few areas that may be outside the technical state-of-the-art. The production and operations technical challenge scores were both a 3, reflecting the relative simplicity of the design and its operational scenario. Based on the status of the design today, considered preliminary, a score of 6 was assigned for Program Immaturity.

e. Launch Schedule Confidence.– The schedule compression subattribute is highly dependent on which combination of booster and RPC is considered. Refer to section 3.2.6.3 for the values related to RPC combinations. The other, percent of flights with delays, was calculated to be 5.88 percent. Both of these calculated values were subsequently used with architecture-particular, flight-rate data to roll up the architecture subattribute value.

f. Environment.– The RPC contributes nothing to the score of environment as it operates exoatmospherically, outside the range of interest for this study's definition of the environment attribute.

3.3.3.12 Crew and Logistics Vehicle (CLV)

System Description

a. Requirements and Concept Selection.– To evaluate the impact of separating people from cargo, it is necessary to compare the Space Shuttle not only with a new people-only transportation system, but also with a new system which carries cargo as well. The people-with-cargo system is required to carry enough cargo to enable these additional missions:

   (1) Pressurized logistics to and from SSF

   (2) Sortie Science missions (e.g., Spacelab-type missions)

   (3) Satellite servicing.

The cargo capacity requirement for these jobs is a tradeable variable against the number of missions flown. But for this study, a weight requirement of 15 000 lbs was levied to enable all the jobs with a minimum of remanifesting.

One additional requirement was levied. To enable this system to replace the ACRV, it must be capable of up to 180 days' quiescent stay at SSF.

All currently studied personnel carriers for early availability were reviewed: upgraded ACRV, upsized Boeing PLS, upsized Rockwell PLS, HL-20, and CLV. The CLV, which is adapted from a study led by the Systems Definition Branch of the Systems Engineering Division at JSC, was selected because its proposed missions include logistics, sortie science, and servicing. The study does not recommend a configuration; several of the above candidates could be modified to carry out these missions. The configuration for CLV (shown in comparison) is provided in Figure 3.3.3.12-1.

b. Configuration.– The starting point for CLV was a scaled-down Orbiter. Linear dimensions are about 50 percent of Orbiter. The aft fuselage was tapered and the OMS pods removed to reduce drag; wing modifications were adopted to move the aerodynamic center forward. The following subsystem changes from Orbiter were made:

   - Thermal Protection - tile plus active cooling (water evaporation)

   - Propulsion - bipropellent plus cold gas nitrogen system for use in proximity to SSF

   - Power - long-life restartable fuel cells (hydrogen-oxygen)

   - Actuators - electromechanical

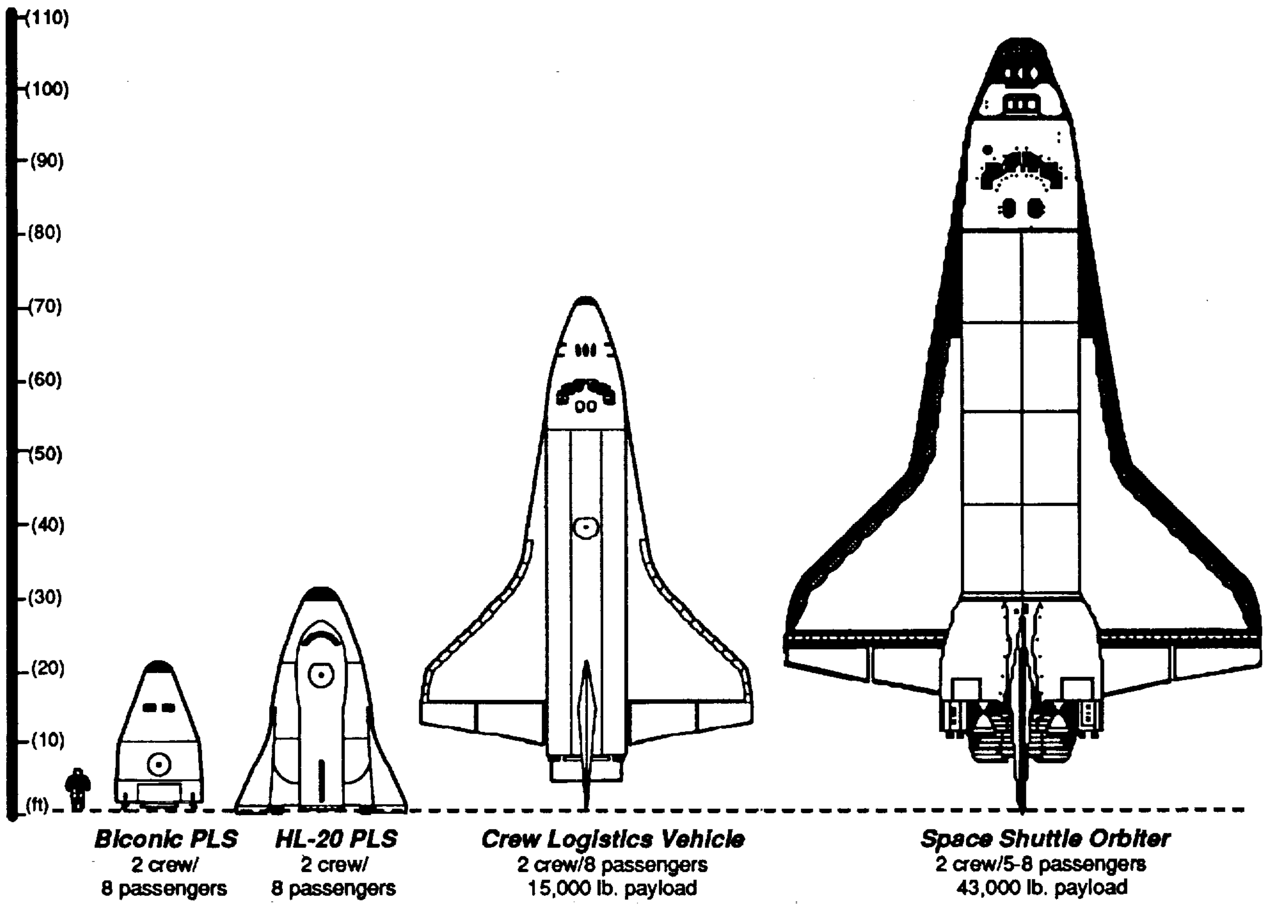


Figure 3.3.3.12-1.– Representative PC concepts.

The CLV contains no main engines. It is designed to be launched on a human-rated ELV. The NLS-1 heavy-lift vehicle could have been used, but has much more capability than is needed. It was decided to adopt a series of human-rated boosters from the NLS family which are optimized for human missions – the MLS family. CLV is launched on the MLS-HL, whose GLOW is optimized for this purpose. See section 3.3.3.10 for a more detailed description of the MLS-HL.

c. Abort Modes.– Abort coverage is provided during all launch phases as follows:

(1) First stage: abort motors provide contingency abort from liftoff; ejection seats provided for crew escape to 90 000 ft. Above 90 000 feet, the CLV would glide to a lower altitude for crew ejection.

(2) Second stage: abort motors provide press-to-main-engine-cutoff capability from second stage ignition with one engine out for benign failures, or intact abort (transatlantic or once-around) for catastrophic failures.

d. Facilities and Operational Flow.– The CLV takes over Space Shuttle facilities at KSC as the Space Shuttle is phased out. The following figure shows the ground processing flow for CLV.

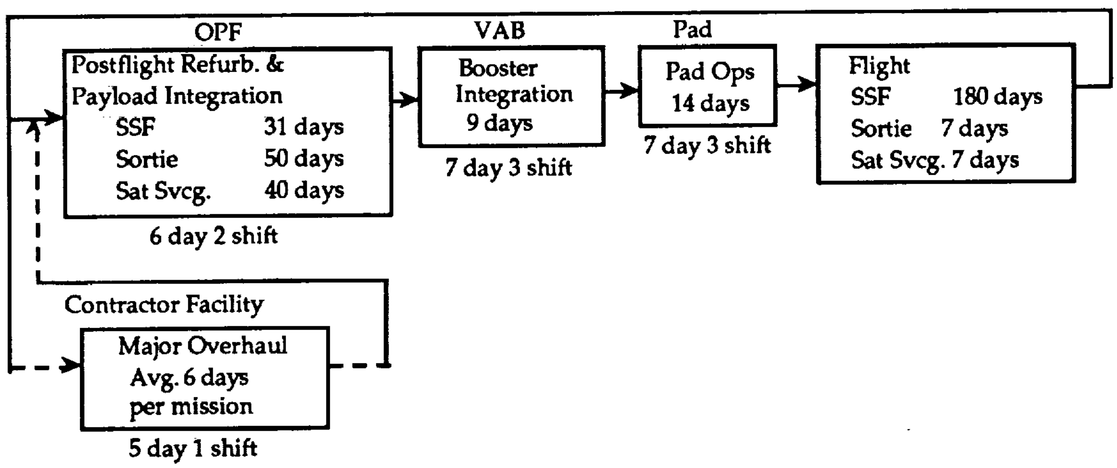


Figure 3.3.3.12-2.– CLV operational flow.

Notes:

(1) Postflight refurbishment time is longer for sortie and satellite servicing missions because mission kit installation is required for these missions.

(2) Major overhaul is required every 30 flights or 4 years and takes 6 months. Six-day time shown is prorated average per processing flow.

Ground processing time (neglecting flight time) varies from 60 to 80 days depending on the mission (see Figure 3.3.1.12-2 above). The number of flights per year, per CLV is most strongly dependent on flight duration, and varies from four per year for sortie mission to three every 2 years for SSF missions of 180 days' duration. If the CLV is not required to perform the ACRV function, all vehicles can be utilized at four flights per year.

Initial Operational Capability is in June of 2000. Figure 3.3.3.12-3 shows the DDT&E Schedule.

The CLV remains in use throughout the study period (to 2020).

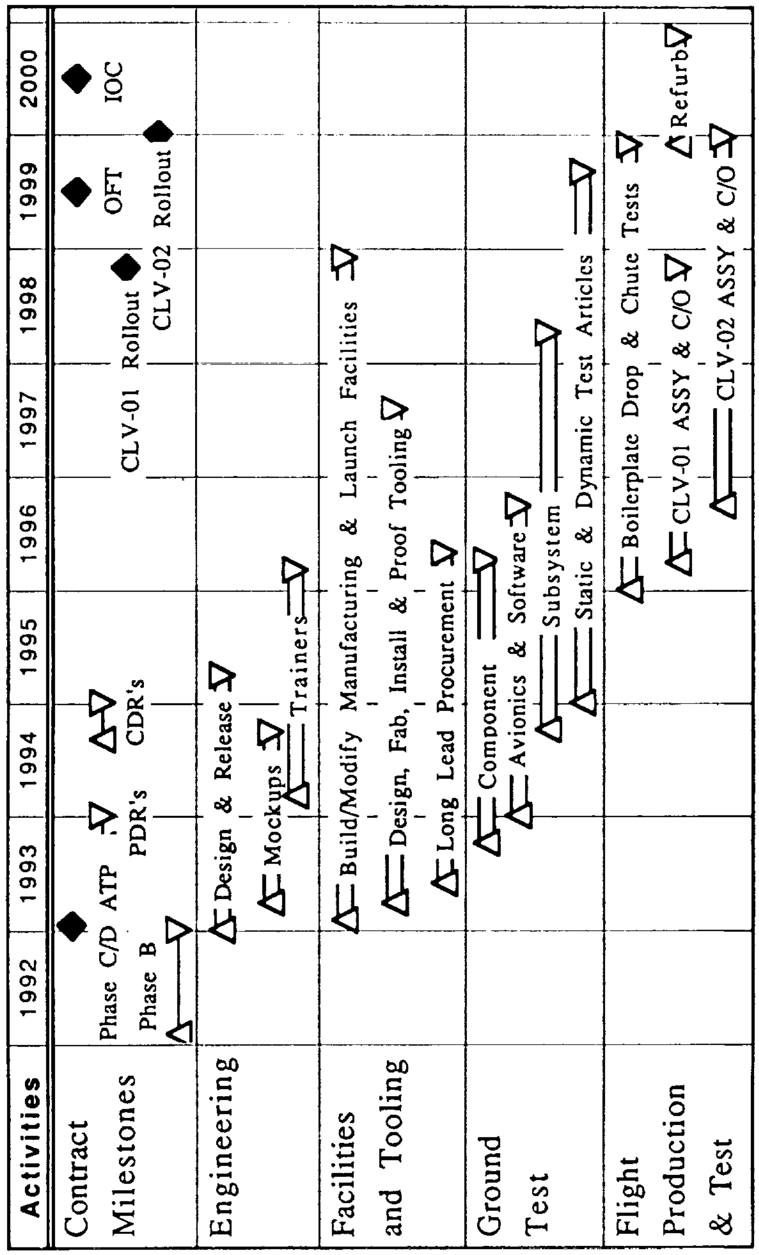


Figure 3.3.12-3.- CLV DDT&E schedule.

Performance Characteristics

The following table shows the key performance characteristics of CLV.

TABLE 3.3.3.12-1.– CLV PERFORMANCE CHARACTERISTICS

Launch Vehicle	MLS - HL
GLOW (lbs.)	86,700
Length (ft.)	54
Height (ft.)	28
Wingspan (ft.)	47
Pressurized Volume (ft3)	1,650
Cargo envelope	7.5 ft. diam x 36.5 ft. length
Cargo capacity (220 NM circ, 28.5°)	15,000 lbs. (up & down)
Human Vehicle Crew capability	Six (four plus vehicle crew)
Mission duration	5 + 2 d. active, 180 d. quiescent
Max Q	1000 psf
Max G	4.5
Delta V capability	1000 fps.
Landing speed	185 knots
Launch site limitations	Same as Space Shuttle

Attribute Values

a. Funding profile.– The following table shows the CLV/MLS-HL system costs.

TABLE 3.3.3.12-2.– CLV/MLS-HL SYSTEM COSTS, $M FY92

	CLV	MLS-HL
DDT&E	7,050	4,091
P^3I	7,410	385
Non-Recurring Prod.	Included in DDT&E	380
Facilities	Included in DDT&E	4,130
Recurring Prod.	737 per vehicle	113 per vehicle
Cost per Flight at 10 Flights/year	267*	

* Includes MLS-HL and wraps.

b. Probability of Mission Success.– Reliability estimates based on the CLV/MLS-HL vehicle configuration (six engines in first stage, three in second stage, engine-out capability in both), reliability tree, and historical data for characterized subsystems results in a combination score of .9543.

c. Human Safety.– The PMS data given above predicts a launch failure rate of 45.7 per thousand flights. The loss rate per thousand flights for CLV is estimated as 6.41. The CLV's high score relative to other systems studied is attributable to its full abort coverage and separation of people from the main engines.

d. Architecture Cost Risk.– The CLV received a Technical Challenge rating of approximately 240 for "If" C (the range for all systems was 0 to 3000), and a Program Immaturity rating of 21.5 (the range was 1 to 100). The CLV is judged to require no new technology; only a few existing drawings can be used, but they are based on a familiar product line.

e. Launch Schedule Confidence.– The ground processing flow is shown in Figure 3.3.3.12-2. The ability of CLV/MLS-HL to achieve schedule compression depends on the mission, since, as shown in the figure, ground processing time varies. An average compression is 20 days out of a processing flow of 72 days. It was estimated that 14.58 percent of CLV/MLS-HL flights would experience delays due to unscheduled maintenance.

f. Environment.– The CLV contributes nothing to the score of environment as it operates exoatmospherically, outside the range of interest for this study's definition of the environment attribute.

3.3.3.13 Reusable Ultralight Personnel Carrier (RUPC)

System Description

The primary mission of this vehicle is to transport crew to and from Earth orbit, with an emphasis on supporting crew rotation for SSF. The primary design reference mission is for accommodating six persons for 5 days, although rendezvous with SSF is nominally accomplished in four revolutions or less. Up to six SSF crew persons may be returned because the RUPC entry-landing sequence is fully automated and does not require a high level of piloting proficiency.

To provide a system which has the lowest feasible cost using an existing ELV, the RUPC has been designed under the constraint that it can be lofted by a Titan-IIS, which therefore requires a lower mass than comparable PLS designs. The penalty for such a requirement includes higher development costs, using advanced materials and advanced equipment, and designing for advanced manufacturing techniques. These higher DDT&E costs are assumed to be compensated over the long term by significantly lowered costs for launch, refurbishment, and other recurring expenses. In many cases, the RUPC design capitalizes on previous programs (e.g., Gemini aerodynamics, Apollo recovery system, Space Shuttle thermal protection system (TPS), planetary mission and DOD-sponsored avionics developments) and space infrastructure that did not exist when previous human systems were developed (e.g., TDRSS, GPS, SARSAT).

The system includes three units: a capsule, an adapter, and an escape tower, as shown in Figure 3.3.3.13-1. The pressurized capsule is reusable for seven flights (on the average), but the other two units are expended on each flight. Within the capsule is a fully pressurized crew cabin, made from lightweight composite materials, sufficient to house crew and small amounts of cargo for SSF, satellite servicing, or modest sortie science. Configuration of the capsule accommodates the following requirements: (1) aeroshield shape to satisfy reentry control and heating requirements, (2) inclusion of a SSF passive Common Berthing Mechanism (CBM) at the narrow end of the cone, and (3) aerodynamically compatible shape to minimize afterbody heating (18° cone half-angle). Avionics, recovery systems, forward RCS, and entry power systems are also located in the capsule. Thermal protection is provided by advanced reusable insulation, derived from Space Shuttle TPS materials.

The adapter configuration is determined by the necessity to provide the mechanical support to transition from the larger-diameter RUPC to the 10-ft diameter Titan-II second stage. Within the adapter are the main power system and the OMS and aft RCS propulsion systems. The same system is also used for rendezvous maneuvering and deorbit. Engine-out maneuvering capability is provided, as well as redundancy in valving and valve drivers, and cross-strapped propellant feeds. Storable hypergolic bipropellants (MMH and NTO) are utilized for all RUPC propulsion.

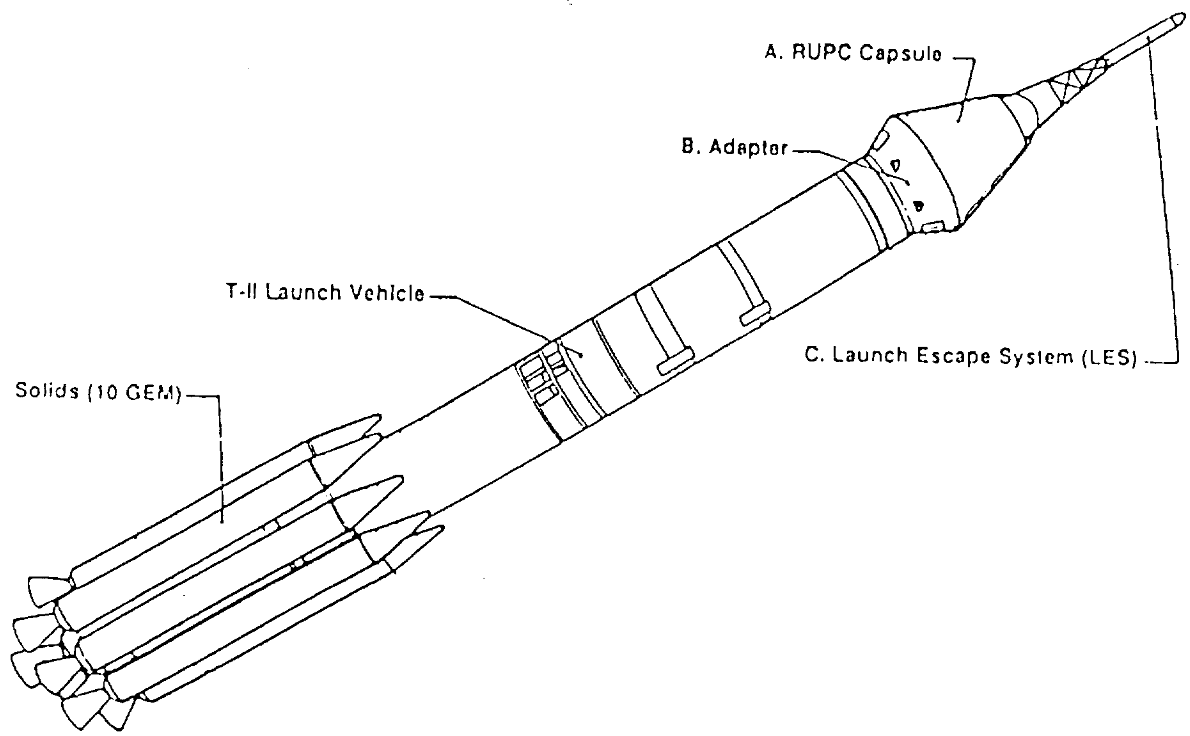


Figure 3.3.3.13-1.– The RUPC/Titan IIS system.

An LES is provided to enable the capsule to be rapidly ejected from the launch stack in the event of a major launch malfunction. This LES, containing a single solid with multiple canted nozzles and a smaller jettison solid rocket, is modeled after, but downsized from the Apollo LES (see discussion below under Safety attribute). It allows both the rapid escape from a malfunctioning vehicle and also sufficient altitude so that the parachute-based recovery system will be effective. RUPC is intended for ballistic reentry, water landing, and retrieval by helicopter. Although the nominal splashdowns will be targeted to occur within aircraft range of KSC, abort via return-to-Earth elsewhere is always possible within less than one revolution because of the high availability of alternative sea landing sites along the ground track.

Performance Characteristics

The following capabilities are based upon injection into an 80 by 220 nmi initial orbit at 28.5° inclination by the HR Titan IIS launch vehicle. The RUPC system has the on board capability to circularize, rendezvous, and berth with SSF, and subsequently perform the deorbit burn.

TABLE 3.3.3.13-1.– SYSTEM SUMMARY - RUPC

RUPC Performance Summary and Specifications	
Type	Ballistic capsule
GLOW (Capsule+Adapter)	12,000 lbs
Pressurized volume	**** ft^3
Crew	6 persons
Cargo	1,000 lbs 7 x 4 x 4-ft
Return capacity	same as up
On-orbit time	5 days
On-orbit propulsion	1,080 ft/s
Configuration	Biconic
Size	14.5-ft dia. 15-ft long
Launch vehicle	Titan IIS

Attribute Values

The following are attribute data to be used in evaluating the RUPC system.

a. Funding Profile Summary.– The costs in Table 3.3.3.13-2 are in millions of 1992 dollars and are based on a 20-year program, after appropriate learning curves and quantity rate reductions.

TABLE 3.3.3.13-2.– SYSTEM COST SUMMARY - RUPC

	Cost (1992 MS)
DDT&E	1425
N/R Production	145
Facilities O&C Mods	 3
First flight article	117
Recurring Production Integration and Ops	 66 51
P^3DI	0

* Per unit, assuming replacement of adapter and LES after each launch, and replacement of capsule after seven flights.

Development is assumed to begin phase C/D in FY95, with an IOC of FY00, as shown in Fig. 3.3.3.13-2.

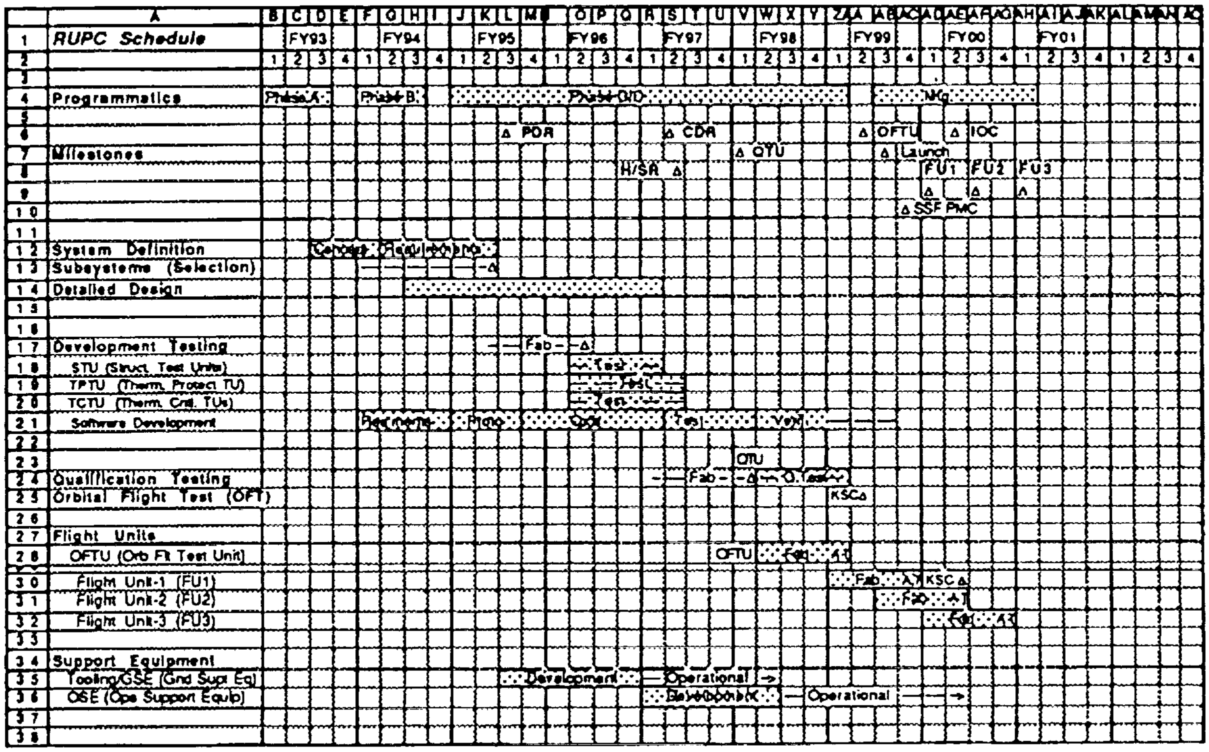


Figure 3.3.3.13-2.– Development schedule.

b. Probability of Mission Success.– The launch vehicle (see Titan family, section 3.3.3.6, HR Titan IIS) contributes approximately two-thirds of the PMS for the system, while the RUPC only contributes the component for orbit circularization to this attribute. However, for the generic assessments made by this study, the unreliability for this OMS is taken to be the same as that for booster propulsion systems, which is overly conservative because of the multiple propellant tanks, valves, and plumbing routes that are embedded in the RUPC design. Because this system must also be used to provide the life-critical function of deorbit, with no other recourse, it is already designed to be of extremely high reliability.

c. Human Safety.– The LES system provides escape from the relatively benign environment of Titan failure modes (hypergolic propellants burning rather than exploding when free together, compared to the possibility of a major explosion of hydrogen or hydrocarbon/LOX launch vehicles). RUPC also has the capability to survive or escape the potential explosion of one of the small strap-on solids, although the hazard risk is small because these solid rockets are the very high reliability monolithic grain configuration, are located 60-ft from the capsule, and sized so that each has a total propellant load only 2 percent of one Space Shuttle SRB. The LES provides uninterrupted escape capability from the launch pad ("0, 0" conditions) through max-Q, solids firings, and second stage ignition – after which it is jettisoned.

d. Architecture Cost Risk.– The RUPC is a new system. However, all subsystems derive from components and/or technologies already developed or currently under development for other flight programs. In addition, the design is compartmentalized so that multiple vendors are available for most subsystems, with the exception of contract integrator. The capsule, LES, and adapter could be supplied by different sources, and integrated at KSC or another appropriate facility. Because of clean interfaces, the lack of system complexity, and the planned retirement of vehicles on a regular basis, this remains the case even for rebuilds. Maintaining the competitive climate is part of the vehicle design philosophy. The ratings of RUPC for Technical Challenge were 8 for non-recurring development, 6 for production, and 3 for operations. The Program Immaturity index was rated as 7.

e. Launch Schedule Confidence.– The RUPC human system utilization includes several phases: flight mission (launch, on orbit operations, deorbit/landing), post-landing recovery, refurbishment, reassembly, fuel and stack, and pad operations, as delineated in Figure 3.3.3.13-3. Also included is a planned contingency phase to provide margin in the processing flow. Post-landing includes the helicopter acquisition of the capsule, transportation to the KSC hazardous processing facility (HPF) to purge RCS propulsion, and then movement to the O&C building. There the capsule is disassembled, then refurbished and tested by multiple teams operating in parallel, with some tasks accomplished on a double-shift schedule. Upon completion of reassembly and functional verification tests, the capsule is transported to a suitable HPF (e.g., SAEF) for mating to the waiting adapter and LES. After fueling the capsule RCS and mate and checkout of the units, the system is transported to the pad for stacking on the log-viewer (LV).

   Up to three flight RUPC's are refurbished in parallel using a single Servicing Stand in the Operations and Checkout Building at KSC. Less than 45 calendar days are required to ready a capsule for next launch. With a fleet of three RUPC systems, allowing for recovery times, adapter plus LES mate, and pad processing, the HR Titan IIS/RUPC could support up to 12 human flights per year.

f. Environment.– The RUPC does not affect the Earth's environment. The Titan-IIS launch vehicle is covered in section 3.3.3.7.

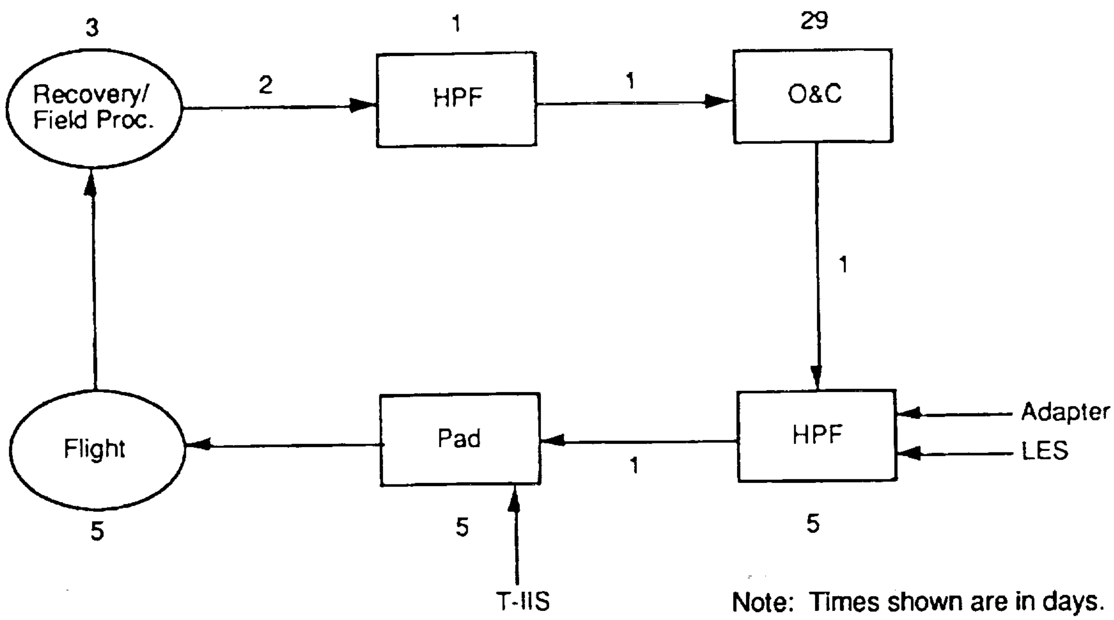


Figure 3.3.3.13-3.– RUPC processing flow.

3.3.3.14 Cargo Return Vehicle (CRV) and Logistics Return Vehicle (LRV) Systems

System Description

a. History.– The original concept of a CRV was developed by NASA/MSFC and General Dynamics Space Systems Division (GDSS) during the STIS. There were three studies performed. The first was for a CRV for Space Station logistics, which began in mid-1989. The driving requirements then included a minimum return capability of one PLM of 40 000 lbs with dry land recovery. This CRV was baselined to operate in concurrence with the Orbital Maneuvering Vehicle (OMV), but could also dock directly to the SSF with appropriate modifications.

   The second study was performed in late 1991. This study incorporated SSF restructuring and focused on design of a CRV that would be carried by a NLS. The result was a cargo delivery and return vehicle that accommodated a 16 klb mini-PLM and was renamed the LRV. With an NLS-1 and CTV available at KSC, three LRV's can be launched together at a time. The third study examined alternative CRV sizes and recovery modes, using previous studies as references.

   The CRV concept selected for this study is the early CRV design (1989) and the LRV concept is from the second study.

b. Configurations.– The CRV system is designed around a 15 by 25 foot cylindrical cargo volume of the PLM. The result is a lifting body configuration with two small aft canards and parafoil recovery system. Access to the payload area is possible through two payload bay doors operating much like those on the Space Shuttle. Figure 3.3.3.14-1 illustrates the CRV configuration.

   Major subsystems of the CRV include its structure, tanks and landing gears, orbital maneuvering and attitude control systems, recovery, avionics, power, and thermal control systems. Total CRV dry weight amounts to just over 34 400 lbs. The CRV is designed for lift-off with 40 000 lbs of payload and landing with about 72 800 lbs of combined CRV and payload weight.

   At almost 80 000 lbs lift-off weight, the CRV and its payload requires a heavy lift booster capacity. For this study the CRV is integrated with the NLS-1 in Architecture 4, and with the MLS-HL in Architectures 5, 6 and 7.

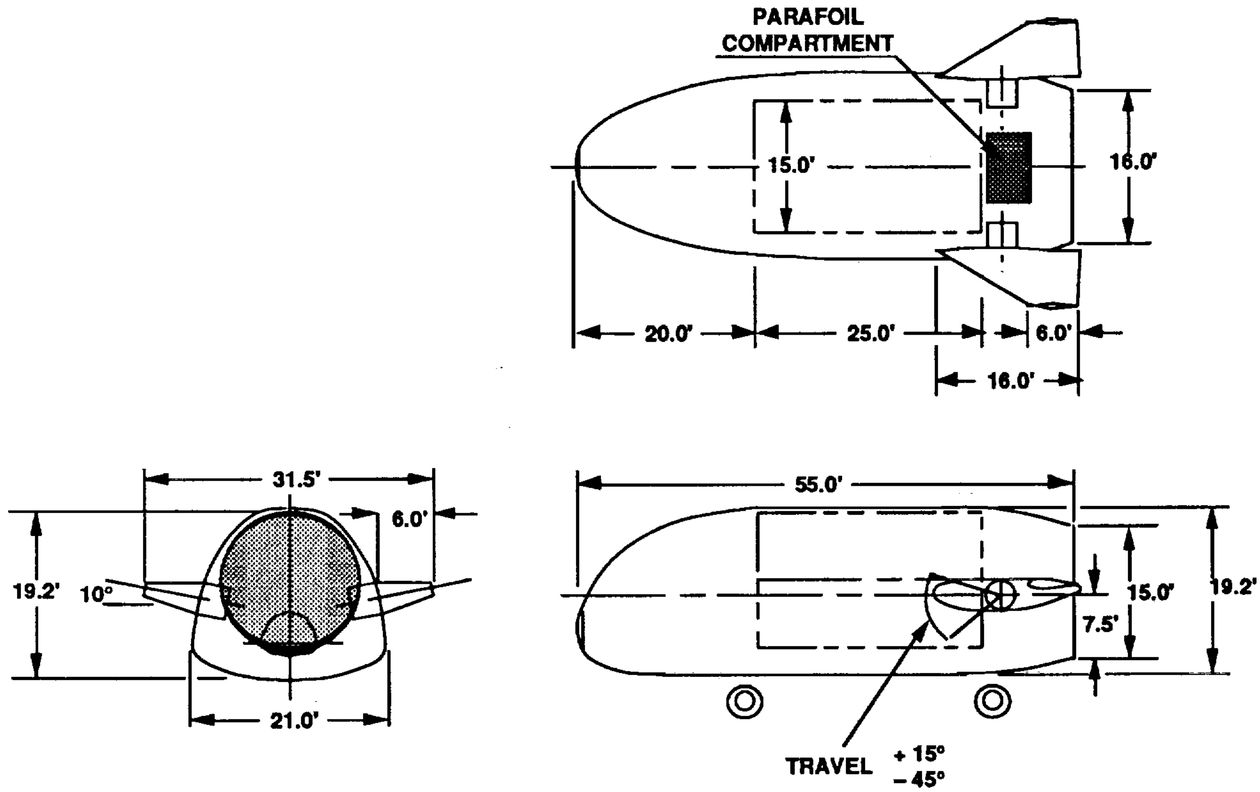


Figure 3.3.3.14-1.– CRV baseline configuration.

The LRV system is designed to deliver and return the Mini-Pressurized Logistics Module (MPLM) of 16 000 lbs. The basic cargo volume is 15 ft in both length and diameter. The system has limited maneuverability and uses a skirt extension in the aft section for trim stability. Access to the payload area is possible through the back of the LRV where the MPLM can be seen exposed. Figure 3.3.3.14-2 illustrates the LRV configuration.

The LRV is also intended to deliver unpressurized logistics carriers, SSF propulsion modules, and returning CTV's. The LRV could be optimized to include an integral PLM, thus reducing some LRV/cargo structural redundancy. Both the current configuration and future derivatives could be designed to remain at the SSF (docked at a node) for the mission duration of its payload.

Major subsystems of the LRV include its structure, orbital maneuvering and attitude control systems, drogue parachute and parafoil recovery systems, and avionics, power, and aeroshield thermal control systems. The total LRV system, including the MPLM, weighs about 31 400 lbs.

For this study, the LRV is integrated with the MLS-HL and RPCmin in Architecture 7, and with the Titan IV/CTF in Architectures 16 and 17.

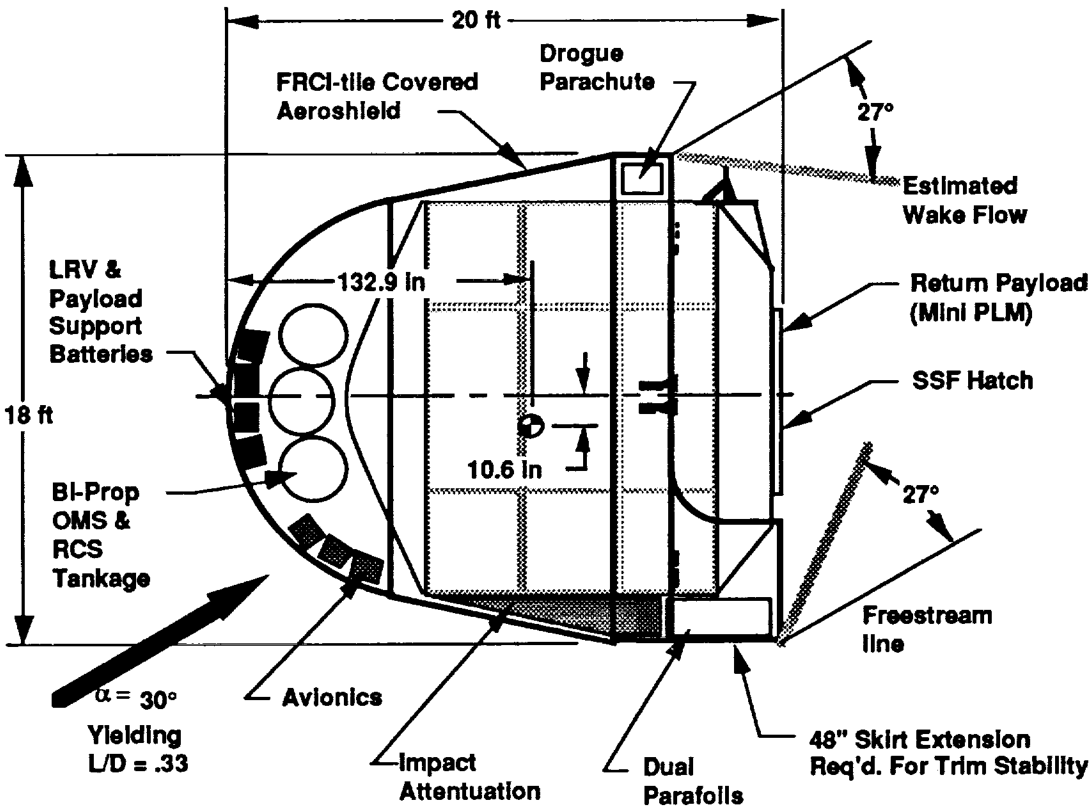


Figure 3.3.3.14-2.– LRV baseline configuration.

c. Facilities.– Since the CRV's main mission will be to support the SSF, the CRV will only operate out of KSC. Regardless of which new booster will be selected to launch it, the CRV will ride as a payload during launch. As such, the CRV-to-booster integration and launch facilities are accounted for as part of the booster system, namely the NLS-1 and MLS-HL. There is only one facility required by and dedicated to the CRV system, the CRV Processing Facility. This is where pre- and post-flight maintenance, system tests, and verifications of the CRV are carried out. In addition, payload installation and removal are also done here.

The LRV system utilizes a decommissioning facility at the landing site in south Texas and a refurbishment and processing facility at the launch site. Integration into the booster occurs in the payload processing facility or vehicle assembly building depending upon the launch system. In this study, the boosters for the LRV are the MLS-HL and the Titan IV/CTF. All launch and mission operations support facilities are shared with those of the boosters.

d. Operational Flow.– Figure 3.3.3.14-3 shows the CRV nominal operations flow at KSC. The facilities called out in this section are generic. Their names describe their functions only, and they are not necessarily associated with any specific launch system.

The CRV will be processed together with its payloads in the CRV Processing Facility. This is where system decommissioning, payload removal (for return missions), and various system maintenance, verifications, and tests are done. The new payload will be integrated into the CRV in this same facility. As this phase is completed, the CRV and its payload will become a single payload from the launch vehicle's perspective. They will then be transported to the Booster Integration Facility (for new launch concepts with integrate-transfer-launch, ITL, philosophy), where integration to the launch booster is performed. The vehicle stack will then be moved to the launch pad for launch.

At the end of its orbital mission the CRV lands at KSC via parafoil. It is then transported to the CRV Processing Facility where the cargo is separated and the ground processing flow is repeated.

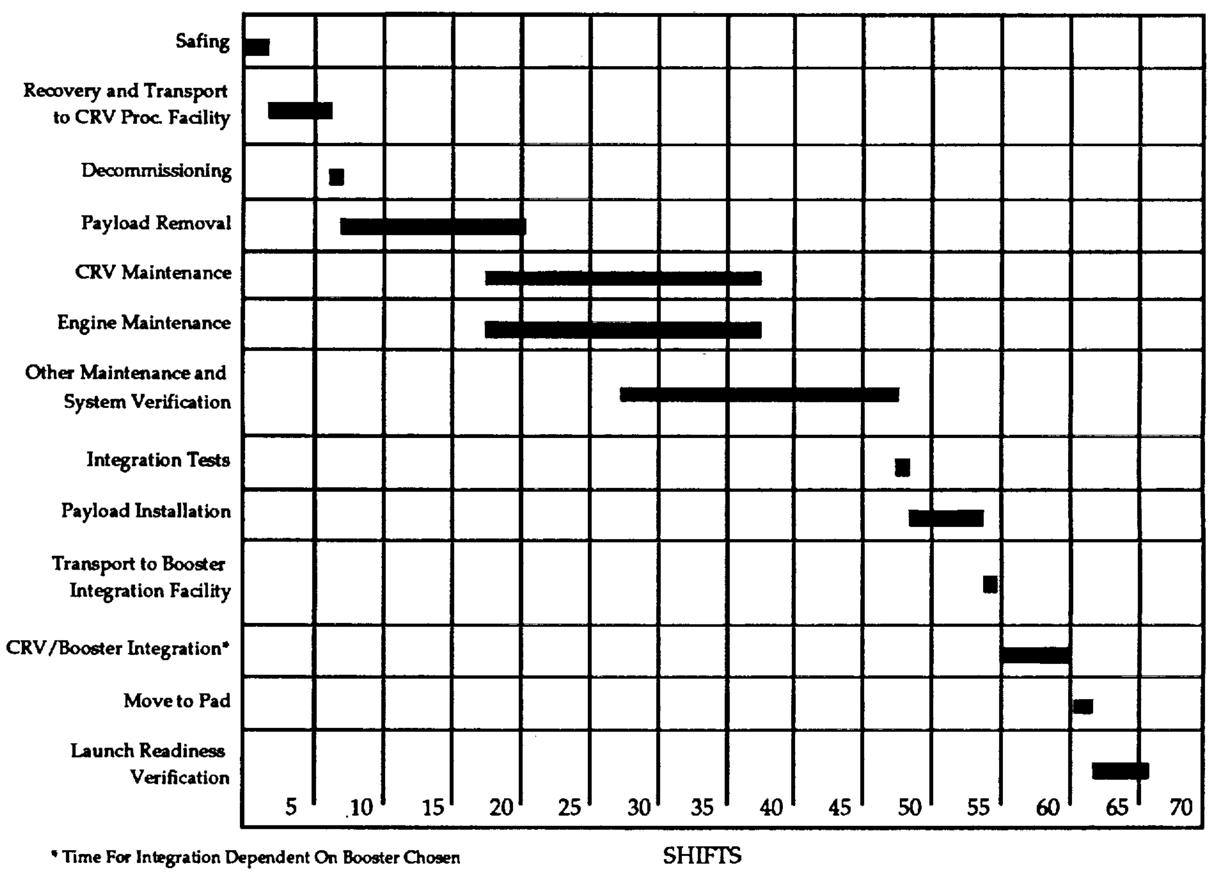


Figure 3.3.3.14-3.– CRV ground-processing flow.

Figure 3.3.3.14-4 shows the LRV nominal operational flow at KSC. The launch vehicle here was assumed to be configured with a main core with ASRM, but any appropriate booster can be substituted with associated launch vehicle processing.

In general, the LRV will be processed together with its payloads (mainly the MPLM) in the refurbishment and processing facility. As this phase is completed, the LRV/cargo will become a single payload from the launch vehicle's perspective. They will then both be transported to the Vehicle Assembly Building (for new launch concepts with integrate-transfer-launch, ITL, and philosophy), where integration to the launch booster is performed. The vehicle stack will then be moved to the launch pad for launch.

For launching on existing systems such as Titan IV, the LRV/MPLM and the CTF system will be mated to the booster on pad in much the same fashion as current Titan IV payloads.

At the end of the orbital mission the LRV lands in south Texas via parafoil. CH-53 helicopters will retrieve the LRV to a facility near the landing site, where the LRV is decommissioned. The cargo is transported on a C-5 to KSC for processing and analysis, while the LRV is ferried to the refurbishment center on a barge via the Intercoastal Waterway. The system is then prepared for its next mission.

<u>Performance Characteristics</u>

The CRV has been designed to deliver and return with 40 000 lbs and at a total landed weight of 72 800 lbs. It can carry approximately 7770 lbs of usable propellant for orbital maneuvering including rendezvous, proximity operations, attitude control, and deorbit burns. Table 3.3.3.14-1 shows the performance and physical characteristics of the CRV and LRV used in this study.

The LRV has been designed to land with 16 000 lbs and at a total landed weight of 29 000 lbs. It can carry approximately 2400 lbs of usable propellant for orbital maneuvering, primarily for attitude control and deorbit burns.

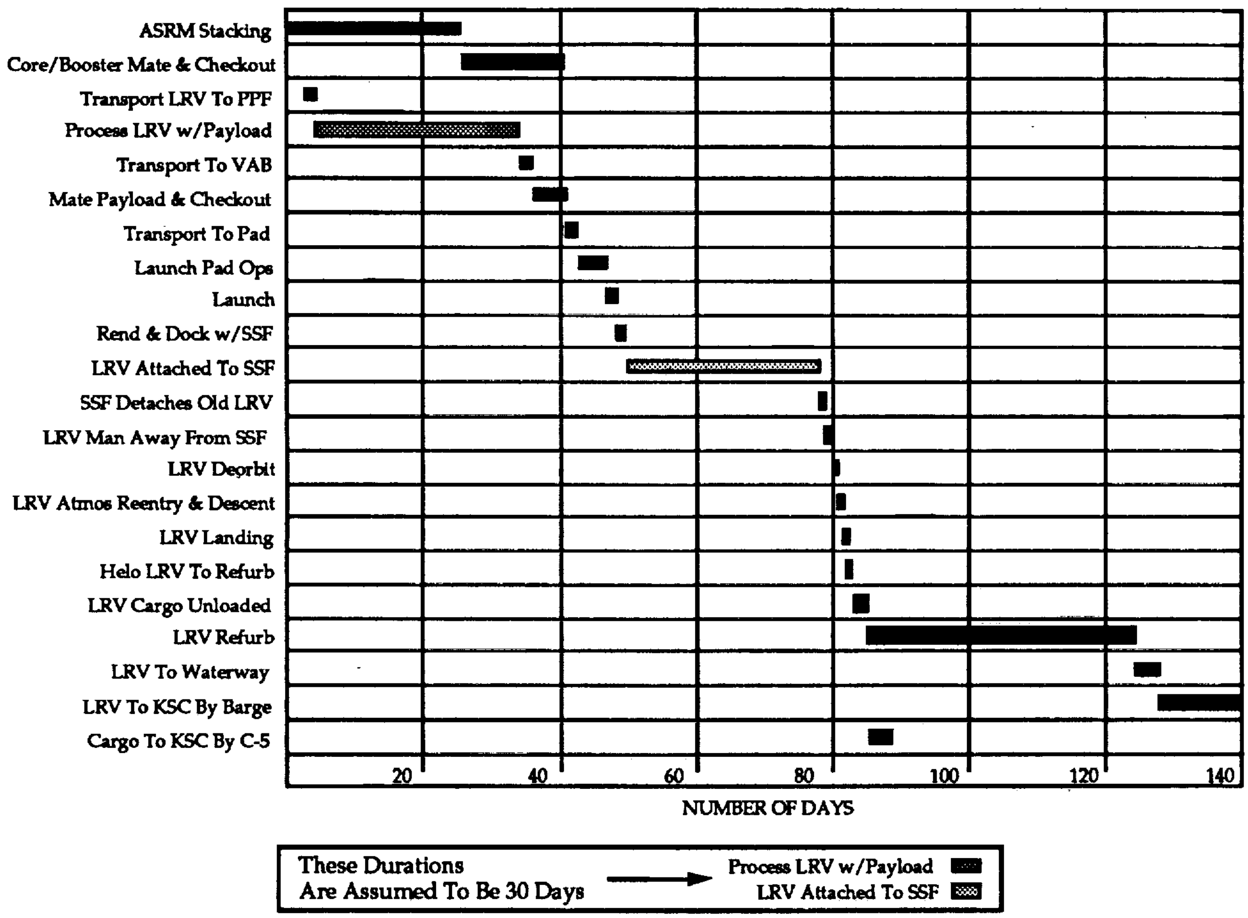


Figure 3.3.3.14-4.– LRV ground-processing flow.

TABLE 3.3.3.14-1.– CRV AND LRV PERFORMANCE CHARACTERISTICS

	CRV	LRV
GLOW (lbs)	82,924	31,400
Press. Volume (ft3)	0	0
Unpress. Volume (ft3)	4418	2651
Cargo Envelope (lxd)	25x15	15x15
Cargo Capacity (lbs):		
220 nmi circ, 28.5°	40,000	16,000
Return Capacity (lbs)	40,000	16,000
Crew Capability (#)	0	0
Launch Site Limits	East Coast	East Coast

Attribute Values

a. Funding Profile Summary.– The development and facility costs for both the CRV and LRV are tabulated in Table 3.3.3.14-2. The LRV landing site facilities are included in the "Other Facilities" category. Cost per flight (CPF) for the two concepts are shown at various flight rates per year in Table 3.3.3.14-3. CPF values are also shown for the CRV/booster and LRV/booster combinations used in the architectures. Total architecture life cycle costs and funding profiles are specific to individual architectures. These can be found in the architecture results sections.

TABLE 3.3.3.14-2.– CRV AND LRV COST ESTIMATES

All Values in $92M	CRV	LRV
DDT&E	1,661	580
N/R Prod	249	193
P3I	0	0
Facilities:		
Processing Facility	10	29
Other Facilities	0	26

TABLE 3.3.3.14-3.– CRV AND LRV COSTS PER FLIGHT

	Flights Per Year					
Costs Per Flight ($92M)	2	4	6	8	10	12
CRV	80.6	41.5	28.3	21.6	17.5	14.8
CRV/NLS-1	248.6	205.5	189.3	179.6	173.5	167.8
CRV/MLS-HL	227.6	188.5	175.3	168.6	163.5	160.8
LRV	69.2	35.4	24.0	18.2	14.8	12.4
LRV/CTF/Titan IV	413.2	310.4	265.0	238.2	219.8	206.4

The CRV development schedule is shown in Figure 3.3.3.14-5. It includes an extensive technology development program for large steerable parafoils, advanced TPS, and autonomous rendezvous and docking capabilities. The major schedule driver is the parafoil technology development which includes several drop tests of an 80 klb recovery system before critical design review (CDR). The CRV development results in an IOC approximately 8 years after start of Phase A.

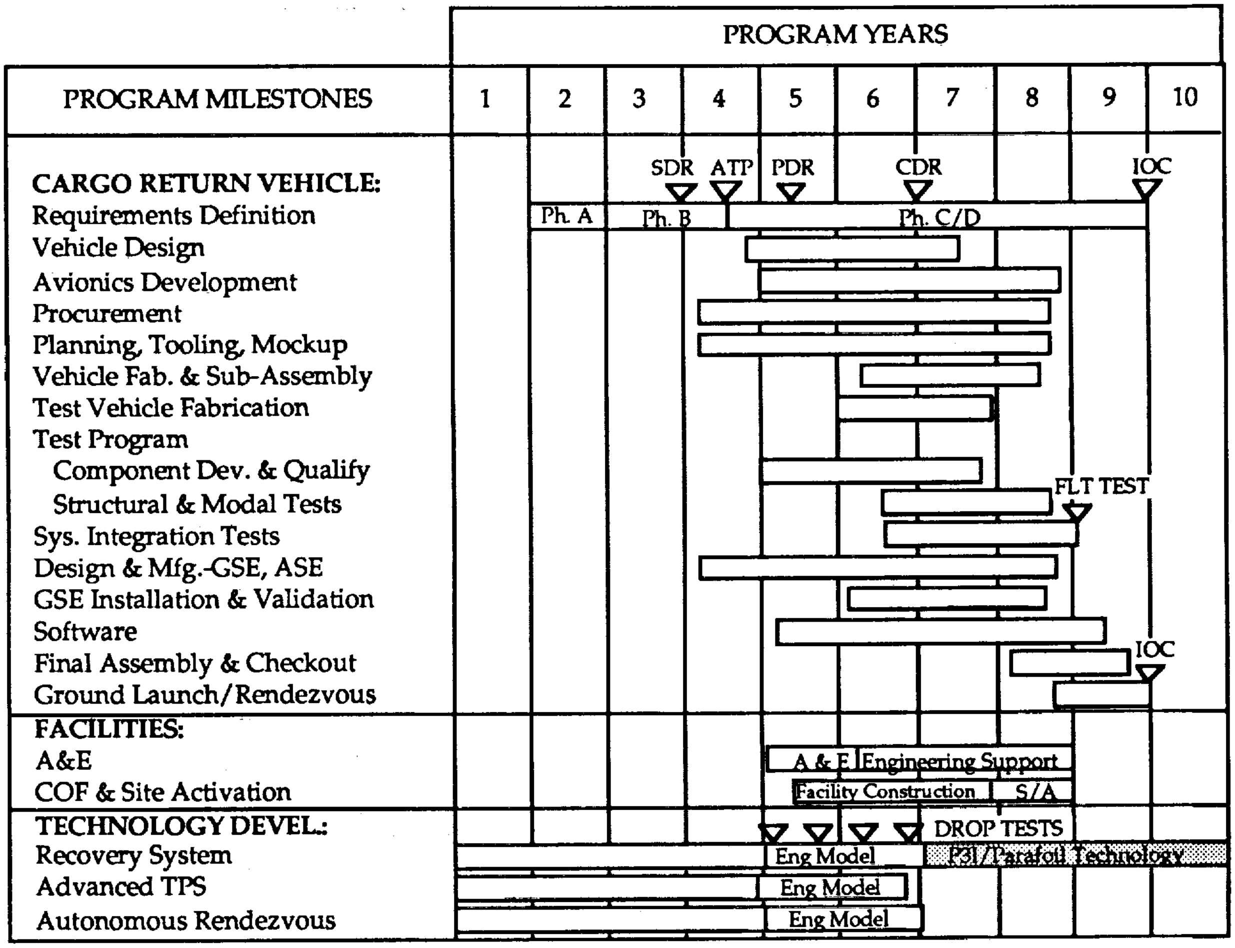


Figure 3.3.3.14-5.– CRV development schedule.

The LRV development schedule is shown in Figure 3.3.3.14-6. The LRV requires less technology development than the CRV because of its smaller size and restricted operational capability. In fact, the technologies are enhancing, not enabling, and there are state-of-the-art fallbacks for all systems. A parafoil recovery system tailored for a 27 klb landed weight is significantly less aggressive than the CRV requirement (80 klb). In addition, the LRV does not perform orbital maneuvering other than attitude control and deorbit. Rendezvous and docking is performed by another system (e.g., cargo transfer vehicle). The LRV has an initial operational capability less than 8 years after Phase A start. The LRV development schedule could be condensed, however, the earliest need date for this study is the year 2000.

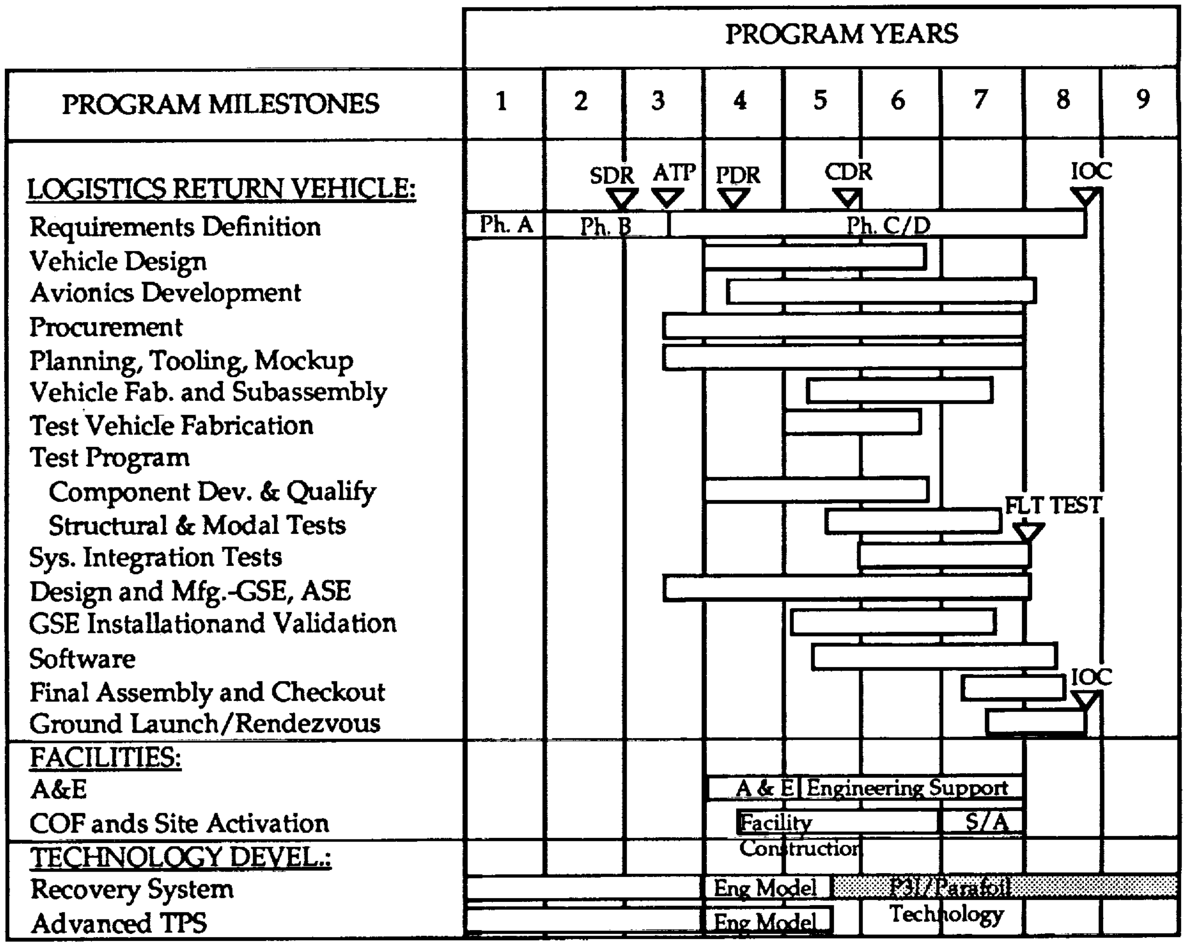


Figure 3.3.3.14-6.– LRV development schedule.

b. Probabilty of Mission Success.– The CRV performs the same function (rendezvous and docking) as a CTV during ascent with a similar orbital maneuvering system, therefore the PMS scores are the same for CRV/NLS-1 and CTV/NLS-1. The LRV is passive throughout the ascent and rendezvous phases and therefore requires a CTF to get to SSF. Further description of how these numbers were derived is included in section 3.2.4.

c. Human Safety.– The CRV and LRV carry only untended cargos in the architectures currently being examined in this study and, therefore, do not have corresponding safety scores.

TABLE 3.3.3.14-4.– PMS FOR CRV AND LRV MISSIONS

System	PMS
CRV:	
CRV/NLS-1	0.9308
CRV/MLS-HL	0.9543
LRV:	
LRV/CTF/Titan IV	0.9307

d. Architecture Cost Risk.– Table 3.3.3.14-5 shows the risk scores for the CRV and LRV. Section 3.2.5 describes the level of risk that these numbers represent. Note that a technical challenge of 5 or less is still within state-of-the-art. However, since there has not been a significant amount of detailed design work on either concept, the program immaturity was ranked high. The booster risk scores are discussed under the specific booster section.

TABLE 3.3.3.14-5.– RISK SUBATTRIBUTE SCORES FOR CRV AND LRV

	Technical Challenge Subattribute			Prgm. Immaturity Subattribute
	Non-Recurring	Production	Operations	
CRV	4	3	3	7
LRV	3	3	2	7

e. Launch Schedule Confidence.– As with ACR, two of the three subattributes for LSC were based on system values or scores. One of these, schedule compression was calculated based on the operations data given earlier in this section. Its value represents the ratio of nominal processing time to the shortest processing time (maximum compression of the critical path). The other, percent of flights with delays, was calculated based upon UMA's for the system (see section 3.2.6). Table 3.3.3.14-6 shows the above two subattribute scores for CRV and LRV. Both of the subattribute values were subsequently used with architecture-particular, flight-rate data to roll up the architecture level values. The schedule margin subattribute score is architecture specific and is described in sections 3.3.5 through 3.3.11.

TABLE 3.3.3.14-6.– LAUNCH SCHEDULE CONFIDENCE SUBATTRIBUTE SCORES FOR CRV AND LRV

Schedule Confidence Attribute	Schedule Compression Subattribute			% Flights With Delay Subasttribute
	Nominal Processing Time (Days)	Compressed Processing Time (Days)	Ratio: Nominal to Compressed	
CRV	42	13	0.310	15.95
LRV	106	33	0.311	5.61

f. Environment.– The CRV and LRV have no significant atmospheric effluents. However the booster used to transport them will contribute to the Environmental attribute scores. NLS-1, MLS-HL, and Titan IV effluents and environment scores are discussed in sections 3.3.3.9, 3.3.3.10, and 3.3.3.7, respectively.

3.3.3.15 Single-Stage-To-Orbit (Vertical Take-Off and Horizontal Landing (VTOHL) Rocket)

System Description

The SSTO-VTOHL is a reusable space transportation system concept studied as part of a DOD contract (Final Report #NA-91-277) by Rockwell International. The concept concluded with VTOHL as the preferred configuration. Design goals of the SSTO-VTOHL are: fail safe operation with engine-out capability during all portions of powered flight; flight crew escape during ascent and entry; simplified vehicle design to allow for 7-day turn around with 350 man-days effort; on-orbit maneuvering velocity change (delta-V) of 600 ft/sec in addition to the reentry delta-V; cabin pressure of 14.7 psia; and launch-rate surge to double the routine launch rate and maintain that rate for 30 days. Two major modifications were made to these goals. The first was to design the SSTO-VTOHL payload bay volume so that it could deliver a large portion of the payloads in its lift capacity. The second was to stipulate that the vehicle must be able to fly in a piloted and unpiloted mode.

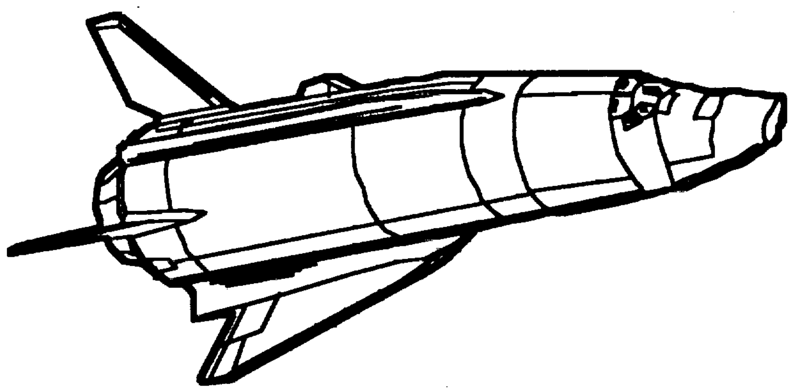


Figure 3.3.3.15-1.– The HTS rocket powered SSTO system is Rockwell's vertical take-off, horizontal landing concept.

Performance Characteristics

The SSTO-VTOHL reusable space transport is designed to launch a crew of two and a payload of 10 000 lbs to polar orbit. In an easterly inclination, payload capacity is 17 700 lbs to the SSF orbit. The 600 fps ΔV provides for delivery and return of the 17 700 lbs to or from SSF. Main propulsion is provided by an aerospike engine with a modular design and the nozzle performance supported by computational fluid dynamics analysis. Thrust vector control is provided by differential throttling and gas injection. Triple-point LOX and LH_2 is required to provide adequate propellant density to meet performance parameters. A standard piloted mission allows for

96 man-hours on orbit with a 96 man-hour contingency. SSTO-VTOHL's payload volume is 3000 cubic feet, it has a maximum cross-range of 1150 nmi, and an approximate landing speed of 180 kts resulting in a roll out of 5900 ft after touchdown.

TABLE 3.3.3.15-1.– SSTO-VTOHL PERFORMANCE CHARACTERISTICS

Inclination (deg)	Apogee X Perigee (nmi)	Payload (klbs)
28.5	160 x 160	17.1
28.5	220 x 220	15.0
90.0	100 x 100	10.0

a. Abort Modes.– The SSTO-VTOHL has a built-in, robust abort capability. It has engine-out capability from lift off. Selected vehicle crossrange allows abort once-around with return to the launch site for all inclinations. Abort modes and their limitations are:

- RTLS – Available during launch when ΔV is less than 10 900 fps.
- AOA – Opportunities are available much earlier than the last RTLS option. Vehicle has a 1050 nmi cross range required to support AOA for polar launches.
- ATO – With full lift-off-thrust capability available throughout the flight phase, SSTO-VTOHL can perform ATO over a large portion of the flight phase.

b. Operational Facilities.– SSTO-VTOHL has five main facilities: Launch Pad, Landing Site, Vehicle Maintenance Facility (VMF), LCC, CPF, and GSE Maintenance Facility. The VMF provides adequate space for performing between-flight maintenance on four operational vehicles and has three unique maintenance cells: a vehicle maintenance cell (VMC), a logistics support cell, and a vehicle isolation cell (VIC). Specialized work areas for pre- and post-flight maintenance as well as cargo module loading are performed in the VIC. Spare parts are stored in and distributed from the logistics support cell. Any "all clear" maintenance or hazardous operations are performed in the VIC, allowing normal processing of other vehicles to continue unabated. An operations flow schematic is shown in Figure 3.3.3.15-2. SSTO-VTOHL's IOC for the HTS is in 2000 to reflect the early goals of this program.

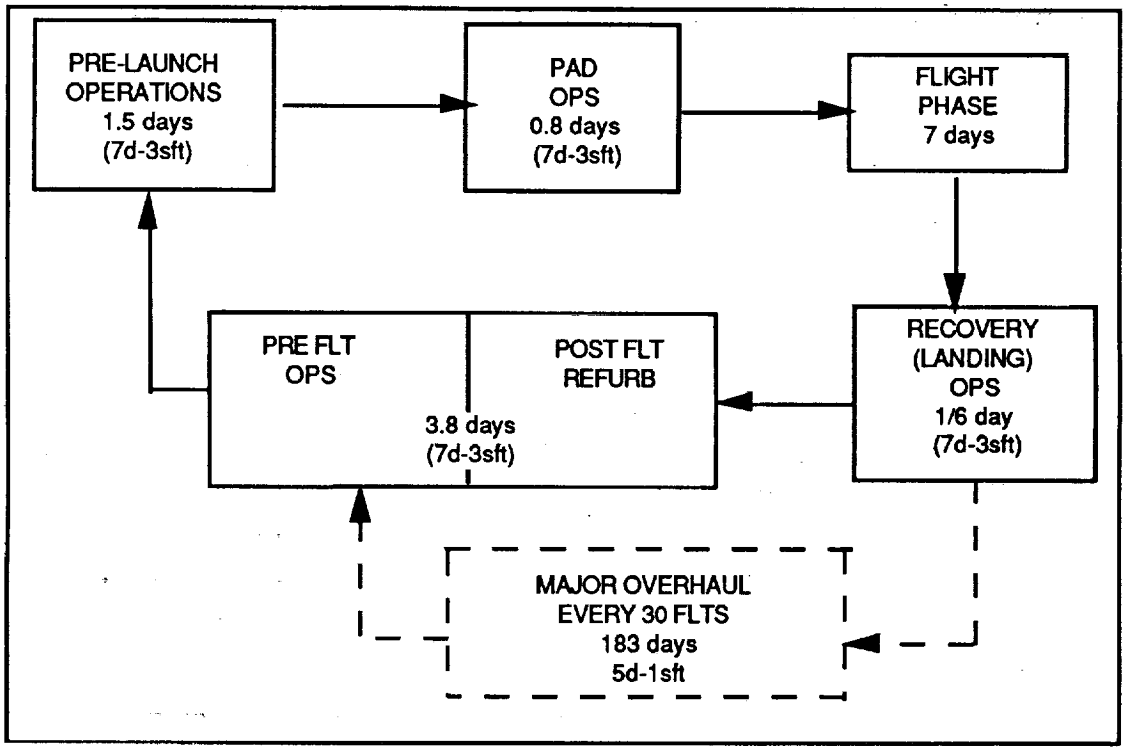


Figure 3.3.3.15-2.– SSTO-VTOHL operations flow schematic.

Attribute Values.

System input data related to each attribute, as well as system-specific attribute values are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level.

a. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. The SSTO-VTOHL does offer ejection seats for flight crew escape during ascent and descent operations. In addition, several abort options (described earlier) exist and can be used in the event of a non-catastrophic engine failure. They are: RTLS, AOA, and ATO. If an ATO is executed, it is possible that the mission will be a success. Another salient feature is that the crew module is in the same element as the liquid engines and main propellant tanks.

b. Funding Profile.– Cost information provided to the HTS included the cost of new facilities, new vehicles, variable and fixed costs per flight for each flight element, and launch and flight operations. In addition, spread factors for each cost item were provided, identifying how much of the total cost was spent in the years preceeding the need or flight date. Table 3.3.3.15-2 presents a summary of this data.

TABLE 3.3.3.15-2.– SSTO-VTOHL FUNDING PROFILE INPUT DATA

COST BREAKDOWN CATEGORIES	TOTAL OR TFU COST ($M)	LEARN-ING CURVE (%)	RATE CURVE (%)	COST PER FLT ($M)	COST PER YEAR ($M)	Y -5 (%)	Y -4 (%)	Y -3 (%)	Y -2 (%)	Y -1 (%)	FLTI OC YR (%)
NON-RECURRING											
RDT&E	2705					15	22	28	25	10	
PRODUCTION	0										
P3I	13.5/YR										
FACILITIES	630						25	30	30	15	
RECURRING											
NEW											
VEHICLE (new)	579	100	100					15	55	25	5
PLUG NOZZLE ENG (new)	74	90	90						10	85	5
FLIGHT TO FLIGHT											
REFURBISHMENT				1.4	115.0						100
LAUNCH OPERATIONS				0.5	92.4						100
FLIGHT OPERATIONS				0.1	25.9						100
PROG MGMNT				0.0	35.2						100

c. Probability of Mission Success.– A system description and flight profile contains the required input information for this attribute. In summary, the SSTO-VTOHL has one liquid propulsion stage, 14 liquid engine modules (with engine-out capability from lift off).

d. Architecture Cost Risk.– Two of three subordinate attribute values for ACR are Technical Challenge and Program Immaturity. The NIT placed SSTO-VTOHL at a scale rating of 9 (Non-recurring), 6 (Production) and 9 (Operations) for Technical Challenge and an 8 for Program Immaturity, resulting in a value of 59.9, 12.9, and 59.9, respectively, for Technical Challenge in "If" C, and a 35.9 for Program Immaturity (see section 3.2.5). The third component, Number of New Systems, is an architecture-level value; SSTO-VTOHL's contribution to this parameter is 1.

e. Launch Schedule Confidence.– As in ACR, there are three subordinate attribute values for LSC: Schedule Compression, Schedule Margin, and Delays (due to unscheduled maintenance activities). Schedule Compression and Delays are architecture independent, while Schedule Margin is architecture dependent since its values are a function of annual flight rates and available facilities and Orbiters. SSTO-VTOHL's Schedule Compression values are nominal cycle time

– 13.3 days, compressed cycle time – 13.3 days, and compression ratio – 1.0. It is estimated that SSTO-VTOHL will experience delays in 9.7 percent of its launch attempts.

f. Environmental Impact.– The SSTO-VTOHL uses liquid hydrogen and liquid oxygen as its only propellants. Its propellant load includes oxygen – 832.029 klbm, and hydrogen – 139.671 klbm. Using the given propellant weights, major effluent constituents were determined and are shown in Table 3.3.3.15-3. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.15-3.– EFFLUENT DATA FOR SSTO-VTOHL

Exhaust Product	Space Shuttle (klbm)
CO	0.0
CO_2	0.0
H2	32.8
H2O	918.5
HCl	0.0
N_2	0.0
OH	0.0
H	0.0
Al_2O_3	0.0

3.3.3.16 National-Aerospace-Plane-Derived Vehicle (NDV)

The NDV is an air breathing SSTO vehicle that takes off and lands horizontally (Figure 3.3.3.16-1). Its hydrogen-fueled engines accelerate it from the standstill through hypersonic speeds to orbital velocities. As its name implies, NDV makes full use of technologies developed in the NASP program. Its current design requirements include commercial runway (12 000 ft) take off and landing (not necessarily the one from which it left); acceleration to orbital velocity in the atmosphere; coast-to-orbit apogee; orbit circularization with a reaction control system; and payload deployment, recovery, servicing, and/or repair. Standard mission length is 24 hours or less, but can be extended to 72 hours with kits. The NDV's design reference mission is either delivery of 10 000 lb payload to or from a 100 nm circular orbit at an inclination of 90°, or delivery and return of 20 klbs to and from SSF (220 nm circular at 28°) from KSC. With its unique ascent cross range, the NDV can deliver approximately the same payload to a 0° inclined orbit as it can to a 90° one from a mid-latitude operational base. Extensive ascent and decent cross range greatly facilitates operational flexibility, extends the launch widow, and enables a full-envelope-abort capability. Payload capacity as a function of inclination and altitude is presented in Table 3.3.3.16-1.

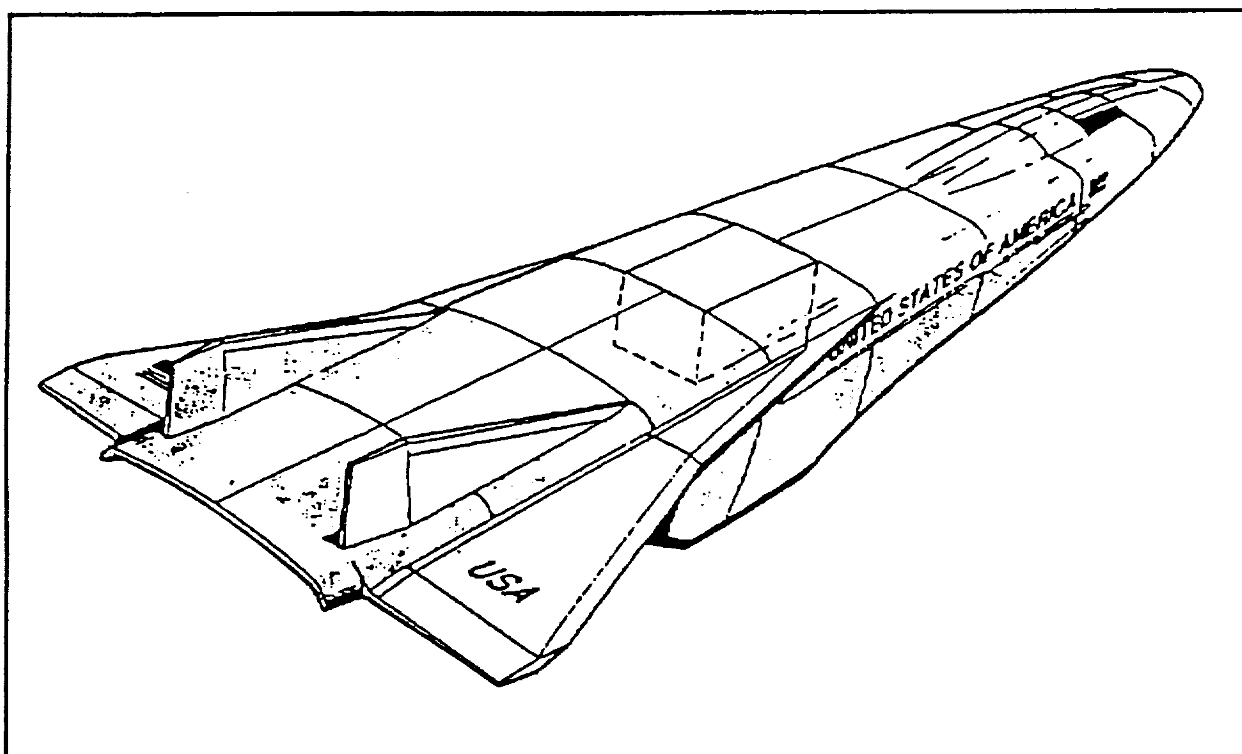


Figure 3.3.3.16-1.– Representative NDV concept.

TABLE 3.3.3.16-1.– NDV PERFORMANCE CHARACTERISTICS

Inclination (deg)	Apogee x Perigee (nmi)	Payload (klbs)	Comments
28.5	100 x 100	26.5	
28.5	150 x 150	25.5	
28.5	200 x 200	23.5	
28.5	250 x 250	20.5	
28.5	262 x 262	18.2	SSF Direct Access
28.5	300 x 300	17.5	
57.0	180 x 180	18.0	
57.0	324 x 324	9.5	
90.0	100 x 100	10.0	Design Point
90.0	150 x 150	9.0	
98.7	300 x 300	1.0	Goes to zero at 340 nmi

Designed for reliable, low cost, "airplane-like" operations, the NDV can be quickly turned around for frequent flights. Designed-in supportability, extensive built-in diagnostics, 200 man-hours per mission scheduled maintenance, and simplified loading and unloading of containerized payloads in less than 4 hours enable routine flight-to-flight process times of less than 3 days. The payload containerization concept uses standard interfaces between the container and the vehicle for flexible operations and versatility. Payload integration flexibilty is maintained by the internal design of the container. Standard payload services provided by the vehicle can be augmented with a wide range of kits that can be installed in the container. The weight of the standard container and services are charged against the vehicle, while the weight of additional special services and kits is charged against the payload. Integration of the payload into the container is performed off-line and is never permitted to delay the vehicle. Also, since the vehicle flight characteristics are designed to accommodate a payload center-of-gravity located anywhere within a volume concentric to the container envelope, with dimensions aproximately 50 percent of the container, they can be rapidly switched to fly on another vehicle in the advent of a problem with the originally scheduled vehicle. Loading the payload into the vehicle can be handled in a clean room environment and the payload operators can have access until shortly before launch, although last minute access is not encouraged.

a. Mission Abort Options.– The NDV has two basic abort options during the air-breathing portion of its trajectory – return to any runway with adequate length or crew module separation. Due to the nature of the NDV propulsion system, failures resulting in significant vehicle damage are considered to be remote. This feature, coupled with the engine design, which has eight air passageways support by four feed systems, enables the NDV to continue flight under diminished power, enabling it to reach any of several airports within its range. The loss of a propellant feed system or air passageway basically eliminates its ability to achieve orbit. In the event that serious vehicle damage has occurred, which may lead to loss of the vehicle, the crew module can be jettisoned. This option is available to the crew throughout the NDV mission profile.

Following shutdown of its air-breathing engines, the NDV requires two rocket burns to achieve orbit. The first burn inserts the vehicle into a transfer orbit and the second is the circularization burn in its destination orbit. Engine-out capability is not available during the first burn but is an option for the circularization maneuver. It is assumed that the NDV OMS system consists of two engines, does not have a dual OMS tank system, and therefore does not have cross-feed. These assumptions were made due to the unavailability of OMS schematics.

b. Operational Facilities.– An overview of a typical NDV operations site is shown in Figure 3.3.3.16-2. Operational facilities include a 12 kft normal runway, a cryogenic hydrogen or oxygen propellant loading station, a fuel conditioning plant to produce densified, or slush, hydrogen (SH_2), a maintenance building, a payload loading and unloading facility, and a mission planning center.

c. NDV Attribute Data.– System input data related to each attribute, as well as system specific attribute values, are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level. These will be discussed following the presentation of the NDV system data.

(1) Human Safety. Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. The NDV's air-breathing propulsion system, discussed above under Mission Abort Options, provides the capability to return to any capable airport under powered flight for most propulsion failures. For situations resulting in significant vehicle damage or loss of control, the crew module can be separated from the main body of the NDV. This protects the crew until the module is returned to an altitude and velocity at which the crew can safely eject from the module for parachute recovery. Other salient features include having the crew module at the forward end of the vehicle, ahead of the main hydrogen tank, and having limited oxygen on board for OMS and RCS engine operation. Probable crew loss events by mission phase are presented as part of the "PMS" discussion.

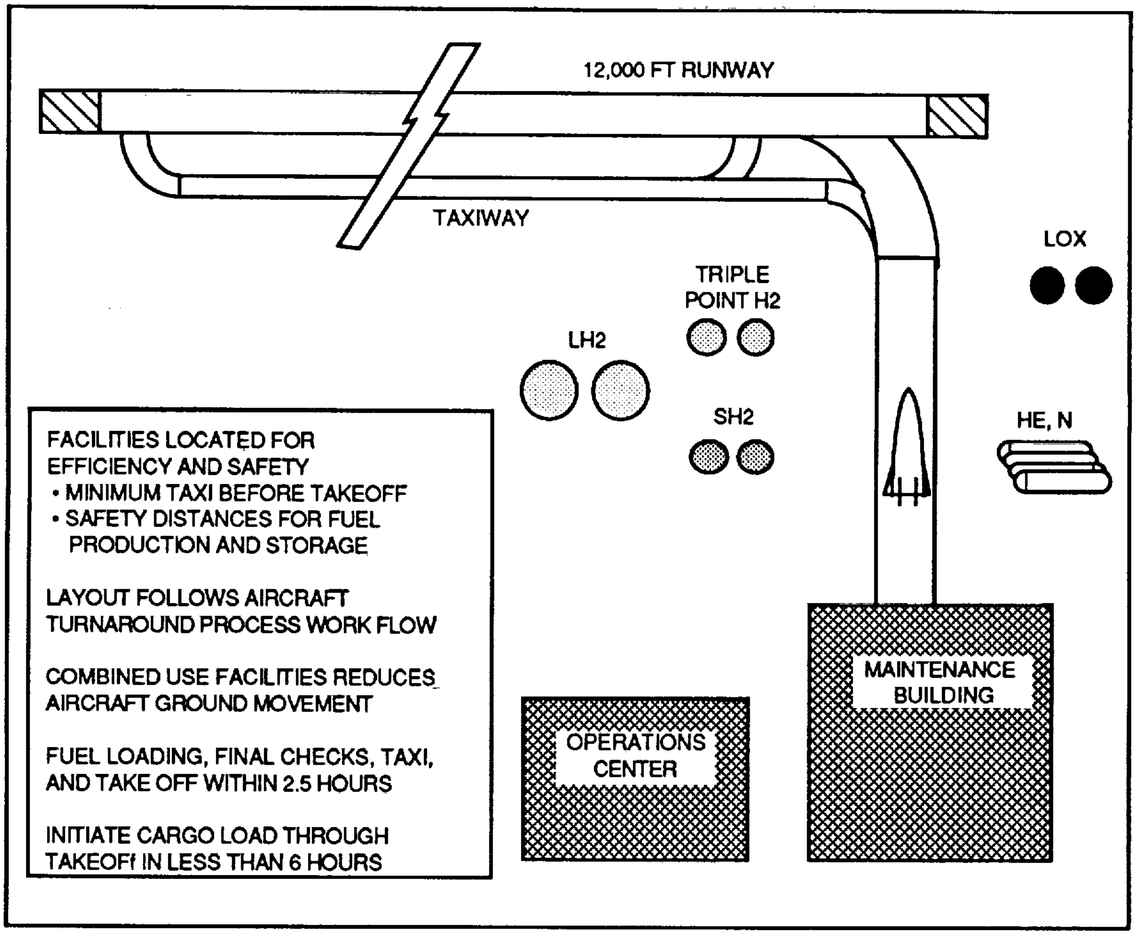


Figure 3.3.3.16-2.– NDV fixed-base-of-operations concept overview.

(2) Funding Profile. This information is from the NDV Operations and Supportability Assessment completed by General Dynamics' Fort Worth Division and presented as Task H8 Final Review on May 16, 1991. The baseline total cost to bring NDV to operational status is $16.7 B in 1986 dollars. This is further defined as $8.9 B86 for DDT&E, $5.4 B86 for procurement, and $2.5 B86 for Operations and Support. Its average cost per flight for a 4-vehicle fleet flying 24 flights-per-year, based on a "Shuttle Down" analysis, is predicted to be $14 M86. Based on discussions between Dan Eimers of the GDSS Division in San Diego and Dr. Toten of their Fort Worth Division, values for the HTS cost input sheet were developed from existing program information. These are presented in Table 3.3.3.16-2. It should be noted that since NDV is a fully reusable vehicle with airline-like operations, all per-flight costs are expended in the year of the flight.

TABLE 3.3.3.16-2.– NDV ACQUISITION FUNDING PROFILE INPUT DATA

NDV Cost Breakdown	Total Or TFU Cost ($M92)	Y-7 (%)	Y-6 (%)	Y-5 (%)	Y-4 (%)	Y-3 (%)	Y-2 (%)	Y-1 (%)	IOC Yr (%)
Non-Rrecurring									
RDT&E	12517	8	16	23	20	16	10	7	
Production									
P3I (Annual After IOC)									
Facilities									
Development	243	8	16	22	20	16	10	6	2
Production	120	8	16	22	20	16	10	6	2
Operational	120	8	16	22	20	16	10	6	2
Recurring	Unit Cost	LC (%)	RC (%)		Y-4 (%)	Y-3 (%)	Y-2 (%)	Y-1 (%)	
Protoflight #1	1120	100	100		15	55	25	5	
Protoflight #2	1030	100	100		15	55	25	5	
Flight Unit #1	2191	100	100			38	58	14	
Flight Unit #2	1961	100	100			38	58	14	
				VAR CPF	Fixed CPY				Yr Of Flight
Launch/Flight OPS				7	186				

(3) Probability of Mission Success. The mission success tree and propulsion systems descriptions are required to quantify the NDV PMS. Referring to Figure 3.3.3.16-3, the NDV ascent trajectory has been divided into six

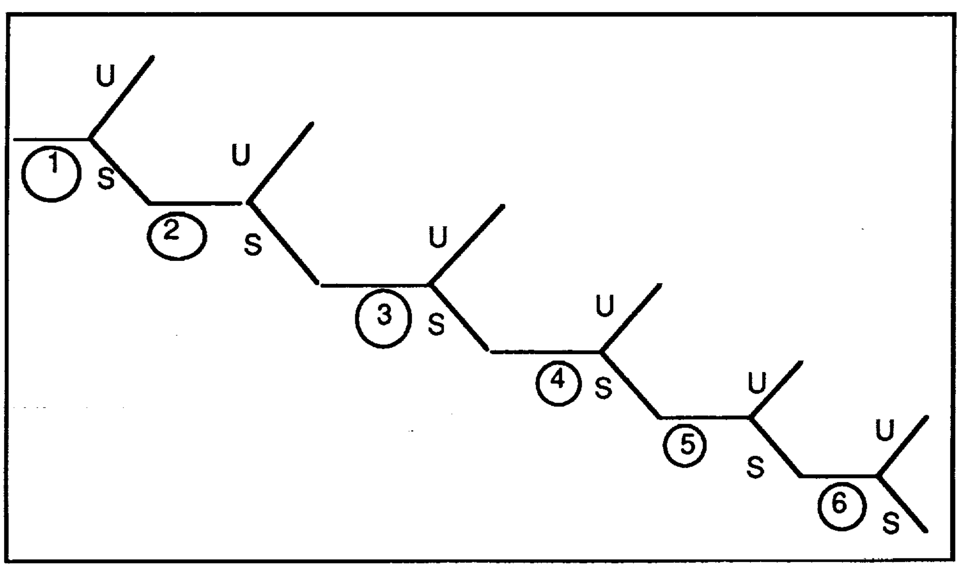


Figure 3.3.3.16-3.– NDV mission success tree.

distinct flight phases, (1) rollout up to ramjet mode, (2) ramjet mode, (3) scramjet mode through engine cutoff, (4) orbit insertion, (5) coast, and (6) orbit circularization. During the first three ascent phases, propulsion is provided by the air-breathing engines, which consist of eight flow paths supported by four propellant pumps drawing from one propellant tank. For purposes of our PMS process, the NDV has four air-breathing engines and one liquid propulsion stage for the OMS/RCS system. Since all engines are required for the NDV to achieve flight conditions necessary for the OMS/RCS to successfully provide orbit insertion and circularization maneuvers, the air-breathing portion of the NDV ascent profile does not have engine-out capability.

Without benefit of an OMS/RCS schematic or description, the NDV is assumed to have a two-engine system with a single set of tanks and feed system. Both engines are required for the insertion burn while only one is required to circularize. Based on this information, the equations defining NDV PMS are as follows:

Flight Phases 1 - 3

$$R_{P1\text{-}3} = (R_{a/b}{}^{4})^{(1/3)} \bullet R_a{}^{(1/6)}$$

Flight Phase 4

$$R_{P4} = (R_{oms}{}^{2}) \bullet R_s \bullet R_a{}^{(1/6)}$$

Flight Phase 5

$$R_{P5} = R_a{}^{(1/6)}$$

Flight Phase 6

$$R_{P6} = [(R_{oms}{}^{2}) + 2 \bullet (1 - R_{oms}) \bullet R_{oms}] \bullet R_s \bullet R_a{}^{(1/6)},$$

where $R_{a/b}$ is the air-breathing NDV engine reliability, R_s is the NDV air-breathing and OMS engine propulsion stage reliability, R_a is the avionics reliability, and R_{oms} is the OMS engine reliability. Values for these terms and for the NDV, both by phase and cumulative through the ascent trajectory, are found in Table 3.3.3.16-3. The values in this table are somewhat higher than those used in the AET and in determining the probability of crew loss, due to an error in the exponent for R_a in equations 1 through 4, above. Results used in the AET are based on R_a having an exponent of 1 to 5, rather than 1 to 6. This error caused the final PMS value to be 0.96458 versus the 0.964595 shown below, resulting in a 0.00650691 probable crew loss as opposed to 0.006583 shown in Table 3.3.3.16-3. These changes, plus a possible data-entry error in the crew loss rate in Phase 6 (0.071 vs. 0.0763), gives an estimated number of flights between crew loss events of 153.7 versus the 151.9 in Table 3.3.3.16-3, or an error of approximately 1 percent.

(4) Architecture Cost Risk. ACR is composed of three distinct subattribute values: Technical Challenge, Program Immaturity, and Number of New Systems. NDV's Technical Challenge attribute values are 10 for the non-recurring aspects, 10 for the production phase, and 9 during operations (based on the HTS NIT range of 7-10). Its Program Immaturity level is thought to be 10. Finally, it counts as one new system within an architecture.

TABLE 3.3.3.16-3.– NDV PMS DATA

NDV Reliability Values	$R_{a/b}$ 0.9999	R_s 0.9847	R_a 0.9999	R_{oms} 0.9977		
NDV PMS	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
By Phase	0.999850	0.999850	0.999850	0.980159	0.999983	0.984678
Cumulative	0.999850	0.999700	0.999550	0.979718	0.979604	0.964595
Probable Crew Losses						
By Phase	0.000019	0.000025	0.000025	0.005343	0.000001	0.001169
Cumulative	0.000019	0.000044	0.000069	0.005411	0.005421	0.006583

(5) Launch Schedule Confidence. This attribute is also a combination of three subattributes: Schedule Margin, Schedule Compression, and Percentage of Flight Delays. Schedule Compression and Percentage of Flight Delays are system-dependent, while Schedule Margin is architecture-dependent. Since NDV operations are based on 7-day, 3-shift weeks, the nominal and compressed times are equal. The estimated number of Percentage of Flight Delays for NDV is 10.44.

(6) Environmental Impact. The NDV uses hydrogen as its ascent propellant, drawing in atmsopheric gases to provide oxygen for the combustion process. In reality, this will probably produce nitrogen oxides and other trace products in the exhaust stream, in addition to water vapor. However, due to the uncertainty of the engine concept and its true combustion characteristics, the HTS has opted to address only the impact of NDV's dominant exhaust product – water. The amount of exhaust product is determined by the vehicle propellant load. Specific design details such as inert weight, propellant load, and engine schematics are restricted access data. For evaluation purposes, the estimated hydrogen quantities on board the NDV are approximately 800 klbs. Based on a mixture ratio of 6 to 1 (oxygen to hydrogen), and equilibrium combustion, the exhaust products consist of 5406.8 klbs of water and 193.2 klbs of hydrogen.

3.3.3.17 Advanced Manned Launch System (AMLS)

System Description

The AMLS (Figure 3.3.3.17-1) configuration and operational concept is a two-stage, fully reusable, launch vehicle defined by Langley Research Center and studied under contract by Rockwell International, Downey, CA. The AMLS has its first flight in 2005 and is expected to fully replace Space Shuttle by 2010. The AMLS is comprised of three major elements: an untended reusable booster, a personnel reusable orbiter, and the Payload Containment System (PCS). The booster and orbiter are fueled with Liquid Oxygen(LO_2)/Liquid Hydrogen (LH_2) propellants. All SSME-derivative engines on the orbiter and booster are ignited on the ground prior to lift off, with propellant transferred to the orbiter from the booster during first-stage operation. After separation, the booster returns to the launch site for horizontal landing while the orbiter with attached PCS continues on to the SSF or on-orbit mission. After its mission is complete, the orbiter returns to the launch site for horizontal landing.

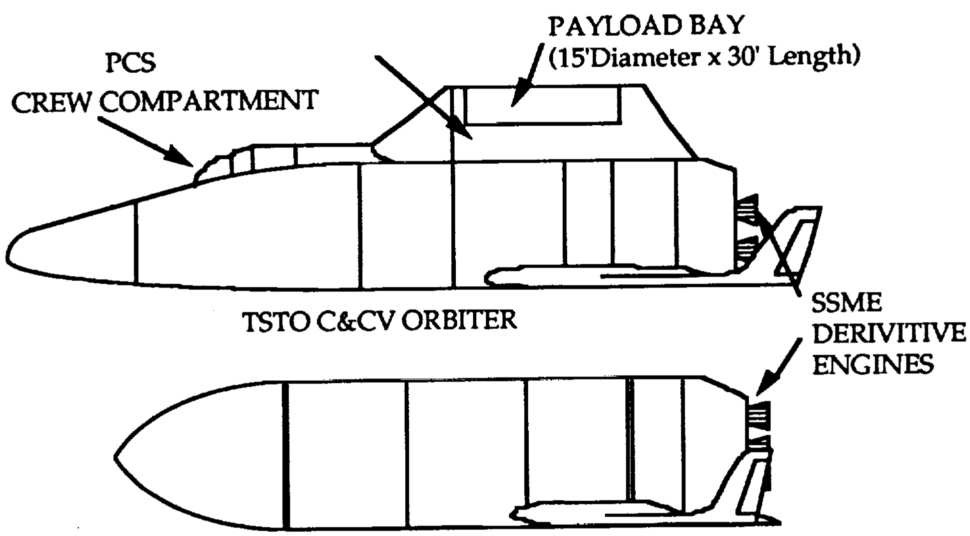


Figure 3.3.3.17-1.– AMLS configuration.

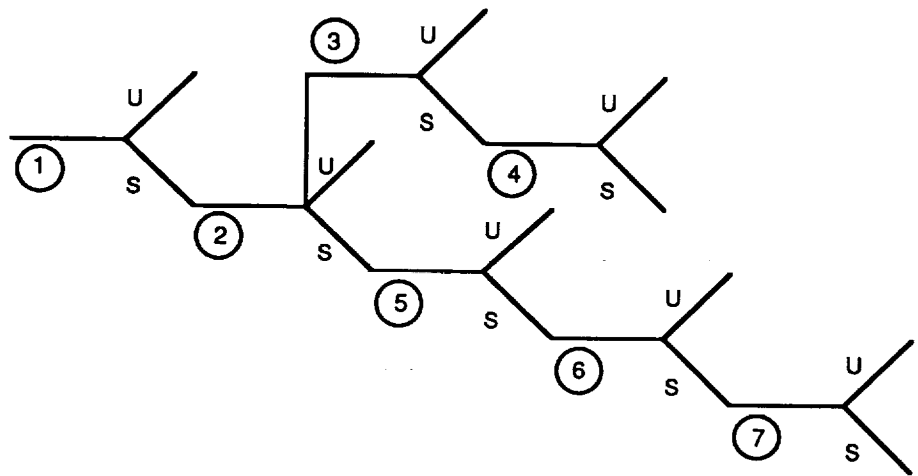
Performance Characteristics

The design reference mission is to provide cargo transport of 40 k payload/logistics and to provide crew rotation of 10 personnel (2 flight crew and 8 passengers) to the SSF (220 nmi at 28° inclination). Additional capabilities allow it to support on-orbit servicing and repair missions.

Attribute Values

a. Funding Profile.– No information supplied at this time.

b. Probability of Mission Success.– The AMLS has two liquid propulsion stages and five liquid engines, per stage, with engine-out capability, per the abort descriptions. The success tree is shown in Figure 3.3.3.17-2. Table 3.3.3.17-1 illustrates the mission success probability by phase.



	Phase	Comments
1	Stage 1 and 2 Ignition	Five SSMEs per vehicle – parallel burn – one engine out in booster, orbiter, or both
2	Stage 1 and 2 Burn	Engine out in each vehicle from lift off
3	Staging	Vehicle separation
4	Booster Return to Launch Site	Dead stick return
5	Stage 2 Burn Phase	Engine out from separation, if no previous failure
6	Coast-to-Launch Apogee	
7	Orbit Circularization	Two OMS engines, one can do job – dual tanks with cross-feed

Figure 3.3.3.17-2.– AMLS success tree.

TABLE 3.3.3.17-1.– AMLS MISSION FAILURES PER 100 MISSIONS

Phase	Losses Per 100 Missions
Stage 1 and 2 Ignition	0.6442
Stage 1 and 2 Burn	0.6442
Staging	0.0117
Stage 2 Burn Phase	0.2592
Coast-to-Launch Apogee	0.0117
Orbit Circularization	0.0117
Total Per 100 Missions	1.56

c. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew and passengers to detach or escape from the main body of the AMLS orbiter during ascent or descent in the event of a mission failure. The crew and passengers may escape from the AMLS by jettisoning the crew module from the main body of the AMLS orbiter. This action may be performed from the time the duct system on the access tower at the pad is no longer available to any time throughout the mission (except for a small portion of the return trajectory). Additional AMLS orbiter abort modes are available as described below:

- Return to Launch Site (RTLS) – An RTLS would be performed for failures occurring between liftoff and the point at which the AMLS orbiter can no longer return to the launch site. An RTLS would be performed by jettisoning the PCS (if required), after which the AMLS orbiter would land at the SLF. During this time period, crew and passenger escape may also be performed by jettisoning the crew module and destroying the AMLS orbiter.

- Trans-Atlantic Abort (TAA) – A TAA may be performed after the point in time when an RTLS is no longer possible. The PCS is jettisoned from the AMLS orbiter and the AMLS orbiter lands at an alternate landing site.

- Abort-to-Orbit (ATO) – An ATO may be performed if it is determined that the AMLS orbiter can safely continue its mission. No jettisoning of the crew module would be performed.

Probability of crew loss events (Table 3.3.3.17-2) were calculated for the AMLS based on engine-out capabilities as follows: (1) one booster engine and one orbiter engine can be lost during ignition and parallel burn, and (2) one orbiter engine can be lost after booster separation if all five were working at booster separation.

TABLE 3.3.3.17-2.– AMLS CREW LOSS EVENTS BY PHASE – PER 100 MISSIONS

Phase	Probability of Losses Per 100 Missions
Stage 1 and 2 Ignition	0.1225
Stage 1 and 2 Burn	0.1129
Staging	0.0013
Stage 2 Burn Phase	0.0818
Coast-to-Launch Apogee	0.0009
Orbit Circularization	0.0001
Total per 100 Flights	0.319

d. Architecture Cost Risk.– The attribute values for ACR are Technical Challenge, Program Immaturity, and Number of New Systems. The AMLS Technical Challenge score is subdivided into Non-Recurring Production, Production, and Operations. The AMLS Technical Challenge subattribute values are Non-Recurring – 7 (ranges from 5 to 7), Production – 6 (ranges from 4 to 7), and Operations – 6 (ranges from 4 to 7). The AMLS final score for Program Immaturity was 8, with a range from 6 to 9. New systems received a score of 1.6, ranging between 1 and 2.

e. Launch Schedule Confidence.– The three subordinate attribute values for schedule confidence – schedule compression, schedule margin, and delays due to unscheduled maintenance activities – are described below:

(1) Schedule Compression. The maximum number of calendar days required for AMLS turnaround is 45.8 (including mission). Operations for processing through transport to the launch pad are performed on a 1-shift-per-day, 5-day-per-week schedule. The calendar days required for ground processing can be reduced to 19.7 when all work is performed on a 3-shift-per-day, 7-day-per-week schedule. The operational scenario is shown in Figure 3.3.3.17-3.

(2) Schedule Margin. Launch rates for the AMLS vary from a minimum of 4 per year in 2005 to a maximum of 13 per year in 2019. Depending upon individual facility usage, additional calendar days are available for contingency processing. A high of 249 additional processing days for a launch rate of 4 per year to a low of 14 processing days for a launch rate of 13 per year are available.

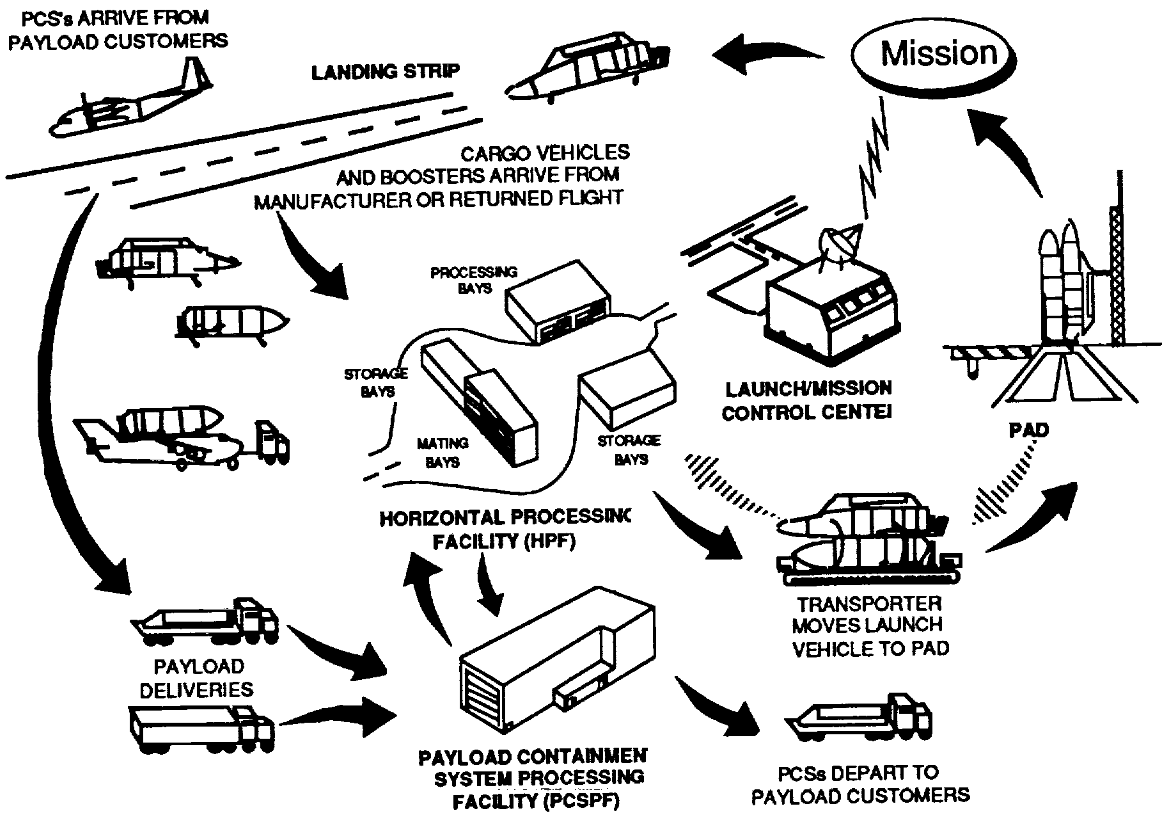


Figure 3.3.3.17-3.– AMLS operational scenario at the launch site.

(3) Delays Due To Unscheduled Maintenance Actions. Based on a flight time of 168 hours and 35 hours of prelaunch checkout, the AMLS orbiter is expected to have a total of 169.5 unscheduled maintenance actions per mission, resulting in 33.9 line replaceable unit (LRU) removals. Approximately 23 percent of flights may be delayed by orbiter problems. The AMLS booster, with 35 hours of prelaunch checkout and a much shorter 15 minute flight, is expected to have only 15.9 unscheduled mainte-nance actions per mission and 4.2 LRU removals. Approximately 5 percent of flights may be delayed by booster problems.

f. Environmental Impact.– The AMLS uses LO_2 and LH_2 as propellants. Toxic fluids have been eliminated. Using the given propellant weight, major effluent constituents were determined and are shown in Table 3.3.3.17-3. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.17-3.– EFFLUENT DATA FOR AMLS

Exhaust Product	AMLS (Klbm)
CO	0.0
CO_2	0.0
H_2	74.3
H_2O	2079.2
HCl	0.0
N_2	0.0
OH	0.0
H	0.0
Al_2O_3	0.0
Total per flight	2153.9

3.3.3.18 Advanced Military Spaceflight Capability (AMSC)

System Description

The AMSC is a one and one-half stage, air-launched system with a 5000 lb LEO payload capability. The system can be launched into any inclination. It uses three LOX/LH_2 engines in its main propulsion system. These are SSME-type engines which generate approximately one-third the thrust of an SSME. The AMSC concept was developed under a USAF study performed by Rockwell International.[9] The study effort used specific vehicle configurations to identify technologies required for an on-demand launch vehicle, and to provide a measure against which the needed technologies could be evaluated. The AMSC system was one of two prime candidates selected by the study team from a large number of possible configurations.

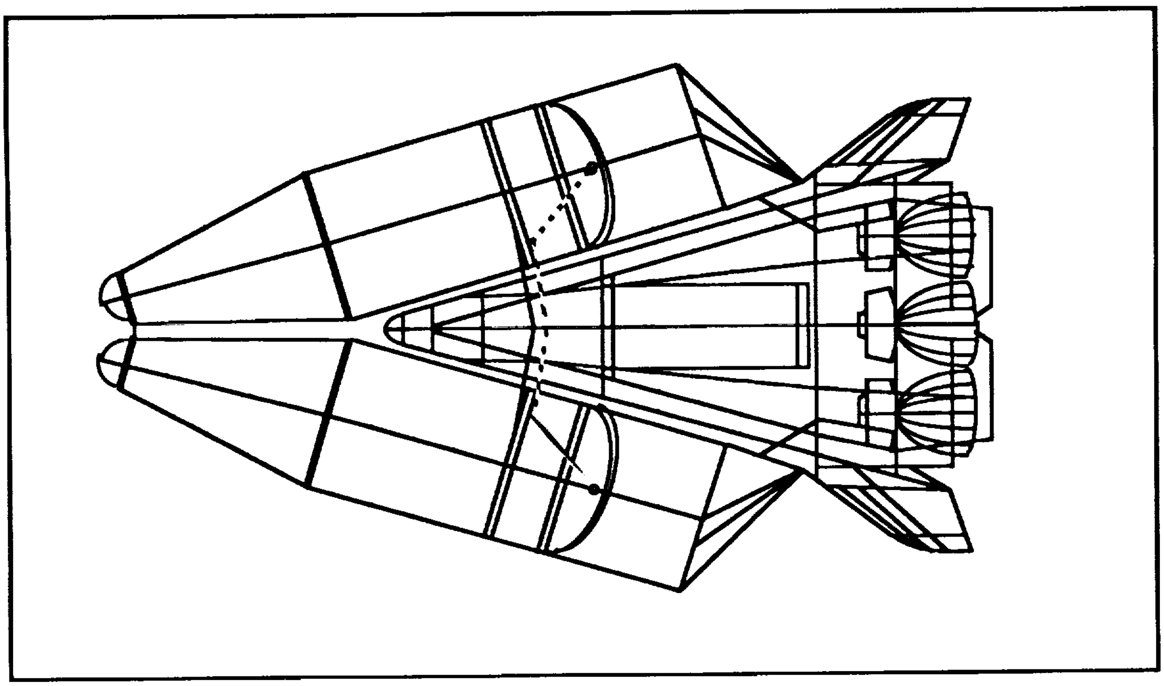


Figure 3.3.3.18-1.– Rockwell's AMSC concept used as a representative air-launched personnel carrier for HTS study.

Performance Characteristics

The AMSC concept was designed to deliver a 5000 lb payload to a 160 nmi polar orbit. Since this is the only performance value defined in the AMSC study, it was used for all AMSC missions. This does tend to overstate the number of missions required to support easterly launch requirements needed for most missions in our data base. It uses LOX/LH_2 propellants and expendable drop tanks. The carrier aircraft is a slightly modified Boeing 747 on which the fuel tank orbiter is carried to a launch altitude of about 24 000 ft. This system provides favorable operational characteristics, such as being air-mobile and having inherent offset launch and base escape capabilities. A key system requirement characteristic was that the AMSC had to be maintained in an alert status, capable of being deployed within hours of notification. The use of existing transport aircraft for launch reduces system acquisition costs. A primary concern with this concept is the use of expendable tanks, which affect operational costs, and cause logistics, mating, and disposal problems.

The drop tank orbiter is mated to the Boeing 747 in somewhat the same way as the Space Shuttle is mated to its carrier aircraft. Fully fueled, this configuration has a take-off weight of approximately 863 000 lbs, including the aircraft. Once airborne, liquid oxygen and hydrogen are transferred from the dewar tanks in the aircraft to the drop tanks; this continues until the aircraft is at approximately 24 000 ft. A pullup maneuver is executed to provide a flight path angle-of-attack of approximately 12° for AMSC separation. The separation-maneuver sequence represents the most technically demanding aspect of the entire vehicle operation. Once the AMSC vehicle and its attached drop tanks are separated from the aircraft, the three main engines are ignited and the vehicle ascends into space. At the time of separation, the GLOW is 277 000 lbs. After drop tank staging, 19 987 lbs of propellants remain in the AMSC vehicle to be burned by the three engines for final orbit insertion. The advanced RCS, which provides on-orbit and deorbit delta velocity, uses gasesous oxygen (GOX)/gaseous hydrogen (GH_2) fed from high pressure accumulators. A top-level, system mass statement is given in Table 3.3.3.18-1.

a. Abort Modes.– Two options for intact abort are available, depending on time from separation from the aircraft. If the center engine is lost prior to 248 seconds, or an outboard engine is lost prior to 330 seconds, an abort to an appropriate runway is initiated. After these time constraints, either the two outer engines are throttled up, or the opposite outboard engine is shut down and the center engine is throttled up to achieve an ATO.

b. Crew Escape Options.– A crew escape option was identified for the AMSC system. The discussed option focused on an ejection seat system although a detailed design was not included in the study. It is safe to assume that altitude and velocity limits as identified for the Shuttle Evolution (section 3.3.3.2) would approximate AMSC ejection operational limits.

c. Operational Facilities.– The ground facilities for the AMSC system could be located at any air base capable of supporting a Boeing 747 that has equipment for mating the AMSC vehicle and its attached drop tanks to the aircraft. While the study did not define the ground facilities in detail, they were identified and discussed. Most of the building requirements are similar to typical commercial

TABLE 3.3.3.18-1.– AMSC MASS STATEMENT

System breakdown	Mass (klbs)
747 Carrier aircraft	581.6
Drop Tanks	
Structure	8.9
Oxygen	185.1
Hydrogen	30.8
Orbiter	
Structure	25.5
Engines (3)	4.7
Oxygen - Ascent	17.1
Hydrogen - Ascent	2.9
Oxygen - RCS	1.2
Hydrogen - RCS	0.2
Payload	5.0
Total - GLOW	863.0

airport hangars, while specific support equipment for mating is considered to be small and portable, due to the small size and low empty-weight of the AMSC and its drop tanks. Fuel and payload facilities also have to be present. This system is designed to be mobile and launched from a variety of locations throughout the world. Since one of the AMSC's key characteristics is its ability to remain on alert status with lift off within hours of notification, its ground facilities had to be capable of continuously maintaining a full AMSC propellant load in the aircraft dewars. An operations flow schematic is shown in Figure 3.3.3.18-2.

Attribute Values

System input data related to each attribute, as well as system-specific attribute values are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level. These will be discussed following the presentation of the AMSC system data.

a. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. Two abort options (described earlier) exist and can be used in the event of a non-catastrophic main engine failure. These are abort to nearest capable runway and ATO. If an ATO is executed, it is possible that the mission will be a success. In addition, the crew can eject from the vehicle with altitude and velocity constraints similar to those defined for Shuttle Evolution (section 3.3.3.2).

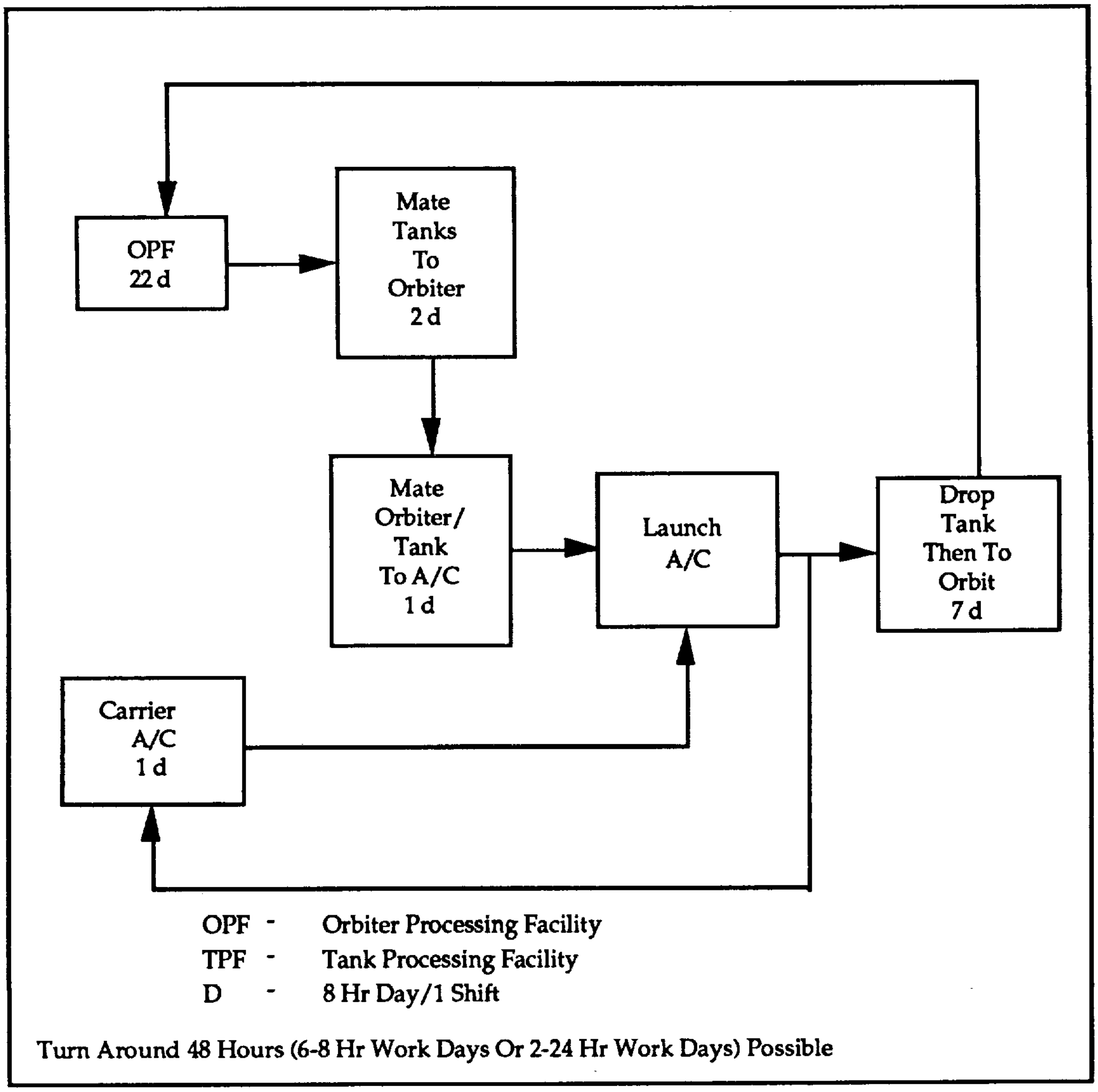


Figure 3.3.3.18-2.– AMSC operations flow schematic.

b. Funding Profile.– Cost information provided to the HTS included DDT&E; new airframe, engine, and drop tank production; and vehicle refurbishment. Spread factors for each cost item were also provided, identifying how much of the total cost was spent in the years preceeding the need or flight date. General Dynamics added annual preplanned product improvement, contractor fee, and government wraps as agreed to by the NIT. Table 3.3.3.18-2 presents a summary of this data.

TABLE 3.3.3.18-2.– AMSC FUNDING PROFILE INPUT DATA

AMSC COST BREAKDOWN CATEGORIES	TOTAL OR TFU COST ($M)	LEARN-ING CURVE (%)	RATE CURVE (%)	COST PER FLT ($M)	COST PER YEAR ($M)	Y-5 (%)	Y-4 (%)	Y-3 (%)	Y-2 (%)	Y-1 (%)	FLT YR (%)
NON-RECURRING											
RDT&E	6478					20	25	30	20	5	
PRODUCTION	0										
P3I	324/YR										
FACILITIES											
RECURRING											
NEW											
AIRFRAME	669	90	100			9	16	26	30	19	
MAIN ENGINE	21	90	90			8	17	27	30	18	
FLIGHT TO FLIGHT											
DROP TANKS	14	90	90			10	15	25	25	25	
REFURBISHMENT				1.4	115.0						100
LAUNCH OPERATIONS				0.5	92.4						100
FLIGHT OPERATIONS				0.1	25.9						100
R & M/SUPPORT				0.0	35.2						100

c. Probability of Mission Success.– A system description and flight profile contains the required input information for this attribute. In summary, the AMSC has one liquid-propulsion stage, three liquid engines (with engine-out capability per the abort descriptions), and two solid motors used during the initial boost period.

d. Architecture Cost Risk.– Two of three subordinate attribute values for ACR are Technical Challenge and Program Immaturity. The NIT, under a consensus process, assigned the AMSC a scale rating of 6 (Non-recurring), 4 (Production) and 6 (Operations) for Technical Challenge and a 7 for Program Immaturity, resulting in a value of 12.9, 4.6, and 12.9, respectively, in "If" C for Technical Challenge and a 21.5 for Program Immaturity (see section 3.2.5). The third component, Number of New Systems, is an architecture-level value. AMSC's contribution to architecture scores for this component of ACR is one.

e. Launch Schedule Confidence.– As in ACR, there are three subordinate attribute values for LSC: Schedule Compression, Schedule Margin, and Delays (due to unscheduled maintenance activities). Schedule Compression and Delays are architecture-independent, while Schedule Margin is architecture- dependent since its values are a function of annual flight rates, available facilities, and Orbiters. AMSC's Schedule Compression values are nominal cycle time – 41.2 days, compressed cycle time – 24.8 days, and compression ratio – 0.6. It is estimated that the AMSC will experience delays in 9.9 percent of its flights.

f. Environmental Impact.– The AMSC uses liquid hydrogen and liquid oxygen as propellants, as well as two solid strap-on boosters. Its propellant load includes oxygen – 1361.936 klbm, hydrogen – 227.641 klbm, and solid propellant – 2216.0 klbm. Using the given propellant weights, major effluent constituents were determined and are shown in Table 3.3.3.18-3. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.18-3.– EFFLUENT DATA FOR AMSC*

Exhaust Product	AMSC (klbm)
CO	0.0
CO_2	0.0
H_2	8.0
H_2O	223.2
HCl	0.0
N_2	0.0
OH	0.0
H	0.0
Al_2O_3	0.0

* Does not include 747 engine effluents.

3.3.3.19 Air Launch Vehicle (ALV)

System Description

a. History.– Air launching a rocket from a subsonic carrier aircraft has several advantages that should result in superior attribute scores. In the first part of the HTS, the NIT selected a candidate air launch concept to build an architecture around; refer to the AMSC description of section 3.3.3.18 of the HTS Final Report. This particular vehicle turned out to be sized incorrectly for the mission needs, and as a result, scored poorly in the AET. The NIT still believed that our *customer* considered the concept of air launching to be attractive, and that a more representative candidate should be included. The ALV is a configuration developed under independent research and development (IR&D) by Boeing Defense and Space Group and offered to this study as a concept better suited to the HTS mission needs.

b. Configuration.– The ALV, see Figure 3.3.3.19-1, is a Boeing 747-launched, two stage LOX/LH_2 rocket that carries either a payload shroud or a small personnel capsule. The ALV 747 carrier airplane is a modified 400 series freighter with larger engines (PW4000's from the 777 program) that is capable of lifting approximately 412 000 lbm to the launch conditions of 30 000 ft at a speed of 770 ft/s. The ALV itself features an expendable wing, used for separation, a recoverable propulsion module with one SSME (operated at 100 percent rating), an expendable first stage tankset holding ~282 000 lbm of propellant, and an expendable second stage featuring one or two RL10A-4B engines and tankage for about 40 000 lbm of propellant. In the cargo version (CALV), a payload adapter and shroud are included. The second stage features one RL10 to reduce the recurring cost associated with expendable hardware. In the personnel version (PALV), the second stage features two RL10 engines, with engine-out capability, and an interface adapter to the human personnel carrier. The personnel capsule is very similar to the RPC biconic, except that it is smaller, carrying a maximum of four people for up to 3 days (72 hours) of travel time.

c. Facilities.– The ALV is capable of taking off from any conventional Boeing 747-capable runway. Facilities for loading cyrogenic propellants are required in the immediate vicinity. The human personnel carrier facilities are nearly identical to those discussed in conjuction with the RPC. Figure 3.3.3.19-2 depicts a typical, ALV launch facility complex at the primary, flight operations site.

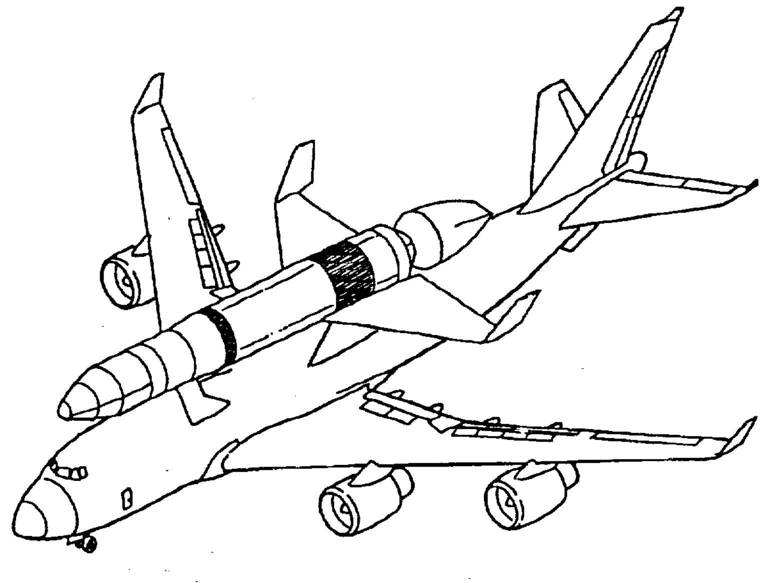


Figure 3.3.3.19-1.– ALV configuration.

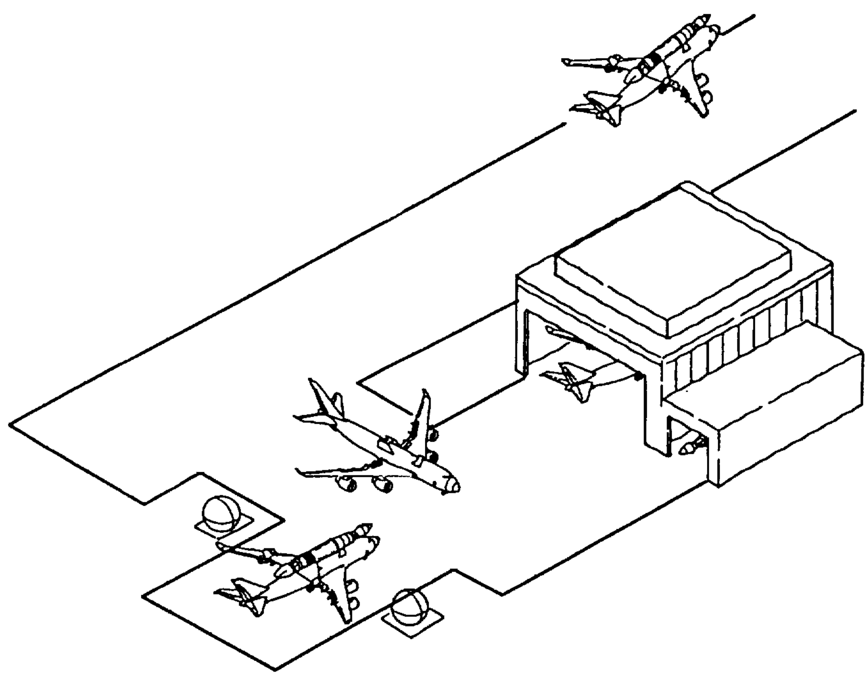


Figure 3.3.3.19-2.– ALV Launch facility.

Performance Characteristics

The PALV performance was sized to provide personnel-only-access for four passengers to the SSF. For the CALV, the payload performance is listed in Table 3.3.3.19-1.

Attribute Values

a. Funding Profile Summary.– The ALV estimates were developed from a variety of cost-estimating techniques. The airplane modifications were estimated using proprietary Boeing airplane modifications and actual cost information analogies for each section of the 747 aircraft. The rest of the cost estimates for the funding-profile-attribute inputs were developed using the Boeing Parametric Cost Model. Table 3.3.3.19-2 is a summary of the system cost estimates.

TABLE 3.3.3.19-1.– CALV PERFORMANCE SUMMARY

Altitude (nmi)	Inclination (deg)	Payload (lbm)
100 x 100	90	17,247
GTO	0	8,104
150 x 150	28.5	20,914
30 x 220	28.5	22,425
220 x 220	28.5	16,681

TABLE 3.3.3.19-2.– ALV COST ESTIMATES SUMMARY ("IF" C)

	(1992 Dollars in Millions) CALV	PLS-Lite/PALV	Total
Development:			
C/D Phase	$ 3,277M	1,648M	$ 4,925M
Facilities	385M	257M	642M
Total:	$ 3,662M	1,905M	$ 5,567M
Production:			
Carrier A/C TFU	$ 244M	(same as CALV)	
Upper Stage TFU	41M	53M (2 RL10's)	
Expendable TFU	36M	42M (OMS/LES)	
Reusable TFU	162M	196M (mini carrier)	
Supt. Equip. Set	$ 10.5M	(in DDT&E est.)	
Oper. & Support			
Variable Cost	$ 26M	37M (first flt.)	
Fixed Annual	$ 56M	(same as CALV)	

- Acquisition Phase Estimates.– The acquisition phase estimates were accomplished using new system weight statements and aircraft modification descriptions from a Boeing internal IR&D project activity.

  The cargo mission flight tests would precede the human mission tests, but the PLS-Lite drop tests and launch escape system tests can be done in parallel with the cargo mission hardware testing. The schedules were compared with Space Shuttle Carrier Aircraft, Airborne Optical Adjunct, and E-4 Command Post modification actual program schedules for content and reasonableness. The cryogenic stages development plan segment was compared with the Inertial Upper Stage program and NLS study program schedules for reasonableness and content. The SSME modification test schedule segment was compared with some prior study information from Rocketdyne and Phillips Labs.

- TFU Estimates.– There are two configurations for the ALV cryogenic upper stage, so there are two TFU values shown in Table 3.3.3.19-2. The CALV upper stage has one RL10 and the PALV upper stage has two RL10's (including extra plumbing and control subsystem impacts,) thus, the upper stage TFU cost estimates difference. Estimates are provided for expendable (exp) and reusable hardware elements. The PLS OMS/LES is expended on every flight.

- Operation and Support Estimates.– The variable cost estimate for the PALV configuration is higher to account for the PLS-Lite processing and refurbishment requirements.

- Funding Profile Attribute Cost Inputs.– The ALV master phasing schedule includes the development plan for both CALV and PALV design and testing. The cost spread data was generated using the 6-year development plan illustrated in the preliminary ALV master phasing schedule. The funding profile, attribute cost estimate input sheet with the cost spread data is documented in Appendix B, section B.1.5.

b. Probability of Mission Success.– The mission success trees are listed in Appendix B. For the PALV, the PMS = 0.96649; for the CALV, PMS = 0.9473.

c. Human Safety.– The PALV includes a launch escape system that can provide for escape in all phases of the ascent. The P_D is equal to 0.00829, or an average of 120.6 flights between crew loss events.

d. Architecture Cost Risk.– The ALV elements were evaluated with the same methods as other boosters. The Technical Challenge score was assigned a value of 4 (for all phases) based on the low level of required technology. The NIT accounted for the CALV and PALV as 1.5 "new systems", and agreed on a Program Immaturity value of 8.

e. Operational Flow.– A summary operational flow for an ALV is shown in Figure 3.3.3.19-3.

f. Environment.– The ALV is a LOX/LH_2 system with a total W_p of 321 482 lbm of propellant, resulting in a score of 32; refer to Table 3.3.3.19-2.

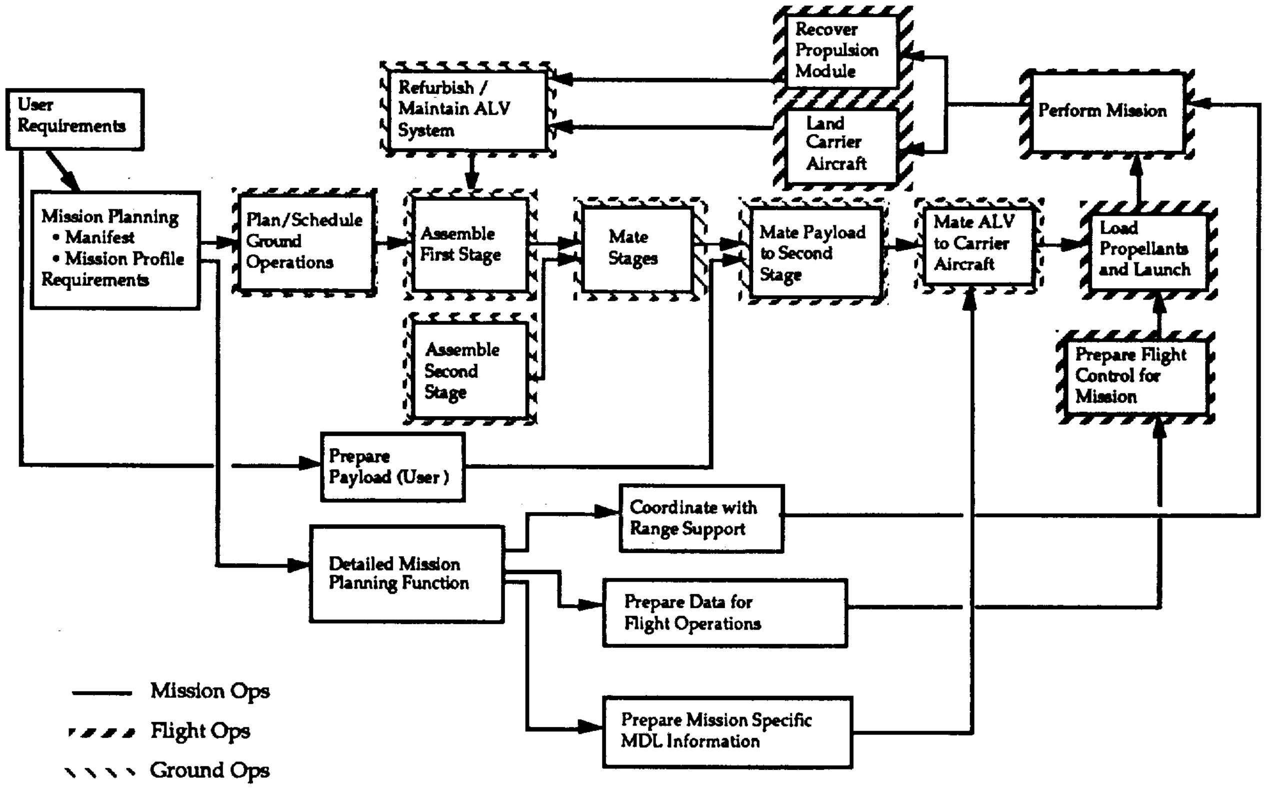


Figure 3.3.3.19-3.– Typical ALV launch operations preparation flow.

TABLE 3.3.3.19-3.– EFFLUENT DATA FOR ALV

Exhaust Product	Effluent Mass (klbs)
CO	0
CO_2	0
H_2	11.1
H_20	310.4
HCl	0
N_2	0
OH	0
H	0
Al_2O_3	0

3.3.3.20 Two-Stage-to-Orbit (TSTO) Beta II

System Description

The Beta II TSTO (Figure 3.3.3.20-1) is a concept developed at the Air Force Wright Laboratory. NASA-Lewis selected it as its baseline TSTO concept in March 1990, bringing Boeing under contract in July as part of the NASA-Lewis/Wright Lab study team. Beta II is one of a family of TSTO's under investigation within and outside of the United States. Other concepts include Sanger (Germany), HOTOL (UK/Russia) STAR-H (France), and LACE Boosted TSTO (Japan). Beta II has an air-breathing first stage, using turbofan and ramjet engines to accelerate up to Mach 6.5. Its orbiter has a single SSME to propel it from its Mach 6.5 staging point up to orbit insertion. The orbiter is loaded into the underside of the carrier aircraft. Performance design criteria is 10 klb of payload delivered into a polar orbit. The reference source for the Beta II is a NASA-Lewis briefing[10], as well as the Boeing HTS team.

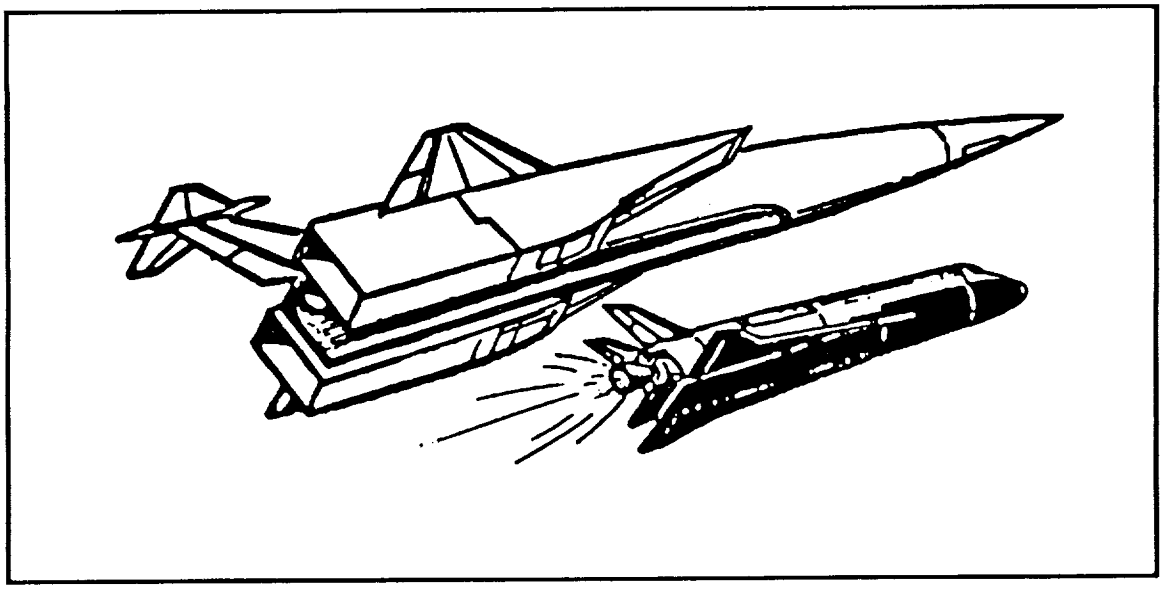


Figure 3.3.3.20-1.– The Beta II concept is representative of fully reusable air-breathing/rocket TSTO systems.

Performance Characteristics

Beta II was designed to deliver a minimum of 10 klbs to polar orbit. Its performance to other orbits of interest is shown in Table 3.3.3.20-1.

TABLE 3.3.3.20-1.– BETA II PERFORMANCE CHARACTERISTICS USED FOR MANIFESTING PURPOSES

Inclination (deg)	Apogee X Perigee (nmi)	Payload (klbs)
28.5	160 x 160	19.1
28.5	220 x 220	18.5
28.5	300 x 300	17.6
57.0	160 x 160	15.6
57.0	324 x 324	14.1
90.0	100 x 100	11.1
90.0	150 x 150	10.6

The Beta II orbiter is mated into the bottom of its carrier aircraft. It sits inside a cavity during ascent or ferry operations. Its payload bay is 20 feet long with a 14-foot diameter. System GLOW is 1.2 Mlbs, of which 651.2 klbs is propellant, consisting of jet propellant (JP), liquid hydrogen, and liquid oxygen. A 20 percent and 10.6 percent weight-growth allowance has been accounted for in the carrier aircraft and orbiter, respectively. Total inert weight is 234.6 klbs. A top-level mass statement is shown in Table 3.3.3.20-2.

TABLE 3.3.3.20-2.– BETA II MASS ALLOCATION

Mass Allocation	Carrier Aircraft (lbs)	Orbiter (lbs)
Inert	181,677	52,948
Propulsion	218,215	
Propellant	377,651	273,499
Crew and Residuals	9,815	2,901
Payload	345,160	10,000
Margin	79,976	5,595
Total	1,212,494	344,943

There is a 217 lb discrepancy between the orbiter total mass and the carrier aircraft payload. This may be due to propellant boil off between take off and staging, round-off error, or other analytical discrepancies. However, this small difference could easily be allocated to margin, propellant, or residuals in order to force numbers to coincide.

Mission operations begin with take off from a Strategic Air Command-type runway using air-breathing propulsion. A total of 10 NASA-Lewis Research Center turbine bypass engines, using JP-fueled high speed civil transport technology, provide initial thrust up through Mach 3. Beginning at Mach 1.5, hydrogen fueled ramjets are brought on line at partial-thrust levels. They provide 100 percent of the thrust between Mach 3 and Mach 6.5, where the orbiter is released. After staging, the carrier returns to its base of operations under powered flight, using ramjets only, down to a speed of Mach 3, and turbofans only from Mach 1.5 to landing. The orbiter's SSME is ignited after release from the carrier aircraft to continue acceleration through orbit insertion. Orbit circularization is provided by two RL10-A4 engines, which draw propellant from the main propulsion tanks. An integral GOX/GH_2 RCS provides attitude and reaction control. At the end of its mission, the Beta II orbiter deorbits and glides to its landing site just as the Space Shuttle Orbiter does today.

a. Abort Modes.– Beta II abort modes are defined in Figure 3.3.3.20-2.

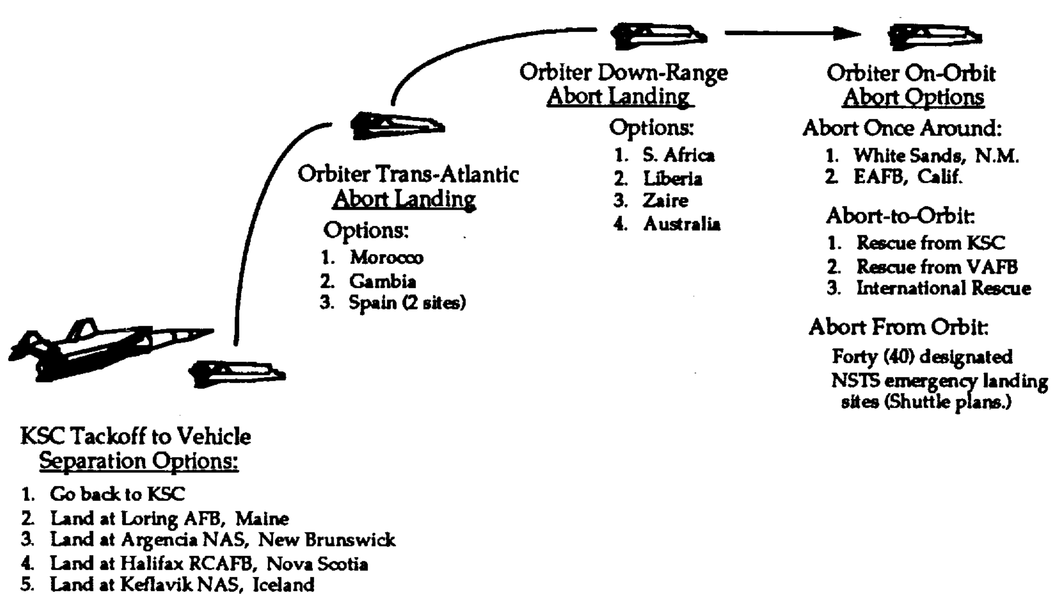


Figure 3.3.3.20-2.– Beta II abort and contingency operations.

b. Crew Escape Options.– B-58-type ejection capsules enable crew escape from both the carrier aircraft and the orbiter.

c. Operational Facilities.– An overview of basing facilities is given in Table 3.3.3.20-3. This study assumed that only one site was developed since all azimuths are available from any launch site for a two stage, fully reusable launch system. Figure 3.3.3.20-3 shows the Beta II operational flow schematic.

TABLE 3.3.3.20-3.– BETA II FACILITIES OVERVIEW

Facility	Kennedy Space Center	Vandenburg Air Force Base
Runway	300 ft wide x 15 000 ft long.	200 ft wide x 15 000 ft long.
Taxiways	Limited to none.	Limited.
Orbiter Processing Facility	Existing are 100 percent utilized by Space Shuttle.	Existing former Space Shuttle orbiter Maintenance and Checkout Facility is not being utilized.
Booster Processing Facility	No hangar facilities - limited facilities at Patrick Air Force Base.	No suitable hangar facility.
Support facilities - Shops, Administrative, and Logistics	Existing Space Shuttle, Titan, Atlas and Delta launch support facilities at KSC and CCAFS plus aircraft maintenance facilities at Patrick AFB.	Existing Titan, Atlas and ballistic missile launch support facilities. Extremely limited aircraft maintenance facilities.
Propellant Storage and Distribution	Cryogenic propellant storage at Launch Complex 39 pads; Suitable distribution nonexistent; Aircraft propellant storage and distribution facilities are limited to nonexistent.	Cryogenic propellant storage at SLC-6 launch pad; Suitable distribution nonexistent; Aircraft propellant storage and distribution facilities are limited to nonexistent.
Payload Processing Facility	Existing facilities to support Space Shuttle, Titan, and Delta payloads	Existing facilities in former Space Shuttle Orbiter Maintenance and Checkout Facility.
Mission Control Facility	Titan, Atlas and Delta facilities with communication links; Established Test Range.	Titan and Atlas "on-pad" facilities with communications links; Established Test Range.
Automated Test and Checkout	Existing Launch Control Center with Launch Processing System - probably completely dedicated to Space Shuttle; Proposed "CORE" update to LPS may be suitable and have required capability.	Space Shuttle equipment and facility status unknown; Ballistic missile programs' current and future status unknown; Highly doubtful that suitable assets exist.

Attribute Values

System input data related to each attribute, as well as system-specific attribute values are discussed below. In most cases, system data is modified by flight rate or cost associated with the particular architecture and/or "If" being evaluated. However, some useful observations can be made at the system attribute level. These will be discussed following the presentation of the Beta II system data.

a. Human Safety.– Relevant system data for human safety consists of system characteristics that enable the crew to detach or escape from the main body of the system during ascent in the event of a mission failure. Several abort options (described earlier) exist and can be used in the event of a non-catastrophic main engine failure. They are abort to nearest capable runway and ATO. If an ATO is executed, it is possible that the mission will be a success. In addition, the crew can eject from either vehicle as described above.

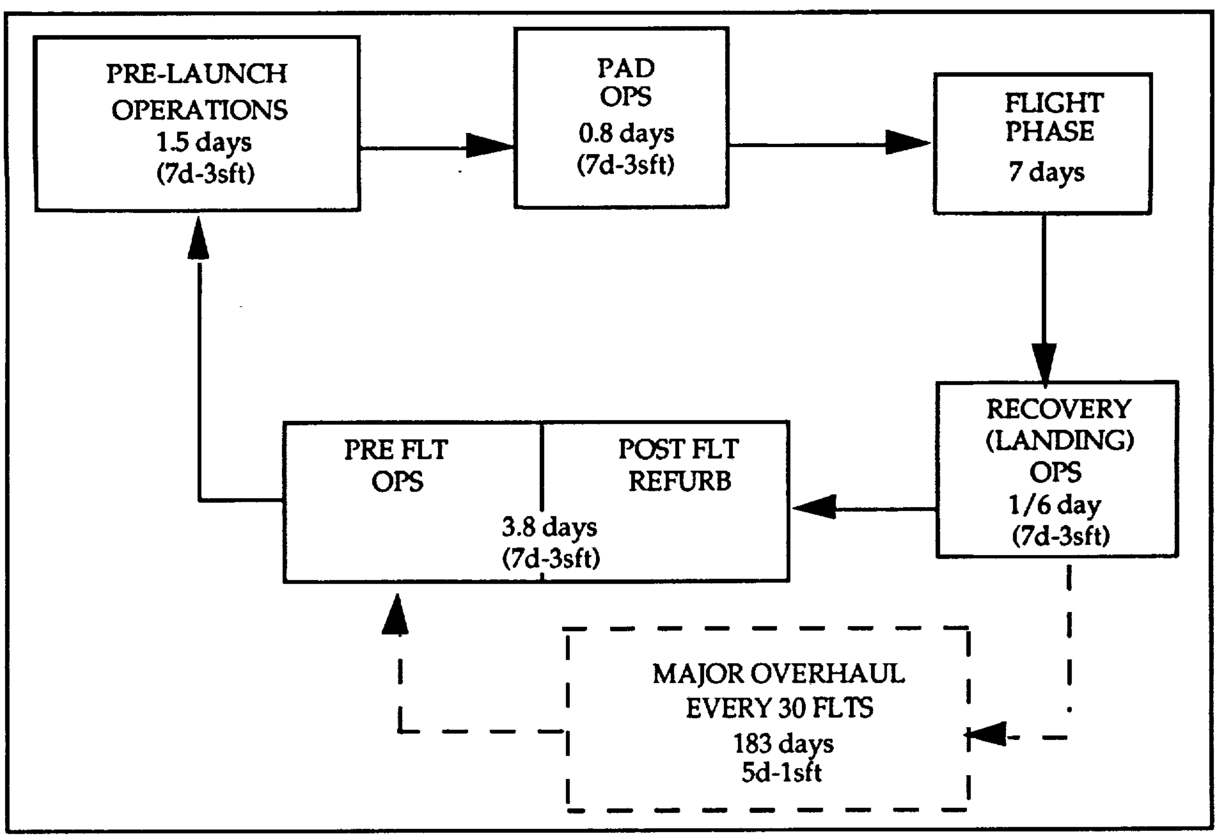


Figure 3.3.3.20-3.– Beta II operations flow schematic.

b. Funding Profile.– Cost information provided to the HTS included DDT&E, production, vehicle refurbishment, and operations. Spread factors for each cost item were also provided, identifying how much of the total cost was spent in the years preceding the need or flight date. General Dynamics added annual pre-planned product improvement, while the AET added contractor fee and government wraps, as agreed to by the NIT. Table 3.3.3.20-4 presents a summary of this data.

c. Probability of Mission Success.– A system description and flight profile contains the required input information for this attribute. In summary, the Beta II has 3 liquid-propulsion stages consisting of 10 turbojet engines and 2 ramjets in the first stage, 1 main rocket engine in the second stage, and an orbital maneuvering system as the third propulsive stage. The PMS process does not use the air-breathing stage to determine mission success rate. This is also true for the AMSC concept.

TABLE 3.3.3.20-4.– BETA II FUNDING PROFILE INPUT DATA

Beta II Cost Breakdown Categories	Total Or TFU Cost ($M)	Learn-ing Curve (%)	Rate Curve (%)	Cost Per Flt ($M)	Cost Per Yr ($M)	Yr -8 (%)	Yr -7 (%)	Yr -6 (%)	Yr -5 (%)	Yr -4 (%)	Yr -3 (%)	Yr -2 (%)	Yr -1 (%)	Flt Yr (%)
Non-Recurring														
RDT&E	15538					5	15	10	20	25	13	10	2	
Production	703					10	55	25	8	2				
P3i	777/Yr													
Facilities														
Eafb Test Facility	348					5	35	45	15					
Ksc Facilities	375					2	10	50	35	3				
Vafb Facilities	452					1	5	20	38	30	6			
Moc/Training	200					2	20	50	25	3				
Flt Training A/C	100					1	15	39		5	40			
Recurring														
New														
Carrier Aircraft	2940	95	100								15	55	25	5
Orbiter	703	92	100								12	48	35	5
19% Rplcmnt Spares	692	92	100											100
Carrier #1 Mod	735	100	100										90	10
Orbiter #1 Mod	176	100	100										80	20
Launch Operations				7	310									100
Flight Operations				7	120									100
R & M/Support					46									100

d. Architecture Cost Risk.– Two of three subordinate attribute values for ACR are Technical Challenge and Program Immaturity. The NIT, under a consensus process, assigned the Beta II a scale rating of 8 (Non-recurring), 7 (Production) and 8 (Operations) for Technical Challenge in "If" C, and a 10 for Program Immaturity, resulting in a value of 35.9 (Non-recur), 21.5 (Production), and 35.9 (Operations) for Technical Challenge and a 100 for Program Immaturity (see section 3.2.5). The third component, Number of New Systems, is an architecture-level value. Beta II's contribution to architecture scores for this component of ACR is 1.

e. Launch Schedule Confidence.– As in ACR, there are three subordinate attribute values for LSC: Schedule Compression, Schedule Margin, and Delays (due to unscheduled maintenance activities). Schedule Compression and Delays are architecture-independent, while Schedule Margin is architecture-dependent since its values are a function of annual flight rates and available facilities and Orbiters. Beta II's Schedule Compression values for the orbiter are: nominal cycle time – 14 days, compressed cycle time – 14 days, and compression ratio – 1.0. It is estimated that 8.9 to 14.8 percent of Beta II flights may experience a flight delay. The estimate is based on assessing the orbiter and carrier aircraft separately, with an orbiter estimate of 8.9 percent and 5.9 percent for the carrier aircraft.

f. Environmental Impact.– The Beta II uses jet fuel, liquid hydrogen, and liquid oxygen as propellants. Propellant load on the carrier aircraft is 377 651 lbs, of which 250 010 lbs is jet fuel and 127 641 lbs is liquid hydrogen. Approximately half (122 270 lbs) of the jet fuel is used during parallel operation of the turbofans and ramjets. The remainder is allocated to take off and acceleration to Mach 1.5, return propulsion, and contingency needs. The orbiter's 273 499 lbs of propellant is 39.1 klbs of hydrogen and 234.4 klbs of oxygen. Using the given propellant weights, major effluent constituents were determined and are shown in Table 3.3.3.20-6. These values are based on equilibrium, non-afterburning calculations.

TABLE 3.3.3.20-5.– EFFLUENT DATA FOR BETA II

Exhaust Product	Beta II (klbm)
CO	0.0
CO_2	377.5
H_2	11.0
H_2O	481.9
HCl	0.0
N_2	0.0
OH	0.0
H	0.0
Al_2O_3	0.0

3.3.4 Architecture Evaluation Process

Having defined the transportation architectures to be analyzed, described the systems which comprise the architectures, and developed methodologies for measuring the important attributes, it is now possible to evaluate the architectures using the tools the HTS study developed. Figure 3.3.4-1 illustrates the architecture evaluation process and the flow of data between the data analysis tools. The figure indicates the major computer models and the data inputs and outputs of each.

The first step in the architecture analysis process is to gather or develop the basic system data required to either determine architecture flight rates or attribute values, such as ascent performance and reliability trees. Then the manifesting and mission capture work is done. For the HTS study, this was accomplished using General Dynamics' Transportation Systems Integration Tool (TRANSIT). TRANSIT applies system performance data, various system constraints, and other data to the mission model to produce a series of manifests. One manifest, which summarizes the total flight requirements by year over the study time frame, is produced for each "If" activity scenario of an architecture.

Once the mission capture analysis is complete and the architecture manifests are produced, the next step is analysis of the ground operations flow. To do this, a top-level flow diagram is developed for each launch system. These diagrams show the major facilities required for a system and the length of vehicle processing time and shift information for each. They also show which processes are done in parallel and which are done in series. From these diagrams, the operations spreadsheet models are developed. The models produce the system level, operations-related, attribute data required for attribute calculation. This includes schedule confidence and schedule margin data for the Launch Schedule Confidence attribute. The models also produce data for the number of facilities and vehicles required for the architecture cost estimation.

Information from the ground operations analysis, manifests, and system cost data inputs are used to produce the cost data for each architecture. This is accomplished in a spreadsheet model which was developed in previous studies and modified to produce cost data in the format required by the study. Data produced for each system, in each architecture, includes year-by-year costs for DDT&E, facilities, non-recurring production, preplanned product improvement, operations, and recurring production.

The cost model also uses PMS and safety values to estimate the cost of vehicle losses due to unreliability. The PMS values come from spreadsheet analysis based on reliability success trees. Safety values come from spreadsheets, which tally the potential losses and their effect on crew survival and abort for each flight phase.

Finally, data for the six study attributes, as well as the flight rate manifests, are input into the HTS AET. The AET is a Macintosh-based evaluation model, developed specifically for the HTS study, which utilizes system and element level data to generate

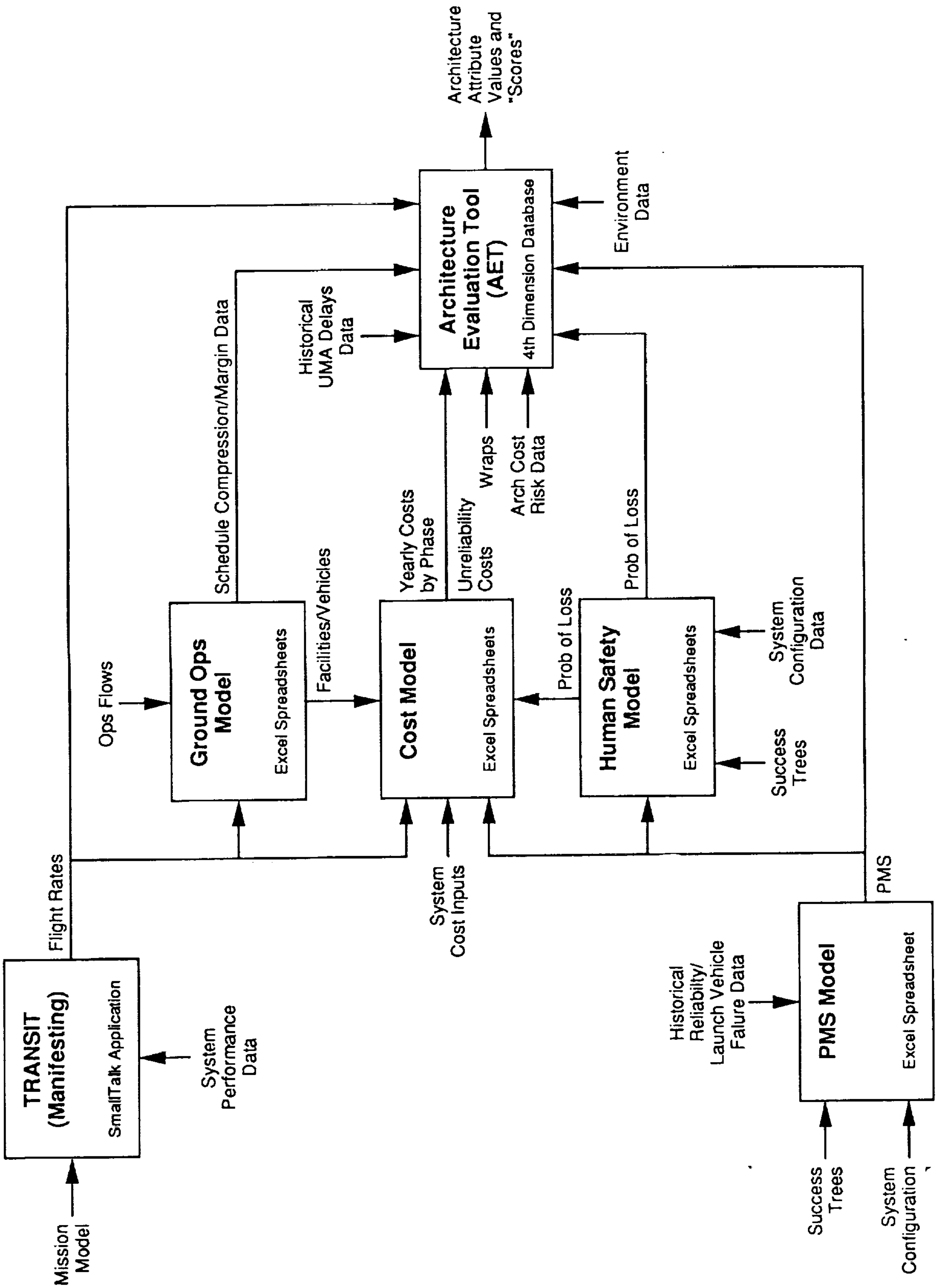


Figure 3.3.4-1.– HTS process data flow.

architecture-level attribute data and utility scores. It contains all algorithms necessary to "roll up" the data, both across all systems in the architecture and over the study time frame, into architecture values. The values are applied against utility curves to produce attribute scores. These scores are then combined using attribute weightings to produce architecture scores. Both attribute and architecture scores can be used to compare architectures and help address various considerations. The AET is the final evaluation tool for the extensive amount of data generated from the various HTS models, tools, and processes.

3.3.5 HTS Reference - Architecture Option 1

The HTS Reference (Architecture 1) provides a benchmark for HTS study processes and a comparative reference for potential replacement architectures. Systems in the HTS Reference comprise the first 8 years of all architectures. NASA's Mixed Fleet Manifest defines the system flights from 1992 through 1998. New systems or capabilities are not introduced until after 2000.

3.3.5.1 Description

Current systems and operational characteristics, defined as those in place or under development, comprise the HTS Reference Architecture. These include: Shuttle with ASRM's; Atlas (E, I, and IIAS); Delta II; and Titan (II, III, and IV) (see figure 3.3.5.1-1). Facilities and operational flow paths are discussed in the relevant system section. Small commercial vehicles (Pegasus, Taurus, Conestoga, etc.) or sounding rockets (Scout, Aires, etc.) are not considered in this study.

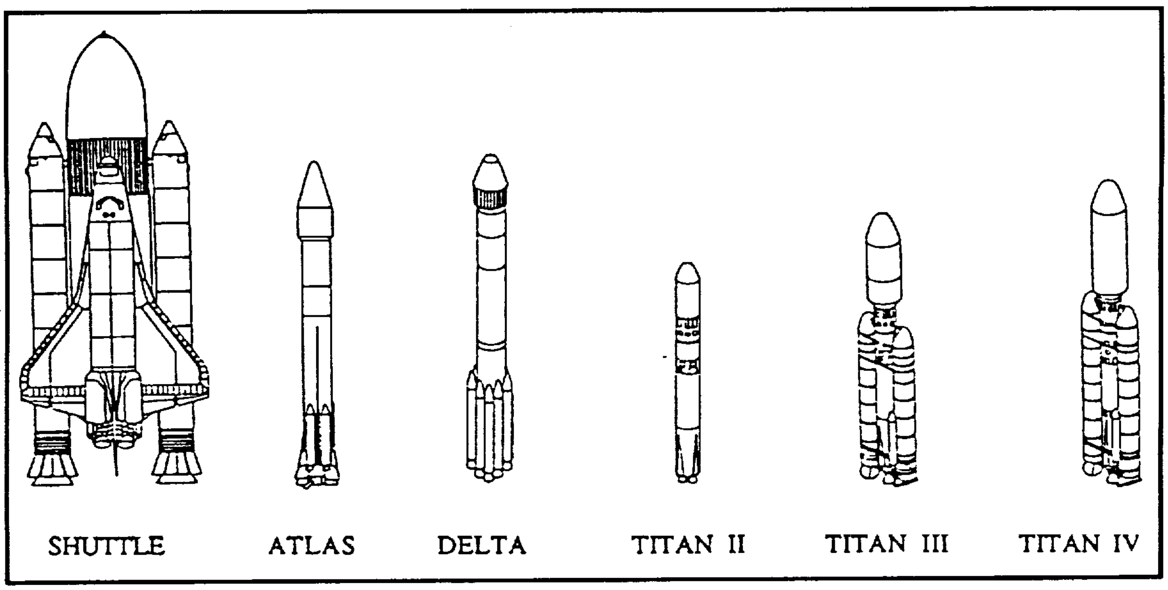


Figure 3.3.5.1-1.– Reference architecture launch system vehicles (not to scale).

Space Shuttle improvements incorporated in the baseline include the ASRM's and EDO. The ASRM's increase payload lift capability by 12 klbs relative to the redesigned solid rocket motors (RSRM's) now being used. The EDO increases on-orbit duration capability from 10 days to 30 days. However, since all personnel mission flights were assumed to be 7 days in length, the extended duration capability is not considered. Also, it does not affect fleet size requirements, even though it provides longer mission times.

Atlas E and I flights are treated as IIAS vehicles from an operational viewpoint since there are only 2 and 4 flights of each, respectively, out of 94 total flights. Also, since there are only two Atlas flights from WTR, the operational analysis has been simplified by assuming that all flights are out of ETR.

The single Titan III flight in the Mixed Fleet Manifest has been treated as a Titan IV in the operational analysis. These simplifications are common to all architectures since the flights occur between 1992 and 1998. They have no bearing on relative comparisons between architectures.

3.3.5.2 Manifesting Philosophy

Missions between 1992 and 1997 are defined by the NASA Mixed Fleet Manifest in effect in August 1991. For all scenarios ("If's") one DOD Space Shuttle mission was included per year. Beyond 1997, all payloads going to the SSF, all human-tended payloads, and all return payloads were manifested on the Space Shuttle. For other destinations, as a priority, untended payloads were manifested onto expendable launch vehicles without crews. The Assured Crew Return Vehicle (ACRV) was delivered to and returned from SSF using the Space Shuttle. This philosophy reflects the way payloads are currently or are planned to be handled using the current systems. Two payloads identified in the CNDB and carried forward into the HTS mission model ("If" D) were modified so the Space Shuttle could deliver them to SSF; assembly payloads MB-19 (70 klb) and MB-24 (69.5 klbs) were split into two equal-mass payloads, with no additional ASE added.

3.3.5.3 Manifesting Results

The ELV flights remain constant across all "If" scenarios, with Space Shuttle increasing from 76 to 389 flights over the 29 years of interest in this study (Table 3.3.5.3-1). Annual rates for Space Shuttle begin at 3 in "If" A, increase to 4 in "If" B, jump to 10 through 12 in "If" C, 11 through 15 in "If" D, 11 through 15 in "If" E-low, and 11 through 17 in "If" E-high.

Annual Space Shuttle flight rates and their Orbiter fleet size for "If's" C and D are shown in Figure 3.3.5.3-1. Space Shuttle flight rate peaks at 12 in 1997 (late FY91 Mixed Fleet Manifest), in 2000, and in 2007. Need for a fifth Orbiter is indicated at a rate of 11 flights per year (approximately 2.5 flights per year, per Orbiter). This is somewhat lower than KSC's estimate of achieving 12 flights per year with a four-Orbiter fleet. A key difference in these rates may be the assumption that each Orbiter is off-line 60 days per year to account for a 180-day major modification every 3 years. "If" D generally requires one to two flights more than "If" C each year to support the EMCC SSF, except in 2002, where the rate peaks at 15 per year during EMCC build up. Thus, a six-Oribter fleet is required for "If" D, beginning in 2000.

The highest traffic model ("If" E-High) Space Shuttle flight rate and Orbiter fleet size is shown in Figure 3.3.5.3-2. Flight rates peak at 17 per year (2011) in this "If". A seven-Orbiter fleet is required in 2007 to meet the demand of 16 flights that year. Sixteen Space Shuttle flights are also required in 2015, 2018 and 2020.

TABLE 3.3.5.3-1.– REFERENCE ARCHITECTURE SYSTEM FLIGHT SUMMARY

SYSTEM	EAST		WEST		TOTAL
	NASA	DOD	NASA	DOD	
Atlas I	4				4
Atlas E			1	1	2
Atlas IIAS	24	64			88
Delta	38	111	10	33	192
Titan II			3	39	42
Titan III	1				1
Titan IV/Centaur	42	56			98
Titan IV/NUS		61	24	57	142
Shuttle -"If" A	47	29			76
-"If" B	119	29			148
-"If" C	271	29			300
-"If" D	309	29			338
-"If" E-LOW	328	29			357
-"If" E-HIGH	360	29			389

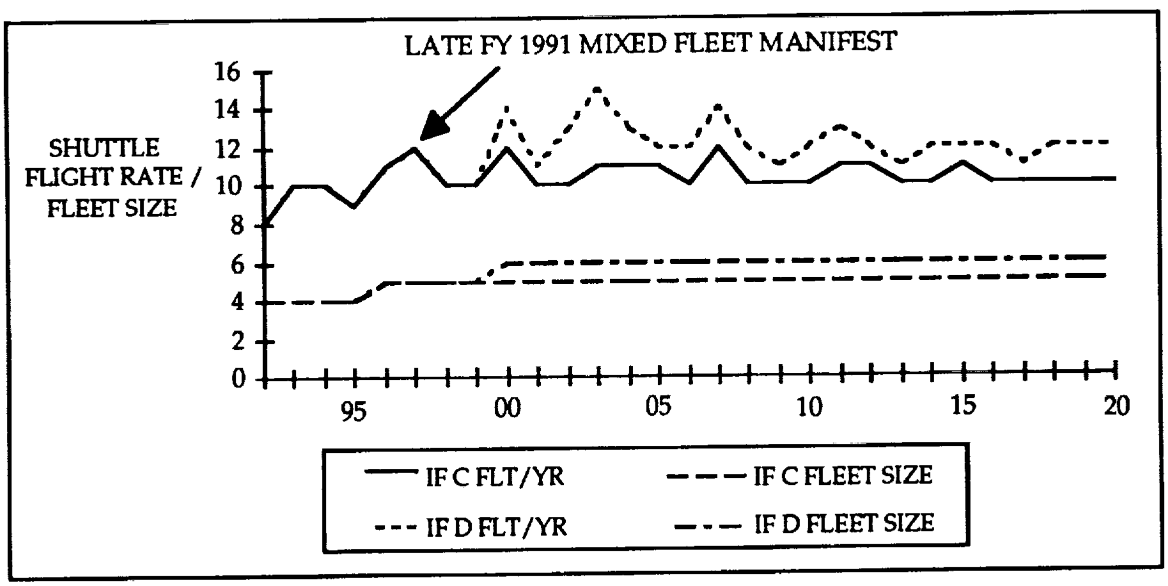


Figure 3.3.5.3-1.– SSF support requirements raise Space Shuttle flight rates up to 16 per year and Orbiter fleet size to 6 per year.

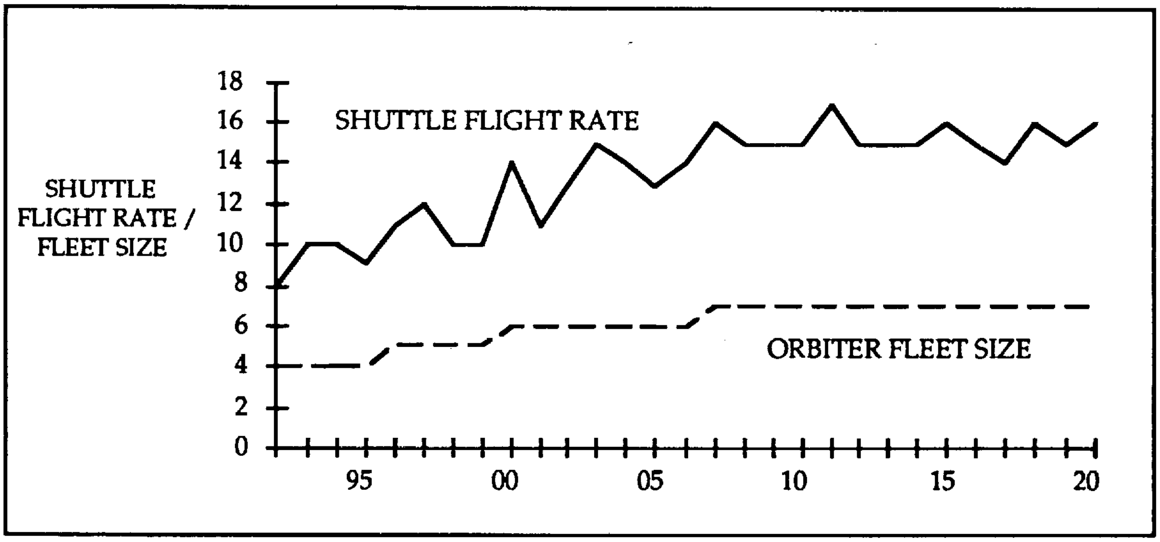


Figure 3.3.5.3-2.- "If" E-High drives Space Shuttle flight rate to a peak of 17 in 2011 and fleet size to 7 in 2007.

Other than a new west coast pad for Titan and a new MLP, the only procurement required for this architecture to satisfy the HTS-defined needs are new Orbiters. The required fleet size increases from four to seven as the mission model expands from "If" C to "If" E-High. With the predicted loss rate for the Orbiter (see section 3.3.5.4.1), the replacement requirements are greater than the fleet build-up requirements.

3.3.5.4 Architecture Evaluation

The Reference Architecture provides a benchmark for the defined methodologies and potential replacement architecture assessments. Therefore, discussion of attribute values, the Space Shuttle's contribution to those values, and increased asset requirements to meet various scenarios is presented.

Increased assets that enable the Reference Architecture to meet ETO requirements include a Titan IV launch pad, Space Shuttle Orbiters, and an MLP. The operations models indicate that all scenarios require an additional Titan IV pad on the west coast in 1999 to support defined DOD flights. Additional Space Shuttle Orbiters and MLP's to support scenarios which include SSF ("If" C through E-high). Annual flight rates in "If's" A and B do not require additional Orbiters or MLP's. The Orbiter fleet must increase from four to five in 1996 ("If's" C through E-high), from five to six ("If" D through E-high) in 2000, and from six to seven ("If" E-high) in 2007. One additional MLP is required in 2003 for "If's" D through E-high. Additional Orbiters are also required to compensate for probable vehicle loss due to catastrophic failures (two in "If" A, three in "If" B, six in "If" C, seven in "If's" D and E-low, and eight in "If" E-high).

3.3.5.4.1 Attribute summary

a. Human Safety – Figure 3.3.5.4.1-1 shows the projected number of crew loss events (to the nearest tenth) by "If" for this architecture. The probability of crew loss (0.02235) is solely attributable to the Space Shuttle, as it is the only personnel system in this architecture. This value projects a crew loss event every 44 to 45 flights. Actual experience resulted in a crew loss event on the 25th Space Shuttle flight. Through the end of calendar year 1992 there has been 1 crew loss in 52 launches, for a demonstrated value of 0.019231.

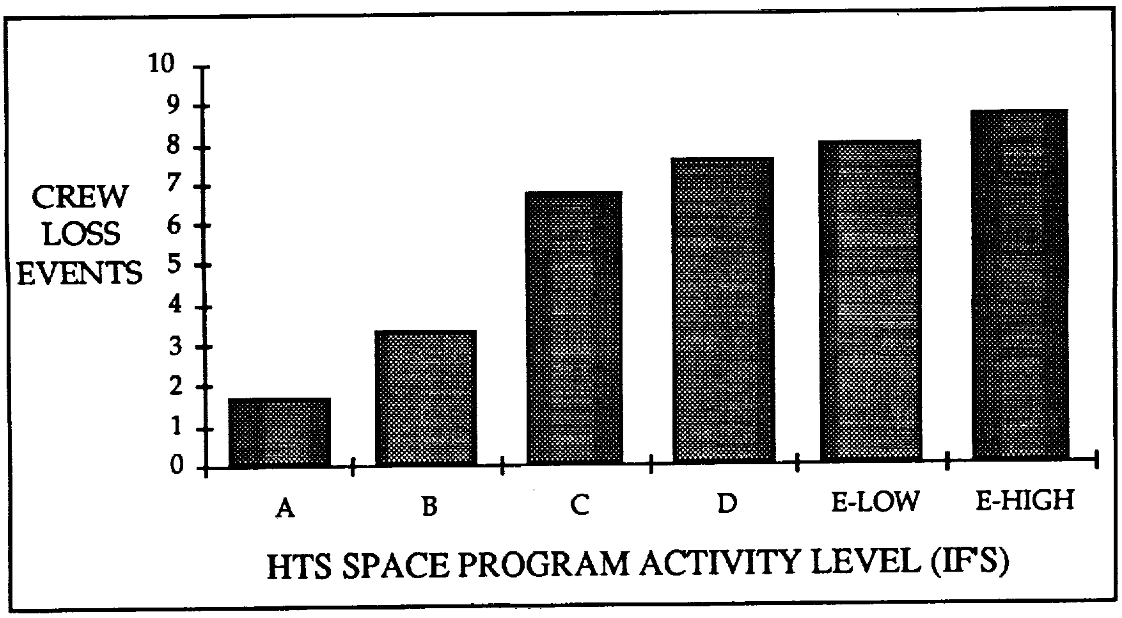


Figure 3.3.5.4.1-1.– Projected crew losses through 2020.

b. Funding Profile – Projected total architecture cost values and peak year funding requirements are shown in Figure 3.3.5.4.1-2. Since expendable vehicle flight rates in this architecture are constant across all "If's", increased cost values are directly related to the increase in Space Shuttle flights as space program activity increases from "If" A to "If" E-High. The Space Shuttle's contribution to the Total Architecture Costs by "If" is shown in Table 3.3.5.4.1-1.

c. Probability of Mission Success – Table 3.3.5.4.1-1 shows the architecture PMS value for each "If", which ranges from a low of 0.9317 ("If" A) to a high of 0.9354 ("If" E-High) and is directly attributable to the increased number of Space Shuttle flights for each successive "If". System PMS values, flight rates, and system contributions to the Architecture PMS for each "If" are shown also. The Architecture PMS value varies by less than one hundredth of a point across the time period of the study. Thus, any replacement system with a significantly different PMS should be readily discernible when viewing the annual PMS values.

TABLE 3.3.5.4.1-1.– SYSTEM CONTRIBUTIONS TO ARCHITECTURE PMS VALUES

SYSTEMS	Pms	IF A Flts	IF A Pms*Flts / Total Flts	IF B Flts	IF B Pms*Flts / Total Flts	IF C Flts	IF C Pms*Flts / Total Flts
Atlas E	0.9326	2	0.002891	2	0.002601	2	0.002146
Atlas I	0.9326	4	0.005783	4	0.005202	4	0.004292
Atlas IIAS	0.9326	88	0.127238	88	0.114461	88	0.094440
Delta II	0.9319	192	0.277402	192	0.249546	192	0.205897
Titan II	0.9626	42	0.062680	42	0.056386	42	0.046523
Titan III	0.9307	1	0.001442	1	0.001298	1	0.001071
Titan IV/NUS	0.9307	142	0.204898	142	0.184322	142	0.152082
Titan IV/Centaur	0.9100	98	0.138263	98	0.124379	98	0.102623
Space Shuttle	0.9431	76	0.111124	148	0.249546	300	0.325581
Architecture Total	———	645	0.9317	717	0.9329	869	0.9347

SYSTEMS	Pms	IF D Flts	IF D Pms*Flts / Total Flts	IF E-LOW Flts	IF E-LOW Pms*Flts / Total Flts	IF E-HIGH Flts	IF E-HIGH Pms*Flts / Total Flts
Atlas E	0.9326	2	0.002056	2	0.002014	2	0.001946
Atlas I	0.9326	4	0.004112	4	0.004028	4	0.003893
Atlas IIAS	0.9326	88	0.090483	88	0.088627	88	0.085666
Delta II	0.9319	192	0.197271	192	0.193223	192	0.186769
Titan II	0.9626	42	0.044574	42	0.043660	42	0.042201
Titan III	0.9307	1	0.001026	1	0.001005	1	0.000971
Titan IV/NUS	0.9307	142	0.145710	142	0.142720	142	0.137953
Titan IV/Centaur	0.9100	98	0.098324	98	0.096306	98	0.093089
Space Shuttle	0.9431	338	0.351452	357	0.363592	389	0.382949
Architecture Total	———	907	0.9350	926	0.9352	958	0.9354

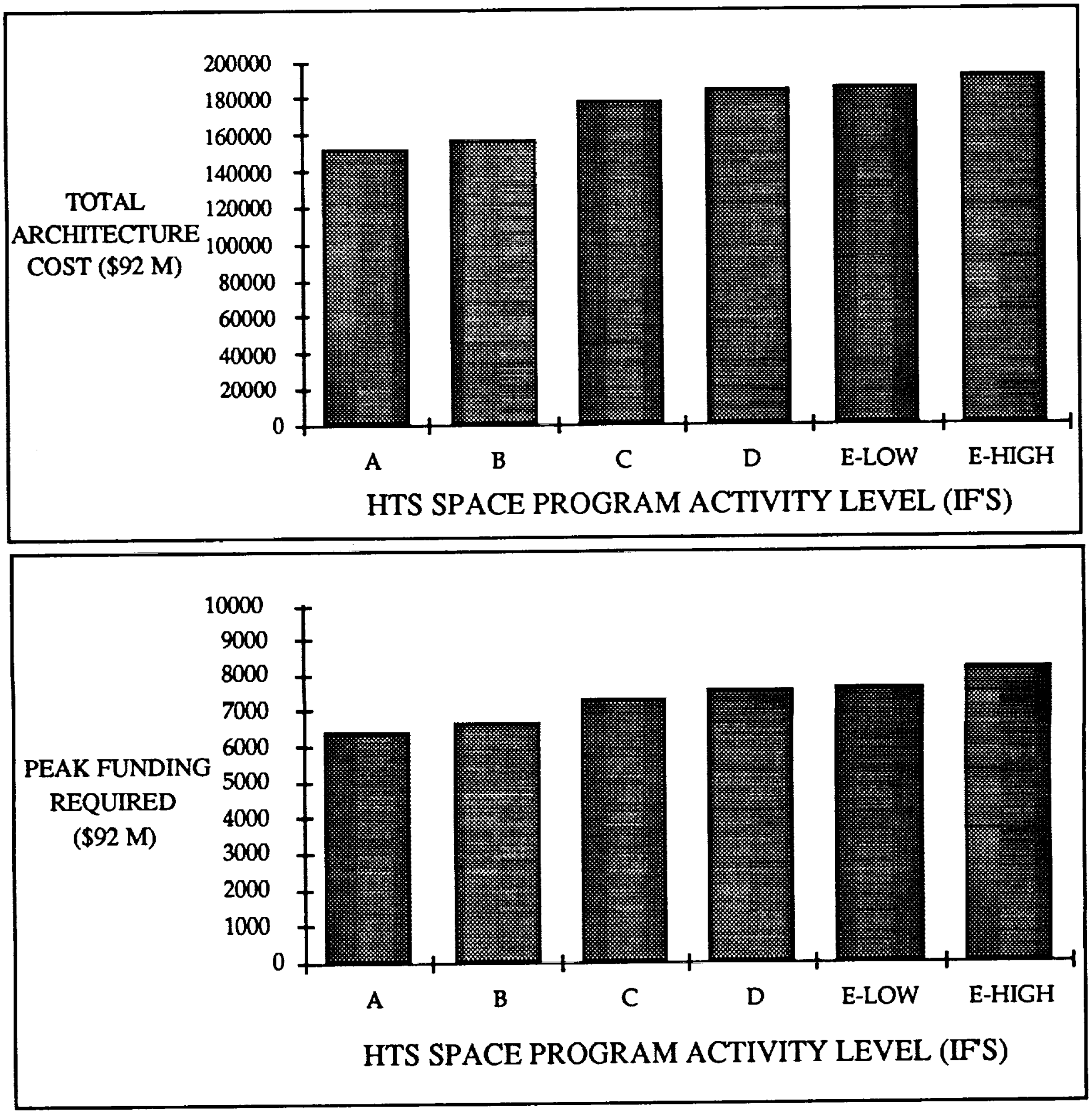


Figure 3.3.5.4.1-2.– Total architecture cost and peak year funding requirement.

d. Architecture Cost Risk – Total values for the Technical Challenge sub-attribute of ACR are shown in Figure 3.3.5.4.1-3. The values associated with "If's" A and B represent the minimum values achievable, since each system in this architecture for those "If's" is currently in operation and, therefore, has zero risk. The change in the risk level for "If's" C and above is attributable to the ACRV program. Program Immaturity for the Reference Architecture has a value of one, reflecting the fact that all launch systems are operational throughout the architecture time frame. There is, however, one new system in this architecture for "If's" C through E-high, namely, the ACRV. Thus, the New System subattribute value for those "If's" has a value of one. These values were developed by consensus using the scale defined in section 3.2.5.

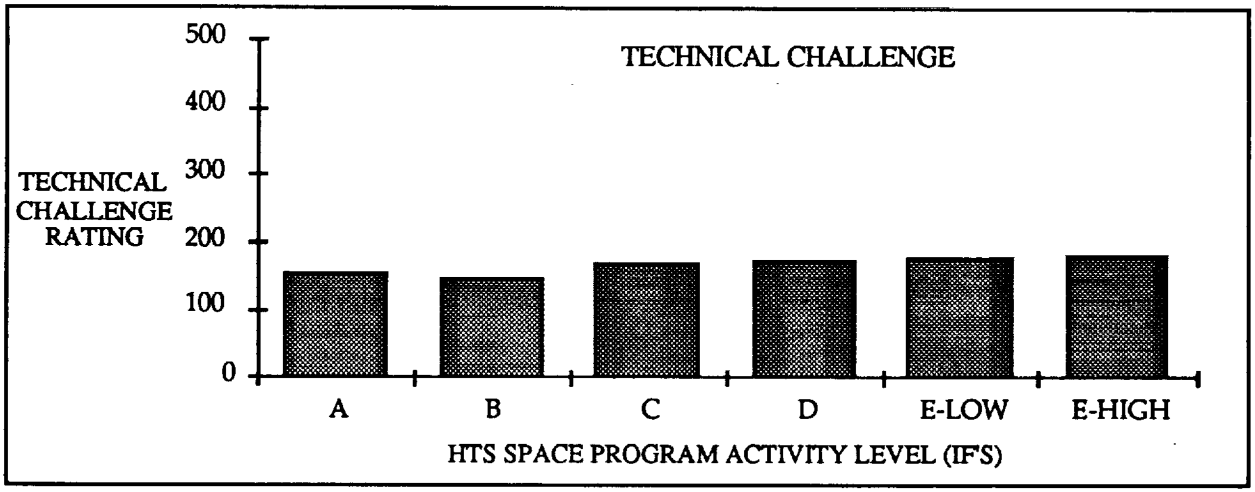


Figure 3.3.5.4.1-3.– Reference architecture subattribute technical challenge value.

e. Launch Schedule Confidence – Operational considerations for the HTS architecture comparison are contained in this attribute, which consists of three sub-attributes: Schedule Compression, Schedule Margin, and Launch Delays. Schedule Compression reflects the amount of time that system processing can be shortened through maximizing personnel utilization; by extending shift durations up to 50 percent and working shifts which are not part of the nominal processing plan. The Reference Architecture can achieve slightly less than a 50 percent reduction in processing clock time (Figure 3.3.5.4.1-4). Schedule Margin indicates how many additional launches can be made using existing assets at nominal processing schedules. The evaluation of the Reference Architecture indicates that an additional four to six flights per year across all systems could be flown using assets required to meet the peak requirements from 1992 through 2020. The analysis indicates that launch delays due to unscheduled maintenance actions would occur on 7 to 12 percent of the scheduled flights between 1992 and 2020.

f. Environment – Figure 3.3.5.4.1-5 shows the relative environmental impact the Reference Architecture has, based on nozzle effluents. These data only have relevance as a reference for other architectures within this study. They should not be used as absolute indicators of damage to the environment. Using "If" C (SSF remains at PMC) as a comparative reference: "If" A has about half the impact, "If" B has 67 percent of the impact, "If" D is 8 percent greater, "If" E-Low is 12 percent greater, and "If" E-High is 19 percent greater. The biggest contributor in all but "If" A is the Space Shuttle, with its contribution to the total growing from 48 percent in "If" B to 71 percent in "If" E-high. Titan contributes the largest percentage of the value in "If" A, accounting for 56 percent of the total.

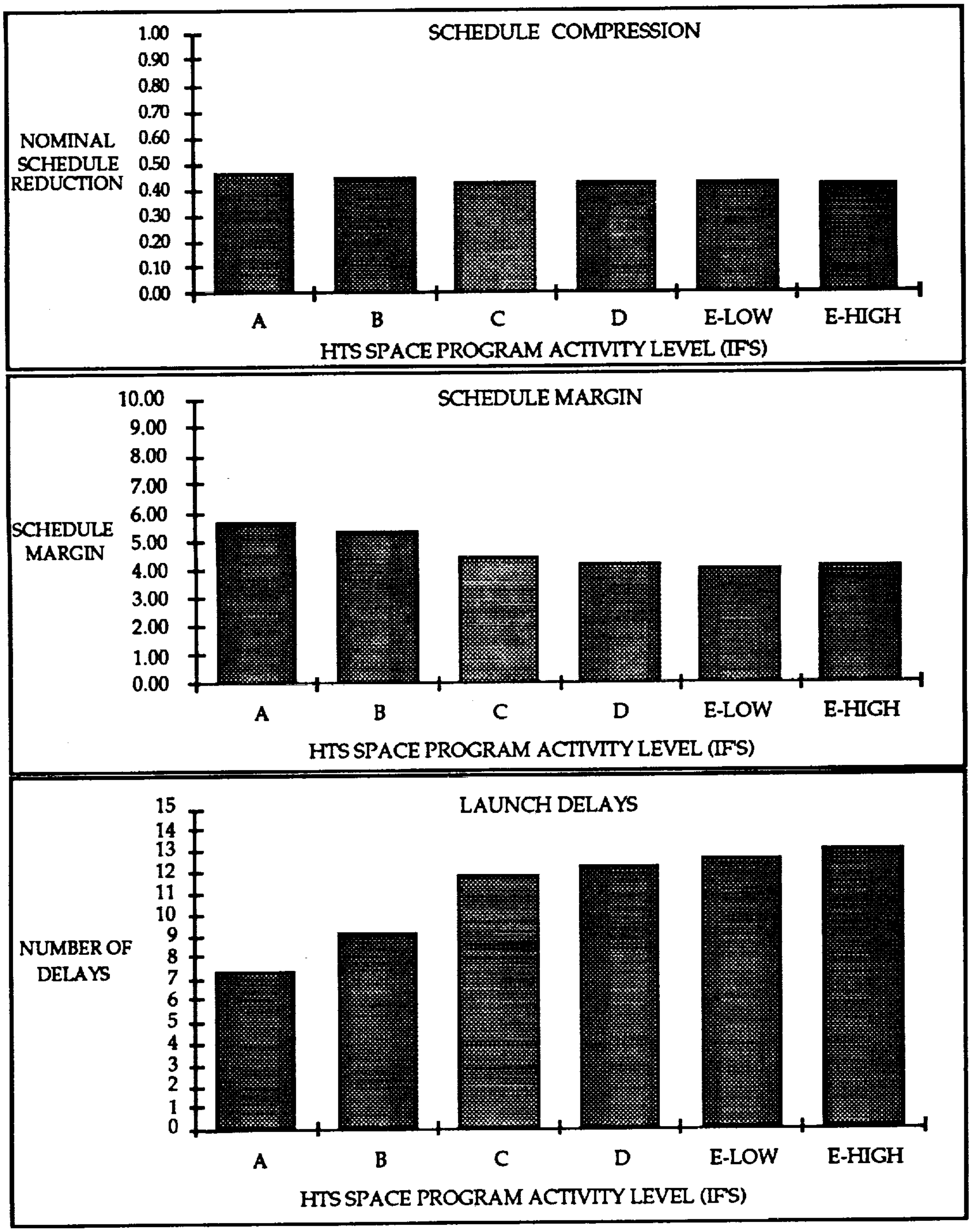


Figure 3.3.5.4.1-4.– LSC subattribute values for schedule compression, schedule margin, and launch delays due to unscheduled maintenance actions.

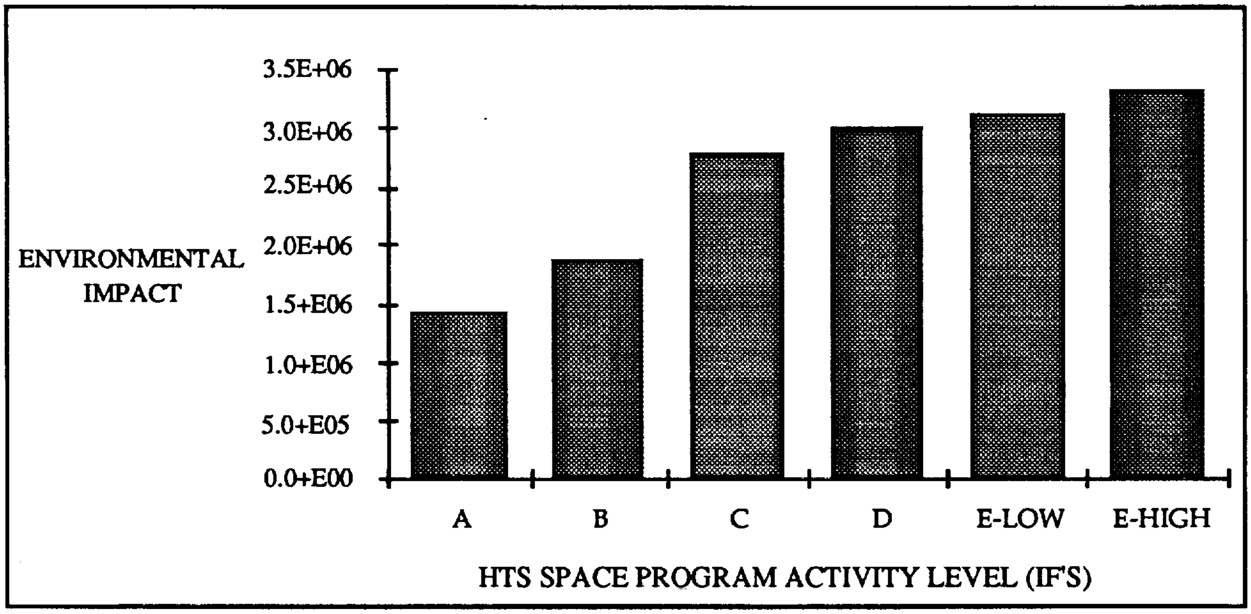


Figure 3.3.5.4.1-5.– Environmental impact attribute values.

3.3.5.4.2 Final scoring.- Figure 3.3.5.4.2-1 shows a stacked bar chart, delineating each attribute in its unweighted and weighted proportions. Comparing the unweighted to weighted scores for this architecture shows that the weighting factors increase the importance of Funding Profile and Human Safety while decreasing the importance of ACR, LSC, and Environment. It appears as though the attribute weights had minimal impact on the relative contribution of PMS.

3.3.5.4.3 Analysis of score.- Reference Architecture and attribute scores provide a basis for comparison with other architectures defined to address specific considerations. As such, it is not possible to say if they are good or bad. The Reference Architecture received a total score of 40 to 55 out of 100 for the various scenarios considered. Architectures with higher scores than the Reference within a specific "If" are deemed to be better than the Reference and may be viable alternatives for the future. However, these scores are highly dependent upon the chosen utility curves and relative weights of each attribute. Therefore, one must examine specific attribute values and total score sensitivity to attribute weightings before discarding or promoting specific architectures. It is possible to conclude that the nation finds the attribute values associated with the Reference Architecture as acceptable consequences, since the operation is continued.

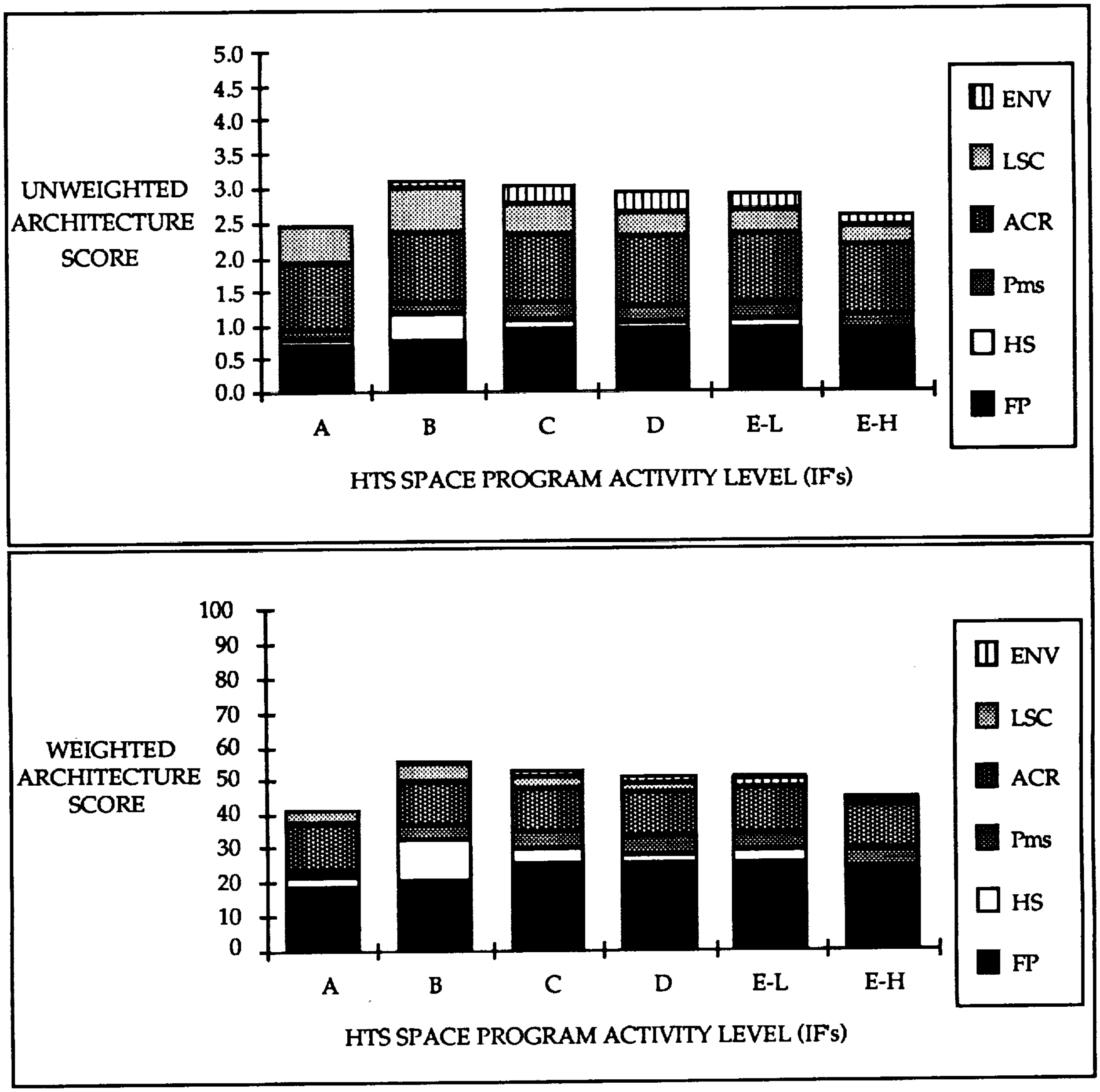


Figure 3.3.5.4.2-1.– Attribute score and weighting contributions to final score.

3.3.6 Shuttle Evolution - Architecture Option 2

A viable way to increase capacity, improve capabilities, or provide more options at low cost is by modifying existing systems. Examples abound in military and commercial aircraft (e.g., B-52, B-1, Boeing 727 and 747, Airbus 300, etc.). The Shuttle Evolution architecture employs this principal to enhance the capabilities of the Space Shuttle, Atlas, Delta and Titan launch systems. Since all systems, except Delta, incorporate evolutionary characteristics, the architecture title Shuttle Evolution is something of a misnomer. This architecture was devised to show how well current systems could handle future space activity requirements if they were improved along a pre-defined path. Evolutionary aspects were not optimized based on initial architecture evaluations or single attribute measurements.

3.3.6.1 Description

As in the Reference Architecture, Shuttle Evolution consists of current operational systems (see Figure 3.3.5.1-1). However, specific performance and operational characteristic enhancements are incorporated, beginning in 2000. Outward appearance changes for Evolution include the replacement of solid motors with liquid boosters on the Space Shuttle and an increase in the Titan IV core diameter from 10 to 14 feet. Specific improvements in each system are described below and in Table 3.3.6.1-1.

Space Shuttle improvements include ET and Orbiter modifications, replacement of solid rocket motors (SRM's) with LRB's, crew ejection capability, and operational flow reductions. Additionally, an unpiloted RCV has been added to the Space Shuttle fleet. This element is a new vehicle with the Orbiter's outer mold line, a unique pressurized volume for the avionics, and redistributed subsystems for center-of-gravity improvements. Its enhanced characteristics allow it to deliver up to 80 klbs to SSF. The impetus for developing the RCV is that it allows untended cargo to be delivered to orbit without using a piloted vehicle, and yet makes full use of the in-place Space Shuttle infrastructure and its fixed-cost base. After evaluation, a second Shuttle Evolution was defined which used hybrid rocket boosters (HRB's) instead of LRB's and incorporated a crew escape module (CEM) in the piloted orbiters. The CEM Orbiters were introduced by replacing the entire existing fleet with the new design. Old orbiters were converted to unpiloted orbiters rather than building new RCV's.

Atlas improvements include reductions in processing flow times and modifications to the Centaur upper stage. These changes reduce prelaunch pad time from 42 to 23 days. Thirty-seven work days with one shift each are reduced to 20 days, also with one shift. The remaining 5 days are reduced to 3 days by going to 24-hour work days at the equivalent of 1.75 shifts per day. On the Centaur, two RL-10 engines have been replaced with a single, higher thrust, RL-10 derivative.

TABLE 3.3.6.1-1.– SYSTEM IMPROVEMENTS IN EVOLUTION ARCHITECTURE

SYSTEM ENHANCEMENTS	BRIEF EVOLUTION CONCEPT DESCRIPTION
Space Shuttle	
Fleet-wide	
Light Weight External Tank	3000 Lbs Weight Reduction
LRB's	LOX/RP; 4 Engines per Booster; Engine Out Each Booster
SSME Limited to 100%	Increased Engine Reliability and Operational Life
Single-Launch I-Loads	Reduction in Nominal Payload and Mission Operations Costs
After Major Modification	
LDO	90-Day On-Orbit Capability to Support Man-Tended SSF Operations
Advanced Thermal Protection System	Reduced Maintenance Items Between Flights
New Vehicles Only	
Light Weight Orbiter	5000 Reduction in Orbiter Weight Due To Material Changes
Electromechanical Actuators	Elimination Of Hydraulic Actuation System
Ejection Seats (8)	Four Seats in Upper and Lower Flight Deck
Reusable Cargo Vehicle	Orbiter Mold Line with Special Pressurized Compartment for Avionics and Redistributed Subsystems for CG Improvement
Atlas	
Reduced Processing Time	Removes Centaur from Critical Flow Path
Single-Engine Centaur	Improves Overall Centaur Stage Reliability; RL-10 Thrust Increased
Titan IV	
14-Ft Diameter Core	Provides Increased Lift Capability - Maintains SRMU'S

The Titan IV evolution concept consists of a 14-ft diameter core, versus the current 10-ft diameter. It retains the two SRMU strap-ons to provide lift-off thrust. This concept also includes modifications to the facilities and a reduction in operational flow times. Performance is increased from 37.7 (28.5 x 160 nmi circular) for Titan IV to 62.1 for Titan Evolution.

3.3.6.2 Manifesting Philosophy

Payloads were manifested following the same basic principles employed in the Reference Architecture: Space Shuttle and Shuttle Evolution captured all human-tended missions, SSF payloads, and return requirements. Untended payloads were preferentially manifested on ELV's. The major difference between this architecture and the Reference is the existence of the RCV as part of the Shuttle Evolution system, which was used for all SSF payloads except crew rotation and SSF "Facility" payloads. Since RCV's role was limited to SSF support, it does not appear in the architecture for "If's" A or B.

3.3.6.3 Manifesting Results

The ELV flights remain constant for all activity levels ("If's"), with Space Shuttle/Shuttle Evolution increasing from 76 to 396 (Table 3.3.6.3-1). RCV accounts for 83 Space Shuttle flights in "If" C and 97 in "If's" D through E-High. Annual flight rates for Space Shuttle/Shuttle Evolution stay below five per year in "If's" A and B. For "If's" C through E-high, the peak Space Shuttle/Shuttle Evolution flight rate increases from 13 to 17.

Relative to the Reference Architecture, total ELV flights are unchanged except that two-thirds to three-fourths of them are now on evolved systems. The Space Shuttle, however, has considerable changes in its total flights, except in "If" A, which has the same total as the Reference with two-thirds being on Shuttle Evolution. Counting Space Shuttle, Shuttle Evolution and RCV flights, there are eight fewer flights in "If" B, 27 more in "If" C, and seven more in "If" D through "If" E-High. On the other hand, the number of human-tended flights is reduced by 0, 8, 56, and 90 for "If's" A, B, C and D through E-High, respectively. The decrease in flights within "If" B relative to the Reference results from increased lift capability of Shuttle Evolution. However, for "If's" C through E-High, the increase in Space Shuttle System flights relative to the Reference Architecture is driven by the manifesting process. The RCV was manifested first, ensuring that its payload bay was full every time it flew. Orbiter flights were forced to fly four crew exchange missions per year, splitting no more than a full RCV cargo bay over four Space Shuttle flights. This utilized about 20 percent of the Orbiter's capacity, on average. Reversing this strategy, i.e., filling the four Orbiters to capacity on crew exchange flights and using the RCV only for what remains, could reduce total flights to SSF by one or two per year.

The alternate Shuttle Evolution Architecture had an increase of nine Space Shuttle system flights (327 to 338) due to the lower performance of the CEM Orbiter and Unpiloted Orbiter relative to the Orbiter and RCV for "If" C. Unpiloted flights remained unchanged at 83; Orbiter flights increased from 97 to 99; and 147 Evolution Orbiter flights increased to 156 CEM Orbiter flights.

TABLE 3.3.6.3-1.- EVOLUTION ARCHITECTURE SYSTEM FLIGHT SUMMARY

SYSTEM	EAST		WEST		TOTAL	SUPER TOTAL
	NASA	DOD	NASA	DOD		
Atlas I	4				4	4
Atlas E			1	1	2	2
Atlas IIAS	5	25			30	
Atlas Evolution	19	39			58	88
Delta II	8	33	6	6	53	
Delta Evolution	30	78	4	27	139	192
Titan II			3	39	42	42
Titan III	1				1	1
Titan IV/Centaur	7	17			24	
Titan Evolution/Centaur	35	39			74	98
Titan IV/NUS		20	4	18	42	
Titan Evolution/NUS		41	20	39	100	142
Space Shuttle - "If" A	18	8			26	
Shuttle Evolution	29	21			50	76
RCV						
Space Shuttle - "If" B	55	8			63	
Shuttle Evolution	56	21			77	140
RCV						
Space Shuttle - "If" C	89	8			97	
Shuttle Evolution	126	21			147	
RCV	83				83	328
Space Shuttle - "If" D	93	8			101	
Shuttle Evolution	126	21			147	
RCV	97				97	345
Space Shuttle - "If" E-Low	93	8			101	
Shuttle Evolution	145	21			166	
RCV	97				97	364
Space Shuttle - "If" E-High	93	8			101	
Shuttle Evolution	177	21			198	
RCV	97				97	396

Facility and reusable element requirements have been estimated based on the required flight rates generated by the manifesting process, vehicle processing times, and facility dwell times. Table 3.3.6.3-2 lists the quantities for each system element comprising Architecture 2. Each system's flight and facility elements are listed in the left hand column.

The column labeled "exist" indicates the number of each facility in 1992. Entries in the "Growth" columns indicate the additional number of elements needed to meet the required flight rate. "Replacement" entries tell the reader how many reusable flight elements are required to offset probable losses due to catastrophic failure.

TABLE 3.3.6.3-2.– FACILITY AND REUSABLE ELEMENT REQUIREMENTS

ARCHITECTURE ELEMENT	EXIST	GROWTH						REPLACEMENT					
		A	B	C	D	E-L	E-H	A	B	C	D	E-L	E-H
Shuttle													
Orbiter	4			1	1	1	1	1	1	1	1	1	1
Evolved Orbiter								2	2	4	4	4	5
Reusable Cargo Vehicle				2	2	2	2			2	3	3	3
Mobile Launch Platforms	3												
Launch Pads	3												
Orbiter Processing Facility	2												
Vertical Integration Cells	2												
Atlas													
Booster Processing Facility	3												
Centaur Processing Facility	1												
Hazardous Processing Facility	1												
Launch Pads - East	2												
Delta													
Booster Processing Facility	3												
Launch Pads - East	2												
Launch Pads - West	1												
Titan III/IV													
Vertical Integration Building Cells	4												
Solid Motor Assembly Building Cells	5												
Titan Transporter	4												
Launch Pads - East	2												
Launch Pads - West	1	1	1	1	1	1	1						
Titan II/IIS													
Vertical Integration Building Cells Shared with Titan III/IV	0												
Solid Motor Assembly Building Cells Shared with Titan III/IV	0												
Titan IIS Transporter	0												
Launch Pads - East	0												
Launch Pads - West	1												

3.3.6.4 Architecture Evaluation

Overall, the Evolution Architecture scores better than the Reference, except in "If's" A and B. This is primarily due to the reduction in crew loss events caused by the introduction of the RCV. In addition, Environmental values for the Evolution Architecture are significantly reduced since the Space Shuttle SRB's were replaced by hydrogen and oxygen LRB's.

The Reference Architecture scored better in "If's" A and B because without SSF there is no need for the RCV, hence, no reduction in crew loss events. There is a reduction in the Environmental Impact values but not enough to overcome the increase in Funding Profile. In fact, the Reference fairs better across all "If's" in Funding Profile, ACR, and LSC. Environmental Impact (the lowest weighted attribute) is the only attribute where the Evolution Architecture consistently outscores the Reference.

PMS is higher for the Reference in "If's" C through E-High because Shuttle Evolution's PMS decreased due to the addition of LRB's. On the other hand, in "If's" A and B, the Evolution Architecture faired better because Centaur modifications for Atlas and Titan IV increased their PMS. This, along with Atlas and Titan having a greater percentage of total flights at these activity levels, raised the Architecture PMS with respect to the Reference.

The Evolution Architecture scores can be improved in two ways: remanifest SSF payloads so that the Orbiter's payload bay is full during crew exchange missions and redefine Shuttle Evolution to provide greater crew abort capability or higher PMS.

3.3.6.4.1 Attribute summary

a. Human Safety – Figure 3.3.6.4.1-1 shows the projected number of crew loss events (to the nearest tenth) by "If" for this architecture and the Reference Architecture. The probability of crew loss is 0.02235 for the Space Shuttle and increases to 0.02278 for Shuttle Evolution. These values equate to a crew loss event every 44 to 45 (44.7) flights for Space Shuttle and 43 to 44 (43.9) for Shuttle Evolution. Changes in Shuttle Evolution definition to used HRB's instead of LRB's, and the incorporation of the CEM, decreased crew loss events by 0.7 (4.8 to 4.1) on over 150 flights compared to a 1.9 reduction (6.7 to 4.8) realized by adding the RCV to the fleet.

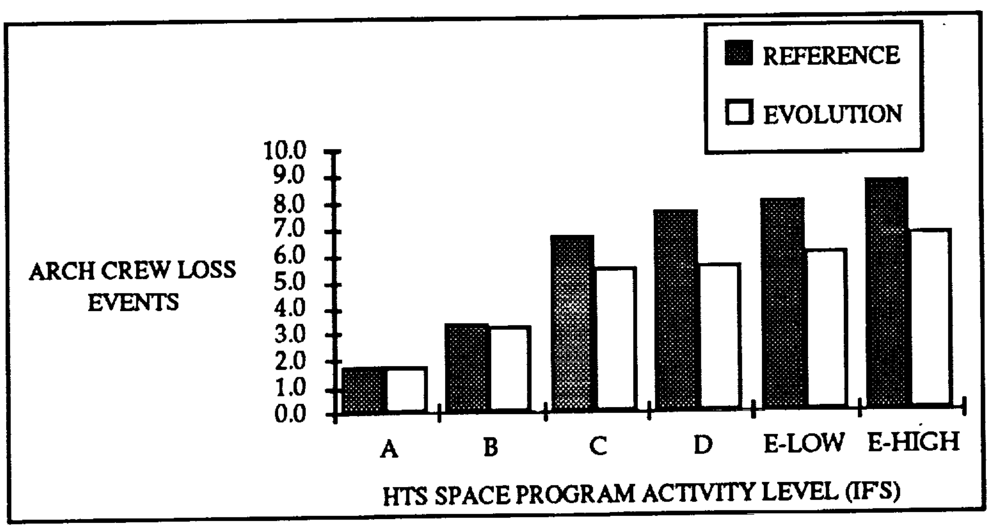


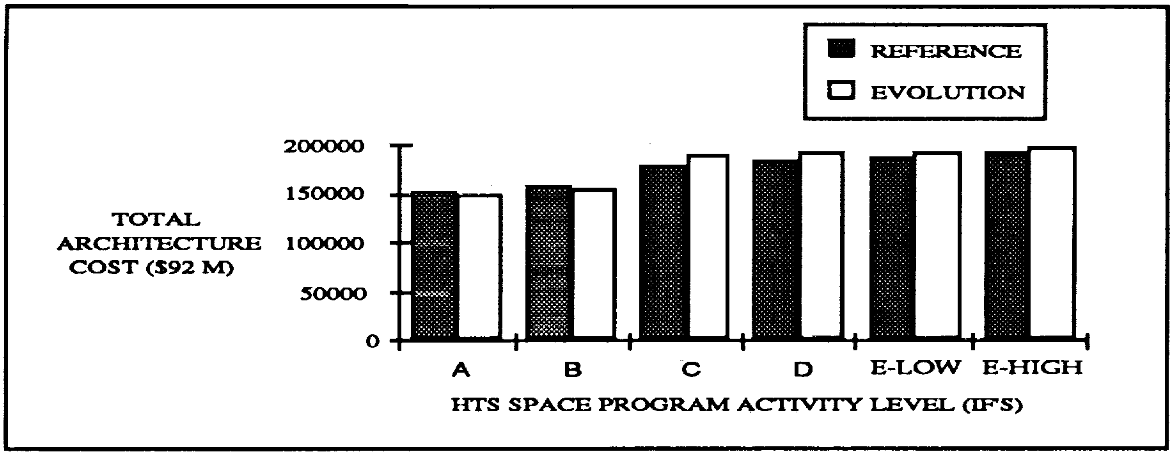
Figure 3.3.6.4.1-1.– Projected crew losses through 2020.

Even with this higher rate, projected crew loss events are lower for the Evolution Architecture due to the addition of the untended RCV, which is used to support SSF. The increase in probability of crew loss events is driven by the PMS, discussed in the next paragraph, and mitigated by Shuttle Evolution characteristics with regard to crew survivability. Specifically, these include the ability to shutdown LRB's during the boost phase and the addition of ejection seats in the Orbiter, and the addition of RCV to the Space Shuttle vehicle fleet. The ability to shut down the LRB's and the addition of ejection seats just offset the increase in mission failures attributed to the LRB's, as can be seen by the similar crew loss events for "If's" A and B. The reduction in piloted missions resulting from the addition of RCV is primarily responsible for the reduction in crew loss events in "If's" C through E-high.

b. Funding Profile – Projected total architecture cost values and peak year funding requirements are shown in Figure 3.3.6.4.1-2. Since expendable vehicle flight rates in this architecture are constant across all "If's", increased cost values are directly related to ELV and Shuttle Evolution costs and the increase in Space Shuttle system flights as space program activity increases from "If" A to "If" E-High. The increase in Total Architecture Cost incurred to implement the alternate evolution concept is approximately $16B in 1992 dollars. This increase is about equally split between DDT&E and fleet replacement.

c. Probability of Mission Success – Figure 3.3.6.4.1-3 shows the architecture PMS for each "If" relative to the Reference Architecture. The absolute value is somewhat higher than the Reference Architecture for "If's" A through C and is lower for "If's" D through E-High. Actual PMS values for this architecture range from 0.9347 ("If" E-High) to 0.9360 ("If" B). This is a function of the relative number of reference and evolution flights for each system, especially within the Space Shuttle system (including RCV). The decrease in PMS from "If" B to "If" E-High is driven by Shuttle Evolution's lower value relative to Space Shuttle and the constant ELV flight rates across "If's". System PMS values, flight rates, and contributory portions for each "If" are shown in Table 3.3.6.4.1-1. For the alternate Shuttle Evolution definition, PMS recovers about half the decrease it experienced between Space Shuttle and Shuttle Evoluation.

d. Architecture Cost Risk – Values for ACR, and each of its subattributes (technical challenge, program immaturity, and number of new systems) are shown in Figure 3.3.6.4.1-4. These values were developed by consensus, using mathematical processes and scales defined in section 3.2.5. Overall risk associated with this architecture is low, as there are no new technology or major operational philosophy changes. The attribute value comes for modifying three of four systems and operating an automated reusable element. This architecture ranks second-highest in all "If's", except A and B. This is expected as all new elements are based on current operational systems. There is an insignificant difference in ACR between the two architectures featuring different Shuttle Evolution approaches.



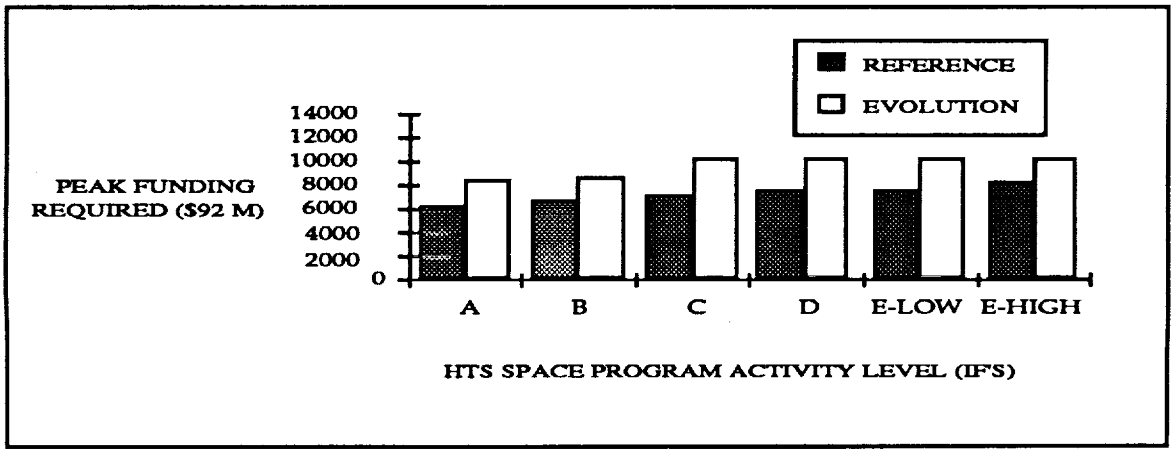


Figure 3.3.6.4.1-2.– Total architecture cost and peak year funding requirements.

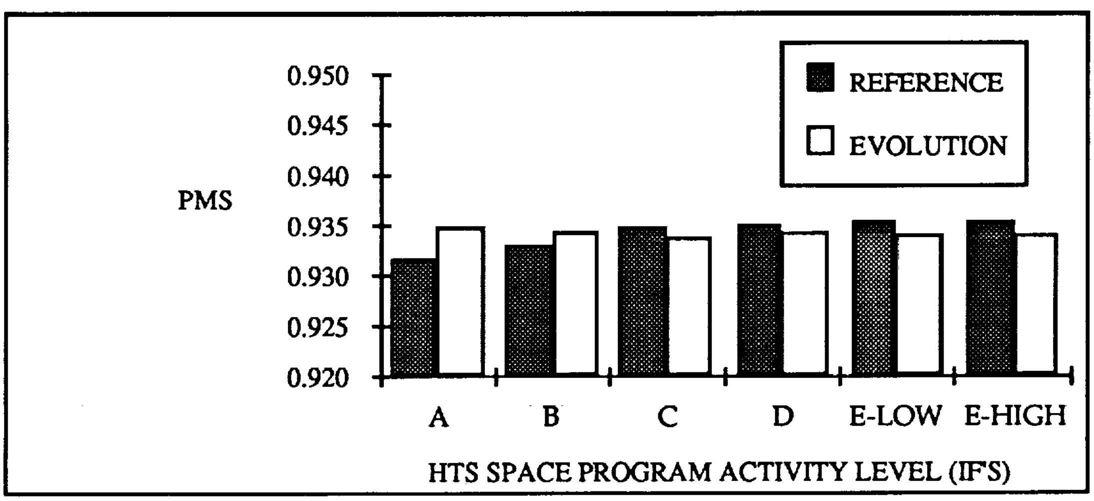


Figure 3.3.6.4.1-3.– PMS values.

TABLE 3.3.6.4.1-1.– SYSTEM CONTRIBUTIONS TO ARCHITECTURE PMS VALUE

		IF A		IF B		IF C	
SYSTEMS	Pms	Flts	Pms*Flts / Total Flts	Flts	Pms*Flts / Total Flts	Flts	Pms*Flts / Total Flts
Atlas E	0.9326	2	0.002892	2	0.002631	2	0.002082
Atlas I	0.9326	4	0.005784	4	0.005261	4	0.004163
Atlas IIAS	0.9326	30	0.043377	30	0.039461	30	0.031225
Atlas Evolution	0.9326	58	0.083862	58	0.076292	58	0.060369
Delta II	0.9319	53	0.076575	53	0.069662	53	0.055124
Delata Evolution	0.9319	139	0.200828	139	0.182700	139	0.144569
Titan II	0.9626	42	0.062681	42	0.057023	42	0.045122
Titan III	0.9307	1	0.001443	1	0.001313	1	0.001039
Titan IV/NUS	0.9307	42	0.060604	42	0.055133	42	0.043627
Titan Evolution	0.9519	100	0.147581	100	0.134260	100	0.106239
Titan IV/Centaur	0.9100	24	0.033860	24	0.030804	24	0.024375
Titan IV/Cent EVO	0.9166	74	0.105160	74	0.094979	74	0.075156
Shuttle	0.9431	26	0.038016	63	0.083802	97	0.102099
Shuttle Evolution	0.9290	50	0.072016	77	0.100893	147	0.152414
RCV	0.9290	---	-------	---	-------	83	0.086057
Architecture Total	———	645	0.9347	709	0.9342	896	0.9337

		IF D		IF E-LOW		IF E-HIGH	
SYSTEMS	Pms	Flts	Pms*Flts / Total Flts	Flts	Pms*Flts / Total Flts	Flts	Pms*Flts / Total Flts
Atlas E	0.9326	2	0.002041	2	0.001999	2	0.001933
Atlas I	0.9326	4	0.004081	4	0.003998	4	0.003866
Atlas IIAS	0.9326	30	0.030611	30	0.029987	30	0.028993
Atlas Evolution	0.9326	58	0.059180	58	0.057975	58	0.056053
Delta II	0.9319	53	0.054038	53	0.052938	53	0.051182
Delta Evolution	0.9319	139	0.141722	139	0.138836	139	0.134232
Titan II	0.9626	42	0.044233	42	0.043332	42	0.041896
Titan III	0.9307	1	0.001018	1	0.000998	1	0.000964
Titan IV/NUS	0.9307	42	0.042767	42	0.041896	42	0.040507
Titan Evolution	0.9519	100	0.104147	100	0.102026	100	0.098642
Titan IV/Centaur	0.9100	24	0.023895	24	0.023408	24	0.022632
Titan IV/Cent EVO	0.9166	74	0.074211	74	0.072699	74	0.070288
Shuttle	0.9431	101	0.104216	101	0.102093	101	0.098708
Shuttle Evolution	0.9290	147	0.149412	166	0.165288	198	0.190613
RCV	0.9290	97	0.098592	97	0.096584	97	0.093381
Architecture Total	———	914	0.9342	933	0.9340	965	0.9339

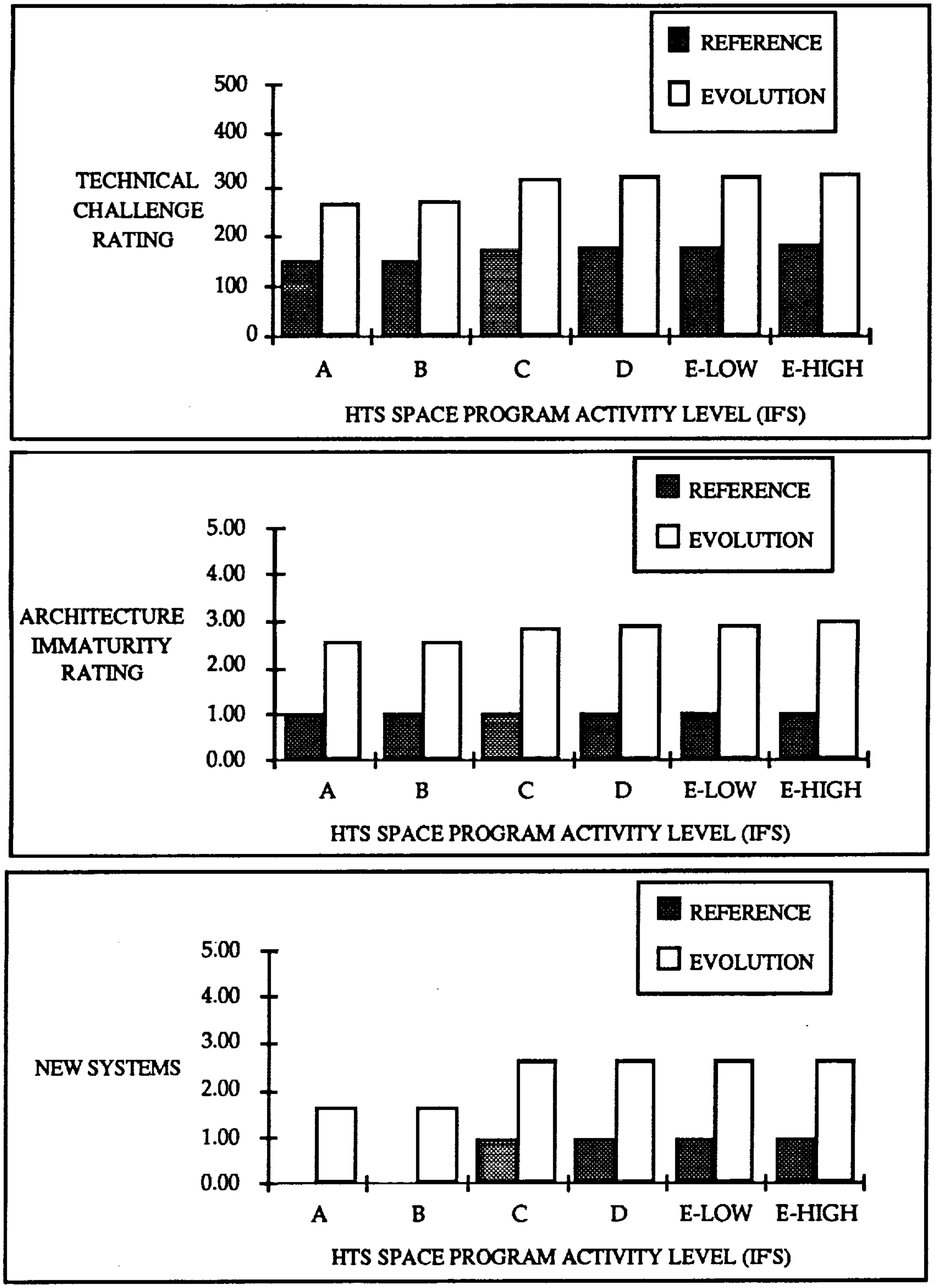


Figure 3.3.6.4.1-4.– ACR subattribute values for technical challenge, program immaturity and number of new systems.

e. Launch Schedule Confidence – Values for the attribute as a whole, and each subattribute are shown in Figure 3.3.6.4.1-5. Evolution's increase in LSC values is attributable to the increase in processing flow margins of the evolved systems (Atlas, Titan, and Space Shuttle). The increase in margins is primarily the result of increased system-lift capacity (fewer flights) and reduced processing times. There is some slight, but insignificant, change in schedule compression due to processing time and shift changes. Also, the projected number of unscheduled maintenance actions resulting in launch delays are virtually identical at this level of system definition. There is very little difference in LSC values associated with the two definitions for Shuttle Evolution.

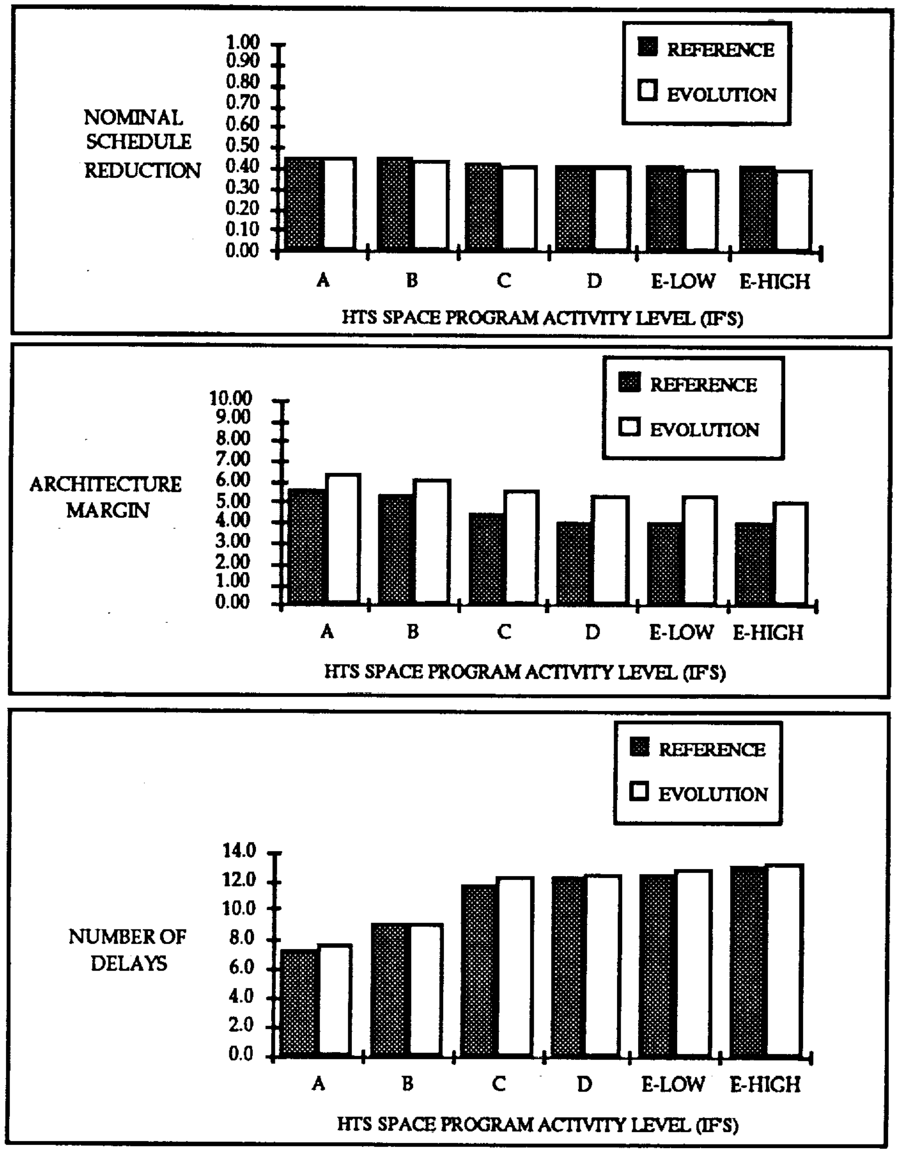


Figure 3.3.6.4.1-5.– Launch schedule confidence subattribute values for schedule compression, schedule margin, and launch delays.

f. Environment – The Evolution Architecture has about one-third the impact of the Reference Architecture, independent of mission activity level (Figure 3.3.6.4.1-6). A key to this reduction is replacement of the Space Shuttle SRB's with LRB's, although the advantage gained is offset in part due to the increased size of the Titan IV core stage. This reduction is significant and indicates that nozzle effluents should be a consideration for future launch system concepts. The two Shuttle Evolution definitions evaluated exhibited a minimal difference in Environmental Impact.

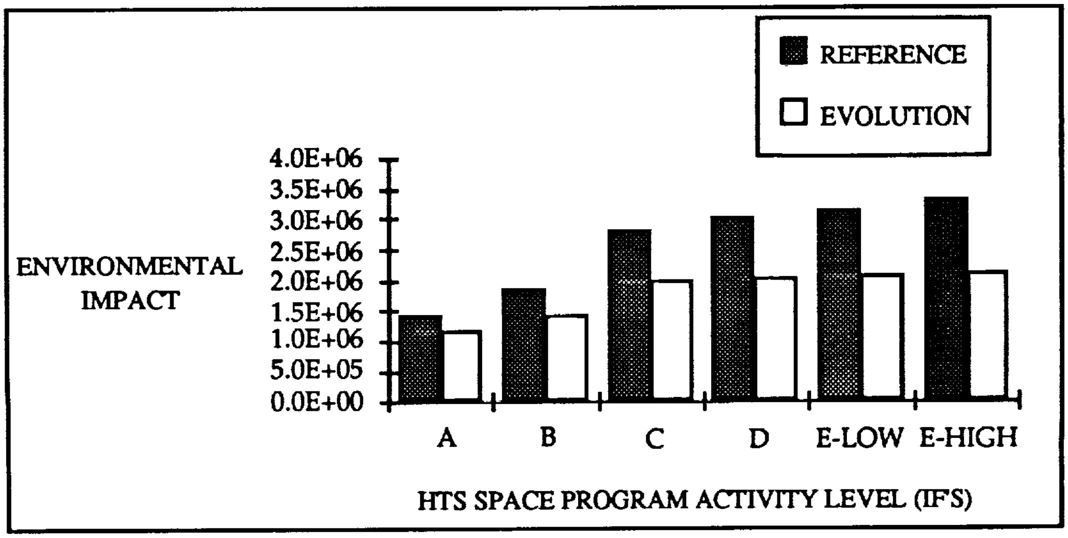


Figure 3.3.6.4.1-6.– Environmental impact attribute values.

3.3.6.4.2 Final Scoring.– Ordinal ranking of all architectures by "If" places the Evolution Architecture between fifth ("If's" C through E-Low) and ninth ("If" A). In "If's" B and E-High, this architecture is ranked sixth. Figure 3.3.6.4.2-1 shows the total weighted architecture score for each "If". To show how unweighted attribute scores compare to the weighted score, a stacked bar chart has been provided, delineating each attribute in its natural and weighted proportions (Figure 3.3.6.4.2-2).

Relative to the Reference Architecture, the Evolution Architecture clearly scores better within "If's" C through E-High, and is equivalent to the Reference for "If's" A and B. The reduction in crew loss events (about two out of seven) resulting from the introduction of the RCV is the biggest contributor to score improvement. Other attributes with improved values include LSC and Environmental Impact. For "If's" A and B, the improvement in crew loss events, PMS, LSC, and Environmental Impact were offset by the increases in Funding Profile and ACR.

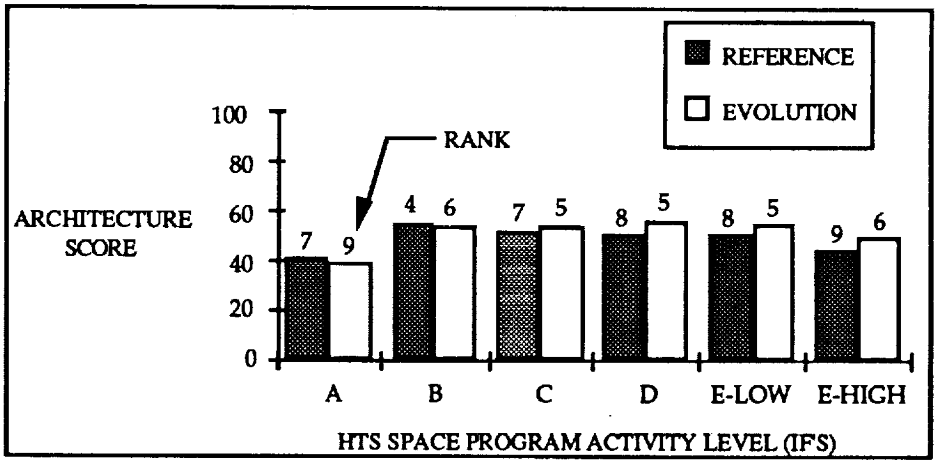
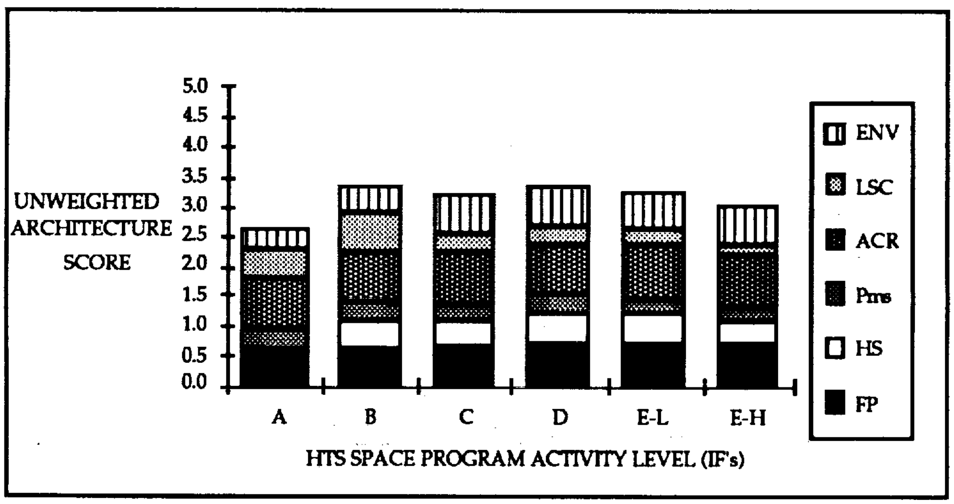


Figure 3.3.6.4.2-1.– Total architecture score and ranking.



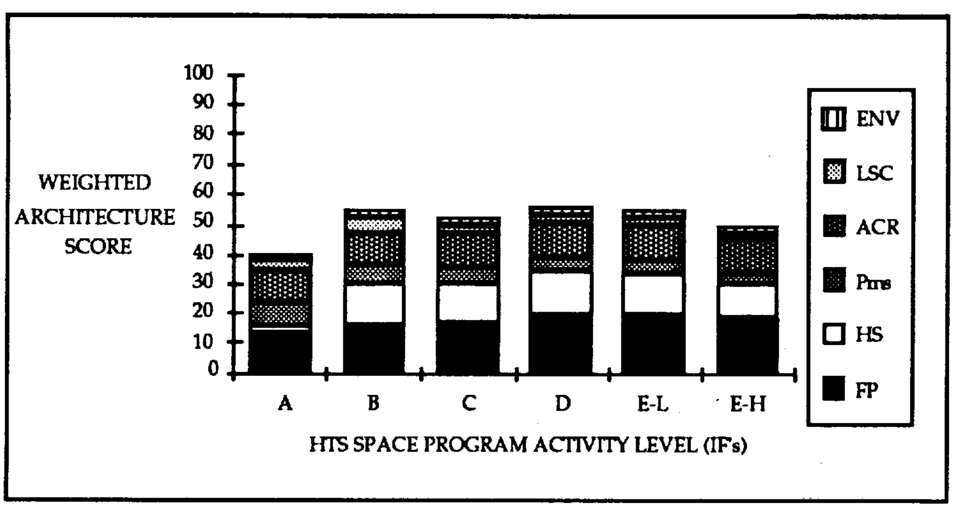


Figure 3.3.6.4.2-2.– Attribute score and weighting contributions to final score.

Figure 3.3.6.4.2-2 shows the impact that the relative attribute ranking has on the make-up of the architecture score.

Overall, the evaluation of the two distinct Shuttle Evolution concepts with regard to booster type and crew escape enhancements provided insignificant improvements in overall architecture scores.

3.3.6.4.3 Analysis of score.– Upon reviewing the architecture scores and their key contributors, Evolution comes out ahead of the Reference in two attributes: Human Safety, the highest weighted, and Environmental Impact, the lowest weighted. Funding Profile and ACR exhibit similar differences, with the Reference scoring higher. Launch schedule confidence scores are equivalent across all "If's", while PMS exhibits a reversal from "If" A to E-High. In "If's" A and B, PMS is significantly better for the Evolution Architecture, whereas, in "If's" C through E-High, Evolution and Reference scores are equivalent, with the Reference lower in "If" C and higher in "If" E-High.

Crew loss events are down because fewer human-tended missions are flown in the Evolution Architecture relative to the Reference. Almost all of the reduction in crew loss events can be attributed to introduction of the RCV. If PMS for Shuttle Evolution could be improved, it would add a great deal to the value of the Evolution Architecture, since the gains in crew safety due to LRB's and ejection seats are offset by the decrease in predicted PMS value for the system. This can be seen by comparing crew loss events in "If's" A and B. This requires further examination of the definition of Shuttle Evolution.

Environmental Impact scores are vastly improved because the solid motors on the Space Shuttle are replaced with LOX rocket propellant boosters. Titan Evolution reduces the potential improvement somewhat, due to its increase in core diameter and propellant load for improved performance. This increases Titan's Environmental Impact value by slightly more than 20 percent.

The analysis of two different Shuttle Evolutions indicated that crew losses were reduced (0.7 events or 41 percent) but at a substantial ($25 B or 12 percent) increase in cost. The customer needs to decide whether this should be spent to eliminate one projected crew loss event.

3.3.6.4.4 Conclusions and recommendations.– Although Shuttle Evolution was defined in a way that was believed to improve its PMS and Human Safety attributes, it turned out that its PMS was diminished. Fortunately, its Human Safety characteristics were enhanced so that it is about equal to that of the existing Space Shuttle. The underlying reason for the reduction in PMS is replacement of the SRB's with LRB's. The process for determining PMS uses historically-demonstrated reliability values for large solid motors, liquid engines, and liquid propulsion stages. Solid motors have the highest value, liquid engines have the next highest, and liquid stages have the lowest. By replacing the Space Shuttle solid motors with

LRB's, the system's PMS is significantly reduced during the initial ascent phases. Enhanced crew safety was realized because of the ability to shutdown and eject the LRB's during this same period, as well as the addition of ejection seats. As a result, the cost of Shuttle Evolution did not produce a net decrease in crew loss events since the enhanced crew safety features only offset the increased rate of mission failures.

It is recommended that the definition of Shuttle Evolution be revisited to ensure a net decrease in crew loss events. This may include retaining the SRB's, incorporating a frangible crew module in the Orbiter design, using hybrid boosters instead of liquid boosters, or using single-engine LRB's. The second Shuttle Evolution definition incorporated a crew escape module with full-ascent capability, and substituted HRB's for the LRB's. These changes provided very little in overall architecture evaluation but indicated that the cost is considerably more to reduce crew loss events by this means, than through the introduction of an unpiloted orbiter.

Finally, the manifesting philosophy should be revisited with regard to RCV and Shuttle Evolution for SSF payloads. It will be possible to reduce total Space Shuttle system flights by one or two RCV's per year simply by filling the Shuttle Orbiter cargo bay to capacity for crew exchange missions, thereby reducing mission failures and unreliability costs through the reduction of total flights.

3.3.7 Alternate Access – Architectures 1, 3, and 4 Compared

3.3.7.1 Description

As referenced in section 3.2.12, the desirability of Alternate Access was addressed through a set of comparative architectures, in addition to the attribute that was dropped at the mid-point of this study. The set of Architectures 1, 3, and 4 have been structured to provide this comparison. While there is a clear advantage to having an Alternate Access to space, it is difficult to *quantify* these benefits. With the programmatic decision not to conduct a Monte Carlo (or similar) mission loss simulation due to the cost and complexity involved, it was realized early-on that a direct comparison between the existing baseline (Architecture 1) and the "baseline plus (never used) Alternate Access" would address only the question of: "How expensive is Alternate Access?" A Monte Carlo simulation could have developed "probable costs" associated with Space Shuttle downtime and resulting forced evacuations of SSF due to lack of Alternate Access. Such costs could then have been used to offset the development costs of new systems. Past experience has indicated NASA's reluctance to invest money in low-probability-of-usage backup capabilities, with a preference to rely instead on making the primary system function as it should.

Consequently, the comparison architectures were prepared from the standpoint of simultaneously off-loading the Space Shuttle to reduce overall costs. First, in Architecture 3, up-cargo was off-loaded from the Space Shuttle as much as possible, using ELV's. In Architecture 4, *people* are also off-loaded from the Space Shuttle, by means of an RPC, and a cargo return vehicle (CRV) is provided to facilitate meeting down-cargo requirements. The specific selection of the Boeing biconic RPC with minimum cargo capacity, implicitly introduces a "separation of people and cargo" philosophy, which is treated in detail in Section 3.3.8. In both cases, the Space Shuttle must remain fully operational in order to provide the reserve, alternate access means, expensive as a result of high fixed costs with low flight rates, for those off-loaded capabilities, either people or cargo.

The ACRV remains the emergency return vehicle for the SSF crew in all cases. It would be rotated to and from SSF by the Space Shuttle under normal circumstances, for periodic maintenance.

3.3.7.2 Manifesting Philosophy

The three architectures have only the following common elements:

- The Space Shuttle remains operational through 2020.
- The ACRV is the SSF crew emergency return vehicle.

In Architecture 1:

- The Space Shuttle is improved through P^3I, and remains the primary vehicle for all human-related missions.

- All payloads to and from SSF go on the Space Shuttle.

- The Delta-Atlas-Titan family of ELV's preferentially carry payloads not requiring human presence.

- No new families of ELV's or personnel/cargo carriers are developed.

In Architecture 3:

- The Space Shuttle continues to carry all personnel and all return-cargo.

- The Space Shuttle handles only those delivery-cargo needs that cannot be carried on ELV's.

- The NLS-family of ELV's is introduced, replacing Atlas and Titan ELV's one (5-year) period after the introduction of NLS-3 and -2, respectively.

- A CTV is introduced to transfer cargo from an NLS-element through rendezvous with a specific orbital target (*e.g.*, SSF).

In Architecture 4:

- An RPC (Boeing biconic concept – minimum cargo capability) is introduced for carrying personnel, and the Space Shuttle is used for personnel transportation only when the RPC is inadequate or unavailable.

- A CRV is introduced that preferentially handles return cargo.

- NLS and CTV introductions are the same as in Architecture 3.

- The only preferential use for the Space Shuttle is non-SSF, "human-at-receipt" missions (*e.g.*, servicing of the Hubble Space Telescope).

3.3.7.3 Manifesting Results

Table 3.3.7.3-1, below, summarizes the flight activity for these three architectures for "If's" C, D, E-Low, and E-High. Owing to the lack of SSF in "IF's" A and B, in terms of which Alternate Access is defined, there is no relevant difference between the architectures therein; the only differences are those caused by the phase-out of Atlas and Titan in favor of the NLS-family.

TABLE 3.3.7.3-1.– ALTERNATE ACCESS IN SUPPORT OF SSF

	(Numbers of Flights of Indicated System)						
	Shuttle	RPC - Min on NLS-50	Total CTV: (NLS-HL & NLS-50)	NLS-HL + CRV	Total Additional Human Flights	Total Additional Flights	Grand Total Flights (Reference)
IF B (Reference)							
Arch 1	148						717
Arch 3	148						707
Arch 4	148						707
IF C minus B							
Arch 1	152				152	152	869
Arch 3	139		79		139	218	925
Arch 4	28	84	79	136	112	324	1031
IF D minus B							
Arch 1	190				190	190	907
Arch 3	163		83		163	246	953
Arch 4	44	85	83	153	129	361	1068
IF E Lo minus B							
Arch 1	209				209	209	926
Arch 3	182		83		182	265	972
Arch 4	44	104	83	153	148	380	1087
IF E Hi minus B							
Arch 1	241				241	241	958
Arch 3	214		83		214	297	1004
Arch 4	44	136	83	153	180	412	1119

In Table 3.3.7.3-1, the "non-SSF" flight activity represented by "If" B has been subtracted out for each architecture, leaving only the effects of SSF operations and, in "If" E, the additional burden of SEI crew transportation. Such subtraction also has the effect of removing the ELV system configurations which have constant flight rates in support of unmanned operations. The reader is referred to in Appendix B, section B.1.2 for the total flight numbers relative to these architectures.

By way of example, Table 3.3.7.3-1 shows that the "If" C configuration of SSF can be supported by an *additional* 152 Space Shuttle flights in the Reference Architecture 1; by an additional 139 Space Shuttle flights *and* 79 CTV flights in Architecture 3; or with 28 additional Space Shuttle flights, 84 RPC flights, and 79 CTV flights in Architecture 4. The RPC's and CTV's are carried on NLS boosters in these architectures, but could just as easily be carried on appropriately rated Titan or MLS vehicles. Also, it may be noted that the entire burden of supporting SEI crew transportation remains on the Space Shuttle in Architecture 3, but is entirely supported by the RPC in Architecture 4.

3.3.7.4 Architecture Evaluation

3.3.7.4.1 Attribute summary.– Table 3.3.7.4-1 contains a summary of attribute values for Architectures 1, 3, and 4, including the presence of SSF.

TABLE 3.3.7.4-1.– ALTERNATE ACCESS ARCHITECTURE ATTRIBUTE SUMMARY

	Human Safety		Funding Profile ($ in Millions)					PMS		ACR	LSC	Environ.	Overall
	WT = 29%		WT = 27%					WT = 19%		WT = 13%	WT = 8%	WT = 4%	Arch Score
	Losses	Score	Total $	Value	Pk Yr $	Value	Score	Value	Score	Score	Score	Score	Max 100%
IF B (Ref)													
Arch 1	3.3	0.435	156,459	0.309	6,649	0.998	0.741	0.9361	0.234	1.000	0.656	0.100	55.6
Arch 3	3.3	0.435	174,000	0.078	11,192	0.310	0.220	0.9478	0.934	0.721	0.149	0.546	49.0
Arch 4	3.3	0.435	174,000	0.078	11,192	0.310	0.220	0.9478	0.934	0.721	0.149	0.546	49.0
IF C													
Arch 1	6.7	0.150	177,404	0.679	7,303	1.000	0.929	0.9374	0.304	1.000	0.409	0.283	52.7
Arch 3	6.4	0.225	208,111	0.467	12,115	0.442	0.503	0.9468	0.737	0.746	0.256	0.527	47.9
Arch 4	4.4	0.725	275,616	0.000	15,931	0.000	0.000	0.9454	0.673	0.563	0.315	0.442	45.4
IF D													
Arch 1	7.6	0.104	183,876	0.677	7,583	1.000	0.921	0.9376	0.307	1.000	0.351	0.280	50.6
Arch 3	7.0	0.229	212,372	0.479	12,575	0.413	0.490	0.9467	0.701	0.750	0.235	0.519	46.9
Arch 4	4.8	0.688	281,078	0.000	16,083	0.000	0.000	0.9451	0.632	0.570	0.299	0.422	43.5
IF E Lo													
Arch 1	8.0	0.132	185,281	0.690	7,583	1.000	0.927	0.9377	0.305	1.000	0.327	0.244	51.2
Arch 3	7.4	0.245	215,514	0.493	12,575	0.413	0.496	0.9466	0.682	0.754	0.229	0.481	47.0
Arch 4	4.9	0.717	285,260	0.040	16,083	0.000	0.020	0.9453	0.627	0.573	0.309	0.428	44.8
IF E Hi													
Arch 1	8.7	0.000	192,109	0.646	8,153	0.993	0.867	0.9379	0.314	0.999	0.270	0.171	45.3
Arch 3	8.1	0.113	219,794	0.466	12,575	0.413	0.482	0.9465	0.678	0.754	0.160	0.408	41.9
Arch 4	5.0	0.698	291,340	0.000	16,058	0.003	0.000	0.9455	0.636	0.569	0.305	0.425	43.8

3.3.7.4.2 Final scoring.– Based on the "Overall Architecture Scores," Architectures 1, 3, and 4 are clustered closely together, roughly in the middle, scorewise, of all of the architectures evaluated in this study. The maximum spread (7.3 percent of Architecture 1 over 4 in "If" C) is only a weak discriminator. It *is* worth noting however, that Architecture 1 (the baseline) ranks higher in overall score than either Architecture 3 or 4 *in all cases.* A cursory examination shows that this is due to the significantly higher Architecture 1 scores for Funding Profile (no DDT&E since system already exists) and ACR (lowest risk since it already exists) overriding the lower scores in the Human Safety and PMS Attributes. Except in "If" E-High, where it appears to have become overburdened, Architecture 3 always ranks higher than Architecture 4.

Based on the analyses in the following sections and the intangible benefits derived from Alternate Access, it would appear that implementation of neither Architecture 3 nor Architecture 4 would be warranted. Based on the manifesting philosophies, guidelines, and attributes utilized herein, the baseline (Architecture 1), with replacement of vehicle losses and a better crew escape system, is clearly superior to either of them.

3.3.7.4.3 <u>Analysis of scores and considerations</u>

a. Human Safety – The improvements in Human Safety arise from two sources, as indicated in the right-hand side of Table 3.3.7.4-2. In Architecture 3, the relatively modest improvement is due to the reduction in the number of Space Shuttle flights. This was achieved by eliminating the need to carry cargo via the Space Shuttle to SSF when there is no associated crew rotation requirement. In Architecture 4, the additional improvements come from the off-loading of crew rotations for SSF and SEI to the RPC, vehicle with its integral crew escape system and more reliable NLS-2 booster.

   Putting this in perspective, one may calculate a "Cost per Life Saved" by assuming a typical crew size of six, multiplying that by the number of crew loss events avoided by employing Architecture 3 or 4, and dividing the result into the associated incremental cost. The results range from $7.3 B per life saved down to $2.8 B in "If" E-High, both associated with Architecture 3. These calculations are crude, and may be offensive to some. The intent, however, is to show the extraordinarily poor return on the dollar in the Human Safety area. Clearly, economical increases in human safety are insufficient justification for implementation of Architectures 3 or 4. It would be more cost effective to retrofit the Space Shuttle with a crew escape system that is effective from the pre-launch, "on-pad" period throughout the launch phase.

b. Funding Profile – To assess the costs attributable to the provision of Alternate Access, it is appropriate to again subtract "If" B from the other "If's." The results are shown in Table 3.3.7.4-2. This has the effect of removing NLS-family DDT&E costs from consideration, as these are incurred in "If's" A and B regardless of whether alternate access is implemented or not. It should also be noted that the RPC, CRV, and cargo transfer vehicle (CTV) are not used at all in "If's" A and B since there is no SSF to support, so their DDT&E costs appear for the first time in "IF" C. From such subtraction and comparison, it is readily apparent that the incremental cost of supporting the basic SSF with "cargo-only" Alternate Access is 1.63 times that of using the Space Shuttle exclusively. Similarly, the cost of providing Alternate Access for both personnel and cargo, as implemented in Architecture 4, is 4.85 times that of using the Space Shuttle alone.

   In the same vein, the incremental peak year funding requirements for the above two cases are 1.41 and 7.25 times greater than with the Space Shuttle, although the peaks do not necessarily occur in the same year from architecture to architecture.

The relevant incremental costs and ratios for the other "If's" are readily discernible in Table 3.3.7.4-2. The cost increment ratios for each architecture decrease with increasing flight utilization (i.e., going from "If" C to "If" E-High) as the lower recurring cost per flight slowly amortizes the investment in infrastructure and DDT&E that went into creating the new elements. In other words, it takes a large number of missions for the lower cost per mission "non-Space Shuttle" systems to show any significant payback of their required investments. Unfortunately, the flight rates required, even in the "If's" E, are insufficient to recapture those investments within the time horizon of this study, much less yield savings.

TABLE 3.3.7.4-2.- ALTERNATE ACCESS COST AND SAFETY

	Cost Comparisons				Safety Comparisons			
	Funding Profile ($ in Millions)				Safety	Savings	Lives Saved	Cost per
		Total		Peak	Loss	Over	If Crew	Life Saved
	Total $	Ratio	Pk Yr $	Ratio	Events	Arch 1	of 6	M$
"If" B (Ref)								
Arch 1	156,459		6,649		3.3			
Arch 3	174,000		11,192		3.3			
Arch 4	174,000		11,192		3.3			
"If" C minus B								
Arch 1	20,945		654		3.4			
Arch 3	34,111	1.63	923	1.41	3.1	0.3	1.8	7,314
Arch 4	101,616	4.85	4,739	7.25	1.1	2.3	13.8	5,846
"If" D minus B								
Arch 1	27,417		934		4.3			
Arch 3	38,372	1.40	1,383	1.48	3.7	0.6	3.6	3,043
Arch 4	107,078	3.91	4,891	5.24	1.5	2.8	16.8	4,742
"If" E Low minus B								
Arch 1	28,822		934		4.7			
Arch 3	41,514	1.44	1,383	1.48	4.1	0.6	3.6	3,526
Arch 4	111,260	3.86	4,891	5.24	1.6	3.1	18.6	4,432
"If" E High minus B								
Arch 1	35,650		1,504		5.4			
Arch 3	45,794	1.28	1,383	0.92	4.8	0.6	3.6	2,818
Arch 4	117,340	3.29	4,866	3.24	1.7	3.7	22.2	3,680

Given the intangible nature of benefits from Alternate Access, it is not possible to compute a Benefit-to-Cost ratio directly. However, the additional costs involved in supporting SSF in this mode in the customarily constrained NASA budgetary environment would appear to be an unacceptably high burden.

c. Probability of Mission Success – In an attempt to quantify the costs of achieving a greater number of flights with mission success through the implementation of Alternate Access, Table 3.3.7.4-3 was developed. Unfortunately, Architectures 3 and 4 are not only significantly more expensive and somewhat more reliable than the reference architecture, but due to the fact that a higher total number of flights is required to fulfill the SSF and SEI needs, have more lost missions. Put another way, more money is being spent to lose more missions (but not human lives – see Safety, above) which is not an inducement for implementation of either Architecture 3 or 4.

TABLE 3.3.7.4-3.– ALTERNATE ACCESS PMS SUMMARY

	Total $	Increment $ "IF" C - E Hi over "IF" B	Absolute PMS	Total # of Flights	Missions Not Accomp	Increment in Missions Not Acc over B	Cost per Mission Saved
IF B (Ref)							
Arch 1	156,459		0.9361	717	45.8		
Arch 3	174,000		0.9478	707	36.9		
Arch 4	174,000		0.9478	707	36.9		
IF C							
Arch 1	177,404	20,945	0.9374	869	54.4	8.6	
Arch 3	208,111	34,111	0.9468	925	49.2	12.3	-3,538
Arch 4	275,616	101,616	0.9454	1031	56.3	19.4	-7,467
IF D							
Arch 1	183,876	27,417	0.9376	907	56.6	10.8	
Arch 3	212,372	38,372	0.9467	953	50.8	13.9	-3,524
Arch 4	281,078	107,078	0.9451	1068	58.6	21.7	-7,277
IF E Lo							
Arch 1	185,281	28,822	0.9377	926	57.7	11.9	
Arch 3	215,514	41,514	0.9466	972	51.9	15.0	-4,060
Arch 4	285,260	111,260	0.9453	1087	59.5	22.6	-7,719
IF E Hi							
Arch 1	192,109	35,650	0.9379	958	59.5	13.7	
Arch 3	219,794	45,794	0.9465	1004	53.7	16.8	-3,238
Arch 4	291,340	117,340	0.9455	1119	61.0	24.1	-7,851

d. Architecture Cost Risk – The Space Shuttle system was considered to be programmatically risk-free since it is fully operational. Architecture 3 includes the NLS development risk as well as that associated with the CTV. Its generally high scores (upper quartile point) show that it is less programmatically risky than many other approaches for getting cargo to the SSF. It may be noted that return cargo from SSF is a significant consideration, and is not off-loaded from the Space Shuttle in this architecture. Architecture 4 adds the additional programmatic risk of developing the RPC and CRV to that already in Architecture 3. This results in its ranking only slightly above the median point (0.563 to 0.573 scores). Inherent to the concept of providing Alternate Access is the development of one or more new systems, which will infallibly increase the programmatic risk over continued use of a mature system.

e. Launch Schedule Confidence – Architecture 3 consistently runs at slightly better than half of the LSC associated with the reference architecture. Architecture 4, with its heavy dependence upon ELV operations and facilities, initially compares favorably with the reference architecture, and surpasses it as the flight rate increases to the maximum in "If" E-High. Although it may appear from a cursory examination of Table 3.3.7.4-1 that Alternate Access increases the LSC Attribute when going from "If" B to C, the effect is really due to changes in the numbers of Space Shuttle flights. In Architecture 1, the number of such flights more than doubles, causing a decrease in LSC. Conversely, the number of Space Shuttle flights goes down in Architectures 3 and 4 – and total (mostly ELV) flights increase by only 31 to 46 percent, resulting in greater LSC.

f. Environment – Most of the environmental benefit of Architecture 3 over Architecture 1 comes from the substitution of all-liquid NLS vehicles for the solid-boosted Titan IV vehicles. The elimination of a few Space Shuttle flights that were for cargo delivery only provides an additional increment. This is all irrelevant from the standpoint of Alternate Access.

   Architecture 4 is still an improvement over Architecture 1, but suffers due to the greater total number of vehicles launched. This is a result of changing the manifesting philosophy, not the provision of Alternate Access, to which it is irrelevant.

3.3.8 Separation of People and Cargo – Architecture Options 5, 6 and 7

3.3.8.1 Description of the Considerations

The principal consideration addressed by this group of architectures is whether the attributes of a transportation architecture improve or worsen by separating people from cargo for transportation to and from low Earth orbit. In the wake of the Challenger accident, it was determined that the Space Shuttle should no longer carry satellite payloads which did not require human presence, to reduce the chance of another crew loss – that is, to improve safety.

But separating people completely from cargo carries penalties as well. It reduces the flexibility of a human-tended system to carry out some sortie science and satellite servicing missions. It mandates cargo transportation without humans to and from SSF, requiring autonomous rendevous and docking systems and return systems. And it may impair the utilization of the multiple systems needed through manifesting inefficiencies.

The NIT devised Architectures 5, 6 and 7 to test these hypotheses by determining the effect on all the study attributes – but especially on Human Safety, PMS, and Funding Profile – of separating people from cargo or keeping them together.

The team made a careful distinction between two types of cargo: untended cargo, which does not require people either during transportation or at its destination (i.e., untended scientific satellites); and "People at Destination" cargo, which does not require people during transportation but does require them at its destination (i.e., SSF logistics). Untended cargo is not carried with people in any of these architectures. "People at Destination" cargo is the category being tested; it is carried with people in some architectures, separated from them in others.

Comparing these three architectures with Architecure 1, the Reference Architecture, permits a second important consideration to be addressed. Does it pay to replace the Space Shuttle with a near-term, existing-technology personnel carrier? Architectures 5, 6, and 7 address this by phasing Space Shuttle out soon after 2000.

Both considerations will be addressed in this section.

3.3.8.2 Description of the Architectures

Architecture 5 keeps people and cargo together. The personnel carrier used is the CLV, a winged vehicle with an internal cargo capacity of 15 000 lbs. This gives the CLV the capability to accomplish pressurized logistics resupply for SSF, and (with mission kits) to conduct science sortie and satellite servicing flights as well. The CLV is launched on the MLS-HL.

Architecture 6 separates people from cargo completely. Its personnel carrier, the Boeing-developed PLS, a biconic, which is used in many other architectures, can carry only crew and their "luggage". It is launched on the smaller MLS-50. Cargo is launched separately in a CRV with a capacity of 40 000 lbs, on an MLS-HL.

Since the PLS has no cargo capability, science sortie and servicing missions must be carried out differently than in Architecture 5. Sortie missions are accomplished by rendezvousing and docking the personnel carrier with a separately launched science payload. Satellite servicing requires that the personnel carrier and the servicing hardware be separately launched, rendevousing first with each other, then with the satellite to be serviced.

Architecture 7 launches people and cargo "in tandem" as separate payloads on the same booster when both have the same destination. Its features are:

- The same people-only PLS is used as in Architecture 6.
- The PLS is launched on the MLS-HL, and the excess capacity of that booster is used to launch cargo on the same launch. The cargo is launched in a Logistics Return Vehicle (LRV) with a cargo capacity of 15 000 lbs.
- The PLS has full-abort-coverage independent of the cargo.
- The logistics return vehicle (LRV) is transported to SSF (or to a satellite requiring servicing) by the PLS, and returns independently.

These arrangements permit these three architectures to carry out SSF crew transfer, logistics resupply, science sortie, and satellite servicing missions without the Space Shuttle. Space Shuttle is phased out early (between 2000 and 2005) in all three Architectures.

Figure 3.3.8.2-1 shows the systems present in each architecture, their functions, and their phasing.

3.3.8.3 Manifesting Philosophy

Each architecture had special manifesting ground rules as follows.

For Architectures 5, 6 and 7:

- All human-tended transportation is carried out by the CLV (5) or the PLS (6, 7). This includes the ACRV function. Therefore, the duration of human-tended flights to SSF matches the SSF crew rotation period at the time, e.g., 90 days at PMC, increasing to 180 days after EMCC.

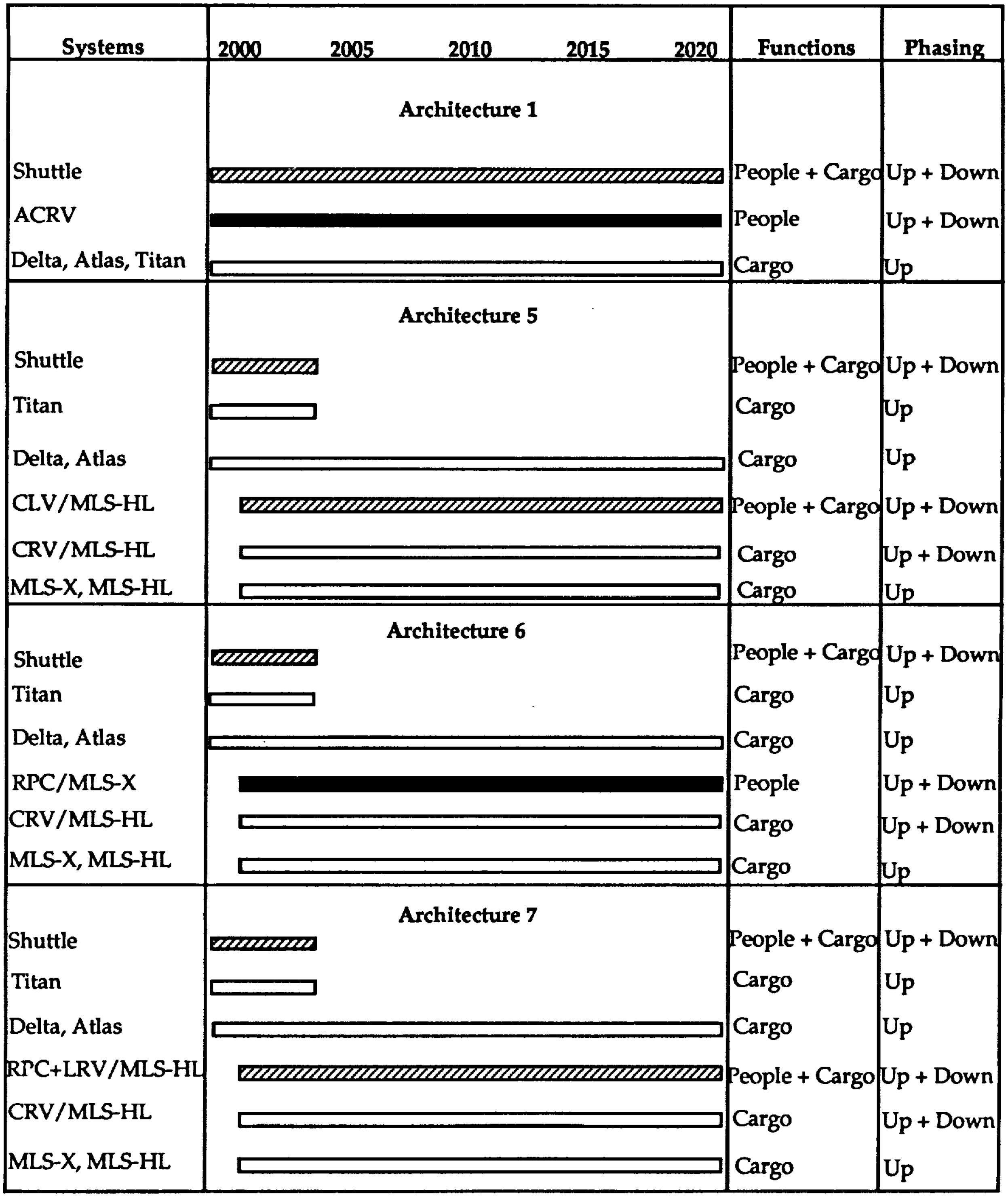


Figure 3.3.8.2-1.– Architecture systems, functions, and phasing.

- The Space Shuttle is phased out by 2005.

Architecture 5:

- Cargo delivery to and return from SSF is carried out by CLV to the extent possible on crew rotation missions (this satisfies the pressurized cargo requirement). The remaining cargo is carried on the CRV, launched on the MLS-HL.

Architecture 6:

- All cargo to and from SSF is carried on the CRV/MLS-HL.

Architecture 7:

- Cargo to and from SSF is carried by the LRV to the extent possible on crew rotation missions. The CRV/MLS-HL carries any remaining cargo.

3.3.8.4 Flight Activity

Table 3.3.8.4-1 summarizes the flight activity in these architectures. It excludes those flights which are invariant across all architectures: the NASA Mixed Fleet Manifest (1992-1997), DOD flights, and west coast flights. Architecture 1, the Reference Architecture, is shown for comparison.

Some of the flights in the table can be ignored in this evaluation, because they do not carry crew, and are constant across all architectures. They are:

- Atlas and Delta flights (columns 6 and 7 in the table).

- A group of 41 flights comprising the Titan IV/Centaur flights (column 8), MLS-X flights (column 9), and 26 of the MLS-HL flights in column 10.

The rest of the table will be used to compare and explain the differences in architecture scores.

TABLE 3.3.8.4-1.– FLIGHT ACTIVITY: ARCHITECTURES 1, 5, 6 AND 7

ARCH.	Space Shuttle	MLS-HL/ CLV	MLS-X /RPC	MLS-HL RPC +LRV	Atlas IIAS	Delta II	Titan IV/C	MLS-X	MLS-HL	Total Human Flights	Total All
IF A											
1	38				23	35	41	0	0	38	137
5	9	29			23	35	7	8	26	38	137
6	7		31		23	35	7	8	57	38	168
7	9			29	23	35	7	8	26	38	137
IF B											
1	76	0			23	35	41	0	0	76	175
5	15	115			23	35	7	8	26	130	229
6	12		81		23	35	7	8	107	93	273
7	14			159	23	35	7	8	26	173	272
IF C											
1	219	0			23	35	41	0	0	219	318
5	48	195			23	35	7	8	26	243	342
6	42		165		23	35	7	8	235	207	515
7	46			227	23	35	7	8	153	273	499
IF D											
1	257	0			23	35	41	0	0	257	356
5	58	225			23	35	7	8	26	283	382
6	41		166		23	35	7	8	295	207	575
7	46			227	23	35	7	8	205	273	551
E Lo											
1	276	0			23	35	41	0	0	276	375
5	58	244			23	35	7	8	26	302	401
6	41		185		23	35	7	8	295	226	594
7	46		19	227	23	35	7	8	205	292	570
E Hi											
1	308	0			23	35	41	0	0	308	407
5	58	276			23	35	7	8	26	334	433
6	41		217		23	35	7	8	295	258	626
7	46		51	227	23	35	7	8	205	324	602

3.3.8.5 Attribute Values and Scores

Table 3.3.8.5-1 summarizes the attribute scores for these Architectures. Note the following features of the table:

- Weighting percentages used to derive total architecture scores are shown at the top of the table.
- The Funding Profile columns list the scores for its two subattributes: total cost and peak-year cost. The Funding Profile score is the average of these two, weighted equally.
- The Human Safety columns list the raw values of the attribute, which are the number of spacecraft losses over the span of the architecture, as well as the score.
- The PMS columns list the raw value of the attribute, as well as the score.
- Raw or subattribute values are not shown for the other attributes. They are less significant to the evaluation.

The "Score" in the last column is the total score for the given architecture and "If" scenario – that is, the average of the individual attribute scores weighted according to the percent weightings shown at the top of the chart.

These scores will differ significantly if different weights are assigned. For example, if Funding Profile is given 100 percent weight, Architecture 1 scores highest.

TABLE 3.3.8.5-1.– ATTRIBUTE SCORES FOR ARCHITECTURES 1, 5, 6 AND 7

	ACR	Env	Funding Profile			Human Safety		PMS		LSC	Score
Wgt:	13%	4%	27%			29%		19%		8%	100%
			Total	Peak	Score	Losses	Score	Value	Score		
IF A											
1	1.000	0.000	0.234	1.000	0.679	1.700	0.100	0.932	0.133	0.532	41.02
5	0.639	0.996	0.377	0.293	0.341	0.900	0.900	0.947	0.967	0.254	68.00
6	0.539	1.000	0.238	0.000	0.082	0.800	1.000	0.947	1.000	0.063	61.73
7	0.562	0.996	0.377	0.482	0.455	0.900	0.900	0.947	0.967	0.185	69.53
IF B											
1	1.000	0.100	0.308	0.998	0.740	3.300	0.435	0.933	0.179	0.656	54.64
5	0.622	0.994	0.229	0.301	0.300	2.400	0.826	0.947	0.967	0.344	65.24
6	0.529	1.000	0.000	0.000	0.000	2.000	1.000	0.948	1.000	0.123	59.86
7	0.525	0.993	0.013	0.078	0.052	2.700	0.696	0.948	0.989	0.022	51.35
IF C											
1	1.000	0.283	0.679	1.000	0.929	6.700	0.150	0.935	0.259	0.409	51.76
5	0.681	0.992	0.405	0.338	0.412	3.800	0.875	0.948	0.894	0.213	68.01
6	0.674	1.000	0.294	0.189	0.268	3.300	1.000	0.949	0.926	0.131	67.64
7	0.612	0.993	0.208	0.191	0.221	4.000	0.825	0.949	0.917	0.000	59.24
IF D											
1	1.000	0.280	0.678	1.000	0.921	7.600	0.104	0.935	0.265	0.351	49.85
5	0.682	0.968	0.338	0.359	0.383	4.200	0.813	0.949	0.861	0.162	64.31
6	0.675	1.000	0.246	0.166	0.226	3.300	1.000	0.949	0.891	0.093	65.55
7	0.613	0.991	0.178	0.192	0.203	4.000	0.854	0.949	0.883	0.000	58.96
IF E LOW											
1	1.000	0.244	0.690	1.000	0.927	8.000	0.132	0.935	0.267	0.327	50.52
5	0.685	0.969	0.351	0.359	0.388	4.300	0.830	0.949	0.843	0.169	64.70
6	0.680	1.000	0.225	0.166	0.239	3.400	1.000	0.950	0.873	0.098	65.66
7	0.618	0.991	0.208	0.192	0.218	4.100	0.868	0.949	0.860	0.000	59.40
IF E HIGH											
1	0.999	0.171	0.646	0.933	0.867	8.700	0.000	0.935	0.275	0.270	44.47
5	0.679	0.967	0.310	0.359	0.366	4.500	0.792	0.949	0.852	0.136	62.82
6	0.675	0.998	0.225	0.166	0.213	3.600	0.962	0.950	0.877	0.082	63.74
7	0.614	0.989	0.162	0.192	0.193	4.300	0.830	0.949	0.869	0.002	57.75

The two following figures show the total scores graphically. Figure 3.3.8.5-1 shows the total scores for Architectures 1, 5, 6 and 7. Figure 3.3.8.5-2 shows the total scores for all Architectures, to illustrate how these Architectures ranked with the others in the study. Note that only Architecture 8 ranked higher than 5, 6 and 7. Architecture 1 is in the middle range of the group.

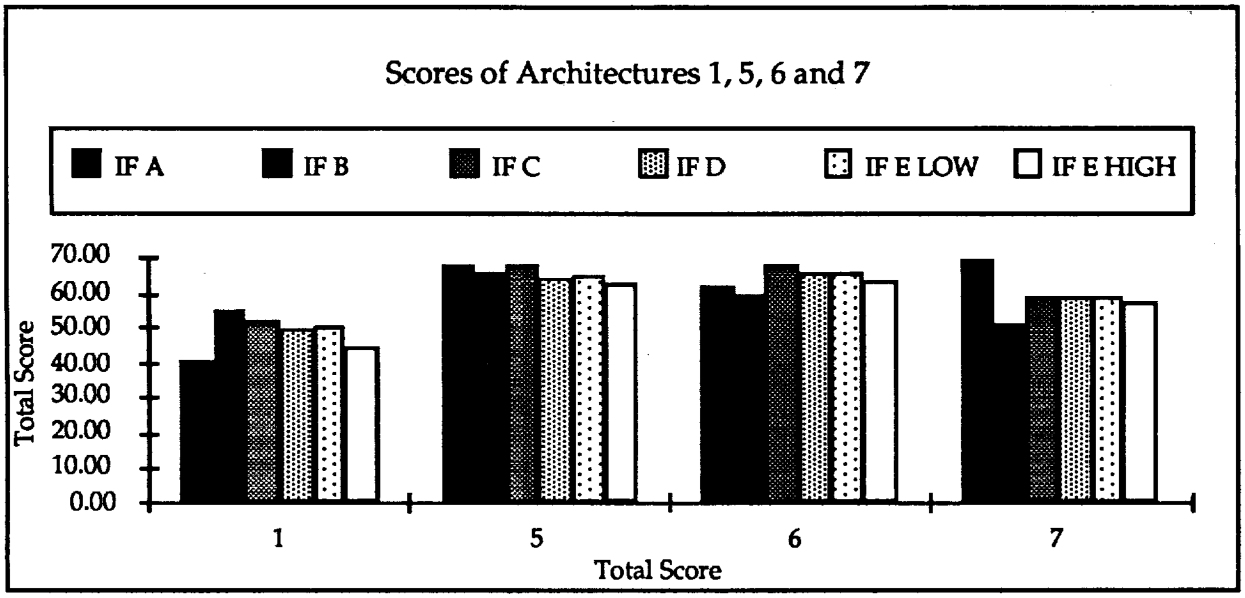


Figure 3.3.8.5-1.– Total scores for Architectures 1, 5, 6 and 7.

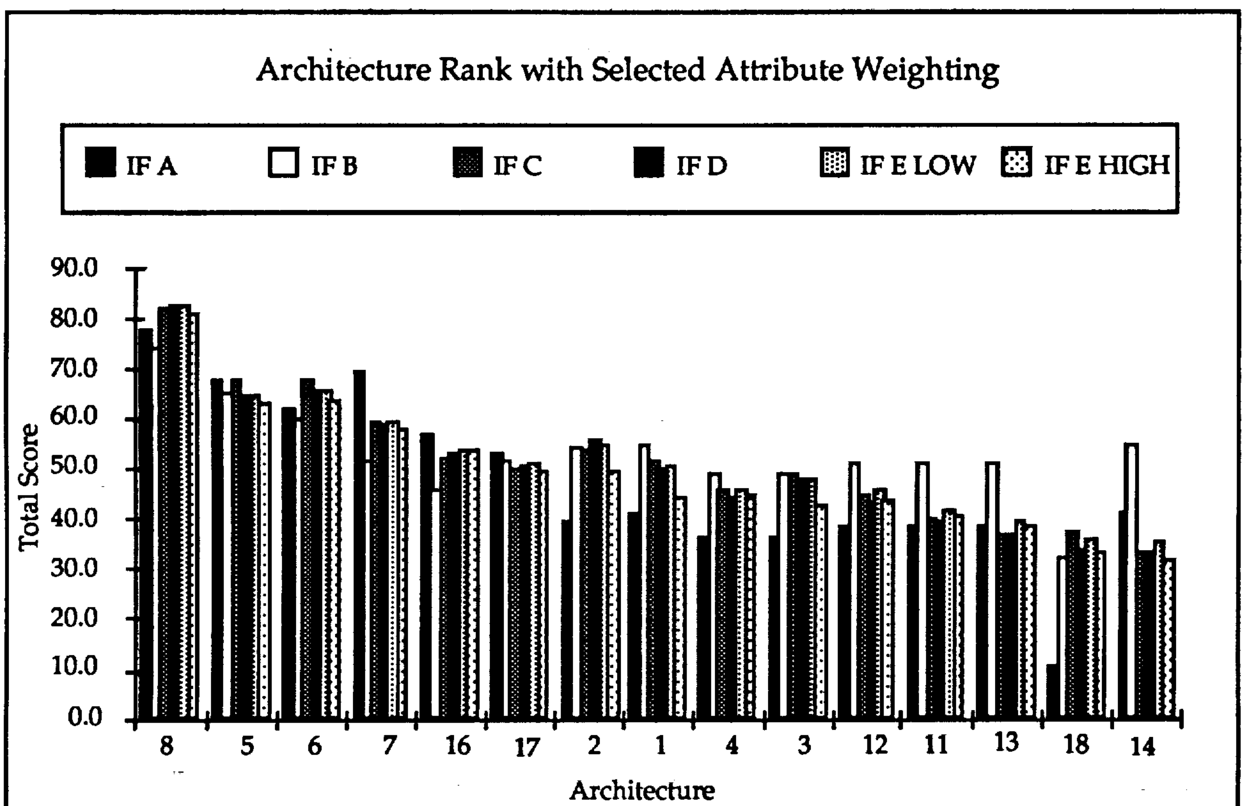


Figure 3.3.8.5-2.– Total scores for all architectures.

3.3.8.6 Findings

This section will describe and explain the significant differences between Architectures 1, 5, 6 and 7 in flight activity and Attribute scores. These findings will be used in the subsequent sections to analyze the two considerations.

Note from the figures above that the relative rankings of these architectures do not vary much with increasing flight activity; they are quite stable across the "If" scenarios. Since no changes of significance appear above "If" C, "If" C is used as an example in most of the findings.

3.3.8.6.1 Flight activity.– Referring to Table 3.3.8.4-1, and taking Architecture 1 as the baseline for comparison, the other architectures show the following significant differences across the period of the study.

- Architecture 5:

  Finding – Human flights increase moderately (from 219 to 243 in "If" C). Total flights increase by about the same number as human flights.

  Rationale – The smaller cargo capacity of the CLV compared to the Space Shuttle results in more flights being required to conduct science sortie missions. These Spacelab-type missions are broken into smaller pieces for flight on CLV.

- Architecture 6:

  Finding – Human flights decrease slightly (from 219 to 207 in "If" C).

  Rationale – In Architecture 1, an occasional extra Space Shuttle flight is required for SSF logistics. In Architecture 6, logistics flights do not carry crew; only the minimum number needed for crew rotation are flown to SSF.

  Finding – Total flights increase greatly (from 342 to 515 in "If" C).

  Rationale – (1) Sortie science missions require two flights each, one of the PLS and one for the science payload to rendevous with the PLS, (2) satellite servicing missions also require two flights each, and (3) the PLS crew rotation flights to SSF carry no cargo; they must be flown in addition to the same number of CRV cargo flights as are flown by the Space Shuttle in the baseline.

- Architecture 7:

  Finding – Human flights increase substantially (from 219 to 273 in "If" C).

  Rationale – More sortie science launches are required. The LRV, used to carry the science payload in tandem with the PLS (on the same booster), has only 15 000 lbs gross capacity compared to Space Shuttle's 40 000 lbs, and has a lower "packaging efficiency" than the 15 000 lb cargo CLV used in Architecture 5. Four or five more flights per year are thus needed after 2005.

Finding – Total flights are greatly increased (from 318 to 499 in "If" C).

Rationale – (1) As in Architecture 6, the crew rotation flights to SSF must be augmented by additional cargo flights. The added flights are not as many as in Architecture 6 because the crew rotation flights carry some cargo in the LRV, and (2) there are more human flights, as explained above.

- Comparing Architectures 5, 6 and 7:

  Table 3.3.8.6-1 contains a summary of flight activity in Architectures 5, 6 and 7 ("If" C).

TABLE 3.3.8.6-1.– FLIGHT ACTIVITY: ARCHITECTURES 5, 6 AND 7

Architecture	Human Flights	Total Flights
5	243	342
6	207	515
7	273	499

3.3.8.6.2 Attribute Scores

This section will state and explain the significant differences in attribute scores between these architectures.

The two most important attributes are Cost (Funding Profile) and Human Safety. The ACR is closely related to cost, and PMS to Human Safety.

The following two figures show the scores of these architectures in Cost and Human Safety. These attributes sharply distinguish Architectures 5, 6 and 7 from Architecture 1.

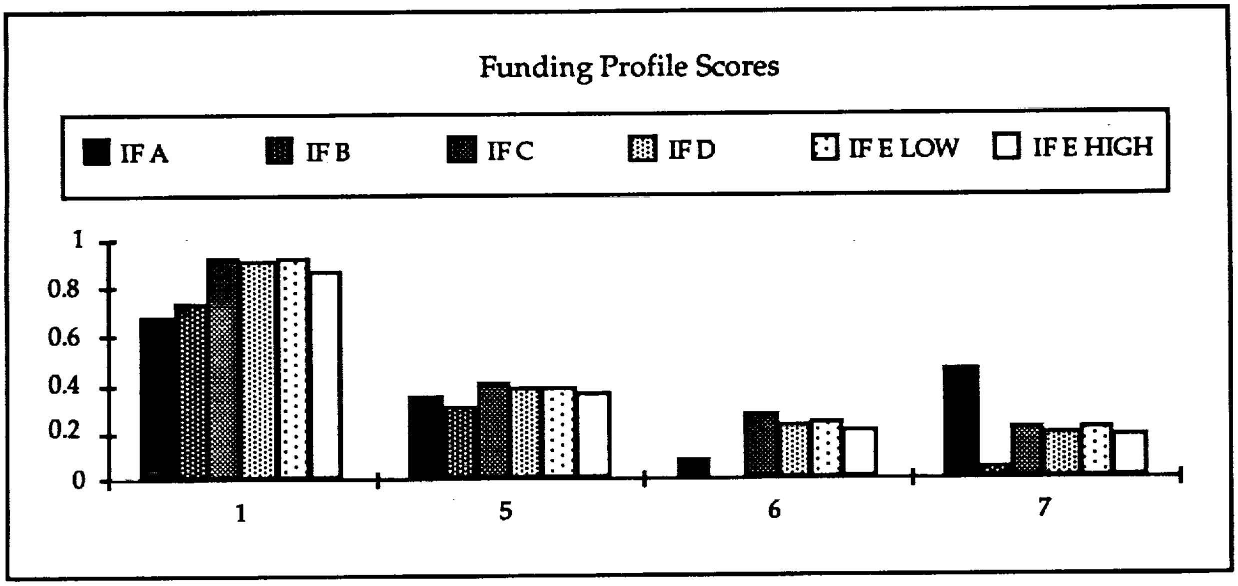


Figure 3.3.8.6-1.– Cost scores of Architectures 1, 5, 6 and 7.

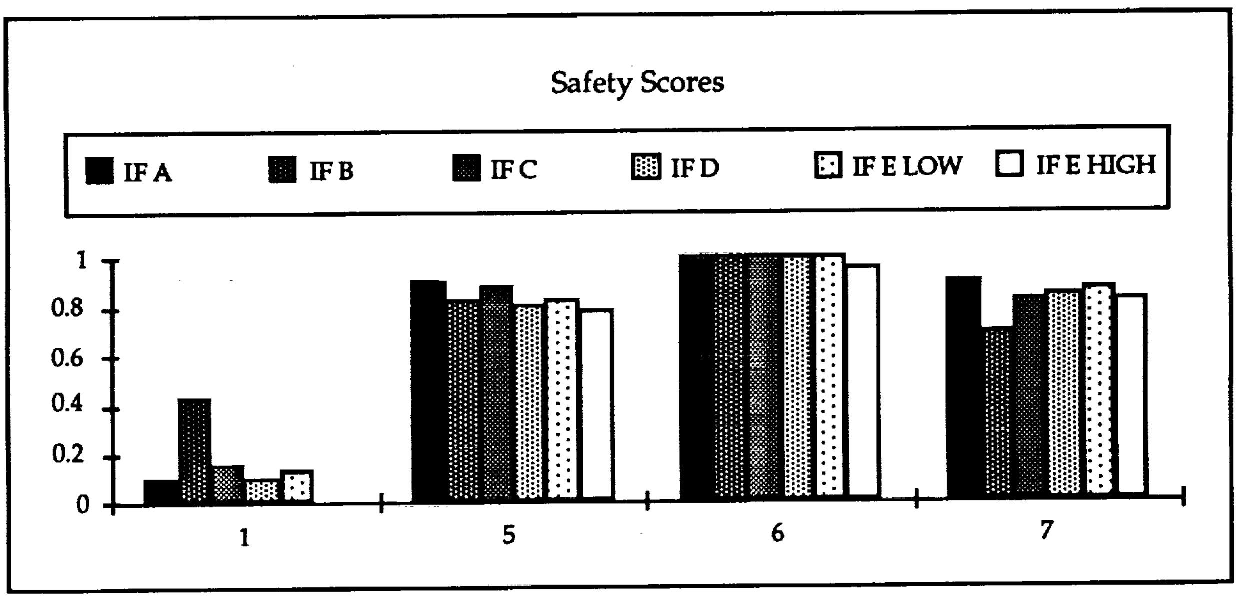


Figure 3.3.8.6-2.– Human safety scores of Architectures 1, 5, 6 and 7.

a. Funding Profile.– The following table shows the actual Funding Profile values for Architectures 1, 5, 6 and 7 in "If" C. This data is shown because, although the differences are substantial, the attribute scores shown in Figure 3.3.8.6-1 above exaggerate them somewhat.

TABLE 3.3.8.6-2.– ARCHITECTURE COST COMPARISON

	UNWRAPPED					WRAPPED				
	Non-Recur	Recur.	Unrel'	Total	Peak	Non-Recur	Recur.	Unrel'	Total	Peak
Arch 1	25.1	136.8	14.3	176.2	7.3	26.3	137.0	14.3	177.6	7.3
Arch 5	28.5	118.0	9.4	155.9	9.8	51.0	156.9	9.4	217.3	13.1
Arch 6	21.0	138.8	7.8	167.6	10.6	37.3	188.1	7.8	233.2	14.3
Arch 7	22.5	144.6	10.2	177.3	10.5	40.1	195.4	10.2	245.7	14.3

Comparing Architectures 5, 6 and 7:

Finding – Architecture 7 has the highest total cost.

Rationale – (1) It has many more human and total flights than Architecture 5, (2) it has many more human flights than Architecture 6 (these are flown on the heavier and more costly MLS-HL, compared to Architecture 6's human flights on the MLS-X), and (3) it has a higher unreliability cost (the cost of replacing vehicles lost in accidents) than Architecture 6 because of its lower safety score.

Finding – Architecture 5 has the lowest total cost.

Rationale – It has many fewer total flights. This more than compensates for the higher DDT&E cost of developing the CLV.

Comparing of Architecture 5 with Architecture 1:

Finding – Architecture 1 total cost is 19 percent lower ($177.6B vs. $217.3B).

Rationale – (1) Architecture 1 has no DDT&E cost for new systems, (2) it has fewer total flights, and (3) a larger proportion of its hardware is reusable, lowering recurring costs. (CLV is reusable, but the MLS-HL is completely expendable including all engines).

b. Human Safety.– The estimated number of crew loss events, which determines the Human Safety score, is a function-of-probability of a catastrophic failure during ascent (the reciprocal of the PMS attribute), the probability of an unsuccessful abort, and the number of flights.

Comparing of Architectures 5, 6 and 7:

Finding – Architecture 6 has the best Human Safety score.

Rationale – (1) Architecture 6 has the fewest human flights, and (2) the PMS score for the Architecture 6 human booster, the MLS-X, is slightly higher than for the MLS-HL used in 5 and 7 (the MLS-X has no upper stage).

Finding – The Human Safety scores of Architectures 5, 6 and 7 are not significantly different. The raw scores are 3.8, 3.3 and 4.0 respectively, well within the error margin for the study.

Rationale – Architecture 5, 6 and 7 human systems all have engine-out capability throughout the launch profile. They all have very low probabilities of unsuccessful abort because they are designed with Launch Escape Systems (LES), and with the people well separated from the engines.

Comparing of Architectures 5, 6 and 7 with Architecture 1:

Finding – All three of the new architectures have significantly better safety scores than Architecture 1.

Rationale – (1) The Space Shuttle has a lower PMS (0.935 versus 0.948 for Architecture 5) because of the gaps in its engine-out capability, and (2) Space Shuttle has a lower probability of successful abort because it was not designed with a full LES, and because of the proximity of the SRB's and SSME's to the crew.

3.3.8.7 Conclusions – First Consideration

- Should people and cargo travel together or separately? (Architectures 5 versus 6 versus 7)

  Architecture 5 transports people and cargo together (as does the Space Shuttle in Architecture 1). Architecture 6 separates them completely. Architecture 7 represents a hybrid solution, launching both on a single booster but with independent abort and return capability, an attempt to evaluate reducing the number of launches required.

  - Summary of Findings

    Finding 1 – Flight activity. Architecture 5 has the fewest total flights. Architecture 6 has the most, but Architecture 7 has almost as many as 6. These differences are reflected in the total architecure costs.

    Finding 2 – Human Safety. Architecture 6 has the highest scores, and 5 is slightly better than 7. But all score well, and the raw scores are very close.

Finding 3 – Cost. Architecture 5 is best, 6 intermediate, 7 worst. The actual cost estimates (see Figure 3.3.8.6-1) are within 13 percent.

A possible additional consideration is operational complexity. Architecture 5, with its cargo capability, can carry out all the missions without rendezvous. Architectures 6 and 7 each present SSF with two vehicles to berth each trip; 6 requires rendezvous to accomplish a science sortie mission, and 7 requires a docking maneuver.

The findings suggest that Architecture 7, the hybrid solution, is not the answer. It scored lower than 5 or 6 overall and in every significant attribute. It is more expensive and slightly less safe, and it has the most new systems to develop.

- Conclusions

Conclusion 1 – If science sortie or satellite servicing missions continue, keeping people and cargo together is the preferred solution.

Conclusion 2 – The PMS can be significantly improved by booster design independent of the people-versus-cargo issue.

Conclusion 3 – Human Safety can be significantly improved by full launch escape capability and separation of the people from the main engines, independent of the people-versus-cargo issue.

3.3.8.8 Conclusions – Second Consideration

- Does it pay to replace the Space Shuttle with a near-term, existing-technology personnel carrier?

  - Summary of Findings

Finding 1 – Architectures 5 and 6 score substantially better than Architecture 1 overall, given the present attribute weights.

Finding 2 – Human Safety. The new architectures score much better than the baseline. In loss events, Architecture 1 has a 6.7 score, compared to 3.8 for 5, and 3.3 for 6 ("If" C) - an improvement by a factor of 2.

Finding 3 – Cost. The baseline has the lowest costs, both total and peak.

A possible additional consideration is environmental impact. The new architectures score much higher than 1; the Space Shuttle scores poorly because of its solid boosters. This was not analyzed in detail because of the low weight given to the Environment attribute.

- Conclusions

Conclusion 1 – Replacing the Space Shuttle with a new personnel carrier can realize major gains in Safety and Environmental Impact.

Conclusion 2 – Replacing the Space Shuttle with a personnel carrier in the near term has not been shown to be cost-effective.

3.3.9 Advanced Technology and New Concepts – Architecture Options 1, 8, 16, 17, 18, and 19

3.3.9.1 Description

The consideration addressed in this section is whether it is appropriate to introduce a new human-tended carrier vehicle incorporating advanced technologies. Studies in the past few decades have investigated such concepts and considerable potential for improvement has been indicated. Typically, these new designs incorporate new technology and/or new operational approaches that would result in a significant improvement over existing systems with regard to some key attribute. Inclusion of these designs in the HTS study was intended to help explore the overall architectural potential, including the cost impacts of using new concepts.

Consequently, seven architectures were defined for assessment, each employing a different advanced technology personnel carrier. These carriers spanned a range of technologies, and developmental and operational philosophies. The criteria for selecting these seven included: (1) the carrier must be representative of a class of concepts, and (2) the availability of attribute data for use in this study. The advanced technology architectures are numbered 8, 9, 10, 16, 17, 18, and 19. The new concept for Architecture 8 is a SSTO vehicle, operable either with or without a crew, that includes a plug nozzle and lightweight materials to achieve its performance goals. A vertical takeoff, horizontal landing two-stage-to-orbit (TSTO) concept, the AMLS, is the centerpiece of Architecture 9. Architecture 10 features an advanced airbreathing, horizontal takeoff and landing, NDV SSTO. Architecture 16 features a subsonic, air-launched concept, based on the Rockwell AMSC studies. For Architecture 17, a personnel capsule, similar in crew size and functionality to the RPC/launch vehicle system, called the RUPC is included. By using advanced materials, the RUPC's weight is sufficiently low to permit using a smaller, less expensive launch vehicle (a HR Titan II with 10 strap-on solid motors). A supersonically staged, fully reusable TSTO system, called the Beta II, is featured in Architecture 18. Finally, another subsonic ALV concept is used for both personnel and cargo flights as Architecture 19.

Table 3.3.9.1-1 provides key data about the new vehicles of the architectures; the reference architecture is included. The new technologies involved are shown, along with the performance and implementation dates. Manifesting results are discussed in detail below; however, it is relevant to indicate here that the cargo capacity of the human-tended carrier has significant effect on the flight rates of the cargo vehicles. The resultant typical flight rates of both the personnel and cargo vehicles are shown (for mission model "If" C).

TABLE 3.3.9.1-1.– KEY CHARACTERISTICS

Arch. No.	Personnel Vehicle	IOC	Major New Technologies	Up' Cargo Capacity 220 nmi @ 28.5°	"If" C typical annual flight rate			
					personnel	T IV	Atlas	Delta
1	Shuttle	1981	• none	46,000 lbm	10	9	3	7
8	SSTO	2000	• new engine (plug nozzle) • composite tanks, blanket TPS • lightweight materials • lightweight subsystems	15,000 lbm	36	14	2	2
9	AMLS	2005	• composite tanks, blanket TPS • lightweight materials • lightweight subsystems	40,000 lbm	18	13	2	3
10	NDV	2010	• new engine (airbreathing) • lightweight materials • lightweight subsystems	18,000 lbm	28	13	2	3
16	AMSC	2005	• new engine • air launch (M = 0.7)	5,000 lbm	24	25	3	7
17	RUPC	2000	• lightweight materials • lightweight subsystems	1,000 lbm	12	36	3	7
18	BETA	2005	• air launch (M = 5.5) • new airbreathing engine • lightweight materials	18,500 lbm	29	13	2	3
19	ALV	2000	• air launch (M = 0.8) • recoverable propulsion mod.	18.400 lbm	11	22	1	0

The performance capabilities, turnaround times, and development and operational costs of the advanced technology vehicles are primarily provided by the companies and agencies which developed the concepts. The PMS, Human Safety, and ACR Attributes were generated on a relative basis, which took into account differences between the vehicles in the architectures. However, no assessment or leveling between concepts has been made of the relative degree of technical conservatism used in design, in estimation of system weights (including provision for weight growth and unknowns), and in the estimation of operational characteristics and costs. In most cases, new concepts either lacked the detailed definition, or were not to be communicated to the NIT, to ensure complete accuracy when assessing attributes. As the estimates of any new technology system's capabilities and costs are the least reliable part of any architecture analysis, conclusions must be considered only point assessments with a wide range of potential variability. In the course of this study, limited resources determined the level to which input data could be normalized, with respect to each other. Thus, direct comparison of, for example, a rapid turnaround SSTO with an ambitious propellant mass fraction to a RUPC capsule atop an ELV is difficult. The designs example used for this study are just that – examples.

It was *not* the intent of this architectural analysis to provide an answer to the question of what the "best" new concept might be. The issue is whether new technologies have merit sufficient to warrant their incorporation into potential architecture options.

3.3.9.2 Manifesting Philosophy

In each of the seven architectures considered here, the Space Shuttle is phased out and the new concept is phased in to become the sole method of transporting people up to orbit. The Space Shuttle flights are complete before 2005 in Architectures 8, 17 and 19. Space Shuttle is phased out before 2010 in Architectures 9, 10, 16 and 18. In all seven cases, the ACRV is used for emergency crew return capability from SSF. After Space Shuttle phase-out, the ACRV is launched on another vehicle.

Cargo-up and-down capability is provided by the new element (although never exclusively for "up" payloads) in Architectures 8, 9, 10, and 18. In Architectures 16, 17 and 19, cargo down is provided by using an LRV. In all architectures except for 9, cargo-up capability is provided by the Delta, Atlas, and Titan CTF fleet (except in Architectures 8, 10, 17 and 19, where this is no need for the Atlas/Delta CTF).

3.3.9.3 Manifesting Results

A summary of the total number of flights by each vehicle type is given in Table 3.3.9.3-1. Note the differences in the percentage of flights that have crews; architectures that score well (e.g., in Funding Profile) significantly reduce the number of ELV flights.

The SSTO of Architecture 8 operates both with and without a crew. Table 3.3.9.3-2 summarizes each type of flight for each mission model.

3.3.9.4 Architecture Evaluation

3.3.9.4.1 Attribute summary.– Table 3.3.9.4-1 summarizes the attribute scores for the reference architecture and the seven advanced technology architectures. The study consensus attribute weightings are shown at the top of the columns for information. The architecture score is shown in the last column; a higher score is better than a lower one. ACR and Funding Profile scores for Architecture 9 are not available due to lack of cost data for the AMLS.

TABLE 3.3.9.3-1.– TOTAL FLIGHTS BY VEHICLE TYPE FOR ARCHITECTURES 8, 9, 10, 16, 17, 18, AND 19

'If'	Arch.	Shuttle	SSTO	AMLS	NDV	AMSC	RUPC	Beta	ALV	With Crew	Total	% With Crew
	8	24	191							76	629	12.1
	9	38		141						179	629	28.5
	10	53			115					168	635	26.4
A	16	40				42				82	608	13.5
	17	28					63			91	659	13.8
	18	39						119		158	602	26.2
	19	23							53	76	698	10.9
	8	66	330							257	817	31.4
	9	82		164						246	696	35.3
	10	103			159					262	736	35.6
B	16	85				285				370	896	41.3
	17	66					158			224	887	25.2
	18	76						192		268	714	37.5
	19	61							551	202	912	22.1
	8	101	678							375	1285	29.2
	9	144		245						389	903	43.1
	10	189			253					442	1000	44.2
C	16	145				350				495	1314	37.7
	17	106					242			348	1363	25.5
	18	142						389		531	1046	50.8
	19	101							801	315	1351	23.3
	8	109	774							383	1388	27.6
	9	163		283						446	989	45.1
	10	218			295					513	1099	46.7
D	16	160				350				510	1395	36.6
	17	112					242			354	1471	24.1
	18	151						484		635	1172	54.2
	19	106							722	320	1443	22.2
	8	109	793							402	1407	28.6
	9	164		301						465	1008	46.1
	10	224			308					532	1118	47.6
EL	16	160				367				527	1412	37.3
	17	112					261			373	1490	25.0
	18	151						501		652	1189	54.8
	19	106							741	339	1462	23.2
	8	109	825							434	1439	30.2
	9	164		333						497	1040	47.7
	10	231			333					564	1150	49.0
EH	16	160				398				558	1443	38.7
	17	112					293			405	1522	26.6
	18	151						532		683	1220	56.0
	19	106							773	371	1494	24.8

TABLE 3.3.9.3-2.– SSTO PERSONNEL/CARGO-ONLY FLIGHT SPLIT

If	Type	Personnel	Cargo-only	Total
A	NASA	31	42	73
	DoD	21	70	91
	WTR	0	27	27
	Total	52	139	191
B	NASA	170	42	212
	DoD	21	70	91
	WTR	0	27	27
	Total	191	139	330
C	NASA	253	307	560
	DoD	21	70	91
	WTR	0	27	27
	Total	274	404	678
D	NASA	253	403	656
	DoD	21	70	91
	WTR	0	27	27
	Total	274	500	774
EL	NASA	272	403	675
	DoD	21	70	91
	WTR	0	27	27
	Total	293	500	793
EH	NASA	304	403	707
	DoD	21	70	91
	WTR	0	27	27
	Total	325	500	825

TABLE 3.3.9.4-1.– NEW CONCEPTS/TECHNOLOGY ARCHITECTURES ATTRIBUTE SCORING

"If"	Arch.	ACR 13%	Env. 4%	FP 27%	Safety 29%	LSC 8%	PMS 19%	Arch. 100%
	1	1.000	0.000	0.703	0.538	0.476	0.538	54.3
	8	0.565	0.437	1.000	1.000	0.309	1.000	80.9
	9	N/A	0.320	N/A	0.692	0.090	0.747	N/A
	10	0.000	0.154	0.391	0.000	1.000	0.000	27.3
A	16	0.850	0.257	0.686	0.769	0.576	0.769	61.1
	17	0.617	0.058	0.894	0.769	0.669	0.769	60.0
	18	0.136	0.277	0.000	0.308	0.000	0.308	19.2
	19	0.437	0.526	0.814	0.646	0.396	0.846	62.1
	1	1.000	0.100	0.754	0.550	0.428	0.550	57.0
	8	0.545	0.567	1.000	0.800	0.290	0.800	79.9
	9	N/A	0.481	N/A	0.800	0.145	0.780	N/A
	10	0.000	0.305	0.430	0.015	1.000	0.150	34.2
B	16	0.776	0.407	0.671	0.000	0.279	0.000	46.6
	17	0.568	0.000	0.769	0.600	0.651	0.600	50.8
	18	0.107	0.391	0.089	0.450	0.000	0.450	27.5
	19	0.469	0.408	0.531	0.650	0.424	0.650	47.3
	1	1.000	0.283	0.931	0.172	0.239	0.172	54.3
	8	0.478	0.685	1.000	0.862	0.333	0.862	82.6
	9	N/A	0.578	N/A	0.759	0.209	0.721	N/A
	10	0.000	0.417	0.600	0.000	1.000	0.000	35.6
C	16	0.683	0.261	0.595	0.207	0.424	0.207	44.6
	17	0.657	0.000	0.592	0.621	0.655	0.621	47.7
	18	0.060	0.491	0.327	0.172	0.013	0.172	27.2
	19	0.605	0.311	0.465	0.621	0.488	0.621	45.6
	1	1.000	0.280	0.923	0.293	0.253	0.293	58.3
	8	0.491	0.701	1.000	0.878	0.332	0.878	83.4
	9	N/A	0.581	N/A	0.732	0.217	0.756	N/A
	10	0.000	0.404	0.608	0.000	1.000	0.000	36.8
D	16	0.690	0.229	0.581	0.366	0.454	0.366	48.0
	17	0.665	0.000	0.558	0.707	0.659	0.707	49.5
	18	0.056	0.487	0.257	0.195	0.000	0.195	26.5
	19	0.628	0.254	0.402	0.732	0.527	0.732	47.1
	1	1.000	0.244	0.931	0.311	0.244	0.311	59.1
	8	0.501	0.705	1.000	0.889	0.343	0.889	83.5
	9	N/A	0.583	N/A	0.756	0.223	0.759	N/A
	10	0.014	0.394	0.614	0.067	0.989	0.067	38.9
E low	16	0.695	0.231	0.599	0.422	0.451	0.422	50.2
	17	0.670	0.006	0.573	0.711	0.668	0.711	50.1
	18	0.072	0.484	0.278	0.267	0.016	0.267	29.3
	19	0.636	0.261	0.424	0.756	0.532	0.756	48.4
	1	1.000	0.171	0.869	0.200	0.205	0.200	54.3
	8	0.498	0.703	1.000	0.867	0.338	0.867	83.1
	9	N/A	0.580	N/A	0.733	0.229	0.801	N/A
	10	0.000	0.373	0.610	0.000	1.000	0.000	37.2
E high	16	0.693	0.229	0.598	0.378	0.473	0.378	49.6
	17	0.668	0.000	0.566	0.667	0.666	0.667	48.9
	18	0.048	0.475	0.231	0.222	0.000	0.222	26.5
	19	0.632	0.261	0.406	0.689	0.523	0.689	46.2

3.3.9.4.2 Final scoring.– Figure 3.3.9.4-1 shows the overall scoring of all the architectures for "If C". Three of the advanced technology architectures score well (16, 17, and 19), but of them only Architecture 8 (the SSTO) was significantly improved. Architecture 9 could not be scored at this time as cost data was unavailable. Architectures 10 and 18 scored poorly, largely due to their respective low score for ACR.

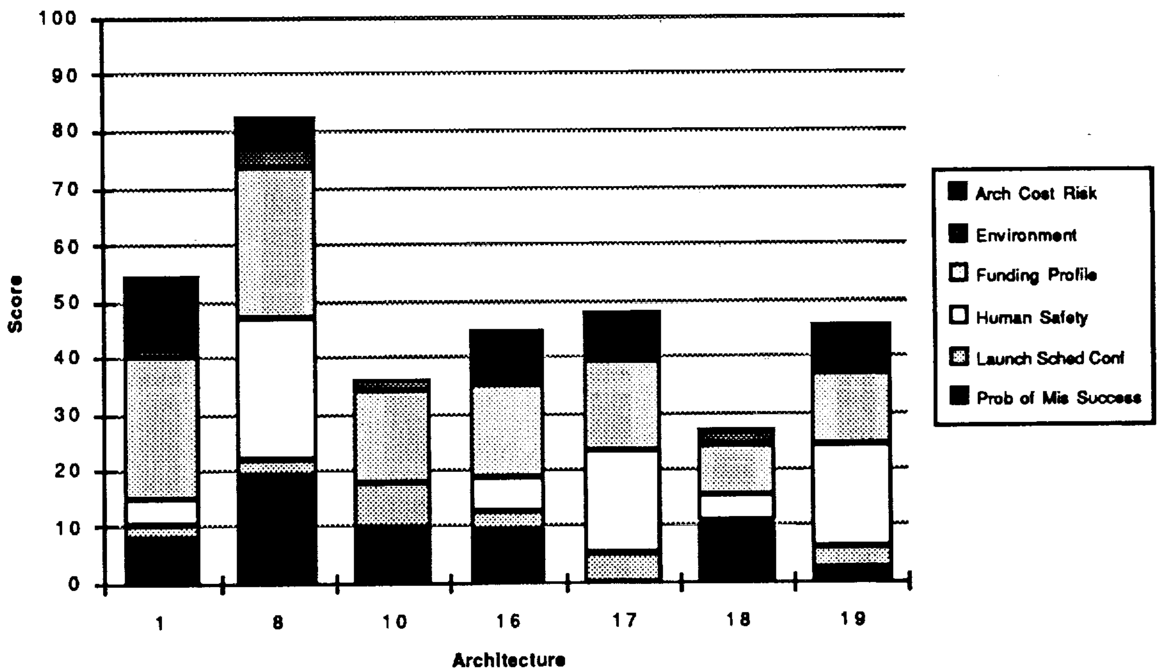


Figure 3.3.9.4-1.– Architecture scores, "If" C.

3.3.9.4.3 Analysis of scores and consideration.– Figure 3.3.9.4-2 provides a ready comparison of the relative scoring of the seven advanced technology architectures and of the reference architecture (Architecture 1) for mission model "If" C. The attribute weighting (e.g., safety weighting is 29 percent) is noted on each of the columns.

a. Human Safety – Observations concerning the scoring include:

(1) All of the advanced technology architectures would enhance human flight safety,

(2) The current personnel system, the Space Shuttle, is less safe than other potential personnel carriers,

(3) The SSTO and the RUPC provide the greatest safety increases. However, the safety attribute scoring indicates that the greatest increase in safety would be provided by other architectures (such as CLV or RPC launched by versions of the MLS), and

(4) It is apparent that Human Safety could be increased, although none of the advanced technology vehicles assessed may be the best choice. Figure 3.2.3.3-1 shows safety-relevant features for all the human-rated systems, including the advanced technology launch systems, and offers some insight as to why different concepts score well.

The RUPC has safety features similar to those of the RPC in that it features a full launch escape system (not merely ejection seats) and humans are in a separate unit from the main propulsion engines. However, the booster involved (Titan II with 10 solid strap on motors) does not have the safety features of the MLS (all liquid with full shut down capability and engine-out).

b. Funding Profile – The non-recurring costs of the architectures of interest are compared in Figure 3.3.9.4-3. The cost elements are the preplanned product improvement P^3I and "other" composed of such items as vehicle development costs (for new engines, structure, software, ground systems, etc.) and facilities costs. Note that there is an approximate five-to-one ratio between the highest and lowest non-recurring cost estimates. The Space Shuttle or the reference architecture (Architecture 1 has effectively no development costs (they are sunk), but only P^3I costs as shown. Two of the above architectures employ person-carrying modules launched by expendable boosters. In Architecture 17, the RUPC is launched by a modified Titan II employing solid, strap-on boosters. The development cost contributions of these human-carrying vehicle elements are RPC, $3.01B and RUPC, $1.43B. The remaining advanced technology vehicle development costs are: SSTO, $2.71B; AMSC, $6.47B; Beta, $15.54B, NDV, $12.5B; ALV, $3.8B; AMLS cost data was not available.

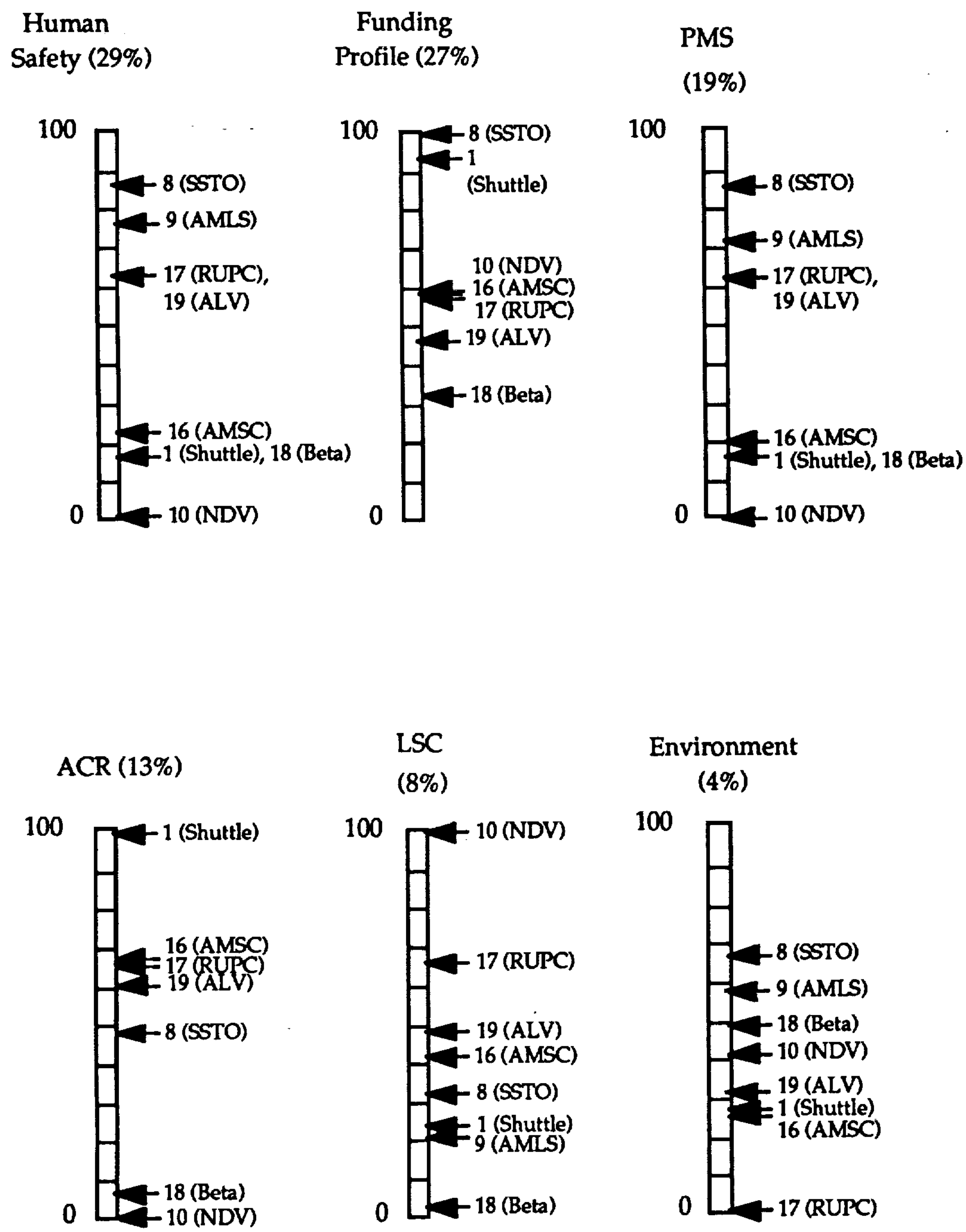


Figure 3.3.9.4-2.– Advanced technology architectures compared by attribute (shown for "If" C).

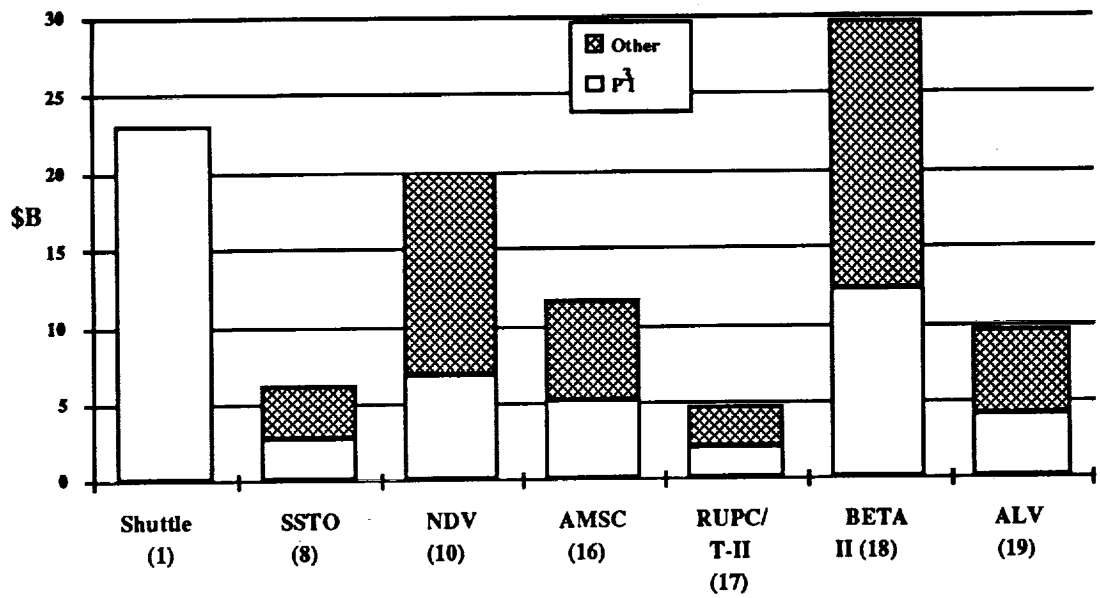


Figure 3.3.9.4-3.– Non-recurring costs compared ("If" C).

The recurring cost per flight of the various vehicles is, of course, a major contribution to the total architecture cost (through the year 2020). The average cost- per-flight (for the full time period) for the advanced technology architectures and two others is shown in Figure 3.3.9.4-4. These costs are related to a specific operations flow and an operating philosophy that may or may not be comparable between concepts.

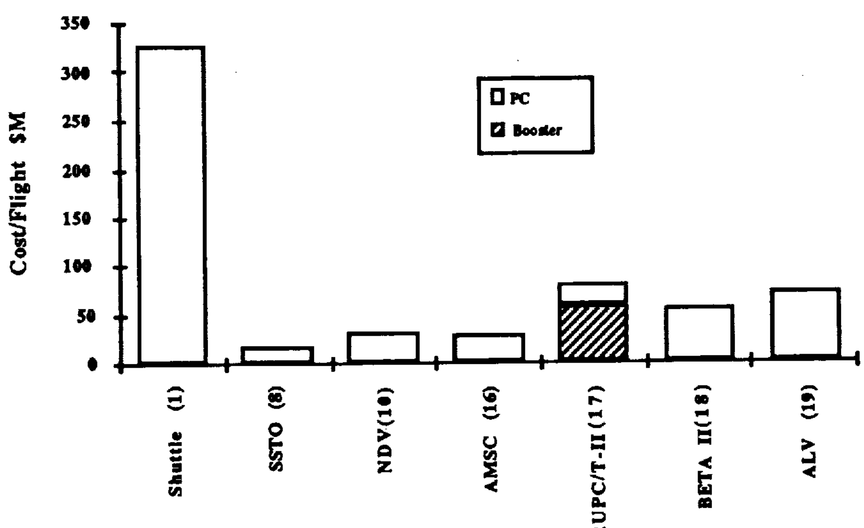


Figure 3.3.9.4-4.– Average cost per flight of human rated vehicles ("If" C).

Visibility of the contributions of the non-recurring and recurring costs can enhance understanding of the total architecture costs. These totals are shown in Figure 3.3.9.4-5. This figure also shows the effects of other factors on the total costs; for example, it is evident that the payload capabilities of the AMSC and RUPC force a large number of flights onto the major cargo vehicle (such as Titan IV) of the architecture. The Space Shuttle cost contribution is low in Architectures 8, 17, and 19 because Space Shuttle phase-out begins in 2000, not in 2005 as in Architectures 16 and 18, or 2010 as in Architecture 10. Costs in the figure that are not included in either the Space Shuttle, new vehicle, or Titan, are grouped as "other" (this category would include Delta, Atlas, LRV's, etc).

The above costs, along with annual peak funding, contributed to the cost attribute scores that were shown in Figure 3.3.9.4-2.

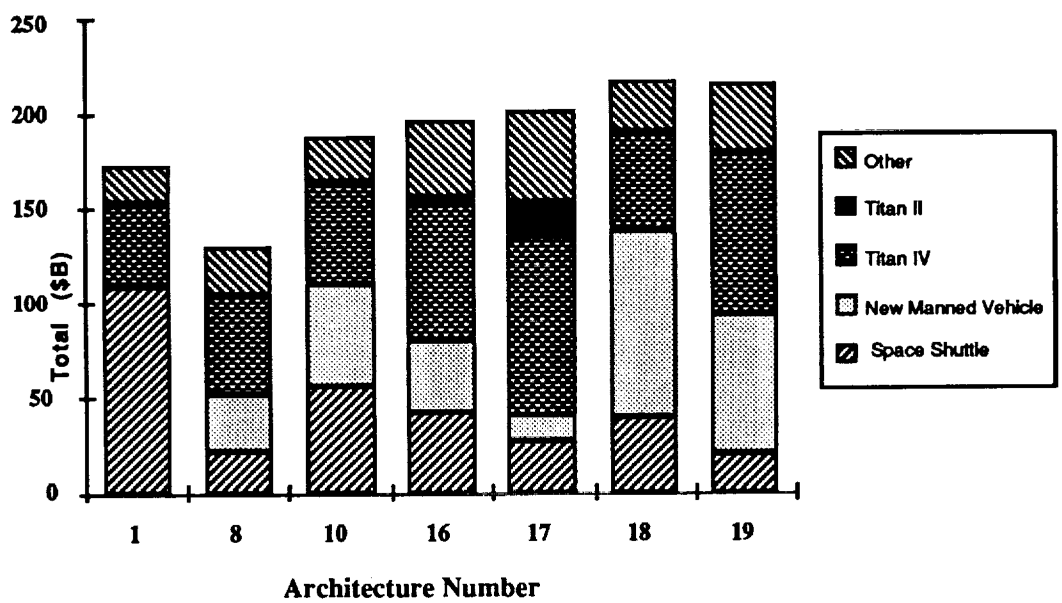


Figure 3.3.9.4-5.– Components of total architecture cost for "If" C.

c. Probability of Mission Success – Architecture 8 (SSTO) scores well above both the reference architecture and the other advanced technology architectures. The SSTO has high estimated reliability and flies many of the cargo-only missions. Conversely, the NDV requires that many missions in Architecture 10 be flown by the Titan IV (due to the requirement for heavier payloads than the SSTO can accommodate), which has a relatively low system PMS, so that overall PMS is reduced. The PMS scores for Architectures 16, 17, 18 and 19 are more strongly driven by the increases they cause in ELV flight rates than by their own reliability characteristics.

d. Architecture Cost Risk – Intuitively, one might expect any new concept architecture involving new technology to score poorly in the risk attribute. In fact, only Architectures 18 (Beta) and 10 (NDV) scored very low. This is primarily due to the cost- weighted nature of the attribute definition; the high non-recurring cost of the Beta system resulted in a high risk value. The Technical Challenge subattribute also worked against the SSTO of Architecture 8, but, in accordance with cost estimates used in this study, it was not weighted as heavily as the Beta or NDV. Similarly, the Program Immaturity subattribute penalized the new concept architectures, but the systems with higher estimated systems cost (such as the Beta and NDV) lost ground relative to the other architectures as the cost weighting was applied.

The Number of New System's subattributes seems to have little impact except in the case of Architecture 17, where the number of vehicle types in the manifest in "Ifs" that do not include SSF are relatively high (the RUPC does not, in itself, replace the functional requirements for other launch vehicle types in the architecture).

e. Environment – While many of the advanced technology architecture vehicles have relatively little environmental impact, they force additional flights of the Titan IV (which has SRB's), due to their limitations in payload performance. The RUPC concept not only requires more Titan-IV flights, but itself employs solid boosters on the Titan II plus graphite-epoxy motor (GEM) launch vehicle, which have a negative impact on the environment score.

f. Overall Findings – With the possible exception of the SSTO, none of the advanced technology architectures appear to offer significant advantage over the MLS-boosted architectures (5, 6 and 7) or the Space Shuttle Architecture 1. This is based on the summation of weighted scorings of attributes as described in the previous paragraphs. The impact of the human-rated vehicles on the flight rates of the cargo vehicles in the architectures, and the nature of these cargo vehicles, seems to have more impact than does the type of human-rated vehicle itself, except with regards to Human Safety (and even here the safety of the booster has a large effect). The advanced technologies of the MLS (engine-out, all liquid, hold down until all engines are lit, new high-reliability engine, redundant avionics, etc.) have a large favorable impact. The results may indicate that the best place for new technology may be in the cargo launch vehicle, which is also used to boost the personnel vehicle. This allows one set of new technology elements to benefit both personnel and cargo only flights.

Upon further reflection on the attribute scoring that produces a superior architecture, one finds that perhaps the method of introducing new architectures used in the study is too limited. After all, many informed people suspect that some forms of new technology, incorporated appropriately into a new architecture, should result in some significant improvement in space transportation. Why then, has it not? One hypothesis is that the score of new architectures was adversely affected by introducing new systems in one, large step which is difficult for the traffic to justify.

The limitation of introducing a new system is that we are faced with a no-win choice: either (a) introduce a new system as soon as possible with the hope of reducing operations costs significantly, while exacerbating poor scores in the Funding Profile, because of peak funding, and ACR attributes, or, (b) delay introduction, reducing ACR and Peak Funding, but moving the benefits (such as lower operations and recurring production costs, safety improvements, schedule confidence, and environment) so far in the future that the total architecture score (which only runs to 2020) is dominated by the shortcomings of existing systems. The only way to break out of this paradox is to propose elements with radically reduced costs, which produces questionable results.

One proposed solution to avoid this dilemma is a phased approach to the introduction of new technology. This is not necessarily just evolution or P^3I derivatives. Interim elements are used to create the funding wedge, reduce the risk, prove the technology, etc., to get to the operational system that is desired. These interim vehicles are developed with the knowledge that their life cycle is purposefully short, and not the end-all solution. There is historical precedence for this. One example is the Apollo/Saturn program, where several vehicles (Gemini, Saturn I, etc.) were developed to provide the program maturity to build the ultimate vehicle.

Why would this approach improve new architecture scores? Many people are of the opinion, at the time of this writing, that the total space transportation budget for the foreseeable future is likely to remain nearly constant. As such, it is imperative for any new system, indeed critical to the idea of proceeding with a new system, that the funds for development cannot significantly increase the space transportation budget. The interim concepts can be described in general terms as ones which could selectively incorporate features that could immediately reduce operations costs and/or stretch key technologies beyond the state of the art, but only if they are in the direction of the ultimate system. Focusing on other attributes, such as safety improvements, may not be warranted over the short life of the interim system. One possible scenario is the use of a recoverable engine module to effect immediate reductions in recurring production costs and provide for experience in reusable launch vehicle hardware. By designing this module using existing engines (SSME's) and using ET derivative tankage, the development cost does not have to be as large as a completely new vehicle. The savings in operations' costs could be directly applied to the development bill of the ultimate vehicle (presuming, of course, that the government would not choose to apply those funds elsewhere).

New technology has a place in improving space transportation. Within the traffic levels envisioned by the HTS study, however, the expense and risk of an all-new system is not warranted, given the attributes the NIT has chosen to evaluate.

3.3.10 ACRV Commonality Architecture Options 11, 12 and 13

There are two feasible approaches to providing on-orbit Assured Crew Return Capability (ACRC).

The first utilizes a special-purpose "lifeboat" attached to SSF, designed only to return the entire SSF crew to Earth in case of a medical or systems problem aboard or a loss of Space Shuttle return capability. This is the approach planned today for SSF; the vehicle is the ACRV.

The second utilizes the crew transport vehicle to and from SSF as the "lifeboat", leaving it docked to SSF during the crew's stay, available for return on need. This is the approach taken by the Russians for MIR crews. It was also utilized by NASA for the Skylab program, where the Apollo Command/Service Module remained docked to the Skylab Workshop throughout the crew stays.

The first approach requires funding the development of the lifeboat, its transportation to SSF in the Space Shuttle, and its return in the Space Shuttle at the end of its operational life, if not used. But a simple vehicle with a long quiescent lifetime is feasible, and life cycle costs are therefore low.

The second approach does not require the development of another personnel vehicle. But it imposes the requirement on the human transport vehicle used for SSF crew rotation that it be capable of on-orbit stays of up to 180 days (the crew rotation time for the SSF EMCC phase,) with attendant increases in complexity and cost.

Architectures 11, 12 and 13 were devised to determine which approach resulted in the best architecture, as measured by the HTS attributes.

3.3.10.1 Description of the Architectures

All three architectures have the following features in common, to permit the differences in approach to ACRC implementation to dominate the results:

- All retain the Space Shuttle for the full duration of the study (through the year 2020). All human missions *except* for SSF crew rotation are performed with the Space Shuttle, and all cargo return missions are also performed with Space Shuttle.
- A people-only reusable personnel carrier is utilized for SSF crew rotation missions as soon as it is available (this varies with architecture). The vehicle concept used is the Boeing/NASA developed PLS, a biconic – the same vehicle used in Architectures 6 and 7. It has no cargo capability. It is launched on the NLS-50 (NLS-2) booster.

- All utilize the NLS-50 for some non-SSF, cargo only missions, and for up-cargo missions to SSF where there is no return cargo requirement (NLS cargo missions require the use of the CTV as the NLS-50's payload).

- All utilize the Delta and Atlas boosters for the same missions as in the reference architecture (Architecture 1).

- All phase out the Titan IV booster by 2005, in favor of the NLS-50.

Architecture 11 achieves ACRC with the PLS only:

- The PLS is available in the year 2000, and conducts all SSF crew rotation flights (4 flights per year for 21 years, a total of 84).

- There is no dedicated ACRV. The PLS is a *long-duration* version, capable of remaining at SSF for full crew cycles of 90 days (during the PMC phase, "If" C) up to 180 days (during the EMCC phase, "Ifs" D and E).

Architecture 12 phases the PLS in later:

- The PLS becomes operational in 2005, and is used for all SSF crew rotation flights thereafter (4 flights per year for 16 years, a total of 64).

- An ACRV is developed, and is utilized for SSF emergency crew return until the PLS is available in 2005. It is then phased out.

- PLS (the long-duration version) is used for SSF emergency crew returns after 2005, just as it is in Architecture 11.

- Space Shuttle is used for SSF crew rotation flights between 2000 and 2005. Thereafter, it is used as in Architectures 11 and 13.

Architecture 13 utilizes both PLS and ACRV throughout:

- PLS is phased-in in 2000 and handles SSF crew rotation flights – 84 flights, the same as Architecture 11. But it is a *short-duration* PLS, designed only for missions up to 7 days, and does not remain at SSF with its crew.

- ACRV is introduced in 2000, and is stationed at SSF thereafter for emergency crew return.

The systems, functions, and phasing in each architecture are shown in Appendix B, section B.1.1.

Thus, these three architectures permit comparison between a dedicated ACRV and a long-duration PLS (Architectures 13 versus 11), and between early and late introduction of the long-duration PLS (Architectures 11 versus 12).

3.3.10.2 Flight Activity

Table 3.3.10.3-1 summarizes the flight activity in these architectures. It excludes those flights which are invariant across all architectures: the NASA Mixed Fleet Manifest (1992-1997), DOD flights, and west coast flights. The reference architecture, Architecture 1, is shown for comparison.

Since we are addressing an SSF consideration (crew emergency return), "Ifs" A and B are not relevant. And, since the results in "Ifs" D and E do not differ from those in "If" C, only "If" C is shown and will be analyzed.

TABLE 3.3.10.2-1.– FLIGHT ACTIVITY, ARCHITECTURES 1, 11, 12 AND 13, "IF" C

ARCH.	Space Shuttle	NLS-50 PLS	Atlas IIAS	Delta II	Titan IV/C	NLS-50 CTV	NLS-50 AUS	Total Human Flights	Total All
IF C									
1	219		23	35	41	0	0	219	318
11	198	84	23	35	10	79	31	282	460
12	201	64	23	35	7	79	34	265	443
13	205	84	23	35	10	79	31	289	467

The significant differences between architectures are restricted to the number of Space Shuttle and PLS flights. (A manifesting anomaly resulted in three Titan flights being manifested on NLS-50 in Architecture 12). These differences will be explained in the analysis below.

3.3.10.3 Attribute Values and Scores

Table 3.3.10.4-1 summarizes the attribute scores for these architectures for "If" C. Note the following features of the table:

- Weighting percentages used to derive total architecture scores are shown at the top of the table.

- The Funding Profile columns list the raw dollar values for the two subattributes: total cost and peak-year cost. The Funding Profile score is the average of these two, weighted equally.
- The Human Safety columns list the raw value of the attribute, which is the number of spacecraft losses over the span of the architecture, as well as the score.
- The PMS columns list the raw value of the attribute as well as the score.
- Raw or subattribute values are not shown for the other attributes. They are less significant to the evaluation.

The "Score" in the last column is the total score for the given architecture and "If" scenario – that is, the average of the individual attribute scores weighted according to the percent weightings shown at the top of the chart. These scores will differ significantly if different weights are assigned.

TABLE 3.3.10.3-1.– ATTRIBUTE SCORES, ARCHITECTURES 1, 11, 12 AND 13, "IF" C

	ACR	Env	Funding Profile			Human Safety		PMS		LSC	Score
Wgt:	13%	4%	27%			29%		19%		8%	100%
	Score	Score	Total	Peak	Score	Losses	Score	Value	Score	Score	Score
IF C											
1	1.000	0.283	173.0	7303	0.931	4.7	0.172	0.9477	0.431	0.239	54.3
11	0.787	0.521	236.7	14.3	0.228	4.6	0.207	0.9552	0.812	0.201	41.2
12	0.714	0.519	231.9	12.1	0.385	4.6	0.207	0.9553	0.817	0.211	45.0
13	0.709	0.503	240.5	14.4	0.204	4.7	0.172	0.9554	0.822	0.207	39.0

3.3.10.4 Findings

This section will describe and explain the differences between architectures in flight activity and in attribute scores. These findings will be used subsequently to analyze the consideration.

3.3.10.4.1 Differences in flight activity. – Finding – PLS flights number 84 in Architectures 11 and 13, but only 64 in Architecture 12.

Rationale – As noted above, PLS is introduced late in Architecture 12; 5 years' crew rotation flights to SSF are accomplished by Space Shuttle in this architecture.

Finding – Space Shuttle Fights decrease from 219 in Architecture 1 only, to 198-201, and 205 in Architectures 11, 12 and 13 respectively. This reduction is much smaller than the added number of PLS flights.

Rationale – Some Space Shuttle flights have been replaced by other vehicles

- SSF crew rotation flights are accomplished by PLS.
- Some up-cargo to SSF is accomplished by NLS-50/CTV

But the total number of Space Shuttle flights to SSF can only be modestly reduced because of SSF's large down-cargo requirements, which can only be accomplished by Space Shuttle.

Finding – Three more Space Shuttle flights are required in Architecture 12 than in 11, and four more are required in Architecture 13 than in 12.

Rationale – These flights are ACRV rotation flights. The study manifest does not have any actual "emergency return" ACRV flights. Every 5 years, the ACRV at SSF is returned in the Space Shuttle for overhaul, and another ACRV is launched.

3.3.10.4.2 Differences in attribute scores.– Finding – There is no significant difference between Architectures 11, 12 and 13 in the follwing attributes: ACR, Environment, Human Safety, PMS, and LSC.

Rationale – All three architectures utilize the same systems (except for the absence of an ACRV in Architecture 11).

This system commonality accounts for the virtually identical scores in Environment, PMS, and LSC.

The Human Safety score is dominated by Space Shuttle in all three architectures: only 0.5 of the 4.6 and 4.7 crew loss events, in Architectures 11 and 13 respectively, and only 0.3 of the 4.6 in Architecture 12, are due to PLS (which flies PLS 20 times less).

The absence of an ACRV in Architecture 11 gives it a slightly higher ACR score than 12 and 13 (i.e., a lower risk of cost or schedule overruns), but the difference is not significant.

Finding – Architecture 12 has a lower total cost than either Architectures 11 or 13 ($231.9 B versus Architecture 11 at $ 236.7 B and 13 at $ 240.5 B).

Rationale – Architectures 11 and 13 both have higher costs than 12 because 12 has the fewest total flights (and all of the difference is in human flights – the number of cargo only flights is identical in each architecture).

This is entirely due to the later introduction of PLS in Architecture 12. We noted above (in section 3.3.10.5.1) that the introduction of PLS adds many more PLS flights than it reduces Space Shuttle flights, because of the large up and down cargo requirements of SSF, and PLS's inability to carry cargo. The introduction of PLS 5 years late in Architecture 12 saves 20 PLS flights at the expense of only 3 Space Shuttle flights.

Finding – Architecture 11 is lower in cost than Architecture 13.

Rationale –The higher cost of Architecture 13 compared to Architecture 11 is based on two factors:

- Seven additional Space Shuttle flights are required in 13 for ACRV rotation
- PLS total costs in both architectures are the same; no additional cost is added for long-duration PLS capability.

The second factor will be challenged in the analysis below, and a set of rationalized costs for these architectures will be presented.

3.3.10.5 Analysis of the Consideration

We noted above that the long-duration PLS of Architectures 11 and 12 was assigned identical costs, both non-recurring and recurring, to the short-duration PLS of Architecture 13. Architecture 11 and 13 total costs for PLS were identical at $27.4 B; Architecture 12 cost was somewhat lower at $23.01 B because fewer PLS flights were manifested.

This is intuitively incorrect. But what cost increment is reasonable for an extended duration, personnel vehicle?

A quick analysis of this question was conducted during the HTS study (the conclusion was not available in time to affect the dollar figures used in our architecture cost model).

Data was examined from the Boeing PLS study, from the CLV study, from the EDO analyses, and from the preliminary studies of changes necessary for the Russian Soyuz to certify it for 2 to 3 years on orbit. Changes were necessary in the following systems:

- Propulsion – The Boeing PLS utilized a "180-day retrofit kit" with isolation and pyro valves and a GN_2 purge system, to purge and seal the system for quiescent on-orbit stay; a cold-gas system was added for stationkeeping and berthing, etc.

- Structure – Changes to external surfaces resistant to degredation by radiation and atomic oxygen, and meeting micrometeoroid protection requirements, were needed.

- Power – Fuel cells or batteries were favored for short-duration missions. But long duration required either a change in battery technology, or certified restartable fuel cells, plus much more efficient cryogenic storage, or solar panels.

- Thermal control – Recertification of flash evaporators, water boilers, and ammonia boilers, or the addition of radiators. Water freezup during passive stay was a problem; continuous circulation, addition of heaters, or elimination of the water loop were proposed solutions.

- Life support – Many of the above solutions apply. Cryogenic storage of O_2 and N_2 are a particular problem; storage as high pressure gas is feasible, but adds weight.

- Other systems – Using one example from the Orbiter, numerous changes were required to the Hydraulics and Water Spray Boiler subsystem, ranging from reducing leakage of hydraulic fluid and pressurant gas, to landing gear strut heaters; all system components required recertification.

Long duration requires technology advances, additonal weight, additional certification testing, and more extensive overhaul between flights. The estimate for the total cost of a system designed to meet these requirements might be 10 percent higher than that of a short-duration system of otherwise equivalent capability.

Using that estimate, the following changes should be made to the total costs of Architectures 11, 12 and 13:

- To Architecture 11– add $ 2.74 B for long-duration PLS.

- To Architecture 12 – add $ 2.30 B for long-duration PLS:
  add $ 177 M to correct for the anomalous addition of three NLS flights in place of Titan flights (see 3.3.10.3).

- To Architecture 13 – no additions. PLS is short-duration.

The corrected architecture total costs then become:

- Architecture 11– $ 236.7 B + 2.74 B = $ 239.4 B
- Architecture 12 – $ 231.9 B + 177 M
  + $ 2.30 B = $ 234.4 B
  $ 240.5 B

Architecture 13 – These cost revisions force us to restate the last finding in 3.3.10.5.2 as follows:

Finding – There is no significant cost difference between Architectures 11 and 13.

Rationale – The cost increase to ferry the ACRV to and from SSF is offset by the increased life cycle cost of a long-duration PLS.

3.3.10.6 Conclusions

To the depth of analysis achieved in the HTS, there is no advantage in achieving ACRC with a dedicated ACRV, as opposed to a long-duration-capable PLS. The two options scored equally well.

Adding an additional PLS to a transportation architecture which retains the Space Shuttle adds significant cost. Thus, delaying such augmentation saves cost by avoiding additional human flights.

More detailed system trade studies are required to determine the true cost of adding long-duration loiter capability to a PLS, as opposed to achieving return capability with a dedicated ACRV.

3.3.11 Which Booster for Human Flight? Architectures 4, 5, 6, 7, 14 and 17

3.3.11.1 Description of the Consideration

A variety of boosters were utilized in the HTS architectures to launch human spacecraft. Both existing boosters (Titan II and Titan IV) and proposed new booster families (NLS and MLS) were used. This was done in an attempt to determine whether a *best* man-rated booster could be identified, and which of its characteristics contributed most to cost-effectiveness, safety, and PMS.

New concept systems are not included in this consideration. The comparison is limited to expendable launch vehicles used to transport cargo to orbit, that can additionally be used to transport one or more of the human spacecraft that were utilized to test other considerations in the study.

3.3.11.2 Description of the Systems

The spacecraft launched on these ELV's included:

- The PLS, a Boeing/NASA-developed personnel-only spacecraft. It requires a 40 000 lb class booster for transportation to SSF orbit.
- The CLV, a scaled-down version of a Space Shuttle-type, winged vehicle developed at JSC. It requires an 87 000 lb booster to reach SSF.
- The RUPC, a Martin concept designed to be launched on the 20 000 lb class Titan II booster.

The boosters used to launch these spacecraft – the key systems to be compared in this consideration – were as follows:

- The NLS-50 was used to launch the PLS in Architecture 4.
- The MLS-X, a Boeing concept which is a derivative of the NLS-50 optimized for human launch, was used to launch the PLS in Architecture 6.
- The MLS-HL, derived as above but in the 90 000 lb weight class, was used to launch the CLV in Architecture 5 and the PLS, together with a cargo carrier in Architecture 7.
- The Titan II was used to launch the RUPC in Architecture 17.
- A human-rated version of the Titan IV was used to launch the PLS in Architecture 14.

Analysis of this consideration requires the comparison of system data, not architecture data. Therefore, the architectures will not be described here, and architecture flight activity and attribute data will not be used. Instead, the pertinent characteristics of the boosters will be summarized. Booster cost data will be *normalized* to equivalent launch rates.

3.3.11.3 Booster Characteristics

Table 3.3.11.3-1 shows the data for each booster which is relevant to its suitability for launching crewed spacecraft.

TABLE 3.3.11.3-1.– HUMAN-RATED BOOSTER CHARACTERISTICS

Booster	Spacecraft & Architecture	PMS	# Flts per Crew Loss	Cost/Flight at 350 Tot Flts
Titan II	RUPC/17	.9626	110	$52M
NLS-50	PLS/4	.9842	191	$91M
MLS-X	PLS/6	.9842	191	$93M
Titan IV	PLS/14	.9474	65	$172M
MLS-HL	CLV/5 PLS/7	.9691	141 141	$177M

Note the following about the data presented in this table:

- The PMS numbers are for the boosters alone, not for the booster and spacecraft combination. These figures are discussed in detail in the Systems Description section of this report.

- The number of flights-per-crew loss event calculations utilize the PMS of the booster and spacecraft combination and the abort characteristics of the spacecraft. They are not pure booster numbers. They are included because booster PMS correlates highly with safety. They are presented as flights-per-loss event to make them independent of the number of flights in an architecture. Thus, they fairly represent the relative safety of the boosters.

- The cost-per-flight numbers are for the boosters, not the spacecraft, and are without wraps. They are normalized to 350 flights per year, a typical value in many architectures. Thus, they represent fair comparisons between the booster costs. It should be kept in mind that the payload launch capabilities of these boosters vary widely.

One additional set of cost data is presented below in Table 3.3.11.3-2: typical recurring costs for each booster.

TABLE 3.3.11.3-2.– BOOSTER RECURRING COSTS

Booster	Architecture	Recurring Costs ($ Millions)			
	(Tot# Flts)	Operations	Production	Unreliability	Total
Titan II	17 (273)	5,336	10,037	712	16,085
NLS-50	4 (310)	4,819	36,284	909	42,012
Titan IV	14 (365)	17,230	45,484	3,754	66,468
MLS X and HL	6 (577) (272X+305HL)	11,296	95,338	2,319	108,953

This table shows the total wrapped recurring costs for each booster in the architecture noted. The number of flights of that booster in its Architecture is given; these have not been normalized.

The MLS costs include both the smaller -X and the larger -HL version; costs for each were not broken out at the architecture level.

The purpose of this table is not to present a strict comparison between boosters, but to show that the life cycle costs of all are dominated by recurring hardware production costs.

3.3.11.4 Findings

Finding – The Titan boosters have the lowest PMS and the fewest flights per crew loss event.

Rationale – These are the only existing boosters in the group. They were not designed to carry human spacecraft, do not have engine-out capability, and do not have a success history as good as that projected for the new systems.

Finding – Of the new systems studied, the larger booster (MLS-HL) has a lower PMS than the smaller ones (MLS-X and NLS-50.)

Rationale – The MLS-HL requires an upper stage, whose failure probability adds to that of the smaller vehicle. The other two have very similar system architectures, and thus, identical scores.

Finding – The cost-per-flight of the three new systems are comparable, given their payload launch weight capabilities.

Rationale – All use similar technology and configurations. No cost-reducing breakthroughs (such as recoverable engines) were utilized.

Finding – The total costs of all the boosters compared are dominated by recurring production costs (see Table 3.3.11.3-2.)

Rationale – Both the existing and the new boosters studied are completely expendable. The costs for new boosters, especially engines, for each flight, far exceeds the operational costs of these launch systems. This situation will continue unless engine costs can be dramatically reduced, or the engines can be recovered for reuse.

3.3.11.5 Conclusions

New human-rated boosters can be designed for significant improvements in PMS and crew safety. Such an approach appears superior to modifying existing boosters.

A new booster should be designed for the spacecraft it is to carry. Excess-lift capability means higher cost and lower PMS.

Booster technology development should emphasize the development of systems which minimize recurring cost. Recoverable engines are one such possibility.

3.4 NEW WAYS OF DOING BUSINESS (NWODB)

The final principal task of the study (Task 4) centered around gathering a set of data regarding "new ways of doing business", and how those new business approaches might reduce cost or increase productivity of space transportation systems. To accomplish this task, the HTS NIT distributed a survey to various functional and program managers within the aerospace industry. Based upon responses to the survey and an assessment of the impact on various stages of systems development (e.g., Pre-Phase A through Flight Operations), the areas of greatest potential benefit were identified. A description of received responses to the survey is found in Appendix F of Volume II.

After gathering and compiling the survey input, the next step was to focus on identifying the level of difficulty in analyzing and implementing the specific NWODB suggestions. The intent was to identify any "low-hanging fruit" which could be integrated into government operations without much delay. In addition, several "attack plans" were formulated for the NWODB suggestions deemed to have the greatest potential benefit.

Most of the information presented below on how the Government could and should do business differently is not new and has been identified in other activities. However, specific suggestions were offered as to what steps should be taken to assess NWODB and how these steps might be implemented with respect to current and future transportation systems. In this study, no credit was taken for any cost savings associated with NWODB, since it was felt the probability with which NWODB could be successfully implemented could not be determined. Moreover, the agency in general must be extremely cautious in taking any credit in estimates of future program costs that assume the introduction of new business practices that have not been demonstrated in NASA.

3.4.1 NWODB Analysis and Implementation Survey

Each NIT representative was asked to identify what they considered the top 10 NWODB options from their perspective and experience. Using these results, the NIT evaluated the level of difficulty associated with analysis and implementation of each suggested option.

The following is a short description of the intent of each of the NWODB options identified.

- *Minimize the Government Role.*– Focus the government role to definition of the top level requirements of a system or mission, and allow the contractor to do the technical job (deciding the best or most cost-effective way to get the job done). Government program offices should be small, should shrink in proportion to the contractor work force reductions, and should be focused on verification that requirements are being satisfied.

- *Cost Reduction Incentives.–* Currently contractors are given incentives to meet technical and programmatic milestones. Incentives should also be written into contracts that encourage cost savings through contractor and employee sharing programs. This encourages innovative approaches to getting the job done by allowing the contractor to receive greater profits, while reducing the total government expense.

- *Provide Program with Adequate Budget.–* Provide multiyear funding at adequate levels to ensure a thorough and efficient effort. Efficiency and momentum are lost when a program has to rejustify its existence every year during the government budget cycle. Stretching program lengths generally increases the total program costs and, therefore, government expenditures. Inadequate levels of funding usually result in a reduction in the focus of the test program, which results in greater annual costs downstream, increasing the overall life cycle costs.

- *Improve Tactical Planning .–* A detailed plan with decision points and technology insertion junctions would prevent many dead-end programs and wasted government and contractor expenditures.

- *Cap Project Growth.–* Plan development programs to occur over a 3 to 4 year period. If this schedule cannot be met, then enabling technologies should be pursued and demonstrated in the interim. In addition, projects should be terminated if they significantly overrun their projected costs.

- *Design for Operations.–* It is better to spend extra money up front during development, than to suffer with a more complex and expensive ground operations system over the life cycle operation of the system.

- *Modify Procurement Process.–* Streamline and reduce the process of soliciting and submitting a proposal and reduce the current proposal boilerplate. In addition, include cost risk as an evaluation parameter to reduce the "low-balling" of contractor bids.

- *Modify Procurement Practices.–* This option covers the government decisions on which programs to solicit proposals for and the type of proposals solicited. Separate technology development from operational system procurements. Do not force fixed price contracts on development programs. Avoid abortive procurements.

- *NASA Center Coordination.–* Establish clear lines of authority and standardize practices. This would provide for a more efficient and focused civil servant work effort.

- *Communication Enhancements.*– Reduce the number of contract data requirements, and the scope and number of formal reviews through electronic communication, on-site visits, or co-location of government and contractor teams.

- *Improve Management and Engineering Techniques* - Utilize concurrent/systems engineering philosophies early in programs, utilize Total Quality Management/ QFD methodologies throughout the program, and operate using a team philosophy between the government and the contractor.

- *Streamline Contracted Research and Development Change Mechanism.*– Reduce the number of people and the amount of time required to make a contract change.

- *Focus Program Requirements.*– Program requirements should focus on what the mission to be accomplished is and not on how to get the job done. These should be specified up front and not modified unless significant cost savings can result.

3.4.2 Survey Results

Once all the inputs were gathered, the team met again to reevaluate the potential benefit, analysis difficulty, and implementation difficulty of the above options. The following three criteria were used to determine how well each suggested option could be implemented. The results of this assessment are shown in Table 3.4.2.

Potential Benefit

- High - Enables new mission and new system starts in the near term.

- Medium - Results in moderate cost savings to current programs that can be reinvested (in technologies, personnel, or equipment) over time to make future programs and systems more cost effective.

- Low - No significant cost savings to current or future programs and systems.

Availability and Access to Data (Analysis Difficulty)

- High - Data readily available with some research.

- Medium - Would require a dedicated NWODB study to quantify the potential benefit.

- Low - Extremely difficult to find data, probably never be able to quantify.

Probability of Implementation (Implementation Difficulty)

- High - Program manager level implementation decision.
- Medium - Within NASA but at higher levels than program manager.
- Low - Outside of NASA, e.g., Act of Congress.

TABLE 3.4.2.– ASSESSMENT OF NWODB OPTIONS

New Ways of Doing Business Options	Potential Benefit	Availability & Access to Data	Probability Of Implementation
1 Minimize the Government Role	H	M	M
2 Cost Reduction Incentives	H	M	M
3 Provide Prog. w/Adequate Budget	H	H	L
4 Improve Tactical Planning	M	M	M
5 Cap Project Growth	M	H	L
6 Design for Operations	H	M	M
7 Modify Porcurement Process	L	M	L
8 Modify Procurement Practices	M	M	L
9 NASA Center Coordination	M	L	M
10 Communication Enhancements	L	H	H
11 Improve Mgt./Eng. Techniques	M	L	H
12 Streamline CRAD Change Mech.	L	M	M
13 Focus Program Requirements	H	M	M

3.4.3 New Ways of Doing Business (NWODB) Attack Plans

The following outlines describe potential attack plans to address the top five areas identified as having the greatest potential benefit.

General Considerations

- Access to data.– To truly understand the impact of new business approaches, it is essential to have quantifiable data such that architectures can be rerun with the projected cost savings. However,
  - some things may be difficult or impossible to measure, in which case one would have to drop back to a qualitative measurement or discussion.

- some analyses may require more effort than can be reasonably expected, given the finite study schedule and resources. In this case, one would identify the potential benefit and recommend further analyses in a follow-on effort by the appropriate agent (e.g., NASA, HTS NIT, OMB, etc.).
- some useful data could be lost due to proprietary considerations. These will be addressed on a case-by-case basis.

3.4.3.1 NWODB Area #1

Limit government role to oversight and verification that requirements are satisfied and allow contractor to perform assigned role. Reductions in government oversight should reduce the contractor costs as well as government costs to manage the contractor (included in the wraps).

Several case studies were recommended for examination in this attack plan. They included Atlas, Delta Star, and the EDO. The General Dynamics (GDSS) Atlas launch vehicle program was selected to compare and contrast the impacts of government oversight on launch costs and schedule, versus similar commercial launches. Although the data research for this task was not completed during the study, a good qualitative assessment was made.

Table 3.4.3.1 shows the level of government oversight categories that GDSS products can be organized into, which ranges from full military to commercial levels of oversight. In the interest of bounding the problem and reducing the amount of research, it may be appropriate to look at an MLV II versus a commercial mission like the payload BS-3H (highlighted in the table). To quantify the differences between these two extremes, several discriminators were identified for which data would be gathered. These discriminators are described below

TABLE 3.4.3.1.– IMPACTS OF VARYING LEVELS OF OVERSIGHT ON SPACE LAUNCH ACTIVITIES.

		Full Military	Partial Military	Commercial Government	Rigorous Commercial	Commercial
	Designation	Titan/Centaur	MLV II (AC101) (AC103) (AC104)	CRRES (AC69) UHF (AC74) (9 others) SOHO GOES	TELSTAR INTELSAT VII	BS-3H (AC70) EUTELSAT (AC102) GALAXY (AC72) (AC71) SAX ORION INMARSAT MSAT
Varying Levels of Oversight Discriminators Between	Oversight	———	Decreasing Oversight (# of Over-viewing Organizations) ——→			
	Costs	———	———	Decreasing Costs	———	——→
	Action Items	———	———	Less Actions	———	——→
	Engineering Changes	———	———	Less Engineering Changes	———	——→
	Integration Time	———	———	Shorter Integration Time	———	——→
	Procedures (test, acct.)	———	———	Fewer Procedures	———	——→
	Documentation	———	———	Less Documentation	———	——→
	Empowerment (auth.)	———	———	Authority at Lower Levels	———	——→
	Others????	———	———	??????????????	———	——→

- *Number of Oversight Organizations.–* As the number of organizations involved in the oversight of a launch increase, the costs incurred by the supplier must also increase. Commercial missions often have few (sometimes none) additional organizations interfacing with the supplier, other than the customer. This is a relatively easy discriminator to measure, but harder to translate into cost impacts.

- *Costs.–* This is obvious; the greater the oversight, the higher the cost for a product or service. Again, it is an easy number to find, but would be company proprietary. However, it can likely be documented in a relative sense (as a ratio between government and commercial).

- *Action Items.–* Generally, the more oversight, the more work will be generated for which the supplier must respond. Action items are tracked, but are difficult to normalize (i.e., which ones are the contribution from the added oversight versus other factors). For example, interfacing with a foreign customer may result in actions related to communication items because of the distance and time differential.

- *Engineering Changes.*– This may not be a good discriminator for quantifying the impacts of oversight. It is more likely a reflection of the technical challenge associated with the job and would, therefore, have to be carefully normalized.

- *Integration Time.*– This may also not be a good discriminator because so many other factors enter into the equation, such as commonality with a previous launch, payload availability, launch vehicle modifications, etc. Again, a careful normalization would be required to determine the impacts of levels of oversight.

- *Number and Type of Procedures.*– This may not be a good discriminator for Atlas because the procedures are fairly consistent across the spectrum.

- *Amount of Documentation.*– This item is fairly easy to measure and translate into costs.

- *Level of Empowerment.*– This item is hard to quantify and translate into costs but may be interesting to see and compare. However, one could show a chain-of-authority diagram with key decision makers identified.

Suggested Attack Plan

1. Identify programs that have limited government oversight (e.g., comparison of commercial vs. government ELV launches).

2. Identify the benefits derived from limited government oversight.

3. Determine how the level of oversight was established or negotiated.

4. Develop justifications to support implementation of reduced oversight (e.g., architecture costs with or without limited oversight).

5. Develop methods for implementation of reduced government oversight to current and future programs.

6. Identify candidate programs for implementation of reductions in government oversight.

7. Present results and recommendations to NASA and Industry representatives. Seek feedback, consensus, and commitment to change.

8. Track implementation of reduced government oversight on programs and document process (i.e., lessons-learned, innovative approaches, road blocks, etc.).

3.4.3.2 NWODB Area #2

Place more emphasis on project accomplishment rather than reporting, documentation, justification, etc. Reporting allows the government to ensure that progress is being made towards the desired goal, and allows the results to be preserved for future reference and to inform a wider distribution of interested parties. The focus here must be to obtain an optimal mix to increase the efficiency of taxpayer contributions.

Suggested Attack Plan

1. Identify the standard reporting and documentation requirements for various programs.

2. Assess the *need* for each data product in terms of government decision making and program direction maintenance.

3. Identify and analyze other ways to satisfy government needs in lieu of excessive reporting or documentation (e.g., co-location of government and contractor program teams, electronic network communications, etc.)

4. Recommend reporting and documentation alternatives available to government program managers that sufficiently cover needs, without hampering productivity.

3.4.3.3 NWODB Area #3

Provide multiyear funding. This would be extremely difficult to accomplish. It will be much easier to analyze the problem than to define a solution that does not require divine intervention.

Suggested Attack Plan

1. Select and examine several programs that have been severely impacted by the lack of multi-year funding (e.g., SSF or NLS).

2. Assess the impacts quantitatively and qualitatively.

3. Identify changes in government procurement and contracting policies, procedures, regulations, and/or laws necessary for multiyear funding commitments. If no changes are required, understand how it is authorized.

4. Recommend and justify the characteristics of programs that should be authorized for multiyear funding.

5. Identify programmatic approaches that would reduce the magnitude of the impacts (e.g., program funding risk assessments and mitigation plans).

3.4.3.4 NWODB Area #4

Institute a rigorous systems engineering approach to definition and development of projects. Application of a systems engineering approach to any program will entail philosophical and operational modifications. The systems engineering approach should be implemented from the very beginning, starting with initial requirements generation and continuing throughout all phases and levels of a program. This approach should be utilized by both contractor and government to assure successful implementation.

Suggested Attack Plan

1. Identify systems and concurrent engineering references.

2. Determine the benefits for application of systems engineering methods to programs of various sizes and focus.

3. Recommend a functional breakdown for a concurrent engineering team.

3.4.4 Conclusions

- The HTS NIT consensus (plus others in the aerospace industry) is that there may be great potential to free up money for new missions and new systems through implementation of NWODB.

- Based upon limited analysis, it is apparent that the availability and access to data prohibits a full understanding of new business impacts. A separate study or group of studies is required to quantify the benefits of NWODB options.

- Many of the NWODB options are under the direct control of NASA, although they need the support and authority of upper level NASA management for implementation.

- There is a need to involve the upper management of NASA and industry to assure the access to data, the commitment to change, and the demonstration of NWODB viability through implementation into existing programs. Until such time as new business practices can be demonstrated within NASA, the agency should be extremely cautious in development and use of future project cost estimates including NWODB.

3.5 SENSITIVITY STUDIES

At the completion of the main body of work for the HTS study, there were a series of questions, sensitivities, or trades which the study team felt were important to address. These included the sensitivity of the results to differing mission needs, additional refinements of the methodology used to calculate attributes, and additional definition of the systems and architectures of the study. This additional work is described in the following paragraphs.

3.5.1 Needs Model Sensitivity

3.5.1.1 SSF Logistics Return Requirement Reduction

Introduction

This section documents the impact of reducing SSF logistics return mass on the study architectures and their attribute values. Among the results reported are the flight rates and the three major contributing attributes of the architecture scores; Human Safety, Funding Profile, and Probability of Mission Success. Since together they make up 75 percent of the architecture scores, only these attributes will be described in the following architecture results.

For the HTS study the return mass is made up of the ISF, Satellite Servicing, Sortie Science and SSF payloads. Most of this mass is included in the SSF program in the form of scientific payloads and pressurized and unpressurized logistics payloads. To assess the effect of reduced SSF return requirements on the architectures, a sensitivity analysis was performed in which portions of the SSF logistics return mass were reduced. In addition, all ISF and Sortie Science missions were eliminated (both delivery and return).

Based on this analysis, several generalized observations were made. Emphasis was placed on understanding both architecture-dependent and architecture-independent impacts.

An analysis of the SSF mass return requirements showed that, on average, SSF scientific payloads make up only 14 percent of the return mass (Figure 3.5.1.1-1). Eighty-six percent of the return mass is attributed to the logistics payloads; 30 percent unpressurized and 56 percent pressurized. In performing the sensitivities analysis, three possibilities were examined:

- Return all mass required in the HTS Mission Model (100 percent return required),

- Return only 50 percent of the pressurized and unpressurized logistics payloads and all SSF scientific payloads (57 percent SSF return required), and

- Return only the scientific payloads (14 percent SSF return required).

In both the 57 percent and 14 percent cases, both the ISF and Science Sortie mission requirements were excluded as mentioned above.

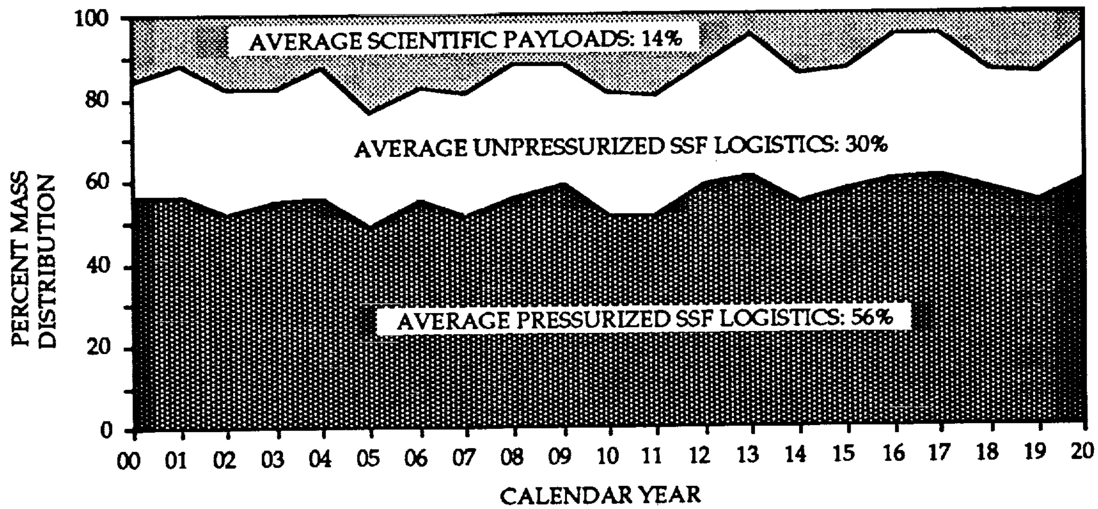


Figure 3.5.1.1-1.– SSF return mass distribution.

Ground Rules and Guidelines

The sensitivity analysis conformed strictly to the HTS manifesting and costing ground rules and assumptions, except for the missions (ISF, Sortie Science and SSF logistics) that were modified, rearranged, or deleted.

Although return mass was eliminated, the corresponding delivered mass was still required in the analysis. By doing this, it was assumed that the basic mission requirements and objectives (with specific mass delivered to orbit at specific time) must still be satisfied. Also assessed was the possibility of disposing of the logistics return mass, together with its consequences on the architecture, but not the effect of additional costs or other requirements on the SSF program itself.

Summary of Results

This section documents the results and observations obtained from the return reduction sensitivity analyses. In most cases, only the baseline manifesting ground rules were used, with the different mass return level being the only change. Some other sensitivities, such as maximizing manifesting efficiency or substituting other appropriate vehicles in the architecture, were performed.

The following sections discuss the flight rate impacts followed by architecture impacts of reducing SSF logistics return mass.

a. Architecture 1 - "If" C.– For this case, reducing the SSF return mass does not necessarily reduce Space Shuttle flights, since the Space Shuttle must deliver payloads to the SSF regardless of how much return mass is eliminated. The cause of the reduced number of flights shown in Figure 3.5.1.1-2 is the elimination of ISF and Sortie Science missions in the 57 percent and 14 percent cases. From the architecture standpoint, this saved one crew loss event, cut the total cost by more than $5 billion, and reduced the number of reflights by more than five flights (Table 3.5.1.1-1).

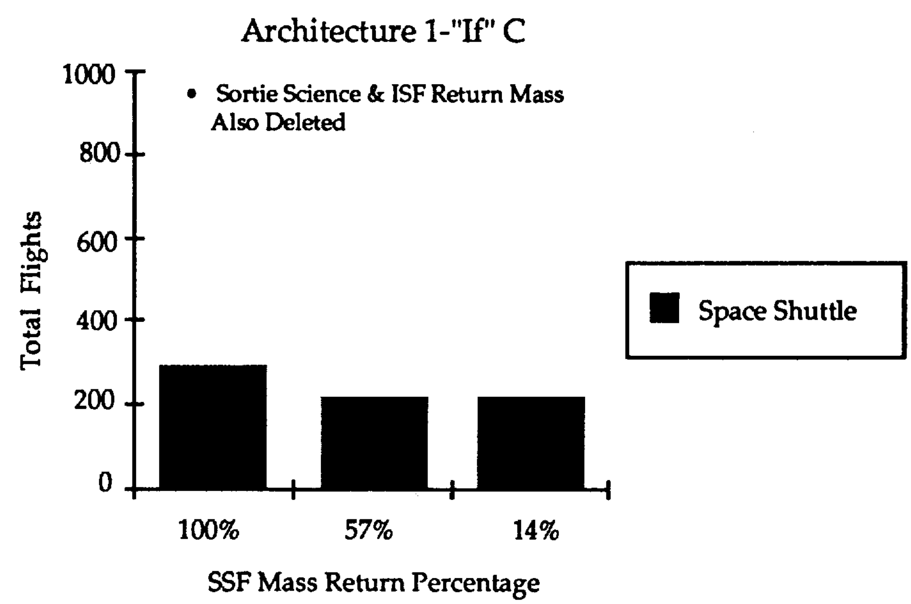


Figure 3.5.1.1-2.– Architecture 1 - "If" C reduced return requirement sensitivity flight rates.

TABLE 3.5.1.1-1.– ARCHITECTURE 1 - "IF" C REDUCED RETURN SENSITIVITY ATTRIBUTE RESULTS

SSF Return Case	Flight Rate				Attributes		
	Space Shuttle	RPC	CTF/CTV	CRV/LRV	Safety (Crew Loss Events)	Total Cost ('92 $B)	Peak Funding ('92 $B)
100%	300	0	0	0	7	97.6	5.28
57%	207	0	0	0	5	92.1	5.15
14%	207	0	0	0	5	92.1	5.15

Note: The 57% and 14% cases do not include ISF and Sortie Science Missions.

b. Architecture 1A - "If" C.– This architecture has two systems flying SSF missions: the Space Shuttle and the Titan IV/CTF. Reducing SSF return mass from 100 percent to 57 percent helps decrease the number of Space Shuttle flights, while increasing CTF flights, as shown in Figure 3.5.1.1-3. The ISF and Sortie Science missions deleted in the 57 percent case further contributes to Space Shuttle flight reduction. The Space Shuttle must continue at least four crew rotation flights per year to the SSF in all cases, including the 14 percent case, therefore its usage does not show any significant reduction. On the other hand, because more SSF logistics payloads which can be off-loaded from Space Shuttle exist in the 14 percent case, the CTF flight rate is increased.

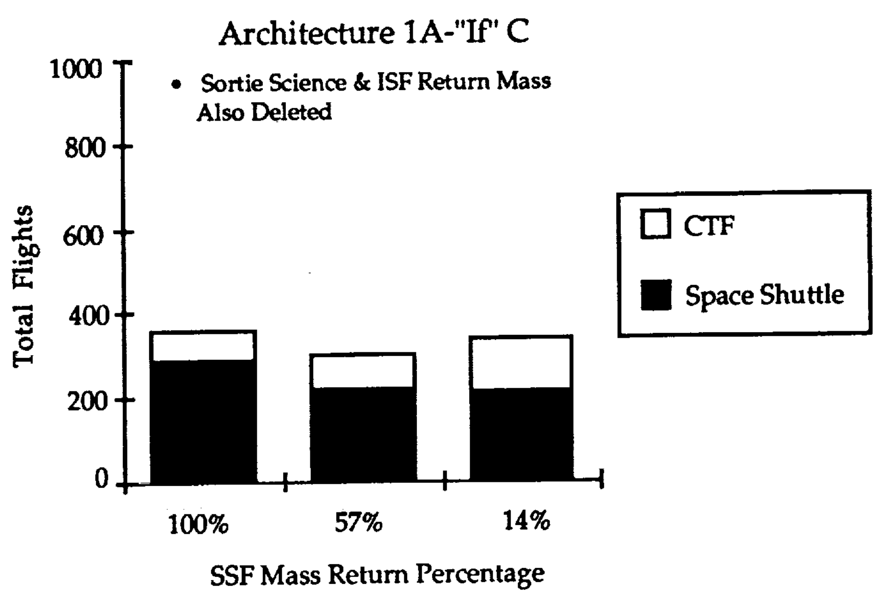


Figure 3.5.1.1-3. Architecture 1A - "If" C reduced return requirement sensitivity flight rates.

As a sensitivity to Architecture 1A, some of the mission capture groundrules and assumptions to maximize payload manifesting on the Space Shuttle before a CTF is utilized were modified. For this case, the Space Shuttle flight rates are maintained at the levels of the previous case. In addition, the manifest on the Space Shuttle flights using SSF payloads with no return mass requirements were optimized. The net effect is to increase Space Shuttle usage, with the few remaining missions having no return mass able to go on the CTF. This results in a somewhat lower number of CTF flights in both the 57 percent and 14 percent cases (Figure 3.5.1.1-4) as compared to Architecture 1A - "If" C.

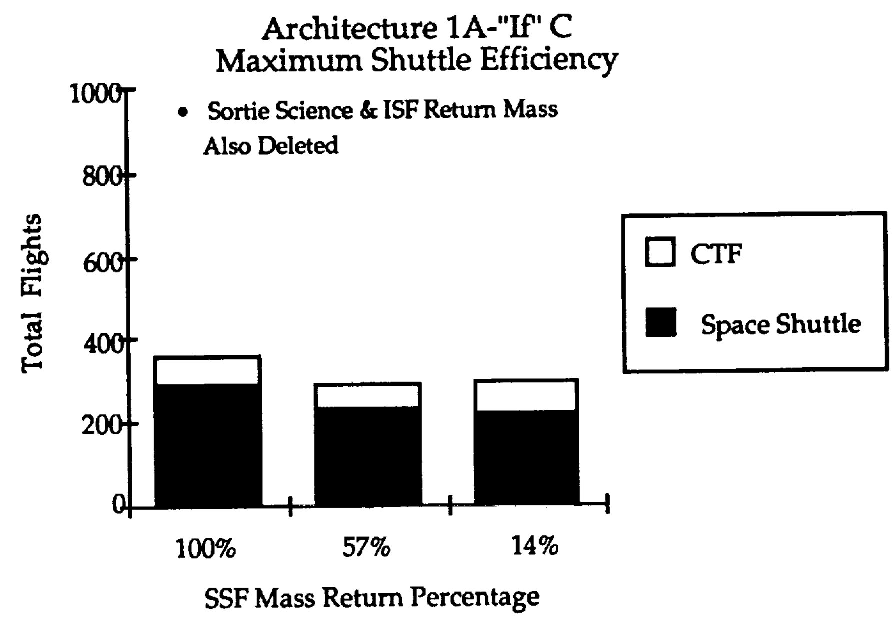


Figure 3.5.1.1-4.– Architecture 1A (maximum efficiency) - "If" C reduced return requirement sensitivity flight rates.

Attribute values of Architecture 1A (with maximum manifesting efficiency) are shown in Table 3.5.1.1-2. Because more one-way payloads fly on the CTF in the 14 percent case than the 57 percent, the total architecture cost and number of reflights are slightly higher. However, the improvement in safety may be worth the extra $1.7B to eliminate one crew loss event.

TABLE 3.5.1.1-2.– ARCHITECTURE 1A (MAXIMUM EFFICIENCY) - "IF" C REDUCED RETURN SENSITIVITY ATTRIBUTE RESULTS

SSF Return Case	Flight Rate				Attributes		
	Space Shuttle	RPC	CTF/CTV	CRV/LRV	Safety (Crew Loss Events)	Total Cost ('92 $B)	Peak Funding ('92 $B)
100%	292	0	78	0	7	106.4	5.40
57%	228	0	54	0	6	98.1	5.26
14%	220	0	74	0	5	99.8	5.31

Note: The 57 percent and 14 percent cases do not include ISF and Sortie Science Missions.

c. Architecture 3 - "If" C.– The result for this architecture is almost identical to that of Architecture 1A. Here the Titan IV/CTF is replaced by the NLS-HL/CTV, which has more than twice the Titan IV/CTF performance (101 000 lbs vs. 40 000 lbs). Therefore, the Space Shuttle flight rate trend is similar, while the NLS-HL/CTV flights are less than half of the Titan/IV/CTF in the previous case (Figure 3.5.1.1-5).

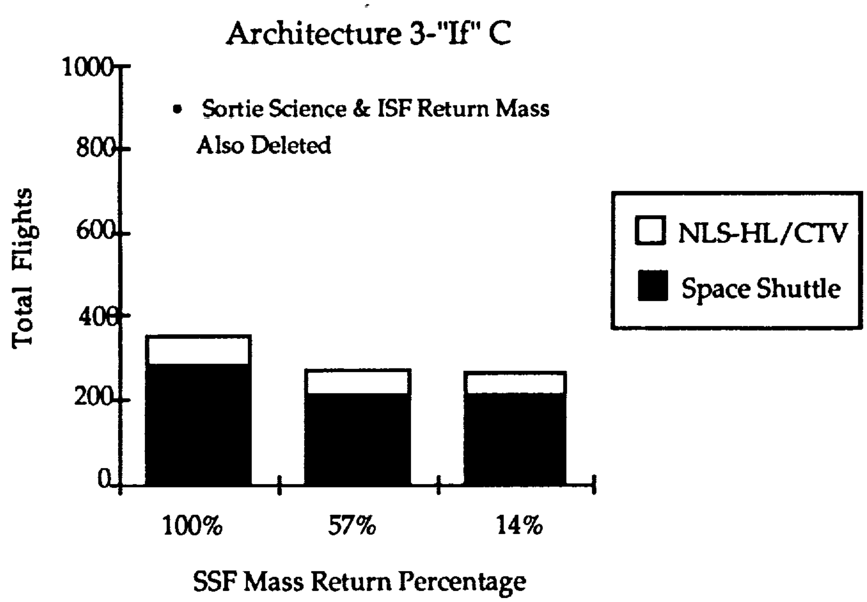


Figure 3.5.1.1-5.– Architecture 3 - "If" C reduced return requirement sensitivity flight rates.

Similar to Architecture 1A-Maximum Efficiency, Architecture 3 with maximum efficiency was also analyzed. In this case, the Space Shuttle flight rates are roughly the same. In addition, the manifest on the Space Shuttle flights with SSF payloads having no return mass were optimized. The net effect is to maximize Space Shuttle payload usage with only the few remaining missions having no return mass flying on the CTV. This results in a somewhat lower CTV flight rate in both the 57 percent and 14 percent cases (Figure 3.5.1.1-6) as compared to Architecture 3-"If" C.

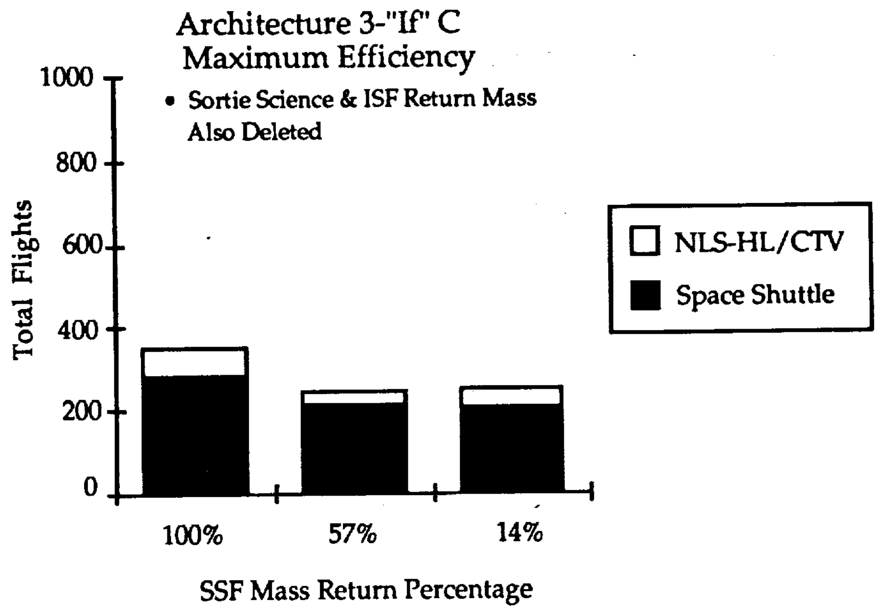


Figure 3.5.1.1-6.– Architecture 3 (maximum efficiency) - "If" C reduced return requirement sensitivity flight rates.

Similarly, for the architecture attributes, there is a drop in the total cost and number of reflights when reducing to the 57 percent mass return level. However, again this slightly increases in the 14 percent case due to additional NLS-HL/CTV flights, as shown in Table 3.5.1.1-3.

TABLE 3.5.1.1-3.– ARCHITECTURE 3 (MAXIMUM EFFICIENCY) - "IF" C REDUCED RETURN SENSITIVITY ATTRIBUTE RESULTS

SSF Return Case	Flight Rate				Attributes		
	Space Shuttle	RPC	CTF/CTV	CRV/LRV	Safety (Crew Loss Events)	Total Cost ('92 $B)	Peak Funding ('92 $B)
100%	287	0	79	0	7	124.0	9.37
57%	222	0	28	0	5	117.3	9.49
14%	218	0	41	0	5	118.6	9.50

Note: The 57 percent and 14 percent cases do not include ISF and Sortie Science Missions.

d. Architecture 5 - "If" C.– In Architecture 5, the Space Shuttle is phased out by a combination of MLS-HL/CLV, MLS-HL/CRV, and MLS-HL/CTF. The CLV can carry a crew of ten and 15 000 lbs to the SSF.

Figure 3.5.1.1-7 shows the total flight results. As less mass needs to be returned, the untended CRV is less likely to be required, until there is no need for it in the 14 percent case, as shown in the figure. On the other hand, as more one-way delivery mass is available, the CTF usage increases. The CLV flights must be maintained to provide the crew rotation function.

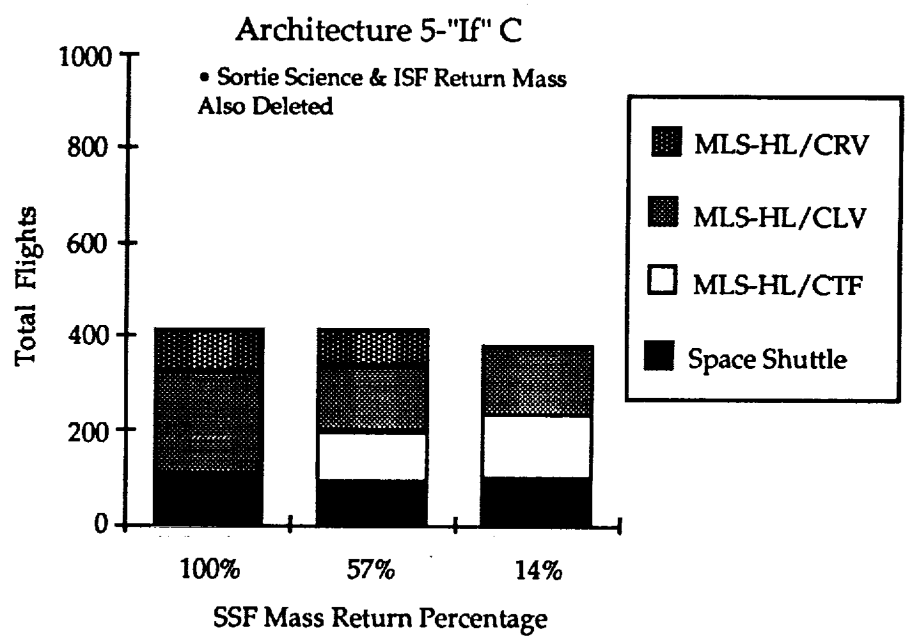


Figure 3.5.1.1-7.– Architecture 5 - "If" C reduced return requirement sensitivity flight rates.

An attempt was made to maximize payload manifesting, as shown in Figure 3.5.1.1-8. Because payload manifesting was maximized on already existing CLV flights for crew rotation and CRV flights, there is no need for the CTF in the 57 percent case. Conversely, in the 14 percent case, only the CLV and the CTF is required payload delivery. This result is similar to the result above, with a lower number of flights due to greater manifesting efficiency. Table 3.5.1.1-4 summarizes the major architecture attributes.

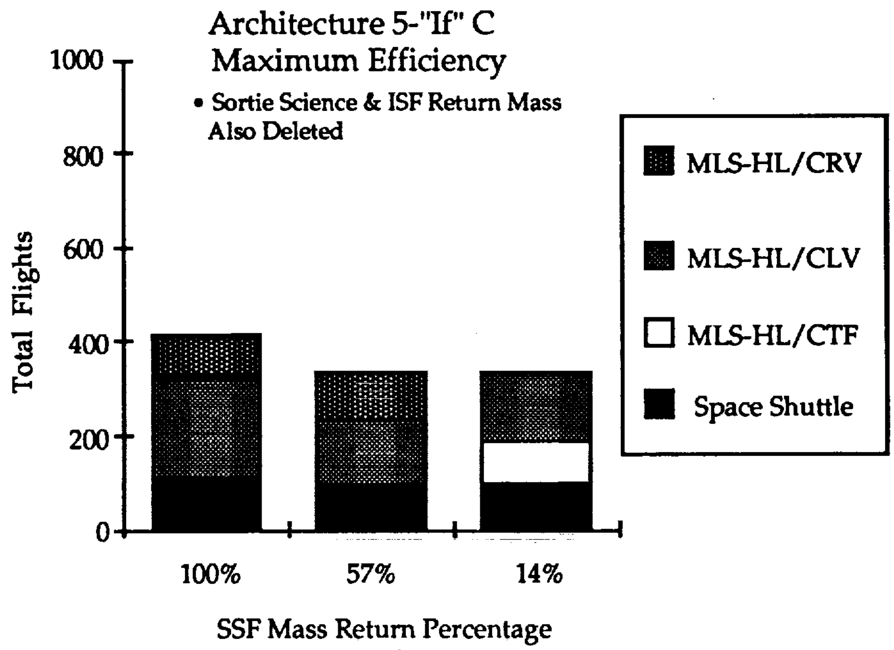


Figure 3.5.1.1-8.– Architecture 5 (maximum efficiency) - "If" C reduced return requirement sensitivity flight rates.

TABLE 3.5.1.1-4.– ARCHITECTURE 5 (MAXIMUM EFFICIENCY) - "IF" C REDUCED RETURN SENSITIVITY ATTRIBUTE RESULTS

SSF Return Case	Flight Rate				Attributes		
	Space Shuttle	CLV	CTF/CTV	CRV/LRV	Safety (Crew Loss Events)	Total Cost ('92 $B)	Peak Funding ('92 $B)
100%	108	216	0	89	4	142.2	10.1
57%	92	140	0	106	3	130.1	9.7
14%	92	145	97	0	3	127.8	9.3

Note: The 57 percent and 14 percent cases do not include ISF and Sortie Science Missions.

e. <u>Architecture 6 - "If" C</u>.– In Architecture 6, the Space Shuttle is phased out by a combination of MLS-X/PLS, MLS-HL/CRV, and MLS-X/CTF systems. All payload return is provided on the MLS-HL/CRV. The flight rate results are shown in Figure 3.5.1.1-9.

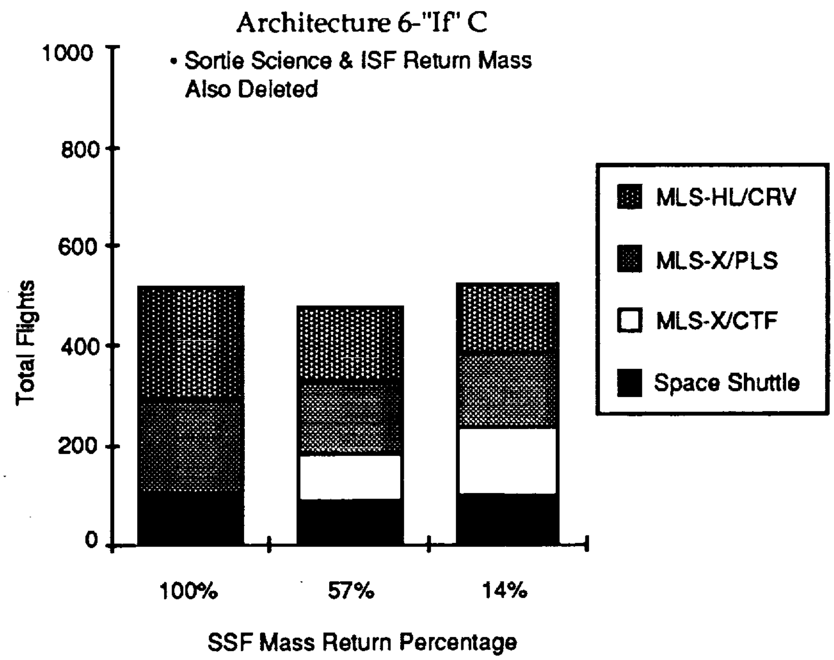


Figure 3.5.1.1-9.– Architecture 6 - "If" C reduced return requirement sensitivity flight rates.

Because all one-way payloads, including SSF logistics, are launched on the MLS-X/CTF, which has less capacity, the total number of flights increased in the 14 percent case. The MLS-HL/CRV still is used for returnable payloads, including SSF scientific, Satellite Servicing and some Base payloads.

The attribute values for this architecture indicate clearly the impact of reducing the return mass requirements (Table 3.5.1.1-5). As the return mass is reduced, and as the Space Shuttle is phased out, the PLS must continue flying to provide crew rotation missions. In addition, both the CTF and CRV flight rates must increase to carry all the payloads. This also increases the MLS-X and MLS-HL flights (since they serve as booster stages for both CTF and CRV), thereby increasing the total cost. Similar results were obtained for Architecture 7 as well. In this case, both a CRV and an LRV (launched on a larger booster concurrently with the PLS) are used to replace the Space Shuttle.

TABLE 3.5.1.1-5.– ARCHITECTURE 6 - "IF" C REDUCED RETURN SENSITIVITY ATTRIBUTE RESULTS

SSF Return Case	Flight Rate				Attributes		
	Space Shuttle	RPC	CTF/CTV	CRV/LRV	Safety (Crew Loss Events)	Total Cost ('92 $B)	Peak Funding ('92 $B)
100%	102	186	0	230	4	147.3	11.3
57%	87	148	96	146	3	144.5	11.6
14%	96	148	137	142	3	149.1	11.6

Note: The 57 percent and 14 percent cases do not include ISF and Sortie Science Missions.

Generalized Findings

The following discussion is based mainly on examination of the 57 percent and 14 percent reduction case results. Because the 100 percent case includes the ISF and Sortie Science missions, it is not directly comparable to the other two cases. Future analyses should provide consistent requirements across all cases for a more accurate comparison.

In all cases, the CTV (or CTF) capability made sense only for delivery-only type missions, i.e., when their return mass requirement is reduced. This is obvious since that is what it is designed to do. However, merely reducing return mass does not necessarily improve architecture attributes. In some architectures, the 14 percent case is better than the 57 percent case (Architecture 1); in others it is not (Architectures 1A, 3, and 6). The main issue involves knowing how much to reduce SSF logistics mass required and to balance its usage, given development and per-flight costs.

On the average, elimination of either half (57 percent case) or nearly all (14 percent case) of SSF logistics return requirements gives similar flight results for the Space Shuttle. Both scenarios indicate savings of two SSF logistics flights per year and one non-SSF logistics flight per year.

With the elimination of SSF logistics return requirements, the combination of the CTF and CLV systems is adequate to replace the Space Shuttle. In this case, there is no need for a separate CRV.

By reducing the requirement for return cargo, as in the 14 percent case, the need for a separate CRV is eliminated in Architecture 5, because of the cargo return capability of the CLV. However, in Architecture 6, where the PLS has no cargo capability, a separate CRV is still required.

3.5.1.2 Flight Rate Smoothing Analysis

A principal study groundrule was that manifesting of each payload would occur in the year identified by the mission model. However, it might be more efficient to allow payloads to float into adjoining years if a facility or element limitation (provided launch window constraints are properly met) was encountered.

To understand this impact, the cost savings that could be achieved, over the baseline case, by allowing an architecture to fully spread its flight rate requirements across the study time frame has been examined. This would level facility, equipment, and reusable element usage. This can be compared to the average flight rate for a system with the flight-rate-delineated trigger points for each facility, equipment, and reusable element (i.e., when new purchases are required) that are accounted for in the cost analysis. The savings are the costs for the triggers that were avoided by flight rate smoothing when compared with the peak annual flight rate of the given architecture. Figure 3.5.1.2-1 depicts this analysis process.

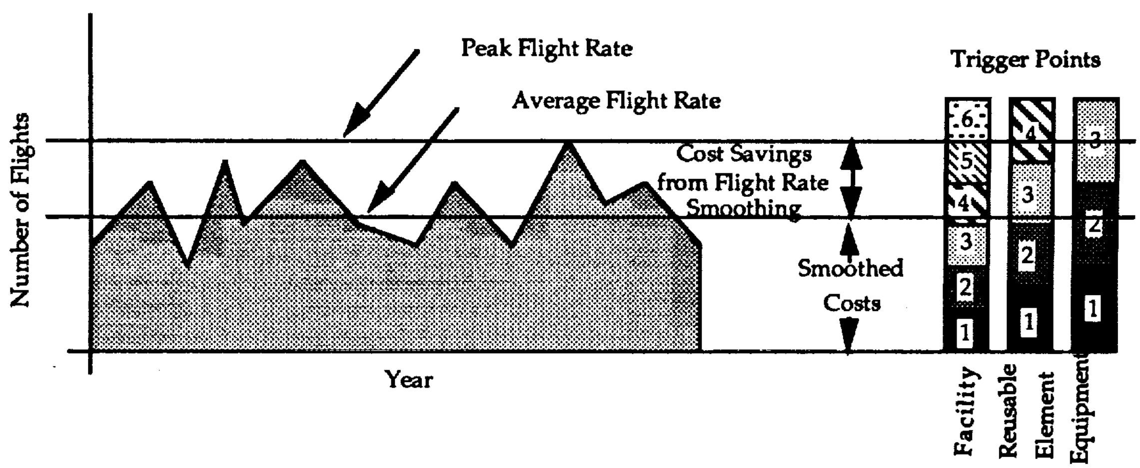


Figure 3.5.1.2-1.– Flight rate smoothing sensitivity methodology.

Architectures 1, 2, 5, and 6 were selected for analysis in "If" Scenario C only. Tables 3.5.1.2-1 through 3.5.1.2-4 present the results of this analysis, respectively. The results range from a cost savings of \$2.2B to \$3.0B for architectures whose total costs range from \$131B to \$234B. The maximum savings could be 2.3 percent (3.0/131) or less. Therefore, flight rate smoothing alone was not considered to have a significant impact upon the total architecture cost. Research into the year in which the triggered costs were incurred showed that they did not coincide with each other or with the PYF in the funding profile curve. Therefore, flight rate smoothing alone was not considered to have a significant impact on the attribute. Thus, this manifesting groundrule was found to have a non-deleterious impact on the study results. However, if a budget-wedge analysis were performed and used as a relative measure of goodness, the smoothed flight rate savings could have a more significant impact. This was not done on this study.

TABLE 3.5.1.2-1.– ARCHITECTURE 1 - "IF" C FLIGHT RATE SMOOTHING

Arch	System	Peak/ Site	Trigger	Ops Yrs	Flts/Site	Ave Flt/Yr	$ Savings
1C	Space Shuttle-ETR	12	Orbiter @ 11 (1)	29	292	10.1	1637
1C	Delta-ETR	7		23	127	5.5	
1C	Delt-WTR	3		23	34	1.5	
1C	Atlas-ETR	3		23	69	3.0	
1C	Titan IV ETR	8		23	135	5.9	
1C	Titan IV WTR	4	SLC @ 4 (1)	23	68	3.0	596
1C	Titan II-WTR	2		23	31	1.3	
						Savings =	2233

TABLE 3.5.1.2-2.– ARCHITECTURE 2 - "IF" C FLIGHT RATE SMOOTHING

Arch	System	Peak /Site	Trigger	Ops Yrs	Flts/Site	Ave Flt/Yr	$ Savings
2C	Space Shuttle-ETR	12	Orbiter @ 11 (1)	12	97	8.1	1637
2C	Space Shuttle Ev-ETR	8		21	147	7.0	
2C	RCV-ETR	5		21	83	4.0	0
2C	*All Space Shuttle*	13		29	*327*	*11.3*	
2C	Delta-ETR	7		23	127	5.5	
2C	Delta-WTR	3		23	34	1.5	
2C	Atlas-ETR	3		6	11	1.8	
2C	Atlas Ev. -ETR	3		21	58	2.8	
2C	Titan IV-ETR	8		5	20	4.0	
2C	TIV Evol-ETR	7		21	115	5.5	
2C	Titan IV-WTR	4	SLC @ 4 (1)	5	9	1.8	596
2C	TIV Evol-WTR	4		21	59	2.8	
2C	Titan II-WTR	2		23	31	1.3	
						Savings =	2233

TABLE 3.5.1.2-3.– ARCHITECTURE 5 - "IF" C FLIGHT RATE SMOOTHING

Arch	System	Peak/Site	Trigger	Ops Yrs	Flts/Site	Ave Flt/Yr	$ Savings
5C	Space Shuttle-ETR	12	Orbiter @ 11 (1)	12	108	9.0	1637
5C	CLV-ETR	13	CLV @ 12.5 (1)	21	216	10.3	738
5C	CRV-ETR	7	CRV @ 5 (1)	21	89	4.2	68
5C	MLS-ETR	24		21	417	19.9	
5C	MLS-WTR	3		21	49	2.3	
5C	Delta-ETR	7		23	127	5.5	
5C	Delta-WTR	3		23	34	1.5	
5C	Atlas-ETR	3		23	69	3.0	
5C	Titan IV-ETR	8		5	23	4.6	
5C	Titan IV-WTR	4	SLC @ 4 (1)	5	9	1.8	596
5C	Titan II-WTR	2		23	31	1.3	
						Savings=	3039

TABLE 3.5.1.2-4.– ARCHITECTURE 6 - "IF" C FLIGHT RATE SMOOTHING

Arch	System	Peak/Site	Trigger	Ops Yrs	Flts/Site	Ave Flt/Yr	$ Savings
6C	Space Shuttle-ETR	12	Orbiter @ 11 (1)	12	102	8.5	1637
6C	PLS-ETR	16		21	186	8.9	
6C	CRV-ETR	13		21	230	11.0	
6C	MLS-ETR	30	CIF @ 25.2 (1)	21	528	25.1	93
6C	MLS-WTR	3		21	49	2.3	
6C	Delta-ETR	7		23	127	5.5	
6C	Delta-WTR	3		23	34	1.5	
6C	Atlas-ETR	3		23	69	3.0	
6C	Titan IV-ETR	8		5	23	4.6	
6C	Titan IV-WTR	4	SLC @ 4 (1)	5	9	1.8	596
6C	Titan II-WTR	2		23	31	1.3	
						Savings=	2326

3.5.1.3 Comparison of HTS Needs Model With Current FY92 Civil Needs Data Base (CNDB)

The conclusions of the HTS study are based on data derived and modified from the 1990 CNDB. A question arose over whether or not the conclusions of this study would be changed if the data from the 1992 CNDB was used in place of the data from the 1990 version. A sensitivity study was performed to address this question by comparing the transportation requirements identified for SSF in the HTS modified 1990 CNDB and the unmodified 1992 CNDB.

As noted previously, the data from the 1990 CNDB has been adjusted and modified for use in the HTS study and, as such, includes some extrapolations and data smoothing. These modifications have been discussed in other parts of this report. In the following discussion, all references to the 1990 CNDB refer to the HTS-modified version.

This study compared the transportation requirements, for SSF as documented in the 1990 and 1992 CNDB's. These transportation requirements were identified for the Base and Expansion phases of the project. The Base phase covers all of the SSF activities up to and including PMC and extending through four crew operations. The Expansion phase includes all of those activities needed to establish and maintain eight crew operations at SSF. Delivered and retrieved cargo masses were tabulated on both an annual basis and a cumulative basis for the Base and Expansion phases, as well as for their combined total. This analysis was performed by extracting all of the SSF payloads from the respective editions of the CNDB, and then using Excel spreadsheets to manipulate, sort, and plot the data.

<u>Total Annual Delivered Masses</u>

Figure 3.5.1.3-1 compares the total annual delivered mass requirements for SSF (PMC phase). Data is shown for the 1990 and 1992 CNDB's.

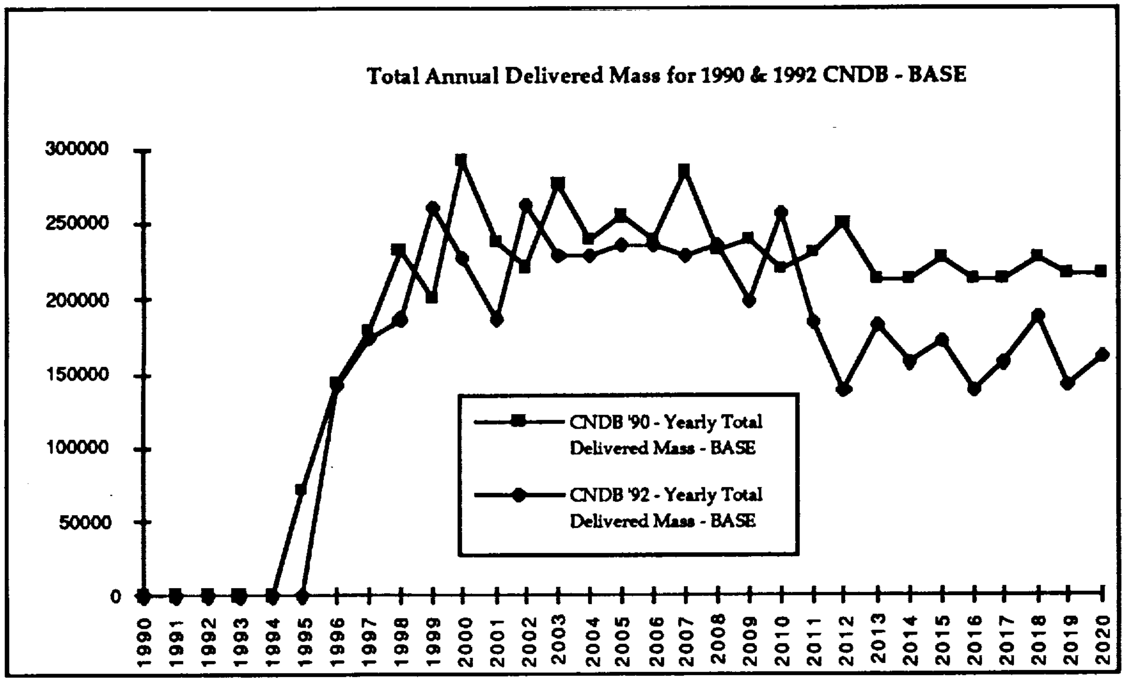


Figure 3.5.1.3-1.– Total annual delivery mass requirements for SSF (PMC Phase).

There is reasonably good correlation between the two models out through the 2010 time frame, at which time the data from the 1992 CNDB shows a significant reduction relative to the data from the 1990 CNDB. This can be attributed to modifications that were performed to the 1990 CNDB to include additional requirements for logistic support, which were beyond the planning horizon of those providing the payloads inputs. (It was assumed that a steady-state operation of the PMC station would not have such a drop-off in the 2010 time frame.) Although differences exist in these two models prior to 2010, these differences are basically fluctuations around the values from the 1990 CNDB that can be attributed to differences in when specific payloads are manifested and to the evolution of the mass estimates for specific payloads.

Total Annual Return Masses

Figure 3.5.1.3-2 compares the total annual return mass requirements for SSF (PMC phase) for the 1990 and 1992 CNDB's.

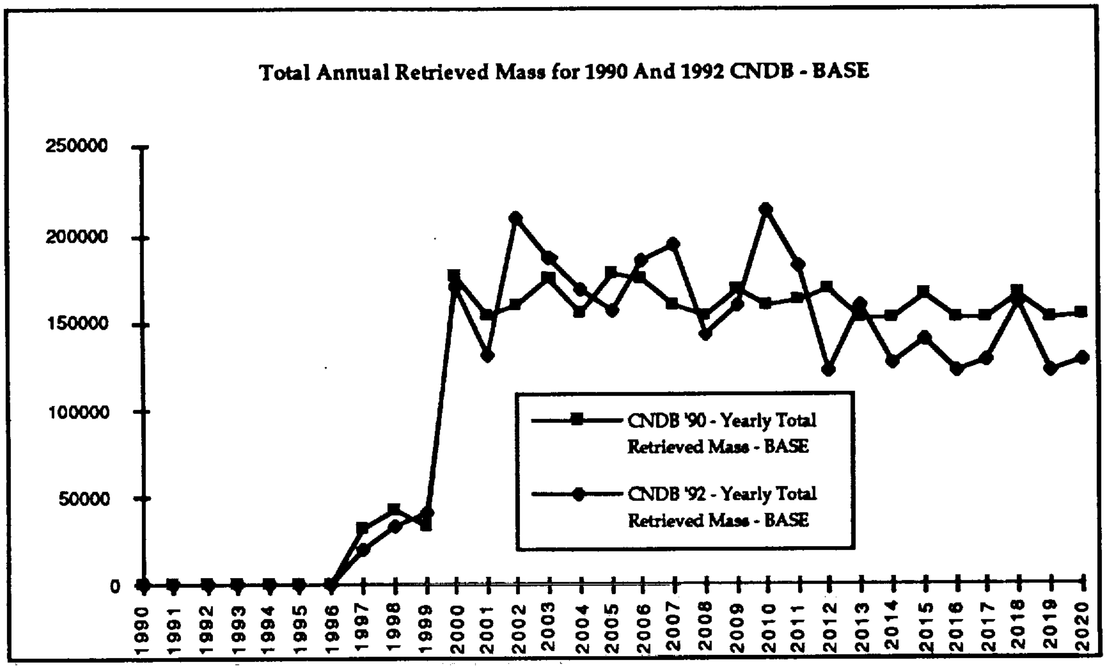


Figure 3.5.1.3-2.– Total annual return mass requirements for SSF (PMC Phase).

Again, this chart shows reasonably good correlation between the 1990 and 1992 CNDB results. The trend lines are similar although there are some significant variations from year to year. However, note that the differences generally average out, i.e., the two curves fluctuate around each other. The only time this is not true is in the post-2010 time frame and those differences are thought to be attributable to the smoothing of the 1990 CNDB data described above.

Cumulative Total Delivery Mass

Figure 3.5.1.3-3 compares the cumulative delivered mass requirements. As one would expect, this curve shows considerably less *scatter* than the annual delivered mass charts previously shown. As with the previous charts, there is a good correlation between the 1992 and 1990 CNDB results, although the cumulative mass values from the 1992 CNDB are slightly lower than those from the 1990 CNDB. The two curves show their most significant divergence in the post-2010 time frame. It is significant to note the similarity of the slopes of the two curves in the pre-2010 time frame. The differences between these two curves can largely be explained by postulating a time shift of roughly 12 to 18 months between the two traffic models. This suggests that the 1992 CNDB can be viewed as a slightly delayed version of the 1990 CNDB. This is consistent with the schedule changes that have occurred in the SSF program subsequent to the development of the 1990 CNDB. Thus, the 1992 CNDB does not represent a change in the mass delivery requirements for SSF, instead it is just a slight adjustment to the schedule for the delivery of that mass.

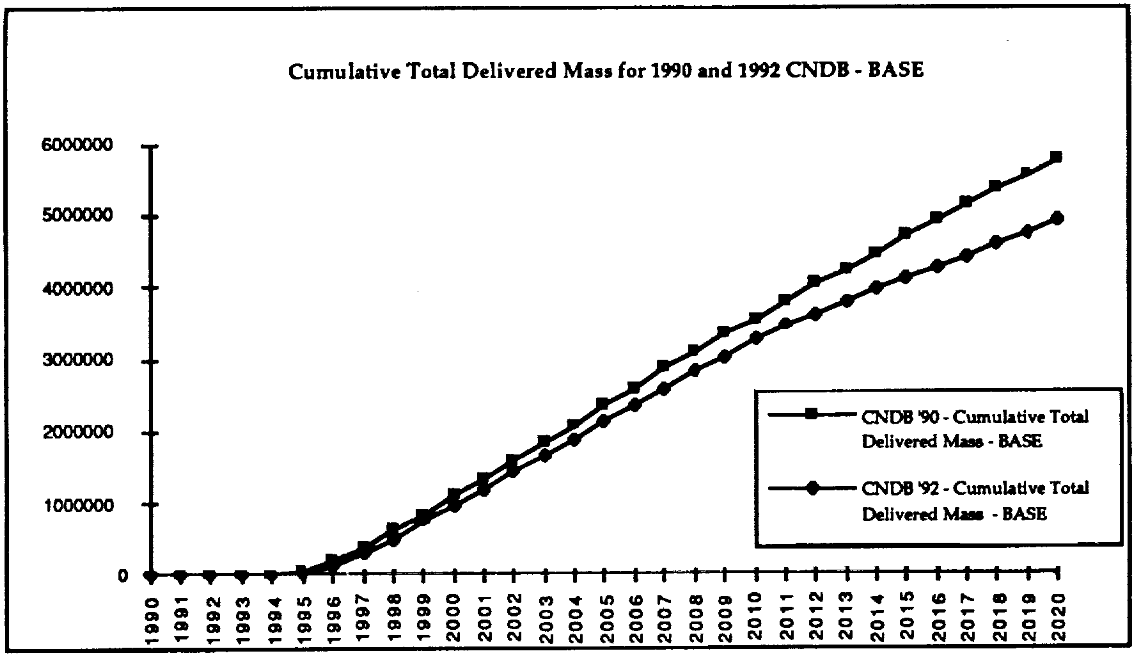


Figure 3.5.1.3-3.– Cumulative delivery mass to SSF (PMC Phase).

Cumulative Total Return Mass

Figure 3.5.1.3-4 compares the cumulative retrieved mass requirements. Notice the very high degree of correlation between the two curves. There are only slight differences between these two curves until the 2010 time frame, and after that time the differences remain small.

a-5.

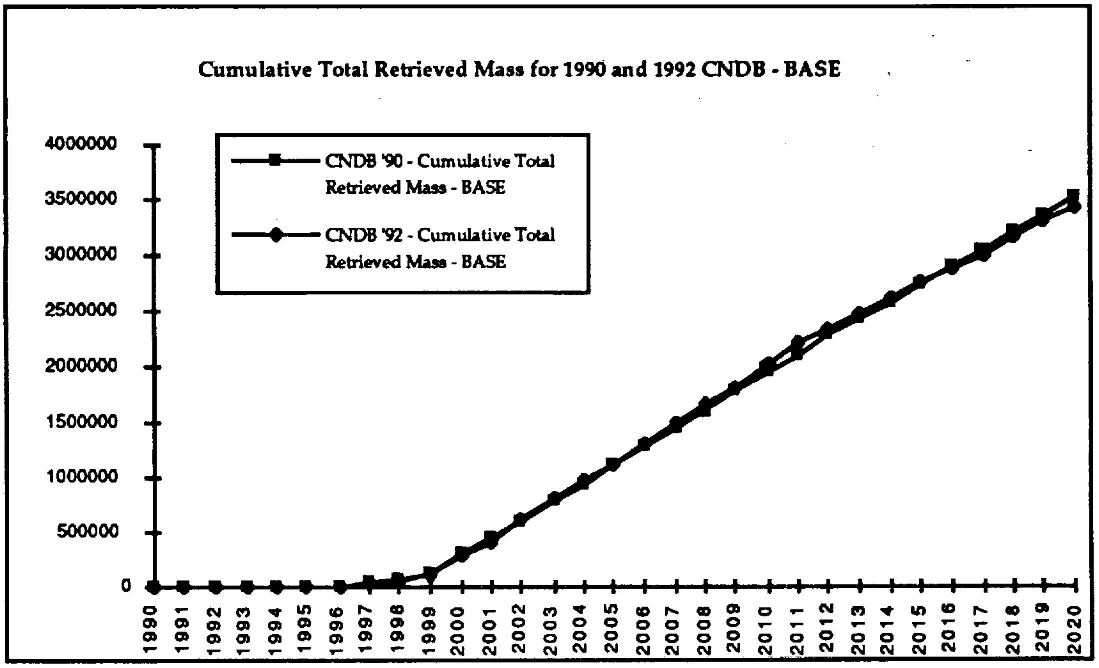


Figure 3.5.1.3-4.– Cumulative return mass to SSF (PMC Phase).

<u>Maximum Annual Mass Transport Requirements</u>

Table 3.5.1.3-1 compares the maximum delivered and return masses for the 1990 and 1992 CNDB's for the various SSF operational phases. The purpose of this is to quantify when the peak transport requirements occur, and to identify their magnitude.

TABLE 3.5.1.3-1.– MAXIMUM ANNUAL MASS TRANSPORT REQUIREMENTS FOR SSF

CNDB Model	Max Annual Mass (lbs)	Year
Delivered Payloads		
1990	291,941	2000
1992	262,847	2002
Return Payloads		
1990	178,700	2005
1992	213,836	2010

Notice that the peak delivered payload transportation requirement for the 1992 CNDB occurs roughly 2 years after the peak for the 1990 CNDB. This is consistent with the notion that the dominant difference between the two CNDB's is that the 1992 CNDB is time-shifted relative to the 1990 CNDB, due to stretch outs in the SSF program that occurred after the 1990 CNDB was formulated. Although there are differences between the maximum annual delivered masses between these two models, those differences are relatively small and are not thought to be significant.

The 1992 CNDB has its maximum annual return mass requirements occurring at a later time than shown in the 1990 CNDB. Again this can be attributed to a stretch out of the SSF program. However, it is significant to note that the 1992 CNDB has larger return mass requirements than the 1990 CNDB, although the absolute value of these differences is relatively small.

Conclusions

This study has shown that although there are some differences between the SSF transportation requirements identified in the 1990 and 1992 CNDB's, these differences are relatively small and do not alter the conclusions of this study.

The annual differences in mass delivery and return requirements reflect the normal adjustments in payload manifesting as missions are planned and flown. This is not expected to alter the conclusions of this study because, in general, slightly higher manifesting rates in any given year are compensated for in other years by correspondingly smaller rates. This conclusion is enhanced by reviewing the cumulative mass delivery and retrieval rates. It becomes obvious that the data in the 1992 CNDB can be viewed as a time-shifted version of the data from the 1990 CNDB. That is to say, the total mass transport requirements have not changed, only the schedule for delivering those masses has been shifted by 12 to 18 months to accommodate on-going changes in the overall schedule of the SSF program. Likewise, there are no significant differences in maximum delivery or retrieval rates. The changes in other payload requirements were not examined, since SSF comprises two-thirds of all transportation requirements, and is, by far, the largest driver to an architecture's required flight rates. None of the factors investigated gives any reason to alter any of the conclusions of this study.

3.5.2 Attribute Model Refinements

3.5.2.1 Safety Model Refinement

The current method for estimating the number of crew loss events has a qualitative step whereby a judgment is made on the failure distribution across six primary causes of flight emergency: explosion, fire, loss of control, damaged vehicle, hazardous environment, or benign.

This process, developed by Boeing Defense and Space Group, allocates mission failures to specific causes, and then assesses immediate crew survival and abort probabilities. Values for each were developed by Boeing through an expert opinion process based on system configuration and ascent flight phase. To define this model, effort was focused on failure allocation and replacing expert opinion with historical failure types and relative occurrence by stage. The data base used to define these relative failure rates was the same as that used to develop engine and stage probability of success values for the PMS attribute. As part of this tool enhancement process, a more rigorous error checking on the original values was performed and the impact of discovered discrepancies was noted. Findings due to a new failure allocation process were shown relative to the original and updated (due to process errors) Human Safety values.

Two other options for enhancing Human Safety were considered and rejected due to time and budget constraints. One option required a geometric definition sufficient to develop metrics for crew module location relative to propellant tanks, solid boosters, engine position, explosive yields, and crew escape methods. This was rejected primarily due to the lack of, restricted, or dynamic state of, system design data for new concepts (AMLS, AMSC, NLS, SSTO-VTOHL, NDV). The other option called for extending the PMS success trees along the mission failure branches by adding failure types, probable rate of failures, and an uncertainty band. Cumbersome documentation and the fact that the selected approach provides similar insight and product were reasons for excluding this option.

Failure scenarios were devised for each of the six failure types defined during the original study (see Figure 3.5.2.1-1). The trigger event shown is the failure type, the protective event (against crew loss) is the inherent system design which precludes immediate loss of life, while the mitigating event is the system's abort capability. Estimated crew survival rates in each mission phase is the sum of PMS and the product of mission failure rate (1-PMS), probability of immediate survival (P_s), and probability of successful abort (P_a). Failure at either the protective or mitigating event results in crew loss. Virtual scenarios (a spreadsheet of failure allocations, probability of immediate survival, and probability of abort) were created for all ascent phases of each piloted system.

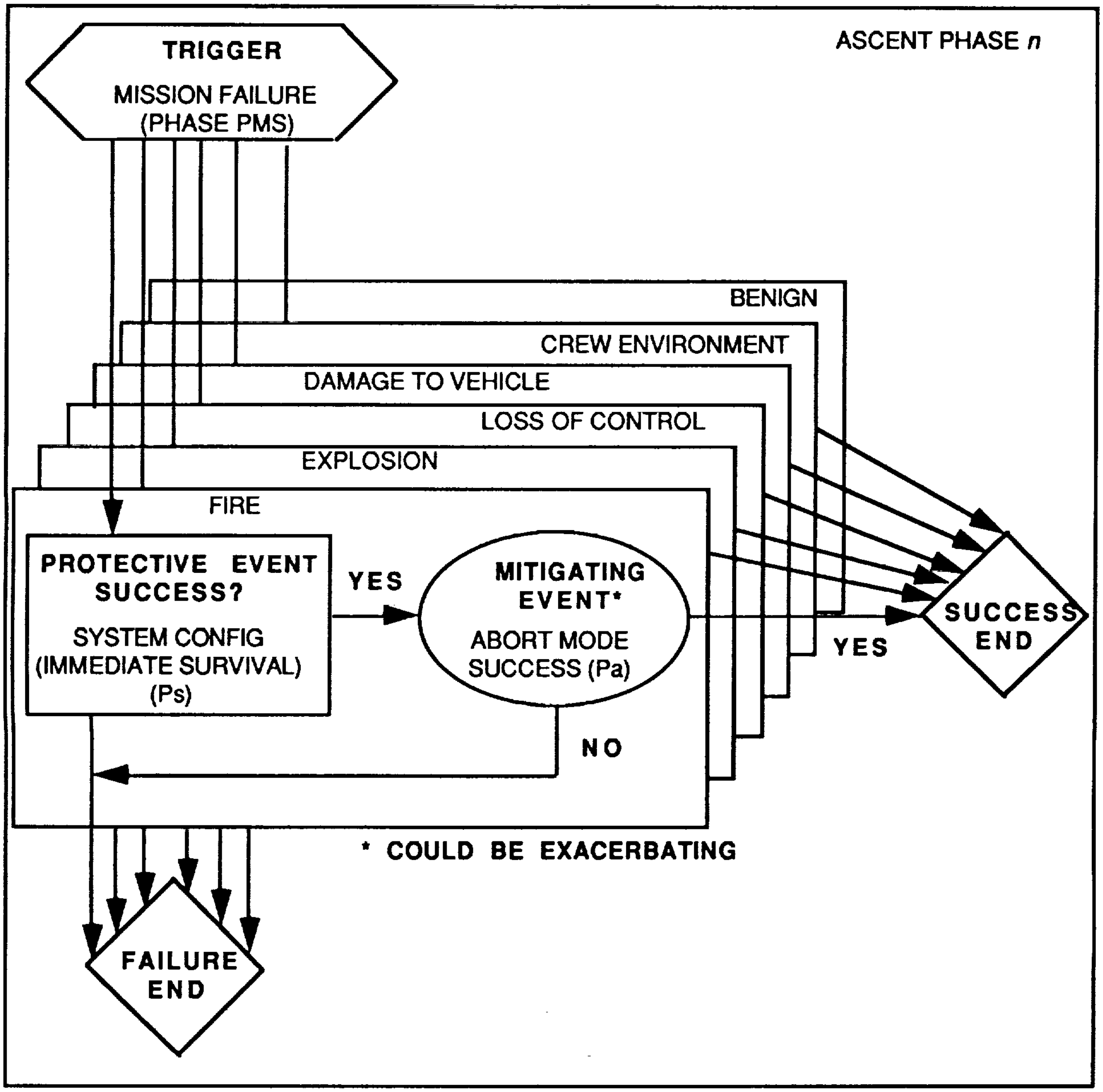


Figure 3.5.2.1-1.– Failure scenario description for crew loss events.

A new approach to quantifying the frequency of each failure type was employed as an enhancement to the original expert opinion approach. Using the same data base that established the probability of success for liquid engines, solid motors, and propulsion systems, previous failures were categorized by type and their relative frequency was noted by stage (Table 3.5.2.1-1).

TABLE 3.5.2.1-1.- HISTORICAL LIQUID ROCKET FAILURE DATA

Published Cause Of Failure	First Stage (%)	Second Stage (%)	Third Stage (%)	All Stages (%)
Control	18.92	20.00	0.00	15.19
Electrical	13.51	8.00	11.76	11.39
Explosion	21.62	4.00	0.00	11.39
Fuel	8.11	16.00	5.88	10.13
Frozen Valve	0.00	0.00	17.65	3.80
Guidance	8.11	4.00	11.76	7.59
Hydraulics	2.70	12.00	0.00	5.06
Ignition	0.00	16.00	17.65	8.86
Lubrication	2.70	0.00	0.00	1.27
Propulsion	24.32	12.00	35.29	22.78
Separation	0.00	8.00	0.00	2.53
Totals	100.00	100.00	100.00	100.00

In order to retain the defined process for determining crew loss event rates, it was necessary to map the failure types from Table 3.5.2.1-1 into the previously defined categories: fire, explosion, loss of control, damage to vehicle, crew environment, and benign. Control and explosion are the only categories that map directly from history to the previously defined list. The balance of historical failures tend to be immediately benign to the crew. However, propulsion and separation failures were mapped into two different categories (propulsion – fire or benign; separation – damage to vehicle or benign), creating a range for probability of crew loss. In addition, for those systems with solid motors, their historical failure rate was added to the percentage of explosions, reducing the benign failure rate. Figure 3.5.2.1-2 illustrates this mapping process.

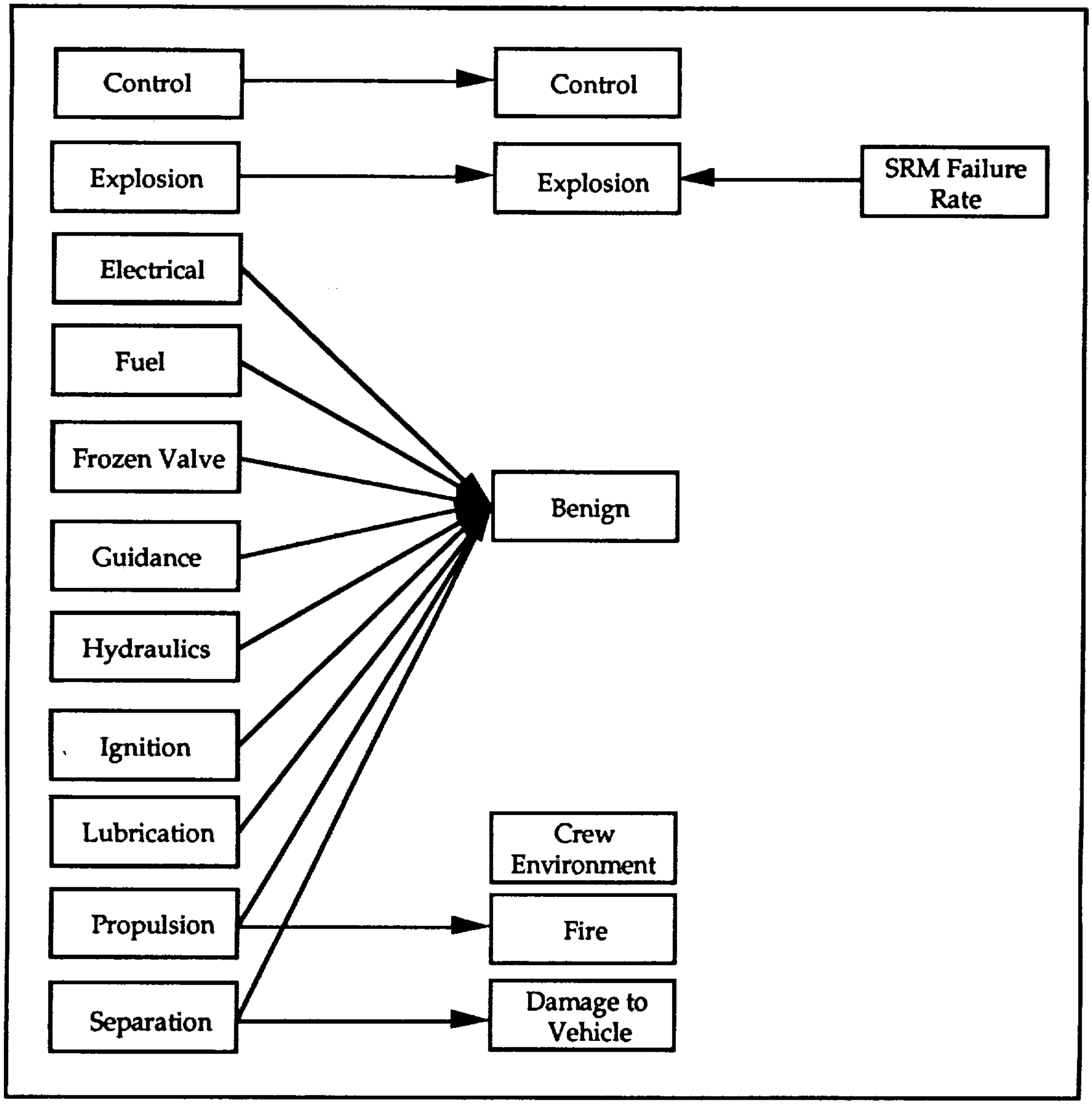


Figure 3.5.2.1-2.– Mapping of historical failure types into previously defined categories.

Findings

Relative failure rates shown in Table 3.5.2.1-2 were allocated at the stage level, using the following guidelines: first stage rates were applied to any and all stages or engines that ignited at ground level; second stage rates were applied to any and all stages that ignited at altitude, except for the circularization stage; and third stage values were assigned to the circularization stage only. The last column is shown for information purposes only.

TABLE 3.5.2.1-2.– COMPARISON OF CREW LOSS EVENT RATES

System	Was	Corrected	New-Low	New-High
AMSC	0.008340	0.008337	0.009264	0.006979
Beta II	0.006240	0.010528	0.009818	0.006105
MLS-HL/CLV	0.006410	0.007080	0.007793	0.006467
MLS-X/RPC	0.005430	0.005228	0.004994	0.003676
NLS-2/RPC	0.005420	0.005225	0.004990	0.003671
TITAN IIS/RUPC	0.010330	0.009065	0.009266	0.007706
HR Titan IV	0.012370	0.010528	0.011975	0.010101
Space Shuttle	0.022350	0.022350	0.023228	0.017550
Shuttle Evo	0.022780	0.017792	0.022338	0.017626
SSTO-VTOHL	0.007020	0.007024	0.012650	0.006005

While applying this process to the piloted systems, differences were found in 7 of 10 systems addressed (MLS-HL/CLV is identical to MLS-HL/LRV/RPC and is documented as a single system), and it was found that the range in crew loss frequency can be very large, depending on the severity of propulsion problems and frequency of separation problems. However, the two methods do provide similar values in terms of flights between crew loss events (Tables 3.5.2.1-2 and 3.5.2.1-3 and Figure 3.5.2.1-3), i.e., the corrected values are within or near the range predicted using historical failures and their relative occurrence.

TABLE 3.5.2.1-3.– MEAN NUMBER OF FLIGHTS BETWEEN CREW LOSS EVENTS

System	Was	Corrected	New-Low	New-High
AMSC	119.9	120.0	107.9	143.3
Beta II	160.3	95.0	101.9	163.8
MLS-HL/CLV	156.0	141.3	128.3	154.6
MLS-X/RPC	184.2	191.3	200.2	272.1
NLS-2/RPC	184.5	191.4	200.4	272.4
Titan IIS/RUPC	96.8	110.3	107.9	129.8
HR Titan IV	80.8	94.9	83.5	99.0
Space Shuttle	44.7	44.7	43.1	57.0
Shuttle EVO	43.9	56.2	44.8	56.7
SSTO-VTOHL	142.5	142.4	79.0	164.9

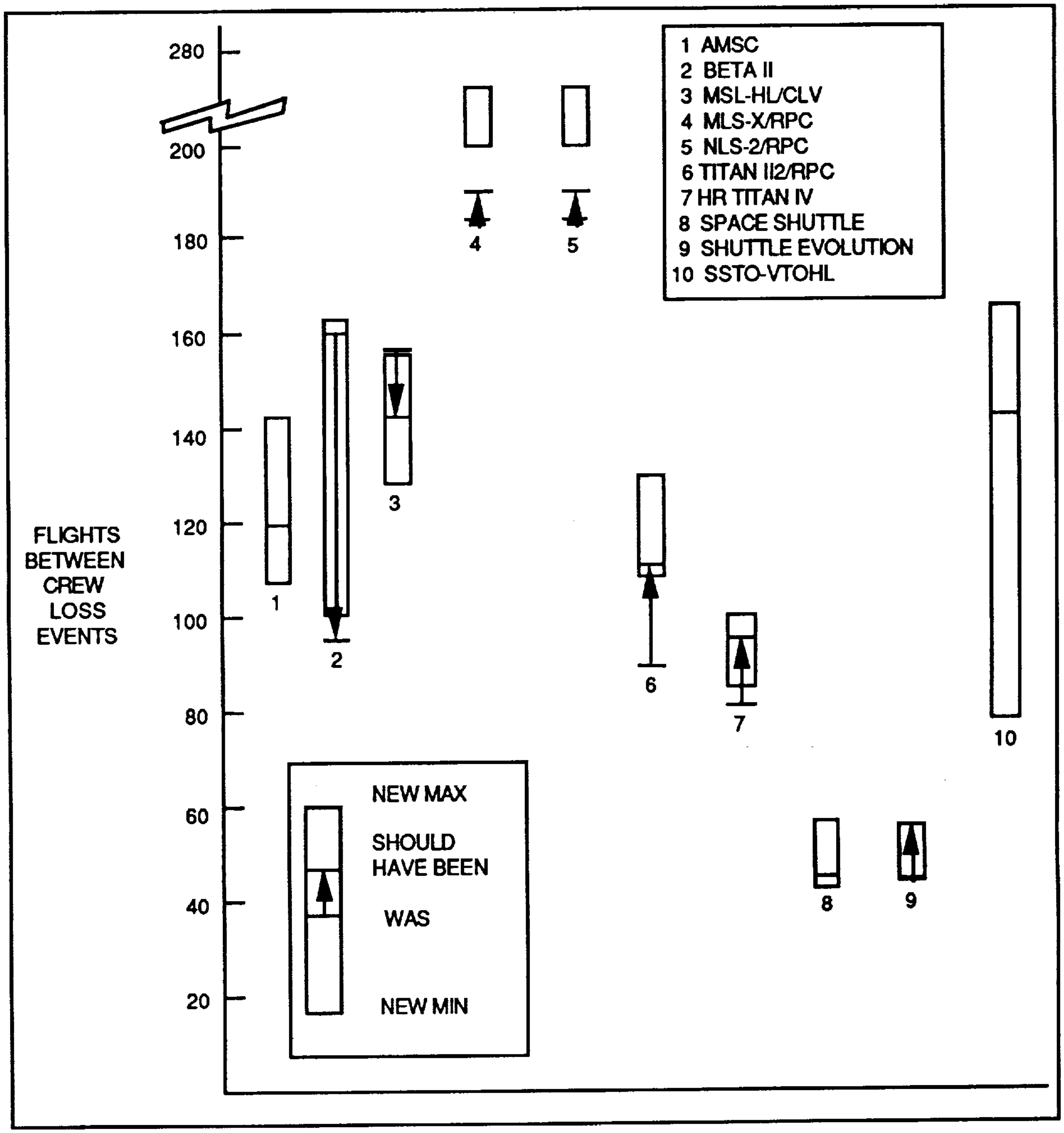


Figure 3.5.2.1-3.– Projected flights between crew loss events.

The new range of crew loss events per system and architecture, by "If", are compared against the original values in Table 3.5.2.1-4. This new process shows the uncertainty in crew loss events and relative architecture goodness.

TABLE 3.5.2.1-4.– CREW LOSS EVENTS COMPARISON

ARCHITECTURE	DESCRIPTION	IF "A"...			IF "B"...			IF "C"...		
		OLD VALUE	NEW LOW	NEW HIGH	OLD VALUE	NEW LOW	NEW HIGH	OLD VALUE	NEW LOW	NEW HIGH
1	REFERENCE	1.70	1.30	1.80	3.30	2.60	3.40	6.70	5.30	7.00
2	EVOLUTION	1.50	1.40	1.70	2.80	2.50	3.20	4.80	4.30	5.60
3	NLS/CTV	1.70	1.30	1.80	3.30	2.60	3.40	6.40	5.00	6.70
4	NLS/RPC/CRV	1.70	1.30	1.80	3.30	2.60	3.40	4.30	3.40	4.50
5	MLS-HL/CLV	1.00	0.80	1.00	2.50	2.10	2.60	3.90	3.30	4.20
6	MLS-X/RPC	0.80	0.60	0.90	1.90	1.50	2.00	3.30	2.50	3.30
7	MLS-HL/RPC/LRV	1.00	0.80	1.00	2.80	2.30	2.90	4.20	3.50	4.40
8	SSTO-VTOHL	0.90	0.70	1.30	2.80	2.40	3.90	4.20	3.50	5.80
11	NLS-50/RPC	1.70	1.30	1.80	3.30	2.60	3.40	6.60	5.20	6.90
12	NLS-50/RPC	1.70	1.30	1.80	3.30	2.60	3.40	6.60	5.10	6.90
13	NLS-50/RPC	1.70	1.30	1.80	3.30	2.60	3.40	6.80	5.30	7.00
14	MR TITAN IV/RPC	1.70	1.30	1.80	3.30	2.60	3.40	7.20	5.70	7.50
16	AMSC	1.30	1.00	1.30	4.40	3.50	4.60	6.10	4.70	6.20
17	TITAN II/RUPC	1.20	1.00	1.30	2.90	2.40	3.00	4.60	3.80	4.70
18	BETA II	2.40	1.50	2.30	3.90	2.60	3.90	7.50	5.00	7.30

ARCHITECTURE	DESCRIPTION	IF "D"...			IF "E" LOW...			IF "E" HIGH...		
		OLD VALUE	NEW LOW	NEW HIGH	OLD VALUE	NEW LOW	NEW HIGH	OLD VALUE	NEW LOW	NEW HIGH
1	REFERENCE	7.60	5.90	7.90	8.00	6.30	8.30	8.70	6.80	9.00
2	EVOLUTION	4.90	4.40	5.60	5.30	4.70	6.00	5.80	5.30	6.70
3	NLS/CTV	7.00	5.50	7.20	7.40	5.80	7.70	8.10	6.40	8.40
4	NLS/RPC/CRV	4.70	3.70	4.90	4.80	3.80	5.00	5.00	3.90	5.20
5	MLS-HL/CLV	4.30	3.70	4.60	4.50	3.80	4.80	4.70	4.00	5.00
6	MLS-X/RPC	3.30	2.50	3.20	3.40	2.60	3.30	3.50	2.70	3.50
7	MLS-HL/RPC/LRV	4.20	3.50	4.40	4.30	3.60	4.50	4.50	3.70	4.70
8	SSTO-VTOHL	4.30	3.60	6.00	4.50	3.70	6.20	4.70	3.90	6.60
11	NLS-50/RPC	7.20	5.60	7.40	7.30	5.70	7.50	7.50	5.80	7.70
12	NLS-50/RPC	7.20	5.60	7.50	7.30	5.70	7.60	7.60	5.90	7.80
13	NLS-50/RPC	7.30	5.70	7.50	7.40	5.80	7.60	7.60	5.90	7.80
14	MR TITAN IV/RPC	7.90	6.40	8.30	8.10	6.60	8.50	8.40	6.90	8.90
16	AMSC	6.50	4.70	6.30	6.70	5.00	6.50	6.90	5.20	6.90
17	TITAN II/RUPC	4.70	3.90	4.80	5.00	4.00	5.00	5.20	4.30	5.30
18	BETA II	8.70	5.80	8.40	8.90	5.90	8.70	9.20	6.10	9.00

The following table (Table 3.5.2.1-5) summarizes mathematical errors discovered in the original process during this task. These corrections are the basis for the differences between the "Was" and "Should Have Been" values for probability of death (P_d) and mean flights between crew loss events.

TABLE 3.5.2.1-5.- CORRECTIONS TO PREVIOUS HUMAN SAFETY PROCESS

System	Phase	Failure	Correction
Beta II	2	Benign	Changed 85 To 80 So Total Failures Total 100 Rather Than 105.
	3	Explosion	Pd Changed To 0.00004 (Product Of 1*0.08* 0.05), It Was 0.05.
MLS-HI/CLV	9	Benign	Change 89 To 88 So Failures Total 100 Rather Than 101
MLS-X/RPC	6	Benign	Changed 89 To 88 So Failures Total 100 Rather Than 101
	8	Benign	Changed 89 To 88 So Failures Total 100 Rather Than 101
NLS-2/RPC	6	Benign	Changed 89 To 88 So Failures Total 100 Rather Than 101
	8	Benign	Changed 89 To 88 So Failures Total 100 Rather Than 101
Shuttle Evolution	3	Benign	Changed 29 To 55 So Failures Total 100 Rather Than 74
Titan II/RUPC	9	Benign	Changed 89 To 88 So Failures Total 100 Rather Than 101
HR Titan IV/RPC	1	Explosion	Changed Pd From 0 To 0.038 To Reflect Product Of Failures, Ps And Pd.
	9	Benign	Changed 89 To 88 So Benign Failures Total 100 Rather Than 101

Discovered math errors did not have a major impact on architecture ranking within the Human Safety attribute except for Architecture 18 (Beta II). The corrected error reduced flights between crew loss events from 160.3 to 95.0, which translated into an architecture ranking change from 8 or 9 to 15 for "If's" C through E-High. In "If" A, Architecture 18 was already ranked fifteenth of 15 and in "If" B, its rank dropped from fifth to fifteenth.

Using historical data to allocate failures into the six categories identified in the original process provides a band of uncertainty for Human Safety. This band is due to the allocation of propulsion failures to either the fire or benign categories and the allocation of separation failures to either the loss of control or benign categories. In general, the corrected system values fall within the band created under the new method of failure allocation, except for MLS-X/RPC and NLS-2/RPC, where the new minimum is 200 flights between crew loss events versus the corrected value of 191. The various band widths of each system cause considerable changes in architecture rankings when comparing cases using the maximum or minimum flights between crew loss events. Scrutiny of the HTS Human Safety calculation process should be continued, and should focus on determining the probability of survival and probability of abort to ensure consistent treatment across all systems with similar configurations and mission phases.

3.5.2.2 Probability of Mission Success Attribute Model Refinement

During the study extension period, two changes were made to the PMS model. These are detailed below.

Launch Pad Hold-Down

A function was added to the PMS model to account for the effects of launch pad hold-down on vehicle reliability. A review of historical launch data and a presentation on launch vehicle failure probabilities[2] indicated that over 50 percent of propulsion system failures develop within 5 seconds after engine start. The HTS study team decided that the ascent failure rate of liquid engines started on the pad should be reduced by half if a vehicle had a hold-down period (to determine engine health) prior to lift-off. The following is an example of how the equations were modified:

Phase 1 - SSME ignition and thrust buildup

$$R_{p1} = AR^{1/8} * RS1^{1/4} * (RL^3)^{1/4}$$

Example Modification:

Phase 1 - SSME ignition and thrust buildup

$$R_{p1} = AR^{1/8} * SQRT(RS1^{1/4} * (RL^3)^{1/4})$$

Note: for probability of success numbers greater than or equal to .91, the square root of reliability is mathematically equivalent to reducing the unreliability by half. This simplified approach was used to develop these equations.

OMS Engine Redundancy

In developing the PMS value for each system in the HTS architectures, all liquid engines and liquid stages, from first stage through orbit circularization, were treated identically and assumed to have the same reliabilities. This produced a lower PMS value than would be expected due to redundancy inherent in the orbit circularization stage of piloted vehicles. For example, first- and second-stage liquid propulsion systems have single-string propellant lines and valves between the tank and engines. However, the Space Shuttle OMS system consists of two separate pods, with cross feed capability from the left pod to the right engine, and vice versa. Also, each propellant line has redundant valves between the tank and engine. This provides redundancy in the propulsion stage that had not been accounted for in the current process. In addition, there are generally-dual OMS engines, each capable of performing the circularization process independently.

Because the stage reliability number is based on a single flow path between tanks and engines, it was decided to incorporate OMS redundancy into the PMS model. Probability of success equations were developed for each system that reflect this configuration and all of the possible success paths for functioning of the orbit circularization engines. These equations were then added to the model.

System Results

Table 3.5.2.2-1 contains the PMS values for the launch vehicles used in this study. Additional columns show the results of accounting for hold-down and OMS engine redundancy refinements.

TABLE 3.5.2.2-1.– PMS VALUES

Vehicle	Original Study Results	With Hold down	With OMS and Hold down
AMSC	0.9577		0.9770
Atlas IIAS	0.9326		
Atlas EVOL	0.9369		
Beta II	0.9652		
Delta	0.9319		
MLS-X (CTV)	0.9455	0.9528	0.9572
MLS-X (RPC)	0.9544	0.9618	0.9618
MLS-X (non SSF)	0.9842	0.9919	
MLS-HL (NUS)	0.9691	0.9767	
MLS-HL (CTV)	0.9499	0.9573	0.9595
MLS-HL (RPC/LRV, CLV)	0.9543	0.9617	0.9617
NLS-20	0.9435	0.9519	0.9519
NLS-50 (CTV)	0.9455	0.9528	0.9572
NLS-50 (RPC)	0.9544	0.9618	0.9618
NLS-50 (NUS)	0.9842	0.9919	
NLS-50 (AUS)	0.9455	0.9528	
NLS-HL (CTV)	0.9308	0.9380	0.9423
NLS-HL (CRV)	0.9309	0.9381	0.9762
RCV	0.9290	0.9394	0.9584
SSTO	0.9691	0.9768	0.9768
Space Shuttle	0.9431	0.9537	0.9730
Shuttle Evolution	0.9290	0.9394	0.9584
Titan II	0.9626		
Titan III	0.9474		
HR Titan II	0.9323	0.9417	0.9562
Titan IV (Centaur)	0.9100		
Titan IV (NUS)	0.9474		
HR Titan IV (RPC)	0.9189	0.9426	0.9426
Titan IV (CTF/LRV)	0.9242		0.9307
Titan Evolution	0.9519		
Titan Evolution/Centaur	0.9186		

In looking at the original study results, the NLS and MLS vehicles scored well primarily due to the engine out capability of the first stage and OMS engines. When hold down effects are accounted for, the engine-out capability in the first stages is less significant. The final change reflecting OMS engine redundancy results in a higher reliability value for the Space Shuttle.

It is important to note that the purpose of this analysis and of the PMS calculation methodology development in general was to provide a way of comparing relative reliabilities of different launch systems, and *not to develop a point reliability value.* In addition, since the avionics reliability value was a single multiplier used on all systems and did not contribute any comparative information, it was eliminated from the final score.

3.5.2.3 Alternate Ground Operation Attribute

During the HTS Study basic contract period, the NIT defined the LSC attribute as an indication of any given architecture's ability to meet its launch schedules. The LSC was a combined measurement of three subattributes: Schedule Compression, Schedule Margin, and Percentage of Flights with Delays. Schedule Compression and Schedule Margin provided an intuitive measurement of architecture and flight system resiliency or the ability to effect schedule recovery. The Percentage of Flights with Delays was a measurement of architecture and flight system availability or dependability, based upon an unscheduled maintenance data base derived from a given flight systems mass, complexity, and mission length. The deficiencies in this methodology are that both the Schedule Compression and Schedule Margin subattributes failed to sufficiently address the relative differences in the proposed launch system designs. The Percentage of Flights with Delays subattribute value was partially derived from the estimated mission length, which is a valid parameter for reusable flight systems only. In addition, it was felt that the attribute gave insufficient insight into how system design choices would affect the ability to operate a proposed system. For these reasons, an alternate approach was considered.

This new ground operability attribute (GOA) definition was refined to consist of the probability of achieving any given launch date, or sustaining any given launch manifest, for any given launch system or space transportation architecture. This revised attribute is expressed as a relative value or Figure of Merit (FOM), rather than an absolute value. The preferred methodology selected in this study measures this attribute as a function of the scheduled event burden plus the unscheduled event burden. The scheduled event burden is equal for all launch systems and all architectures since it is requirements-driven and is therefore a non-discriminator. The remaining variable in the equation is the unscheduled event burden. The unscheduled event burden is defined as a function of the weighted utility of a series of ground operation's complexity factors or subattributes.

The 10 ground operation's complexity factors are described below. The complexity factors were down-selected from a lengthy candidate list and represent only the value-added factors that may effect LSC and the unscheduled event burden variable. The weight percentages and utility values were developed through the application of engineering judgment by a team of launch site engineers with operations experience in the ground processing of the Space Shuttle, Atlas I, Titan III, Titan IV, Centaur upper stage, and Fleet Ballistic Missiles.

(1) *Number of Fights* is the total number of flights for all launch systems in the selected mixed fleet manifest. The analysis is at the architecture level, weighted at 14.1 percent.

(2) *System Commonality* is the ratio of common types of flight elements to the total types of flight elements for all launch systems in the selected mixed fleet manifest. The analysis is at the architecture level, weighted at 10.8 percent.

(3) *Number of Elements* is the total number of significant flight elements for each launch system in the selected mixed fleet manifest. The analysis is at the launch system level, weighted at 11.7 percent.

(4) *Crew Rating* is the factor which distinguishes between a crew-tended and untended launch system configuration. A high value mission with no crew is also addressed under this complexity factor. The analysis is at the launch system level, weighted at 12.5 percent.

(5) *Processing Concept* distinguishes between the launch site processing concepts of Integrate on Pad (IOP), Integrate/Transfer/ Launch (ITL), and mixed ITL/IOP. The analysis is at the launch system level, weighted at 6.7 percent.

(6) *Reliability* is the complexity factor which addresses the predicted level of unscheduled system maintenance. The analysis is at the launch system level, weighted at 4.2 percent.

(7) *Number of Fluids* is the total number of fluids for each launch system in the selected mixed fleet manifest. The analysis is at the launch system level, weighted at 10.0 percent.

(8) *Expendable/Recoverable Hardware* is the complexity factor which distinguishes between recoverable or refurbishable, and expendable flight hardware. The analysis is at the flight element level, weighted at 9.2 percent.

(9) *Propellant Type* is the propellant (if any) utilized by the flight element. The analysis is at the flight element level, weighted at 7.5 percent.

(10) *Number of Significant Components* is the total number of significant components for each flight element. The analysis is at the flight element level, weighted at 13.3 percent.

A total of 40 existing ETO launch systems or conceptual ETO launch system designs were identified and incorporated into the various HTS architecture options by the NIT. For each launch system, a complexity factor data sheet was developed using resource data provided by the NIT or extracted from HTS Study interim reports and other current source material defining the existing or proposed launch system configurations.

Figures of Merit for this attribute were calculated for each launch system and architecture. Refer to Volume II, Appendix B.1.10 for a summary of the analysis.

The FOM's for the individual launch systems varied from a low value of 0.5947 for the conceptual SSTO configuration to a high value of 0.8836 for the conceptual NLS-20 configuration. In general, the reusable human flight systems ranked lower than the expendable flight systems. The relative rankings of the existing Atlas, Delta and Titan launch system configurations are comparable. These results are intuitive, and consistent with the experience base for ground processing of domestic launch systems.

The FOM's for the architecture options vary from a low value of 0.5036 for Architecture 8 (Advanced Technology Phasing/SSTO) to a high value of 0.7288 for Architecture 17 (New Concept Option/RUPC). Architecture 2 (Shuttle Evolution Option) is the preferred architecture, based on the highest average FOM across all architecture options (A through E High). Architectures 8, 16 (New Concept Option/AMSC) and 18 (New Concept Option/TSTO Beta II) values rank at the low end of the distribution. These three architectures rely extensively on new, reusable, human flight systems.

3.5.3 Improving System and Architecture Scores

3.5.3.1 New ELV Cost Sensitivities

Architectures 5 and 6 both scored well in the overall architecture evaluations. However, both have higher architecture costs than the reference, Architecture 1. Architecture 5 has high recurring cost in the early years due to the relatively high recurring production costs associated with the procurement of the reusable crew carriers. These costs occur in the years that the DDT&E costs are tailing off, with the combination producing the high peak costs in the years 1998 to 2003. Beyond 2003 there is a quasi-steady-state period for the costs. To justify the high initial costs, these out-year costs must be substantially lower than those of the baseline architecture. Since the cost associated with the architecture is dominated by the annual costs during this time period, sensitivities to ELV costs were examined.

These sensitivities are shown in Figure 3.5.3.1-1. The effect on total architecture cost of varying different ELV cost categories, both singly and in combination over the architectural time frame, is presented in the figure. As can be seen, the single most sensitive cost (steepest slope) is associated with recurring production (as represented by the filled triangles). Conversely, wide variations in either non-recurring or operations cost produced relatively small variations in total cost. Also shown for reference is the total cost of Architecture 1, as represented by the horizontal dashed line. Within the range of the sensitivities shown, the reduction of no single cost category produced a cost for Architecture 5 which was at or below that of the baseline. Since the costs during the out-years was of greatest interest (in terms of justifying the up-front costs), the combination of recurring production and operations costs was investigated. This sensitivity, represented by the open triangles in the figure, showed that at a reduction of about 50 percent for both these cost categories, Architecture 5 costs were equivalent to those of the baseline. The actual required reduction in the combination of ELV recurring production and operation costs over the life of the architecture, for equivalence with Architecture 1, was calculated to be 50.33 percent.

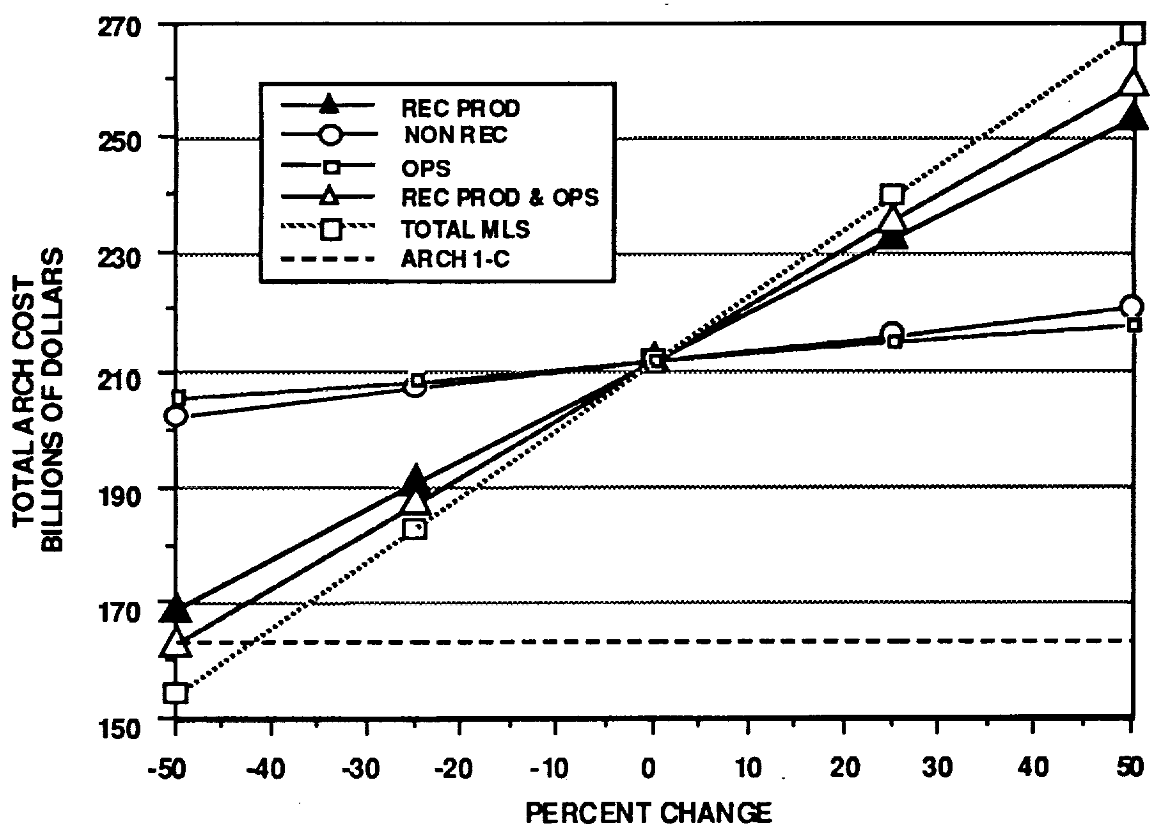


Figure 3.5.3.1-1.– MLS cost sensitivity - Architecture 5C.

The recurring production cost of the new ELV's (MLS, NLS, Spacelifter, etc.) has a large effect on the total architecture cost due to the relatively high flight rate combined with the MLS design assumption of expendability. Reducing this cost in half, under the current design assumptions, is probably not achievable because of the large amount of expendable hardware. This realization led to the effort to define a partially reusable MLS design and evaluate its use in a revised architecture (5A).

The partially reusable MLS concept, developed by Boeing, uses a module with SSME engines on the one and one-half stage and the addition of the equipment necessary to recover the engines and avionics from the stage. The half-stage engines are parachuted to the water in protective waterproof enclosures and recovered from the ocean, down range from the launch site. The engines and avionics on the first stage orbit once-around, reenter in a protective module, and parachute to a land recovery. These units are returned to the launch site, refurbished, and flown again on subsequent launch vehicles. As such, both the development and recurring production costs are appreciably lower than the new development ELV. Table B.1.6.2-16 of Volume II shows vehicle cost input used for this comparison with the baseline Architecture 5.

As can be seen in Figure 3.5.3.1-2, Architecture 5A shows a marked improvement in the annual cost during the operational phase (2003 and beyond), when compared to Architectures 5 and 1. All of the following comparisons are done for "If" C, unless otherwise noted.

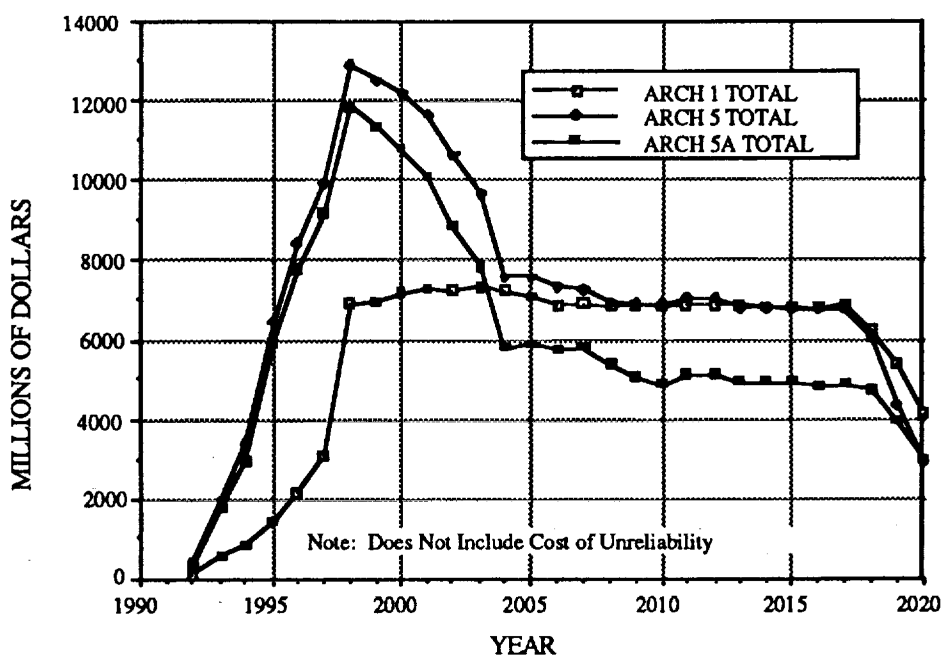


Figure 3.5.3.1-2.– Architectures 1, 5, and 5A - "If" C annual cost comparison.

The net reduction in recurring cost is a result of the change in the concept from an all-expendable MLS (Architecture 5) to a partially reusable MLS (Architecture 5A). This concept change produced a reduction in the recurring production cost as seen in Figure 3.5.3.1-3. There was, however, a slight increase in the operations cost, due to the added requirement to refurbish the recovered components.

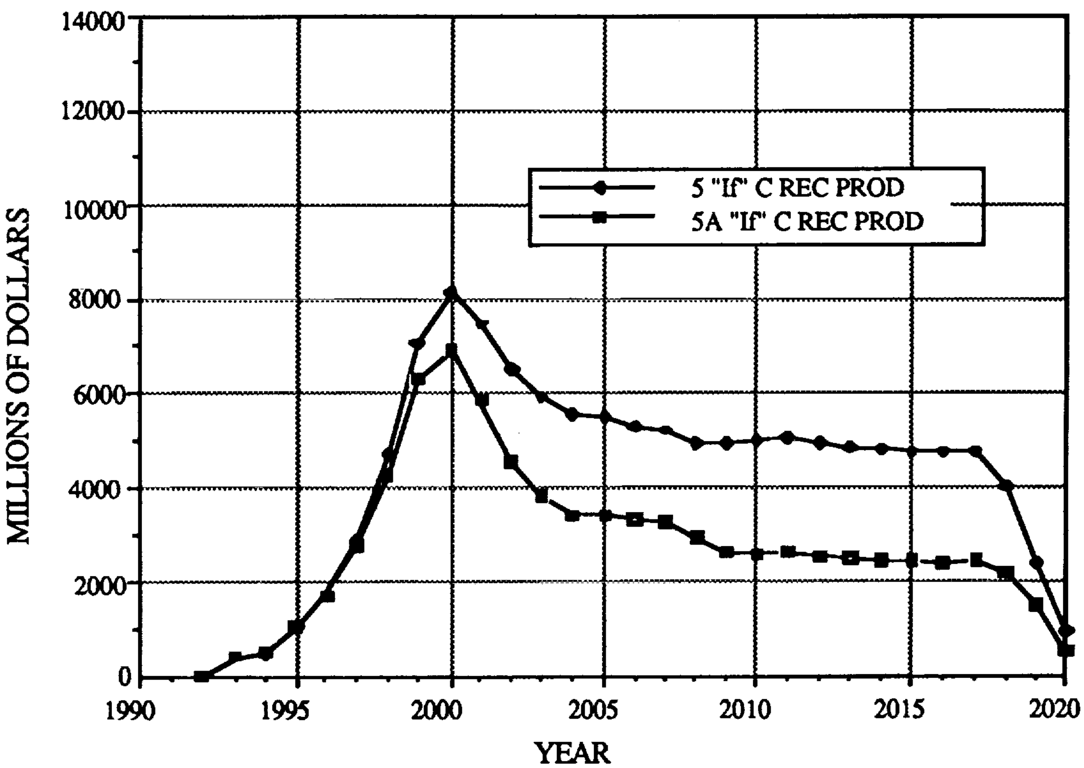


Figure 3.5.3.1-3.– Architectures 5 and 5A - "If" C recurring production cost comparison.

The initial trade study identified a need to reduce the combination of recurring production and operations cost a factor of 50 percent to achieve cost parity with Architecture 1 ("If" C), not including the cost of unreliability. As can be seen in Figure 3.5.3.1-4, the total of recurring and non-recurring cost for Architecture 5A is still slightly higher than that for Architecture 1 in "If" C. When the cost of unreliability is added, the difference is reduced, since there is improved reliability of Architecture 5A over 1. As can also be seen, the effect of reducing flight rate, "If's" A and B, is to further reduce the cost of Architectures 5 and 5A compared to Architecture 1.

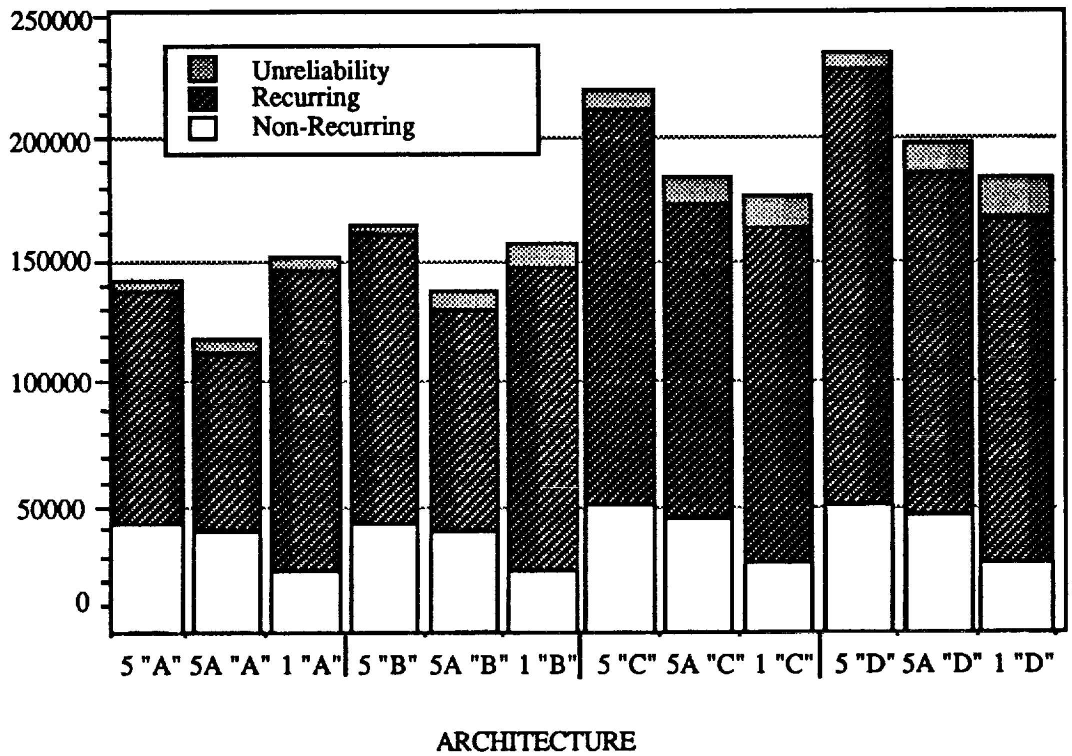


Figure 3.5.3.1-4.– Architectures 1, 5, and 5A - "Ifs" A through D total architecture cost comparison.

3.5.3.2 Space Shuttle Impacts

3.5.3.2.1 Space Shuttle design improvements.– The conceptual definition for Shuttle Evolution used in the study resulted in reduced PMS and equivalent Human Safety (crew loss events rate) relative to the current Space Shuttle system. Titan Evolution also resulted in a lower PMS relative to its current model.

Since these attributes were highly weighted, it was attempted to redefine an evolution concept that provided improved PMS and a lower crew loss event rate than the current Orbiter stack offered in the Evolution Architecture. The ELV's in the Evolution Architecture would not be changed in this effort so the impact of Shuttle Evolution changes could be readily identified.

Suggested improvements were to: (1) retain SRB's in Evolution Concepts, (2) provide for crew module separation and recovery for Space Shuttle Orbiter, (3) use hybrid boosters instead of liquids, and (4) retain SRM's on HR Titan IV.

For Shuttle Evolution redefinition, three key changes would have a dramatic impact on our attribute values: retain ASRM's, replace them with hybrids, or define a means for crew escape for the entire mission. Retention of ASRM's will maintain the Reference Architecture's PMS value. With increased crew survival due to the addition of ejection seats and the reduction of piloted missions due to the RCV, Human Safety should be improved dramatically. Hybrids will offer a less degraded PMS than liquids but should regain credit due to non-catastrophic failure and shutdown capabilities. Applying a means for crew escape over the entire ascent phase will greatly decrease the number of crew loss events. Due to the way the Evolution Architecture was manifested, only non-SSF flights will see an increase in flight quantity due to loss of performance caused by the addition of the frangible seam and recovery system of the CEM.

Shuttle Evolution, including the RCV, is redefined as follows for this analysis: ASRM's replaced by HRB's is with identical performance as the LRB's used previously; ejection seat concept replaced by separable crew module with lanyard rocket ejection capability; and manifest crew exchange flights to capacity, with remaining cargo placed on RCV. All other aspects of Shuttle Evolution as initially defined remain the same. A summary of attribute input data is shown in Table 3.5.3.2-1.

TABLE 3.5.3.2-1.– SUMMARY COMPARISON OF "IF" C FINDINGS FOR SHUTTLE EVOLUTION II

Attribute	Reference	Evolution	Evolution II	Improvement (EVO To EVO II)
Architecture Cost Risk				
Tech Challenge	168.700	370.800	419.000	(48.200)
Program Immaturity	1.000	2.740	2.754	(0.014)
New Systems	0.970	2.600	2.600	(0.00)
Environment	27825450	2067017	2086503	(19486)
Funding Profile (M$92)				
Total	177,404	209,653	224,537	(14884)
Peak Year	7303	11485	13605	(2120)
Human Safety (Crew Losses)	6.7	4.8	4.1	0.7
LSC				
Compression	0.425	0.408	0.407	0.001
Margin	4.429	5.684	5.474	0.210
Delays	11.800	12.000	12.200	(0.200)
PMS	0.9374	0.9354	0.9363	0.0009

Data required for complete analysis included: a recheck of flight rates based on a 20k reduction in Orbiter capacity with the separable crew module (report estimated 15k – add-on of 33 percent additional assumed) and fully-manifesting crew exchange missions; recalculate PMS based on HRB stage reliability of 0.99232 (square root of 0.9847 due to single fluid path) and HRB engine reliability of 0.99491 (square root of product of liquid engine and segmented solid engine reliability); reestimation of probability of survival and abortability based on separable crew module; reestimation of program risk; propellant quantities for environmental; and cost estimates for new orbiters to replace existing fleet at one per year from 2000. It is assumed that schedule delays will not be appreciably changed for Shuttle Evolution with this modification to the Orbiter.

Table 3.5.3.2-2 shows a comparison of attribute values for Space Shuttle, Shuttle Evolution, and Shuttle Evolution II Architectures, "If" C. A full assessment of the changes made to Shuttle Evolution is to be completed.

3.5.3.2.2 Cost reduction impacts.– The objective of this "quick-look" analysis effort was to assess the impact of a fixed per-year reduction in resources on the Space Shuttle flight rate and total architecture cost.

Using the study attribute and architecture analysis tools, Rockwell incorporated a fixed percentage reduction in Space Shuttle costs with 1992 as the base year and each subsequent year being reduced, relative to the previous year, by that fixed percentage. The reduction per year was defined so that a total cost reduction of 5, 15, 30, and 50 percent was realized by 1997. This was used because the HTS Funding Profile attribute is a summation of costs for flights between 1998 and 2020, inclusive. Figure 3.5.3.2.2-1 shows the results of this analysis. Based on this analysis, a good rule of thumb is that for every one percent decrease in Space Shuttle operations cost achieved by 1998, the HTS Reference Architecture total cost is reduced by $1B.

TABLE 3.5.3.2-2.– EXTENSION TASK INPUT DATA FOR SHUTTLE EVOLUTION II

Attribute	Previous Value	New Value
Human Safety		
Separable Module (Figure)	N/A	Entire Mission
Crew Escape (Figure)	Ejection	Extraction
Funding Profile		
DDT&E		
Orbiter *	$1.966 B(92)	$6.7 B(90)
Booster^	$1.140 B(92)	Same As LRB
First Unit		
Orbiter #	$1.756 B(92)	In DDT&E
Booster^	$0.176 B(92)	62% Of LRB
Production		
Orbiter #	$1.756 B(92)	$2.5 B(90)
Booster^	$0.176 B(92)	62% Of LRB
Fleet Replacement Logic	@ 90% Lc/88% Rc Attrition	1/Yr (2000-2004) + Attrition
PMS		
Booster Stage Success Rate	0.9847	0.99232
Booster Engine Success Rate	0.9977	0.99491
ACR		
Technical Challenge		
Non-Recurring Costs	3	4.2
Production	2	2.8
Operations	3	3.6
Program Immaturity	4	4.0
Number Of New Systems	0.93	1.0
(Figures Attached)		
LSC		
Schedule Compression	85/128	85/128
Schedule Margin	797.42	797.42
Percent Delays	24.02	24.02
Environmental Impact		
Liquid Oxygen	2032.9 Klb	2951.9 Klb
Liquid Hydrogen	227.6 Klb	227.6 Klb
RP-1	268.7 Klb	N/A
Solid Propellant	N/A	600.0 Klb

*Spread over 8 years: 1, 4, 10, 15, 25, 30, 15, 5.
^Use the same spread as for the LRB's.
#Use the same spread as for the Orbiter

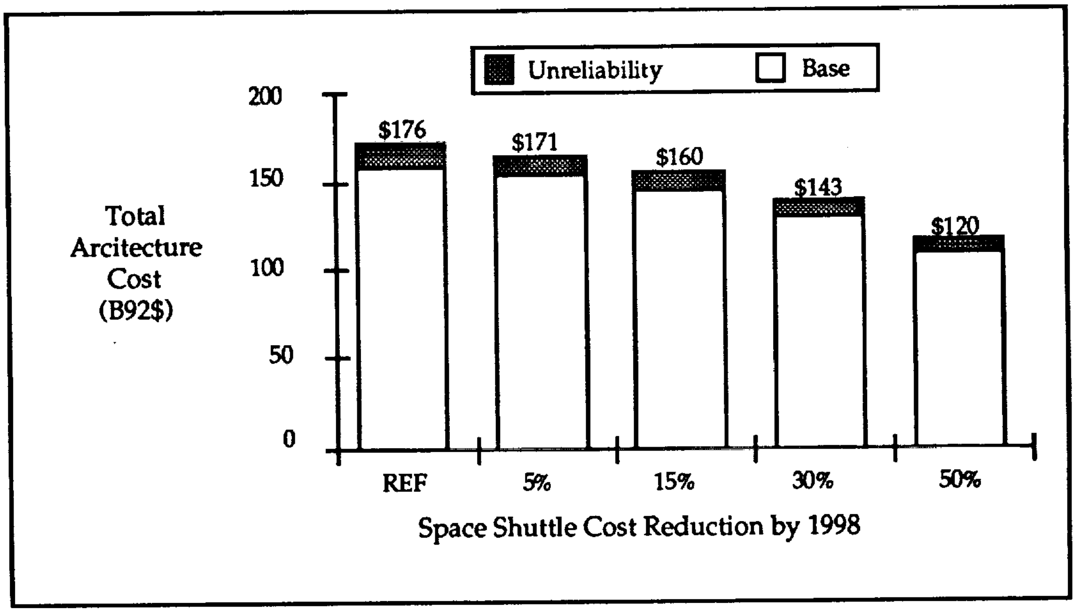


Figure 3.5.3.2.2-1.– Space Shuttle cost reduction impact on total architecture costs of HTS reference architecture.

3.5.3.3 Improving Architecture Scores

As a result of the work performed in the HTS study, and the extension, it was discovered that improved architectures could be found by learning from the shortcomings of the existing architecture set. Improving or modifying existing architectures, as well as looking at what a new, clean-sheet architecture would look like is discussed below.

3.5.3.3.1 "Improved" architectures.– Features of systems that score well in the HTS methods of quantifying attributes are listed in the following paragraphs. This is essentially a compilation of study findings; there are many other ways to improve each attribute, but some produce secondary improvements and/or cannot be measured by study metrics. It is interesting to note that, in some cases, the desirable vehicle concept features are contradictory across two or more attributes.

a. Human Safety

A system should feature full flight, envelope escape capability (maximize P_A), maximum separation of crew from propellants and propulsion (maximize P_S), and no SRM's (maximize time for warning and initiating abort). Also, a system should minimize correlated failure potential (maximize P_S and P_A) by physically isolating flight critical systems, such as control actuators, from sources of likely hazards (such as turbomachinery).

b. Probability of Mission Success

High scores are obtained for those systems that have engine-out capability, ground start of as many engines as possible, hold-down on the pad, minimum number of engines, and a minimum number of staging events.

c. Funding Profile

(1) Peak Funding: Successful architectures and elements minimize new development, separate engine development from airframe development, incorporate appropriate reusability (relates to the total number of flights; however, some components designed for reuse may not be justified by some traffic model flight levels), and minimize recurring production buys during development or slide buys of recurring hardware until later.

(2) Life Cycle Cost: Elements score well if they feature high reusability (minimize or eliminate recurring production) and if manifesting is done at most-favorable flight rates and payload levels. In addition, a system should be designed for 'operability' – here defined as minimizing fixed costs and short turnaround times, including minimizing the recurring production hardware introduced into the cycle.

d. Architecture Cost Risk

In an ideal situation, architectures ideally would minimize the number of new systems, minimize technology advances, and minimize development costs.

e. Launch Schedule Confidence

Successful architectures maximize number of operational sites, include the ability to launch with failures (minimum equipment list), plan for nominal one-shift operations, and plan on less than 80 percent facilities utilization.

f. Environment

The best scores are obtained with systems that feature no solid rocket motors and minimize the launch vehicle size for a given payload.

3.5.3.3.2 "Better" architectures.– For the purposes of this section, an architecture is considered "better" within the context of the overall HTS study rather than the current set of architectures (i.e., using the consensus-based approach of determining weighted attributes deemed important to the customer). Therefore, one would conclude that the "best" possible architecture would be reflected in scoring higher in each and every attribute, rather than any other architectural option. Therefore, the approach for developing a better architecture starts with an examination of what design or operational features result in high attribute scores. As noted in the previous section, there are identifiable features of better scoring systems. An objective search of all concept options is then performed to reveal maximum correspondence between desirable features, and concept and architecture characteristics.

The ideal architecture would meet all these constraints. Since some are contradictory, this is impossible, so the best architecture should conform with most of these constraints. At this point in the study, NIT members were invited to submit proposals for a "best" architecture. These architectures were compared to the reference architecture and Architecture 8 (SSTO), which scored the highest in the HTS architecture evaluation process using the NIT's weightings of attributes. As a result, two architectures comprised of two similar launch vehicle families, are discussed below.

Family "X" flies people and cargo together in a glider (although external shape is secondary to the findings) that can carry an eight-person crew and a 15 ft diameter by 40 ft long payload bay. This is essentially a larger (135 klbs) version of the CLV, the 40 klbs of payload capacity is more closely optimized to the manifesting requirements than the CLV. The launch vehicle is based on a family approach, whereby the development costs of the new systems are offset by improvements in reliability, safety, operability, and lower recurring production costs of all the vehicles in the architecture. Figure 3.5.3.3.2-1 depicts the vehicles used in the architecture. Engine-out capability, existing SSME's (at 100 percent power level), all-engine ground start on human flights, and NLS-type health monitoring, etc., are all hallmarks of an architecture that would score well in the HTS architecture evaluation process. Note that other non-study considerations are addressed as well: heavy polar missions from ETR without overflights, an excellent commercial class launcher, and ready-growth path to current SEI launcher plans.

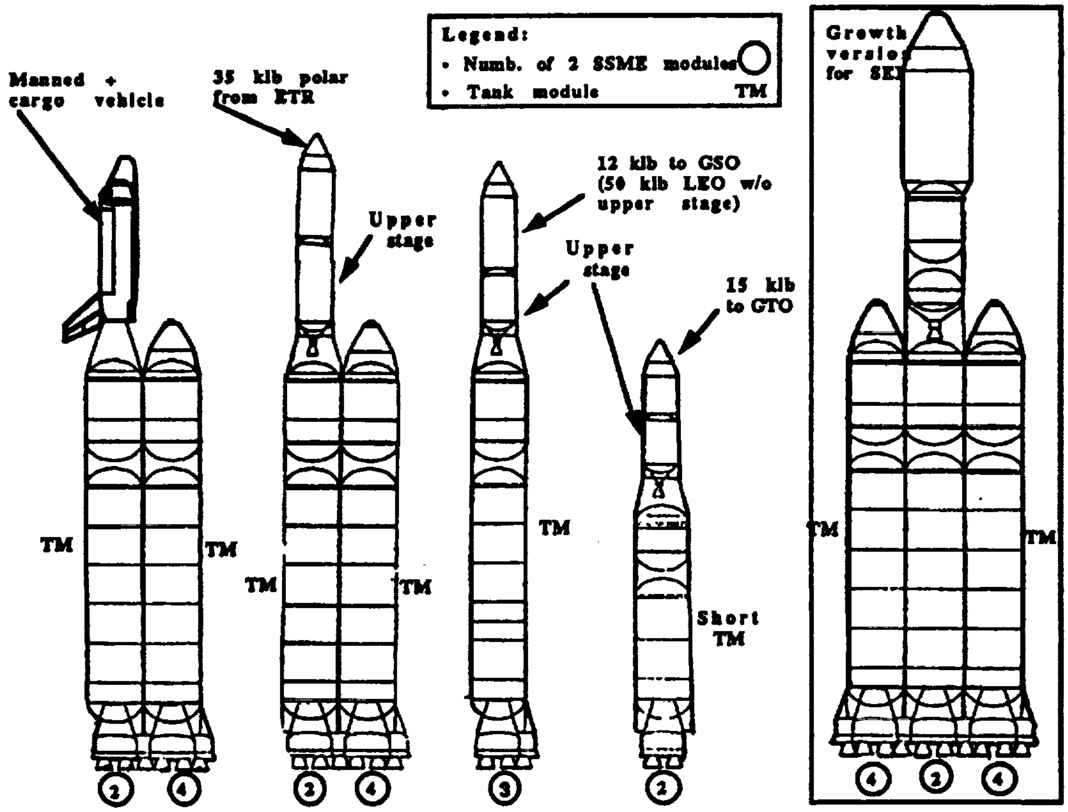


Figure 3.5.3.3.2-1.– Family "X".

Family "Y" essentially separates the job of flying people and cargo, although the HTS findings would indicate that it is desirable to include some small amount of cargo on all human flights; the throw-weight capability of the launch vehicle (to SSF transfer orbit) is approximately 65 klbs, which is adequate for an eight-person crew and some limited cargo. Figure 3.5.3.3.2-2 depicts the elements of the architecture. The glider (again, shape is not that important) would be flown in two versions called "A" and "B". The external shape and many of the subsystems are identical. In configuration "A", there is a 15 ft by 22 ft cargo bay with no provisions for a crew; configuration "B" has accommodations for an eight-person crew and a small pressurized cargo compartment. The desirable features of the launch vehicles are similar to those explained for Family "X" above.

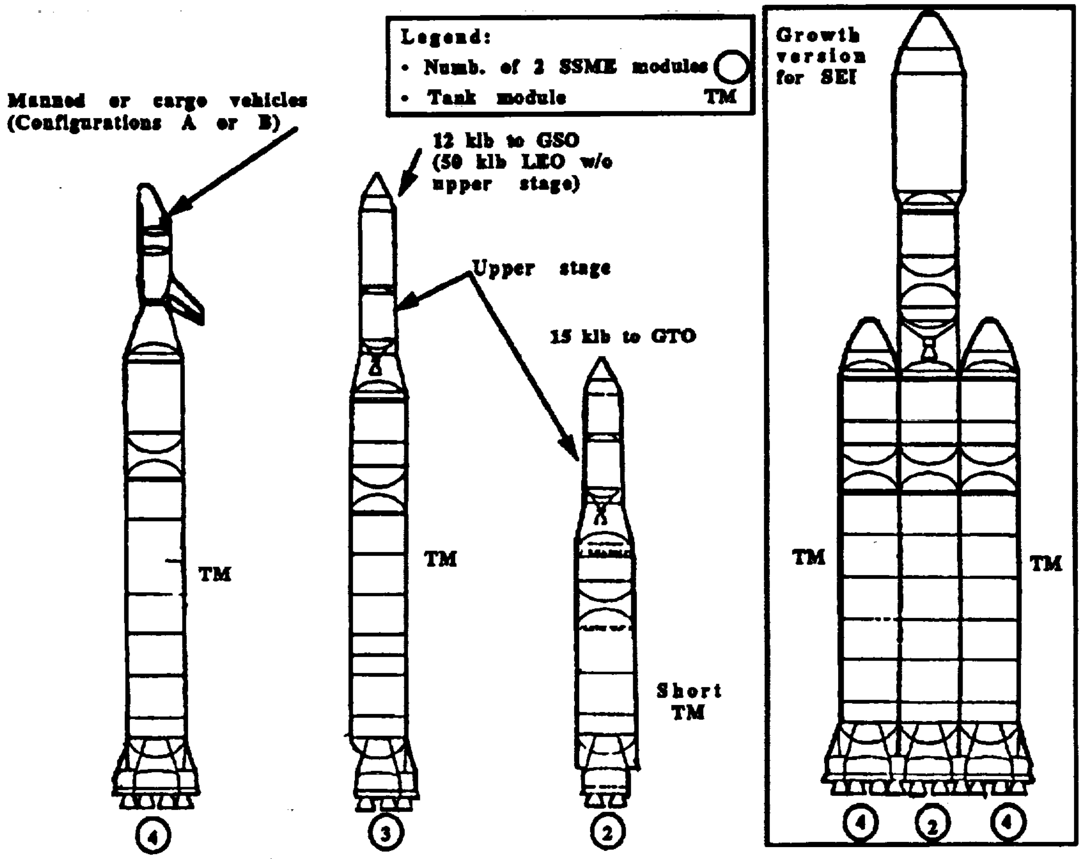


Figure 3.5.3.3.2-2.– Family "Y".

The two reference architectures (Architectures 1 and 8) and the two proposed architectures are compared in Table 3.5.3.3.2-1. In this case, it is less the intent to propose a *right* answer than it is to show how using features of the current concepts and attribute weightings can derive new architecture options. It remains to be seen how future architecture can score better than the options proposed here, but it is likely that based on the analysis of attributes, better architectures than this original set can be formulated.

TABLE 3.5.3.3.2-1.- ATTRIBUTE COMPARISON OF PROPOSED "BETTER" ARCHITECTURES WITH REFERENCE ARCHITECTURES

	Ref (1)	"X"	"Y"	SSTO
Human Safety				
Escape Capability		●	●	●
Max Separation		●	●	○
No SRM's		●	●	●
Min Correlation		●	●	
PMS				
Engine-Out		●	●	●
Ground Start	○	●	●	●
Hold-Down	○	●	●	●
Min Engines	●			
Staging Events		○	●	●
Fund Profile-Peak				
Min New Dev				
Sep Eng A/F Dev		●	●	
Reuse/Init Buy				
Fund Profile-Total				
Reusability		○	○	●
Favorable Manifest		●	●	
ACR				
Min New Systems	●			
Min Technology	●	○	○	
Min Dev Costs	●			
LSC				
Max Op Sites				●
Launch w/failures		●	●	?
One Shift Operation		?	?	?
Fac Util <80 percent		?	?	?
Environment				
No SRMs		●	●	●
Min LV Size		●	●	●

● - Significantly Better
○ - Somewhat Better
? - Need More Data

SECTION 4
HTS FINDINGS: PUTTING IT ALL TOGETHER

4.1 DETAILED FINDINGS BY ARCHITECTURE PATH

The significant findings relevant to pursuing each of the possible paths are provided below. This information is provided to aid agency planners in determining how to best meet the nation's transportation needs. These results are also useful for understanding the consequences that may likely result along a potential path should they choose not to use attributes and their associated priorities in determining which path to follow. In other words, it quantifies the impact of a customer's decision. Of course, all findings, conclusions, and recommendations are based on the assumptions, methodologies, and data presented in this report. When findings lead to recommendations that can be substantiated by the data, they are cited in section 5.0 of this report.

As a result of the HTS study, the NIT has developed the following findings and consequences that would be encountered as a function of the chosen path. Unless otherwise noted, findings apply to the "If" C activity level (continue current missions plus SSF PMC). Similar findings for the "If" B mission activity level (continue current missions only) can be obtained from the architecture data in Volume II, Appendix C.

If we *retain current systems*, then the HTS process indicates that:

- New Space Shuttle Orbiters are likely to be needed for future demand and/or probable losses, since the flight demand is driven by SSF deployment and support, and other transport.
- An additional MLP is the only Space Shuttle facility element needed to support this implementation.
- HTS needs model cannot be supported with the eight flight-per-year restriction on Space Shuttle.

If we *evolve current systems*, then the HTS process indicates that:

a. For the baseline Space Shuttle evolution compared with current systems

   - Total architecture costs increase $20B to $27B, with a $3B higher peak funding requirement and a $3 to 4B higher unreliability cost.
   - Crew loss events are reduced 12 to 34 percent.
   - Architecture risk increases 12 to 16 percent, inversely with activity level.

- Piloted flights decrease by 0 to 90 from "If" A through "If" E-High due to the introduction of the RCV and increased Space Shuttle performance.
- Unpiloted flights increase by 0 to 97 from "If" A through "If" E-High due to the introduction of the RCV.
- Mission success is not significantly affected.
- Environmental impact is reduced 12 to 33 percent for "If's" A through E-High due to Space Shuttle LRB's.
- Additional Space Shuttle facility elements are not required.

b. For evolution including HRB's and CEM's compared with current systems

- Piloted flights decrease by 45 with respect to current systems and increase by 11 with respect to baseline evolution due to the introduction of the RCV, and the decreased Space Shuttle performance due to the addition of a CEM.
- Unpiloted flights increase by 83 with respect to current systems due to the introduction of the RCV.
- Mission success is not significantly affected.
- Total architecture costs increased by $47.1B over the current systems and by $14.8B over the baseline evolution case. In addition, the peak funding requirement was $6.3B higher than the current systems and $2.2B higher than the baseline evolution case. Unreliability costs were increased $6.3B over current systems and $2.2B over the baseline evolution case.
- Crew loss events are reduced by 39 percent with respect to current systems and 15 percent with respect to baseline evolution.
- Cost risk increases 13 percent with respect to current systems and 0.5 percent with respect to evolution architectures.
- Environmental impact is decreased 25 percent with respect to current systems and increased 1 percent with respect to baseline evolution.
- Additional Space Shuttle Orbiters are likely to be needed for future demand and/or probable losses.
- The CEM's contributed less than 0.7 of 2.6 crew loss reduction.

If we *replace current systems* with new systems, then the HTS process indicates that:

- Significant improvements in safety can be achieved by several alternative transportation architectures. This is due to the addition of features such as vehicle hold-down on the pad, engine-out capability, abort capability during all ascent phases, and careful selection of the major propulsive systems. The additional cost to achieve this added safety ranges from $40B to $60B, for Architectures 5 and 6 respectively.

If we *augment the current systems with new systems,* then the HTS process indicates that:

- Total architecture costs increase $55.6B to $ 94.9B, with a $2.5B to $9.6B higher peak funding requirement and a -$6.4B to + $1.5B change in unreliability cost
- Crew loss events vary from -48 percent to +7.5 percent
- Architecture risk increases 15 percent to 40 percent
- Piloted flights vary by -61 to +70 for "If" C through "If" E-High
- Unpiloted flights increase by 68 to 222 for "If" C through "If" E-High
- Mission success does not vary significantly
- Environmental impact varies from -21 percent to +10 percent

4.2 RESPONSES TO VIEWPOINTS

Prior to the HTS study, there were several inconsistent viewpoints common among discussions concerning the need for a next transportation system. These viewpoints usually began with a statement born out of some frustration with the Space Shuttle, and were followed by some expression of desire for a replacement system. Too often, however, these viewpoints were contradictory and provided no useful direction for agency planners. We believe it is important to specifically respond to these viewpoints, since they impact discussions of whether or how new systems can or should be justified.

As a result of having evaluated the data relative to these questions during the course of this study, and the extreme emphasis put on definition and measurement specifics during the HTS study, the NIT can provide their insightful responses to these conflicting viewpoints.

- "The nation should not buy a new Orbiter OR the nation should continue to rely on the Space Shuttle for the next 20 to 30 years."

  Without taking attrition into account, the current fleet does not support transportation requirements which would continue current missions and subsequently add SSF build-up and support ("If" Scenario C), if it is necessary to fly the payloads in the year in which they are currently planned. However, the current fleet can support these requirements with the addition of an additional Space Shuttle Orbiter and a MLP. The bottom line is: the decision on the number of required orbiters in the future must be based both on potential attrition and the expected usage rate required to meet future demand.

- "The Space Shuttle costs too much to operate."

  This viewpoint incorrectly assumes that *operations* costs are the dominant attribute the agency is trying to minimize, when in fact, *minimizing the agency's annual expenditure on transportation* is the objective we are trying to achieve. A decision made on only one component of cost (DDT&E, operations, or production of components) which comprises an annual expenditure will almost certainly be a bad one. Other than the single-stage-to-orbit (vertical take-off and horizontal landing) concept studied, the current transportation systems (Space Shuttle, Delta, Atlas, Titan) have the lowest total architecture cost (integrated annual expenditures from the present to 2020) based on current ways of doing business. All other Space Shuttle replacement architectures add at least 30 percent to transportation costs over this study time period. This finding applies if we engage in transportation activity levels greater than or equal to assembly and support of SSF. For less aggressive transportation models, some architectures {5, 6, 7, 14, 16, 17 ("If" A)} and {14, 16, 17 ("If" B)} become cost competitive with the current systems.

- "We need alternate access to space in the event of an extended Space Shuttle downtime."

  To provide alternate access for people and cargo, the nation should be prepared to spend an additional $50 to $100 billion between now and 2020 to develop, operate, and maintain this capability. The range depends upon whether alternate access is provided for cargo-up only, cargo-up and -down, or people-and cargo-up and -down. The sheer expense of providing alternate access dictates that we develop a strategy for minimizing the contribution of non-technical reasons to "Space Shuttle downtime".

- "We should separate people from cargo in the name of safety."

  The presence of some cargo capability on the human-tended carrier was not found to have a deleterious impact on the number of crew losses that could be expected.

- "We should separate people from cargo in the name of cost."

  The presence of some cargo on a personnel carrier can be cost advantageous when crew and cargo are being delivered to the same destination. This is especially true of vehicles with higher cargo capacity, given that the support of SSF comprises the majority of our transportation activity.

  As a replacement for existing systems, new systems currently under study which either combine or separate people from cargo are still more expensive than continued use of current systems.

- "New systems based upon newer technology promise significant improvements, and therefore we need to develop new systems."

  SSTO, with its reliance on more advanced technology relative to many of the other options studied, would be a cost effective alternative to the Space Shuttle were it to actually achieve its stated cost goals. However, the low confidence level in the cost data provided puts this finding in serious question.

- "There should be commonality between the ACRV and the next HTS."

  Architecture level trades, such as the HTS study, do not possess the fidelity required to evaluate this point. From a total architecture standpoint, whether a new personnel carrier should also double as the ACRV or not is a secondary concern, due to the relatively low cost and usage rate of the ACRV, and not a primary factor in determining the transportation system. Once that basic decision is made, assessing commonality with the ACRV would be in order.

- "Air launch systems promise significant attribute improvements for any new transportation system."

  Candidate air-launched systems evaluated in this study did not fare well due to the small cargo levels and the resulting high flight rates associated with them. Life cycle architecture costs were still dominated by the cost of ELV's to fly heavy payloads.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the extensive work performed in this study, the NIT has gained a unique insight into the quality and consistency of work performed by both industry and government on candidate transportation systems. From this unique vantage point, the NIT concludes the following:

a. Many of the systems defined in section 3.3.3 have sufficient definition so that vehicles in their class can be evaluated and specific systems down-selected without further study at the architecture level. (Of course, once the architectural path is selected, there would be additional system definition required.) "Sufficient definition" is defined here as either (a) having enough level of detail in an absolute sense, or (b) improving the system definition beyond the current point is not warranted since architecture considerations dominate. Those concepts having sufficient definition at this time are:

- MLS (NLS)
- Space Shuttle/Shuttle Evolution
- Beta II
- AMSC
- CLV
- Titan (including human-rated versions)
- personnel-only carriers (e.g., PLS, RUPC, etc.)

b. Further system concept definition is required on the following concepts before they can be evaluated for their suitability in a future personnel transportation system.

- SSTO
- NASP-derived vehicles
- advanced TSTO concepts (e.g., AMLS)
- air-launched concepts

c. Sufficient definition of potential new ways of doing business exists, and it is now time to quantify and verify these new business practices on the existing systems.

d. Providing alternate access by developing new dedicated U.S. assets is not cost effective.

e. Significant improvements in crew safety were realized through the introduction of launch escape, engine-out, and hold down on new systems.

f. There is no inherent safety benefit from separating crew and cargo. (This does not mean that untended payloads should be placed aboard human-tended vehicles. It means that if the crew will be working with the payload while in orbit, having both delivered on the same launch vehicle, in and of itself, does not adversely impact safety.)

5.2 RECOMMENDATIONS

The intent of the HTS study was to provide the information necessary for senior agency management to make a determination on the path to follow for the next HTS, and *not* to recommend the specific architecture. To reach recommendations on the transportation system for the future, the HTS study process requires prioritization of desired transportation attributes by the NASA administrator. Since he or she is the ultimate transportation customer and the executive branch's steward of the nation's space program, any recommendations are a direct function of his attributes and their relative priority. **As a result, while the study did compare architecture options based on *the team's assessment* of missions and attributes, the study team is not able to recommend a preferred or optimal transportation architecture, or any specific concepts which are a part of them, at this time.** However, the HTS study process provides a very valuable tool to aid the administrator's evaluation of options for the next human transportation system once his or her requirements are known.

There are however, recommendations that can be made as a direct result of the experience gained during this study. They are:

a. Development of Mission Requirements and Evaluation Criteria – Prior to deciding what the next transportation system should be, focus senior agency management on customer-desired attributes, their measurements, and mission requirements for new systems, rather than on system or vehicle concepts. Acceptance of this recommendation will allow convergence more quickly on the desired human transportation system. For a national program, space program managers, the DOD, and other potential users should be included in the working group to define desired attributes and their measurements.

b. New Ways of Doing Business – Implement a plan for instituting new business practices immediately on existing systems. The plan should be constructed so that any actual savings realized should be "banked" first for verification accounting and confirmation purposes, before using the savings to pay for new programs.

c. Crew Escape Modules on Space Shuttle – Do not pursue retrofit of a crew escape module on the existing Space Shuttle fleet due to the high cost and small improvement in safety.

d. Human-Tended versus Untended Transportation – Consider both the human-tended and untended aspects of transportation *simultaneously* (at the architecture level) when considering what the next human transportation system should be.

e. Separation of People and Cargo – Do not pursue development of a transportation system which separates people from cargo in the name of increased safety. Architectural considerations (i.e., additional flight rates) and other transportation requirements were found to dominate over safety. Since the HTS study found that the presence of cargo capability with the human-tended vehicle has little effect on safety, and that other architectural considerations dominate, the amount of cargo capability in any next human transportation system should be predominantly driven by providing the transportation needs in an effective manner. (For the mission model used in this study, SSF resupply and logistic support was the largest driver of delivery and return requirements.)

f. New Personnel Vehicles Derived from an ACRV – Do not base the decision as to what the future transportation system should be based on whether the ACRV function should be common with the primary transportation function, since the inclusion of an ACRV had negligible effect on the architecture attributes. Once the overall transportation architecture decision has been made, the decision as to whether an ACRV is even required, or whether its function should be provided by the basic transportation capability, would be determined by whether it produced a favorable impact on the primary system-level attributes.

g. Areas of additional study – Redefine new technology programs in such as way as to support a go/no-go commitment for these approaches within a total transportation architectural context. While new technology solutions such as SSTO appear advantageous, the fidelity of the cost and technical data does not currently allow commitment to this alternative. For example, the SSTO requires further definition in ground processing turnaround to validate the costs relative to other transportation alternatives that have much better cost definition. (The HTS study results indicate that the total SSTO program costs, DDT&E, production, and operations, would have to increase by a factor of only 2.3 to negate any cost advantage over the Space Shuttle.) Redefining the early SSTO definition activities to obtain that data for comparison on an equal architectural basis would foster an early decision from among the transportation alternatives. This also holds true for NASP-derived vehicles, AMLS, and air-launched concepts with significant cargo capacity.

SECTION 6
SUMMARY

The NIT arrangement proved to be an excellent forum for conducting this type of study. Bringing the combined analytical capabilities of industry and NASA to bear on a single objective yielded more thorough study results than could have been achieved otherwise. This approach also allowed the evaluation of more architecture and system options, to a greater level of detail, than could otherwise have been evaluated. One primary reason for this is because the team often had one or multiple "models", "tools", or "techniques" already available to it, which had been developed and refined with significant monetary investment. In fact, the tools available to us were in some cases better than our ability to use them in the 1 year available for this study.

Although the industry team members each had vested interests in particular system concepts, this did not present a problem as long as the concepts were all passed through the same analytical process and reviewed by the entire NIT. In fact, this approach had the significant advantage of providing the built-in checks and balances that are often missing in studies conducted by single organizations, whether government or contractor. It was the consensus of all participants that this approach warrants more consideration for similar architectural evaluations.

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13. ABSTRACT *(Maximum 200 words)*
This report summarizes work completed under the Human Transportation System Study. This study was conducted by the New Initiatives Office at JSC with the technical support of Boeing, General Dynamics, Lockheed, McDonnell-Douglas, Martin Marietta, and Rockwell. The study was designed to generate information on determining the appropriate path to follow for new system development to meet the Nation's space transportation needs. The study evaluates 18 transportation architecture options using a parametric set of mission requirements. These options include use of current systems (e.g., Shuttle, Titan, etc.) as well as proposed systems (e.g., PLS, Single-Stage-to-Orbit, etc.) to assess the impact of various considerations, such as the cost of alternate access, or the benefit of separating people and cargo. The architecture options are compared to each other with six measurable evaluation criteria or attributes. They are: funding profile, human safety, probability of mission success, architecture cost risk, launch schedule confidence, and environmental impact. Values for these attributes are presented for the architecture options, with pertinent conclusions and recommendations.

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