Helium Valve Improvement

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Code 548 Mechanical Systems Branch
Structures, Loads, and Mechanical Systems (SLaMS)
Introduction

• Hometown
  → Salisbury, MD

• Graduated NC State (2017)
  → B.S. Aerospace Engineering

• NASA Journey
  → Internships
    - National Space Club Scholars (2009)
    - Science Technology Engineering Pipeline for Under-served Populations (Step Up) Internship (2010-2011)
    - NASA Sounding Rocket Operations Contract (NSROC) Internship (2012-2013)
  → Pathways Program (2014-2017)
  → PREP I- Aerothermal Heating
  → PREP II- Helium Balloon Valve Design
Overview

• Background
• Objective
• Current Design
• Mechanical Design Change
• Analysis
• Forward Work
• Challenges & Lessons Learned
• Super Pressure Balloon (SPB)
  → Closed system, pressurized with excess gas to maintain altitude
  → Three valves on apex fitting
    □ Two for inflation
    □ One for venting

• Zero Pressure Balloon (ZPB)
  → Open system, more leak tolerant
  → One valve on apex fitting for venting
Objective

• The Engineering Review Team anomaly investigation of the April 24, 2017 SPB mission determined that the valve was a potential source of helium leakage.

• Tasks initially requested by Balloon Program Office (BPO):
  → Stiffen the valve plate to increase rigidity/stiffness.
  → Increase stiffness of the metal brackets supporting the motor/electronics.
  → Explore use of a silicon gasket.
  → Perform ground tests representative of flight environment.

• Additional requirements
  → Valve shall have the same bolt pattern as apex fitting.
  → Valve shall provide the same interface to the inflation cans.
  → Valve shall weigh 7lbs or less.
Current Design

- Helium gas valves have been standard on large scientific balloon systems since the 1960’s
- Design was mainly unchanged since the early 1990’s and uses the following components:
  - Apex interface ring (6061-T6)
  - Modified Globe motor (24V)
  - Rack & pinion with open/close limit switches
  - Single gasket seal: closed cell silicone
  - Valve plate (“pie plate”)
  - Electronics Housing
  - Sheet Metal Gussets (5052- H34)
Current Design - Pie Plate

- Material: Al 5052-AHC
- Thickness: 0.0625 in.
- Design Concerns
  - When closing, the plate deflects and gaps at the edge, under the force from the motor
  - Holes are thru, which is a potential leak path
Current Design - Gussets

- Material: Al 5052-H34
- Thickness: 0.032”
- Design Concerns
  - Gussets aren’t of a common design
  - Multiple components for assembly
  - Easily deflects under small amount of torque
Mechanical Design Changes

Existing Design

Design Review (Dec. 2018)

Delta Design Review (May 2019)
Final Design

Closed

Open

Section View
Ring

Changes from Original:
- Removed side mounting holes for gussets
- Ribs and a mounting surface for the electronics package
- Maintained outside diameter of ring for inflation cans and original mounting holes for apex plate
- Scalloped the outside diameter to reduce weight
- Dovetail O-ring groove to seal the flange: 0.188” width, silicone rubber
Piston

Changes from Original:

• Material: Al 6061-T6

• Three-piece piston assembly
  → Top plate
  → Retaining ring
  → Seal: Spring-energized seal by Marco Rubber
    □ Forms seal between piston and bore.
Piston Top Plate

- Material: Al 6061-T6
- Designed features for ring and top plate according to Marco Rubber design guide
- Designed for weight savings and stiffness
- Threaded center hole with thick wall to provide stability to gear rack
- All holes are blind to minimize leak paths

16 #4-40 threaded holes for retainer ring
3/8 - 24 Hole Thread

Chamfer for guiding piston into valve ring bore to seal
Chamfer for spring seal
Assembly Overview with New Parts

- Thru hole for apex attachment
- Rib support
- Piston top plate
- Alignment chamfers
- Retaining ring
Electronics Mount

- Not in the original design
- Provides interface for the electronics and motor package
- Material: Al 6061-T6
- Custom design
- Height: 5.40”, width: 3.13”, depth: 1.77”
Electronics Mount Continued

Front
- PCB Enclosure
- Power Connector
- Globe Motor
- Gear Rack

Rear
- Limit Switch
- Limit Switch Tab
- Limit Switch
- 3/8”-28 thread for piston attachment
Components of Electronics Mount

- Gear Rack
- Limit Switch Tab
- Electronics

- ABS Plastic PCB Cover
- PCB
Final Product

- Improved seal function
- Wider positional tolerance of piston seal
- Improved verification of seal with apex fitting
- Streamlined electronics package
- Maintained same bolt hole pattern
- Maintained mating surface for inflation cans
- Internal holes are blind to reduce a leak risk
- Weighs 6.7 lbs. (CAD estimate)
- Can be standardized for SPB and ZPB
- Keeps similar open area for helium flow into balloon
- Utilizes the same electronics interface except smaller limit switches
Helium Valve Animation
Ring Mount Assembly Analysis

- Condition: 140 lb. applied to center hole

Von Mises Stress (ksi): 16.73 ksi

Displacement (in): 0.05 in
Piston Top Plate Analysis

- Condition: 140 lb. applied to piston center

- **Von Mises Stress (ksi)**: 32.9 ksi
- **Displacement (in)**: 0.018 in
### Analysis Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>Material</th>
<th>Standard</th>
<th>Safety Factor (Ultimate Tensile)</th>
<th>Stress from FEA (ksi)</th>
<th>Stress at Failure (ksi)</th>
<th>Margin of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring</td>
<td>Aluminum 6061-T6</td>
<td>MMPDS-12</td>
<td>1.4</td>
<td>16.73</td>
<td>42</td>
<td>1.51</td>
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<tr>
<td>Piston Top Plate</td>
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<td>0.28</td>
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<table>
<thead>
<tr>
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<th>Standard</th>
<th>Safety Factor (Yield Tensile)</th>
<th>Stress from FEA (ksi)</th>
<th>Stress at Failure (ksi)</th>
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<tr>
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<td>MMPDS-12</td>
<td>1.25</td>
<td>29.27</td>
<td>35</td>
<td>0.20</td>
</tr>
</tbody>
</table>

MMPDS-12, Table 3.6.2.0(d). Design Mechanical and Physical Properties 6061 Aluminum Alloy Rolled, Drawn, Cold Finished Bar, Rod, and Shapes
Future Work

• Complete drawings
• Fabricate prototype parts
• Develop assembly procedure
• Assemble parts

• Testing: Working closely with Balloon Research and Development Lab (BRDL) to use facility to conduct environmental testing
  → Develop test plan and procedure for each test
  → Operation in multiple mission environments
Challenges & Lessons Learned

• Challenges
  → Communication between design team and customer
  → Determining the right path forward during design phase
  → Finalizing design requirements

• Lessons Learned
  → Improved CAD skills
  → Better understanding of mechanical designs
  → Learned more about the NASA Balloon Program
  → Professional development when communicating among team and others
Questions ?

Current Design

New Design
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>BPO</td>
<td>Balloon Program Office</td>
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<tr>
<td>BRDL</td>
<td>Balloon Research and Development Lab</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CSBF</td>
<td>Columbia Scientific Balloon Facility</td>
</tr>
<tr>
<td>DR</td>
<td>Design Review</td>
</tr>
<tr>
<td>DRR</td>
<td>Delta Design Review</td>
</tr>
<tr>
<td>in</td>
<td>inch</td>
</tr>
<tr>
<td>ksi</td>
<td>kilopound per square inch</td>
</tr>
<tr>
<td>lb</td>
<td>Pound</td>
</tr>
<tr>
<td>OD</td>
<td>Outside Diameter</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
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<tr>
<td>SPB</td>
<td>Super Pressure Balloon</td>
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<tr>
<td>WFF</td>
<td>Wallops Flight Facility</td>
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<tr>
<td>ZPB</td>
<td>Zero Pressure Balloon</td>
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Back Up
3.4 - The helium valve shall be designed to fit within the static and dynamic envelope of the current standard helium valve.

3.5 - The weight of the helium valve assembly not be greater than 7.0 lb.

3.6.2 - The valve shall be designed to meet all strength and performance requirements when subjected to ambient pressure between 1,013 millibar and 2 millibar.

3.6.3 - The valve shall be designed to meet all strength and performance requirements when subjected to a differential pressure between 0 – 200 Pa.

3.7 - The fittings shall be designed to show positive margins of safety when exposed to temperatures within the range -70°C to +65°C.

3.11.5 - The valve shall have a mating surface on its outside perimeter for attaching a CSBF fill can.
Performance Requirements

Mechanical

4.1.1 - A test plan shall be implemented to demonstrate that the valve will perform desirably without damage when subjected to a minimum of 200 open/close cycles.

4.1.2 - The valve shall provide confirmation of closure.

4.1.3 - The valve shall demonstrate that the duration full travel to open or close is less than or equal to 22 seconds.

4.1.4 - At room temperature, the flight configured fitting shall maintain seal at all interfaces with detectable gas loss of no more than $1.44 \times 10^{-4}$ g/s.

4.1.5 - When fully open, the valve shall have a helium gas flow rate equal to or greater than the flow rate of the current helium valve.

Electrical

4.2.1 - The valve shall maintain the same electrical interface to CSBF equipment as the current valve.

4.2.2 - The valve shall operate acceptably over a voltage range of 22 VDC to a maximum of 29.5 VDC.

4.2.3 - The valve shall have a maximum power consumption of 15 watts when operating.
## Weight Breakdown

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight (lb)</th>
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</thead>
<tbody>
<tr>
<td>Ring</td>
<td>2.427</td>
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<tr>
<td>Piston Top</td>
<td>1.974</td>
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<tr>
<td>Piston Bottom</td>
<td>0.316</td>
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<tr>
<td>Seal</td>
<td>0.154</td>
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<tr>
<td>Electronics Mount</td>
<td>0.674</td>
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<tr>
<td>Gear Rack</td>
<td>0.36</td>
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<tr>
<td>Motor</td>
<td>0.8</td>
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<tr>
<td>PCB</td>
<td>TBD</td>
</tr>
<tr>
<td>Limit Switch</td>
<td>0.003</td>
</tr>
<tr>
<td>Limit Switch</td>
<td>0.003</td>
</tr>
<tr>
<td>Power Connector</td>
<td>TBD</td>
</tr>
<tr>
<td>PCB Enclosure</td>
<td>0.023</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.734</strong></td>
</tr>
</tbody>
</table>

8/16/2019
## Estimated Mechanical Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost for single prototype</th>
<th>Cost per unit for set of 8</th>
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<tbody>
<tr>
<td>Ring</td>
<td>$1764.82</td>
<td>$631.60</td>
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<tr>
<td>C-Channel</td>
<td>$533.98</td>
<td>$201.70</td>
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<tr>
<td>Top Piston Plate</td>
<td>$1242.99</td>
<td>$420.39</td>
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<tr>
<td>Retaining Ring</td>
<td>$1059.01</td>
<td>$215.77</td>
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<tr>
<td>Electronics Mount</td>
<td>$704.38</td>
<td>$253.01</td>
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<tr>
<td>Gear Rack</td>
<td>$1347.05</td>
<td>$360.07</td>
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<td>Limit Switch Tab</td>
<td>$213.57</td>
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<tr>
<td>Spring Energized Seal</td>
<td>$600</td>
<td>$600.00</td>
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<tr>
<td>Hollow O-Ring</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$7465.80</strong></td>
<td><strong>$2739.96</strong></td>
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</table>
Electrical Design Changes

- No changes to original PCB
  → Will be housed in enclosure

- Additional interface adapter cable from PCB enclosure to CSBF interface, switches, and motor
  → No change to original CSBF interface (MS3102A-14S-2P)
  → PCB enclosure interface – MDM-15S

- Replace mechanical limit switches with smaller, lower profile switches (Honeywell 311SX64-H58)
  → 28VDC, 5A
  → SPDT
  → -53/+121°C
Final Product

- Number of custom parts is less than current valve
- Piston seal design allows the same electrical interface with wider positional tolerance
- The original seal function and DR design made seal confirmation over-complicated and would change the electrical interface
- Open area for flow is 133.3 $in^2$, compared to 138.5 $in^2$ from the current valve.
- Weighs 6.73 lbs. according to CAD