58/NP/1N/34

Overview of TPS tasks

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- Quick Processed, Low Cost Erosion Resistant TPS
- SmarTPS
- Advanced, High-Temperature Structural Seals
- UHTC Sharp Leading Edges
- High Temperature Felt TPS

3rd Gen Airframe/TPS:

Thermal Protection Systems

- **Quick Processed, Low Cost Erosion Resistant TPS**
  - **POC's:**
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Quick Processed, Low Cost, Erosion Resistant TPS

- **Objective**
  - Develop light weight & low cost durable TPS for easy application to RLV payload launchers
  - Develop quickly processed composite TPS processing & repair techniques
  - Develop higher temperature capability tile TPS
- **Benefits**
  - **Reduced installation & operations cost**
  - **Enhanced payload capability resulting from TPS weight reduction**
  - **Enhanced flight envelope & performance resulting from higher temperature capability TPS which can result in improved safety**

Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

More Capable Ceramic Tile TPS Demonstrated

POC: Dr. Daniel Leiser

September 2000

Relevant Milestone: Task 2 - Quick Processed Erosion Resistant TPS,

- Higher temperature capability (above 3,000°F) , and
- Faster processed ceramic tile TPS produced, 8/15/00

Shown: A graphic of an entry vehicle with a higher temperature capability tile TPS leading edge being tested in a hypersonic arc plasma stream that will be cheaper, safer and easier to repair.

Accomplishments

- Arc jet testing was completed on candidate ceramic tile TPS at 3,000°F for 2 and 4 minutes (Tile TPS currently limited to 2700°F);
- Arc jet testing was completed on candidate QUICTUFI tiles at 2800°F for 5 minutes.

Relation to Milestone

- This reduces the cost of ceramic tile TPS substantially by reducing the labor required and extends its usage capability to higher temperature locations (I.e., leading edges) where much more expensive (i.e., carbon/carbon), difficult to replace and flaw sensitive materials are characteristically applied .

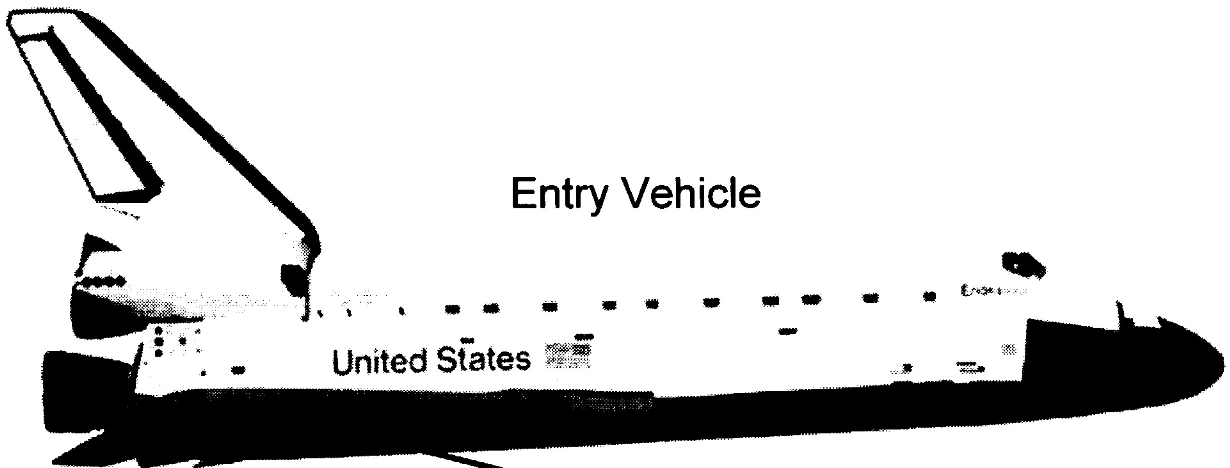
Future Plans: Continue extending the temperature capability of the materials reduce the labor required to produce these materials.

Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

Higher Temperature Capability Tile Leading Edge

Entry Vehicle



Ceramic Tile TPS in
Hypersonic Arc Plasma Stream

3rd Gen Airframe/TPS:

Thermal Protection Systems

Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

Aerogel–Tile Development

POC: Dr. Dan Leiser & Dr. Susan White

September 2000

Relevant Milestone: Autoclave equipment on-line to produce large scale Aerogel-Tiles. (September FY99)

Shown: Large Scale Autoclave Supercritical Processing Equipment that is used to produce either pure aerogels or aerogel-tile composites. Aerogels are organic, inorganic or metal oxide-based highly porous monoliths or nano-particulate materials.

- Extremely light weight - critical for Space
- Lowest solid conductivity: Superinsulator

Aerogel tiles exploit low thermal conductivity and low density of aerogels and AETB's high temperature capability and moderate density

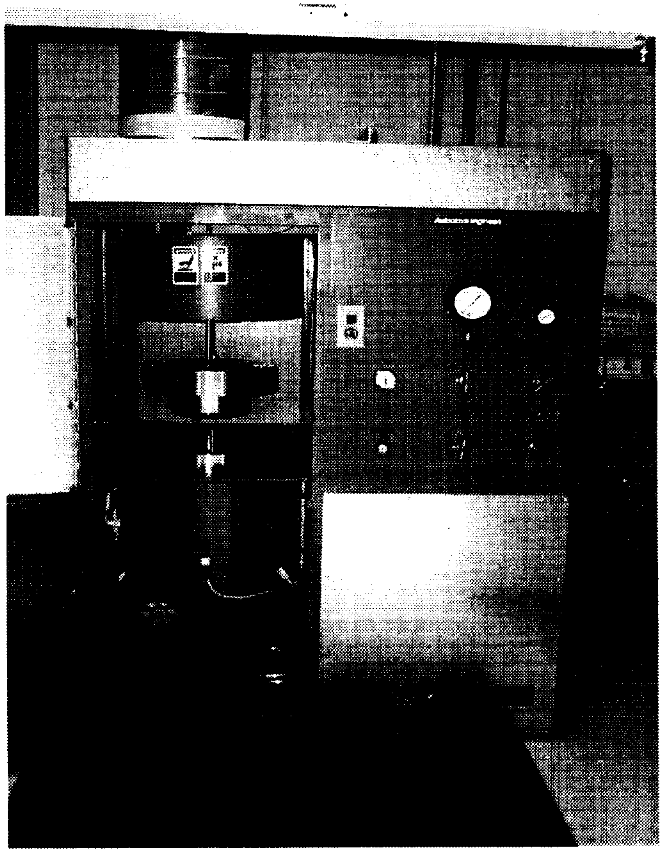
Accomplishment / Relation to Milestone and ETO: The Autoclave equipment is currently on-line and the operational procedures are being developed to produce large scale aerogel tiles, enabling progress towards the goal of reducing TPS weight.

Future Plans: Continue producing, characterizing and optimizing aerogel-tile composites tailored for specific spacecraft insulation applications.

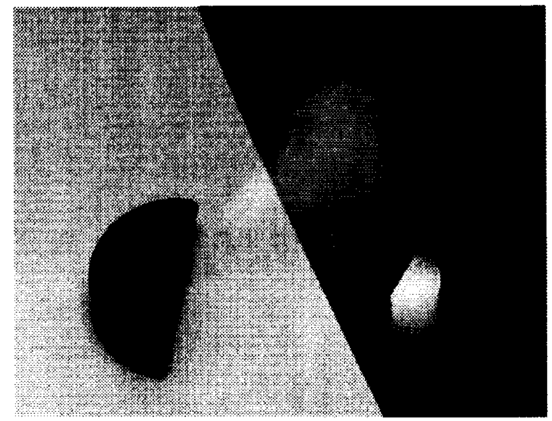
Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

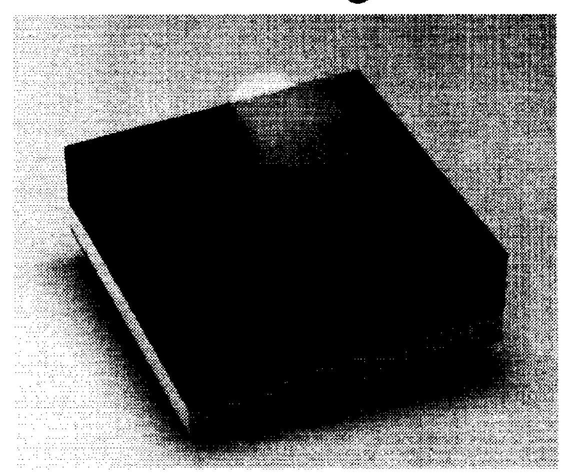
Aerogel Tile Development



Large-Scale Autoclave Equipment



Pure Aerogels



Aerogel-Tiles

3rd Gen Airframe/TPS:

Thermal Protection Systems

Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

Erosion Resistant TPS

POC: Huy Tran

September 2000

Relevant Milestone: Task 2 - Quick Processed Erosion Resistant TPS,

- Resin impregnated fabric reinforced erosion resistant tile TPS surface successfully tested at 2200°F for 30 min.

Shown: A graphic of an erosion-resistant leading edge tile TPS with a fabric reinforced face.

Accomplishment

- Testing was completed on a fabric reinforced erosion resistant TPS at 2200°F for 30 minutes.

Relation to Milestone

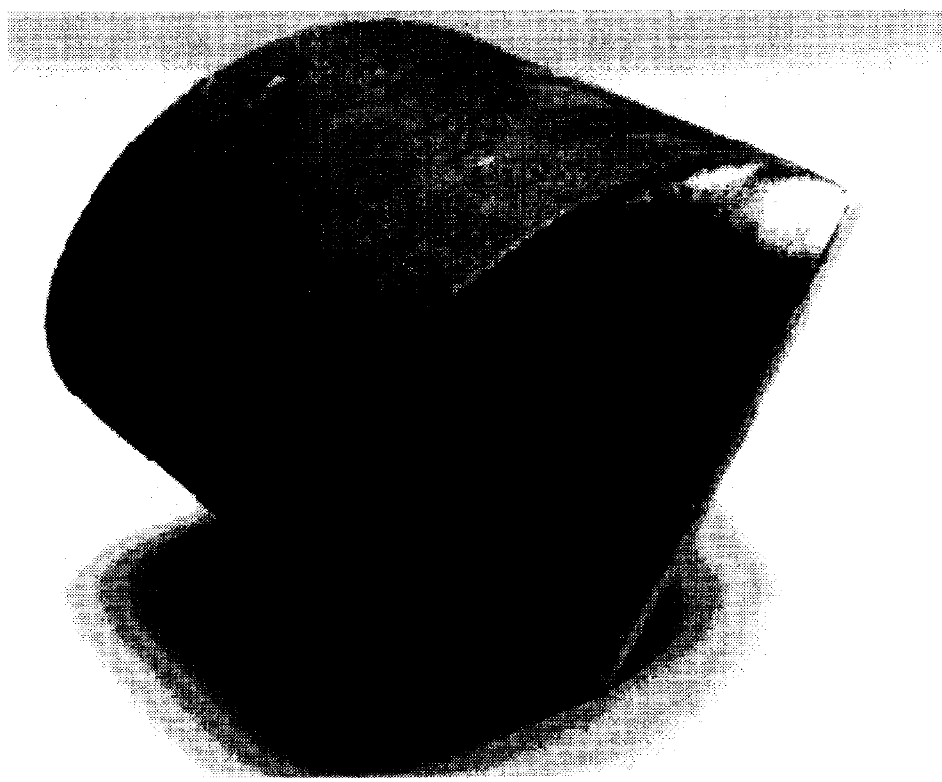
- This material concept will reduce the cost of ceramic tile TPS substantially by extending its usage capability to more damage prone locations where characteristically much more expensive materials are applied .

Future Plans: Develop adhesion technique for multi-layered fabric reinforced face on tile TPS, further improving erosion resistance and perform arc jet testing on leading edge configuration test model

Quick Processed, Low Cost, Erosion Resistant TPS

Technical Accomplishment

Erosion Resistant Leading Edge Concept



- SmarTPS
  - POC:
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SmarTPS

Passive Wireless Thermal-Overlimit Sensor

- **Background:** Inspection of intertile gaps, primarily for evidence of hot-gas inflow and subsurface charring, is a slow and labor intensive task that involves close-up, hand-on visual inspection. The highest priority for health monitoring of TPS is development of a sensor system that can automatically monitor the subsurface temperature and rapidly communicate the sensor data to outside the vehicle using wireless communications technology.

- **Technology goals and objectives:** The goal of this subtask is to develop a miniature sensor that combines a passive temperature measurement, an identification microchip, and a micro-antenna to enable wireless communications.

SmarTPS

Passive Wireless Thermal-Overlimit Sensor

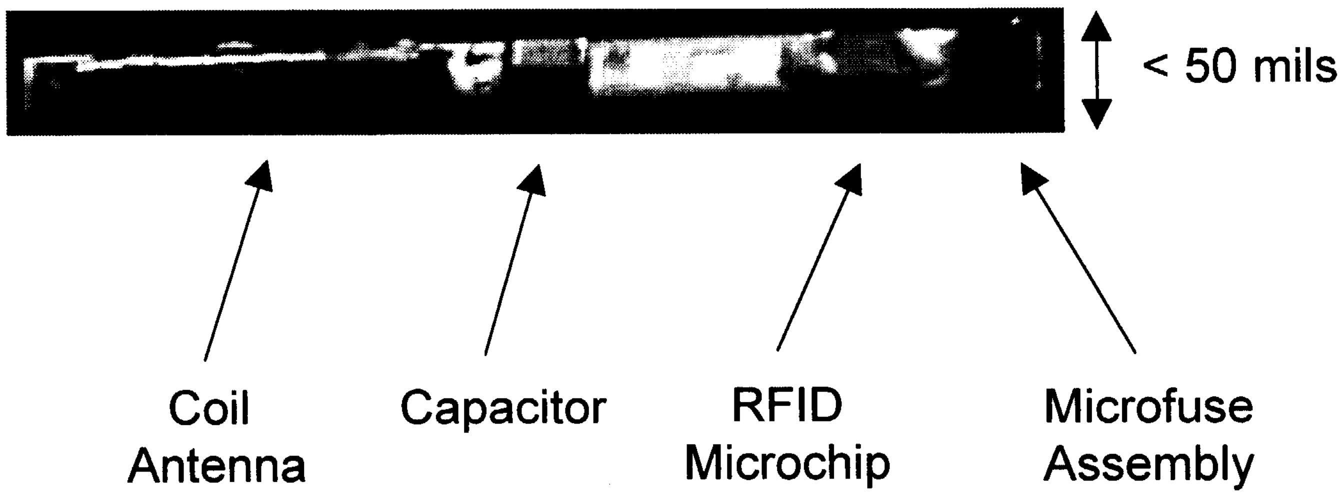
- **Current Status and major accomplishments:** A prototype passive sensor was designed and manufactured. The sensor fits into a 50-mil gap, can survive 15 minute exposure to about 650 °F (345 °C), and indicates a thermal-overlimit event using a fuse that melts at 558 °F (292 °C).

- **Near-term plans:** As required, additional sensors of the same (or slightly modified) design will be manufactured, and sensors will be tested in preparation for possible Shuttle Orbiter flight experiments.

- **Note:** currently TRL=4 to 5. After arc jet/qualification testing we will be at TRL= 5 to 6.

SmarTPS

Passive Wireless Thermal-Overlimit Sensor



- Sensor fits into 50-mil gap between TPS tiles
- Tag mass is 75 mg
- Microfuse opens at 558 °F to indicate a thermal-overlimit event
  (other fuse temperatures using different solder alloys are possible)
- Sensor should survive 15 minutes exposure to 650 °F

SmarTPS

Active Wireless Thermal-Profile Sensor

- **Background:** In some cases, rather than simply indicating a thermal-overlimit event, it is desirable to measure and record TPS temperatures. For example, in-flight TPS gap or surface temperatures may be useful for environment characterization and performance evaluation.

- **Technology goals and objectives:** The goal of this subtask is technology development to combine active sensors, micro-batteries, an identification microchip, and a micro-antenna for communications to enable in-flight data acquisition with on-ground data readout. In the long-term, real-time data acquisition is desirable for applications such as MMOD impact detection.

SmarTPS

Active Wireless Thermal-Profile Sensor

- **Current Status and major accomplishments:** A proof-of-concept prototype active sensor using COTS components was designed and manufactured. The electronics are bonded to the back of a TPS tile, and an attached Type-K thermocouple is placed anywhere within a TPS tile. The time and some criteria for data acquisition are downloaded to the microchip, subsequently temperature data are acquired and stored, and finally the time-tagged data are retrieved using wireless communications.

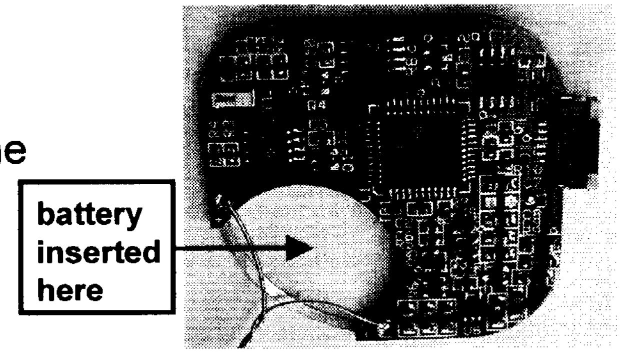
- **Near-term plans:** The prototype sensor will be tested and a demonstration model will be manufactured.

- **Note:** After some testing we will be at TRL= 3 to 4.

SmarTPS

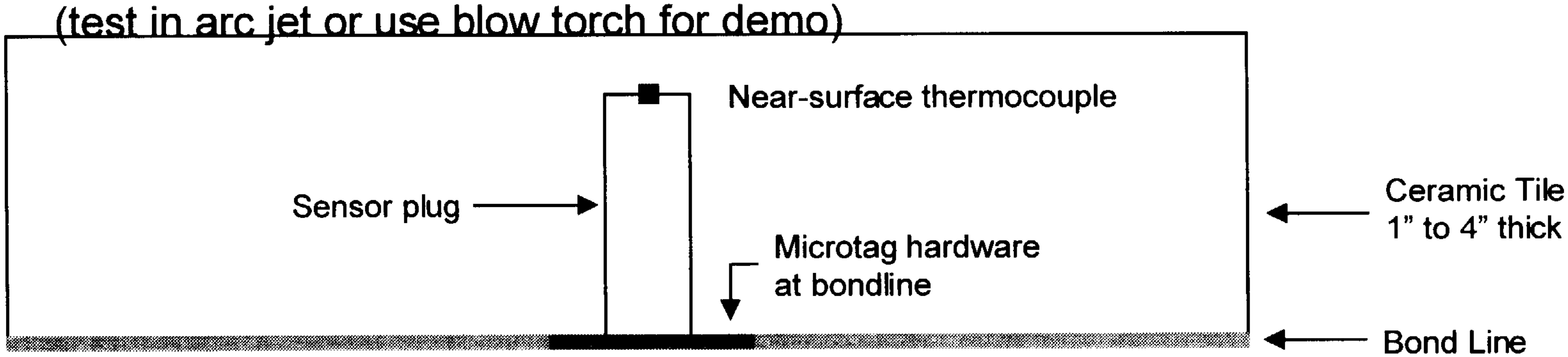
Active Wireless Thermal-Profile Sensor

- Tile sensor plug bonded to Microtag, this assembly then inserted into tight-fitting hole at back of tile.
- Periodically monitors temperatures at bond line and near the surface.
- Time-tagged data will be output to wand-style reader.
- Technique can be generalized for many uses
  - limited by microbattery life.
- For future designs, several thermocouples may be monitored simultaneously (however wires must be run to each TC location) with data output from one RFID device.



Prototype Active Microtag
(to scale)

Front Surface: transient temperature can exceed 2000°F
(test in arc jet or use blow torch for demo)



Back Surface: transient temperature below 300°F
(transient temperature to 650°F may be ok in future versions)

3rd Gen Airframe/TPS:

Thermal Protection Systems

SmarTPS

Surface Laser Measurement Tool

- **Background:** Surface TPS defects can be detected by a post-flight inspection. Currently for Shuttle a team of humans performs a hands-on inspection using rulers and other tools to measure the dimensions of holes, inter-tile steps and gaps, etc. In principle, this inspection could be performed more rapidly and reliably using smart automated scanning tools.

- **Technology goals and objectives:** The goal of this subtask is to develop portable laser-based tools for rapid surface inspection of TPS.

SmarTPS

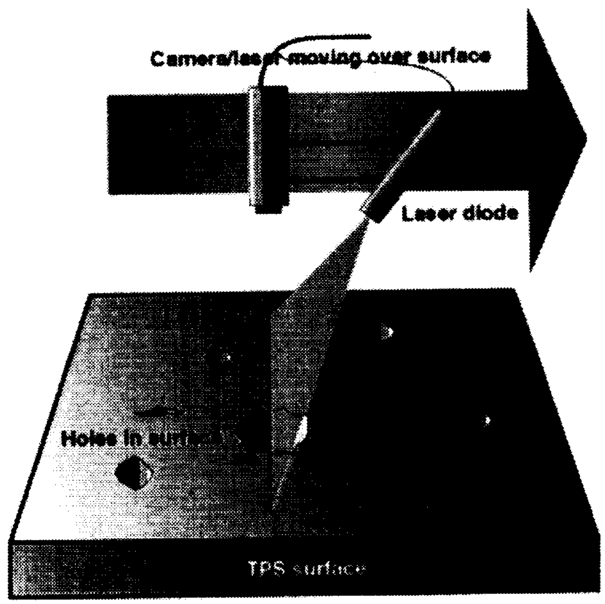
Surface Laser Measurement Tool

- **Current Status and major accomplishments**: Working with Joe Lavelle in Code SFT, a pre-prototype laser-scanning tool was manufactured and demonstrated. This hand-held tool scans a 3" x 3" surface area and obtains quantitative measurements of the surface depth suitable for obtaining full dimensions of surface flaws such as impact chips and holes.

- **Near-term plans:** An improved prototype device that uses two lasers has been designed. The prototype will be manufactured and tested in FY01.

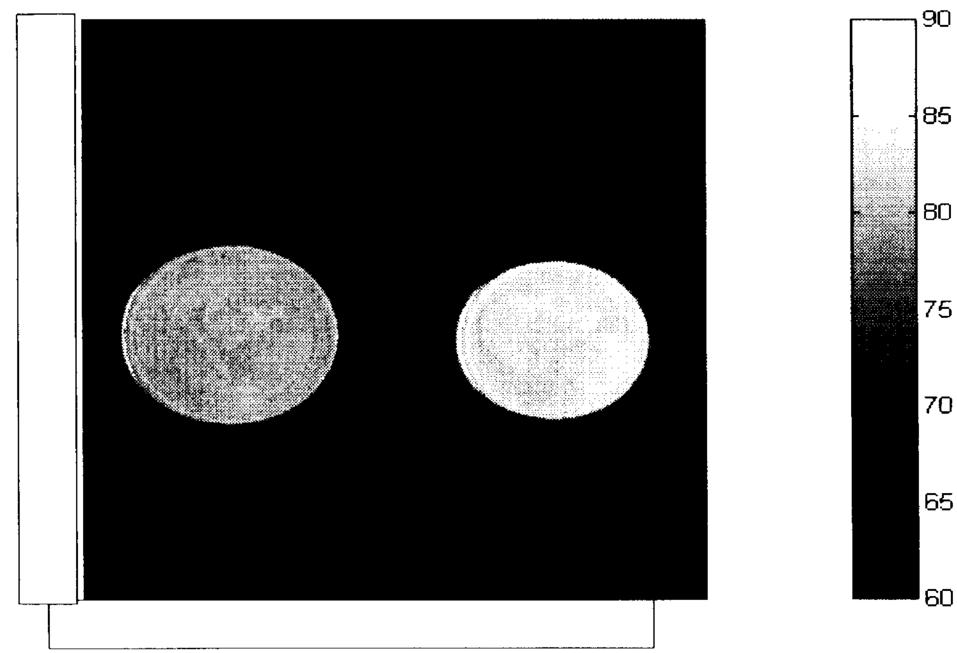
- **Note:** TRL =3, will be 4 after new prototype is tested.

SmarTPS
Surface Laser Measurement Tool



Theory of Operation
- The camera/laser sensor head moves across the surface.
- A straight laser line is projected down onto the surface at an angle from normal.
- Distortions in the reflected line indicate the depth of the surface.
- The prototype will use two lasers to eliminate masking effects.

Image of coins and holes from pre-prototype (shading indicates depth)



3rd Gen Airframe/TPS:

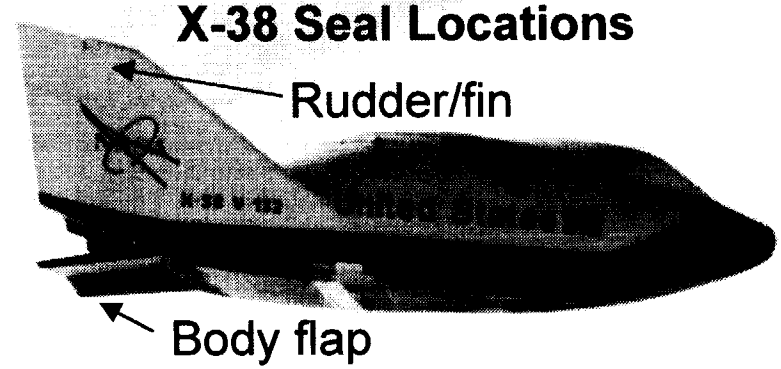
Thermal Protection Systems

- Advanced, High Temperature Structural Seals
  - POC:
    - patrick.dunlap@grc.nasa.gov

Advanced High Temperature Structural Seals

- **Technology goals and objectives**
  - Development and testing of advanced high temperature structural seal concepts for control surfaces of new generation of small reusable launch vehicles
- **Background**
  - Control surfaces of reusable launch vehicles require resilient seals to block high temperature flow between components that move relative to one another for multiple cycles
  - Current seal designs exhibit loss of resiliency after repeated load cycles at high temperatures
  - Advanced seals are required with higher levels of resiliency, flexibility, temperature endurance, and flow blocking capabilities
- **Significant program synergy with X-38 (CRV) control surface seal testing at JSC & GRC as well as X-37 program**
- **TPS-20 program partners:**
  - NASA GRC lead
  - NASA Ames & Boeing support

X-38 Seal Locations

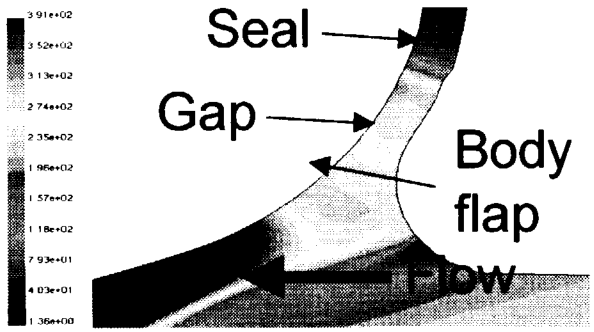


3rd Gen Airframe/TPS:

Thermal Protection Systems

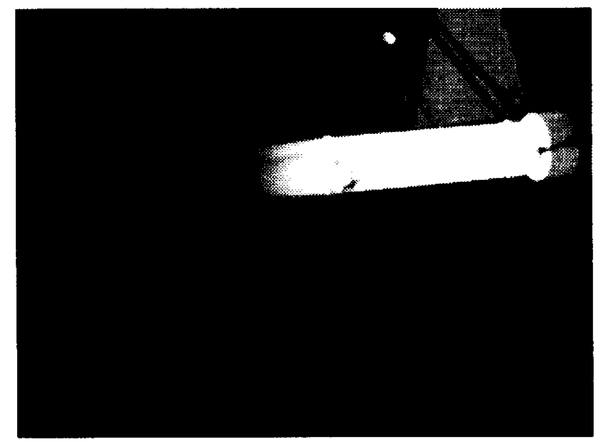
Advanced High Temperature Structural Seals

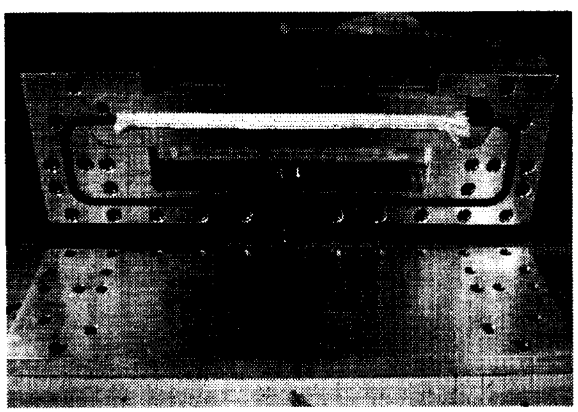
- **Major accomplishments**



⇐ Preliminary aerothermal analyses revealed X-38 body flap seal temperatures of 2300°F

GRC temperature exposure tests show reduction of resiliency & seal preload in baseline seal design (used on Shuttle) ⇒

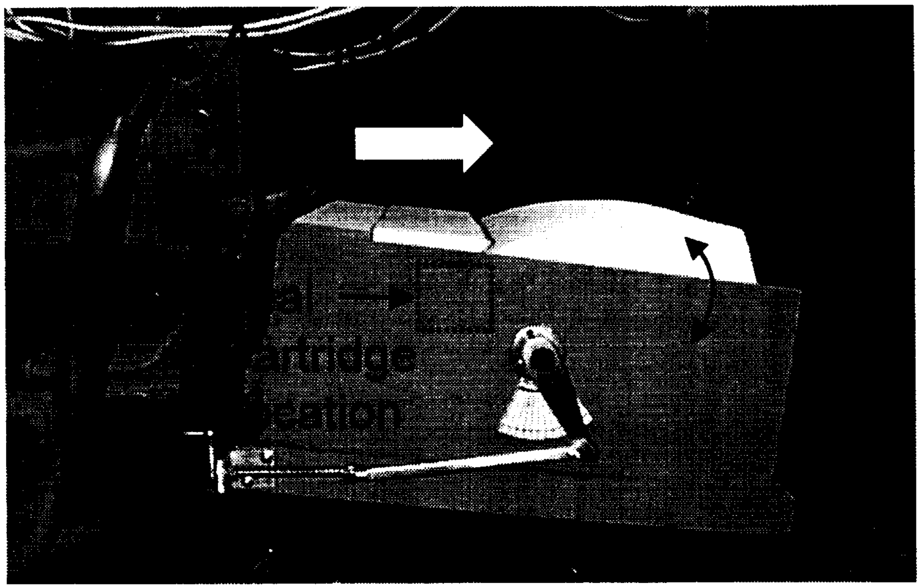


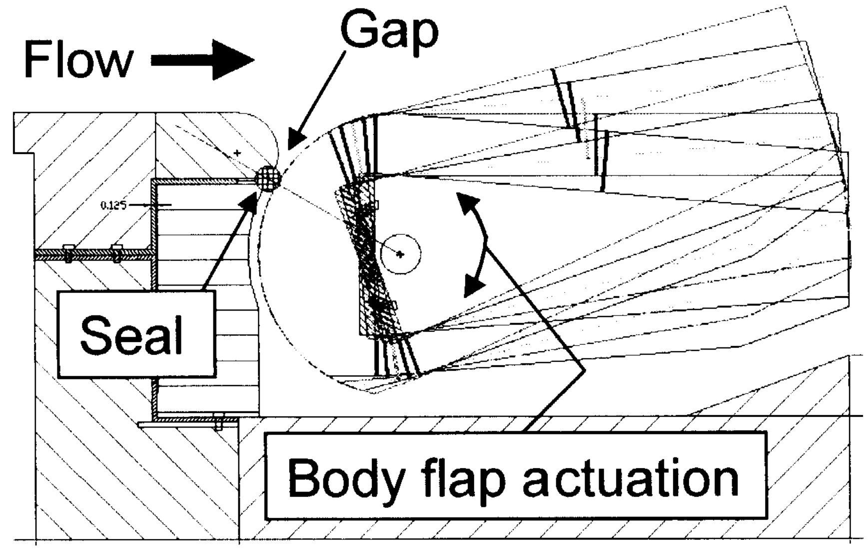


⇐ GRC flow tests of baseline control surface seal before & after temperature exposure showed 25% increase in flow after exposure

Advanced High Temperature Structural Seals

- Major accomplishments (continued)





- Fabricated one-of-a-kind arc jet model to test simulated body flap seals under representative temperature and heating conditions in Ames panel test facility
- Baseline and advanced seals will be tested using replaceable seal cartridge
- Upstream and downstream temperature and pressure measurements will be used to validate aerothermal model
- Body flap actuation during test will be used to assess:
  - Effects of seal scrubbing
  - Increased aerthermal loads due to body flap deflection

Advanced High Temperature Structural Seals

- **Current status**
  - Element seal designs (Gen 1) identified and will be tested at Ames arc jet test facility (1QFY01)
  - Arc jet test fixture being assembled and instrumented at Ames
- **Near term plans & milestones**
  - Complete fabrication of arc jet test fixture
  - Complete arc jet tests on baseline and advanced seal designs (Gen 1/Gen 2) at Ames
  - Validate aerothermal model based on results of arc jet testing
  - Assess gap width effects on seal heating rates & maximum temperatures
  - Assess effects of seal flow rates on maximum seal temperatures
- **Contact info:**

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  - Patrick H. Dunlap, Jr., (216) 433-6374, Patrick.H.Dunlap@grc.nasa.gov

- **UHTC Sharp Leading Edges**
  - **POC's:**
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    - Jeff Bull 650-604-5377
    - GRC: slevine@grc.nasa.gov
    - Stan Levine 216-433-3246
    - LaRC: d.e.glass@larc.nasa.gov
    - David Glass 757-864-5423

UHTC Sharp Leading Edges

- **Goal:** Advance TRL of UHTC sharp leading edges

- **Background:** UHTC sharp leading edges have been demonstrated in flight and ground tests to operate at temperatures as high as 5100 ^{o}F. The TRL of these materials and systems must be advanced in order for them to be adopted in viable sharp leading edged aerospace vehicles.

- **Major Accomplishments:**
  - ARC: Measured the thermal and mechanical properties of ZrB_2/SiC (ZS), $ZrB_2/C/SiC$ (ZCS), and HfB_2/SiC (HS) at 72, 742, 2192 and 2552 ^{o}F. Performed process refinement based on results of post-mortem micro-structural analysis of sharp leading edge components and flexure bars. Integrated NASA GRC CARES into UHTC design tools.

UHTC Sharp Leading Edges

- **Major Accomplishments (cont.):**
  - GRC: Hyper-X, Mach 10 selected for sharp leading edge case example. Identified low cost leading edge transition material (Honeywell C/SiC). Developed preliminary designs for leading edge using C/SiC transition to UHTC. Modified NASA CARES for use with ARC finite element analysis application (MARC).

- **Near Term Plans:**
  - ARC: Characterize UHTC materials. Process thermal mechanical data and update UHTC engineering database (TPSX). Identify ground test facility, geometry, and conditions for joint center evaluation of sharp leading edge systems per PLT (7/01).
  - GRC: Continue development of transition material. Hold PDR on sharp leading edge design (9/01).
  - ARC, GRC, LaRC: Investigate improved sharp leading edge materials, coated CMCs, improved UHTC compositions, etc.

- **Felts**
  - **POC's:**
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    - Marc Rezin
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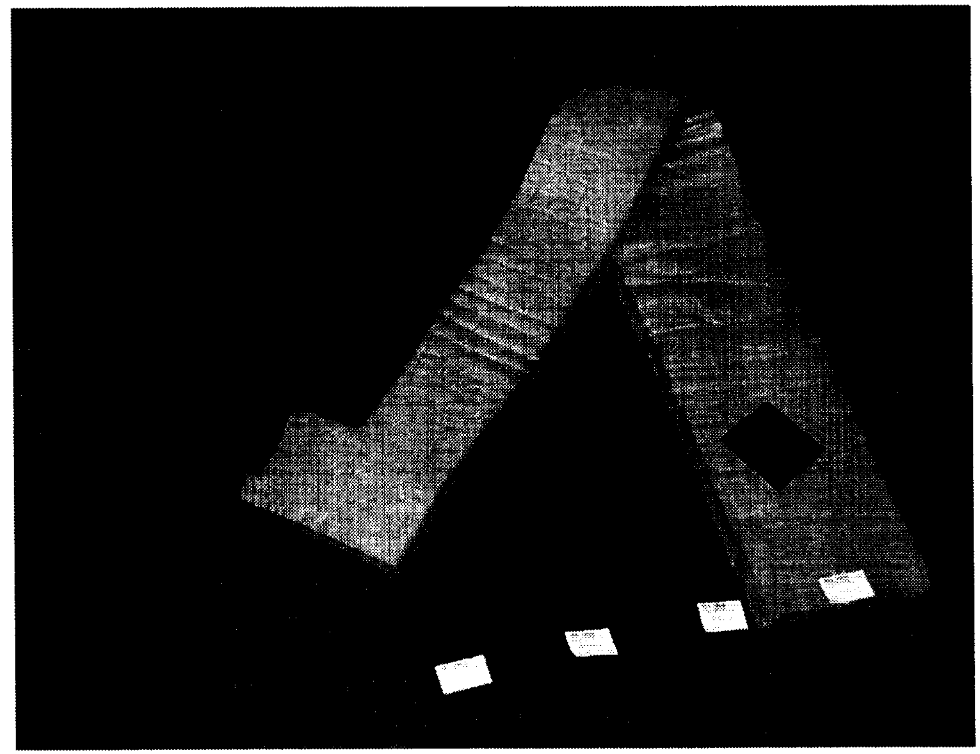
High Temperature Felt TPS

- **Technology Goals and Objectives**

  Development of a family of low cost, high temperature felts with multiple use temperature limits of up to 1500°F. By blending fibers of several types (carbon, refractory oxide, organic, and pre-ceramic), specific combinations of durability, temperature capability and cost can be produced.

- **Background**

  Current felt TPS (FRSI) has a multiple use temperature limit of 750°F, limiting its areas of use. Current TPS blankets (AFRSI) for multiple use up to 1500°F are more costly, less durable, and requires more labor for inspection and repair than the felt TPS under development in this task.
  High Temperature Felts contribute to lower initial and recurring costs for Reusable Launch Vehicles while enhancing their rapid turn-around capability.



3rd Gen Airframe/TPS:

Thermal Protection Systems

High Temperature Felt TPS

- **Current Status, Major Accomplishments**

  Four different organo-ceramic hybrid felt types and three carbon-based felts have been fabricated.
  Coupon-level thermo-chemical stability assessment and mechanical property testing has produced promising results.

- **Near Term Plans**

  Component-level thermo-chemical stability assessment in the Ames AHF arc jet facility, and durability screening in a vibro-acoustic environment, are currently scheduled for the week of 11/13/00.