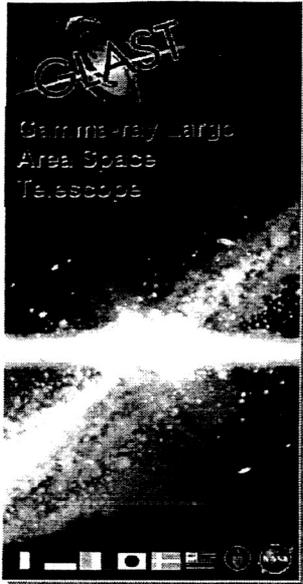


Swales Aerospace
(301)-902-4584
kdahya@swales.com
3816 Gawayne Terrace
Silver Spring, MD. 20906
Preference: Poster Session

Title: *Failure Investigation & Design Optimization of a Photo-Multiplier Tube Assembly Under Thermal Loading.*

By Kevin Dahya

Abstract: Analysis of GLAST ACD Photo-Multiplier Tube (PMT) assembly under thermal loading demonstrates that the glass tube experiences high stresses due to Coefficient of Thermal Expansion mismatch, as well as increased stress due to high stiffness and incompressibility of potting compound. Further investigation shows adverse loading effects due to the magnetic shield, a thin piece of steel wrapped around the PMT. This steel, Mu Metal, contained an overlap region that directly attributed to crack propagation in the outside surface of the tube. Sensitivities to different configurations were studied to reduce the stress and provide a more uniform loading throughout the PMT to ensure mission success. Studies indicate substituting a softer and more compressible potting compound and moving the Mu metal from the glass tube to the outside wall of the aluminum housing yields lower stress.

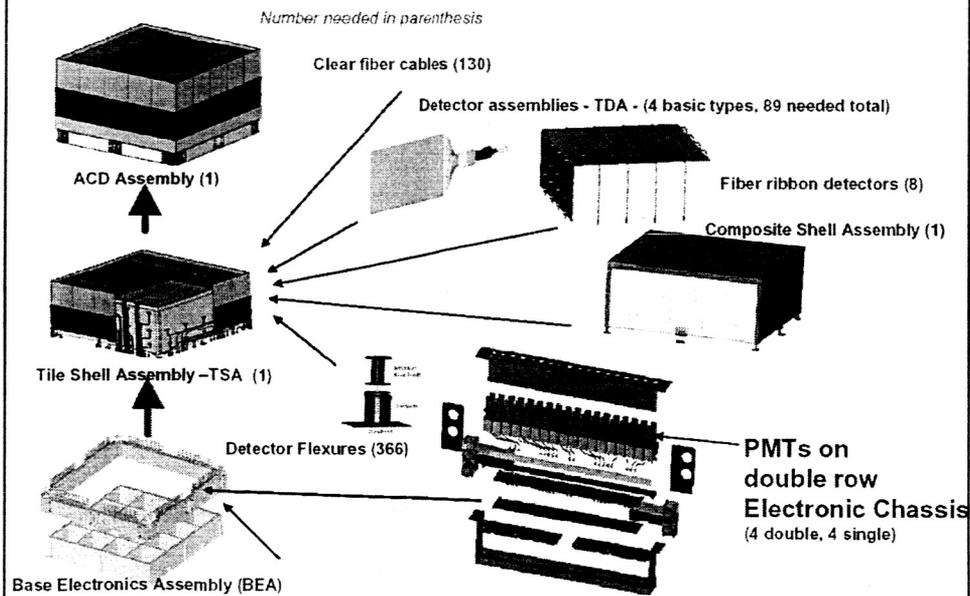


Glasm Large Area Telescope: AntiCoincidence Detector (ACD) PhotoMultiplier Tube Glass Failure

Kevin Dahya

Michael Amato, Steve Schmidt, Charles He

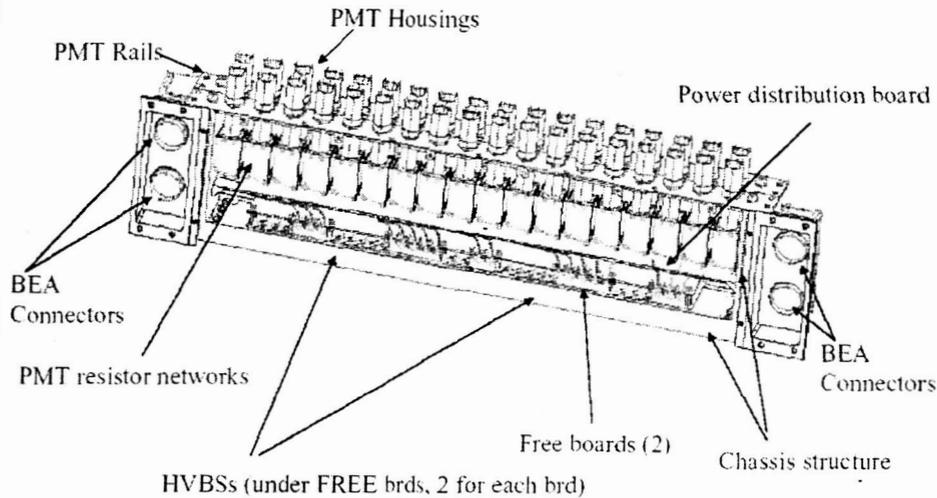
Background - PMTs in the assembly flow





Background – PMTs in the Electronic Chassis

- Electronics Chassis

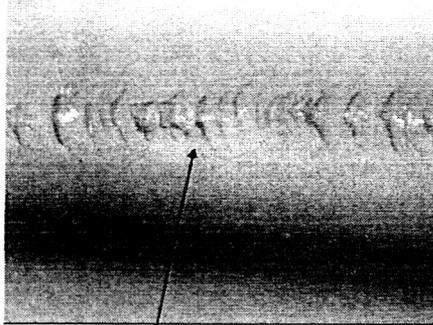


The Issue

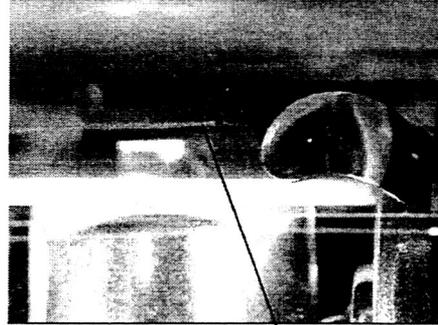
- Over a year ago 4 engineering model PMTs were qualified in thermal vacuum (3 cycles to -30C, 1 cycle to -38C) and vibration with all passing – successful qualification test
- Before we assembled an electronic chassis engineering model we decided to retest some new PMT assemblies. Some minor changes had been made to the resistor networks and their housings. These changes did not effect the PMT housing and did not change the stresses on the PMTs
- PMT engineering model failure – During this second qualification test one of 5 PMTs cracked during first -30C cold cycle of thermal vac test. Again this was a repeat of successful test one year ago. Remaining four from latest test survived two more cycles to -30C and one cycle to -40C. They are six to nine month lead time items, all have been received and performance tested. None have begun flight processing.
 - Inspection of PMTs not yet in housings revealed 4 sets of score marks along inside of all tubes consisting of 2 to 3 thousand microcracks caused by insertion of dynode assembly. Also discovered microscopic air bubbles in tube to window transition area. Inspection of earlier PMT failed by excessive vice force shows it failed at score marks.
- Very recently, towards the end of our investigation, the Electronic Chassis engineering model thermal vacuum test failed 3 more PMTs out of 23.



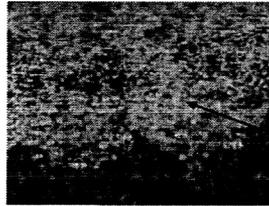
Investigation



Close up of one score line, PMT vulnerable at scores



Score line ending at dynode mount

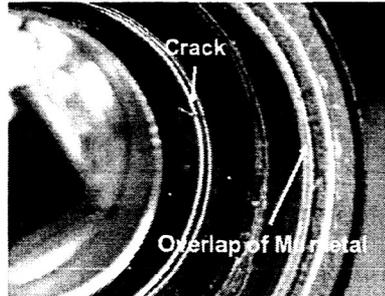


Bubbles at window to tube transition

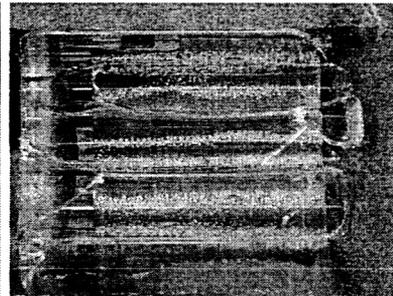


Investigation

- Crack in failed PMT is aligned with Mu metal overlap. Removal of flight unit to confirm crack origination was not successful despite success of practice unit. Could not identify initiation point of failed PMT. But surprisingly did not appear to fail at one of the scores.



Crack position relative to Mu metal



Soaking in toluene destroyed the tube



Path 2

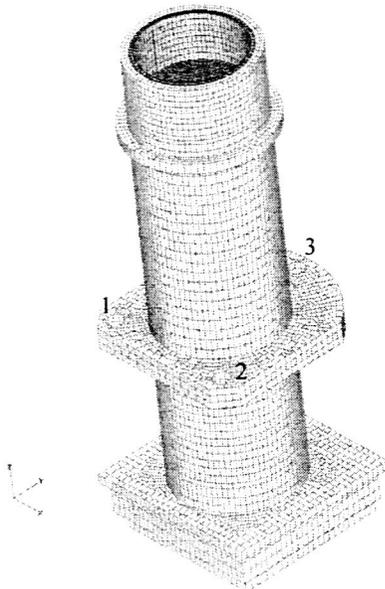
What are our current stresses in the existing design

- Review of initial analysis shows 2-d simplified analysis did show low stresses but was overly simplified and had some at temperature material properties off that made a large difference in stress upon our review of that analysis.
- Stresses on surfaces of PMT tube for existing design initially showed tensile hoop stresses peaking at ~4.3 ksi on inner surface and ~3.2 ksi on outer surface.

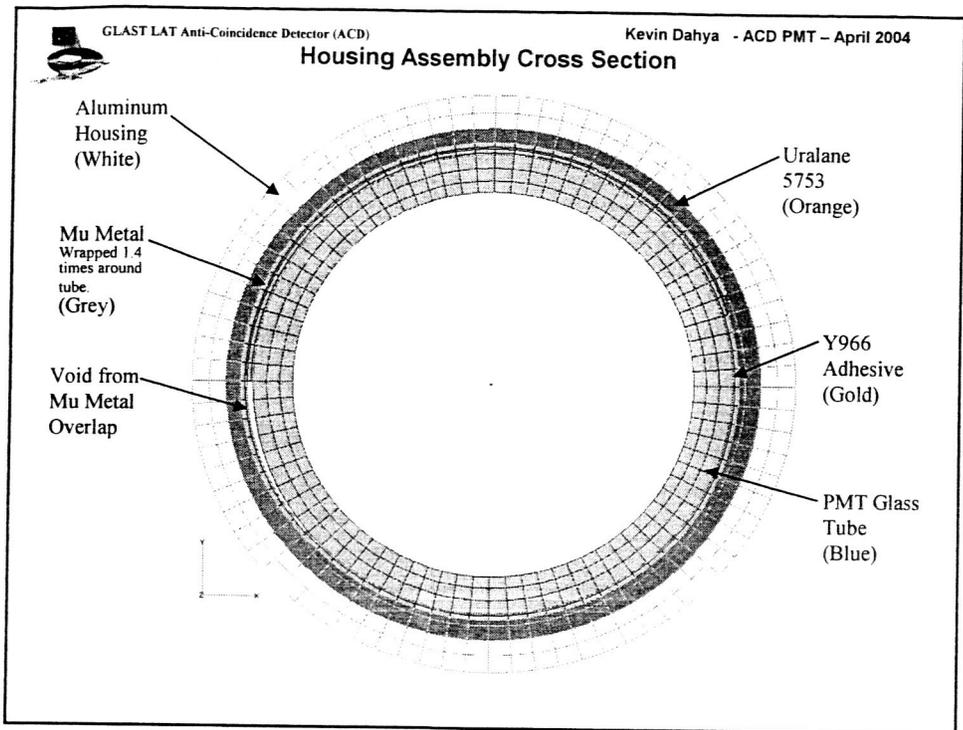


PMT Detailed Stress Analysis

Kevin Dahya - SAI



- Composed completely of solid elements.
- Constrained with pure kinematic conditions. (1-XYZ, 2-YZ, 3-Z).
- Threads for PMT Cap not modeled. Assumed nominal OD.
- Model does not include R/N (Resistor Network) & R/N housing.
- Assumed worst case is cold temperature of -40 deg C.



GLAST LAT Anti-Coincidence Detector (ACD) Kevin Dahya - ACD PMT - April 2004

Initial Dimensions & Material Properties

| | mm | inches |
|------------------------------|--------|--------|
| OD PMT Tube | 14.5 | 0.571 |
| PMT Tube Wall Thickness | 1.19 | 0.047 |
| Y966 Adhesive Tape Thickness | 0.0508 | 0.002 |
| Mu Metal Thickness | 0.132 | 0.005 |
| ID Aluminum Housing | 16.15 | 0.636 |
| OD Aluminum Housing** | 18.19 | 0.716 |

**OD dimension does not include any flanges or threads.

| Material | Manufacturer | -40°C | | | All Temps | |
|------------------|--------------|-----------------|----------|-----------------|-------------------|---------------------|
| | | Young's Modulus | CTE | Poisson's Ratio | Density | |
| | | MPa | psi | ppm / °C | g/cm ³ | lbs/in ³ |
| Al Alloy 5061-T6 | | 68948 | 10.0E+06 | 23.6 | 2.7 | 0.98 |
| Mu Metal | | 206843 | 30.0E+06 | 12.6 | 8.8 | 318 |
| 7056 | Coming | 63432 | 9.2E+06 | 5.15 | 2.29 | 0.83 |
| 966 | 3M | 596 | 86442 | 584 | 4.9 | 1.102 |
| 5753 Black | Huntsman | 35.7 | 5181 | 222 | 4.5 | 1.05 |



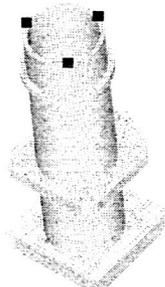
Model Checks

Passed all grounding checks and element geometry checks as well as free-free check.

- Higher order modes (7-10) unrealistic. Mass properties not incorporated in all material cards.

| MODE NO | EXTRACTION ORDER | EIGENVALUE | REAL EIGENVALUES | | GENERALIZED | |
|---------|------------------|------------|------------------|----------|-------------|-----------------------|
| | | | RADIANS | CYCLES | MASS | GENERALIZED STIFFNESS |
| 1 | 1 | 3.12E-03 | 5.58E-02 | 8.89E-03 | 1.00E+00 | 3.12E-03 |
| 2 | 2 | 3.50E-03 | 5.92E-02 | 9.42E-03 | 1.00E+00 | 3.50E-03 |
| 3 | 3 | 3.90E-03 | 6.30E-02 | 1.00E-02 | 1.00E+00 | 3.90E-03 |
| 4 | 4 | 5.05E-03 | 7.10E-02 | 1.13E-02 | 1.00E+00 | 5.05E-03 |
| 5 | 5 | 7.60E-03 | 8.72E-02 | 1.39E-02 | 1.00E+00 | 7.60E-03 |
| 6 | 6 | 8.93E-03 | 9.45E-02 | 1.50E-02 | 1.00E+00 | 8.93E-03 |
| 7 | 7 | 3.82E+09 | 6.18E+04 | 9.84E+03 | 1.00E+00 | 3.82E+09 |
| 8 | 8 | 3.83E+09 | 6.19E+04 | 9.85E+03 | 1.00E+00 | 3.83E+09 |
| 9 | 9 | 5.83E+09 | 7.64E+04 | 1.22E+04 | 1.00E+00 | 5.83E+09 |
| 10 | 10 | 5.84E+09 | 7.64E+04 | 1.22E+04 | 1.00E+00 | 5.84E+09 |

- Thermal displacement of Aluminum housing checked with hand analysis.
 - T3 displacement, at 3 locations shown, compared using $\delta = \alpha \Delta T L$



| PRINT ID. | X | Y | Z | R1 | R2 | R3 |
|-----------|--------------|--------------|--------------|----|----|----|
| 182748 | -1.780379E-2 | -2.474672E-2 | -4.837430E-2 | 0. | 0. | 0. |
| 182749 | -2.399179E-2 | -4.872374E-3 | -4.866474E-2 | 0. | 0. | 0. |
| 182453 | -2.975852E-4 | -1.131379E-2 | -4.852147E-2 | 0. | 0. | 0. |

Using minimum shear requirements :

$$\alpha = 2.365e^{-5} / ^\circ C$$

$$\Delta T = -60^\circ C \quad (+20 \text{ to } -40 \text{ degrees Celsius})$$

$$L = 41.15mm \quad (\text{Distance from top surface of mounting flange to top of cylinder})$$

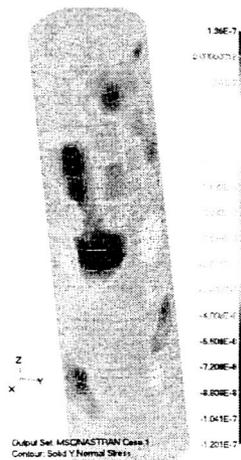
$$\delta = -0.058mm \quad \text{vs. } -0.06mm \text{ shown above in T3 direction of Displacement Vector box.}$$



Model Checks (Contd.)

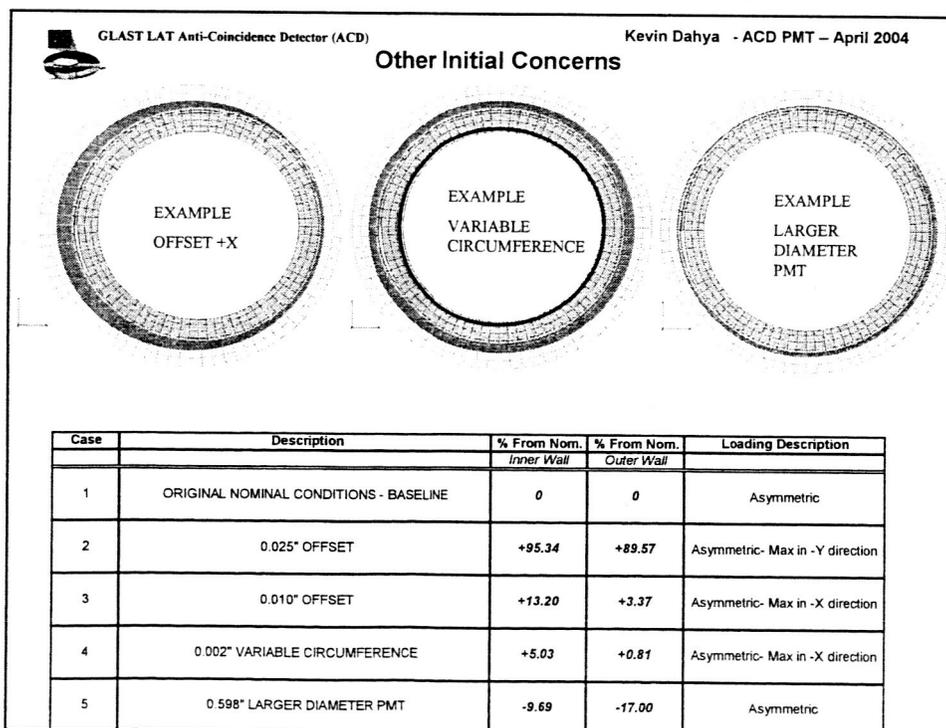
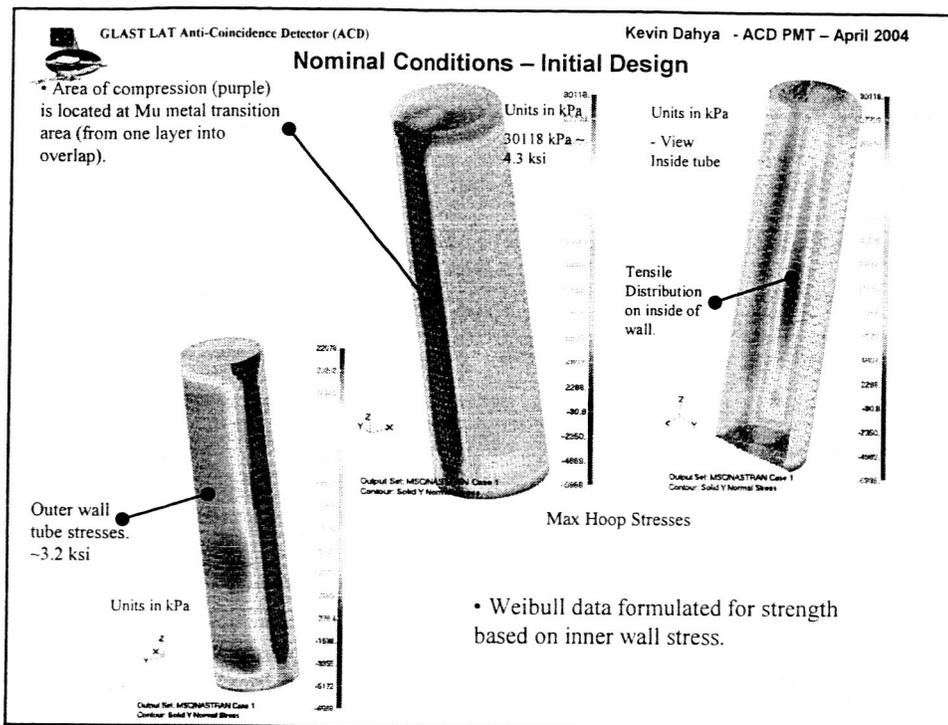
- Relative stress free conditions shown assuming uniform CTE for all materials, bulk temperature change, and kinematic constraints.

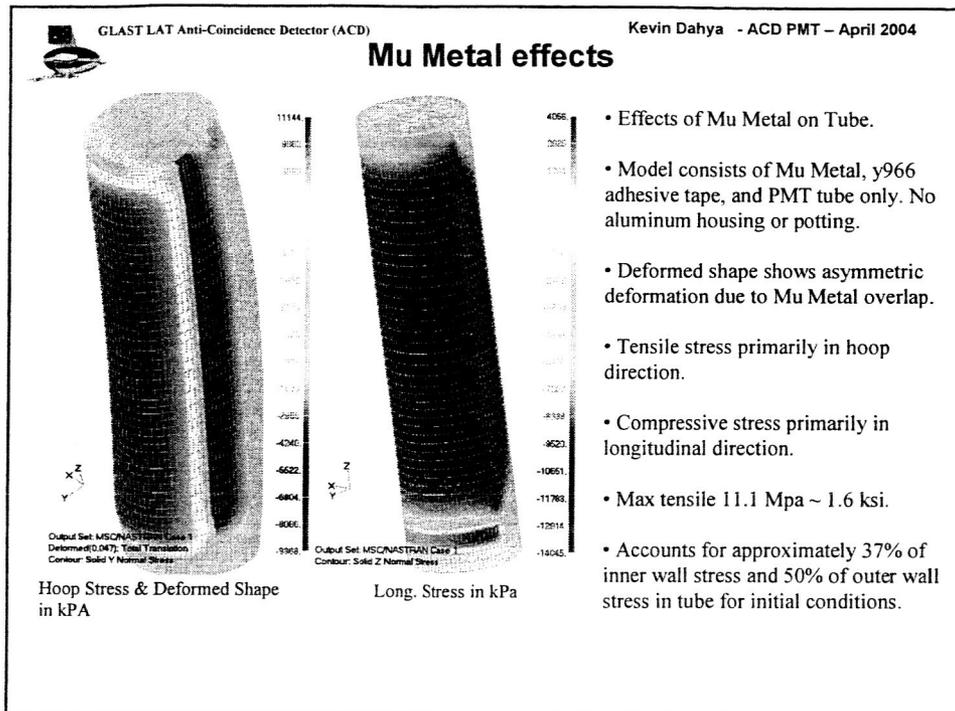
Glass Tube Stresses in kPa.



Full assembly shows approximate stress free conditions.







- GLAST LAT Anti-Coincidence Detector (ACD) Michael Amato - ACD PMT - Mar 2004
- ### Investigation
- Well into our work, a second set of failures in the old design
 - The full E.U chassis qual testing in late February failed 3 more PMTs (out of 17) in thermal vac at the second cycle (which was down to -40C).
 - All three units removed successfully with extremely careful but time consuming approach.
 - A week of inspections revealed the score lines were not the cause for the failure. All failed from defects on the outer surfaces. We learned this after we had made our preliminary solution decision.
 - All three PMTs failed at similar positions: circumferentially near middle of mu-metal overlap and longitudinally near the middle of the tube [AA0005 - 35 mm, AA0021 - 22 mm, & AA0128 - 27 mm (from window end)]. Similar to the first failure



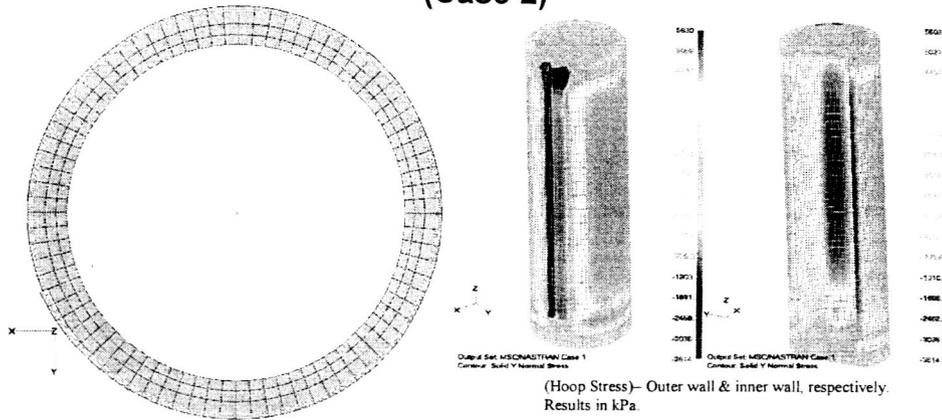
GLAST/LAT Anti-Coincidence Detector (ACD) Michael Amato - ACD PMT - Mar 2004

Path 2 – Defects on the outer surface of PMTs

- Predicted stress on outside surface in region of Mu metal overlap is not 4300 psi but around 3200 psi.
- Inspected outer surfaces of 8 NG PMTs. Scores/pits/scratches were found, but are small in size compared to scores on inner surface. NG tubes handled very little at GSFC
- No new strength tests have been performed on the outer surfaces of the PMT.
 - More difficult to test the strength of outer surface.
 - Time constrain
 - PMTs better used for qualification of new designs.
 - The data we have: failed 4 of 23, in an area with calculated stress around 3200 psi



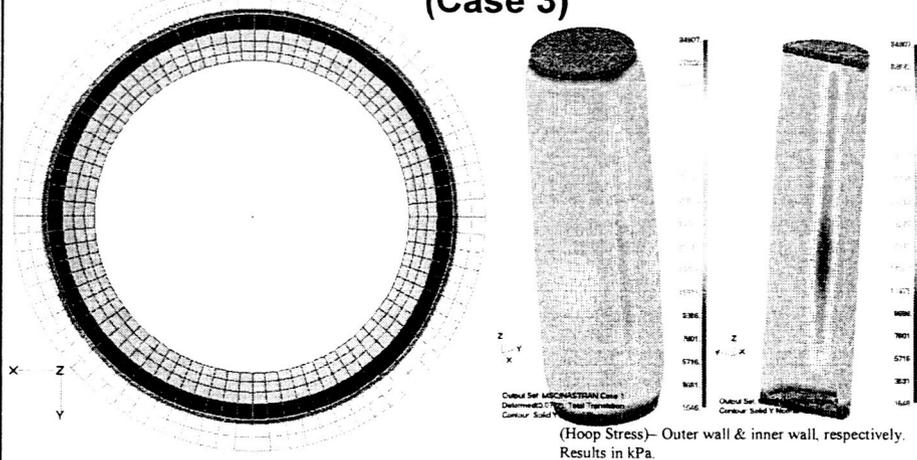
Eliminating Mu Metal Effects with Double Wrap (Case 2)



- Mu Metal effects only. No aluminum housing or potting included in model.
- *Comparable to results from previous slide titled "Mu Metal effects".
- Peak stress due to Mu Metal reduces 50% on inner wall (~1600 psi to ~800 psi) and 67% on outer wall (~1600 psi to ~691 psi).



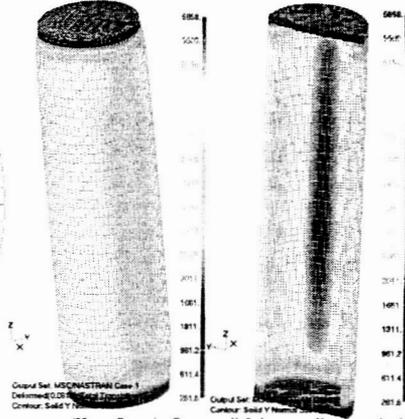
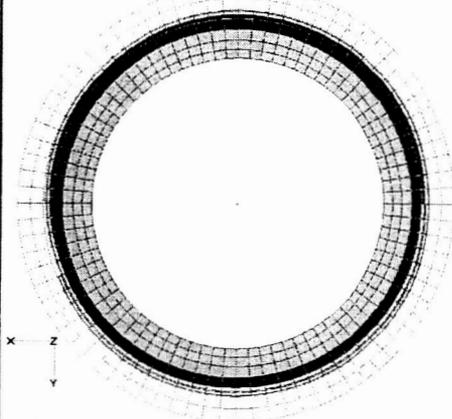
Moving Mu Metal to inside wall of housing (Case 3)



- Mu Metal transition still causing asymmetric loading.
- Potting material causing higher peak stress on PMT inner wall than initial configuration (~5 ksi, approx. 16% increase) !!
- PMT outer surface stresses ~ 3.5 ksi.



Mu Metal on inside wall of housing, RTV-566 substitution for uralane potting (Case 4)



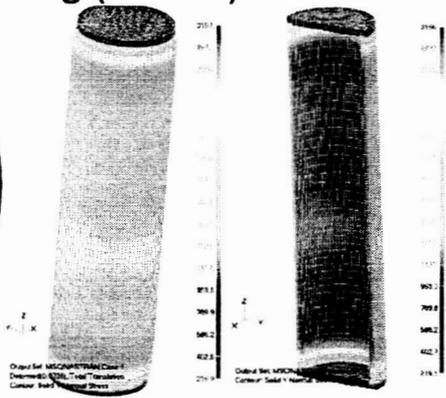
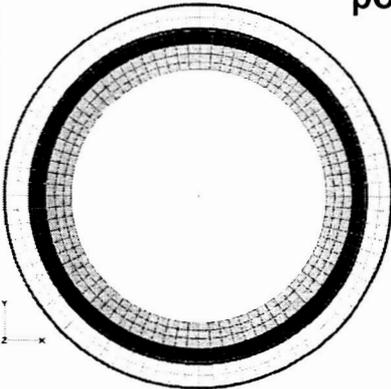
- Slight adverse reaction due to Mu Metal.
- Softer potting material “dampens” asymmetric effects effects.
- PMT inner surface peak stress ~ 850 psi.
- Outer surface peak stresses ~ 653 psi.

(Hoop Stress)– Outer wall & inner wall, respectively. Results in kPa.

$E_{rtv} = 609 \text{ psi}$
 $CTE_{rtv} = 233 \text{ ppm/deg C}$
 $Nu_{rtv} = 0.46$



Nickel coated housing with RTV-566 potting (Case 5)

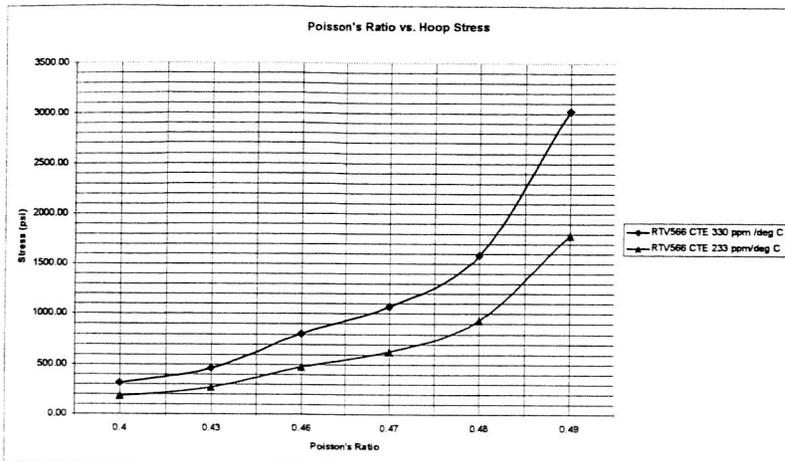


- Inner wall stress ~ 458 psi.
- Outer wall stress ~ 420 psi.
- Nickel coated housing with RTV-566 potting gives favorable results. However, Nickel coating did not meet magnetic shielding requirements.
- Also sensitive to Poisson’s ratio of potting compound (See Plot 1).

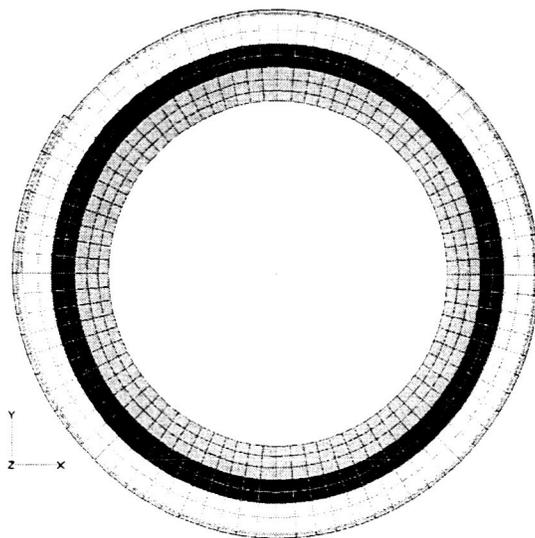
(Hoop Stress)– Outer wall & inner wall, respectively. Results in kPa.



Plot 1 – Poisson's ratio sensitivity for Nickel Coated Housing PMT Assembly

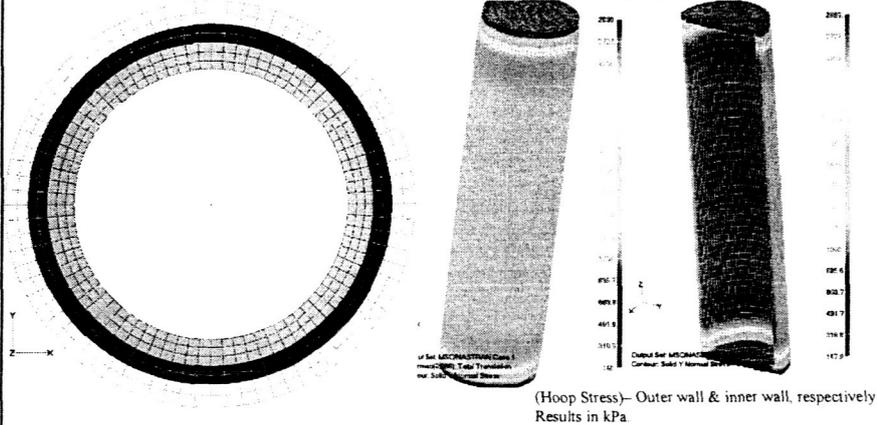


Mu Metal tacked to outside wall of housing with y966, RTV-566 potting.





Mu Metal tacked to outside wall of housing, RTV-566 potting (Case 7)



(Hoop Stress)– Outer wall & inner wall, respectively
Results in kPa

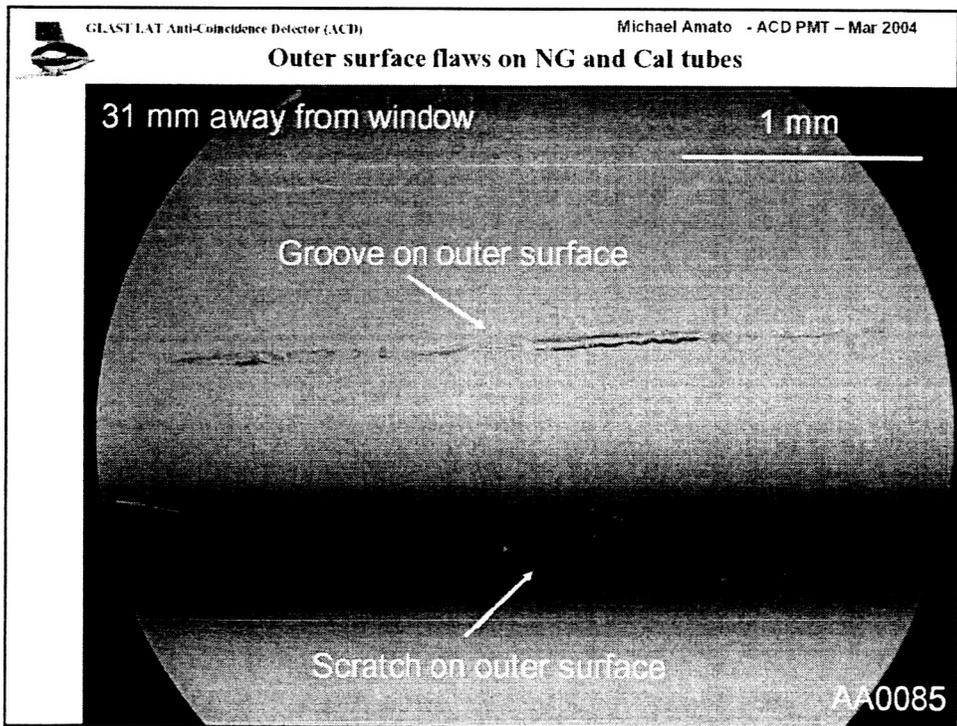
- Assuming tacked Mu Metal does not transfer much load into housing, PMT demonstrates uniform loading.
- PMT inner surface stresses ~ 419 psi.
- PMT outer surface stresses ~ 384 psi

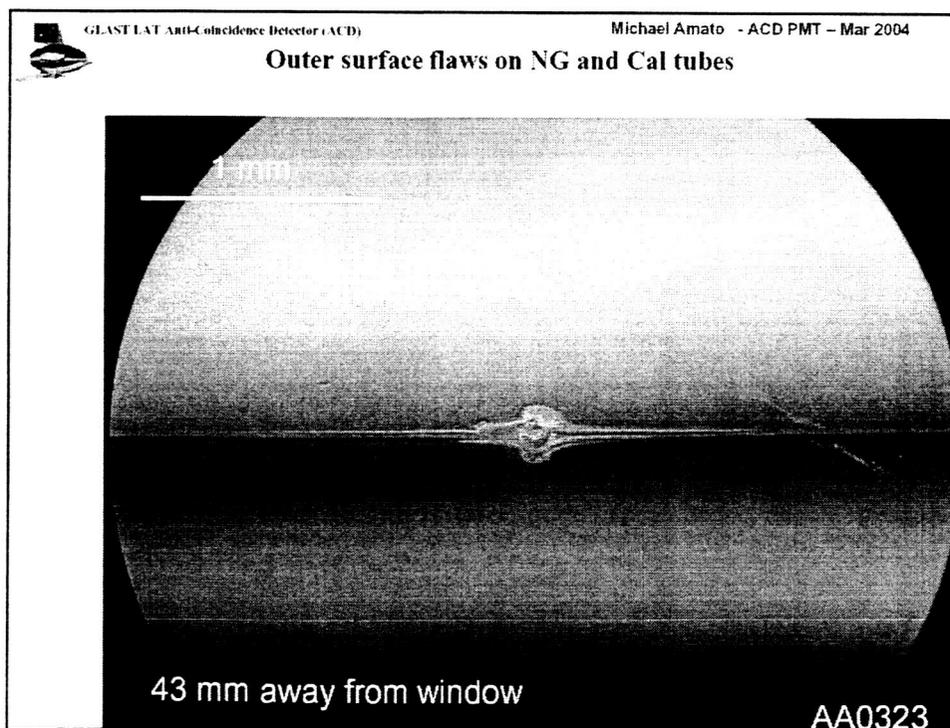
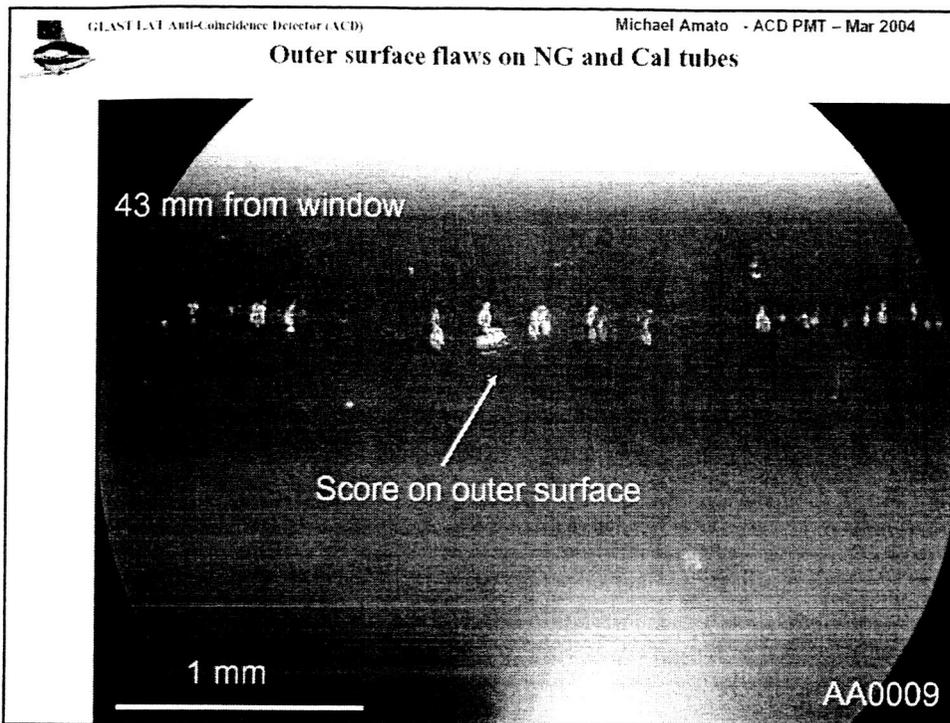


Initial Investigation & Solutions

- Initial conditions show high stresses on inner and outer walls of PMT tube.
- Mu Metal causes adverse loading conditions on PMT tube at a relatively high tensile stress (~ 1.6 ksi).
- Uralane stiffness also adds to tube stress
 - High CTE of uralane “pulls out” on PMT tube adding stress in tube.
- Evidence shows cracks propagate from center of Mu Metal overlap region.
 - Area of peak tensile stress on outer wall
- Solution path needs to eliminate adverse effects of Mu Metal on PMT tube and effects of high stiffness and CTE of Uralane.

| GLAST LAT Anti-Coincidence Detector (ACD) | | Kevin Dahya - ACD PMT - April 2004 | | | |
|---|---|------------------------------------|--------------------|-------------|-------------|
| Stress Reduction Analysis Summary | | | | | |
| Case | Description | Inner Wall of Tube | Outer Wall of Tube | % From Nom. | % From Nom. |
| | | psi | psi | Inner Wall | Outer Wall |
| 1 | ORIGINAL NOMINAL CONDITIONS - BASELINE | 4368.38 | 3202.32 | 0 | 0 |
| 2 | MU METAL with Double overlap, Y966, PMT ONLY. NO HOUSING OR POTTING (To see effects of Mu Metal on tube). | 816.53 | 691.81 | N/A | N/A |
| 3 | MU METAL ATTACHED TO INSIDE WALL OF HOUSING, URALANE POTTING. | 5061.64 | 3553.30 | +15.87 | +10.96 |
| 4 | MU METAL ATTACHED TO INSIDE WALL OF HOUSING, WITH RTV 566 SUBSTITUTION FOR 5753 POTTING. | 855.69 | 652.65 | -80 | -80 |
| 5 | NICKEL COATED HOUSING WITH RTV 566. Sensitive to poisson's ratio, see Plot 1. | 458.30 | 420.59 | -90 | -84 |
| 6 | MU METAL ATTACHED TO OUTSIDE WALL OF HOUSING, CONTINUOUSLY ATTACHED. Using RTV 566 potting. | 1039.88 | 770.12 | -76 | -71 |
| 7 | MU METAL ATTACHED TO OUTSIDE WALL OF HOUSING, NOT CONTINUOUSLY ATTACHED. Using RTV 566 potting. | 419.14 | 384.34 | -90 | -86 |
| 8 | MU METAL ATTACHED TO OUTSIDE WALL OF HOUSING, NOT CONTINUOUSLY ATTACHED. Using GASED RTV 566 potting (nu=0.42, cte=318 ppm/degC, E=290psi). | 104.42 | 95.72 | -98 | -96 |







Outer surface flaws on NG and Cal tubes

