EARTH SCIENCES TECHNOLOGY FORUM 2010

Thermal stability of a 4 meter Primary Reflector for the Scanning Microwave Limb Sounder

Instrument Partnership/Study

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June 24, 2010

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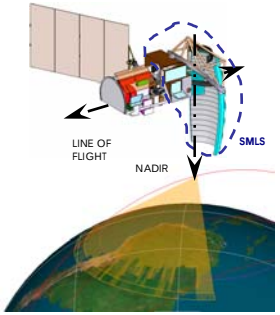
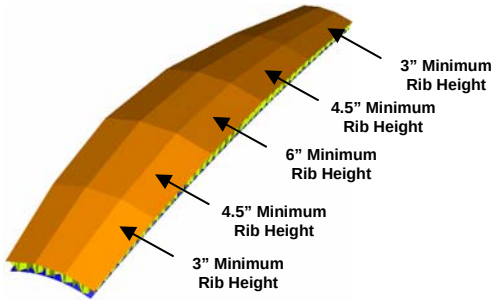
SMLS 4m Primary: ESTO Quad Chart

Objectives:

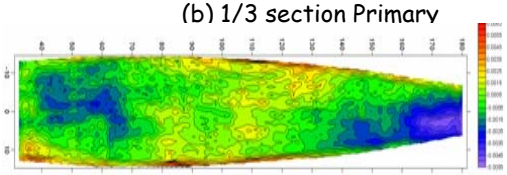
- Demonstrate fabrication of a 4-m primary reflector for the toric Cassegrain antenna of the Scanning Microwave Limb Sounder (SMLS) on the Global Atmospheric Composition Mission (GACM)
  - Fabricate a Graphite Fiber Reinforced Composite (GFRC) panel using a mold recently delivered for a phase II SBIR
  - The panel will provide full diffraction-limited performance of the center pixels of GACM SMLS.
- Verify figure performance under flight-like thermal environments using photogrammetric measurements



(a) SMLS Concept



(b) 1/3 section Primary



(c) Mold OPD/2 map

Approach:

- Fabricate full height, 1/3 width Primary Reflector on an existing (SBIR) mold
- Design remaining antenna reflectors and structure.
- Develop Thermal/Mechanical/Optical math models
- Test Reflector at temperature to verify performance; infer orbital figure deformations using antenna design and math models.

Co-Is:

- Eri Cohen, JPL
- Eldon Kasl, DR Technologies

11/24/2009

Key Milestones:

		entry	final
1.	Issue 4mx1/3w reflector contract	1/09	2/09
2.	Complete SMLS antenna design	4/09	5/09
3.	Complete Thermal/Mechanical math model	5/09	7/09
4.	Complete Reflector Fabrication	6/09	8/09
5.	Issue Thermal Testing contract	6/09	2/09
6.	Complete Thermal Testing	8/09	9/09
7.	Complete Final Report	9/09	11/09

$TRL_{in} = 3$ $TRL_{current} = 4$

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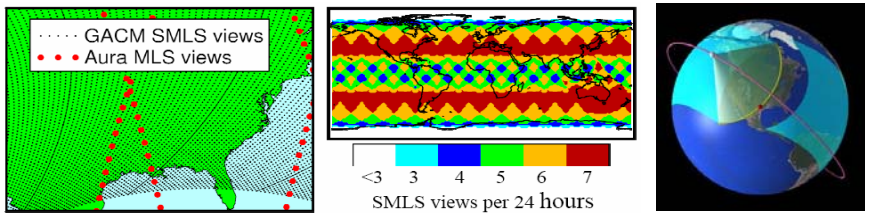
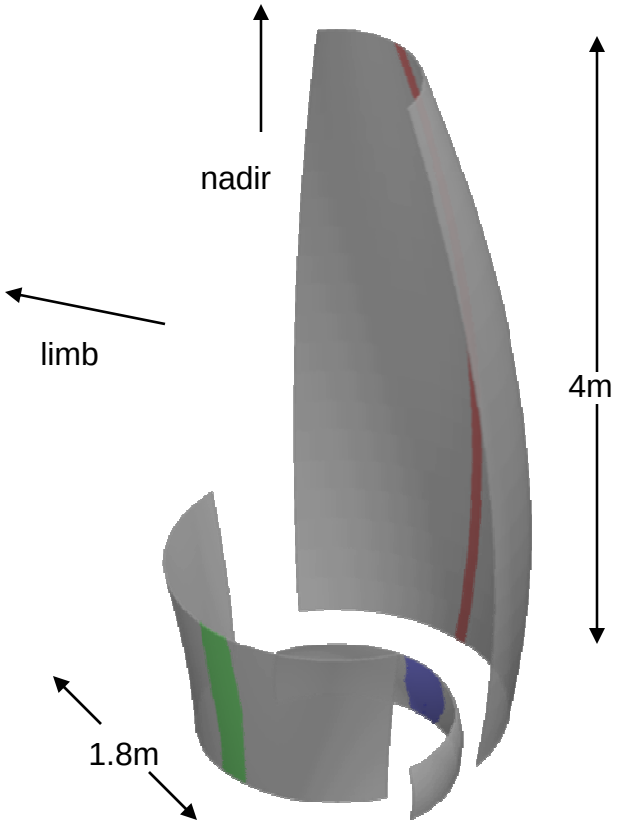
SMLS measurement concept

- The toric Cassegrain antenna designed for SMLS provides azimuth-independent scanning over a ±65° swath of a conical scan from the 830km GACM orbit.
  - Primary, Secondary and Tertiary surfaces are generated by rotating conic sections about a common toric axis in the nadir direction.
  - Proper choice of the conic foci and the toric axis transforms a feed pattern with circular symmetry into a very narrow vertical illumination of the Primary.
  - The resulting footprint is diffraction limited in the limb vertical direction and ~20x broader, independent of azimuth, in the horizontal.
  - A small (~10cm diameter) mirror scans the beam over the antenna, while a slower ~2° nod of the entire antenna provides the vertical scan.



SMLS coverage: (LEFT) compared to Aura MLS for part of 1 orbit; (CENTER) Temporal coverage; (RIGHT) azimuthal scan



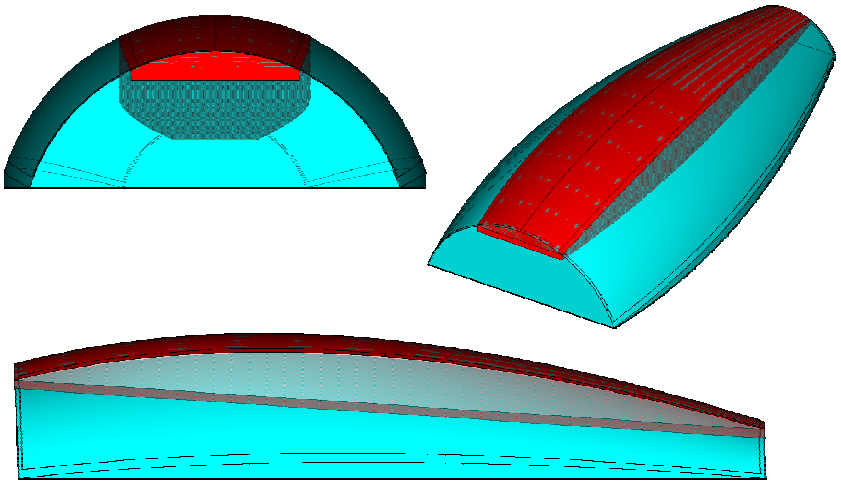
Footprints of the +10° azimuth pixel on SMLS Primary, Secondary and Tertiary reflectors

Objectives

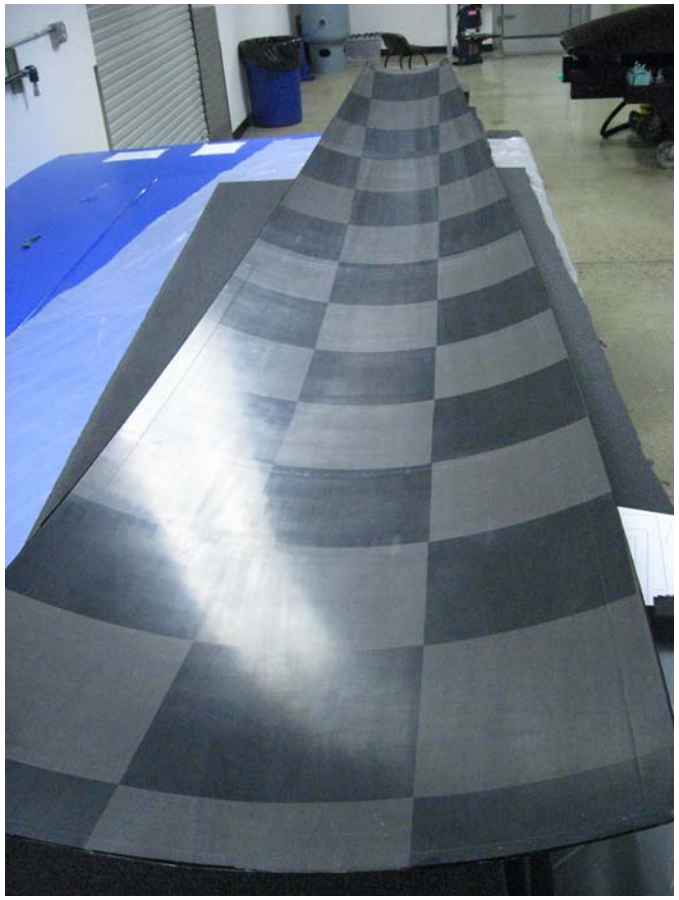
- Demonstrate fabrication of a 4-m primary reflector for the toric Cassegrain antenna of the Scanning Microwave Limb Sounder (SMLS) on the Global Atmospheric Composition Mission (GACM).
- Fabricate a Graphite Fiber Reinforced Composite panel of size 4m x (1/3 width of flight SMLS)
  - provides full diffraction-limited performance of the center pixels of GACM SMLS
  - Uses a mold made in a phase II SBIR by Vanguard Composites (DR Technologies, Inc.)
- Verify figure performance under flight-like thermal environments using photogrammetric measurements.
- Correlate test results with Finite Element Models developed by Vanguard and JPL, and predict performance in GACM orbit.
- Study Plan for $250K award:
  - $150K contract to Vanguard to fabricate and test reflector
  - $100K at JPL for analysis and model development

Bulk Graphite Mold from Vanguard SBIR

- Mold received December 2008
- Cost saving measures to fit within SBIR budget:
  - Reduced aperture (see figure)
    - Full SMLS aperture (blue)
    - 1/3rd-width mold (red)
  - Used CS grade (coarse grain)
  - 0.005 inch RMS spec. (GACM 640 GHz needs 0.0005)
    - 0.0016 inch as delivered
- GACM Primary would need truss or mold extensions for full width, as well as improved accuracy.



SMLS primary reflector fabrication



Completed front skin after cure and removal from mold. Both skins were tiled to improve isotropy, cut under computer control, and assembled using a laser projection system.

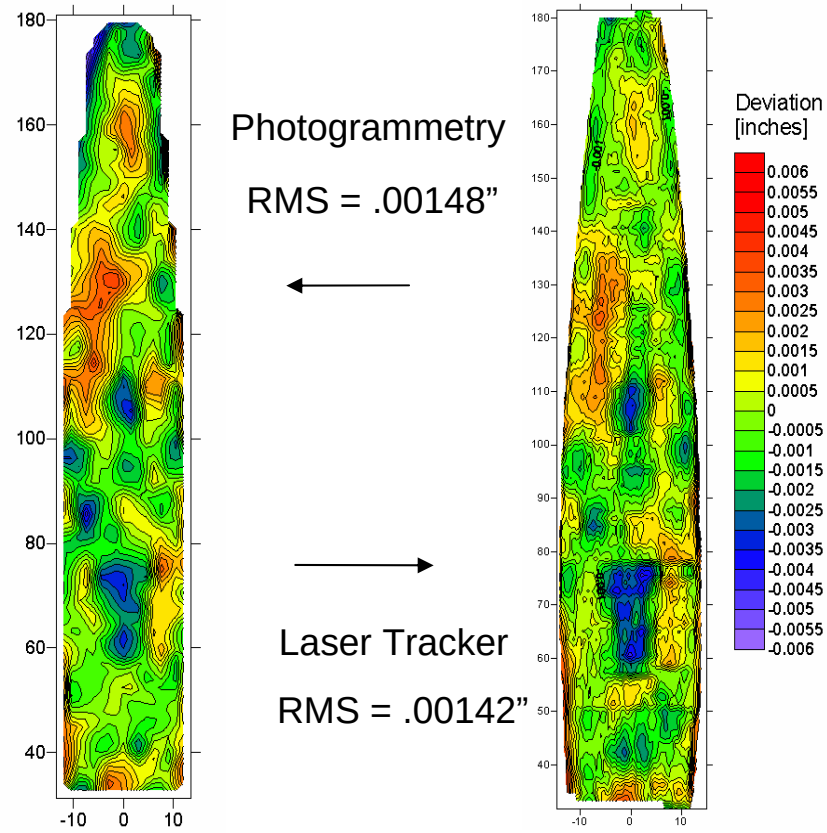
Rib Laminate Cross-Section (Aluminum mesh embedded in composite)

Assembling core ribs on mold.

Closure of faceted back skin with angle clips

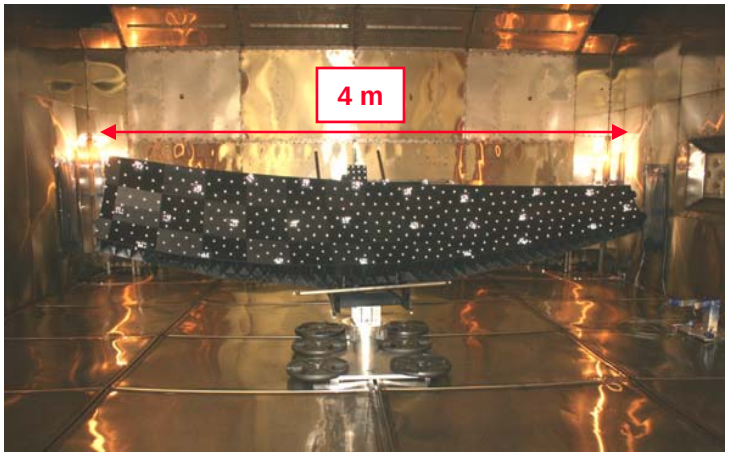
Primary reflector surface measurement

Laser Tracker metrology technique developed at University of Arizona by J.Burge was implemented for micron-level surface measurement of the reflector and compared to prior mold measurements by Coordinate Measuring Machine and to photogrammetry for later thermal tests

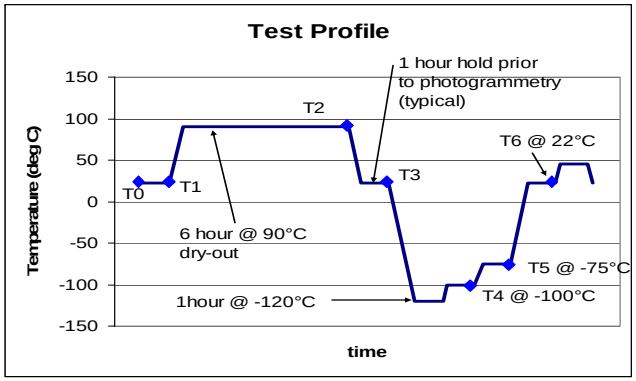


Surface maps compared: photogrammetry vs. laser tracker/SMR probe; also cf. mold contour maps shown earlier

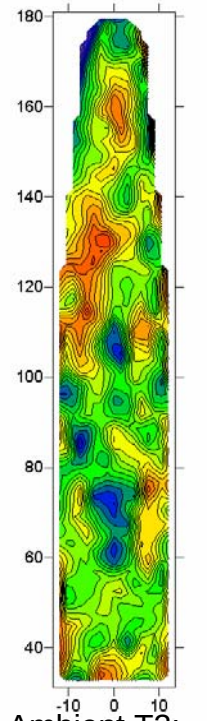
Primary reflector ThermoElastic Distortion (TED) test complete



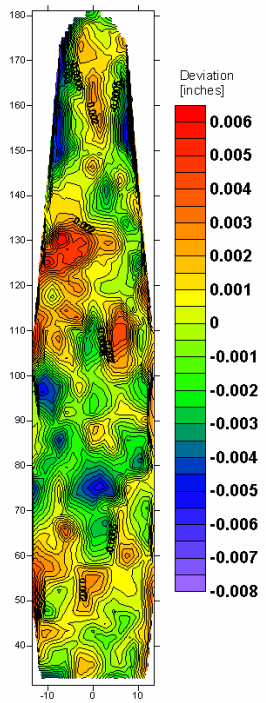
Reflector in Wyle Labs chamber; photogrammetry targets illuminated



Soak ΔT exceeds orbit prediction by ~7x; infer effective measurement accuracy <~2 μm



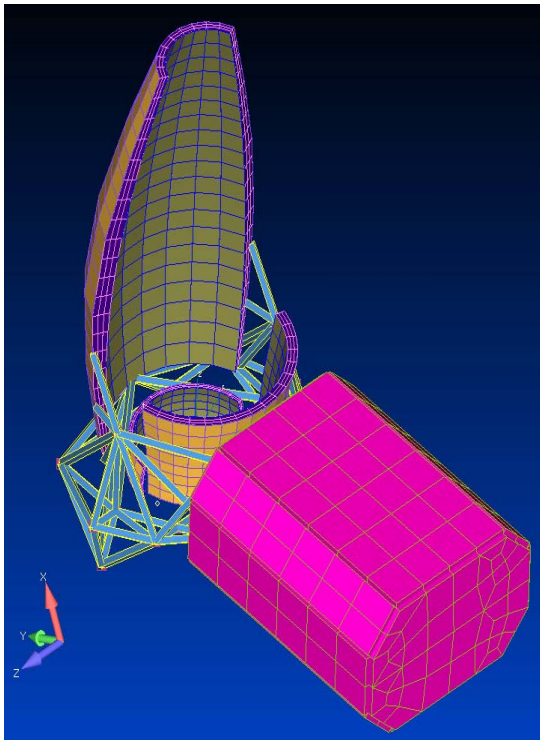
Ambient T3:
0.0015 inch rms



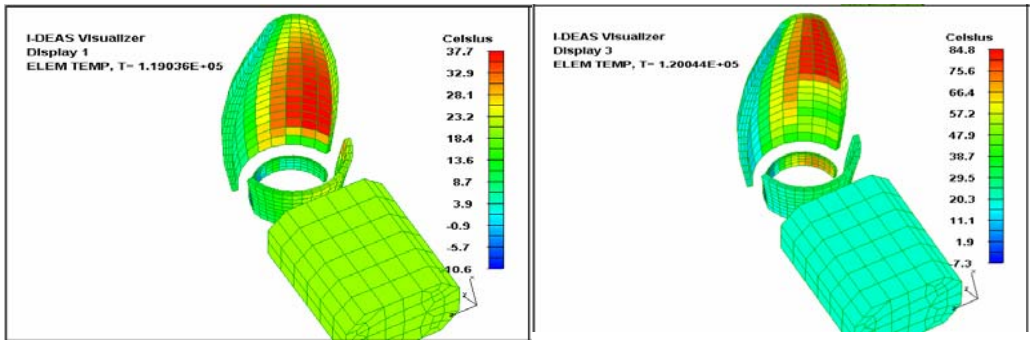
-100°C soak T4:
0.0011 inch rms

- Photogrammetry maps compared: ambient dry-out vs. cold soak
- Initial order-of-magnitude correlation with FEM to be refined in future work

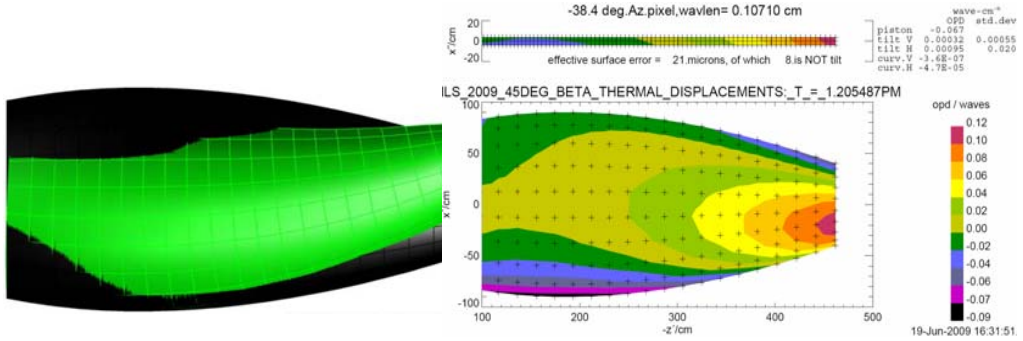
SMLS predicted orbital thermal deformations



JPL I-deas finite element model



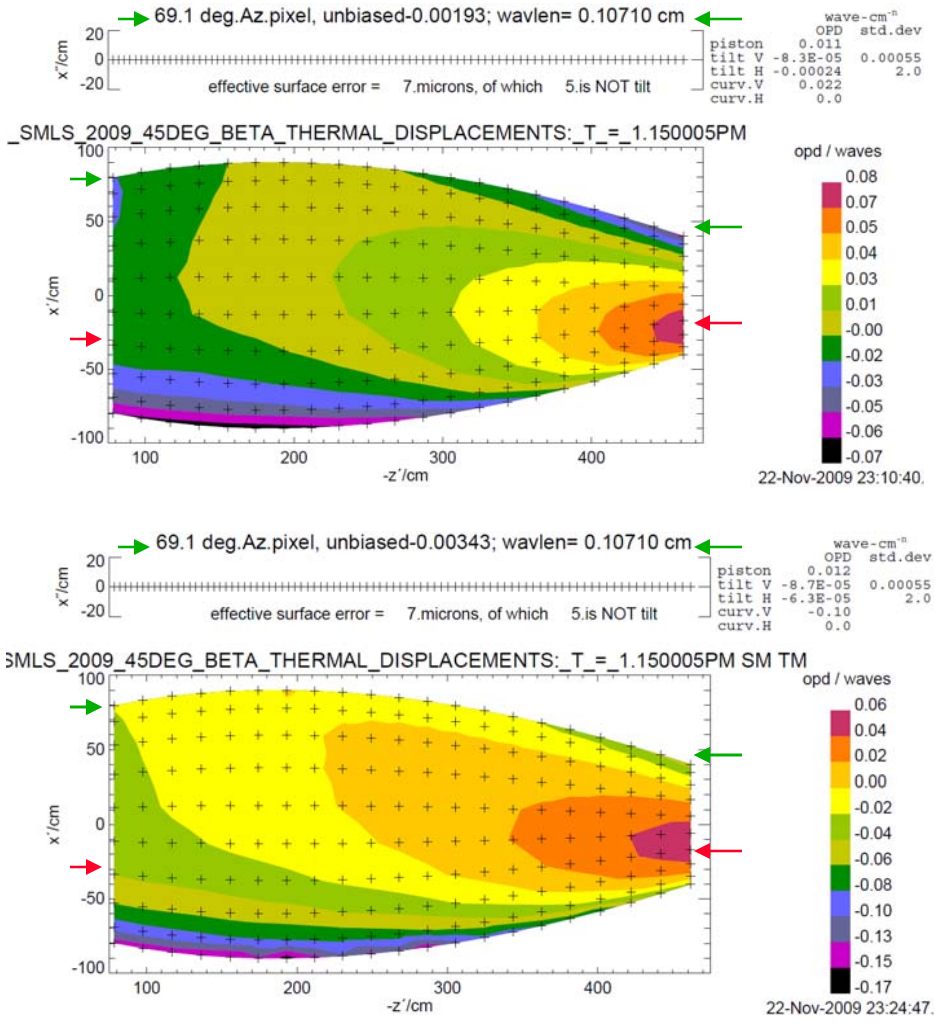
Thermal model: Antenna reflector and spacecraft bus temperatures at 2 times in $\beta = 45°$ orbit.



Primary reflector: Deformations (left,5000x) and Optical Path Differences (OPDs, right)

- Updated Thermal, Mechanical and Optical models from a 2006 study
  - Lowered orbit from MEO (1500km) to LEO (830km)
- Models were also extended to include Secondary and Tertiary reflectors, and support structure.

Optical Performance: thermal deformations on all reflectors



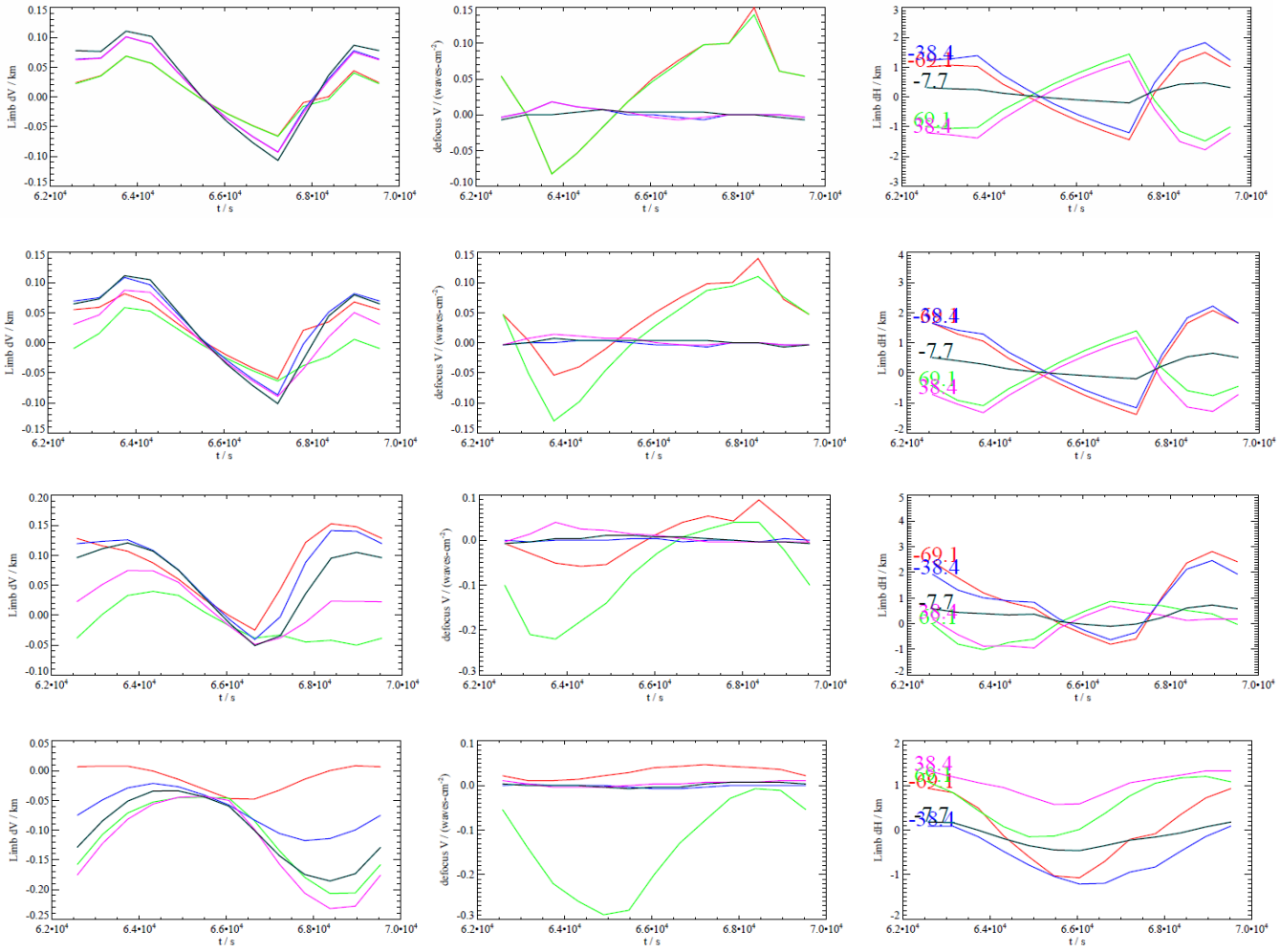
- Secondary and Tertiary Reflector deformations contribute significantly to optical performance (though less than Primary).
  - Rms OPDs suggest contribution is in pixel pointing more than in beam shape.
  - Current model (based on Aura MLS) uses only translations of each node; given the narrow Primary footprints, more accurate horizontal pointing and beam width can be gotten using slope data already in the deformations file.
  - Further study is needed.

→ -23° Azimuth pixel ←					
reflectors included			**Optical Path Difference / waves**		
			min	**max**	**rms**
PM	SM	TM	-0.0405	0.0534	0.0242
PM			-0.0107	0.0740	0.0223
	SM		-0.0125	0.0011	0.0035
		TM	-0.0216	-0.0130	0.0019

Performance at 4 solar β angles (830 km GACM orbit)

Vertical pointing | Vertical defocus | Horizontal pointing

time series for 5 azimuths in each panel



β=0°

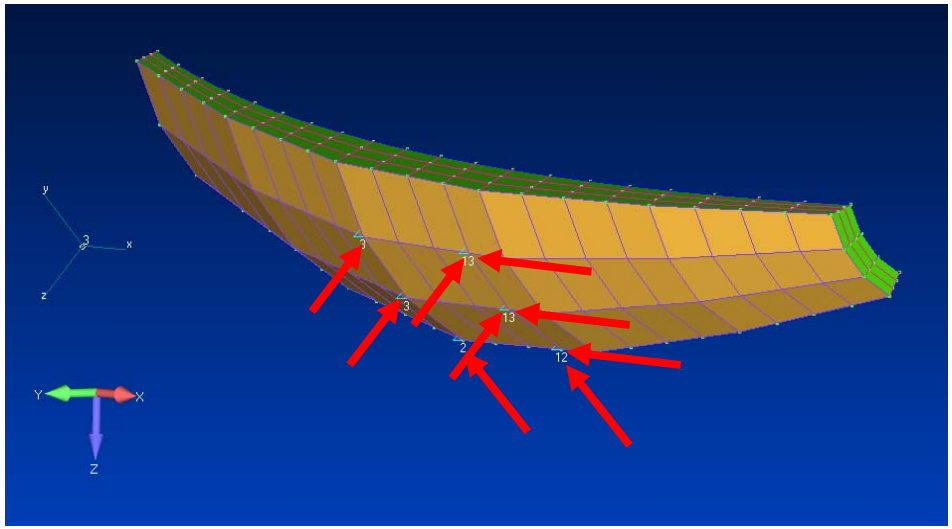
β=15°

β=45°

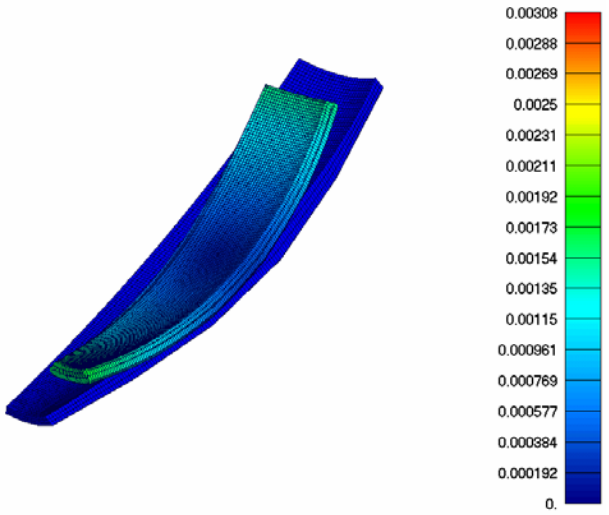
β=75°

•Beam patterns and further analysis in future work

predicted TED test deformations

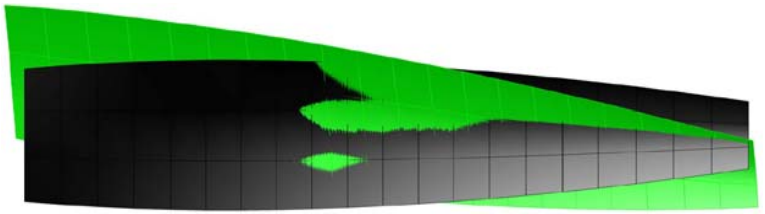


JPL finite element model, TED support constraints



Vanguard model: representative cold case deformations

- Modified JPL model for 1/3-width Primary in TED test, and updated to final Vanguard material properties.
- Calculated deformations for 1°C soak,53→0% RH dryout, {X,Y,Z} 1G loads
  - FEM results to be scaled to TED conditions
- Correlation with Vanguard FEM and photogrammetric measurements in future work



JPL model: ΔT=100°C predicted deformations (shown 5000x). OPDs will be calculated as for orbital cases.

Accomplishments and Future Plans

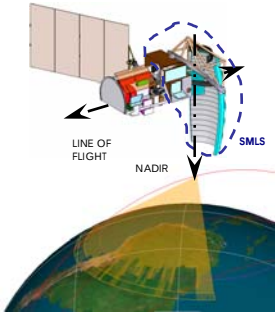
- A full height(4 meter), 1/3width breadboard SMLS primary reflector was fabricated and thermal tested. Reflector thermal stability meets SMLS requirements (0.21 mm RMS / [°C]) for 830km orbit.
- Laser tracker techniques, which can improve surface measurement to near-micron accuracy, were verified in reflector fabrication by comparison with photogrammetry and conventional CMM measurements .
- Finite element models have been developed by both Vanguard and JPL for design studies and to correlate with the thermal test data. The JPL model was extended to include Secondary and Tertiary reflectors with support structure, then used to study 4 orbital thermal environments being considered for GACM.
- Applications of composite reflector technology, to meet SMLS optical requirements, include faceted and tiled laminate facesheets and aluminum/composite hybrid ribs.
- Design options were studied for future fabrication of a full-width SMLS primary on the current mold and/or a full width mold having improved surface accuracy for the GACM SMLS requirements.

- Further SMLS reflector development is proposed as an IIP, led by JPL :
    - Vanguard to reconcile FEM, CTE and photogrammetric measurements from September 2009 thermal tests.
    - Vanguard to fabricate full size SMLS primary on either
        - full width mold with better surface accuracy, or
        - Current 1/3 width mold, polished to flight SMLS optical finish; assemble 3 panels using integration/alignment fixture
    - JPL to subject existing (SBIR) 1/3 width reflector to thermal gradient testing (as predicted for GACM orbit) in its Large Deployable Aperture facility
    - JPL to design antenna structure, demonstrate azimuth and elevation scan
    - Beam patterns from 8'x8' Near field range used for Aura MLS at 660 GHz
    - Evaluate nominal and thermally perturbed beam patterns effect on geophysical retrievals

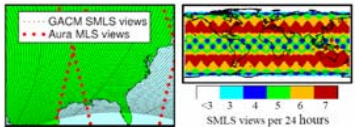
GACM SMLS Antenna: IIP Quad Chart

Objectives:

- Demonstrate fabrication and performance of the toric Cassegrain antenna of the Scanning Microwave Limb Sounder (SMLS) on the Global Atmospheric Composition Mission (GACM)
  - Fabricate a Graphite Fiber Reinforced Composite (GFRC) panel using a recently delivered SBIR mold
  - Verify reflector performance in flight-like thermal environments using JPL's Large Aperture facility.
  - Demonstrate GACM requirements are met by SMLS antenna design.
  - Verify antenna performance using SMLS breadboard components.



(a) SMLS Concept



(b) SMLS vs. Aura coverage

(c) 4-m x 1/3 width breadboard Primary reflector from Phase II SBIR

Approach:

- Refurbish existing (SBIR) mold and fabricate composite Primary Reflector
- Design and fabricate remaining antenna reflectors, scan mechanism, and structure.
- Develop Thermal/Mechanical/Optical and retrieval math models
- Test Reflector at temperature to verify performance; test antenna on Near Field Range

Investigators:

- Rick Cofield (PI), Paul Stek, Nathaniel Livesey, Bill Read, Greg Agnes, Mark Thomson; JPL
- Eldon Kasl; DR Technologies

6/14/2010

Key Milestones:

1.	Thermal-test SBIR Primary (JPL ALPS facility)	9/11	
2.	Model deformations effect on beam patterns	10/11	
3.	Geophysical retrievals with model patterns	12/11	
4.	Refurbish mold and Fabricate Primary meeting GACM/SMLS requirements	9/12	
5	Build antenna structure, partial secondary and tertiary reflectors, and scan mechanisms	12/12	
6	Integrate antenna with demonstration dewar from 2007 IIP	9/13	
7.	Beam pattern measurements on Near Field Range	12/13	

$TRL_{in} = 3$

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