Shuttle & Transfer Orbit Thermal Analysis & Testing of the Chandra X-Ray Observatory CCD Imaging Spectrometer Radiator Shades

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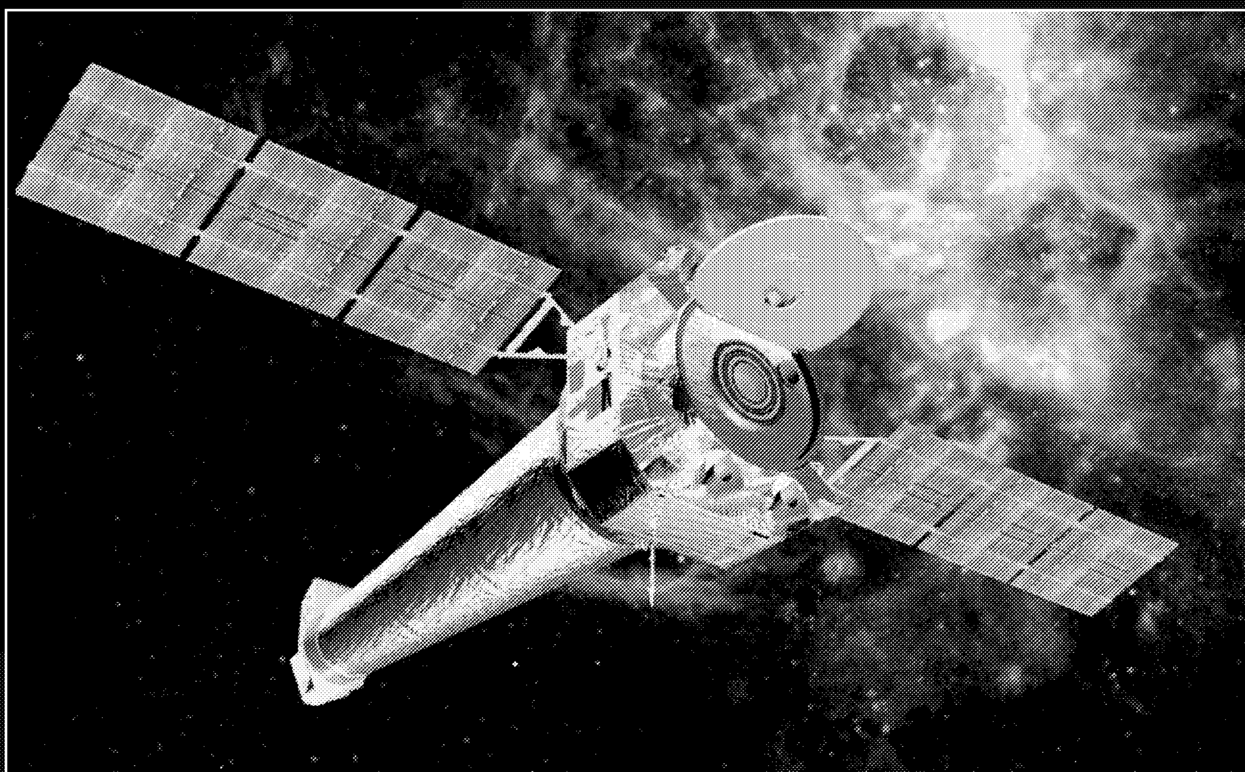
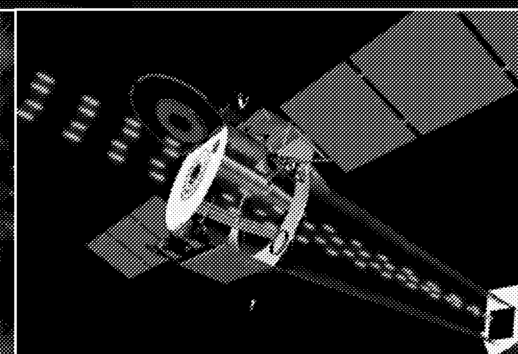
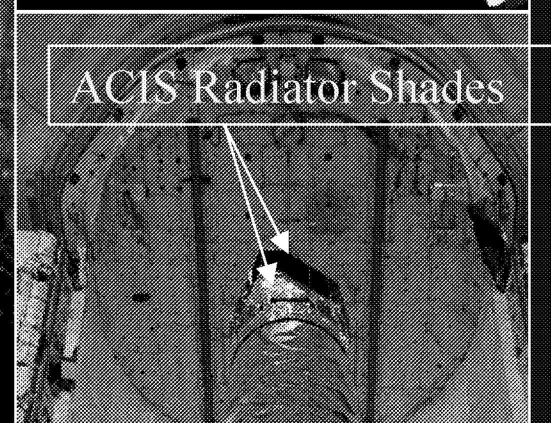
Introduction

- Chandra X-Ray Observatory
- Advanced CCD Imaging Spectrometer (ACIS)
  - CCD cooled to -120 °C $\pm$ 1 °C . Utilizes "Shades" to optimize Radiator environment

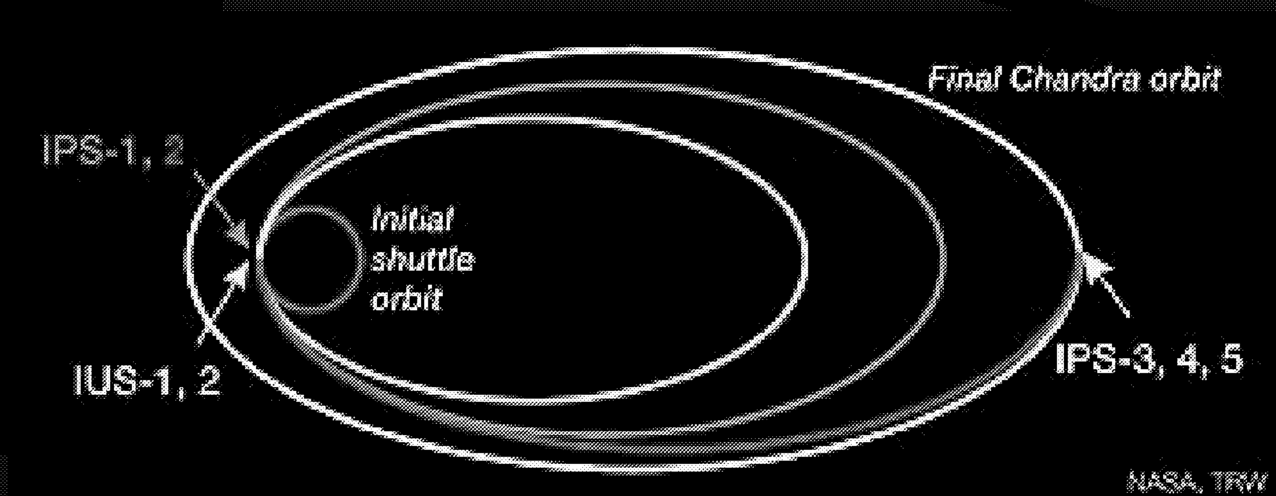






Introduction (Cont.)

- Chandra launched aboard STS-93 into ~130nm LEO
- Transfer to final orbit consisted of 2 Inertial Upper Stage burns and 5 Integral Propulsion System Burns
- Final target orbit: 10,000 km x 140,000 km

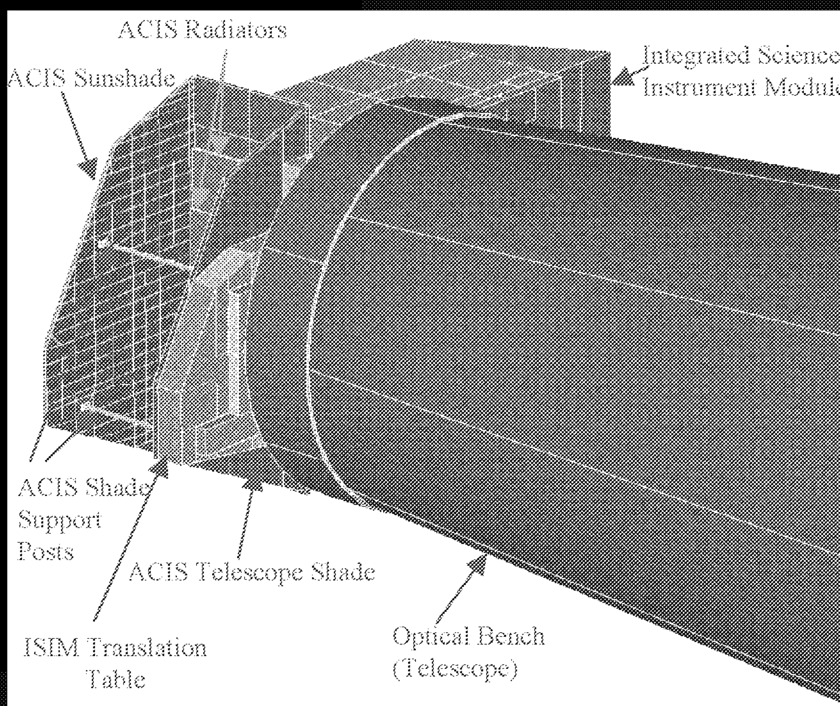


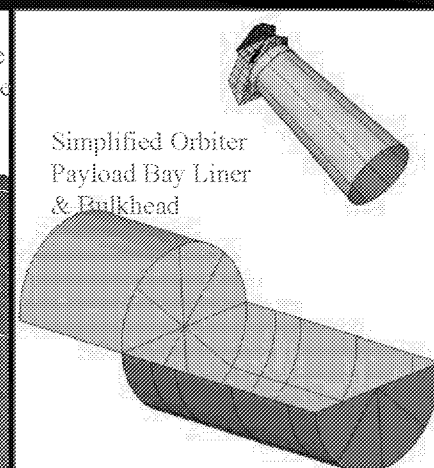
Introduction (Cont.)

- Transfer Orbit thermal analyses of Chandra w/low fidelity radiator shades did not show temperature exceedances.
- MSFC highly detailed models developed of shades revealed that LEO heating and subsequent transfer orbit solar impingement on high α/ε goldized Kapton resulted in very high localized temperatures.
- This overview discusses the analytical results and solutions/testing of over-temperature problem

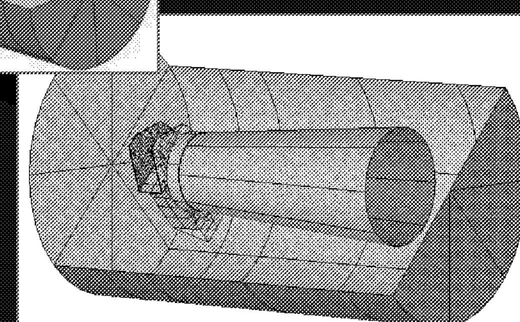
LEO & Transfer Orbit Analyses

- Geometric Modeling in TSS w/specularity
  - 800 surfaces to represent radiator facesheets, support posts and edgefill
  - 3 Orbital Heating configurations (In-bay, elevated stack & free flying)





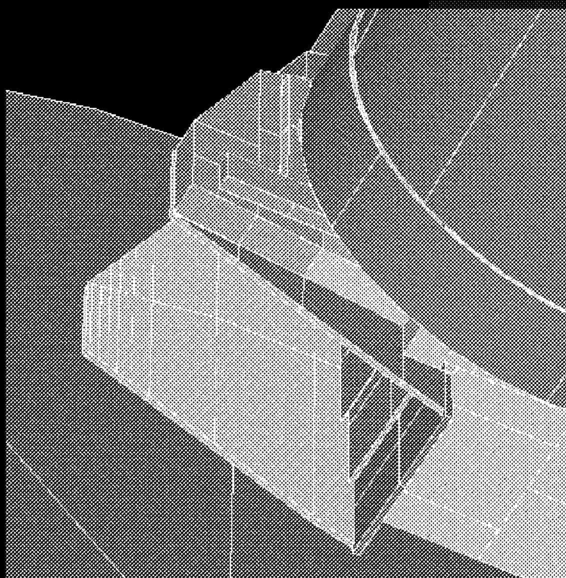
29° Elevated (prior to deploy)



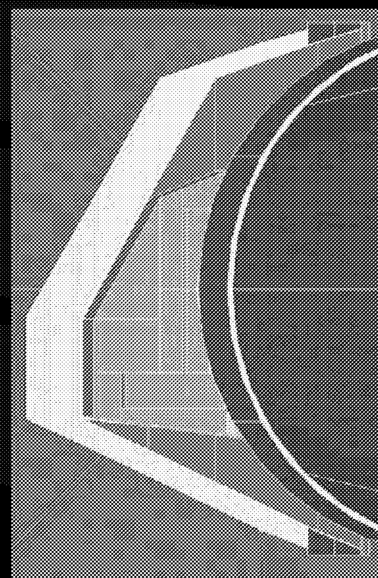
Stowed

LEO & Transfer Orbit Analyses

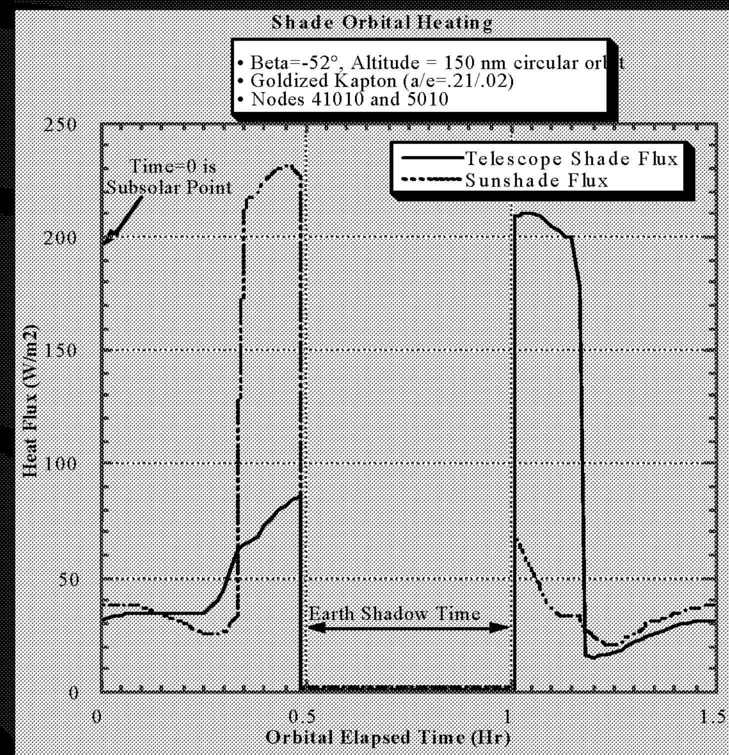
- Low Earth Orbital Heating Calculations
  - TSS used to calculate LEO heating to determine worst Beta Angle
  - β=-52° exposes larger area to solar impingement for longer time



Sun View of Shades at Terminator Entry (β=-52°)



Sun View of Shades at Terminator Entry (β=0°)



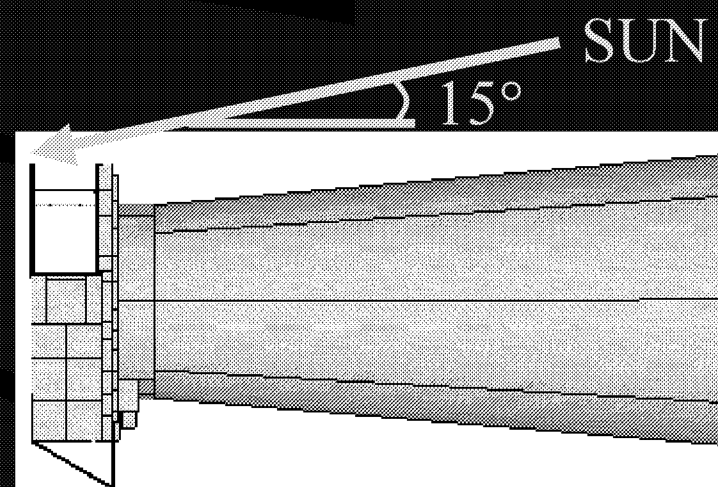
β=-52° LEO Heat Flux

LEO & Transfer Orbit Analyses

- Transfer Orbit Heating Calculations
  - TSS used to calculate heating post-IUS 320 km x 64,000 km orbit
  - Free Drift & burn attitudes assumed to result in worst-case solar view

Event Start Time (HR:MIN)	Event Duration (HR:MIN)	Event Description
0:00	3:50	**+ZLV**, β=-52° Stowed Shuttle Orbit
3:50	0:35	Deep Space Viewing **IMU** Alignment
4:25	11:25	**+ZLV**, β=-52° Stowed Shuttle Orbit
15:50	0:35	Deep Space Viewing **IMU** Alignment
16:25	5:15	**+ZLV**, β=-52° Stowed Shuttle Orbit
21:40	1:54	**-ZSI Elevated Stack**
23:34	0:10	Sun on ACIS sunshade during post-deploy **free drift**
23:44	0:31	**-ZSI Free Flight**, low earth orbit
24:15	0:20	IUS **SRM burns**, full sun on ACIS sunshade
24:35	16:54	Post SRM burns **-ZSI** thermal attitude, 320km X 64000 km orbit
42:29	0:30	**IPS-1** burn, full sun on ACIS sunshade
41:59		Analysis Complete

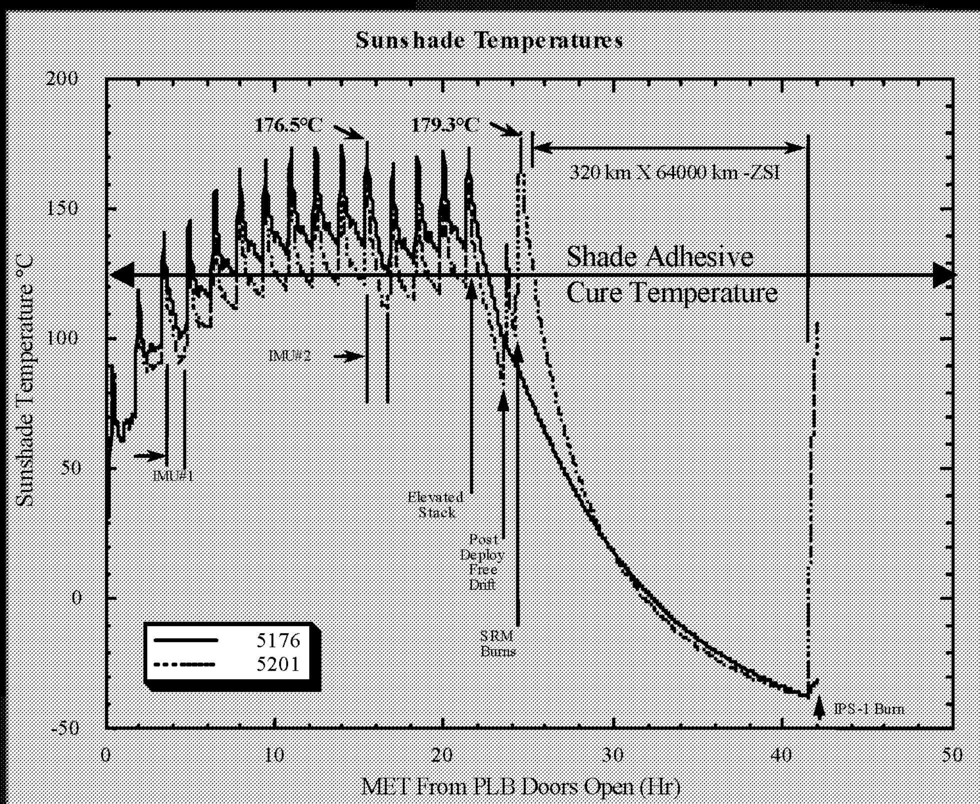
Worst-Case Hot
Transfer Orbit Timeline

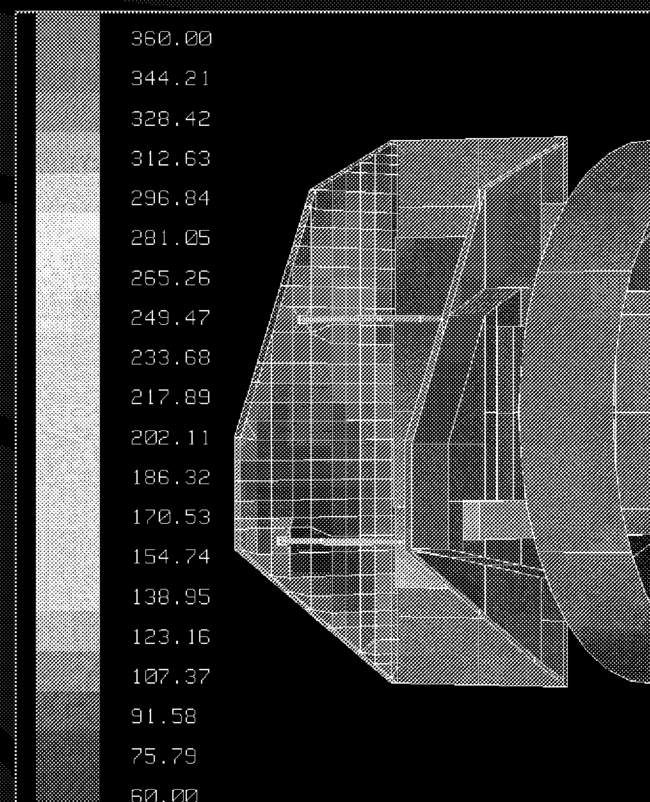


Free Drift & Burn
Attitude Solar Heating

LEO & Transfer Orbit Analyses

- Results:
  - Temperatures reach ~180°C during LEO, which is 55 °C above adhesive cure temperature used to bond Kapton to facesheet & facesheet to core.





Thermal Testing @ LMAC

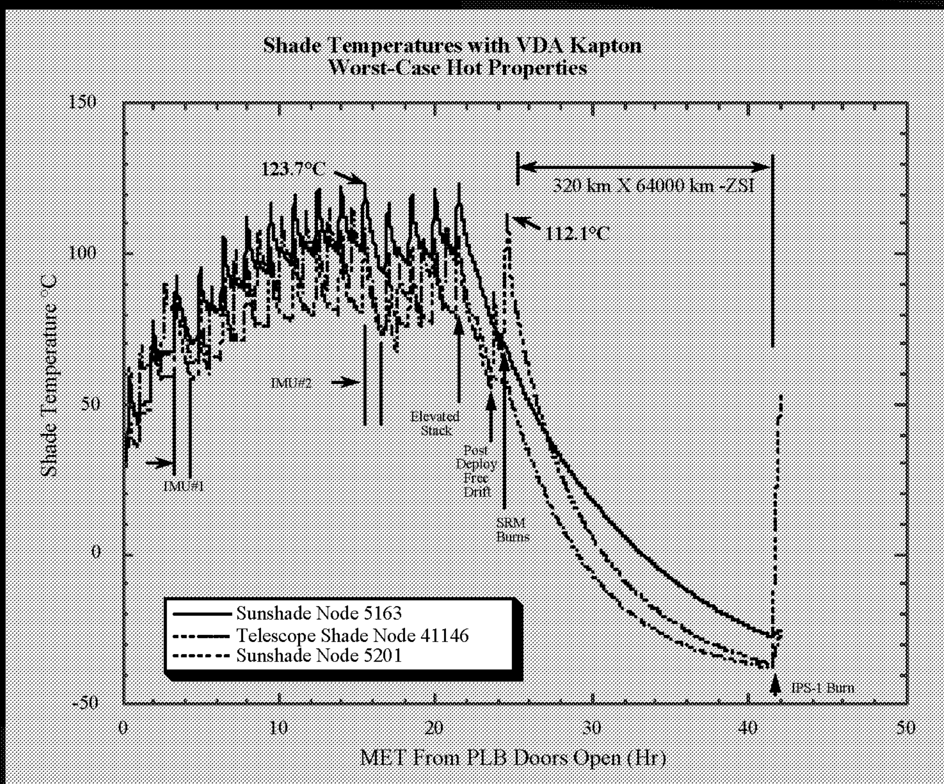
- Due to high MSFC temperature predictions, an EU shade was tested to 180 °C @ LMAC.
  - Bubbling of goldized Kapton noticed at ~120 °C. Rupture at 180 °C dwell due to moisture desorption and outgassing

Problem Resolution

- Several options were generated for solving the debonding/overheating issue:
  - Options to lower temperature could not affect subsequent on-orbit performance (e.g., reaching -120 °C focal plane)
  - LMAC proposed crosscuts in Kapton to allow outgassing
  - Rebuilding shade w/higher temp adhesive ruled out by cost/schedule
  - Operational workarounds not feasible due to effects on rest of Observatory, JSC/IUS interface impacts, schedule.
  - MSFC proposed overcoating existing shade with vapor-deposited aluminum (VDA) to lower solar absorptance to 0.10-0.12 with increase in emittance from 0.02 to 0.03. ($\alpha/\varepsilon \sim 4.0$ instead of ~ 10.0)
    - Overcoating required intermediate Chrome for robustness and overcoat of silicon dioxide

VDA Overcoat Analyses

- Worst-Case Analysis w/VDA is 123.7 °C.
- RSS of assumption uncertainty reduces to 102 °C



	Shuttle (ZLV) Operations	
Case Description	Sunshade Hottest Temperature	Telescope Hottest Temperature
Nominal	82.0°C	83.0°C
ΔT_{α}	12.5°C	13.7°C
ΔT_{ε}	12.2°C	11.1°C
ΔT_{ε^*}	9.0°C	7.0°C
RSS Hot	101.6°C	102.0°C
Worst Hot	123.7°C	121.4°C

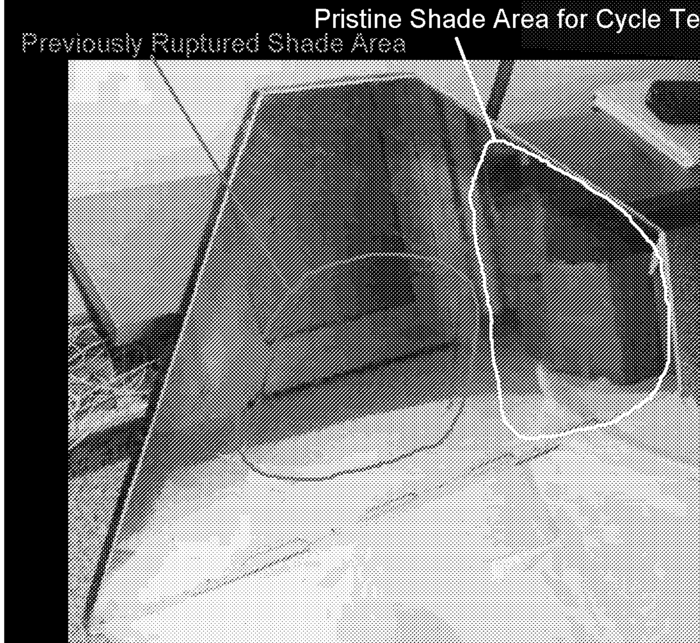
Note: Nominal $\alpha / \varepsilon = 0.10/.03$ and $\varepsilon^* = 0.015$. Hot $\alpha = 0.12$.

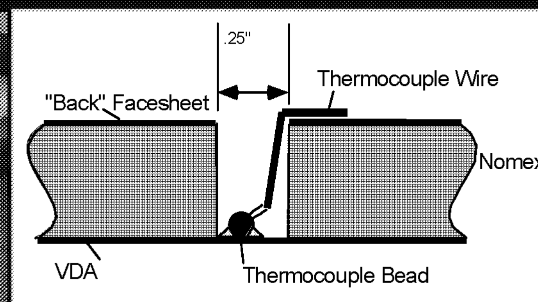
$$T_{RSS-HOT} = T_{NOMINAL} + \left[\Delta T_{\varepsilon^*}^2 + \Delta T_{\varepsilon}^2 + \Delta T_{a}^2\right]^{0.5}$$

	Nominal	Worst-Case Hot
Solar Absorptance	0.10	0.12
Hemispherical Emittance	0.03	0.02
MLI effective emittance	0.015	0.005

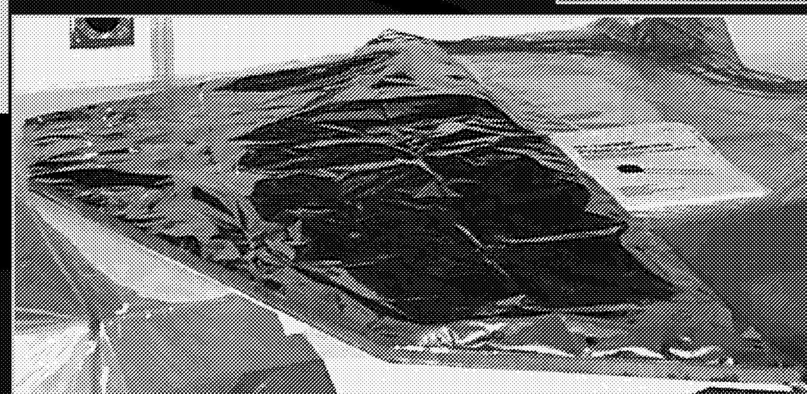
VDA Overcoat Testing @ MSFC

- Thermocouples bonded w/high temp., thermally conductive adhesive to backside of VDA facesheet via holes drilled through back facesheet/core



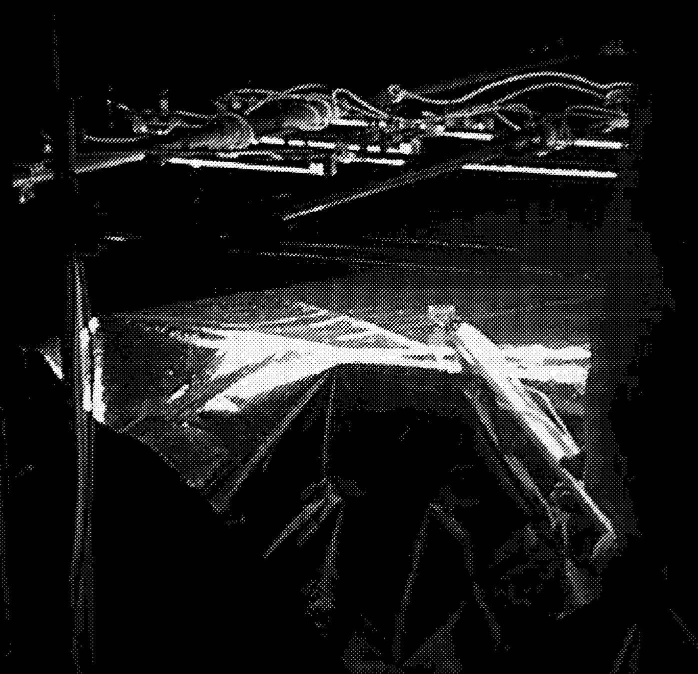


Thermocouple Mounting

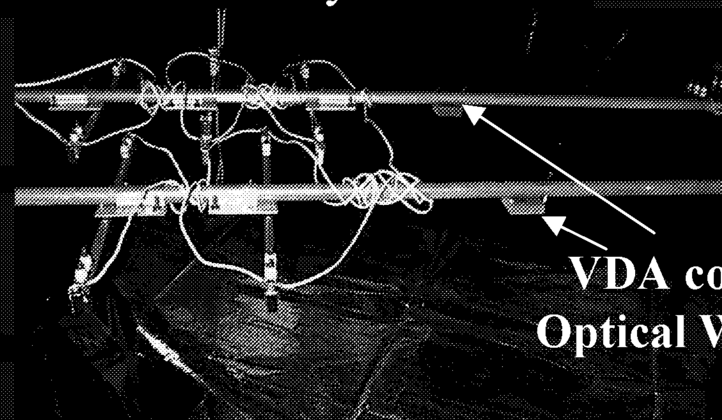


VDA Overcoat Testing @ MSFC

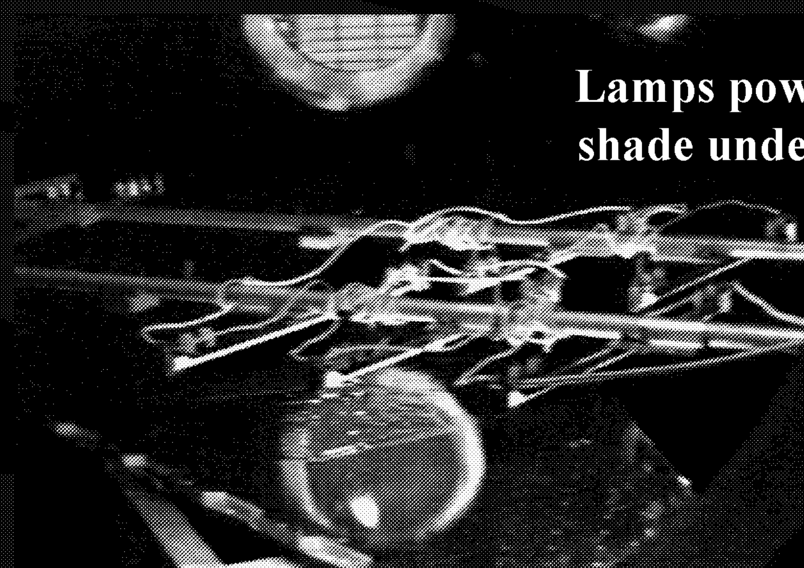
- Infra-red lamp arrays positioned to radiatively heat the VDA surface.



IR Lamp Flux Mapping with Water-Cooled Pyrheliometer



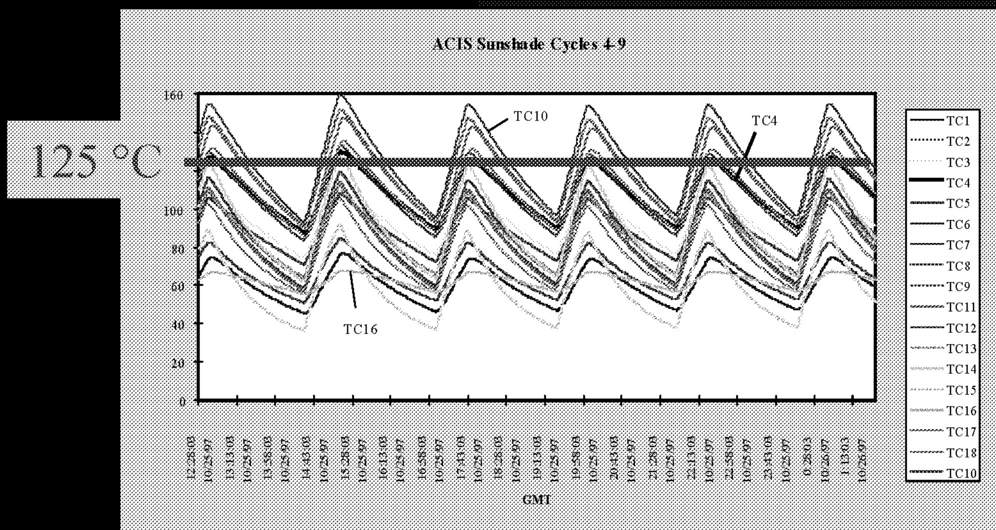
VDA coupons used as Optical Witness Samples

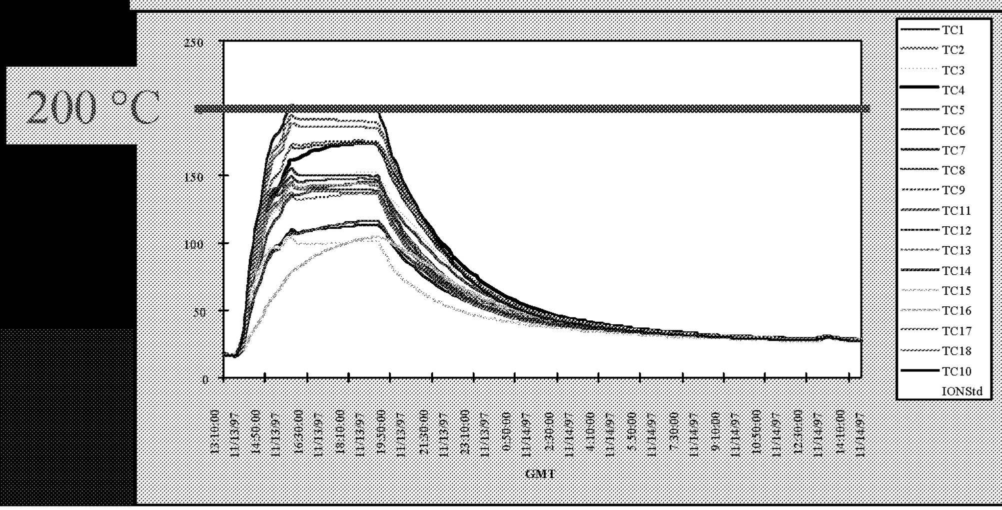


Lamps powered with shade under vacuum

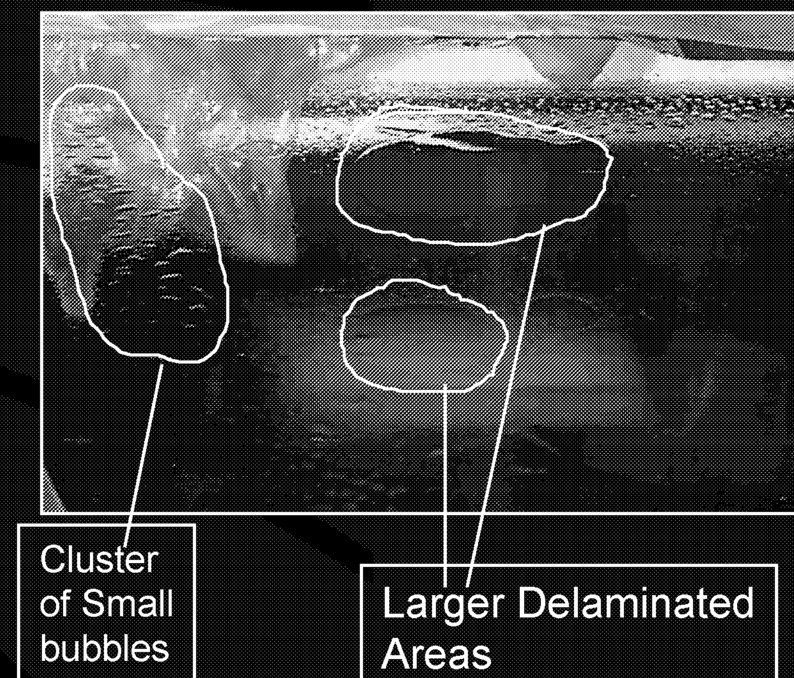
VDA Overcoat Testing @ MSFC

- 24 Cycles to above 125 °C performed. Unit removed for Inspection, then replaced into chamber for crosscut venting hot soak test (>180 °C)





Post-Cycle Test:



Post-MSFC Test Evaluation

- Following the T/V testing, the shades were visually inspected and evaluated:
  - Crosscuts in “bubble” areas were found to not fully penetrate Kapton
  - A “Tape test” performed to test adhesion
  - Solar absorptance & emittance compared to pre-test on shade and Optical Witness Samples (No Change)
- Based on MSFC analysis/testing, the Chrome/VDA/SiO_2 overcoat approved for flight.