Observations, Ideas, and Opinions
Systems Engineering and Integration for Return to Flight

George K. Gafka
Project Management Challenge Conference
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• **Upfront Disclaimer #1**
  • Material transmitted in this presentation may not represent the opinion or policy of NASA!

• **Upfront Disclaimer #2**
  • Presenter is conveying some very contextual examples of personal experiences which are not meant to be interpreted as the absolute truth or the right answer for everyone or every situation!

Process/digest the material as you see fit and decide what may be worth taking away.
Observations, Ideas, and Opinions
Presentation Outline

- Project Management & Systems Engineering Challenges
  - In The Beginning…What is your mission? Can you “certify” to it?
  - Team Roles/Responsibilities/Requirements/Contracts/Deliverables
  - Use-As-Is becomes most critical capability!
    - Flight History Database, a surprisingly contentious topic
  - Tile Repair is really tough, becomes “best effort” for RTF
    - Killer/“Golden” Requirements: Bubbles
    - Tough Trade Spaces
  - Delivery for RTF
- STS-114
- Conclusion

- Understanding/Influencing/Accepting Your Environment
  - Cost, schedule, technical/safety, political, emotional
  - Evaluating/maximizing your influence potential
- Effective People Skills and Communication, a key to success!
  - Integrity/creditability
  - Teamwork/relationships/advocacy/negotiation
  - Up and out, (Presentation! Presentation! Presentation!)
  - Down and in, (reaching consensus where possible and recognizing where not)
  - Healthy tension, good push back
In The Beginning…
Project Documentation Philosophy

Thermal Protection System (TPS) Tile Repair Project
Documentation Tree

- Should convey need for Tile Repair Capability. “SRD go figure it out”
- Should establish Ground rules for Tile Repair Capability, i.e. criticality, one-time-use, etc.
- The “tile repair” shall...
- Integrated “capability” performance requirements, both performing the repair and re-entry
- Integrated EVA ops/hardware performance
- Design-to requirements
- Sub-allocations

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REQUIRED Communication with Program Requirements Flow and Philosophy

Fix Everything
All types of impactors, ascent and MMOD, everywhere on vehicle TPS

PRD Subset Requirements

Current SRD Requirements

RTF Requirements
Non-RTF Requirements

Who is responsible to set boundary and accept risk?
Who is responsible to substantiate boundary?
MA, MS, MV?
Tile Repair Project RTF Mission

- Per our revised SRD and Verification Plan, the Tile Repair Project is responsible for delivering the capability to:
  - Assess tile damage locations and provide near real-time technical rationale to support “Use-as-is” disposition
  - Provide repair materials (qualified vendor), physical tools and operational techniques to conduct a developmental DTO and constitute an emergency tile repair capability if needed
  - Document Limited material and system level test results
- The Tile Repair Project is responsible for validating the PRD inspection requirements for size of tile damage not requiring inspection by OBSS
  - 3” for acreage tile
  - 1” for tiles near door penetrations

NOTE: We should think of our “Use-As-Is” capability being comprised of two parts: Analytical Tools & Flight History Database!!!
Planned TRP Deliverables/Documentation

Thermal Protection System (TPS) Tile Repair Project
Documentation Tree

JSC TBD
Thermal Protection System (TPS) Tile Repair Project
System Requirements Document

JSC TBD
Thermal Protection System (TPS) Repair Project
Project Management Plan

NTS 07700
Space Shuttle Program Definition and Requirements

JSC TBD
Shuttle Thermal Protection System (TPS) Repair Kit
Program Requirements Document

JSC TBD
Thermal Protection System (TPS) Repair Kit Development Test Objective
System Requirements Document

JSC TBD
Thermal Protection System (TPS) Repair Kit DTO
End Item Specifications

JSC TBD
Thermal Protection System (TPS) RCC Repair Project
System Requirements Document

GFE
“Use-as-is” Analytical Tools (USA/Boe)
- EVA Hardware (JSC EC/XA)
  - EVA Repair Mat'l Aplicators
  - EVA Handtools

CFE
- “Use-as-is” Analytical Tools (USA/Boe/LM/OSS)
  - STA-54
  - EW

CFE
- Cavity Heating Tool
- Catalytic Heating Tool: Damaged
- 3D Acreage Tile Thermal Tool
- Special Config. Thermal Models
- Tile Stress Tool – RTV Bondline (45 deg)
- Stress Assessor Tool
- Repair Materials (USA/Boe/LM/OSS)
  - STA-54
  - EW

GFE
- “Use-as-is” Analytical Tools
  - CFD for Cavity Heating: Baseline (Ames)
  - CFD for Cavity Heating: Fit Trace. (Ames)
  - Boundary Layer Transition Predict. (LaRC)
Planned TRP Documentation For RTF

- Verified analytical tools for damaged acreage tile
- Validation of damage size inspection requirement
- Repair materials qualified to Material Specifications (physical properties and processes)
- EVA tools verified for Crit 3 safety
- Limited material and system level test data
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Results to date (early 2005)
Best Estimate of Damage “Map”

Primary failure mode is RTV overtemp. Other modes are structural temperature (S), structural margin (M), and excessive OOPD (O)
Development of TRP “Use-As-Is” Analytical Tools
Development of Inspection Criteria (need for OBSS/depth)

Pre-Flight Development

- Descent trajectory parameters (revised trajectory plan in work)
- Selected: Tile Damage Locations & Geometries: Cavity Length, Width, Depth “shoebox” w/slope-able walls

Real-Time Mission Specific Use

- Derived Aeroheating environments for an undamaged Orbiter
- Cavity heating augmentation factors (modified by roughness effects)
- Convert: “shoebox” w/slope-able walls

Mission Specific:
- Descent trajectory parameters
- Mission Specific: Tile Damage Location(s) & Geometry(s): Cavity Length, Width, Depth, 3D “point cloud”

Damaged Tile Thermal Analysis Tool:
- Tile sintering prediction (“New” Physics being modeled!)
- Tile and Tile-to-SIP RTV bondline temperatures
- Local structure temperatures in the vicinity of the damage.

Structural analysis tools

- Structural integrity of the damaged tile and of the tile(s) adjacent to damage site
- Capability of remaining RTV bond to hold tile in place
- Local Structural Margin of Safety for a Factor of Safety of 1.4

Legend
- Analysis Tools
- Data
- Relief
- Results

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In-Scope Damage Geometries

Limitations:
TBD \leq L_1 \leq 20
TBD \leq L_2 \leq 20
(L_1 \geq L_2)
0.02 \leq d \leq \text{full tile}
0.25 \leq w_1 \leq 10
0.25 \leq w_2 \leq 10
(w_1 \geq w_2)
0 \leq \alpha \leq 90
0 \leq \beta \leq 90
0 \leq \theta \leq 90
0 \leq \gamma \leq 90
Examples of Out-of-Scope Damage Types/Geometries

1. **Tile Side View**
   - Penetration into structure (with possible underlying structural damage)

2. **Tile Side View**
   - Damage geometry out-of-scope ($w_2 > w_1$, represents damage from certain MMOD impacts)
   - Damage geometry out-of-scope ($\beta$ constraint violation, represents damage from certain high density impactors, i.e. ablator material)
   - And/or Impactor remaining in cavity

3. **Tile Side View**
   - Impactor remaining in cavity

4. **Tile Side View**
   - Penetration into structure (with possible underlying structural damage)

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**NOTICE**

- Although 3-D models and analytical tools are being developed for these special penetration areas, there is no current plan to correlate analysis to any test data!
- Penetration flow and understanding response of thermal barrier is a very complicated scenario.

---

**Scenario 1**

- On-orbit Initial damage
- During Entry ET Door (for example)
- Thermal barrier
- Assess tile separately
- Assess elevated heating on healthy thermal barrier/seals
- Probably can be dispositioned using currently planned analytical tools

**Scenario 2**

- On-orbit
- During Entry
- Thermal barrier
- Assess tile slumping into thermal barrier/seals
- Elevated downstream heating
- Analytical tools will not be correlated by test data

**Scenario 3**

- On-orbit
- During Entry
- Thermal barrier
- Assess tile damage on thermal barrier/seals
- Elevated downstream heating
- Current analytical tools may not be able to model this scenario

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Risk of “missing something with only 2D inspection” versus Ops Trade-space result unknown at this time!

“Standard Gouge”

Dimension seen in 2D photo

Underlying Orbiter structure

Depth of damage strong determining factor in threshold for non-conformance determination

“Deep Penetration”

Protecting for this could seriously affects OBSS activities and ops!

Dimension seen in 2D photo

Underlying Orbiter structure

Can this occur? How much risk exists for this scenario?
OV-102 Flight Damage History

<table>
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<tr>
<th>Mission</th>
<th>Impacts &gt; 1”</th>
<th>Total Impacts</th>
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<td>OV-102 Average</td>
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<tr>
<td>Fleet Average</td>
<td>30.5</td>
<td>144.9</td>
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</table>

STS-109 Lower Surface Impact Damage
Flight Damage History

Average Number of Impact Damages Exceeding Length L per Flight

- The data was taken from the post-flight Debris/Ice/TPS Assessment Reports for 89 shuttle missions.
- It includes all areas, not just lower surface
- The data does not include the damages from the first 21 missions because post flight debris impact reports could not be located.
**Historical Tile Damage Background**

- Orbiter has sustained greater than ~15,000 tile damage events (of varying degree) throughout life of Program
- Per knowledgeable TPS technical community, only “a few” damage sites would have been candidates for even considering an on-orbit repair, had that option been available, based on ground inspection post-flight
- Our flight history tells us that tile gets damaged during ascent on every flight
  - Judgment would also say that the modifications to the other elements will not preclude our tile damage “flight history” from being generally repeated on future flights (although some possible improvement against “big” damages is predicted)
- Our flight history tells us that the vehicle is robust to enter with the tile damage suffered to date for the particular mission conditions experienced

**Two potential “really tough” scenarios brewing:**

- Pre-flight risk: TRP, solely using TRP delivered use-as-is analytical tools, is only able to validate a very small inspection criteria and, based on our flight history, drive a recommendation toward a very ops intensive / timeline impacting OBSS inspection process per flight. (an inspection criteria that just doesn’t “feel right” based on our gut)
- Real-time risk: Real-time team, solely using TRP delivered use-as-is analytical tools, recommends performing high-risk repairs at a high rate of frequency (a rate that just doesn’t “feel right” based on our gut)... but has nothing else to provide any technical rationale to stand behind.
Pre-Flight Risk Assessment
Philosophical Approach

Raw Data Activity, Creating the RAIV data set

Data Mining/Formatting
“Retro-actively” apply the tile damage inspection criteria
(3” for acreage, 1” around door seals)
to previous flight history capturing violations
per flight and per PRACA zone

Note: No available information for STS-41B & STS-41D, STS-1 through STS-5
eliminated from data set due to old and significantly different configs we were not interested in capturing, other major excursion flights (STS-27R, STS-87) to be discussed in more detail later.

TPS PRT Review
Review all inspection criteria violations and provide a judgment as to which of the violations should be considered “close calls”

TPS PRT Review
Review “close calls” and provide a judgment as to whether “close calls” should be filtered out of data (i.e., not ascent debris, confidently corrected and verified debris source, etc.)

TPS PRT Review
Review “close calls” and provide a judgment as to whether any other “forward looking” augmentation factors should be applied

Result: “Residual Risk”

Statistical Activity

Statistical “Crunching”
Using flight history data and “residual risk”, perform assessment to determine:
1) Likelihood of OBSS inspection requirement
2) Likelihood of “close call” damage

Any “Big Damage” trends seen along the way?
## Pre-Flight Risk Assessment
### Observations, Results, & Conclusions

<table>
<thead>
<tr>
<th>Region</th>
<th>CASE1</th>
<th>CASE2</th>
<th>CASE3</th>
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<tbody>
<tr>
<td></td>
<td>Total Hits</td>
<td>Percent of Total</td>
<td>Laplace Score</td>
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<tr>
<td>Vehicle Total</td>
<td>549</td>
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<td>Lower Surface Tile Total</td>
<td>431</td>
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<td>Generic Acreage Subtotal</td>
<td>189</td>
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<td>Wing Glove Subtotal</td>
<td>60</td>
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<td>Aero Surfaces Subtotal</td>
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<td>20.2%</td>
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</table>

**Legend**

CASE1 = Total RAIV data set (103 missions), excluding STS-1 thru STS-5 and STS-27R
CASE2 = RAIV data set for the last 50 missions only
CASE3 = RAIV data set for the last 50 missions only, excluding STS-87

* Green denotes a decreasing trend, red denotes an increasing trend

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Pre-Flight Risk Assessment: Observations, Results, & Conclusions

These graphs portray the total significant hits by mission ordered chronologically, less STS 1-5 and 27R. Evident from both graphs is the general downward trend in total number of significant hits with a greater degree of variability in the first 50 as compared with the last 50. This is indicative of a distribution that, over time, has a decreasing mean and variance. This is similar to a production process that has increasing control and a lowering set point.

Legend

| CASE1  | Total RAIV data set (103 missions), excluding STS-1 thru STS-5 and STS-27R |
| CASE2  | RAIV data set for the last 50 missions only |
| CASE3  | RAIV data set for the last 50 missions only, excluding STS-87 |
Tile Models to Determine Impact and Damage Tolerance Thresholds
### RCC and Tile Tools and Models

<table>
<thead>
<tr>
<th>Models</th>
<th>New / Updated / Existing</th>
<th>Used For Pre-Flight C/E</th>
<th>Launch Go/No-Go</th>
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• STS-114
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Repair Procedure Overview

1. Trim Gap Filler as Required
   Clean Tile with Gel Brushes

2. Layer Material

3. Flatten / Smooth Repair
Development of TRP Repair Disposition Analytical Tools

Pre-Flight Development

- Descent trajectory parameters (revised trajectory plan in work)

Selected:
- Tile Damage Locations & Geometries: Cavity Length, Width, Depth
- "shoebox" w/slope-able walls

Swell and ablation characteristics of STA-54 repair material

Mechanical, vibration and aerodynamic environments (revised mechanical load factors in work)

Real-Time Mission Specific Use

- Derived Aeroheating environments for an undamaged Orbiter

Mission Specific: Descent trajectory parameters

- Cavity heating augmentation factors (Modified by roughness effects)

Mission Specific:
- Tile Damage Location(s) & Geometry(s): Cavity Length, Width, Depth, 3D "point cloud"

- Convert: "shoebox" w/slope-able walls

Swell and ablation characteristics of STA-54 repair material

- Repaired Tile Thermal Analysis Tool:
  - Repair swelling, char, ablation prediction
  - Tile and RTV/Repair bondline temperatures
  - Local structure temperatures in the vicinity of the damage.

Structural analysis tools

- Structural integrity of the repair, the damaged tile and the tile(s) adjacent to the damage site
- Local Structural Margin of Safety for a Factor of Safety of 1.4
Test Article Exposed to Low Shear Test Condition
Model #2169 – 9”x5” Cavity Filled in HTV 2

Pre-Test Photo
~0.25” underfill

Post-Test Photo
~0.25” swell above tile

Repair Site Geometry
Time Dependent

Underfill

On-Orbit
- Geometry after EVA application and cure.

Early Reentry
Mach 25
- Char layer forms
- Virgin material begins to swell

Mach 18
Early BL Transition
- Roughness height limit
NOT to be exceeded prior to Mach 18.
Development of Transition Prediction Methodology

Wind tunnel simulation of tile “patch” swelling

Tile repair

Insulating char layer (ablating/swelling)

Temperature increase from disturbed (turbulent) flow

Graph showing the relationship between transition parameter and disturbance parameter.
LOCAL DAMAGE SITE
Trade-space result unknown at this time!
RESULT: Possible Capability Black-Out Zones

Note: There is also a “global” or downstream effect that must be considered. This can result in additional blackout zones if “low margin” healthy or damaged downstream tiles see elevated temperatures that would result in the underlying structure temperature exceeding allowable limits. Relief via scrubbing, FOS reduction, etc.
Killer/”Golden” Requirements
Thou shall have NO bubbles…

- Initial sample, Part A - CIPAA 1005

Following Dispense

15 minutes Post-Dispense

- Initial sample, Part A - CIPAA 1005
- 30 minutes Post-Dispense
Five possible sources of gas that contribute to bubbling:

1. **Internal-to-the-material “generation” of gas post-fill:**
   - Residual gas remaining in material (Part A) post degassing
     - Resulting gas could nucleate into bubbles over time, could be “pulled out” of solution with pressure drop (cavitation)
     - *Data suggests likely contributor, can’t fully exonerate or confirm*

2. **Micro-balloons breaking post degassing**
   - Resulting gas could nucleate into bubbles over time, could be “pulled out” of solution with pressure drop (cavitation)
   - *Analysis suggests extremely sensitive to number allowed to break, possible contributor, can’t fully exonerate or confirm*

3. **Ethanol??**
   - External-to-the-material influences “feeding” the material gas:

4. **External-to-the-material influences “feeding” the material gas:**
   - Ambient air leaking past environmental seal during storage
     - Could nucleate into bubbles over time, could be “pulled out” of solution with pressure drop (cavitation)
     - *Data suggests likely contributor, can’t fully exonerate or confirm*

5. **External-to-the-material influences “feeding” the material gas:**
   - Nitrogen pad pressure leaking past dynamic seal during system pressurization
     - Could nucleate into bubbles over time, could be “pulled out” of solution with pressure drop (cavitation)
     - *Data suggests NOT a likely contributor, can’t fully exonerate or confirm*

**Conclusion:** No way to fully preclude bubbling with this material/hardware system!

So, instead how sensitive is system/entry performance to bubbles?
Logistics Deployment Chart
Near Term Planning Tool

Tile Repair Project – Major Material and Equipment Logistics
Deployment Chart (AKA “Swim-lane Chart”)

Sites:

LM Houston (Development)
- 07/02 1003
- 07/14 1002-304

LM Houston (Refurb)
- 07/02 1004-309
- 07/03 1002-303

LM Denver
- 07/19 1004-303

0G Aircraft
- 07/10 1002-305

Code Key:
- Equipment List (Find Number)
- Start Date
- Key Process, Step, or Event
- CIPAA Config (core, Gen, S/N)

HTV
- 08/11 Dry Run (Vol Mockup)
- 08/17 Dry Run

Other
- 07/26 Training
- 09/1 Test Validation (Firebox)

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3 Months (Rolling)
Updated: 7/14/2004

Special Considerations:
Cleaning/CIPAA Ship – 7 days
Vacuum Fill – 2 days
Tile Repair – STA-54 Material / Hardware Process Improvements and Test Timeline

- Bubbles Appear
  - KC135 Gun (Experimental)
  - June 2004

- Fully Dense Material
  - ROSS 12 Gal. Vacuum Mixer
    - July 2004
  - Aug. 2004
    - Flight Prototype Gun
      - Variable Flow Rate
      - Small orifice
  - Sept. 2004
    - Flight Prototype Gun
      - Single Flow Rate
  - Sept. 2004
    - Modified Flight Gun
      - Swivel
      - Dual Hose
      - Oct. 2004
  - Sept. 2004
    - Modified Flight Gun
      - Swivel
      - Positive Flow Shut-off
      - Single Hose
  - Nov. 2004
    - 12 Gallon Degas
      - Current Improved Material
        - 12/6/04
  - Nov. 2004
    - Flight Prototype Gun
      - Single Hose
      - Oct. 2004
    - HTV Run 1
      - 12/8/04
    - HTV Run 2
      - 12/15/04
  - Jan. 2005
    - Cure as expected

- CIPAA 1002 11/19/04
  - Gel Cup #2 @ 300 psi

- Fault Tree Analysis
  - June 2004

- Material / Hardware Process

- STA-54 on +70 deg F Surface

- STA-54 on -70 deg F Surface
Repair Ground Test Equipment
Gantry System Configuration

C-3 Chamber Interior Outline

CIPAA unit

24”x24” Damaged Tile Arrays

X-Y-Z Linear Motors
STA-54 VOID EFFECTS TEST PROGRAM
MODEL #2216 PRE AND POST TEST PHOTOS
0.25 INCH UNDERFILL
COMPRISED OF THREE 0.50 INCH THICK LAYERS
Observations, Ideas, and Opinions
Presentation Outline

• Project Management & Systems Engineering Challenges
  • In The Beginning…What is your mission? Can you “certify” to it?
  • Team Roles/Responsibilities/Requirements/Contracts/Deliverables
  • Use-As-Is becomes most critical capability!
    • Flight History Database, a surprisingly contentious topic
  • Tile Repair is really tough, becomes “best effort” for RTF
    • Killer/“Golden” Requirements: Bubbles
    • Tough Trade Spaces
  • Delivery for RTF
• STS-114
• Conclusion

• Understanding/Influencing/Accepting Your Environment
  • Cost, schedule, technical/safety, political, emotional
  • Evaluating/maximizing your influence potential
• Effective People Skills and Communication, a key to success!
  • Integrity/creditability
  • Teamwork/relationships/advocacy/negotiation
  • Up and out, (Presentation! Presentation! Presentation!)
  • Down and in, (reaching consensus where possible and recognizing where not)
  • Healthy tension, good push back
Tile Repair Hardware Suite
Tile Repair Project – A View of Project Scope

RTF
- Door Seals
- Acreage

Future
- No Access
- Challenging Geometry
## Tile Repair Project – A View of Project Scope

<table>
<thead>
<tr>
<th>TPS Area</th>
<th>Likelihood of Damage</th>
<th>Conseq. of Damage</th>
<th>Detect-ability</th>
<th>Current EVA Access-ability</th>
<th>Current Design Appr Compatible w/damage?</th>
<th>RTF Support-ability</th>
<th>Required for RTF (TRP opinion)</th>
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<tbody>
<tr>
<td>Acreage Tile (Lower Surface)</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>H</td>
<td>Yes</td>
</tr>
<tr>
<td>Chine/Wing Glove</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>Yes</td>
<td>Yes</td>
<td>At risk</td>
<td>L</td>
<td>Yes/No?</td>
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<tr>
<td>Door Seals</td>
<td>?</td>
<td>H &gt; 1”</td>
<td>Yes</td>
<td>Yes</td>
<td>At risk</td>
<td>M</td>
<td>Yes</td>
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<tr>
<td>LESS Carrier Panels</td>
<td>?</td>
<td>H &gt; 1”</td>
<td>Yes</td>
<td>1 – 20, Yes</td>
<td>At risk</td>
<td>M</td>
<td>Yes</td>
</tr>
<tr>
<td>Elevon</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>Acreage Only</td>
<td>Acreage, Yes</td>
<td>Yes</td>
<td>Acreage, H</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>No</td>
<td>No</td>
<td>At risk</td>
<td>L</td>
<td>No</td>
</tr>
<tr>
<td>OMS Pod Tile</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>Not Inspected</td>
<td>Forward edge only</td>
<td>Accessible Acreage only</td>
<td>Acreage, H</td>
<td>Yes</td>
</tr>
<tr>
<td>Body Flap</td>
<td>?</td>
<td>H &gt; 3”</td>
<td>Acreage Only</td>
<td>Forward acreage, Yes</td>
<td>Acreage, Yes</td>
<td>Acreage, H</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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Figure 3.2-1  Tile Damage Assessment and Repair Locations

Wing Glove
Note: only analytical tools to support use-as-is disposition shall be developed for the Wing Glove area.

All Port and Accessible
Starboard Wing
Leading Edge
Carrier Panel Tiles
(both sides)

Forward OMS

Elevon Acreage Tiles

MLGDS

ETDs

Acreage Tiles

NLGD

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System Requirements for RTF

Figure 3.2-2  Examples of Tile Locations Not Explicitly Repairable by TRP

NOTES:
(1) No EVA Access
(2) Repair Configuration Cannot be Standardized or Analyzed
Real-Time

Tile Damage Assessment Process

Ascent Data
Imagery, Radar
Indicates Debris Event

Debris Transport Analysis
Input: Imagery, Video, Radar etc.
Output: Debris Characterization
(Material, Mass/Volume, Velocity (vector and angle), Location of impact)

Automated Tile Cavity Definition Tool
Input: Debris Impact Characterization
(Material, Mass/Volume, Velocity (vector and angle), Location of impact)
Output: Damaged Cavity Dimensions, Geometry, Volume, Location

Nominal Data (RPM Photos, etc) [continuously updated]
Input: Indications of Tile Damage.
Output: Estimated Cavity Dimensions, Geometry, Volume, Location

Possible Tile Damage?
Yes
Prioritize data review by critical locations and events

Tile Damage Quick Look Inspection Criteria
Input: Damaged Cavity Dimensions, Geometry, Volume, Location
Output: Acceptable Damage or Needs Further Definition/Analysis

No

Tile OK as-is?
Yes
Is Tile Damage OK As-is?
No or Maybe

Is Tile Damage OK As-is?
Yes
Post Repair Evaluation
Repair Operations

Yes
Repair OK as-is?
Post Repair Evaluation
Repair Operations

No
Final Damage Assessment using measured dimensional data

Tile Cavity Aerothermal Database
Input: Damaged Cavity Dimensions, Geometry, Volume, Location, Depth, Repaired Insulation
Output: Cavity Heating Augmentation

Thermal Models
Input: Damaged Cavity, Geometry, Volume, Location, Cavity Heating Augmentation (no repair and emittance), repair material chart and (no repair)
Output: Structure Temperatures and Gradients, SIP Bondline Temperatures

Stress Models
Input: Location of damage, Structure Temperatures and Gradients, SIP Bondline Temperatures
Output: Margin of Safety for Structure

Tile OK as-is?
Yes
Repair Operations

No
Tile Repair

Done

Prioritize Damage sites for Inspection and Analysis
Request Focused Inspections of Damage Sites

Reprioritize OBSS or detailed inspection requests

Detailed Inspection Data (OBSS or other)
Input: Direct measurement of damage sites.
Output: Damaged Cavity Dimensions, Geometry, Volume, Location

Reprioritize OBSS or detailed inspection requests

(Indicates a MER Process)

Tile Cavity Aeroheating Database
Input: Damaged Cavity Dimensions, Geometry, Volume, Location, Depth, Repaired Insulation
Output: Cavity Heating Augmentation

Thermal Models
Input: Damaged Cavity, Geometry, Volume, Location, Cavity Heating Augmentation (no repair and emittance), repair material chart (no repair)
Output: Structure Temperatures and Gradients, SIP Bondline Temperatures

Stress Models
Input: Location of damage, Structure Temperatures and Gradients, SIP Bondline Temperatures
Output: Margin of Safety for Structure

Tile OK as-is?
Yes
Repair Operations

No

Post Repair Evaluation
Repair Operations

No
CSCS

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Real-time Ground Test Capability (HTV, arc jet, etc.)
for mission-specific damage/repair

- OPO/Program Direction
  - Should TRP SRD contain requirements for providing deliverables and damage capability or continue to work to OPO action?
    » Envisioned to be a part of nominal mission capability or short-term requirement for first few flights?
  - What is the forward plan to take the “Real-Time Ground Test Capability” story forward to the Program for discussion?

- Real-time facility Support becomes “bigger” than TRP

- Currently, Supporting PLAN DEVELOPMENT via OPO action.
  ISSUE: Via SRD?

- Provide real-time arc jet capability
- Repair damage in HTV?
- Repair damage in unmanned Thermal Vac?
- Repair damage at ambient?
- Provide real-time capability (and tools!) to repair damage
- Provide real-time capability to damage specimen panels
- Provide the “right number” of undamaged specimen panels for RTF
- Determine the “right number” of undamaged specimen panels

Increasing levels of commitment/protection

ISSUE: Via SRD?
Thermal Protection System (TPS) Repair Development Test Objective (DTO)
Tile Repair Project Conclusion

• Use-As-Is Analytical Tools
  • Rigorously developed, test anchored, peer reviewed, documented, “simmed” and “certified” in support of Return To Flight (STS-114)
  • Required and used successfully during STS-114 mission

• Historical Database
  • Supplemental tool developed/delivered in support of Return To Flight (STS-114)
  • Used as a sanity check for use-as-is predictions pre-flight
  • Used successfully during STS-114 mission as a supplement to damage disposition activities

• Tile Repair Capability
  • Best effort delivered and flew on STS-114
  • Safe to fly, safe to use, system level functional performance for repair not certified, best data to date available for assessment
  • Further CIPAA (“goo-based”) development recently canceled with continued support of other repair capabilities

We had to, and we did!

We made happen!

Best we could do!
Observations, Ideas, and Opinions
Presentation Outline

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  - Down and in, (reaching consensus where possible and recognizing where not)
  - Healthy tension, good push back
STS-114...
Flight Day 3, RPM “Quick Look”

Gap Filler
(pst. protruding 1.2 ±0.3")
Use-As-Is Risk Summary

KEY ASSUMPTION

1. BLT, Mach ~ 18
2. BLT, Mach 21.5
3. BLT, Mach 24

Current, “best estimate”

UNCERTAINTIES AND SAFETY RISKS

Aero Heating: trajectory, BLT Mach number and heat rate/heat load
Thermal/Structural Analysis for specified case
Flight History support of analysis
Flight Control Performance (Certified to Mach 19)

POTENTIAL CONSEQUENCES

- Minor Vehicle Damage
  Structural Integrity Maintained
- Major Structural Damage / LOCV
- Major Structural Damage / LOCV

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EVA Repair Risk Summary
EVA 3 - Shuttle Airlock - SSRMS

1. Gap Filler Extraction - Finger
2. Gap Filler Extraction - Forceps
3. Hacksaw Cut
4. Scissors Cut

Expected outcome per KSC and TPS experts

Translation to/from Worksite and Inadvertent Damage

Common

Unique

Inadvertent Damage
Inadvertent Damage
Inadvertent Damage
Inadvertent Damage
Repair Confidence
Repair Confidence
Repair Confidence
Repair Confidence
Contamination/Dust/FOD
Contamination/Dust/FOD

Common

Mission Impacts
For a nominal EVA 3, all primary Mission objectives can be accomplished (no significant impact). Unexpected/off-nominal EVA task durations may result in significant, but manageable, Mission impacts (additional EVA 4).
Recommend use-as-is disposition if, and only if:

- Confidence exists that on-orbit configuration represents Case 1 (BLT, Mach 18)
- NOTE: Likelihood appears low that we will get to here with confidence, especially in time frame that supports required MMT decision milestones
- NOTE: This risk is driven solely by high uncertainties in key areas!

Recommend repair attempt/disposition if:

- Confidence can not be established in the aero heating environments or vehicle response to those environments
- Case 2 (BLT, Mach 21.5) or Case 3 (BLT, Mach 24) is likely scenario
- Recommended repair order of implementation
  - Try first: Gap Filler extraction – Finger
  - Next: Gap Filler extraction – Forceps
  - Next: Hacksaw
  - Last resort: Scissors
  - NOTE: Consistent with current EVA plan
  - NOTE: This risk is driven by consciously choosing to accept a, better understood and easier to control/manage (relative to use-as-is), risk
Observations, Ideas, and Opinions
Presentation Outline

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  • Healthy tension, good push back
Typical “Peer Review” of Documentation

- Understanding/Influencing/Accepting Your Environment
  - Cost, schedule, technical/safety, political, emotional
  - Evaluating/maximizing your influence potential
- Effective People Skills and Communication, a key to success!
  - Integrity/creditability
  - Teamwork/relationships/advocacy/negotiation
  - Up and out, (Presentation! Presentation! Presentation!)
  - Down and in, (reaching consensus where possible and recognizing where not)
  - Healthy tension, good push back
## Typical day at the Space Shuttle Program Requirements Control Board (SSPRCB)

<table>
<thead>
<tr>
<th>CR/ACTION</th>
<th>OPR TITLE/ACTION DESCRIPTION</th>
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<tbody>
<tr>
<td>S042013EV</td>
<td>DELETE NITROGEN TANK AND AFT BALLAST BOX FROM JSC-MO STS 121, STS 300 AND STS 115 DEFER - 10/29/04 SSP PRCB PRESENTER(S): JSC-MO3</td>
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<td>S050411AF</td>
<td>SUBMITTAL OF DCN 041 TO HAZARD REPORT S.10, JSC-MX PARTIALLY OPEN GO2/GH2 VENT/ RELIEF VALVE INDICATED CLOSED DEFER - 10/29/04 SSP PRCB PRESENTER(S): MSFC-ET</td>
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<td>RETURN TO NIGHT LAUNCH OPPORTUNITIES JSC-MS JSC-MS/1-1 DEVELOP A PLAN TO DOCUMENT CRITERIA FOR RETURN TO NIGHT LAUNCH, INCLUDING OBJECTIVES WHICH MUST BE MET AND HOW OBJECTIVES ARE MET FOR DAY LAUNCHES AND NIGHT LAUNCHES. REPORT TO THE PRCB. DEFER - 11/18/04 SSP PRCB PRESENTER(S): TBD</td>
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<td>S062343</td>
<td>ACTIONS ASSIGNED FROM THE JUNE 9, 2004 SPACE JSC-MS FLIGHT LEADERSHIP COUNCIL JSC-MS/2-1 USING PREVIOUS ORB FLT HISTORY, DEVELOP &amp; VALI- JSC-MV/1-1 DATE CRITERIA FOR DETERMINING WHEN DISPOSITION OF DAMAGE OR SUSPECTED DAMAGE TO THE ORB TPS REQUIRES ADDITIONAL, HIGHER RESOLUTION, ON-ORBIT INSPECTION, DETERMINING WHEN AN ON-ORBIT REPAIR OF THE TPS MUST BE ATTEMPTED, &amp; DETERMINING READINESS TO COMMIT TO THE DEORBIT BURN AFTER A TPS ON-ORBIT REPAIR HAS BEEN ACCOMPLISHED. REPORT TO THE PRCB. DEFER - 10/29/04 SSP PRCB PRESENTER(S): JSC-EA4/G. GAFKA</td>
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<td>BASELINE SHUTTLE SYSTEM INTEGRATION PLAN JSC-MS (SIP) FOR PRE-LAUNCH AND ASCENT DEBRIS CERTIFICATION WITHDRAWN PRESENTER(S): JSC-MS</td>
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Conclusion

• Technical Wizard Success Mandatory Requirements
  • “Hard” technical skills
  • “Soft” People Skills

• Leadership Success Mandatory Requirements
  • “Hard” technical skills
  • “Soft” People Skills

• Success =
  • Loving what you do today (adding recognized value),
  • Knowing what you want to do tomorrow (adding recognized value),
  • Knowing how to get there,
  • Enjoying the journey along the way.

I wish you your own personal situational success! Thank you!