IR Thermography of International Space Station Radiator Panels

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Outline

• Background
  – ISS radiator anomaly

• IR Technique configurations
  – 1. On-orbit IR camera technique
  – 2. Ground IR camera technique

• International Space Station ISS radiator on-orbit IR measurement and analysis
  – Alignment of data
  – Filtering of data
  – Comparison of panels

• Ground IR measurement and analysis on qualification test radiator panels
  – Derivative and contrast image analysis
Ground IR Inspection System for Space Shuttle Orbiter

Space Shuttle Orbiter Wing Leading Edge IR Inspection using Flash Heating

Phoenix Mid-wave Camera,
Wavelength = 3 to 5 micron
FLIR Thermacam S65
Wavelength ~ 9 micron
ISS External Vehicular Activity

Sunlight as a heat source

EVA IR Camera DTO – Objective #2

RCC Damaged Sample Test Article

IR Images
Detect Damage
International Space Station (ISS)

Radiator panels
Damage to Radiator Panel Detected
September 2008

Peeled facesheet

Panel size 10 ft x 10 ft
Space walk performed and EVA IR camera used to obtain IR data on both sides of all radiators (48 panels)
On-orbit Infrared Images of Radiator Panels

Peeled side

Back side

Light areas are warmer
Black areas - space
Transformation of Images to Simplify Panel Comparisons

Panel images need to be transformed so that panel sides are aligned with sides of the image and magnification is fixed. Aligned images allow easy comparison between panels.

Matlab routine and data processing provided by Dr. William Winfree and Patty Howell.
Affine Transform

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T_{2,1} & T_{2,2} & T_{2,3} \\
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\end{bmatrix}
\begin{bmatrix}
x \\
y \\
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\end{bmatrix}
= 
\begin{bmatrix}
x' \\
y' \\
1
\end{bmatrix}
\]

Each panel image is mapped as a rectangular image to extract data for comparison

\(T_{1,1}, \ T_{1,2}, \ T_{1,3}, \ T_{2,1}, \ T_{2,2}, \ T_{2,3}\) varied to give best mapping of four points on radiator to fix size rectangle based on summed differences of coordinates of radiators and coordinates of corners on rectangle
Laplacian enhances detection of temperature gradients. Used to locate the internal Ammonia flow tube bracket locations for temperature mapping.
IR Detection Areas of Interest

- Facesheet core contact (no foam)
- Unfilled foam cavity along chamfer
- White paint
- Facesheet to core and foam contact on either side of the bracket
- Facesheet to bracket epoxy bond

Sectioned Panel

Flow Tube, Inconel 718

Aluminum facesheet 0.010” thick
Aluminum core

Aluminum bracket
IR Detection Areas of Interest

- Facesheet overlap bond
- Closeout bracket to facesheet bond
- Cross Section
- Facesheet edge adhesive fairing bond

Panel size 10 ft x 13 ft
Comparison of Laplace of Infrared Images of Damage and Undamaged Panels

Backside

Damaged

Undamaged

Flowtube location
Comparison of Vertical Temperature Profiles Back Side of Disbonded Facesheet

Laplacian

Temperature profiles along Centerlines of flowtube bracket vertical lines

Hotside
Comparison of Vertical Temperature Profiles of Same Flow tube location in neighboring panels

Location for temperature profile

Flow Direction

Hot side

Data analysis by Gary Reynolds
Summary of On-orbit IR Inspection

- Infrared Imager Developed for RCC Inspection on orbit
- Successfully Demonstrated Damage Detection in RCC
- Imager Successfully Imaged ISS Radiator
- No Significant Indications Detected in Other ISS Panels
A “root cause study” was undertaken to investigate the cause of the peeled facesheet of the ISS radiator.

One of the actions was to determine if manufacturing process left debonds weakening the structure.

Investigate feasibility of IR flash thermography in ground inspection of ISS radiator panels to detect debond of face sheet with honeycomb core, flow-tube bracket, overlapping facesheet, overlapping brackets, edge closeout.

Note: IR thermography does not provide a measure of bond strength but can provide assessment of “thermal contact”.

- Comparative qualitative image assessment of thermal contact at bondline.
- Detect out-of-family indications using the Echotherm/Mosaic software
  - Use raw and second derivative image processing to evaluate the images
IR Thermography Set-up

13 mm lens 120 Hz

Data acquisition and control
IR Thermography Set-up – close up

Shot Area = 9” x 11”
Indication Types

- Narrow Linear Indications
- Large Rectangular Indications
- Interface De-bond Indications
- Small Circular Indications

- IR Data acquisition – Gary Reynolds
- IR Data Analysis – Walter Wilson and Ajay Koshti
- System support – Richard Morton, Bruce Harkness
### Shot Layout

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10 ft x 13 ft
Narrow Linear Indications

- Often Span Multiple Shots
- Film Adhesive Overlap Areas (more material)
- Show Up in Early Frames (10+)
- Tube signatures show through.
- Often ‘dead-end’ in face sheet overlap.
- Not an anomaly
Typical Thin Linear Indications
Frame 26 2D

Strain gage on the surface

Facesheet overlap

Panel 1B
Adhesive Sheet Overlap

2D image

Comment: Provides negative contrast (cold area) due to additional adhesive
Large Rectangular Indications

- Show Up Early
- Only Appear on Panel 2B
- Tube signatures evolve through these indications so they aren’t very thick
- Most likely ‘patches’ in film adhesive
Typical Large Rectangular Indications
Frame 45 2D
Additional Adhesive Patch

Red dot on the patch
Blue outside the patch

Comment: Provides a negative contrast (cold area) due to additional adhesive layer or layer of other material
Face Sheet Bond Anomalies

• Show up Early
• Show up hot/bright in Raw image indicating poor thermal contact
• Evident boundary lines and timing indicate that they occur in between face sheets where facesheets overlap
Face Sheet Debonds
Panel 4a Frame 15 2D
Suspect Void/Unbond at Facesheet Overlap

Raw Image

Comment: Warm spot indicating a void/unbond
Linear Indication – Lack of Adhesive
Frame 30 Raw and 2D

Panel 8A
Lack of Adhesive or Debond

Raw Image

Comment: Provides positive contrast (Hotspot) due to lack of adhesive or gap
Summary of Flash Thermography Inspection

• Several non-flight qualification test radiators were inspected using flash thermography
• Flash thermography data analysis used raw and second derivative images to detect anomalies (Echotherm and Mosaic)
• Simple contrast evolutions were plotted for the detected anomalies to help in anomaly characterization
• Many out-of-family indications were noted
  – Some out-of-family indications were classified as cold spot indications and are due to additional adhesive or adhesive layer behind the facesheet
  – Some out-of-family indications were classified as hot spot indications and are due to void, unbond or lack of adhesive behind the facesheet
• The IR inspection helped in assessing expected manufacturing quality of the radiators