Thermal Protection System (TPS)  
Return-to-Flight Activities  

Steve M. Poulos, Jr.  
Orbiter Project Office  
September, 2003
Five Levels of Crew/Vehicle Protection

1. Eliminate/minimize debris sources
2. Improve/develop inspection capability
3. Define TPS impact tolerance
4. Develop TPS repair capability
5. Evaluate ISS to keep the crew safe until they can be returned to Earth
TSN RTF Activities Comprise Hardware Processing, Impact Testing, and Model Development

- Both Tile and Reinforced Carbon Carbon (RCC) for STS-114 Will Complete Their Normal Turnaround Flow Processing
  - RCC panels will also be subjected to non-destructive evaluation (NDE) to look for potential hidden damage such as cracks, voids, delaminations, or sub-surface oxidation.

- Analytical Models Will Be Developed to Predict Damage to Tile or RCC
  - Basic material properties testing will provide data necessary for model development
  - Impact test results will verify the model predictions

- Impact Testing Will Be Performed on Both Tile and RCC to Determine the Damage Threshold
  - Tile impact tests will be performed on acreage tile, carrier panels, and door edge tile configurations
  - RCC impact testing will be conducted on coupons and full-scale panels
Tile Turnaround Processing

- **Tile RTF Preparation Will Meet All Turnaround Requirements and Include All Processing Verifications**
  - Complete Visual TPS inspection for damages/discrepancies
    - Nose Landing Gear Door (NLGD), Main Landing Gear Door (MLGD), External Tank Door (ETD) perimeter tile and Leading Edge Support Structure (LESS) Carrier Panel (C/P) tile/previous repair integrity inspection
  - Elevon Cove Leak Check verification
  - MLGD environmental seal contact verification
  - Perform all lower surface flow path inspections
    - ET Doors
    - MLGD
    - NLGD
    - LESS C/P’s
    - Chin Panel C/P’s
RCC Turnaround Processing

- RCC RTF Preparation Will Meet All Turnaround Requirements and Include All Processing Verifications
  - Step and gap evaluation (alignment)
  - Spar fitting shimming to original build condition
  - Panel/tee clevis fitting, shear fitting and spanner beam fitting shimming to per-print gap requirements
  - Addressed all spar corrosion issues and hole thread mark issues
  - Visual inspection of RCC for pin holes

- RCC Panels Are Also Undergoing NDE to Look for Potential Damage or Degradation Not Visible to the Naked Eye
  - Ultrasound to look for delaminations and voids
  - Eddy Current to look for localized oxidation
  - X-ray to look for cracks
  - Thermography to look for delaminations or cracks
RCC Metallic Attach Hardware Is Being Subjected to NDE

- Visual to look for corrosion
- Dye-penetrant and eddy current on Selected Components to Look for cracks/embrittlement
Analytical Model Will Be Developed to Predict Damage to RCC

RCC Testing Plan Organized in a “Building-Block” Approach

Level 3 – Flight Panel Tests
RCC leading edge panel attached to representative wing structure

→ Panels 9, 10, 16, and 17

Level 2 - Subcomponent Tests
Damage Model Validation
Flat Panel Impact Testing
Combined Loading Evaluation

Level 1 - Coupon Tests
RCC Characterization (material properties)
Material characterization program (strength, stiffness, stress-strain curves, fracture) to evaluate the effects of several variables:

- Silicon Carbide (SiC) Coating
- High strain-rate
- Mass loss (max value = 0.03 lb/ft³)
- Laminate thickness (19-ply and 38-ply)

Test data will be used to update the material model input in the analytical tools used to predict impact damage (primarily LS-DYNA)

NDE scans required on all coupons prior to testing
Fracture property coupons – Goal is to determine critical fracture properties of RCC material for use in damage tolerance analysis

- 4-point toughness test – delamination mode
- Compact Tension Toughness – through-thickness crack
Level 2 Flat Panel Tests Will Validate RCC Damage Model

- Level 2 Flat Panel Tests Will Validate the RCC Damage Model (LS-DYNA) and Determine the Threshold Between Acceptable and Unacceptable damage.
  - Flat panel impact tests used to determine threshold of damage initiation
  - Follow-on structural tests used to determine threshold of acceptable damage (damage tolerance program to evaluate residual strength and damage propagation)

- Phase A (RTF Critical): Initial Flat Panel Impact Tests Examine the Effects of Different Projectile Materials Corresponding to Most Likely Vehicle-Generated Debris Types:
  - Foam (BX-265)
  - Ablator (select from Super Lightweight Ablator (SLA), Marshall Convergent Coating (MCC)-1, Booster Trowelable Assembly (BTA), others)
  - Ice
  - Metal (steel or aluminum)

- Subsequent Tests (Phases B and C) Will Examine Variable Impact Angles, Projectile Sizes, and Velocities
  - These tests are required for full model validation but not RTF

- NDE Scans Required Prior to and After Testing (Ultrasound, Thermography, etc.)
Level 3 Full-Scale Tests Provide System Validation of the Analytical Model

- **Level 3 structural testing approach**
  - Supports model validation
    - Follows completion of Level 1 & 2 testing
    - Maximizes model validation developed in a building block approach
  - Uses RCC assets: Panels #9, 10, 16, & 17
    - 2 foam impacts
      - 1 at low damage condition (below survivable damage threshold)
      - 1 at high damage condition (above survivable damage threshold)
    - 1 ablator impact at survivable damage threshold
  - A two panel test configuration required
    - One target RCC panel/T-seal, & one real or fiberglass downstream panel
    - Wing spar structure may be present, but not required
      - Current analysis shows support structure is not critical
  - Compare model predictions to test results
Objectives:

- Generate test data to support the development of a refined analytical impact model
  - Characterize threshold velocity and total damage
    - Available debris sources and tile types
  - Characterize damage scatter
  - Characterize benefit of densified layer
  - Characterize effect of projectile orientation
  - Compare damage tolerance of new and aged tile types
- Characterize tile damage levels which have a potential for on-orbit repair
- Evaluate tile configurations sensitivity to available impact debris (MLGD, Carrier Panel)
Approach:
- Refined tile damage models will be established for most prevalent debris sources
  - Foam and ice constitute the spectrum of debris hardresses
  - Lockheed Insulation (LI)-900 tile most sensitive to impact
- Remaining variables will be inserted at various points in the testing to support model correlation
  - Additional foam types
  - Ablators including MCC1, SLA, Cork
  - Metal
- Existing and proposed tile types will be evaluated
  - LI-2200, Fiber Reinforced Composite Insulation (FRCI)-12, Boeing Reuseable Insulation (BRI)-20 and BRI-8
- Total number of shots required expected to be ~1000 for the program
Phase I Tile Impact Testing

● Phase I Objectives:
  - Characterize LI-900 with foam impactors on main landing gear doors and wing acreage test articles at Southwest Research in San Antonio
  - Square and rectangular foam cross sections will be utilized
    - Will characterize damage caused by foams (North Carolina Foam, Inc., BX-265, Polymer Development Lab)
  - Impact aged tiles versus new
    - Determine if damage is greater for aged tiles
  - Determine if densified layer remains for through-the-thickness damage

● Phase I Parameters:
  - Particle sizes chosen to bound expected debris
  - Angles chosen to bound impacts on lower surface

● Initial Velocities Chosen to Create Damage
  - Velocities will vary and be defined by test results
Phase II & Phase III Tile Impact Testing

- **Phase II**
  - Testing evaluates ice, metals and ablators on LI-900 substrate
  - LI-900 Tile Repairs

- **Phase III**
  - Test alternate tile configurations
    - MLGD edge tile
    - Carrier panels
  - Test alternate tile types (BRI 20, FRCI)
    - Impactors include foam, ice, metal and ablators