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Selection Process for Trade Study -- Reusable Hydrogen Composite Tank System (RHCTS)

Cooperative Agreement NCC8-39

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HERCULES

INTRODUCTION

This TA 1 document describes the selection process that will be used to identify the most suitable structural configuration option for an SSTO winged vehicle capable of delivering 25,000 lbs to a 220 nm circular orbit at 51.6 degree inclination. The most suitable RHCTS is within this configuration and will be the prototype design for subsequent design and analysis and the basis for the design and fabrication of a scale test article to be subjected to life cycle testing.

The selection process for this TA 1 trade study is the same as that for the TA 2 trade study.

As the trade study progresses additional insight may result in modifications to the selection criteria within in this process. Such modifications will result in an update of this document as appropriate.

SELECTION PROCESS

A. Candidate Vehicle Options -

The selection process will select the most suitable structural configuration option from those derived from the 4 vehicle options shown in Figure 1 and trade options shown in Table 1 which are summarized in Table 2 of RHCTS-TSP-1 dated July 29, 1994. These figures and tables are included herein for convenience.

B. Selection Process Logic

The selection process is illustrated in Figure 2 and starts with the establishment of selection criteria categories . There are 10 selection criteria categories namely, (1) Design and Production Effort, (2) Miscellaneous weights, (3) Gross Fueled Weight Sensitivity, (4) Propulsion Interface, (5) Vehicle Controllability, (6) On-Pad Operations, (7) Maintenance Operations, (8) Safety , (9) Development Risk, and (10) Cost .

The line item criteria within each of the 10 categories are then determined within the 10 categories and listed in Table 3. There are a total of 42 criteria.

A dictionary of these selection criteria is presented in Section C to clearly illustrate the meaning of each of the criteria to permit a common understanding of these criteria amongst the Rockwell and NASA team personnel.

The 10 categories, criteria line items within each category, dictionary, and % weighting of the relative importance of the categories of Selection criteria were determined through team brainstorming sessions. In view of the extreme importance of cost it is removed from the point allocation method. The % weightings of the 9 categories are (1) Design and Production Effort - 10 % (2) Miscellaneous weights - 7 % (3) Gross Vehicle Weight Sensitivity - 13 % (4) Propulsion Interface - 6 % , (5) Vehicle Controllability- 9 %, (6) On-Pad Operations - 12 %, (7) Maintenance Operations - 18 %, (8) Safety - 15 % , and (9) Development Risk - 10 % for a total of 100 %.

Having established the % rating of each category the percentages within each category are established as shown in Table 3. These percentages have not been studied, as yet, to the level of detail of the category weightings and are presented to solicit comments. These are expected to change as the trade study progresses.

The scoring method for each line item is identified in the dictionary as quantitative or qualitative.

The quantitative scoring applies to quantitative data such as weights or operations hours or number of fracture critical joints to determine the relative scores for each criteria line item as shown in Figure 3. For example if inspection hours are the line item and the least hours among the options is 8 and the most hours is 48 then 10 points is used for the 8 hour option and 1 point for the 48 hours option. An option requiring 28 hours would be scored by straight line interpolation to be 5.5 points.

The qualitative scoring assigns 10 points to the best option and 1 point to the least desirable option and by judgment assigns points to the other options according to how they are perceived to compare to the best and worst options.

The scores of the 9 categories will be placed on Excel spread sheets that will be available to NASA. The spread sheets will be interrelated in the same manner, as those provided to

Figure 1
Four Candidate SSTO Vehicle Configurations are Studied

REUSABLE CRYOTANKS

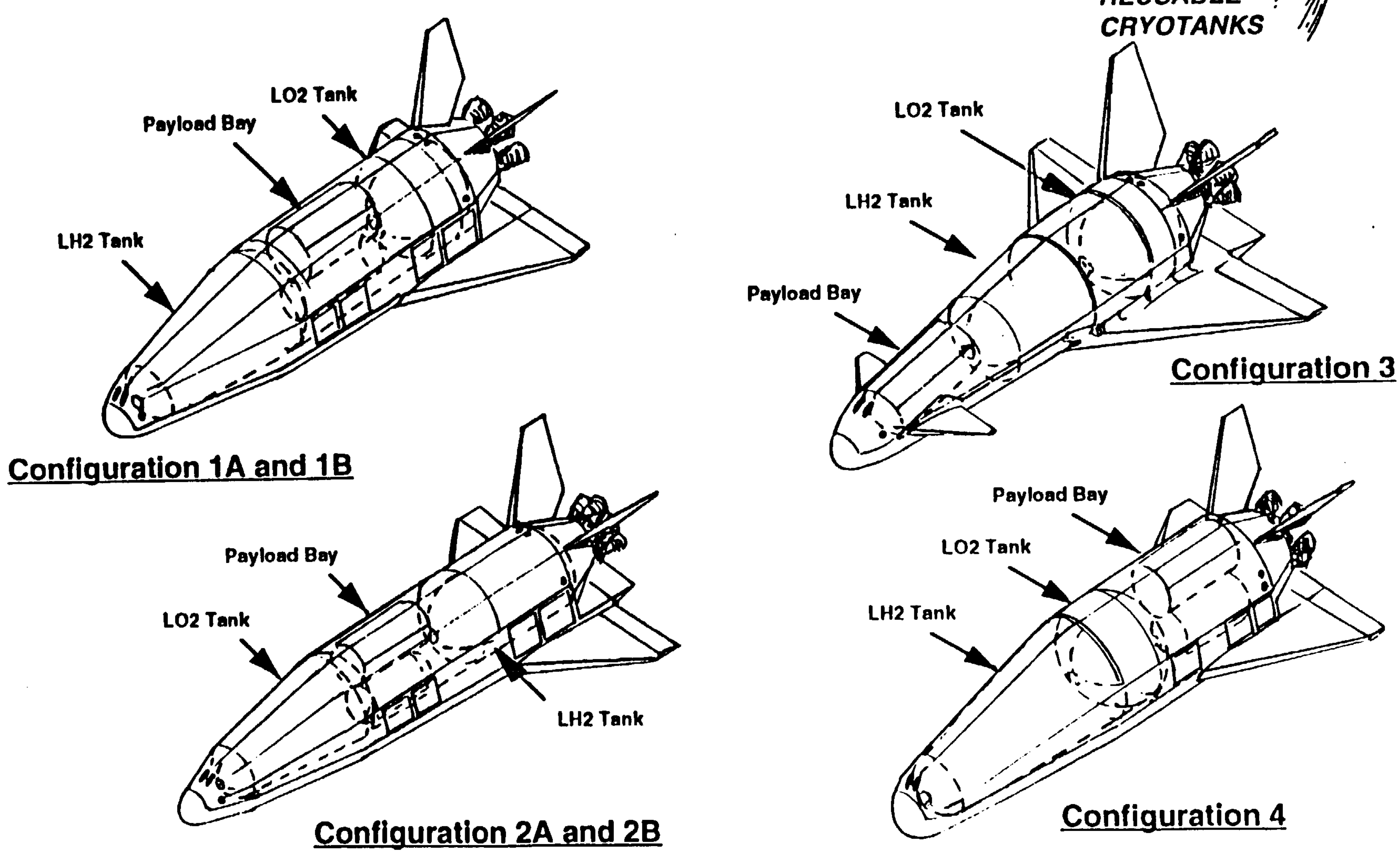

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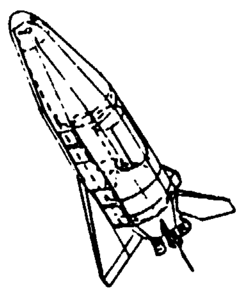
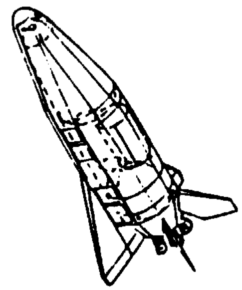
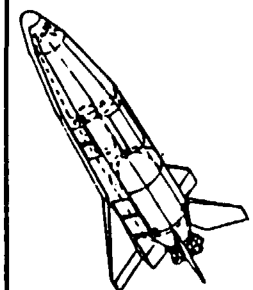
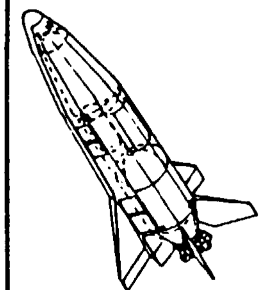
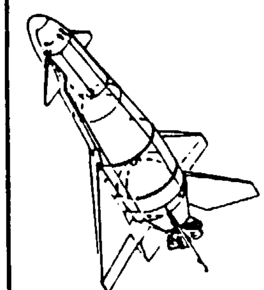
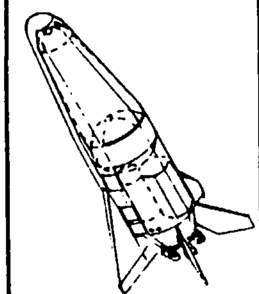
Table 1
These trade study options will be studied

REUSABLE CRYOTANKS

Design Options	Configuration 1A Forward LH tank 	Configuration 1B Forward LH Tank 	Configuration 2A Forward LO tank 	Configuration 2B Forward LO Tank 	Configuration 3 Common Bulkhead 	Configuration 4 
Integral or Non-integral Tanks	Both tanks are integral	Non-integral LH tank Integral LO Tank	Both tanks are integral	Non-integral LH tank Integral LO Tank	Both tanks are integral	Both tanks are integral
Wing Attachment *	LO Tank Thrust Structure	LO Tank Thrust Structure	LH Tank Thrust Structure	Fuselage Thrust Structure	LO Tank Thrust Structure	Into Payload Bay Unpressurized Structure
LH Tank Cryo Insulation	External to skin/str core of sandwich	External to skin/str core of sandwich	External to skin/str core of sandwich	External to skin/str core of sandwich	External to skin/str core of sandwich	External to skin/str core of sandwich
Composite Fuselage	None external to LH tank	Gr/BMI external to LH tank	None external to LH tank	Gr/BMI external to LH tank	None external to LH tank	None external to LH tank
TPS on LH Tank	PBI, TABI, AETB	PBI, TABI, AETB, C/Sic Multipost	PBI, TABI, AETB	PBI, TABI, AETB, C/Sic Multipost	PBI, TABI, AETB	PBI, TABI, AETB
Chines	minimum to maximum size	minimum to maximum size	minimum to maximum size	minimum to maximum size	minimum to maximum size	minimum to maximum size

* Trade study analysis supplemented by TA2 analyses.

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Table 2
These Detailed Trade Options will be Studied

Trade Option No.	LH Tank	LH Tank Insulation	Tank Outer Fuselage	Wing Attach	Chines	TPS on LH tank	TPS on tank Outer Fuselage
1A-1	Integral	external	none	to LO tank	1A baseline	Bonded designs	none
1A-2	Integral	sandwiched	none	to LO tank	1A baseline	Bonded designs	none
1A-3	Integral	external	none	to LO tank	reduced	Bonded designs	none
1A-4	Integral	external	none	to thrust structure	1A baseline	Bonded designs	none
1B-1	Non-Integral	external	Gr/BMI	to LO tank	1B baseline	none	Bonded/Mech attchd
Not req'd	Non-Integral	external	Gr/BMI	to LO tank	reduced	none	Bonded/Mech attchd
1B-2	Non-Integral	external	Gr/BMI	to thrust structure	1B baseline	none	Bonded/Mech attchd
2A-1	Integral	external	none	to LH tank	2A baseline	Bonded designs	none
2A-2	Integral	sandwiched	none	to LH tank	2A baseline	Bonded designs	none
2A-3	Integral	external	none	to LH tank	reduced	Bonded designs	none
2A-4	Integral	external	none	to thrust structure	2A baseline	Bonded designs	none
2B-1	Non-Integral	external	Gr/BMI	to outer fuselage	2B baseline	none	Bonded/Mech attchd
Not req'd	Non-Integral	external	Gr/BMI	to outer fuselage	reduced	none	Bonded/Mech attchd
Not req'd	Non-Integral	external	Gr/BMI	to thrust structure	2B baseline	none	Bonded/Mech attchd
3A-1	Integral	external	none	to LO tank	3A baseline	Bonded designs	none
3A-2	Integral	sandwiched	none	to LO tank	3A baseline	Bonded designs	none
3A-3	Integral	external	none	to LO tank	reduced	Bonded designs	none
3A-4	Integral	external	none	to thrust structure	3A baseline	Bonded designs	none
4A-1	Integral	external	none	to payload bay fuselage	4A baseline	Bonded designs	none
LO Tank Is Integral for All Options							

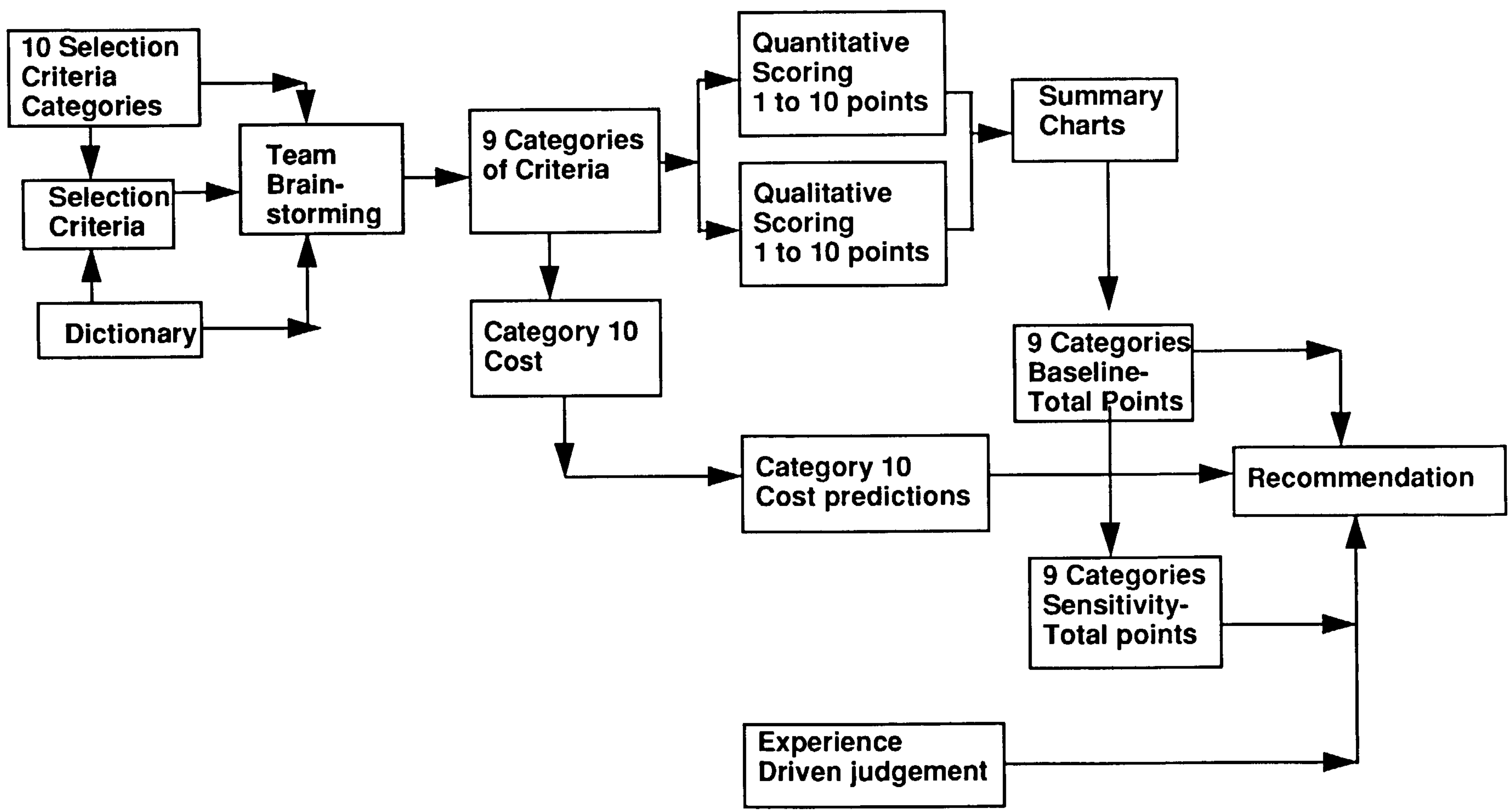

Figure 2 - Selection Process Logic

TABLE 3 - 42 Evaluation Criteria to identify most suitable structural configuration option					
	Points				
1. DESIGN AND PRODUCTION EFFORT	**10**				
a. Certification Effort	3.0				
b. Verification Effort	3.0				
c. Producibility`Effort	2.0				
d.IHM Effort	2.0				
2. MISCELLANEOUS WEIGHTS	**7**				
a. Primary Structure weight	2.0				
b. TPS weight	1.0				
c. Total Dry Weight	2.0				
d. Gross fueled Weight	2.0				
3.. GROSS FUELED WEIGHT SENSITIVITY	**13**				
a. Gross Vehicle weight sensitivity	13				
4. PROPULSION INTERFACE	**6.0**				
a. Number of feed line penetrations	1.5				
b. Number of propellant suction lines	1.5				
c.Ease of slosh baffle integration	1.5				
d. Ease of tank cleaning	1.5				
5. VEHICLE CONTROLLABILITY	**9**				
a. Ascent controllability	3.0				
b. Hypersonic controllability	3.0				
c.Subsonic controlability	3.0				
6. ON PAD OPERATIONS	**12**				
a. Pressurization/fueling flexibility	3.0				
b. Sub-systems for on-pad operations	3.0				
c. Systems requiring disconnect	3.0				
d. Facilities	3.0				
7. MAINTENANCE OPERATIONS	**18**				
a. Wide area coverage inspection	4.0				
b. Localized area coverage inspection	2.0				
c. Acessibility	1.0				
d. number of inspection points	2.0				
g. Re-waterproofing	1.5				
l. Sustained personnel	1.5				
m. Turn around time	3.0				
n.Facilities	1.5				
o. Equipment Rements	1.5				

TABLE 3 - 42 Evaluation Criteria to identify most suitable structural configuration option- continued					
8. SAFETY	**15**				
a. Probability of tank Penetration	4				
b. Tank rupture due to debris impact	4				
b. Number of fracture critical parts	3				
c. Probability of LH/LO Contact	2				
e. Amenability to IHM	2				
9. DEVELOPMENT RISK	**10**				
a. Structural Design risk	3				
b. TPS Design Risk	3				
c. Technology Development	4				
TOTAL	**100**				
8. COST					
a. DDT & E cost					
b. Operations cost					
c. Production Cost					
d. Life Cycle Cost					
e. Cost per flight					

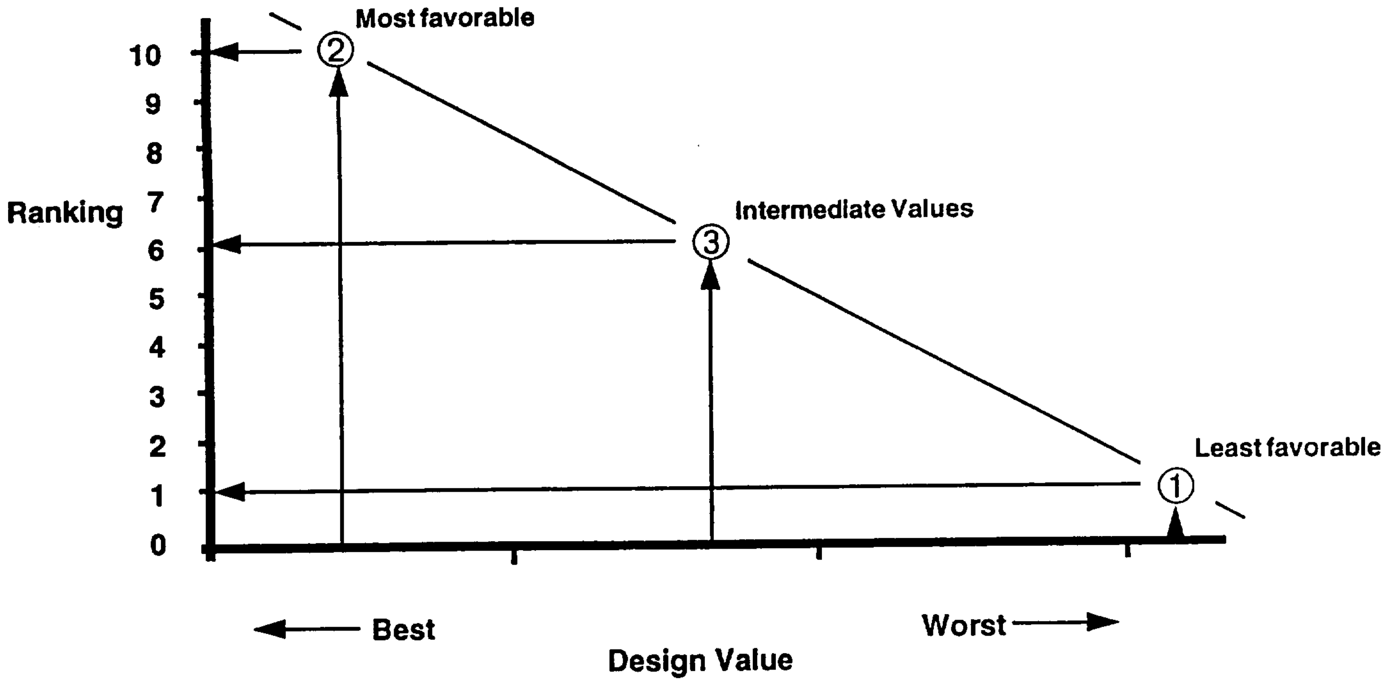

Figure 3. Scoring Methodology

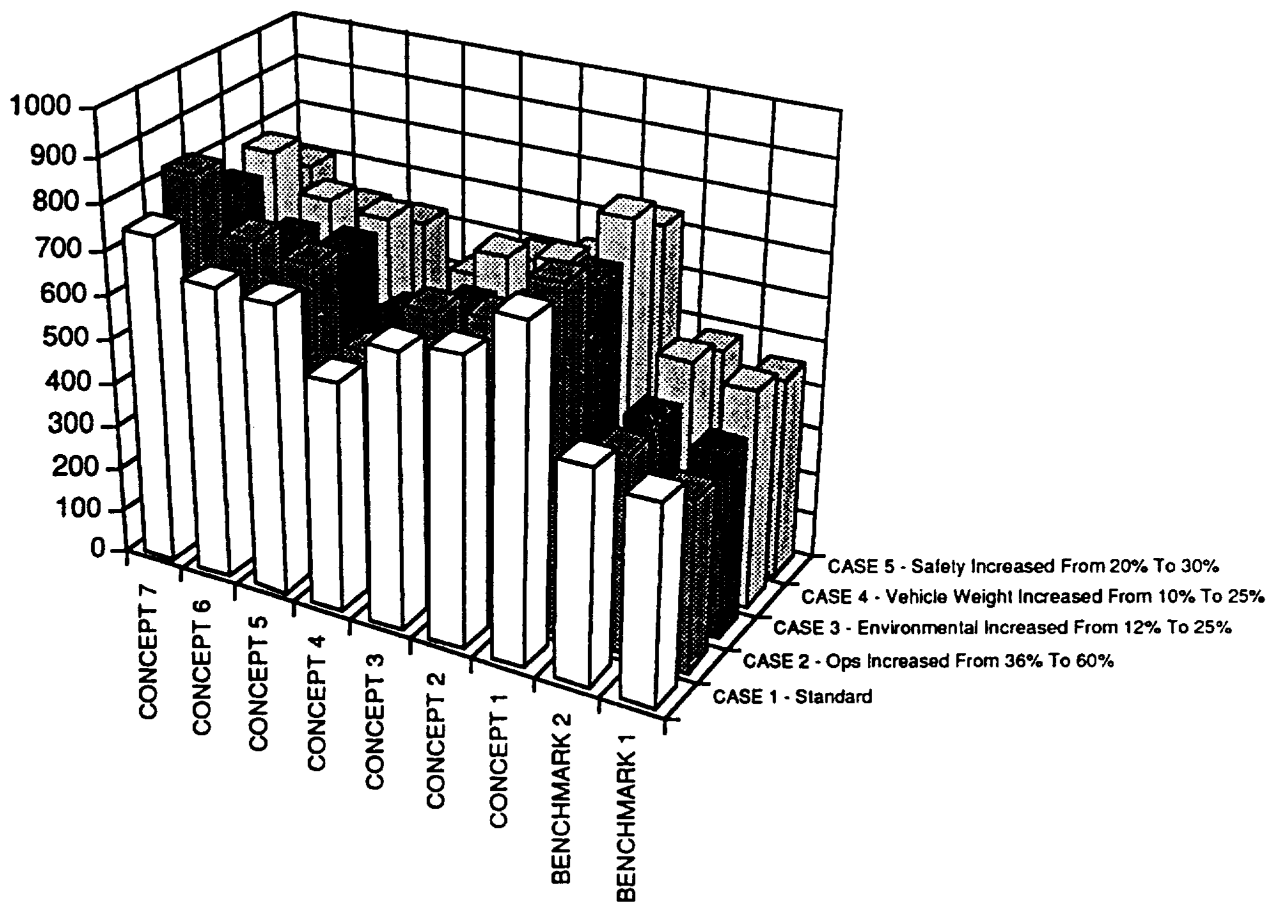

Figure 4. Example of Sensitivity Study

NASA/LaRC for the Task 5 AMLS study. The interrelation of the spread sheets will permit the conduct of sensitivity studies to be discussed subsequently.

It is recognized that the assignment of % weightings may vary depending on the background of the team, and it is important to know the sensitivity of the selection process to various % variations amongst the categories. Therefore, as was done on the AMLS Task 5 TPS study, for this very reason, in addition to the baseline points determination shown a sensitivity study of the points due to % weighting variations will be included. The variations in percentages will be determined during the study. An example of the method of presentation of the sensitivity study is shown in Figure 4.

The total points for the baseline and sensitivity scorings and the separate cost data will be evaluated along with experience driven judgment by the entire Rockwell and NASA team to recommend the most suitable structural configuration option of those listed in Table

C. Evaluation Criteria Dictionary

The intent of this dictionary is to define each of the line item parameters that comprise the total selection criteria. The goal of these definitions is to clearly illustrate how the candidate vehicle options will be compared for each line item criteria parameter.

The line items parameters use either a quantitative or qualitative analysis to establish the points allocated to each option as discussed in section B. This dictionary states which of these scoring methods is used.

1. DESIGN AND PRODUCTION COMPLEXITY

a. Certification effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of analysis, development testing, and demonstration testing required for certification of structure and TPS. Certification refers to only the design and is achievable without fabrication of a vehicle.

b. Verification Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of analysis, development testing, demonstration testing, and inspection required for verification of structure and TPS. Verification includes certification plus the addition of inspection to acertain adherence of the as-built vehicle to drawings and specifications.

c. Producibility Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of producibility (tooling and fabrication).

d. IHM Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of development and installation of IHM.

2. MISCELLANEOUS WEIGHTS

a. Primary structure weight- (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total structure weight.

b. TPS weight - (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total TPS structure weight.

c. Total dry weight - (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total Vehicle dry weight -

d. Gross fueled weight - (Quantitative Evaluation) - The candidate vehicle options are rated according to the determined gross fueled weight

3. GROSS FUELED WEIGHT SENSITIVITY

a. Gross fueled weight sensitivity - Quantitative Evaluation - The candidate vehicle options are rated according to the determined increase in gross fueled weight due to a 5 % increase in total dry structure weight.

4.0 PROPULSION INTERFACE

a. Number of feed line tank penetrations - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the number of penetrations required for the propellant feed system. Included in this comparison is whether internal or external sumps are required, and if so how many.

b. Number of propellant suction lines - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the number of propellant suction lines (similar in principle to that used on the STS-ET LH2 tank) which penetrate the tank. The use of suction lines, though offering advantages in intertank length, results in additional complexity feed system design and operational complexity due to the incorporation of high point bleeds.

c. Ease of integrating propellant slosh baffles within the tank - (Qualitative evaluation) - The candidate vehicle options are rated according to the fabrication process and degree of difficulty associated with fabricating and installing propellant slosh baffles to the inside tank walls.

d. Ease of tank cleaning - (Qualitative evaluation) - The candidate vehicle options are rated according to the complexity associated with cleaning the propellant tanks with non-freon based chemicals following both initial tank fabrication, and subsequent maintenance activities within the tank.

5.0 VEHICLE CONTROLLABILITY

a. Ascent controllability- (Quantitative evaluation) - The candidate vehicle options are compared on the basis of ascent controllability provided by engine thrust vector control and vehicle characteristics.

b. Hypersonic controllability- (Qualitative evaluation) - The candidate vehicle options are compared on the basis of hypersonic controllability during entry.

c. Subsonic controllability - (Qualitative evaluation) - The candidate vehicle options are compared on the basis of subsonic controllability during entry.

6. ON PAD OPERATIONS

a. Tank pressurization /depressurization and fueling/draining timelines- (Quantitative and Qualitative evaluation) - The candidate vehicle options are compared on the basis of the complexity of the systems (qualitative) and the time lines required to fill and pressurize the main propellant tanks (quantitative).

b Subsystems for on pad operations - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the additional on pad systems necessary to support launch. The scoring will include a complexity factor applied to the additional systems. A purging system for frost avoidance is an example of such a system.

c. Systems requiring disconnect - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of additional disconnects necessary to permit vehicle launch. The scoring will include a complexity factor applied to the additional disconnects. A purging system disconnect for frost avoidance is an example of such a system.

d. Facilities (Qualitative evaluation) - The candidate vehicle options are compared according to the number of additional on-pad facilities and height of such facilities and other differences that may be surface during the study.

7. MAINTENANCE OPERATIONS

Potential maintenance operations include: outer surface inspection, tank insulation inspection, leak tests, tank/insulation adhesive bond line inspection, TPS/insulation adhesive bond line inspection, tank structure inspection and repair, unpressurized structure inspection and repair, and TPS repair or replacement. The following criteria will be evaluated according to these operations:

a. Wide area coverage - (Quantitative Analysis) - The candidate vehicle options are compared based on the wide area coverage (square footage) that will have to be inspected, monitored, and maintained.

b. Localized area coverage - (Quantitative Analysis) - The candidate vehicle options are compared based on the complexity of local area coverage requirements (critical joints; localized high stress areas) within the each of the candidate vehicles.

c. Accessibility - (Qualitative Analysis) - The candidate vehicle options are compared based on the ease of accessibility to inspect, monitor and maintain the structural elements.

d. Number of inspection points - (Quantitative Analysis) - The candidate vehicle options are compared based on the number of elements that have to be inspected, monitored, and maintained during operations (i.e. sandwich construction with multiple bondlines will potentially have more inspection requirements).

g. Re-waterproofing-(Quantitative evaluation) - The candidate vehicle options are compared on the basis of the total time required, over 300 missions, to re-waterproof the TPS experiencing temperatures above 1100 F.

h Sustained personnel-(Quantitative evaluation) - The candidate vehicle options are compared on the determined number of technicians, and engineers required over 300 missions.

i. Turn-around time - (Quantitative evaluation) - The candidate vehicle options are compared on the required time of turn around.

j. Facilities- (Qualitative evaluation) - The candidate vehicle options are compared by the relative size, number, and complexity of operations facilities required.

k. Equipment requirements - (Qualitative evaluation)- The candidate vehicle options are compared on the basis of unique or additional equipment requirements to perform the maintenance operations from a to j.

Optimized maintenance over 300 missions will be on an "as required basis" and will be accomplished by a combination of several approaches: no inspection required for certain structural elements based on designed in robustness, highly automated inspection after every flight for critical areas that cannot be cost effectively monitored during operations, cost effective on-board monitoring to determine maintenance exceptions (actions), and periodic depot level inspections with a frequency rate to be determined.

8.0 SAFETY

a. Probability of tank penetration- (Quantitative Analysis) - The candidate vehicle options are compared on the analysis prediction (based on test data) of the probability of cryogenic tank penetration (leakage) for vehicle on-orbit duration's of 900 days.

b. Susceptibility of tank rupture due to on-orbit debris impact - (Qualitative Analysis) - The candidate vehicle options are compared on the perceived susceptibility to tank rupture for vehicle on-orbit duration's of 900 days.

c. Number of fracture critical joints - (Quantitative Analysis) - The candidate vehicle options are compared on the number of joints perceived to be fracture critical.

d. Potential for/ LH/LO contact - (Qualitative evaluation) - The candidate vehicle options are compared on the potential of LH/LO contact that would be catastrophic.

e. Amenability of IHM to detect critical faults - (Qualitative Analysis) - The candidate vehicle options are compared on the amenability of IHM to detect critical faults such as tank leakage, critical cracks in primary structure, TPS debond, insulation debond. etc...

9.0 DEVELOPMENT RISK

a. Structural design and analysis risk- (Qualitative evaluation)- The candidate vehicle options are compared on the perceived risks associated with tank, and primary structure analysis and design forseeable problems and potential problem resolution.

b. Thermal Design Risk-(Qualitative evaluation)- The candidate vehicle options are compared on the perceived risks associated with insulation, and TPS thermal analysis and design foreseeable problems and potential problem resolution.

c Technology Development Needs- (Qualitative evaluation)- The candidate vehicle options are compared on the current technology development needs and perceived assessment of the magnitude of the development required.

10.0 COST

a. DDT & E Cost - (Quantitative Evaluation) - The candidate vehicle options are compared on the determined DDT & E vehicle costs based on the structure and TPS determined weights and complexity and associated subsystems

b. Operations Cost- (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the cost of operations as determined from the operations hours and sustained engineering personnel

c. Production Cost (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the determined production cost.

d. Life Cycle Cost- (Quantitative Evaluation) - The candidate vehicle options are compared on the determined life cycle vehicle costs based on the operations analysis derived hours

e Cost per flight -Quantitative Evaluation) - The candidate vehicle options are compared on the determined Cost per flight based on the operations analysis derived hours and other costs per flight.