R. EVANS KSC. PT-EL

STME UPDATE

10 October 1991

STME UPDATE AGENDA

Topic	Speaker
• Generalized Description of Engine	Connell
Physical Features	
Characteristics	
• How Program Will Operate	Connell
• Detailed Description by Component	
LOX Pump	Connell
Fuel Pump	McMillion
Gas Generator	Lacefield
Controls	Lacefield
Injector	Lacefield
Chamber	McMillion
Nozzle	Connell
• Vehicle Trade Influencing Engine	Connell

GENERAL DYNAMICS
SPACE SYSTEMS DIVISION

Report No. GDSS-NLS-91-003

LEVEL III TRADE STUDY 3P006 INTERIM REPORT

PROPULSION MODULE CONCEPT DISCRIMINATOR APPLICABILITY

17 December 1991

FOREWORD

This document is arranged in two sections. Section 1 describes the baseline Reference Zero concept, with some suggested features thought to be viable for incorporating into the baseline for Cycle 1. The description is written in four subsections, each dealing with a level of the trade tree established by GDSS for this trade study. The four subsections are:

1. ENGINE ARRANGEMENTS
2. THRUST STRUCTURES
3. SEPARATION CONCEPT
4. PROPELLANT FEED SYSTEMS

The concept descriptions also include descriptions of viable alternative subsystem concepts which will be discussed with the discriminators in Section 2.

Section 2 is organized with 20 subsections, one for each of the discriminators. Each discriminator section includes a written discussion of the concept in terms of the discriminator. A table lists the applicable Pro's and Cons as we see them today. Most of the discriminator sections have subsections dealing directly with the four levels of the trade tree listed above. Omission of a writeup for a specific trade tree level signifies that the discriminator does not apply or that the discussion for another level already covers the subject.

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1.0 DISCUSSION OF THE FEATURES OF THE BASELINE PROPULSION MODULE ARRANGEMENT

The baseline design, incorporating GDSS suggested features for the propulsion module, is shown in figure 1.0-1. This view shows a cutaway view of the 1.5 Stage configuration, which is common with the HLLV (with appropriate deletion of the center thrust cone engines and subsystems). The booster engines (and core engines for the HLLV) for the 1.5 stage vehicle are located on the skinline of the vehicle protected from the aero loads by aerodynamically optimized fairings. The thrust loads from the engines are carried through longerons integral with the booster skinline structure. The sustainer engines for the 1.5 stage vehicle are mounted on a conical adapter which carries the engine thrust loads to the skinline of the tank.

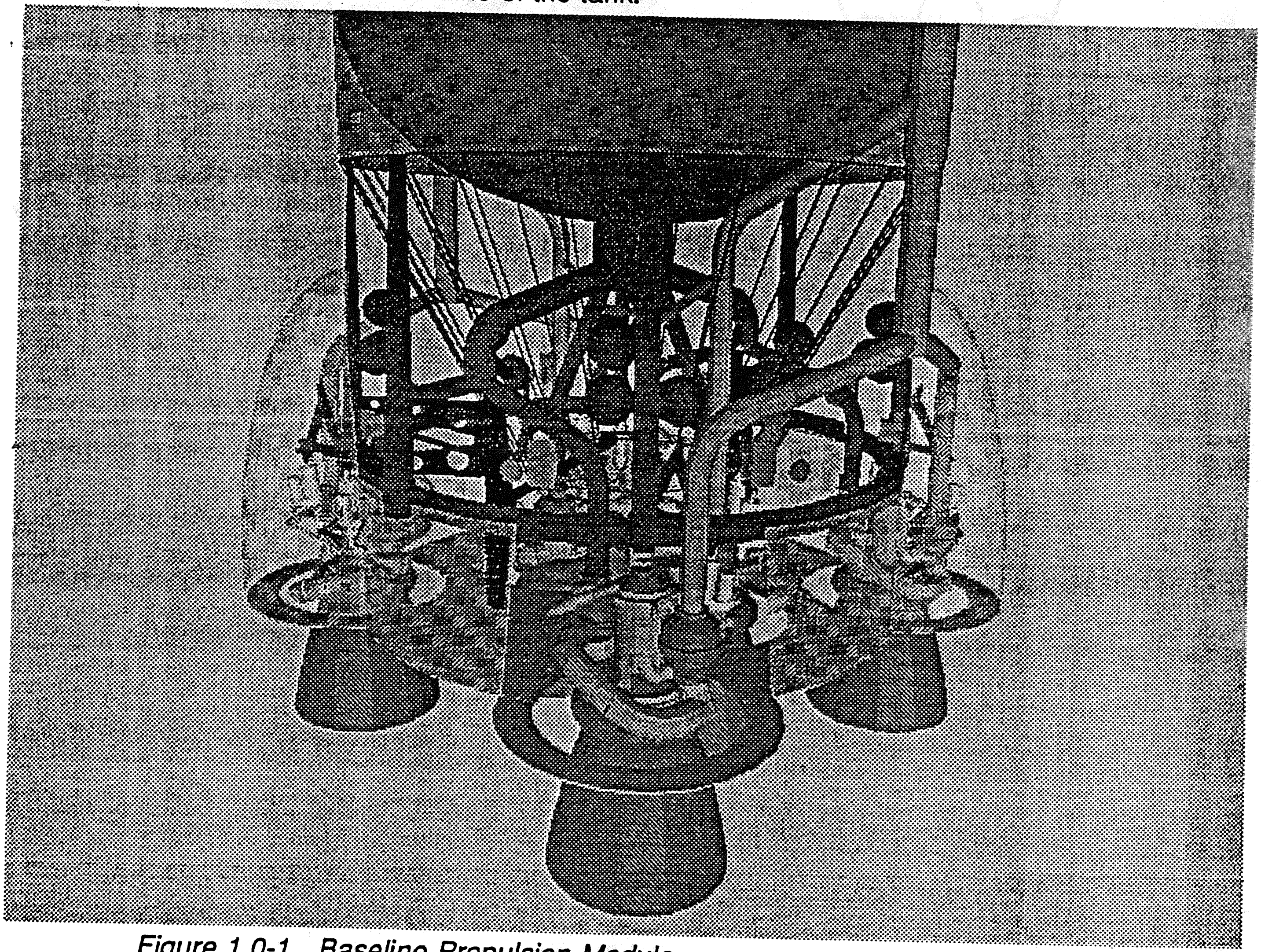


Figure 1.0-1. Baseline Propulsion Module

1.1 ENGINE ARRANGEMENT

The baseline engine arrangement has four booster engines positioned on the skinline of the thruster barrel and two sustainer engines positioned on a conical adapter. (See figures 1.1-1 and 1.1-2) The booster engines are located on 90° centers, thus giving the maximum engine gimbal angle possible with the HLLV configuration and its associated ASRM boosters.

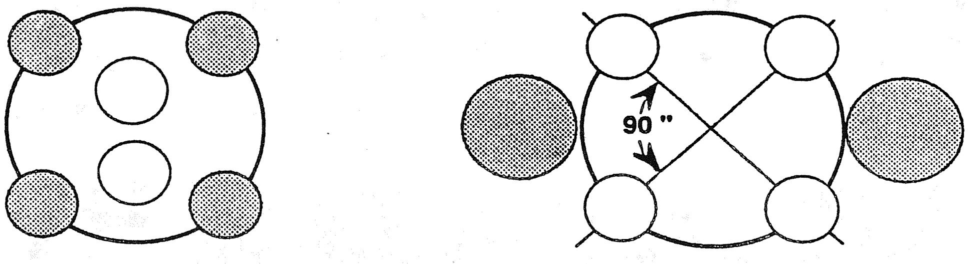


Figure 1.1 - 1 Baseline engine arrangement for 1.5 Stage and HLLV

The engine arrangement is sensitive to several ground and airborn system interface design issues, as listed in Table 1.1-1.

Table 1.1-1 Interface elements with the engine arrangement

Ground systems interfaces with the engine arrangement
  - Manufacturing tooling fixtures
  - Manufacturing Assembly process
  - Technican access for small LRU (maintainability)
  - Engine replacement
  - Work platforms for horizontal and vertical checkout

Airborne systems interfaces with the engine arrangement
  - Arrangement of thrust longerons
  - Gimbal capability with the sustainer engines
  - Gimbal capability with the ASRBs
  - Compatibility with the 1/2 stage jettison system

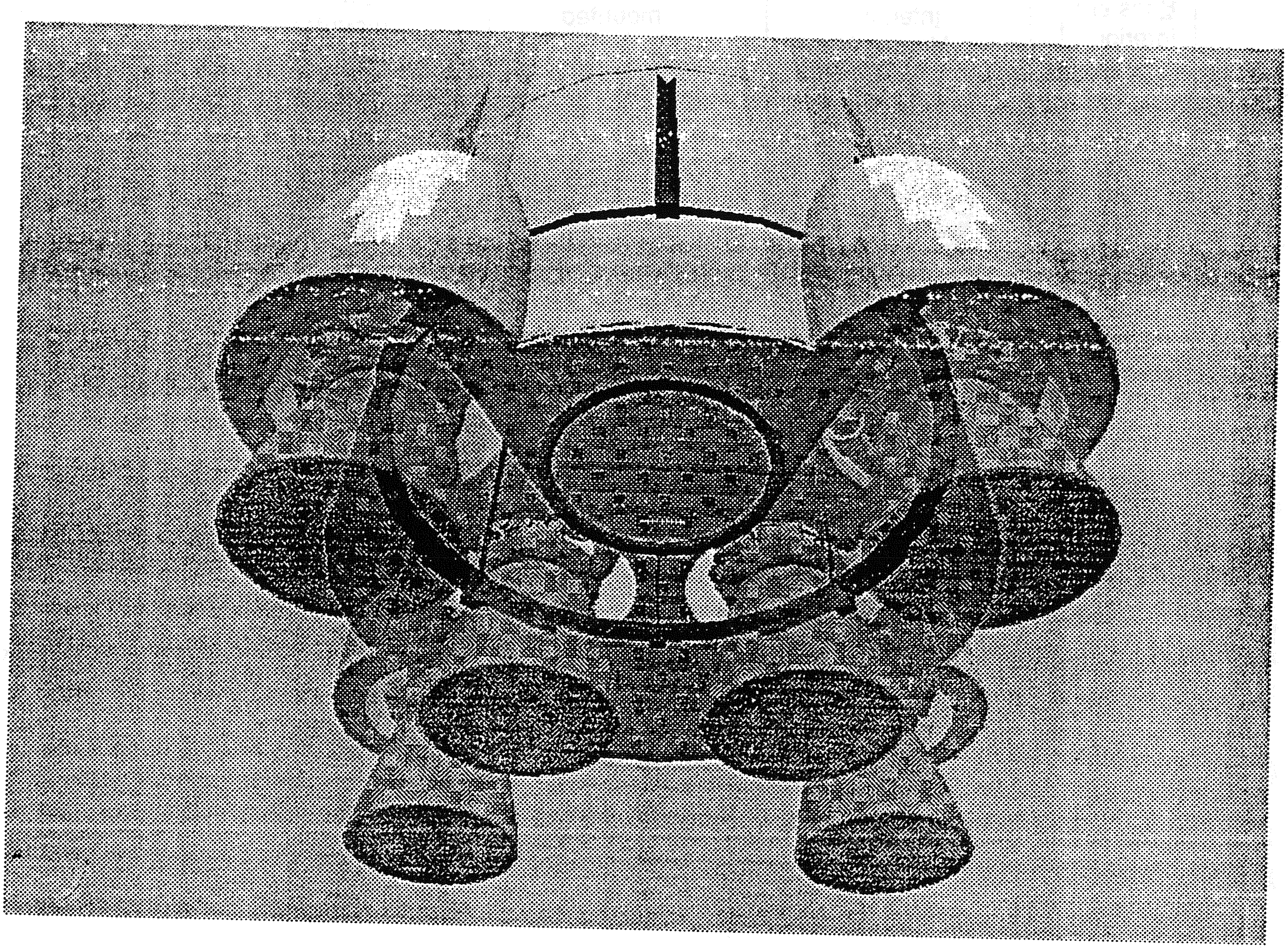


Figure 1.1-2 Pictorial layout of the engines in the propulsion module

The reference zero baseline engine arrangement was included in the trade tree representing the various options of the engine arrangements for the NLS vehicles. Figure 1.1-3 shows various representative options for the 1.5 stage configuration. The number shown represents the number of options within that leg of the tree that were viable candidates for further consideration. The baseline (reference zero) concept is outlined for identification in the option list.

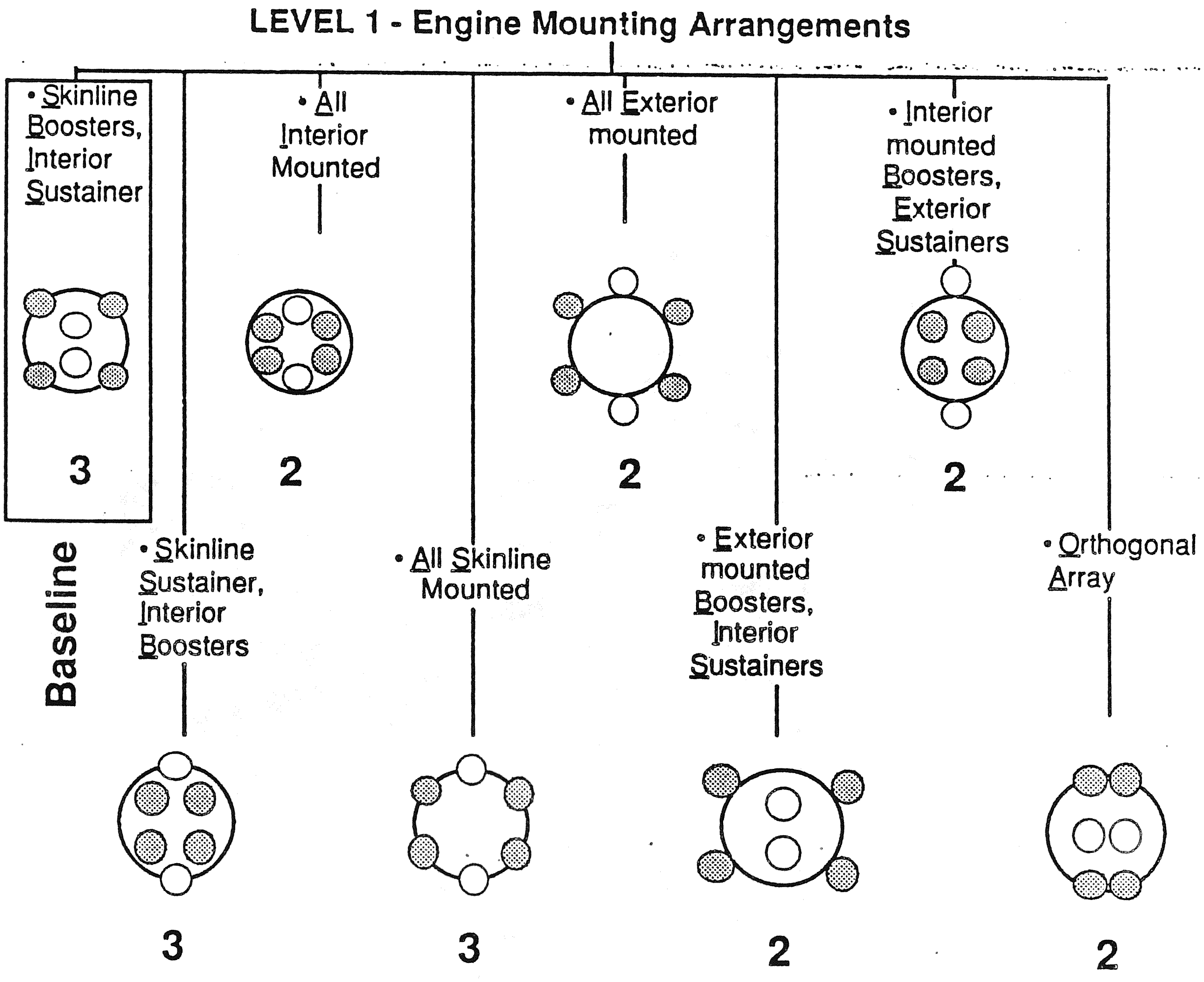


Figure 1.1-3 Trade tree used for consideration of engine arrangement

1.2 THRUST STRUCTURE

The 1-1/2 stage thrust structure for NLS is comprised of two major elements. The sustainer structure, which supports two 580k engines and the booster structure which supports four 580k engines and provides an interface for launch platform holddowns and attachment to the aft skirt. Additionally, the thrust structure shall provide for secondary attachment hardware such as propellant feed-lines, TVC actuators, separation and guide rail systems, electrical and pneumatic disconnects, avionics packages, heat shield, and helium bottles. The basic booster and sustainer sections are composed of rolled ring forged/machined frames, integrally machined skin/stringers, and thrust posts at the engine locations. Figure 1.2-1 illustrates the basic thrust structure configuration.

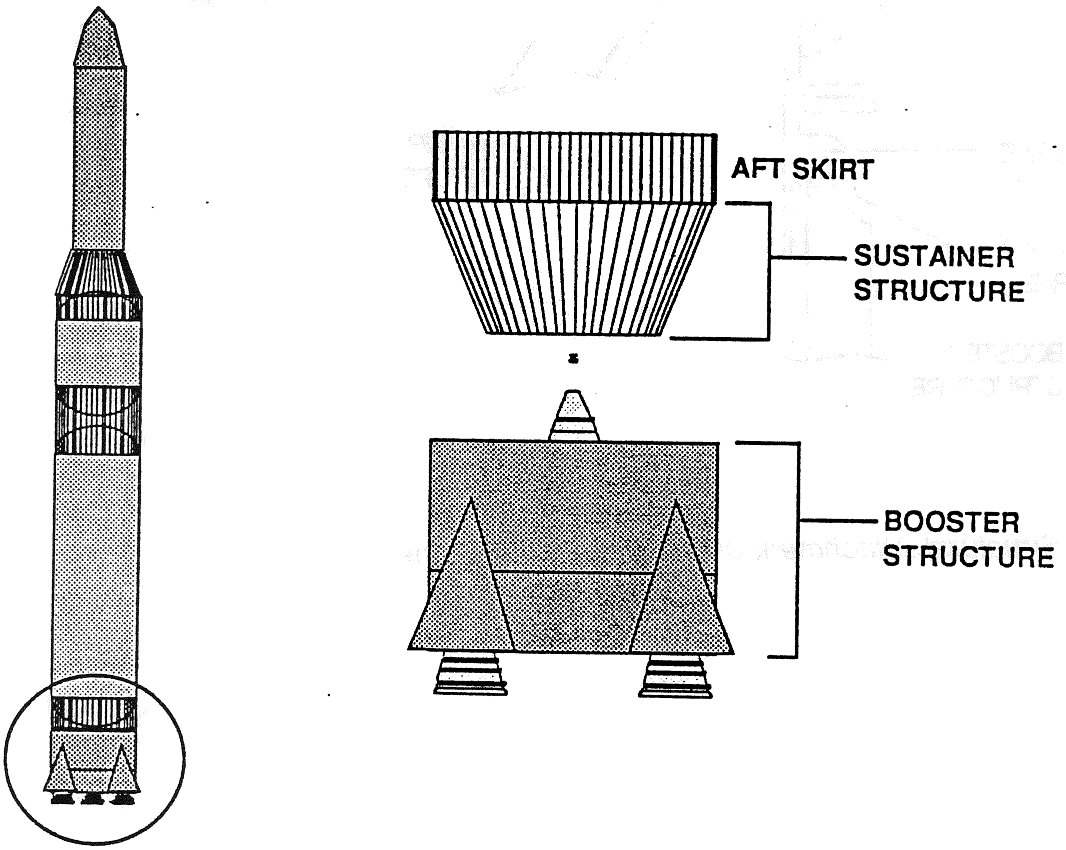


Figure 1.2-1 Basic Structural Configuration

The interface of the aft skirt to the booster and sustainer structure is illustrated in figure 1.2-2. This configuration eases manufacturing, and assembly and allows for easy removal of the sustainer structure for HLLV vehicles. Analytically, this configuration provides an optimum load path to the aft skirt which results in reduced weight.

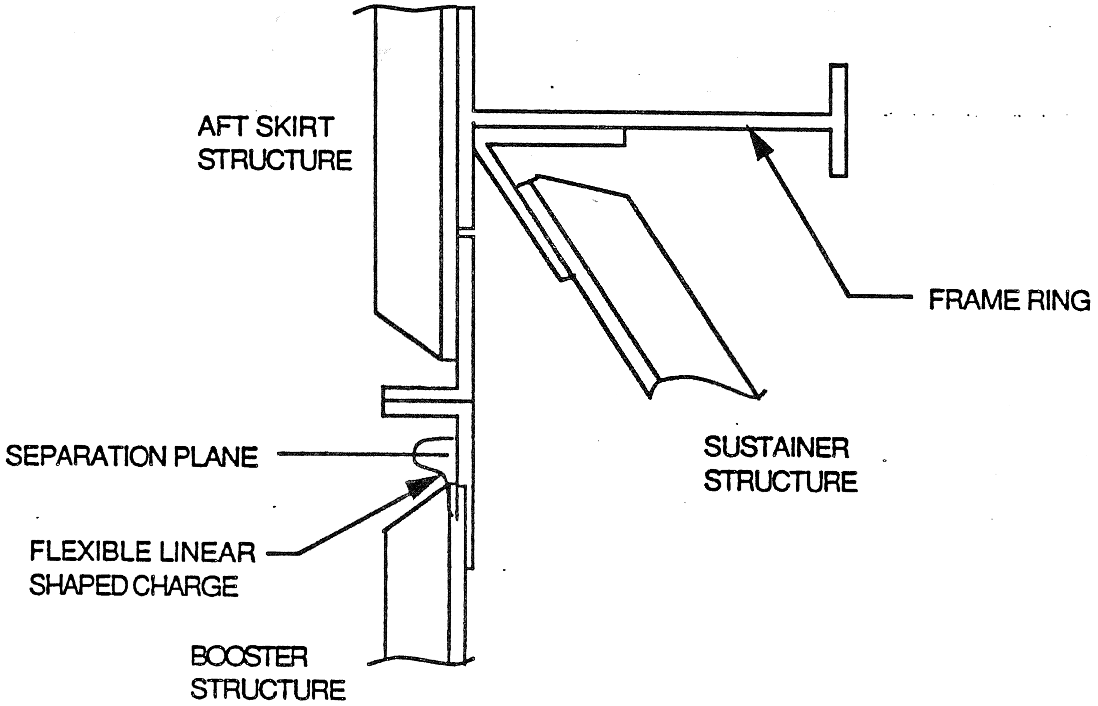


Figure 1.2-2 Structural Attachment of Booster and Sustainer

The NLS holddown system illustrated in Figure 1.2-3 is very similar to the operationally-proven Atlas holddown system, providing a soft lift-off release. This configuration utilizes the already strengthened area near the thrust posts, eliminating additional structural weight if it were located elsewhere on the booster section.

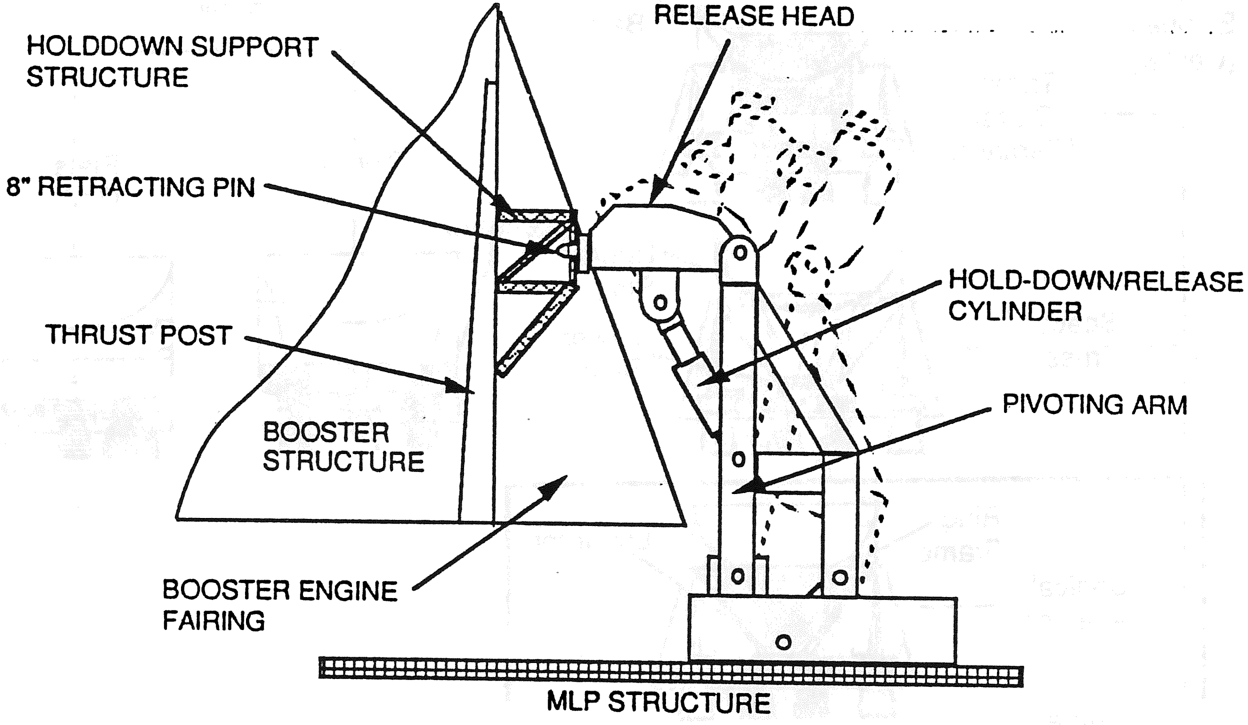


Figure 1.2-3 Structural Holddown Concept

The baseline thrust structure arrangement was considered against the trade tree representing the various options of the engine arrangements for the NLS vehicles. Figure 1.2-4 shows various options for the 1.5 stage configuration . The baseline (reference) concept is outlined for identification in the option list.

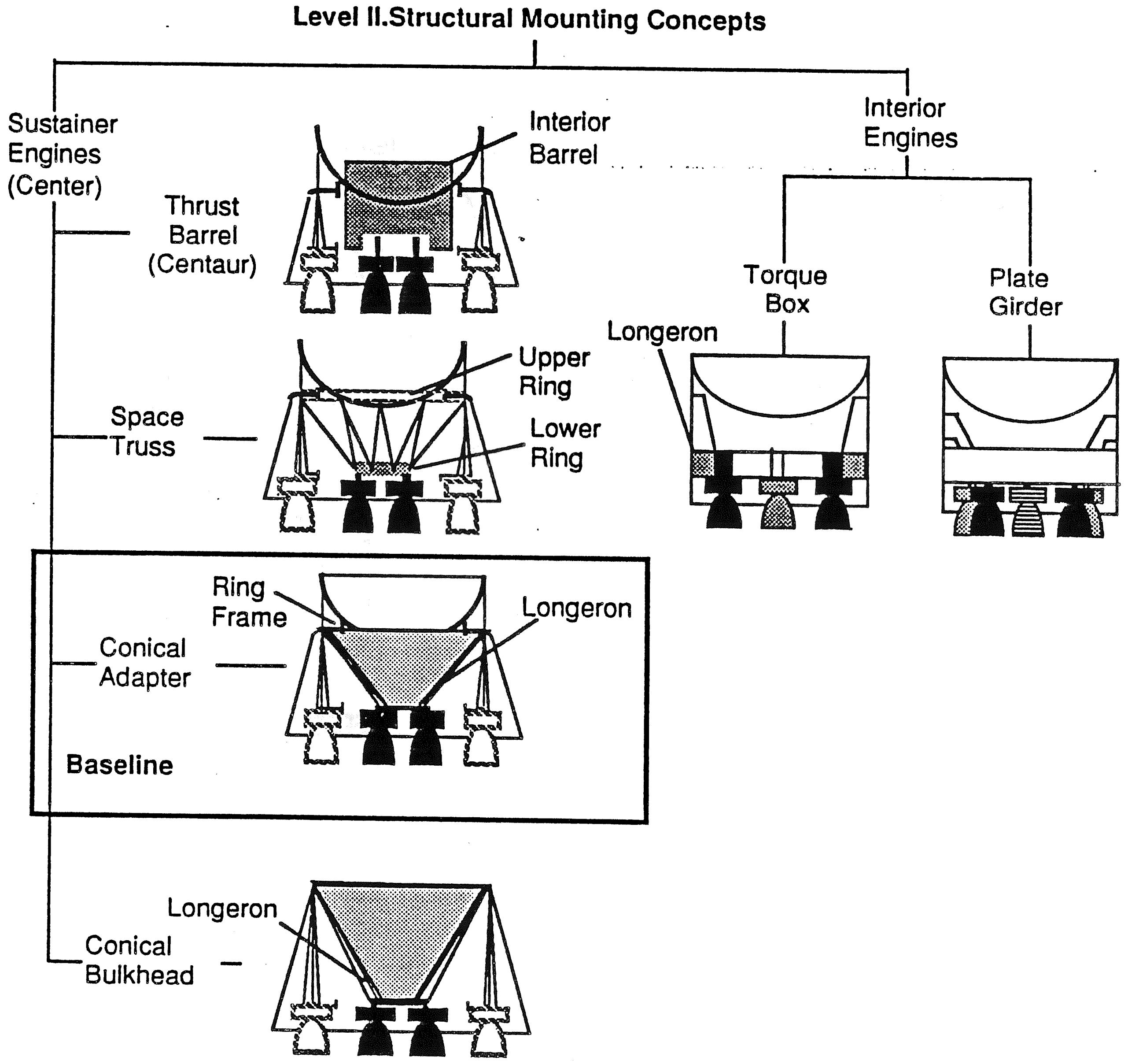


Figure 1.2-4 Trade Tree for Thrust Structure Concepts

The thrust barrel concept is being evaluated to determine feasibility for use in a 10 foot stretch of the the LH2 tank, as illustrated in Figure 1.2-5. The configuration is similar to the Atlas/Centaur engine support system and is composed of rolled ring forging/machined frames, aluminum skin/stringers and thrust longerons. Preliminary loads analysis shows that this concept is viable, and will reduce the weight of the sustainer structure by approximately 1500 lbs,. but will require increased strengthin the tank bulkhead. The weight increase of the bulkhead is dependent on tank pressure, in addition to the bulkhead structure. This analysis is not yet completed.

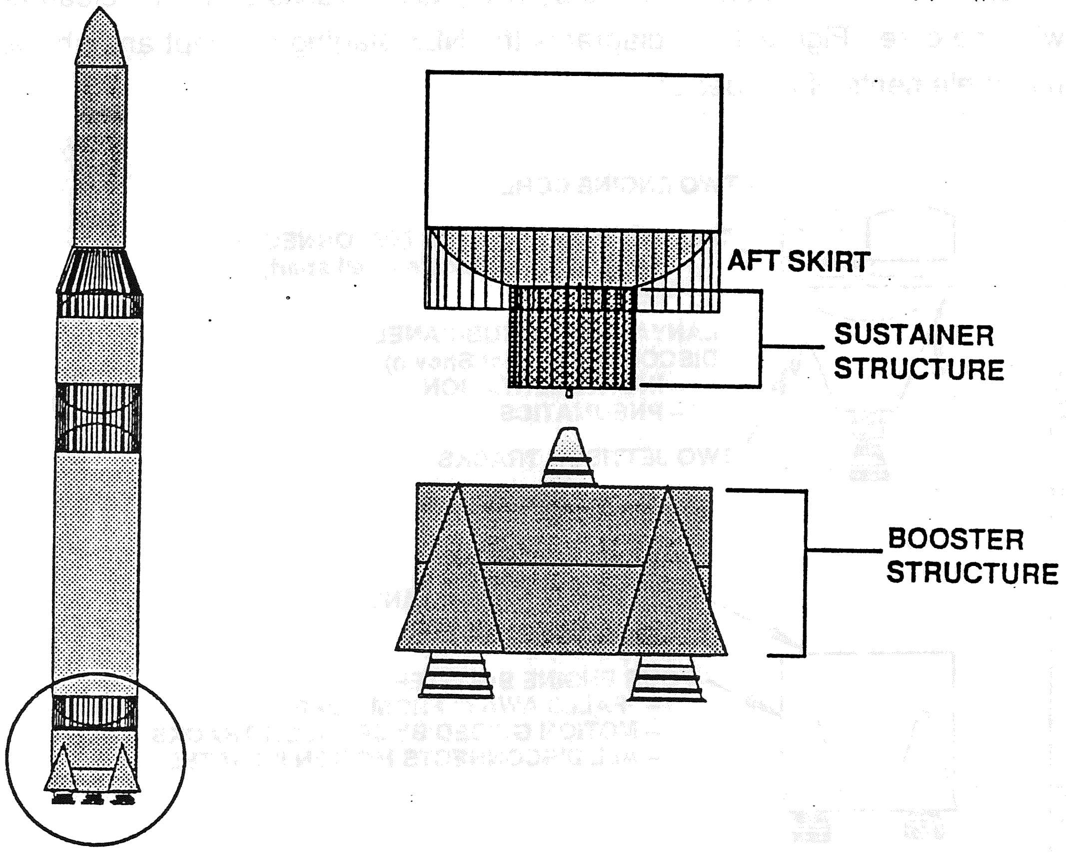


Figure 1.2-5 Alternate Sustainer Concept

1.3 SEPARATION CONCEPT

The 1-1/2 stage NLS-2 vehicle baseline concept uses a four engine booster module which is jettisoned after flying through most of the atmosphere (about 2 to 3 minutes of flight). The concept is based on proven technology and the experience of 501 Atlas flights since June, 1957. The booster module will be separated mechanically using a pyro linear shaped charge to sever the barrel section structure shortly after the booster engines are shut down. The continuing thrust of the sustainer engines on the core cause the core to accelerate out of the booster. The relative motion of the booster module "falling away" then initiates disconnect and closure of the propellant feed lines, pneumatic lines, and electrical connections. Initial motion is guided by two jettison tracks until safe clearance is established with the core. Figure 1.3-1 diagrams the NLS staging concept and shows the locations of major elements of the design.

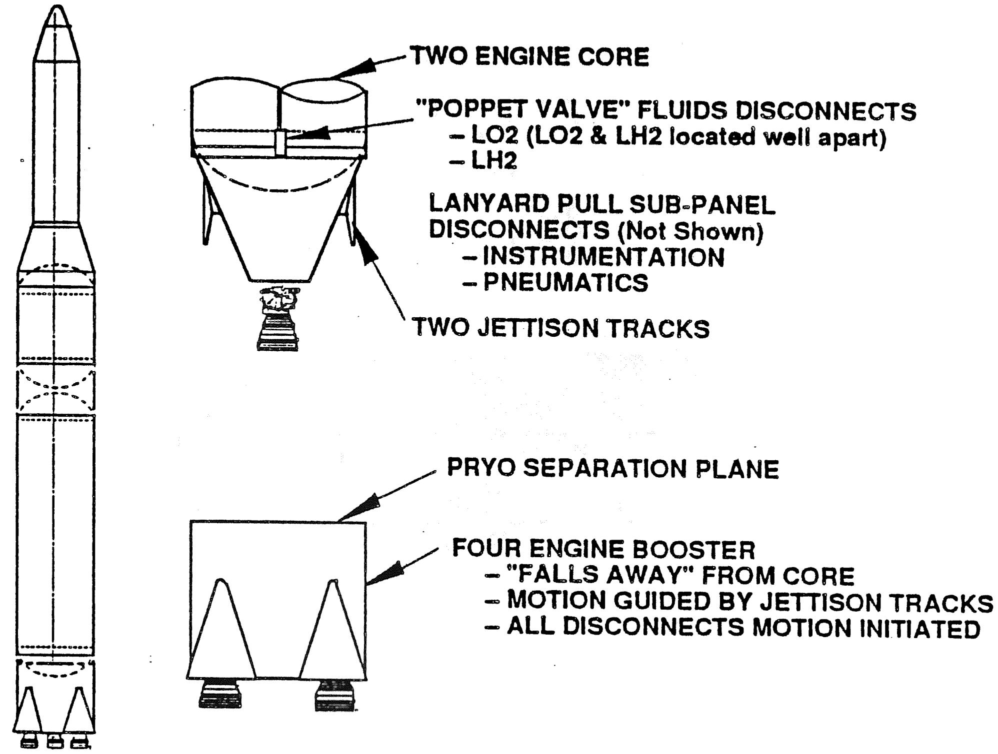


Figure 1.3-1 NLS-2 Staging concept for 1-1/2 stage booster.

The lanyard-pull panel disconnect concept uses telescoping guide pins and short lanyards to control the flailing motion of individual disconnects. Locating multiple disconnects together minimizes clearance space required and allows consolidated inspection.

The lanyard disconnects as used on the Atlas are shown in Figure 1.3-2. A lesson learned from an Atlas flight failure was to keep the lanyards as short as possible. Originally almost 4 feet long, the current Atlas lanyard is about 12 inches long.

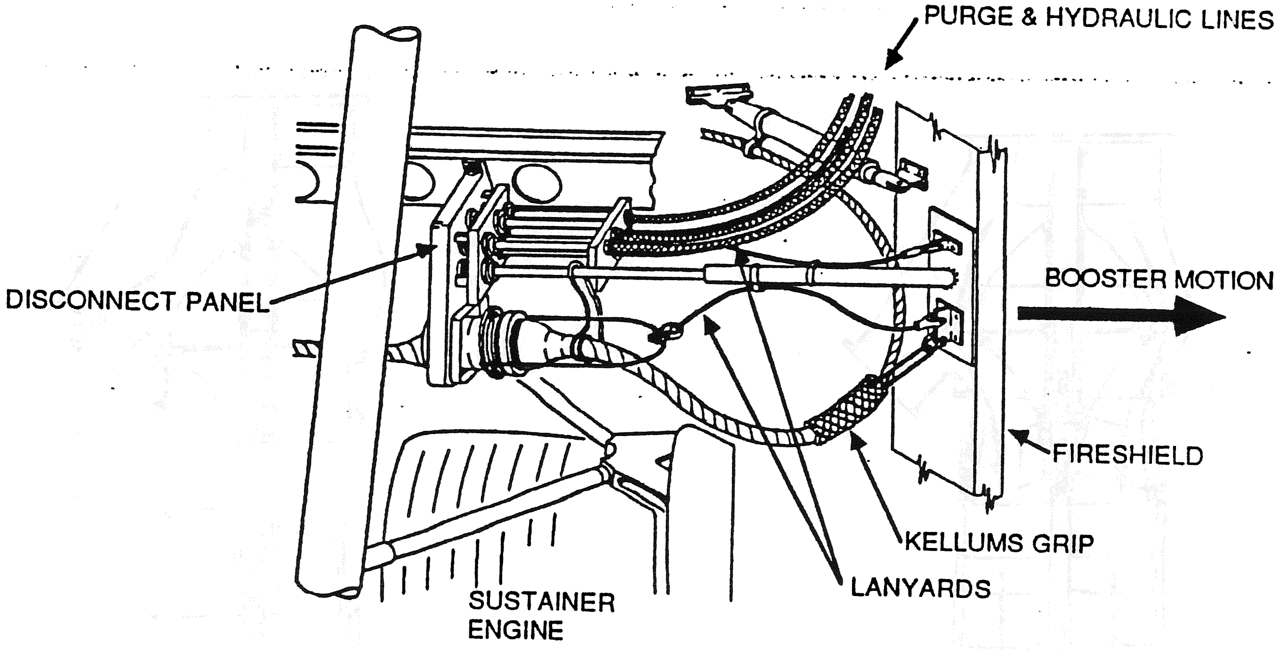
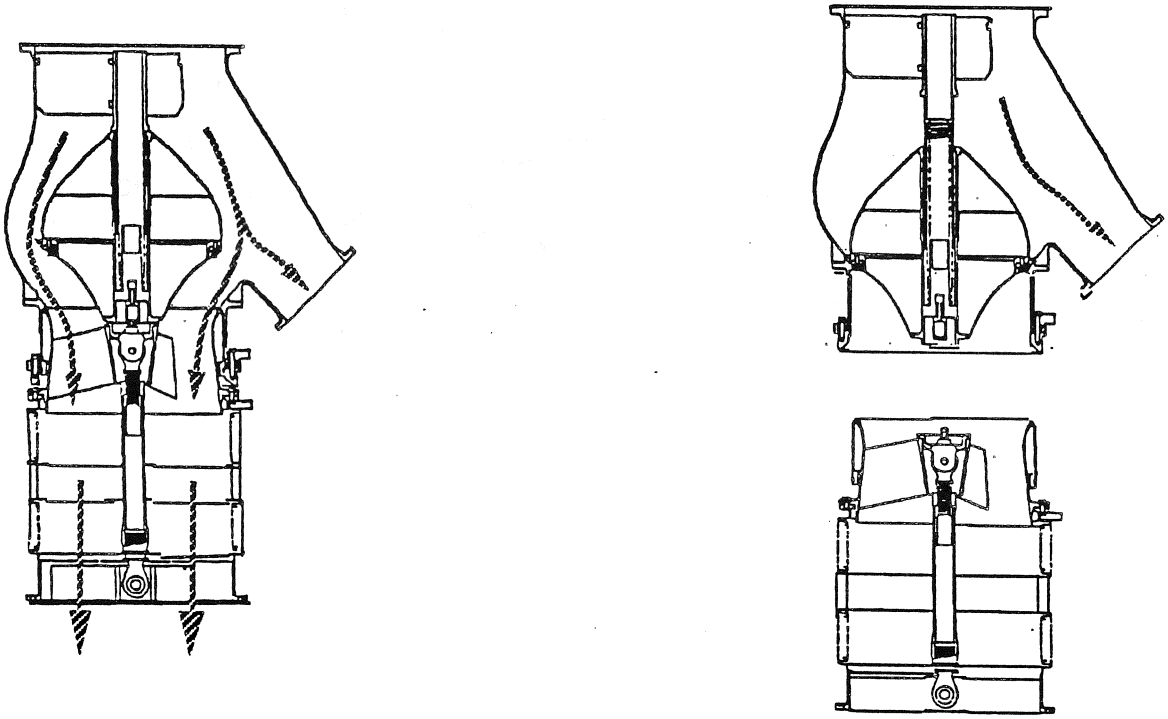


Figure 1.3-2 Typical Lanyard-Pull disconnect panel used on Atlas.

The propellant disconnect must allow for continued flow to the sustainer engines. This requirement also applied to the Atlas, with the resulting design solution being a poppet valve disconnect as shown in Figure 1.3-3. A center plunger on the booster side pushes the poppet up to allow flow to the booster. As the plunger withdraws at booster separation, the poppet seals off the booster flow before the rise-off seal of the disconnect disengages. Flow to the sustainer is not interrupted. Flow to the booster engines stops at BECO, seconds before separation, so there is virtually no flow effects to the sustainer engines at booster separation.



VALVE ENGAGED & OPEN

VALVE DISCONNECTED & CLOSED

Figure 1.3-3 Typical propellant disconnect used on Atlas.

1.4. PROPELLANT FEED SYSTEM

The baseline propellant feed system for the Reference zero vehicle (to which the GDSS concept is similar) consists of dual LO2 main feed ducts emanating from the LO2 tank aft bulkhead. The ducts feed the center engine inlet gimbal ducts for the 1.5 stage vehicle from a point upstream of the staging disconnects. The main ducts each feed, via transition ducts, a pair of booster skinline engine inlet gimbal ducts. The LH2 feeds the 1.5 stage center engines directly from a centerline tank sump via a pair of gimbal inlet ducts.

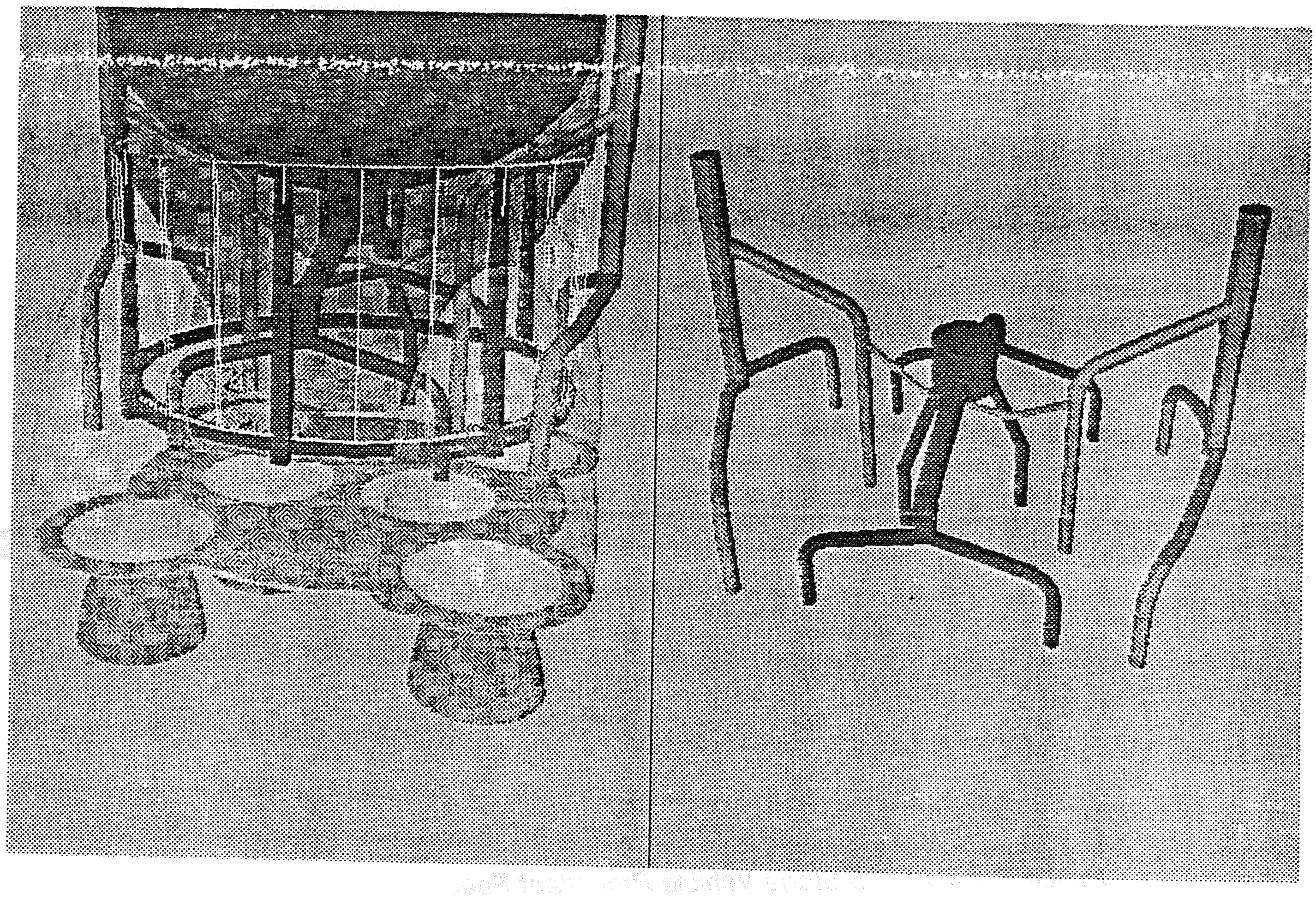


Figure 1.4-1 Three Dimensional Layout of the Baseline Propellant Feed System 1.5 Stage Vehicle

of gimbal inlet ducts. The booster (skinline) engines are fed from a pair of main ducts (each feeding a pair of gimbal inlet ducts), also from the center LH2 tank sump. An overall layout for the propellant feed system is shown in Figure 1.4-1.

Schematics for the propellant feed system for the 1.5 stage and HLLV vehicles is shown in Figures 1.4-2 and 1.4-3. These include the use of three flex-joint gimbal duct assemblies in lieu of the initial Reference zero baseline of scissors ducts.

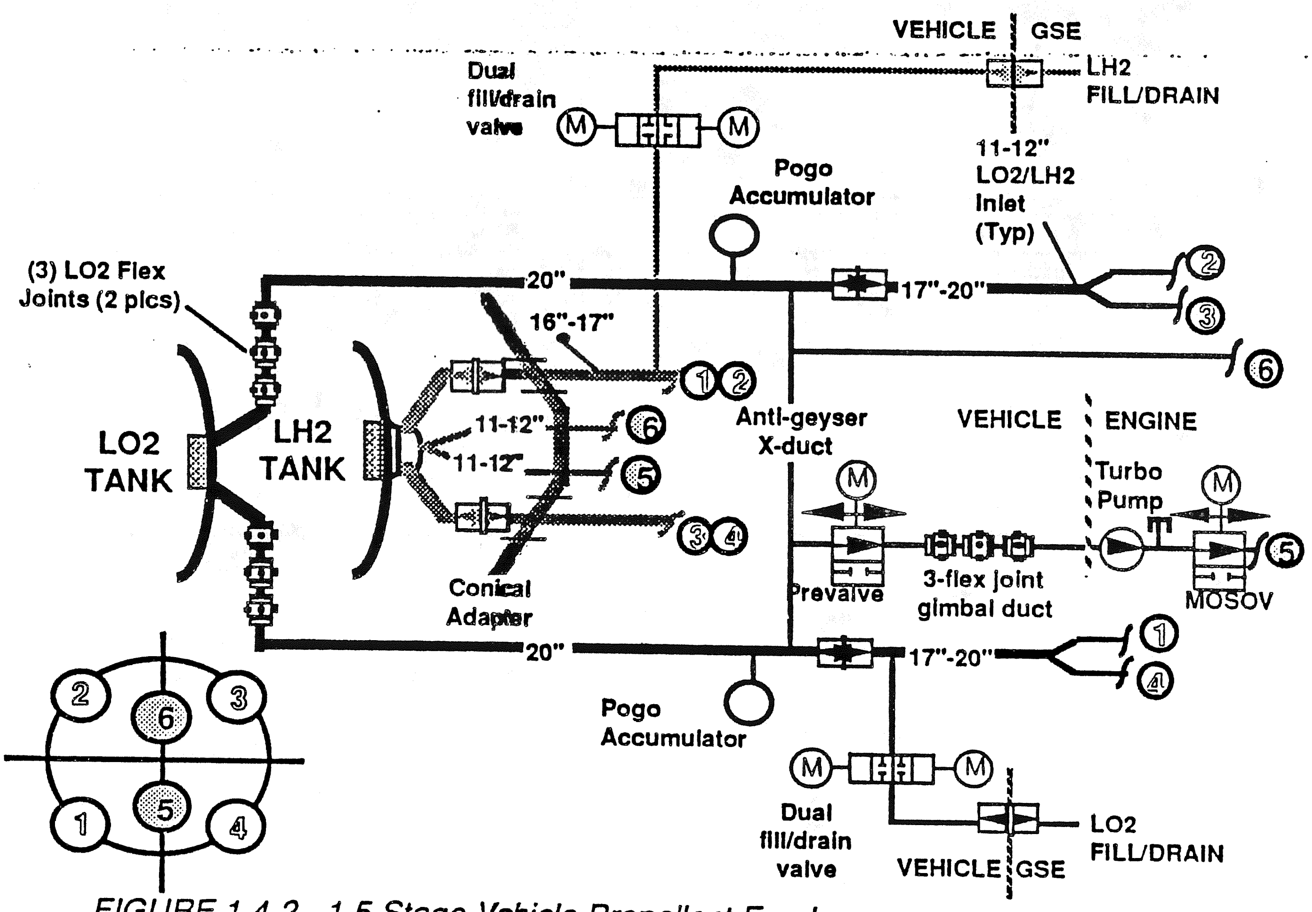


FIGURE 1.4-2 1.5 Stage Vehicle Propellant Feed

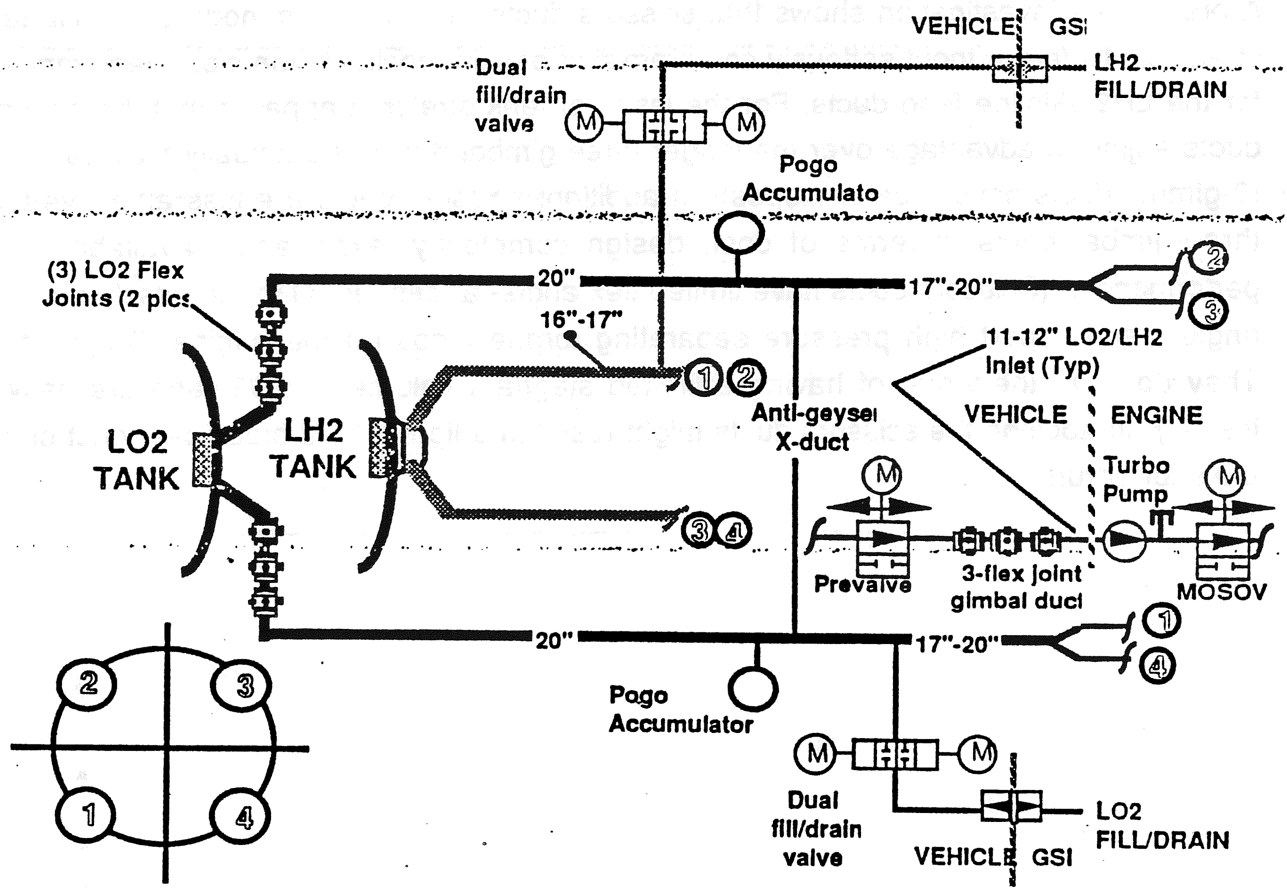


FIGURE 1.4-3 HLLV Vehicle Propellant Feed

Staging disconnects (1.5 stage vehicle) are located in each of the two LO2 main ducts. LH2 staging disconnects are located in each of the two main ducts that feed the skinline engines.

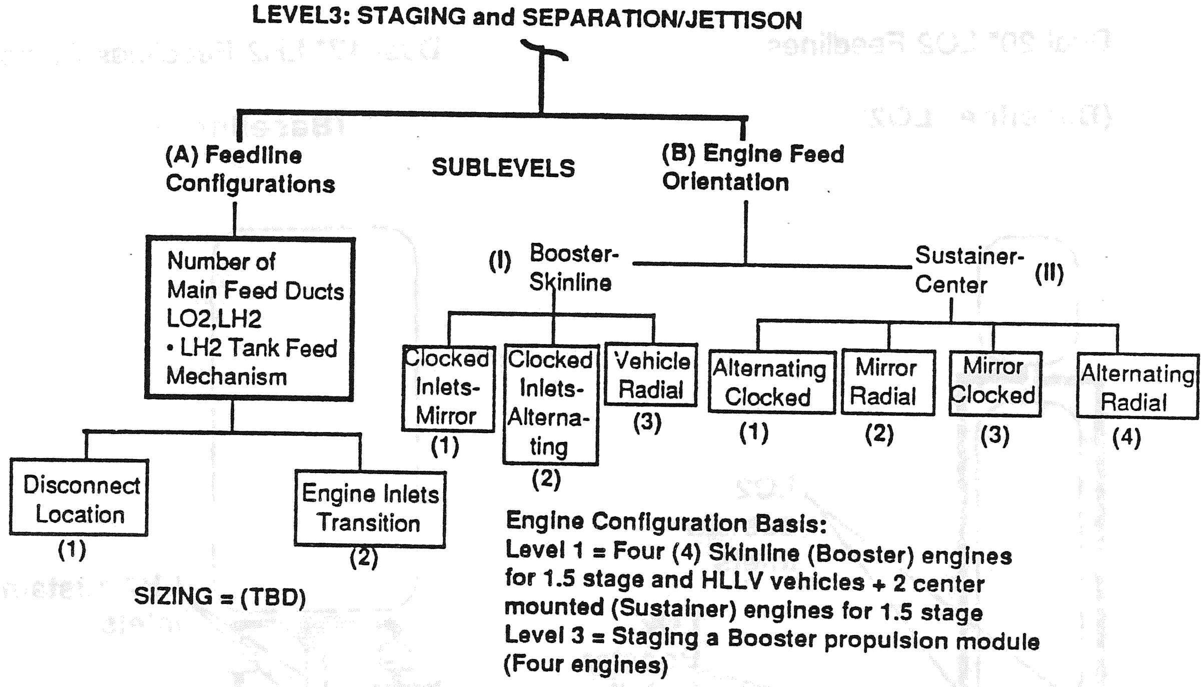
With respect to the engine inlet ducts that must accommodate engine gimbal motion, it should be noted that the three flex-joint gimbal duct concept has significant advantages over use of the scissors ducts (refer to Trade Study 3-P-013, "Feedline Gimbal Configuration").

A preliminary investigation shows that scissors ducts will not accommodate an LH2 tank stretch of 10 feet without seriously compromising passive recirculation slope requirements for the LH2 skinline feed ducts. For the issue of tank stretch it appears that the scissors ducts enjoy no advantage over the longer three-gimbal ducts and actually may be worse (3-gimbal ducts have greater slopes). In addition, scissors ducts are less attractive than three-gimbal ducts in terms of cost, design complexity, experience, availability and performance. (Scissors ducts have limited flex angle- at best equal to the baseline gimbal angle - and impart high pressure separating torque loads on the engine TVC system. They do have the virtue of having a limited stagnant volume of LO2 and are easy to install.) In addition the scissors ducts might result in a lighter LO2 cross-over duct due to the shorter run.

1.4.1. PROPELLANT FEED SYSTEM TRADE TREE

For purposes of trade study 3-P-006 the major options for arrangement of the feed system which will have the most significant impact on the overall Propulsion Module arrangement is shown in Figure 1.4-4 and discussed in section 1.4.2. Issues such as location of the prevalves, disconnect type and sizing, inlet gimbal duct arrangement and type are not specifically addressed at this time. Propellant fill and drain issues are addressed briefly in section 2.3 for the Propellant Feed.

The trade tree (Figure 1.4-4) for the propellant feed system shows the options for skinline mounted booster engines with center mounted sustainer engines for the 1.5 stage vehicle. The engines for the HLLV vehicle are mounted on the skinline identically to the 1-1/2 stage vehicle.



Engine Configuration Basis:
Level 1 = Four (4) Skinline (Booster) engines for 1.5 stage and HLLV vehicles + 2 center mounted (Sustainer) engines for 1.5 stage
Level 3 = Staging a Booster propulsion module (Four engines)

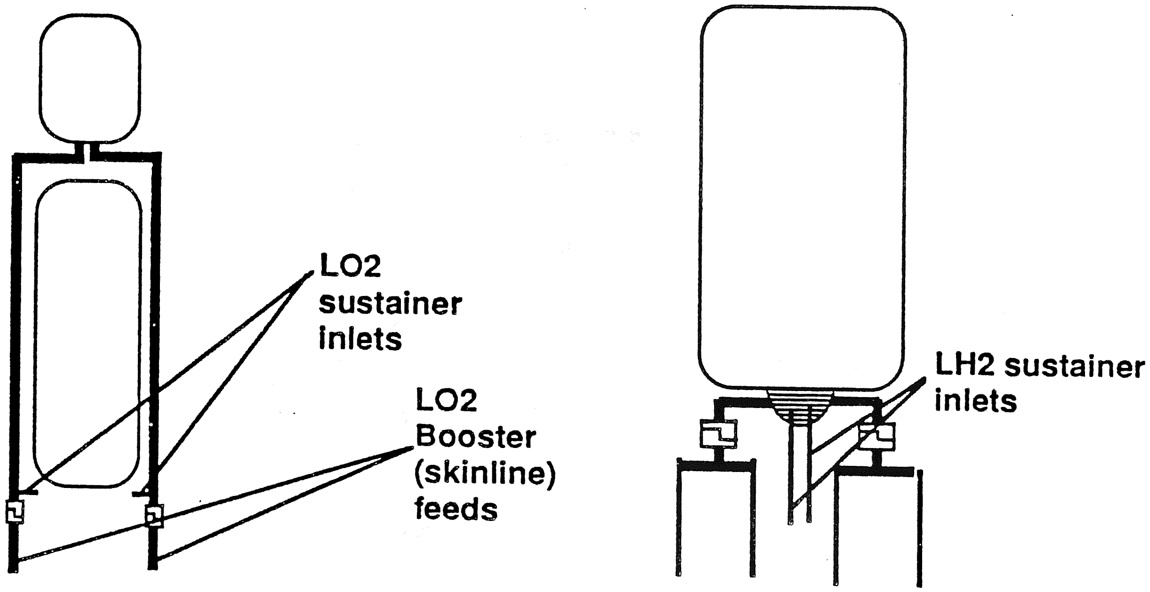
Figure 1.4-4 Propellant Feed System Arrangement Trade Tree

1.4.2. DISCUSSION - PROPELLANT FEED SYSTEM BASELINE AND ALTERNATIVES.

The following Figures 1.4-5 thru 1.4-13 show the configuration of the various aspects of feed system arrangement derived from the trade tree shown in the previous section. The degree of detail of the various options has been selected to reflect the major impacts on the Propulsion Module.

Each figure shows the Reference zero with a suggested "alternate" arrangement (if applicable) that will be covered in section 2 for trade study discriminators.

1.4.2.1 Feedline Configurations

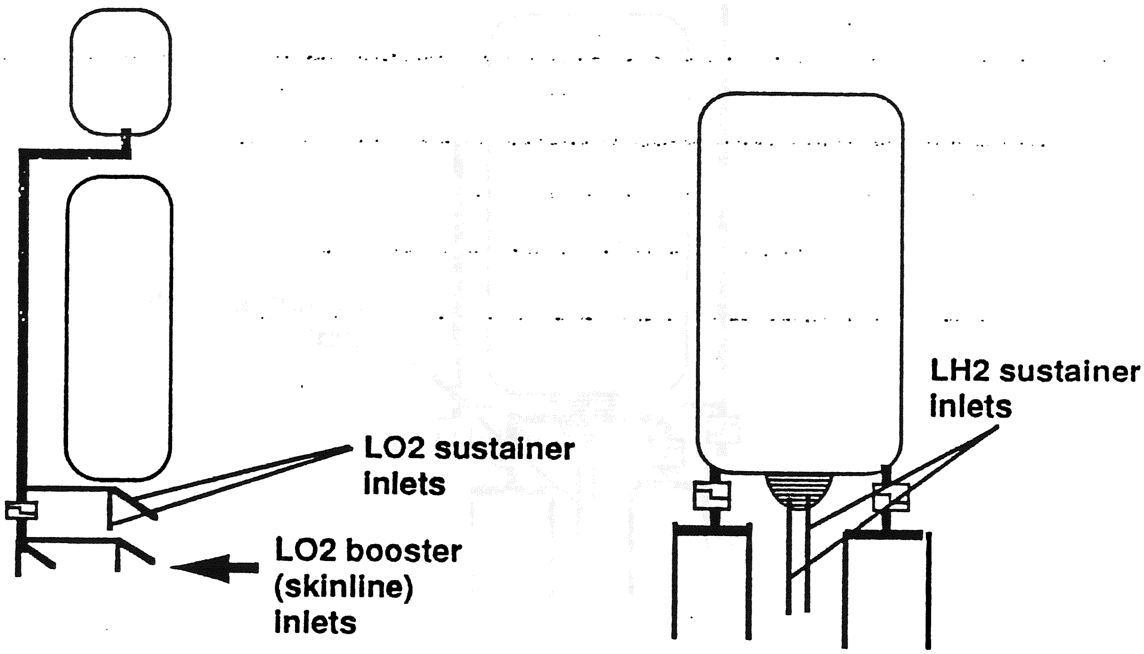

Dual 20" LO2 Feedlines

(Baseline LO2)

Dual 17" LH2 Feedlines Sump Fed

(Baseline LH2)

Figure 1.4.-5 Baseline Arrangement of the Main Feed Ducts



Single 26" LO2 Feedline **(Alternate)**

Dual 17" LH2 Feedlines

Bulkhead Fed **(Alternate)**

Figure 1.4-6 Alternate Arrangement of the Main Feed Ducts

Separation at the Main Ducts (Baseline)

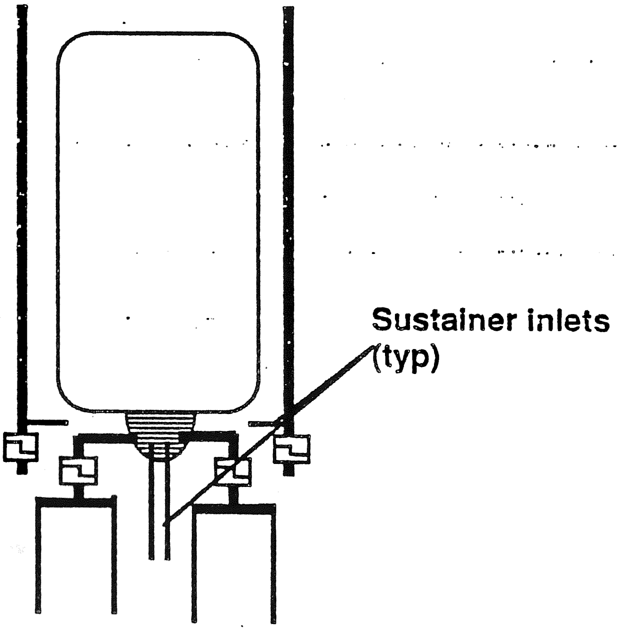


Figure 1.4-7 Baseline Arrangement of the Main Feed Disconnects

Splitter Manifolds + Size Transition Ducts **(Baseline)**

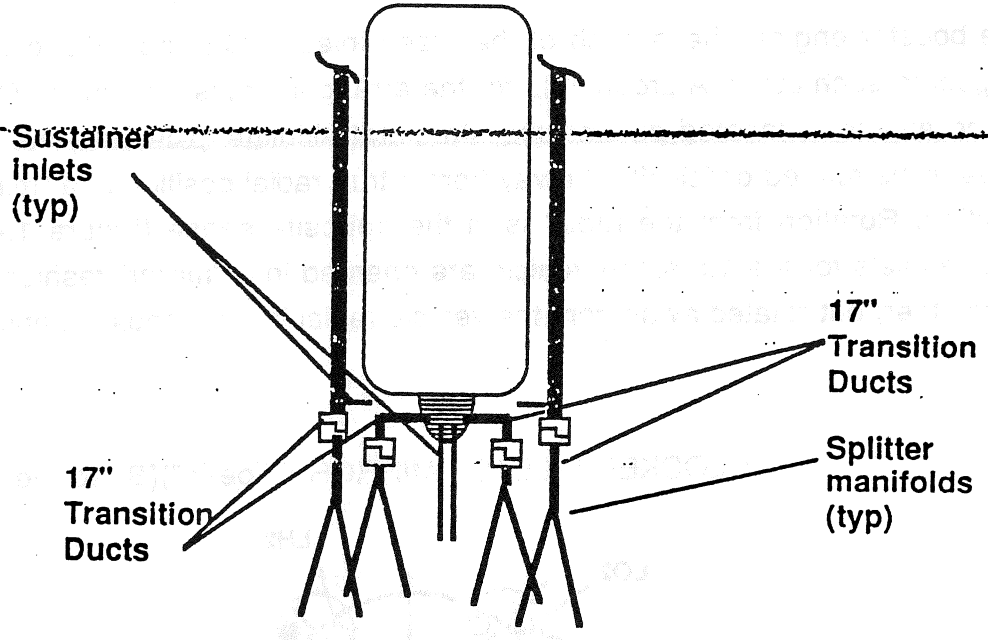


Figure 1.4.-8 Baseline Arrangement of the Transition to Engine Inlet Ducts

Splitter Manifolds + No LO2 Size Transition Ducts **(Alternate)**

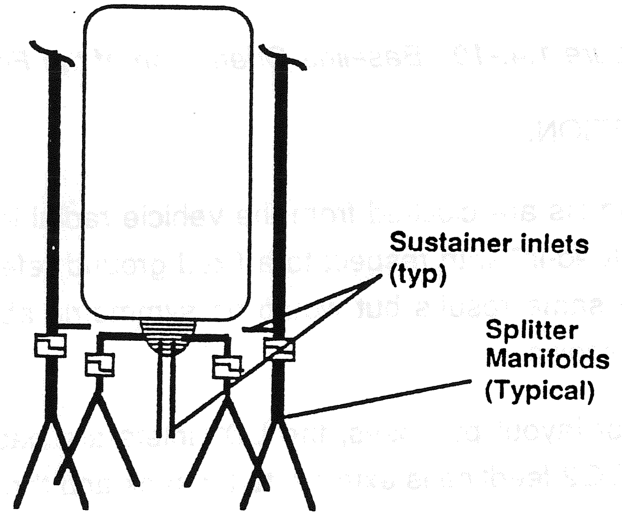


Figure 1.4-9 Alternate Arrangement of the Transition to Engine Inlet Ducts

1.4.2.1 ENGINE FEED ORIENTATION - BOOSTER/SKINLINE

The booster engines have each of their feed inlets (LO2 and LH2) clocked at 180° with respect to each other. A groundrule for the arrangement is that each LO2 turbopump inlet to the engine is located outside the structural skinline. The baseline arrangement has these inlets rotated or "clocked" away from a true radial position in a "mirror" or orthogonal position. Rotation from the radial is in the opposite sense (Figure 1.4-10). The center engine inlets for the 1.5 stage vehicle are oriented in a "mirror" fashion (like inlets facing each other) but rotated away from the vehicle radial in the opposite sense (Figure 1.4-12).

CLOCKED INLETS - MIRROR ("Toe-in")(**Baseline**)

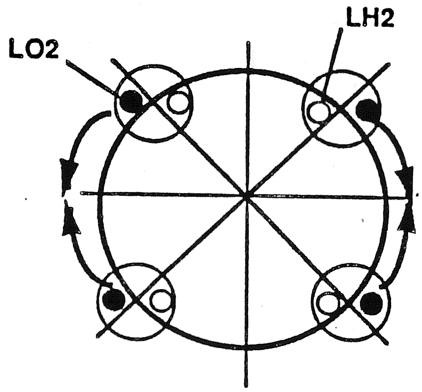


Figure 1.4.-10 Baseline Orientation of the Feed Inlets - Skinline Engines

DESCRIPTION:

Engines inlets are clocked from the vehicle radial location in mirror or symmetric fashion and are "toed-in" with respect to a fixed ground reference direction. "Toe-out" would yield much the same results but would be symmetric about a ground reference direction 90° from that shown.

NOTE: For layout purposes, the LO2 inlets are baselined outboard of the skinline since the main LO2 feedline is external to the tank and thrust structure.

CLOCKED INLETS - ALTERNATING (Alternate)

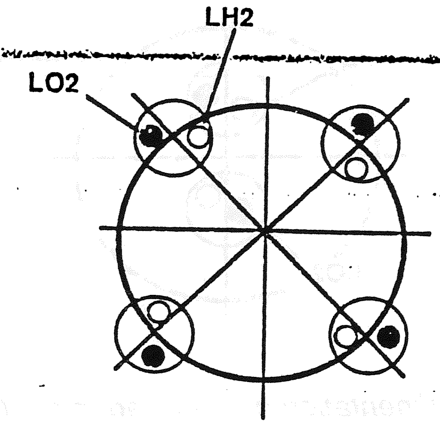


Figure 1.4-11 Alternate Orientation of the Feed Inlets - Skinline Engines

DESCRIPTION:

Engines inlets are clocked from the vehicle radial location in the same rotational direction (counter-clockwise shown). This is a more general case of the "Vehicle Radial" option which is nothing more than "Alternating" clocked at 0° from the radial.

A benefit of this orientation is the TVC actuator mounting to the PM structure. This clocking puts the TVC orientation identical with respect to the structure for all the skinline engines.

1.4.2.2 ENGINE FEED ORIENTATION - SUSTAINER/CENTER

ALTERNATING CLOCKED **(Baseline)**

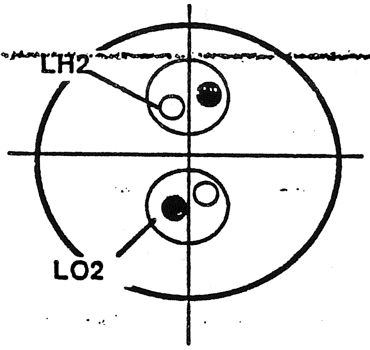


Figure 1.4-12 Baseline Orientation of the Feed Inlets-Center Engines

DESCRIPTION:

The engine inlets are clocked from the vehicle radial direction in the same rotational direction. This is a more general case of the "Mirror Radial" option which is clocked at 0°.

MIRROR CLOCKED **(Alternate)**

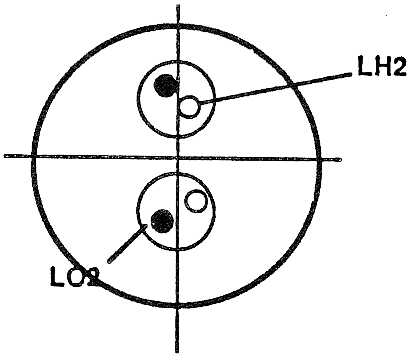


Figure 1.4-13 Alternate Orientation of the Feed Inlets-Center Engines

DESCRIPTION:

The engine inlets are clocked from the vehicle radial direction in opposite rotational directions. This is much like the skinline engine inlets "toe-in" or "toe-out" configurations.

2.1 COST/FLIGHT: FINAL ASSEMBLY, STACKING AND CHECKOUT COST

NOTE: The following section also covers discriminators (4) Manufacturing Cost, (5) Assembly Cost and (11) Manufacturing Development

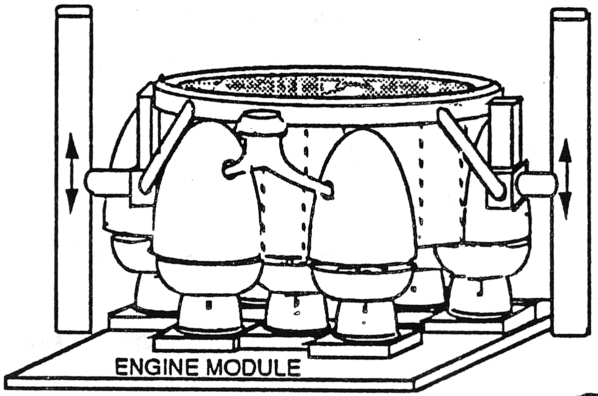
2.1.1 DEVELOPMENT OF METHODOLOGY FOR ESTABLISHING COST

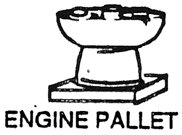
The approach for establishing costs for the propulsion module are derived by the use of supporting trade studies to select the optimum Manufacturing concepts and design. The work accomplished on ALS phase 1 and 2 established a methodology for accomplishing this with great detail and quantifiable costs. The key element for selecting a specific design or manufacturing process is the Producibility of that selection. Our concurrent engineering effort has given us the information required to select the optimum design and processes. These selections have been validated through solid modeling and our electronic pathfinder software. The use of these tools allows us to understand the actual "Life Cycle Costs" and span time of the design and process. Understanding that up front Producibility effort is the key element to a successful design, we have implemented all these efforts to design for Manufacturability.

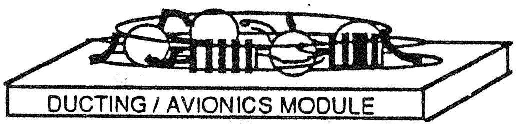
The baseline design requires Manufacturing Development of specific designs and processes. Lessons learned from our current launch vehicle design, helped to identify key processes and design concerns that need to be addressed in our baseline design. These items were then developed through trade studies and material and process testing. Examples of this effort are the use of Vacuum Cast Parts to replace machined or hammer formed weldments. Cryogenic tests were performed to validated the material strengths and establish a base for design allowables.

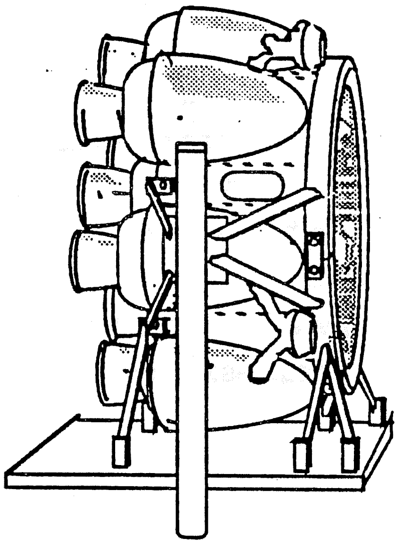
Other items such as Gimble joints design and use were reviewed. The producibility of these joints are being developed to make them more producible through the elimination of piece parts. Alternative manufacturing processes such as machined laser cut sleeve details, or vacuum cast details to replace sheet metal weldments, have reduced detail costs, span time and inventory costs. The use of vacuum cast housings for fuel quick disconnects will reduce the cost by 60% of current design and processes. The elimination of as many field splices as possible will reduce the use of critical seals and flanges, and allow us to weld the manifold into the fuel lines. These process enhancements reduce production span time and life cycle costs.

The producibility of our baseline design assures the ability to reduce cost, while improving the reliability of the propulsion module. The concurrent engineering effort to meet the Producibility Criteria through all areas, provides assurance that we have selected the optimum design and process. This approach is demonstrated in the Manufacturing and assembly equipment. The use of our Manipulator Concept for NLS propulsion assembly, uses proven manufacturing equipment and improves assembly over current methods. This process also supports Producibility Criteria for next assembly condition.







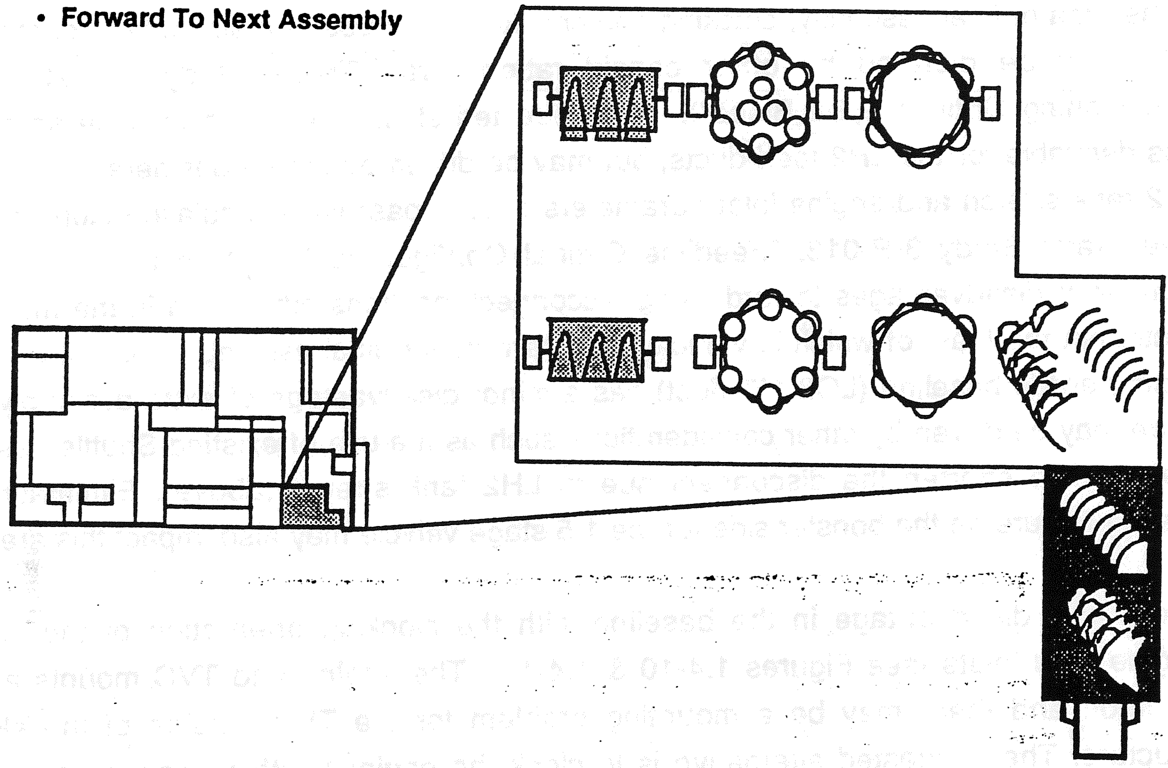


Producibility being one of the key factors of cost, has proven to be the guide for the concurrent engineering effort to select optimum concepts.

Concurrent engineering concept for stacking for next assembly condition is validated in our NLS Propulsion Module assembly cell. This cost effective concept reduces span time, life cycle costs and improves the reliability of the propulsion module, with systems checkout at the instillation cell. Reduction in product moves, reduces facilities requirements and possibility of material handling damage. All concepts are validated by Producibility factors being met.

MANUFACTURING AND ASSEMBLY
NLS Propulsion Module Assembly Cell

- **Receive & Install Structural Components Into Assembly Manipulator**
- **Install Structure To Systems Manipulator**
- **Install Systems & Checkout**
- **Forward To Next Assembly**



Test and check out requirements have been modeled and validated using electronic parthfinder, potential work arounds have been modeled to validate this activity. Cost avoidance through the use of this process is assured.

Using this methodology to develop costs, has given us a quantifiable data base. The total sum of elements that are required to support the manufacturing, testing, integration, and transportation have been traded and validated to be the optimum concept.

2.1.2 PROPELLANT FEED SYSTEM

2.1.2.1 PROPELLANT FEED SYSTEM FEATURES

There is no significant driver to use an alternative to the baseline of dual LO2 feed ducts in the area of final assembly, stacking and checkout. The use of a single feed duct for the LO2 may be dictated by other considerations (ref. Trade Study 3-P-019, "LO2 Conditioning Options -LO2 Bleed"). Bulkhead fed skinline engines may be somewhat less desirable for the LH2 feed ducts, but may be driven by other considerations such as LH2 tank stretch and engine inlet parameters of L/D, passive recirculation slope and r/D (see Trade Study 3-P-013, "Feedline Gimbal Configuration"). There are a significant number of disadvantages toward using disconnect locations other than in the main feed ducts, not the least of which is vehicle alignment during final assembly. Use of transition ducts per the baseline (LO2 17" duct) has a minor disadvantage of extra assembly. This issue may be driven by other considerations such as the use of existing Shuttle assets or the need to shorten the disconnect due to LH2 tank stretch (above). Eliminating the sealing feature on the booster side for the 1.5 stage vehicle may also impact this area.

There is a disadvantage in the baseline with the clocking orientation of the skinline engine feed inlets (see Figures 1.4-10 & 1.4-11). The engine and TVC mounts are not common and there may be a mounting problem for the TVC outside of the skinline structure. The suggested alternative is to clock the engines with respect to the vehicle radial in the same rotational sense. Assembly commonality of engine and TVC mounting is maintained and yet flexibility is introduced in routing the feed system away from primary structure. There is no significant penalty to feed system commonality. The orientation of the main LO2 feed ducts may be driven more by intertank adapter issues than by connection with the feed transition ducts.

2.1.2.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for final assembly, stacking and checkout are shown in Tables 2.1.2-1 and 2.1.2-2. The baseline and alternate concept descriptions are in Section 1.4.2.

Table 2.1.2-1 Baseline Propellant Feed Concept

<u>PRO</u>

- When compared with the alternative of a single large feedline (or multiple feedlines), the dual LO2 main system system offers the easiest assembly.

- The sump fed 17" LH2 ducts offer the easiest interface and assembly (with the LH2 tank sump).

- The disconnect locations for the 1.5 stage vehicle result in a simple checkout and disconnect alignment during vehicle stacking when compared with location on the individual engine inlet (11-12") gimbal ducts.
  - Disconnects on the inlet ducts may result in a severe installation and removal problem due to the limited space available upstream of the gimbal flex joints (also contain the feed inlet prevalves).

- The center engine mounting assembly is simple. TVC attach points and TVC structural mounting is all common with the feed inlets located in a clocked, mirror fashion

<u>CON</u>

- Checkout costs are higher when compared with a single main LO2 feed duct.

- More separable joints (flanges) than a single LO2 duct.

- Transition ducts from the LO2 main ducts to the engine inlet gimbal ducts result in extra assembly.

- Final assembly complexity with the skinline engine feed inlets located in a clocked, mirror fashion.
  - There will be two types of engine-TVC attach points or......
  - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.1.2-2 Alternate Propellant Feed Concept

PRO

- Checkout costs for functional flow, leak checks etc. are lowest for a single LO2 feed line.

- The stacking for the vehicle is easiest with a single main LO2 feed duct. There is only one disconnect for the 1.5 stage vehicle to align when compared with dual ducts or multiple ducts.

- The alternate LH2 bulkhead main feed may allow easier installation of the main LH2 feed duct away from the center of the vehicle.

- There are fewer assembly parts with no transition duct between the LO2 main feed and the engine inlets.

- For the skinline engines the alternating clocked feed inlets present the opportunity for not only common TVC engine mounts but also common TVC mounting of the structure with all mounts interior to the skinline.

CON

- There may be limitations on handling equipment for large 26" or more LO2 feed ducts and mounting brackets.

- There may be a complex LH2 aft bulkhead interface for an aft bulkhead LH2 feed. For the 1.5 stage vehicle the main LH2 disconnects might need partial mounting inside the tank.

- The mirror clocked position may result in uncommon assembly of the engine inlet ducts for the center engines on the 1.5 stage vehicle.

2.2 COST/FLIGHT: MAINTENANCE COST

The characteristics to be considered in the evaluation of maintenance cost include accessibility and ease of LRU repair and replacement

Maintenance costs are directly proportional to the accessibility of LRU's and ease of LRU repair and replacement. These two characteristics drive maintenance costs by defining personnel requirements, timelines, and resource requirements necessary to perform a task. Studies have been conducted to understand the inter-relationships between these elements, and have identified two main design drivers. They are (1) spatial volume required for the access, and (2) time to provide that volume. Access is determined by the space available to perform a task. The following ratio is used to calculate the access value:

$$\frac{\text{(Volume Of Work Space) - (Volume Of All Components In That Space)}}{\textbf{(Volume Required By People, LRU, GSE, Other Task Resources)}}$$

The access ratio is illustrated in figures 2.2.1 and 2.2.2. The numerator in the access ratio determines the amount of unoccupied space around the LRU. The **volume of work space** includes the volume of the LRU, surrounding components and unoccupied space. This is the volume enclosed by the outside circle in figure 2.2.1. Subtracting the **volume of all components within that space** leaves the amount of unoccupied space. This is illustrated by the lightly shaded region in figure 2.2.1.

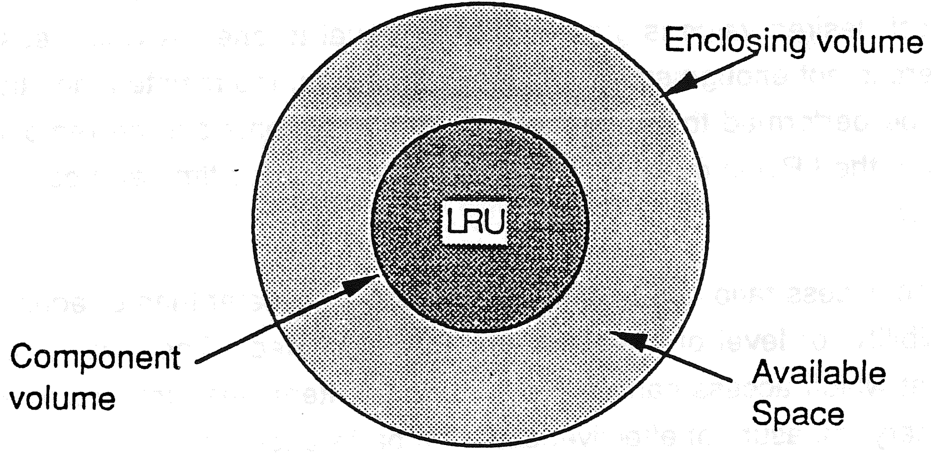


Figure 2.2.1 Available Space to Access LRU

Figure 2.2.2 illustrates the denominator of the access ratio by using the turbopump as an example for LRU removal. The denominator sums the total volume needed to perform the maintenance task. The people volume is the volume occupied by the maximum number of people present in the available space, from figure 2.2.1, during the task. The LRU space is needed to remove the LRU after it is unattached from the propulsion module. Volume occupied by handling equipment must also be accounted for, as shown in figure 2.2.2.

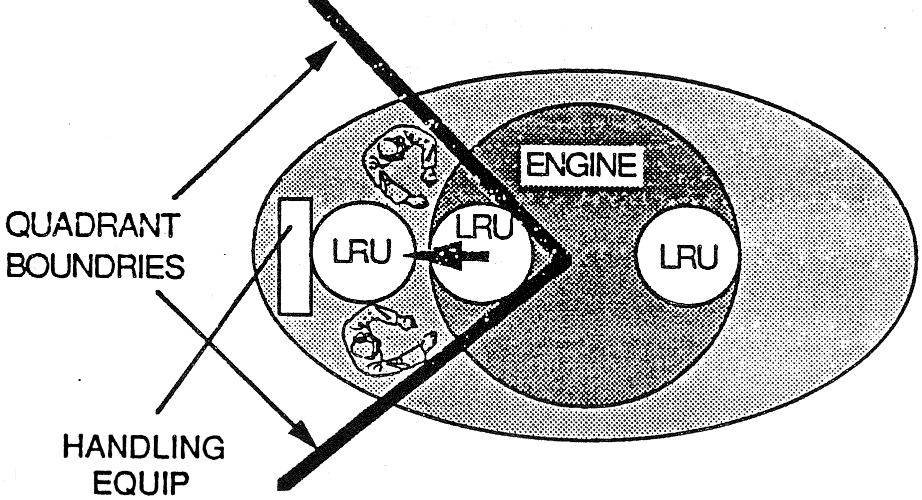


Figure 2.2.2 Turbopump Access

The volume in the denominator must be smaller than the volume of unoccupied space. The most desired value is greater than or equal to one. A value less than one implies that there is not enough space available to perform the maintenance task and an analysis should be performed to determine if other components can be removed in order to gain access to the LRU in question. This disassembly adds time and cost to the maintenance operation.

Once the access ratio has been determined to be greater than or equal to one, the level of accessibility, or level of effectiveness, is determined. The level of effectiveness is the speed at which access can be provided to the item when integrated with the vehicle. A preliminary "measure of effectiveness" of a part's accessibility is a ratio as follows:

$$\frac{\text{Time To Perform The Task Integrated}}{\text{Time To Perform The Task Unintegrated}}$$

The **time to perform the task integrated** is the time to perform the maintenance task with the LRU integrated with the propulsion module. The **time to perform the task unintegrated** is the time to perform the task without a space constraint which is the case in a maintenance shop or repair depot. The difference in these two times is reflected in Figure 2.2.3. Traditionally, the critical difference in times is in dissassmbly and re-assembly associated with gaining access. The dissassembly time is driven by the packaging of the part in an integrated assembly, and dictates the number of related and/or non-related systems which will incure "break-of-Inspection" (BOI). Furthermore, dissassembly of surrounding systems results in use of additional GSE and resources above what is required for a specific task. Re-assembly activities are also required and normally take longer due to importance of re-establishing production tolerances, quality, and inspection levels.

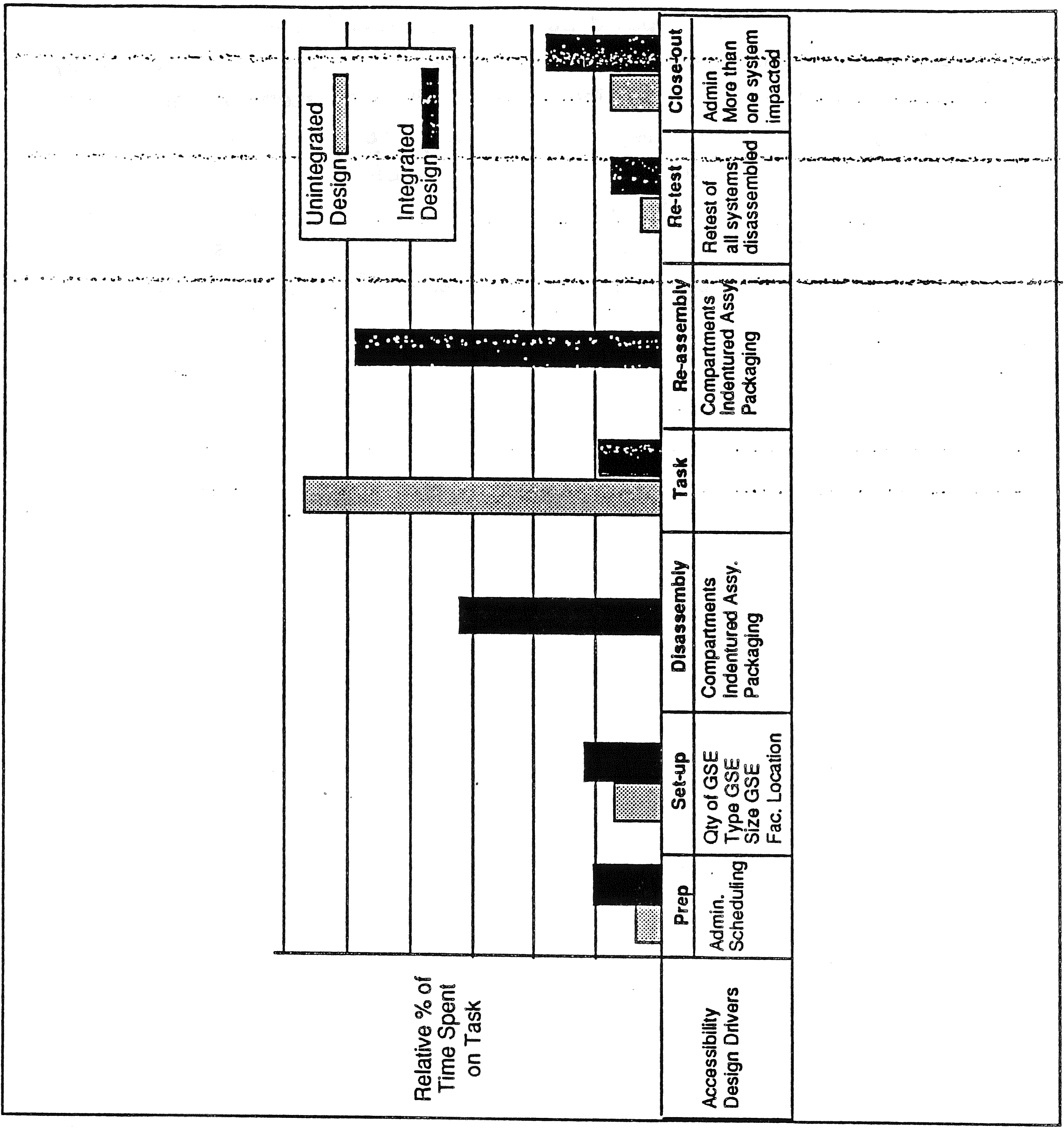


Figure 2.2.3 Time to Perform Task-Integrated Design vs. Unintegrated

Design Ease of LRU repair and replacement is determined by accessibility. Reliability of the LRU determines the relative importance of providing proper accessibility to an LRU and should play a major factor in determining its placement on the propulsion module. The least reliable components are placed such that they are most accessible.

Maintenance costs are severely increased if other components have to be removed to access the component.

The pros and cons of the General Dynamics' propulsion module concept based on maintenance costs are shown in tables 2.2.1 and 2.2.2.

Table 2.2.1 Accessibility Pro/Cons

PRO

- Easy access to LRU's when propulsion module is in the vertical position
- no special access platforms/GSE required for access.
- Use of existing vehicle structure as access platforms reduces cost of special platforms which represent initial cost and maintenance costs. For example, the heat shield is used as platform to access engines, actuators, engine feed system, etc. providing unhindered access to zones 1 and 2 of the engine. Refer to figure 2.2.4.

CON

- Access must be provided to propulsion module through the side of the vehicle
- Access doors must be large enough to accommodate the LRU and handling equipment if removal is through the door.
- Different handling equipment is needed when the propulsion module is in the horizontal position.

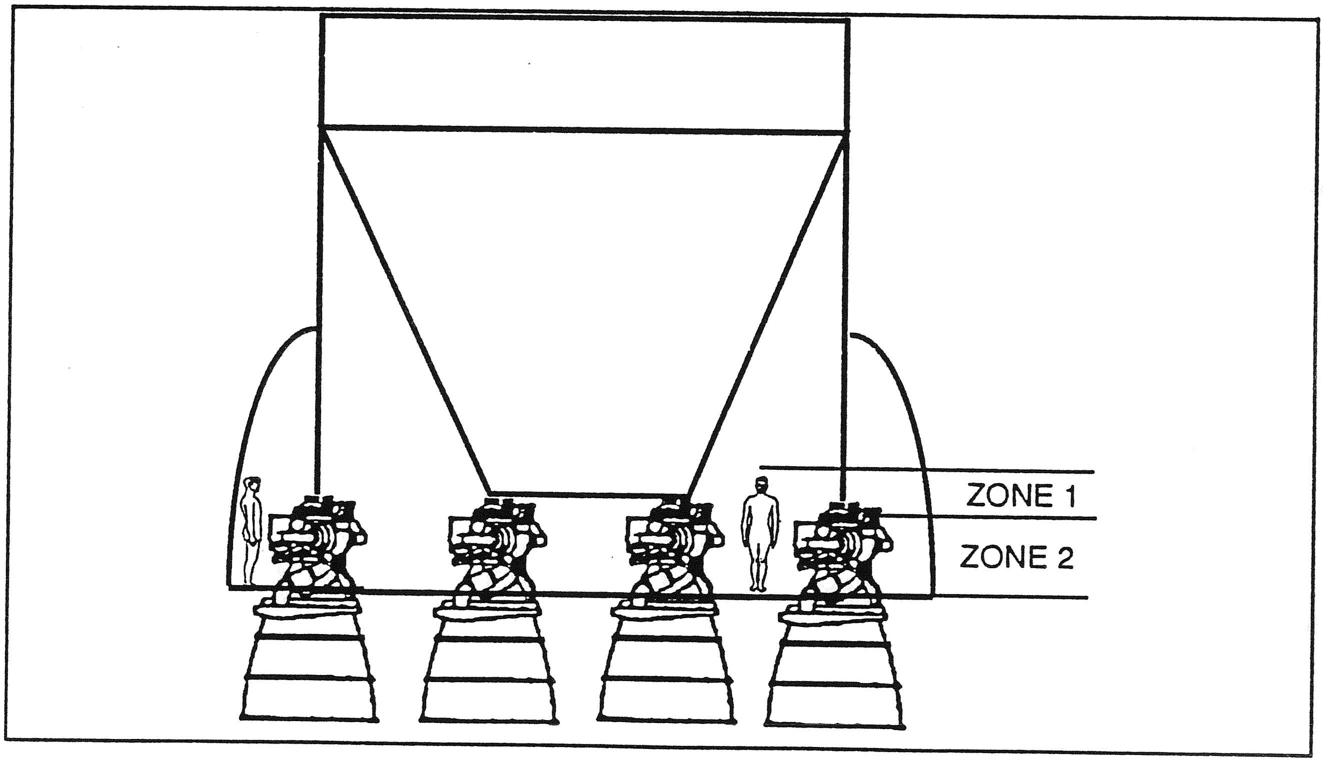


Figure 2.2.4 Use of Vehicle Structure for Access

Table 2.1.2 Ease of LRU Repair and Replacement

PRO

- LRU's are placed for easy removal and checkout based on their reliability
- LRU's are in small modules consisting of individual parts. (modules do not include complex assemblies of different systems with different failure rates)
- LRU's are placed within limits of human factors reach limitations minimizing need for apecial access platforms.

CON

- Different handling equipment is needed when the propulsion module is in the horizontal position

2.2.2 PROPELLANT FEED SYSTEM

2.2.2.1 PROPELLANT FEED SYSTEM FEATURES

The baseline LO2 main feed system offers distinct advantages for replacement and removal of ducting and disconnects. The 17"-20" is within current orbiter technology for handling tools. A single 26" or more LO2 duct may present serious problems with size and weight (ref. Trade Study 3-P-019, "LO2 Conditioning Options").

The baseline orientation for the feed inlets on the skinline engines has a serious drawback. There will either be two types of TVC attach points for the engines (very undesirable) or else the mounting of the TVC to the structure will not be the same. Two of the TVC's will be external to the skinline structure and not be common with the other two skinline engine TVC mounts. There might be more accessibility for these exterior TVCs but the replacement and removal procedures would not be common.

2.2.2.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for maintenance cost are shown in Tables 2.2.2-1 and 2.2.2-2.

Table 2.2.2-1 Baseline Propellant Feed Concept

PRO

- The disconnect locations for the 1.5 stage vehicle results in a simple removal and replacement when compared with location on the individual engine inlet (11-12") gimbal ducts.
  - Disconnects on the inlet ducts may result in a severe installation and removal problem due to the limited space available upstream of the gimbal flex joints (also contain the feed inlet prevalves).

- The center engine mounting assembly is simple. TVC attach points and TVC structural mounting is all common with the feed inlets located in a clocked, mirror fashion. Replacement and removal would be simplest for this concept.

CON

- Removal and replacement with the skinline engine feed inlets located in a clocked, mirror fashion may be compromised.
  - There will be two types of engine-TVC attach points or......
  - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.2.2-2 Alternate Propellant Feed Concept

PRO

- The alternate LH2 bulkhead main feed may allow easier removal and replacement of the main LH2 feed duct away from the center of the vehicle.

- For the skinline engines the alternating clocked feed inlets present the opportunity for not only common TVC engine mounts but also common TVC mounting of the structure with all mounts interior to the skinline. This makes removal and replacement far easier along with common handling tools.

CON

- There may be limitations on handling equipment for large 26" or more LO2 feed ducts and mounting brackets. Removal may be difficult.

- For the 1.5 stage vehicle the main LH2 disconnects might need partial mounting inside the tank. LRU maintenance may be compromised.

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2.3 COST/FLIGHT: LOADING & LAUNCH COST

2.3.1 GENERAL FEATURES

Characteristics to be considered in the evaluation include:
(1) The number of LCC's
(2) Fill/drain complexity
(3)Number of active systems
(4)Propellant conditioning complexity

Loading and Launch Costs are directly proportional to the number of systems involved and their complexity. These factors translate into costs through manpower, computer hardware and software, and time. As the number of active systems increases, the number of consoles (LCC's) required to control and monitor that system increase. Furthermore, an engineer is required at that station. Additional software is required to control, sequence, and monitor the system. The complexity of the logic and coding of this software increases as the system complexity increases.

The pros and cons of the General Dynamics' propulsion module concept based on loading and launch costs are shown in tables 2.3-1, 2.3-2, 2.3-3 and 2.3-4.

Table 2.3-1 Number of LCC's

PRO
• EMA actuators eliminate Hydraulic system and separate power system • EMA actuators are more readily monitored for health
CON
• Actuators are larger and heavier than hydraulic

Table 2.3-2 Fill/Drain Complexity

PRO
•TBD
CON
•TBD

Table 2.3.-3 Number of Active Systems

PRO

- No hydraulics
- No hypergolics provide great savings in capital equipment, manpower, and monitoring equipment.
- Rail system separation does not require additional pyroes, or other stored energy systems) to eject item away from vehicle reducing complexity of the system

CON

-

Table 2.3-4 Propellant Conditioning Complexity

PRO

•TBD

CON

•TBD

2.3.2 PROPELLANT FEED SYSTEM

2.3.2.1 PROPELLANT FEED SYSTEM FEATURES

The principal features as related to the loading and launch costs involve the dual LO2 duct versus single large duct, LH2 bulkhead feed and the concept of dual fill/drain isolation valves.

The baseline dual LO2 duct not only limits the size to 20" but also provides a natural recirculation path for LO2 passive propellant conditioning and to avoid geysering during propellant fill. One of the conditions for accepting the single feedline concept is to provide for a separate smaller recirculation loop (~6") going back to the LO2 tank aft bulkhead. This is a rather major design concept contingency. In addition, helium bubbling is needed to condition the LO2 when using a single main feed duct.

In addition, dual LO2 ducts provide more flexibility in the interfacing between the ground LO2 supply and the single tie-in point to the vehicle. Location of the main feed ducts may be driven by intertank adapter issues and the spacing between the tanks so the more flexibility the better.

The LH2 aft bulkhead feed concept similarly offers more flexibility at the interface of the ground fill/drain with the airborne feed lines. The fill/drain tie-in is downstream of the staging disconnect for the 1.5 stage vehicle and there may be more vertical run for the tie-in point.

Dual fill/drain valves was an outgrowth of ALS 0II studies in which it was determined that operations could be severely hampered during on pad cryogenic demonstration tests if the fill/drain valve were to fail closed. In addition, launch safety might be compromised if the same situation were to occur during a launch hold of any duration that required detanking.

2.3.2.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for loading and launch cost are shown in Tables 2.3.2-1 and 2.3.2-2.

Table 2.3.2-1 Baseline Propellant Feed Concept

PRO
• The dual main LO2 feed duct arrangement allows for flexibility in location of the interface with the fill/drain system - Fill/drain locations may be associated with the holddown posts - Ground safety will dictate separation of the LO2 and LH2 fill/drain
• Propellant conditioning and anti-geysering may be more effectively prevented with a dual LO2 feed duct that allows for passive recirculation more effectively than a single feed duct
CON
• None identified

Table 2.3.2-2 Alternate Propellant Feed Concept

PRO

- Fill/drain flow rates though the main system will be quicker with a single large LO2 feed duct.
- LH2 aft bulkhead feed would provide an easier interface with the LH2 fill/drain system. If the location of the location of the fill/drain valve is near the main feed line to avoid dead-leg problems then the bulkhead feed is more desirable.
- A dual fill/drain valve improves the reliability of fill/drain operations (reference Figures 1.4-1 and 1.4-2)

CON

- Ties-in the location of the LO2 fill/drain ground system more closely with the single main feed duct
- Anti-geysering may require the addition of a recirculation duct to the single LO2 main feed.
- Helium bubbling required for LO2 conditioning.

2.4 COST/FLIGHT: Manufacturing Cost

See Section 2.1 for manufacturing/producibility discussion.

2.4.1 PROPELLANT FEED SYSTEM

2.4.1.1 PROPELLANT FEED SYSTEM FEATURES

The baseline feed system is preferred over the alternates basically due to reasonable sizing and lower costs due to economy of scale. Existing Shuttle disconnects could be used in the 17" transition ducts.

The feed inlets for the baseline skinline engines have a potentially high component cost due to the differences in engine-TVC mounts. This can be avoided through the alternative of rotating the engine feed inlets in the same direction (assuming it is necessary to rotate the engines from the radial position due to interference with main support structure).

2.4.4.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for manufacturing cost are shown in Tables 2.4.1-1 and 2.4.1-2.

Table 2.4.1-1 Baseline Propellant Feed Concept

<u>PRO</u>

- The dual main LO2 feed duct can result in lower component costs than the single LO2 duct due to economy of scale and smaller size. (Multiple feed duct economy of scale may be more than offset by higher assembly and installation costs)

- Use of transition ducts may drive costs down through use of existing Shuttle assets (disconnects).

- The sump fed LH2 main feed from the skinline engines can result in more component commonality (aft bulkhead design) and lower costs.

<u>CON</u>

- The skinline engine feed inlet orientation can result in high component costs if the engine TVC attach points are not common.

Table 2.4.1-2 Alternate Propellant Feed Concept

PRO

- Reduced component (engines, mounting, associated handling hardware) costs if the skinline engine feed inlets are rotated form the radial in the same direction ("clocked inlets- alternating")

CON

- The large size of the single 26" plus single LO2 feed duct may result in higher manufacturing costs for tooling. In addition if the disconnect is located in the main feed line (no transition duct) the cost of the disconnects could be prohibitive.

- Higher manufacturing cost for the LH2 aft bulkhead for the bulkhead LH2 feed option.

2.5 COST/FLIGHT: ASSEMBLY COST

See Section 2.1 for manufacturing/producibility discussion.

2.5.1 PROPELLANT FEED SYSTEM

2.5.1.1 PROPELLANT FEED SYSTEM FEATURES

The LO2 main feed duct which has the easiest hardware assembly but more operations when compared with the single duct. The LH2 baseline offers the easiest interface with the LH2 tank aft bulkhead but may not be the easiest to install at the vehicle centerline. Transition ducts from the main LO2 feedline to the engine inlet ducts might result in an extra operations. The baseline can have a serious assembly sequence problem with uncommon engine attach points for the TVC or uncommon TVC mounting to the structure.

5.4.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for assembly cost are shown in Tables 2.5.1-1 and 2.5.1-2.

Table 2.5.1-1 Baseline Propellant Feed Concept

PRO

- When compared with the alternative of a single large feedline (or multiple feedlines), the dual LO2 main system system offers the easiest assembly from the standpoint of handling hardware.

- The sump fed 17" LH2 ducts offer the easiest interface and assembly (with the LH2 tank sump) sequence of operations.

- The center engine mounting assembly is simple. TVC attach points and TVC structural mounting is all common with the feed inlets located in a clocked, mirror fashion. Assembly sequence is simplified.

CON

- Transition ducts from the LO2 main ducts to the engine inlet gimbal ducts result in extra assembly.

- Assembly sequence complexity with the skinline engine feed inlets located in a clocked, mirror fashion.
  - There will be two types of engine-TVC attach points or......
  - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.5.1-2 Alternate Propellant Feed Concept

PRO

- The assembly sequence for the vehicle is easiest with a single main LO2 feed duct. There is only one disconnect for the 1.5 stage vehicle to align when compared with dual ducts or multiple ducts. However handling may be problematical.

- The alternate LH2 bulkhead main feed may allow easier installation of the main LH2 feed duct away from the center of the vehicle.

- There are fewer assembly parts with no transition duct between the LO2 main feed and the engine inlets.

- For the skinline engines the alternating clocked feed inlets present the opportunity for not only common TVC engine mounts but also common TVC mounting of the structure with all mounts interior to the skinline.

CON

- There may be limitations on handling equipment for large 26" or more LO2 feed ducts and mounting brackets. This may complicate the assembly sequence and operation.

- There may be a complex LH2 aft bulkhead interface for an aft bulkhead LH2 feed. For the 1.5 stage vehicle the main LH2 disconnects might need partial mounting inside the tank.

- The mirror clocked position may result in uncommon assembly of the engine inlet ducts for the center engines on the 1.5 stage vehicle. Assembly procedures could be compromised.

2.6 COST/FLIGHT: ACCEPTANCE TESTING

2.6.1 ENGINE ARRANGEMENT

2.6.1.1 FEATURES

The arrangement and orientation of the engines in the propulsion module has an effect in the structure of the acceptance testing. The use of a module which has four engines will reduce the time and cost of an acceptance test program relative to those configurations which require either individual engine modules or two engine modules. Even though the four engine module would have larger size and heavier weight than a lesser number of engine modules, current handling equipment can meet the requirements without difficulty. The smaller engine modules would need equipment of the same capabilities for their transportation and installation.

The design of the propulsion module was developed with operability benefits in mind such that technician access and large module replacement /LRU refurbishment can be accomplished without a great deal of delay. The available area interior to the propulsion module whether with or without sustainer engines installed give adequate clearance for test stand personnel to access most parts of the module for test setup and removal.

The sustainer engine package can be treated has an engine module with transportation and installation in the test stand for acceptance testing. The sustainer propulsion module (two engines and the conical adapter) could be tested as an individual unit or with the booster propulsion package. In the development testing of the Atlas, the sustainer was tested with the booster engine module. The booster engines were cut off at the BECO command and remained fixed to the vehicle while the sustainer engine continued the burn to SECO. The vehicle did not suffer from any adverse effects from this testing style. This could be done for the NLS propulsion module.

2.6.1.2 PROS/CONS

The pros and cons for the engine arrangement are presented in table 2.6.1.2-1.

Table 2.6.1.2-1 Pro/cons for Engine Arrangement Concept
System Level of Testing

PRO

- Baseline engine arrangement is compatible with the process flow of single engine testing going to propulsion module assembly and test

- Booster propulsion module can be tested as a four engine module thereby reducing the acceptance test cost of the module relative to a two engine module or single engine module (1 test gets 4 engines vs 2 tests of 2 engine modules)

- Sustainer engines can be tested as a two engine unit reducing the acceptance test cost

- Sustainer and booster engine package could be tested if desired on a battleship test stand if all up assembly test is required for the program - maybe required if manrating is envisioned for the launch vehicle

- Booster booster section is a "plug in - plug out" assembly - ease in all up system test

- Accessability of the booster module/ sustainer core allows for easy access on the test stands - by removal of the engine fairings or thru access areas in heat shield

- Propellant costs should be less for large four engine acceptance test than for a (4 x single engine test) or (2 x 2 engine module) - one time system chilldown

- Acceptance test for a full module is better validation of the launch conditions

CON

- transport and assembly in the test stand of a four engine module is more difficult because of the increased weight and size

2.6.2 SEPARATION CONCEPT

2.6.2.1 FEATURES

Acceptance testing of the separation software and hardware will be simplest for this concept, compared with the other various separation concepts. This concept does not use active mechanical systems nor energy storage devices to push or power the booster clear of structure.

All the closure disconnects are sealed and released by the motion of the single booster assembly along a set of jettison guide tracks.

Basically, the acceptance will start with inspection and certification of meeting fit and function standards by the component manufacturers. Certain critical assemblies will require fit and clearance checks during the build-up of teh vehicle. Our concept will minimize the need for fit checks by emphasizing robust clearances in the design, ie. ensure that the separation motion has sufficient clearances to obviate the need for fit checks. Our experience with the Atlas booster separation, with initial clearances of fractions of an inch, required intensive measurements and slow assembly, disassemby, and reassembly of the booster. The NLS has the opportunity to incorporate design features to minimize cost of acceptance testing by using robust clearances.

Some acceptance testing will be neccessary on certain components and subsystems. Combining the pneumatic and instrumentation disconnects onto one or two disconnect panel groups will allow combined checkout of multiple disconnect circuits. We currently show the use of a linear shaped charge to sever the structure to initiate booster separation. Lot testing of the explosive material, and system checkout of the laser initiator will probably be required on a regular basis. The separation software commands would only require checks if changes are made, however this concept is a one-shot separation that should be very repeatable, with refinement of the timing of signals during the first few flights.

2.6.2.2 SEPARATION CONCEPT PRO/CONS

Several pros and cons are listed in Table 2.6.2-1. They represent elements of the baseline separation system which could also be incorporated to varying degrees in other concepts.

Table 2.6.2-1 Separation Baseline Concept

PRO

- Very repeatable separation behavior without costly subsystems nor energy storage devices to checkout.
- Robust design clearances minimize cost of assembly checks and disaasembly
- Uses low cost pyro linear separation charge
- use laser initation of pyro to allow normal assembly and checkout operations without explosive danger.
- Functional disconnects on localized panels allow single combined acceptance tests.

CON

- Requires some acceptance checks and testing on each vehicle to ensure proper fit and operation for separation.
  - Jettison track & mating shoe alignment
  - Pyro batch testing
  - Laser initiator operation
  - Software operation on initial flights and as required.

2.6.3 PROPELLANT FEED SYSTEM

2.6.3.1 PROPELLANT FEED SYSTEM FEATURES

The only significant area in which acceptance testing would be a major issue for this discriminator would be the baseline dual LO2 feed ducts versus the large single 26" duct. The staging disconnects for the 1.5 stage vehicle could be severely impacted with the single duct concept. A size of 26" or greater (reference Trade Study 3-P-019, "LO2 Bleed") would be very difficult to check out both at the component and at the system level. A 26" dual-poppet disconnect weighs close to 500 pounds. The baseline 17" disconnect making use of transition ducts may weigh a little over 200 pounds. The leak check systems would be very large to handle the component checkout.

This impact could be reduced by a transition down to ~24" duct that feeds four engines after supplying the sustainer and that contains the disconnect.

2.7 NON-RECURRING COST: VEHICLE DESIGN & DEVELOPMENT ENGINEERING

2.7.1 ENGINE ARRANGEMENT

2.7.1.1 ENGINE ARRANGEMENT FEATURES

The arrangement and orientation of the engines in the propulsion module has a profound effect in the design and development of the propulsion module. The engine placement dicitate the selection of the other subsystems that the propulsion module uses. Its for this reason that in the development of the trade study for th propopulsion module, the design should focus on the arrangement of the engines first. Are there any favored configuration for the location of the engines that might impose design restrictions on the vehicle that must be accomadated before additional design continue? The trade tree developed and shown in section 1.1 displays the options considered in the engine arrangement. The baseline described in section 1.1 is similar to the cycle 0 reference vehicle. Experience learned from our sister divisions in regards to submarines and ships which also have large complex structures, point to the desire to reduce the design to small number of large components, bring these large components together for assembly. This example is readily demonstrated in many other commericial enterprises today. For this reason, the arrangement of 4 booster engine thrust structure assemblied in one piece and mated to the 2 engine engine sustainer structure followed most assembly examples seen today.

The booster outside ring with the sustainer interior conical adapter is similar in appearances and operation to the Atlas vehicle. The arrangement of the engines in the NLS propulsion module is very much like the very early Atlas concepts (with up to five engines) when the required payload deliver weight of the vehicle was much higher than the vehicles which became operational. The outer ring (skinline) of engines carried the load of the engine thrust up into the "ballon" tank structure without requiring additional tank structure (the most efficient technique). The center sustainer was mounted on the ogive tank bulhead of the RP-1 tank thus allowing maximum volume of usable propellant for payload delivery.

Table 2.7.1.2-1 Pro/cons for engine arrangement regarding vehicle design and development engineering discriminator

PRO

- Baseline engine arrangement for the design reduces the number of system components (ie, 1 booster thrust barrel, 1 sustainer conical thrust structure, 6 engines vs arrangements that have a thrust structure for two engines or structure for an individual engine) - less number of large system parts is desirable (ie make the component with the least number of parts)

- Booster design is very similar conceptually to the Atlas staging design - design problems have been worked out over 500 Atlas launches

- Booster engines thrusting through to the tank skinline Is the best load path for the lightest structure

- Booster engine spacing is the best for maximum available engine gimbal angle

- Booster module recovery can be "kitted" (added in strap-on modules) without extensive redesign of the propulsion module - conceptualized in Booster Recovery Module Advanced Development program in ALS phase II - no major design scar to the expendable mode of propulsion module design

- Current technology of large scale part handling equipment is capable of propulsion module equipment - examples are air pallets, lampson crawlers

CON

- transport and assembly in large size is more difficult requires the use of large tooling and transport equipment

2.7.2 THRUST STRUCTURE

2.7.2.1 THRUST STRUCTURE FEATURES

The baseline thrust structure is the least complex of the trade tree options shown in Figure 2.1-4. Assembly of two major components reduces the number of structural interfaces and ,therefore, minimizing coordinated tooling requirements for the thrust structure. Implementing integrally machined skin/stringer reduces part count and also thrust structure weight by beefing up specified areas where the loads are greatest, engine and holddown locations. The conical sustainer section is sensitive to tank stretch and becomes less attractive as tank length increases aft. A thrust barrel sustainer section shown in Figure 1.2-5 appears more favorable structurally at ten (10) feet of tank stretch. This type of structure is less sensitive to engine thrust changes because the structure can be adjusted locally to offset the increased load without major critical dimension changes (ie. booster diameter or length). The booster section can be common for both HLLV and 1.5 stage with the possible addition of crossbeams to replace the sustainer section.

2.7.2.2 THRUST STRUCTURE PRO/CONS

The pros and cons for vehicle design and development engineering are listed in Table 2.7.2-1.

Table 2.7.2-1 Vehicle Design and Development Pros & Cons

PRO

- Low part count due to integrally machined skin/stringer arrangement on both sustainer and booster sections.
- A larger scale version of the proven Atlas design can be utilized for the holddown mechanism on the booster section.
- Skinline mounting of booster engines is most structurally efficient load path and reduce impacts to tank.
- Booster section separates as one unit, therefore reducing the complexity of additional separation systems, hardware and software for modular type arrangements.
- Sustainer structure can be readily removed and replaced with cross beams, if required, for HLLV vehicle.

CON

- Skin arrangement restricts access to components mounted inside the sustainer structure.
- Large tooling and facility required for assembly.
- Conical sustainer structure is sensitive to tank stretch. Alternate concept of sustainer thrust barrel may be more viable if tank stretches ten (10) feet.

2.7.3 SEPARATION CONCEPT

2.7.3.1 SEPARATION CONCEPT FEATURES

The development of the single booster module for the 1-1/2 stage is based on current and past launch vehicle designs. The LH2 disconnect seals on STS as well as the poppet valve disconnects and well behaved mechanical jettison of the Atlas booster half stage provide a strong legacy for the NLS design. This legacy will require less development time and cost to produce a reliable, workable design.

2.7.3.2 SEPARATION CONCEPT PRO/CONS

Several pros and cons are listed in Table 2.7.3-1. The propulsion module is a significant part of NLS design and development. This single module arrangement uses common components and subsystems throughout. The separation systems are based on proven designs and technology from current launch vehicles. The complexity of staging a booster is the source of the "con". Design and development should be as straight forward and inexpensive as any other low cost concept due to repetition of design and no technology development.

Table 2.7.3-1 Separation Baseline Concept

PRO

- No new technology development required. The design is based on existing vehicle hardware and systems (STS, Saturn, and Atlas).
- Single Module design to develop
- Module design uses mostly common/idendical components with HLLV
- Early development testing using adapted existing vehicle components will yeild early design information of system operation in NLS environments

CON

- Will require design of concept demonstrator hardware and development and maintenance of (electronic) Mockup.

2.7.4 PROPELLANT FEED SYSTEM

2.7.4 PROPELLANT FEED SYSTEM FEATURES

The advantages for the baseline system is apparent in most of the options except a rather minor one of removing the LO2 transition ducts (which may be offset by use of somewhat larger staging disconnects - 20" vs. 17").

The major exception is the baseline skinline engine feed orientation. Commonality is compromised with the skinline engine feed inlets located in a clocked, mirror fashion. Either the engine TVC mounts are different or more importantly for the design effort uncommon structural mounting and exterior mounting points would result in design problems.

2.7.4.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for vehicle design and development engineering are shown in Tables 2.7.4-1 and 2.7.4-2.

Table 2.7.4-1 Baseline Propellant Feed Concept

PRO

- Dual LO2 main feed is a relatively simple concept. Feed transition to the engine inlets is symmetrical and simple.

- Sizing for the components (17"-20") is not outside the current state-of-the-art for flex joints and disconnects. Current shuttle assets may be used for the 17" transition ducts (LO2 disconnect, LH2 and possibly LO2 flex joints).

- The sump fed LH2 ducts is a relatively simple concept used on previous vehicles.

- The center engine feed inlet orientation results in a completely symmetrical set of inlet ducts.

CON

- Commonality is compromised with the skinline engine feed inlets located in a clocked, mirror fashion.
    - There will be two types of engine-TVC attach points or......
    - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.7.4-2 Alternate Propellant Feed Concept

PRO

- The elimination of transition ducts for LO2 would simplify the design and development.
- The alternating clocked feed inlets for the skinline engines result in a simple and symmetrical mounting for the TVC-engine and TVC-structure interfaces.

CON

- The transition for the single large feed duct to the engine inlets is relatively complex. The system is asymmetrical. The "throw run" to the opposite side engine inlet ducts would be a difficulty.
- Component design and development for large (26" and greater) LO2 main duct component sizes (flex joints and possibly disconnects) is problematical.
- More design development and analysis is required to handle propellant conditioning and anti-geysering issues with the lack of a natural recirculation loop.
- The bulkhead feed for the LH2 may present design development problems especially if the staging disconnect is located partially inside the tank.

2.8 NON-RECURRING COST: Development Testing

2.8.1 ENGINE ARRANGEMENT

The aspect of development testing for the propulsion module is tied to the engine development testing. The development of confidence in the propulsion module for first flight is independent of the engine arrangement chosen. All options for the engine arrangement will need to be addressed with a plan pursuing the goals established as requirements for the program.

2.8.2 SEPARATION CONCEPT

2.8.2.1 SEPARATION CONCEPT FEATURES

The development of the single booster module for the 1-1/2 stage is based on current and past launch vehicle designs. The LH2 disconnect seals on STS as well as the poppet valve disconnects and well behaved mechanical jettison of the Atlas booster half stage provide a strong legacy for the NLS design. This legacy will require less development time and cost to produce a reliable, workable design.

2.8.2.2 SEPARATION CONCEPT PRO/CONS

Several pros and cons are listed in Table 2.8.2-1. The propulsion module is a significant part of NLS design and development . This single module arrangement uses common components and subsystems throughout. The separation systems are based on proven designs and technology from current launch vehicles. The early development testing amy be able to adpt existing vehicle hardware components to yield early design information of NLS operating environments. The complexity of staging a booster is the source of the "con". Design and development should be as straight forward and inexpensive as any other low cost concept due to repetition of design and no technology development.

Table 2.8.2-1 Separation Baseline Concept Pros & Cons

PRO

- No new technology development testing required. The design is based on existing vehicle hardware and systems (STS, Saturn, and Atlas). Testing of design concept to obtain engineering design data is all that is required.
- Early development testing using adapted existing vehicle components will yield early design information of system operation in NLS environments

CON

- Will require design of concept demonstrator test hardware.

2.8.3 PROPELLANT FEED SYSTEM

The only significant area in which development testing would be a major issue for this discriminator would be the baseline dual LO2 feed ducts versus the large single 26" duct. The staging disconnects for the 1.5 stage vehicle could be severely impacted with the single duct concept. A duct size of 26" or greater (reference Trade Study 3-P-019, "LO2 Conditioning Options") would be present difficulties in development at the component level. A 26" dual-poppet disconnect (which might be reduced in a transition duct arrangement to ~ 24") weighs close to 500 pounds. The baseline 17" disconnect making use of transition ducts may weigh a little over 200 pounds. The leak check systems would be very large to handle the component performance. Poppet leakage for the disconnect would also be a problem as would misalignment allowances and the flex joint design for these misalignments. In addition, there also would be the problem of development of flex joints for these large sizes.

For the large single LO2 main feed duct development testing for propellant conditioning and anti-geysering issues would present a challenge. It is possible that a smaller additional duct would be necessary to provide a recirculation loop for propellant conditioning.

2.9 NON-RECURRING COST: VERIFICATION TESTING

2.9.1 ENGINE ARRANGEMENT

The aspect of verification testing for the propulsion module is tied to the engine verification testing. The propulsion module can be used as a method to verify both the engines and the propulsion module prior to transportation to the core assembly site. Instead of 4 single engine verification engines runs, the propulsion module could be run as a unit and verification can be gotten for the engines and propulsion module systems simultaneously.

Table 2.9.1.-1 Pro/cons for Engine Arrangement Concept

PRO
• Use of the 4 engine booster propulsion module can permit reduction in the engine development time by firing 4 engine each time — single engine testing for 99% reliability at 50% confidence ~50 + single engine tests but only ~13+ tests of a 4 engine module
• Propulsion module designed for expendable use would be less expensive than a fully reusable module — impact of loss would be less to the program
CON
• TBD

2.9.2 THRUST STRUCTURE

2.9.2.1 FEATURES

The baseline thrust structure will require both structural and modal survey testing. A structure test will eliminate the factor of safety requirement of two (2) placed on untested structure. The modal survey test will reduce loads model uncertainty factor. Both of these tests will reduce the thrust structure weight but increase the development costs of the vehicle. However, a cost savings to the program could be incurred if the modal survey article were utilized for the full scale separation tests which will be required of the new separation system. The holddown structure located on the booster section shown in Figure 1.2 -3 will be tested at a component assembly level through inspection of the hardware during manufacture and assembly. The design of the launch bearing in the booster section will be similar to the Atlas design a should not require any developmental tests. The holddown mechanism located on the MLP will require both clearance and operational tests, prior to flight readiness acceptance.

2.9.2.2 PRO/CONS

The pros and cons for acceptance testing are listed in Table 2.6.2-1.

Table 2.9.2-1 Thrust Structure Verification Testing

PRO

- A Structural test and Modal Survey article will eliminate the large weight penalty associated with carrying a factor of safety of two (2) and large model uncertainty factors.
- The holddown mechanism would utilize existing Atlas designs whereever possible, which would eliminate some costly subsystem level tests.

CON

- A Structural test and Modal Survey article will increase the overall cost to develop the vehicle, however, the design contains fewer parts (integrally machined skin/stringers) and therefore, lower manufacturing costs than other concepts.

2.9.3 SEPARATION CONCEPT

2.9.3.1 SEPARATION CONCEPT FEATURES

The development of the single booster module for the 1-1/2 stage is based on current and past launch vehicle designs. The disconnects for the propellants and pneumatic/electrical disconnect panels will have to be tested to verify design operation to meet specifications. Verification of the concept. should culminate with an all-up test of the separation process with actual flight weight hardware with cryogenics.

2.9.3.2 PRO/CONS

The pros and cons are listed in Table 2.9.3-1. The propulsion module is a significant part of NLS design and development. This single module arrangement uses common components and subsystems throughout. The separation systems are based on proven designs and technology from current launch vehicles. The component verification testing may be able to adapt test fixturing from earlier developmental tests. Verification testing should be as straight forward and inexpensive as any other low cost concept due to its single module, single separation event design.

Table 2.9.3-1 Separation Baseline Concept Pros & Cons

PRO

- No new technology development testing required. Some development tests and fixtures will be useable for the verification test program.

CON

- TBD

2.9.4 PROPELLANT FEED SYSTEM

Similarly to section 2.8 - Propellant Feed- verification testing would be problematical for the large single 26" duct (versus the dual 20" ducts). A 26" or greater duct (reference Trade Study 3-P-019, "LO2 Conditioning Options") would be present difficulties in verification at the subsystem and system level and might present operational difficulties. It is possible that a smaller additional duct would be necessary to provide a recirculation loop for propellant conditioning if not determined at the development stage for the vehicle. A degree of uncertainty might exist for the single duct (versus dual duct) during vehicle level MPS testing.

Verification of the performance of the disconnects over and above development and acceptance testing would also be a problem. Simulating environmental conditions for a large component can be time consuming and expensive. Functionally, the comparative difference might be between a 17" Shuttle derived disconnect and qualified to a great extent by order of similarity (BOS) and a 24-26" (or greater) brand new part.

2.10 NON-RECURRING COST: HANDLING EQUIPMENT

2.10.1 HANDLING EQUIPMENT GENERAL DISCUSSION

Characteristics to be considered in the evaluation include assembly complexity (complexity due to non symmetric parts) and number of unique modules to handle (how many of the modules could use common GSE vs. unique requirements)

Handling equipment non-recuuring costs are directly proportional to complexity of the assembly process. Factors which increase the assembly complexity are:

1) Tight assembly tolerances
2) Number of connections/fasteners
3) Indentured assemblies
4) Size of component or module
5) Post assembly Inspection
6) Damage tolerance

Tight assembly tolerances increase handling equipment costs in placing requirements on the equipment to provide delicate control motions. Costs are further increased when the component is of very large size and mass. The equipment must be designed to handle this weight in a delicate fashion for proper alignment and to avoid damage to the part during assembly. The size/mass of the part is important in the damage tolerance area. A large mass under motion is hard to control delicately. Even slight motion of a large mass can cause extensive damage to itself or surrounding structure due to the large momentum involved.

The pros and cons of the General Dynamics' propulsion module concept based on handling equipment are shown in tables 2.10.1-1 and 2.10.1-2

Table 2.10.1-1 Assembly Complexity

PRO

- EMA Batteries do not require last minute charging, conditioning, and installation prior to launch.
- Modules have built-in production assembly handling interface points facilitating maintenace nad LRU repair and replacement

CON

-

Table 2.10.1-2Number of Unique Modules to Handle

PRO

- There are a larger number of smaller, identical modules which translates into less expensive GSE with better utilization rates. Very specific GSE to handle large multi-system modules are costly and have low utilization rates. Large multi-system modules still require additional GSE in off-line repair and overhaul shops to dissassemble the module

CON

-

2.10.2 PROPELLANT FEED SYSTEM

2.10.2.1 PROPELLANT FEED SYSTEM FEATURES

The baseline system offers advantages for handling equipment in the areas of dual LO2 feed ducts with their smaller size than the single feed duct. In addition, the baseline orientation for the engine inlets for the center engines simplifies handling fixtures.

A minor problem exists in the handling area with the use of transition ducts but a major concern is the feed inlet orientation for the skinline engines. Commonality for attachment of the engines to the TVC and or mounting of the TVC to the structure could be compromised in the baseline system where the engine inlets are clocked in an opposite rotational sense to meet commonality requirement for the feed system ducting. Rotation in the same sense from the radial position would alleviate this problem and have little or no impact on feed system duct commonality.

2.10.2.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparisons between the baseline feed system concept and alternatives for GSE handling equipment are shown in Tables 2.10.2-1 and 2.10.2-2.

Table 2.10.2-1 Baseline Propellant Feed Concept

<u>PRO</u>

- When compared with the alternative of a single large feedline (or multiple feedlines), the dual LO2 main system system offers the advantage of simpler handling equipment for the smaller size ducts.

- The center engine mounting assembly is simple. TVC attach points and TVC structural mounting is all common with the feed inlets located in a clocked, mirror fashion

<u>CON</u>

- Transition ducts from the LO2 main ducts to the engine inlet gimbal ducts result in extra assembly and possibly extra tooling.

- Handling equipment complexity with the skinline engine feed inlets located in a clocked, mirror fashion.
  - There will be two types of engine-TVC attach points or......
  - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.10.2-2 Alternate Propellant Feed Concept

PRO

- The stacking for the vehicle is easiest with a single main LO2 feed duct. There is only one disconnect for the 1.5 stage vehicle to align when compared with dual ducts or multiple ducts. The handling for this interface match would be minimized.

- The alternate LH2 bulkhead main feed may allow easier installation of the main LH2 feed duct away from the center of the vehicle.

- For the skinline engines the alternating clocked feed inlets present the opportunity for not only common TVC engine mounts but also common TVC mounting of the structure with all mounts interior to the skinline. Handling for these engines would be common.

CON

- There may be limitations on handling equipment for large 26" or more LO2 feed ducts and mounting brackets.

- There may be a complex LH2 aft bulkhead interface for an aft bulkhead LH2 feed. For the 1.5 stage vehicle the main LH2 disconnects might need partial mounting inside the tank. This might require special handling and tools for installation.

- The mirror clocked position may result in uncommon assembly of the engine inlet ducts for the center engines on the 1.5 stage vehicle. Again two sets of tools and fixtures might be required.

2.11 NON-RECURRING COST: Manufacturing Development

See Section 2.1 for manufacturing/producibility discussion.

2.11.1 PROPELLANT FEED SYSTEM

Two Large disconnects and flex joints for the alternative single LO2 feed duct concept may incur some additional manufacturing tooling costs. The alternative LH2 bulkhead feed concept may require new or more complex installation tooling for the disconnects for the 1.5 stage vehicle. Engine mounting may result in additional tooling costs if the skinline engine feed inlet orientation remains per the baseline; clocked in a mirror fashion.

2.12 CONSTRUCTION OF FACILITIES: LAUNCH FACILITIES

2.12.1 LAUNCH FACILITIES GENERAL DISCUSSION

Characteristics to be considered in the evaluation the degree of MPS design changes, pad/flame trench modifications (what mods are required to accommodate the HLLV/1.5 stage vehicles, do they impact STS operations), and MLP commonality of design with HLLV/1.5 stage

The pros and cons of the General Dynamics' propulsion module concept based on launch facilities are shown in tables 2.12.1-1, 2.12.1-2 and 2.12.1-3

.Table 2.12.1-1 Degree of MPS design changes

PRO

- All current MLP-to-PAD interfaces remain unchanged
- Use of existing shuttle systems

CON

- Use of existing shuttle systems implies inheritance of shuttle inefficiencies
- Existing systems may become over used and fail earlier (and more) than normal
- Existing shuttle "standing army" required for launch

Table 2.12.1-2 Pad/flame Trench Modifications

PRO

- Plume impingement from liquids within bounds of current deflector
- MLP-to-PAD location and orientation identical to shuttle
- Payload services supplied from MLP mounted umbilical mast

CON

- Multiple towers (on pad and MLP) decreases allowable drift at lift-off

Table 2.12.1-3 MLP Commonality of Design with HLLV/1.5 Stage

PRO

- All core umbilicals remain the same
- 1.5 stage orientation on MLP same as HLLV

CON

- New MLP(s) dedicated to NLS - no common MLP for shuttle and NLS

2.12.2 PROPELLANT FEED SYSTEM

It is not anticipated that there will be any propellant feed system baseline design concepts or alternatives that would have a major impact or show significant differences for the launch facility.

2.14 DESIGN CAPABILITY: Weight

2.14.1.1 ENGINE ARRANGEMENT FEATURES

The Reference Zero concept, with four engines mounted on the skinline is the lightest possible structure because the loads are immediately distributed into the skin for as a distributed load for the tank attachment. It has the least effect on ET structures, and elliminates the need for heavy separation attach fittings to the tank. The concept allows jettison of the maximum weight of booster structure for the 1-1/2 stage vehicle. The sustainer engines also use a common structure, which distributes the thrust loads throught the thrust cone to the tank skin.

Table 2.9.1.2-1 Pro/cons for engine arrangement regarding weight discriminator

PRO

- The 4 booster engine skinline module (baseline) is the lightest system relative to payload impact
  - 2 engine sustainer is centrally located with a common structure - no separate structure for each sustainer engine.
  - maximum weight is jettisoned with the 4 engine skinline system (largest diameter section)

CON

- TBD

2.14.2 THRUST STRUCTURE

2.14.2.1 THRUST STRUCTURE FEATURES

The baseline thrust structure weight is the second lightest of the trade tree options shown in Figure 1.2-4. Preliminary weight estimate of the sustainer weight for 5 ft. stretch of the tank is approximately 4500 lbs for the primary structure only. The weight at 10 feet of tank stretch is approximately 4100 lbs. Incorporation of the holddown structure into the booster thrust post as shown in Figure 1.2-3 adds to the weight reduction by eliminating excess structure if the holddown were located elsewhere on the vehicle. Because the aft skirt will be designed to loads for 1.5 stage, HLLV will suffer a weight penaltly to carry that same aft skirt and cross beams to counteract ovaling modes in the aft skirt. These weight impacts are currently being evaluated. The thrust barrel sustainer is the lightest, however, tank heating, structural attachment to the severe temperature environment of LH2 bulkhead, and bulkhead weight impacts are concerns which must be investigated.

2.7.2.2 THRUST STRUCTURE PRO/CONS

The pros and cons for thrust structure weight are listed in Table 2.14.2-1.

Table 2.14.2-1 Thrust Stucture Weight Pros and Cons

PRO

- Integrally machined skin/stringer arrangement on both sustainer and booster sections reduces weight over conventional skin and stringer arrangements.
- Load increases from the engines or holddowns can be offset locally to avoid large weight increases from uniform thickness skins and stringers.
- Incorporation of holddown structure in booster thrust post further reduces booster weight.

CON

- HLLV weight penalty to carry aft skirt designed for 1.5 stage.
- 10 foot tank stretch does reduces the sustainer weight by only 400 lbs.
- Alternate Thrust barrel sustainer is lightest option, however, many impacts to tank are not yet available.

2.14.3 SEPARATION CONCEPT

2.14.3.1 SEPARATION CONCEPT FEATURES

The single booster module for the 1-1/2 stage is the lightest weight concept. The structure for the booster engines efficiently transfer thrust and ground loads into the skirt on the LH2 tank. One distributed pyro linear shaped charge separation system severs the skin, without heavy localized hard points or fasteners. The booster disconnects allows the booster feed system, pneumatic, and fill-drain systems to be jettisoned with the booster module to keep the core stage light. The HLLV will have the booster section installed as its core propulsion, without the cone mounted center engines. The feed line disconnects could be replaced with adapter sections to minimize use of more expensive disconnects to minimize the scarring of the HLLV.

2.14.3.2 SEPARATION CONCEPT PRO/CONS

The pros and cons are listed in Table 2.14.3-1. This concept provides for the highest payload performance of the NLS. There is minimal scarring of the HLLV, which currently has a performance margin. There are design

Table 2.14.3-1 Separation Baseline Concept Pros & Cons

PRO

- The single module concept has the lowest overall weight of any of the current concepts, which gives the highest payload capability.
- The single module stages all of the booster systems, leaving the core systems at optimal weight for the sustainer portion of flight. for max performance.
- The structure and PM systems are common for both the 50K booster and the HLLV core, with minimal scarring.
- This concept has minimzed structure, loads and weight impact on the ET.

CON

- Single module is a large, heavy structure for transport and assembly.

2.14.4 PROPELLANT FEED SYSTEM

2.14.4.1 PROPELLANT FEED SYSTEM FEATURES

The propellant feed system is affected by the choice of design concept but only in special cases. The single feed duct concept (from the LO2 conditioning trade study, 3-P-019) results in a comparative weight savings of 2000 lbs but only for the 1.5 stage vehicle that incurs a sustainer engine out. The residuals result from a differential flow path for each main duct to a single engine. The differential weights of the single duct components versus a pair of smaller disconnects or flex joint sets are smaller. For example, a single 26" disconnect (alternate design) weighs about 75 lbs more than two 17" disconnects (baseline design).

Trade Study 3-P-013, " Feedline Gimbal Configuration" has estimated that relative to the center sump feed (baseline) the alternate design of a LH2 aft bulkhead feed for the skinline engines results in a potential weight penalty for the HLLV of 2000-3000 lbs of residual LH2. This might not be a driver depending on the final payload margins for this vehicle. In addition, the LH2 feed concept may be established by the requirement to provide a minimum slope, radius of curvature and minimum inlet straight section for the engine turbopump. The bulkhead LH2 feed has a higher probability of providing these requirements.

Another issue is the location of the dual LO2 duct antigeysering or cross-over duct. The scissors duct concept to accommodate engine gimbal motion might result in a lighter cross-over duct relative to the 3-flex joint gimbal duct. This assumes that the prevalves are located downstream of this cross-over duct.

2.14.4.2 PROPELLANT FEED SYSTEM PROS/CONS

The comparison between the baseline feed system concept and alternatives for weight is shown in Table 2.14.4-1.

Table 2.14.4-1 Baseline Propellant Feed Concept (versus the alternate)

PRO
• The baseline LH2 sump feed might result in ~2000-3000 lbs less residual LH2 than the alternative bulkhead LH2 feed for the skinline engines. This only applies for the HLLV vehicle.
CON
• The 1.5 stage vehicle might incur ~2000 lb penalty for a dual LO2 duct when compared with a single large LO2 duct. This only applies for sustainer engine out.

2.15 DESIGN CAPABILITY: AERODYNAMIC DRAG

2.15.1.1 ENGINE ARRANGEMENT FEATURES

The Reference Zero concept, with four engines mounted on the skinline is the lightest possible structure because the loads are immediately distributed into the skin for as a distributed load for the tank attachment. Fairings are required over the skinline mounted engines to protect the engine and feed system from aero drag loads and aero heating. There is a weight penalty on the vehicle for the fairings and support structure. This penalty should be more than offset by the savings in primary engine mounting weight, compared to mounting on discrete structures.

Table 2.15.1.-1 Pro/cons for engine arrangement regarding weight discriminator

PRO

- Fairings allow the mounting of the engines with the lightest possible structure weight and structural complexity
- The skinline engine fairings reduce vehicle aero drag.
- The fairings protect the engine power head and LO2 feedlines from aeroheating and aero drag loads.

CON

- Exterior LOX feed system will need to have aerodynamic fairing - increased complexity and weight for the fairings (should be more than offset by the savings in structural support for engine mounting).

2.15.2 THRUST STRUCTURE

2.15.2.1 THRUST STRUCTURE FEATURES

The baseline thrust structure aerodynamic drag will be increased over the MSFC baseline due to the extended heat shield skirt which extends aft to a point approximately one-third the way down the engine bell. This will, however, reduce aero loading on the booster engine bells, which reduces engine actuator loads. The holddown structure is located inside the booster fairing and therefore is not a consideration in the drag effects on the booster unlike externally mounted holddown structure.

2.15.2.2 PRO/CONS

The pros and cons for thrust structure aerodynamic drag are listed in Table 2.15.2-1.

Table 2.15.2-1 Thrust Stucture Aerodynamic Drag Pros and Cons

PRO

- Holddown structure is located internal to booster engine fairing and does effect booster drag like externally mounted structure.
- Extended aft skirt reduces aerodynamic loads on booster engines.
- Incorporation of holddown structure in booster thrust post further reduces booster weight.

CON

- Extended aft skirt increases aerodynamic drag of booster due to increased surface area.

2.15.3 SEPARATION CONCEPT

2.15.3.1 SEPARATION CONCEPT FEATURES

The only impact of the single module concept on aerodynamic drag is the slightly increased drag of the exposed LO2 cirumferential ducts leading from the disconnect to the booster skinline engine fairings.

2.15.3.2 SEPARATION CONCEPT PRO/CONS

The pros and cons are listed in Table 2.15.3-1. The increased aero drag on exposed LO2 ducting may be balanced by the increased access to those components during assemby and prelaunch checkout.

Table 2.15.3-1 Separation Baseline Concept Pros & Cons

PRO

- Exposed LO2 feedline disconnects and ducting give good access for installation and inspection

CON

- LO2 feedlines run circumferentially from external disconnect to engine fairing, there is a slight drag penalty with aero loads on feed ducts, and some aeroheating on exposed ducts.

2.15.4 PROPELLANT FEED SYSTEM

It is not anticipated that there will be any propellant feed design alternatives that would significantly affect the performance impact of aerodynamic drag.

2.16 DESIGN CAPABILITY: Useable Propellant

2.16.1 SEPARATION CONCEPT

2.16.1.1 SEPARATION CONCEPT FEATURES

The single module feed system can accommodate some LH2 tank stretch. The tank stretch results in compressing the propellant feed system, mainly by reducing straight sections for flow distortion and reduced slope of lateral ducting. Separate LH2 feedlines for the booster engines can mitigate the feedline effects by moving the disconnects olong the gore panel and making bulkhead disconnect installations.

2.16.1.2 SEPARATION CONCEPT PRO/CONS

The pros and cons are listed in Table 2.16.1-1. Tank stretch can be accommodated with some compromise of feedline standards for straight sections and lateral minimum slopes.

Table 2.16.1-1 Separation Baseline Concept Pros & Cons

PRO
• The single module feed system allows for LH2 tank stretch up to about 10 feet downward, compressing the propulsion module and increasing LH2 volume.
CON
• Tank stretch may force LH2 feed Disconnects up on the LH2 Tank gore, possibly extending into the tank. This would reduce useable LH2 for the HLLV or cause the use of uncommon HLLV LH2 feed system components.

2.16.2 PROPELLANT FEED SYSTEM

In Trade Study 3-P-013, " Feedline Gimbal Configuration" it was estimated that relative to the center sump feed (baseline), the alternate design of a LH2 aft bulkhead feed for the skinline engines results in a potential weight penalty for the HLLV of 2000-3000 lbs of residual LH2. This is really a comparison of usable propellant for each concept. Again, this might not be a driver depending on the final payload margins for this vehicle. The LH2 feed concept may also be driven by the requirement to provide a minimum slope, radius of curvature (r/D) and inlet straight section (L/D) for the engine turbopump. The bulkhead LH2 feed has a higher probability of providing these requirements.

As discussed in Section 1.4.2.1 the issue of using scissors ducts as opposed to 3 flex joint gimbal ducts was investigated in Trade Study 3-P-013. A preliminary assessment for the LH2 feed to the skinline engines showed that there was no advantage to the use of scissors ducts. The scissors ducts provided a slightly higher L/D but with a lower slope angle than the 3-gimbal ducts for a 10 foot LH2 tank stretch. This issue relative to usable propellant shows no advantage (there are significant disadvantages) to using scissors ducts.

A single LO2 feed duct might make LH2 tank stretch more possible. With a single duct, the chances of spontaneous ignition may be lowered to the point that the LH2 booster side disconnect poppets may be removed, which shortens the disconnect assembly and thereby shortens the feed system to more easily accommodate the tank stretch.

2.17 MISSION RELIABILITY: SYSTEM/SUBSYSTEM COMPLEXITY

2.17.1 THRUST STRUCTURE

2.17.1.1 THRUST STRUCTURE FEATURES

The baseline thrust structure system complexity is minimal compared to other trade tree options. Low part count from integrally machined skin/stringer and use of Atlas proven designs in the holddown structure all help to reduce the complexity of the structure. Booster separattion as a single unit reduces additional complex separation sequences, software and hardware interfaces. The modular design of the booster and sustainer also enhances producibility and operations aspects of the thrust structure.

2.17.1.2 THRUST STRUCTURE PRO/CONS

The pros and cons for thrust structure system complexity are listed in Table 2.17.1-1.

Table 2.17.1-1 Thrust Stucture Aerodynamic Drag Pros and Cons

PRO

- Low part count due to integrally machined skin/stringer arrangement on both sustainer and booster sections.
- A larger scale version of the proven Atlas design can be utilized for the holddown mechanism on the booster section.
- Booster section separates as one unit, therefore reducing the complexity of additional separation systems, hardware and software for modular type arrangements.
- Modular sustainer and booster structure reduces complexity of production and operations.

CON

- Holddown system is complex due to mechanical motion required.
- Complex tooling required for manufacture, assembly and transport of large structure..
- Alternate concept of sustainer thrust barrel may be more complex due to bulkhead impacts, and thermal heating into tank. Different bulkhead required for HLLV.

2.17.2 SEPARATION CONCEPT

2.17.2.1 SEPARATION CONCEPT FEATURES

The single module feed system has the highest reliability due to having the least complexity by numbers of components, numbers of disconnects, and numbers of active separation systems, compared with multiple module concepts. Our concept is based on the 1-1/2 stage booster module, with skinline mounted engines on a jettisoned monocoque structure, leaving the center mounted core engines continuing to operate. This concept has been used on 501 Atlas flights without a failure to separate (some Atlas boosters failed to achieve BECO for other causes).

2.17.2.2 SEPARATION CONCEPT PRO/CONS

The pros and cons are listed in Table 2.17.2-1. The separation of the single module is a single event. The only active system is the laser initiation of the pyro linear shaped charge to sever structure and mechanically release the booster. All other events during the jettison are triggered by the inertial motion of the booster away from the core.

Table 2.17.2-1 Separation Baseline Concept Pros & Cons

<u>PRO</u>

- Simple separation concept, using one active separation system to disconnect structure and relative inertial motion of the booster stage to disconnect all other systems.
- Proven separation concept used on 501 Atlas flights (no failure of booster to separate from sustainer).
- Fewer number of parts compared to multi-module concepts
- Fewer number of airborne disconnects compared to multi-module concepts
- Monocoque structure of single module distributes ground loads efficiently.

<u>CON</u>

- TBD

2.17.3 PROPELLANT FEED SYSTEM

2.17.3.1 FEATURES

The baseline propellant feed system is relatively simple in its arrangement of the main LO2 feed ducts and the LH2 feed ducts for the skinline engines. The problem lies in the use of two versus a single disconnect which may have the effect of increasing the complexity of the LO2 disconnect system and reducing staging reliability. In addition, the baseline skinline engine feed inlet orientation may result in a complex structural mounting issue.

The alternate feed system introduces complexity with a single LO2 feed duct. The layout and arrangement for the transition to the feed inlets may be problematical due to the asymmetry. Ducts slopes may be affected due to the long run to the other side of the vehicle. The bulkhead feed concept might have problems, not so much the complexity of the LH2 staging disconnects, but their mounting to the aft bulkhead.

2.17.3.2 PROS/CONS

The comparisons between the baseline feed system concepts and alternatives for system/subsystem complexity are shown in Tables 2.17.3-1 and 2.17.3-2.

Table 2.17.3-1 Baseline Propellant Feed Concept

PRO

- The dual LO2 main feed ducts offer a relatively simple and symmetrical transition interface with the engine inlet ducts.

- The sump fed 17" LH2 ducts offer the easiest interface and assembly (with the LH2 tank sump).

- The center engine feed inlet orientation results in a simple arrangement. TVC attach points and TVC structural mounting is all common with the feed inlets that are located in a clocked, mirror fashion. Mounting complexity is minimized.

CON

- Complexity of the dual LO2 feed duct (two staging disconnects for the 1.5 stage vehicle) is somewhat higher when compared with a single main LO2 feed duct.

- Greater chance of spontaneous ignition at separation with dual LO2 feed ducts possibly neccessitating the use of booster side poppets in the 1.5 stage LO2 disconnects. Results in greater component complexity

- More separable joints (flanges) than a single LO2 duct.

- Increased complexity with the skinline engine feed inlets located in a clocked, mirror fashion.
    - There will be two types of engine-TVC attach points or......
    - The use of common engine attach points result in uncommon attachment of the TVC to the structure and potential difficulties in mounting a pair of TVC systems outside the skinline.

Table 2.17.3-2 Alternate Propellant Feed Concept

PRO

- For the skinline engines the alternating clocked feed inlets present the opportunity for not only common TVC engine mounts but also common TVC mounting of the structure with all mounts interior to the skinline.

CON

- The transition to the engine inlet ducts from a single large LO2 feedline on one side of the vehicle would result in a complex arrangement and packaging.

- There may be a complex LH2 aft bulkhead interface for an aft bulkhead LH2 feed. For the 1.5 stage vehicle the main LH2 disconnects might need partial mounting inside the tank.

2.18 MISSION RELIABILITY: CONFIDENCE LEVEL

2.18.1 ENGINE ARRANGEMENT FEATURES

The Reference Zero concept, with four engines mounted on the skinline has the LO2 turbopump and LO2 feedline ducts outside the skin. Turbopump failure of the LO2 system would be to open space, with little chance of propagation to the other engine or subsystems. The separation of propellant feed ducts by the skin minimizes the chance that leakage would mix fuel and oxidizer, except near the sustainer engines. There is a direct view between the sustainer engines and the booster engines which could allow flying object propagation damage.

Table 2.18.1.-1 Pro/cons for engine arrangement regarding weight discriminator

PRO

- Booster engines are mounted such that 1/2 of the engine (LOX turbopump) is outside the skinline - most likely failure propagation mode is to the outside
- Disconnects for the LOX system is isolated outside the thrust structure - only fixed non-disconnecting lines lead into the sustainer engines
- Majority of leak paths of the LOX system is outside the thrust structure - ie. since the major line lengths/joints of the occur outside the structure less likely to have mixing of fuel/oxidizer combinations

CON

- Location and arrangement of the booster engines and sustainer engines is such that the engines have a view to one another - propagation of failure due to flying objects is greater

2.18.2 SEPARATION CONCEPT

2.18.2.1 SEPARATION CONCEPT FEATURES

The single module feed system has been used on 501 Atlas flights without a failure to separate The concept is a simple, proven design, developed in the 1950's and working with little change today on the Atlas launch system. The module structure distributes the thrust and ground loads with minimal change to the ET structure.

the highest reliability due to having the least complexity by numbers of components, numbers of disconnects, and numbers of active separation systems, compared with multiple module concepts. Our concept is based on the 1-1/2 stage booster module, with skinline mounted engines on a jettisoned monocoque structure, leaving the center mounted core engines continuing to operate. This concept has been used on 501 Atlas flights without a failure to separate (some Atlas boosters failed to achieve BECO for other causes).

2.18.2.2 SEPARATION CONCEPT PRO/CONS

The pros and cons are listed in Table 2.18.2-1. The separation of the single module is a single event, well proven through 34 years of Atlas flights. The only active system is the laser initiation of the pyro linear shaped charge to sever structure and mechanically release the booster. All other events during the jettison are triggered by the inertial motion of the booster away from the core.

Table 2.18.2-1 Separation Baseline Concept Pros & Cons

PRO

- Simple separation concept, using one active separation system to disconnect structure and relative inertial motion of the booster stage to disconnect all other systems.
- Proven separation concept used on 501 Atlas flights (no failure of booster to separate from sustainer).
- Fewer number of parts compared to multi-module concepts
- Fewer number of airborne disconnects compared to multi-module concepts
- Monocoque structure of single module distributes ground loads efficiently.

CON

- TBD

2.18.3 PROPELLANT FEED SYSTEM

Both single (Orbiter and current Atlas-"D" type- and Atlas /Centaur) fly with a single LO2 feed duct. The Atlas E flew with a dual feed duct. The differences on the Atlas vehicles was more due to engine design and packaging than a preference or discriminator for one concept over another.

The Centaur vehicle uses a sump feed for the bottom (LO2) tank. The Atlas "E" vehicles had the fuel (RP-1) staging disconnects mounted partially inside the aft bulkhead. The disconnects were mounted on the tank outlet flange with the sealing poppet assembly inside the tank proper.

2.19 DEPENDABILITY: Maintainability

Subcriteria to be considered in the evaluation —

- Test and checkout requirements
- Potential for work around
- Ease of LRU replacement

Maintainability features of the baseline design have been studied in the cycle 0 trade study 3-P-061 "engine powerhead clearance." This study has looked at the accessibility of the major "zones" of the engine, ie. gimbal block for engine install/removal (zone 1), engine powerhead for major possible LRU (zone 2) and the engine nozzle (zone 3). Each of these zones, presents unique requirements for the propulsion module design and presents favorable attributes for the maintainability aspects of the engine packages. Other areas of the propulsion module have requirements for maintainability features. These areas are listed in table 2.19-.1.

Maintainability features for the baseline propulsion module need to consider the orientation of the vehicle since maintenance may be imposed on the vehicle in the vertical as well as the horizontal position. The horizontal position may have different rotated position of the vehicle so that "up" may not be a fixed orientation for the technician. Work platforms and GSE must be flexible to accommodate the use of various orientations of the vehicle in servicing all areas shown in table 2.19-1 .

Discussion of the pro/cons of the baseline propulsion module arrangement

Tables 2.19-2, 2.19-.3 and 2.19-.4 present the pros and cons for the propulsion module arrangement relative to the characteristics mentioned earlier. No numerical score or quantitative comparison data is presented for this criteria, since the available data limits the analysis to a qualitative manner. See Section 2.2 for explanation of numerical data that can be quantified in the future.

Table 2.19-.1 Major Maintainability Areas of the Propulsion Module

- Engine
  - zone 1
    - thrust gimbal block
    - H2 propellant inlet
    - O2 propellant inlet
    - GHe purge supply line
    - power electrical disconnect
    - Data link disconnect
    - engine end of TVC actuator
  - zone 2
    - H2 turbopump
    - O2 turbopump
    - Gas generator
    - large scale engine ducting
    - small plumbing
    - instrumentation probes (such as TCs)
    - electronic controller
    - electrical and data link disconnects
    - structural brackets and clamps
    - thermal insulation
    - inspection sites (boroscope)
  - zone 3
    - thrust chamber/nozzle joint
    - regenerative tubes in nozzle
    - purge lines to nozzle exit
    - heat shield closeout joint
    - nozzle hatbands (structural)
    - thermal insulation

- TVC actuators
  - Vehicle end of the TVC actuator
  - Electrical power lead to the TVC
  - brackets / clamps
  - data link disconnect
  - motor drive inspection area
  - gear train inspection area

- Heat shield
  - brackets
  - thermal insulation

- Propellant ducting
  - each gimbal joint
  - filter locations
  - flanged joints in duct
  - thermal insulation
  - inspection sites (boroscope)
  - propellant prevalves
  - brackets

- LH2 tank bottom
  - thermal insulation
  - access hatches
  - tank penetrations in lower dome
  - brackets and clamps
  - inspection sites (boroscope)

- Structural elements
  - general surface accessibility
  - brackets and clamps
  - major structural joints

- Accessories (electrical)
  - cable trays and raceways
  - batteries

- Pneumatics
  - GHe bottles
  - plumbing
  - brackets
  - filters
  - valve packages
  - instrumentation

- Ground/airborne disconnects
  - general surface accessibility
  - thermal insulation

- Environmental Control System
  - ducting
  - brackets
  - instrumentation

Table 2.19-.2 Pros and Cons of the Maintainability Criteria for Test and Checkout of the Propulsion Module

<u>PRO</u>

- Arrangement of the engine position allows access for 360° around zones 1, 2 and 3 for largest percentile (95th percentile) technician
- Access is available for all critical areas on the engine and ducting for leak testing
- Provisions are envisioned for boroscope inspection of critical elements of the propulsion module (ie. filters, pump bearings) - no limitations seen

<u>CON</u>

- Large areas between some elements of the module make accessibility difficult in a horizontal position - requires extensive use of work platforms

Table 2.19-.3 Pros and Cons of the Maintainability Criteria for Potential for Work Around of the Propulsion Module

<u>PRO</u>

- Individual engine and some large element changeout can be accommodated - no replacement of large modules
- Accessibility in the boattail allows for some parallel remove and replace operations
- TVC can be replaced with engine removal
- Stocking parts for the propulsion module are at component level (engine, TVC, bottle) not at assembly or full module level
- EMA Batteries do not require last minute charging, conditioning, and installation prior to launch.

<u>CON</u>

Table 2.19-.4 Pros and Cons of the Maintainability Criteria for Ease of LRU Replacement of the Propulsion Module

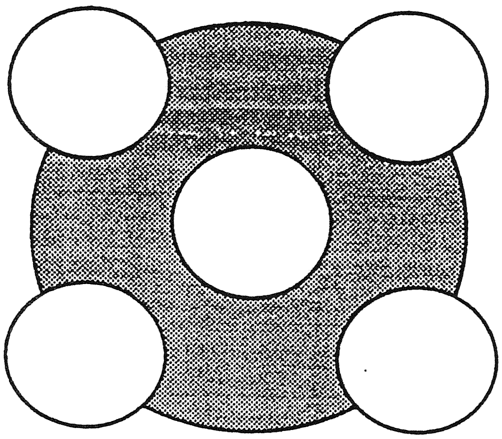
PRO

- Accessibility in the boattail allows for LRU replacement without major disassembly of surrounding elements
- Clearances allow for use of tools and GSE
- EMA batteries smaller than conventional and can be handled by 2 people without need of special handling equipment

CON

- None identified

An analogy that can be drawn for the propulsion module arrangement in terms of accessibility and maintainability is to visualize the Saturn V vehicle with 6 engines somewhat larger than the STME. The Saturn V had a total of five large (143.5 inches in diameter 220.4 inches in length) engines in the boattail region. The accessibility was generous and capable of supporting large GSE intrusions into the region without major teardown of surrounding elements. The boattail design for the NLS is only slightly constrained for that of the Saturn V in that the tank diameter is 27.5 ft instead of 33 ft. This comparison is shown in Figure 2.19-.1.



	Saturn V	NLS 2
Total exit area / base area	.66	.42
% change in accessibility	—	36

Figure 2.19-.1 ROM for Accessibility

2.19.2 PROPELLANT FEED SYSTEM

It is not anticipated that there will be any propellant feed design alternatives that would significantly affect the maintainability other than that previously discussed in Sections 2.1 and 2.2.

2.20 DEPENDABILITY: LAUNCH SCHEDULE RELIABILITY

Characteristics to be considered in the evaluation —

Propellant loading/preconditioning margins
Number of components
Number of active systems
Number of LCC's
Sensitivity to uncontrollable parameters (will the concept be sensitive to wind, launch day conditions, hot or cold side environments, launch holds, etc.)

2.20.1 LAUNCH SCHEDULE RELIABILITY GENERAL DISCUSSION

The pros and cons of the General Dynamics' propulsion module concept based on launch schedule reliability are shown in tables 2.20-1, 2.20-2, 2.20-3, 2.20-4 and 2.20-5.

Table 2.20-1 Propellant Loading/Preconditioning Margins

PRO
• TBD
CON
• TBD

Table 2.20-2 Number of Components

PRO
• TBD
CON
• TBD

Table 2.20-3 Number of Active Systems

PRO

- TBD

CON

- TBD

Table 2.20.-4 Number of Active Systems

PRO

- TBD

CON

- TBD

Table 2.20-5 Sensitivity to Uncontrollable Parameters

PRO

- Elimination of on-pad pyro initiator installation reduces sensitivity to lightning conditions. Installation of traditional intitators is prohibited with lightning in the area

CON

- Multiple towers/masts at the launch pad decreases allowable drift at lift-off and lowers the allowable wind speed for launch.

2.20.2 PROPELLANT FEED SYSTEM

It is not anticipated that there will be any major propellant feed concepts that would significantly affect the launch schedule reliability.

Propulsion Module Discriminator Evaluation Summary

COST / FLIGHT	NOTEWORTHY DIFFERENCES
1. FINAL ASSY., STACKING & C/O COST	CBM BETTER ACCESSIBILITY, 7 LESS FLANGED JOINTS, 1 LESS QD BUT LARGER DIAMETER
2. MAINTENANCE COST	CBM BETTER ACCESSIBILITY, EASIER LRU R & R
3. LOADING & LAUNCH COST	CBM LO2 BLEED ADDS COMPLEXITY BUT IMPROVES OPERATIONS & ROBUSTNESS
4. MANUFACTURING COST	CBM HAS MORE IMPACT ON ET PRODUCTION PROCESS (3 LH2 TANK PENETRATIONS)
5. ASSEMBLY COST	CBM PRE-MATES UMBILICALS WITH FLANGE FOR ASSY., REFERENCE USES NON-COMMON HLLV / 1.5 STAGE PROPULSION MODULE
6. ACCEPTANCE TESTING	NON DISCRIMINATOR
NON-RECURRING COST	
7. VEHICLE DESIGN & DEVEL. ENG'R	REFERENCE REQUIRES INTEGRATION OF TANK AND PROPULSION MODULE; CBM MORE COMPLEX LOADS
8. DEVELOPMENT TESTING	REFERENCE SEPARATION TESTING REQUIRED WILL BE MORE EXTENSIVE, CBM REQUIRES MORE TESTING FOR TOROIDAL MANIFOLD, REFERENCE PLUME HEAT RATE HIGHER
9. VERIFICATION TESTING	REFERENCE SEPARATION TESTING REQUIRED WILL BE MORE EXTENSIVE, CBM AMENABLE TO PARALLEL TESTING
10. GSE HANDLING EQUIPMENT	NOT DISCRIMINATOR
11. MANUFACTURING DEVELOPMENT	NON DISCRIMINATOR

Propulsion Module Discriminator Evaluation Summary

	NOTEWORTHY DIFFERENCES
CONSTRUCTION OF FACILITIES	
12. LAUNCH FACILITIES	NON DISCRIMINATOR
13. TEST FACILITIES	CBM RESULTS IN 10-20% COST INCREASE TO MPTA TEST STAND OVER REFERENCE REFERENCE SEPARATION TEST FACILITY LARGER, MAY BE MORE COSTLY
DESIGN CAPABILITY	
14. WEIGHT	CBM RETAINS 2000 LBS. LESS RESIDUALS, INERT WEIGHT 10000 LBS. LESS
15. AERODYNAMIC DRAG	CBM 18% MORE DRAG RESULTING IN 770 LBS (1.2%) PERFORMANCE LOSS
16. USABLE PROPELLANT	NON DISCRIMINATOR
MISSION RELIABILITY	
17. SYSTEM / SUBSYSTEM COMPLEXITY	REFERENCE SEPARATION SYSTEM MORE COMPLEX, HIGHER HEAT RATE AND LOAD, CBM 1 LESS AIRBORNE QD
18. CONFIDENCE LEVEL	CBM HAS HIGHER CONFIDENCE FOR MAKING LO2 PRECONDITIONING WORK, CBM LOWER LIKELIHOOD OF SUSTAINER FAILURE PROPAGATION
DEPENDABILITY	
19. MAINTAINABILITY	CBM EASIER LRU R&R
20. LAUNCH SCHEDULE RELIABILITY	CBM BETTER LO2 PRECONDITIONING MARGIN, LESS SENSITIVE TO LAUNCH HOLDS

PROPULSION MODULE ARRANGEMENT DISCRIMINATOR EVALUATION
(TRADE 3-P-006)

Prepared for

MARSHALL SPACE FLIGHT CENTER
(MSFC)
Contract NAS8-37144
Submitted: December 18, 1991

Prepared by

Rockwell International
Space Systems Division

Introduction

The purpose of this report is to supply to the MSFC Propulsion Panel data concerning an alternate engine arrangement design for the propulsion module of the 1 1/2 Stage Launch Vehicle which was developed by Rockwell International IR&D projects in FY1991. For the purpose of clarification, this alternate concept will be referred to as the Common Booster Module (CBM) and consists of an aft interstage which physically attaches to the core tankage, two sustainer modules and a boost module. See Figure I.1 for a CAD representation of this alternate concept. The boost module is configured to be common with the four engine module required for the HLLV. Also provided in Figure I.2 and I.3 are schematic representations of the CBM.

This report is separated into six (6) major standalone sections consistent with the discriminator criteria supplied by the MSFC Propulsion Panel. Since each section is standalone, this submittal is capable of being separated. However, where the same discriminators are used in multiple sections, repetitive responses occur.

Where possible, comparisons are provided between the CBM and the MSFC reference, a.k.a. cycle 0 baseline. In a few areas detailed data was not available for the reference configuration, therefore, only the CBM configuration evaluation is provided. Much of the comparison data is preliminary in nature. Subjective evaluations are supplied where needed to facilitate the engine arrangement trade decision and should be verified with more complete future analyses.

Figure I.1 Common Booster Module Consists of Four Major Assemblies

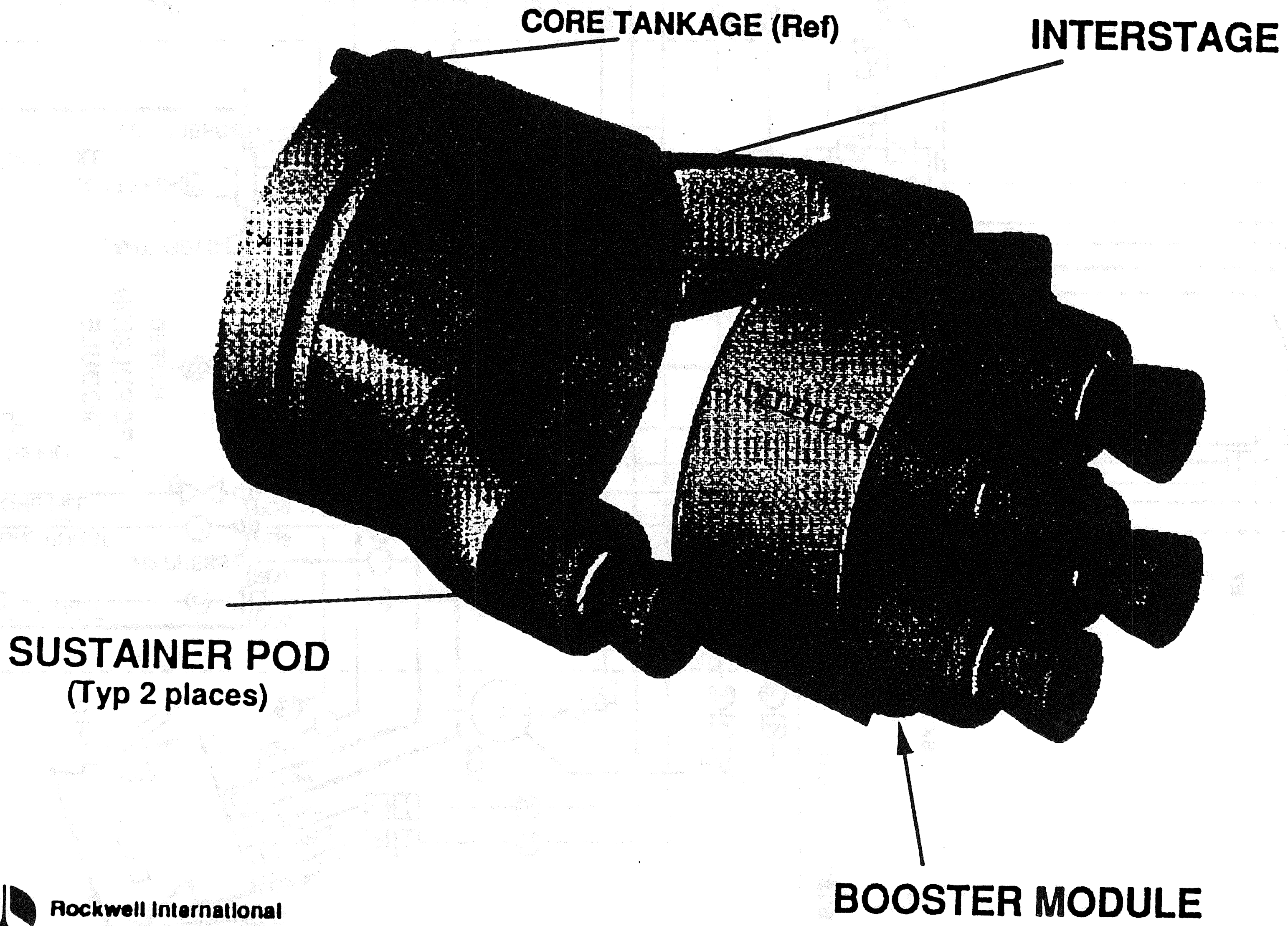


Figure I.2 Common Booster Module Propulsion System Schematic

Ⓧ = Line ID (inches)

MEP 5/10/91
JZ 5/13/91

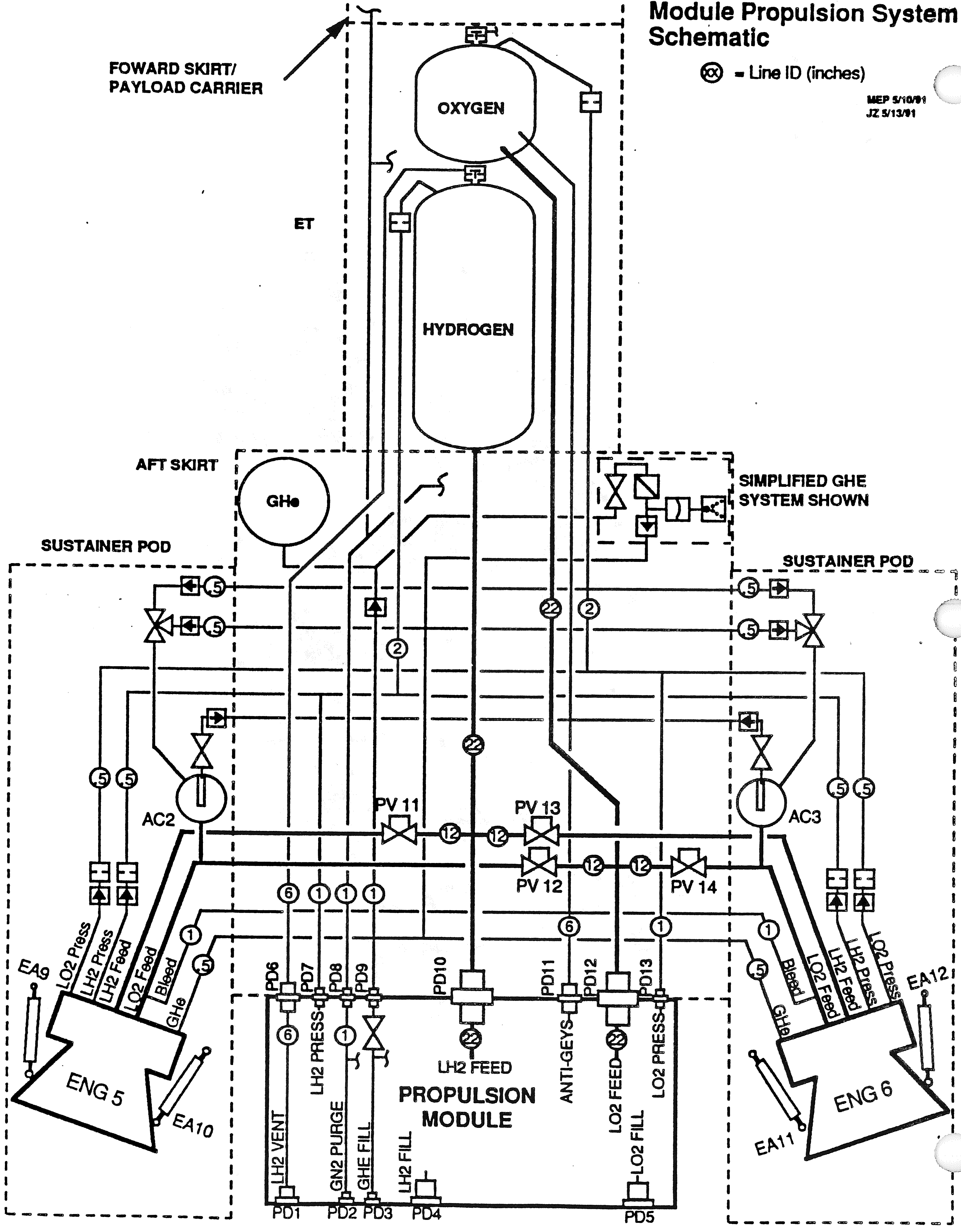
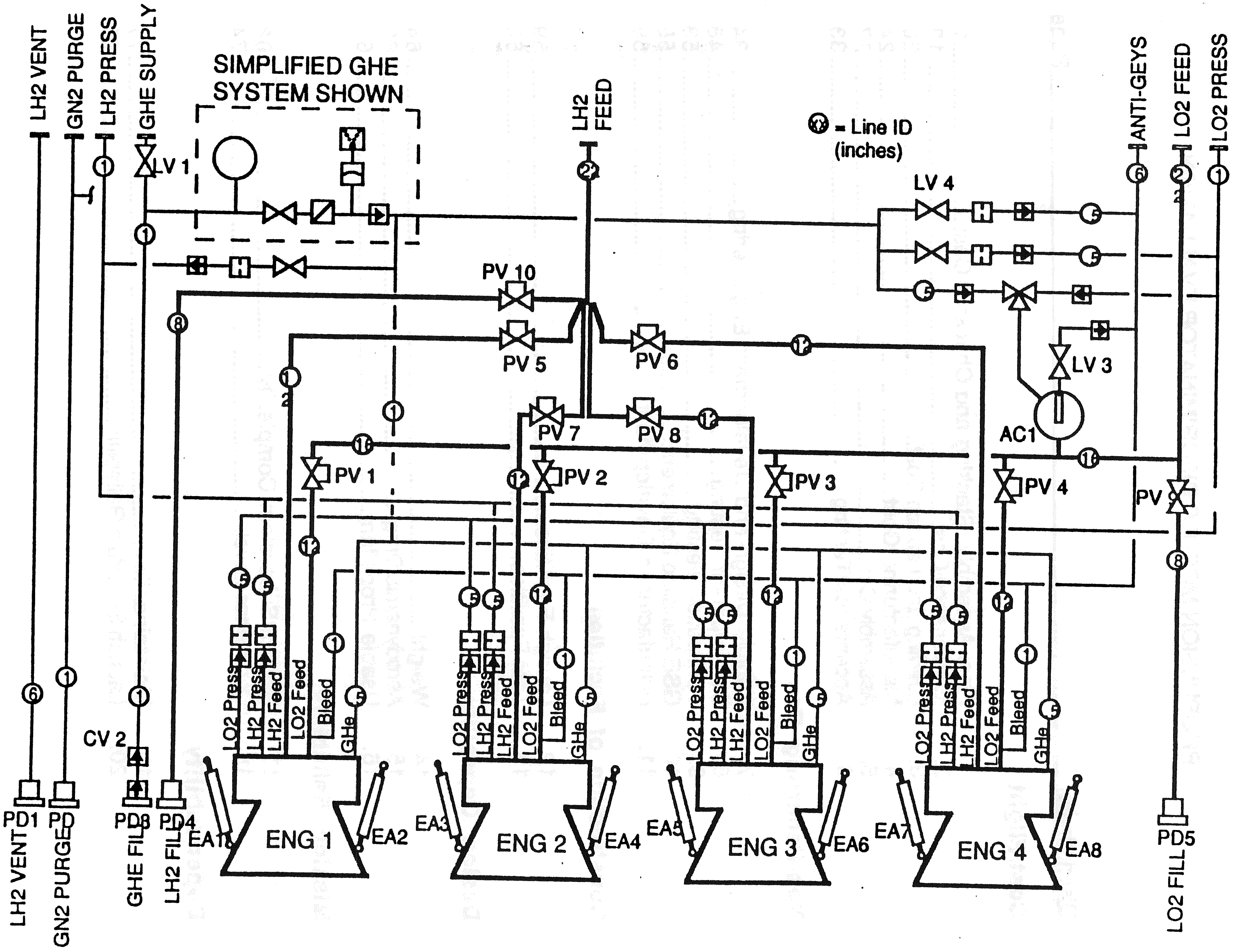


Figure I.3 Boost Module Propulsion Schematic



PROPULSION MODULE DISCRIMINATOR EVALUATION

Discriminator Page

Cost/Flight

Non-Recurring Cost

Construction of Facilities

Design Capability

Mission Reliability

Dependability

TANK STRETCH STUDY

TASK 3 - P - 001

Rockwell International
Space Systems Division

Issue/Objective

ISSUE/OBJECTIVE

- ASSESS THE IMPLICATIONS (PERFORMANCE, STRENGTH, ETC.) OF HAVING BIGGER LH2 AND LOX TANKS

GROUNDRULES/ASSUMPTIONS

- CONFIGURATIONS A & B WILL USE REFERENCE ENGINE ARRANGEMENT
- CONFIGURATIONS C & D WILL USE ALTERNATE ENGINE/LH2 FEEDLINE ARRANGEMENTS

Requirements Summary

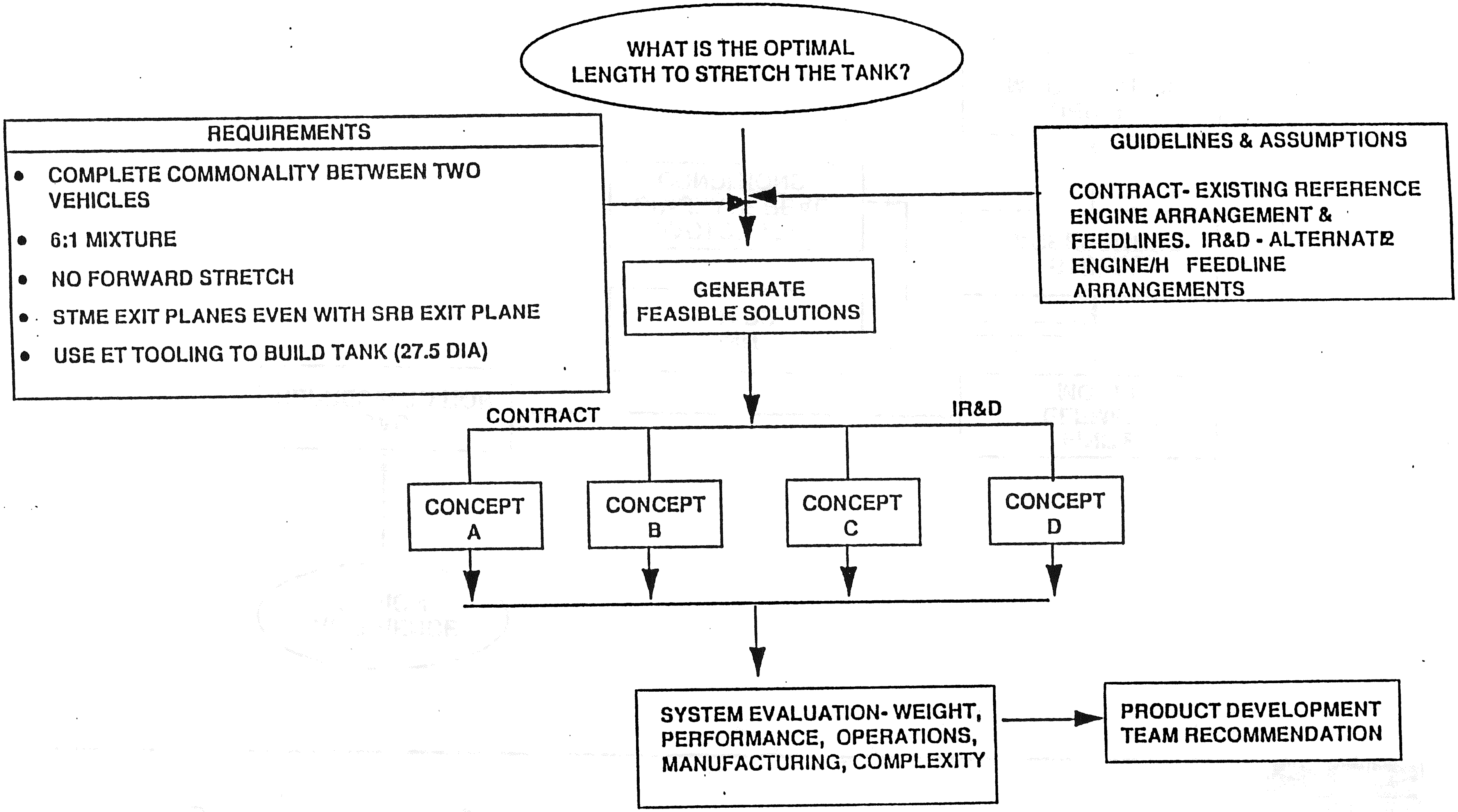
KEY REQUIREMENTS

- COMPLETE COMMONALITY BETWEEN TWO VEHICLES
- 6.0 MIXTURE RATIO
- NO FORWARD STRETCH OF THE LH2 TANK
- STME AND SRB EXIT PLANES REMAIN THE SAME AS THE CYCLE "0" REFERENCE VEHICLE
- USE ET TOOLING TO BUILD TANK (27.5 DIA)

Four Configurations Were Studied For Stretching The Tank

- A SYSTEM ENGINEERING APPROACH USING A PRODUCT DEVELOPMENT TEAM WAS FOLLOWED
- TWO ARE BEING DONE USING CONTRACT FUNDS AND TWO UNDER IR&D

A Systems Engineering Approach Was Used To Guide The Study



WHAT IS THE OPTIMAL LENGTH TO STRETCH THE TANK?

REQUIREMENTS

- COMPLETE COMMONALITY BETWEEN TWO VEHICLES
- 6:1 MIXTURE
- NO FORWARD STRETCH
- STME EXIT PLANES EVEN WITH SRB EXIT PLANE
- USE ET TOOLING TO BUILD TANK (27.5 DIA)

GUIDELINES & ASSUMPTIONS

CONTRACT- EXISTING REFERENCE ENGINE ARRANGEMENT & FEEDLINES. IR&D - ALTERNATE ENGINE/H FEEDLINE ARRANGEMENTS

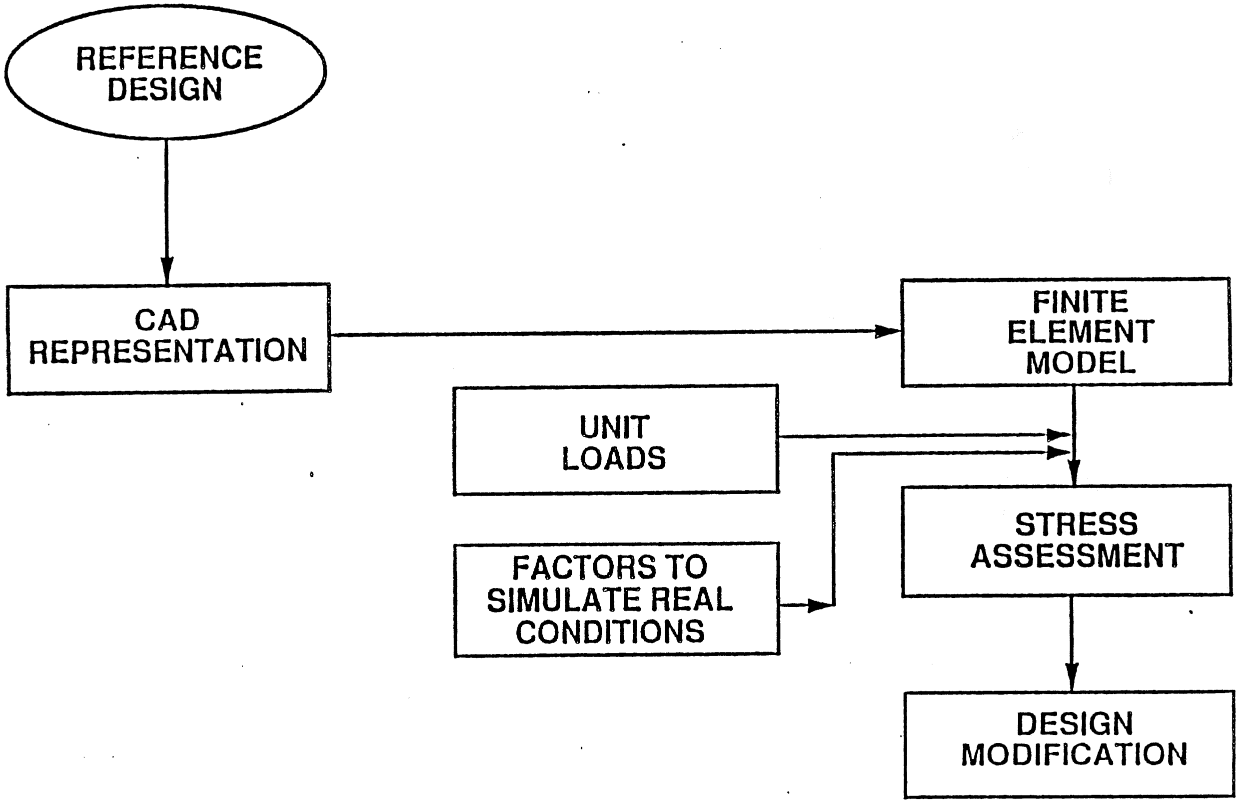
GENERATE FEASIBLE SOLUTIONS

SYSTEM EVALUATION- WEIGHT, PERFORMANCE, OPERATIONS, MANUFACTURING, COMPLEXITY

PRODUCT DEVELOPMENT TEAM RECOMMENDATION

Rockwell International
Space Systems Division

An Integrated Approach To Structural Design and Analysis Is Taken


REFERENCE DESIGN

CAD REPRESENTATION

FINITE ELEMENT MODEL

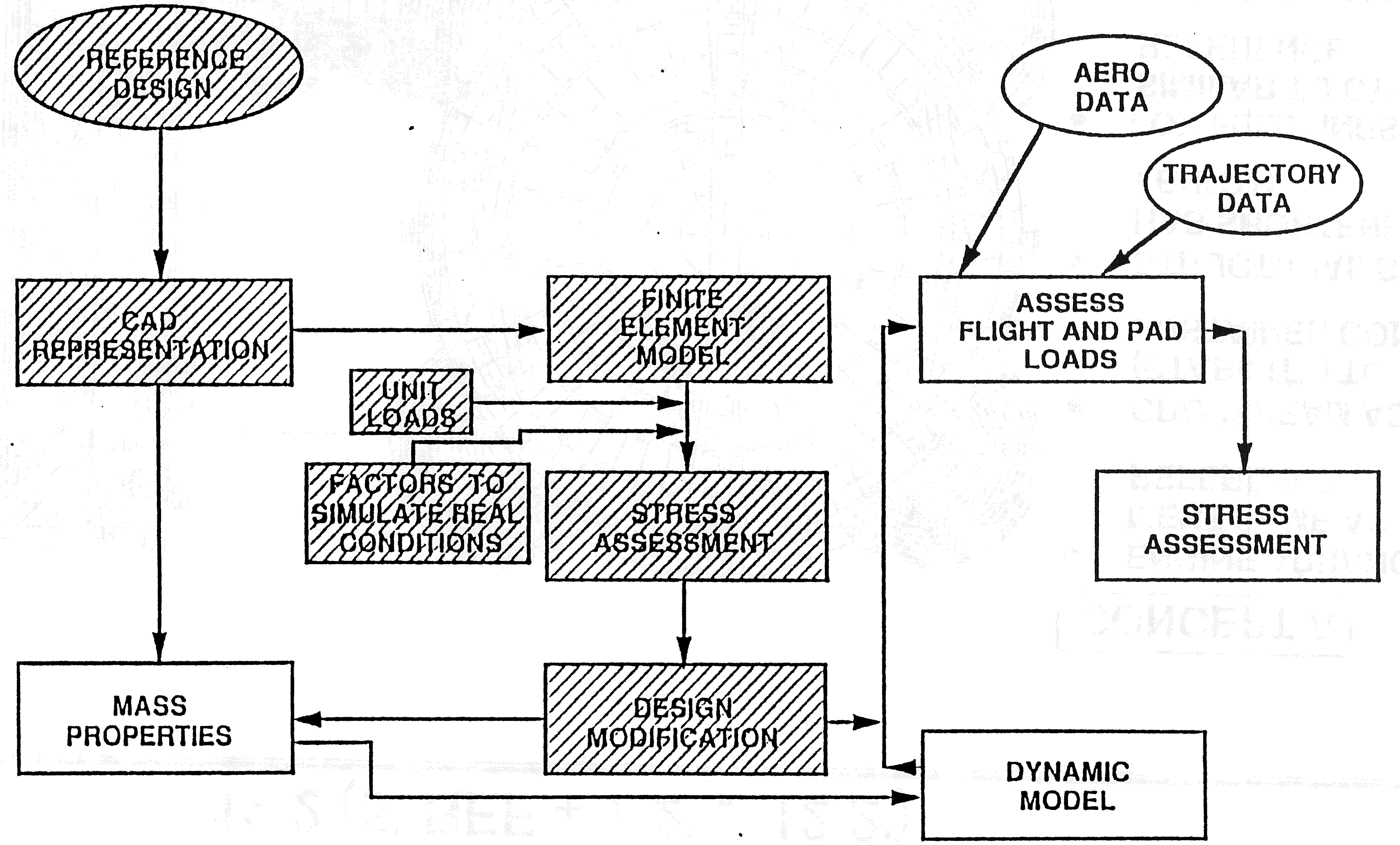
UNIT LOADS

FACTORS TO SIMULATE REAL CONDITIONS

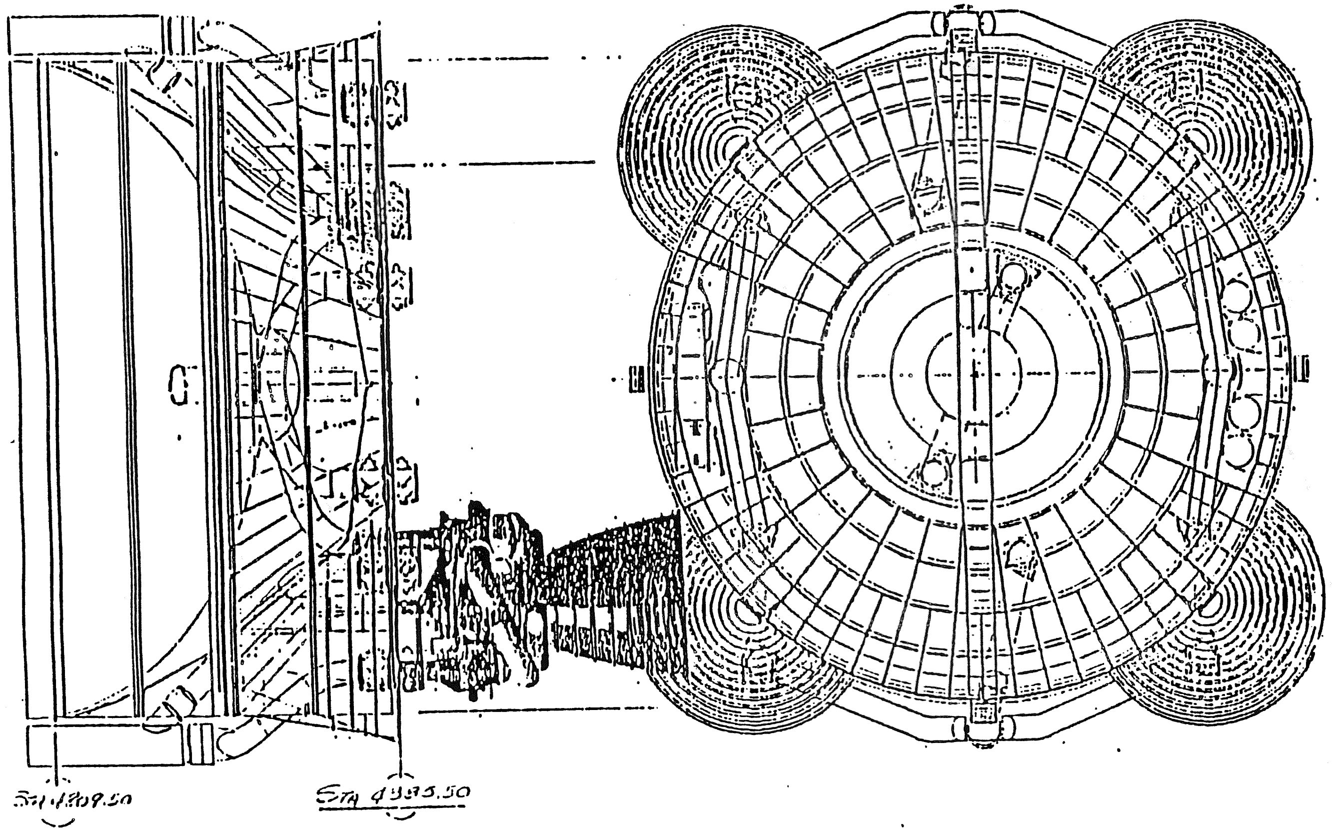
STRESS ASSESSMENT

DESIGN MODIFICATION

Aerodynamic Data Is Used In the Process



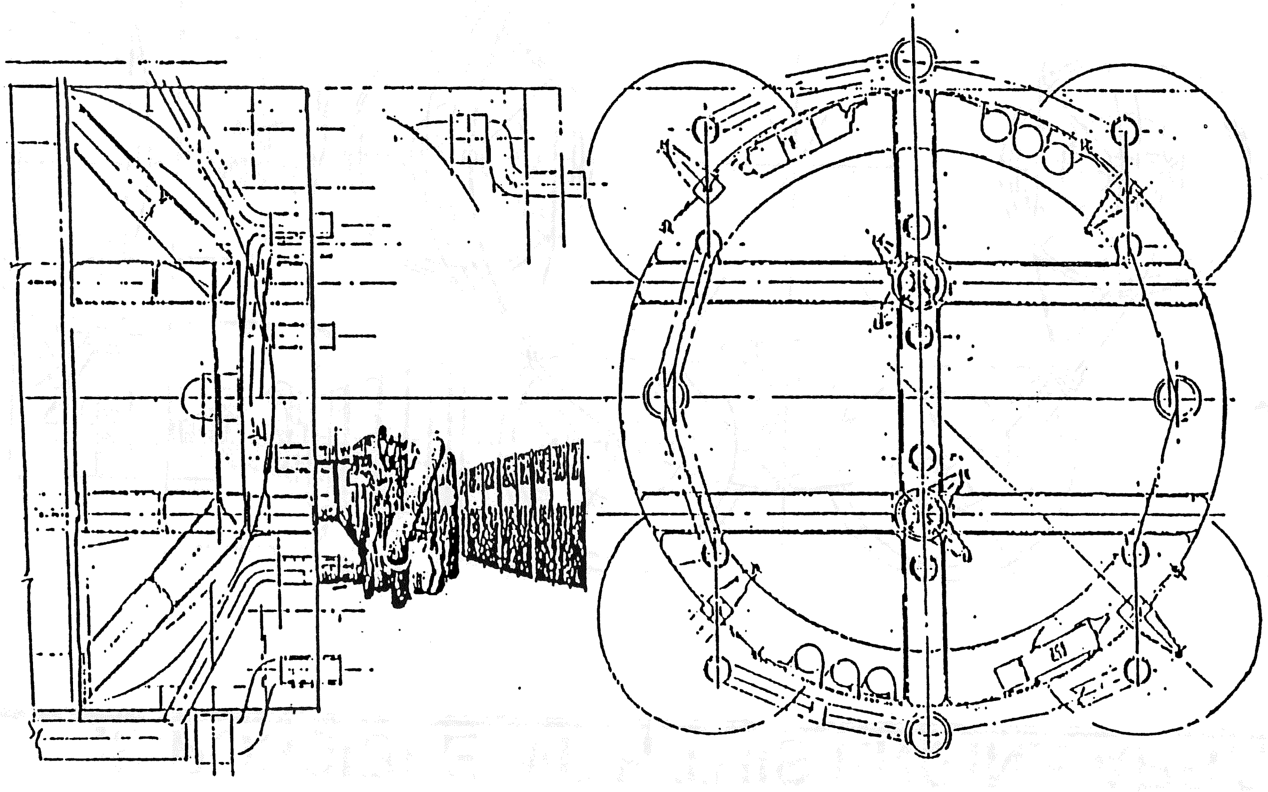
REFERENCE ENGINE ARRANGEMENT PLUS A FEW STRUCTURAL MODS YIELD A STRETCH OF 12.2 (5' REF + 7.2' = 12.2')



CONCEPT A

- ENGINE ARRANGEMENT SAME AS REFERENCE
- CROSSBEAM ADDED (STABILITY) TO SUSTAINER CONE
- STRUCTURAL SYSTEM HAS SHORTENED LENGTH
- LOX FEEDLINES SIMILAR TO CYCLE 0 REFERENCE
- BOOSTER LH2 LINES PENETRATE TANK DOME GORES
- REQUIRES FIXED FEEDLINES & SCISSORS DUCT BELLOWS FOR EXPANSION & GIMBALLING

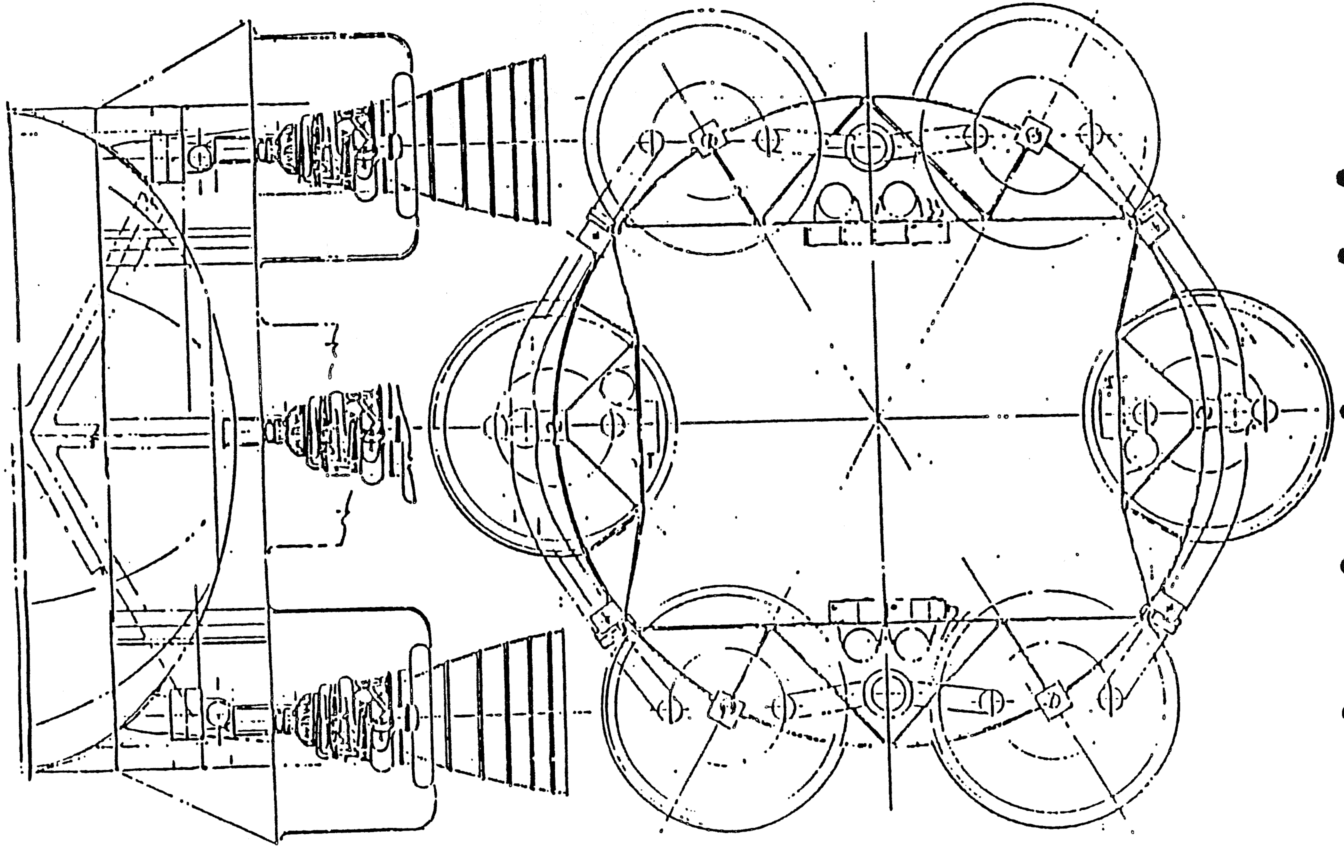
INTERNAL SUSTAINER THRUST STRUCTURE LEADS TO A STRETCH OF 15.8' (5' REF + 10.8' - 15.8')



CONCEPT B

- ENGINE ARRANGEMENT SAME AS REFERENCE
- SHORTENED AFT SKIRT
- INTERNAL THRUST STRUCTURE FOR SUSTAINER ENGINES
- LOX FEEDLINES SIMILAR TO REFERENCE
- LH2 FEEDLINES PENETRATE DIRECTLY INTO TANK GORES (4 PLACES)
- SCISSORS DUCTS REQD FOR EXPANSION, TOLERANCE, GIMBALLING

A TOTAL TANK STRETCH OF 16.7' (5' REF + 11.6' = 16.7') IS POSSIBLE WITH THIS ENGINE ARRANGEMENT



CONCEPT C (IR&D)

- ENGINE SPACING = 60°
- ENGINE CENTERLINES ON TANK CIRCUMFERENCE
- BOOSTER ENGINES WITH SYSTEMS STAGED AS PAIRS
- EXPOSED AFT TANK DOME CARRIES THERMAL PROTECTION
- DIRECT LH2 TANK PENETRATION & SIPHON ARRANGEMENT
- SCISSORS DUCTS

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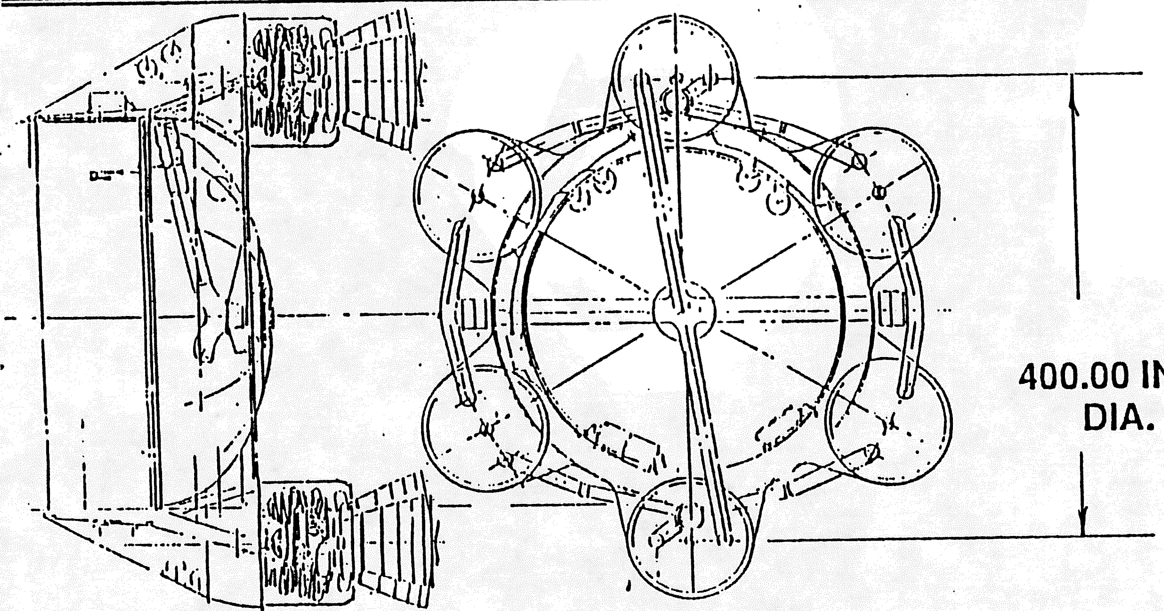
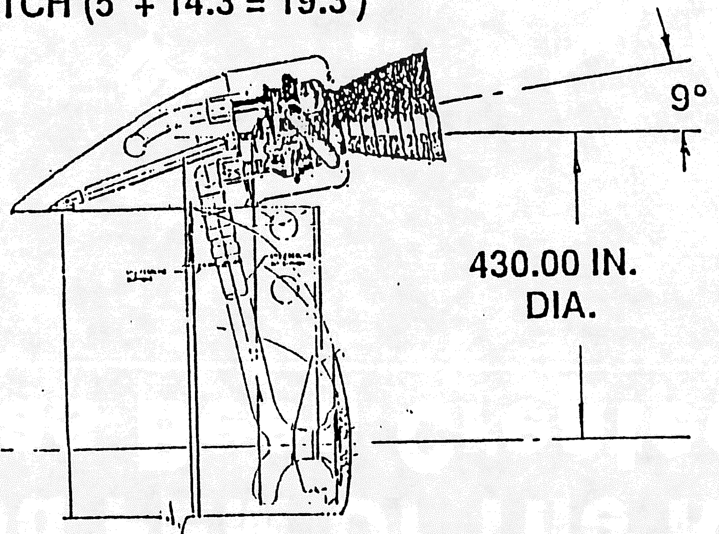
THE ALTERNATE ENGINE ARRANGEMENT ALLOWS A TOTAL TANK STRETCH OF 24 FEET MAXIMUM (5' REF + 19' = 24')



OPTION A = 19.3 STRETCH (5' + 14.3 = 19.3')

OPTION B

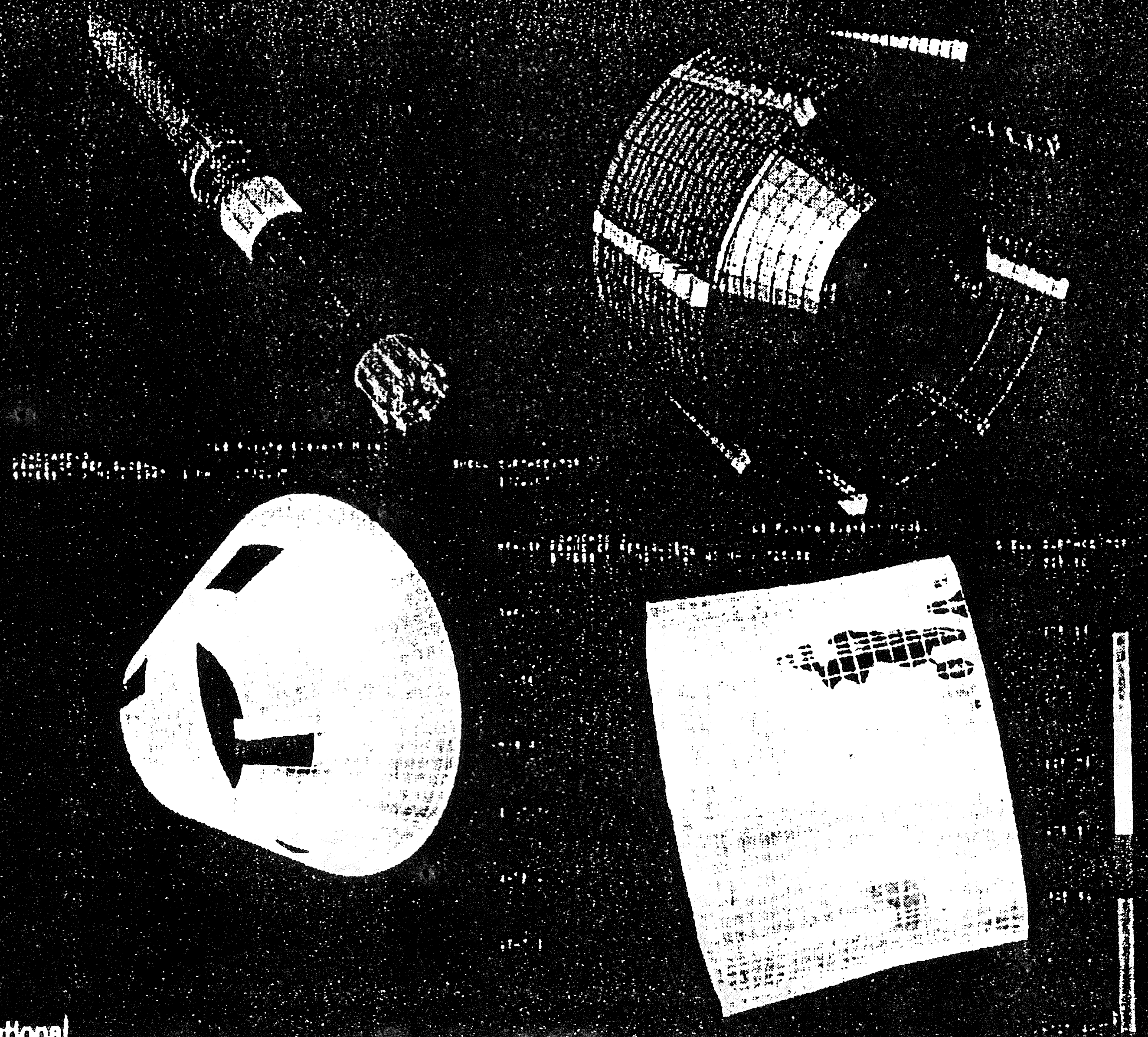
24 FT. STRETCH



CONCEPT D (IR&D)

- ENGINE SPACING = 60°
- EXTERIOR ENGINE PODS
- REMOVABLE GUIDERAIL THRUST POSTS (OPTION A)
- H2 FEED SYSTEM USES STS SIPHON SYSTEM (4 PLACES)
- SCISSORS DUCTS
- SUBSYSTEMS STAGE WITH PODS
- OPTION "B" PROVIDES MAXIMUM GROWTH POTENTIAL AT AFT END OF LH2 TANK

A Detailed FEM Of The Reference Design Has Been Created



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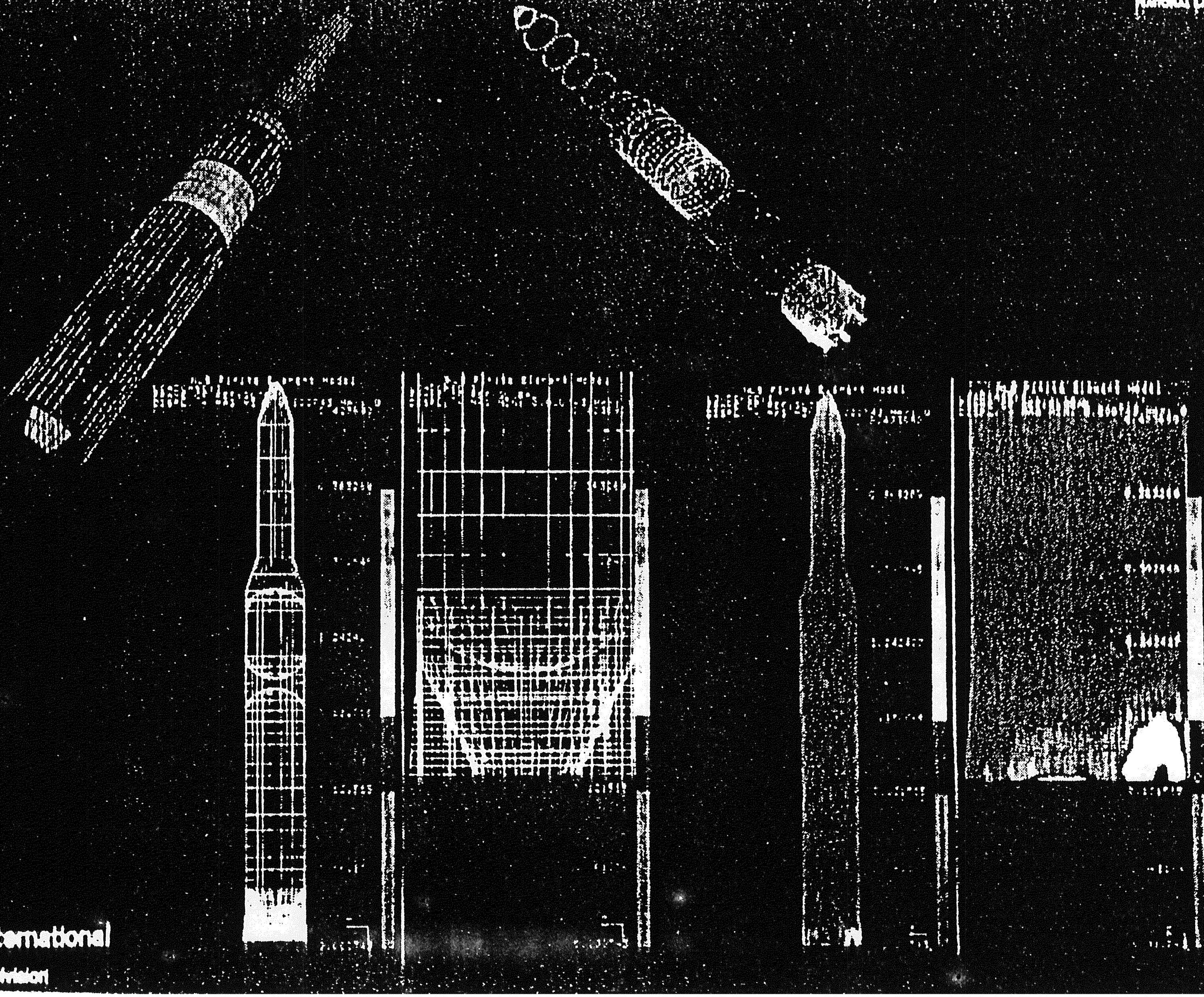
The FEM Has Been Used To Compute Stresses And Deflections



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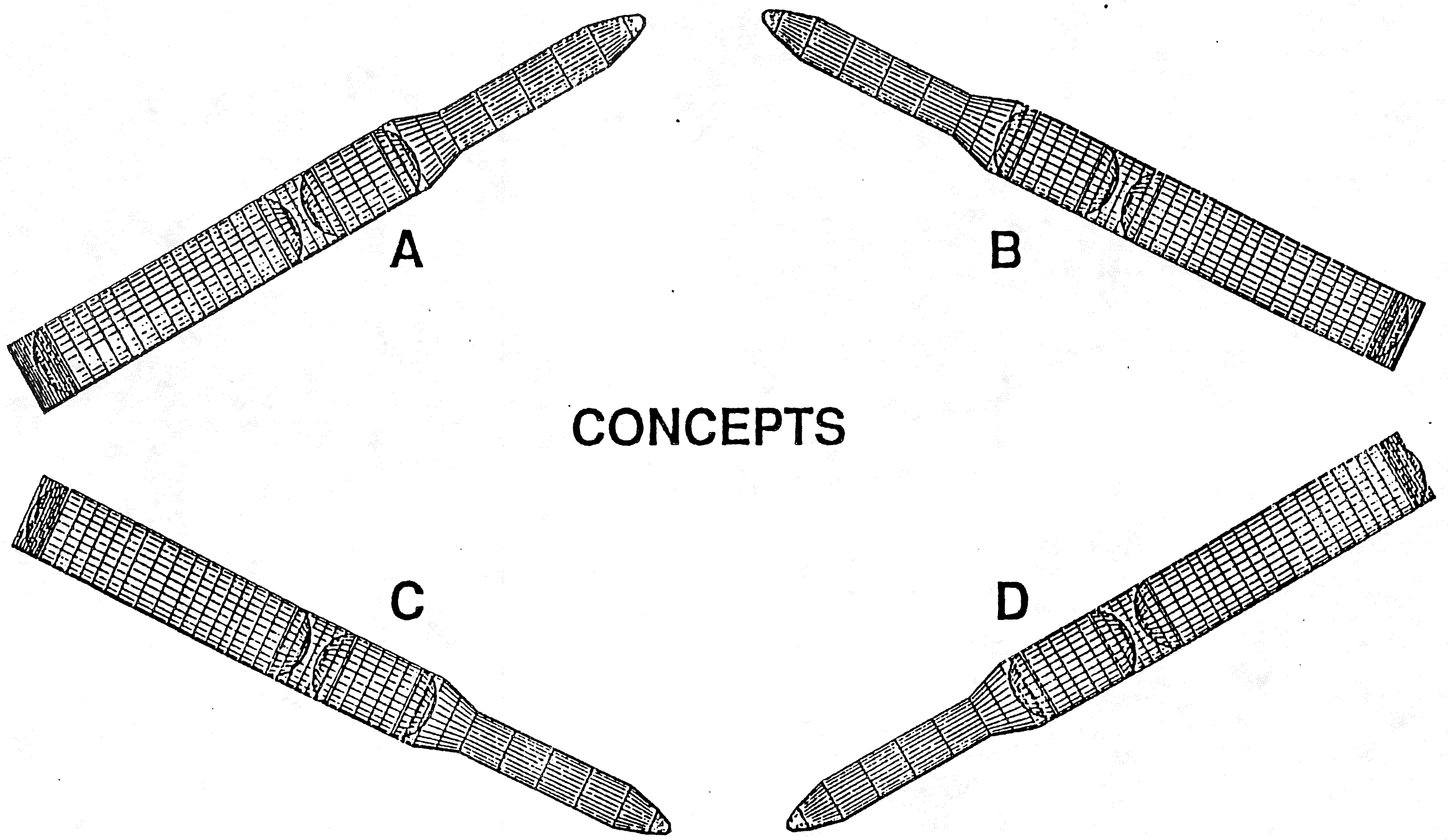
Separate Models Were Used To Analyze Versions A, B, C, & D



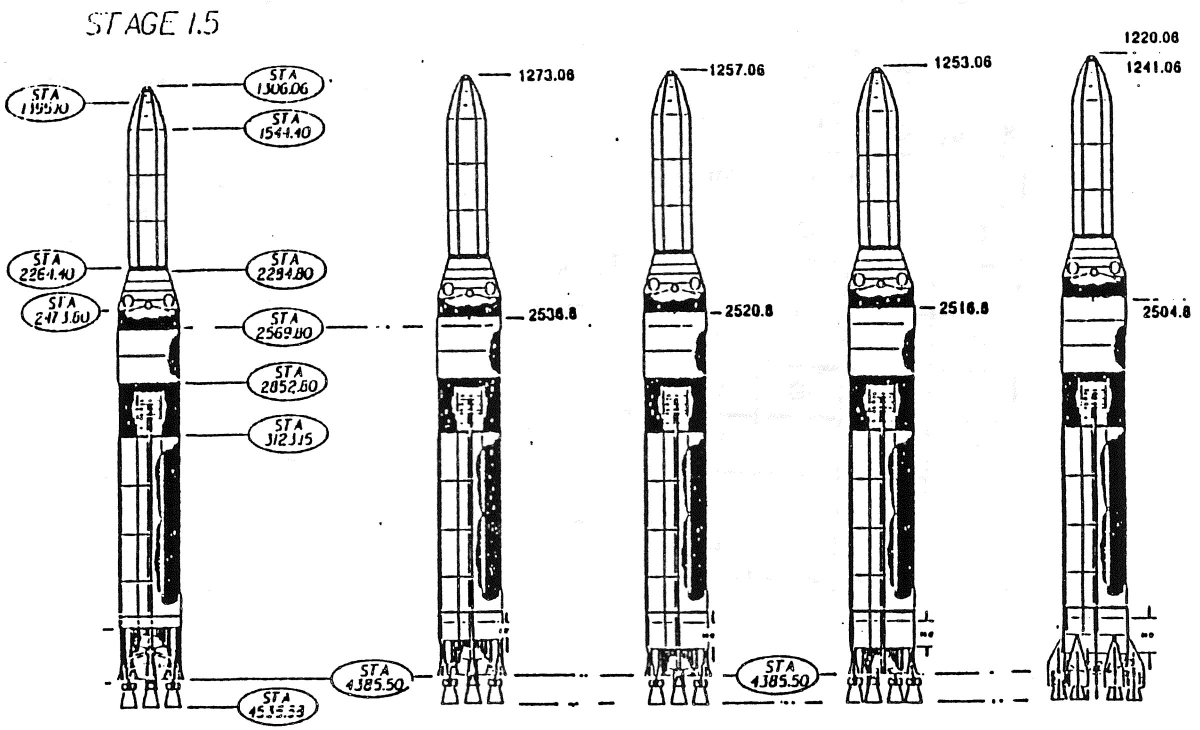
The Tank Stretch Study Models Were Developed From the Reference

CONFIGURATION STUDIES

OPTION / STAGE	REFERENCE	TANK STRETCH			
	S (STANDARD)	A	B	C	D
UPPER (INCLUDES SHROUD)	S	S	S	S	S
LOX TANK	S	A	B	C	D
INTERTANK	S	S	S	S	S
H_2 TANK	S	A	B	C	D
AFT SKIRT	S	A	B	C	D
AFT PROP MODULE	S	A	B	C	D
CREATE FEM	COMPLETE; 1,200 NODES, 3,000 DOF	C	C	C	C
CHECK/REVISE FEM	COMPLETE; PLOTS GENERATED	C	C	C	C
RUN UNIT LOADS	15 CASES RUN	IW	IW	IW	IW
MASS PROPERTIES	TOTAL - 230.7 K lb	221 k	221 k	222 k	221 k
AERO	ON PAD, ALSO M = 1.25	C	C	C	C
STRESS ASSESSMENT	COMPLETE	IW	IW	IW	IW
DESIGN REVISIONS	TBD	TBD	TBD	TBD	TBD
DYNAMIC MODEL	IW	IW	IW	IW	IW

IW = IN WORK
C = COMPLETE

Concept Weights Increase Slightly From Concept A To D



CONF. / RESULTS	S	A	B	C	D
Wt. 0% Fuel Klb	230.7	221.2	221.7	222.4	221.8
Wt. 100% Fuel Klb	1,960.9	2,079.3	2,143.7	2,158.6	2,206.0

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Aerodynamic Loads Have Been Generated For The Four Versions

ON PAD AND HI-Q CASES WERE USED

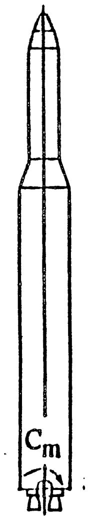
- EXISTING DATA WERE MODIFIED TO ACCOUNT FOR CHANGES IN SHAPE/LENGTH

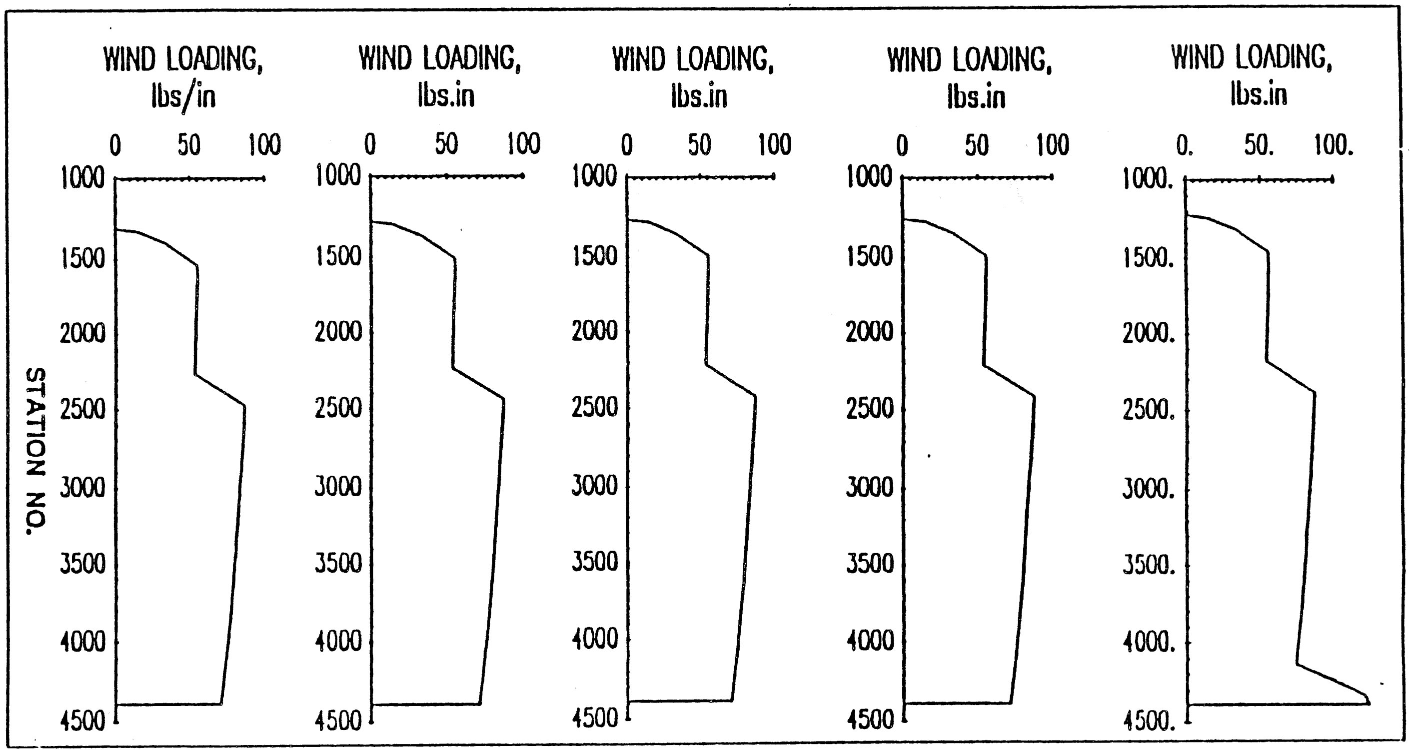
- THE ON-PAD CONDITION (RESULTS OF TASK 3-FM-001) IS BASED ON A 1% RISK FACTOR, 180 DAY EXPOSURE PERIOD WIND PROFILE, HAVING A SPEED OF 74.5 KNOTS AT A REFERENCE ALTITUDE OF 60 FT.

- THE HI-Q CONDITION USES AERO DATA FROM $M = 1.25$

The Total Moment At The Base Varies Slightly

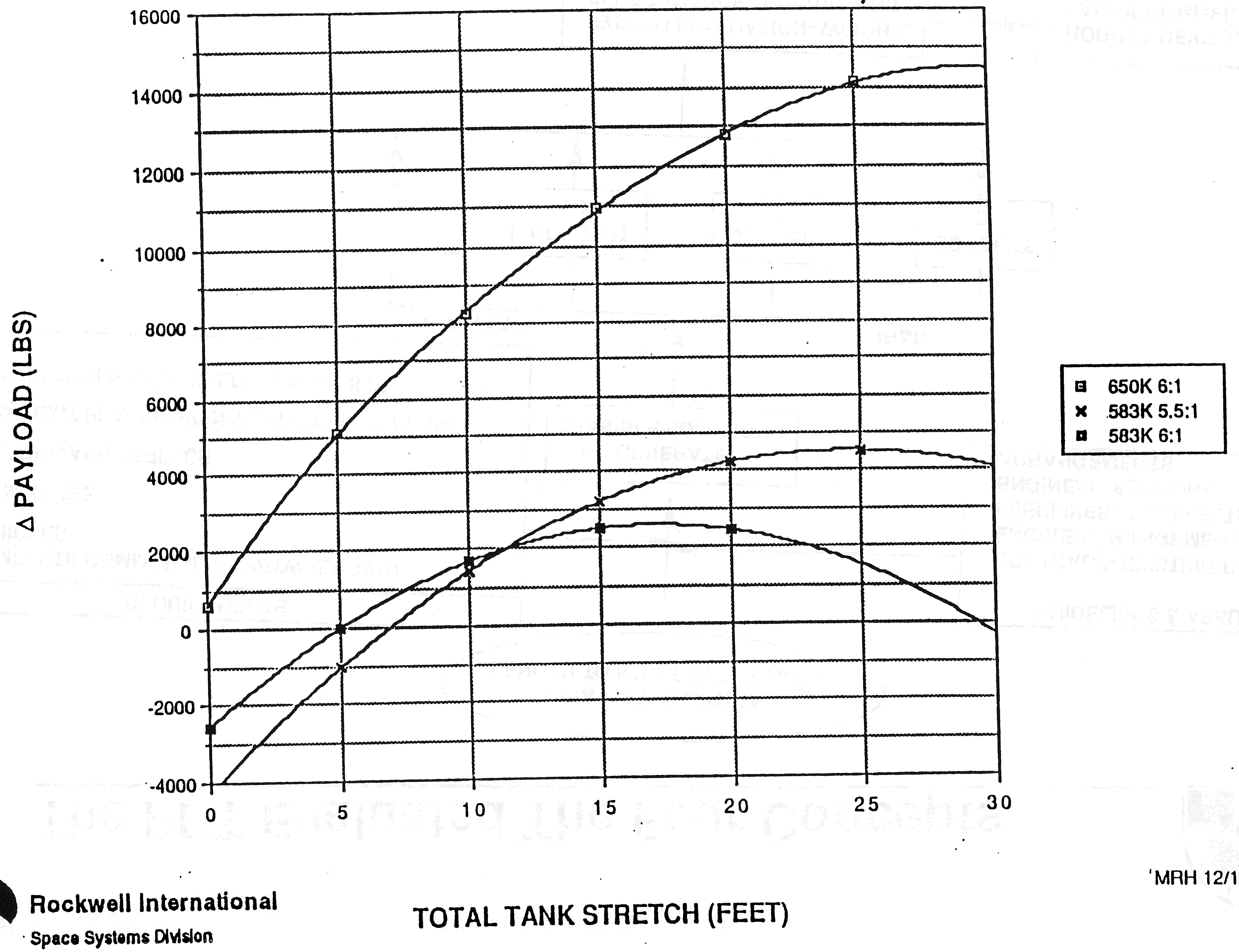
ON-PAD AERODYNAMIC DISTRIBUTIONS





CONFIG	S	A	B	C	D
BASE MOMENT (ft-lbs)	2.52×10^7	2.58×10^7	2.62×10^7	2.63×10^7	2.70×10^7

Δ PAYLOAD VS. TOTAL TANK STRETCH



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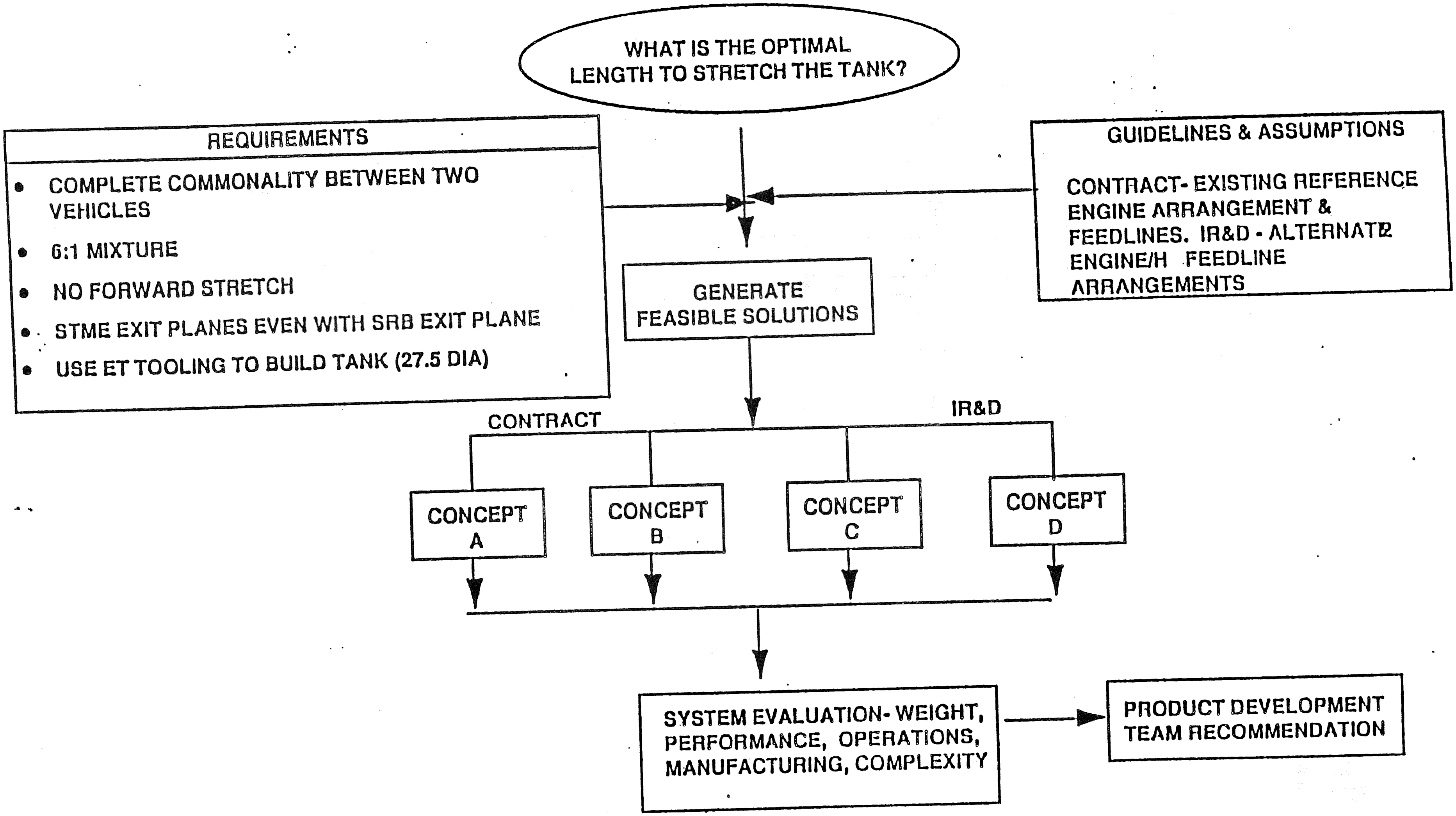
The PDT Evaluated The Four Concepts



WHAT IS THE OPTIMAL LENGTH TO STRETCH THE TANK?

REQUIREMENTS

- COMPLETE COMMONALITY BETWEEN TWO VEHICLES
- 6:1 MIXTURE
- NO FORWARD STRETCH
- STME EXIT PLANES EVEN WITH SRB EXIT PLANE
- USE ET TOOLING TO BUILD TANK (27.5 DIA)

GUIDELINES & ASSUMPTIONS

CONTRACT- EXISTING REFERENCE ENGINE ARRANGEMENT & FEEDLINES. IR&D - ALTERNATE ENGINE/H FEEDLINE ARRANGEMENTS

GENERATE FEASIBLE SOLUTIONS

SYSTEM EVALUATION- WEIGHT, PERFORMANCE, OPERATIONS, MANUFACTURING, COMPLEXITY

PRODUCT DEVELOPMENT TEAM RECOMMENDATION

Weighting Factors Were Established

ITEM	WEIGHTING FACTOR
OPERATIONS	25
• PROCESSING	
• ACCESSIBILITY	
• MAINTAINABILITY	
• LAUNCH FACILITIES	
PERFORMANCE	25
• P/L WEIGHT TO ORBIT	
COST	20
• MANUFACTURING	
• DDT&E	
• LCC	
RISK	15
• COST	
• SCHEDULE	
• PERFORMANCE	
COMPLEXITY	10
WEIGHT	5
TOTAL	100

Each Concept Was Rated Using The Criteria

CRITERIA	Ref.	A	B	C	D
OPERATIONS					
• PROCESSING	5	5	5	5	5
• ACCESSIBILITY	5	4	4	3	4
• MAINTAINABILITY	5	4	3	3	4
• LAUNCH FACILITIES	5	5	5	5	5
TOTAL	20	18	17	16	18
PERFORMANCE					
• P/L WEIGHT TO ORBIT	1	3	5	5	3
COST					
• MANUFACTURING					
• DDT&E					
• LCC					
TOTAL	3	2	1	5	4

Each Concept Was Rated Using The Criteria

CRITERIA	Ref.	A	B	C	D
RISK					
• COST	3	2	1	5	4
• SCHEDULE	3	2	1	4	4
• PERFORMACE	3	2	2	4	3
TOTAL	9	6	4	13	11
COMPLEXITY	3	2	2	4	3
WEIGHT	1	1	1	2	2

Concepts C & D Score Significantly Higher

ITEM	S	A	B	C	D
OPERATIONS (25)	20 500	18 450	17 425	16 400	18 450
PERFORMANCE (25)	1 25	3 75	5 125	5 125	5 125
COST (20)	3 60	2 40	1 20	5 100	4 80
RISK (15)	9 135	6 90	4 60	13 195	11 165
COMPLEXITY (10)	3 30	2 20	2 20	4 40	3 30
WEIGHT (5)	1 5	1 5	1 5	1 5	2 10
TOTAL	755	680	655	865	860

Conclusion - Concept C Is An Efficient Load Path / Weight Solution

THE INITIAL PDT EVALUATION SELECTED CONCEPT C ON THE BASIS OF OPERATIONS, PERFORMANCE, COST, RISK, COMPLEXITY, AND WEIGHT

STRESS EVALUATION, REFINED WEIGHT DATA, REFINED PERFORMANCE DATA WILL BE USED TO TEMPER THE INITIAL EVALUATION

ADDITIONAL ANALYSES WILL BE COMLETE BY JANUARY 20

- STRESS EVALUATION OF CONCEPTS A-D
- MODE SHAPES AND FREQUENCIES OF CONCEPTS A-D

COST / FLIGHT

1.0 Final Assembly, Stacking and Checkout Costs

- Accessibility

The Common Booster Module (CBM) concept considered accessibility for component removal and replacement with operability being the highest concern. Our design incorporates two operational capabilities- one providing access for quick removal, replacement and retest of propulsion and other system LRUs and another option of removing and replacing the total propulsion module from the tank if desired or needed.

The majority of feed system LRUs will be accessible through two doors, located 180 degrees apart, in the aft interstage area. Ladders either GSE or an integral part of the thrust cone will be used from the doors to a permanent platform on the inner periphery of the thrust cone. (Figure 1.1) The platform will be stressed to accommodate the equivalent weight of four people and the assembly of the ground support equipment required for the repair/replacement of LRUs.

Access to the LRUs forward of the thrust cone will be accomplished through the same doors in the aft interstage area. Ground support equipment platforms would be assembled from the doors to reach the airborne quick disconnects, the sustainer engine prevalves and upper feedlines. Ground support equipment shall be provided to manipulate the LRU's to and from the access doors in the aft interstage area when required.

The major difference between the concepts regarding LRU accessibility is in the LO2 system line routing. The reference contains two "downcomers" with lines teeing off to the sustainer engines, while the CBM concept contains a toroidal manifold with the same part number feedline supplying four booster engines. This CBM feature, i.e., more room, appears to provide slightly better LRU access in the boost module to remove components or gain access for troubleshooting. The oxidizer feedlines in the vicinity of the engines are in an annular area between the thrust cone and outer mold line. Accessing these feedlines will be through four doors, one door will be positioned at the oxidizer side of each engine on the bottom surface of the Propulsion Module (Figure 1.2). These doors will also be an opening to a walkway between the engines for LRU maintenance/removal (Figure 1.3). No similar provisions are apparently provided in the reference configuration to allow ground walk-around access. Access to the remaining engine LRU's will be by removal of the appropriate engine heat shields. Access to the sustainer engines feedlines and prevalves will be through the doors in the aft interstage area and the sustainer engine flight fairings. Gaining access to the sustainer engine subsystems on the reference concept appears to be slightly more difficult since the outer skirt and thrust cone must both be penetrated (assuming side access).

The EMA controllers and their batteries for each engine shall be accessible from the bottom of the Propulsion Module, using an integral screw jack mechanism to lower them from the boost module or sustainer modules as appropriate. (Figure 1.4).

- Degree of Serial Processing

The degree of serial processing will be somewhat shorter than that projected for the reference flow. This is due both to the CBM design and to an innovative processing concept that would apply to any design. The design allows the core tank, CBM and engines to be installed at the MAF or KSC and checked out as a single entity. Utilization of KSC test equipment and personnel during any systems level testing whether at the manufacturing site or assembly site will streamline the test and checkout required at KSC upon arrival. The complete vehicle could then be transported to KSC under a controlled and monitored environment and put in the Horizontal Processing Facility (HPF). Confidence testing and some ancillary activities would be conducted requiring approximately 10-14 days (Figure 1.5). The vehicle would then be stacked and taken to the pad for launch.

- Number of Active Systems

The number of active systems are comparable between the CBM concept and the reference configuration. No unique active systems have been identified to discriminate between the two configurations.

- Number of Flanged Joints

Based on an assessment of available data on both the CBM and the reference concepts, several differences have been noted related to flange joints. The CBM concept contains seven less joints than the reference concept and also contains less joints in the larger line diameter sizes (> 16"). From an operations viewpoint, it is much easier to install smaller diameter flanges and associated seals. Experience on Saturn resulted in development of guide devices to assist in installing seals on the tank manhole covers as an example.

Number of MPS Flanges

Line Dia-In.	6	8	11	12	16	17	20	22	TOTAL
No. in Reference	2	5	38	-	-	10	6	-	61
No. in CBM	4	5	-	38	2	-	-	5	54

Unknown, but similar in either configuration:
LH2 vent flanges
Sump flanges.
Tank man-hole flanges.

- Holddown Complexity

Both concepts presently use a four point support system similar to the STS SRB post concept. The CBM holddown post description, MLP arrangement and trade options are shown in Figure 1.6. The four point holddown concept requires shimming to assure proper alignment of the vehicle. This four point system characteristic is well understood and should present no major operations impacts.

- Airborne Disconnects

The table below was developed to compare the booster to core fluid airborne disconnects of the reference and CBM configurations. The two concepts are relatively the same with the exception of the LO2 and LH2 feed disconnects. The CBM concept has a single LOX and LH2 "downcomer" servicing both the booster and sustainer modules. A LO2 anti-geyser system is also included in the CBM configuration which results in an additional fluid airborne disconnect. The reference concept contains two "downcomers" for each of the cryogens using passive recirculation principles in the lines (Figure 1.7). The number and complexity of electrical disconnects are basically the same between both concepts.

Table 1.1 Fluid/Electrical Airborne Disconnects

SYSTEM	REFERENCE		CBM	
	SIZE	QUANTITY	SIZE	QUANTITY
LO2 Feed	17"	2	22"	1
LH2 Feed	17"	2	22"	1
Anti-Geyser	-	-	6"	1
LH2 Press	*	*	1"	1
LO2 Press	*	*	1"	1
Helium	*	*	1"	1
GN2 Purge	*	*	1"	1
LH2 Vent **	*	*	6"	1
Electrical System		SAME FOR BOTH CONCEPTS		

* Assume same size and quantity as CBM

** For LC-39 assume same vent as STS ET and for CCAFS vent may be at bottom of vehicle to eliminate new launch arm.

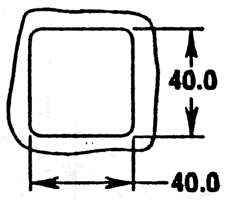
- Hazard Isolation

The CBM configuration is somewhat less vulnerable to propagation of a catastrophic failure from one sustainer engine to another due to wide separations and angular alignments between sustainer engine centerlines. Whereas, the reference configuration utilizes a relatively closely spaced engine arrangement ,and therefore, more susceptible to a catastrophic sustainer engine loss.

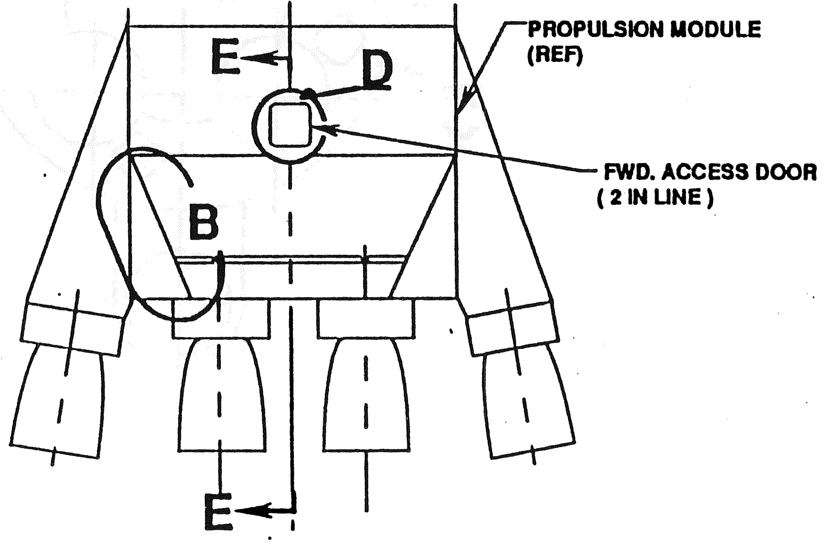
- Pneumatic System Complexity

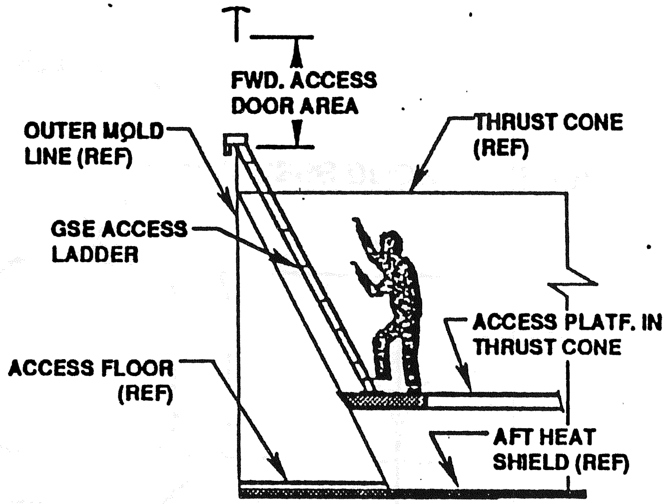
The pneumatic systems between the two concepts are very similar and, therefore, no discriminators exist between the concepts. Figure 1.8 schematically represents both concepts at the present state of definition. The CBM pneumatic system will be palletized to facilitate removal and replacement as well as initial installation.

Figure 1.1 - Fwd. Access Doors & Thrust Cone Platform Enhance LRU Access

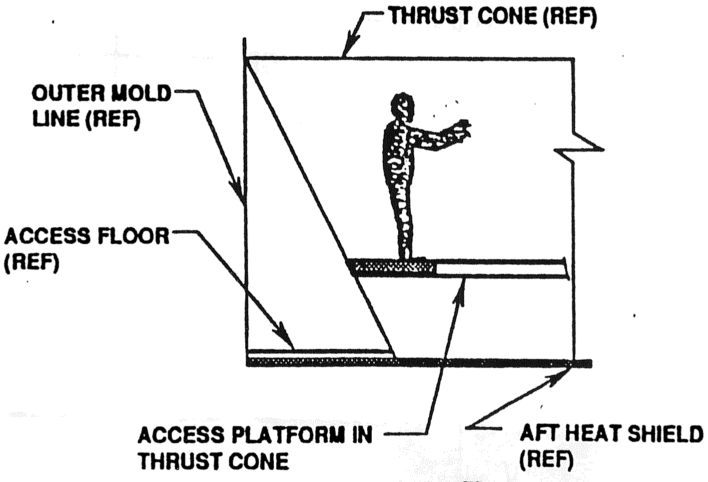


DETAIL D



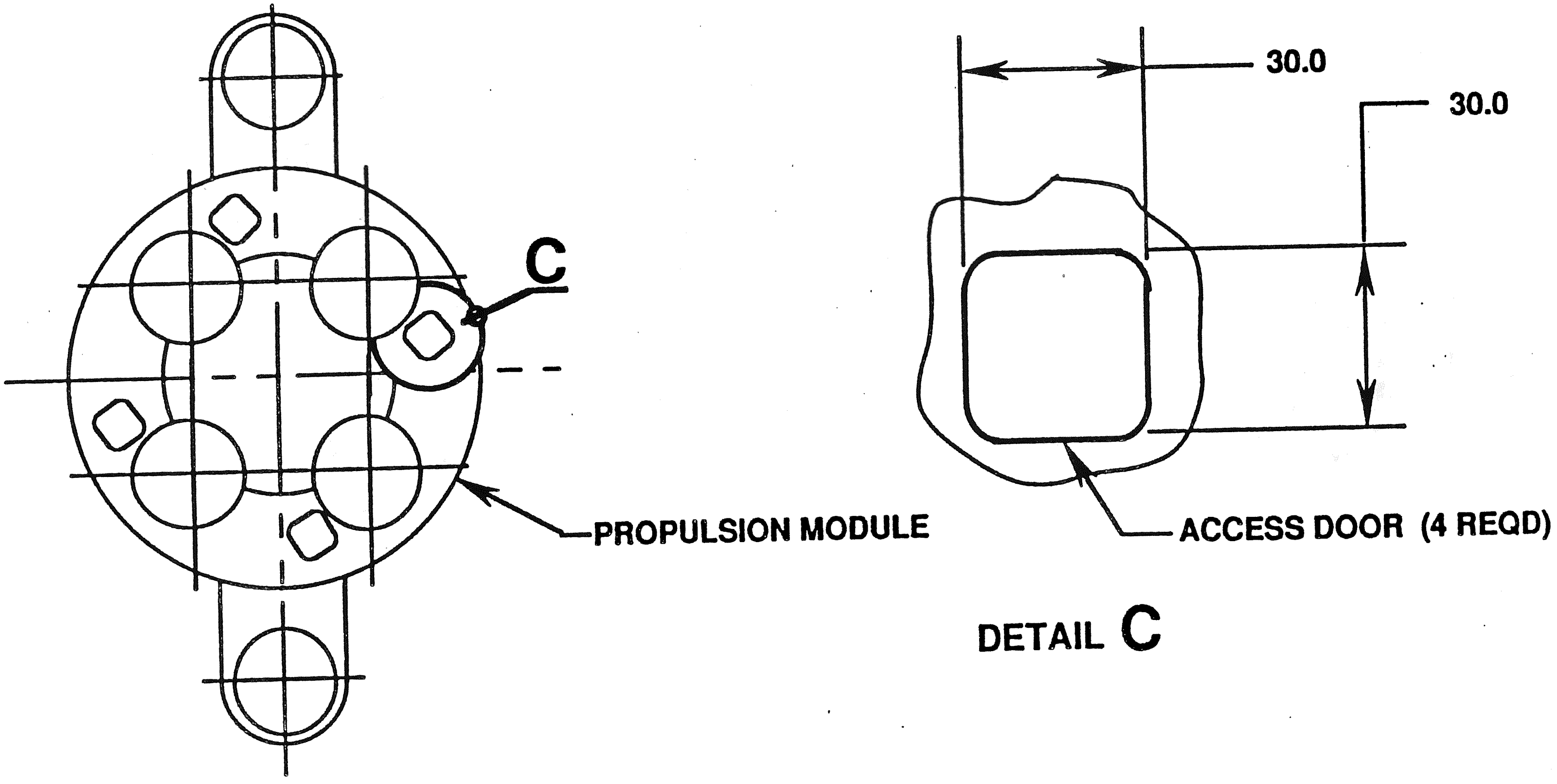


SECTION E-E



DETAIL B

Figure 1.2 Aft Door Allows Access to Propellant System LRU's



VIEW LOOKING FORWARD

DETAIL C

Figure 1.3 - Access Floor Facilitates Contingency Repair and Removals

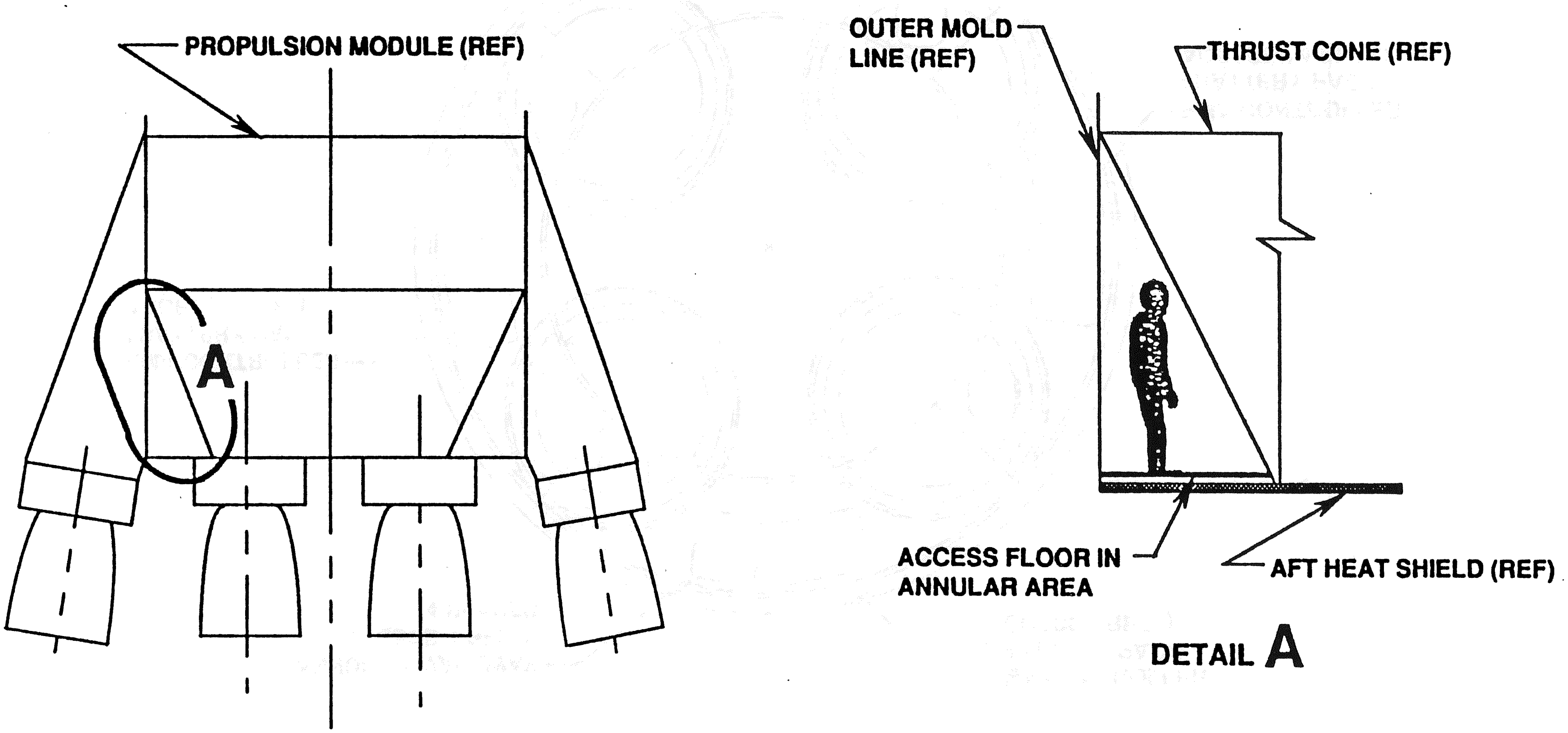


Figure 1.4 Pull Down Access Racks

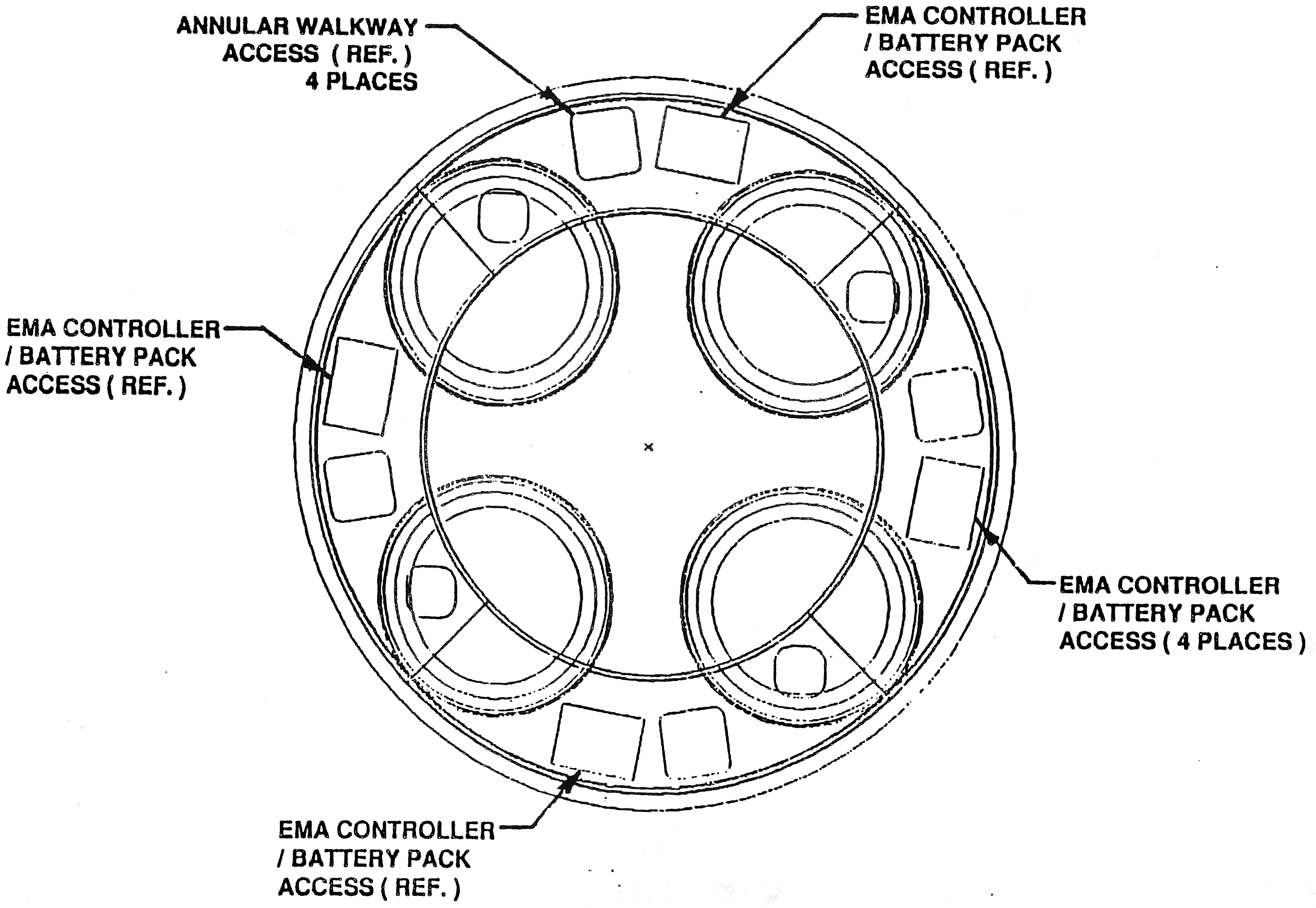
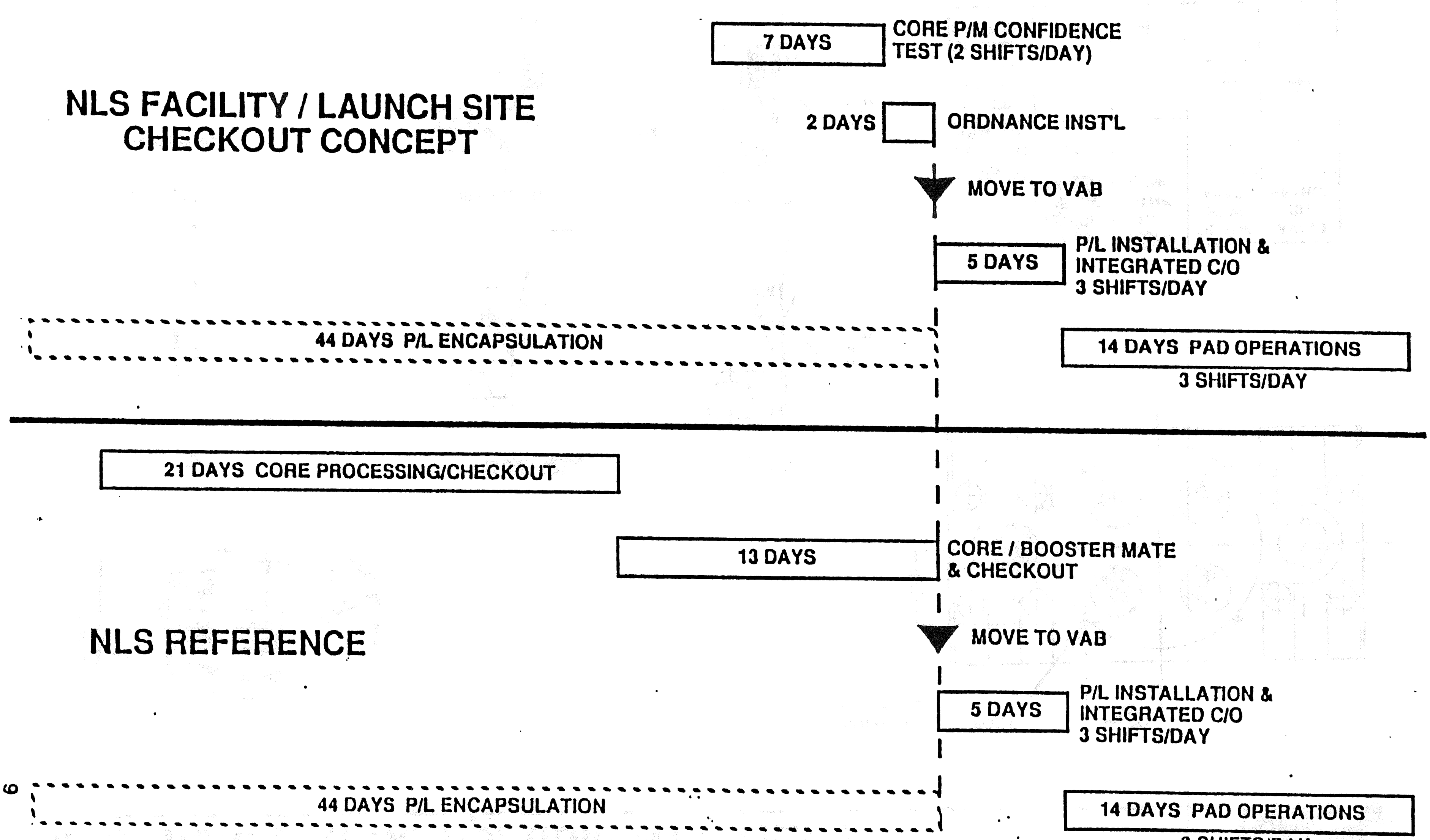


Figure 1.5 NLS Processing Concept Requires Confidence Test Only



NLS FACILITY / LAUNCH SITE CHECKOUT CONCEPT

7 DAYS CORE P/M CONFIDENCE TEST (2 SHIFTS/DAY)

2 DAYS ORDNANCE INST'L

MOVE TO VAB

5 DAYS P/L INSTALLATION & INTEGRATED C/O 3 SHIFTS/DAY

44 DAYS P/L ENCAPSULATION

14 DAYS PAD OPERATIONS 3 SHIFTS/DAY

NLS REFERENCE

21 DAYS CORE PROCESSING/CHECKOUT

13 DAYS CORE / BOOSTER MATE & CHECKOUT

MOVE TO VAB

5 DAYS P/L INSTALLATION & INTEGRATED C/O 3 SHIFTS/DAY

44 DAYS P/L ENCAPSULATION

14 DAYS PAD OPERATIONS 3 SHIFTS/DAY

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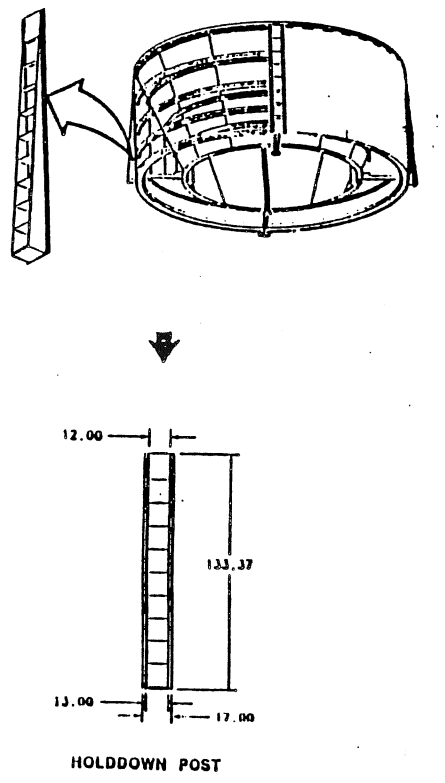
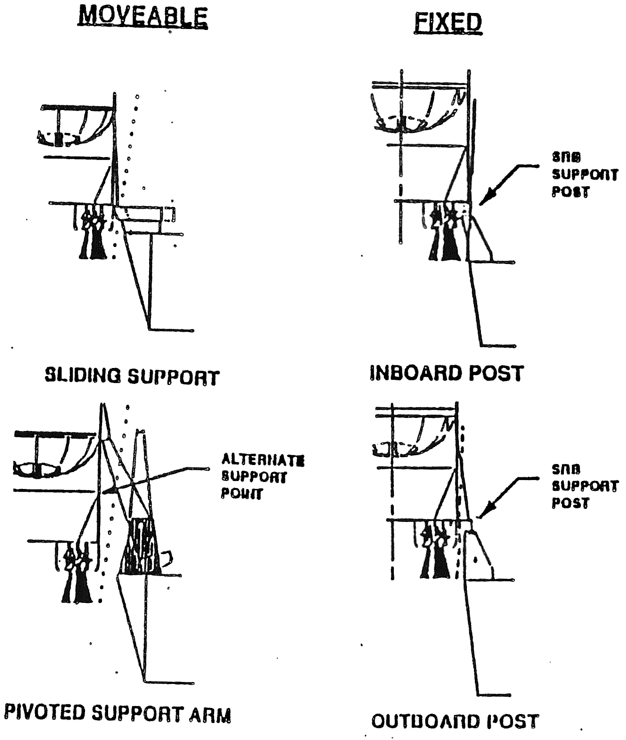
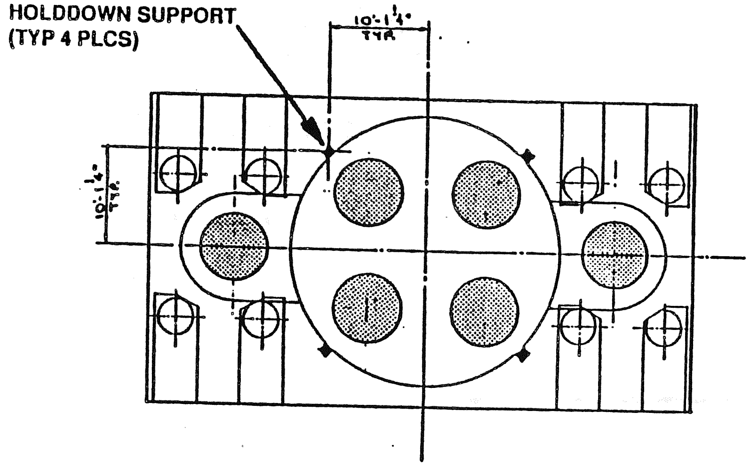
Figure 1.6 CBM Holddown Post Concept Is Simple and Compatible with HLLV







	MIN VEHICLE WEIGHT IMPACT	ACCOM ANY STME ARNMGT	QUALIF HDW AVAIL	AVOID CRIT 1 RETRCT
PIVOTED SUPPORT ARM (B/L)	+	+	-	-
OUBT'D POST	-	+	+	+
SLIDING SUPPORT	+	+	-	-
INBOARD POST	+	-	+	+

Figure 1.7 Reference Main Propulsion Feedline Configuration

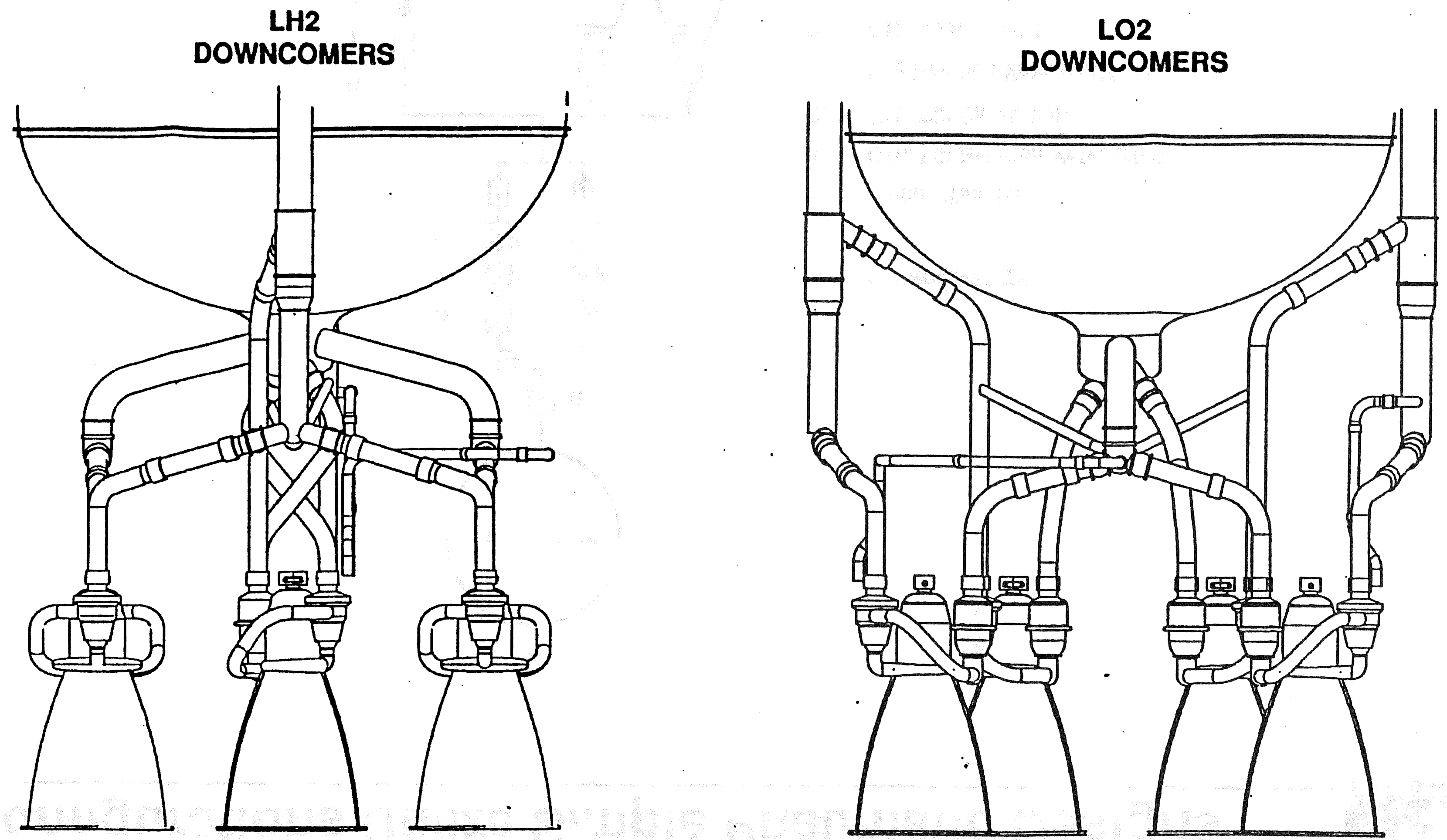
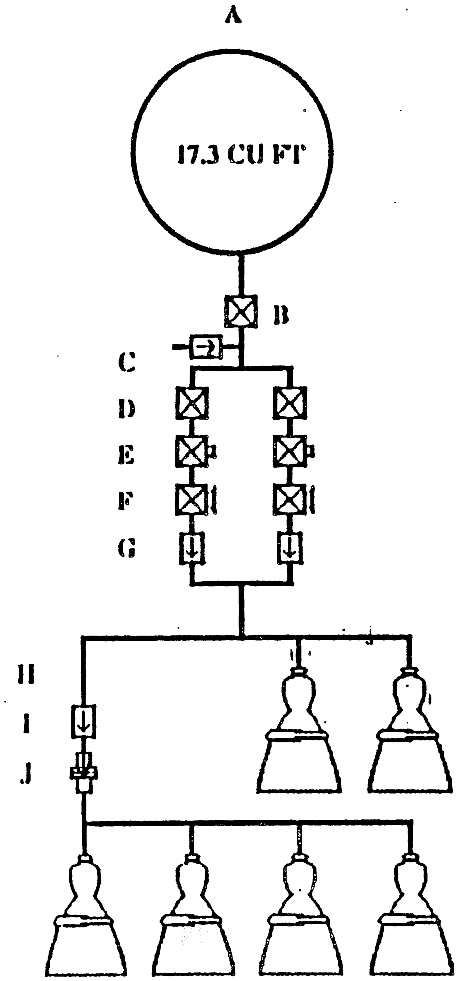


Figure 1.8 Reference and Common Booster Module Configurations Utilize Simple Pneumatic Designs



COMPONENTS

A.	Helium Tank(s)
B.	GHe Fill Isolation Valve (NO)
C.	GHe Fill Check Valve
D.	Reg Isolation Valve(s) (NC)
E.	GHe Regulator(s)
F.	GHe Relief Valve(s)
G.	Reg Outlet Check Valve(s)
H.	GHe Lines
I.	GHe Feed Check Valve
J.	GHe Disc Valve

2.0 Maintenance Cost

- Accessibility

As previously stated in paragraph 1, the Common Booster Module (CBM) concept considered accessibility for component removal and replacement with operability being the highest concern. Our design incorporates two operational capabilities- one providing access for quick removal, replacement and retest of propulsion and other system LRUs and another option of removing and replacing the total propulsion module from the tank if desired or needed.

The majority of feed system LRUs will be accessible through two doors, located 180 degrees apart, in the Aft Interstage Area. Either GSE ladders or an integral part of the thrust cone will be used from the doors to a permanent platform on the inner periphery of the thrust cone. (Figure 1.1) The platform will be stressed to accommodate the equivalent weight of four people and the assembly of the ground support equipment required for the repair/replacement of LRU's.

Access to the LRUs forward of the thrust cone will be accomplished through the same doors in the aft interstage area. Ground support equipment platforms would be assembled from the doors to reach the airborne quick disconnects, the sustainer engine prevalves and upper feedlines. Ground support equipment shall be provided to manipulate the LRU's to and from the access doors in the Aft Interstage Area when required.

The major difference between the concepts is in the LO2 system. The reference contains two "downcomers" with lines teeing off to the sustainer engines, while the CBM concept contains a toroidal manifold with the same part number feedline supplying four booster engines. This CBM feature, i.e., more room, appears to provide slightly better LRU access in the boost module to remove components or gain access for troubleshooting. The oxidizer feedlines in the vicinity of the engines are in an annular area between the thrust cone and outer mold line. Accessing these feedlines will be through four doors, one door will be positioned at the oxidizer side of each engine on the bottom surface of the Propulsion Module (Figure 1.2). These doors will also be an opening to a walkway between the engines for LRU maintenance/removal (Figure 1.3). No similar provisions are apparently provided in the reference configuration to allow ground walk-around access. Access to the remaining engine LRU's will be by removal of the appropriate engine heat shields. Access to the sustainer engines feedlines and prevalves will be through the doors in the aft interstage area and the sustainer engine flight fairings. Gaining access to the sustainer engine subsystems on the reference concept appears to be slightly more difficult since the outer skirt and thrust cone must both be penetrated (assuming side access).

The EMA controllers and their batteries for each engine shall be accessible from the bottom of the Propulsion Module, using an integral screw jack mechanism to lower them from the boost module or sustainer modules as appropriate. (Figure 1.4).

- Ease of LRU Repair and Replacement

Both configurations were assessed for ease of LRU repair and replacement. In comparing the structure of the two concepts, both have a thrust cone (reference supporting 2 sustainer engines while the CBM thrust cone supports 4 boost engines), an outer 27.5 ft. diameter skirt to close-out the boattail, and engine fairings. The CBM concept also utilizes sustainer pods. Gaining access to the sustainer engine subsystems on the reference concept appears to be more difficult since the outer skirt and thrust cone must both be penetrated (assuming side access). Whereas, the CBM concept requires removal of the sustainer pod fairing.

The fluid line routing assessment shows both concepts to contain 8 feedlines within the 27.5 ft. diameter skirt (6 LH2 / 2 LO2 for the reference and 4 LH2 / 4 LO2 for the CBM). The reference concept utilizes a sump for the LH2 feedline attach point while the CBM requires three (3) penetrations of the LH2 tank each with flange interfaces. All manifolding for the CBM is done downstream of the LH2 tank interface.

The other difference between the concepts is in the LO2 system. The reference contains two "downcomers" with lines teeing off to the sustainer engines, while the CBM concept contains a toroidal manifold with identical part number feedlines supplying four booster engines. This approach appears to provide more room and slightly better LRU access in the booster module to remove components or gain access for troubleshooting. The CBM concept also includes permanent access platforms (Figure 1.1) as an integral part of the flight structure to provide access in this area. The ladders to provide a means to get to the permanent access platforms may also be an integral part of the thrust beams similar to the access platform concept.

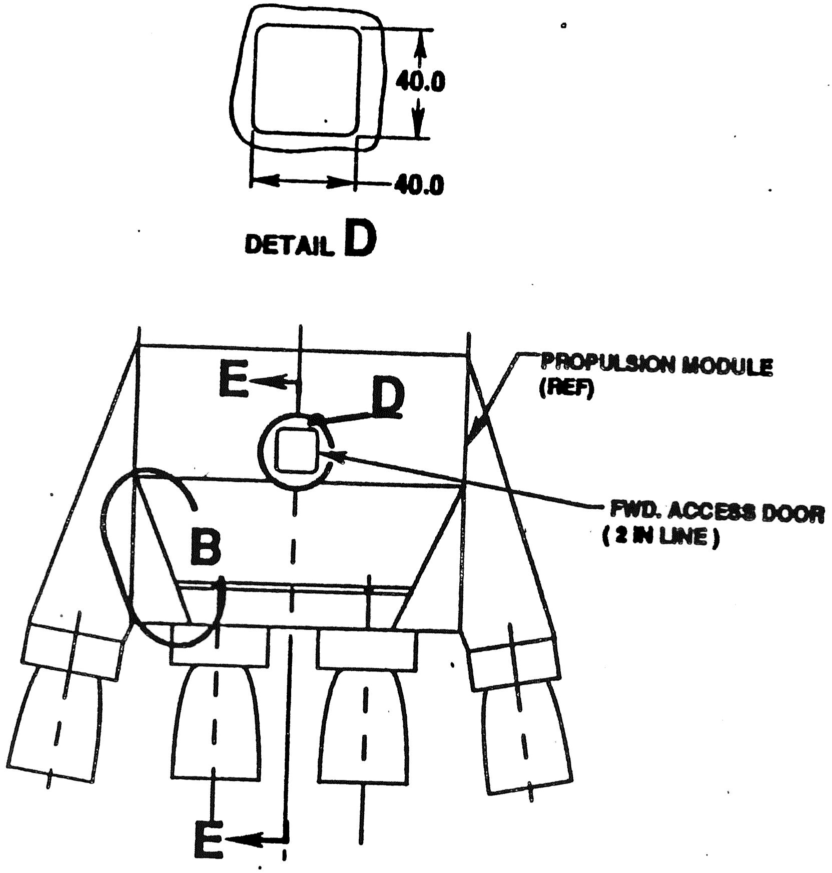
The repair and replacement of LRUs will also be facilitated by key design features. Subsystems will be designed to be palletized where possible, i.e., pneumatic panels, or provided with a drop down feature to enhance initial installation or repair and replacement, i.e., EMA controllers and batteries. The main propulsion system will utilize identical feedlines, i.e., one dash number would apply to all feedlines within the boost module both LO2 and LH2 thus improving the installation and removal learning curve. Structural flooring in the annulus area above the heat shield and permanent access platforms attached to the thrust cone structure will provide the personnel support structure to allow LRU repair and replacement.

Lower level design goals which enhance the LRU repair and replacement features of the CBM concept will also be pursued as the design matures. These include:

- Replaceable sub-units (actuators, filters, position indicators) in heavy or awkward components which can be replaced without removal of the component
- Line and component locations to minimize damage by personnel
- LRU sizing to minimize extensive GSE handling equipment
- LRU location to minimize removal of other hardware for access

In summary, considering the accessibility provisions and the LRU design features, the CBM concept appears to offer better LRU access/removal capability than the reference concept.

Figure 1.1 - Fwd. Access Doors & Thrust Cone Platform Enhance LRU Access



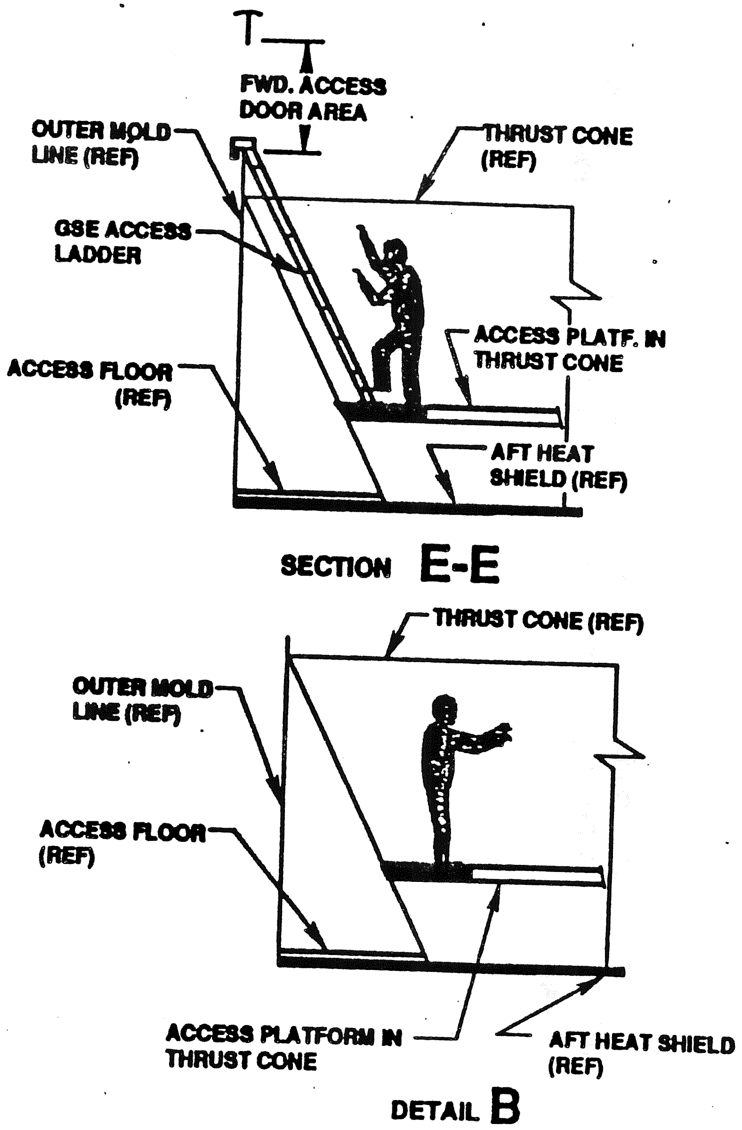


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Figure 1.2 Aft Door Allows Access to Propellant System LRU's

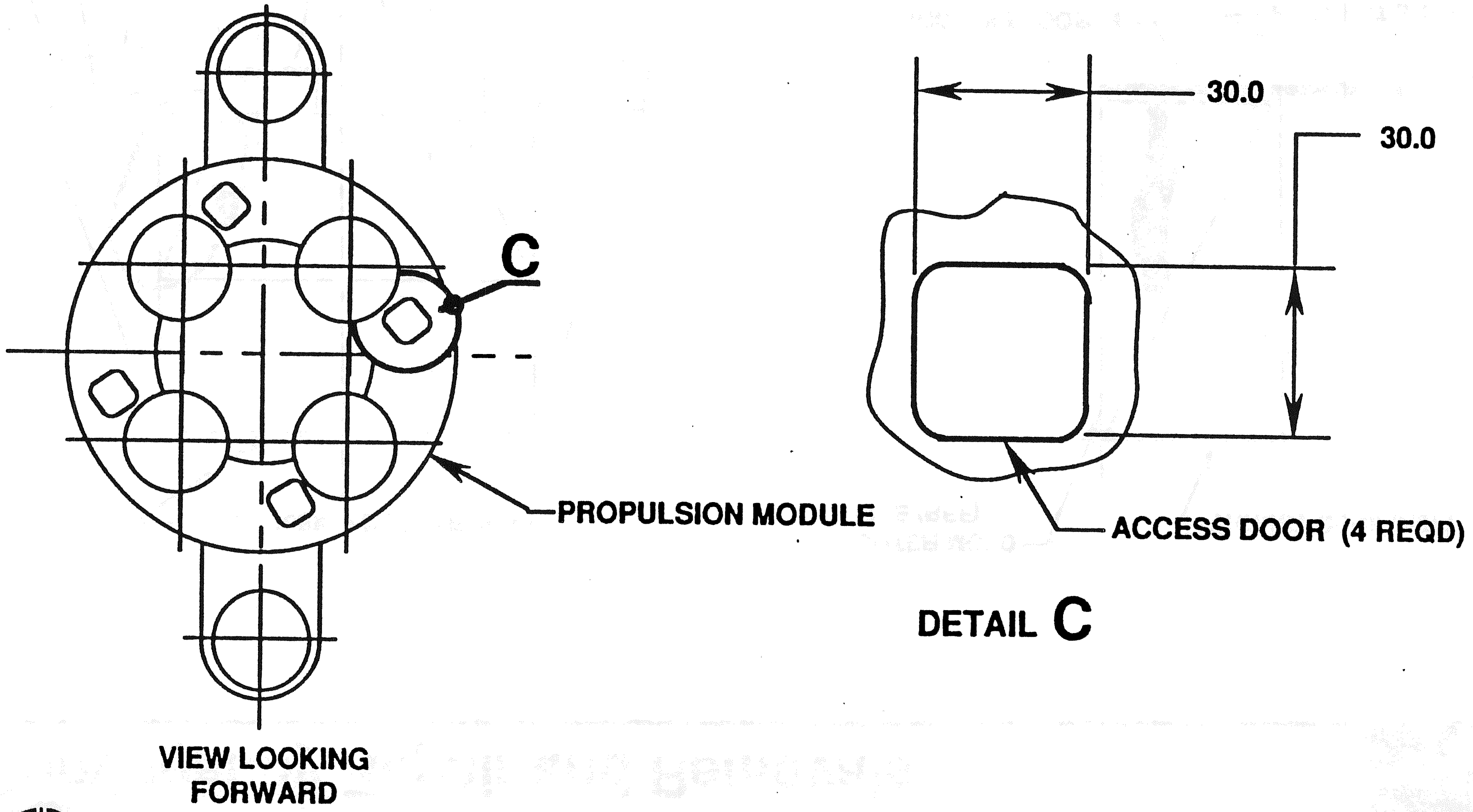
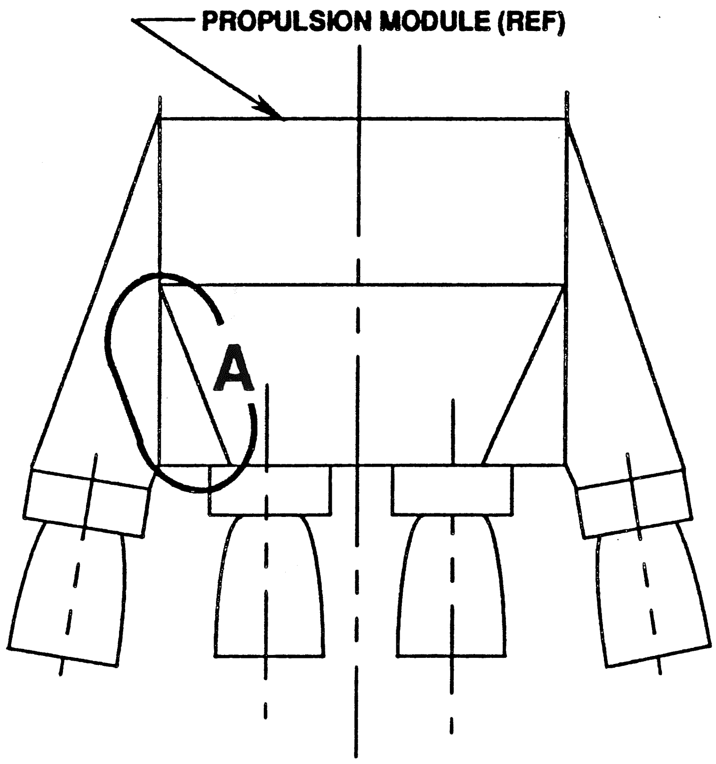
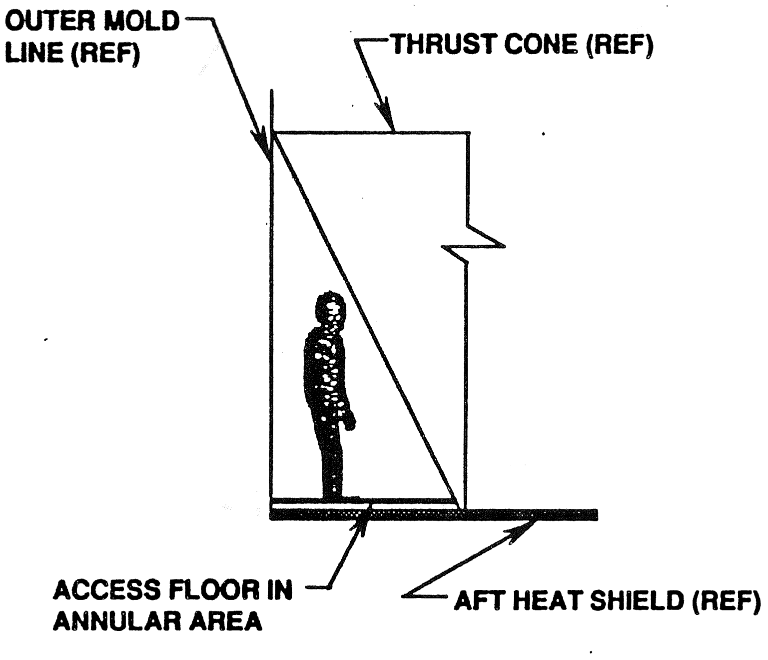


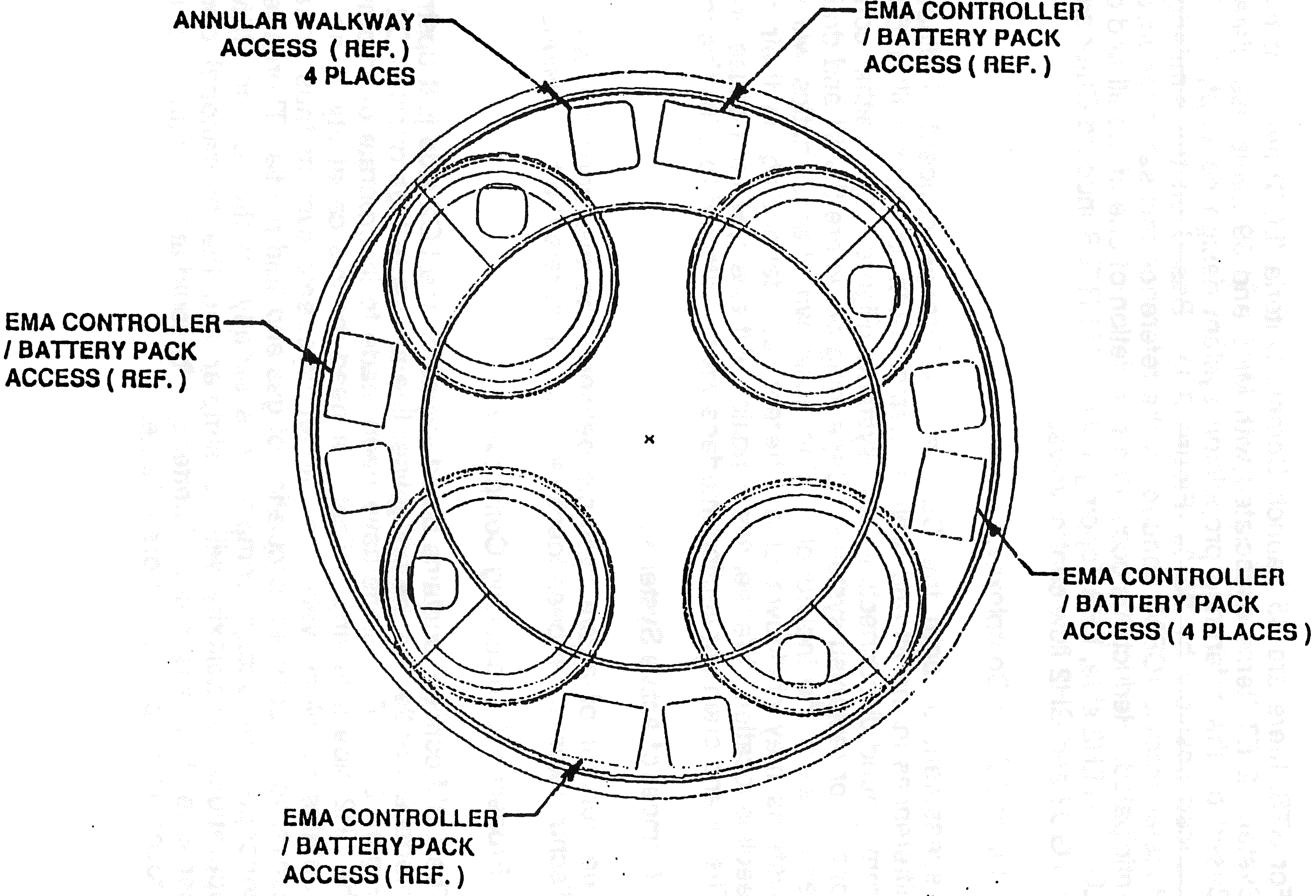
Figure 1.3 - Access Floor Facilitates Contingency Repair and Removals





DETAIL A

Figure 1.4 Pull Down Access Racks



3.0 Loading and Launch Costs

- Number of Launch Commit Criteria.

For STS, there are 45 Launch Commit Criteria (LCC) items for the Main Propulsion System, 2 ET items associated with MPS and 39 items associated with the SSME. Based on the reference propulsion system design concept, the LCC items will be reduced possibly by 25 % (Figure 3.1). Based on the similarity of the Common Booster Module (CBM) concept to the reference this same reduction in LCC items is anticipated. Reductions occur due to deletion of one of the fill and drain valves on the LO2 and LH2 side, LH2 Topping Valve, LH2 RTLS Inboard/Outboard Dump Valve and the GO2 and GH2 flow control valves.

- Fill and Drain Complexity.

Assessment of both the CBM and reference concepts indicates no significant differences in the fill and drain systems. Both use simple fill and drain lines leading from ground disconnects to feed systems (Figure 3.2). Neither concept has separate topping or replenish systems. Depending on where the fill and drain line ties into the feed system the individual engine chilldown characteristics will vary. Some feed systems may chilldown at a different rate depending on their relationship to the feedline location. We feel this condition, if it exists, will not cause any loading problem. The fill and drain connection interface will be selected to minimize these variations.

- Number of Active Systems.

The number of active systems between the two concepts are the same and no discriminators have been identified which separate the two designs.

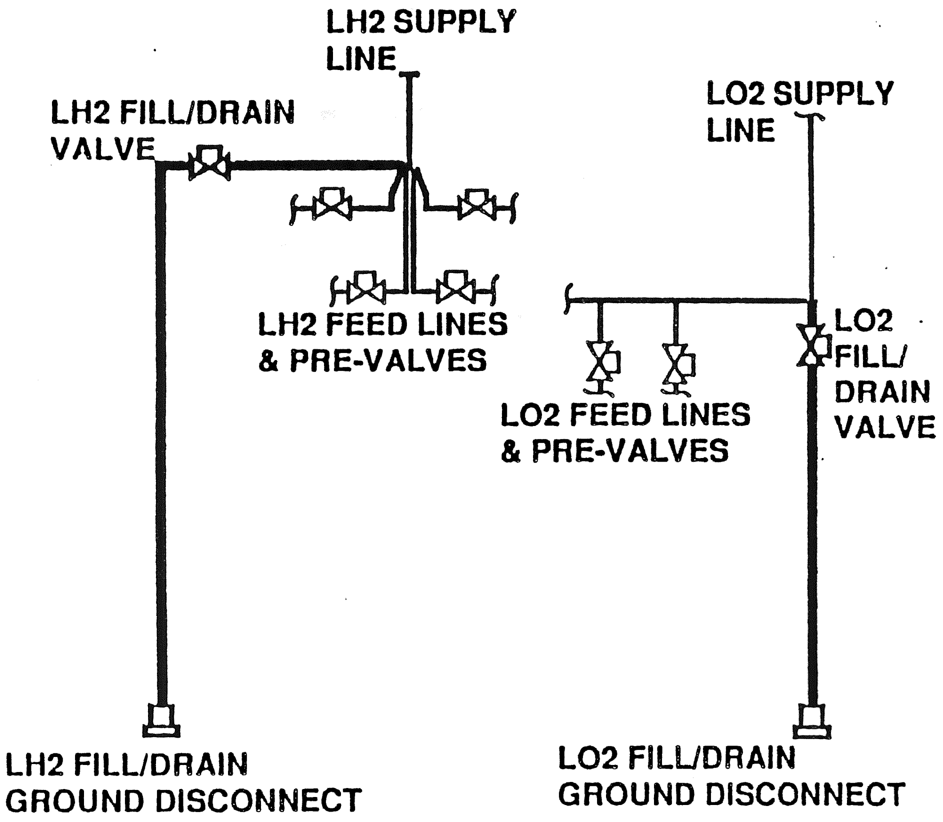
- Propellant Conditioning Complexity.

The CBM concept contains bleed valves on the LO2 side just upstream of the engine interface that tie into the antigeyser line to assure high quality LO2 at the engine inlet (Figure 3.3). Provisions have been made to incorporate overboard bleed valves on the LH2 side if testing indicates a need for this capability. The reference concept contains no bleed valves on either cryogenic system thus depending on natural convection to assure recirculation of gas and fluid media. Therefore, comparing these concepts, the design complexity is slightly greater for the CBM version but the operational complexity will be simpler and the operational dependability higher because of the assurance of better quality liquid at the engine inlet making the loading procedure simpler and more reliable.

Figure 3.1 - NLS MPS Concept Significantly Reduces Launch Commit Criteria

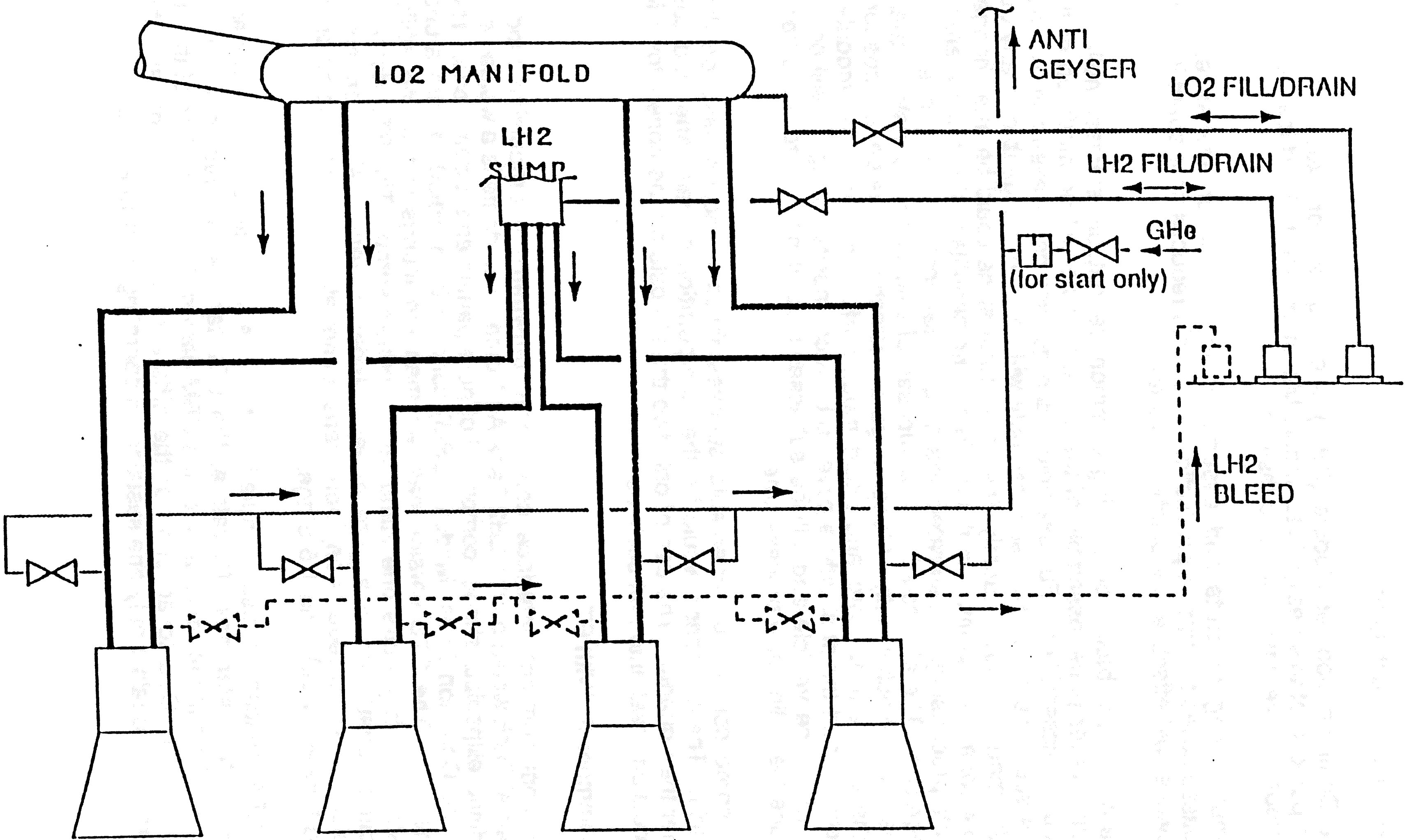
FLUID SYSTEM	STS	CBM CONCEPT	REFERENCE
GASEOUS HELIUM	7	3	SIMILAR TO CBM CONCEPT
LOX TRANSFER	7	5	
LH2 TRANSFER	14	10	
DISCONNECTS	7	6	
LIQUID LEVEL	3	3	
TEMPERATURE	3	3	
PRESSURIZATION	4	0	
TOTAL	45	30	

Figure 3.2 Fill and Drain System Integrated with Booster Feed System



- DESIGN REQUIREMENTS
  - PROVIDE PROPELLANT FLOW PATHS FROM GROUND TO TANKS
  - PROVIDE SHUT-OFF AFTER TANKING
  - ACCOMMODATE TANK DRAIN
- DESIGN FEATURES
  - FOAM INSULATED LINES
  - SELF-SEALING RISE-OFF GROUND DISCONNECTS
- PRODUCIBILITY/OPERABILITY FEATURES
  - COMMON FILL/DRAIN VALVES
  - COMMON DISCONNECTS
- ADDITIONAL TRADES/ANALYSES
  - LOADING ANALYSIS
  - FILL LINE DRAIN ASSIST ASSESSMENT

Figure 3.3 Passive System Accomplishes Propellant Conditioning



4.0 Manufacturing Cost

- Amount of Touch Labor

The Common Booster Module (CBM) is configured for axes-symmetric orientation. The purpose of this design is to enable Manufacturing to build identical subassemblies composed of very few parts and fasteners.

Manufacturing of parts and assemblies for production makes extensive use of subassemblies to support production rate. This reduces time spent in major tools and provides cost effective use of labor resources.

The concept is based on utilizing common, repeatable subassemblies (Figure 4.1). Each quarter panel assembly of the boost module will be made up of the same (3) three subassemblies. For example, each quarter panel assembly will have a thrust cone sub-assembly. That subassembly will be interchangeable to any quarter panel in the module. Subsequently, the detail cone skins could be interchangeable to any thrust cone sub-assembly in the module. The benefits to this feature are repeatability, batch processing, accelerated learning in fabrication, and ease of replacement integration. The aft interstage is composed of skin/stringer panels in quarter sections to be joined mechanically. Flange rings are attached at the panel ends for attachment to the LH2 tank forward and boost module aft. The sustainer modules contain a machined part thrust structure covered by a composite fairing. It will be used only for the 1.5 Stage vehicle and will be subassembled in parallel to the other modules to reduce the in-line flow process time.

The same concept of repeatable subassemblies would be used on the reference vehicle. The difference would be the incorporation of half panel and cone sections rather than quarter. The use of only two thrust posts on the cone allows for a natural production break into half sections.

- Commonality With ET

The most common interface component between the propulsion module and the External Tank would be the LH2 Tank Aft Dome. The dome is a welded assembly of a modified ellipsoidal shape, comprised of gore panels and a dome cap. The reference and the Common Boost Module (CBM) concept both would require a change to the dome cap. The STS version has two manhole fittings in the cap while the HLLV versions would require one fitting for the center sump. The STS dome has an LH2 feedline penetration in a gore panel. Under current design concepts, the HLLV version would not require any gore panel penetrations unless a common core tank is used between HLLV and 1.5 Stage.

The CBM concept utilizes a single LO2 feedline from the tank, as opposed to the dual lines for the reference. Therefore, the LO2 tank sump design would require less redesign from the existing tank for the CBM design. The orientation of this sump will be different than STS to account for the difference in thrust vector, and the desire to minimize residuals if only one sustainer is operating prior to MECO.

- Commonality Between HLLV / 1.5 Stage

CBM Boost Module - The manufacturing build and flow for the four (4) engine boost module is identical for the HLLV and the 1.5 stage. No changes in detail parts, assembly techniques or tooling is required except removal of the 1.5 Stage airborne disconnects and the structural separation linear shaped charges.

CBM Aft Interstage - The aft interstage will have provisions for attachment of sustainer modules for the 1.5 Stage that would be scar to the HLLV. The manufacture of the interstage assemblies will be identical with the exception of cover plates that would be placed over the sustainer penetrations for an HLLV but would not change the processing or assembly techniques for either vehicle.

CBM Sustainer Modules - The sustainer modules are separate assemblies, required on the 1.5 Stage only. They will be assembled to the aft interstage in the mate tool, and does not hinder the flow process of aft interstage or boost module. These sustainer modules will be subassembled in parallel to the other components on a non-interference basis.

- Impact on ET Production Process

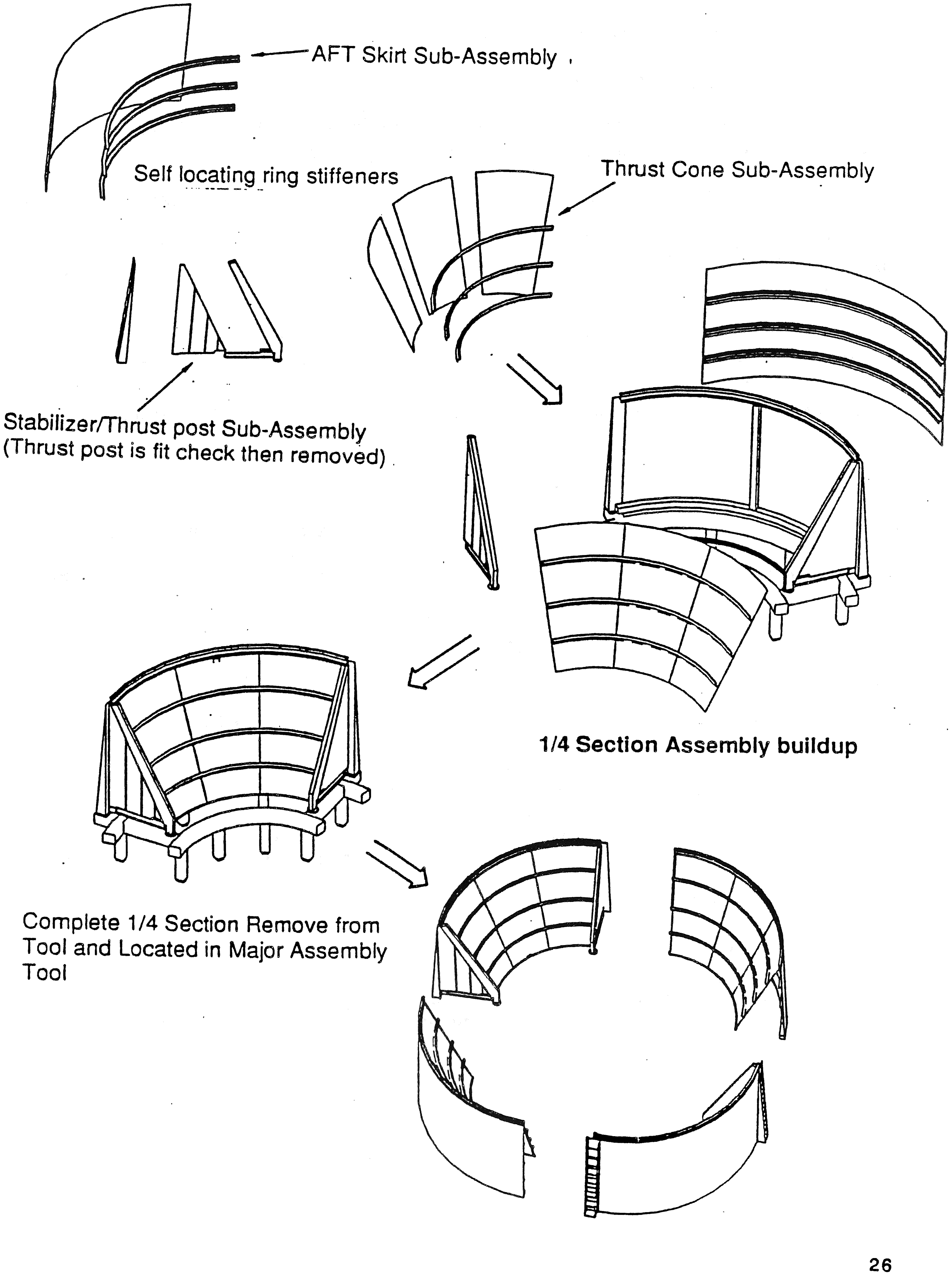
The production process for the STS ET flow will change under current HLLV and 1.5 Stage concepts. Both the Common Boost Module (CBM) and reference require revised tank wall gages in the aft barrel section to take out tie-down & engine thrust loads.

The attach points for the aft interstage to the tank dome would cause a change in the manufacturing process of the dome; however, the construction and fabrication techniques of the gore panels and subsequent welding processes would not change. Currently one gore panel on the STS dome requires a 5-axis machined fitting to be installed at a line penetration point. With the CBM for the propulsion module of the HLLV concept, and assuming a common tank with the 1.5 Stage, penetration of two gore panels would be required in addition to the center flanged outlet. These gore panel penetrations would be blanked off for the HLLV since they are the sustainer module LH2 feedlines. The dome cap change for the HLLV center sump concept with the reference propulsion concept would change the cap assembly, but would not interfere with overall flow. Therefore, the CBM concept is judged to have more impact to the ET production process than the reference.

- Component Cost

No unique or peculiar components have been identified in either configuration that would significantly impact the manufacturing cost.

Figure 4.1 Parallel Sub-Assembly Operation



5.0 Assembly Cost

- Assembly Sequence Complexity

A visual representation of the boost module assembly process for the Common Booster Module (CBM) configuration is portrayed in Figure 5.1.

- MPS Interfaces for Separation

The main CBM propulsion system fluid line interfaces between the boost module and the core stage are a series of quick disconnects which separate during staging. Two umbilicals are required, each containing one of the large propellant disconnects and several of the smaller disconnects. The reference configuration requires four large feed line disconnects and therefore four umbilicals between the boost module and the core stage.

The booster module to core separation interface will be a simplified flange interface with the fluid/electrical disconnect interface plates being premated in the booster module during fabrication. This alleviates many of the alignment and mating problems associated with the assembly of major elements of a cryogenic launch vehicle (Figure 5.2). Comparison to the reference concept for this discriminator item was difficult due to lack of design detail.

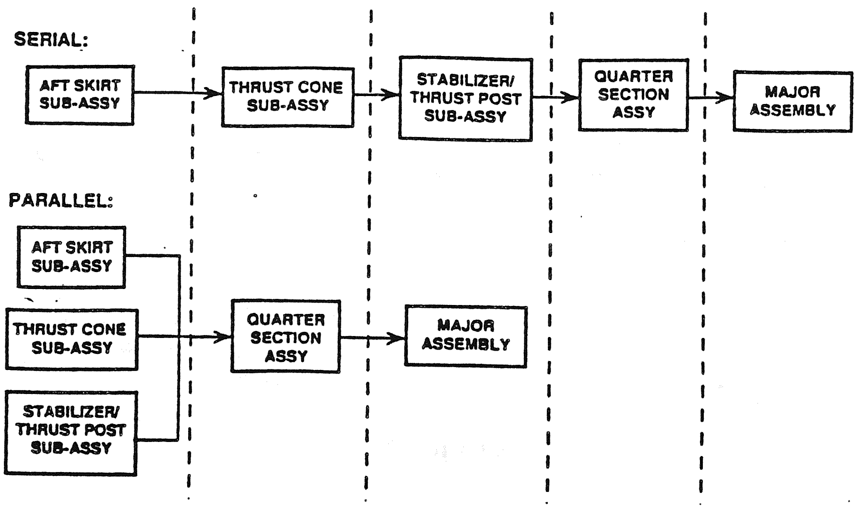
Shown below are the fluid line staging disconnects for both the reference configuration and the CBM configuration:

System	CBM	Reference
LO2 Feed	22" (1 reqd)	17" (2 reqd)
LH2 Feed	22" (1 reqd)	17" (2 reqd)
Anti-geyser	6" (1 reqd)	N/A
LH2 Pressurization		
LO2 Pressurization	1" (1 reqd)	Assumed same as CBM
LH2 Pressurization	1" (1 reqd)	Assumed same as CBM
Helium	1" (1 reqd)	Assumed same as CBM
GN2	1" (1 reqd)	Assumed same as CBM
LH2 Vent (if reqd)	6" (1 reqd)	Assumed same as CBM

- Degree of Serial Operations

The design of the CBM allows efficient assembly techniques. Multiple subsystems will be assembled in parallel as subassemblies, reducing the end to end production flow (see below).

ASSEMBLY - PARALLEL OPERATIONS



The benefit is maximum utilization of labor, reduced tooling costs and minimum assembly interference.

- Amount of Touch Labor

The assembly of the CBM is characterized by extensive use of subassemblies reducing time spent in major assembly stations and providing cost effective use of manpower. The thrust cone subassembly, aft skirt subassembly and stabilizer / thrust post subassembly will be assembled using automatic riveters, conveyers, and handling devices to facilitate production flow. Palletized tooling, and holding fixtures are used to assemble components in setup areas adjacent to the automatic fastener installation stations. Some of the larger and more complicated panel assemblies are pre-assembled in conventional floor mounted assembly jigs. Tack rivets, setup bolts and/or a minimum number of permanent fasteners required to maintain a configuration are installed while in the tool. Holding fixtures are used to handle and transport assemblies to the automatic riveting machines for installation of the remaining fasteners.

The completed subasssemblies are brought together into a quarter panel assembly jig. Two (2) quarter panel sections are installed into the major assembly jig and mated to the floor assembly as shown in the assembly flow plan (Figure 5.1). The remaining two (2) quarter sections are built-up in the major assembly tool utilizing subassemblies coming directly from the automatic riveters. This allows for maximum interfacing in the major jig and minimizing quarter panel tooling.

A drill template fabricated from an inteface control tool will be positioned on the upper ring and the mating holes to the aft interstage will be drilled. Secondary structure, system brackets / clips / supports and initial systems installation and test will be performed concurrently. The engine fairings and engine compartment close-out covers will be installed / fit checked and then removed from the module for shipment. The boost module half sections will be removed from the assembly fixture, packaged and shipped to the core element integration site. A similar assembly sequence for the interstage module (i.e., quarter sections loaded into an assembly fixture and joined to allow for one-half module section shipment) is envisioned at this time. The engine stabilizer mounts and engine fairing subassemblies will be fit checked and removed from the module for shipment. Removal of the interstage half sections from the assembly fixture is performed and the module sections packaged and transported to the integration facility.

The boost and aft interstage module half sections will be loaded into the mating jig at the core element integration site facility. Permanent joining of the module(s) half sections will be accomplished at this time. The boost module upper ring will be used to match drill the mating holes to the aft interstage structure and permanent joining of the modules performed (Figure 5.3). The aft interstage to the LH2 tank ring interface holes will be drilled using a drill plate attached to the interstage upper ring. Final systems installation and test will be accomplished in a concurrent mode. Sustainer engine stabilizer mounts for the 1.5 Stage or close-out covers for the HLLV will be installed on the interstage depending on the vehicle flight configuration. The main propulsion system feed lines, vent lines and STMEs will be installed and tested after the boost/interstage module is interfaced to the LH2 tank ring. A checkout of the total vehicle is accomplished prior to transport to the launch pad.

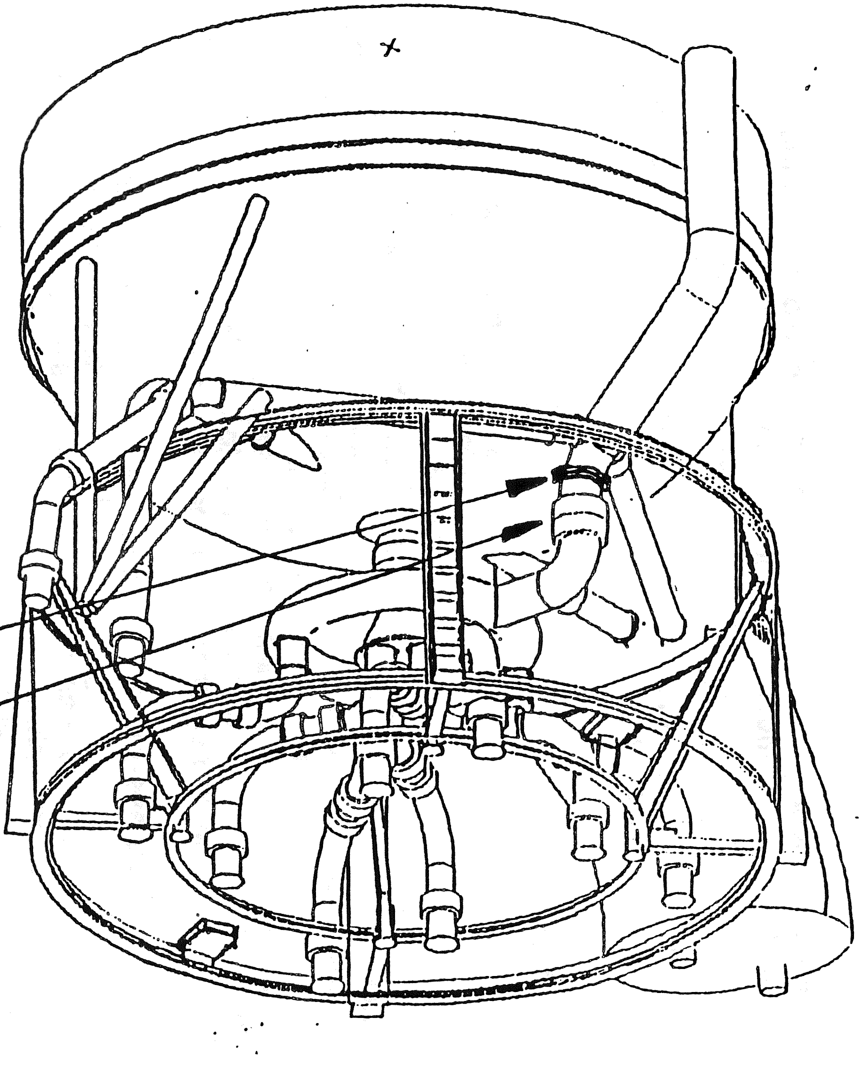
Major structure assemblies for the reference 1.5 Stage consist of an aft skirt, sustainer thrust cone and boost ring. The sustainer structure is not required for the HLLV. The subassembly hardware associated with the aft skirt, sustainer cone and boost ring are positioned in assembly fixtures to support a one-half module buildup. As secondary structure, systems attach hardware is installed as a concurrent activity. The module half sections are joined and close out of the interfaces completed but not permanently joined. Structure interfaces joining module structures will be accomplished via tooling derived from Interface Control Tooling (ICT) and/or matched drilled at the integration site as required. Initial systems installations and test is performed utilizing simulator and/or flight hardware. The modules are disassembled into the one-half sections, packaged and shipped to the integration facility. Early program definition of which vehicle (1.5 Stage or HLLV) is to enter the Manufacturing flow and build cycle is required to assure structure and system interface compatibilities between modules to support the two reference vehicle configurations.

Joining of the one-half sections of the aft skirt, sustainer cone (depending on vehicle configuration) and boost ring is accomplished at the integration site facility. The modules are joined to the core vehicle structure and final systems (i.e. feedlines, engines, close out tubing, electrical harnesses, etc.). Installation and test is then performed. An integrated vehicle test is performed, close out covers/shrouds and hardware installed prior to vehicle transport to the launch pad.

Figure 5.2 Pre-mated Disconnects Reduce Final Assembly Complexity

AIRBORNE DISCONNECTS (8 REQ'D)

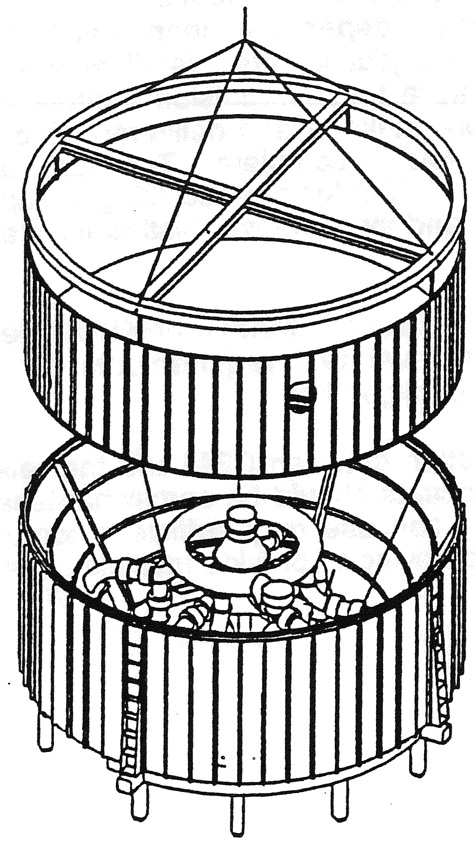
- **PREMATE AIRBORNE DISCONNECTS IN BOOST MODULE**
- **UTILIZE FLANGE INTERFACE FOR PROPULSION MODULE TO CORE INTEGRATION**
- **INTEGRATION OPERATION CONDUCTED AT MAF OR KSC**
- **FLUID SEPARATION AT PREMATED INTERFACE**



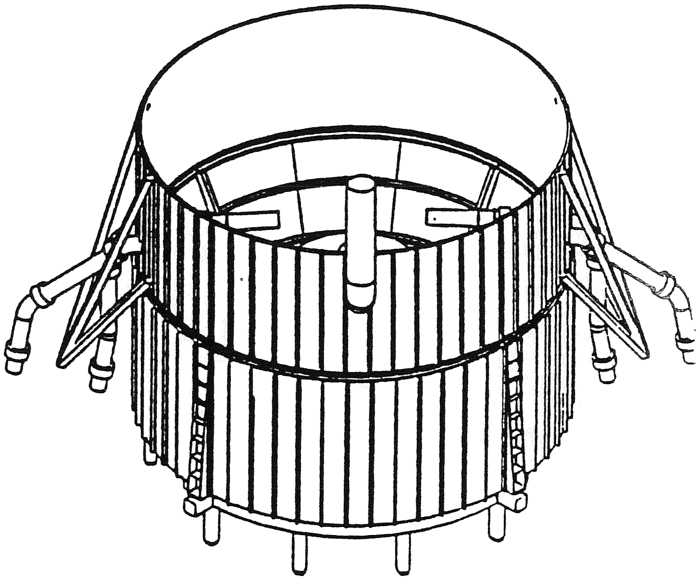
**FLANGED JOINT
USED FOR FINAL MATE**

**AIRBORNE DISCONNECT
PREMATED PRIOR TO
BOOST MODULE MAATING**

Figure 5.3 Booster and Interstage Major Assembly Operations



- Mate and install Inter-stage to Booster
- Perform drilling operation using matched holes of upper ring of Booster Module
- Install feed lines and subsystem



- Install Sustainer engine stabilizer mounts to Inter-stage
- Install Sustainer feed lines and subsystems
- Locate and install Sustainer close out cover panels

6.0 Acceptance Testing

- System Level of Testing

An acceptance hot firing of short duration is necessary prior to flight for initial hardware deliveries. These firings can be suspended, dependent upon real time program evaluations, after three or more firings - subject to later detail evaluation. The reference configuration will be delivered as a total propulsion module unit. This propulsion module will be mated to the core tankage and delivered as one unit for system level testing, after all system checkout is complete. The hardware will be shipped to the Stennis Test Site, KSC or CCAFS for a static firing as appropriate. Propulsion module mating with its tankage and system level testing for static test or flight can be done at MAF, KSC or CCAFS.

The Common Booster Module (CBM) upon delivery to MAFG (or KSC if desired) will be mated to the core tankage. System level test requirements for the CBM configuration are the same as the reference configuration.

In general, there is no significant discrimination between CBM and the reference as related to acceptance testing. But both concepts should be somewhat less complex than highly modular designs because they can use only sufficient components to achieve required redundancy, as opposed to having to provide multiple subsystems to populate independant modules.

NON-RECURRING COST

7.0 Vehicle Design and Development Engineering

- System Complexity

System complexity is defined here as a qualitative parameter which describes the degree of difficulty associated with integrating the major hardware subassemblies and systems, and also hardware impacts on operational efficiency and producibility. Factors included in this assessment are the degree of complexity for each major system such as propulsion and structures, as well as the number of parts which comprise the system.

Assuming a similar subsystem design approach, and the use of separate sustainer, and boost modules, no appreciable difference can be identified between the reference and the Common Booster Module (CBM) concepts in terms of system complexity. However, if the reference incorporates a sustainer propulsion system integrated within the core tankage, then higher system complexity will result. This is due to the need to ensure that the core tankage be designed and integrated with the sustainer propulsion system prior to propulsion system testing. Whereas, the CBM concept requires a simple flanged interface between the tank and the propulsion module. All manifolding is accomplished on the CBM side of the interface thus allowing separate tank and propulsion testing.

The reference contains a sump which is integral to the base of the tank and the Propulsion Module. Therefore, the tank and module needs to be integrated and tested as a complete propulsion unit which may add to the list of critical system developments.

- Complexity of Boattail Structure

Both the reference and the CBM concepts consist of a conic thrust structure, and a cylindrical structural arrangement which reacts engine thrust loads to forward ring frames prior to the tank interface. The only major difference between the two approaches is that the CBM concept reacts booster loads (instead of sustainer engine loads) through the conic section. It is not readily apparent that this difference would allow a distinction in structural complexity.

As seen in Figure 7.1, the booster engine loads for the reference are transmitted directly into the boattail cylindrical aft structure. This allows engine point loads to be more evenly distributed prior to the aft interstage, and eventually the tank interface. The CBM transmits sustainer loads directly into the aft interstage with thrust beams which shear these loads into the aft interstage through longerons. This will result in either a less evenly loaded interface, or a heavier more complex aft interstage forward ring-frame. Due to this difference in load path, it is felt that the CBM concept results in a slightly more complex structural arrangement.

- MPS Complexity

Both system concepts incorporate prevalves, and ancilliary systems such as pogo, fill and drain, and pneumatics. The primary difference between concepts are the feed systems, and the use of a LO2 passive recirculation with bleed system for the CBM configuration.

The CBM design is based on maintaining axes-symmetric orientation for the boost module. This allows commonality in feedlines regardless of booster engine location, and propellant type (Figure 7.2). This concept also utilizes a toroidal manifold for LO2, however, a truncated torus resulting in a "C" shaped manifold is a trade option which may provide flow dynamics and residuals benefits. Feedline component commonality is also incorporated between sustainer modules, although the exact geometry is different between modules.

The reference concept consists of dual LO2 lines from the tank which results in a more complicated cryo system when considering propellant fill and terminal drain during an engine-out condition. It also results in a higher potential for re-ingesting warm fluid at the tank outlet during preconditioning. The engine orientation of the reference design will make a single LO2 tank feedline option more difficult to accommodate (should it be desired) than the CBM configuration due to a higher engine density. Additional differences between single and dual LO2 tank feedlines are specified in Table 7.1.

The LO2 passive recirculation approach in the CBM concept (Figure 3.3), uses bleeds, adds to part count, and thus hardware complexity. This is due to the incorporation of check-valves or solenoid valves in the recirculation lines. These valves would be activated only if there is a catastrophic engine loss. However, we feel that a passive recirculation system with bleed provides lower development risks, and operational complexity associated with verifying propellant quality during nominal and launch hold situations. We feel that for these reasons, the CBM approach offers a less complex MPS system overall.

- Number of Components and Number of Common Parts

A review of the candidate manufacturing approach, structural design, and feed system layout for both the CBM and reference concept was performed to estimate the number of components. No attempt was made to determine part count for systems such as avionics, pneumatics, or TVC actuation in which similar design approaches were utilized between concepts. Results of this assessment for the structural configuration is presented in Table 7.2. Note that the greater number of components associated with the CBM reflects the use of our truss thrust structure approach for the sustainer modules. Additional structural members are also required to integrate the sustainers into the aft interstage. This higher part count is typical of highly adaptable designs using modular structural arrangements.

Results of the feed system part count assessment shown in Table 7.3 indicates a slight advantage for the CBM concept. This is due to the need for one less line assembly and disconnect for the CBM. Also provided in Figure 7.3 and Figure 7.4 is a summary of the feed system geometric characteristics that can be used to evaluate the CBM concept.

The number of common parts were assessed using the same procedure is used in estimating the number of components. In reviewing these designs, it became apparent that a sum value for the number of common parts (presented in Tables 7.2, and 7.3) can be misleading due to the frequency of use. For example a particular design could have a greater number of parts each of which are used only in one other location. On the other hand, another design could have fewer parts that are common, but those that are common are used in several places. This is illustrated in Table 7.3 in which the CBM has fewer total number of common parts, but utilize common line assemblies more often. This is due to having identical LO2 and LH2 feedlines within the four engine booster module. However, using only sum values, the CBM has a higher percentage of common structural components and a lower percentage of common feed system components than the reference.

Table 7.2 Structural Configuration Parts Evaluation

STRUCTURAL COMPONENTS		CBM	REFERENCE	
	QTY	# OF COMMON PARTS		# OF COMMON PARTS
INTERSTAGE				
• SUSTAINER MODULE				
- PANELS	4	4	4	4
- UPPER RING FRAME	1	0	1	0
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	3	1	0
- THRUST LONGERONS	4	4	0	0
• THRUST STRUCTURE				
- ENGINE MOUNT	2	2	0	0
- THRUST BEAM 1	4	4	2	2
- THRUST BEAM 2	4	4	0	0
- PANELS	0	0		
• W/LO2 CUT-OUT			2	2
• W/O CUT-OUT			10	10
- UPPER RING FRAME	0	0	1	0
- LOWER RING FRAME	0	0	1	0
- INTERMEDIATE FRAMES	0	0	2	0
BOOSTER MODULE				
• SKIRT			0	0
- PANELS	4	4		
- UPPER RING FRAME	1	0		
- LOWER RING FRAME				
• PIECE 1	1	0		
PIECE 2	1	0		
PIECE 3	1	0		
- HOLDDOWN POST	4	4		
- INTERMEDIATE FRAMES	3	3		

Table 7.2 Structural Configuration Parts Evaluation (cont'd))

• THRUST STRUCTURE				
- PANELS			4	4
• W/LO2 CUT-OUT	4	4		
W/O CUT-OUT	8	8		
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	0	4	3
- ENGINE MOUNTING BLOCK	4	4	2	0
- THRUST BEAM	4	4	4	4
- STABILIZING BEAM	4	4	0	0
- STABILIZING PANEL	4	4	0	0
- HOLDDOWN POSTS	0	0	4	4
	70	60	42	33

Table 7.3 Propulsion Configuration Parts Evaluation

PROPULSION COMPONENTS	CBM		REFERENCE	
	TOTAL	COMMON	TOTAL	COMMON
LINE ASSYS	16	8 2 2 1 } MIRROR 1 } IMAGES 1 1	15	2 2 } MIRROR 2 } IMAGES 2 4 2 1
PREVALVES	6	6	6	6
DISCONNECTS	3	2 1	4	4
SUMP	1	1	1	1
OTHER (MANIFOLDS. TEES, ETC.)	4	1 1 1 1	6	2 2
	30	20	32	30

- Use of Existing Design

Since both the CBM and the reference concepts are new configurations tailored to the interface requirements of the ASRM's, and modified ET, both concepts are essentially new designs. Shuttle, Centaur, or Atlas components, such as, pneumatic tanks, solenoid valves, or disconnects, may be applicable with some modification to the NLS. However, a review of subsystem volume capability for both concepts indicates that either concept should be able to accommodate existing hardware assuming cost benefit trades shows this as advantageous.

The CBM concept uses 12 inch foam insulated feedlines for both LH2 and LO2. Therefore, some components such as seals, flanges, prevalves (modified for electromechanical actuation) and straight line sections may be applicable from STS. However, some of this hardware may still be usable with appropriate reducer sections if a smaller line diameter (such as the 11 inch diameter line tentatively being considered for the reference) is used. No significant difference in ability to use existing designs is readily apparent between the two concepts.

- Off-the-Shelf Hardware

Except for the potential of using existing designed components as discussed in the previous paragraph, neither concept utilizes off-the-shelf subsystem components. When considering the processes used in the manufacturing of structural components, standard 2219 or 2024 sheet stock is planned for major skinned areas of the CBM concept. Frames and stiffners, although not necessarily off-the-shelf, will be formed using existing extrusion processes with little or no machining.

It is anticipated that the reference also utilizes existing manufacturing processes and materials; therefore, no discrimination is readily apparent between the two concepts.

- Degree of New Tank Design

The primary differences between concepts as they affect the core tank are associated with feedline configuration, prepressurization requirements, and aft interstage load distributions.

The CBM concept utilizes a single LO2 feedline from the tank, as opposed to the dual lines for the reference. Therefore, the LO2 tank sump design would require less redesign from the existing tank for the CBM design. The orientation of this sump will be different than STS to account for the difference in thrust vector, and the desire to minimize residuals if only one sustainer is operating prior to MECO.

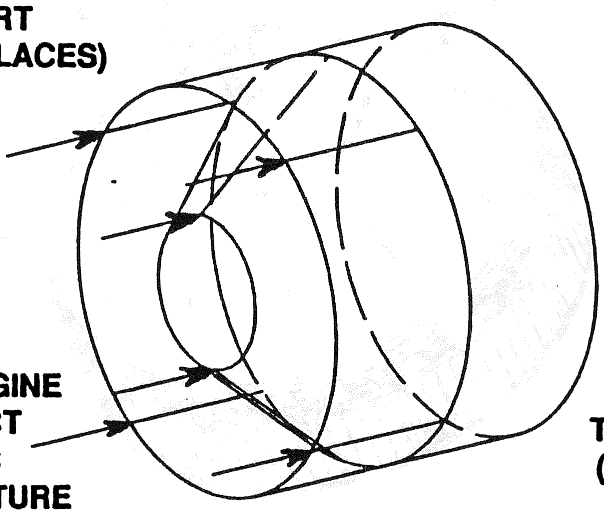
The LH2 tank outlet is at the base of the aft dome for both concepts (reference uses a sump, CBM uses a flange) thus requiring a new design. Since the outlet for the CBM concept supplies propellant only to the boost module, two additional 12 inch feedline penetrations in the tank aft dome(for the sustainer modules), are required. Due to the need for these penetrations, it is assumed that slightly more design work is required for the LH2 aft tank dome for the CBM concept than for the reference configuration.

The existing tank would need to be redesigned for both concepts due to the higher NPSP requirements of the STME compared to the SSME (13.1psig vs. 4.8-5.1psig). Since the CBM concept utilizes a passive re-circulation with bleeds concept, a pre-pressurization requirement of 22 psig has been estimated to ensure subcooled propellants at the STME inlet for pre-start. However, the reference concept has no propellant recirculation or bleed systems. Therefore a higher pre-pressurization value (ie. 49 psig) is required to subcool the propellants. Assuming similiar NPSP requirements, the higher tank pressures for the reference concept may require slightly more design activity than the CBM configuration.

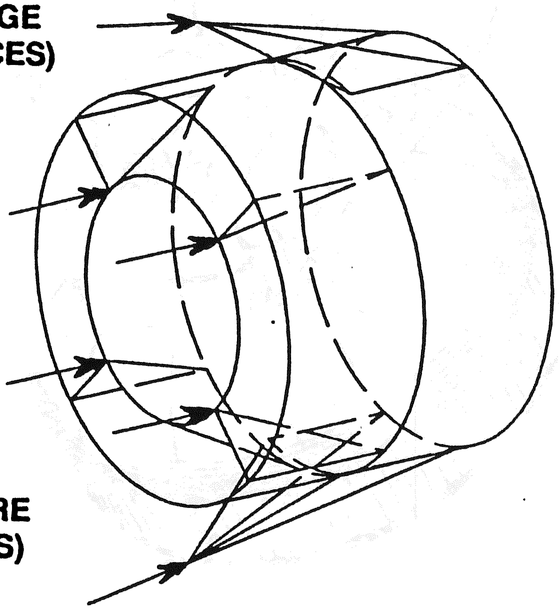
Since sustainer engine thrust loads for the CBM design are transmitted to the aft interstage in the vicinity of the tank attachment location, the tank aft frames will probably see a less uniform load than for the reference design. This will probably result in a more complicated load distribution which must be accounted for in the redesign of the LH2 tank aft region. Therefore this may result in a slightly more complicated design activity for the CBM concept.

Combining both propulsion and structural differences to make an overall assessment shows no significant advantage between the two propulsion arrangements. Each concept would affect the design of tank components to varying degrees. However, it is felt that these changes are somewhat insignificant to the overall tank design changes associated with placing the propulsion module at the base of the ET.

Figure 7.1 Engine Loads Are Transmitted Somewhat Differently for Each Concept

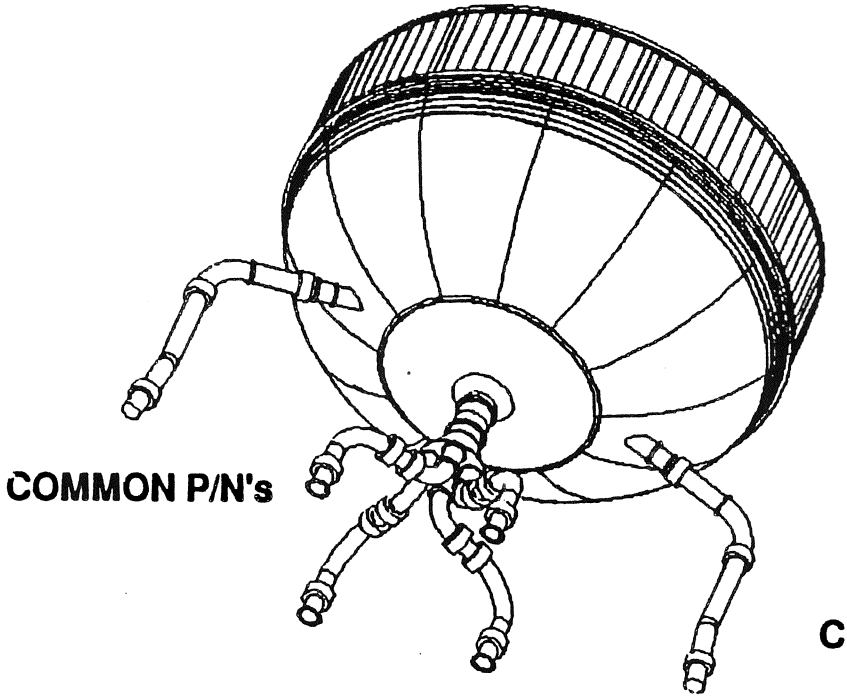


REFERENCE

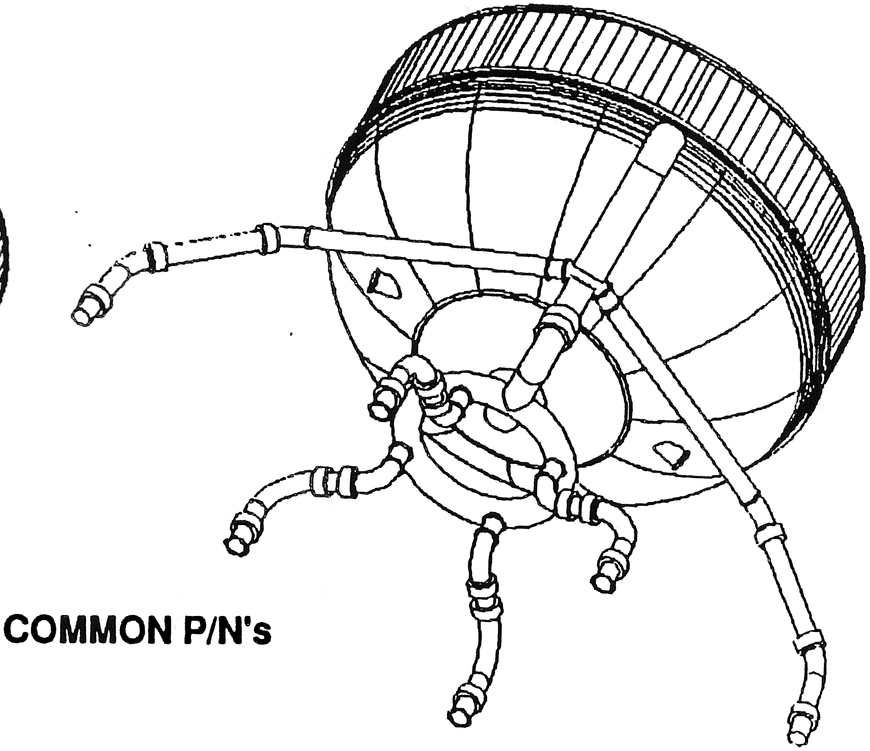


CBM

Figure 7.2 CBM Propellant Feed System Uses Common Feedlines



CBM
LH2 FEEDLINE
CONFIGURATION



CBM
LO2 FEEDLINE
CONFIGURATION

TABLE 7.1 COMPARISON OF DUAL AND SINGLE O_2 SUPPLY SYSTEM

PARAMETER EVALUATED	COMPARISON
1) O2 Tank Dome	1) Two line configuration adverse relative to tank structural aspects, potential flow interference between two lines thus warmer engine inlet/line O2 temperature, larger more complex vortex/screen configurations, and two large entrance sections. Adversely effected are weight, DDT&E cost, cost per flight, test cost, design complexity, and tank entry. 2) Geysering influence of warmer temperatures unknown. 3) Small O2 residuals at tank bottom between two outlets. 4) Dome cap (ET) with two inlet ducts entrance diameters may impact manhold provisions.
Conclusion: Clearly favors single supply line.	
2) Supply Line	1) Two 20 inch diameter feedlines and crossover weigh more than single line and anti-geyser line. 2) Two lines cost more. 3) Two line configuration requires more support/ties to ET. 4) Two supply line configuration requires two pogo accumulators. 5) Two supply line configuration requires two low level liquid cutoff systems. 6) Two supply line configuration requires more feedline measurements and control measurements. More failure points. 7) Two supply system total drag is greater than single system. 8) Vehicle drag/vehicle loading from feedline "T" and four ~ 43 inches long - 11 inch diameter booster feedlines for two feedline configuration. Extra shrouds required. 9) Two line configuration has equivalent larger vehicle diameter, thus complicating manufacturing, shipping, handling, etc.

TABLE 7.1 COMPARISON OF DUAL AND SINGLE O_2 SUPPLY SYSTEM

PARAMETER EVALUATED	COMPARISON	
3) Boat Tail Ducting	1) Two line configuration has feedlines generally "outboard", thus improving accessibility in center area for LH2 feed system. .2) Two line configuration is compatible with sustainer engines located either inboard (base line configuration) or outboard (CBM configuration). 3) Single line configuration and no O2 manifold distribution system likely involves long lines which are difficult to support, have high residuals, and are uncommon.	4) Excessively large diameter feedline interconnect duct is required to control residuals for engine out. Locating extremely difficult. Weight, cost, and residuals impact. 5) Two line configuration has less common hardware than single line configuration and O2 manifold. 6) Two line configuration requires two approximately 17 inch booster engine disconnects vs. one larger disconnect located upstream of manifold (four 11 inch diameter disconnects if manifold is not separated with booster engines). 7) Two line configuration has greater propellant mass downstream of prevalve, sustainer and booster engines, than does single line and manifold configuration. Safety issue. 8) Two line with external lox lines transverse to air flow increases drag, line heating and proturburance loads over buried single lines system.
Conclusion:	Best feedline configuration dependent on structure/engine geometry Single feedline best for alternate, further work is required to optimize feedlines on reference.	
4) Residuals/Line Propellant Quantities. - O2 lines	1) Two feedline sustainer engine out <u>minimum</u> residual - 269 inch - 11 inch diameter line = 1,100 pounds per line- is less than single line configuration with manifold but more than engine feedline with manifold having six outlets. 2) Two feedline booster engine out minimum residual is 345 pounds per engine line but is <u>unrealistically low</u>. Single line manifold to engine is approx. 500 pounds per engine lines. <u>Unrealistically low</u>.	3) Two feedline approximately 10 inch diameter Crossover duct residual is large -- 80+ pounds minimum, <u>but heavily dependent on routing</u>. 4) Each feedline from tank bottom to "Y" contains approx. 16,500 pounds. 5) Supply line from "Y" to "T" contains approximately 1,800 pounds per supply line. 6) A 4" anti-geyser line the length of tank contains approx. 550 pounds of O2.
Note:	**No conclusions now! Is apparent single supply line configuration can have less residuals but probably not significantly. More work needed!**	

TABLE 7.1 COMPARISON OF DUAL AND SINGLE O_2 SUPPLY SYSTEM

PARAMETER EVALUATED	COMPARISON	
5) Thermal/NPSP Performance	1) Geyser control acceptable with both two and one configuration line once flow loop established. 2) Geyser effects will be less severe for a two line system than for one, should any occur 3) Sustainer engine flow distribution acceptable both two and one line configuration. 4) Booster engine flow distribution acceptable with both two and one line configuration. 5) Sustainer engine feedline Delta P less for two line configuration. Both two and one line configuration not excessive. 6) Booster engine feedline Delta P approx. the same for two and one line configuration. Both acceptable. 7) Success questionable with either two or one line configuration without forced circulation. 8) Assisted recirculation can be successful with two or one line configuration.	9) Pump inlets O2 temperature more uniform between engines and possibly lower for one line configuration. Both probably acceptable. 10) Geysering is concern with both one and two line configurations prior to establishing flow loop. Two line configuration has two line geyser potential vs. one line geyser.
Conclusion: Not a major discriminator.		
6) Growth	1) Two feedlines for odd booster or substainer. Number of engines creates unsymmetrical design. Undesirable. 2) ET additional 5 feet length extension removes all booster engine feedline slope or shortens 11 inch diameter feedline straight section length by one half. Unacceptable!	
Conclusion: Favors single feedline.		
Overall Conclusion: Favors single downcomer in CBM configuration.		

Figure 3.3 Passive System Accomplishes Propellant Conditioning

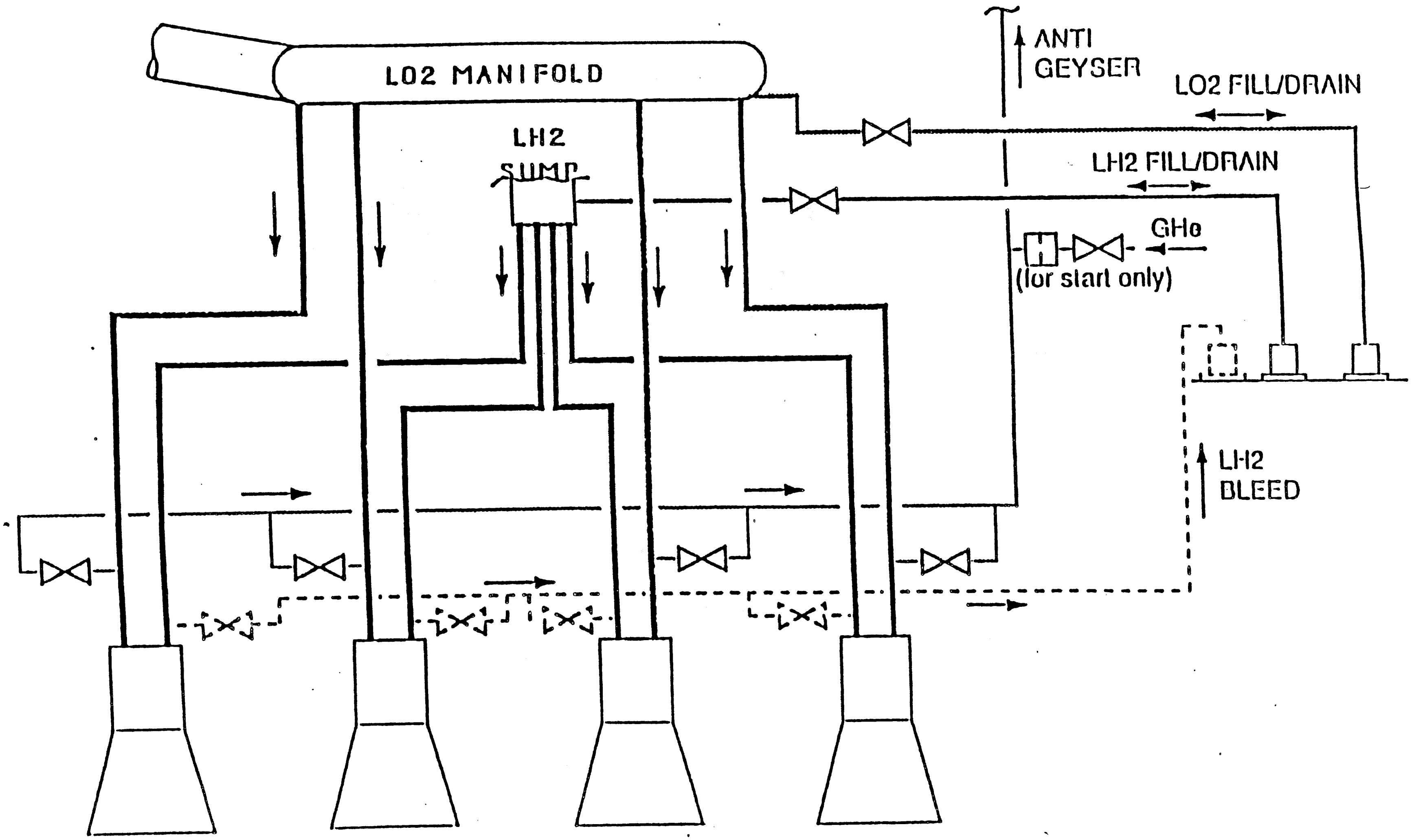
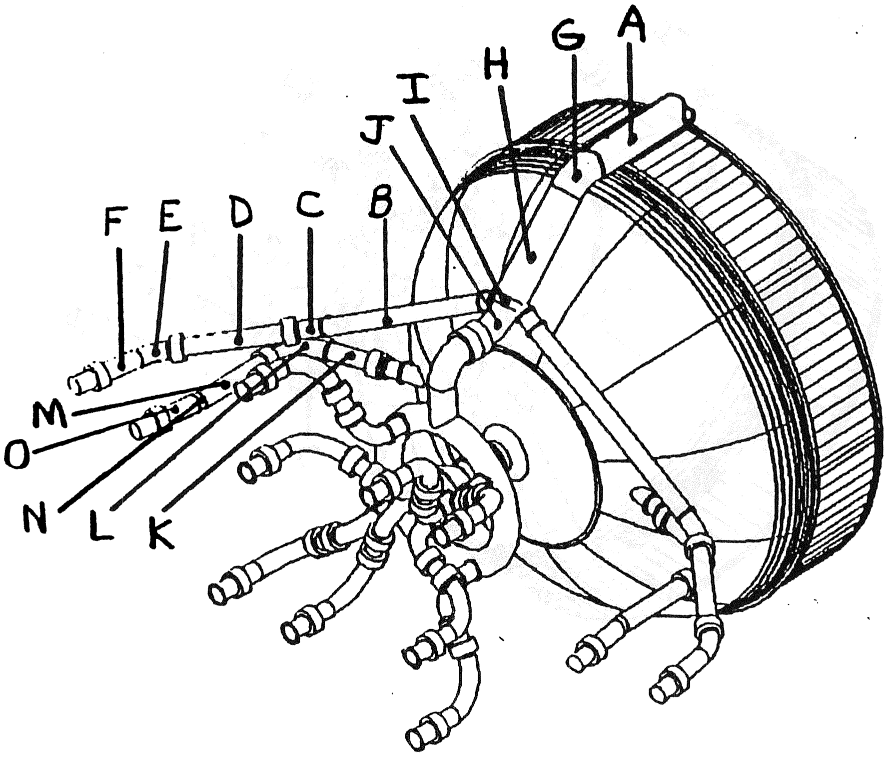


Figure 7.3 CBM Sustainer Propellant Feed System Component Characteristics Have Been Defined



	PART	NO.	$\frac{L}{S}$ (1)	DIA (IN)	R/D	ANG (DEG)
LO2						
A	DOWNCOMER	1	$\frac{1100}{90}$	22	-	-
B	STRAIGHT	2	$\frac{157.9}{3}$	12	-	-
C	ELBOW	2	-	12	2.5	40
D	STRAIGHT	2	$\frac{85.6}{41.3}$	12	-	-
E	ELBOW	2	-	12	2.5	40
F	STRAIGHT	2	$\frac{50}{81}$	12	-	-
G	ELBOW	1	-	16	2.25	45
H	STRAIGHT	1	$\frac{75.6}{45}$	16	-	-
I	REDUCER	1	$\frac{6}{45}$	$\frac{22}{16}$	-	-
J	ELBOW	1	-	16	2.25	45
LH2						
K	STRAIGHT	2	$\frac{42.5}{15}$	12	-	-
L	ELBOW	2	-	12	2.5	87
M	STRAIGHT	2	$\frac{66}{90}$	12	-	-
N	ELBOW	2	-	12	2.5	9
O	STRAIGHT	2	$\frac{48}{81}$	12	-	-

(1) $\frac{\text{LENGTH (IN)}}{\text{SLOPE FROM HORIZONTAL (DEG)}}$

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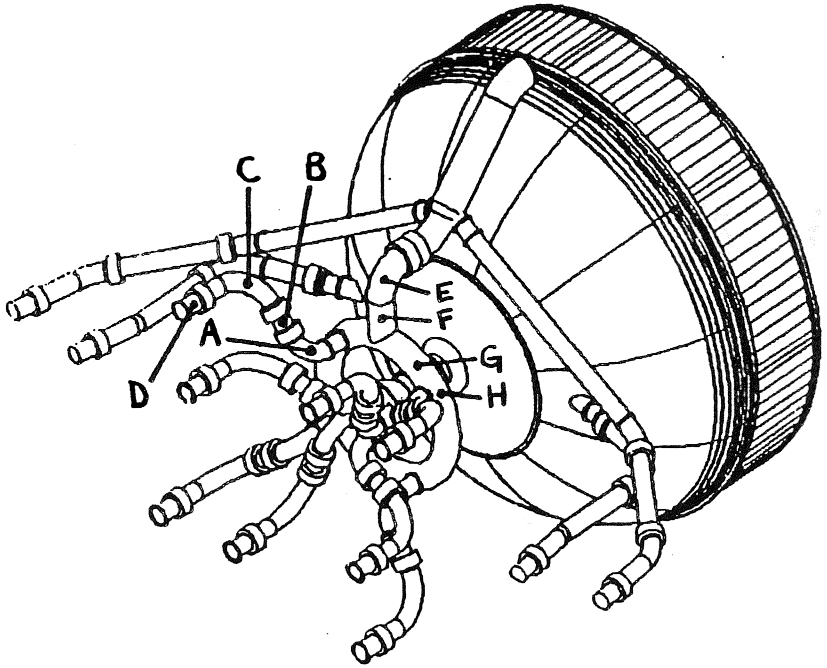
Figure 7.4 CBM Booster Propellant Feed System Component Characteristics Have Been Defined



PART		NO.	$\frac{L}{S}$ (1)	DIA (IN)	R/D	ANG (DEG)
COMMON LO2/LH2						
A	ELBOW	8	-	12	1.5	85
B	STRAIGHT	8	$\frac{29}{5}$	12	-	-
C	ELBOW	8	-	12	2.5	85
D	STRAIGHT	8	$\frac{36}{90}$	12	-	-
LO2						
E	ELBOW	1	-	16	1.13	90
F	STRAIGHT	1	$\frac{31.6}{0}$	16	-	-
G	MANIFOLD	1	-	16	3.25	360
LH2						
H	MANIFOLD	1	29.3	22	-	-

(1) $\frac{\text{LENGTH (IN)}}{\text{SLOPE FROM HORIZONTAL (DEG)}}$

8.0 Development Testing

- Propellant Conditioning Requirements

Both the reference and the Common Booster Module (CBM) configurations for LO2 utilize the natural convective system providing analysis and exploratory testing is positive. The CBM LO2 configuration incorporates a small bleed between the feedline near the pump inlet and the anti-geyser line thus differing in that respect from the reference configuration. Helium injection is utilized to initiate flow circulation and will not be required after this initiation. LO2 testing for the CBM concept will be the same or possibly less than the reference LO2 approach due to less sensitivity to changing propellant conditions.

Both concepts utilize a natural convective system to provide pre-start conditioning of the LH2 feedlines. If the natural convective system is maintained as baseline, development testing of the LH2 systems for the two configurations will be the same and cost approximately the same although hardware may differ somewhat. If an LH2 bleed is determined necessary, testing of such a system will be no more expensive and maybe actually less than a natural convective system. The CBM design has volume set aside to accommodate a similar bleed line for LH2 should it be required.

In summary, differences in propellant conditioning system design for the reference and the CBM configuration do not result in significant development testing differences and are not a significant discriminator between the two engine arrangements.

- Separation Mechanism Testing

The reference configuration hardware which is separated includes 4 booster engines, aft skirt, heat shield for booster engines, booster engine feedline and electronics. This hardware is separated as a structural unit and slides aft on guide rails.

The CBM configuration separates aft and the separated hardware includes the same hardware as the reference as well as the conical thrust cone and the LO2 and LH2 feedline manifolds. Sustainer engines are outboard of the separated hardware vs the centralized location for the reference configuration and as such have more clearance for separation. Initial analysis indicates that a simple release and drop separation is adequate requiring no guide rails.

Both configurations will require complete booster module separation systems and mass simulators for testing. All interfaces between the aft interstage and the booster module must be tested.

The approach to testing will vary due to guide rails being used on the reference. For the reference configuration ease of traversing the necessary distances under varying load conditions will be emphasized. Load applications will involve mechanical and fluid simulations. An elaborate test facility is not required. However, stands for supporting hardware, stopping hardware movement, simulating loads, measuring forces/clearances etc., are necessary.

For the CBM configuration hardware testing will emphasize the structural and disconnect separation events but will not require major translations of mass simulators. These tests will also need to characterize the separation forces and moments necessary to allow analytical modeling of the separation dynamics under 3 sigma conditions. The test facility could, therefore, be smaller but would require alternate test instrumentation from the reference configuration test setup.

- Numbers of Test Articles and Required Tests

The CBM design philosophy maximizes the use of common parts, i.e., feedlines, prevalves, disconnects, structure, etc. This will minimize the amount of development testing and the cost associated with that testing. However, the use of the toroidal LO2 manifold will result in an increase to development testing/cost which requires further evaluation to assure net savings. A summary of tests required for both configurations is provided in Table 8.1.

Major Systems Tests

Several major systems tests will be required for both configurations. They are described briefly below.

1.) Propulsion System Test.

ET plus booster module and aft interstage / MPTA type tests are required. Multiple tests are required including 1.5 Stage and HLLV requirements.

2.) Structural Static Deflection Test.

Test configuration requires a booster module and aft interstage. One test article is required. Multiple tests are required for 1.5 Stage and HLLV requirements.

3.) Booster Separation Test - (discussed in detail previously)

Test configuration requires a booster module and aft interstage or simulations thereof. One test article is required. Multiple tests are expected for both configurations.

4.) Mated Vehicle Ground Dynamics Test.

Test configuration requires a tank plus booster module, aft interstage, CTV, cargo shroud, payload simulation. One test article maximum is required but debatable as to need. Test number is undefined.

5.) Pathfinder.

A path finder set of hardware is required for facility development/checkout operations.

- Special Test Equipment.

No differences in special test equipment have been identified when comparing CBM with the reference configuration.

Table 8.1 Summary Test Mattrix

TEST REQUIREMENT	PURPOSE OF TEST	CBM	REFERENCE	REMARKS
1) Component Dev. Testing - Propulsion Components	1) Dev. & Qualify Propulsion	X	X	CBM has fewer components, more commonality.
2) Subscale Feed System	2) Develop geyser criteria.	X	X	
	Feed System Conditioning Capability	X	X	Config. other than pump overboard bleed.
	Pogo - Transfer Functions	X	X	Need probably 50% or less.
3) Subscale Rocket Motor Firings	3) Plume impingement compatibility w/KSC flame trench - 1 1/2 stage	X	X	Both concepts impinge on flame deflector differently than Shuttle.
	Ignition over pressure evolution for HLLV config.	X	X	
	Vib - acoustics			
4) Wind Tunnel Model Testing	4) Stability & control (aerodynamics)	X	X	
	Base heating/Base pressure	X	X	
	Booster separation	X	X	Doubtful if requirement.
5) Heat Shield/Thermal Protection Development/Verification	5) Thermal/Structural/Dynamics Development/Verification	X	X	Max. temp., heat rate, & heat load may be higher for reference.
6) Avionics Components	6) Develop & Qualify Components	X	X	
7) Software Development	7) Develop software	X	X	
8) Fluid Disconnect Test	8) Demonstrate Fluid Disconnect Separation.	X	X	
9) Booster Separation Mechanics	9) Booster separation clearance/ operations.	X	X	
	Phy. clearance w/load dispersions	X	X	
	Booster Module/Track interactions		X	
10) Avionics /subsystem H/W	10) Characterize avionics & selected hardware	X	X	Where time or function critical.

Table 8.1 Summary Test Mattrix

TEST REQUIREMENT	PURPOSE OF TEST	CBM	REFERENCE	REMARKS
11) MLP Support Post Loads Test	11) Demonstrate Loads/Separation Capability	X	X	
12) System Level Testing (MPT Type)	12) Structure/Prop/Avionics compatibility	X	X	
13) Structures Static Load/Deflection Test	13) Structural Adequacy	X	X	Boost module/aft interstage sustainer thrust beams for CBM. Boost module, sustainer thrust cone for reference. Both for 1.5 & HLLV configurations.
14) Mated Vehicle Ground Dynamics Test	14) Vehicle Modes	X	X	Requirement doubtful.
15) ET Structural/Proof	15) Loads/Deflection/Pressure development/Verification	X	X	
16) Avionics subsystem	16) Avionics integration	X	X	
17) Software/Hardware Integration	17) Integration compatibility	X	X	
18) Path Finder Vehicle	18) Vehicle/Facility interface verification.	X	X	
19) Vehicle Acceptance Test	19) Manufacturing Integrity	X	X	Short Static Firing at Launch Site

9.0 Verification Testing

- Thrust Structure Test Requirements

As seen in Figure 7.1, the thrust structure for the reference and the Common Booster Module (CBM) configurations differ significantly. CBM's thrust cone and booster module are tied together and are discarded at boost module separation. The thrust cone for the reference configuration does not separate. Thrust beams independent of the thrust cone for CBM's sustainer engines transmit loads into the aft interstage. Whereas, the thrust post is an integral part of the thrust cone for the reference configuration which transmits sustainer loads to the aft interstage.

The structural test programs for each configuration will utilize complete boost module and aft interstage. Sustainer engine structural thrust beams will also be required for the CBM configuration. Structural deflection, load carrying capability, TVC thrust structure interaction and distribution of peaking loads to the tank are the test objectives.

The type testing, required type of test facilities, instrumentation and numbers of tests are anticipated to be the same for each configuration. No significant difference in testing complexity has been identified to allow discrimination of the two concepts.

Dynamic testing of the reference or CBM configuration has not been established as a requirement at this time. If such testing is necessary, differences between required facilities, test hardware, test conduct and instrumentation required will differ insignificantly between the two configurations.

- Separation Test Requirements

The reference configuration hardware which is separated includes 4 booster engines, aft skirt, heat shield for booster engines, booster engine feedline and electronics. This hardware is separated as a structural unit and slides aft on guide rails.

The CBM configuration separates aft and the separated hardware includes the same hardware as the reference as well as the conical thrust cone and the LO2 and LH2 feedline manifolds. Sustainer engines are outboard of the separated hardware vs the centralized location for the reference configuration and as such have more clearance for separation. Initial analysis indicates that a simple release and drop separation is adequate requiring no guide rails.

Both configurations will require complete booster module separation systems and mass simulators for testing. All interfaces between the aft interstage and the booster module must be tested.

The approach to testing will vary due to guide rails being used on the reference. For the reference configuration ease of traversing the necessary distances under varying load conditions will be emphasized. Load applications will involve mechanical and fluid simulations. An elaborate test facility is not required. However, stands for supporting hardware, stopping hardware movement, simulating loads, measuring forces/clearances etc., are necessary.

For the CBM configuration hardware testing will emphasize the structural and disconnect separation events but will not require major translations of mass simulators. These tests will also need to characterize the separation forces and moments necessary to allow analytical modeling of the separation dynamics under 3 sigma conditions. The test facility could, therefore, be smaller but would require alternate test instrumentation from the reference configuration test setup.

The facility for Verification Testing should be the facility utilized for Development Testing. For Verification Testing the test hardware would involve more flight hardware and less simulation hardware than used in Development Testing.

Load magnitude, angularity, timing, load locations and their simulation may be critical parameters for development and verification purposes. Limited analysis of the CBM separation process shows promise of insensitivity to load dispersions. Detailed analysis may void the necessity for Verification Testing.

- Number of Parallel System Test.

The CBM configuration by design incorporates a self-contained four STME integrated structure/propulsion stand-alone module which allows verification testing independent from the remainder of the core stage with sustainer modules. Proper determination of interface conditions and parallel testing of the sustainer interstage structure/propulsion will allow complete verification of the propulsion module configuration. This approach can be accomplished due to the relatively simple interfaces selected by design. However, the reference configuration is a much more integrated propulsion module and therefore, it is not clear whether a similar approach will be acceptable.

- Number of Required Tests.

Requirements for testing should be quite similar in totality, however, the sequencial order for each concept will be different.

- Number of Test Articles

Both concepts are expected to require the same number of test articles; however, the reference configuration will probably require a somewhat more complex separation test article.

10.0 GSE Handling Equipment

- Assembly Complexity

The structural interface between the propulsion module and the core assembly will be similar to the structural interfaces between the ET LOX Tank, Intertank and the LH2 Tank. The structural interface consists of two horizontal machine flanges along the outer mold line. These flanges are mechanically fastened for final assembly.

The most convenient mating procedure would be in the vertical position, with the Propulsion Module (PM) supported within an access stand and the core lowered onto the Propulsion Module. This method would allow for the alignment of the center lines of the components and the proper clocking of the components.

Mating the Propulsion Module to the Core in the horizontal position would require alignment of the centerline of the components and the ability to rotate each component individually to achieve the proper clocking for mechanical fastening.

When the mating operation is completed, access will be provided to the interior of the Propulsion Module via multiple access panels in the interstage, booster modules and via removal of the sustainer fairings. The LH2 and LO2 inflight Q.D.'s will be mated prior to core tankage mating. The final feedline attachments use flange fittings which allow greater alignment tolerances.

- Number of Unique Modules to Handle.

The major modules that would need handling during the operational phase will be the Propulsion Module and the STME's.

The Propulsion Module would require hoisting equipment for either a direct vertical lift or to transition the Propulsion Module from the vertical to the horizontal for transportation.

A mobile transporter shall be provided. The transporter shall be a towed vehicle capable of transporting the Propulsion Module in the horizontal position. The combined weight of the transporter and the Propulsion Module shall not exceed the allowable wheel loading for any road it will move over.

Installation of the STME's will be accomplished primarily using the existing, or modified version of the H70-0774 Vertical Engine Installer. An alternative horizontal installation will use the existing or a modified version of the H70-0568, Horizontal Installation Fixture. The H70-0568 shall be used in conjunction with a forklift model H70-0764 or equivalent.

11.0 Manufacturing Development

- New Tooling Cost

The approach for propulsion module tooling is to design and fabricate tooling to support a production program. The basis for performing production assembly tooling analyses is provided by the assembly flow diagrams (assembly flow plans, build & flows, etc.). These diagrams illustrate the optimum method for assembly and will be augmented by crew/load charts to determine duplicate tool requirements. This technique ensures the proper phasing for bringing tools on-line and provides the basis for exploring alternative approaches in lieu of additional tooling.

The final assembly of the Common Booster Module (CBM) will consist of mating the aft interstage to the boost module in a vertical position join tool. This tool will be of sufficient levels to accommodate the assembly of the two structures, and to attach the sustainer modules for the 1.5 Stage version. Final subsystem installation will be done in a pick-up tool during production; however, in the early stages of the program that can be accomplished in the mate tool.

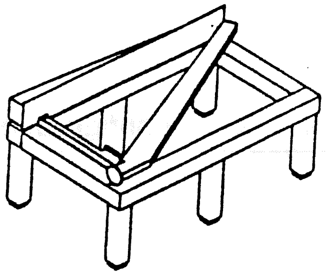
Major assembly tooling for the boost module will be provided for production based on stationized assembly logic plans. It will consist of A) Quarter Panel Assembly Jig, B) Floor Panel Jig, and C) Boost Module Assembly Jig (Figure 11.1). They will be constructed from aluminum square tubing. Provisions for optical alignment will be incorporated for construction as well as periodic inspection during the production phase, work platforms and ladders, required as an integral part of the tool, will be designed and fabricated as part of the assembly tool. The aft interstage will be subassembled in half sections, joined in a separate assembly jig prior to mating with the boost module.

Subassembly tooling will be provided to pre-assemble structural / system components prior to installation in the module and to optimize "in-tool" time in major assembly tooling. Subassembly tooling will consist of weld tools, automatic fastening tools, and bench-type for pre-assembly and secondary structures, systems components and structural subassemblies such as the thrust cone subassembly, the aft skirt subassembly, and the stabilizer / thrust post subassembly.

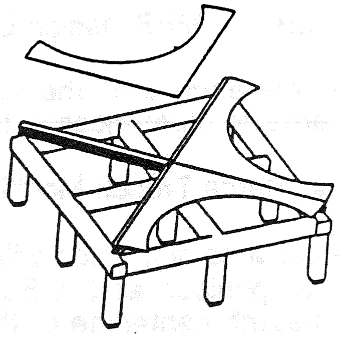
Tooling for sheet metal detail parts will be provided to eliminate hand fabrication and layout where an effective trade-off between tool and fabrication costs are shown. Tooling will be provided for blanking, piercing of holes / cutouts, routing of shapes, and forming when standard power brakes, rolls, etc. cannot be used. Standard punches and joggle dies will be used for flat and angular shapes, where possible. Numerical Control (N/C) routers will be used where applicable to reduce tooling costs.

Machine part tools will be provided in two categories, 1)heavy machining and 2) general machining. Heavy machining includes numerical controlled machines which require N/C programs as control media for work holders, indexers, and vacuum-chuck tools for holding the parts and providing accurate locations for different cutters. The tool design and N/C program will be developed from the same CAD data set and by the same employee thereby decreasing design and programming hours as well as numbers of employees required for these tasks. Schedules for tooling development and fabrication should be based on production need dates and assembly sequences.

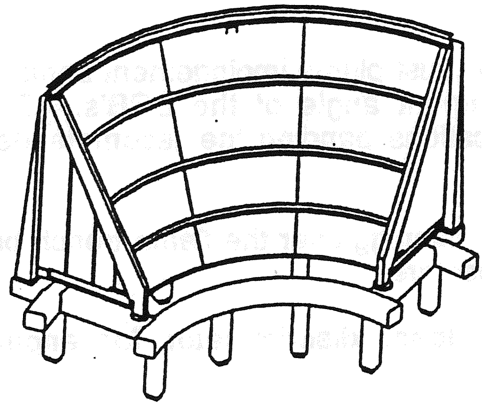
Figure 11.1 Tooling Concepts for Booster Module Structure



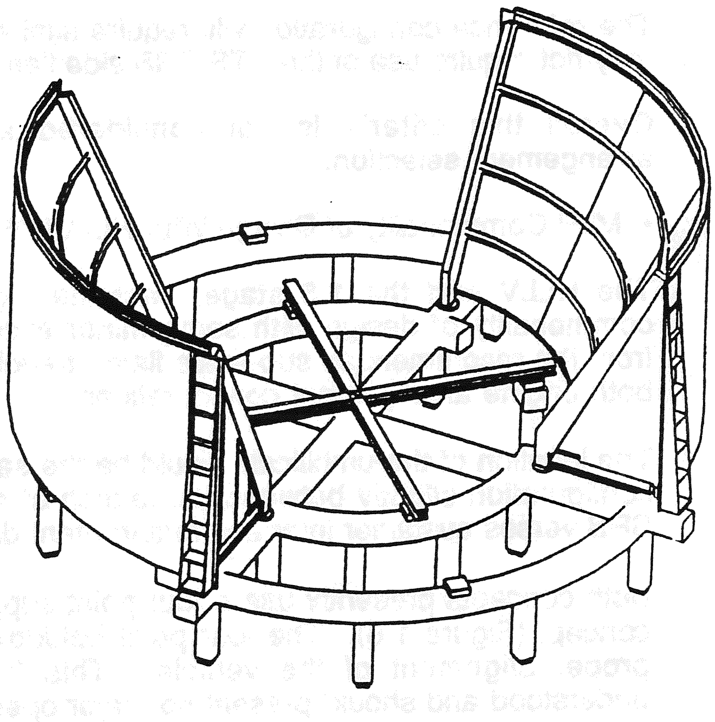
Subassembly Tool for Hold
down Post/Stabilizer Support Frame
& Thrust Post Assembly



Subassembly Tool for X Beam
assembly and Inner Heat Shield
pre drill operations



1/4 Section Tool for buildup
of 1/4 Sections using Hold Down
Post assemblies as alignment and
supports for outer skins and cone
installation



Major Assembly Fixture
1/4 Section are located and
positioned in Tool and used as
locaters for the remaining 1/4
Section close outs

CONSTRUCTION OF FACILITIES

12.0 Launch Facilities

- Degree of MPS Design Changes

The reference and the Common Booster Module (CBM) configurations have no discernable differences in terms of MPS design changes.

- Pad/Flame Trench Modifications

The CBM configuration will be positioned on the Mobile Launch Platform in the same relative position as the Space Shuttle System. The vehicle would be placed on the north-south centerline of the MLP with the sustainer engines on the same east-west centerline as the SRB's, with two boost module engines on each side of the east-west centerline. (Figure 12.1). This position would take advantage of the existing flame deflector, flame trench, and sound suppression water system. The SRB side flame deflectors will be positioned to direct exhaust plumes from the sustainer engines into the flame trench.

The location of the vehicle would assure that the exhaust plume impingement angle of the 1.5 Stage vehicle approximates the impingement angle of the SRB's. This positioning will eliminate the need for any modifications pending the recommended sub-scale flame trench test results.

The reference configuration will require similar repositioning over the flame trench but may not require use of the STS SRB side flame deflectors.

Overall this criteria is not considered a significant discriminator for engine arrangement selection.

- MLP Commonality of Design With HLLV/1.5 Stage

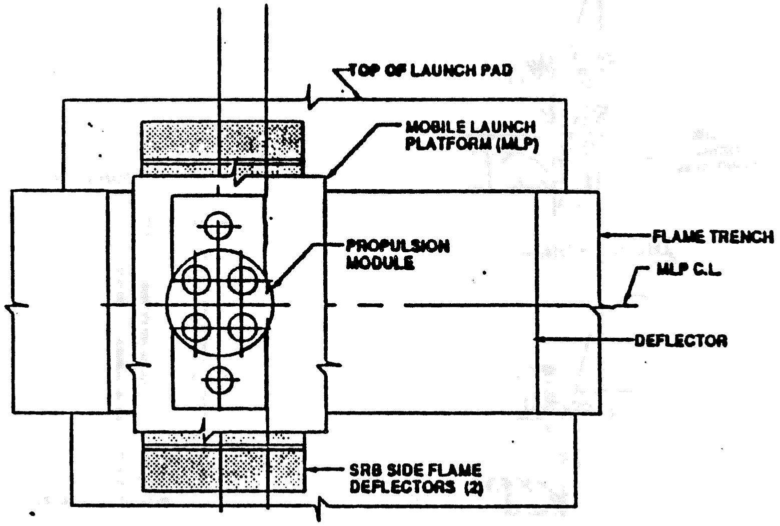
The HLLV and the 1.5 stage, each having the same core element, will have a commonality of design with some minor exceptions, again depending on the results from the recommended sub-scale flame trench test results. These exceptions apply to both engine arrangement configurations.

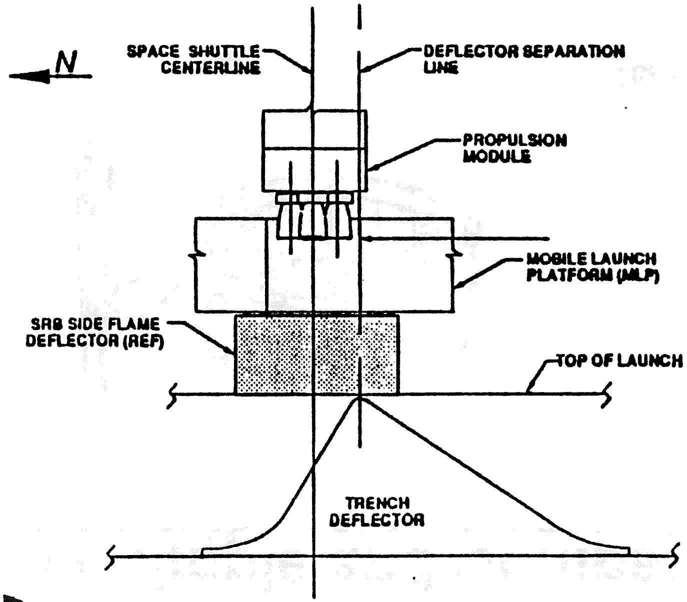
The location of the umbilicals would be the same, but the umbilical plates may change configuration slightly between the launch of an HLLV and a 1.5 Stage vehicle due to SRB verses sustainer interface requirement differences.

Both concepts presently use a four point support system similar to the STS SRB post concept (Figure 1.6). The four point holddown concept requires shimming to assure proper alignment of the vehicle. This four point system characteristic is well understood and should present no major operations impacts.

Figure 12.1 1.5 Stage Requires Use of Existing SRB Flame Deflectors

- MAINTAINS EXISTING PAD 39 INTERFACES.
- ALL ENGINES IMPINGE ON SRB SIDE OF TRENCH DEFLECTOR.
- SRB SIDE FLAME DEFLECTORS DIRECT SUSTAINER PLUMES INTO FLAME TRENCH.
- SUSTAINER START GIMBAL POSITION OPTIMIZATION.





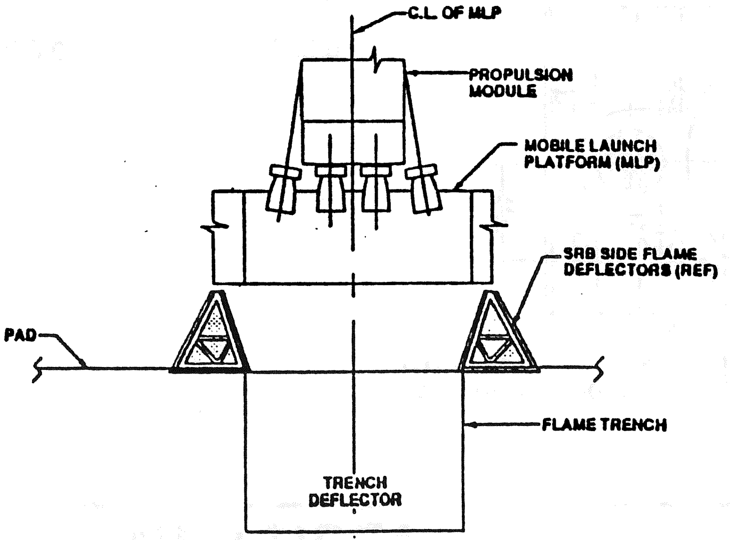
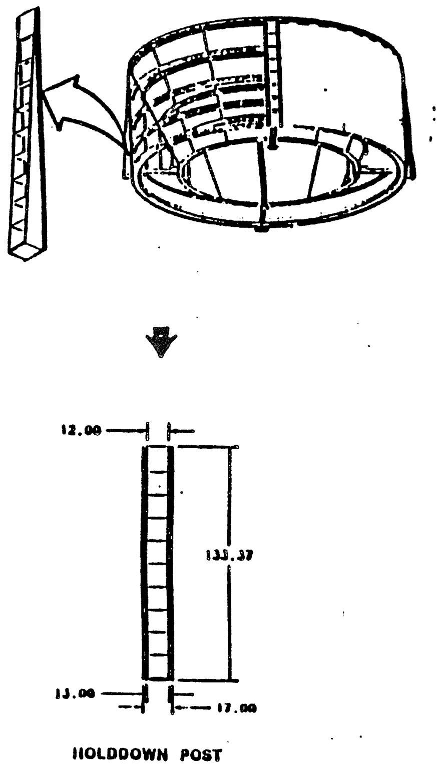
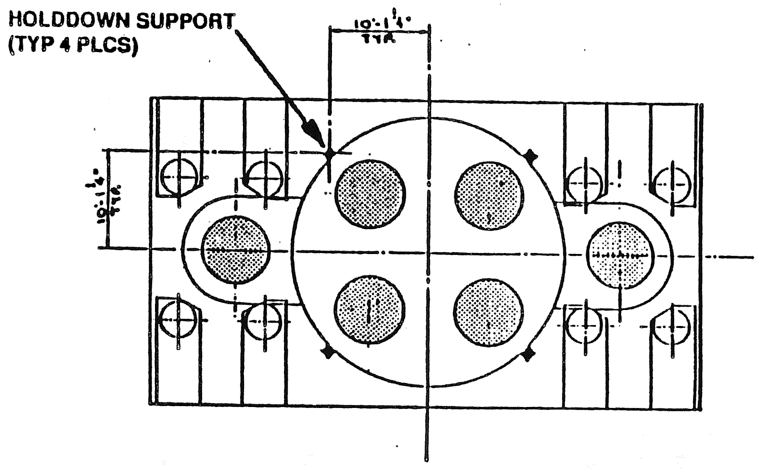
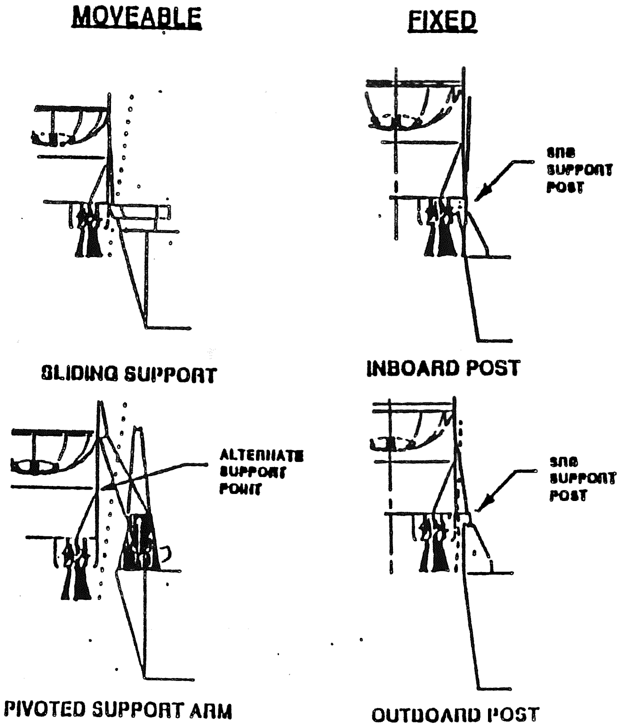


Figure 1.6 CBM Holddown Post Concept Is Simple and Compatible with HLLV







	MIN VEHICLE WEIGHT IMPACT	ACCOM ANY STME ARRMGT	QUALIF HDW AVAIL	AVOID CRIT 1 RETRCT
PIVOTED SUPPORT ARM (B/L)	+	+	-	-
OUBT'D POST	-	+	+	+
SLIDING SUPPORT	+	+	-	-
INBOARD POST	+	-	+	+

13.0 Test Facilities

- MPS Test Facility Impacts

Development Facility - B-2 Stand (MPTA Test Stand)

Both configurations will require major modifications to the B-2 test stand e.g., SRB forward attach point 12 ft 6 inches higher than MPTA, HLLV should be located on the test position EAST-WEST centerline, and the 1 1/2 Stage located on the test stand centerline (Figure 13.1). The detailed structural modifications necessary to accommodate these modifications will be somewhat different for each configuration; however, no more than 20% increase in cost is estimated to handle the Common Booster Module (CBM) sustainer locations and cant angles. These delta impacts are probably more like 10% if factored in at the beginning of design. Both development and verification firings are appropriate for this facility.

- Integrated Vehicle Static Test Requirements.

Test requirements for both engine arrangement options are the same.

- Separation Test Facility Requirements.

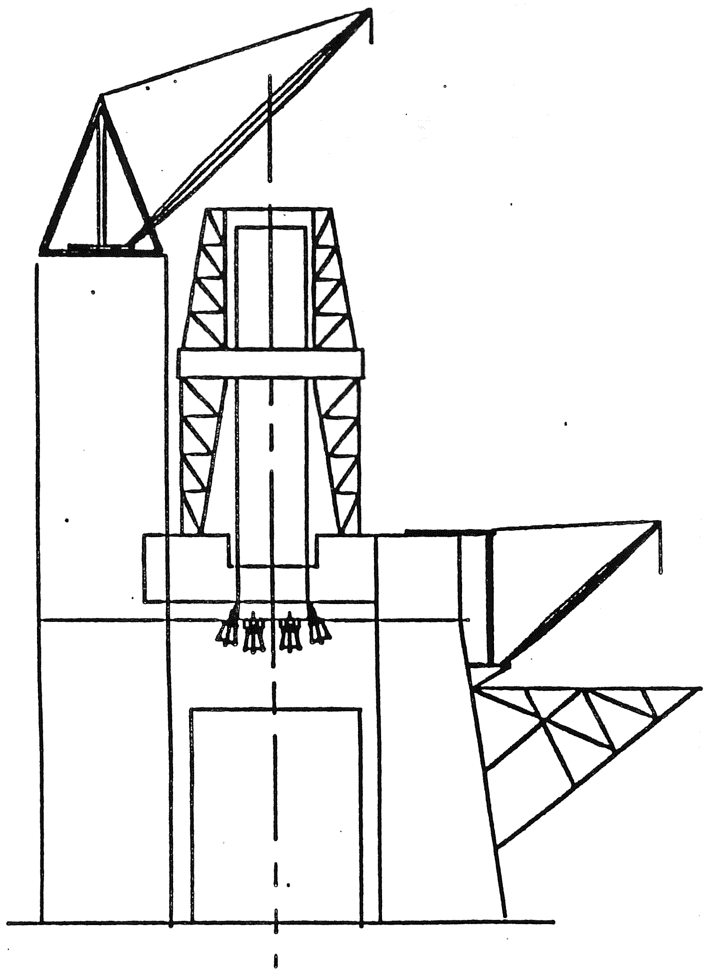
The reference propulsion module configuration will require a complete propulsion module as well as a test facility that can simulate full rail travel to verify separation conditions/acceptability. The CBM configuration will just require the aft interstage and boost module with the associated separation hardware and a test facility that can handle small separation distances (sufficient to allow verification of separation hardware acceptability). The sustainer modules will not be required since the final separation clearance verification will be accomplished via analysis and simulations.

- Structural Test Facility Requirements.

The type test which must be conducted and the type facility required will be the same for the two configurations. This applies to both static and dynamic (if determined necessary) tests.

Facilities for testing the thermal protection design possibly do not exist and may be major. It may be necessary to simulate both thermal and flow. Such was the case for S-1C thermal protection which was verified at Edwards in an aircraft jet exhaust. Total vehicle base exposure may be unnecessary. Testing required also depends upon detailed design, materials, etc., which are not defined.

Figure 13.1 Impacts to Stennis Test Center



MAJOR MODIFICATIONS

DRIVERS

- RELOCATE TEST ARTICLE AT TEST STAND C.L.
- SRB FORWARD ATTACH POINT 12' 6" HIGHER THAN MPTA

IMPACTS

STRUCTURAL

- RAISE LOAD PLATFORM
- MODIFY BOOSTER SUPPORT FRAME
  - REMOVE 17 ' FOR TEST ARTICLE INST'L
- MODIFY ENGINE ACCESS PLATFORM
  - 4 REMOVEABLE PANELS
  - 4 FOLD DOWN PANELS
- MODIFY ASPIRATOR

MECHANICAL

- MODIFY FLUID LINE/INTERFACES TO ACCOMMODATE RELOCATION OF TEST ARTICLE
- MODIFY/ADJUST FIREX SYSTEM TO ACCOMMODATE NEW TEST ARTICLE POSITION

DESIGN CAPABILITY

14.0 Weight

The Common Booster Module (CBM) configuration gross liftoff weight is approximately 12, 035 lbs. lighter than the baseline configuration. This weight difference is attributed to propellant and structural weight differences. In general, the performance impacts of these weight differences can be evaluted by breaking down the propulsion module weights into those which are jettisoned with the boost module and those which remain with the core.

- Residuals- Liquids and Gases

The overall propellant load for the CBM configuration is 2011 lbs lighter than the reference configuration. This difference is due to differences in the residuals which are either jettisoned with the boost module or retained in the propulsion module through MECO.

	LOX	LH2	TOTAL
Jettisoned with boost module			
• In lines (liquid)	6111	200	6311
Retained to MECO			
• In lines (liquid)	6521	720	6521
• In tank (Gaseous)	2670	1060	3730
• In tank (liquid on walls)	175	0	895
• Fuel Bias	0	1508	1508
	9366	3288	12654

The differences in these residual weights with respect to the reference are as follows:

	CBM	Reference	Ref-CBM
• Residuals Jettisoned	6311	1759	+ 4552
• Residuals Retained to MECO	12654	19217	- 6563
	18965	20976	- 2011

- Inert Weight of Boattail

The overall inert weight of the CBM configuration is +10,025 lbs lighter than the reference. This weight difference is due to the differences in propulsion module weights. Tank inert weights are assumed to be identical to those of the reference. The following table indicates the differences in propulsion module weights between the two configurations depending on whether they are jettisoned with the boost module or retained to MECO.

	CBM	Reference	Ref-CBM
• Jettisoned w/Boost Module	59,121	64,203	-5,082
• Retained to MECO	30,888	35,831	-4,943
	90,009	100,034	-10,025

- ET Weight Impacts

Currently there are no weight impact differences identified to differentiate the two concepts. The aft tank ring frame will have to sustain the CBM sustainer point loads, but also will incur impact from the reference boost engine loading. The difference is presently uncertain.

15.0 Aerodynamic Drag

- Performance Impact

A top level assessment was performed in which the differences in aerodynamic drag for the Common Booster Module (CBM) and reference concepts were compared with respect to the impact on performance. For this assessment a simplified but conservative drag estimate was developed using the projected frontal areas for the exposed fairings for each concept. Drag forces were determined assuming subsonic through supersonic freestream flow impinging on the canted surface of each fairing. Flow effects associated with boundary layer thickness and flow separation (due to plume effects) were not included in this assessment and are expected to further reduce any drag effects predicted.

It was determined that the two CBM fairings have 8 sq. ft. less exposed frontal area than the four reference fairings. However, the lower cant angle of the reference fairing design (20 vs. 30 degrees) resulted in approximate 18 % reduction in overall drag for the reference compared to the CBM. Applying performance sensitivities associated with the higher drag of the CBM resulted in an estimated 770 lbs. (1.2 %) reduction in payload capability with respect to the reference. Due to this small difference, and the fact that the drag forces were estimated using a conservative approach, drag does not appear at this time to be a significant discriminator between concepts.

Cosine Loss

The CBM configuration's sustainer engines are canted 9 degrees with respect to the body axis. This results in the component of thrust in the direction of the body axis to be thrust x cos 9° = 98.8% thrust. This thrust reduction produces a performance hit of 572 lbs for the engine-out trajectory and 717 lbs for the no-fail trajectory if one assumes that these engines are basically always canted through their null position. However, both engines can be gimballed 6 degrees toward being parallel with the centerline of the vehicle thus reducing this performance loss significantly (EO loss ~ 64 lbs., NEO loss ~ 80 lbs to LEO).

16.0 Usable Propellant

- Allowable Tank Stretch.

The fundamental groundrules used to determine maximum allowable tank stretch for the Common Booster Module (CBM) configuration are, 1) the height of the LH2 tank above the MLP to be held where it currently is for the 5 ft stretch. This is to maintain the current location for the SRB forward attach point for the HLLV configuration, which uses a common core with the 1.5 stage vehicle and 2) the STME exit planes remain at their current location with respect to the MLP to maintain SRB/STME exit plane relative positioning.

Given the above groundrules, the CBM configuration was successfully applied to a 10' LH2 tank stretch. The following table indicates the increase in usable propellant, residuals, ET structural weight and decrease in boost module weight due to stretching the ET a total of ten (10) feet. These weight deltas will be with respect to the current CBM 5' stretch configuration.

	10' Stretch	5' Stretch	Delta Wt.
• Usable Propellant	1,771,296	1,683,246	+88,050
• Residuals to MECO	13,411	12,654	+ 757
• Residuals Jettisoned	6,311	6,311	0
• ET Structural Weight	88,057	84,889	+ 3,168
• Boost Module Structure	58,121	59,121	- 1,000

The combined effect of the increase in usable propellants, the increase in residuals and ET structural weight and the decrease in propulsion module weight is to produce a performance increase of ~ 1700 lbs over the current CBM configuration performance.

The total performance improvement due to the total reduction from the reference for the CBM configuration weight is as follows:

	Reference (Lbs)	CBM (Lbs)	Delta Ref-CBM (Lbs)
• Prop. Module inert.	100,034	90,009	- 10,025
• Prop. Module wet.	121,010	108,974	- 12,036
• Separated Booster module inert.	64,203	59,121	- 5,082
• Separated Booster module wet.	65,962	65,432	- 530
• Sustainer inert.	35,831	30,888	- 4,943
• Sustainer wet.	55,048	43,542	- 11,506
• Delta Aerodynamic Drag Performance Loss	0	- 770	770
• Cosine Loss	0	- 64	64
• Delta P/L to 80 x 150 nml = 28.5	48,335	59,166	+ 10,831

MISSION RELIABILITY

17.0 System/Subsystem Complexity

- Total Number of Parts

A review of the candidate manufacturing approach, structural design, and feed system layout for both the Common Booster Module (CBM) and reference concept was performed to estimate the number of components. No attempt was made to determine part count for systems such as avionics, pneumatics, or TVC actuation in which similar design approaches were utilized between concepts. Results of this assessment for the structural configuration is presented in Table 7.2. Note that the greater number of components associated with the CBM reflects the use of our truss thrust structure approach for the sustainer modules. Additional structural members are also required to integrate the sustainers into the aft interstage. This higher part count is typical of highly adaptable designs using modular structural arrangements.

Results of the feed system part count assessment shown in Table 7.3 indicates a slight advantage for the CBM concept. This is due to the need for one less line assembly and disconnect for the CBM. Also provided in Figure 7.4 and Figure 7.5 is a summary of the feed system geometric characteristics that can be used to evaluate the CBM concept.

The number of common parts were assessed using the same procedure is used in estimating the number of components. In reviewing these designs, it became apparent that a sum value for the number of common parts (presented in Tables 7.2, and 7.3) can be misleading due to the frequency of use. For example a particular design could have a greater number of parts each of which are used only in one other location. On the other hand, another design could have fewer parts that are common, but those that are common are used in several places. This is illustrated in Table 7.3 in which the CBM has fewer total number of common parts, but utilize common line assemblies more often. This is due to having identical LO2 and LH2 feedlines within the four engine booster module. However, using only sum values, the CBM has a higher percentage of common structural components and a lower percentage of common feed system components than the reference.

Table 7.2 Structural Configuration Parts Evaluation

STRUCTURAL COMPONENTS		CBM	REFERENCE	
	QTY	# OF COMMON PARTS		# OF COMMON PARTS
INTERSTAGE				
• SUSTAINER MODULE				
- PANELS	4	4	4	4
- UPPER RING FRAME	1	0	1	0
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	3	1	0
- THRUST LONGERONS	4	4	0	0
• THRUST STRUCTURE				
- ENGINE MOUNT	2	2	0	0
- THRUST BEAM 1	4	4	2	2
- THRUST BEAM 2	4	4	0	0
- PANELS	0	0		
• W/LO2 CUT-OUT			2	2
• W/O CUT-OUT			10	10
- UPPER RING FRAME	0	0	1	0
- LOWER RING FRAME	0	0	1	0
- INTERMEDIATE FRAMES	0	0	2	0
BOOSTER MODULE				
• SKIRT			0	0
- PANELS	4	4		
- UPPER RING FRAME	1	0		
- LOWER RING FRAME				
• PIECE 1	1	0		
PIECE 2	1	0		
PIECE 3	1	0		
- HOLDDOWN POST	4	4		
- INTERMEDIATE FRAMES	3	3		
• THRUST STRUCTURE				
- PANELS			4	4
• W/LO2 CUT-OUT	4	4		
W/O CUT-OUT	8	8		
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	0	4	3
- ENGINE MOUNTING BLOCK	4	4	2	0
- THRUST BEAM	4	4	4	4
- STABILIZING BEAM	4	4	0	0
- STABILIZING PANEL	4	4	0	0
- HOLDDOWN POSTS	0	0	4	4
	70	60	42	33

Table 7.3 Propulsion Configuration Parts Evaluation

PROPULSION COMPONENTS	CBM		REFERENCE	
	TOTAL	COMMON	TOTAL	COMMON
LINE ASSYS	16	8 2 2 1 } MIRROR 1 } IMAGES 1 1	15	2 2 } MIRROR 2 } IMAGES 2 4 2 1
PREVALVES	6	6	6	6
DISCONNECTS	3	2 1	4	4
SUMP	1	1	1	1
OTHER (MANIFOLDS. TEES, ETC.)	4	1 1 1 1	6	2 2
	30	20	32	30

- Separation Complexity

Both the reference and the CBM concepts are designed for small clearances between the boost module and sustainer engines prior to separation. However, the reference concept maintains a constant separation clearance as the boost module is jettisoned. Whereas, the separation clearance increases during jettisoning for the CBM concept due to the divergence associated with the outboard canted sustainer modules. A preliminary dynamics model was run for the CBM concept to simulate this separation process. Results indicate that the clearance afforded by this concept would permit separation without the use of guide rails. Analysis of the reference was inconclusive as to whether guide rails would be required. Until more rigorous analytical or test results are available, the reference configuration will include guide rails to assure proper separation clearances.

The CBM has two large airborne disconnects for the propellant feedlines (22 in. for LO2, and 22 in. for LH2), and one disconnect for a 6 in. LO2 antigeyser line. These propellant disconnects and associated secondary disconnects for tank pressurization, vent, interstage purge, and electrical cabling are grouped within two umbilical panels that will separate after booster engine shutdown and prior to structural separation.

The reference has two 17in. LO2, and two 17in. LH2 propellant lines that separate inflight. Due to the feedline configuration within the propulsion module, four separate umbilicals (which will also contain disconnects for tank pressurization, vent, etc.) are required for the reference configuration. In addition, the LH2 disconnect for the CBM concept is located on the vehicle center line, therefore any moment created by the CBM umbilicals during separation would be from the single LO2 umbilical. In contrast, the reference has all four umbilicals off-set from the vehicle centerline. Although the CBM concept has larger disconnects, this disadvantage is off-set by the additional complexity of separating two additional umbilicals for the reference configuration.

- Holddown Complexity

The both configurations utilize four holdown attach points spaced 90 degrees around the circumference of the aft skirt section of the boost module. Both employ similiar holddown attachment fittings so that it is not readily apparent that a distinction can be made with respect to this discriminator. The CBM holddown post description, MLP arrangement and trade options are shown in Figure 1.6.

- Ground Structural Loads Capability

Since both concepts use similar holdown structure and attach provisions, the method used to transfer holdown loads is similar. The only distinction readily identified is the outboard-canted orientation of the CBM configuration sustainer modules which produce radial loads during thrust build-up, prior to lift-off. This operational characteristic is within design margins and is not expected to create any significant loads problems.

- Thermal Loads Capability

Due to the engine orientation of the CBM configuration sustainer modules, the number of engines under the core tank is reduced from six (for the reference), to four. Although a detail thermal analysis of the CBM concept has not been performed, the fewer number of engines may result in a lower amount of base heating associated with burning residual GH2 from the engines.

Localized external aero-heating may be slightly higher for the CBM concept, due to the somewhat larger protuburence of the two sustainer modules compared to the four booster engine fairings of the reference concept. Initial thermal analysis performed for the reference indicates residual GH2 burning is more of a concern than the aeroheating of engine fairings. If so, the CBM concept may offer an overall advantage, since the reference concept has a more closely spaced engine arrangement which will concentrate the GH2 dumping. Either concept can be designed to provide the required thermal load capability based on the anticipated thermal environments but the expected lower GH2 burning for the CBM configuration should provide some advantage.

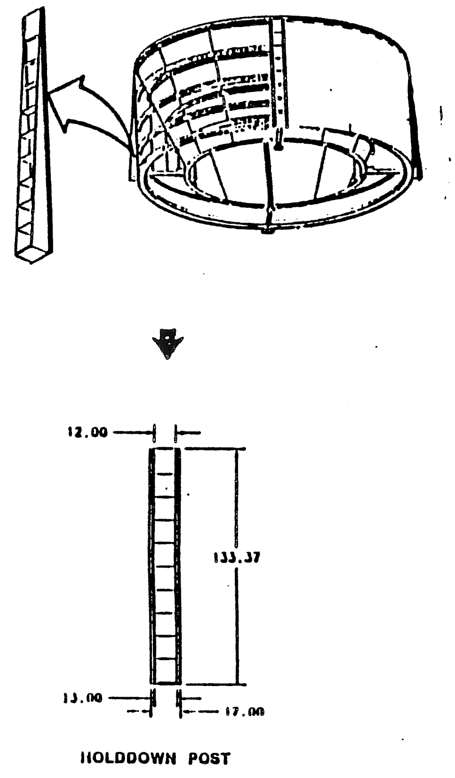
- Number of Airborne Disconnects

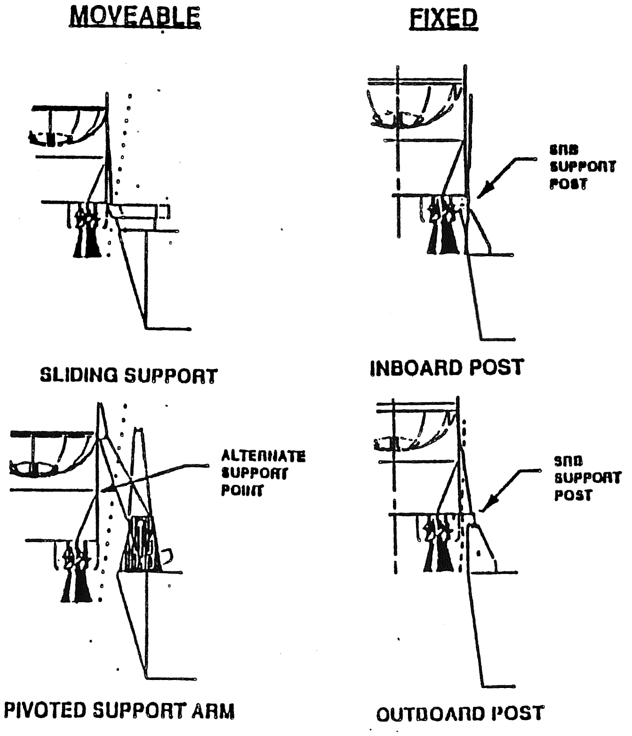
The CBM concept consists of two-22 in. feedline and one 6 in. anti-geyser airborne disconnects mounted within two umbilicals. The reference consists of two 17 in. LO2, and two 17 in. LH2 disconnects which, due to feedline geometry, requires four umbilicals. Both concepts are assumed to contain the same number of secondary disconnects for tank pressurization, interstage GN2 purge, and electrical interfaces distributed among the umbilicals. Therefore, these secondary interfaces do not appear to be a discriminator. If it is decided to eliminate the GH2 vent arm, an additional airborne disconnect for GH2 tank vent would be required regardless of propulsion module option.

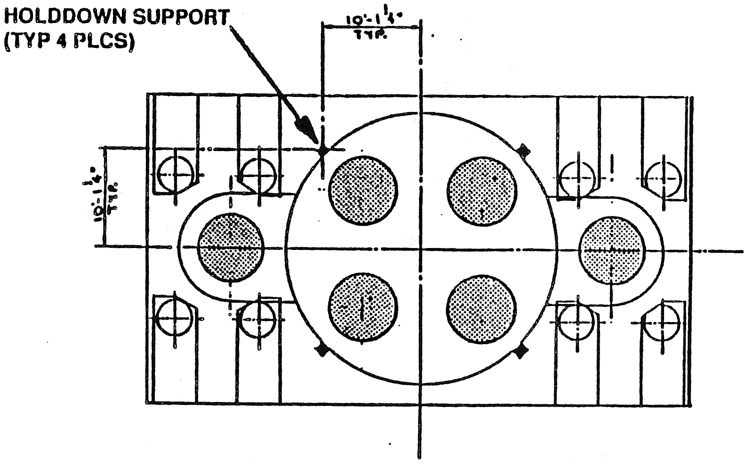
- Number of Ground Disconnects

Both concepts will have the same number of ground disconnects, most likely configured within two rise-off umbilical panels. These include fill/drain of LO2 and LH2, Helium for tank pre-pressurization and propellant preconditioning, GN2 for aft compartment and interstage purge, and electrical connectors. An unresolved issue is whether to use the existing GH2 vent arm or include this as a rise-off disconnect. However, this decision would result in similar system impacts regardless of propulsion module option.

Figure 1.6 CBM Holddown Post Concept Is Simple and Compatible with HLLV







	MIN VEHICLE WEIGHT IMPACT	ACCOM ANY STME ARNMGT	QUALIF HDW AVAIL	AVOID CRIT 1 RETRCT
PIVOTED SUPPORT ARM (B/L)	+	+	-	-
OUBT'D POST	-	+	+	+
SLIDING SUPPORT	+	+	-	-
INBOARD POST	+	-	+	+

Rockwell International
Space Systems Division

18.0 Confidence Level

We interpret this discriminator to refer to the level of confidence (or, conversely, the degree of uncertainty) in estimates of operability, reliability and capability that have been based on each concept's preliminary design.

- Overall Maturity of Preliminary Design.

Both the reference and the Common Booster Module (CBM) concepts use conventional materials, employ standard construction techniques and rely on well-understood processes throughout. By groundrule, both designs incorporate essentially identical levels of technology/advanced development effort for Space Transportation Main Engines (STMEs), electro-mechanical actuators (EMAs) and natural H2 recirculation. Therefore, the overall degree of preliminary design maturity is roughly equivalent between the two, although (as indicated later) there are differences in their capability to adapt to technology shortfalls.

Potential Risk Impacts (Thrust Vector Control): Both concepts rely on battery-powered, electro-mechanical actuators (EMAs) for effecting thrust vector control (TVC). The fact that EMAs are currently in an "advanced development" phase of technical maturity, and have not been demonstrated in launch vehicle TVC application poses a degree of technical risk during engineering development.

As a hedge against failure of either EMA or silver-zinc battery technology to mature sufficiently, several larger volume alternative TVC actuator and electrical power supply candidates (e.g., turbine-drive hydraulics) are currently under active investigation. Due to its greater free volume in the boattail region, the CBM configuration's relatively uncluttered booster module should be much easier to repackage for alternative TVC actuators and/or power sources than the densely-packed reference.

Potential Risk Impacts (Booster/Sustainer Separation Event): Both concepts have some exposure to the risk of recontact between the booster module and the core stage immediately after separation, due to different issues associated with separation dynamics under sustainer "engine out" conditions. The CBM sustainer configuration is somewhat sensitive to sustainer engine out just prior to, or during, the separation event. Separation under sustainer engine out conditions induces both a rotation moment and a sideslip motion into the core stage.

The reference centerline sustainer configuration is also somewhat sensitive to separation under sustainer engine out conditions, but for a different reason. In the reference, those conditions create asymmetric STME plume impingement on the separated booster module structure, inducing a rotation moment into the booster module and endangering recontact with the dead engine. To preclude recontact, the TVC would be required to fly the remaining (operational) sustainer's engine plume through the "doughnut hole" of the separated booster module, or guide rails will have to be of sufficient length and operational characteristics to prevent early tumbling.

Potential Risk Impacts (Natural Convection Propellant Conditioning): Both concepts incorporate undemonstrated "natural convective recirculation" technology. Assuming similar heat inputs from engines/sidewalls, each concept's potential for successfully using natural fuel recirculation is directly related to ease of (or resistance to) fuel flow. The use of one LO2 downcomer line in the CBM configuration requires a somewhat more complex manifolding arrangement, therefore producing more resistance to flow. The recirculation via natural convection will be enhanced through the use of Heliuminjection to assure proper conditioning. Whereas the reference depends on a completely natural convection process.

Potential for Failure Propagation: The CBM configuration is less vulnerable to propagation of a catastrophic failure from one sustainer engine to another due to wide separations and angular alignments between sustainer engine centerlines. The reference configuration would be more susceptible to a catastrophic sustainer engine failure propagating to the good sustainer.

- Reduction of Common Mode Failures.

The use of common parts can increase generic failure possibilities if proper attention is not applied during the design/development and qualification phases. The significant use of common components, i.e., feedlines, prevalves, disconnects, etc., by the CBM configuration allows significant cost advantages to the program. The risk of generic failure modes is acceptably reduced by more complete failure evaluation and testing history than a concept where more individual designs will limit development and qualification testing due to cost. So in summary, fewer parts means more testing and a more understood design.

- Structural Integrity of Mods to ET

It is assumed that the structural integrity of any modifications to the tank will be guaranteed through development and verification testing. Therefore, this parameter reflects a qualitative assessment of each propulsion module's main load path impacts on tank loads. (Quantification of risks involved in tank modification is beyond the level of preliminary design definition at this time and, therefore, has not been performed).

Holddown Loads: Both configurations shear holddown loads into its booster module skin. Any load-path differences between the two configurations are inconsequencial with respect to their impact on ET structure.

Booster Engine Thrust Loads: The CBM configuration distributes booster engine thrust loads through its conic thrust cone skin via thrust longerons to become evenly distributed at the forward ring frame (separation plane) of its booster module. The reference configuration distributes booster engine thrust loads through its cylindrical booster skin via thrust "posts" (longerons). Based upon preliminary loads analyses, it appears that both configurations result in an adequately uniform load distribution at the ET mating flange. Therefore, differences between the two are inconsequential.

Sustainer Engine Thrust Loads: Thrust loads from the CBM sustainer engines are sheared through thrust beam longerons into the aft interstage (skirt) skin and the tank major ring frame. The reference sustainer thrust loads are distributed through thrust posts located on the conical thrust cone. The CBM configuration imposes loads on the aft interstage and point loads on the tank aft ring frame while the reference provides a relatively equal distribution of sustainer thrust loads.

- Structural Margin.

Both concepts incorporate identical factors of safety (1.4, appropriate for man-rateable) and identical contingency factors (10%) on structural weight estimates. Therefore, there is probably no important "structural margin" discrimination between the two concepts. However, the CBM configuration is estimated ~10,000 lbs lighter than the reference. (At ~90,000 lbs total, the CBM concept is ~ 5,000 lbs lighter in its booster section and another ~ 5,000 lbs in its sustainer.) In total, the lower weight propulsion module translates into an estimated payload advantage of ~ 5,500 lbs over the reference.

19.0 Maintainability

- Test and Checkout Requirements.

The Propulsion Module, being expendible and not subject to turnaround testing, will have a completely unique test and checkout procedure. Launch costs will be reduced by replacing the major portion of the pre-stacking testing with one "Confidence Test".

The factory test and checkout requirements will be a combination of the factory system test requirements and selected duplicate launch site test requirements.

The testing equipment at the factory will interface and be electronically linked with the launch site testing equipment. This will give launch site personnel the following real time options:

1. Discuss/resolve testing problems with the factory personnel during the testing of the initial vehicles.
2. Input to the test.
3. Assist/perform the test
4. Process test data
5. Verify results.

When testing is completed the module will be pressurized to the required blanket pressures, valves placed in their normal positions, and the vehicle monitored during its transportation for any change of state. Following a Verification/Confidence Test performed at the launch site, the vehicle should be ready for stacking/mating to the core.

- Potential for Workaround

The potential for workarounds should not be very different from the existing reference. Workarounds are determined by scheduling, planning and system engineers using the safest and most efficient performance methods.

- Ease of LRU Repair/Replacement

Both configurations were assessed for ease of LRU repair and replacement. In comparing the structure of the two concepts, both have a thrust cone (reference supporting 2 sustainer engines while the Common Booster Module (CBM) thrust cone supports 4 boost engines), an outer 27.5 ft. diameter skirt to close-out the boattail, and engine fairings. The CBM concept also utilizes sustainer pods. Gaining access to the sustainer engine subsystems on the reference concept appears to be more difficult since the outer skirt and thrust cone must both be penetrated (assuming side access). Whereas, the CBM concept requires removal of the sustainer pod fairing.

The fluid line routing assessment shows both concepts to contain 8 feedlines within the 27.5 ft. diameter skirt (6 LH2 / 2 LO2 for the reference and 4 LH2 / 4 LO2 for the CBM). The reference concept utilizes a sump for the LH2 feedline attach point while the CBM requires three (3) penetrations of the LH2 tank each with flange interfaces. All manifolding for the CBM is done downstream of the LH2 tank interface.

The other difference between the concepts is in the LO2 system. The reference contains two "downcomers" with lines teeing off to the sustainer engines, while the CBM concept contains a toroidal manifold with the identical part number feedlines supplying four booster engines. This approach appears to provide more room and slightly better LRU access in the booster module to remove components or gain access for troubleshooting. The CBM concept also includes permanent access platforms (Figure 1.1) as an integral part of the flight structure to provide access in this area. The ladders to provide a means to get to the permanent access platforms may also be an integral part of the thrust beams similar to the access platform concept.

The repair and replacement of LRUs will also be facilitated by key design features. Subsystems will be designed to be palletized where possible, i.e., pneumatic panels, or provided with a drop down feature to enhance initial installation or repair and replacement, i.e., EMA controllers and batteries. The main propulsion system will utilize identical feedlines, i.e., one dash number would apply to all feedlines within the boost module both LO2 and LH2 thus improving the installation and removal learning curve. Structural flooring in the annulus area above the heat shield and permanent access platforms attached to the thrust cone structure will provide the personnel support structure to allow LRU repair and replacement.

Lower level design goals which enhance the LRU repair and replacement features of the CBM concept will also be pursued as the design matures. These include:

- Replaceable sub-units (actuators, filters, position indicators) in heavy or awkward components which can be replaced without removal of the component
- Line and component locations to minimize damage by personnel
- LRU sizing to minimize extensive GSE handling equipment
- LRU location to minimize removal of other hardware for access

In summary, considering the accessibility provisions and the LRU design features, the CBM concept appears to offer better LRU access/removal capability than the reference concept.

20.0 Launch Schedule Reliability

- Propellant Loading/Preconditioning Margins

Comparison of the two concepts regarding propellant servicing margins indicates that the Common Booster Module (CBM) concept may have a distinct advantage. The CBM concept contains bleed valves on the LO2 side just upstream of the engine interface that tie into an antigeyser line to assure high quality LO2 at the engine inlet. Provisions have been made to incorporate a overboard bleed system on the LH2 side if testing indicates a need for this capability. Bleed systems allow for greater flexibility during loading operations and provides a greater confidence that inlet temperatures will be satisfied and will not result in loading delays and drainbacks. Although bleed systems result in design complexity, they provide greater operability which is a driving requirement for the NLS.

- Number of Components

A review of the candidate manufacturing approach, structural design, and feed system layout for both the CBM and reference concept was performed to estimate the number of components. No attempt was made to determine part count for systems such as avionics, pneumatics, or TVC actuation in which similar design approaches were utilized between concepts. Results of this assessment for the structural configuration is presented in Table 7.2. Note that the greater number of components associated with the CBM reflects the use of our truss thrust structure approach for the sustainer modules. Additional structural members are also required to integrate the sustainers into the aft interstage. This higher part count is typical of highly adaptable designs using modular structural arrangements.

Results of the feed system part count assessment shown in Table 7.3 indicates a slight advantage for the CBM concept. This is due to the need for one less line assembly and disconnect for the CBM. Also provided in Figure 7.3 and Figure 7.4 is a summary of the feed system geometric characteristics that can be used to evaluate the CBM concept.

The number of common parts were assessed using the same procedure is used in estimating the number of components. In reviewing these designs, it became apparent that a sum value for the number of common parts (presented in Tables 7.2, and 7.3) can be misleading due to the frequency of use. For example a particular design could have a greater number of parts each of which are used only in one other location. On the other hand, another design could have fewer parts that are common, but those that are common are used in several places. This is illustrated in Table 7.3 in which the CBM has fewer total number of common parts, but utilize common line assemblies more often. This is due to having identical LO2 and LH2 feedlines within the four engine booster module. However, using only sum values, the CBM has a higher percentage of common structural components and a lower percentage of common feed system components than the reference.

Table 7.2 Structural Configuration Parts Evaluation

STRUCTURAL COMPONENTS	CBM		REFERENCE	
	QTY	# OF COMMON PARTS		# OF COMMON PARTS
INTERSTAGE				
• SUSTAINER MODULE				
- PANELS	4	4	4	4
- UPPER RING FRAME	1	0	1	0
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	3	1	0
- THRUST LONGERONS	4	4	0	0
• THRUST STRUCTURE				
- ENGINE MOUNT	2	2	0	0
- THRUST BEAM 1	4	4	2	2
- THRUST BEAM 2	4	4	0	0
- PANELS	0	0		
• W/LO2 CUT-OUT			2	2
• W/O CUT-OUT			10	10
- UPPER RING FRAME	0	0	1	0
- LOWER RING FRAME	0	0	1	0
- INTERMEDIATE FRAMES	0	0	2	0
BOOSTER MODULE				
• SKIRT			0	0
- PANELS	4	4		
- UPPER RING FRAME	1	0		
- LOWER RING FRAME				
• PIECE 1	1	0		
PIECE 2	1	0		
PIECE 3	1	0		
- HOLDDOWN POST	4	4		
- INTERMEDIATE FRAMES	3	3		
• THRUST STRUCTURE				
- PANELS			4	4
• W/LO2 CUT-OUT	4	4		
W/O CUT-OUT	8	8		
- LOWER RING FRAME	1	0	1	0
- INTERMEDIATE FRAMES	3	0	4	3
- ENGINE MOUNTING BLOCK	4	4	2	0
- THRUST BEAM	4	4	4	4
- STABILIZING BEAM	4	4	0	0
- STABILIZING PANEL	4	4	0	0
- HOLDDOWN POSTS	0	0	4	4
	70	60	42	33

Table 7.3 Propulsion Configuration Parts Evaluation

PROPULSION COMPONENTS	CBM		REFERENCE	
	TOTAL	COMMON	TOTAL	COMMON
LINE ASSYS	16	8 2 2 1 } MIRROR 1 } IMAGES 1 1	15	2 2 } MIRROR 2 } IMAGES 2 4 2 1
PREVALVES	6	6	6	6
DISCONNECTS	3	2 1	4	4
SUMP	1	1	1	1
OTHER (MANIFOLDS. TEES, ETC.)	4	1 1 1 1	6	2 2
	30	20	32	30

- Number of Active Systems

The number of active systems between the two concepts are the same and no discriminators exist to separate the two designs.

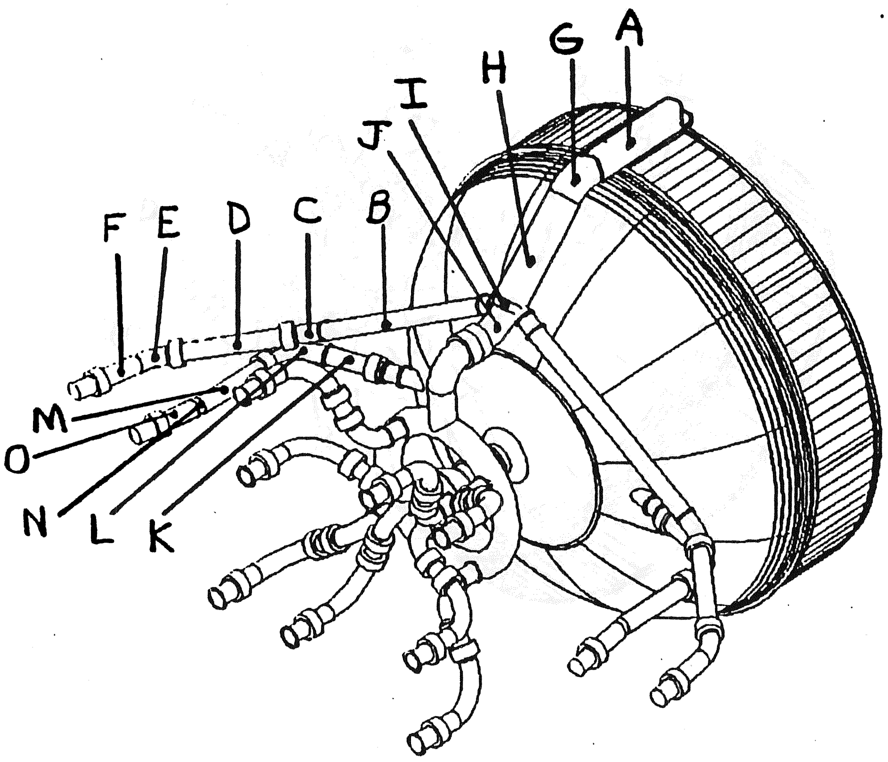
- Number of Launch Commit Criteria

For STS, there are 45 Launch Commit Criteria (LCC) items, 2 ET items associated with MPS and 39 items associated with the SSME. Based on the reference propulsion system design concept, the LCC items will be reduced possibly by 20%. Based on the similarity of the CBM concept to the reference this same reduction in LCC items is anticipated. Reductions occur due to deletion of one of the fill and drain valves on the LO2 a nd LH2 side, LH2 Topping Valve, LH2 RTLS Inboard/Outboard Dump Valve and the GO2 and GH2 flow control valves.

- Sensitivity to Uncontrollable Parameters

Comparison of the two concepts to sensitivity to natural environments such as wind, temperature, and launch day conditions indicates no discriminators. Vehicle constraints will still exist concerning launching in a rainstorm, lightning in the area of the launch pad and upper level winds or hurricanes. However, regarding launch holds, it would appear that the CBM concept with the LOX bleed capability would accommodate launch holds more readily due to high quality LOX being maintained indefinitely with the bleed capability.

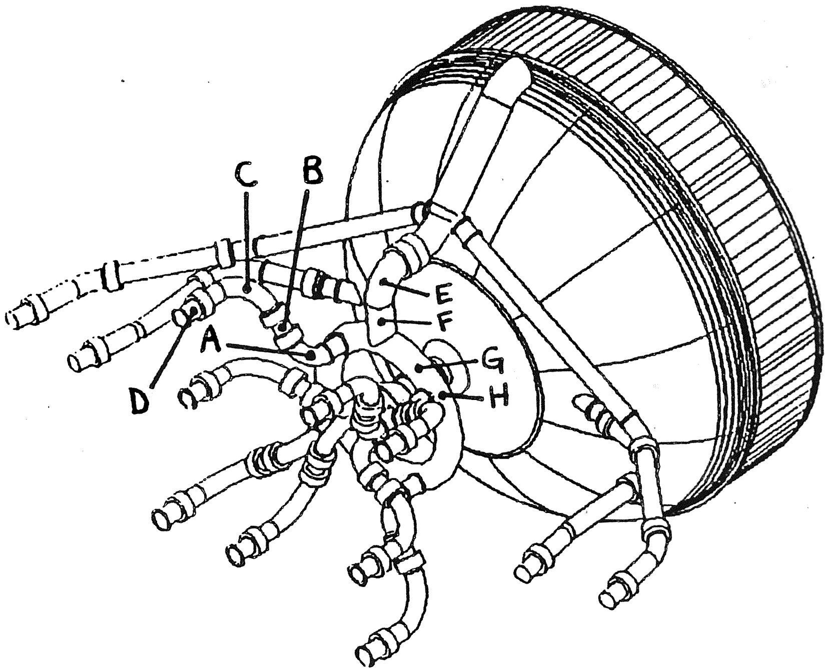
Figure 7.3 CBM Sustainer Propellant Feed System Component Characteristics Have Been Defined



	PART	NO.	$\frac{L}{S}$ (1)	DIA (IN)	R/D	ANG (DEG)
LO2						
A	DOWNCOMER	1	$\frac{1100}{90}$	22	-	-
B	STRAIGHT	2	$\frac{157.9}{3}$	12	-	-
C	ELBOW	2	-	12	2.5	40
D	STRAIGHT	2	$\frac{85.6}{41.3}$	12	-	-
E	ELBOW	2	-	12	2.5	40
F	STRAIGHT	2	$\frac{50}{81}$	12	-	-
G	ELBOW	1	-	16	2.25	45
H	STRAIGHT	1	$\frac{75.6}{45}$	16	-	-
I	REDUCER	1	$\frac{6}{45}$	$\frac{22}{16}$	-	-
J	ELBOW	1	-	16	2.25	45
LH2						
K	STRAIGHT	2	$\frac{42.5}{15}$	12	-	-
L	ELBOW	2	-	12	2.5	87
M	STRAIGHT	2	$\frac{66}{90}$	12	-	-
N	ELBOW	2	-	12	2.5	9
O	STRAIGHT	2	$\frac{48}{81}$	12	-	-

(1) $\frac{\text{LENGTH (IN)}}{\text{SLOPE FROM HORIZONTAL (DEG)}}$

Figure 7.4 CBM Booster Propellant Feed System Component Characteristics Have Been Defined



PART		NO.	$\frac{L}{S}$ (1)	DIA (IN)	R/D	ANG (DEG)
COMMON LO2/LH2						
A	ELBOW	8	-	12	1.5	85
B	STRAIGHT	8	$\frac{29}{5}$	12	-	-
C	ELBOW	8	-	12	2.5	85
D	STRAIGHT	8	$\frac{36}{90}$	12	-	-
LO2						
E	ELBOW	1	-	16	1.13	90
F	STRAIGHT	1	$\frac{31.6}{0}$	16	-	-
G	MANIFOLD	1	-	16	3.25	360
LH2						
H	MANIFOLD	1	29.3	22	-	-

(1) $\frac{\text{LENGTH (IN)}}{\text{SLOPE FROM HORIZONTAL (DEG)}}$

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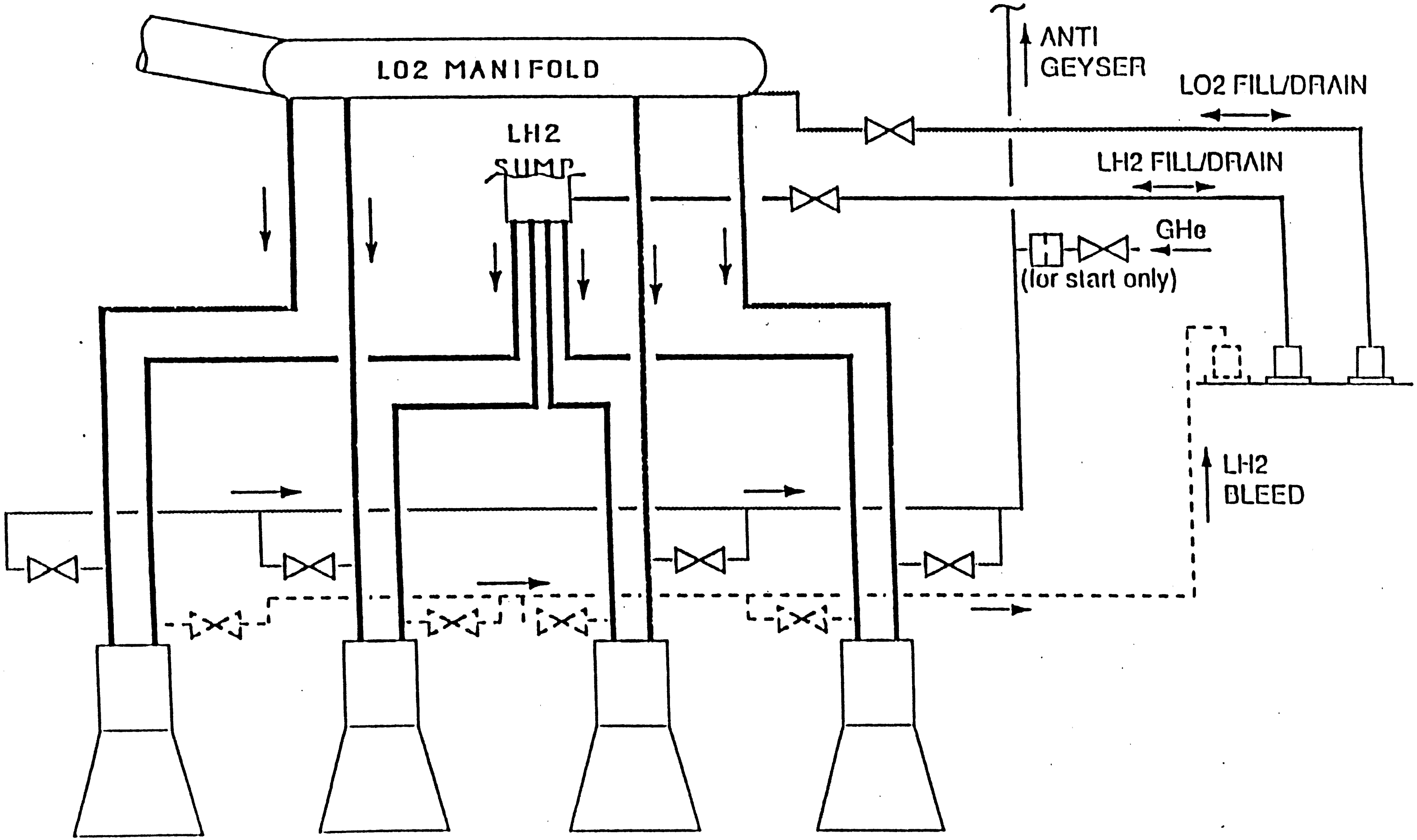
Figure 3.3 Passive System Accomplishes Propellant Conditioning



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