Space Propulsion Synergy Team

Architectural Assessment Tool

A tool for evaluating architectural concepts to determine relative operational gains & limitations

Opening up space for everyone

December 1997

Abstract

This document describes the purpose of architectural assessments for advanced space transportation concepts, the methods utilized by the Space Propulsion Synergy Team (SPST) to conduct the assessments, how to use the assessments, as well as descriptions of the ranking and scoring methodology. It also contains a blank Architectural Assessment Form in the back of the document—the basis of gathering information from the concept developer for assessing the concept for 1) operational effectiveness, 2) the programmatics of maturing the needed technologies for the concept, and 3) the maturity of the concept for commercial acquisition commitment.

Further Information

For further information regarding the Architectural Assessment Tool, contact:

Carey M. McCleskey
NASA John F. Kennedy Space Center
Mail Code: PK-E
Kennedy Space Center, FL 32899
Ph: (407) 861-3775
Fax: (407) 861-0103
email: Carey.McCleskey-1@ksc.nasa.gov

or

Russel E. Rhodes
NASA John F. Kennedy Space Center
Mail Code: PK-G
Kennedy Space Center, FL 32899
Ph: (407) 861-3874
Fax: (407) 861-3036
email: Russel.Rhodes-1@ksc.nasa.gov

Additionally, the Space Propulsion Synergy Team wishes to acknowledge the following members for their unique contribution to the creation of the Architectural Assessment Tool:

- *Walt Dankhoff/AIAA and SPST Executive Secretary*
- *John C. Mankins/HRST Study Manager/NASA Headquarters (Code MP)*
- *Mike Nix/NASA MSFC PS03*
- *Edgar Zapata/NASA KSC/PK-G4*
- *Daniel J. H. Levack/Boeing-Rocketdyne*
- *Dr. John Olds/Georgia Tech School of Aerospace Engineering*
- *William Escher/Kaiser Marquardt*
- *Ray Byrd/Boeing*
- *Kevin Ingoldsby/Lockheed Martin*

Introduction

Purpose

The Architectural Assessment Tool (AAT) is a space transportation concept evaluation tool that can be used during the early conceptual phase in an environment where accurate operations models of reusable launch systems are not readily available. More than that, however, the AAT was created to bring “architectural” visibility to vehicle concept provider(s) in a user-friendly, interactive process that can optimize a concepts evaluation score.

As space transportation evolves toward a vision of commercially viable space travel—that one day may even encompass public space travel—several challenges now arise. How does one understand the potential flight rate, or vehicle utilization, of a given space transportation concept? Can some measure be made of the dependability of the proposed flight and ground systems, relative to our current experience, that would be required for something like public space travel? Challenges also arise in foreseeing the operational infrastructure needed to sustain a concept. In other words, how does one obtain visibility into the operational design aspects in relation to commercial viability criteria and long-term technology investment? Databases are practically non-existent at this early evolutionary stage to construct operations models that can derive accurate flight rates and infrastructure estimates (labor, facilities, etc.). The Space Propulsion Synergy Team (SPST), in supporting NASA’s Highly Reusable Space Transportation (HRST) Study, needed a method, nonetheless, for evaluating proposed architectural concepts that would determine the operational gains and limitations. The Architectural Assessment Tool (AAT) was created to overcome this lack of needed information for operational benefit, as well as to provide some programmatic insight prior to commitment beyond the early concept phase.

Architectural Concepts vs. Vehicle Concepts

Architectural concepts are here distinguished from *vehicle concepts*. Architectural concepts include the vehicle design as well as the proposed supporting infrastructure (the spaceport and its facilities, the logistics tail, the manufacturing infrastructure, etc.). In addition to the infrastructure itself, a launch vehicle placed in such an architecture interacts with the ground systems to establish such things as vehicle utilization (vehicle flight rates), process flows, hardware component repair rates, etc., and are therefore highly sensitive to the design of the vehicle.

The AAT was carefully constructed to be anchored and traceable to the *Design Guide’s* design features and programmatic factors and was approved with SPST’s input and consensus. The team placed four criteria on the design of the tool:

1. User-friendly to the concept designer (multiple choice)
2. Use of criteria that can be *quantified* and *scored*
3. Anchored to other SPST products/processes, e.g., *Design Guide* which were derived by consensus with government/industry/academia representatives
4. Traceable to the HRST CAN’s Technical Requirements of space transportation affordability (**$100-200 per pound to orbit cost**). *Ref. HRST CAN § 3.1, p. 22*:
    - Primary Functional Objectives (§ 3.1.1, p. 22)
    - Desirable System Attributes (§ 3.1.2, p. 23)
    - Programmatic Boundary Conditions (§ 3.1.3, p. 26)

Background

Affordability

The tool assesses the “operations” of proposed concepts within the broader view of the total life cycle of investments required to bring about affordable, highly reusable space transportation. The desirable attributes of a system concept’s architecture (i.e., vehicle concept, ground support infrastructure, and operations concept) during all the programmatic phases (i.e., technology R&D, system acquisition, and operations) is captured under the overall term of *affordability*.

Many programmatic factors surface during the process of developing a commercially viable HRST concept—and then a set system attributes emerge when bringing the whole system into affordable, highly productive operation. The factors present during the development phase set of attributes are characterized by the non-recurring investments required in technology maturation, system development, and testing (both flight and ground). This phase includes investments in propulsion component testing, engine element testing, avionics and systems tests, prototype vehicles (X and Y vehicles), as well as any necessary ground system technology maturation, development and testing. The operational set of attributes relate to the recurring, or “fielded” system attributes—which tend to dominate the return-on-investment of a long-term operational reusable space transportation system. Pursuing true affordability will require a movement from access-to-space performance optimization towards a new emphasis in the space transportation architectural design process—*solid attention to the attributes of operational effectiveness*. The AAT relates the concept to these phases and attributes.

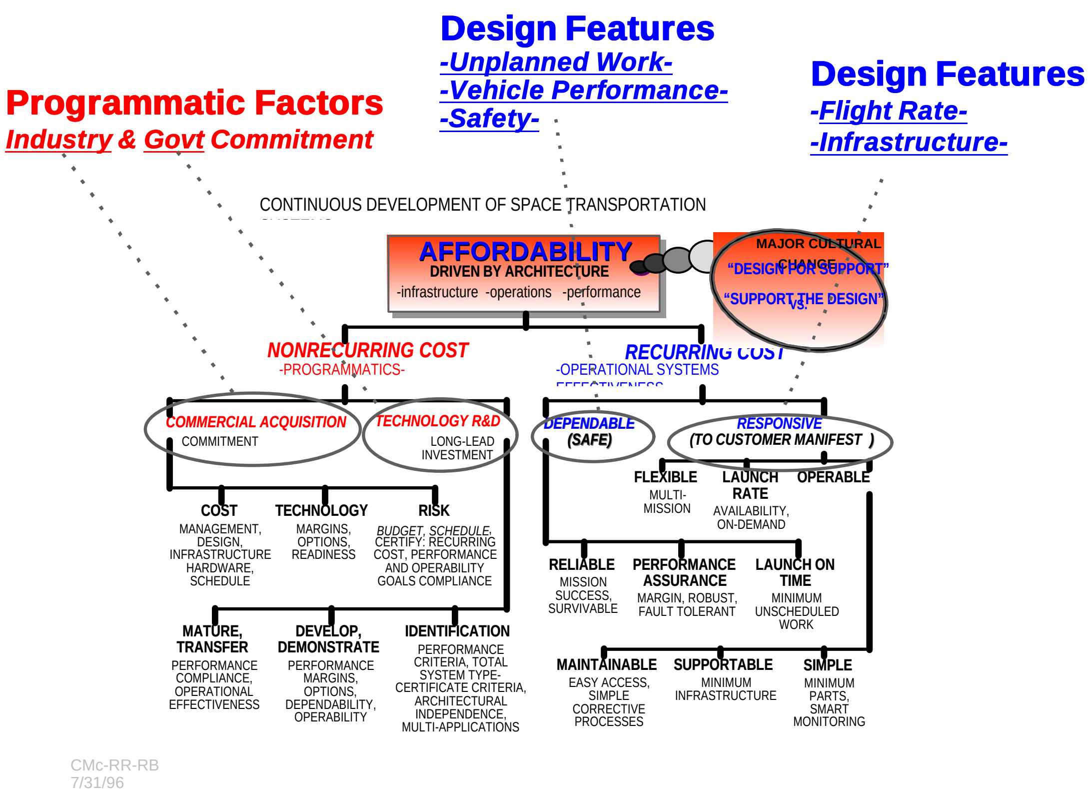

Fig. 1—Affordability Factors & Attributes Across the Programmatic Phases (Acquisition, R&T and Operations)

How the Architectural Assessment Tool Works

The **Architectural Assessment Tool** includes:

- An Architectural Assessment Form for concept designers to provide information necessary to perform a first-order assessment and derives an overall score in three assessment areas:

  1. **Operational Effectiveness** (Recurring Benefit)
  2. **Technology R&D** (Research and Development Programmatics)
  3. **Program Acquisition** (Non-Recurring Programmatics)

- An electronic spreadsheet (Excel 7.0) that applies scores and weightings

The concept provider interacts with the tool through a series of assessment questions that are in a multiple-choice format for user-friendliness. The boxes receive a score value from one to ten (1-10). Each of the above three assessment areas receives an overall score, with the total of the three having a possible maximum value of one hundred (100). The maximum value items relating to the top box score in each question were designed to stretch the concepts towards the two orders of magnitude increase over currently operated systems as defined in the HRST Study guidelines. Specific values for the scoring and weightings given to each assessment question are in the document. A blank *Input Form* is also provided.

Evaluation Tied to SPST's Design Guide

The relative weight assigned each major design area (eighteen in all) correlates with the highest ranking Design Guide *design feature* referenced. In cases where more than one design feature is referenced, they are of the same family and are very supportive to the highest ranking design feature. All top twenty design features are referenced in the eighteen major design areas except one, which is really a resultant feature, and not a direct driver of design (this is *the "hours for turnaround between launches"*) The relative weight of these design features have a range of 291 to 597 and represent the top fifty percent (50%) relative weight in the Design Guide. The concept scores are mathematically normalized so that they can be evaluated against a default concept, in this case, the Access To Space (ATS) Option 3 All Rocket SSTO (bi-propellant) concept or the Space Shuttle Transportation System (STS).

> Reference: **A Guide for the Design of Highly Reusable Space Transportation**. Space Propulsion Synergy Team, Aug. 29, 1997. Specifically, the pareto charts "*Prioritized Measurable Criteria*", Top 20 and Middle 22 Design Features, pages 19 and 20.

The results are given to show "order of magnitude" increase from current experience (Shuttle). Also, the Access-to-Space Option 3 (All-Rocket/Single-Stage-to-Orbit) concept is scored and shown in the results, to show the relative gains.

Note: To go from the 1-100 score to the 10-10,000 score, the tool applies the following:

Order of Magnitude Score *= (Basic Score)**4/100,000*

Results

The AAT results are graphically presented in two forms, pareto charts (see Figure 2) displaying the relative concept rankings, and “quad” charts (see Figures 3 & 4) that place the concepts in regions of benefit versus programmatic factors. Examples are shown with the STS and ATS “anchor points” and with example concepts marked as ‘A’, ‘B’, ‘C’, etc.

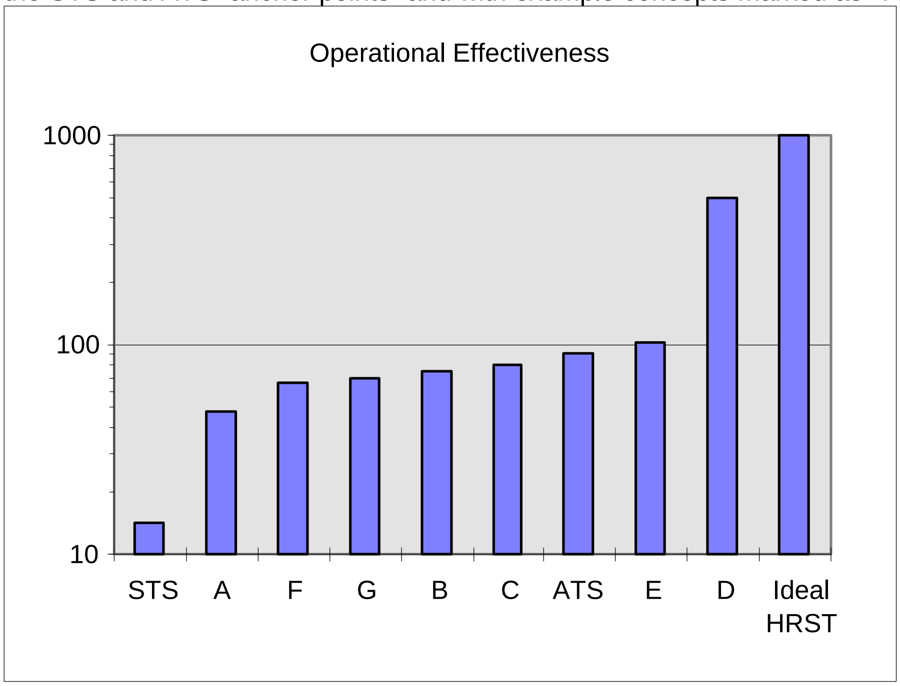

Figure 2—Example AAT Concept Ranking Pareto

	OPERATIONAL EFFECTIVENESS Benefit Score from 10 from 1000	COMMERCIAL ACQUISITION Programmatic Score from 1 to 100	TECHNOLOGY R&D Programmatic Score from 1 to 100
STS	***-- 14 --***	***-- 36 --***	***-- N/A --***
ATS All-Rocket SSTO	***-- 60 --***	***-- 32 --***	***-- 46 --***
Concept A	. . . .	. . . .	. . . .
Concept B . .	. . .	. . .	. . .

Table 1—Example Scoring Results of the Architectural Assessment Tool

There are two different quad charts generated from the Architectural Assessment Tool. The first relates the benefit (operational effectiveness) to the programmatics of commercial acquisition of an HRST system. The second quad chart displays the concepts in regions of benefit vs. the programmatic factors that arise during the technology research and development phase prior to the system acquisition investment commitment.

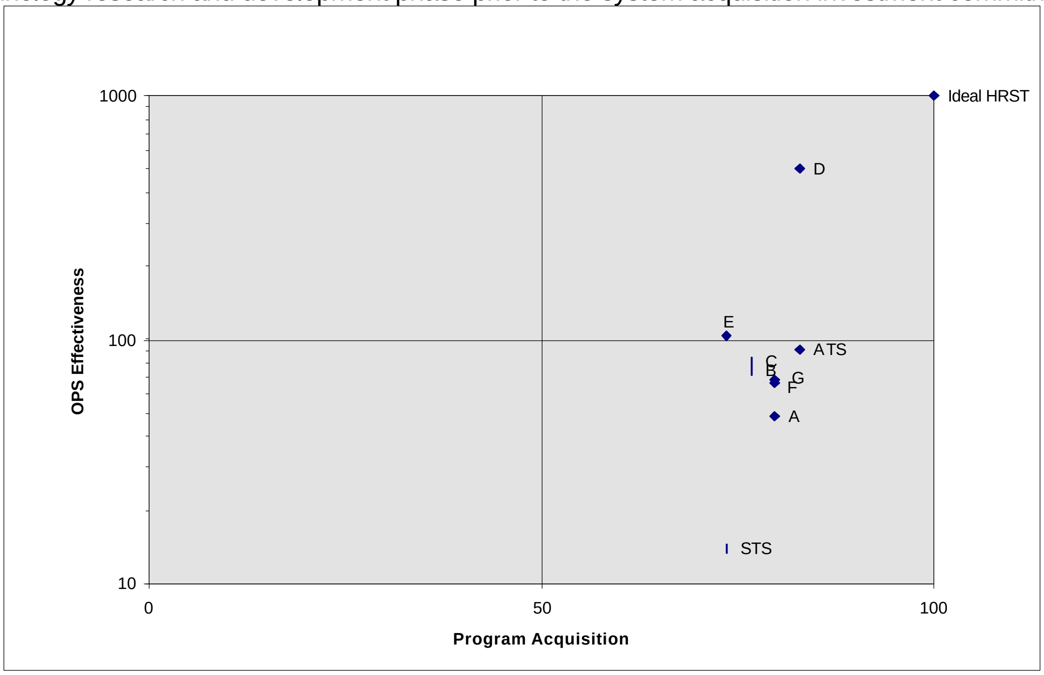

Figure 3—Example "Quad Chart" showing relative Operational Effectiveness vs. Non-Recurring Investment Commitment among various concepts

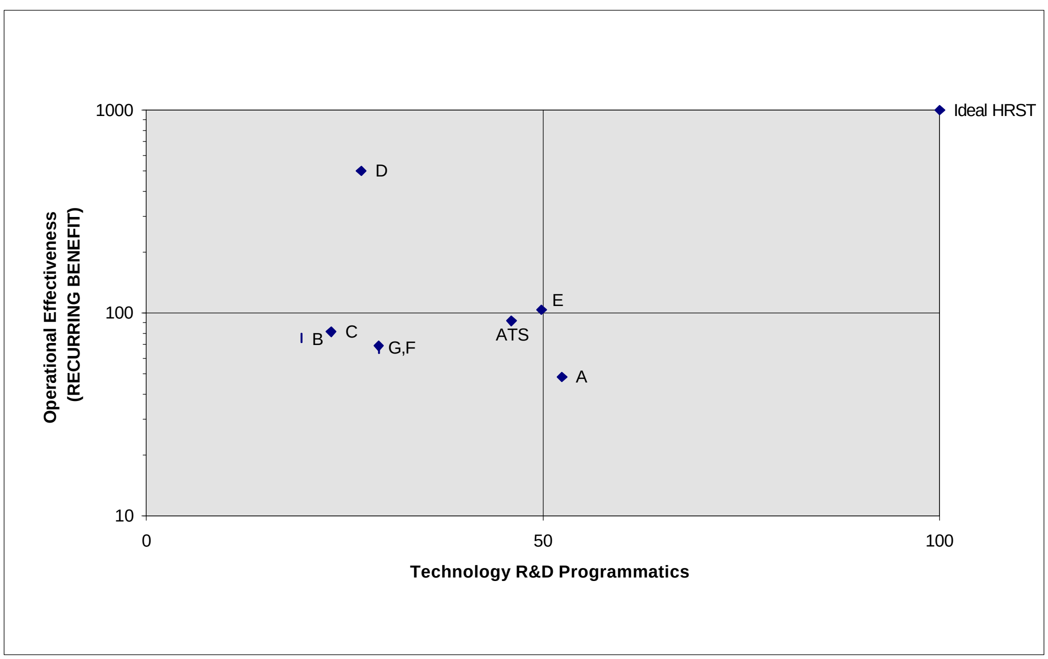

Figure 4—Example "Quad Chart" showing relative Operational Effectiveness vs. Technology R&D Non-Recurring Investment

The Architectural Assessment Form

Highly Reusable Space Transportation

Architectural Assessment Form

Characterizing Reusability and Affordability of Space Transportation System Concepts

Shuttle System Reference

Each HRST Architectural Concept provides a generic Summary Sheet for communication and assessment

Concept Title: ______________________________

Identify the overall *propulsion concept* for assessment:

- ❑ All Rocket
- ❑ Combination Cycle
- ❑ Rocket-Based Combined Cycle (RBCC)
- ❑ Launch Assist/All Rocket
- ❑ Launch Assist/RBCC
- ❑ Launch Assist/Combination Cycle
- ❑ Microwave Beaming
- ❑ Very Advanced (Specify)

Notes:

Each numbered assessment category contains a cross-reference to particular design feature(s) that may be found in the Space Propulsion Synergy Team's *A Guide for the Design of Highly Reusable Space Transportation*, August 29, 1997. (e.g., designations such as *DF #6*). This guide contains more specific information regarding the assessment items in this form.

Designations of "STS" or "ATS" on the assessment form indicate the current state-of-the-art in each numbered assessment category.

> *STS* — refers to the Space Shuttle (Space Transportation System) baseline
>
> *ATS* — refers to the Access-to-Space study (Option 3) all-rocket single stage to orbit (SSTO) vehicle reference (the HRST study project's reference vehicle)

Part 1.1
Operational Effectiveness Assessment

Each numbered assessment category in Part 1.1 contains a cross-reference to particular design feature(s) (DF) that may be found in the Space Propulsion Synergy Team's *A Guide for the Design of Highly Reusable Space Transportation*, August 29, 1996, (e.g., designations such as *DF #6*). This guide contains more specific information regarding the assessment items in this form.

Designations of "STS" or "ATS" on the assessment form indicate the current state-of-the-art in each numbered assessment category.

STS — refers to the Space Shuttle (Space Transportation System) baseline

ATS — refers to the Access-to-Space study (Option 3) all-rocket single stage to orbit (SSTO) vehicle reference (the HRST study project's reference vehicle)

1. Overall propulsion packaging architecture—(DF#6):

	All propulsion systems totally integrated with one set of tanks
	Partially integrated propulsion systems
	(STS/ATS) Separate systems, such as, MPS, OMS, RCS, Power drivers, etc
	Main propulsion system definition addressed—remainder TBD
	Current definition of concept insufficient to determine

2. Main propulsion packaging architecture—(DF#26):

	One main propulsion engine element
	Two main propulsion engine elements
	(STS) Three main propulsion engine elements
	Four main propulsion engine elements
	Five main propulsion engine elements
	Six main propulsion engine elements
	(ATS) Seven main propulsion engine elements
	More than seven main propulsion engine elements
	Current definition of concept insufficient to determine

3. Main propulsion operating dynamic events & operating modes excluding start-up & final shutdown (e.g., staging, mixture ratio changing, throttling, mode changes like low speed to high speed system) —(DF#15):

	No active engine system required to function during flight (i.e., no moving parts—Redstone, Jupiter, Thor-like)
	(ATS) Active engine throttle systems required to function during flight
	(STS) Multi-stage separation, throttling & early single-engine shutdown dynamics
	Active engine throttling systems with variable engine geometry nozzles
	Active engine inlet geometry & mode changes
	Current definition of concept insufficient to determine

4. Space Transportation System material selection—(DF#23):

	Architectural concept requires no use of pollutive or toxic materials
	Architectural concept requires no use of pollutive or toxic materials on the flight vehicle and ground servicing operations, but may use a few during manufacturing, assembly, cleaning operations
	Architectural concept requires no use of pollutive or toxic materials on the flight vehicle, but may use a few during manufacturing, assembly, cleaning & ground servicing operation
	(STS) Architectural concept requires use of pollutive or toxic materials on the flight vehicle, but may use a few during manufacturing, assembly, cleaning & ground servicing operations—into the atmosphere during flight, and requires much cleanup at launch site following launch (along with toxic waste management and disposal)
	(ATS) Current definition of concept insufficient to determine

5. Structural interface architecture (# of stages and design-to interfaces) (DF#7, 3):

	Single stage w/ integral propulsion system (including tanks) and with no element-to-element interfaces—no stand alone engine & no separate aeroshell
	(ATS) Single stage w/ non-integral propulsion system and with vehicle element-to-element interfaces—stand-alone engine & no separate aeroshell
	Single stage w/ non-integral propulsion system and with vehicle element-to-element interfaces and non-integral tanks (aeroshell concept)
	(STS) Multiple stages with many interfaces
	Current definition of concept insufficient to determine

6. Conceptual approach for reliability & dependability —(DF#10, 16):

	Uses only commercial-off-the-shelf (COTS) w/ demonstrated highly reliable components
	Uses a mix of COTS & custom, minimum weight-driven components with high technology maturity (TRL)
	(ATS) Uses a mix of COTS & custom, minimum weight-driven components with low technology maturity (TRL)
	(STS) Uses only custom minimum weight components
	Current definition of concept insufficient to determine

7. Concept for system/mission safety & reliability (Crit 1 = loss of life/vehicle, Crit 2=loss of mission) —(DF#25, 29):

	Transportation system has no "Criticality 1 or 2" failure modes (i.e., completely fault tolerant to support both mission success & total safety)
	Transportation system has no "Criticality 1" failure modes (i.e., completely fault tolerant to support safety of flight, but accepts mission failure through safe abort modes)
	Transportation system has a few "Criticality 1 and 2" failure modes (i.e., Crit 1's accepted by rationale and uses abort modes for safety, and Crit 2's accepted for loss of mission)
	(STS) Transportation system has many "Criticality 1" failure modes (accepted by rationale), accepts loss of mission, and additionally accepts loss of vehicle (1:500 flights probability)
	(ATS) Current definition of concept insufficient to determine

8. Transportation system vehicle complexity & safety dynamics (DF#12, 15, 19, 33, 39):

	Vehicle requires only a few active components to function during flight— requires no active systems to maintain safe vehicle (i.e., fail safe)— contains no active systems that require monitoring due to hazards which require corrective action to "safe" the vehicle
	Vehicle requires only a few active components to function during flight—requires no active systems to maintain safe vehicle (i.e., fail safe)—contains no more than three systems that require monitoring due to hazards which require corrective action to "safe" the vehicle
	Vehicle requires only a moderate number of active components to function during flight—requires a few active systems to maintain safe vehicle (i.e., fail safe)—contains a few systems that require monitoring due to hazards which require corrective action to "safe" the vehicle
	(STS) Vehicle requires many active components to function during flight— requires several systems to maintain safe vehicle (i.e., not-fail safe)— contains many systems that require monitoring due to hazards which require corrective action to "safe" the vehicle
	(ATS) Current definition of concept insufficient to determine

9. Space transportation system complexity—(DF#8, 20, 37):

	Space Transportation with minimum number of flight systems, minimum ground support required, and overall parts count is controlled to a minimum
	Space Transportation that's complex—i.e., has single stage and some integration of similar or like functions to reduce number of systems and components—results in several systems and an elevated level of ground support infrastructure, with an associated level of parts count
	(ATS) Space Transportation that's very complex—i.e., has single stage and no integration of similar or like functions to reduce number of systems and components—results in many systems and a large ground support infrastructure with a high parts count
	(STS) Space Transportation that's extremely complex—i.e., has multiple stages and no integration of similar or like functions to reduce number of systems and components—results in many systems and a very large ground support infrastructure with a very high parts count
	Current definition of concept insufficient to determine

10. Space transportation maintainability (on-line operation, not depot-level repair) (DF#32):

	Single stage vehicle architecture permits component/element replacement requiring no personnel entry into vehicle and without the use of any special access kits, platforms and hardware, and will accommodate changeout and verification in no more than one hour—may not require propellant drain
	Single stage vehicle architecture permits component/element replacement requiring no personnel entry into vehicle and without the use of any special access kits—allows external platforms and hardware, and will accommodate changeout and verification in no more than one hour after gaining external access—requires propellant drain
	Multi-stage vehicle architecture permits component/element replacement requiring no personnel entry into vehicle and without the use of any special access kits—allows external platforms and hardware, and will accommodate changeout and verification in no more than one hour after gaining external access—requires propellant drain
	Single-stage vehicle architecture that requires compartment entry, ground supplied purge system in air mode, installation of access platform hardware, removal of another system's components (which now lose their certification for flight) in order to gain access—all of the above only doable after vehicle is drained of propellant and "safed" (e.g., propellant tank and compartment purges, separation ordnance safely disarmed, etc.)
	(STS) Multi-stage vehicle architecture that requires compartment entry, ground supplied purge system in air mode, installation of access platform hardware, removal of another system's components (which now lose their certification for flight) in order to gain access—all of the above only doable after vehicle is drained of propellant and "safed" (e.g., propellant tank and compartment purges, separation ordnance safely disarmed, etc.)
	(ATS) Current definition of concept insufficient to determine

11. Fluid selection —(DF#1):

	Uses no toxic fluids in flight or ground system that restrict ground handling operations
	Uses no toxic fluids in flight or ground system that restrict ground handling operations at launch site—some toxics used for manufacturing, assembly and cleaning only
	(ATS) Uses no toxic fluids for flight minimum ground system restriction for on- line ground handling operations at launch site (like TPS water-proofing), except those that are serviced and sealed in off-line facilities—some toxics used for manufacturing, assembly and cleaning only
	(STS) Uses some toxic fluids for flight and ground operations
	Current definition of concept insufficient to determine

12. Number of different fluids & flight vehicle-to-ground interfaces — (DF#8, 12):

	Single stage vehicle with fully integrated design that only requires two fluids and stored in two tanks
	Multi-stage vehicle with fully integrated design that only requires two fluids and stored in two tanks per stage (common fluids between stages)
	Single stage vehicle with fully integrated propulsion design that only requires two fluids and stored in two tanks per stage, but has separate system(s) for other fluid system functions (e.g., active cooling)
	(ATS) Single-stage vehicle with separate tanks for each function & different fluids for each fluid (e.g., main propulsion = LH2/LO2 & orbital maneuvering propulsion = MMH/N2O4 & hydraulics & reaction control = MMH/N2O4 & environmental control working fluid = Freon 21 & other coolants = XXX & etc.)
	(STS) Multi-stage vehicle with separate tanks for each function & different fluids for each fluid (e.g., main propulsion = LH2/LO2 & orbital maneuvering propulsion = MMH/N2O4 & hydraulics & reaction control = MMH/N2O4 & environmental control working fluid = Freon 21 & other coolants = XXX & etc.)
	Current definition of concept insufficient to determine

13. Number of different gases & flight vehicle-to-ground interfaces — (DF#9, 7):

	Single stage vehicle that requires no on-board stored gases
	Single stage vehicle that requires only one on-board stored gas
	Multi-stage vehicle that requires no on-board stored gases
	(ATS) Single stage that requires many different gases for flight operations (e.g., GH_2, GO_2, GHe, GN_2, NH_3, etc.) which are stored in many separate vessels and each requiring flight-to-ground interfaces for servicing
	(STS) Multiple-stage that requires many different gases for flight operations e.g., GH_2, GO_2, GHe, GN_2, NH_3, etc.) which are stored in many separate vessels and each requiring flight-to-ground interfaces for servicing
	Current definition of concept insufficient to determine

14. Ground electrical power requirements for turnaround—(DF#8, 38):

	No vehicle ground power system required with minimized ground power infrastructure
	One vehicle ground power system required with minimized ground power infrastructure
	(STS/ATS) Many vehicle ground power systems required (multi-voltages, dc/ac, single-phase, multi-phases, etc.) resulting in large ground power infrastructure
	One vehicle ground power system required with ground power production infrastructure
	Current definition of concept insufficient to determine

15. Vehicle Health Management (VHM) capability (i.e., for all on-board systems including passive ones, such as thermal protection & structures) (DF#3, 13, 14, 22, 24):

	All systems—both passive and active—have BIT/BITE from on-board, with non-intrusive/non-mechanically active sensors only, requiring no hands-on or ground support aided activity—utilizing an architecture with minimum number of conductor paths, connectors, interfaces, etc.
	All systems—both passive and active—have BIT/BITE from on-board, with non-intrusive sensors only, requiring no hands-on or ground support aided activity—utilizing an architecture with minimum number of conductor paths, connectors, interfaces, etc.
	All systems—both passive and active—have BIT/BITE from on-board, with limited use of intrusive sensors, requiring no hands-on or ground support aided activity—utilizing an architecture with minimum number of conductor paths, connectors, interfaces, etc.
	All systems—both passive and active—have BIT/BITE from on-board, with limited use of intrusive sensors, requiring limited hands-on or ground support aided activity—utilizing an architecture with minimum number of conductor paths, connectors, interfaces, etc.
	(STS/ATS) Only traditional electrical functions have BIT/BITE (e.g., propulsion controller boxes, navigation & communications LRUs, guidance & control LRUs, data processing LRUs, etc.) — most mechanical hardware/systems require either hands-on or ground support aided activities to verify functional for flight
	Current definition of concept insufficient to determine

16. Concept for controlling fluid/gas leakage in the transportation system architectural design—(DF#11):

	All fluid/gas systems use component connections that are maintainable, but require no process control (i.e., leak-checking) following removal & replacement (i.e., welded integrity)—remainder of system is all-welded construction
	All fluid/gas systems use component connections that are maintainable, with automated process control (no hands-on leak-checking) following removal & replacement without compromising maintainability—remainder of system is all-welded construction (no fittings and flanges between components for ease of assembly)
	All fluid/gas systems use best traditional component connections that are maintainable, with automated process control (no hands-on leak-checking) following removal & replacement without compromising maintainability— remainder of system is all-welded construction (no fittings and flanges between components for ease of assembly)
	STS Traditional techniques are used that require leak checks (i.e., process controls) and many fittings and flanges are used for ease of assembly
	ATS Current definition of concept insufficient to determine

17. Environmental control—(DF#4, 9):

	Flight vehicle aerodynamic architecture provides all needed environmental control without the use of closed compartments, removable heat shields, and ground support system aids—and without compromising safety on the ground or in flight
	Flight vehicle architecture provides adequate environmental control during flight without use of closed compartments and removable heat shields— but, requires ground support systems control during launch preparations and launch operations
	Flight vehicle architecture provides adequate environmental control during flight with very few closed compartments with simple thermal protection—but not requiring ground support systems control during launch preparations and launch operations—and without compromising safety on the ground or in flight
	(STS) Flight vehicle contains several closed compartments, removable heat shields, and ground support systems to provide environmental control, both on the ground and in flight
	(ATS) Current definition of concept insufficient to determine

18. Fielded transportation system margin (i.e., for all on-board systems including passive ones, such as thermal protection & structures) —(DF#2, 18, 27, 40):

	Transportation system has a reasonable amount of fielded margin so as to provide payload flexibility (i.e., no performance margin assessments required operationally for flight) and growth, e.g., 15-20% (has positive operational margin)
	Average Isp and vehicle mass fraction require management assessment for flight performance margin before each flight, i.e., no real margin and little payload flexibility (has no operational margin)
	(STS) Lack of performance margin (required mass fraction) in the system, such that robustness and responsiveness are compromised on features such as on-board BIT/BITE VHM, subsystem simplicity, robust thermal protection (has negative operational margin)
	(ATS) Current definition of concept insufficient to determine

Programmatic Assessment
Part 1.2A—Program Acquisition

The numbered assessment questions in Part 1.2A have been developed by the HRST Operations Assessment Team to provide the Assessment Team additional insight to the programmatic factors of the concept as they relate to the HRST acquisition guidelines. As with the Operational Effectiveness parameters referred to by their "DF" designation in the first eighteen (18) questions (Part 1.1), these questions cross-reference programmatic factors in the *Design Guide*'s "Program Considerations" section.

19. Program Acquisition—Number of major new technology development items (#*1-PA*):

	There are no immature technologies required (flight or ground), i.e., technologies have demonstrated high reliability/dependability (flight and ground), compliance with all operational effectiveness functions (Part 1.1), and provides the required fielded margin.
	There are no immature technologies required (flight or ground), i.e., technologies have demonstrated high reliability/dependability (flight and ground) in a like environment, but have not demonstrated operational effectiveness functions other than reliability/dependability.
	(STS) There are no immature technologies required (flight or ground), i.e., technologies have been demonstrated in a like environment (TRL 6 and above), but have not demonstrated compliance with operational effectiveness functions.
	There are no immature technologies required (flight or ground), except one major technology at TRL 5. All other technologies have been demonstrated in a like environment (TRL 6 and above), but have not demonstrated compliance with operational effectiveness functions.
	There are no immature technologies required (flight or ground), except two or three major technologies below TRL 6. All other technologies have been demonstrated in a like environment (TRL 6 and above), but have not demonstrated compliance with operational effectiveness functions.
	There are more than three major technologies below TRL 6 (flight or ground) requiring demonstration in a like environment, and have not demonstrated any compliance with operational effectiveness functions.
	Current definition of concept insufficient to determine or outside programmatic boundaries.

List major new technologies:

20. Program Acquisition--Technology Readiness Level @ program acquisition milestone: TRL-6+margin (#*2-PA*):

	All technologies are at TRL-8 or 9 and have high demonstrated reliability and dependability (COTS)
	All technologies are at TRL-8 or 9 and have high demonstrated reliability/dependability but only 50% commercially available (COTS)
	(STS) All technologies are at the TRL-6 level and only some have demonstrated reliability/dependability, but many are commercially available (COTS)
	One major technology has not achieved TRL-6 but others are at TRL-8 or 9 and have demonstrated high reliability/dependability with many commercially available (COTS)
	More than one major technology has not achieved TRL-6 and all others are at TRL-8 or 9 and have demonstrated high reliability/dependability with many commercially available (COTS)
	Current definition of concept insufficient to determine or outside programmatic boundaries.

21. Program Acquisition—Infrastructure Cost: Initial system implementation (i.e., capital investment) (*#4-PA, #16-PA*):

	All infrastructure investment required for technology maturation provided for full scale manufacturing and test capability (i.e., are all available for acquisition phase @ no additional cost) and the launch, landing, logistics, payload processing, and transportation acquisition costs are estimated @ less than one-half billion dollars (**$0.5B**).
	All infrastructure investment required for technology maturation provided full scale manufacturing and test capability (i.e., are all available for acquisition phase @ no additional cost) and the launch, landing, logistics, payload processing, and transportation acquisition costs are estimated @ less than one billion dollars (**$1.0B**).
	Most infrastructure investment required for technology maturation is provided for full scale manufacturing and test capability (i.e., mostly available for acquisition phase @ no additional cost) and the launch, landing, logistics, payload processing, and transportation acquisition costs (including any additional developmental manufacturing & test infrastructure) are estimated @ less than one-and-a-half billion dollars (**$1.5B**).
	Infrastructure investment required for technology maturation did not provide for any available capability for full scale manufacturing and test capability for the acquisition phase. Therefore this investment for acquisition includes manufacturing, major test, launch, landing, logistics, payload processing, and transportation, and these acquisition costs are estimated at less than two billion dollars (**$2.0B**).
	(STS) All infrastructure investment required for technology maturation provided full scale manufacturing and test capability (i.e., are all available for acquisition phase @ no additional cost) and the launch, landing, logistics, payload processing, and transportation acquisition costs are estimated @ much greater than two billion dollars (**$>2.0B**).
	Current definition of concept insufficient to determine or outside programmatic boundaries.

22. Program Acquisition—Total system DDT&E (design, development, test & evaluation) and TFU (theoretical first unit) concept development and implementation cost (i.e., includes estimated first unit cost) (*#5-PA*):

	Combined DDT&E and TFU cost are less than one-half billion dollars (**$0.5B**). (This is achievable by accomplishing a very thorough R&D maturation program that demonstrates compliance to all performance and operational effectiveness parameters.
	Combined DDT&E and TFU cost are less than one billion dollars (**$1.0B**).
	Combined DDT&E and TFU cost are less than one-and-a-half billion dollars (**$1.5B**) with the TFU cost @ less than 20% of total.
	Combined DDT&E and TFU cost are less than two billion dollars ($2.0B) with the TFU cost @ less than 20% of total and the flight rate capability must exceed the required 200 flights per year
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

23. Program Acquisition—Technology capability margin (performance as fraction of ultimate) (*#7-PA*):

	All major technologies have been demonstrated far beyond the TRL-6, including the performance parameters, and operational effectiveness parameters with a resultant fielded margin of fifteen to twenty percent over intended operating requirements.
	Most major technologies (above 80%) have been demonstrated far beyond the TRL-6, including the performance parameters, and fifty percent (50%) of the major technologies have demonstrated operational effectiveness parameters with a resultant fielded margin of fifteen to twenty percent over intended operating requirements.
	Most major technologies (above 80%) have been demonstrated far beyond the TRL-6 including performance and less than twenty percent (20%) of the major technologies have demonstrated operational effectiveness parameters with a resultant fielded margin of fifteen to twenty percent over intended operating requirements.
	Most major technologies (above 80%) have been demonstrated far beyond the TRL-6, including the performance parameters, but have not demonstrated any operational effectiveness parameters. The performance parameters result in a fielded margin of approximately 15% over intended operating requirements.
	(STS) Most major technologies (above 80%) have been demonstrated far beyond the TRL-6, including the performance parameters, but with no definition of any margin over intended operating requirements.
	Current definition of concept insufficient to determine or outside programmatic boundaries.

24. Program Acquisition—Number of other technology options available at program acquisition commitment milestone *(#11-PA)*:

	All major technology areas have at least one backup option available at system acquisition commitment without any loss of fielded margin or demonstrated operational effectiveness characteristics (i.e., backup has also demonstrated reliability/dependability and responsiveness).
	All major technology areas have at least one backup option available at system acquisition commitment with only losses in fielded margin, but without any loss of demonstrated operational effectiveness characteristics (i.e., backups have also demonstrated reliability/dependability and responsiveness).
	More than fifty percent (50%) of the major technology areas have at least one backup option available at system acquisition commitment without any loss of fielded margin or operational effectiveness characteristics (i.e., backups have also demonstrated reliability/dependability and responsiveness), and the remaining technology areas only have loss of fielded margin.
	Only a few major technology areas have at least one backup option available at system acquisition commitment without any loss of fielded margin or operational effectiveness characteristics (i.e., backups have also demonstrated reliability/dependability and responsiveness), and the remaining technology areas only have loss of fielded margin.
	(STS) No major technology area backup options are available at system acquisition commitment.
	Current definition of concept insufficient to determine or outside programmatic boundaries.

Programmatics
Part 1.2B—<u>Technology</u> Research & Development Phase

The numbered assessment questions in Part 1.2B have been developed by the HRST Operations Assessment Team to provide the Assessment Team additional insight to programmatic considerations of the concept, particularly as they relate to specific technology research & development factors. As with the Operational Effectiveness parameters referred to by their "DF" designation in the first eighteen (18) questions (Part 1.1), and the six Program Acquisition Assessments (Part 1.2A), these questions cross-reference <u>programmatic factors</u> in the *Design Guide*'s "Program Considerations" section, and are designated as "(*#X-R&D*)"

25. Technology R&D—Time required to establish infrastructure (schedule of technology R&D phase) (*#3-R&D*):

	Infrastructure already exists without any upgrades required to do the technology R&D identified.
	Infrastructure already exists, but, some minor upgrades are required to accommodate the technology R&D identified. Upgrades (i.e., the funding, build and test cycle) can be accomplished in parallel with the design/build schedule of the test article, i.e., is not in the schedule critical path.
	Infrastructure already exists for development testing with minor upgrades required; but, the manufacturing & tooling infrastructure are not existing without major upgrades (basic manufacturing plant facility exists) and can be established in less than one year.
	Only the basic manufacturing (plant facility), the test article, and also the developmental testing infrastructure exist. Major upgrades are required for both the manufacturing and tooling and at the test facility, but, they can be established in less than two years.
	Infrastructure does not exist for either the major article testing or the manufacturing & tooling for the new test article. Acquisition and the establishment of these infrastructure elements will require in five or more years.
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

26. Technology R&D—Number of technologies considered high risk/difficult to achieve that are required to be developed and demonstrated (*#6-R&D*):

	No technologies considered high risk/difficult to achieve required. However, large subscale and full-scale demonstrations are required. (i.e., all enabling technologies are at TRL-4 or above).
	Only one technology considered high risk/difficult to achieve is required. (e.g., new material of which technology application feasibility has not been demonstrated). All other enabling technologies have been developed and demonstrated (i.e., technology readiness level-TRL-6 or above).
	Two to three technologies considered high risk/difficult to achieve are required (i.e., technology feasibility has not been demonstrated). All other enabling technologies have been developed and demonstrated (i.e., technology readiness level-TRL-6 or above).
	Five or less technologies considered high risk/difficult to achieve are required (i.e., technology feasibility has not been demonstrated). All other enabling technologies have been developed and demonstrated (i.e., technology readiness level-TRL-6 or above).
	Many technologies considered high risk/difficult to achieve are required (i.e., technology feasibility has not been demonstrated). Some other enabling technologies have been developed and demonstrated (i.e., technology readiness level-TRL-6 or above).
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

27. Technology R&D—Number of full-scale ground or flight demonstrations required (#*8-R&D*), (#9-R&D):

	All technologies are at TRL-6 or above (do not require additional full-scale ground or flight tests) and satisfy the Program Acquisition Criteria (Part 1.2A).
	All technologies are at TRL-6 or above, except one that requires flight test demonstration at full-scale to satisfy the Program Acquisition Criteria (Part 1.2A).
	All technologies are at TRL-6 or above, except one that requires both a full-scale ground and flight test program to satisfy the Program Acquisition Criteria (Part 1.2A).
	The concept architecture requires two to three full-scale technology area ground and flight test programs to satisfy the Program Acquisition Criteria (Part 1.2A).
	The concept architecture requires five or more full-scale ground test programs and at least one flight test program to satisfy the Program Acquisition Criteria (Part 1.2A).
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

28. Technology R&D—Degree of Difficulty to reach test in like environment (flight or ground) (i.e., technology readiness level is TRL-6); (#9-R&D), (*#13-R&D*), (#14-R&D), (*#17-R&D*),

	For the system being assessed, all basic principles have been observed and reported. All technologies and/or applications have been formulated. All necessary experimental proofs of concept are completed. All necessary, analogous hardware/software/database items exist. (i.e., technology readiness level is TRL-5). Demonstration in like environment still required. Time is estimated to take about **one to two (1-2) years**. (*Very low degree of difficulty*)
	For the system being assessed, all basic principles have been observed and reported. All technologies and/or applications have been formulated. All necessary experimental proofs-of-concept are completed. However, some analogous hardware/software/database items do not exist. (TRL-3,4). Time is estimated at about **two-four (2-4) years**. (*Moderate degree of difficulty*).
	For the system being assessed, all basic principles have been observed and reported. All technologies and/or applications have been formulated. However, necessary experimental proofs-of-concept are necessary and some analogous hardware/software/database items do not exist. (TRL-2,3). Time estimated **up to six (6) years.** (*High degree of difficulty*).
	For the system being assessed, all basic principles have been observed and reported. However, one or more technologies and/or applications have not been formulated. In addition, a few experimental proofs-of-concept are necessary and some analogous hardware/software/database items do not exist. (TRL-1,2). Time is estimated at **more six to ten (6-10) years.** (*Very high degree of difficulty*).
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

29. Technology R&D—Number of operational effectiveness attributes previously demonstrated (eight major attributes as related to design features in *Design Guide*) (*#10-R&D*):

	All operational effectiveness attributes (affordable, dependable, responsive, safe and environmentally compatible with public support) have been demonstrated (acquisition cost, schedule and recurring cost have no risk)
	All high priority operational effectiveness attributes have been demonstrated.
	Affordable (low acquisition & recurring), dependable and responsive attributes have been demonstrated.
	No operational effectiveness attributes (affordable, dependable, responsive, safe and environmentally compatible with public support) have been demonstrated.
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

30. Technology R&D—Number of applications beyond space transportation (*#12-R&D*):

	Greater than ten applications identified or highly visible from the new technology R&D required.
	Five to ten applications identified or highly visible from the new technology R&D required.
	Two to five applications identified or highly visible from the new technology R&D required.
	At least one application identified or highly visible from the new technology R&D required.
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

31. Technology R&D—Number of new facilities required that cost over $2M (#*15-R&D*); Cost to reach TRL-6 (#17-R&D); Total annual funding by item at peak dollar requirements (#*18-R&D*):

	There are no new facilities required that cost over $2M and the cost to reach TRL-6 is estimated at less than two hundred million dollars per year ($200M/yr) exclusive of large scale flight demonstration vehicles.
	There are no new facilities required that cost over $2M and the cost to reach TRL-6 is estimated at less than three hundred million dollars per year ($300M/yr) exclusive of large scale flight demonstration vehicles.
	One new facility is required that cost over $2M and the cost to reach TRL-6 is estimated at less than three hundred million dollars per year ($300M/yr) exclusive of large scale flight demonstration vehicles.
	One new facility is required that cost over $2M and the cost to reach TRL-6 is estimated at less than three hundred million dollars per year ($300M/yr) exclusive of large scale flight demonstration vehicles.
	(STS) Current definition of concept insufficient to determine or outside programmatic boundaries.

HRST Architectural Assessment Form
Design Feature Weighting

HRST Major Design Areas — Relative Weight

1. *Overall propulsion packaging* architecture.
   DF#6 - Number of different propulsion systems 496
2. Main propulsion packaging architecture.
   DF#26 - Number of engines 335
3. Main propulsion operating dynamic events & operating modes excluding start-up & final shutdown (e.g., staging, mixture ratio changing, throttling, mode changes like low-speed-to-high-speed system.
   DF#15 - Number of active components required to function including flight operations 412
4. Space Transportation System *material selection.*
   DF#23 - Number of confined spaces on vehicle 355
5. *Structural interface* architecture (number of stages and design-to interfaces).
   DF#7 - Number of unique stages (flight and ground) 493
   DF#30 - Number of element-to-element interfaces requiring engineering control (294)
6. Conceptual approach for *reliability & dependability.*
   DF#10 - Number of components with demonstrated high reliability 458
   DF#16 - Technology readiness levels (406)
7. Concept for *system/mission safety & reliability* (Crit 1 = loss of life/vehicle, Crit 2 = loss of mission).
   DF#25 - Number of propulsion sub-systems with fault tolerance 341
   DF#29 - Number of criticality 1 failure modes (320)
8. Transportation system *vehicle complexity & safety dynamics.*
   DF#12 - Number of active systems required to maintain a safe vehicle 439
   DF#15 - Number of active components required to function including flight operations (412)
   DF#19 - Number of systems requiring monitoring due to hazards (390)
   DF#33 - Percent of propulsion sub-systems monitored to change from hazard to safe (279)
   DF#39 - Number of active engine systems required to function (220)
9. Space transportation system complexity.
   DF#8 - Number of active ground systems required for servicing 464
   DF#20 - Number of parts (different, backup, complex) (370)
   DF#37 - Number of manufacturing, test and operations facilities (249)

10. Space transportation *maintainability* (on-line operation, not depot-level repair).
    DF#32 - Number of physically difficult-to-access areas 291
11. Fluid selection.
    DF#1 - Number of toxic fluids 597
12. Number of *different fluids* & flight vehicle-to-ground *interfaces.*
    DF#8 - Number of active ground systems required for servicing 464
    DF#17 - Number of different fluids in system (398)
13. Number of *different gases* & flight vehicle-to-ground *interfaces*.
    DF#9 - Number of purges required (flight and ground) 463
    DF#17 - Number of different fluids in system (398)
14. Ground *electrical power requirements* for turnaround.
    DF#8 - Number of active ground systems required for servicing 464
    DF#38 - Number of ground-power systems (234)
15. *Vehicle Health Management (VHM) capability.* (i.e., for all on-board systems including passive ones, such as thermal protection & structures).
    DF#3 - Number of systems with BIT BITE 521
    DF#13 - Percent of propulsion system automated (420)
    DF#14 - Number of hands-on activities required (416)
    DF# 22 - Number of checkouts required (360)
    DF#24 - Number of inspection points (346)
16. Concept for *controlling fluid/gas leakage* in the transportation system architectural design.
    DF#11 - Number of potential leakage connection sources 443
17. Environmental control.
    DF#4 - Number of confined spaces on vehicle 501
18. *Fielded* transportation system *margin* (i.e., for all on-board systems including passive ones, such as thermal protection & structures).
    DF#2 - System margin 526
    DF#18 - Mass fraction (395)
    DF#27 - Average Isp on reference trajectory (331)
    DF#40 - Margin, mass fraction (209)

HRST Architectural Assessment Form
Design Feature Weighting Summary

HRST Major Design Areas (Design Feature Alpha-Numeric)	QFD Score - %
A. 11. Fluid selection.	
DF#1 - Number of toxic fluids	597 -100
B. 18. Fielded transportation system margin.	
DF#2 - System margin	526 - 88
C. 15. Vehicle Health Management (VHM) capability.	
DF#3 - Number of systems with BIT BITE	521 - 87
D. 17. Environmental control.	
DF#4 - Number of confined spaces on vehicle	501 - 84
E. 1. Overall propulsion packaging architecture.	
DF#6 - Number of different propulsion systems	496 - 83
F. 5. Structural interface architecture (# of stages & design-to interfaces).	
DF#7 - Number of unique stages (flight and ground)	493 - 83
G. 9. Space transportation system complexity.	
DF#8 - Number of active ground systems required for servicing	464 - 78
H. 12. Number of different fluids & flight vehicle-to-ground interfaces.	
DF#8 - Number of active ground systems required for servicing .	464 - 78
I. 14. Ground electrical power requirements for turnaround.	
DF#8 - Number of active ground systems required for servicing .	464 - 78
J. 13. Number of different gases & flight vehicle-to-ground interfaces.	
DF#9 - Number of purges required (flight and ground)	463 - 78
K. 6. Conceptual approach for reliability & dependability.	
DF#10 - # of components with demonstrated high reliability	458 - 77
L. 16. Concept for controlling fluid/gas leakage in transp. sys. arch. design.	
DF#11 - Number of potential leakage connection sources	443 - 74
M 8. Transportation system vehicle complexity & safety dynamics.	
DF#12 - # of active systems required to maintain a safe vehicle .	439 - 74
N. 3. Main propulsion operating dynamic events & operating modes excluding start-up & final shutdown.	
DF#15 - # of active comps. reqd. to func. including flight opers . .	412 - 69
O. 4. Space Transportation System material selection.	
DF#23 - Number of confined spaces on vehicle	355 - 59
P. 7. Concept for system/mission safety & reliability	
DF#25 - Number of propulsion sub-systems with fault tolerance .	341 - 57
Q. 2. Main propulsion packaging architecture.	
DF#26 - Number of engines	335 - 56
R. 10. Space transportation maintainability (on-line operation)	
DF#32 - Number of physically difficult-to-access areas	291 - 49

SUMMARY OF ASSESSMENT CATEGORIES

ASSESSMENT CATEGORY	RELATIVE WEIGHT
1. *Overall propulsion packaging* architecture.	496
2. Main propulsion packaging architecture.	335
3. Main propulsion operating dynamic events & operating modes excluding start-up & final shutdown	412
4. Space Transportation System *material selection.*	355
5 *Structural interface* architecture (number of stages and design-to interfaces).	493
6 Conceptual approach for *reliability & dependability.*	458
7. Concept for *system/mission safety & reliability*	341
8. Transportation system *vehicle complexity & safety dynamics.*	439
9. Space transportation system complexity.	464
10. Space transportation *maintainability*	291
11. Fluid selection.	597
12. Number of *different fluids* & flight vehicle-to-ground *interfaces.*	464
13. Number of *different gases* & flight vehicle-to-ground *interfaces*.	463
14. Ground *electrical power requirements* for turnaround.	464
15. Vehicle Health Management (VHM) capability.	521
16. Concept for *controlling fluid/gas leakage* in the transportation system architectural design.	443
17. Environmental control.	501
18. *Fielded* transportation system *margin.*	526

The number at the right-hand side of each category is a relative-weight indicator described in the supplement.

HRST ARCHITECTURAL ASSESSMENT FORM

ASSESSMENT CATEGORY WEIGHT SUMMARY