Next Generation Solid Boosters

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Thiokol CORPORATION
Space Transportation Solid Rocket Motor Systems

Large Launch Booster  Small Launch Vehicle  Reusable Flyback Booster System  Space Propulsion Motor

Concept objectives:
- Reduce booster costs to $5–6/lbm of booster weight (60% decrease)
- Increase booster reliability and safety (demonstrate 0.999X reliability/booster)
- Clean propellant exhaust (no HCl)

INFORMATION ON THESE PAGES WAS PREPARED TO SUPPORT AN ORAL PRESENTATION AND CANNOT BE CONSIDERED COMPLETE WITHOUT THE ORAL DISCUSSION
Shuttle-Derived Heavy Lift Launch Vehicles

- Booster: 2 ASRBs
- Core Stage: Standard ET
- Core Propulsion: 3 SSMEs
- Net Payload: 71 t
- 92 ft length
- 183.7 ft height

Mars

- Booster: 2 ASRBs
- Core Stage: Standard ET
- Core Propulsion: 3 SSMEs
- Net Payload: 61 t
- 89.9 ft length
- 183.7 ft height

Lunar

- Booster: 4 ASRBs
- Core Stage: Standard ET
- Core Propulsion: 3 SSMEs
- Net Payload: 140 t
- 96.4 ft length
- 321.2 ft height

ALS-Derived Heavy Lift Launch Vehicles

- Booster Thrust (k lb): 8–460
- Booster: 6–600
- Payload (k lb): 88
- 117
- 250
- 41 ft dia/
- 24.9 ft dia/
- 15.1 ft dia/
- 89.9 ft length
- 82 ft length

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### Enabling Technologies

<table>
<thead>
<tr>
<th>Design</th>
<th>Process/Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>S.A.F.E.R&lt;sup&gt;SM&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nose cone</td>
<td>Stiffened shell</td>
</tr>
<tr>
<td>Forward skirt extension</td>
<td>Stiffened shell</td>
</tr>
<tr>
<td>Forward attach structure</td>
<td>Pivot</td>
</tr>
<tr>
<td>Case/skirts</td>
<td>Monolithic</td>
</tr>
<tr>
<td>External insulation</td>
<td>Variable thickness</td>
</tr>
<tr>
<td>Internal insulation</td>
<td>Single material</td>
</tr>
<tr>
<td>Propellant/grain</td>
<td>Slotted CP</td>
</tr>
<tr>
<td>Aft attach structure</td>
<td>Aft end thrust reaction</td>
</tr>
<tr>
<td>Aft skirt extension</td>
<td>Stiffened shell</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Submerged centerline</td>
</tr>
<tr>
<td>Ignition/ordnance</td>
<td>Pyrogen/laser-initiated igniter</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Performance/cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Optimization</td>
</tr>
<tr>
<td>Stiffened shell</td>
<td>Composite/aluminum</td>
</tr>
<tr>
<td>Aluminum welded</td>
<td>Midstrength D6AC</td>
</tr>
<tr>
<td>Pivot</td>
<td>Filament wound on &quot;green&quot; insulation</td>
</tr>
<tr>
<td>Single material</td>
<td>Bonded cork</td>
</tr>
<tr>
<td>Flapless</td>
<td>Kevlar EPDM</td>
</tr>
<tr>
<td>Slotted CP</td>
<td>Strip wrap on mandrel</td>
</tr>
<tr>
<td>Aft end thrust reaction</td>
<td>Co-cure with case</td>
</tr>
<tr>
<td>Stiffened shell</td>
<td>Clean exhaust</td>
</tr>
<tr>
<td>Machined grain</td>
<td>Batch or continuous mix</td>
</tr>
<tr>
<td>PAN carbon phenolic</td>
<td>Direct bond</td>
</tr>
<tr>
<td>Submerged centerline</td>
<td>Midstrength D6AC</td>
</tr>
<tr>
<td>Canted boss</td>
<td>Aluminum welded or chem-milled</td>
</tr>
<tr>
<td>Symmetric nozzle</td>
<td>PAN carbon phenolic Molded</td>
</tr>
<tr>
<td>Pyrogen/laser-initiated igniter</td>
<td>Tailored clean propellant</td>
</tr>
<tr>
<td>Forward dome termination</td>
<td>Shaped charge detach</td>
</tr>
</tbody>
</table>

### S.A.F.E.R<sup>SM</sup> Philosophy

**Statistical Analysis for Engineering Reliability**

- Link reliability and producibility to affect design
- Conduct design to meet allocated reliability
  - Estimate design reliability based on estimated performance and capability distributions
  - Base capability distribution on historical test data and established requirements
  - Develop approach to estimate performance distribution from standard engineering models
  - Link process control variables and key design variables to critical failure modes
  - Establish test program to demonstrate reliability (tailor test data to establish capability and performance distributions)
Independent Performance and Capability Distributions Combined Into One Failure Distribution: \( X = C - P \)

Small Launch Vehicle Concept Objectives

- Provide family of small launch vehicles to increase user flexibility in delivering a broad range of payloads (600 to 2,000 lb) into LEO
  - Remote sensing satellites
  - Communication and scientific research satellites
  - Recoverable capsules for industrial applications
- Retain high reliability of military systems
- Vehicle family based on basic motors (building blocks) derived from current strategic motor systems
- Minimize launch operations relating to vehicle
- Provide resiliency and responsiveness to launch on alert
Small Launch Vehicle Concept

Small Launch Vehicle Enabling Technologies

Improved Manufacturing Processes

Optimized Designs for Low Cost

Standardized Materials and Specifications

Efficient Program Management

Inherent High Reliability of "Solid" Motors Maintained

Launch Operations Consideration

Integrated Technologies

Building Block Vehicle Concept

Minimum Cost Per Pound of Payload into Orbit

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Reusable Flyback Booster System

- Concept objectives:
  - Solid rocket or hybrid propulsion
  - Booster transportation system for manned shuttle II and unmanned cargo carriers
  - Vertical launch, horizontal landing
  - Short turnaround cycle time
  - No preflight assembly required (load fuel and launch)
  - Lower recurring cost

- Enabling technologies:
  - Composite cases, struts, and wings
  - Cartridge-loaded propellant (SRM) or fuel (hybrid) grains
  - Integral removable aft dome/nozzle/skirt for quick fuel loading
  - Quick-change moldable nozzle insert or completely reusable (3-5 flights) advanced ceramic, passively cooled nozzle

High-Performance Solid Motors for Space

- Concept objectives
  - High-performance space propulsion system for:
    - Mars and lunar ascent propulsion
    - Orbit transfer propulsion
    - Long space storage capability
    - High $I_{sp}$ performance
    - High mass fraction performance

- Enabling technologies
  - High-performance beryllium propellants
    - $I_{sp}$ (theoretical) = 360–400 lbf·sec/lbm at 100:1
    - High propellant density (~0.05–0.06 lbm/in.$^3$)
    - Braided carbon–carbon exit cone
    - 4D carbon–carbon throat
    - Consumable igniter
    - Laser-diode safe-and-arm device
    - Graphite composite case
Measured Comparison of Be and Al Propellants

<table>
<thead>
<tr>
<th>Propellant</th>
<th>TP–H–3062</th>
<th>TP–H–1092</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal fuel</td>
<td>Al</td>
<td>Be</td>
</tr>
<tr>
<td>Solids/metal (%)</td>
<td>86/16</td>
<td>86/12</td>
</tr>
</tbody>
</table>

Ballistics (BATES)

<table>
<thead>
<tr>
<th></th>
<th>TP–H–3062</th>
<th>TP–H–1092</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn rate, 500 psi (in/sec)</td>
<td>0.246</td>
<td>0.260</td>
</tr>
<tr>
<td>Pressure exponent (n)</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>Theoretical $I_{sp}$, vac, $\varepsilon = 50$ (lbf–sec/lbm)</td>
<td>315.50</td>
<td>342.20</td>
</tr>
<tr>
<td>Measured $I_{sp}$, $\varepsilon = 50$ (lbf–sec/lbm)</td>
<td>293.00</td>
<td>312.50</td>
</tr>
<tr>
<td>Efficiency, $\eta$ (%)</td>
<td>92.80</td>
<td>91.30</td>
</tr>
</tbody>
</table>

Conclusions

- Solids have multiple uses
  - Boosters
  - Small launch vehicles
  - Flybacks
  - Space transfer motors
- Keys to use
  - "Designed in" reliability
  - Low cost
  - Simplicity
ADVANCED LAUNCH SYSTEM