SSD94D0219
RHCTS-TSP-1

# Trade Study Plan for Reusable Hydrogen Composite Tank System (RHCTS)

Cooperative Agreement NCC8-39

July 29, 1994


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Rockwell Aerospace
Space Systems Division

Rockwell Aerospace
North American Aircraft

HERCULES

# INTRODUCTION

This TA 1 document describes the trade study plan (with support from TA 2) that will identify the most suitable structural configuration for an SSTO winged vehicle capable of delivering 25,000 lbs to a 220 nm circular orbit at 51.6 degree inclination. The analyses uses information derived in the TA 2 study and is identified within the study plan. In view of this, for convenience, the TA 2 study plan is included as an appendix to this document.

All activities within this TA 1 trade sudy plan are in Task 2 of the Project Plan document presented to NASA/MSFC on June 22, 1994.

# TA 1 TRADE STUDY PLAN

## 1. Objective

To determine (with the support from TA 2) the most suitable SSTO vehicle structural configuration in order to identify the associated RHCTS tank construction, cryogenic insulation arrangement, and TPS designs. This integrated design 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 later in the project.

## 2. Approach

The four vehicle configurations shown in Figure 1 are the candidate vehicles to which the options shown in Tables 1 and 2 are applicable. The four candidate tri-propellant SSTO vehicle configurations are shown in Figure 2. Configurations No. 1 and No. 2 place the payload bay between the cryogenic tanks. The $LH_2$ tank is forward in configuration 1 and aft in Configuration 2. Configurations No. 3 and No. 4 , respectively, place the payload bay forward and aft of the tanks. The major pros and cons of each configuration using integral tanks are:

- No. 1 - Expected lightweight, most difficult ascent control , complex wing attachment design

- No. 2 -Expected heaviest weight , best ascent control, complex wing attachment design (The wing attachment is simplified for a non-integral tank)

- No. 3 - Expected lightest weight, most difficult ascent control , complex wing attachment design, worst payload in/out c.g excursion, added design risk and operations with common bulkhead

- No. 4 - Expected heavy weight, adequate ascent control, simplest wing attachment , least payload in/out c.g excursion, worst payload acoustic environment, added design risk and operations with common bulkhead.

The common bulkheads are compression -stable designs using 2 face sheets, with honeycomb sandwich core, between the $LO_2$ and $LH_2$ propellants. For safety a GSE purge system senses any $LO_2$ or $LH_2$ leakage into the honeycomb sandwich core.

The options encompass integral and non-integral Hydrogen tanks, external and sandwich insulation arrangements (Figure 2), wing attachment variations, and minimization of chines. These options are further discussed as follows:

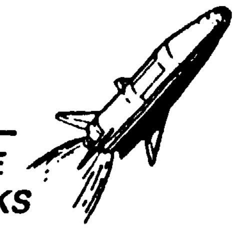
Each of the options listed in Table 2 will be analyzed to the necessary level of detail in order to select the most suitable design. Where similarity exists structure weights may be determined by scaling from similar structure determined in detail. Further as the design progresses if it is apparent that an option is not worth investing further the SSD team will recommend that the option be removed.

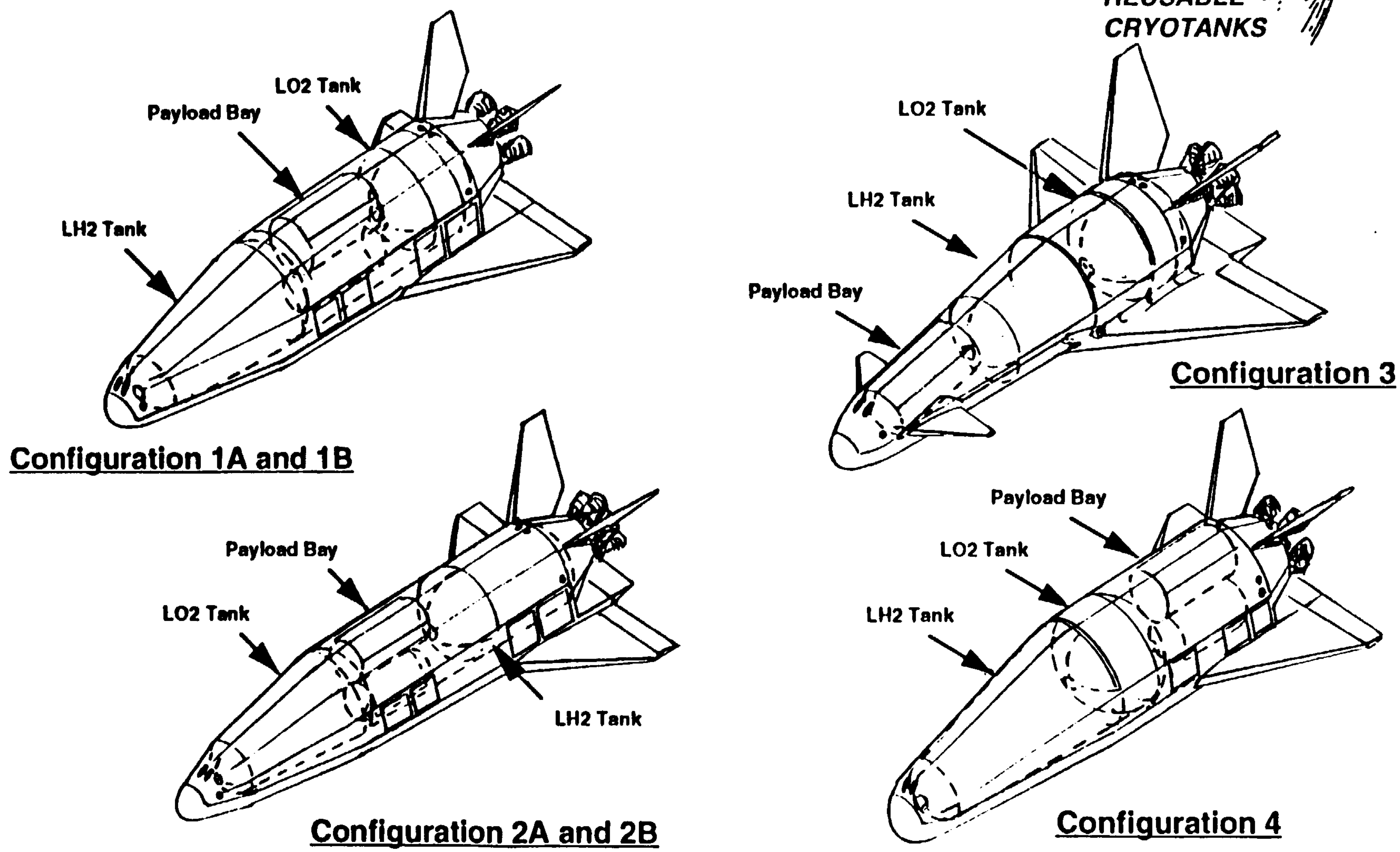
## 3. Schedule

The schedule for the trade is shown in Figure 5. The tasks shown in the schedule correspond to those listed below.

# Figure 1
# Four Candidate SSTO Vehicle Configurations are Studied

*REUSABLE CRYOTANKS*



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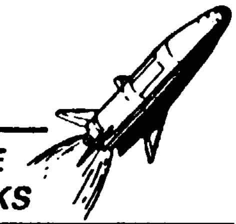
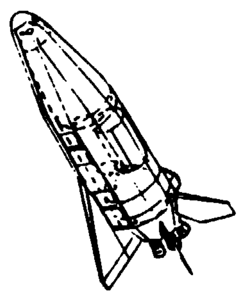
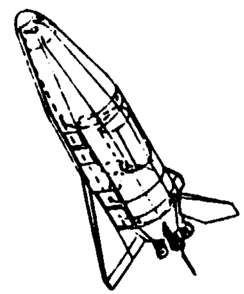
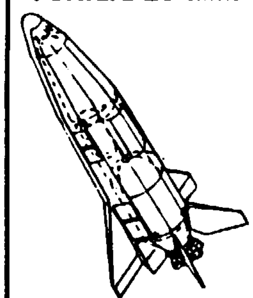
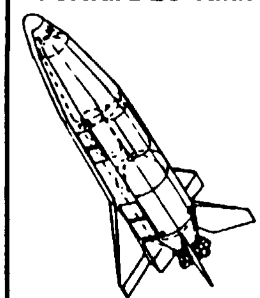
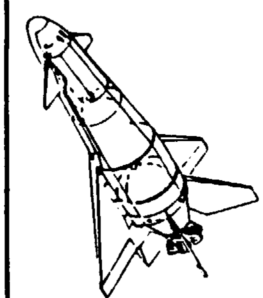
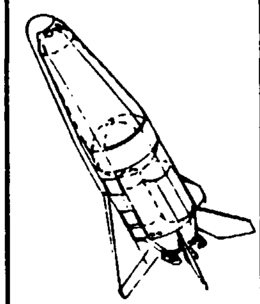
# Table 1
# These trade study options will be studied



*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 | | | | | | | |

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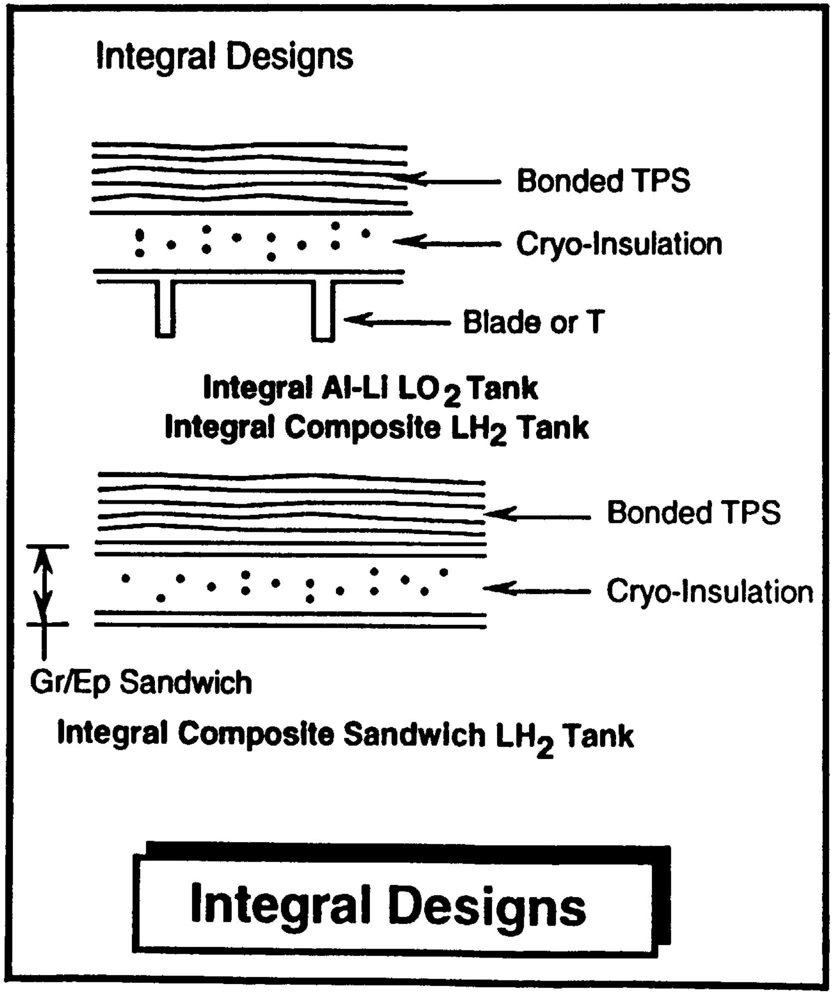
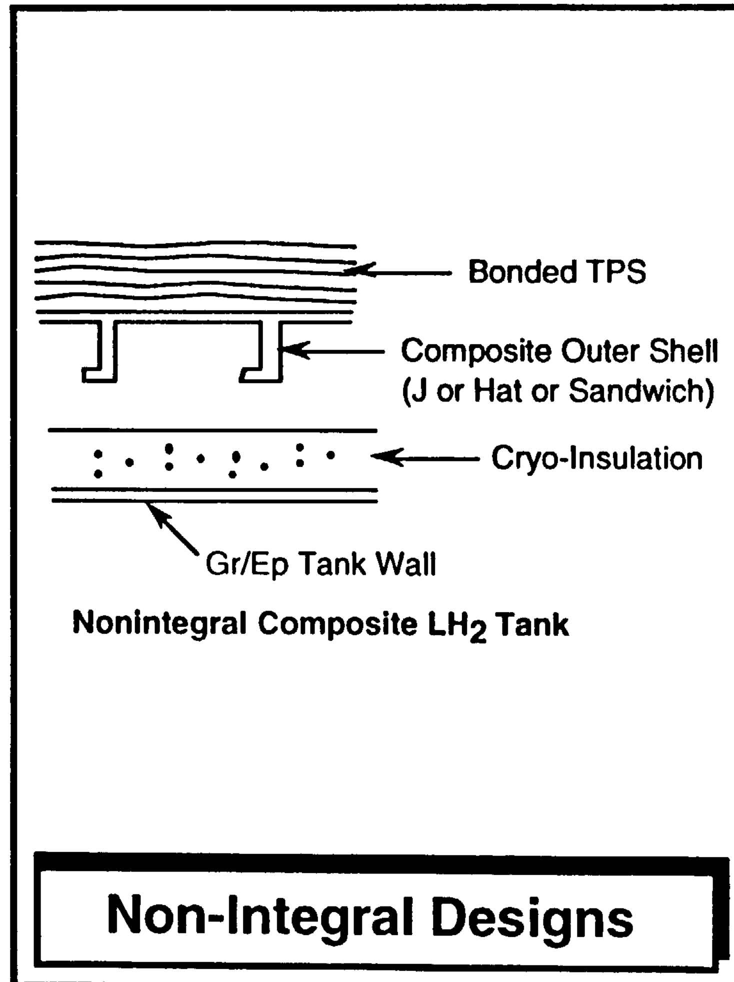
# Figure 2
# Most Promising Tank Insulation Arrangements

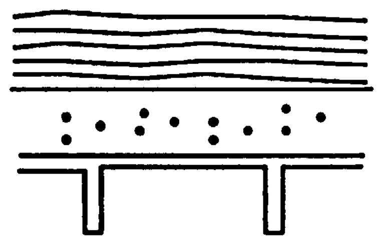




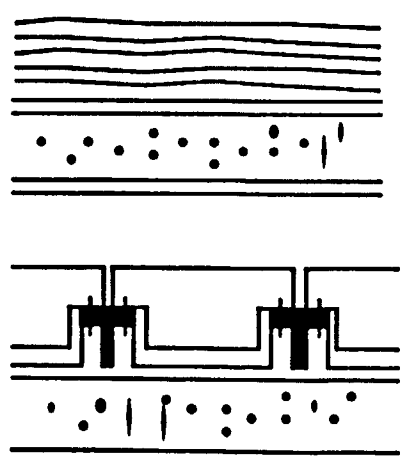



# Figure 3
# Trades Will Identify Most Suitable Designs

*REUSABLE CRYOTANKS*



**Integral Skin-Stringer Frame – External Insulation**
- Concept Very Compatible With Bonded-on TPS
- Insulation Must Maintain Adequate Strength for TPS Support
- Concept Not Compatible With Mechanically Attached TPS
- Single Skin Is Visually Inspectable From Inside
- Potential Frost Accumulation Due to Cold TPS to Insulation Bond Line (-160°F)



**Foam Insulation Sandwiched Between 2 Gr/Ep Face Sheets**
- Concept Very Compatible With Bonded-on TPS
- Concept Can Be Compatible With Mechanically Attached TPS
- Outer Skin Is Not Visually Inspectable From Inside Unless TPS Is Removed
- Insulation Is Integral Part of Primary Structure
- Additional Adhesive Bond Line for Inspection
- Potential Frost Accumulation Due to Cold TPS-to-Insulation Bond Line (-160°F)
- Constant Depth Insulation Contrary to Variation of Depth for Heating Variation Along and Around Tank

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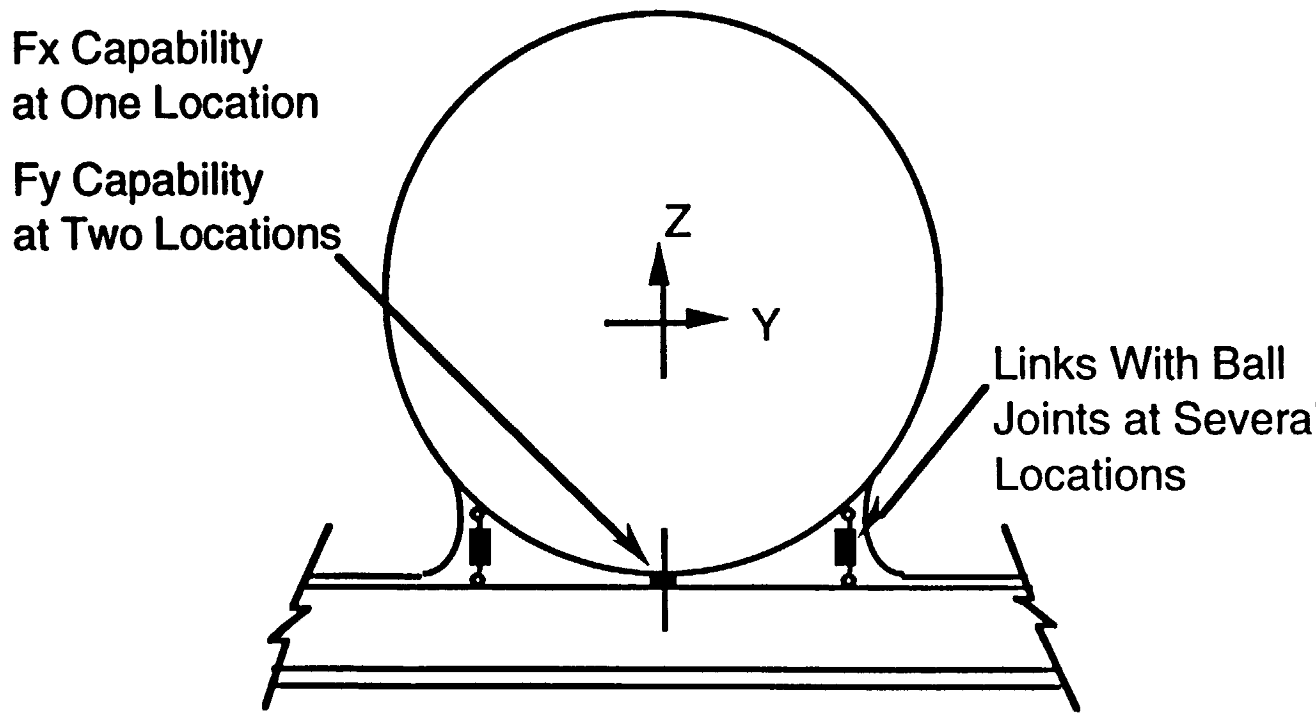
# Figure 4
# Wing Attachment Concept





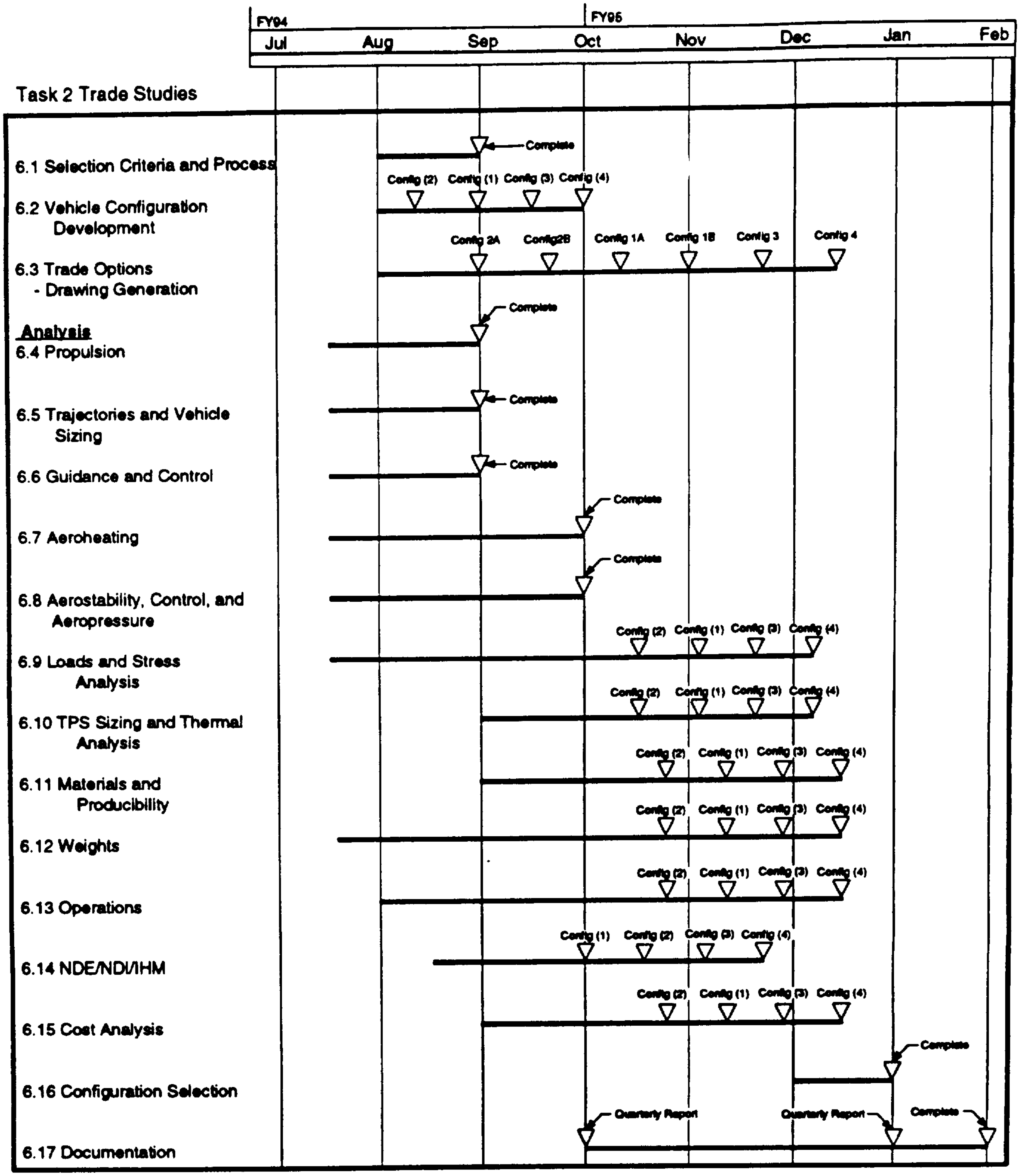
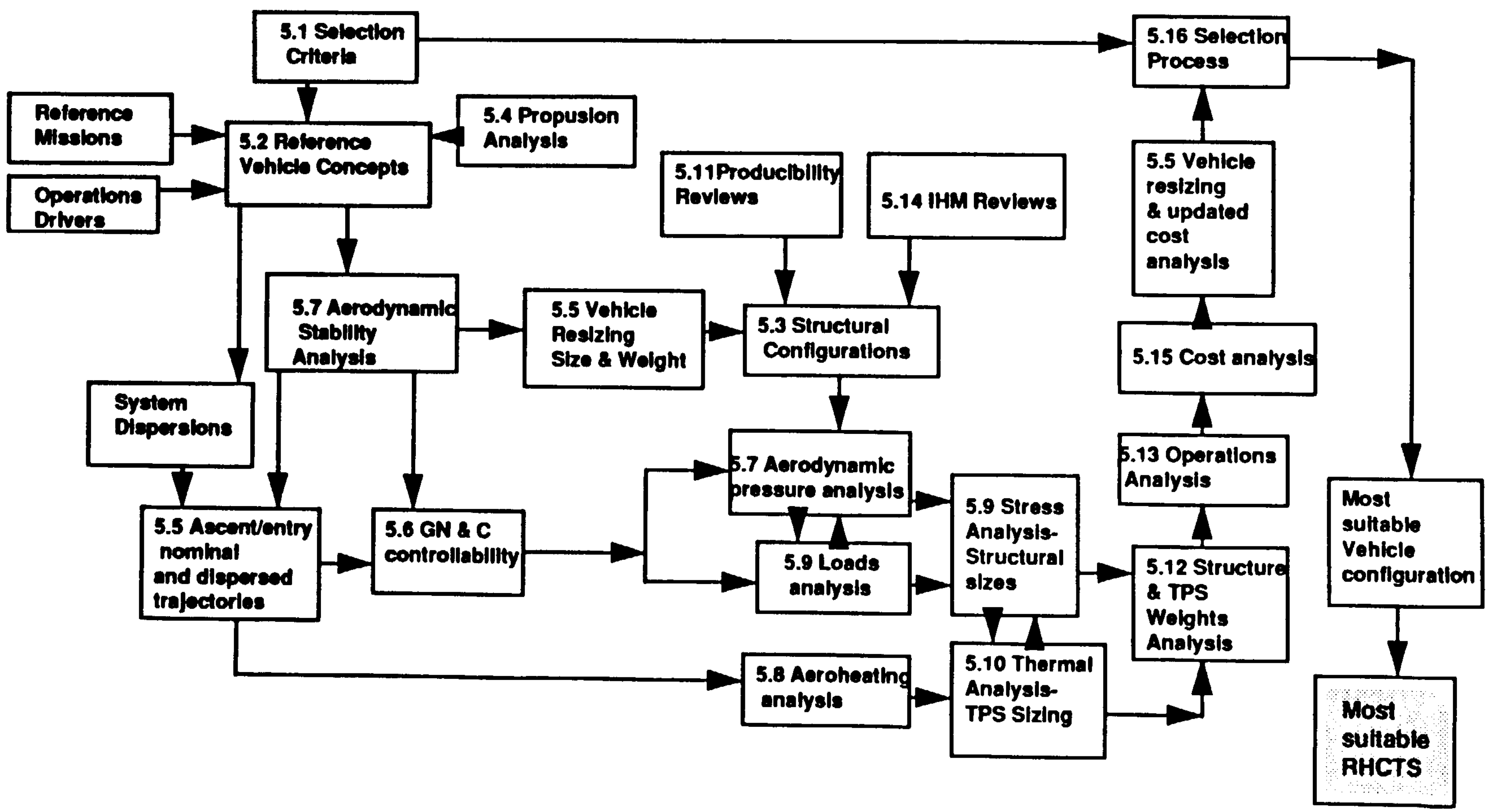



**Figure 5 - Trade Studies Will Identify Most Suitable Vehicle Configuration By Jan 1995**

## Figure 6 - Trade study Approach to establish Most Suitable RHCTS




Selection Criteria

## 4. Selection criteria

The selection criteria will include total structure and TPS weight, Design risk, development cost, operations cost, Subsystems compatibility, ascent controllability, hypersonic and subsonic aerodynamic stability, Certification, Inspectibility and amenability to IHM, Repairability, and Safety. These categories will be further detailed as necessary in a manner similar to the Task 5 AMLS study and documented in a separate report furnished by Sept 2, 1994.

## 5. Study Logic

The study logic is shown in Figure 6.

## 6. Study Subtasks

The study subtasks to be performed and expected hours are described herein. The analysis tasks will be performed according to the requirements and criteria developed in Task 1 of the project plan presented June 22, 1994 and delineated in the requirements report SSTO-REQ-1that will be issued July 29, 1994 and update on a timely basis.

6.1 Selection Criteria and Process - Selection Criteria will be established by the SSD team and NASA participation. A dictionary explicitly defining the criteria and a rating and point system will be established. NASA will also participate in the rating system. The method of allocating points to qualitative and quantitative criteria will be identified. The system will be placed on Excel spread sheets for SSD and NASA sensitivity studies - NAAD/Tulsa and Northrop/Grumman support this task. -Hours from Management Task 7, NAAD/Tulsa and Northrop/ Grumman.

6.2 Vehicle Configuration development- Establish the baseline vehicle configuration drawing for integral LH and LO tanks that is compatible with vehicle mass characteristics, aerodynamic stability, and structure load paths. Also establish the 5 other vehicle configuration drawings associated with the options of Table 1. These configurations will also be compatible with vehicle mass characteristics, aerodynamic stability, and structure load paths. NAAD/Tulsa and Northrop/Grumman support this task. - 450 hours plus NAAD/Tulsa and Northrop/Grumman

6.3 Trade options and drawing generation - The structural design will provide the appropriate load paths for the candidate vehicle options shown in Table 2. In conjunction with stress reviews appropriate candidate constructions will be established. In-board profile drawings illustrating the structural arrangement of the candidate vehicle configurations of Table 2 will be prepared. The profiles will be supplemented by additional detail for tank construction and support, insulation arrangement, wing attachment, and chine details. Support from TA 2 by Northrop/Grumman for intertank, wing and tail structures and NAAD/Tulsa for thrust structure. -1080 TA 1 hours plus half of TA1 manager hours.

6.4 Propulsion analyses - Provide engine propulsion and engine characteristics to configuration design, trajectory analysis , and GN&C for system integration and analyses. Provide pressurization system maximum relief, minimum regulator, and peak operating pressures- Define propellant flow rates, drain rates etc. - 108 hours

6.5 Trajectory definition and Vehicle sizing - Establish the nominal ascent trajectory for an SSTO mission that delivers 25, 000 lbs of payload to a 220 nm orbit at inclination of 51.6 degrees and the nominal reentry trajectory. Appropriate dispersions from the nominal trajectories are also established to support guidance and control, loads, and aeroheating requirements definition and trade study analysis. Further establish the vehicles size/mass characteristics compatible with these trajectories for a vehicle performance margin of 15 %. Provide worst case single engine out trajectories and mass properties data supporting Aft LOX tank controllability analysis.- 342 hours

6.6 Guidance and control analysis - Provide support for system requirements development and trades/analyses. Provide statistical estimates of system dispersions (thrust variation, thrust misalignment, GN&C errors, etc.) for nominal and engine out conditions to define flight environment conditions to support vehicle loads analysis. Rigid body stability analyses will be performed to assess the ascent phase controllability of a family of SSTO vehicles with aft LOX tanks. This is for engine out conditions. The approach is to determine vehicle controllability by analyzing aerodynamic derivatives and control acceleration capability. Quantify results in terms of control gains and phase margins. Rigid body analyses will be performed to determine the engine actuator loads associated with vehicle control during ascent. This is for nominal flight conditions.The analysis uses vehicle geometries showing engines gimbal and actuator attach points, mass properties data, engine characteristics , propulsion flow rate, nominal and engine out trajectories, estimate of aerodynamic forces and loads on the engines, and 6 DOF aerodynamics for ascent conditions. - 252 hours

6.7 Aeroheating analysis - Establish the equilibrium temperatures, heating rates and total heat loads, at designated points on the candidate vehicles surfaces, during ascent and entry. The analysis will include the effects of TPS roughness, steps, gaps, and surface catalycity for the baseline TPS system of PBI, TABI, CFBI, and AETB ceramic tiles. - 360 hours

6.8 Aerodynamic stability and control analyses and aerodynamic pressure definitions- Perform aerodynamic analysis to determine wing and tail location and size, elevon and flap location, size, and articulation to assure stability and control of the baseline and candidate vehicles- The analysis will also determine hinge moments for the control surfaces. Also, perform aerodynamic analysis using APAS to determine the matrix of aerodynamic pressure distributions for appropriate ascent and entry mission phases including but not limited to max qa (positive $\alpha$, negative $\alpha$, and $\beta$ angles of attack) max q, pull-up maneuver, and main gear landing. Provide ascent vehicle aerodynamic data (3 DOF and 6 DOF) to support aft LOX tank controllability analyses. Provide estimates of aerodynamics loads on main engines supporting engine actuator loads during ascent for the reference vehicle concepts. - 540 hours

6.9 Loads and stress Analysis - Loads analysis will be performed to define rigid body internal loads on the baseline configuration, during roll-out to the pad, prelaunch fueled and unfueled, lift-off (including ignition overpressure), Max $q\alpha$ (positive and negative), Max $q\beta$ , Max q and Max g (including throttling variations), Max thrust, pull-up maneuver (Mil Spec 8861) , and landing (main gear and nose gear slap down per Mil Spec 8862). Amplification due to dynamic responses are accounted for. Loads will be determined for the other vehicles and options for the appropriate critical conditions as determined from the baseline vehicle loads. Structural reviews will be conducted to assure that required load paths are provided. Candidate constructions will be agreed upon with the design group. Structural sizing analyses will be performed upon these constructions to support determination of the structures weights. The sizing will be based on the critical loading intensities determined from the internal loads. Conventional methods, on spread sheets, for pressure induced tensile and stability designs are used. Support from TA 2 by Northrop/Grumman for structural sizing of intertank, wing, and tail Gr/BMI designs and from NAAD/Tulsa for the thrust structures of IM7/977. - 1563 hours (TA 1)

6.10 TPS sizing and thermal analysis - Determine the thicknesses of TPS and cryogenic insulation for the candidate vehicles TPS designs, to satisfy specified temperature constraints on tankage and unpressurized structures. The sizing analysis for tankage will consider prelaunch fueled, ascent, and entry and as appropriate once around abort. The unpressurized structures will consider ascent, and entry, and once around abort.- 504 hours

6.11 Producibility reviews - Review the structural configuration concepts for produceablility. Support from NAAD/Tulsa and Northrop/Grumman- 162 hours plus NAAD/Tulsa and Northrop/Grumman.

6.12 Weights analysis- The weights analysis will support the initial vehicle sizing analysis with weight history data obtained from prior baseline and candidate vehicle weight studies. Also the structure, cryogenic insulation, and TPS weight will be determined for the configuration options shown in Table 2. The weights will use the actual data from the structural analysis and TPS sizing analysis supplemented as necessary by appropriate historical data. Support from NAAD/Tulsa and Northrop/Grumman- 576 hours plus NAAD/Tulsa and Northrop/Grumman.

6.13 Operations - Perform analysis of the Structures and TPS options shown in Table 2 to support configuration selection. The analysis will use the STS Orbiter data base as an initial basis, modified by the benefits of advanced more durable TPS (AMLS and IR & D data) for determination of operational variables such as No. of TPS repairs, No. of TPS removals/replacements, time requirements, technician requirements, turnaround time, propellant loading impacts, etc... Other areas of impact such as LO tank aft vs forward and common bulkhead filling constraints will be assessed as issues arise during the study.- 576 hours

6.14 NDE/NDI/IHM - Assess each of the design options for ease of inspection and maintainability to support the configuration selection process.- 120 Hours from Task 6 (not included in total hours herein)

6.15 Cost Analysis - Cost estimates for design, development, test, and evaluation (DDT&E), production, and operations will be developed for each option in Table 2. The SSTO Cost Model will be expanded in the structures and TPS areas and updated using data from Rockwell and Northrop/Grumman.These cost histories, together with "expert judgments", will be used to adjust the cost estimating relationships(CER's) to reflect technological enhancements and capabilities feasible for an SSTO type program. Hours estimates developed in task 5.13 will be used to adjust the SSTO Operations Model, which will be used to estimate total operations costs forecasts for an SSTO System. The two models will also utilize inputs from the weight sizing program to develop total costs for an SSTO launch vehicle sized for a fixed-payload capability and given mission flight rate for each option. Quantifying the cost uncertainty for each option will utilize a commercially available software program @Risk using "expert judgments" as inputs-410 hours plus NAAD/Tulsa and Northrop/Grumman.

6.16 Configuration Selection - The data developed in the above described tasks will provide the information for the selection criteria. The same method as that used in Task 5 of the AMLS study and documented in SSD 93D0310 will be used. The method provides scores for the various design options. The scores in conjunction with experience driven judgment will be the basis for recommendation of the most suitable vehicle configuration to NASA. Support from NAAD/Tulsa and Northrop/Grumman - 672 hours plus NAAD/Tulsa and Northrop/Grumman.

6.17 Documentation - The trade studies will be documented in briefings in early October 1994, and early January 1995 and in a final briefing in March 1995.- Hours from Management task and NAAD/Tulsa and Northrop/Grumman.

Management reserve hours - 835 hours

Total hours - 8550 hours

Estimated total hours from TA 2 for wing, tail, and intertank structure analysis - 2400

Grand total hours - 10,950 hours

# APPENDIX

# TA2 TRADE STUDY PLAN

## 1. Objective

To determine (with the support from TA 1) the most suitable SSTO vehicle structural configuration in order to identify the most suitable Intertank, Wing and Wing attachment system, and Thrust structure designs and materials systems. These designs will be the prototype designs for subsequent design definition that will be the basis for the design and fabrication of full scale segments for verification of fabricability, and strength suitability later in the project.

## 2. Approach

The four configurations shown in Figure 1 are considered for this study. Configurations No. 1 and No. 2 place the payload bay between the cryogenic tanks. The $LH_2$ tank is forward in configuration 1 and aft in Configuration 2. Configurations No. 3 and No. 4 , respectively, place the payload bay forward and aft of the tanks. The major pros and cons of each configuration using integral tanks are:

• No. 1 - Expected lightweight, most difficult ascent control , complex wing attachment design

• No. 2 -Expected heaviest weight , best ascent control, complex wing attachment design (The wing attachment is simplified for a non-integral tank)

• No. 3 - Expected lightest weight, most difficult ascent control , complex wing attachment design, worst payload in/out c.g excursion, added design risk and operations with common bulkhead

• No. 4 - Expected heavy weight, adequate ascent control, simplest wing attachment , least payload in/out c.g excursion, worst payload acoustic environment, added design risk and operations with common bulkhead.

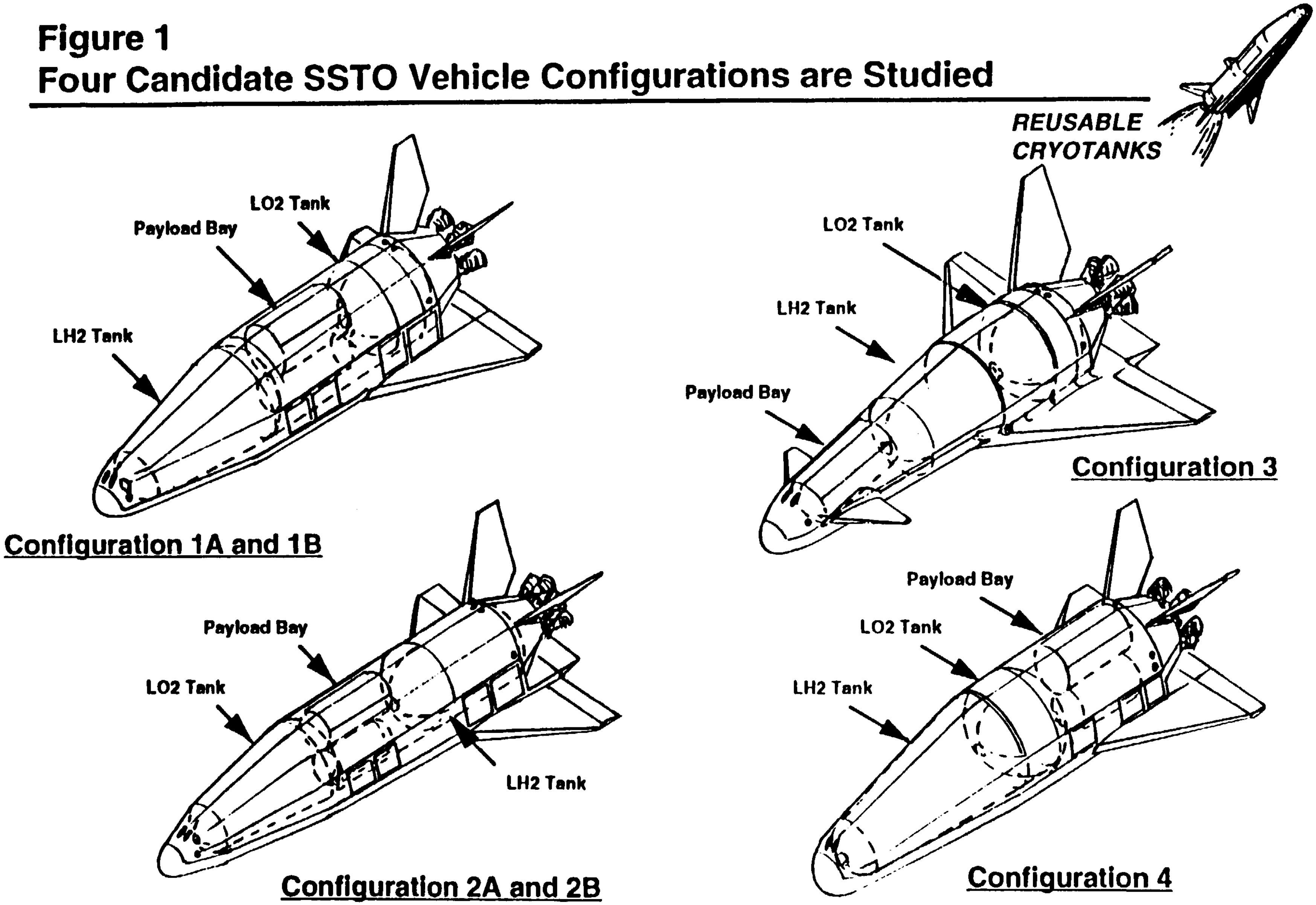
The common bulkheads are compression -stable designs using 2 face sheets, with honeycomb sandwich core, between the $LO_2$ and $LH_2$ propellants. For safety a GSE purge system senses any $LO_2$ or $LH_2$ leakage into the honeycomb sandwich core.

Table 1 illustrates the design options for this configuration that are included in the larger matrix of trades in Tables 1 and 2 of TA-1. This TA 2 matrix provides all the necessary combinations for support of TA 1 and the basis for the material and TPS trades delineated in Tables 2 and 3 herein. Each option also (see Table 1) contains a different way of attaching the wing. These options are further discussed as follows:

• Wing attachment variations - A potential concept for wing attachment in Configurations 1 to 3 is shown in Figure 2. Attachment to a cryogenic tank involves penetration of the insulation, requires accommodation of fueling/pressurization 3 dimensional changes, and imposes a more complex stress environment in the tank. Attachment to the thrust structure avoids this , but may represent increased wing weight. Attachment to the fuselage in configuration 2B- avoids the foregoing but may have the heavier tank and fuselage design associated with a non-integral tank. Configuration 4 is the best option for wing attachment but is expected to have the heaviest payload bay structure design and most severe payload acoustic environment. This wing attachment method avoids the weight penalty of the fairing structure that is in Configurations 1 to 3.

• Composite Materials/TPS variations - The lower temperature materials have higher strength and stiffness properties and are therefore expected to represent the lightest weight intertank, wing, tail, control surface and thrust structure. The lower temperatures will also represent the highest TPS weights. The use of materials with increased temperature capability also minimizes the extent of TPS which is highly desirable for reduction of operation time and cost. The materials options represented in Table 2 and 3 are the basis for this

## Figure 1
## Four Candidate SSTO Vehicle Configurations are Studied

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| TRADE OPTION NO. | LH TANK | LH TANK INSULATION | TANK OUTER FUSELAGE | WING ATTACH | CHINES | TPS ON LH TANK | TPS ON TANK OUTER FUSELAGE |
|---|---|---|---|---|---|---|---|
| 1B-1 | NON-INTEGRAL | EXTERNAL | Gr/BMI | TO LOX TANK | 1B BASELINE | NONE | BONDED/MECH ATTACHED |
| 1B-2 | NON-INTEGRAL | EXTERNAL | Gr/BMI | TO THRUST STRUCTURE | 1B BASELINE | NONE | BONDED/MECH ATTACHED |
| 2B-1 | NON-INTEGRAL | EXTERNAL | Gr/BMI | TO OUTER FUSELAGE | 2B BASELINE | NONE | BONDED/MECH ATTACHED |
| 3A-1 | INTEGRAL | EXTERNAL | NONE | TO LOX TANK | 3A BASELINE | BONDED DESIGN | NONE |
| 4A-1 | INTEGRAL | EXTERNAL | NONE | TO PL BAY FUSELAGE | 4A BASELINE | BONDED DESIGN | NONE |

TABLE 1 - CONFIGURATIONS UNDER CONSIDERATION WITH TA2

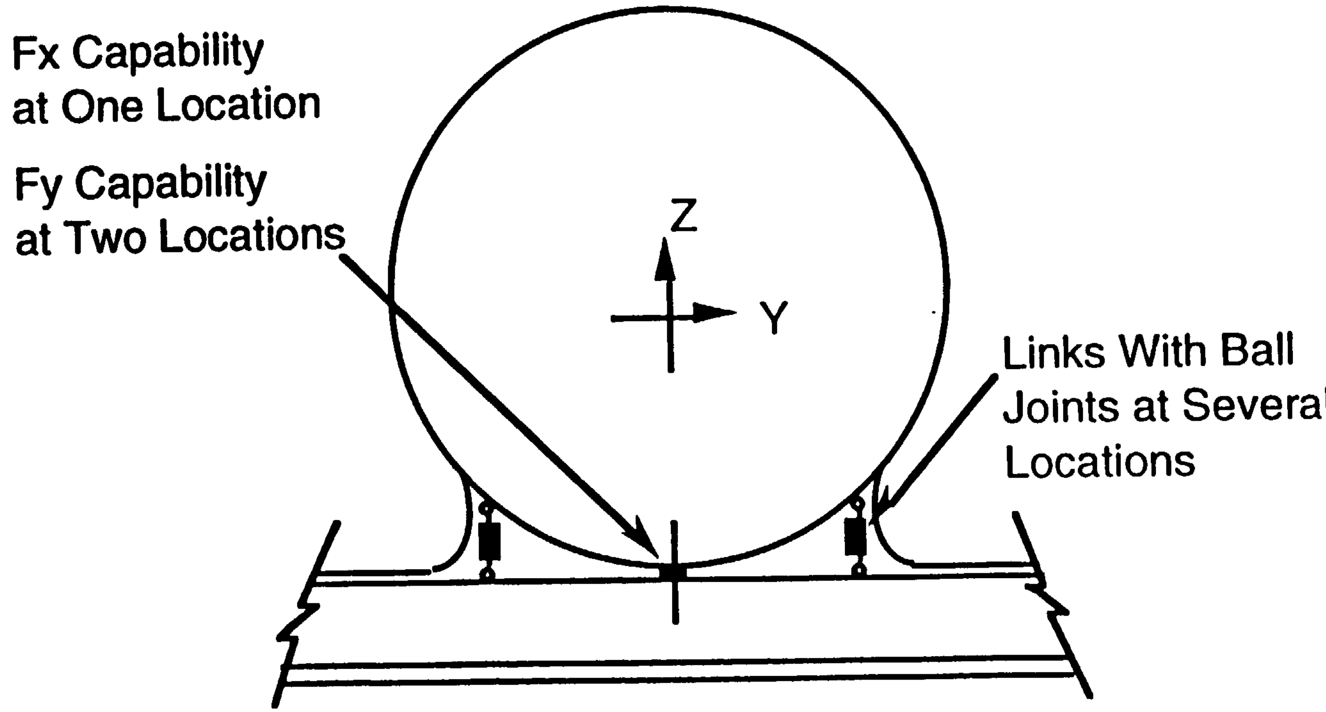
| SECTION \ CANDIDATE MATERIAL | LTM (250 F) | IM7/977-2 (300 F) | Gr/BMI (375 F) | AFR 700 (700 F) | TMC (1200 F) | BLACKGLAS (1200 F) |
|---|---|---|---|---|---|---|
| INTERTANK | YES | NO | YES | YES | NO | NO |
| WING | YES | NO | YES | YES | YES | NO |
| CONTROL SURFACES | YES | NO | YES | YES | YES | YES |
| THRUST STRUCTURE | YES | YES | YES | YES | NO | NO |

TABLE 2 - CANDIDATE MATERIALS FOR VARIOUS SECTIONS OF VEHICLE

| COMPOSITE MATERIAL AND TEMPERATURE LIMIT | TYPE OF THERMAL PROTECTION SYSTEM | | | | |
|---|---|---|---|---|---|
| | INTERTANK | THRUST STRUCTURE | WING | TAIL | CONTROL SURFACES |
| LTM - 250°F | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI ON HEAT SHIELD | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED |
| IM7/977-2 - 300°F | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI ON HEAT SHIELD | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED |
| Gr/BMI - 375°F | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI ON HEAT SHIELD | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED |
| AFR 700 - 700°F (ADHESIVES TO 550°F) | PBI, TABI, AETB, MECH ATTACHED | N.A. | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED | PBI, TABI, AETB, MECH ATTACHED |
| BLACKGLAS - 1200°F | N.A. | N.A. | N.A. | N.A. | N.A. |
| TMC - 1200°F | N.A. | N.A. | MECH ATTACHED | MECH ATTACHED | MECH ATTACHED |

TABLE 3 - COMBINATIONS OF COMPOSITE MATERIALS AND TPS

# Figure 2
# Wing Attachment Concept



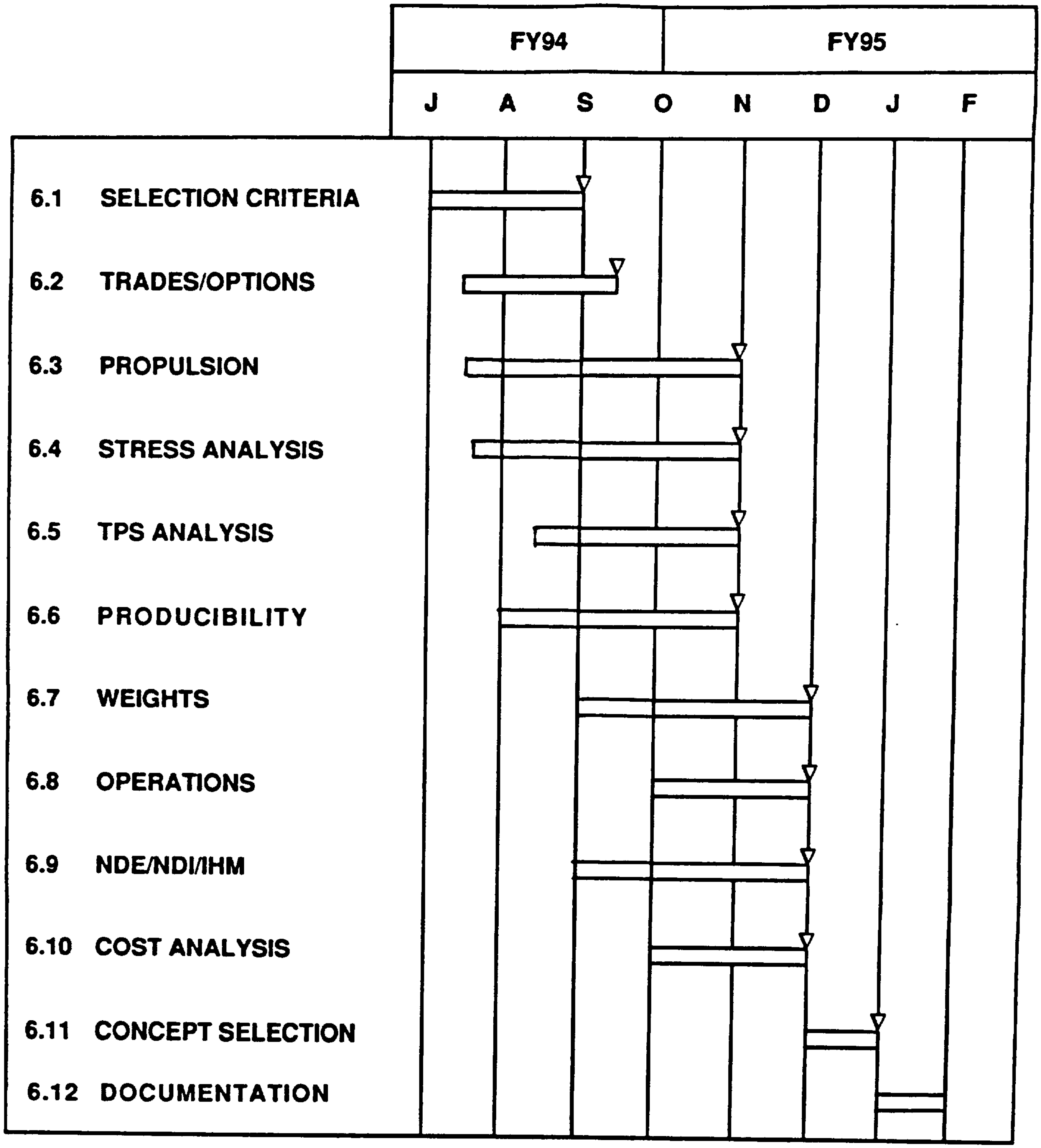



FIGURE 3 - TRADE STUDIES COMPLETE BY JANUARY 1995

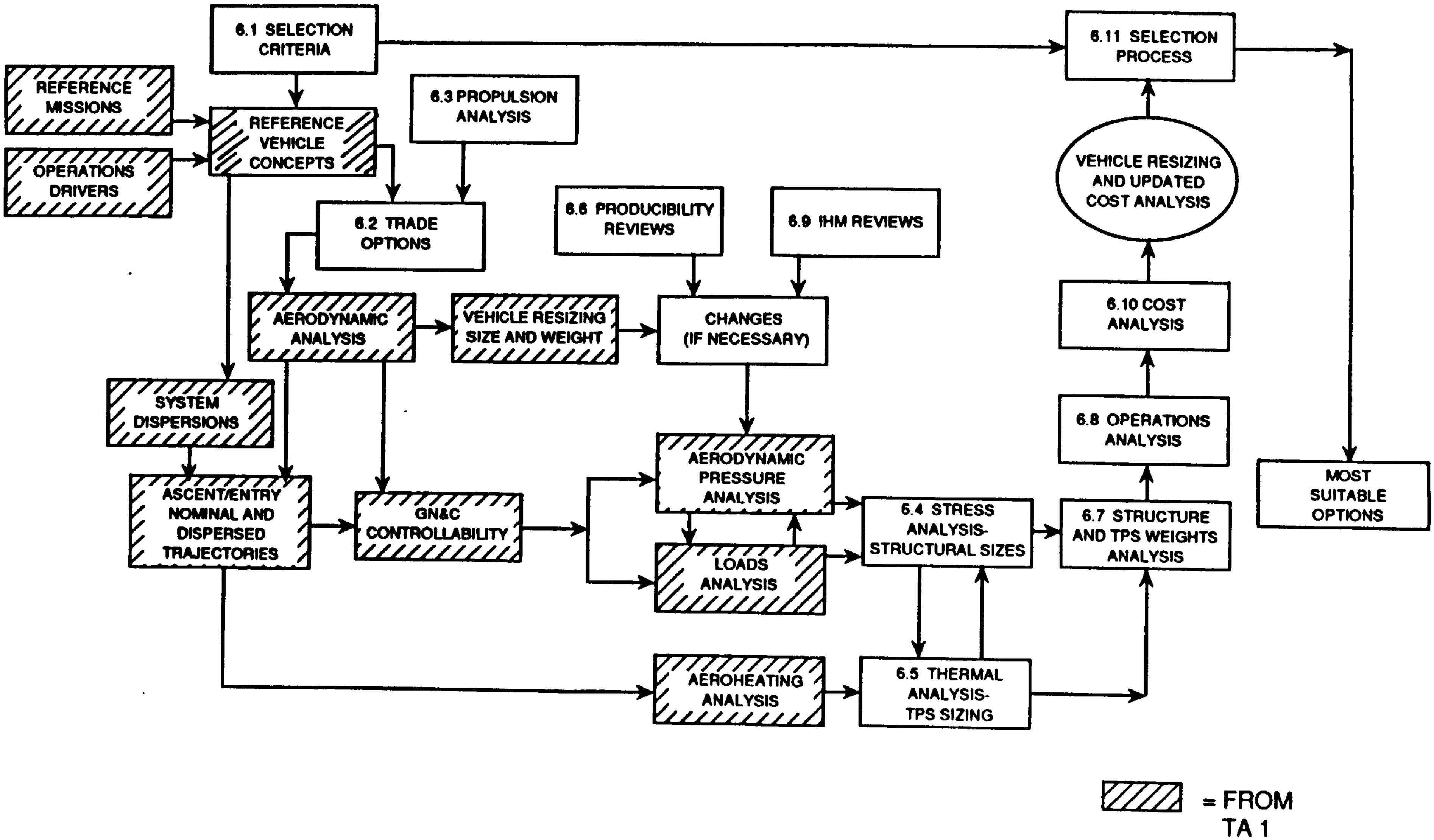



FIGURE 4 - TRADE STUDY APPROACH TO INVESTIGATE OPTIONS

trade study within TA 2 (TA 1 will be based on use of Gr/BMI for all structures except the thrust structure which is IM7/977-2).

• Thrust structure and heat shield- The comments above regarding intertank, wing, tail and control surface lower temperature materials usage and TPS are applicable to the thrust structure. In addition the implication of thermal protection of the engines feedlines and another subsystems must be considered.

Each of the options listed in Table 1 to 3 will be analyzed to the necessary level of detail in order to select the most suitable design. Where similarity exists structure weights may be determined by scaling from similar structure determined in detail. Further as the design progresses if it is apparent that an option is not worth investing further the SSD team will recommend that the option be removed.

## 3. Schedule

The schedules for these trade studies are shown in Figure 3.

## 4. Selection Criteria

The selection criteria will include total structure and TPS weight, design risk, development cost, operations cost, subsystems compatibility, certification, inspectibility and amenability to IHM, repairability, and Safety. These categories will be further detailed as necessary in a manner similar to the Task 5 AMLS study and documented in a separate report furnished by Sept 2, 1994.

## 5. Study Logic

The study logic is shown in Figure 4.

## 6.0 Study Subtasks

The study subtasks to be performed and expected hours are described herein. The analysis tasks will be performed according to the requirements and criteria developed in Task 1 of the project plan presented June 21, 1994 and delineated in the requirements report SSTO-REQ-1 that will be issued July 29, 1994 and updated on a timely basis.

6.1 Selection Criteria and Process - Selection Criteria will be established by the SSD team and NASA participation. A dictionary explicitly defining the criteria and a rating and point system will be established. NASA will also participate in the rating system. The method of allocating points to qualitative and quantitative criteria will be identified. The system will be placed on Excel spread sheets for SSD and NASA sensitivity studies - NAAD/Tulsa and Northrop/Grumman support this task. -Hours from Management Task 9, plus 300 hours from NAAD/Tulsa and Northrop/ Grumman

6.2 Trade options and drawing generation - The vehicle configuration options shown in Figure 1 and detailed in TA 1 will be used. The structural design will provide the appropriate load paths for the candidate vehicle options shown in Table 1. In conjunction with stress reviews appropriate candidate constructions will be established. Structural arrangement of the intertank, wing, tail and thrust structure and heat shield will be prepared and supplemented by additional details of wing attachment, intertank payload support, propulsion system layouts, and heat shield design. - 1400 hours

6.3 Propulsion - Establish engine thrust levels, dimensions and mounting requirements, engine actuator mountings, feed line sizes and routings, and temperature limits for critical engine items to support thrust structure and heat shield design and analysis. - 300 hours

6.4 Stress Analysis - The loads determined in TA 1 will be used. Structural reviews will be conducted to assure that required load paths are provided. Candidate constructions will be agreed upon with the design group. Structural sizing analyses will be performed upon these constructions to support determination of the structures weights. The sizing will be based on the critical loading intensities determined from the internal loads. Conventional methods, on spread sheets, for stability of sandwich or ski-stringer designs are used- 1300 hours

6.5 TPS Sizing and Thermal Analysis - The aeroheating data determined in TA 1 will be used. Determine the thicknesses of TPS for the materials and TPS options shown in Tables 2 and 3. The sizing analysis will consider ascent, and entry and as appropriate once around abort. The thrust structure and heat shield thermal analysis will use plume heating determined in TA 1.- 500 hours

6.6 Producibility Reviews- - Review the structural configuration concepts for produceablility. - 420 hours

6.7 Weights Analysis - Generate structure and TPS weights for the baseline Gr/BMI intertank wing, tail, and control surfaces, and IM7/977-2 thrust structure and heat shields for the attachment options shown in Table 1. Also generate the structure/TPS weights for the intertank wing, tail, and control surfaces for the material and TPS options shown in Tables 2 and 3 The weights will be generated using the structural sizing and TPS data supplemented by historical data. - 700 hours

6.8 Operations - Perform analysis of the Structures and TPS options shown in Tables 2 and 3. The analysis will use the STS Orbiter data base as an initial basis, modified by the benefits of advanced more durable TPS (AMLS and IR & D data) for determination of operational variables such as No. of TPS repairs, No. of TPS removals/replacements, time requirements, technician requirements, turnaround time, propellant loading impacts.- 500 hours

6.9 NDE/NDI/IHM - Assess each of the design options for ease of inspection and maintainability to support the configuration selection process.- 120 Hours from Task 7 (not included in total hours herein)

6.10 Cost Analysis - Cost estimates for design, development, test, and evaluation (DDT&E), production, and operations will be developed for each option in Table 2 and 3. The SSTO Cost Model will be expanded in the structures and TPS areas and updated using data from Rockwell and Northrop/Grumman. These cost histories, together with "expert judgments", will be used to adjust the cost estimating relationships(CER's) to reflect technological enhancements and capabilities feasible for an SSTO type program. Hours estimates developed in the operations task will be used to adjust the SSTO Operations Model, which will be used to estimate total operations costs forecasts for an SSTO System. The two models will also utilize inputs from the weight sizing program to develop total costs for an SSTO launch vehicle sized for a fixed-payload capability and given mission flight rate for each option. Quantifying the cost uncertainty for each option will utilize a commercially available software program @ Risk using "expert judgments" as inputs- 760 hours.

6.11 Selection Process -The data developed in the above described tasks will provide the information for the selection criteria. The same method as that used in Task 5 of the AMLS study and documented in SSD 93D0310 will be used. The method provides scores for the various design options. The scores in conjunction with experience driven judgment will be the basis for recommendation of the most suitable vehicle configuration to NASA. Support from NAAD/Tulsa and Northrop/Grumman -570 hours

6.12 Documentation - The trade studies will be presented/ documented in briefings in early October 1994, early January 1995, and March 1995- TA 2 Management hours plus 600 hours

Total hours allocated - 7350

Management Reserve = 949

Total Hours = 8299