ACD Phototube Breakage – Choosing a solution

**Approach:**

- Basic listing of solution options done. Layed out the options in sufficient detail to understand the basic issues.
- Established basic solution decision criteria.
- Distinguish two cases and the possibility of combine solution
  - What we do with the 100 tubes already potted
  - What we do with the 140 bare tubes
- Established and executed top level flow and individual flows for each path with dates
- Options that begin to look very hard early were put on back burner. This allowed elimination options as quickly as possible as initial prime candidates at least by completing the most critical actions.
Interpretation of latest data from failures and materials testing – preliminary conclusion July 30

Develop general set of failure causes July 19

Assess solutions based on early feasibility results and failure cause analysis

Begin preliminary solution analysis and feasibility tests of a few promising concepts, (see separate solution flows) July 22

Lay out more detailed set of solution options, feasibility results and selection criteria Aug 5

Complete analysis and preliminary testing Aug 12 - 18

PMT solution down-select Goal date - Aug 18

Assess solutions based on early feasibility results and failure cause analysis

Develop general set of solution paths from general set of failure causes July 20

Develop general set of solution paths from general set of failure causes July 20

PMT Top Level Solution Path flow

See detailed flow for chosen solution and actions list

Investigate failure July 6-Aug 2

Goal date - Aug 18

Interpretation of latest data from failures and materials testing – preliminary conclusion July 30
Selection Criteria

• **STRESS AND STRAIN** - Reliably lowers stress to under 1000 psi for tensile stresses with a goal of < 500 psi. (Tensile limit from our test data, literature and gives margin from inside score Weibull test results.) Keeps compressive stresses under 6000 psi (goal < 3000psi). Show by analysis and strain test if possible. Higher compressive stresses must be shown to truly be compressive with no variables that could cause associated tensile stresses.

• **FEASIBILITY** - Passes prototype feasibility tests (assemble-able, controllable, seems repeatable). Friendly to being assembled in large numbers.

• **MINIMUM PROTOTYPE TESTS** - Passes prototype thermal test in a rail, light tight and vibration test

• **LOW VARIABLY RISK** – low number of variables or that could effect stresses or ACD performance. Low sensitivity effect on stress on variables we cant control.

• **SCHEDULE** (& cost). Subjective, could also be used as tie breaker, some solutions could be eliminated sooner solely on this basis.
Options no longer being actively pursued –

Some were deemed early on to be too complicated for the potential return, or too long to fully implement and test etc.. Some did not look good in early analyses

- Slit design – looked promising in first cut analysis and machining tests but later analysis showed it would not do the job

- Kinematic Mount – 3 point flex mount. Very low stress but complicated to design and implement. High risk of requiring new housings and more mass which could have ripple effects on rail

- Thermal yield screening. Hard to select test that screens out bad RTV or week PMTs that also does not consume or partially damage PMTs that pass. Could be done but a large number (>30) tubes would have to be put through the proposed screening then put through partial life test to show screening worked

- CTE compensation mechanical design – Uses inserts to hold PMTs, no RTV. Inserts compensate for some but not all of CTE difference in long direction, radial clearances aid CTE compensation. Rapidly designed and machined early version to get it into testing. Early tests show we can not hold preload due apparently to creep issues in some of the CTE compensation inserts

- New potting material – same design – This is essentially what we did the first time. Given the radical changes in RTV materials between batches and between cures within batch, we see this is a larger development and test effort. Includes finding ways to control RTV
ACD Phototube Breakage –Heater Option

**Concept:**
- Heat phototubes to prevent breaking
- Mount heaters to rails that hold tubes
- Use thermostats to keep temperatures above set point where there is a risk of PMT failure

**Pros:**
- Can use existing potted tubes
- Could heat some chassis and use lower-stress mounting for other tubes.

**Cons:**
- New wiring and electrical control for heaters needed (LAT and/or spacecraft changes required)
- EMI risk from switching high current near front-end electronics (has been seen on other missions) if heaters are needed during science operations
- Erodes LAT survival and possibly operational power margins
- Greater thermal heat load being dumped to the grid if heaters required during science operations
- May require redesign to Electronic Chassis and/or PMT rails

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
ACD Phototube Breakage – Heater Option

**Status:**

- Baseline survival feed from spacecraft limits available power to ~75W OAP with MAR 30% duty cycle requirement
  - Assumes increase of LAT allocation on that feed from 220W to 285W
  - Would require modifications to the LAT Heater Control Box
    - Update and release of drawings
    - Re-layout of the HCB board
    - Retest of HCB
    - Routing ACD heater cables on BEA looks doable

- If we hold this concept to our minimum selection criteria, **15C is required to keep the worst RTV batches under 1000 psi tension**
  - This puts heater switching into the operational temperature range
    - Would need a set point of 0C to prevent switching during science operations
  - We are taking a new look at the 15C for 1000 psi calculation looking for relief to allow more heated possibilities

- **100W to 140W just to heat already potted PMTs to 15C, double to heat all rails**
  - Hot operational case limits prevents use of thermal isolation of PMTs

- Modifications to survival feed from spacecraft not explored because of observatory safemode energy reserve concerns

- Heating a few rails (could be less than needed to accommodate all already potted PMTs ) could be considered

- Heating to **-15C is the only temperature that the current spacecraft feed can support**
  - Could be used in combination with some type of design change and rework (for example another potting option that is not good enough for -40 or -30C but good enough for -15C)
Alternate Design – PMT Heater Design

Preliminary Heater Power Analysis
July 14

Determine HTR, TSTAT locations
July 29

Determine temperature Set point
Aug 6

Re-visit temperature Set point
Aug 6

Heater Power Analysis
Aug 12

Sufficient power Available?
NO

NO

PMT Solution Down-select
Aug 18

PMT Rail Re-design ok?

YES

New Parts Selection

Preliminary Parts selection
July 29

PMT Solution

Preliminary Parts ok?

NO

YES

Order Parts

Build Chassis Qual. Unit
TBD (date)

Chassis Qual. Testing
TBD (date)

Fabricate new Rail design, TVAC test of PMT temp?
TBD (date)

Revisit HTR, TSTAT Locations, Rail Re-design

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
## Backup - Heater solution power

**Survival Orbit Scenario:** +Z axis sun pointed, all rails heated

<table>
<thead>
<tr>
<th>Temperature Set Point °C</th>
<th>-15</th>
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<tr>
<td>+X Chassis htr power</td>
<td>22</td>
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<tr>
<td>Total hp (Watts)</td>
<td>79</td>
<td>128</td>
<td>191</td>
<td>318</td>
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**Survival Orbit Scenario:** +X axis sun pointed, +Y,-X rails heated

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<tr>
<td>Total hp (Watts)</td>
<td>58</td>
<td>117</td>
<td>154</td>
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**Survival Orbit Scenario:** +X,+Y sun pointed, all rails heated

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<tr>
<td>Total hp (Watts)</td>
<td>39</td>
<td>93</td>
<td>131</td>
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**Survival Orbit Scenario:** +X,+Y sun pointed, -X,-Y rails heated

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<tr>
<td>Total hp (Watts)</td>
<td>39</td>
<td>78</td>
<td>100</td>
<td>163</td>
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- Based on "old conductance value for PMT rail to base frame
- Newer conductance value reduces power estimates by ~15%

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
Thermal Design Results

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<td>Trackers Boundary</td>
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<td>PMT Rail</td>
<td>15</td>
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<td>30</td>
<td>34</td>
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<td>15 to 35</td>
<td>15 to 45</td>
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<td>Heater Power (Watts)</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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</table>

Old conductance value for PMT Rail to FRAME

- All temperatures in °C
- Predictions shown are raw predicts and margin does not reflect 5 °C analytical uncertainty
ACD Phototube Breakage – De-bonded PMT Housing Design (grooved and strip versions)

- **Concept:** Add a release agent to the inner wall of the housing so the RTV-566 will not adhere, thus reducing stress on the glass tubes.

- De-bonding agent applied to Al housing
- Grooves, threads or some other method added to prevent longitudinal glass tube motion
- Glass tube potted as before
- RTV-566 is allowed to expand and contract with glass
- May try to select RTV batches that tend towards better properties

- **Pros:**
  - Used with glass tubes not already potted,
  - Uses existing design and process adding grooves and release agents steps
  - Stress on glass tube is reduced because RTV is not adhering to the Al housing, therefore the RTV can expand and contract freely with temperature

- **Cons:**
  - De-bonding agent will be a contamination concern
  - Must ensure that RTV does not adhere to Al housing during potting; workmanship issue, will require strain screening
  - Not applicable for existing potted PMT housings
  - Takes longer to assemble than mechanical solutions
  - Cant remove PMTs easily after assembly
  - Cant directly measure strain in glass on prototypes
  - Strip approach prototyped without release agent because of cross contamination concerns with primer

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
ACD Phototube Breakage – De-bonded PMT Housing Design

- **Status:**
  - Analysis shows both are effective in reducing stress. The strip version has some minor stress riser concerns
  - 1 prototype of each bonded and successfully thermally tested Tuesday. Can not directly measure strain on glass.
  - Strain data showed de-bonding on both. Strip approach produced confusing data that would need to be pursued. Both may be showing some warm side strain increases due to RTV expansion

- **Actions:**
  - Vibration test
Alternate Design – De-bonded PMT Housing Design

Design Prototype, Test release agents Aug 6

Modify Housing Aug 9

Modify Design

Pot Glass Tube Aug 11

Cure Assembly Aug 16

Assembly procedure mods Aug 11

Assembly Procedure Aug 2

1st Thermal And strain Test – Pass? August 18

Margins OK

NO

YES

PMT solution Down-select Aug 18

Start Build 20 Qual Units August 31

Fabricate Parts August 26

Finalize Flight Design August 26

Vibration test

Margins OK

Qual Testing September 12

PMT Production (40/week) September 20

Thermal Screen September 27

First Batch Ready For Electronic Chassis Integration Oct 1

PMT Production (40/week) September 20

Finalize Flight Design August 26

Vibration test

Start Build 20 Qual Units August 31

Fabricate Parts August 26

Finalize Flight Design August 26

Vibration test

Margins OK

Qual Testing September 12

PMT Production (40/week) September 20

Thermal Screen September 27

First Batch Ready For Electronic Chassis Integration Oct 1

Aug 2004—Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
Mechanical mount - Partial CTE Compensation Option

Concept:
- No potting, hold the tubes at the ends with inserts
- Small clearances and some CTE compensation limit radial stress
- Longitudinal stress partially compensated by insert CTE

Pros:
- Can use existing housing design
- No RTV or other potting material and related material properties variables and testing.
- PMTs removable and design modifiable if there is a problem
- Relatively easy assembly, and it can be converted to the spring compensation design anytime before Resistor Network assembly

Cons:
- CTE difference is not fully compensated. Force exerted will increase at cold extremes approximately 4X initial preload to 1500 psi
- Preload required on PMT. Should be in compression but tube dimension errors will likely cause small tensions
- Custom machined parts to match PMTs
- Very small (.002-.004”) radial motion could occur during vibration if preload is overcome
Mechanical mount - Partial CTE Compensation Option

**Status:**
- Rapidly prototyped last week
- Room temperature prototype torque testing completed
- Stress analysis completed
- 1 prototype successfully tested with longitudinal strain measurements which were close to analysis prediction

**Actions:**
- Vibration test
- Confirm hoop strain with strain gauge
Mechanical mount - Partial Spring Compensation Option

**Concept:**
- No potting, hold the tubes at the ends with inserts
- Small clearances and some CTE compensation limit radial stress
- Longitudinal stress limited by spring

**Pros:**
- Can use existing housing design,
- No RTV or other potting material and related material properties variables and testing.
- PMTs removable, and modifications possible if there is a problem. Spring limits preload on PMT
- Relatively easy assembly, relatively easy assembly, and it can be converted to the CTE compensation design anytime before resistor network assembly

**Cons:**
- Spring constant will vary.
- Preload still required on PMT. Limited by spring so less of a concern. Should be in compression but tube dimension errors will likely cause tension.
- Very small (.002-.004”) radial motion could occur during vibration if preload is overcome, does it matter as long as clear fiber spring has throw left and leads are ok?
- Custom machined parts to match PMTs, strain not tracking analysis as well as CTE comp does, why?
Mechanical mount - Partial Spring Compensation Option

**Status:**
- Rapidly prototyped last week
- Room temperature prototype torque testing completed
- Stress analysis completed
- 1 prototype successfully tested with longitudinal strain measurements which were close to analysis prediction

**Actions:**
- Vibration test
- Confirm hoop strain with strain gauge
Mechanical mount - Partial Spring Compensation and CTE Compensation Options

- Design Prototype, Preliminary Stress Analysis Aug 2
- Fabricate Parts Aug 3
- Modify Design
  - NO
  - Margins OK
  - YES

  - Start Build 25 Qual Units Aug 31
  - Fabricate Parts August 28

  - Finalize Flight Design & proc August 27
  - Vibration test

- Strain Gage PMT Aug 5
- 1st Prototype Assembly Aug 5

- Assembly Procedure Aug 5
- 1st Thermal And strain Test – Pass? August 10

- PMT solution Decision Aug 18

- Detailed Stress Analysis Aug 10

- Margins OK

- YES

- NO

- Start Build 25 Qual Units Aug 31

- Thermal Screen September 29

- First Batch Ready For Electronic Chassis Integration Oct 5

- Qual Testing September 9

- PMT Production (40/week) September 17

- Qual Testing September 9
# Solution stress comparison table

<table>
<thead>
<tr>
<th>ACD PMT Design Solution Stress Comparison</th>
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</thead>
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<tr>
<td><strong>Design Option Description</strong></td>
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<td>------------------------------------------</td>
</tr>
<tr>
<td>Original potted design</td>
</tr>
<tr>
<td>Notched potted design</td>
</tr>
<tr>
<td>0.25&quot;-wide bonded strip design, fully potted tube</td>
</tr>
<tr>
<td>0.5&quot;-wide bonded strip design, fully potted tube</td>
</tr>
<tr>
<td>0.25&quot;-wide RTV strip only</td>
</tr>
<tr>
<td>Mechanical design w/ spring compensation</td>
</tr>
<tr>
<td>Mechanical design w/ Delrin CTE compensation</td>
</tr>
<tr>
<td>Glass tube and RTV only</td>
</tr>
</tbody>
</table>

Note: positive values are in tension, negative values are in compression.

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al
Prototype strain tests – mechanical concepts

Non-RTV Compensated Designs
(Tested 8/9/04)

Note: Strains presented here incorporate installation strains.
The decision based on what we know today

Both versions of the mechanical and de-bonded solutions appear to meet minimum selection criteria.

We have decided to try and qualify the spring compensation method

Pros:

• The mechanical solutions show primarily compressive stresses rather than tensile. Glass is much stronger in compression. This is even more true of glass with significant flaws like ours. The spring method is less than 10% of the selection criteria stress (as are the two de-bonded solutions)

• The mechanical solutions offer what appears to be considerably faster production time.

• Of the mechanical solutions, the spring solution offers lower stress and built in preload margin.

• The spring solution can easily be converted to the CTE compensation solution by bottoming out the spring or removing it (they use the same parts other than the spring)

• The spring provides preload control – lowers intial preload and gives margin for preload release (warm temps or delrin creep)

• No RTV or other potting material and related material properties variables and testing.

• We are leery of putting the PMTs into a potted design (with RTV or any potting material). Not just because the challenges it poses are fresh in our memory, possibly giving us some built in bias. Potted solutions reduce flexibility to handle problems. The PMTs can not be easily removed and recovered, the design can not be modified if we run into trouble later using existing parts like the mechanical solutions can.
The decision based on what we know today

- This flexibility could serve us well considering we still have to make it through a qualification program. Since four solutions appeared to meet minimum requirements, the flexibility and ‘fixability’ of the mechanical designs.

- There are some details and ‘cons’ in the design that need to be worked – we will reduce try and reduce vibration motion if preload is exceeded with design tolerance changes. We may need to certify springs. We want to know why the measured strain to analysis was more off than the CTE compensation method. We have to work out minor tacking and locking details, drawings and procedures for qual units.

- Our non mechanical back up approach (in case there is something we don’t understand, some surprise in the mechanical designs) will be the groove debonding method. It is actually the absolute lowest stress solution. The CTE compensation method is also an easy backup if problems arise that are specific to the spring washer design, they are interchangeable in a way.

- Can use existing housing design
Mechanical mount - Partial Spring Compensation and CTE Compensation Options - draft of more detailed future flow

1. **PMT solution Decision Aug 18**
   - YES
   - **Start Build 25 Qual Units Sept 3**
   - **Start Qual Testing Sept 9 or 10**
   - **First Batch Ready For Rail and Electronic Chassis Integration Sept 19?**

2. **Vibration and second strain tests Aug 19, 20**
   - **Fabricate Qual Parts (& 1st flight units) August 26 or 31**
   - **Start some (18) flight assembly before qual done? Sept 10 or 13**
   - **Drawings & procs for qual units Aug 30**

3. **Finalize Flight Design August 26**
   - **Fab of rest of flight parts Sept 15**
   - **PMT Production (50/week, fab rate ?) Sept 17 or 20**
   - **Start 1st batch Par coating and test Sept 15**
   - **Thermal Screen Sept 14**
What do we do with the already bonded PMTs?

If viable they will be strain screened. All but the very low strain PMTs will be removed via the turn, peel and Dynasol method. They will be reassembled into the spring compensation method.

- If the strain screening method shows it could be viable we will strain screen the bonded PMTs.

- The low strain PMTs (extrapolate to <1000 psi at -30C) would then be thermally screened and could fly as is.

- All others will be removed via the slow low load turning of the housing, peeling the remaining thin housing skin, and Dynasol off the RTV. This has been successfully tried twice.

- There could be drop out during the removal process. We have ordered additional spares.

- Because of the time involved these PMTs will take longer to process into new housings.
ACD Phototube Breakage – Screening of Potted Phototubes

Concept: Determine the variations in stress on the potted phototubes

- Mount strain gauge to the aluminum housing.
- Thermal cycle the phototubes from 0°C to +40°C and evaluate the thermal stresses.
- Thermal cycle the lower stressed phototubes to the acceptance temperatures (-30°C to +40°C)

Pros:
- Determine what is driving the phototube failures (flaws population or variations in stress).
- Screen the existing potted phototubes by determining the variations in stress.
- Potted phototubes that showed lower stresses can be used as is.
- Low cost (Save in materials and labor cost to rework the lower stress phototubes)

Cons:
- Possible brakeage of phototubes in thermal screening.
- Adhesive used to bond the gauges is a cyanoacrylate (outgasser).
- Rework potted phototubes that show higher stresses.

Status:
- 4 PMTs shown suggest this is possible. Testing 9 tubes now to prove concept.

Actions:
- Verify the ability to remove the cyanoacrylate adhesive from the housing for the bonding of the strain gauge.
- Order additional single strain gauges from the same lot number.
Strain screening tests

For the six units tested the maximum strain rates and associated approximate stresses at -30°C are
(ue/C & psi) - 0.5/250, 1.1/550, 1.2/600, 2.9/1450, 4.5/2250, 5.1/2550

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<th>PMT Ident</th>
<th>Gauge Location</th>
<th>Strain Rate</th>
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<td>Window</td>
<td>-0.2</td>
<td>-60 to 40</td>
</tr>
<tr>
<td>S/N 5</td>
<td>Window</td>
<td>-1.5</td>
<td></td>
</tr>
</tbody>
</table>
Screening and removal of Potted Phototubes

Strain Gauge Phototube ZL0887 -30°C July 6

Strain Gauge Phototube SN2 & SN5 Test Run 2, -60°C July 13

Results of Final Strain Gauge Phototube AA322 -60°C Aug. 3

Variations in Stress? – Down-select Aug 18

NO

Remove Potted Phototubes (~10/wk) Start Aug 31

YES

Start with 10 Potted Phototubes for Strain Gauge Screening August 9-18

Strain screen thermal test all Potted Phototubes August 24-31

Low Strain Phototubes to Resistor Network Integration Sept 10

First Batch Ready For Electronic Chassis Integration Oct 1

Higher Strain Phototubes

Parylene Coat September 30

Aug 2004 - Amato, Schmidt, He, Veins, Joy, Simmons, Dahya, Marsh, et al