LRB STUDY ORGANIZATION

PROGRAM MANAGER
Paul Bialla

STUDY MANAGER
Dan Heald (Olen Britnell, Deputy)

Contracts & Administrative Support

Terry Abel--Perf & Sizing
John Beveridge--Propulsion
Hal Britton--Propulsion, Feedlines
Al Orillon--PLS Applications Lead
John Burgeson--Design
Gopal Mehta--Man-rating, Propulsion

Vinod Shekher--Structures, Loads
Jerry Shelby--Design, Launch Site Analysis
Joe Szedula--Perf & Sizing, PLS Launcher Lead
Richard Webb--Cost Analysis
Mike Vaccaro--Sys Eng, STS-C Lead
CONCEPT SUMMARY
LO$_2$/LH$_2$ PUMP-FED WITH STE (JAN '90 DESIGN)

SELECTION RATIONALE
- CLEAN EXHAUST PRODUCTS; NON-TOXIC
- PROPELLANT COMMONALITY WITH STS LAUNCH
- SUBSTANTIAL EXPERIENCE BASE
- LIGHTEST GROSS WEIGHT IN CLASS
- NEW "LOW COST" ENGINE (STE)
- PREFERRED FOR ALTERNATE APPLICATIONS (ALS, STANDALONE)
- EXPENDABLE

PROGRAMMATIC DATA (1987 $)*
- TOTAL NON-RECURRING COST: $3,673 M
- AVERAGE UNIT COST, FOR 140 FLIGHTS: $35.2M
- LIFE-CYCLE COST, FOR 10 YEARS: $14,466M

<table>
<thead>
<tr>
<th>ENGINE THRUST</th>
<th>LRB ASCENT PROPellant WEIGHT</th>
<th>SHUTTLE GLOW</th>
<th>THRUST/WEIGHT @L/O (NOMINAL)</th>
<th>ISP</th>
</tr>
</thead>
<tbody>
<tr>
<td>510,475 (sl)</td>
<td>549,492 (v)</td>
<td>1,359,305</td>
<td>3,564,861</td>
<td>1.46</td>
</tr>
<tr>
<td>510,475 (sl)</td>
<td>549,492 (v)</td>
<td>1,359,305</td>
<td>3,564,861</td>
<td>1.46</td>
</tr>
</tbody>
</table>

* EXCLUDES CONTRACTOR FEE, GOVERNMENT SUPPORT AND CONTINGENCY
LRB DESIGN IMPROVEMENTS

- RESOLVED FORWARD ATTACH POINT PROBLEM
  - SIZE WAS 17.2 FT IN DIAMETER BY 183 FT IN LENGTH
  - ATTACH POINT IS IN INTERTANK STRUCTURE

- ADOPTED STE AS BASELINE ENGINE
  - 20:1 EXPANSION RATIO

- ADOPTED 2090 AL-LI AS MATERIAL FOR TANKS AND STRUCTURE
  - 7% WEIGHT SAVINGS
  - RECENT NASA ACCEPTANCE FOR USE WITH OXYGEN

- REDESIGNED AFT SKIRT TO ACCOMMODATE STE AND ALLOW FOR CLOSE MOUNTING OF LRB (PARALLEL CONFIGURATION)

- REFINED WEIGHT ESTIMATES FOR SUBSYSTEMS AND FEEDLINES
**BASELINE LRB (APRIL '90 DESIGN)**

**Design Goals:**
- Safe abort at any point in trajectory
- ATO Capability with single LRB engine out at lift off
- Minimum impacts to current STS

**Weights (lbs):**
- Payload: 70,500
- LRB Dry Weight: 113,039
- LRB Inert Weight: 123,141
- LRB Ascent Propellent: 655,640
- LRB GLOW: 788,781
- STS/LRB GLOW: 3,521,797

**LRB Propulsion:**
- Number of engines per LRB: 4
- Engine type: STE
- Area Ratio: 20:1
- Vacuum Thrust (lbs): 558,542
- Sea Level Thrust (lbs): 514,232
- Vacuum Isp (sec): 413
- Sea Level Isp (sec): 380
ATTACH POINT SOLUTIONS

GOAL: Move Forward ET attach point out of LRB LO2 tank into inter-tank.

New Baseline

183.0'

180.9'

184.4'

182.2'

175.7'

172.2'

124'

hemi-spherical dome 70.5

eccentric dome 70.5

elliptical dome 70.5

Feb '90 reference

Payload: 68.7 (Klbs)

materials, updated systems, additional systems
**LRB USING STE20 vs. STE40**

**Question:** What are the advantages/disadvantages of modifying STEs for a STS LRB?

<table>
<thead>
<tr>
<th></th>
<th>STE20</th>
<th>STE40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle Area Ratio</td>
<td>20:1</td>
<td>40:1</td>
</tr>
<tr>
<td>Payload (lbs)</td>
<td>70,500</td>
<td>62,690</td>
</tr>
<tr>
<td>LRB Length (ft)</td>
<td>183.0</td>
<td>182.6</td>
</tr>
<tr>
<td>LRB Diameter (ft)</td>
<td>17.2</td>
<td>16.8</td>
</tr>
<tr>
<td>Aft Skirt:</td>
<td>Square with rounded corners, permits side-by-side LRB placement</td>
<td>Flared, requires large attach beam for side-by-side LRB placement</td>
</tr>
<tr>
<td>Engine:</td>
<td>Requires STE to have two nozzle designs but can use common combustion chamber and turbo pumps</td>
<td>Single STE design</td>
</tr>
</tbody>
</table>
ABORT CAPABILITY

**MECO**
- T=495.8: Nominal
- T=497.4: Earliest STE shutdown
- T=476.8: ATO
- T=544.2: Make mission with SSME out
- T=572.0: ATO with SSME out

**LAUNCHER**

**LRB Separation**
- T=151.4: Nominal
- T=154.8: Earliest STE shutdown
- T=163.8: ATO

**Make Mission with single LRB engine out**
- T=37.1: Nominal
- T=27.1: Earliest STE shutdown

**Make Mission with single SSME out**
- T=301.8: ATO with SSME out
- T=366.7: Make mission with SSME out

**T=3.9:** SSMEs to 104% @ 60 ft/sec (not performed if engine out at T=0)

**T=0:** ATO capability with single LRB engine out & 70,500 lbs payload

**Lift-off:** SSMEs at 100%, LRB STEs at 100%
OBJECTIVE

- Evaluate Options of Developing a PLS Launch Vehicle (LV)
  - Utilize LRB
  - Optimize from LRB

- Determine the Best Commonality and Cost Effective Concept
LRB LAUNCH VEHICLE CONCEPTS

1 1/2 Stage

Parallel Stage

Drop Tanks

183 ft

170 ft

4 STE

2 x 2 STE

4 & 2 STE

4 STE
LV FOR PLS STUDY PLAN

APPROACH

- Utilize the LaRc 10 Man PLS as Basic Concept

- Conduct Trade Analyses on four LV from LRB concepts:
  1) 1 1/2 Stages
  2) Parallel
  3) 2 Stages (2nd Stg = Centaur & LRB)
  4) Drop Tanks

- Evaluate for PLS Insertion Orbits, nmi, of:
  A) 50 X 100
  B) 39 X 217 (SSF Transfer Orbit)
  C) 220 X 220 (2 Stage only)
PLS LV
GROUND RULES AND CONSTRAINTS

PLS

- LaRc 10 Man Orbiter, Wt = 22,744 lb
- Adapter (initial) W/Escape System, Wt = 10,543

\[
\text{Lift Off, payload Wt} = 33,287 \text{ lb}
\]

LRB LAUNCH VEHICLES FOR PLS

- Boosters = LRB materials and STEs
- 2nd Stage Engines = RL-10 for Centaur and STE for LRB Derivative
- 2nd Stage to have Controlled Reentry from 220 X 220 NMI Orbit
- Avionics for G&N = GD Adaptive G & N Type
- Trajectory Constraints: Max \( q = 850 \text{ psf} \); Max \( g = 3 \)
# BASELINE PROPULSION SUPPORT SYSTEMS

## VENT SYSTEM - DUCTED TO MLP QD

### LINE LENGTHS
- **LO2**: 2114 inches
- **LH2**: 1561 inches

### LINE WEIGHTS
- **LO2**: 524 lbs
- **LH2**: 387 lbs

### COMPONENT WEIGHT
- PER LINE: 209 lbs

### TOTAL WEIGHTS
- **LO2**: 733 lbs
- **LH2**: 596 lbs

### SYSTEM TOTAL: 1329 lbs

## PRESSURIZATION SYSTEM

### LINE LENGTHS
- **INTERNAL**: 73 inches
- **EXTERNAL**
  - **LO2**: 2062 inches
  - **LH2**: 1509 inches

### LINE WEIGHTS
- **INTERNAL**: 27 lbs
  - **EXTERNAL**
    - **LO2**: 143 lbs
    - **LH2**: 127 lbs

### TOTALS
- **LO2**: 266 lbs
- **LH2**: 250 lbs

### SYSTEM TOTAL: 515 lbs

## PNEUMATIC SYSTEM

- **ESTIMATED FROM ORBITER**

### TOTAL WEIGHT: 591 lbs

## FILL AND DRAIN SYSTEM

- **SAME AS ORBITER**

### TOTAL: 503 lbs
1.5 STAGE PLS LAUNCH VEHICLE

PLS
--- Orbiter
--- Adapter

LRB/PLS 1.5 STAGE VEHICLE
- Would not reach destination orbit of 50x100nm.
- Ascent Trajectory Simulation Aborted.

Performance Parameters at
Termination of Simulation:

- GLOW = 1,780 Klbs
- H2 Weight = 225 Klbs
- O2 Weight = 1,348 Klbs
- Qty STEs = 4, drop 2
- LV Length = 356.7 ft.
- LV Diameter = 17.4 ft.
- PL to 50x100 = 0

1.5 LRB MFrac = 0.88
Atlas MFrac = ~0.95

1.5 STAGE LRB IS INCAPABLE OF DELIVERING PLS TO LEO DUE TO LRB/STS WEIGHT REQUIREMENTS
PARALLEL PLS LAUNCH VEHICLE

- Minimum Modifications to STS - LRB =  
- Simulations performed with 1 Core engine out

<table>
<thead>
<tr>
<th>Vehicle Parameters</th>
<th>50 x 100 nm LRB min mod</th>
<th>Optimized from LRB</th>
<th>SSF Transfer LRB min mod</th>
<th>Optimized from LRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload (Klbs)</td>
<td>53.5</td>
<td>33.3</td>
<td>49.4</td>
<td>33.3</td>
</tr>
<tr>
<td>Booster Inert Weight (Klbs)</td>
<td>123.1</td>
<td>112.6</td>
<td>123.1</td>
<td>114.7</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>665.6</td>
<td>531.5</td>
<td>665.6</td>
<td>558.0</td>
</tr>
<tr>
<td>Upper Stage Inert Weight* (Klbs)</td>
<td>95.8</td>
<td>88.8</td>
<td>95.8</td>
<td>90.9</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>665.6</td>
<td>531.5</td>
<td>665.6</td>
<td>558.0</td>
</tr>
<tr>
<td>GLOW (Klbs)</td>
<td>1,603.7</td>
<td>1,297.7</td>
<td>1,599.6</td>
<td>1,355.0</td>
</tr>
<tr>
<td>Vehicle Length (ft)</td>
<td>211</td>
<td>185</td>
<td>211</td>
<td>190</td>
</tr>
<tr>
<td>Vehicle Diameter (ft)</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
</tr>
<tr>
<td>Qty Booster Engines (STE-20)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Qty Core Engines (STE-20)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
</tr>
</tbody>
</table>

*Upper stage inert weight includes: dry weight + residuals + FPR
LRB SQUARE SKIRT

2 - STE ENGINE CONFIGURATION

CONTOUR AT BOTTOM OF SKIRT
CONTOUR AT TOP OF SKIRT

STE ENGINE
LONGERON
ENGINE THRUST STRUCTURE

SPLICE-PLATE
TRUSS
WEB & STIFFNERS

ENGINE ATTACHMENT
THRUST FITTING
ENGINE THRUST STRUCTURE
TWO ENGINE CONFIGURATION

VIEW LOOKING DOWN (AFT) AT ENGINES
2 STAGE PLS LAUNCH VEHICLE
2-STE "LRB" UPPER STAGE

- Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter
- Minimum Modifications to STS - LRB =

<table>
<thead>
<tr>
<th>Vehicle Parameters</th>
<th>50 x 100 nm LRB min mod</th>
<th>Optimized from LRB</th>
<th>50 x 100 nm LRB min mod</th>
<th>Optimized from LRB</th>
<th>220 x 220 LRB min mod</th>
<th>Optimized from LRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster Inert Weight (Klbs)</td>
<td>111.8</td>
<td>99.8</td>
<td>111.8</td>
<td>102.9</td>
<td>111.8</td>
<td>113.7</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>665.6</td>
<td>592.5</td>
<td>665.6</td>
<td>632.9</td>
<td>665.6</td>
<td>645.9</td>
</tr>
<tr>
<td>Upper Stage Inert Weight* (Klbs)</td>
<td>60.0</td>
<td>62.6</td>
<td>62.3</td>
<td>62.7</td>
<td>71.3</td>
<td>75.1</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>223.2</td>
<td>256.2</td>
<td>252.3</td>
<td>257.5</td>
<td>285.4</td>
<td>330.3</td>
</tr>
<tr>
<td>Glow (Klbs)</td>
<td>1,099.6</td>
<td>1,044.3</td>
<td>1,131.0</td>
<td>1,089.3</td>
<td>1,173.2</td>
<td>1,198.3</td>
</tr>
<tr>
<td>Vehicle Length (ft)</td>
<td>286</td>
<td>277</td>
<td>292</td>
<td>285</td>
<td>300</td>
<td>305</td>
</tr>
<tr>
<td>Vehicle Diameter (ft)</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
</tr>
<tr>
<td>Qty Booster Engines (STE-20)</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>59%</td>
<td>75%</td>
<td>63%</td>
<td>75%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Qty Upper Stage Engines (STE-20)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>25%</td>
<td>26%</td>
<td>26%</td>
<td>26%</td>
<td>28%</td>
<td>30%</td>
</tr>
</tbody>
</table>

*Upper stage inert weight includes: dry weight + residuals + FPR + [restart + deorbit] 220x220 only
## 2 Stage PLS Launch Vehicle

### 1-Ste "LRB" Upper Stage

- **Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter**
- **Minimum Modifications to STS - LRB =**

### Vehicle Parameters

<table>
<thead>
<tr>
<th></th>
<th>50 x 100 nm</th>
<th>SSF Transfer</th>
<th>220 x 220</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booster Inert Weight (Klbs)</td>
<td>111.8</td>
<td>95.6</td>
<td>111.8</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>665.6</td>
<td>539.1</td>
<td>665.6</td>
</tr>
<tr>
<td>Upper Stage Inert Weight* (Klbs)</td>
<td>62.7</td>
<td>50.6</td>
<td>65.9</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>242.7</td>
<td>212.3</td>
<td>282.1</td>
</tr>
<tr>
<td>GLOW (Klbs)</td>
<td>1,121.8</td>
<td>930.9</td>
<td>1,164.4</td>
</tr>
<tr>
<td>Vehicle Length (ft)</td>
<td>308</td>
<td>258</td>
<td>316</td>
</tr>
<tr>
<td>Vehicle Diameter (ft)</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
</tr>
<tr>
<td>Qty Booster Engines (STE-20)</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>62%</td>
<td>75%</td>
<td>67%</td>
</tr>
<tr>
<td>Qty Upper Stage Engines (STE-20)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>52%</td>
<td>45%</td>
<td>53%</td>
</tr>
</tbody>
</table>

*Upper stage inert weight includes: dry weight + residuals + FPR + [restart + deorbit](220x220 only)*
2 STAGE PLS LAUNCH VEHICLE
CENTAUR UPPER STAGE

- Payload Delivered = 33,287 lbs; PLS Orbiter and Adapter
- Minimum Modifications to STS - LRB =
- Centaur sized for Payload Requirements (man-rated)

<table>
<thead>
<tr>
<th>Vehicle Parameters</th>
<th>50 x 100 nm</th>
<th>SSF Transfer</th>
<th>220 x 220</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LRB</td>
<td>Optimized</td>
<td>LRB</td>
</tr>
<tr>
<td></td>
<td>min mod</td>
<td>from LRB</td>
<td>min mod</td>
</tr>
<tr>
<td>Booster Inert Weight (Klbs)</td>
<td>111.8</td>
<td>95.1</td>
<td>111.8</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>665.6</td>
<td>533.4</td>
<td>665.6</td>
</tr>
<tr>
<td>Upper Stage Inert Weight* (Klbs)</td>
<td>8.3</td>
<td>9.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Ascent Propellant (Klbs)</td>
<td>36.2</td>
<td>58.2</td>
<td>38.7</td>
</tr>
<tr>
<td>GLOW (Klbs)</td>
<td>880.0</td>
<td>729.3</td>
<td>863.6</td>
</tr>
<tr>
<td>Vehicle Length (ft)</td>
<td>235</td>
<td>212</td>
<td>236</td>
</tr>
<tr>
<td>Vehicle Diameter (ft)</td>
<td>17.15</td>
<td>17.15</td>
<td>17.15</td>
</tr>
<tr>
<td>Qty Booster Engines (STE-20)</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>26%</td>
<td>35%</td>
<td>26%</td>
</tr>
<tr>
<td>Qty Upper Stage Engines (RL10-A4)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lowest Throttle Setting</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Upper stage inert weight includes: dry weight + residuals + FPR + restart + deorbit

220x220 only
<table>
<thead>
<tr>
<th>CONCEPT</th>
<th>RATING</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/2 Stage</td>
<td>2</td>
<td>Unable to achieve orbit; Mass Fraction too low; may work if unconstrained</td>
</tr>
<tr>
<td>Parallel</td>
<td>3</td>
<td>Offers most commonality, fits PAD tower best for man ingress/egress, STE throttling req'd within current range</td>
</tr>
<tr>
<td>2 Stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- LRB Type Upper Stage W/1 Eng</td>
<td>2</td>
<td>Greatest commonality of 2 Stg concepts, high 2nd Stage throttling req'd</td>
</tr>
<tr>
<td>- LRB Type Upper Stage W/2 Eng.</td>
<td>1</td>
<td>2 STEs on 2nd Stage too much, very high Throttling req'd</td>
</tr>
<tr>
<td>Centaur Type Upper Stage</td>
<td>3</td>
<td>Shortest and lightest of 2 Stage concepts, high throttling req'd on 3 &amp;4 STE Boosters, 2 STE Booster probably better option</td>
</tr>
<tr>
<td>Drop Tanks</td>
<td>1</td>
<td>Plumbing too complex, no advantages over Parallel</td>
</tr>
</tbody>
</table>
# FINDINGS AND RECOMMENDATIONS

## FINDINGS TO-DATE

<table>
<thead>
<tr>
<th>CONCEPT ITEMS</th>
<th>ATTRIBUTES</th>
<th>CONCERNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Parallel</td>
<td>- Most common to LRB</td>
<td>- Involves 2 LRBs</td>
</tr>
<tr>
<td></td>
<td>- Least PAD Tower Impact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- within STE throttle (75%)</td>
<td></td>
</tr>
<tr>
<td>B. 2 Stage W/1 Eng LRB US</td>
<td>- Uses LRB components</td>
<td>- High STE throttle (2 engine Booster will reduce)</td>
</tr>
<tr>
<td>C. 2 stage W/Centaur</td>
<td>- Shorter &amp; lighter 2 Stage</td>
<td>- High STE throttle (2 engine Booster will reduce)</td>
</tr>
<tr>
<td>D. 1 1/2 Stage</td>
<td>- Simplified Concept</td>
<td>- PAD Tower Impact</td>
</tr>
<tr>
<td>E. Both 2 Stage W/2 Engines &amp; Drop Tanks</td>
<td>- None</td>
<td>- STS Constraints Effect Wts.</td>
</tr>
</tbody>
</table>

## RECOMMENDATIONS FOR REMAINING MOD 10 EFFORTS

- Cease further work on Concepts in Item E.
- Continue further design studies on Concepts in Items A, B, C & D
- Refine concepts with size and structures unconstrained by STS, as required
- Provide cost analyses
OBJECTIVE:

Develop a Conceptual Design To Determine The Feasibility Of Utilizing The LRB Boattail (Aft Skirt) For Shuttle-C Application
• Maximized use of STS-C boattail subsystems shall be made

• No impact to ET, ET Aft Attach Provisions, Cargo Carrier, Flame Trench, and only minor mods to other subsystems and GSE

• The baseline STE shall be used without mods except to the nozzle expansion ratio

• The Shuttle-C LRB boattail conceptual design shall be the 2-STE configuration

• The STS 3-g load factor limit shall apply to the LRB configured Shuttle-C

• LRB boattail STEs shall have same thrust vector angle as the STS-C boattail SSMEs

• The SRBs are replaced by LRBs on Shuttle-C with an LRB Boattail
CARGO ELEMENT (CE) SUB-ELEMENTS

Cargo Element

Boattail

Payload Carrier

Shroud

Noose Cone

Shroudback

Shuttle-C (SH-C)
PROPELLANT FEED LINES OF STS-C LRB BOATTAIL

PROPELLANT LINES INTERFACE OF ET AND LRB BOATTAIL IDENTICAL TO STS
## SHUTTLE-C BOATTAIL WEIGHTS COMPARISON

<table>
<thead>
<tr>
<th>SUBSYSTEM / ITEM</th>
<th>STS-BOATTAIL / 2-SSME</th>
<th>LRB-BOATTAIL / 2-STE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DRIY WEIGHT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>14,127</td>
<td>13,181</td>
</tr>
<tr>
<td>BASIC SHELL STRUCTURE</td>
<td>6,474</td>
<td>7,355</td>
</tr>
<tr>
<td>THRUST STRUCTURE</td>
<td>3,702</td>
<td>1,905</td>
</tr>
<tr>
<td>OMS/RCS POD</td>
<td>3,031</td>
<td>3,031</td>
</tr>
<tr>
<td>SECONDARY STRUCTURE</td>
<td>920</td>
<td>890</td>
</tr>
<tr>
<td>ENVIRONMENTAL PROTECTION</td>
<td>2,483</td>
<td>2,012</td>
</tr>
<tr>
<td>THERMAL PROTECTION</td>
<td>624</td>
<td>341</td>
</tr>
<tr>
<td>BASE HEAT SHIELD</td>
<td>810</td>
<td>622</td>
</tr>
<tr>
<td>THERMAL CONTROL SYSTEM</td>
<td>661</td>
<td>661</td>
</tr>
<tr>
<td>PURGE &amp; VENT SYSTEM</td>
<td>361</td>
<td>361</td>
</tr>
<tr>
<td>DRAIN/HAZARDOUS GAS DETECTION</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>AFT ET ATTACH ASSEMBLY</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td><strong>MAIN PROPULSION</strong></td>
<td>21,206</td>
<td>18,735</td>
</tr>
<tr>
<td>MAIN ENGINES</td>
<td>13,925</td>
<td>13,308</td>
</tr>
<tr>
<td>TVC</td>
<td>2,185</td>
<td>2,203</td>
</tr>
<tr>
<td>PROPELLANT SYSTEM</td>
<td>4,352</td>
<td>2,479</td>
</tr>
<tr>
<td>PNEUMATIC SYSTEM</td>
<td>706</td>
<td>706</td>
</tr>
<tr>
<td>PROPELLANT MNGMT</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td><strong>AUXILIARY PROPULSION SYSTEM</strong></td>
<td>3,424</td>
<td>3,424</td>
</tr>
<tr>
<td>ELECTRICAL PWR &amp; DISTRIB</td>
<td>1,583</td>
<td>1,583</td>
</tr>
<tr>
<td>AVIONICS</td>
<td>820</td>
<td>820</td>
</tr>
<tr>
<td>HYDRAULIC PWR &amp; DISTRIB</td>
<td>1,330</td>
<td>0</td>
</tr>
<tr>
<td>ENVIRONMENTAL CONTROL</td>
<td>642</td>
<td>642</td>
</tr>
</tbody>
</table>

A 5 Klb Lighter And Simpler Structural Design Are Attributes Of An LRB vs An STS Boattail
SHUTTLE-C PERFORMANCE WITH LRB vs SRB

Payload (Lbs)
- SRB/SSME: 83,140
- LRB/SSME: 113,264
- LRB/STE40: 127,240
- LRB/STE77: 140,224

Percent P/L Increase
- SRB/SSME: ---
- LRB/SSME: 36 %
- LRB/STE40: 53 %
- LRB/STE77: 69 %

Boattail Engine Type
- SRB/SSME: 2-SSME
- LRB/SSME: 2-SSME
- LRB/STE40: 2-STE40
- LRB/STE77: 2-STE77

Boattail Engine Isp(v) (sec)
- SRB/SSME: 452.55
- LRB/SSME: 452.55
- LRB/STE40: 429.28
- LRB/STE77: 441.98

Boattail Dry Weight (Lbs)
- SRB/SSME: 46,115
- LRB/SSME: 46,115
- LRB/STE40: 40,896
- LRB/STE77: 42,694

Booster Engine Type
- SRB/SSME: SRB
- LRB/SSME: 4-STE20
- LRB/STE40: 4-STE20
- LRB/STE77: 4-STE20

LRB CONFIGURED STS-C LAUNCH VEHICLES PROVIDE SIGNIFICANTLY HIGHER PAYLOAD CAPABILITY
FINDINGS

CONCEPT DESIGN-LRB BOATTAIL FOR SHUTTLE-C

- A 69% increase in Shuttle-C payload performance possible with an LRB configured Shuttle-C that includes an LRB boattail Cargo Element (140,224 lb vs 83,140 lb)

- A 5000 lb weight reduction possible by replacing STS with an LRB boattail

- LRB and LRB boattail engine commonality simplifies Shuttle-C design

- A third engine can be integrated in the LRB boattail without major modification

- No problems expected in the integration of the OMS pods and the ET attach assembly based on conceptual layouts

- Cylindrical shaped LRB vs "breadloaf" shaped boattail simplifies design and makes possible Cargo Carrier segments commonality for significant fabrication cost savings

The many advantages of LRB/LRB boattail make it a viable candidate for Shuttle-C
Continuation of Shuttle-C LRB BOATTAIL Study:

- Do feasibility study to develop a conceptual design of an LRB Boattail optimized APS Pod or integration of the APS components within the boattail structure as options to the present large/heavy STS OMS Pod.

- Extend the conceptual design to determine the feasibility/compatibility of integrating the Shuttle-C subsystems in the LRB Boattail that were not addressed in this phase, viz: Avionics; Electrical; ECS; etc.

- Develop a conceptual design of the 3-STE LRB Boattail configuration.

- Conduct performance analyses of following STS-C configurations:
  - Baseline LRBs with 3-STE40 LRB Boattail
  - Baseline LRBs with 3-STE77 LRB Boattail
  - ASRM with 3-SSME STS Boattail
  - ASRM with 3-STE77 LRB Boattail
  - ASRM with 2-SSME STS Boattail

- Cost analysis of STS vs LRB Boattails for Shuttle-C application
MANNED TRANSPORTATION SYSTEMS
• ATLAS (RELIABLE) TO MERCURY-ATLAS (MAN-SAFE)

• SHUTTLE-CENTAUR TO TITAN-CENTAUR (FROM MANNED UPPER STAGE TO UNMANNED UPPER STAGE)
BASIC PRINCIPLES ON
MERCURY-ATLAS PROGRAM

- MINIMUM OF NEW DEVELOPMENTS
  - NO CHANGE TO BOOSTER VEHICLE

- PILOT SAFETY PROGRAM
  - ENHANCE SYSTEM RELIABILITY
  - ESCAPE SYSTEM TO FILL GAP BETWEEN 100% RELIABILITY AND BOOSTER RELIABILITY
CHANGE IN PROGRAM MANAGEMENT EMPHASIS

PHASE-IN OF PILOT SAFETY PROGRAM

RESULTS:

1) ENGINE DEMONSTRATED RELIABILITY SUBSTANTIALLY ENHANCED (THROUGH TESTING AND TIGHTENING OF QUALITY CONTROL)

2) ATLAS ICBM RELIABILITY SIGNIFICANTLY INCREASED

3) 100% SUCCESSFUL MANNED FLIGHTS WITH ATLAS
PILOT SAFETY PROGRAM

8. SPECIAL FAILURE ANALYSIS
7. SPECIAL HANDLING PROCEDURES
6. REVIEW OF ALL PREVIOUS TEST DATA
5. COMPONENT RELIABILITY DEMONSTRATION
4. SPECIAL QUALITY-ASSURANCE PLAN
3. SPECIAL DESIGN FEATURES
2. PERSONNEL
1. TEAMWORK

[ATLAS EXPERIENCE]
### Major Changes from Missile to Mercury-Atlas

<table>
<thead>
<tr>
<th>Major Change</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhance Reliability</td>
<td>System components hand picked to have close to spec values</td>
</tr>
<tr>
<td>Addition of ASIS (Abort Sensing &amp; Instrumentation System)</td>
<td>Number of instrumentation &amp; logic systems to sense hazards, abnormal engine operation, spurious signal to the RSS escape system</td>
</tr>
<tr>
<td>Escape System</td>
<td>Capsule ejected to provide safe escape from impending failure</td>
</tr>
</tbody>
</table>
GROUND RULES FOR SHUTTLE-CENTAUR

- CARGO P/L RULES OR LAUNCH SYSTEM RULES?
  - INITIALLY ONLY MINOR MODS EXPECTED
  - LOTS OF CONFUSION
  - UNIQUE MISSION REQUIREMENTS

- FAIL OPERATIONAL  FAIL SAFE
  - PRESSURIZATION, VENTING, AVIONICS, ....

- PROPELLANT DUMP SYSTEM FOR ABORT

- ALMOST AUTONOMOUS SYSTEM
  - ASTRONAUT INITIATE ABORT DUMP SEQUENCE & P/L RELEASE
## ELV Upper Stage to Shuttle Upper Stage

**Shuttle-Centaur vs. Titan-Centaur**

<table>
<thead>
<tr>
<th>Major Change from ELV to Shuttle Upper Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Safety Enhancement</td>
<td>• As shown in schematic, number of extra components were added to make system dual failure tolerant, and start dump sequence in case of any hazard</td>
</tr>
<tr>
<td>• Addition of Dump System &amp; HSOS</td>
<td></td>
</tr>
<tr>
<td>• High Degree of Redundancy</td>
<td></td>
</tr>
<tr>
<td>• Lot of Analysis</td>
<td>• More fracture control and &quot;what if&quot; scenario of a more complex system investigated</td>
</tr>
<tr>
<td>• Display and Controls</td>
<td>• Some critical displays and degree of manual control on propellant dump provided</td>
</tr>
<tr>
<td>• Rigid Quality Control Management Review</td>
<td>• Number of integration panels, and review committees</td>
</tr>
</tbody>
</table>

**General Dynamics**

*Space Systems Division*

---

*S/C to T/C 10*
1. JSC-23211, "GUIDELINES FOR MAN RATING SPACE SYSTEMS" (SEPTEMBER 1988)

2. JSCM-8080, "MANNED SPACECRAFT CRITERIA & STANDARDS" (MARCH 2, 1982 / CHANGE 10)

3. AFSC DH3-2, "DESIGN HANDBOOK, SERIES 3-0, SPACE AND MISSLE SYSTEMS" (MARCH 20, 1969)

4. KHB 1700.7, SPACE TRANSPORTATION SYSTEM PAYLOAD HANDBOOK

5. NHB 1700.7, SAFETY POLICY AND REQUIREMENTS

6. SSP 30000, SPACE STATION PROGRAM DEFINITION AND REQUIREMENTS

7. GDSS-ALS-RPT-89-011, "ALS ADAPTATION FOR MANNED CARGO" (SEPTEMBER 1989)
# Classification of Space Systems (JSC-23211)

<table>
<thead>
<tr>
<th>Space System</th>
<th>Mission Objective</th>
<th>Attributes</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Man-Rated System   | Mission Success & Mission Safety equally important          | • Highest possible reliability  
• Fail safe operation designed into total system  
• Escape system provides ultimate back-up | • Space Station                                                              |
| Highly Reliable    | • Mission success primary importance  
• Mission (or crew) safety enhanced as a by product          | • Highest possible reliability  
• Fail safe operation designed into total system                     | • Shuttle - LRB  
• Apollo Lunar Lander  
• Precious Cargo  
• Commercial Airlines |
| Man Safe           | • Mission (or crew) safety higher emphasis than mission success | • Reliable  
• Fail safe operation only of escape system                      | • Crew Emergency Return  
• Vehicle (CERV) - LRB  
• Mercury Space Program  
• Fighter Aircraft     |
| Replacable         | • Not very high emphasis on mission safety or mission success | • Emphasis on cost, schedule, etc.                                        | • Low value cargo  
(Propellants, re-supply and expendables) |
# Structural Factors of Safety

<table>
<thead>
<tr>
<th>Loading Source</th>
<th>Factor</th>
<th>Aircraft</th>
<th>Shuttle ET</th>
<th>Atlas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Loads</td>
<td>Yield</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>1.5</td>
<td>1.4*</td>
<td>1.25</td>
</tr>
<tr>
<td>Unregulated Pressure</td>
<td>Yield</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>1.5</td>
<td>1.4</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td>2.0</td>
<td>1.4</td>
<td>1.25</td>
</tr>
<tr>
<td>Regulated Pressure</td>
<td>Yield</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>1.5</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td>2.0</td>
<td>1.25</td>
<td>1.25</td>
</tr>
</tbody>
</table>

* For well defined loads, F.S. = 1.25 (MMC-ET-SE25-0, NAS8-303000)
DIFFERENCES BETWEEN MANNED AND UNMANNED SYSTEM

SYSTEM FAILURE ANALYSIS

- FAULT TREE
- FMEA
- RELIABILITY ANALYSIS
- PROCESS & DESIGN CONSIDERATIONS

RELIABILITY

- PERFORMANCE
- SYSTEM SAFETY (C.O.F)
- QUALITY
- MAINTAINABILITY
- PRODUCIBILITY

UNMANNED
- MISSION SUCCESS

CONSCIOUS DECISION MADE ON COST EFFECTIVENESS, RELIABILITY DESIRED DEPENDS ON SYSTEM (ATLAS GOAL > .95; ALS GOAL > .985)

RANGE SAFETY SYSTEM

CREW SAFETY

- EX. PROPELLANT DUMP
- REDUNDANT VENT VALVES
- ASIS

MANNED
- MISSION SUCCESS
- CREW SAFETY

COST EFFECTIVENESS MAY INDIRECTLY INFLUENCE DECISIONS REGARDING CREW-SAFETY (EXAMPLE - SRB, ET H2 VENT DURING ASCENT)
- CREW SAFETY GOAL (APOLLO) > .999 NASA-TM-89226

MAN VALUE
ATTRIBUTES OF HIGHLY RELIABLE UNMANNED SYSTEM

- PROVEN TECHNOLOGY AND WELL CHARACTERIZED MATERIAL
- FLY THROUGH FAILURES (CRITICAL SYSTEM EXCEPT STRUCTURES, PRESSURE VESSELS & THERMAL PROTECTION SYSTEM SHOULD BE DESIGNED WITH APPROPRIATE DEGREE OF FUNCTIONAL REDUNDANCY)
- ROBUST - A LOT OF MARGIN, SIMPLE DESIGN
- CONTROL OF FAILURE PROPAGATION (HDSS, IHM, LOW CORRELATION OF FAILURE ETC.)
- DEMONSTRATION & VERIFICATION OF RELIABILITY

ADDITIONAL ATTRIBUTES OF HIGHLY RELIABLE MANNED SYSTEM

- CREW DISPLAY AND POSSIBLE PROVISION FOR INTERVENTION (EXTRA REDUNDANCY BY CREW)
- EXTRA REDUNDANCY, DETECTION AND CONTROL WHICH ENHANCES CREW SAFETY AND SAFE ABORT CHANCES
PRELIMINARY CONCLUSIONS

- A HIGHLY RELIABLE SYSTEM IS ESSENTIAL FOR ALL SPACE SYSTEMS (ENGINE-OUT, PAD-HOLD DOWN, VERIFIED STRUCTURAL MARGIN, ....)

- CREW SAFETY MAY IMPOSE
  - HIGHER MARGINS THAN NEEDED FOR AN OPTIMIZED COST EFFECTIVE UNMANNED SYSTEM
  - REDUNDANCY TO ENHANCE CREW ESCAPE POSSIBILITY (DETERMINED THROUGH ANALYSIS)

- ABORT SENSING AND IMPLEMENTATION SYSTEM IS NEEDED TO FILL THE GAP BETWEEN 100% RELIABILITY AND SYSTEM RELIABILITY

- GENERAL GUIDELINES AVAILABLE. PARTICULAR REQUIREMENTS ARE HIGHLY MISSION SENSITIVE
CONTINUING ACTIVITIES

- COMPLETE ONGOING CONCEPT DEFINITION & EVALUATION
  - LRB FOR PLS
  - SHUTTLE-C PROPULSION APPLICATION
  - COST DATA FOR SELECTED CONCEPTS
- ET-CORE LAUNCHER SYSTEM
  - TWO LRB'S
  - LRB PROPULSION SECTION TECHNOLOGY FOR ET
  - VARIED PAYLOAD CAPABILITY
- ASSESSMENT OF LRB APPLICATION TO CURRENT PLANS FOR FUTURE LAUNCHERS
- FINAL REPORT & DOCUMENTATION OF CONCEPTS