Atlas Centaur Sun Shield Design and Testing: An Update

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Enables GSO Missions for 400 Vehicle

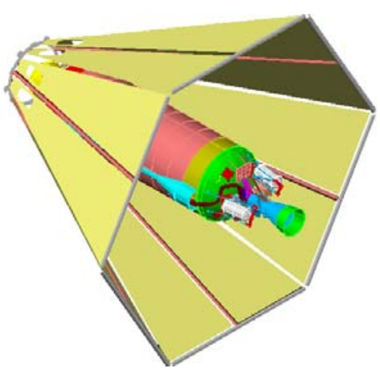
Centaur Sun Shield for an Atlas 400

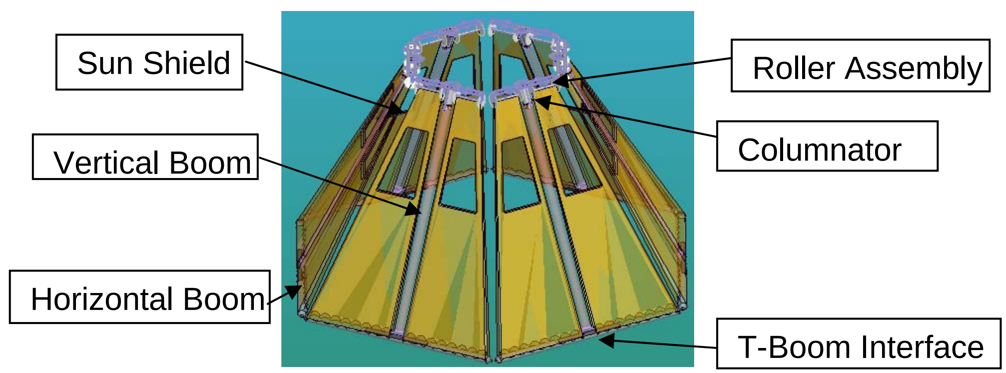
Centaur Upper Stage

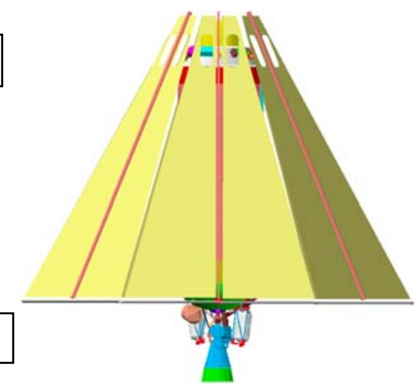
- Provides for longer coast missions on the 400
- Thermal shields, used in the past on the Atlas 500 vehicle, are protected from atmospheric air loads during launch by virtue of the fact that the Centaur is enclosed within the payload fairing
- On the Atlas 400 vehicle, the Centaur is exposed to the atmosphere during launch, and therefore has not flown with thermal blankets shielding the Centaur
- The sun shield design is also scalable for use on a Delta upper stage
- The deployable sun shield technology can be applied to:
  - Telescope Shades
  - Re-entry Shields
  - Solar Sails
  - Propellant Depots

What's a Centaur Sun Shield?

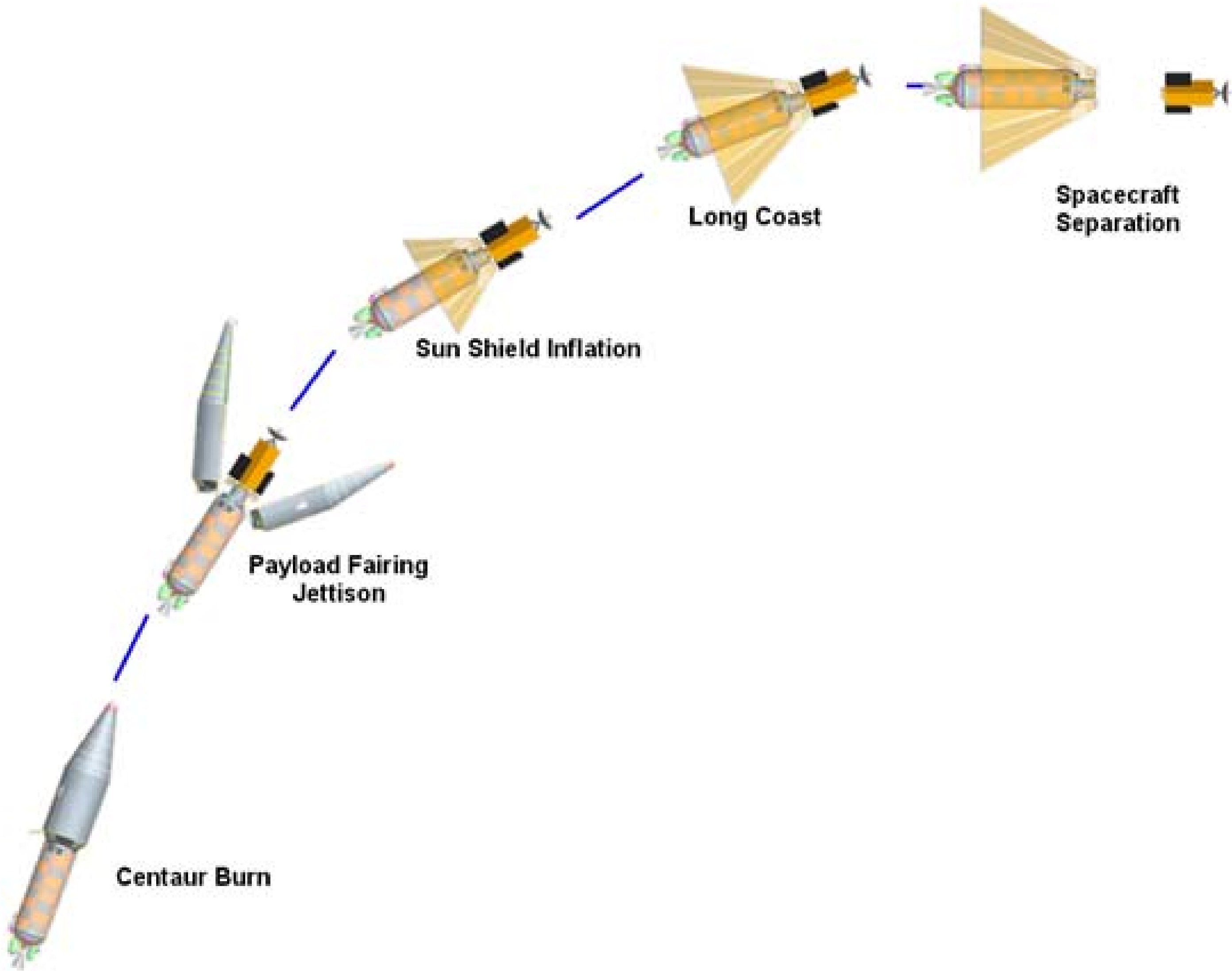
- A light weight, segmented thermal radiation shield that launches in a stowed configuration
- Deploys after payload fairing jettison by the inflation of booms
- Surrounds the Centaur's cryogen tanks to reduce radiation heat transfer
- A boom located at the center of each of the six trapezoids inflates independently of the other five
- Window openings at the forward end to allow the Avionics components to meet their thermal environment requirements
- An assembly called a columnator provides for boom stowage in a small package, and provides controlled inflation pressure and speed during deployment







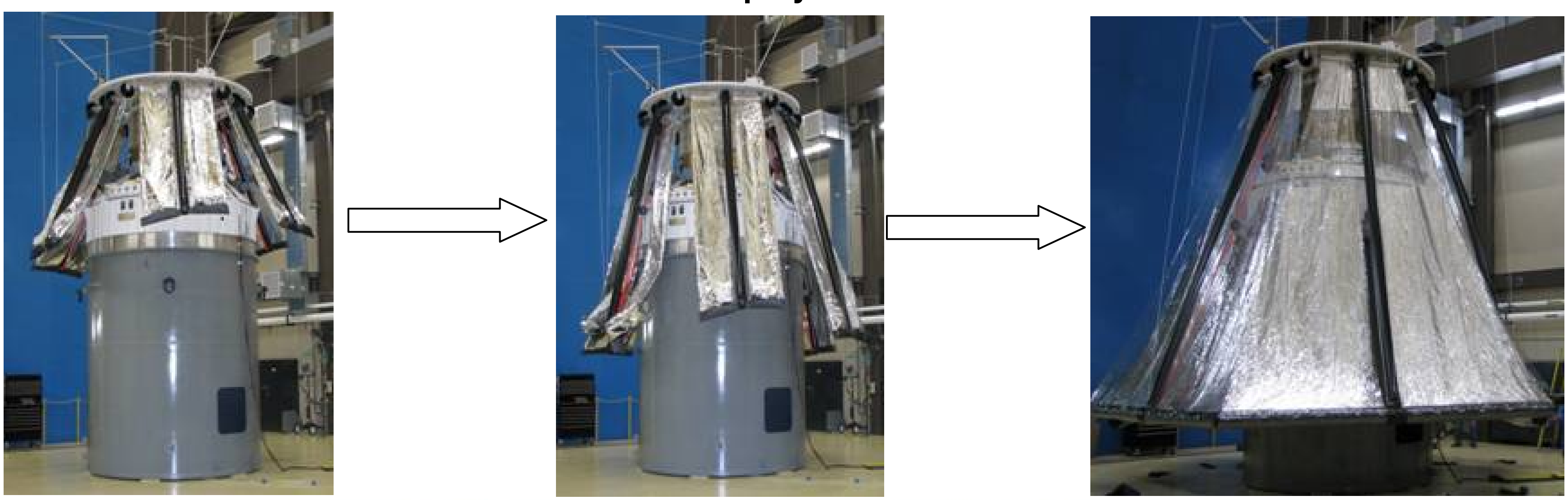
Concept of Operations



CSS First Deployment Test

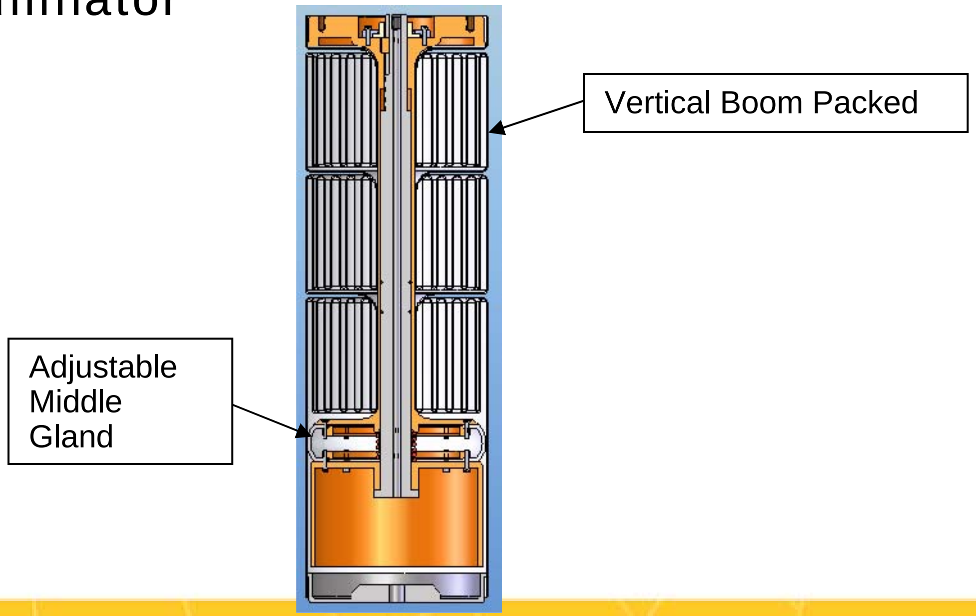
- A Phase I effort took place during 2007 in a partnership between ULA and ILC Dover which resulted in a deployable proof-of-concept Sun Shield being demonstrated at a test facility in Denver
- Centaur Sun Shield Phase I Accomplishments – April thru Dec, 2007
  - Completed design of demo unit, developed manufacturing processes, built one
  - Successful multiple tests conducted of both individual petals and a full-up CSS Assembly
  - Recording and documentation of the tests in the form of boom pressure readings, digital photos and digital movies, with 8 different camera angles
- A Phase II effort took place in 2008 thru March 2009 with a partnership between ULA, ILC, NASA Glenn Research Center (GRC) and NASA Kennedy Space Center (KSC) to define requirements, determine materials and fabrication techniques, and to test components in a vacuum chamber at cold temperatures

Sun Shield Demo Deployment in Dec 2007



Centaur Sun Shield - Components

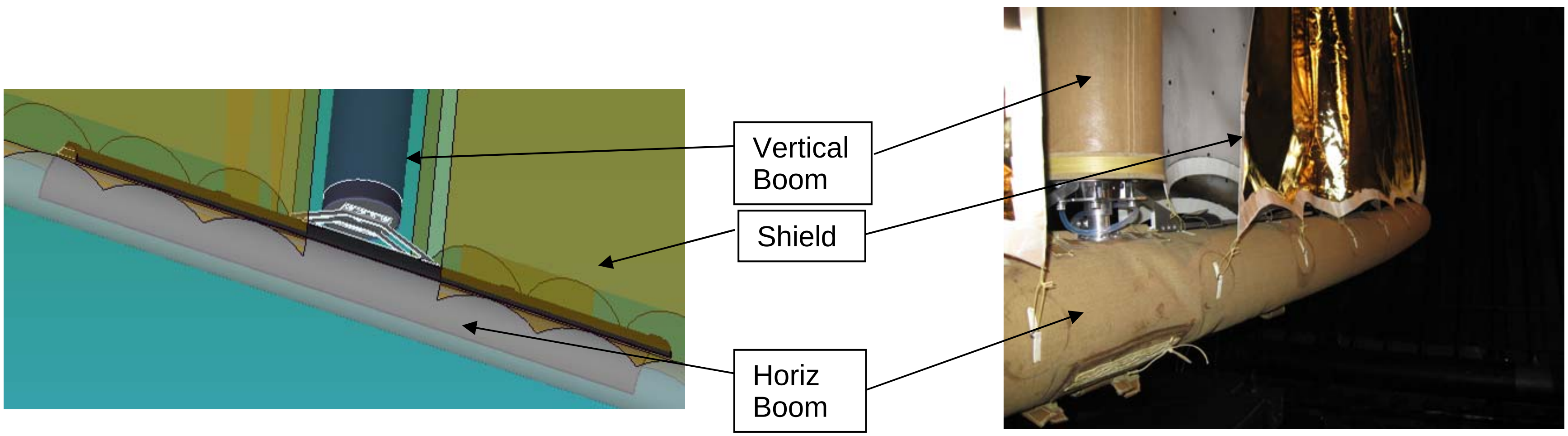
- Columnator is located inside the forward end of the vertical boom. It acts as an inflation port and packing volume for the boom, and has the appropriate packing volume for boom length
- The middle gland is adjustable externally from the boom, and is used during the packing and deployment stages
  - Compressed for the deployment stage, allowing it to regulate the speed and the pressure of the boom deployment
  - It is decompressed and retracted for the packing stage
- The top disc of the columnator helps stabilize and straighten the vertical boom during deployment. During the deployment stage, the inflation gas pushes the aft end of the vertical boom extruding the boom out and over the columnator



Centaur Sun Shield - Components

- The T-boom is the interface between the horizontal and vertical booms
- Horizontal boom inflates after the vertical boom fully inflates

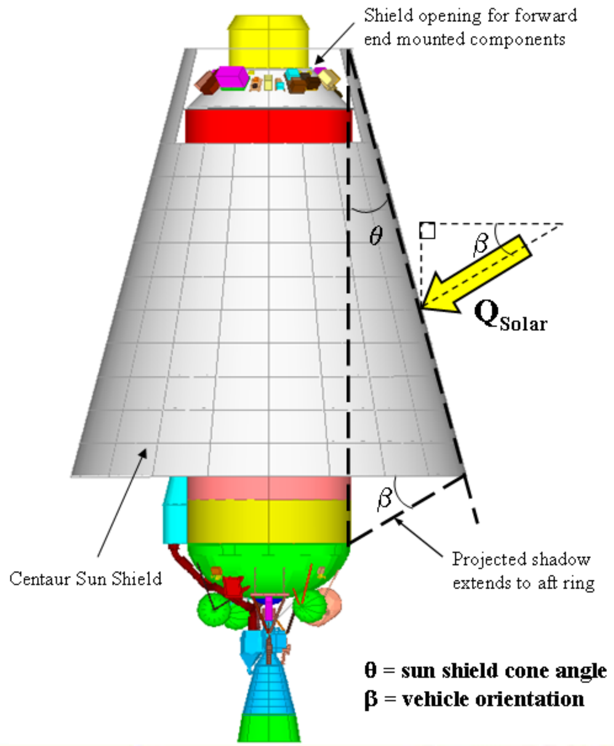
Photo from within Vacuum Chamber



Vertical-to-Horizontal Boom Interface

Centaur Sun Shield – Thermal Model

- A thermal analysis was performed to help define key design parameters for the CSS
- The Figure illustrates the key CSS design parameters which are sun shield cone angle (θ), vehicle orientation with respect to the Sun (β), and shield lay-up
- The thermal analysis focused on predicting hydrogen tank sidewall heating performance as a function of those shield design parameters



Thermal Analysis Assumptions

- The CSS is deployed on-orbit after the effects of ascent aeroheating are washed away
  - Fixed foam on Centaur tank
- The initial CSS will be designed to reduce on-orbit hydrogen tank sidewall heating rates to the levels experienced by the Titan Centaur launch vehicle
- The analysis considered varying sun shield cone angles
- The vehicle orientation was limited so the Centaur forward end and aft end mounted components will still meet their thermal requirements
- The analysis also considered number of shield layers ranging from 1 to 5, and two different shield material lay-ups
- While the sun shield is deployed it was assumed that the Centaur vehicle will be rolling about the flight axis such that it is evenly heated
- In modeling the heat transfer thru the sun shield, a radiation shield degradation factor was applied to account for on-orbit optical property degradation and contact between individual shield layers
- The liquid hydrogen was modeled as a boundary condition and was constrained to a temperature of -420°F

Thermal Analysis

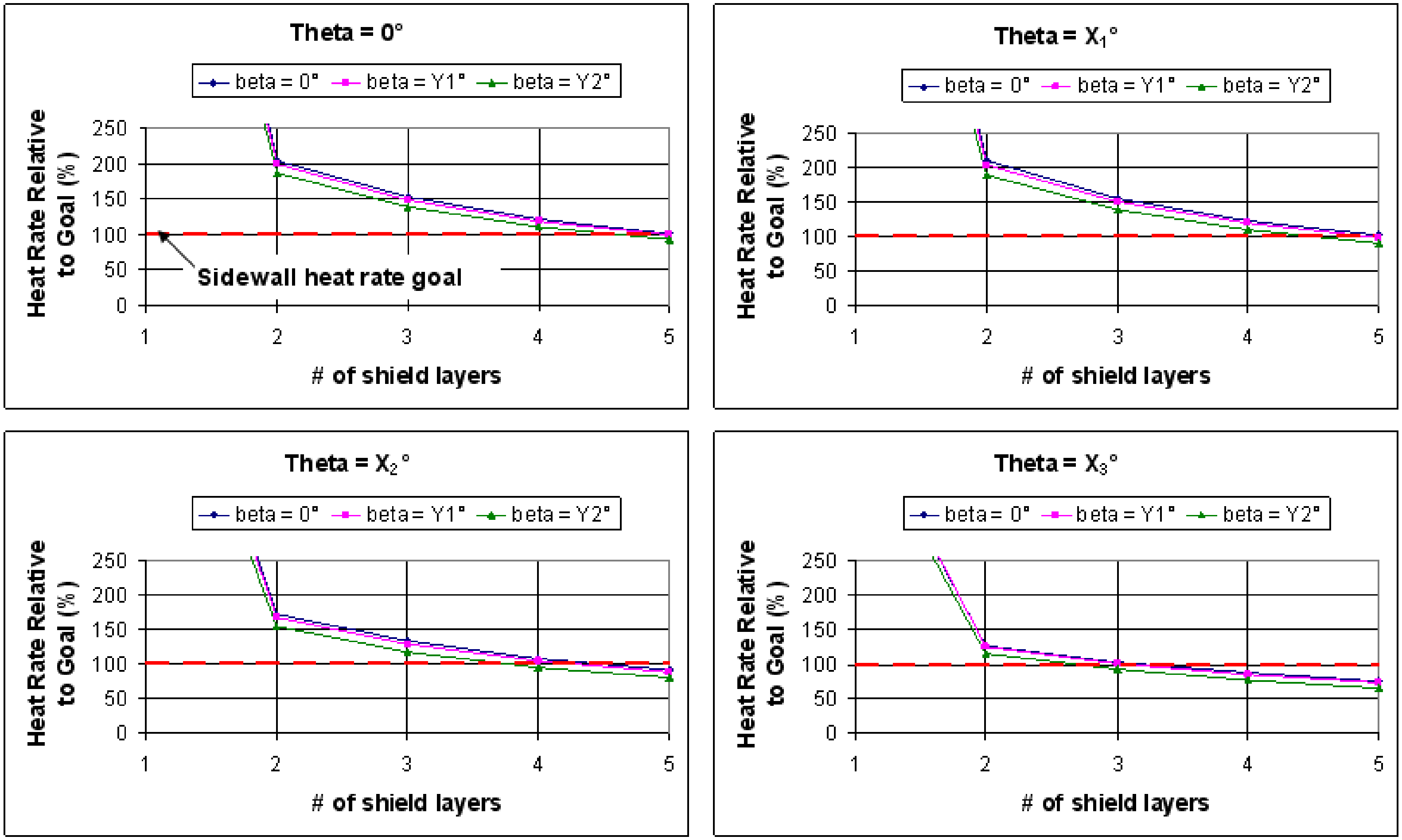
- The tables below list two of the shield configuration cases analyzed, with optical properties for each shield
- The Figures on the next slide show the predicted sidewall tank heating performance as a function of the various shield design parameters
- With the glass cloth-VDG as the outer layer, the heating rate goal can be met with a 3 to 5-layer blanket
- By changing the outermost shield layer to silver coated Teflon, with its lower solar absorptivity, a substantial decrease in tank heating is realizable with the same number of layers

Shield Layer	Shield Material	
	Case 1	Case 2
Outermost layer	Glass Cloth-VDG	Silver coated Teflon
Middle Layer(s)	DAK	DAK
Innermost Layer	DAK	DAK

Shield Materials	Optical Properties			
	Outboard		Inboard	
	emissivity	absorptivity	emissivity	absorptivity
Glass Cloth-VDG	0.81	0.35	0.03	0.21
Silver Coated Teflon	0.85	0.10	0.85	0.10
DAK	0.05	0.14	0.05	0.14

Thermal Analysis

Number of shield layers to accommodate heat rate design goal for different half-cone angles



Testing

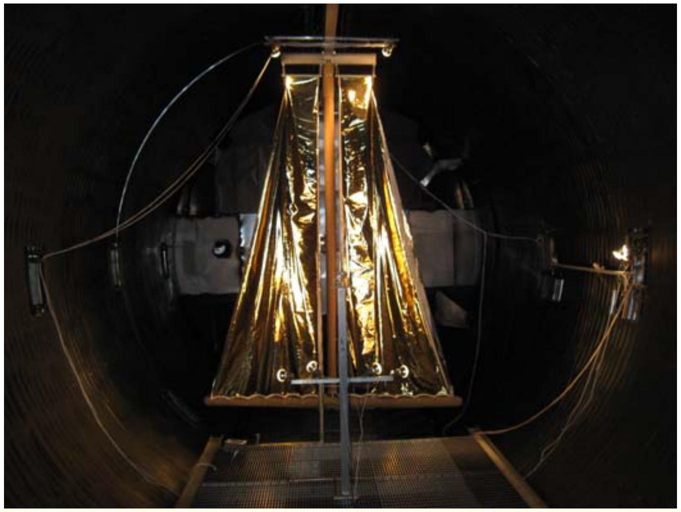
- Thermal vacuum chamber (TVAC) tests were conducted at NASA Glenn Research Center, Cleveland in Dec 2008 thru Feb 2009
  - A single petal subscale engineering unit was tested
  - The first series of tests was deployment of the single petal at its expected cold temperature
    - Observation and measurement of the CSS mechanical and pneumatic components' operation within a vacuum
  - The second test measured the thermal performance of the sun shield in vacuum
    - Measurement of shield layer temperatures; cold plate heat flux, etc.
- Separate from the TVAC tests (at a different location and time), a number of material coupon tests were also performed at low temperature

Testing

TVAC Chamber at NASA Glenn, Dec 2008
Ø22’ x 54’ Long

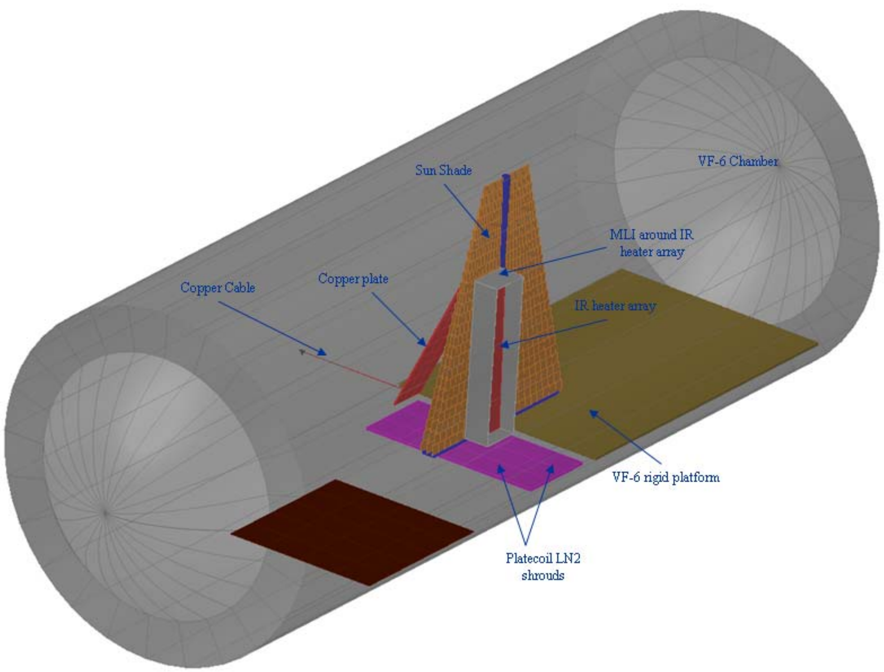
- CSS single petal tests in TVAC chamber
  - Deployment Test: Tested the Sun Shield materials and mechanisms in a vacuum at cold temperature
  - Thermal Test – See next slide

Test Article After Deployment in TVAC Chamber at GRC, Dec 08 –Feb 09

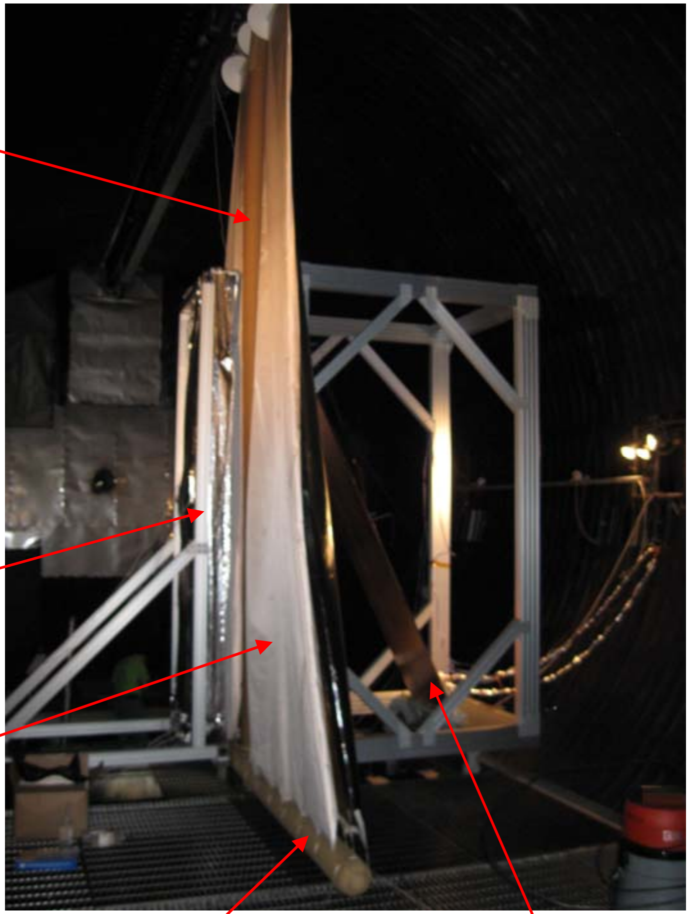


Thermal Tests at NASA Glenn

- Test Set Up Model



TVAC Chamber with single petal Test Article



Sun Shield Development Tasks

Project Tasks Going Forward

- Materials evaluation and testing at low temp
- Complete component designs for the Engineering Development Unit (EDU), leading to the flight test
- Analyze data from GRC tests and correlate data to analytical model
- Further define the requirements to be used in the design, development and testing of the Sun Shield
  - Conduct a Systems Requirements Review in Sept 2009
- Continue with the design of the support structure for the Sun Shield attachment to the Atlas Launch Vehicle
- Define flight test measurements and instrumentation
  - Conduct a Preliminary Design Review in late 2009
- Build an EDU and perform more development tests – 2010/2011
- Flight Test - 2012

Summary

- Design and testing to date has led to a successful demonstration of the sun shield in both ambient atmosphere, and in vacuum at low temperature
- The maturity of the sun shield design and development is leading to an SRR and PDR this year
- The ULA-ILC-NASA team made significant advancements in Sun Shield development with a relatively small budget
- The next steps are:
  - Complete the design
  - Conduct more material tests
  - Release drawings
  - Build an Engineering Development Unit (EDU)
  - Perform ground tests with the EDU
  - Use the EDU as the first flight test article
- With continued funding, the team is on-track for a test flight in 2012