“Characterization and Analysis for Flying COTS Electronics On-Orbit”

Paper Number: SSC11-XII-3

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AFIT/ENY

11 Aug 11
Agenda

The AFIT of Today is the Air Force of Tomorrow.

• Introduction & Background
• Design & Methodology
• Test Campaign Results
• Conclusions & Future Work
Program Background

AFIT has developed high-speed chromatography in the lab and field environments to capture and characterize fast transient events (explosions).

Simple mechanical design: optical telescope, rotating DVP, camera.

Desire to move the technology from terrestrial environment to space.

Goals: Reconstruct static scene; Image fast transient event; Characterize transient spectral signature.

TRL: 3 (currently), 6 (post orbital validation).

Optical Configuration

Notional Fast-Transient Response
AFIT currently working toward use of an ELC exposed facility assignment for Space-Based Chromotomography Experiment (CTEx)
**Research Motivation**

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- Demonstrate new/innovative ways to develop & build the experimental payload in order to reduce cost/schedule
  - Use of COTS & hermetic enclosures used for: camera, computer, controllers, rotation stages
  - Opens the door to the use of aircraft grade components and computers which may not be available in a space-qualified form for years

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**Notional Payload Configuration**

- Telescope
- ICU
- Strong-Back Frame
- CIU
- Motor/Encoder
- ExPA Pallet
- TCU
- PTCU

**Goal:** Validate the process to scale up to a larger hermetic enclosure (TCU)
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Design Requirements

- Objective: Validate thermal models developed for a hermetically-sealed computer intended for space ops

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Utilize commercial, off-the-shelf (COTS) electronics and mechanical hardware as much as possible</td>
<td>AFIT</td>
</tr>
<tr>
<td>2. Minimize mass to 10 kg, or less</td>
<td>AFIT</td>
</tr>
<tr>
<td>3. Ensure the fundamental frequency is above 50 hertz in all axes</td>
<td>STP</td>
</tr>
<tr>
<td>4. Ensure the design will survive normal operations in a high vacuum/space environment</td>
<td>STP</td>
</tr>
<tr>
<td>5. Meet all regulatory requirements associated with HTV, EXPA and ISS</td>
<td>STP</td>
</tr>
<tr>
<td>6. Do not dissipate excess thermal loading to the ISS (or surrounding structure/devices)</td>
<td>STP</td>
</tr>
</tbody>
</table>
Payload System Architecture

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- Space Station
- ELC STP-IIU
- HTV Launch Vehicle
- SSRMS
- Exposed Pallet (EP)
- CTEx Payload Control Unit (PCU)
- Instrument Computer Unit (ICU)
- Telescope Control Unit (TCU)
- Power/Thermal Control Unit (PTCU)
- CTEx Instrument
- Power, Data
- Star Tracker
- Power, Control, Data

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Layout & Assembly

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- Dry Nitrogen Purge & Fill To 17 psia
- Primary Seal: Face-seal, .25-inch Diameter Fluorocarbon (Viton) O-Ring
- Swagelok Sealed, Welded Bellows Valve
- .25-inch VCR Fittings
Mass Properties

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- ICU Design Size: 8.0W x 8.5H X 12.0L in
- Mass: 26.91 lbm / 12.2 kg
- Parvus Card Cage With Shock Rocks Utilized (Cuts high frequency shock loads by up to a factor of 10)
- Card Cage Can Accept Up To 8 Cards (~7 Required)
- Fan To Be Designed Into Enclosure To Circulate Across A Machined Heat Sink In The Top/Front Of The Enclosure

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>Mass (lbm)</th>
<th>Mass (Kg)</th>
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<tbody>
<tr>
<td>1</td>
<td>Housing Lower ICU R0b 101007</td>
<td>7.225</td>
<td>3.277</td>
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<tr>
<td>2</td>
<td>Housing Upper ICU R0b 101007</td>
<td>8.679</td>
<td>3.937</td>
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<td>3</td>
<td>Bracket Fan ICU R0 100929</td>
<td>0.278</td>
<td>0.126</td>
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<tr>
<td>4</td>
<td>Fan McMaster-Carr 1939K77</td>
<td>1.21</td>
<td>0.549</td>
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<tr>
<td>5</td>
<td>Plate Thermal Baffle ICU R0 101004</td>
<td>0.418</td>
<td>0.190</td>
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<td>6</td>
<td>Parvus Cage w/ Shock Rocks</td>
<td>0.84</td>
<td>0.381</td>
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<tr>
<td>7</td>
<td>PCB - CPU (Helios)</td>
<td>0.209</td>
<td>0.095</td>
</tr>
<tr>
<td>8</td>
<td>PCB - UPS</td>
<td>0.364</td>
<td>0.165</td>
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<tr>
<td>9</td>
<td>PCB - Relay Board</td>
<td>0.187</td>
<td>0.085</td>
</tr>
<tr>
<td>10</td>
<td>PCB - Weather Board</td>
<td>0.033</td>
<td>0.015</td>
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<tr>
<td>11</td>
<td>PCB - IMU/GPS Board</td>
<td>0.187</td>
<td>0.085</td>
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<tr>
<td>12</td>
<td>Feedthru Pave Tech Co PN-1649 12-Wire</td>
<td>0.67</td>
<td>0.304</td>
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<tr>
<td>13</td>
<td>Purge Valve Assy</td>
<td>2</td>
<td>0.907</td>
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<tr>
<td>14</td>
<td>Wiring</td>
<td>0.9</td>
<td>0.408</td>
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<tr>
<td>15</td>
<td>Hardware</td>
<td>0.2</td>
<td>0.091</td>
</tr>
<tr>
<td>16</td>
<td>Margin (add 15%)</td>
<td>3.51</td>
<td>1.592</td>
</tr>
</tbody>
</table>

TOTAL ESTIMATE 26.91 12.206
Thermal Concept

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Feedthru

5” Fan

PC/104

Baffle

Housing / Heat Sink
Thermal Concept (Cont’d)

- Estimated Nominal Power Consumption: ~13 Watts (25 W peak)*
- Fan Selection 148CFM, size 127mm^2, McMaster-Carr 1939K77
- Assume airflow m^3/s ~40% = 0.028 m^3/s*
- 4 center fins plus end plates, 0.246m long x 0.02045m high x 0.0025m wide, baseplate width 0.12065m
- Al 6061 T6 Thermal Conductivity 167 W/m-k*

* Steady-state assumptions
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Characterization

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- Goal: Thermal model validation
- Test-Campaign
  - Assembly & Integration
  - Operational/Functionality Checkout
  - Thermal-Vacuum
  - Vibe-Table

Safety Factor: 3.5

Purge/Fill Stress Analysis

TVAC Setup
Results

- Assembly procedures seamless
- Pressure held in ICU for duration
- Thermal model valid, +/- 1% error
- Fundamental freq. >50 Hz (376 Hz)

Thermal Model Validated; Design Meets Minimum Req’ts
Conclusions

**Summary**

- Goal: Validate baseline ICU process
- Designed, analyzed and tested prototype ICU on-orbit concept
- Design feasible/functional
- Model tracked to +/- 3°C of actual

**Conclusions / Future Work**

- Threshold requirements met
- ~20-25 Watts maximum load
- Inexpensive electronics issues (weather board)
- Thermal surface coating required (emissivity ~0.90 recommended)
- Scale designs for controller assembly

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Achieved First-Iteration Design → Further Optimization Needed
QUESTIONS?
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Intro & Background

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- **Spatial Resolution**
- **Temporal Resolution**
  - (sample rate)
- **Spectral Resolution**
  - (# bands)

**HSI CT Scanner**

- Sample Rate
- Spatial Resolution
- Temporal Resolution
  - (sample rate)
- Spectral Resolution
  - (# bands)

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CTEx Lineage

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Mooney (AFRL)*
- AMSI
- DVP & IR camera
- Demo’d concept

Mooney, et al (AFRL/SSSC)*
- CTHIS (MWIR & VNIR)
- Applied to any band
- Small envelope (6 lbs, 20W, 64 bands)

Dearinger, Gustke, LeMaster, Gould (AFIT)
- Developed S/W algorithms and optical science/reconstruction

Bostick (AFIT)*
- Resolution & Errors
- Resolution: 0.5nm (400nm) – 7nm (750nm)
- Alignment of the prism mount most significant error (1° angular error = 50-100% spectral degradation)

Sheirich (AFIT)*
- Space-msn baseline
- Initial space CONOPS
- Mapped trade-space

Book (AFIT)*: Baseline GCTEx, assessed RCOS telescope, provided calibration/alignment/focus schemes
Miller (AFIT)*: Passive 6DOF vibe-isolation system baseline
Morse (AFIT)*: Avionics baseline (hardware and software)
O'Dell (AFIT)*: Characterization of the Newtonian GCTEx
Starr (AFIT)*: Slewing/attitude requirements, on-orbit CONOPS

* Concepts used in this thesis

1994........................2000..............................2004.........................Present

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Research Problems

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- **SCTEx Layout**: Design of the space-based experiment mechanical layout to integrate components, determine mass properties and explore trade-space options

- **GCTEx Linear Revision**: Design and characterize a linear revision to the ground-based experiment in order to acquire higher-fidelity data and assess on-orbit calibration schemas

- **SCTEx ICU**: Design and characterize the space-based experiment Instrument Computer Unit (ICU) in order to validate modeling and predict on-orbit performance
CTEx Road-Map

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- Chromotomography Science: Algorithm & Physics Development
- Concept of Operations: Req’ts, Calibration, Collection Plans, Ground/Space Ops
- Support Equipment: Structure, Mechanisms, Electronics, Software
Methodology: Design

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- Goal: Package previously selected components into ELC constraints
- Baseline layout (non-optimization)
- Optics “beam” through breadboard
- Star-tracker integrated
- Orientation can rotate about Z-axis
- Strong-back required

Telescope Configured with ExPA

Telescope layout

Strongback

Telescope

Payload Envelope

ExPA

“Jewel” Vibration-Isolators

Integration Baseplate

Baseplate
Methodology: Design

- One-dimensional lumped-capacitance model developed
- Assumed single primary passive radiator, Nadir-facing
- Hermetically-sealed assembly based on HREP (18 psia GN2)