National Aeronautics and
Space Administration

Technology Readiness Assessment for HEEET TPS

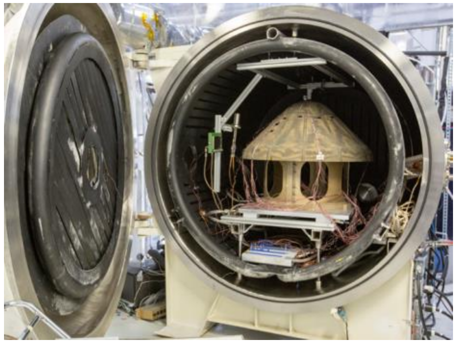
Peter Gage, Milad Mahzari, Keith Peterson, Don Ellerby, Ethiraj Venkatapathy

IPPW July 11, 2019

TECHNOLOGY DRIVES EXPLORATION

Heatshield for Extreme Entry Environment Technology (HEEET)

- **Leverages advanced 3-D weaving and resin infusion.**
- **A dual layer system - robust and mass efficient across a range of extreme entry environments**
- **Objective to:**
  - Mature HEEET to TRL 6
  - Develop and verify:
    - ➢ Manufacturing processes
    - ➢ Design tools:
      - ❖ Thermostructural
      - ❖ Aerothermal Response
    - ➢ Documentation



Thurs 11:54 am The Challenges of Seam Design in Tiled Thermal Protection Systems. Cole Kazemba
Thurs 1:34pm. Damage Assessment During a Structural and Thermal Test Campaign of a 1-meter Diameter Heatshield with a 3-D Woven Thermal Protection System for Extreme Environments. Sarah Langston
Fri. 10:54am Challenges In Qualification Of Thermal Protection Systems In Extreme Entry Environments. Milad Mahzari
Fri 1:57pm White Papers For The Next Decadal Survey: Thermal Protection Systems And Instrumentation. Helen Hwang.
Poster Session I: A25 IV.1 High Velocity Impact Performance of a Dual Layer Thermal Protection System for the Mars Sample Return Earth Entry Vehicle. Ben Libben
Poster Session 2: B25. VII.4. Maturation of Heatshield for Extreme Entry Environment Technology (HEEET) through Extreme Aero-thermal Ground Testing at Arnold Engineering Development Complex (AEDC). Joseph Williams
Mission Applications:
Tues 2:48pm. Robotic Mars Sample Return Earth Entry Vehicle Concept Development. Marcus Lobbia
Tues 3.00pm. HEEET Material Modeling and Earth Entry Vehicle Landing Analyses for Potential Mars Sample Return. Aaron Siddens

TRL Assessment

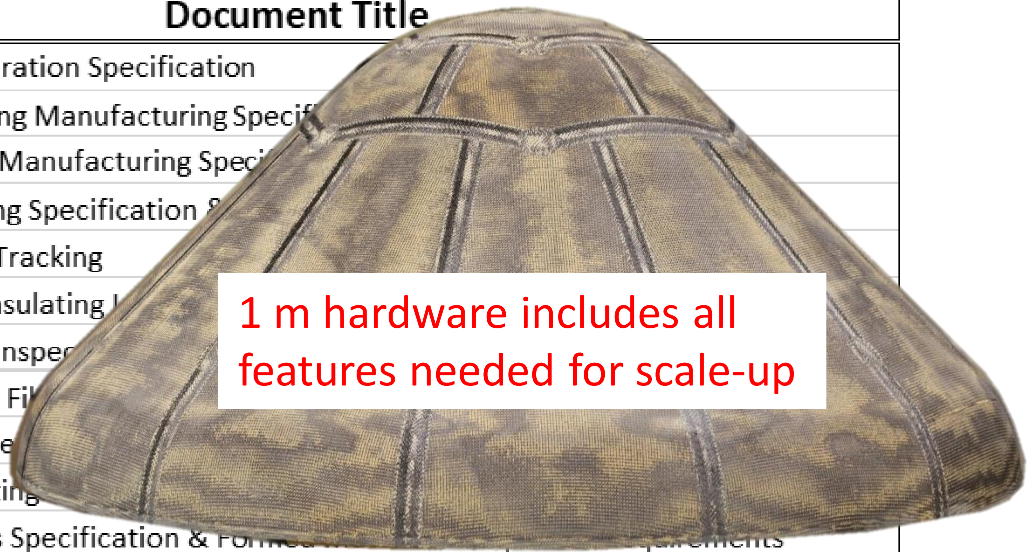
- **Goal: Decide whether HEEET technology is at TRL 6**
  - Technology elements
    - Acreage material
    - Seams including gap-filler in channel between acreage tiles with Nitrile Phenolic film adhesive around gap-filler
- **Definition for TRL 6 (NASA Systems Engineering Handbook)**
  - *A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.*
- **Exit (or success) criteria are:**
  - *Documented test performance demonstrating agreement with analytical predictions.*

- **Have we built high-fidelity prototypes that address scaling issues?**
- **Have we operated in relevant environments? Difficult for TPS for extreme environments**
  - Structural (pressure, thermal-vacuum and point loads on 1 m ETU)
  - Thermostructural (combined loading of flexures)
  - Aerothermal (arc-jets)

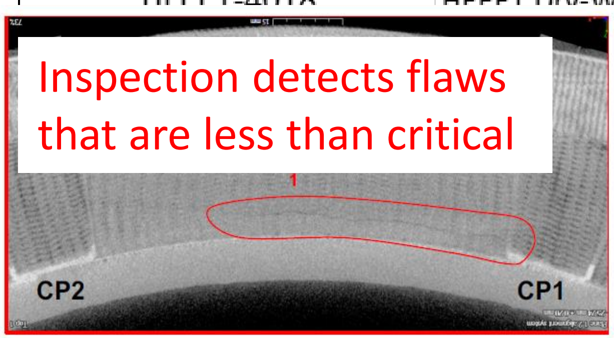
- **Have we documented test performance demonstrating agreement with analytic predictions?**

Prototype Hardware

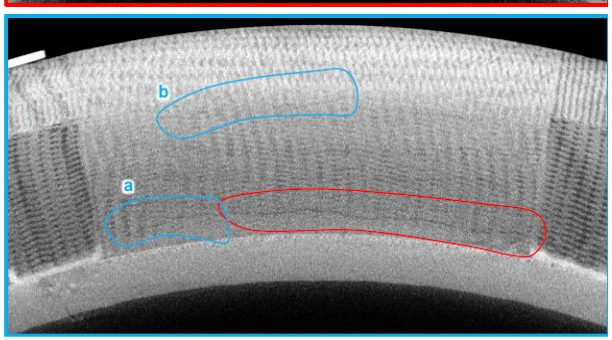
Document Number	Document Title
HEEET-4001	Infusion Solution Preparation Specification
HEEET-4002	Resin Infusion and Curing Manufacturing Specif
HEEET-4003	Drying and Post Curing Manufacturing Speci
HEEET-4011	HEEET Material Handling Specification &
HEEET-4013	HEEET Part Marking & Tracking
HEEET-4014	HEEET Blended Yarn (Insulating L
HEEET-4015	HEEET Fiber Receiving Inspec
HEEET-4016	HEEET Recession Layer Fil
HEEET-4018	HEEET Dry-Woven Mate
	'oven Cuttin
	ng Process Specification & Form
	Receiving Inspection for Recession Layer AS4 Tows
	d Material Inspection and Acceptance Requirements
	anufacturing Process Specification
	spection & Acceptance Requirements
	ial Machining Process Specification & Acceptance Requirements
	tegration Proce
	spection and A
	facturing Requi
	urface Densification
	out Plug Manuf. and Integration Process Specification



1 m hardware includes all features needed for scale-up



Inspection detects flaws that are less than critical

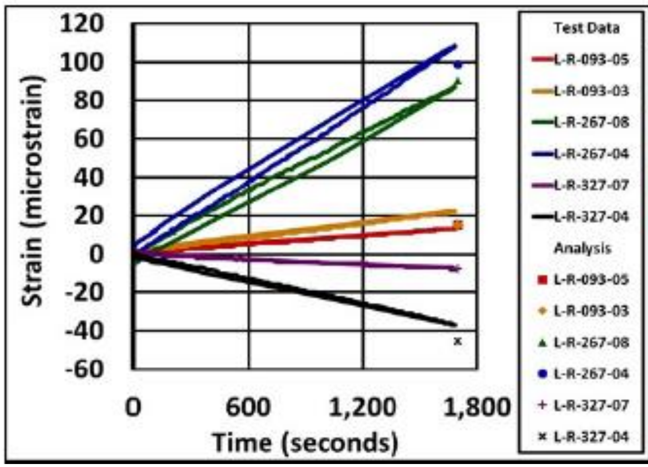


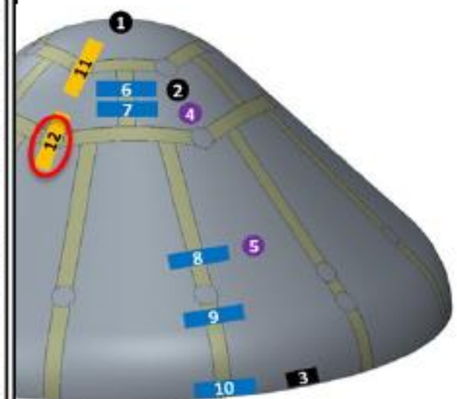
Comprehensive procedures support consistent reproducibility

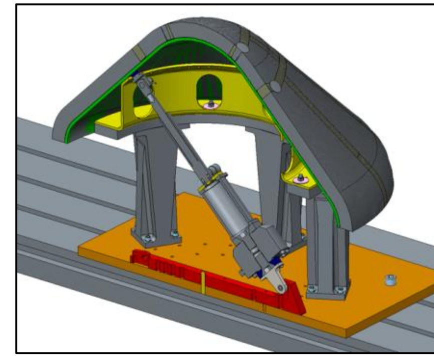
Small test articles use consistent procedures

Structural Capability
Load Cases other than Entry

- **Sample result for point load case**







Component	Mode	Property	Basis for Allowable	Margin Approach	Margin / Factor	Confidence
Tile Failure	TTT cracks	IP tensile strength	Material Testing	Structural	> 5	High
		IP shear strength	Material Testing	Structural	> 3	High
	IP cracks	TTT tensile strength	Material Testing	Structural	> 5	High
		Interlayer Shear Strength	Material Testing	Structural	> 1	High
Base bond	Adhesive mech. failure	Joint tensile strength	Joint Testing	Structural	> 5	High
		Joint shear strength	Joint Testing	Structural	> 5	High
Seam bond	Mech failure	Joint tensile strength	Joint Testing	Structural	> 5	High
		Joint shear strength	Manufacturer Database	Structural	> 5	High
		Triple point strain	Joint Testing	Structural	> 1	High

Weakest correlation in regions of high curvature

- Material properties affected by forming
- Uncertainty is acceptable

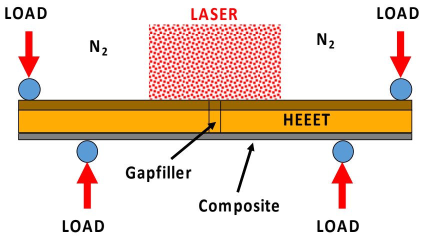
Margins much larger than model uncertainty

Evaluation

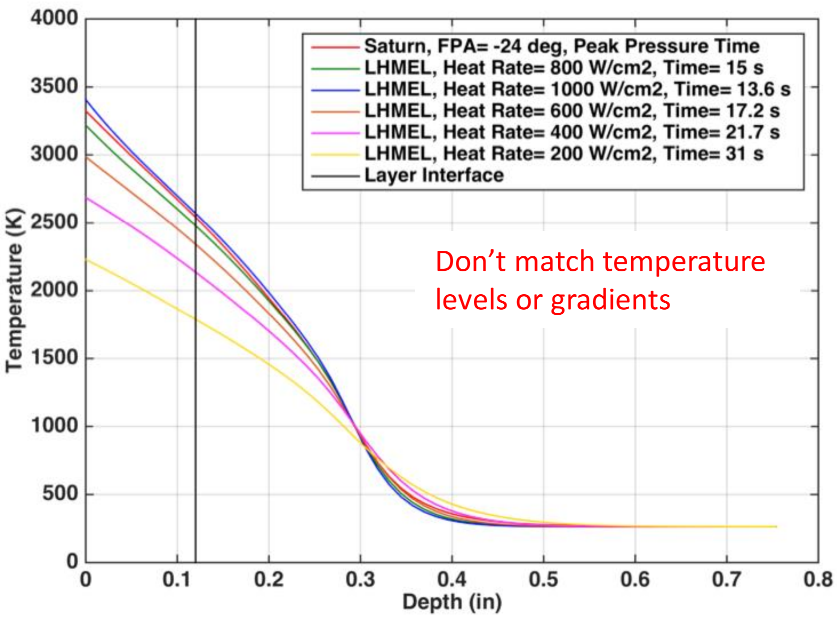
- Delivered test results that correlate with model

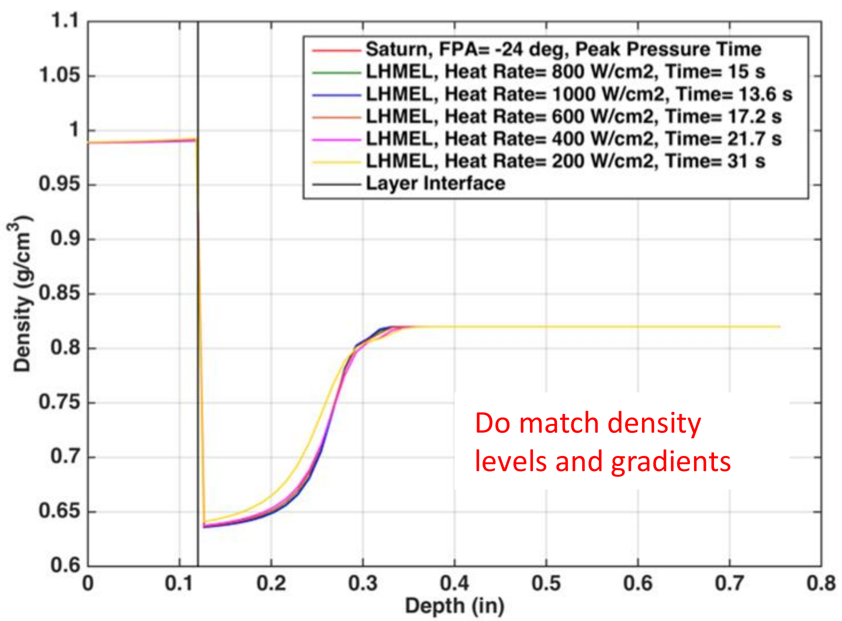
Thermostructural Environments for Entry

- **Mission-accurate heating rates on seam article are challenging in ground facility**
  - Can deliver relevant material state by heating for longer at lower rates
  - Can apply bending load throughout heating (as material changes state)
  - Can vary bending load after material state changes are in progress



Schematic of LHMEL Structural Panel Test





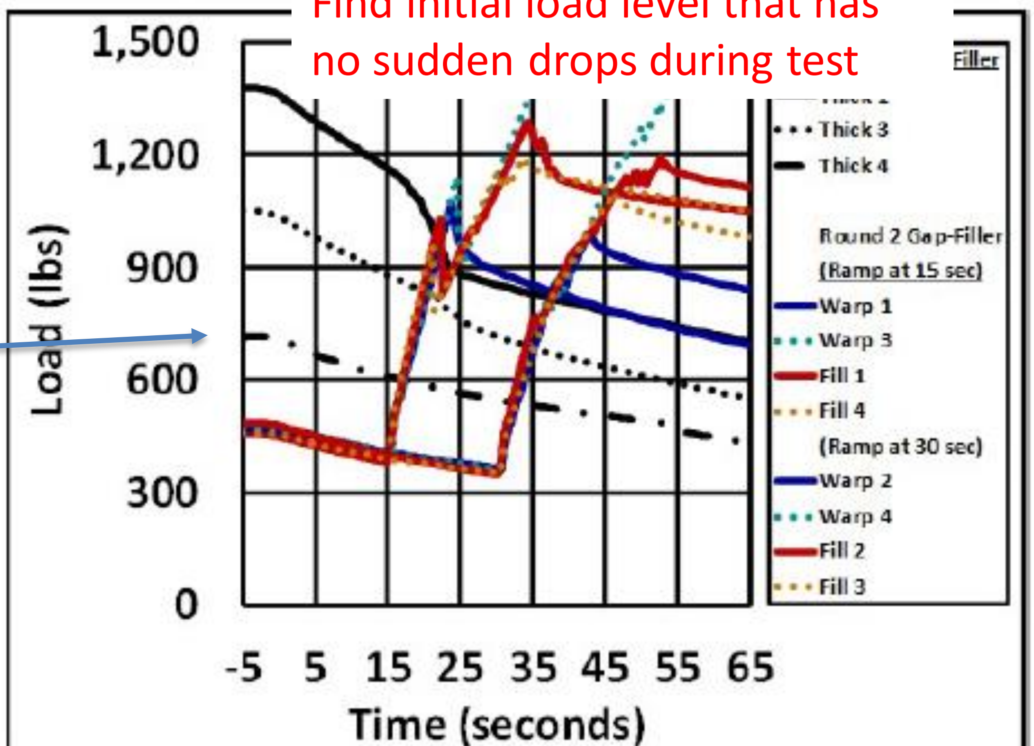
- **Evaluation**
  - Achieved relevant environments for thermostructural load throughout entry

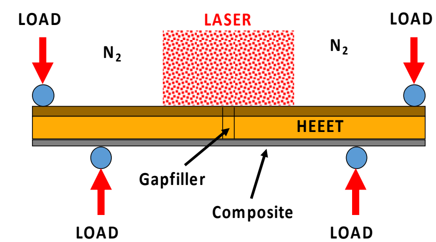
Thermostructural Capability at Entry

- **Challenging to develop predictive model for local stresses at seam**
  - Uncertainty in material properties
  - Stress concentration at interface between char and virgin adhesive
- **Rely on estimation of gapfiller expansion at RT pre-loading**

Find initial load level that has no sudden drops during test

FEM predicts 0.02” gapfiller expansion at this load





Schematic of LHMEL Structural Panel Test

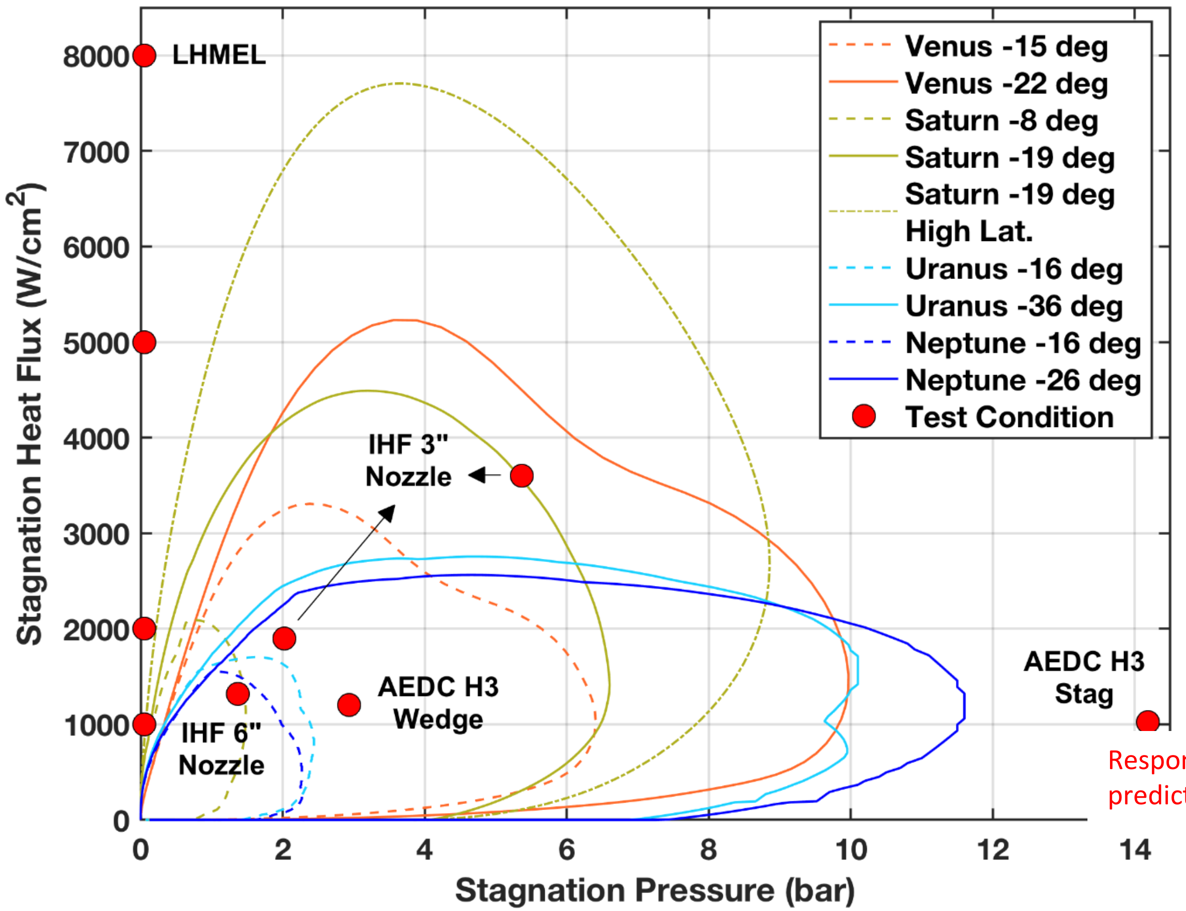
Panels with closeout plugs had no failure below 0.009” expansion (not shown)

Need up to 0.003” expansion.

Large margins

Aerothermal Environments

- **Challenging to achieve extreme environments in ground facilities (Mahzari, Friday at 10:54)**
  - Introduced testing of 1” models in 3” nozzle at IHF
  - All parameters are not matched simultaneously
  - Need to account for cold wall vs hot wall
  - Limitations would apply to ANY material intended for extreme environment applications

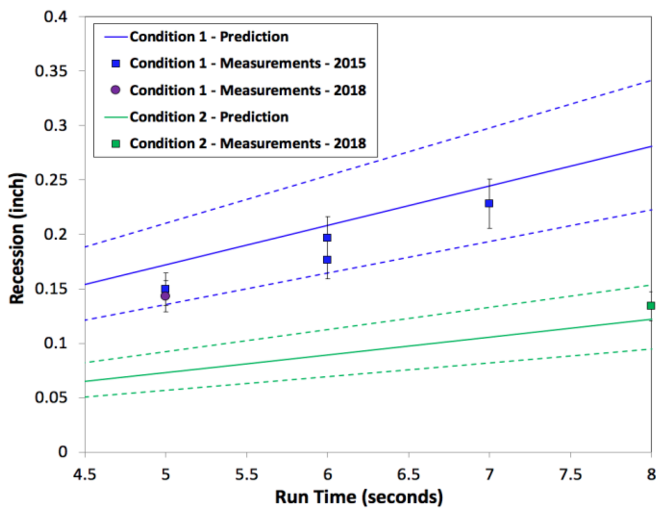


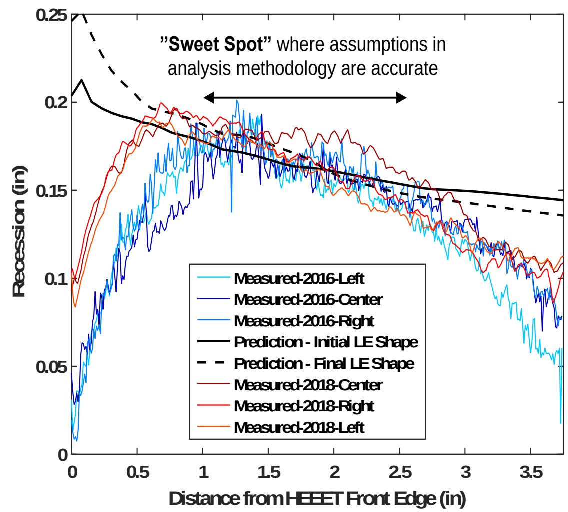
Response model not predictive at this condition

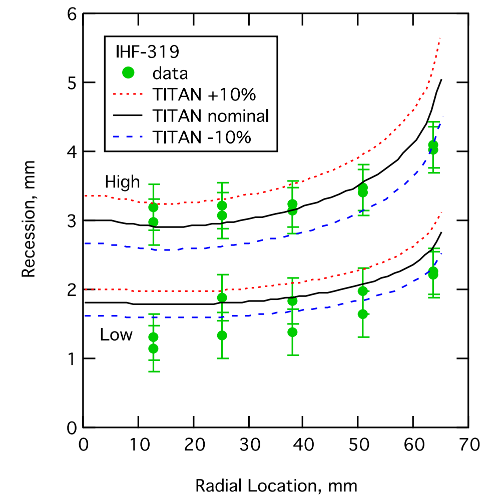
Evaluation: achieved adequate aerothermal environments

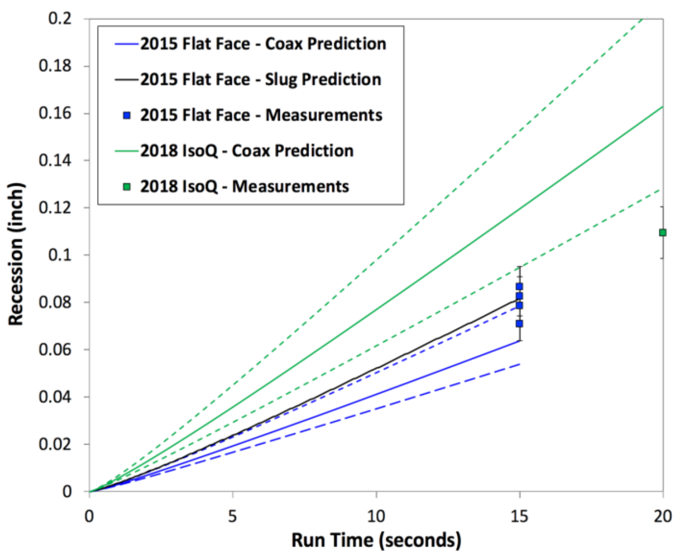
NOT High latitude Saturn
NOT steep Venus

Recession Prediction



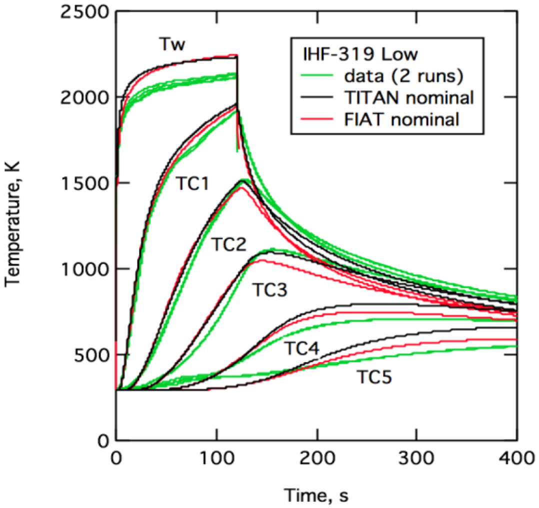


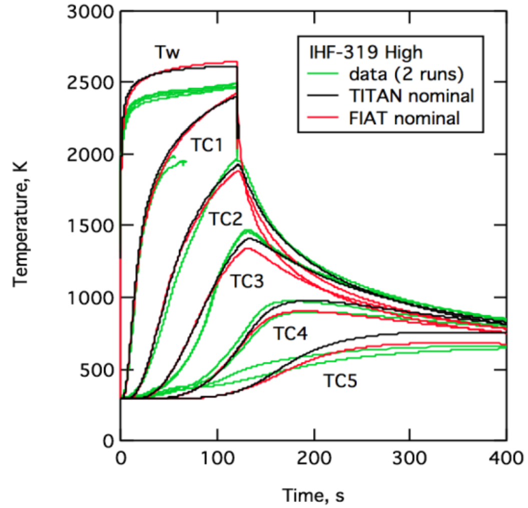




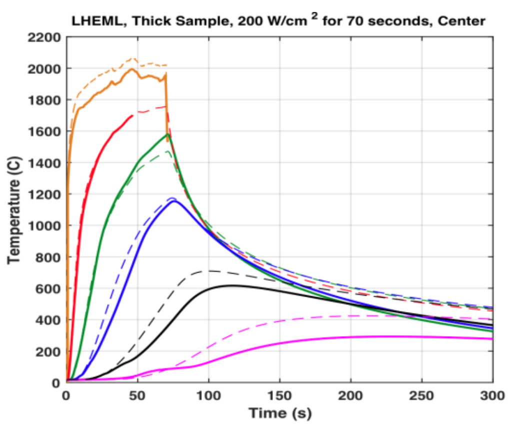
- **Excellent results for most tests**
  - Concern for 2" models in 6" nozzle
    - Over-predicts for iso-Q in 2018
    - Under-predicts for flat face in 2015
    - Uncertainty is bounded by recession margin (50% recommended)
- **Evaluation**
  - Test results have adequate agreement with recession model

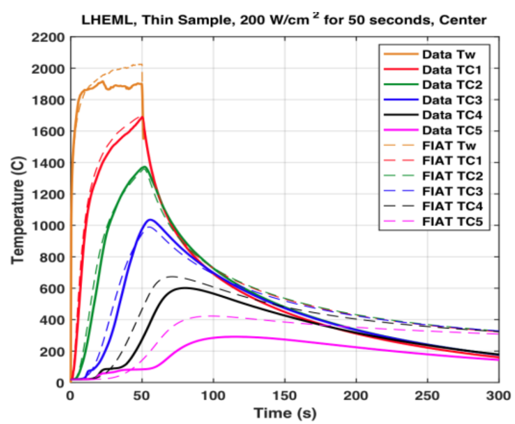
In-depth Temperature Prediction





Stagnation testing in IHF 13” nozzle



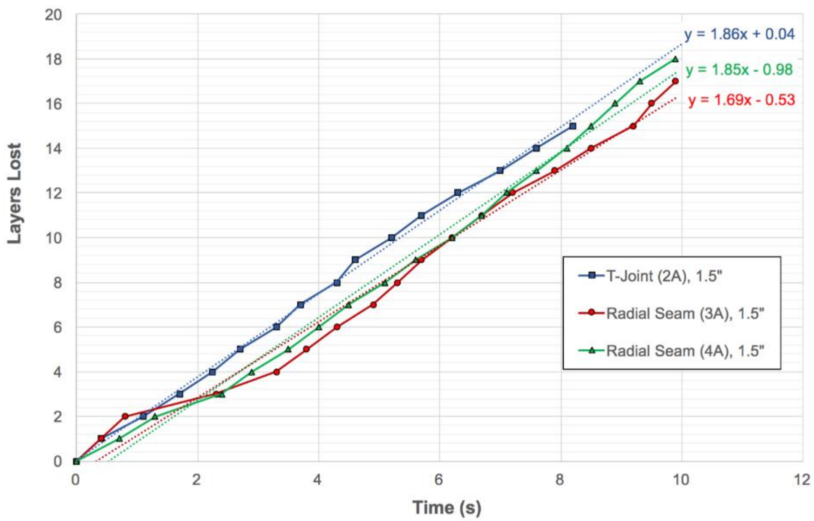


Laser testing at LHMEL

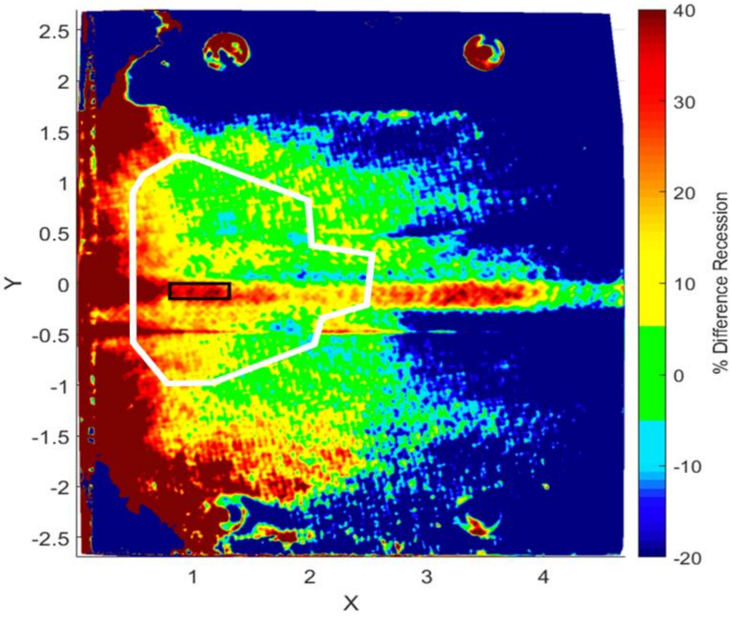
Limited measurements under seams show no elevated temperatures relative to acreage

- **Evaluation**
  - Test results have adequate agreement with model predictions of temperature

Recession of Seams



No run-away observed



Difficult to assess augmentation due to uncertainty in applied environment

- **Measured recession augmentation in 2018 test ranged from 11 to 51%**
  - Most measurements in 20-40% range
  - Probably exacerbated by thin leading edge
- **Evaluation – adequate recession predictability, can be handled with margin**

Final TRL Assessment

- **Have we built high-fidelity prototypes that address scaling issues? Yes**
- **Have we operated in relevant environments?**
  - Aerothermal (arc-jets) Yes
  - Thermostructural (combined loading of flexures at LHMEL) Yes
  - Structural (pressure, thermal-vacuum and point loads on 1 m ETU) Yes
- **Have we documented test performance demonstrating agreement with analytic predictions? Yes**

- **HEEET system is assessed to be at TRL 6**

- **Limitations**
  - Not at TRL 6 for thickness much greater than 2”
  - Not at TRL 6 for applied environments above 5 atm and 3600 W/cm2
  - No mission opportunity (except Jupiter) appears to require these levels

- **But don’t just take our word for it**
  - “The IRB concurs […] that the overall objective of achieving TRL 6 has been completed”