Flight Vehicle Structural Design Processes for a Common Bulkhead and a Multipurpose Crew Vehicle Spacecraft Adapter

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MSA: Design Overview

- MPCV/Orion
- (MSA) MPCV Stage Adapter MSFC
- Delta IV DCSS

MPCV/MSA Joint ORION Responsibility

DCSS/MSA Joint ORION Responsibility
MSA: Design Overview

- Primary Structure
  - Single Piece Fwd & Aft Rings
  - Conical Isogrid Panels
  - All Welded Construction

- Secondary Structure
  - Diaphragm & Doghouse
  - Electrical Panels
  - Access Panel Covers
MSA: Pocket Parameter Optimization
MSA: Historical Comparison

MSA: Design Overview
Common Bulkhead: Design Overview

Ares I Upper Stage
Common Bulkhead

Ares I Upper Stage 5.5m diameter
Pressurized Structure

LH2 Tank

LO2 Tank

Ares I Upper Stage 5.5m diameter
Pressurized Structure
Common Bulkhead Design Overview

- LH2 Side Bond Surface Area (Bonded Area Only)
- CB Core Volume
- LOX Side Bond Surface Area (Bonded Area Only)
- Total CB Inside Volume
- Bolting Ring to Seal Plate Volume
Common Bulkhead: Thermal Gradient

- Thermal stress across a common bulkhead is a major contributor to the driving load case [1]
  - Problem: Thermal mismatch along with pressure differential define the driving loads for a common bulkhead. There is a significant temperature gradient across the common bulkhead. The CB FWD dome temperature = -423F, CB aft dome temperature = high temperature ullage pressurant
  - Solution:
    - Core must have low thermal conductivity and sufficient shear strength
    - Choose dome and core thicknesses to balance thermal effect and structural efficiency
    - Hold tight tolerance on domes skin thickness for thermal stress effects
    - Reduce LO2 ullage pressurant temperature through additional chilled helium ullage pressurant

1: “Structural Design Considerations for the Storage of Liquid Hydrogen in a Space Vehicle” Sagata, note error in thermal stress equation
Common Bulkhead: Trades

Trade Study Example

♦ **Sandwich vs. Machined / stiffened dome**

<table>
<thead>
<tr>
<th></th>
<th>Composite Common Bulkhead</th>
<th>Machined / Stiffened Common Bulkhead</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td><em>Lighter</em></td>
<td><em>Heavier</em></td>
</tr>
<tr>
<td><strong>System Impact</strong></td>
<td>Core volume thermal conditioning</td>
<td>Easier to mount auxiliary hardware to LO2 side</td>
</tr>
<tr>
<td><strong>Design Complexity</strong></td>
<td>No exterior dome insulation required</td>
<td>Simplified dome design</td>
</tr>
<tr>
<td><strong>Manufacturing and Assembly</strong></td>
<td>Complex core bonding to domes Hermetic seal weld around joint Match drilling of bolting ring</td>
<td>Isogrid machined spun form dome and joint ring forging Complex insulation installation</td>
</tr>
</tbody>
</table>

♦ **Elliptical vs. Spherical Cap**
Stability Trades for common bulkheads

- **Pressure Stabilized**: Must maintain positive pressure on concave side of bulkhead
- **Structurally Stable**: Designed for negative pressure
  - Designed for 1g acceleration for loss of pressure during testing
  - Designed for 4+g acceleration flight loads
    - Ares was design for a loss of pressure in aft tank, this protects for inadvertent venting during testing and flight
- **Fail Safe FOS**: 1.0 for loss of pressure failure?
Common Bulkhead: Core Volume Thermal Conditioning

- Design Issue: Maintaining and verifying common bulkhead volume integrity can be operationally difficult and costly
  - **Problem:** Core volume environment. It is necessary to maintain a pure core volume absent of any air ingestion and provide the ability to check medium for any dome leaks.
    - To protect bondline during shelf life (moisture absorption)
    - Prohibit core pressurization during testing
    - Prevent mixing of propellants
    - Provide thermal insulation
  - **Solution:**
    - On pad operational access
    - Quantify leak rate of bulkhead then determine pad stay time based on total allowable pressure decay (small volume compared to tankage)
    - Monitor core from initial leak test through T0

- **LCC:** Excessive common bulkhead core volume pressure
  - Core volume monitored with pressure transducers

- **If leakage does occur post T0**
  - Some ambient air with a typical atmospheric humidity \((0.026 \text{ lbm}_{H_2O} / \text{ lbm}_{Dry \text{ Air}})\) will be ingested into the core volume at subatmospheric pressure
  - The moist ambient air ingestion would be short lived as atmosphere depressurization occurs, immediately following this event, the moist air ingestion will be of short duration
    - Atmospheric pressure decays rapidly on ascent
  - Moisture ingestion at its maximum level is not catastrophic
Common Bulkhead: Tanking

- **Tanking generates temperature and pressure gradients across a common bulkhead**
  - A common bulkhead configuration can require additional operational constraints than a separate tank configuration

- **The following tanking sequence is based on a “sandwich” common bulkhead conceptual design, similar to the heritage S-IVB and S-II designs**
  - Facilities tanking first
  - LOX followed by LH2
  - Common Bulkhead driven impacts
    - Minimize $\Delta T$ across common bulkhead
    - Design is structurally sensitive to cryo-loading anomalies
    - Potential launch turnaround delays
  
  - Operational procedures for on-pad “core” purging
    - A different, more complex purge method may be applied for a Common Bulkhead to eliminate cryopumping or accumulation of haz gas levels.
    - Purge effluent may be analyzed for haz gas prior to launch