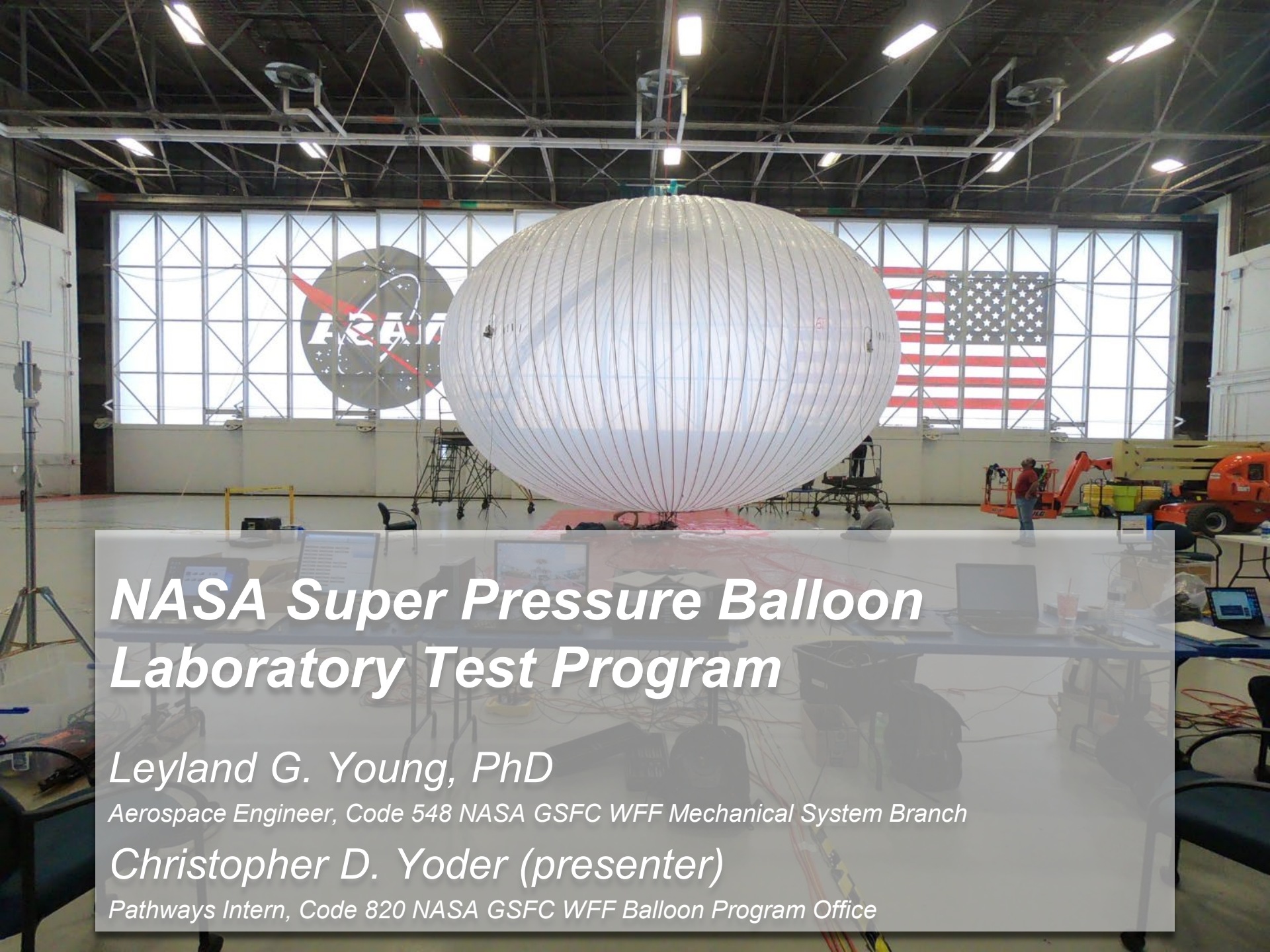

NASA Super Pressure Balloon Laboratory Test Program

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Agenda

- *NASA 18.8mcf background*
- *Performance and concerns*
- *Scale Model Test*
- *Observations*
- *Conclusions*

18.8 mcf SPB with the COSI gondola (Flight 669NT) during inflation.

NASA's 18.8mcf SPB

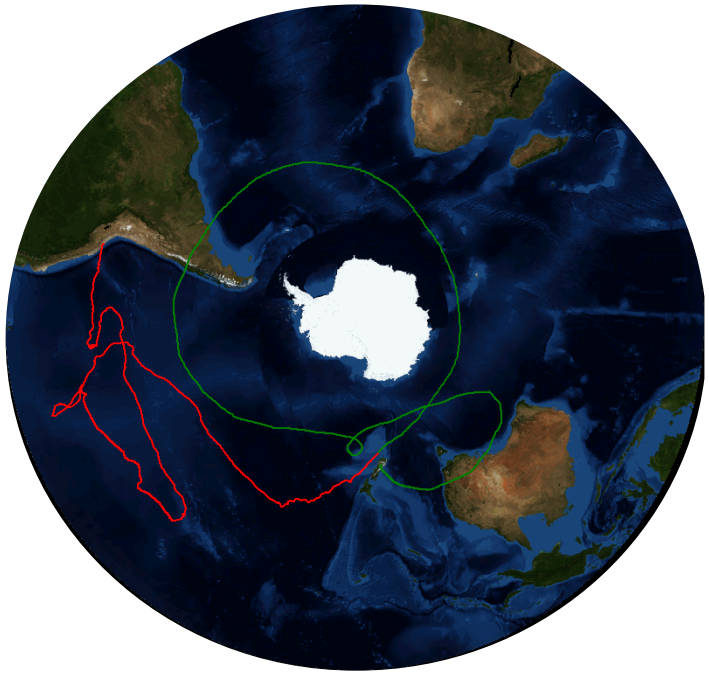
- *The design goals of NASA's Super Pressure Balloon (SPB) are[1]:*
  - *Lift 1 ton of science*
  - *Sustained nominal flight at 110 kft (33.53 km)*
  - *Sustained flight of 100+ days*
  - *Independent of mission type and float latitude*
- *Incremental size development has led to the 18.8 mcf (532,200 m^3) size*

18.8 mcf SPB with the COSI gondola (Flight 669NT) after launch from Wanaka, NZ in 2016.

[1]https://sites.wff.nasa.gov/code820/spb_development_goals.html

Recent performance

- *Two recent flights: 662NT (2015) and 669NT (2016)*
  - *Both balloons were recovered post-flight*
  - *Inspections identify film damage in the form of film pullout and elongated fastener holes*
- *Design paradigm: the tendons should strain arrest the film*
  - *No evidence of pullout or elongation prior to 662NT*



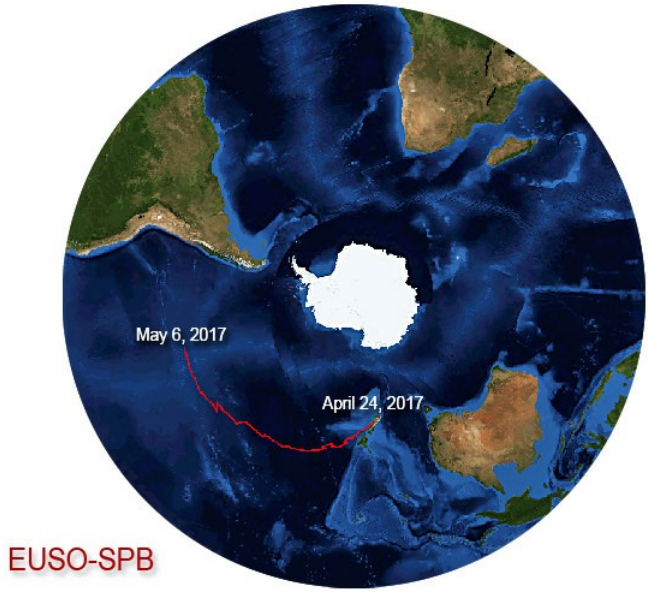
Flight 669NT, SPB SN05 with COSI.

Post-flight end fitting inspection showing elongated holes.

Need for a scale model test

- *Flight 679NT (EUSO-SPB, 2017, Wanaka)*
  - *Launched April 24th, 2017*
  - *Flight time:12 days, 4.5 hrs*
- *Several items were identified as potential contributors*
  - *Prompted the BPO to implement a scale model test program*
    - *To investigate the addition of the WBW sleeve over Zylon*
    - *To investigate the glue bond strength in the WBW sleeve*

Flight 679NT, SPB SN06 with EUSO prior to launch.



Flight 679NT flight trajectory. Courtesy of https://eusospb.uchicago.edu/follow.php

Scale Model Test (SMT) design

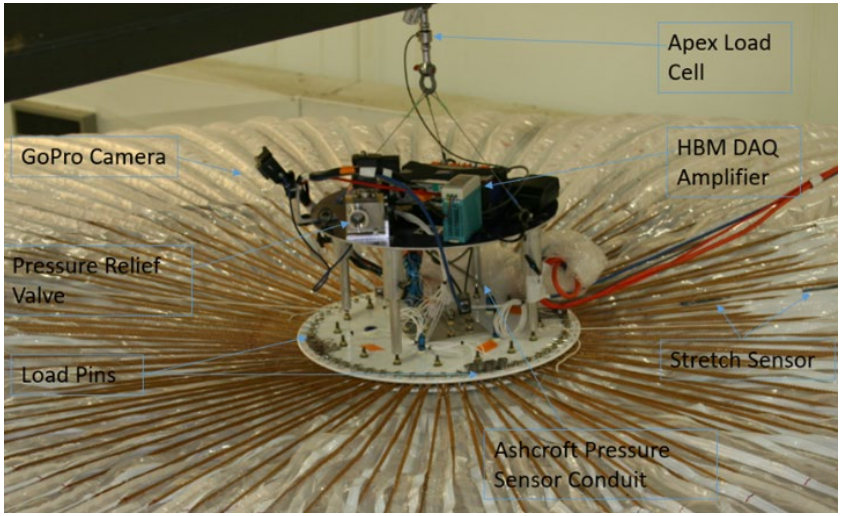
- *Three Scale Model Balloons (SMBs)*
  - *SMB-1: Same fabrication technique, glue as SN06*
  - *SMB-2: Same fabrication technique, no glue*
  - *SMB-3: Same fabrication technique, new glue*
- *Complete pressurization at RT (at WFF) and TVAC (at Neil A. Armstrong Test Facility)*

Critical parameters of the SMT balloon design.

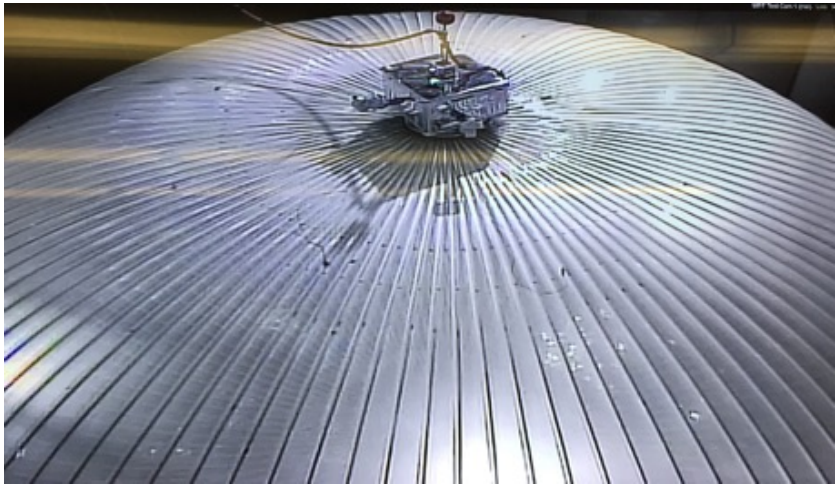
Balloon volume, cubic meters (ft^3)	257.8 (9104.1)
Balloon max diameter, m (ft.)	8.756 (28.73)
Balloon max height, m (ft.)	5.928 (19.45)
Balloon Unstressed Cap Length, m (ft.)	4.16 (13.65)
Unstressed gore length, m (ft.)	11.413 (37.44)
Max unstressed gore width, m (ft.)	0.52 (1.71)
Max bulge angle, degrees	33.9
Max bulge radius before creep strain, m (ft.)	0.873 (2.86)
Total Balloon Material Mass (excluding end fittings), kg (lbs.)	18.3 (40.34)
Skin shell mass, kg (lbs.)	7.1 (15.65)
Cap material mass, kg (lbs.)	2.1 (4.63)
Seal Area: Load tape/tendons/fin/backup tape material mass, kg (lbs.)	9.1 (20.10)
Tendon unstressed length, m (ft.)	11.413 (37.44)

Instrumentation

- *Apex, base tendon loads (load pins)*
- *Apex, base WBW sleeve and film strain (stretch sensors, hand measurements, camera images)*
- *Equator film strain (stretch sensors, photogrammetry)*
- *Apex, base differential pressure (Ashcroft DP sensors)*
- *Apex, base, equator temperatures (thermocouples)*
- *Balloon height (laser range finder)*
- *Helium mass flow rate (mass flow meter)*
- *Ambient air temperature, barometric pressure, humidity (HOBO datalogger)*

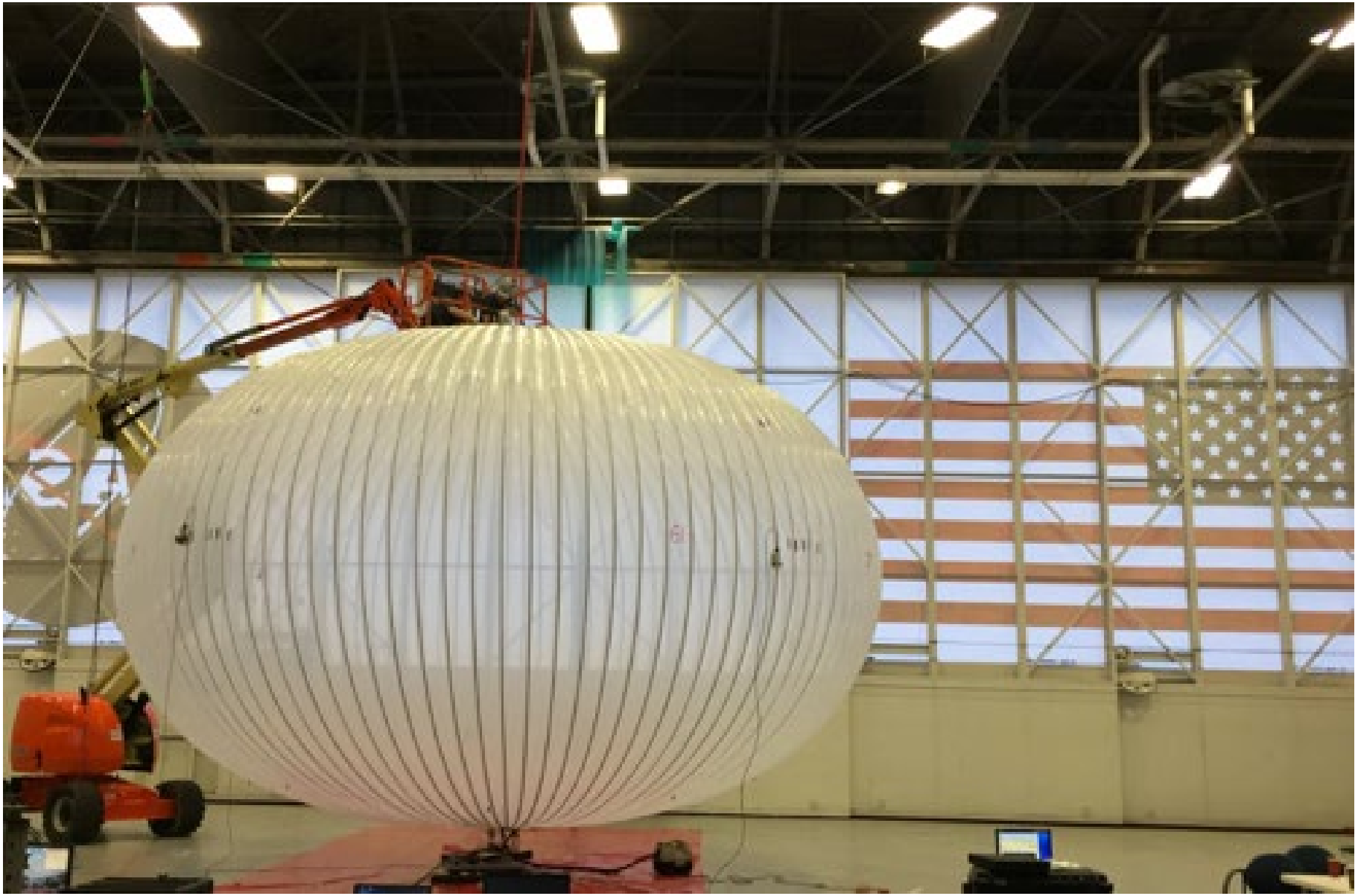


Apex instrumentation attached to the SMB during RT testing.

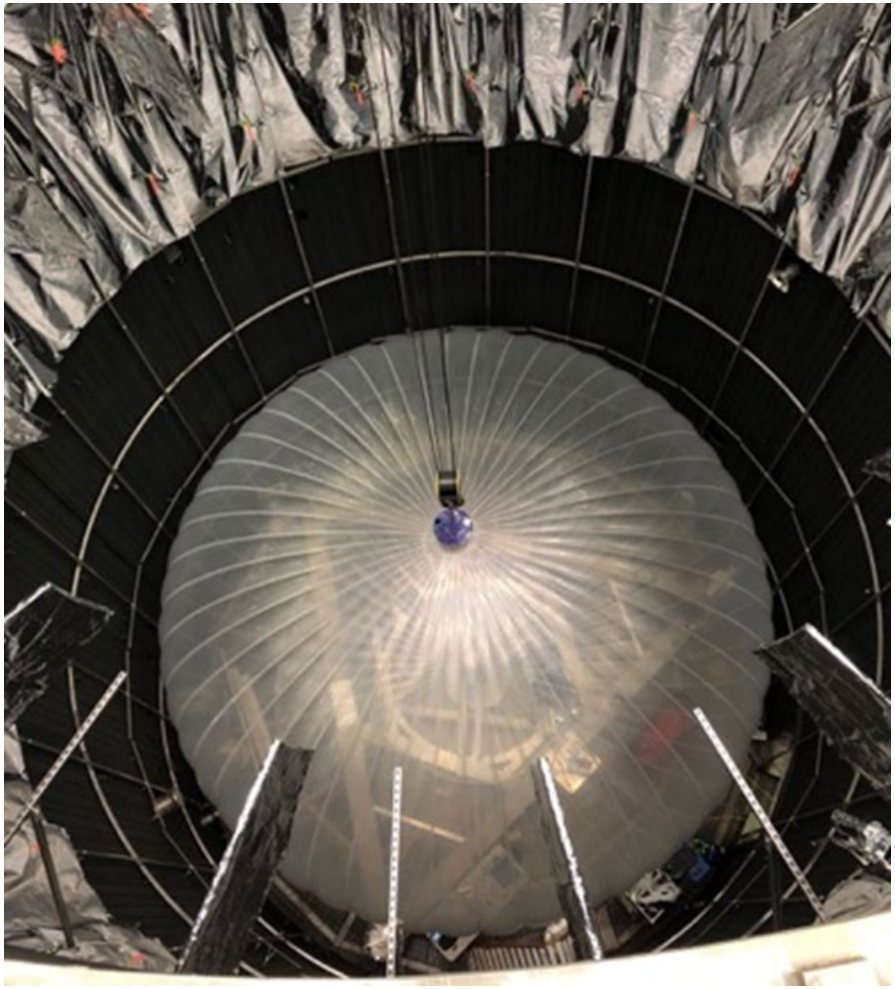


Apex instrumentation attached to the SMB during a TVAC test with the SMB fully deployed.

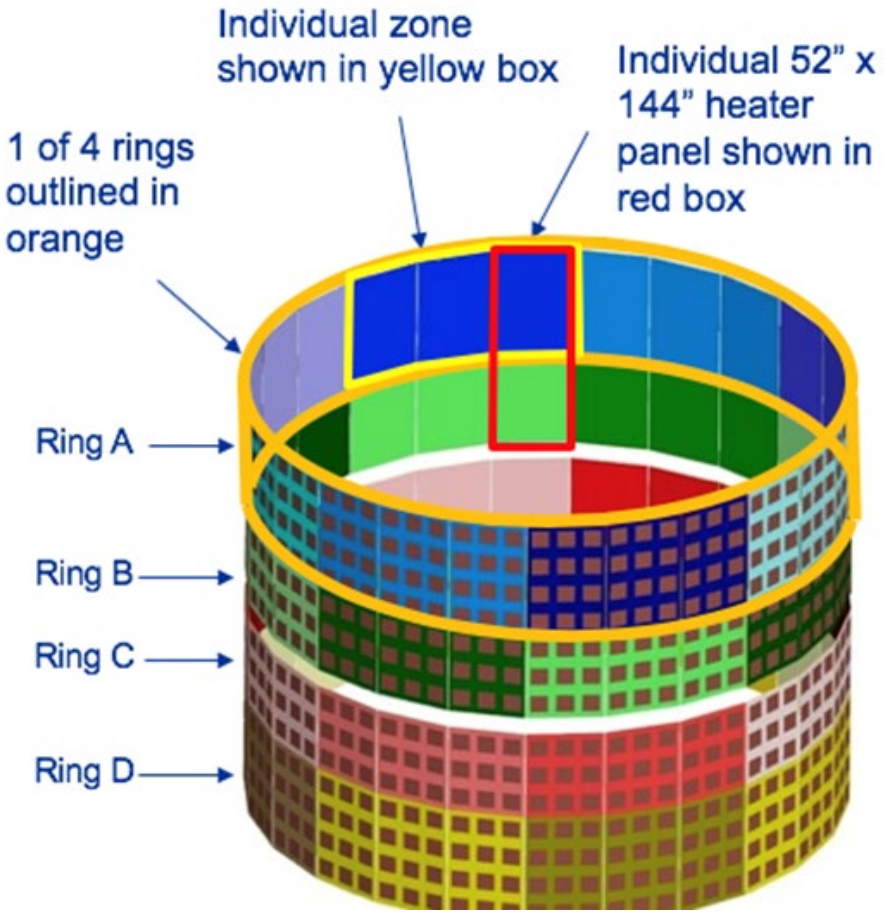
Room temperature – setup



TVAC - setup



Practice inflation of a similar SMB inside the chamber at sea-level conditions. Courtesy of the ISP group.



Schematic of the heating scheme to control the balloon during the TVAC test. Not shown are the top heater plate and the bottom heater panels for apex and base control. Courtesy of the ISP group.

TVAC - simulated profile

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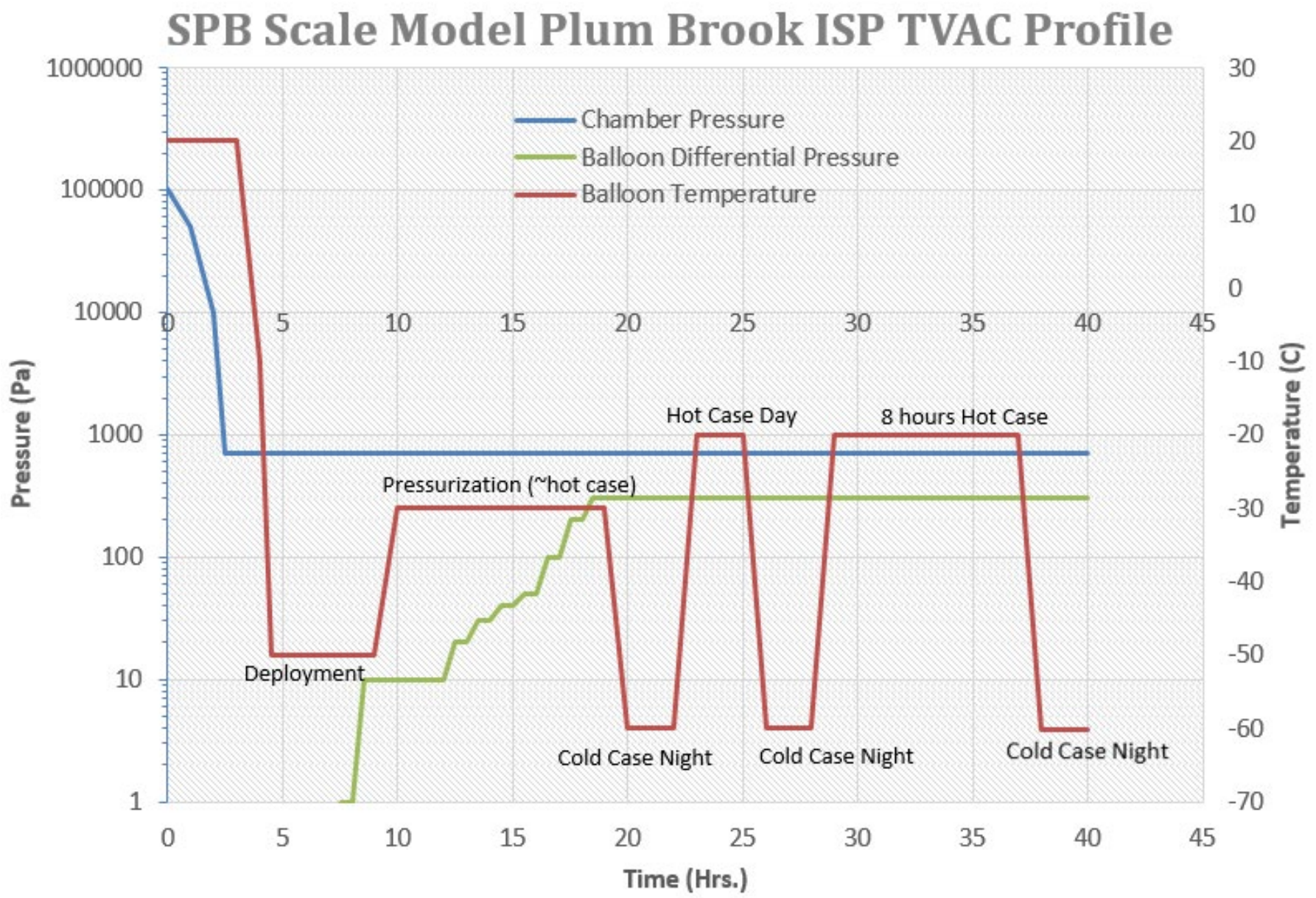
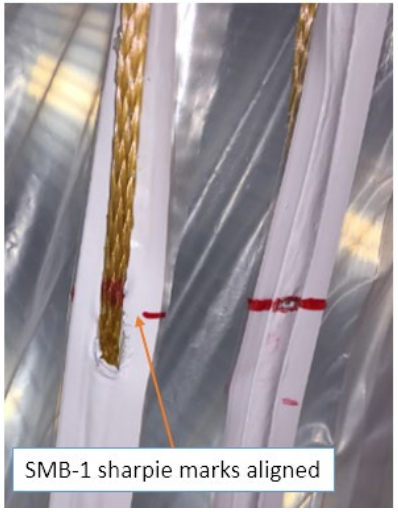
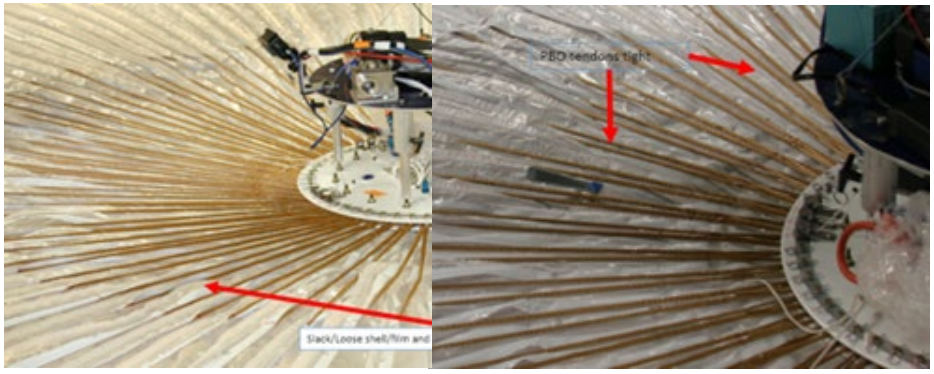


Observations – Room Temperature

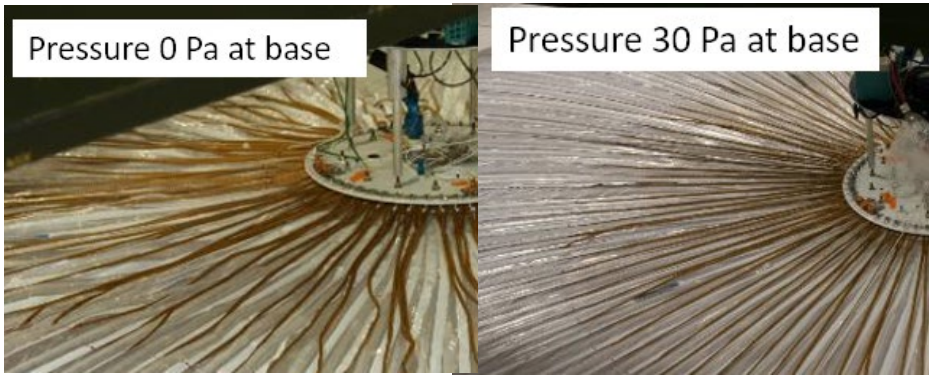
- *SMB-1, SMB-3*
  - *Shell motion towards the equator with increasing pressure*
- *SMB-2*
  - *Tendon displacement was found for SMB-2 (handling)*
  - *Tendon slack was removed with increasing pressure (due to tendon slipping into the sleeve)*



(left) SMB-1 showing alignment of the sharpie lines (made during manufacturing). (right) SMB-2 showing mis-alignment of sharpie lines due to a lack of glue.



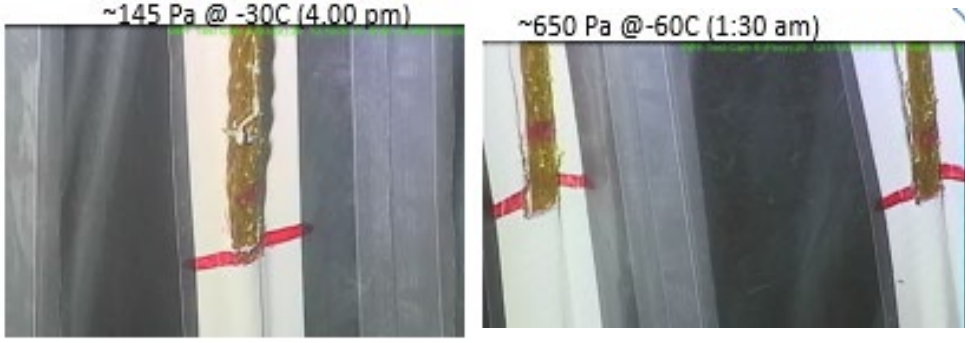
SMB-1 at 10 Pa (left) and 100 Pa (right) demonstrating the motion of the PE shell towards the equator.



SMB-2 at 0 Pa (left) and 30 Pa (right) demonstrating tendons taking up the load during pressurization.

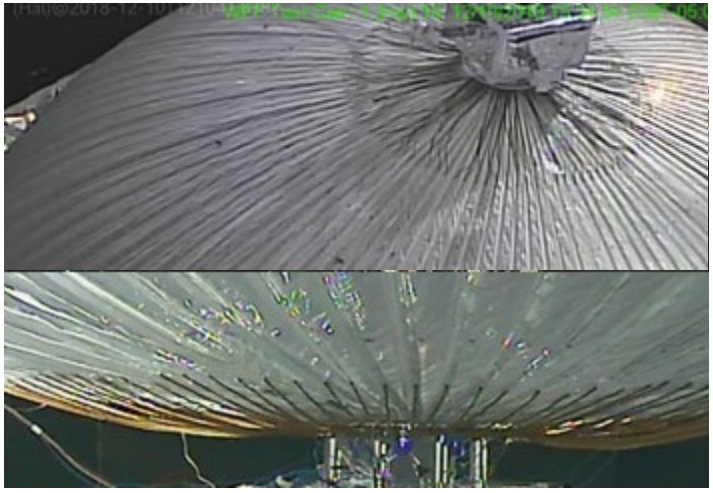
Observations – TVAC (tendon)

- *SMB-1, SMB-3*
  - *Slack tendons at low pressure (~0 Pa, test start) show length mismatch between PE film and tendon.*
  - *Necking observed at stripout due to pressurization, similar to FLT 669NT recovered sleeves.*

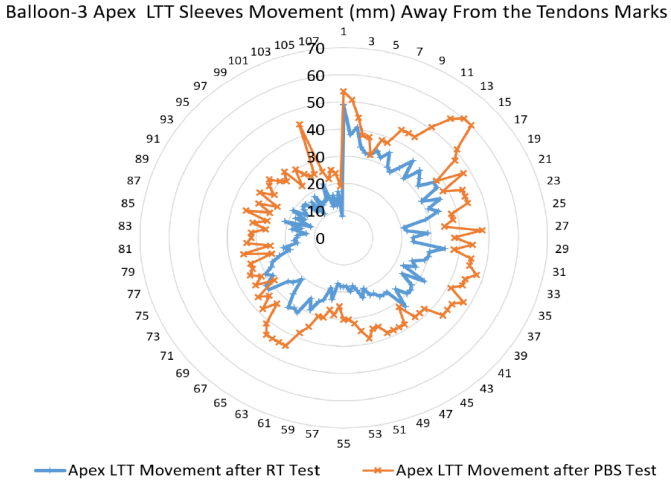


An example of sleeve necking due to pressurization and temperature.

- *SMB-2*
  - *Tendons were seen to move into the sleeves during pressurization.*



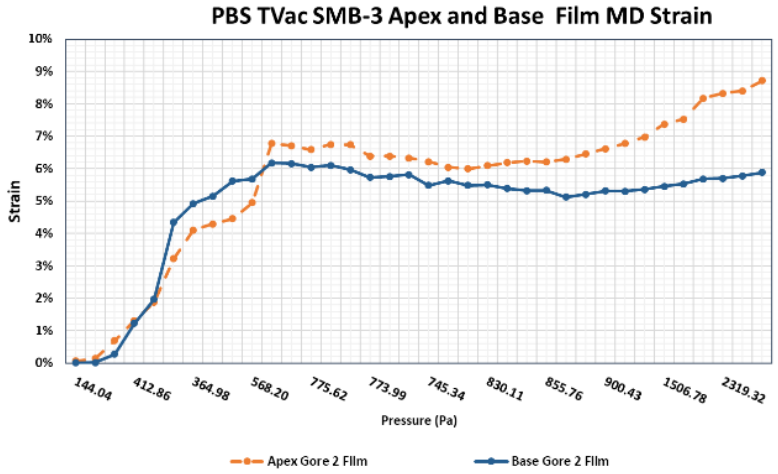
SMB-3 apex (top) and base (bottom) inside the TVAC chamber at cold temperatures with loose tendons when pressurized. The slack tendon is believed to be due to the shrinkage due to temperature.



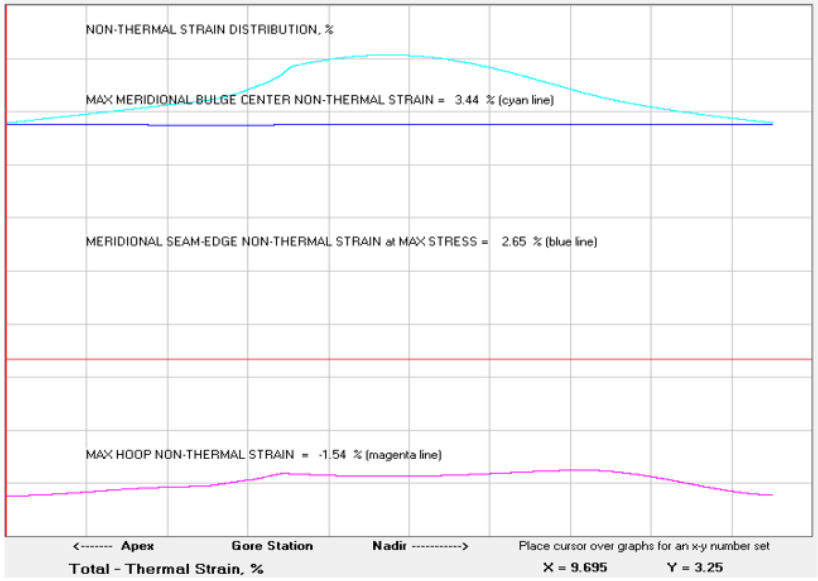
SMB-3 post-test measurements of apex tendon mismatch for RT (blue) and TVAC (orange)

Observations – TVAC (strain)

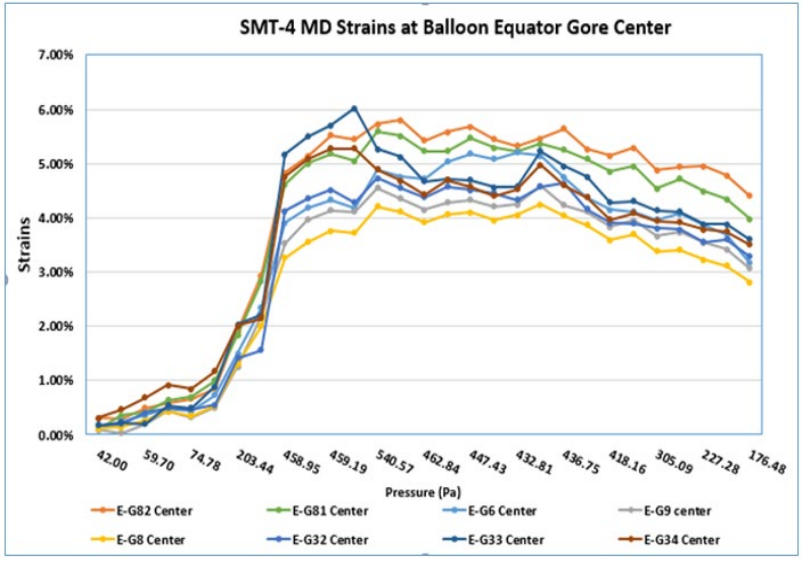
- *Strains*
  - *Polar regions had large strains (7-10%, measured from 560-2300 Pa)*
  - *Equator strains designed as 3.44% (mechanical only)*
  - *Total measured ranged from 3.5-5.5% (includes thermal strain)*



SMB-3 apex and base strains measured in MD.



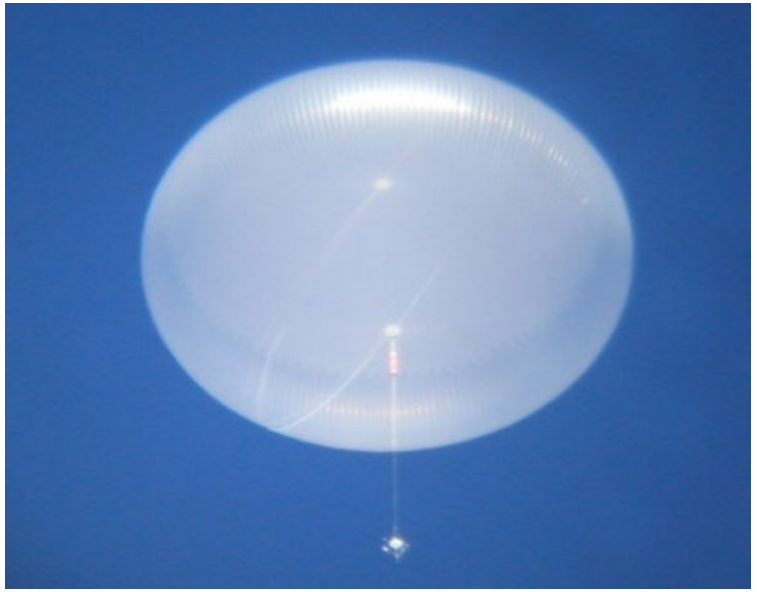
Design case for SMB-1, generated using the PlanetaryBalloon design tool.



SMB-2 (used for SMT-4) measured strains at the equator for several gore center locations.

Conclusions

- *Concerns exist that the tendon/sleeve behavior is not captured in existing models*
  - *Affects the "strain arrest" design paradigm*
- *Three SMBs were tested and compared in RT and CT*
  - *SMBs with glue show LTT motion away from the stripout similar to 662NT and 669NT*
  - *SMB-2 (no glue) had tendons slide into the sleeves, resolving film-tendon length mismatch*



Thank you!

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