EO-1 Advanced Land Imager (ALI) Technology Transfer Forum

Integration and Environmental Testing

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Outline

• Test Guidelines
  • Structural Thermal Model
  • Flight Unit Mechanical Tests
    – Electronics Box and Instrument Level
    – Mass Properties
    – Mechanism Life
• Thermal Tests
• Mechanical Ground Support Equipment
• Documentation and Summary
ALI Environmental Test Guidelines

- ALI environmental testing guidelines established in Environmental Test Specification - 30 (ETS - 30)
  - Lincoln Document Number ALI-S1003
  - Release Date 31 July 1997

- Vibration Test Levels for ALI established in the “EO-1 Spacecraft to Advanced Land Imager (ALI) Interface Control Document (ICD)”
  - GSFC Document Number EO-1 ICD-018
  - Release Date 4 February 1998 (Rev A)

- Temperature Cycling Profile for ALI established by mutual agreement with the EO-1 Project Office at GSFC
  - Lincoln Document Number ALI-S1031
  - Release date 17 September 1998
ALI Mechanical Design and Testing Philosophy

• Instrument design subjected to quasi-static loads of 12.5 g’s axial & 10 g’s lateral, applied simultaneously
  – Factors of Safety
    1.25 on microyield (telescope)
    1.60 on yield (ICD requires minimum 1.25)
    2.0 on ultimate (ICD requires minimum 1.4)
  – Design driven by minimum 65 Hertz instrument frequency requirement

• STM sine burst tested in each axis to qualify basic design
  – Qual-level quasi-static loads: 12.2 g’s axial and 9.6 g’s lateral

• Instrument random vibration inputs notched
  – 3 sigma g loads not allowed to exceed qual-level quasi-static load inputs at M1 or the focal plane (i.e. close to c.g.)

• No notching applied for electronics box testing
Outline

• Test Guidelines

• Structural Thermal Model

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  – Mass Properties
  – Mechanism Life

• Thermal Vacuum Tests

• Mechanical Ground Support Equipment

• Documentation and Summary
Structural Thermal Model (STM)

• STM ALI Assembly Contains:
  – SSG STM Telescope and SBRS EDU Focal Plane Assembly
    No optics or photon sensitive chips
  – SBRS Breadboard Focal Plane Electronics (FPE) and Lincoln EDU Mechanisms, Radiators and ALICE
    Mass mock-ups of FPE and ALICE on pallet during vibration
    Mass mock-up of ALICE in vacuum tank during thermal balance tests; EDU ALICE outside tank

STM Phase Duration: 1/13/98 - 9/8/98

Assemble STM ➔ Vibration Testing
  Includes Pre and Post Test Measurements ➔ EMI-EMC Testing
  ➔ Thermal Balance Testing
  (In Thermal Vacuum)

• Verify Interfaces and Assembly Procedures
• Verify Structural Integrity and Computer Model Results
• Characterize potential for interference
• Verify Thermal Design
  • System
  • Focal Plane
STM ALI Vibration Test Flow

1. Measure Mass & C.G.; Mount ALI Assembly on Vibration Fixture; Mount Fixture on Vibration Table
2. Low Level Random Survey @ 0.25 G rms; Verify Frequencies & Amplifications
3. Quarter, Half and Full Level Sine Burst Tests at Qualification Level
4. Low Level Random Survey @ 0.25 G rms; Verify Frequencies & Amplifications
5. Blue Test Elements Are Repeated for All Three Axes
6. Half and Full Level Sine Sweep Tests at Qualification Level
7. Low Level Random Survey @ 0.25 G rms; Verify Frequencies & Amplifications
8. -12 dB, -6dB and Full Random Vibration at Qualification Level with or without Notching
9. Low Level Random Survey @ 0.25 G rms; Verify Frequencies & Amplifications
10. Remove ALI Assembly from Table and Fixture

Note: Accelerometers are installed in pre-selected internal and external locations of STM ALI Assembly.
STM Vibration Test Highlights

- Nothing broke; almost everything worked afterward

- Two anomalies found
  - Diffuser fail-safe did not operate properly
    Torsion spring disengaged during vibration
    Problem corrected by elongating spring tangs
  - F1 mirror blank shifted
    Problem traced to defect in the adhesive joint between silicon carbide mirror and nickel plated invar mount

  **Recommended Action:** Conduct vibration test of as delivered flight telescope and look for mirror frequency shifts *(done)*

- Post vibration diffuser fail-safe design/testing dilemma
  - Torque associated with deployment of diffuser fail safe exceeds maximum allowable back drive torque for motor gear head

    i.e. “one time only” device works very well but can damage motor gear head during testing
ALI Silicon Carbide Mirrors

M1  M2

M3  F1
STM Thermal Balance Testing

Objectives: Thermal Design Verification
Analytical Model Verification
Worst Case Condition Simulation
Establish Criteria for Flight System Testing

Install MLI on STM; Install STM Assembly in Thermal Vacuum Tank
Set up Prototype Thermal Control System, Data Acquisition System & EDU ALICE Outside The Tank
Install IR Lamps, Heaters, Test GSE, Guard Heaters, Cables, MLI and Instrumentation in Tank
Calibrate Test Arrangement

Test at Nominal Orbit Conditions: Pallet = 20 C, Cover Closed or Open
Test at Mission Hot Conditions: Pallet = 50 C, Cover Closed
Test at Mission Cold Conditions: Pallet = -10 C, Cover Closed
Return to Room Temperature and Remove from Tank

EO1 ALI TTF-2
SEF 10/23/01
Mechanism Life Testing

- Mechanism Life Tests conducted using EDU mechanisms
  - EDU units made from same drawings & materials as flight units
    Different surface treatments for non-bearing parts
- Governing Document:
  - “Mechanism Life Test Plan”; LL Document ALI-S1017; last revised 28 September 1998
- Testing Details:
  - No. of Cycles = 1.5 times design life
    Thermal survival cycle (-10 C to + 50 C) before and after operational cycles
    Operational cycle temperatures: Cold = 0 C; Hot = 40 C
  - Testing successfully completed on Aperture Selector (240 cycles), Aperture Cover (3900 cycles) and Calibration Diffuser (240 cycles)
    All cycles in vacuum; half hot, half cold
- No problems encountered
- EDU Mechanisms returned to STM after testing
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    - Mass Properties
    - Mechanism Life
- Thermal Tests
- Mechanical Ground Support Equipment
- Documentation and Summary
Board Level Qualification Testing

• Objective: Qualify mounting of largest ceramic leaded components on ALI Control Electronics FR-4 boards

  – Issue: Fatigue due to mismatched coefficients of thermal expansion (CTE) between board sandwich and components
    Ceramic CTE ~ 6-7 ppm/C;  Board sandwich CTE ~ 18-20 ppm/C

  – Components: 392 lead Surface Mount Multi-Chip Module, 40 pin Dual In-Line Package & 28 pin Surface Mount Device

  – Test Environments: Sine burst, sine sweep & random vibration

  – Thermal cycling: -50 to 50 C, 20 cycles; 0 to 100 C, 200 cycles
Flight Control Electronics Vibration Testing

Protoflight Testing Suite - 3 Axes

- **Sine Burst (quasi-static loads)**
  - 12.2 g’s axial
  - 9.6 g’s lateral

- **Sine Sweep (5-50 Hz)**
  - 3.5 g’s axial
  - 5.9 g’s lateral (15-35 Hz)
  - 3.0 g’s lateral (35-50 Hz)

- **Random Vibration (20-2000 Hz)**
  - 10.6 g rms for electronics
  - 5.8 g rms for instrument

ALICE on the Vibration Table
Box Level Testing

• Vibration Tests
  – First ALICE protoflight vibration test (prior to PER)
    Sine burst, sine sweep & random (for electronics)
    Problem: 5 of 6 wedgelock screws loosened
  – Second ALICE protoflight vibration retest
    Sine burst, sine sweep & random (for electronics)
    No problems encountered
    Wedgelocks remained tight over all tests
    Primary fix: installation procedure changed
  – ALICE filter box protoflight vibration test
    Sine burst, sine sweep & random (for electronics)
    No problems encountered
Flight ALI Integration and Testing

28 April 98
- Flight Telescope Delivery from SSG
  - Unit delivered without housing

28 April - 7 July
- Telescope Vibration; Disassembly, Cleaning, Re-assembly & Realignment

19 June - 3 Aug
- Focal Plane Delivery, Warm Testing, Integration & Alignment “Telescope Integration”
  - Housing delivered 7 July

3 Aug - 2 Sept
- Instrument Integration
  - Pre-Environmental Review 5 Aug

3 Sept - 24 Oct
- Vibration and Thermal Cycling in Vacuum

Calibration
- Pre-Ship Activities, Reset Mechanisms, Clean, Pack & Ship
- Replace one 1773 transceiver
- Vibrate, thermal cycle ESN board
- Add contamination heaters
- Instrument outgassing

25 Oct - 22 Jan 99
- Deliver to Swales

25 Jan - 22 Feb
- Integrate with Spacecraft

23 Feb
- 10 March
Environmental Test Dates (1998)

- Telescope Thermal Vacuum at SSG 13-17 April
- Telescope Vibration at LL 19-21 May
- Focal Plane (FP) Vibration at SBRS 18-20 May
- Focal Plane Electronics (FPE) Vibration
  - at SBRS (sine sweep & random) 8-12 May
  - At LL (sine burst only) 1 July
- FP & FPE Thermal Cycles at SBRS 21-25 May
- ALICE Thermal Cycles at LL 13-17 July, 3 Aug
  PER 5 Aug
- ALICE Vibration at LL 7 July, 7 Aug, 17 Sept (FB)
- Flight ALI Vibration at LL 3-4 September
- Flight Thermal Cycles at LL 4-25 October
Vibration Test Configuration
Mass Properties

• ALI weight & center of gravity
  – Weight 197.8 pounds (~90 kg)
    FPE to WARP data cable not included
  – Center of Gravity at x = - 0.5 in., y = 5.7 in., z = 10.5 in.
  – All measurements within ICD allowables

• Weight Distribution
  – Telescope (Truss, Diffuser, Wiring) 76 pounds
  – Housing (Structure, Mechanisms, Wiring) 30
  – Pallet (Structure, Wiring) 40
  – Focal Plane Radiator (Structure, Wiring) 16
  – Focal Plane Electronics (Structure, Wiring) 17
  – ALICE (Including Filter Box) 19
Prototflight Testing Suite - 3 Axes

(1) 0.5 Grms White-Noise Random Signature Test
(2) Half-Level Sine Sweep Test
(3) Full-Level Sine Sweep Test
(4) 0.5 Grms White-Noise Random Signature Test
(5) –12 dB down Random Level
(6) –6 dB down Notched Random Level
(7) Full-Level Notched Random
(8) 0.5 Grms White-Noise Random Signature Test
Instrument Vibration Testing

- Test exceptions
  - Mass mock-up used for ALICE filter box
  - MLI not present

- Post-test results
  - All electrical, mechanical & optical checks successful
    Optics in focus and all electrical & mechanical functions verified
    Two anomalies found:
      Aperture selector slightly ajar
      Some black paint and lint particles on M1 & M3
  - Anomaly resolution
    Aperture selector: Jam nut found loose; tightened and epoxy staked
    Durability of fix verified through vibration testing of EDU selector
    Particles: Feathered paint edges and thoroughly cleaned telescope at the truss level prior to instrument assembly
    Considerably less particles found than after truss vibration test
**Vibration Test Data**

### Resonance Frequencies

<table>
<thead>
<tr>
<th>Component</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope</td>
<td>68, 78, 170</td>
</tr>
<tr>
<td>Housing</td>
<td>68, 110</td>
</tr>
<tr>
<td>FPE</td>
<td>110, 180</td>
</tr>
<tr>
<td>ALICE</td>
<td>105, 180</td>
</tr>
<tr>
<td>Focal Plane Radiator</td>
<td>68, 100, 190</td>
</tr>
</tbody>
</table>

### Sine Sweep Component Responses (g's)

<table>
<thead>
<tr>
<th>Components</th>
<th>5-35 Hz</th>
<th>35-50 Hz</th>
<th>5-35 Hz</th>
<th>35-50 Hz</th>
<th>5-35 Hz</th>
<th>35-50 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>5.9</td>
<td>3.0</td>
<td>5.9</td>
<td>3.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Telescope</td>
<td>8.2</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Housing</td>
<td>7.0</td>
<td>4.6</td>
<td>9.2</td>
<td>9.8</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>FPE</td>
<td>7.0</td>
<td>4.6</td>
<td>7.2</td>
<td>4.8</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>ALICE</td>
<td>5.8</td>
<td>3.3</td>
<td>6.0</td>
<td>3.2</td>
<td>3.9</td>
<td>4.1</td>
</tr>
<tr>
<td>FP Radiator</td>
<td>8.1</td>
<td>6.2</td>
<td>9.4</td>
<td>10.0</td>
<td>4.0</td>
<td>3.6</td>
</tr>
</tbody>
</table>

### 3σ Random Peak Responses at f<sub>n</sub>&lt;200Hz (g's)

<table>
<thead>
<tr>
<th>Components</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowables @ c.g.</td>
<td>9.6</td>
<td>9.6</td>
<td>12.2</td>
</tr>
<tr>
<td>M1</td>
<td>9.5</td>
<td>9.5</td>
<td>11.0</td>
</tr>
<tr>
<td>Housing</td>
<td>2.7</td>
<td>6.6</td>
<td>9.8</td>
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<tr>
<td>FPE</td>
<td>3.7</td>
<td>2.8</td>
<td>4.2</td>
</tr>
<tr>
<td>ALICE</td>
<td>6.7</td>
<td>5.7</td>
<td>2.0</td>
</tr>
<tr>
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<td>4.6</td>
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Control Electronics Thermal Cycling

Protoflight Temperature Limits
Survival -30 to +50 C
Operating -20 to +40 C
ALI in Tank with MLI
EO-1 Temperature Limits

* Reference: Nick Teti (Swales) to Ralph Welsh (GSFC) memo of 13 August 1998
Instrument Thermal Vacuum Testing

- MLI installation 14-22 September
- ALI installed in vacuum tank 25 September
  - Pre-cycling optical focus measurements completed with ALI in tank at room temperature 28 Sept - 1 Oct
  - Thermal cycling initiated 4 Oct; completed 25 Oct
    - 50 C spacecraft simulator “hot soak” & “bakeout” conditions at start
    - 30 C spacecraft simulator “baseline” data condition established
      All temperature sensors, heaters and mechanisms operated properly
  - Anomalies:
    - Focal plane thermal control system noisy & operating improperly; new system implemented in ALICE software
    - Best ALI focus position altered by tank window thermal gradients; optical test equipment adjusted to compensate for focus shift
    - Thermal cycling & data taking continued to completion
      - Cold soak at -30C; data taking at -10C & 40C over 4 cycles
      - 1 week delay due to LN2 plumbing problem outside clean room
- ALI thermal computer model verified
ALI Thermal Vacuum Cycling

![Graph showing temperature variations during hot soak and cold soak with four cycles.](image-url)
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Mechanical Ground Support Equipment

- Instrument lifting fixture
  - Successfully used throughout all I&T handling operations
  - Proof tested to 1000 pounds (5 X ALI weight)

- Instrument shipping container
  - Shock isolation system
  - External electrical and purge connections
Vacuum Tank Handling Fixture

- Upright

- 90° Rotation for insertion in tank
Mounting ALI on EO-1 Spacecraft

EO-1 Spacecraft Integration at Swales Aerospace
Outline

• Test Guidelines

• Structural Thermal Model

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• Documentation and Summary
Documentation - 1

• Drawings
  – Detail drawings from LL, SBRS & SSG completed
  – Many assembly drawings red lined
  – LL Drawing Listing available

• Vibration Test Reports
  – STM 21 April
  – Telescope 19-21 May 98
  – FPE Sine Burst 1 July
  – ALICE 7 July, 28 July, 7 Aug
  – ALI 3 Sept
  – EDU Aperture Selector 15 Sept
  – ALICE Filter Box 17 Sept
  – Focal Plane & FPE at SBRS 8 May, 18 May
• Thermal Cycle Testing
  – Instrument data files available
  – Mechanism Life Test summary report, 29 Sept 98

• Log Books
  – STM I&T activities
  – Flight unit I & T activities (not including calibration)

• Materials (ML) and Electronic Parts (EPL) Lists
  – ML submitted to GSFC 24 July, 17 Sept 97; approved 9 Oct 97
  – EPL submitted to GSFC 1 July, 1 Sept 98; not formally approved by GSFC Parts Engineer

• Computer Models
  – Pre-Hyperion ALI structural finite element model (NASTRAN)
  – Post- Hyperion ALI thermal models (SSPTA & LLTTA)
Summary

• ALI integration and environmental testing successfully completed with few anomalies
  – All test-related anomalies documented and resolved
  – Test data documented in reports and at Web site

• ALI mass properties met ICD guidelines

• Design drawings mostly completed
  – Some red lined

• Handling and shipment MGSE available