NASA Technical Memorandum 104780

# Human Transportation System (HTS) Study

## Executive Summary

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# Contents

Section Page

## PART I OVERVIEW AND RESULTS

## PART II PROCESS AND METHODOLOGY DESCRIPTION

## PART III ARCHITECTURE SCORES AND ATTRIBUTE DATA

## TABLES

## FIGURES

# List of Acronyms

| | |
|---|---|
| ACRV | Assured Crew Return Vehicle |
| AET | Architecture Evaluation Tool |
| AMLS | Advanced Manned Launch System |
| CEM | Crew Escape Module |
| CNDB | Civil Needs Data Base |
| DDT&E | Design, Development, Test, and Evaluation |
| DOD | Department of Defense |
| ELV | Expendable Launch Vehicle |
| ET | External Tank |
| ETO | Earth-to-Orbit |
| HTS | Human Transportation System |
| IOC | Initial Operational Capability |
| ISF | Industrial Space Facility |
| LEO | Low Earth Orbit |
| MECO | Main Engine Cut-off |
| MLP | Mobile Launch Platform |
| MSFC | Marshall Space Flight Center |
| NASP | National Aerospace Plane |
| NIT | NASA-Industry Team |
| NLS | National Launch System |
| NS | Number of New Systems |
| $P^3I$ | Pre-planned Product Improvement |
| $P_A$ | Probability of Abort |
| PI | Program Immaturity |
| $P_L$ | Probability of Loss |
| PLS | Personnel Launch System |
| PMC | Permanently Manned Capability |
| PMS | Probability of Mission Success |
| $P_S$ | Probability of Survival |
| PYF | Peak Year Funding |
| RCV | Reusable Cargo Vehicle |

| | |
|---|---|
| SEI | Space Exploration Initiative |
| SRB | Solid Rocket Booster |
| SSF | Space Station Freedom |
| SSME | Space Shuttle Main Engine |
| SSTO | Single-Stage-to-Orbit |
| TAC | Total Architecture Cost |
| TC | Technical Challenge |

# PART I

# OVERVIEW AND RESULTS

# SECTION 1
# INTRODUCTION

In December 1990, NASA Headquarters requested that JSC develop a plan to help senior agency management determine which path to follow to meet the nation's future human transportation needs. In August 1991, JSC initiated the Human Transportation System (HTS) study, a comprehensive study assembling the combined resources of NASA, Boeing, General Dynamics, Lockheed, Martin Marietta, McDonnell Douglas, and Rockwell under a NASA-Industry Team (NIT). **This study quantified those parameters, for existing and alternative transportation architectures, which were felt to be important to senior agency management in deciding how to best meet the nation's transportation needs. These parameters were: cost, safety, cost risk, probability of mission success, launch schedule confidence, and environmental impact.** The customer for this data is the NASA administrator, or the agent he designates.

This Executive Summary:

(a) summarizes the findings of the study that compared potential architecture options which satisfy the missions that are projected from the present to the year 2020 and;

(b) briefly illustrates the study process and depth of the technical data that characterize the HTS findings on the architecture options considered, including **evolving the current launch systems, augmenting the Space Shuttle with new systems (alternate access), and replacing the Space Shuttle with a combination of new and existing systems.**

(c) presents architecture results as a function of a parametric mission model. This includes space activity levels both with and without Space Station Freedom (SSF).

The Executive Summary is divided into three parts. Part I provides a study overview and lists the principal study results. Part II describes the study process, including the definition and calculation methodology of the six major attributes. Finally, Part III provides overall architecture scores and the associated attribute data for these architectures.

The in-depth discussion of these options, as well as detailed descriptions of the processes, analyses, and systems used in the HTS study to identify and quantify the cost versus benefit trades of each option, is contained in the HTS Study Final Report, NASA TM-104779.

# SECTION 2
# STUDY APPROACH AND GROUND RULES

From the beginning of the study, it was recognized that if this study was to build upon the results of previous studies (and to address the limitations of these studies), it was essential to have broad NASA and industry participation to assess the best data from previous concept design efforts. Also, since there was interest in determining just what convergence existed in the data so that future resources could be better focused on those areas with the highest potential pay-off, it was determined 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 the Johnson Space Center, Langley Research Center, Marshall Space Flight Center (MSFC), and Kennedy Space Center, 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 cannot 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 is 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 a 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, based on the best understanding of current and proposed missions, were assembled into five levels of space activity to comprise the components of the parametric transportation needs model. This is the HTS "mission model." Refer to Part III, Section 5.1 for additional information.

### 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. See Part II, Section 5.2.

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.

*"If the range of expected space activity includes..."*

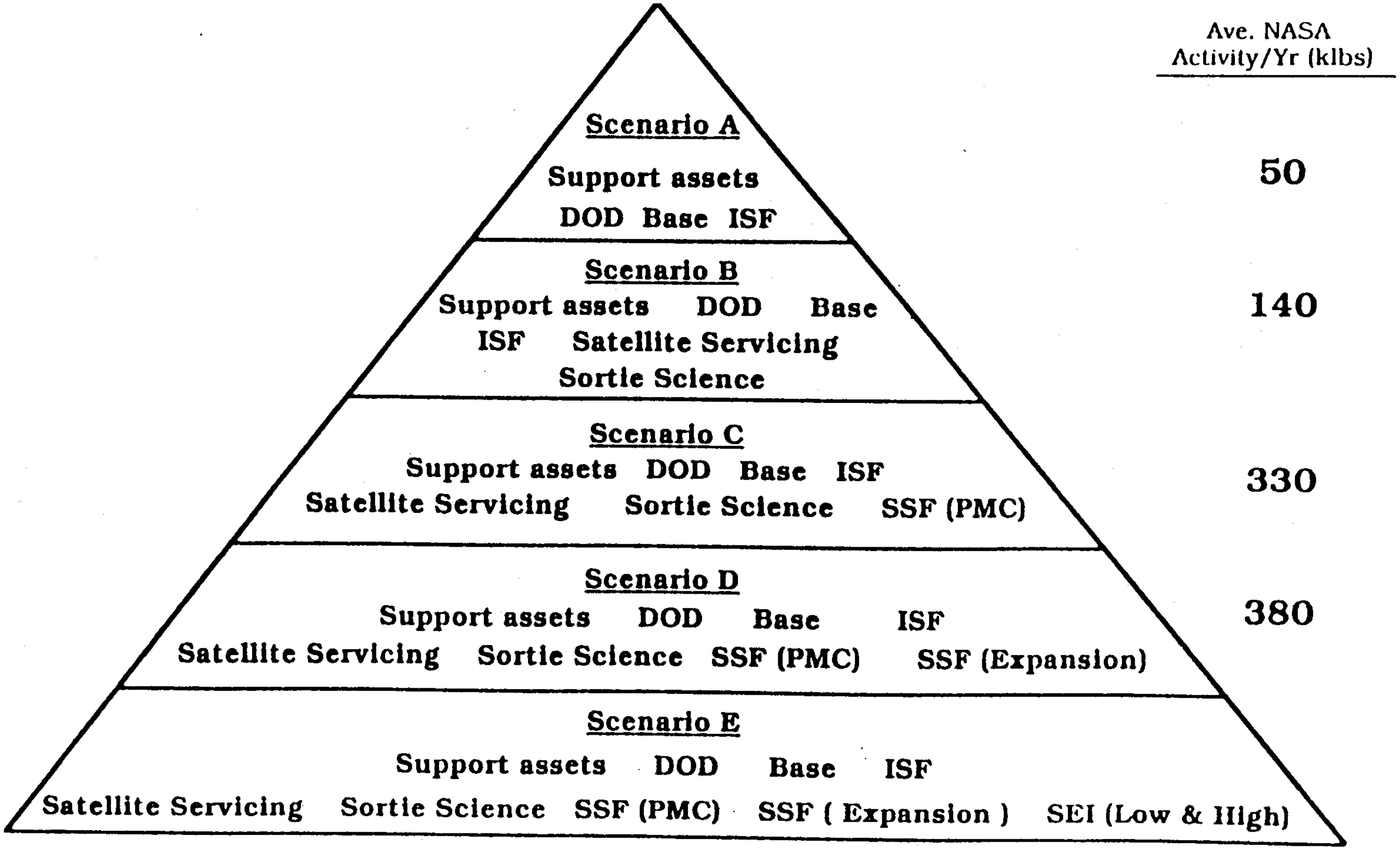


Figure 2.1.1-1.- Transportation needs "If" scenarios.

These considerations included:

- 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 Assured Crew Return Vehicle (ACRV).
- the evolution of current systems.
- the size and features of an expendable booster developed specifically from the outset with manned 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.

### 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.

## 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 (LEO).

- 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 expendable launch vehicle (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 Space Exploration Initiative (SEI) transportation requirements. Because transportation requirements for SEI would be of such a magnitude greater than Earth-to-orbit (ETO) 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 of 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 trade-study to be done at a level lower than the architecture-level focus of this study.

- 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 GROUNDRULES AND ASSUMPTIONS

We examined the existing constraints or groundrules which would limit the scope of 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: ________". Section 2.3.1 contains the groundrules (or "stone tablets") the study adhered to, while section 2.3.2 contains those which were rejected. The reader should refer to the final report for the rationale behind imposing or rejecting these requirements.

### 2.3.1 HTS Stone Tablet Requirements

- *There can be no reliance on foreign countries to develop elements.*
- *SSF will be assembled with the Space Shuttle up to permanently manned capability (PMC).*
- *The SSF design through PMC is fixed.*
- *The operational requirements, procedures, and constraints of the SSF and other on-orbit assets are fixed.*
- *Mixed fleet manifest will be used to define the architecture through 1996.*
- *No international treaties will be violated.*

2.3.2 Rejected Stone Tablet Requirements. Here are the most important "stone tablets" which were rejected by the study team. Refer to the final report for the complete list with supporting rationale.

- *Must be consistent with National Launch Policy.*
- *Must ensure dual access.*
- *New ways of doing business must be included in candidate architectures.*
- *New elements must advance the state-of-the-art.*
- *Reliability is greater than X.*
- *Dependability of 95 percent within 2 weeks of scheduled launch.*
- *All systems must be at least as safe as Y.*
- *Total Life Cycle Cost is less than Z.*
- *Abort must be provided for in all flight phases.*

# SECTION 3
# HTS FINDINGS: PUTTING IT ALL TOGETHER

## 3.1 DETAILED FINDINGS BY ARCHITECTURE PATH

The significant findings relevant to pursuing each of the possible architectural paths are provided below. This information is provided to aid agency planners in determining how best to meet the nation's transportation needs. These results are also useful in understanding the potential 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 4.0 of this summary.

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 mission model activity level (continue current missions plus SSF PMC) over the time frame 1992-2020. Note that the study findings are a strong function of the activity level. Similar findings for the "If" B mission activity level (current missions only), as well as the other activity levels, can be obtained from the summary tables in Part III. Refer to section 5 for an explanation of the systems and architectures described below.

Other than the single-stage-to-orbit (SSTO) concept used in this study (see Part III), 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 (IFC). For less aggressive transportation models, some architectures become cost competitive with the current systems.

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 mobile launch platform (MLP) is the only Space Shuttle facility element needed to support this implementation.
- The HTS needs model cannot be supported with the eight flight-per-year restriction on the 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 cost increased by $ 20B to $ 27B, with a $ 3B higher peak funding requirement and a $ 3B 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 reusable cargo vehicle (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 liquid rocket boosters.
- Additional Space Shuttle facility elements are not required.
- Additional Space Shuttle Orbiters are likely to be needed for future demand and/or probable losses.

b. For evolution including Hybrid Rocket Boosters and Crew Escape Modules (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 cost 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. The CEM's contributed less than 0.7 of 2.6 crew loss reductions. The remaining reductions were primarily due to fewer human flights through use of the RCV.

- 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.

- One more Orbiter/RCV is required for demand and also attrition with respect to current systems.

- A new Space Shuttle MLP is not required.

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 additional development and operations costs for Architectures 5 and 6 respectively. Refer to Part II, section 5.3 for a description of these architectures.

If we *augment the current systems with new systems,* then the HTS process indicates that:

- Total architecture cost increased by $ 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.

## 3.2 RESPONSES TO VIEWPOINTS

Prior to the HTS study, there were several inconsistent viewpoints common among discussions concerning the need for a new 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 an additional Space Shuttle Orbiter and an 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 (only) 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 (Design, Development, Test, and Evaluation – DDT&E, operations, or production of components) which comprises an annual expenditure will almost certainly be a bad one.

- "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 $ 50B to $ 100B 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 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."

  The 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 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 4
# CONCLUSIONS AND RECOMMENDATIONS

## 4.1 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 the study 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:

   - Manned Launch System (New Launch System (NLS))
   - Space Shuttle/Shuttle Evolution
   - Beta II
   - Advanced Military Spaceflight Capability
   - Crew and logistics vehicle
   - Titan (including human-rated versions)
   - personnel-only carriers (e.g., PLS, reuseable ultralight personnel carrier, 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
   - National Aerospace Plane (NASP)-derived vehicles
   - advanced two-stage-to-orbit concepts (e.g., advanced manned launch system (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 holddown 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.)

## 4.2 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 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 transportation system. For a national program, space program managers, the Department of Defense (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. CEM's 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 contribute most to 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.

f. New Personnel Vehicles Derived from an ACRV. The decision on any future transportation system should not be based on whether the ACRV function should be common with the primary transportation function. 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 attributes.

g. Areas of additional study. Redefine new technology programs in a way that will 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.

# PART II

# PROCESS AND METHODOLOGY DESCRIPTION

# SECTION 5
# STUDY RESULTS

## 5.1 HTS MISSION MODEL

The needs model for the study was based on the NASA Mixed Fleet Manifest and the Civil Needs Data Base (CNDB) FY90 version with Space Station Restructure modifications and a "strawman" DOD mission model. All delivery and return masses identified were for the payload only and did not include the launch vehicle. Also not included were upper stage weights for those payloads going beyond LEO or required support equipment.

An analysis was performed to identify the number, mass, type, and destination of human-tended and untended payloads to space. The payloads were then broken into several categories based on a common mission or theme. Some of these mission types were easily defined as they were presented within the CNDB (e.g., ISF). Others were defined from different sources or were created and extracted from the CNDB (e.g., Sortie Science). All mission payload crew sizes were four persons, although extra persons might be required to support and operate the personnel vehicle.

### HTS MISSION TYPES

The payloads in the FY90 CNDB and the subsequent HTS Needs Model were divided into eight mission types or groups of activity that had similar characteristics. These mission types are described below:

#### DOD

This category includes human-tended and untended DOD missions. The untended 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 human mission requirement, we noted that of the 45 Space Shuttle flights since 1981, 10 have been dedicated to DOD, an average of about 1 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, we recommend a human requirement for DOD of one mission per year. It is also assumed the DOD mission will require some cargo, but not necessarily on the same flight or vehicle. This is a reduction from the Next Manned Transportation System Study in 1989 which identified a human 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 the Gamma Ray Observatory, the Earth Observing System, Cassini, and CRRES. All payloads in this category have a return requirement of less than 1000 lbs. It should not be confused with the CNDB Base Model.

### 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, GOES, and INMARSAT. There are no human requirements in this category, although a few of these payloads will be carried aboard the Space Shuttle.

### Industrial Space Facility (ISF)

This category includes those payloads which comprise the ISF. For the HTS study, a reduced-scale ISF payload model was used based partially on recommendations from the MSFC Space Transportation Infrastructure Study. 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, ASTRO, and International Microgravity Laboratory. Payloads in this mission type strongly reflect the Shuttle-based transportation architecture.

### Satellite Servicing

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

### Space Station Freedom (SSF)

This category includes those payloads which comprise the SSF. This includes assembly, utilization, logistics, crew rotation, and expansion flights based on the latest SSF design configuration restructure. However, the actual payloads were the same as those of the FY90 version of the CNDB.

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

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 due to restructure.

### Crew Rotation Assumptions

Since no official SSF crew rotation policy exists, the following assumptions were made for the study:

- 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.) This establishes the number of flights required to support SSF crew rotation.

- During an eight-crew phase, only four persons can be rotated during a human flight. This implies a 180-day tour of duty.

- All Space Shuttle flights to the Space Station have a crew of seven. Other personnel vehicles have crew sizes ranging from four to seven.

## Space Exploration Initiative

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 will 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.

## HTS ACTIVITY SCENARIOS

Finally, the eight mission types were combined into five levels of possible future space activity (see Figure 2.1.1-1). 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 (Remote Manipulator 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.

## 5.2 ATTRIBUTE DEFINITION AND MEASUREMENT TECHNIQUE DESCRIPTIONS

Attributes are the means with which an architecture's goodness is determined so that it may be compared with other architecture options. To be useful in comparison, an attribute must be definable and be measurable. The measurements must also be repeatable, which in turn means that the calculations are well understood and the assumptions are clear and used consistently across each architecture. In addition, we felt that it was less important to determine an absolute value for a given attribute than to use a consistent methodology which would yield values for a relative comparison of architectures.

The attributes defined in detail for this study include: Funding Profile, Probability of Mission Success (PMS), Safety, Architecture Cost Risk, Launch Schedule Confidence, and Environment. Each of these is summarized below, along with a definition and description of the measurement technique used. These were derived from a list of nearly 130 attributes that were initially proposed by the HTS team. Certain techniques used in a quality function deployment process were used to arrive at consensus on the final list. Additional analyses, such as payload manifesting and ground operations assessments, which were required to determine architecture-level values, are described in the final report.

### 5.2.1 Funding Profile

#### Definition

The Funding Profile attribute is comprised of two subattributes, Total Architecture Cost (TAC) and Peak Year Funding (PYF), and 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 and system costs associated with providing the capability to satisfy the mission model, as defined in the particular "If" scenario of interest. The TAC is the total architecture cost over the life of the study, including the cost of vehicle losses due to unreliability. The PYF is the dollar amount in the year of peak (maximum) costs. All the costs were estimated in constant 1992 dollars.

#### Measurement of the Attribute

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

Cost Analysis Data Flow.

The cost analysis was carried out as an integrated process, requiring key inputs be supplied by each of several different NIT groups which were developing and measuring different architecture attributes. Resulting architecture cost estimates were passed to the Architecture Evaluation Tool (AET) for final processing and inclusion in the overall architecture scoring process. Figure 5.2.1-1 outlines this data flow.

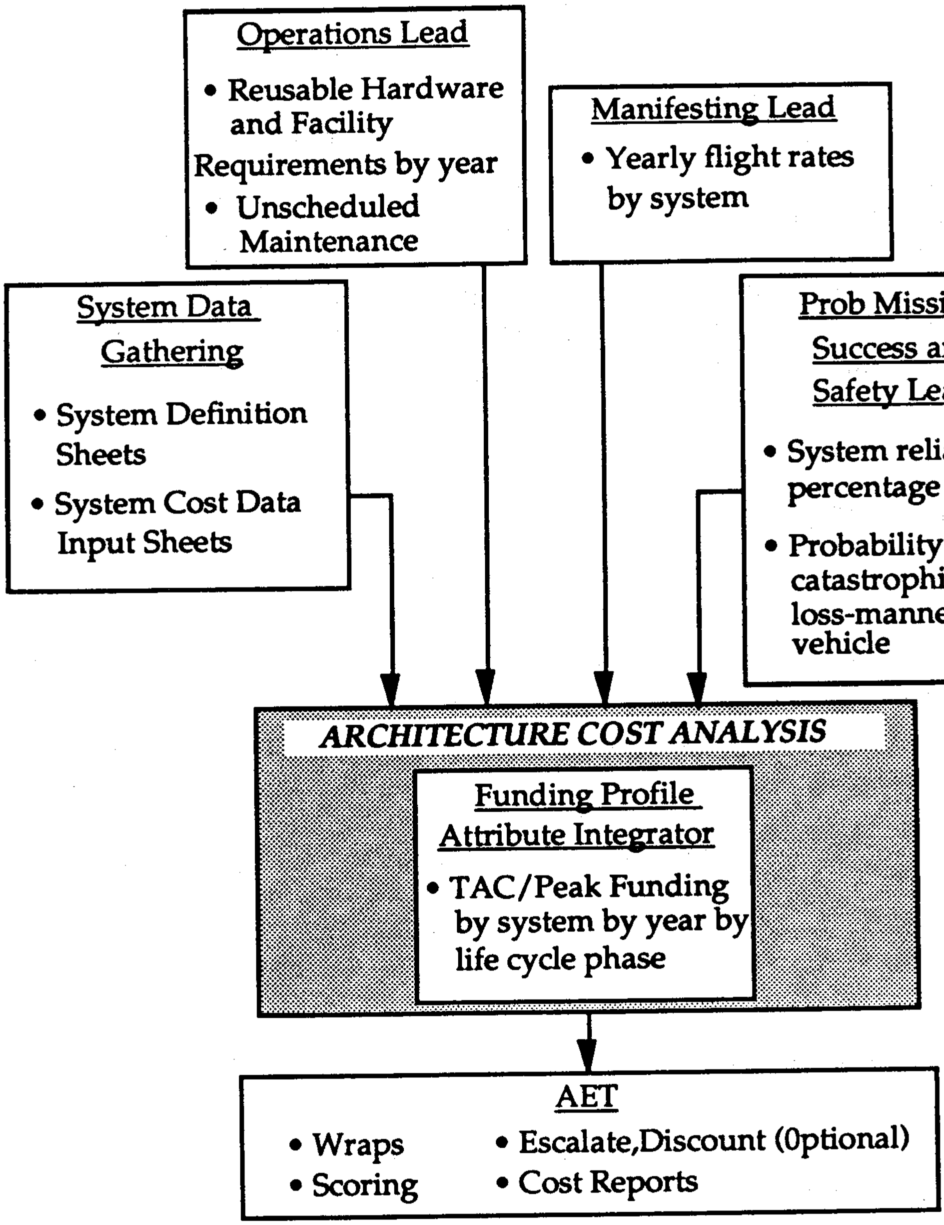


Figure 5.2.1-1.– Funding profile cost analysis data flow.

Cost input data for each system included the non-recurring costs for DDT&E and facilities, as well as flight-rate-sensitive recurring production and operations cost inputs in the form of Theoretical First Unit plus learning and rate curves, and/or fixed per year and variable per flight costs. In addition, year-by-year spread factors for each cost element, to reflect the year in which costs were incurred, were provided. Figure 5.2.1-2 illustrates the general input-process-output connections within the cost model.

Cost Analysis Definitions.
The following define the costs used in determining the Funding Profile Attribute.

(a) The TAC of an architecture includes the total cost of all transportation systems in the architecture, where total system TAC is the sum of Non-recurring, Recurring, and Transportation System Failure costs as defined below.

(b) The TAC for each architecture includes the following phases of the system's life cycle:

Non-Recurring - DDT&E
Non-Recurring Production
Facilities
Pre-Planned Product Improvement ($P^3I$)
Recurring - Recurring Production
Operations
Transportation System Failures (unreliability)

Refer to the final report for additional breakdown of these cost categories.

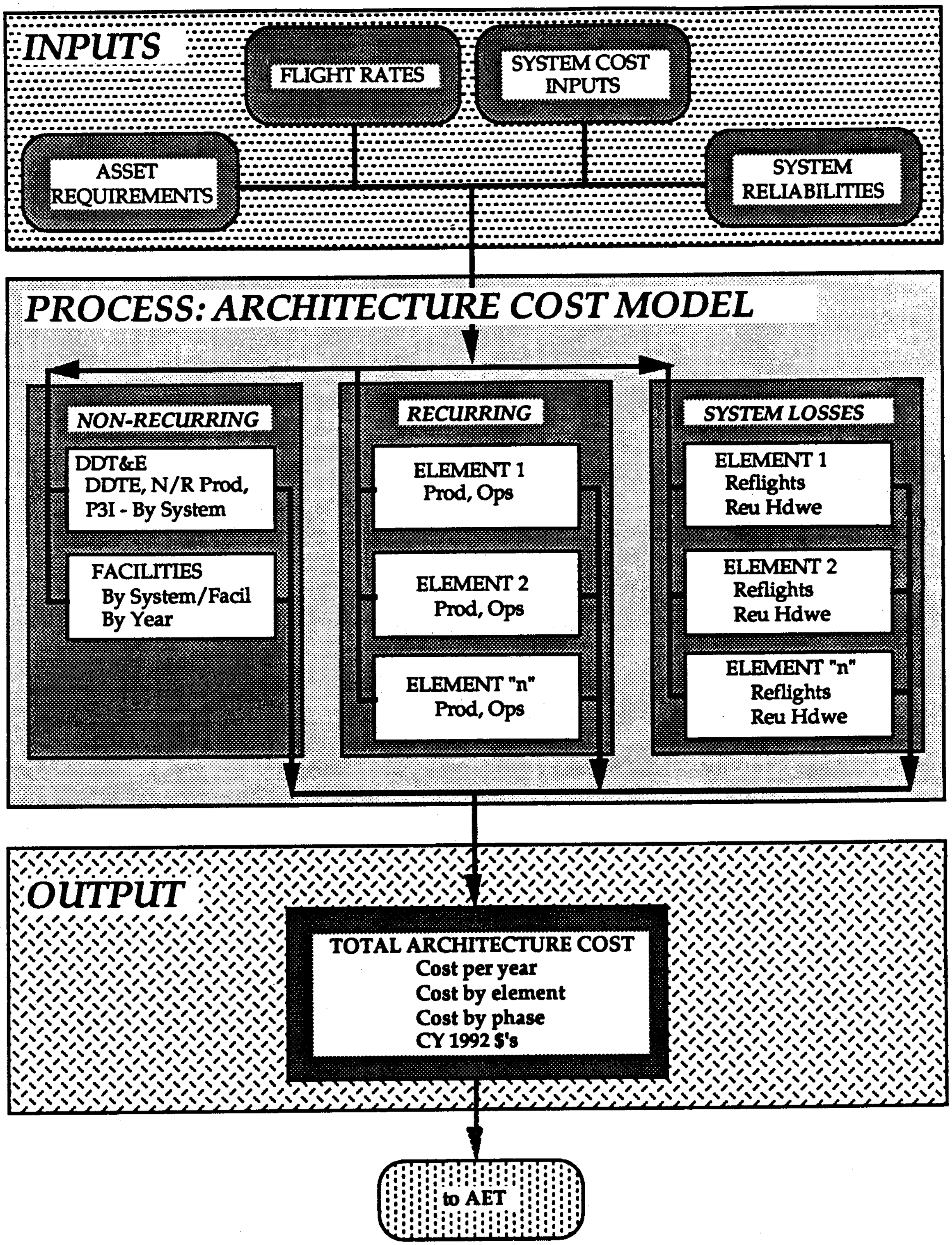


Figure 5.2.1-2.– Architecture cost modeling process.

Cost Analysis Groundrules And Assumptions.

- All costs are reported in constant 1992 dollars.
- 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.
- Cost wraps: Program wrap factors for contractor fee, government support and reserves, and contingency, were consistently applied to all systems. Baseline wrap factors, obtained from NASA Headquarters Code B, are shown in Table 5.2.1-1.

TABLE 5.2.1-1.– HTS STUDY COST 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

### 5.2.2 Safety

#### Definition

For the purposes of this study, the NIT consensus definition of 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 the death or incapacitating injury of flight personnel. No attempt was made to determine loss of the general populace as would be associated with a catastrophic event involving a major population center. This definition is meant to exclude the impact on property.

#### Measurement of the Attribute

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

Inflight emergencies can be caused by any number of failures and often involve complex system interactions involving secondary and tertiary effects. Some of these emergencies will require contingency procedures (possibly including abort) if the crew is to remain safe. Because it was deemed 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 <u>primary</u> cause of the flight emergency. The six failure categories considered in this study are:

Explosion
Fire
Loss of Control
Damaged Vehicle
Benign Failure
Hazardous Environment

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, there is a chance that the 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 by historical analogy and 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. Depending on the system design, flight regime, and the nature of the failure, there will be some probability of a successful abort, defined as up to 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. The study team determined from a quick analysis that the risk to the crew in the on-orbit and descent phases of flight were much less than that experienced during ascent and, therefore, the ascent portion of the flight only was examined for this attribute.

To determine the probability of a loss event then, the probabilities of unsuccessfully surviving and aborting are multiplied together with the relative percentage of occurrence (F, in %) of the major failure category (a forced distribution) 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.

In the case of benign failures, the percentage F represents the balance of failure modes not accounted for by the other five cases. An example of how a "benign" failure can effect safety is found in the case where an external tank (ET) fails to separate from the Shuttle Orbiter. There would 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 5.2.2-1 is an example worksheet of how the $P_D$ value is derived. 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 <u>relative</u> comparison should be valid.

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 5.2.2-1.– Example safety worksheet.

For the entire mission, then, 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:

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

where k is the total number of flight phases.

The value of PD takes into account 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 PD 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 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 5.2.2-2 depicts the average number of flights between crew loss events for the ten human systems examined. The figure below points out some major features related to safety that help to understand the relative loss rates.

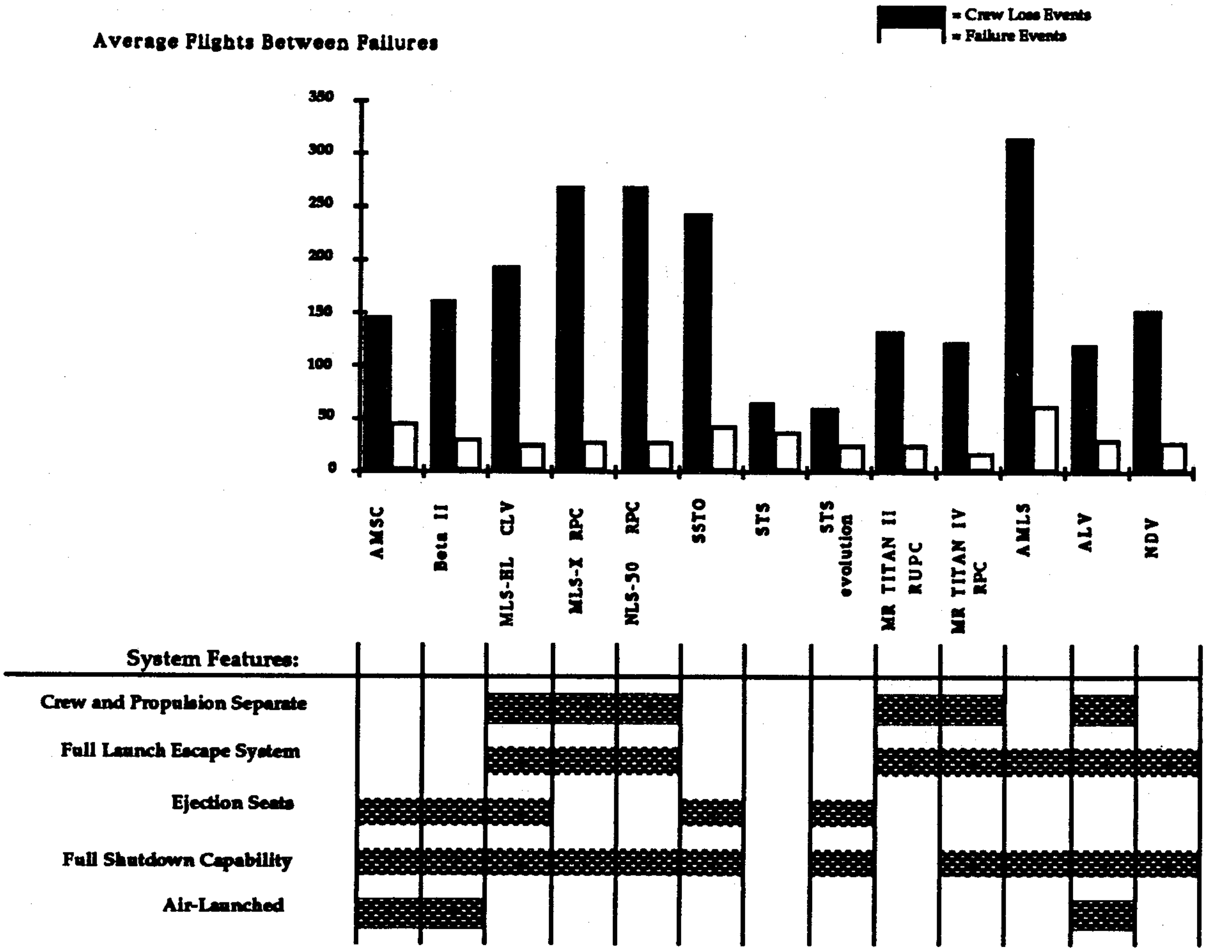


Figure 5.2.2-2.– Relative loss rates for human systems.

### 5.2.3 Probability of Mission Success (PMS)

Definition

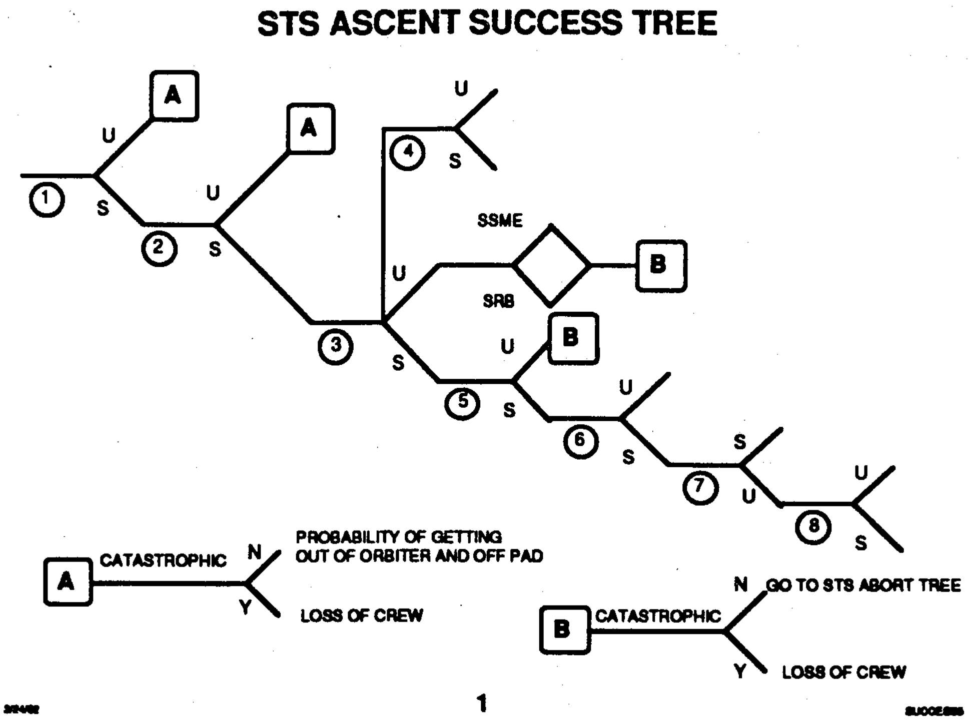
The PMS is the number of successful missions divided by the total number of missions. Successful missions are defined as delivering or accomplishing the jobs described in the mission model, not necessarily returning the reusable hardware or flight crew safely. Payload failures were not estimated or included in the measurement.

Measurement of the Attribute

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 5.2.3-1) is used here to explain their development.

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: Space Shuttle main engine (SSME) ignition and thrust buildup (Phase 1), solid rocket booster (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 burnout and ET jettison, occur during ascent. SRB jettison (Phase 3) separates Phase 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.



| 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 5.2.3-1.– Space Shuttle ascent success tree.

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 that was modeled for reliability analysis.

Modeling system reliability.

A review of space launch attempts shows that failures can be grouped into three major 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

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

### System Results

The final calculated PMS values for the systems used in this study are presented in Table 5.2.3-1. 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 roughly two percent.

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.

## TABLE 5.2.3-1.– 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 |
| 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 |
| Shuttle | .9431 | 2 | 5L,2SS | N |
| Shuttle Evolution | .9290 | 4 | 13 | Y |
| RCV | .9290 | 4 | 13 | Y |
| TITAN II | .9626 | 2 | 3 | N |
| HR 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 |
| TITAN IV (Centaur) | .9100 | 4 | 7L,2SS | N |
| TITAN IV (CTF/LRV) | .9242 | 3 | 7L,2SS | N |
| HR TITAN IV (RPC) | .9189 | 5 | 18 | Y |

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

### 5.2.4 Architecture Cost Risk

Definition

The Architecture Cost Risk is 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 absolute dollar amounts or to estimate required levels of program reserves.

The Architecture Cost Risk was determined to be a function of three primarily parameters, or subattributes:

(1) the **technical challenge** (TC) of the individual systems comprising the architecture. 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 essentially entirely new technologies. The TC of transportation systems can be determined independent of the architecture those systems are in.

(2) the **program immaturity** (PI) of the individual systems comprising the architecture. 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 the architecture those systems are in.

(3) the **number of new systems** (NS) that comprise the architecture. The NS is simply the count of the number of new systems in the candidate architecture, with credit acknowledged for families of systems. This is a direct architecture level measurement.

In addition, it was the consensus of the NIT that the contribution of each subattribute to the overall architecture cost risk was determined to be as follows:

| | |
|---|---|
| Technical Challenge | 45% |
| Program Immaturity | 30% |
| Number of New Systems | 25% |

Measurement of the Attribute

Technical Challenge.

The relative technical challenge of each system comprising the architectures was assessed by the HTS team. This was accomplished by determining the TC of each of the phases in the life cycle of each system comprising the architectures: the development, or non-recurring phase (which includes DDT&E, non-recurring production, facilities, and pre-planned product improvement), the production phase, and the operations phase.

These were then cost-weighted for 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 5.2.4-1 provides the consensus results of this phase-level assessment, along with the range of inputs received during the process.

TABLE 5.2.4-1.– PHASE-LEVEL TECHNICAL CHALLENGE
FOR TRANSPORTATION SYSTEMS

| System | Non-Recurring TC | Range | Production TC | Range | Operations TC | Range |
|---|---|---|---|---|---|---|
| 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

Program Immaturity.

The relative PI of each system comprising the architectures 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 a predefined, common level of current drawing counts. The program immaturity scale with the explanation of the program immaturity levels is provided in Table 5.2.4-2.

TABLE 5.2.4-2.– 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 5.2.4-3 provides the consensus results of this assessment, along with the range of inputs received during the process.

# TABLE 5.2.4-3.– 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 |
| *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 | - |

Number of New Systems.

The number of new systems comprising the architectures was assessed by the HTS team. 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 having less than the stated number of new systems. A consensus value was then selected to represent the assessment of the NIT. Table 5.2.4-4 provides the consensus results of this assessment, along with the range of inputs received during the process.

TABLE 5.2.4-4.– 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 |
| 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 |
| STS Evolution + RCV | 1.0 | 0.5-1.1 |
| Titan CTF | 1.0 | 0.9-1.0 |
| Titan Evolution | 0.5 | 0.1-0.8 |

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 on real programs, an algorithm was developed to spread the consensus input TC values 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. This 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 result in 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.

Refer to the final report for the architecture-level risk values.

### 5.2.5 Launch Schedule Confidence

Definition

This attribute is an indication of an architecture's ability to meet its launch schedules.

Measurement of the Attribute

The Launch Schedule Confidence attribute has three parts. Each is measured separately and combined.

Schedule Compression.
This is a measure of a system's ability to make up schedule slips by extending shifts to the processing flow. The operations flows for each system are analyzed to determine the critical paths. Those parts of the ground operations flow that are in the critical path are boosted to 7-day-a-week operation along with increasing the shift size by 50 percent. For example, if the nominal processing flow has one shift, the compressed flow would have one and one-half shifts. This shows the effect of not hiring new crews, but having the existing ones work overtime. The difference between this compressed flow time and the nominal flow time, in days, is divided by the nominal processing time to give a feeling for how long the added time is relative to the normal process flow. This number is then multiplied by the number of flights per year for the system. This indicates the reliance of the given architecture on this system. The values for each system are then summed for each year, and then the annual values are summed and divided by the total number of flights of all systems in the architecture.

Schedule Margin.
This is a measure of a system's ability to make up schedule slips by using excess facilities and personnel. The difference between the nominal flight rate and the design

flight rate is converted to a number of days. This is divided by the nominal processing time to indicate the added time relative to the normal process flow. This number is then multiplied by the number of flights per year for the system. This indicates the reliance of the given architecture on this system. The values for each system are then summed for each year, and then the annual values are summed and divided by the total number of flights of all systems in this architecture.

Percentage of flights with delays.

This is a measure of a launch system's likelihood to have a launch delay based on unscheduled maintenance items occurring at critical times in the flow. This measurement does not, however, attempt to measure the length of the delays. The mass, complexity, and mission length for each system are used to calculate a number of unscheduled maintenance action items that the system would experience each time it is used. 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 in the critical path of flight countdown, and how many of those actually cause a delay. The architecture value is a flight-rate-weighted average of the percent delays of every system in the architecture.

### System Results

Refer to the final report for system and architecture results.

## 5.2.6 Environment

### Definition

The definition of the Environment attribute, as determined by the NIT, is the degree to which a given architecture has a long term effect on the Earth's environment during the course of nominal space launch 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.

### Measurement of the Attribute

Mankind's relationship with the Earth's environment has been the focus of much attention in the recent past. The NIT consensus was that the decision makers are sensitive to public scrutiny of any space program and would not want to ignore the popular concern for the environment. Effects on the environment can result from several distinct mechanisms. Only the effect on the environment caused by launch vehicle effluents through the atmosphere were considered in this study.

The most consistent and readily available data to this study for assessing environmental impacts was a comparison of exhaust effluents using equilibrium chemistry calculated at the exit plan on the rocket engine(s). Using these chemical equilibrium calculation tools, all the candidate launch vehicle elements were analyzed to arrive at a total effluent mass by specie ($CO$, $CO_2$, $H_2$, $H_2O$, $HCl$, $N_2$, $OH$, $H$, and $Al_2O_3$ were considered). This was multiplied by the number of launch vehicle flights in the architecture to get a total environmental impact metric.

An attempt was made to derive a weighted score for each exhaust product based on a perceived environmental impact. This impact factor is multiplied by each species mass to get the weighted score. To properly arrive at an environmental impact factor would involve much research and complex biosphere models. In this simplistic approach, five key types of environmental concern were simultaneously considered to subjectively select an average figure of relative environmental impact that would result from the introduction of a particular chemical into the atmosphere. These concerns included:

Ozone depletion
Acid rain
Cloud nucleation
Greenhouse gases
Particulates

Each effect should ideally be compared separately to the natural background variability and to other anthropogenic sources. For the purposes of this study, however, the impact factors used in developing a weighted score considered these effects. Refer to the final report for additional detail.

## 5.3 ARCHITECTURE ANALYSIS AND EVALUATION

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. We called this grouping of transportation elements 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.

We defined an architecture 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, we constructed this architecture set 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 5.3-1 is a flow chart showing how input data from various sources was used in the study and the relationships between data input and output in the process of an architecture's evaluation.

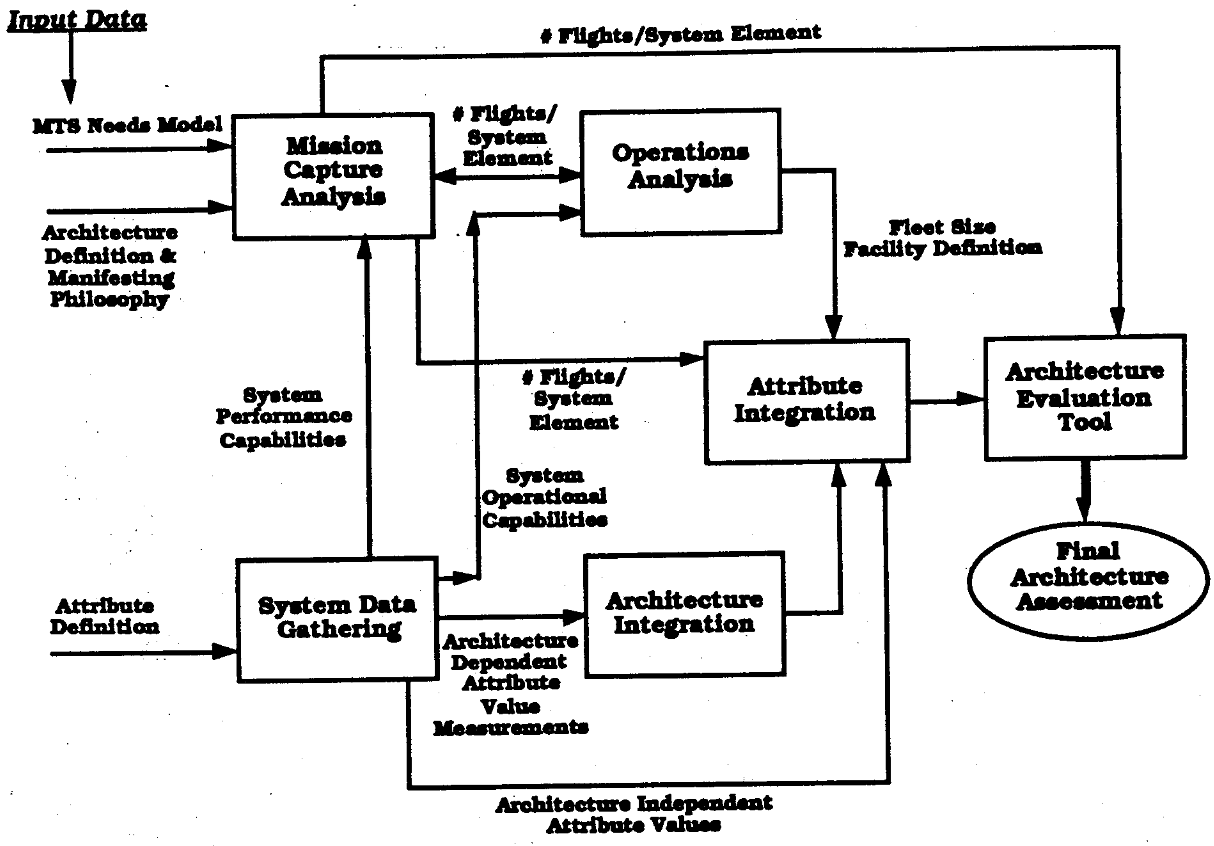


Figure 5.3-1.– Study data flow.

### 5.3.1 Architecture Options Development

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. The architectures were comprised of elements which provided crew and cargo delivery and return functions from 1992 to 2020.

To understand the impact of these considerations on future system options, we compared a set of architectures for each consideration. For example, to understand the separation of people and cargo, we constructed three architectures. The first kept people and cargo together by using the Space Shuttle or a miniature "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, we identified which elements 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 we believed 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 we felt it was unlikely that NASA will introduce new systems prior to this date. Finally, for each architecture, a set of manifesting philosophies were developed which governed how an element would be used. This allowed us to assign priority, consistent with the architecture intent, to different vehicles which could carry the same payload. Figure 5.3.1-1 shows an example template for a representative architecture and Figure 5.3.1-2 provides a summary of the architectures considered in the study. A detailed explanation of these architectures is provided in the final report.

| Function | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|
| **People Up** | •Shuttle | •Shuttle | •Shuttle | •Shuttle |
| **People Down** | •Shuttle<br>•ACRV | •Shuttle<br>•ACRV | •Shuttle<br>•ACRV | •Shuttle<br>•ACRV |
| **Cargo Up** | •Shuttle<br>•Titan, Atlas, Delta | •Shuttle<br>•Titan, Atlas, Delta | •Shuttle<br>•Titan, Atlas, Delta | •Shuttle<br>•Titan, Atlas, Delta |
| **Cargo Down** | •Shuttle | •Shuttle | •Shuttle | •Shuttle |

Figure 5.3.1-1.– Example architecture template.

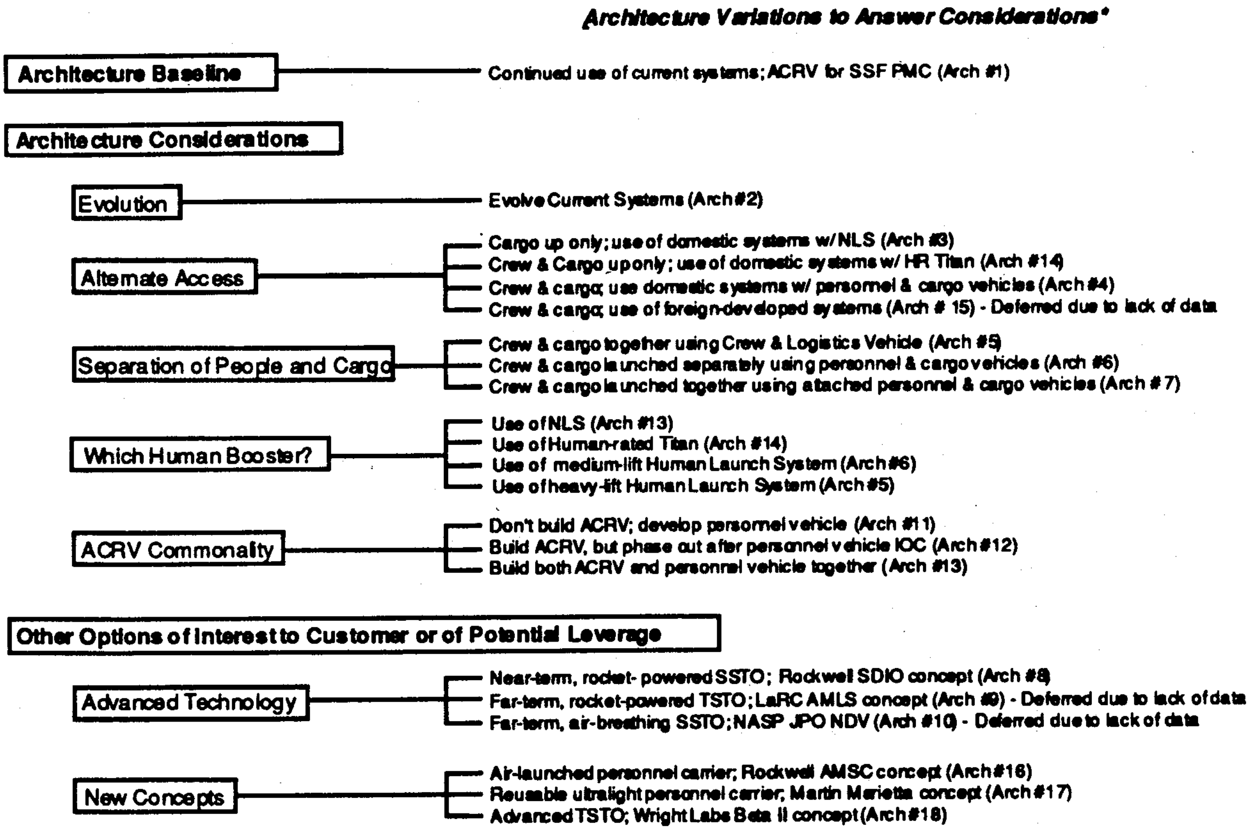


Figure 5.3.1-2.– Architecture summary.

In addition, other analyses, beyond the evaluation of the above considerations, were conducted. For example, to assess the impact of return cargo requirements, we selected a group of architectures and modified the needs model 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 Shuttle system phase-out dates by comparing architectures with early and late Shuttle phase-outs. One should use caution, however, in trying to get absolute answers from these architectures (e.g., how many more 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. We have however, gone into sufficient accuracy and depth to meet the objectives of the HTS study.

## 5.3.2 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. We identified a list of roughly 25 elements which could be incorporated into the architectures. Many of these elements were selected not only on their ability to fill a capability or function gap in some architecture set but also to incorporate concepts which are well known and are having resources devoted to study them. For example, we felt 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, we were largely able to incorporate most of the concepts we felt were of principal interest to the customer.

Table 5.3.2-1 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 the final report.

TABLE 5.3.2-1.– 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 | 15 | 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 | | |

# PART III

# ARCHITECTURE SCORES AND ATTRIBUTE DATA

## 5.4 ARCHITECTURE RESULTS

The following tables and figures summarize both final architecture attribute values, as well as the relative scores, of the set of 18 architectures. An architecture's score is determined by rolling-up the respective attribute values for each architecture using utility curves and the study team consensus of the attribute weightings. These weightings were determined by considering what the customer would feel were most important. If the customer has different weightings or desires to understand the sensitivity of the answer to different weightings, the raw data can be used to generate new architecture scores. The study team weighted the six study attributes as follows:

| | |
|---|---|
| Human Safety | 29% |
| Funding Profile | 27% |
| Probability of Mission Success | 19% |
| Architecture Cost Risk | 13% |
| Launch Schedule Confidence | 8% |
| Environmental Impact | 4% |

Detailed architectural examinations of these architectures, as well the considerations (e.g., alternate access), can be found in the final report.

There are two sets of data presented in Tables 5.4-1 through 5.4-12 and Figures 5.4-1 through 5.4-12: the first is the baseline set of values. This summarizes 15 of the 18 study architectures; three architectures could not be completely assessed due to incomplete data. The second set resulted from corrections and modifications made primarily to the Human Safety and PMS attributes, plus an additional nineteenth architecture added near the end of the study. Note that the values don't change significantly, although the modified set has, in general, lower crew losses and unreliability costs. None of the conclusions are changed as a result of these modifications.

# TABLE 5.4-1.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO A (MINIMUM LEVEL OF ACTIVITY)

| Arch | Major Elements | Total Flights (1) |  | Funding Profile (in millions,'92) |  | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Crew | No Crew | Total | Peak Yr |  |  |  |  |  |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 76 | 569 | $151,440 | $6,388 | 0.9354 | 1.7 | 1.000 | 0.561 | 1,433,252 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 76 | 569 | $171,494 | $9,480 | 0.9364 | 1.5 | 0.841 | 0.572 | 1,265,102 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 76 | 559 | $168,979 | $11,075 | 0.9438 | 1.7 | 0.743 | 0.216 | 927,776 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 76 | 559 | $168,979 | $11,075 | 0.9438 | 1.7 | 0.743 | 0.216 | 927,776 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 76 | 559 | $142,288 | $10,879 | 0.948 | 1.0 | 0.691 | 0.381 | 597,649 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 76 | 611 | $149,204 | $12,940 | 0.9485 | 0.8 | 0.609 | 0.257 | 594,706 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 76 | 559 | $138,375 | $12,197 | 0.948 | 1.0 | 0.629 | 0.336 | 597,649 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 76 | 569 | $94,248 | $7,947 | 0.9442 | 0.9 | 0.581 | 0.622 | 1,066,800 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $168,693 | $11,075 | 0.9436 | 1.7 | 0.826 | 0.312 | 950,718 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $168,693 | $11,075 | 0.9436 | 1.7 | 0.826 | 0.312 | 950,718 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $168,693 | $11,075 | 0.9436 | 1.7 | 0.826 | 0.312 | 950,718 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 76 | 569 | $151,440 | $6,388 | 0.9354 | 1.7 | 1.000 | 0.561 | 1,433,252 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 82 | 569 | $117,670 | $9,326 | 0.9364 | 1.3 | 0.864 | 0.865 | 1,217,385 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 91 | 605 | $115,921 | $7,233 | 0.9325 | 1.2 | 0.691 | 0.685 | 1,384,266 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 177 | 468 | $164,759 | $12,786 | 0.941 | 2.4 | 0.150 | 0.334 | 1,243,214 |

Notes:(1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

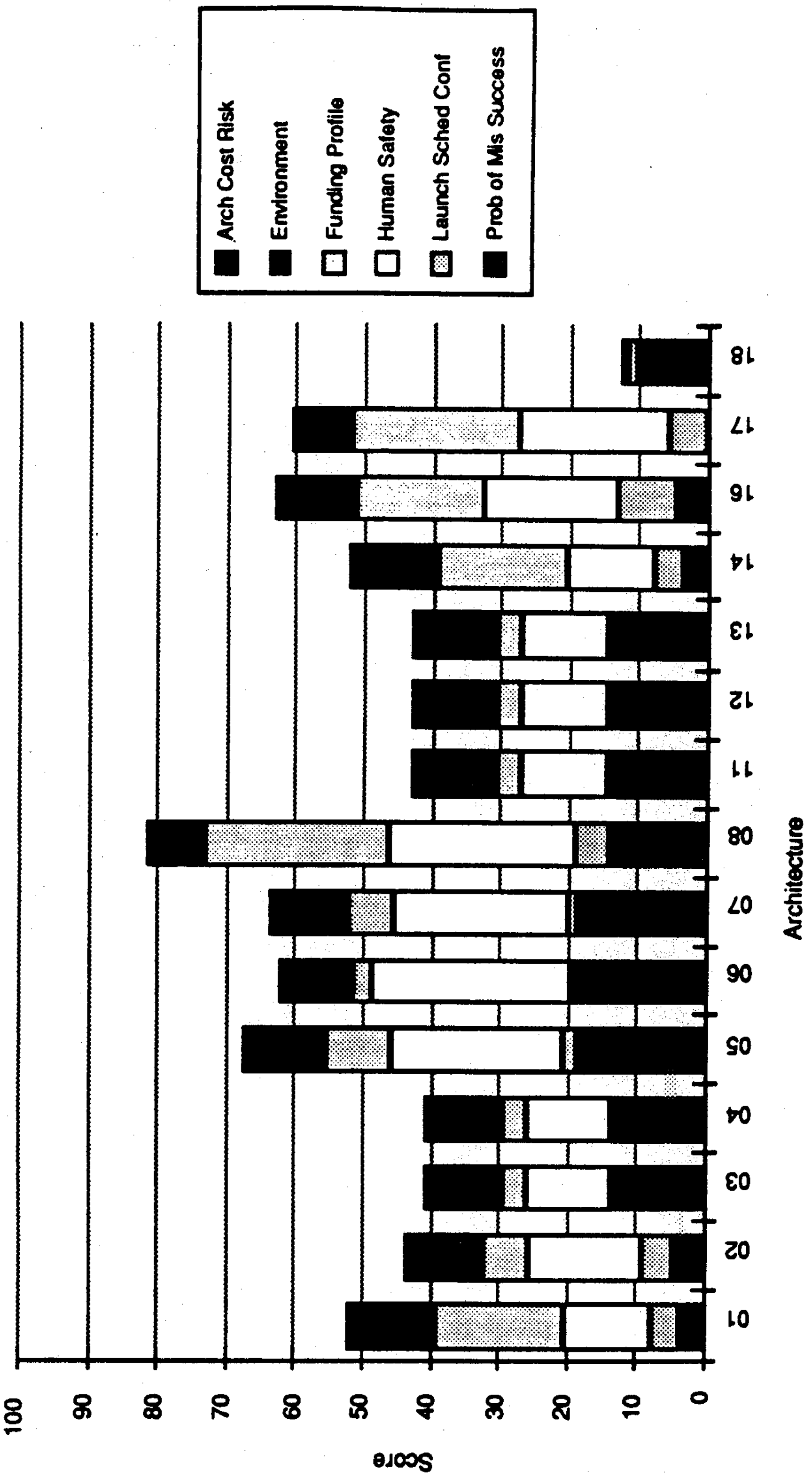


Figure 5.4-1.– HTS architecture scores - "If" scenario A (baseline).

# TABLE 5.4-2.- HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO B (CURRENT MISSIONS WITHOUT SSF)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (In millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 148 | 569 | $156,459 | $6,649 | 0.9362 | 3.3 | 1.000 | 0.498 | 1,866,922 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 140 | 569 | $174,990 | $9,620 | 0.9365 | 2.8 | 0.846 | 0.526 | 1,544,102 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 148 | 559 | $174,000 | $11,192 | 0.9437 | 3.3 | 0.763 | 0.246 | 1,361,446 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 148 | 559 | $174,000 | $11,192 | 0.9437 | 3.3 | 0.763 | 0.246 | 1,361,446 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 202 | 559 | $165,145 | $11,023 | 0.9484 | 2.5 | 0.678 | 0.343 | 853,083 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 165 | 661 | $179,660 | $13,076 | 0.9489 | 1.9 | 0.599 | 0.233 | 846,479 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 245 | 559 | $179,510 | $12,515 | 0.9488 | 2.8 | 0.594 | 0.183 | 854,476 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 257 | 576 | $104,010 | $8,193 | 0.9482 | 2.8 | 0.578 | 0.39 | 1,337,062 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $173,714 | $11,192 | 0.9435 | 3.3 | 0.839 | 0.3 | 1,384,388 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $173,714 | $11,192 | 0.9435 | 3.3 | 0.839 | 0.3 | 1,384,388 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $173,714 | $11,192 | 0.9435 | 3.3 | 0.839 | 0.3 | 1,384,388 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 148 | 569 | $156,461 | $6,638 | 0.9362 | 3.3 | 1.000 | 0.498 | 1,866,922 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 374 | 569 | $133,564 | $9,402 | 0.9423 | 4.4 | 0.812 | 0.482 | 1,518,137 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 224 | 700 | $137,715 | $7,952 | 0.9321 | 2.9 | 0.660 | 0.669 | 1,979,947 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 287 | 470 | $170,378 | $12,812 | 0.9434 | 3.9 | 0.150 | 0.173 | 1,512,155 |

Notes:(1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

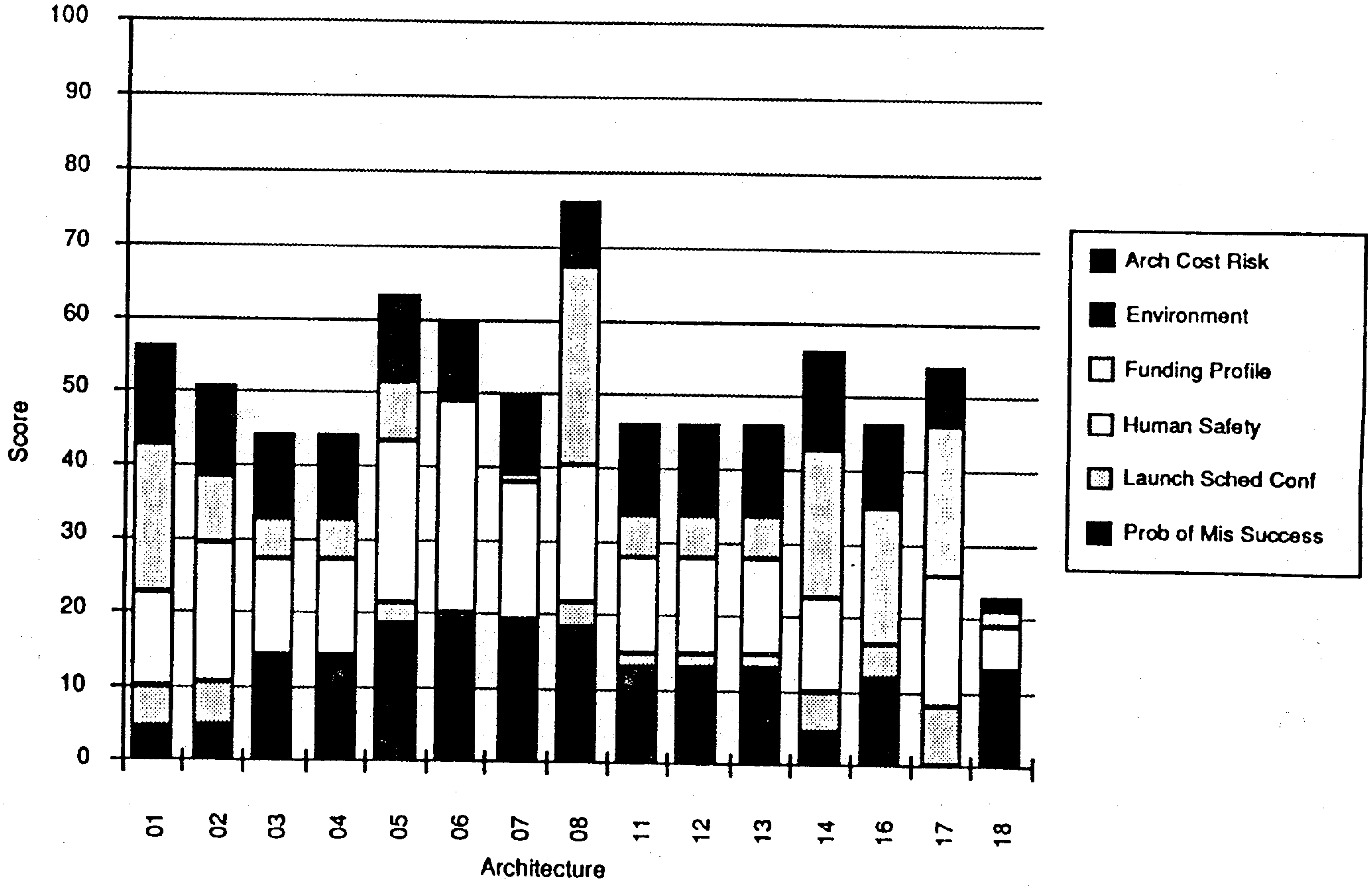


Figure 5.4-2.- HTS architecture scores - "II" scenario B (baseline).

# TABLE 5.4-3.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO C (CURRENT MISSIONS PLUS SSF PMC)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 300 | 569 | $177,404 | $7,303 | 0.9374 | 6.7 | 1.000 | 0.355 | 2,782,450 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 244 | 652 | $209,653 | $11,485 | 0.9354 | 4.8 | 0.878 | 0.331 | 2,067,017 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 287 | 638 | $206,111 | $12,115 | 0.9437 | 6.4 | 0.768 | 0.268 | 2,215,156 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 260 | 771 | $271,433 | $15,918 | 0.9429 | 4.3 | 0.603 | 0.302 | 2,413,326 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 324 | 648 | $221,241 | $12,884 | 0.9492 | 3.9 | 0.707 | 0.243 | 1,134,554 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 288 | 789 | $234,206 | $14,393 | 0.9498 | 3.3 | 0.702 | 0.196 | 1,117,133 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 354 | 686 | $249,083 | $14,146 | 0.9496 | 4.2 | 0.643 | 0.121 | 1,134,315 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 374 | 927 | $130,959 | $8,959 | 0.9521 | 4.2 | 0.513 | 0.468 | 1,847,511 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 363 | 638 | $239,061 | $14,315 | 0.9442 | 6.6 | 0.791 | 0.294 | 2,229,404 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 346 | 638 | $234,397 | $12,125 | 0.9441 | 6.6 | 0.751 | 0.306 | 2,234,602 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 370 | 638 | $244,613 | $14,429 | 0.9442 | 6.8 | 0.744 | 0.302 | 2,271,571 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 364 | 647 | $233,987 | $9,842 | 0.9347 | 7.2 | 0.845 | 0.43 | 3,055,613 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 495 | 862 | $196,869 | $11,072 | 0.9391 | 6.1 | 0.726 | 0.663 | 2,833,665 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 348 | 1,052 | $204,202 | $10,818 | 0.9304 | 4.6 | 0.710 | 0.671 | 3,438,581 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 550 | 558 | $216,203 | $14,034 | 0.9458 | 7.5 | 0.088 | 0.204 | 2,299,257 |

Notes:(1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

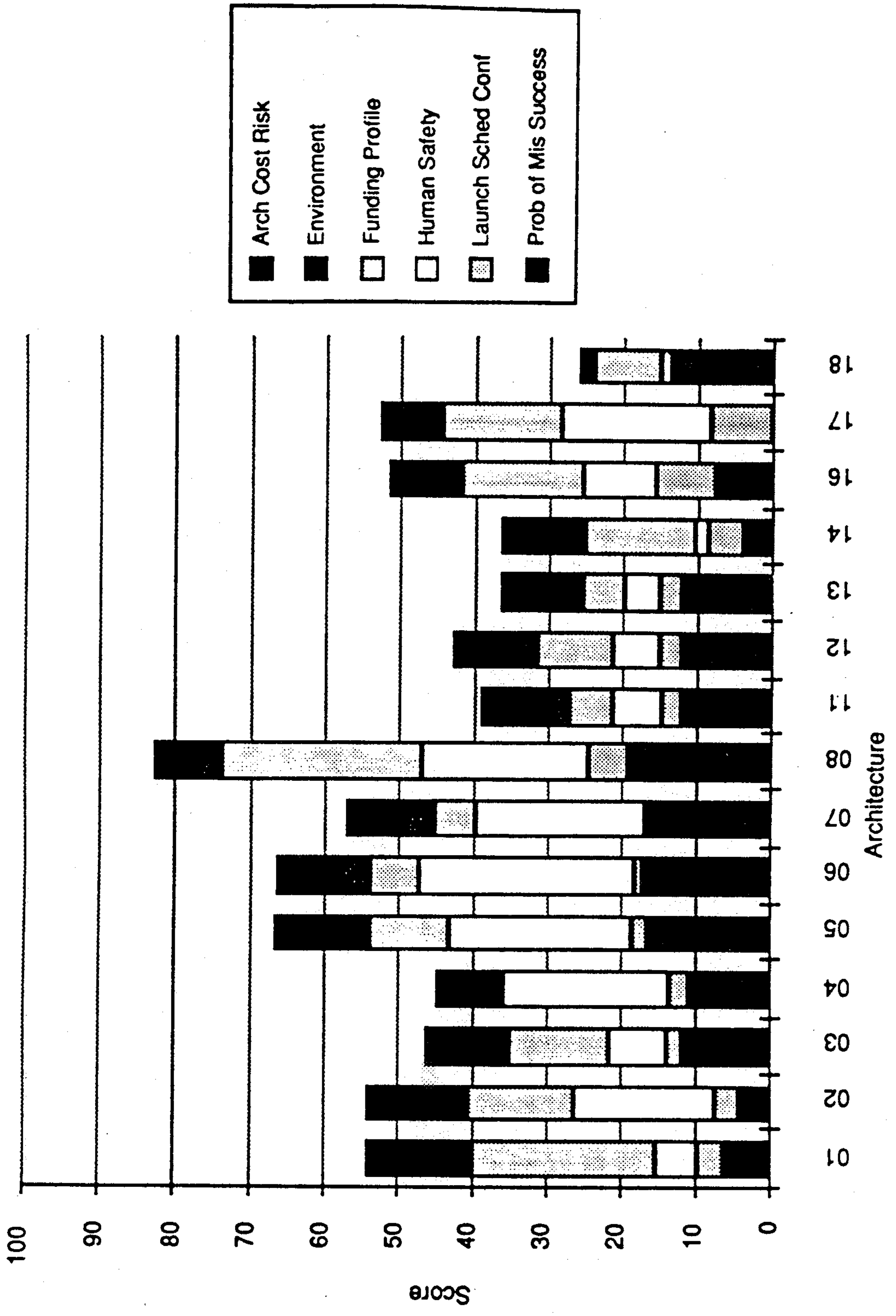


Figure 5.4-3.– HTS architecture scores - "If" scenario C (baseline).

# TABLE 5.4-4.- HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO D (CURRENT MISSIONS PLUS EXPANDED SSF)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions '92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 338 | 569 | $183,876 | $7,583 | 0.9376 | 7.6 | 1.000 | 0.36 | 3,011,335 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 248 | 666 | $212,741 | $11,618 | 0.9354 | 4.9 | 0.882 | 0.356 | 2,120,227 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 311 | 642 | $212,372 | $12,575 | 0.9437 | 7.0 | 0.772 | 0.294 | 2,384,532 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 277 | 791 | $276,905 | $16,057 | 0.9427 | 4.7 | 0.610 | 0.331 | 2,636,791 |
| 5 | Seperation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 364 | 673 | $237,832 | $12,901 | 0.9494 | 4.3 | 0.707 | 0.251 | 1,204,063 |
| 6 | Seperation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 268 | 849 | $248,069 | $14,611 | 0.95 | 3.3 | 0.702 | 0.212 | 1,121,400 |
| 7 | Seperation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 354 | 748 | $259,900 | $14,369 | 0.9498 | 4.2 | 0.644 | 0.158 | 1,144,771 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 382 | 1,023 | $137,588 | $9,107 | 0.9532 | 4.3 | 0.527 | 0.481 | 1,904,825 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 387 | 641 | $245,043 | $14,766 | 0.9441 | 7.2 | 0.797 | 0.317 | 2,395,912 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 372 | 642 | $240,552 | $12,581 | 0.944 | 7.2 | 0.755 | 0.327 | 2,416,023 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 392 | 642 | $248,850 | $14,880 | 0.9441 | 7.3 | 0.750 | 0.324 | 2,426,198 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 399 | 647 | $238,531 | $10,006 | 0.935 | 7.9 | 0.848 | 0.44 | 3,261,992 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 510 | 929 | $209,002 | $11,190 | 0.9385 | 6.5 | 0.732 | 0.707 | 3,147,357 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 354 | 1,133 | $214,216 | $11,259 | 0.9301 | 4.7 | 0.716 | 0.681 | 3,744,732 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 654 | 561 | $227,835 | $15,020 | 0.9473 | 8.7 | 0.088 | 0.2 | 2,413,720 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

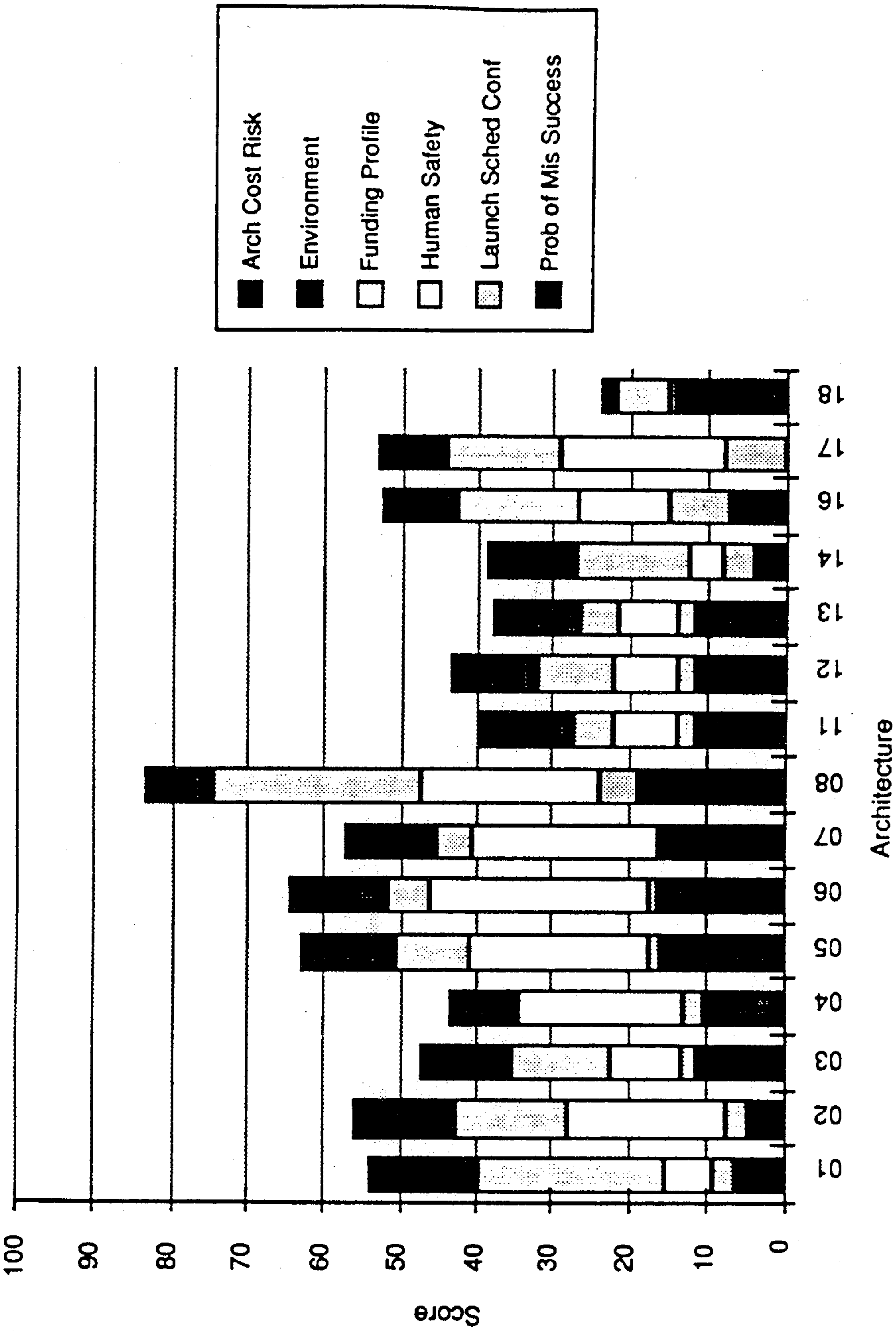


Figure 5.4-4.– HTS architecture scores - "If" scenario D (baseline).

# TABLE 5.4-5.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO E LOW (CURRENT MISSIONS PLUS EXPANDED SSF AND LOW LEVEL SEI)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 357 | 569 | $185,281 | $7,583 | 0.9378 | 8.0 | 1.000 | 0.35 | 3,125,773 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 267 | 666 | $214,445 | $11,618 | 0.9353 | 5.3 | 0.882 | 0.351 | 2,159,732 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 330 | 642 | $215,514 | $12,575 | 0.9437 | 7.4 | 0.776 | 0.296 | 2,498,969 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 296 | 791 | $281,176 | $16,055 | 0.9429 | 4.8 | 0.613 | 0.341 | 2,639,994 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 383 | 673 | $241,749 | $12,901 | 0.9495 | 4.5 | 0.710 | 0.264 | 1,207,266 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 307 | 849 | $252,981 | $14,611 | 0.9501 | 3.4 | 0.705 | 0.224 | 1,124,605 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 373 | 748 | $264,130 | $14,369 | 0.9499 | 4.3 | 0.648 | 0.17 | 1,147,976 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 401 | 1,023 | $137,650 | $9,107 | 0.9535 | 4.5 | 0.539 | 0.447 | 1,906,633 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 406 | 641 | $249,029 | $14,766 | 0.9443 | 7.3 | 0.797 | 0.325 | 2,399,115 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 391 | 642 | $244,660 | $12,581 | 0.9442 | 7.3 | 0.756 | 0.34 | 2,430,932 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 411 | 642 | $252,837 | $14,880 | 0.9443 | 7.4 | 0.750 | 0.337 | 2,429,401 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 418 | 647 | $243,210 | $10,006 | 0.9347 | 8.1 | 0.848 | 0.441 | 3,292,215 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 529 | 929 | $209,975 | $11,199 | 0.9387 | 6.7 | 0.737 | 0.629 | 3,159,797 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 373 | 1,133 | $215,336 | $11,296 | 0.9302 | 4.9 | 0.720 | 0.677 | 3,754,761 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 673 | 561 | $228,370 | $15,052 | 0.9475 | 8.9 | 0.111 | 0.19 | 2,436,229 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

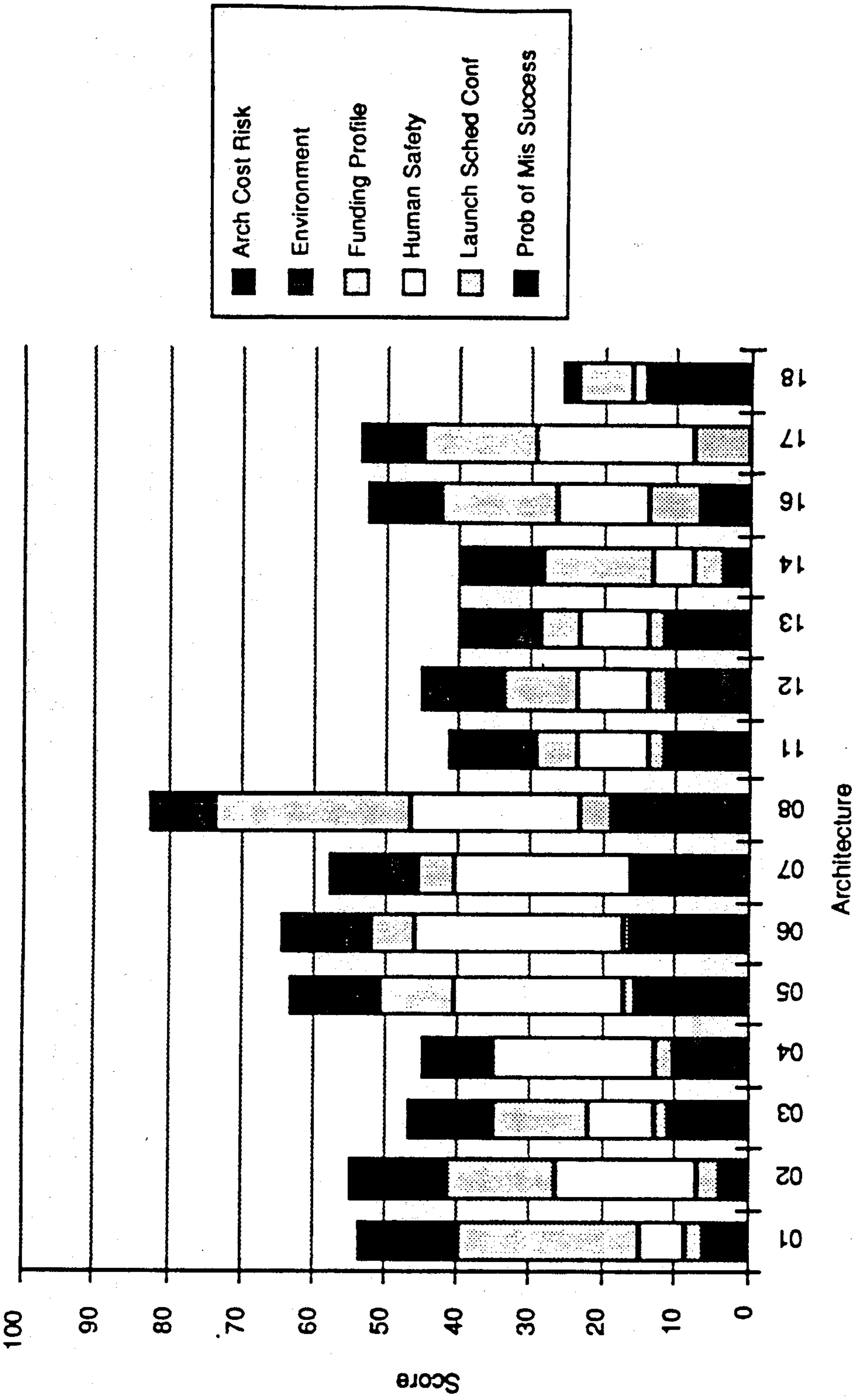


Figure 5.4-5.– HTS architecture scores - "If" scenario E-Low (baseline).

# TABLE 5.4-6.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - BASELINE
# "IF" SCENARIO E HIGH (CURRENT MISSIONS PLUS EXPANDED SSF AND HIGH LEVEL SEI)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions '92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 389 | 569 | $192,109 | $8,153 | 0.9379 | 8.7 | 0.999 | 0.319 | 3,318,514 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 299 | 666 | $219,147 | $11,618 | 0.935 | 5.8 | 0.882 | 0.316 | 2,226,268 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 362 | 642 | $219,794 | $12,575 | 0.9436 | 8.1 | 0.776 | 0.259 | 2,691,712 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 328 | 791 | $287,407 | $16,055 | 0.9432 | 5.0 | 0.609 | 0.338 | 2,645,392 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 415 | 673 | $248,639 | $12,901 | 0.9497 | 4.7 | 0.703 | 0.246 | 1,212,664 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 339 | 849 | $260,351 | $14,611 | 0.9502 | 3.5 | 0.701 | 0.216 | 1,130,001 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 405 | 748 | $272,028 | $14,369 | 0.95 | 4.5 | 0.644 | 0.171 | 1,153,372 |
| 8 | Advanced Technology<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 433 | 1,023 | $137,754 | $9,107 | 0.9538 | 4.7 | 0.537 | 0.443 | 1,909,677 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 438 | 641 | $256,261 | $14,766 | 0.9446 | 7.5 | 0.792 | 0.312 | 2,404,513 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 423 | 642 | $251,494 | $12,581 | 0.9445 | 7.6 | 0.751 | 0.332 | 2,442,189 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 443 | 642 | $259,465 | $14,880 | 0.9446 | 7.6 | 0.745 | 0.336 | 2,434,799 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 450 | 647 | $251,638 | $10,169 | 0.9342 | 8.4 | 0.844 | 0.431 | 3,343,116 |
| 16 | New Concept - Air Launch<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 561 | 929 | $210,362 | $11,199 | 0.9391 | 6.9 | 0.735 | 0.692 | 3,166,539 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 405 | 1,133 | $217,250 | $11,296 | 0.9302 | 5.2 | 0.717 | 0.675 | 3,771,642 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 705 | 561 | $231,806 | $15,588 | 0.9479 | 9.2 | 0.088 | 0.172 | 2,461,331 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

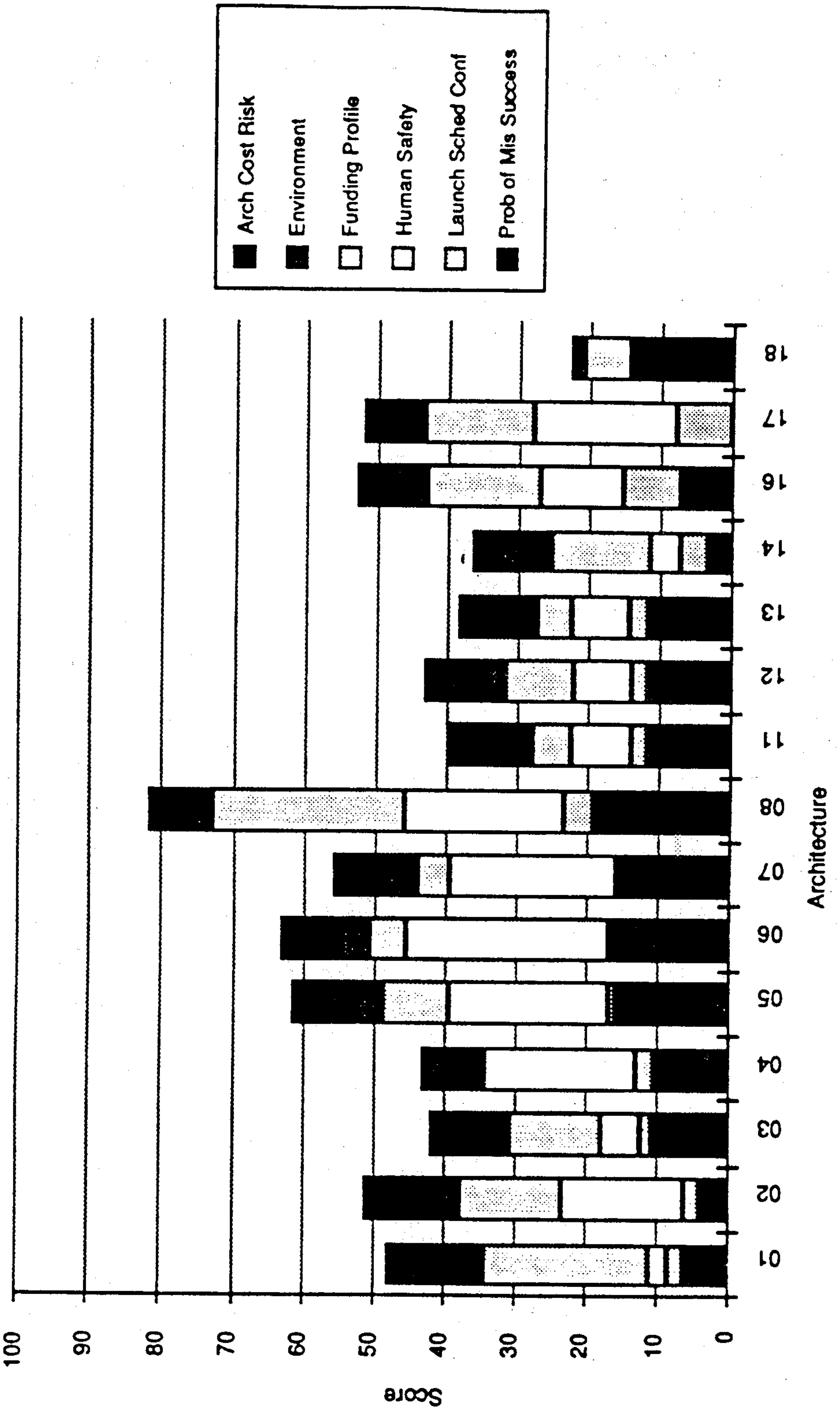


Figure 5.4-6.– HTS architecture scores - "If" scenario E-High (baseline).

# TABLE 5.4-7.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - UPDATED
# "IF" SCENARIO A (MINIMUM LEVEL OF ACTIVITY)

| Arch | Major Elements | Total Flights (1) |  | Funding Profile (in millions,'92) |  | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Crew | No Crew | Total | Peak Yr |  |  |  |  |  |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 76 | 569 | $149,681 | $8,388 | 0.9389 | 1.2 | 1.000 | 0.490 | 1,433,252 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 76 | 569 | $169,717 | $9,480 | 0.9399 | 1.3 | 0.853 | 0.479 | 1,265,102 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 76 | 559 | $167,142 | $11,075 | 0.9501 | 1.2 | 0.758 | 0.214 | 927,776 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 76 | 559 | $167,252 | $11,075 | 0.9501 | 1.2 | 0.758 | 0.214 | 927,776 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 76 | 559 | $142,033 | $10,879 | 0.9515 | 0.7 | 0.720 | 0.371 | 597,649 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 76 | 611 | $148,725 | $12,940 | 0.9523 | 0.6 | 0.636 | 0.253 | 594,706 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 76 | 559 | $137,902 | $12,197 | 0.9515 | 0.7 | 0.651 | 0.331 | 597,649 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 76 | 569 | $93,604 | $7,947 | 0.9476 | 0.6 | 0.665 | 0.370 | 1,066,800 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 168 | 466 | $141,355 | $10,522 | 0.9432 | 1.9 | 0.229 | 0.867 | 1,303,863 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $166,966 | $11,075 | 0.9491 | 1.2 | 0.839 | 0.281 | 950,718 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $166,966 | $11,075 | 0.9491 | 1.2 | 0.839 | 0.281 | 950,718 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 76 | 559 | $166,966 | $11,075 | 0.9491 | 1.2 | 0.839 | 0.281 | 950,718 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 76 | 569 | $149,790 | $8,388 | 0.9389 | 1.2 | 1.000 | 0.491 | 1,433,252 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 82 | 569 | $117,768 | $9,326 | 0.9395 | 0.9 | 0.884 | 0.562 | 1,217,385 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 91 | 605 | $115,537 | $7,233 | 0.9365 | 0.9 | 0.705 | 0.629 | 1,384,266 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 177 | 468 | $164,834 | $12,786 | 0.9428 | 1.5 | 0.334 | 0.148 | 1,243,214 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 76 | 622 | $120,838 | $7,654 | 0.9403 | 0.8 | 0.566 | 0.433 | 992,475 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

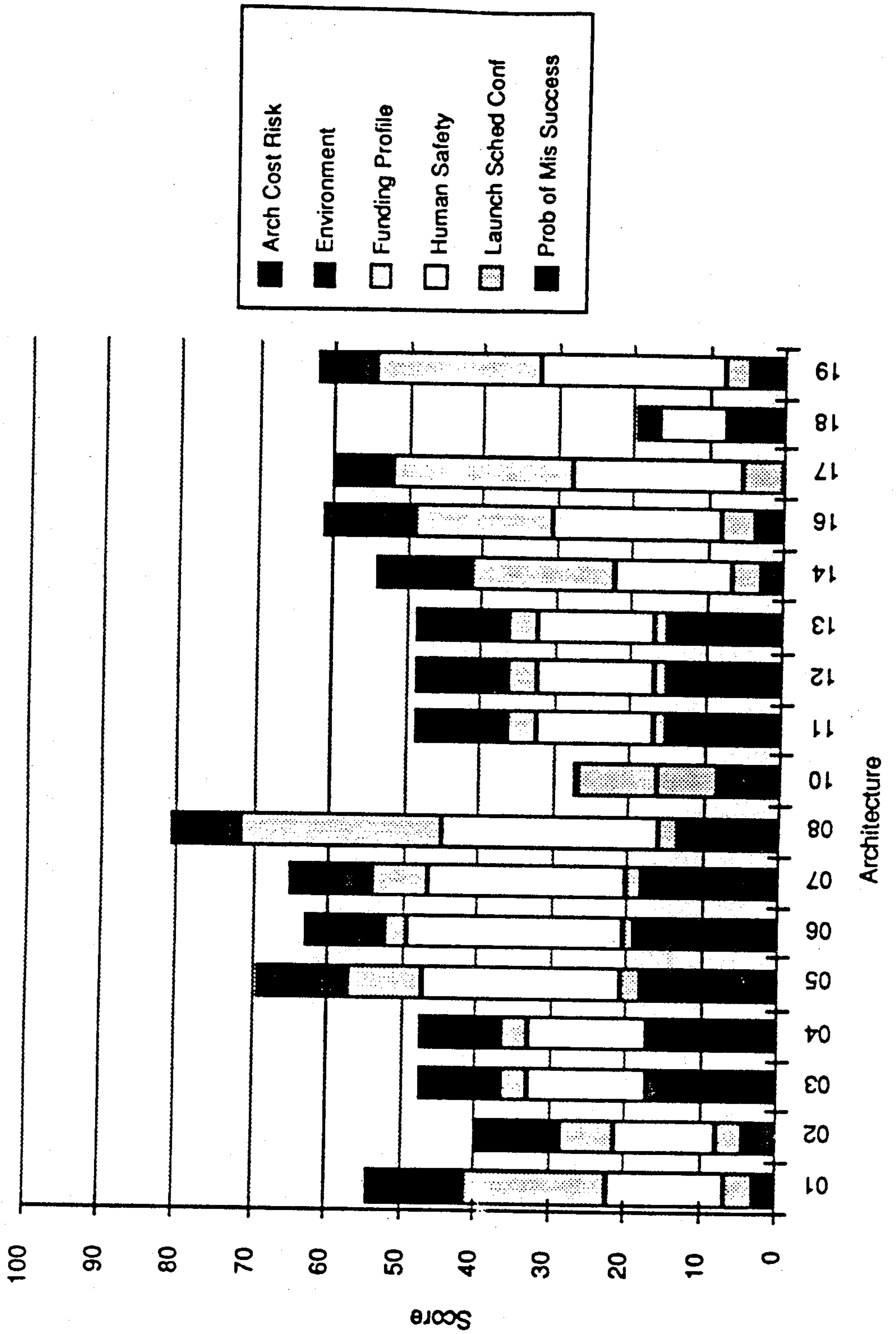


Figure 5.4-7.– HTS architecture scores - "If" scenario A (updated).

# TABLE 5.4-8.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - UPDATED
# "IF" SCENARIO B (CURRENT MISSIONS WITHOUT SSF)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 148 | 569 | $154,231 | $6,649 | 0.9424 | 2.3 | 1.000 | 0.447 | 1,866,922 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 140 | 569 | $174,710 | $9,620 | 0.9423 | 2.3 | 0.858 | 0.472 | 1,544,102 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 148 | 559 | $171,694 | $11,192 | 0.9524 | 2.3 | 0.776 | 0.239 | 1,361,446 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 148 | 559 | $171,915 | $11,192 | 0.9524 | 2.3 | 0.776 | 0.239 | 1,361,446 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 202 | 559 | $164,774 | $11,023 | 0.9538 | 1.7 | 0.710 | 0.329 | 853,083 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CTV) | 165 | 661 | $179,088 | $13,076 | 0.9544 | 1.4 | 0.632 | 0.232 | 846,479 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 245 | 559 | $178,861 | $12,515 | 0.9542 | 1.9 | 0.626 | 0.187 | 854,476 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 257 | 576 | $103,362 | $8,193 | 0.9536 | 1.8 | 0.659 | 0.343 | 1,337,062 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 262 | 474 | $151,119 | $10,591 | 0.9465 | 3.1 | 0.250 | 0.878 | 1,634,355 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $171,629 | $11,192 | 0.9515 | 2.3 | 0.852 | 0.279 | 1,384,388 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $171,629 | $11,192 | 0.9515 | 2.3 | 0.852 | 0.280 | 1,384,388 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 148 | 559 | $171,629 | $11,192 | 0.9515 | 2.3 | 0.852 | 0.279 | 1,384,388 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 148 | 569 | $154,452 | $6,638 | 0.9424 | 2.3 | 1.000 | 0.447 | 1,866,922 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 374 | 569 | $133,002 | $9,402 | 0.9509 | 3.4 | 0.832 | 0.334 | 1,518,137 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 224 | 700 | $137,063 | $7,952 | 0.9394 | 2.2 | 0.676 | 0.615 | 1,979,947 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 291 | 470 | $170,394 | $12,812 | 0.9465 | 2.5 | 0.330 | 0.124 | 1,536,244 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 202 | 710 | $153,122 | $9,279 | 0.9418 | 2.1 | 0.602 | 0.444 | 1,517,538 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

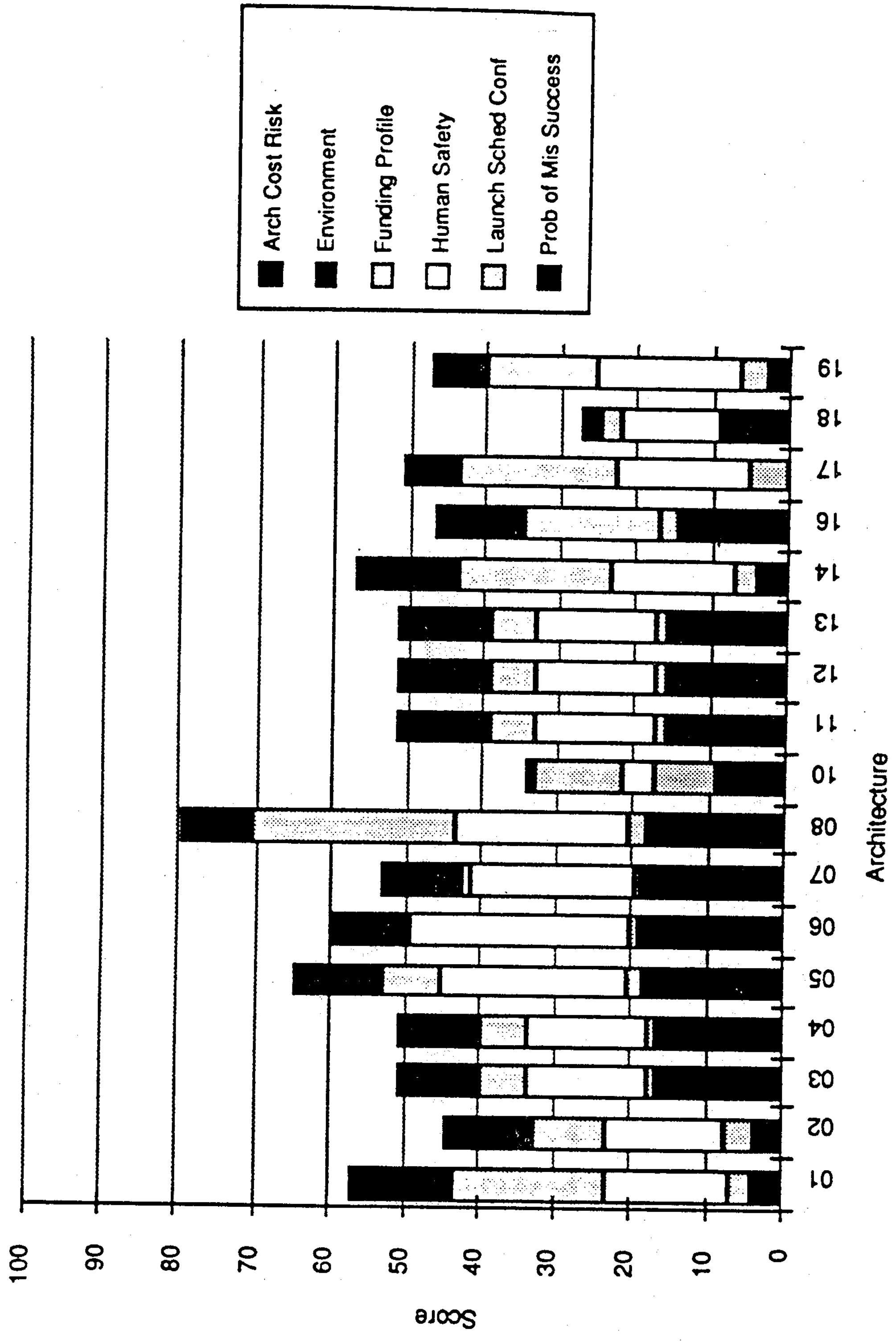


Figure 5.4-8.– HTS architecture scores - "If" scenario B (updated).

# TABLE 5.4-9.– HTS STUDY DATA
# ARCHITECTURE ATTRIBUTE VALUES - UPDATED
# "IF" SCENARIO C (CURRENT MISSIONS PLUS SSF PMC)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (in millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 300 | 569 | $173,035 | $7,303 | 0.9477 | 4.7 | 1.000 | 0.295 | 2,782,450 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 244 | 652 | $207,086 | $11,485 | 0.9462 | 4.0 | 0.890 | 0.265 | 2,067,017 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 287 | 638 | $203,410 | $12,115 | 0.9559 | 4.5 | 0.783 | 0.241 | 2,215,156 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 260 | 774 | $267,159 | $15,918 | 0.9571 | 3.0 | 0.635 | 0.276 | 2,413,831 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 324 | 648 | $218,926 | $12,884 | 0.9560 | 2.8 | 0.744 | 0.225 | 1,134,554 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 288 | 789 | $233,383 | $14,393 | 0.9565 | 2.3 | 0.739 | 0.186 | 1,117,133 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 354 | 686 | $246,523 | $14,146 | 0.9564 | 2.9 | 0.681 | 0.113 | 1,134,315 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 374 | 927 | $129,645 | $8,959 | 0.9589 | 2.7 | 0.584 | 0.367 | 1,847,511 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 442 | 558 | $186,768 | $11,629 | 0.9493 | 5.2 | 0.203 | 0.875 | 2,471,009 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 363 | 638 | $236,669 | $14,315 | 0.9552 | 4.6 | 0.814 | 0.266 | 2,229,404 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 346 | 638 | $231,935 | $12,125 | 0.9553 | 4.6 | 0.772 | 0.274 | 2,234,602 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 370 | 638 | $240,521 | $14,429 | 0.9554 | 4.7 | 0.768 | 0.271 | 2,271,571 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 364 | 647 | $231,146 | $9,842 | 0.9455 | 5.0 | 0.855 | 0.372 | 3,055,613 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 495 | 862 | $196,585 | $11,072 | 0.9487 | 4.6 | 0.747 | 0.436 | 2,833,665 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 348 | 1,052 | $201,570 | $10,818 | 0.9392 | 3.4 | 0.727 | 0.612 | 3,438,581 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 550 | 558 | $216,062 | $14,034 | 0.9501 | 4.7 | 0.251 | 0.123 | 2,299,257 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 315 | 1,093 | $216,022 | $11,884 | 0.9413 | 3.4 | 0.685 | 0.485 | 2,717,314 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

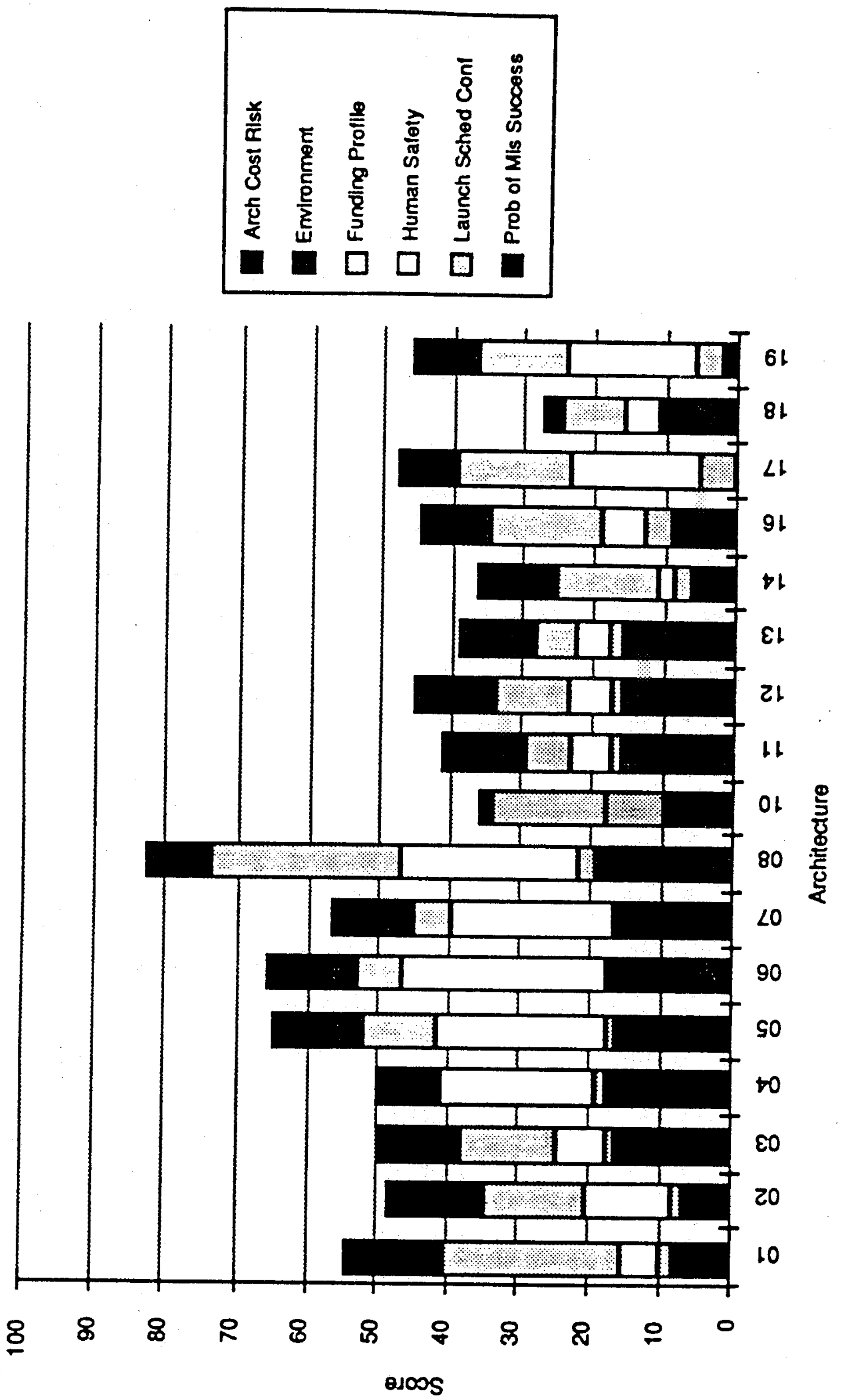


Figure 5.4-9.– HTS architecture scores - "If" scenario C (updated).

## TABLE 5.4-10.- HTS STUDY DATA
## ARCHITECTURE ATTRIBUTE VALUES - UPDATED
## "IF" SCENARIO D (CURRENT MISSIONS PLUS EXPANDED SSF)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (In millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 338 | 569 | $179,347 | $7,583 | 0.9488 | 5.2 | 1.000 | 0.298 | 3,011,335 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 248 | 666 | $208,641 | $11,618 | 0.9465 | 4.1 | 0.892 | 0.286 | 2,120,227 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 311 | 642 | $207,548 | $12,575 | 0.9563 | 4.8 | 0.786 | 0.263 | 2,384,532 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 277 | 795 | $274,235 | $16,057 | 0.9576 | 3.3 | 0.639 | 0.297 | 2,637,465 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 364 | 673 | $235,438 | $12,901 | 0.9565 | 3.1 | 0.742 | 0.230 | 1,204,063 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 288 | 849 | $247,005 | $14,611 | 0.9568 | 2.3 | 0.737 | 0.202 | 1,121,400 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 354 | 748 | $257,270 | $14,369 | 0.9567 | 2.9 | 0.680 | 0.144 | 1,144,771 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 382 | 1,023 | $134,657 | $9,107 | 0.9602 | 2.8 | 0.591 | 0.358 | 1,904,825 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 539 | 559 | $191,445 | $11,712 | 0.9510 | 6.4 | 0.196 | 0.870 | 2,684,402 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 387 | 641 | $240,904 | $14,766 | 0.9555 | 5.0 | 0.817 | 0.286 | 2,395,912 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 372 | 642 | $236,282 | $12,581 | 0.9657 | 5.0 | 0.775 | 0.292 | 2,416,023 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 392 | 642 | $244,651 | $14,880 | 0.9556 | 5.1 | 0.771 | 0.290 | 2,426,198 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 399 | 647 | $233,889 | $10,006 | 0.9464 | 5.6 | 0.856 | 0.374 | 3,261,992 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 510 | 929 | $206,752 | $11,190 | 0.9481 | 4.9 | 0.751 | 0.452 | 3,147,357 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 354 | 1,133 | $211,549 | $11,259 | 0.9389 | 3.5 | 0.731 | 0.609 | 3,744,732 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 663 | 561 | $225,976 | $15,020 | 0.9516 | 5.6 | 0.241 | 0.104 | 2,467,924 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 319 | 1,197 | $233,843 | $12,313 | 0.9407 | 3.4 | 0.701 | 0.508 | 3,079,507 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.
(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.
(3) Human Safety - represents crew loss events per thousand flights.
(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)
(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).
(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

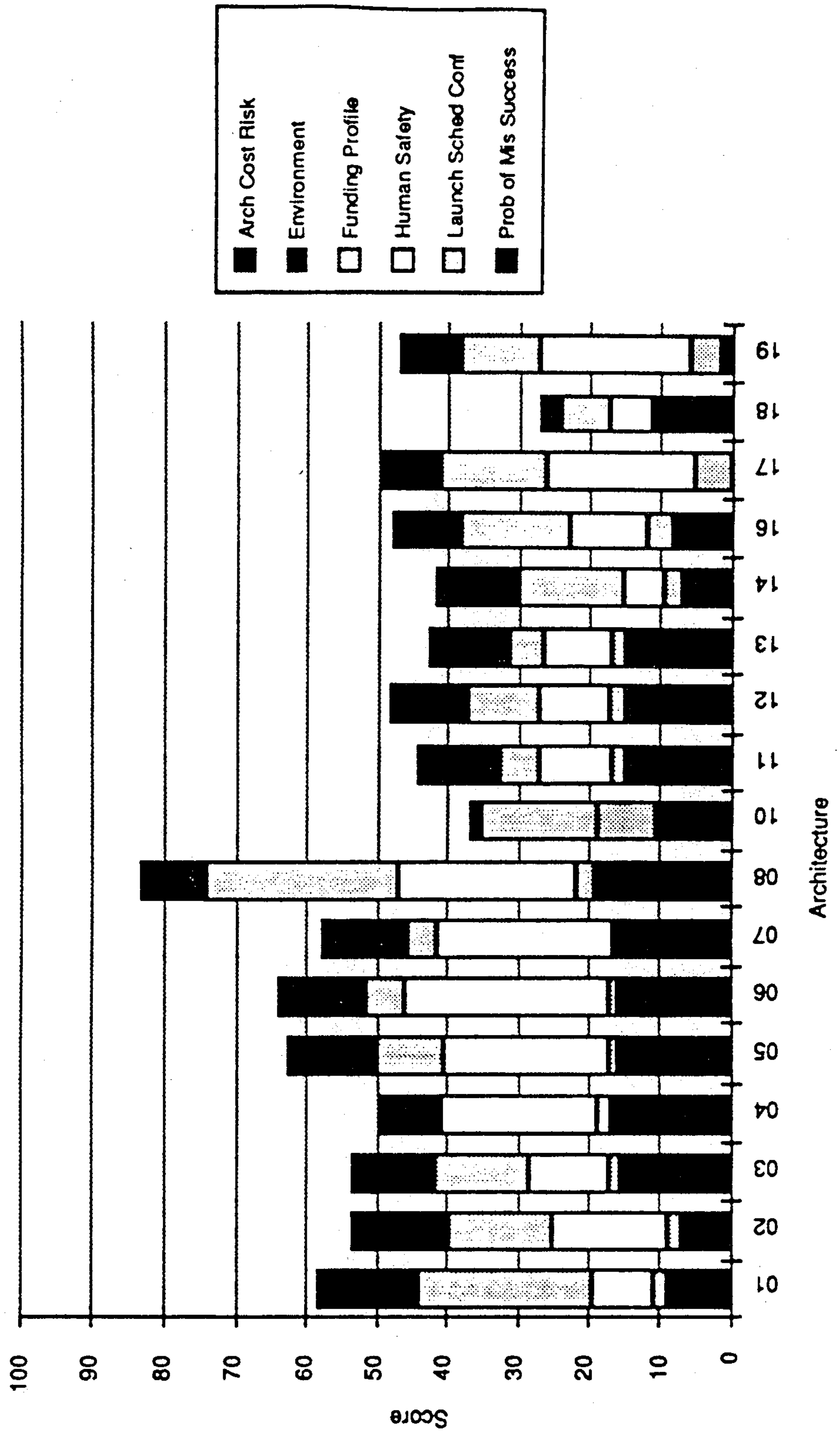


Figure 5.4-10.– HTS architecture scores - "If" scenario D (updated).

# TABLE 5.4-11.- HTS STUDY DATA ARCHITECTURE ATTRIBUTE VALUES - UPDATED "IF" SCENARIO E LOW (CURRENT MISSIONS PLUS EXPANDED SSF AND LOW LEVEL SEI)

| Arch | Major Elements | Total Flights (1) |  | Funding Profile (in millions,'92) |  | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Crew | No Crew | Total | Peak Yr |  |  |  |  |  |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 357 | 569 | $180,764 | $7,583 | 0.9493 | 5.5 | 1.000 | 0.286 | 3,125,773 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 267 | 666 | $210,261 | $11,618 | 0.9468 | 4.4 | 0.892 | 0.282 | 2,159,732 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 330 | 642 | $210,595 | $12,575 | 0.9566 | 5.1 | 0.788 | 0.262 | 2,498,969 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 296 | 795 | $278,439 | $16,055 | 0.9577 | 3.4 | 0.640 | 0.304 | 2,640,668 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 383 | 673 | $239,357 | $12,901 | 0.9566 | 3.2 | 0.742 | 0.238 | 1,207,266 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 307 | 849 | $251,828 | $14,611 | 0.9569 | 2.4 | 0.738 | 0.210 | 1,124,605 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 373 | 748 | $261,503 | $14,369 | 0.9567 | 3.0 | 0.682 | 0.153 | 1,147,976 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 401 | 1,023 | $134,719 | $9,107 | 0.9604 | 2.9 | 0.597 | 0.361 | 1,906,633 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 558 | 559 | $194,054 | $11,712 | 0.9513 | 6.6 | 0.204 | 0.853 | 2,727,819 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 406 | 641 | $244,820 | $14,766 | 0.9557 | 5.1 | 0.816 | 0.291 | 2,399,115 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 391 | 642 | $240,399 | $12,581 | 0.9558 | 5.1 | 0.774 | 0.301 | 2,430,932 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 411 | 642 | $248,568 | $14,880 | 0.9557 | 5.2 | 0.770 | 0.298 | 2,429,401 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 418 | 647 | $238,358 | $10,006 | 0.9463 | 5.8 | 0.855 | 0.377 | 3,292,215 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 529 | 929 | $207,093 | $11,199 | 0.9485 | 5.0 | 0.754 | 0.443 | 3,159,797 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 373 | 1,133 | $212,679 | $11,296 | 0.9391 | 3.7 | 0.734 | 0.608 | 3,754,761 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 682 | 561 | $226,489 | $15,052 | 0.9518 | 5.7 | 0.251 | 0.112 | 2,490,434 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 338 | 1,197 | $237,080 | $12,199 | 0.9408 | 3.5 | 0.706 | 0.505 | 3,000,217 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

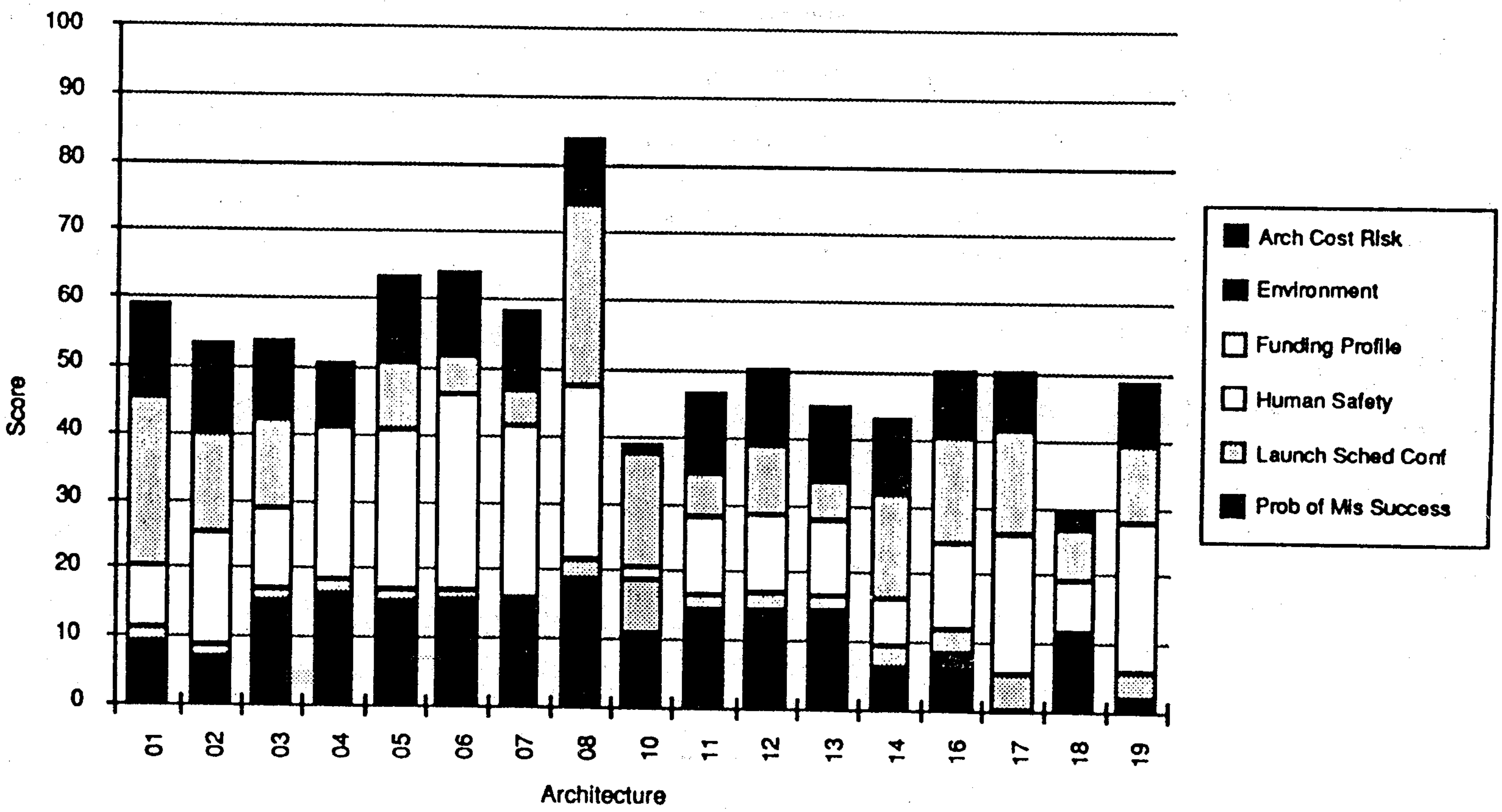


Figure 5.4-11.- HTS architecture scores - "If" scenario E Low (updated).

## TABLE 5.4-12.- HTS STUDY DATA
## ARCHITECTURE ATTRIBUTE VALUES - UPDATED
## "IF" SCENARIO E HIGH (CURRENT MISSIONS PLUS EXPANDED SSF AND HIGH LEVEL SEI)

| Arch | Major Elements | Total Flights (1) | | Funding Profile (In millions,'92) | | PMS (2) | HS (3) | ACR (4) | LSC (5) | ENV (6) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crew | No Crew | Total | Peak Yr | | | | | |
| 1 | Reference<br>(Shuttle, DAT, ACRV) | 389 | 569 | $187,368 | $8,153 | 0.9501 | 6.0 | 1.000 | 0.256 | 3,318,514 |
| 2 | Evolution of Current Systems<br>(Shuttle, DAT, ACRV, Shuttle Evolution) | 299 | 666 | $214,914 | $11,618 | 0.9472 | 5.0 | 0.891 | 0.249 | 2,226,268 |
| 3 | Alternate Access - Cargo only<br>(Shuttle, DAT, ACRV, NLS, CTV) | 362 | 642 | $214,821 | $12,575 | 0.9571 | 5.6 | 0.788 | 0.226 | 2,691,712 |
| 4 | Alternate Access - Crew & cargo<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV, CRV) | 328 | 795 | $284,676 | $16,055 | 0.9578 | 3.5 | 0.637 | 0.308 | 2,646,066 |
| 5 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, CLV, MLS, CRV) | 415 | 673 | $246,271 | $12,901 | 0.9567 | 3.4 | 0.738 | 0.222 | 1,212,664 |
| 6 | Separation of People & Cargo/Human Booster<br>(Shuttle, DAT, PLS, MLS, CRV) | 339 | 849 | $259,200 | $14,611 | 0.9570 | 2.5 | 0.735 | 0.203 | 1,130,001 |
| 7 | Separation of People & Cargo<br>(Shuttle, DAT, PLS, MLS, CRV, LRV) | 405 | 748 | $269,413 | $14,3[illegible]9 | 0.9569 | 3.1 | 0.679 | 0.156 | 1,153,372 |
| 8 | Advanced Technology - SSTO<br>(Shuttle, DAT, ACRV, SSTO, CTF) | 433 | 1,023 | $134,823 | $9,107 | 0.9607 | 3.0 | 0.595 | 0.357 | 1,909,677 |
| 10 | Advanced Technology - NDV<br>(Shuttle, DAT, ACRV, NDV, CTF) | 590 | 559 | $195,349 | $11,712 | 0.9518 | 6.9 | 0.193 | 0.861 | 2,783,987 |
| 11 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 438 | 641 | $251,997 | $14,768 | 0.9558 | 5.2 | 0.812 | 0.280 | 2,404,513 |
| 12 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 423 | 642 | $247,166 | $12,581 | 0.9560 | 5.2 | 0.770 | 0.295 | 2,442,189 |
| 13 | ACRV Commonality<br>(Shuttle, DAT, ACRV, PLS, NLS, CTV) | 443 | 642 | $255,132 | $14,880 | 0.9559 | 5.3 | 0.768 | 0.299 | 2,434,799 |
| 14 | Human Booster<br>(Shuttle, DAT, ACRV, PLS, MR Titan, CTF) | 450 | 647 | $246,790 | $10,169 | 0.9462 | 6.0 | 0.852 | 0.370 | 3,343,116 |
| 16 | New Concept - Air Launch (AMSC)<br>(Shuttle, DAT, ACRV, AMSC, CTF, LRV) | 561 | 929 | $207,482 | $11,199 | 0.9491 | 5.2 | 0.752 | 0.460 | 3,166,539 |
| 17 | New Concept - Titan Evolution<br>(Shuttle, DAT, ACRV, RUPC, CTF, LRV) | 405 | 1,133 | $214,561 | $11,296 | 0.9394 | 3.9 | 0.732 | 0.607 | 3,771,642 |
| 18 | New Concept - Beta II<br>(Shuttle, DAT, ACRV, Beta II, CTF) | 714 | 561 | $229,974 | $15,588 | 0.9521 | 5.9 | 0.232 | 0.100 | 2,515,543 |
| 19 | New Concept - Air Launch (ALV)<br>(Shuttle, DAT, ACRV, ALV, CTF, LRV) | 370 | 1,197 | $239,498 | $12,317 | 0.9411 | 3.8 | 0.703 | 0.498 | 3,081,246 |

Notes: (1) Total flights includes east coast and west coast launches. DOD flights are included.

(2) Probability of Mission Success - flight weighted composite of the probability of mission success for all systems in the architecture.

(3) Human Safety - represents crew loss events per thousand flights.

(4) Architecture Cost Risk - linear measure of risk incurred in acquiring all systems in the architecture ( 1.0 = lowest risk, 0.0 = highest risk)

(5) Launch Schedule Confidence - linear measure of ability of all systems in the architecture to meet launch schedules (1.0 = lowest risk, 0.0 = highest risk).

(6) Environment - a composite of pounds of effluents multiplied by environment impact factors. Lower numbers indicate a smaller environmental impact.

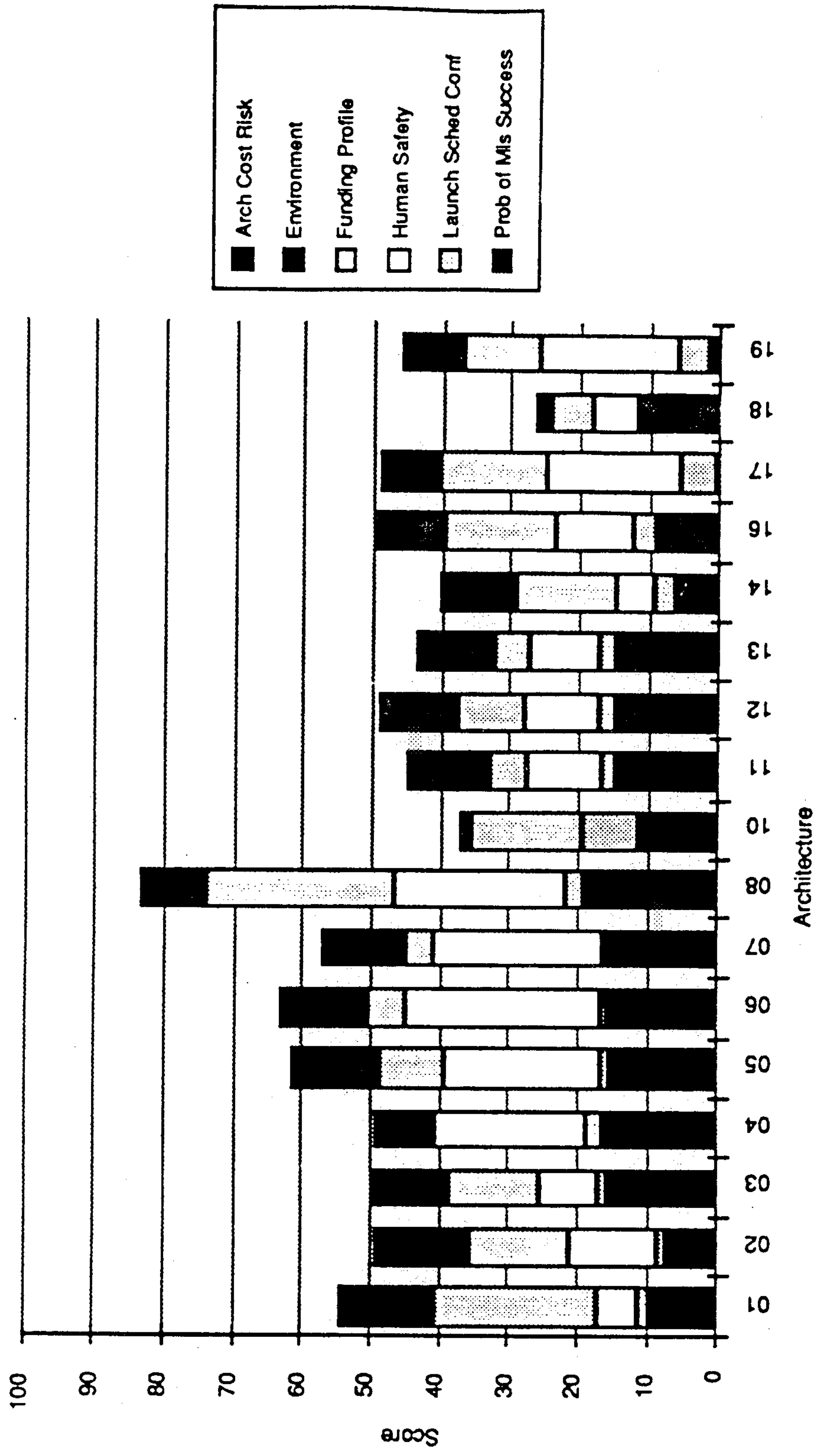


Figure 5.4-12.– HTS architecture scores - "If" scenario E High (updated).

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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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