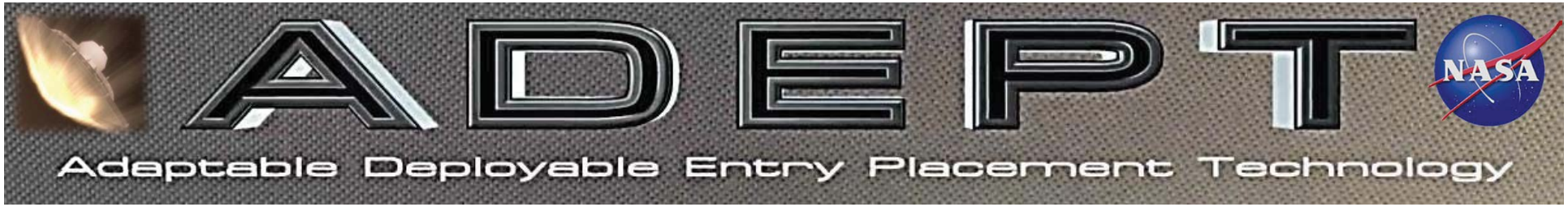

Deployment Testing of the ADEPT Ground Test Article

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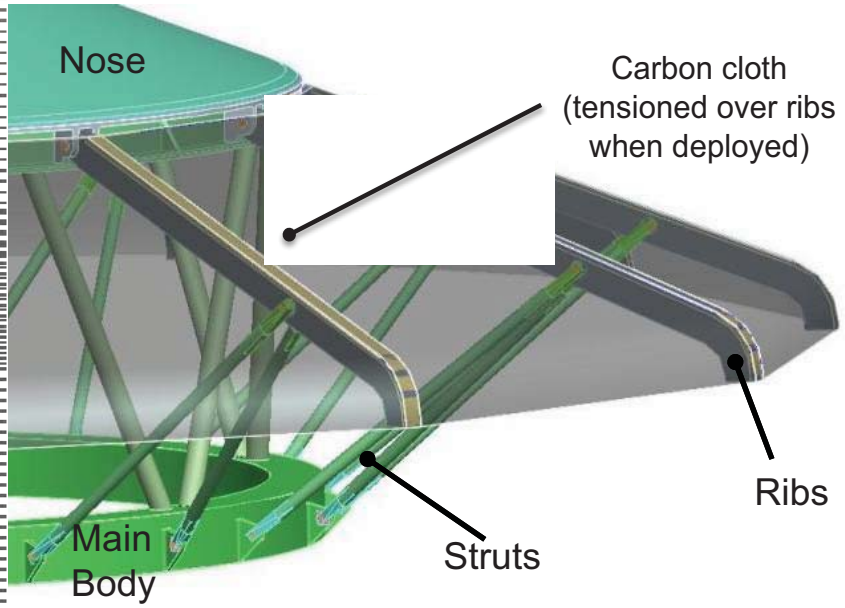
ADEPT Background
(Adaptive Deployable Entry and Placement Technology)

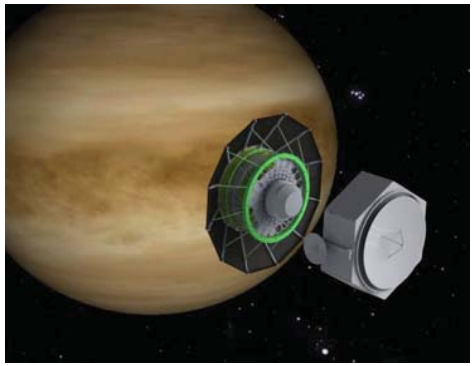
ADEPT is an atmospheric entry *architecture* that is Game Changing for missions to most planetary bodies with atmospheres.

- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Provides a benign deceleration and thermal environment to the payload.
- High-temperature ribs support 3D woven carbon fabric to generate drag and withstand high heating.

← Stowed for Launch

Earth Departure





Venus Arrival

ADEPT Benefits

Decreasing G-load (~ 10X reduction)

- Enables delivery of alignment-sensitive instruments such as those involving lasers
- Reduces flight qualification costs for instruments

Flight-system mass reduced by 25%

- Increases mass available for science or extended surface survival by factors of 2-10 times
- Enables use of next-generation instruments (more sensitive and massive)

Low peak heating rates (> 10X reduction)

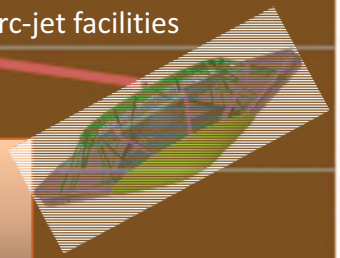
- Eliminates the need for traditional carbon phenolic
- TPS materials can be qualified in existing arc-jet facilities

Traditional Venus Entry:

- 200-300g's
- ~4000 W/cm^2

ADEPT Venus Entry

- 20-30 g's
- ~300 W/cm^2



GTA: Deployment Test Objectives

The ADEPT Ground Test Article (GTA) is intended to mitigate some of the mechanical risks associated with a large multi-element deployable system by developing and testing the configuration at a reduced scale.

Deployment Test Objectives

1. Demonstrate feasibility & reliability of the concept
   - Design configuration of mechanisms & actuators
   - Fabric behavior (unfolding, pre-tension, surface characteristics)
   - Control logic

2. Identify proper assembly procedures and tolerances
   - Verify that proposed integration procedure can be performed
   - Does resulting assembly meet requirements?

3. Study system response to off-nominal conditions during deployment
   - Robustness to imperfect conditions = higher probability of success

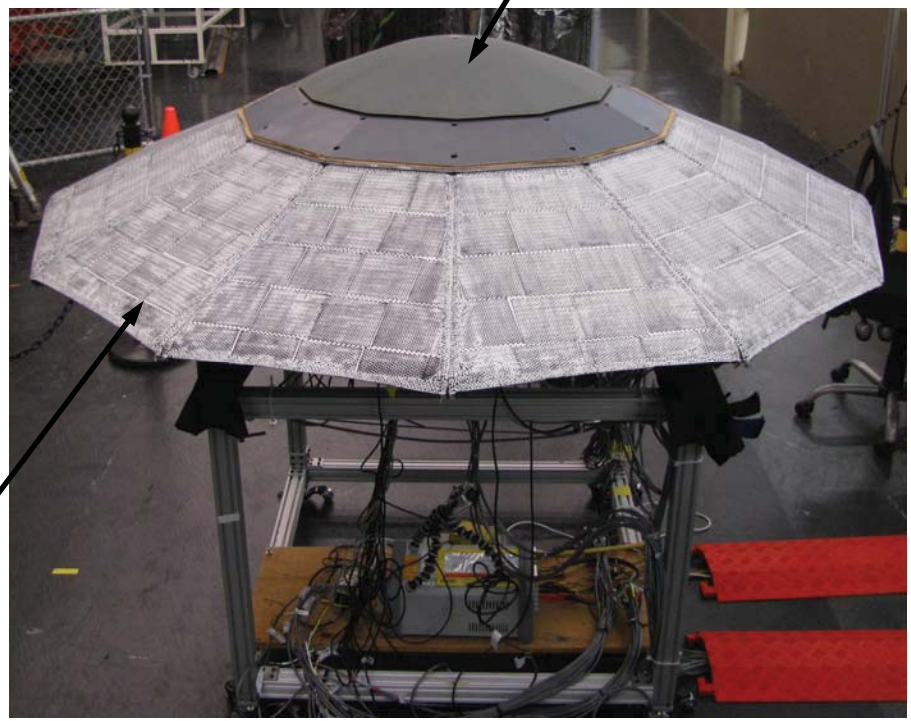
GTA Description

1/3 scale version of 6m ADEPT-VITaL (Venus mission) configuration

- Used scaling laws for structural & kinematic similitude where possible (scaling rigor limited by GTA budget and schedule)

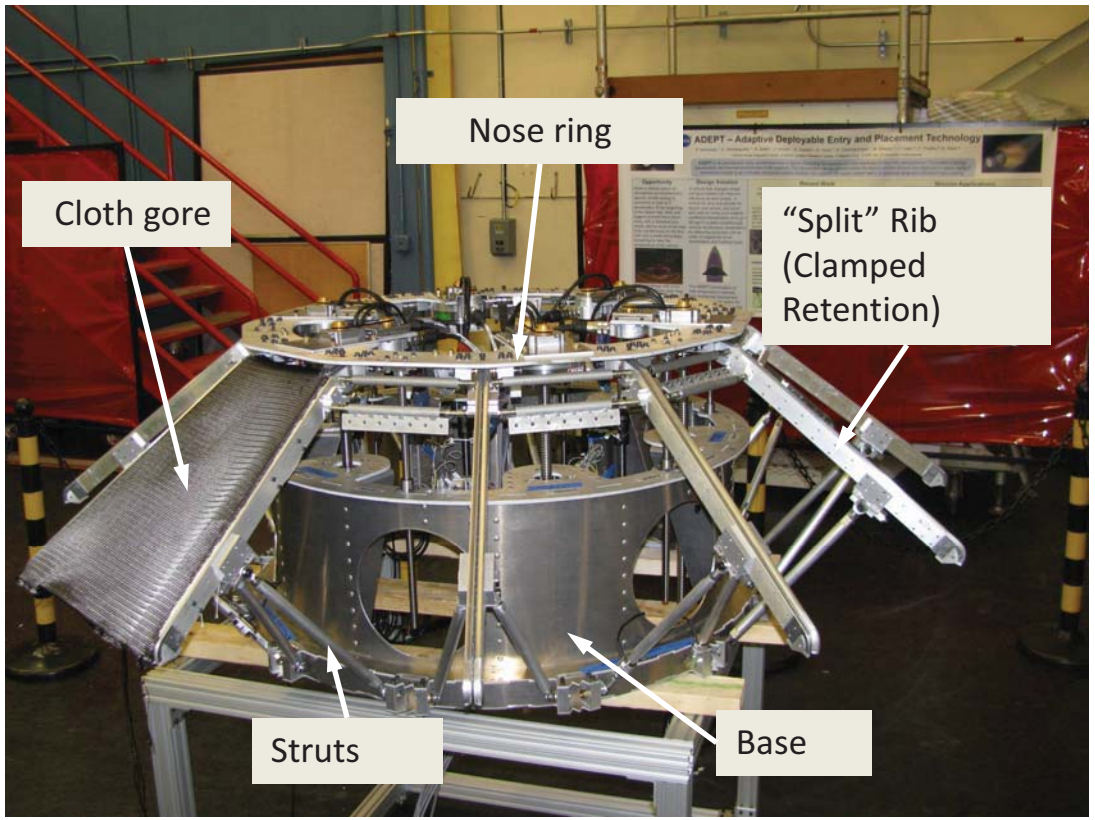
- 2 meter deployed diameter
- 70 degree sphere cone (12 facets)
- 1 meter diameter rigid nose cap
- Four layer 3-D woven carbon fabric manufactured by Bally Ribbon Mills

- COTS parts used extensively for rapid development and cost savings



GTA skeleton

- Cylindrical **base** is primary structure and acts as payload bay
- **Nose ring** supports rib pivots and drive system
- 12 **ribs** support cloth "gores"
  - Cloth gores are clamped between "split" rib halves
- 24 **struts** (2 per rib) support the ribs and allow them to articulate from the stowed to deployed position
- 6 synchronized **linear actuators** pull the nose down towards the base to deploy the aeroshell

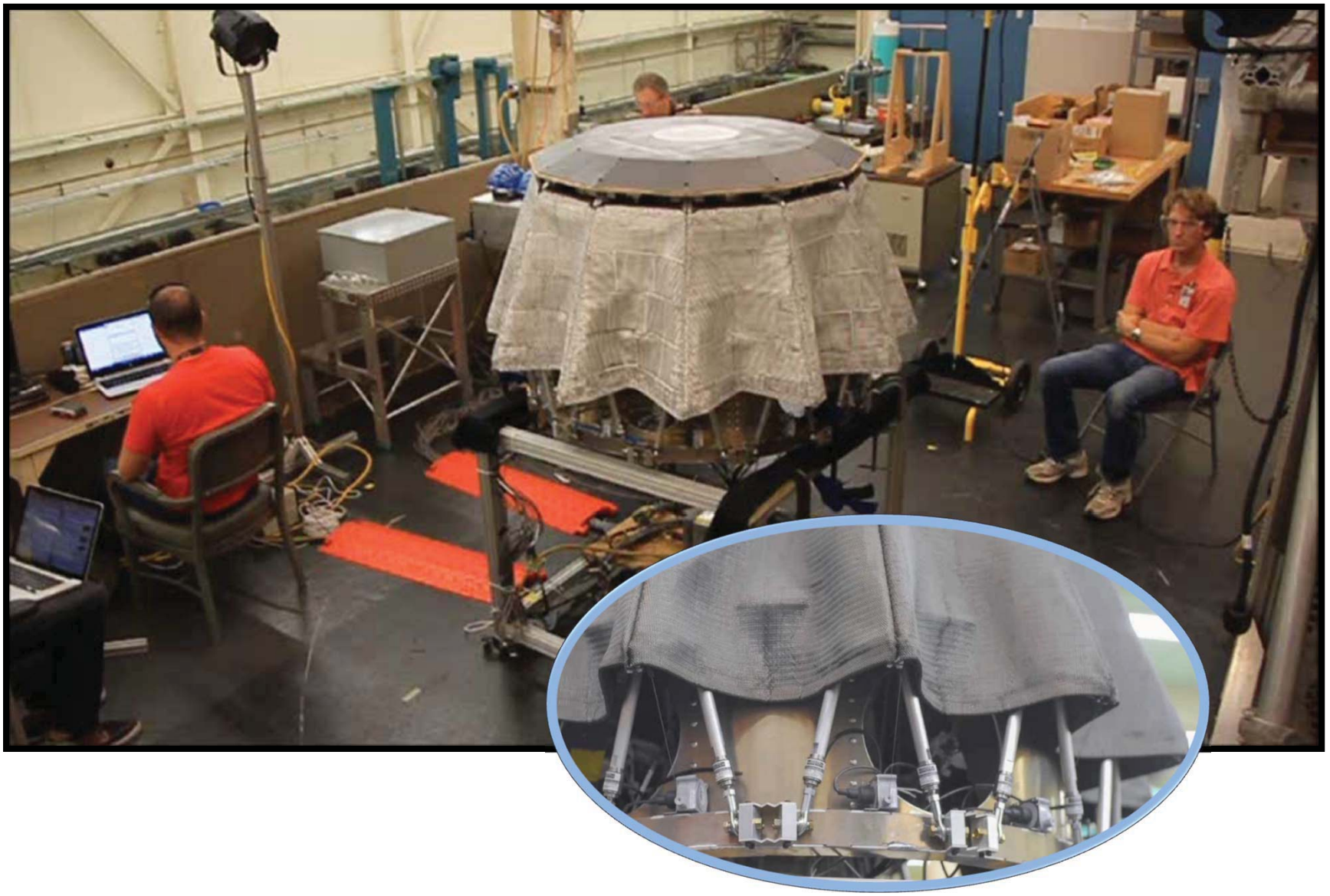


GTA Deployment Test Series

Series of deployment "runs" performed to address objectives:

- **Debug and fabric integration:**
  - Basic mechanism function was evaluated incrementally
  - Fabric was installed after deployment of bare "skeleton" checked out
- **Fabric tensioning and control system adjustments:**
  - Slowly increased deployment angle and deployment speed while evaluating fabric behavior and resulting tension
  - Adjusted control system parameters and fabric clamp position
  - Verified integrated system function & determined "nominal" conditions
- **Nominal testing:**
  - Performed multiple deployment runs (15+) to the nominal condition to observe repeatability & reliability
    - Resulting aero shell shape & fabric tension distribution
- **Off-nominal testing:**
  - Under-deployed one rib to create uneven fabric tension
  - Mismatched strut lengths to cause improper joint loading
  - Deployed with a simulated actuator failure (stopped 1 of 6 actuators)
  - Installed pin joints (in place of ball joints) at strut ends to evaluate DOF

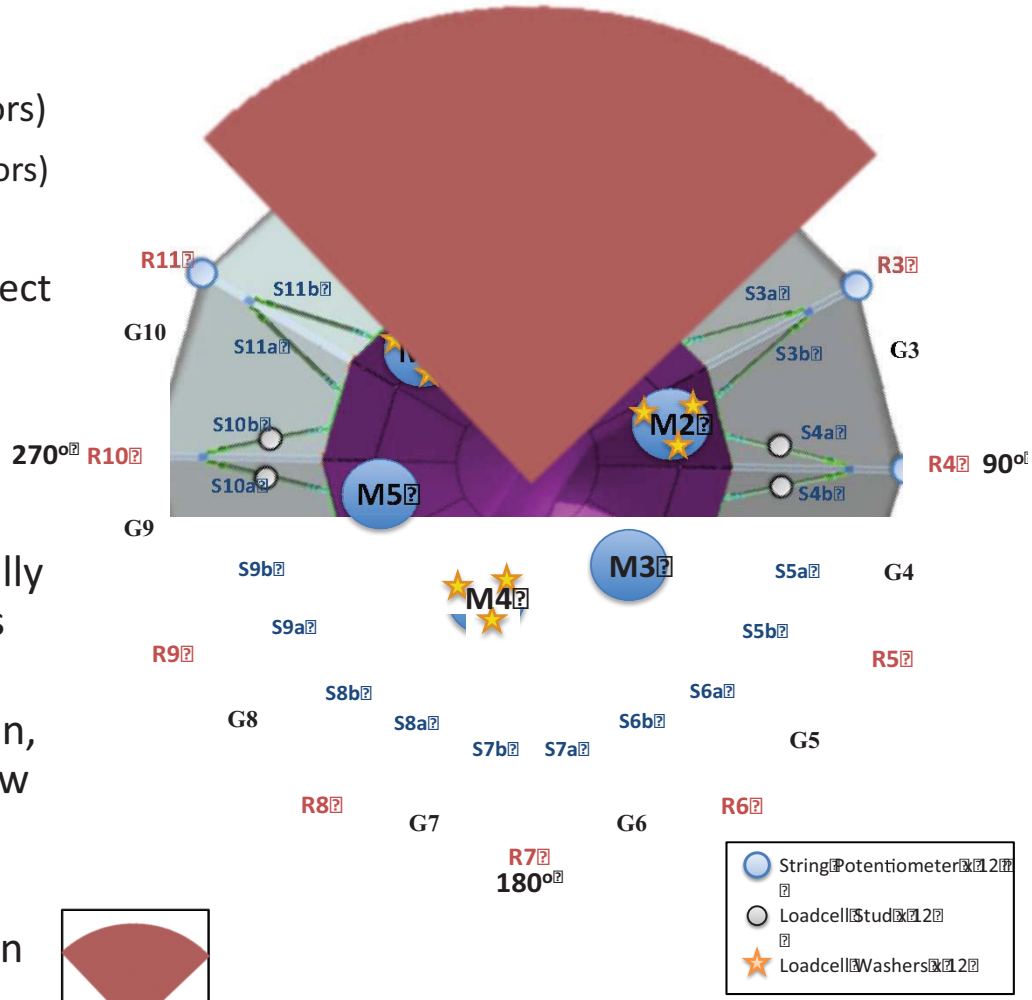
Time Lapse Deployment Video



Instrumentation

Measurement Methods & Locations:

- Rib angle (string pots: all 12 ribs)
- Strut loads (load studs: 12 of 24 struts)
- Actuator loads (load washers: 4 of 6 actuators)
- Actuator position (rotary encoders: all 6 motors)
- Photogrammetry (image top surface)
- Fabric tension (custom deflection tool: select locations)



- Only one quadrant of the model was fully instrumented due to budget limitations (symmetry was expected)
- Load distribution was somewhat uneven, so missing instrumentation did not allow complete load mapping
- Off-nominal conditions applied in region shown:

Results Summary

Deployment Feasibility & Reliability

•After the debug and adjustment runs were complete, all nominal and off nominal runs deployed successfully: (over 40 full deployment runs)

- ✓ All primary mechanisms and actuators performed as expected
- ✓ Fabric unfolded/deployed without problems
  - •No hang-ups or snags, no significant wear or fiber breakage
  - •Required fabric tension levels were achieved and maintained over multiple runs
- ✓ Control system maintained synchronization between actuators and deployed the aeroshell to the set rib angle within tolerance
- Missions will only require one deployment, but repeated successful deployments in varying conditions provides confidence in the ADEPT system

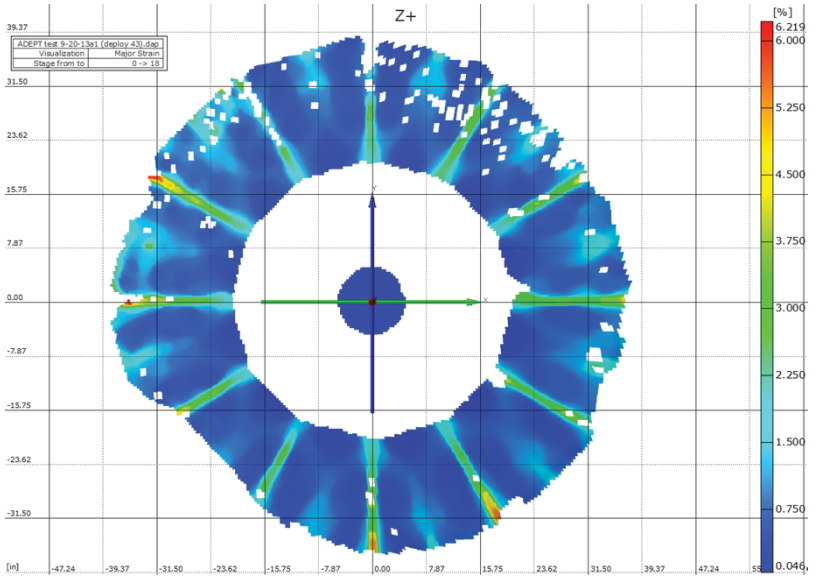
Average Gore Tension Prior to Run 33 and After Run 43

Run 43 deployed 0.1° more than Run 33

Results Summary (2)

- Assembly procedure and tolerances
  - Assembly procedure was satisfactory from an operations standpoint
    - ✓ The GTA was assembled without significant difficulty and operated mostly as planned
  - Deployment requirements were <u>partially</u> met via assembly procedure & tolerances
    - ✓ Able to generate and maintain tension at required <u>levels</u>
    - ○ Deployment stopped 0.7° short of target deployment angle (tension achieved prior to target)
    - ○ Gore tension distribution was not as consistent as desired
      - Photogrammetry of the 3-D woven carbon fabric did not provide reliable strain data (possibly due to the varying through-thickness construction of the fabric)

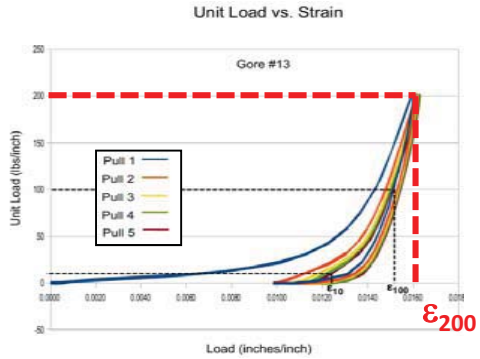
Measured Tension Within Gores – Run 43

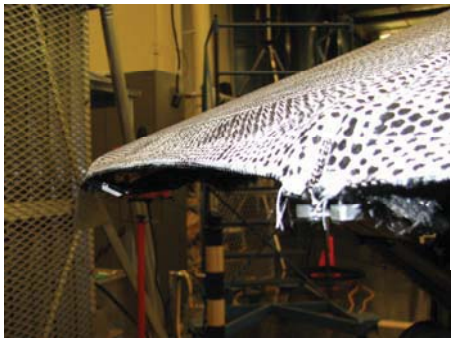


Photogrammetry Strain Plot – Run 43

Observations / Conclusions

- ***The high in-plane stiffness of the fabric makes integration tolerances critical to achieving the desired fabric tension and uniformity***
  - Fabric tension is very sensitive to deployed rib angle (small angle change ➔ large change in loads)
  - Clamped rib-fabric interface not conducive to load redistribution
- Fabric wear, wrinkling and fiber breakage not a problem
- First attempt at outboard shoulder shape generation was inadequate and needs improvement





<u>The GTA deployment test series was successful and informative:</u>

Test Objectives Addressed:

1. The ADEPT configuration was shown to be feasible and reliable
   - Deployed reliably / no primary mechanism or fabric problems
2. Assembly procedure was successful → functional system
   - ➢ Better fabric tension uniformity desired via improved integration methods and/or tolerances
3. System was robust to the off-nominal conditions applied