Balloon Working Group Meeting
The NASA Ultra Long Duration Balloon Vehicle

Henry M. Cathey, Jr.
ULDB Balloon Vehicle Manager
NMSU/Physical Science Laboratory
Wallops Flight Facility
Discussion Topics

• ULDB Vehicle Requirements
• Brief Overview of ULDB Vehicle Development
  – Phase III Flight
  – Australia 2001 Flights
• Developments and Test Flights Since Last BWG Meeting
  – Ground and Model Testing
  – Ft. Sumner/Palestine 2002 Test Flight
  – Australia 2003 Test Flight
• Next Steps
Vehicle Performance Design Requirements

- Duration up to 100 days
- Global flight capability
- Total suspended weight
  - CREAM requirement 2,720 kg (6,000 lbs.)
    - Includes 340 kg (750 lbs) of ballast
- Desired float altitude targeted 33.5 km (110,000 ft)
  - CREAM requirement is 33.0 km (108,000 ft)
- Stability – -1.5 km (-5,000 ft) and +
ULDB Test Flights

- 09/1997  ULDB Project team assigned
- 10/1998  Phase I: Fabric-film spherical balloons - 16.5 meter diameter
- 2/24/2001  Phase IV: 18.38 MCF co-extruded pumpkin – Flight 495NT
- 3/9/2001  Phase IV: 18.38 MCF co-extruded pumpkin – Flight 496NT
Phase III Flight

• The Phase III flight was an unmitigated success
  – All minimum and comprehensive success criteria were met
• All systems worked as designed
• Nominal Desired Float Altitude ~28,350 m (93,000 ft)
• Balloon was stable to within < - 1% (-272 m, -890 ft) and ~ +1.7% (+491 m, +1,611 ft) of the float altitude
• Balloon was pressurized during entire flight (>200 Pa max DP)
• Flight time of over 30 hours
• This balloon flew over a very bad thunder storm at night (worst case cold condition) and maintained a stable altitude for the duration of the flight
• Balloon was ready to be scaled up to the “full size” balloon
## Phase III to Phase IV Flights

<table>
<thead>
<tr>
<th></th>
<th>Phase III</th>
<th>Phase IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td>68,554 m³ (2.42 MCF)</td>
<td>520,483 m³ (18.38 MCF)</td>
</tr>
<tr>
<td><strong>Material weight</strong></td>
<td>37.7 g/m²</td>
<td>37.7 g/m²</td>
</tr>
<tr>
<td><strong>Number of gores</strong></td>
<td>150</td>
<td>290</td>
</tr>
<tr>
<td><strong>Gore length</strong></td>
<td>78.34 m (256.9 ft)</td>
<td>152.7 m (501 ft)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>637 kg (1404 lb)</td>
<td>2,155 kg (4,740 lb)</td>
</tr>
<tr>
<td><strong>Inflated height</strong></td>
<td>35 m (115 ft)</td>
<td>68.9 m (226 ft)</td>
</tr>
<tr>
<td><strong>Inflated diameter</strong></td>
<td>58.5 m (192 ft)</td>
<td>144.9 m (377 ft)</td>
</tr>
<tr>
<td><strong>Float Altitude</strong></td>
<td>~28,350 m (93,000 ft)</td>
<td>~34,110 m (111,900 ft)</td>
</tr>
<tr>
<td><strong>Suspended Load</strong></td>
<td>53 kg (1,660 lbs)</td>
<td>2,045 kg (4,500 lbs)</td>
</tr>
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Phase IV Australia

- Phase IV Flight #1 – 495NT
  - Ascent very close to predicted ascent
  - Balloon failed to pressurize
  - Maximum altitude of ~26 km (~85,000 ft)
  - Release of collar at launch tore a hole in the balloon shell under the cap
- Program made decision to fly second balloon
- Phase IV Flight #2 – 496NT
  - Balloon launch and ascent were nominal
  - Ascent rate
    - Slightly slower than predicted before entering the tropopause
    - Averaged near predicted ascent rate after the tropopause
  - Balloon pressurized as predicted
Phase IV Australia

- Balloon pressurization and stable altitude occurred at 32.8 km (107,500 ft) (GPS altitude 33.8 km or 111,000 ft)
- Maximum daytime pressurization 120 Pa
- Observations and decision
  - Telescope observation showed shape discontinuity in the balloon
  - Flight continued through the day with minor variations in pressure observed
  - Altitude was very stable, holding at 32.8 km (107,500 ft) plus or minus 120 m (400 ft.)
- The decision was made to continue with the flight because performance was very close to that predicted and the pressure and altitude were very stable.
Phase IV Australia – Anomalous Shape
Up-Looking Video
Phase IV Australia

- As the sun set, the pressure in the balloon fell off as expected
  - Balloon flew over thunderstorm
  - Ballast drops at night
    - To maintain altitude
    - Much greater quantity of ballast dropped than predicted
- After sunrise the MKS altitude returned to 32.6 km (107,000 ft)
- Differential pressure barely moved above the nighttime pressure
- As soon as the discovery of this was made, it was reported to operations personnel who executed flight termination
- Determined that the balloon developed a leak at some point during the flight
Flight 496 - Flight Profile

Mission Elapsed Time

Differential Pressure (Pa)

Altitude (feet)
Addressing the Issues

- Material Deficiency in Shell Film
- Study Shape Anomaly
  - Removed “excess film” from the design

- Material Redesign
- Model Balloon Tests
- Payload Requirement Increase (2,720 kg or 6,000 lbs)
Post Australia Flight Development Steps

• Two areas required improvements – Materials and Deployment
• Materials
  – Very high rate (“snatch testing”) and very low rate (creep testing) loading requirements
  – Developed and selected new material
  – New material meets existing proven standards and improved “dart impact” characteristics, high strain rate characteristics, and acceptable long term creep
• Structural
  – Deployment issue studied
  – New design criteria developed and documented – includes material requirements, service life considerations, factors of safety, and more
  – Deployment test structures fabricated and tested
Model Test Balloons

FLT 496NT Shape Anomaly

Scaled Hangar Test Structure

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June 2003
Remove Excess Material for Proper Deployment
## Balloon Design

<table>
<thead>
<tr>
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<th>Phase IV</th>
<th>Phase IVA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td>520,483 m³ (18.38 MCF)</td>
<td>610,533 m³ (21.56 MCF)</td>
</tr>
<tr>
<td><strong>Material weight</strong></td>
<td>37.7 g/m²</td>
<td>37.7 g/m²</td>
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<tr>
<td><strong>Number of gores</strong></td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td><strong>Gore length</strong></td>
<td>152.7 m (501 ft)</td>
<td>160.3 m (526 ft)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>2,155 kg (4,740 lb)</td>
<td>2,578 kg (5,692 lb)</td>
</tr>
<tr>
<td><strong>Inflated height</strong></td>
<td>68.9 m (226 ft)</td>
<td>71.6 m (235 ft)</td>
</tr>
<tr>
<td><strong>Inflated diameter</strong></td>
<td>144.9 m (377 ft)</td>
<td>121.0 m (397 ft)</td>
</tr>
<tr>
<td><strong>Float Altitude</strong></td>
<td>~34,110 m (111,900 ft)</td>
<td>~33,600 m (110,200 ft)</td>
</tr>
<tr>
<td><strong>Suspended Load</strong></td>
<td>2,045 kg (4,500 lbs)</td>
<td>2,720 kg (6,000 lbs)</td>
</tr>
<tr>
<td><strong>LSI</strong></td>
<td>~1780 psi</td>
<td>~1560 psi</td>
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Flight 1580PT – Flight Line Issue

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In Flight Video Captures
Balloon Recovery

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Flight 1580PT – Differential Pressure

Mission Elapsed Time

Tendon Load (kg)

Differential Pressure (Pa)
Flight 1580PT – Conclusions

• Break down in manufacturing process
• Tendon attachment was a “blind” process
• Inspection of tendon attachment difficult - also a “blind” process
• Punctured tendons were inherent problem
• NSBF QA observed rather than inspected for this balloon
• Numerous recommendations made to BPO
• Full review and revision of production documentation completed – Material Specifications, Fabrication Procedures, and Quality Procedures
• Additional inspections with sign-off’s added
Australia 2003 Mission Success Criteria

• This was a Test Flight
• Synopsis of balloon minimum mission success criteria
  – Successful Launch
  – Successful Deployment
  – Pressurization
  – Altitude Stability During Flight
  – One Circumnavigation (Australia to Australia precluding Safety required termination)
Test Flight 517NT

- ULDB Test Flight 517NT on March 16, 2003
- ULDB Test Flight Preparations
  - Balloon “unpacking” and prep for flight was very smooth and efficient
  - Checklist procedures previously developed allowed flight preps to be completed in about half the time
- Long Wait for Acceptable Launch Conditions
- Launch Operations
  - Followed previously established procedures and checklists
  - Launch went like “clockwork” – no issues, surprises, or delays
  - Tow balloon and inflation tube releases with primary squibs – no issues
  - Usual “vacuum” at base fitting indicating a sealed balloon
  - Stand-up and launch were very smooth (“Best to date” for ULDB)
Notes on the Balloon Vehicle

- Flanges on red wrap worked very well
  - Easier unloading and handling on flight line
  - No damage found on balloon on flight line (significant improvement)
  - Improvement recommended to be instituted on ZP balloons
- No swirl in apex or base where balloon attaches to the fittings
- Balloon deployment through spool was as expected
  - Balloon carefully stacked and packaged for inflation deployment
  - Better than previous balloons
- Base fitting cart worked as designed
ULDB Test Flight Photographs
ULDB Test Flight Operations

• Ascent rates were within the expected ranges
• Smoothly transitioned into float.
• Auto-valve function activated to maintain balloon within pre-flight specified differential pressure limits – Auto-valve system worked as designed
• Balloon did not deploy properly (confirmed by up looking videos and telescope)
• Float altitude was a couple hundred feet below designed altitude
• After reviewing undeployed shape and performance data, decision made to terminate flight
• Flight terminated over a remote area on Aboriginal lands “near” a road
Flight Plot

Load Cell and Balloon Apex Pressure

UTC

Load Cell (pounds)

DP 4 reading (Pascals)

Prior to Inflation

During Inflation

Spool Release

Ballon Ascent

Ballast Drops

Balloon pressurization

Load Cell

DP 4
ULDB Test Flight Photographs
ULDB Test Flight Photographs
ULDB Test Flight Photographs
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ULDB Test Flight Photographs
Recovery and Post Flight

• Payload found the only water for 100’s of kilometers (“clay pan” Aboriginal Holiday spot)
• Balloon pile was a mess (like all balloons after flight) – damaged on descent
• Impact area measured (~33 ft by ~66 ft)
• Apex and base fittings looked as they did on launch
• All tendons were attached on apex and base
• Three small pieces of the balloon retrieved – final balloon recovery completed
• Balloon returned to the U.S. on June 20
Recovery and Post Flight Photographs
Recovery and Post Flight Photographs

Henry M. Cathey, Jr.
NMSU/PSL/WFF
June 2003

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Next Steps

• ARB - Investigating issues identified from “fishbone analysis”
• Balloon has just returned to the NSBF on June 20
• Inspection of balloon and accessories to be done July 7 to 11
• Design and modeling of potential fixes in process
  – Pattern design changes to ensure deployment
  – Approaches to “force” deployment being investigated
• Proposed verification plan to test “fixes” will be presented to BPO
  – All potential “fixes” will require fabrication and testing
  – Will include recommendations for each approach, test structures to be built, proposed test flights, schedule, and cost
Next Steps

• Specific final “fixes” are TBD
  – Pending completion of identified efforts from “fishbone analysis”
  – Pending review and recommendations by investigation committee
  – Pending BPO selection of approaches to be tested

• Next test flight date, location, and success criteria are TBD