SOFI/Substrate Integrity Testing For Cryogenic Propellant Tanks

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Introduction

- Thermal Protection System Integrity in launch systems is a critical factor in both manned and unmanned spaceflight.
- Testing of bond integrity and TPS durability through multiple fill drain cycles is required to simulate possible lifecycle use.
- NASA Cryoflex tensile test has historically been done using Liquid Hydrogen (LH$_2$).
The Cryoflex Test Concept

- Apply both thermal and mechanical strains to a SOFI/Substrate specimen which reflects actual use conditions
- Rapid substrate cooling simulating sudden exposure to cryogen as tank fills
- Repeated fill/drain cycles - Mechanical strain
- Thermal gradient forms between low temperature substrate and ambient condition exposure to SOFI outer surface
Design Parameters

- Grips to hold 6500+ lbs load, potentially at 20 K
- Needed to cool substrate to 20 K -5/+0 K, while keeping the TPS exposed to ambient conditions
- Use Liquid Helium (LHe) to cool rather than Liquid Hydrogen (LH$_2$)
- Measure temperature of substrate at 2 points minimum
- Measure average strain of substrate
Design Challenges

• Cooling of substrate to 20 K evenly
• Maintaining TPS exposure to ambient temperature
• Perform real time temperature measurements at substrate without interfering with cooling
• Perform real time strain measurements of substrate without interfering with cooling
• Two specimens to be tested at once
• Reduce parasitic losses
Test System Solutions

• Use the Endothermic property of expanding gases to augment the heat extraction from the substrate

• Create a cold shroud through intelligent gaseous Helium (GHe) exhaust routing

• Cool both sides of the block evenly by minimizing and equalizing the thicknesses that contact the substrates

• Constrain the cooling block using the substrates themselves with no parasitic attachments

• Slots in cooling block to clear strain gage wires and Silicon Diodes
Test Procedure

• Initial cool-down from 295 K to 50 K
  - Ramp rate of 12-16 K/min

• Secondary cool-down from 50 K to below 20 K
  - Ramp rate of >18 K/min
  - Simulates rapid fill of tank

• Initiate mechanical loading
  - All loading performed at a rate of ~900 lbs/sec

• Maintain substrate temperature and perform load cycling
  - Maximum and minimum loads determined by substrate thickness and desired strain level
  - Holds at certain stress or strain levels can be used

• Repeat load cycling (mission cycles) while holding substrate at <20 K
• Monitor TPS foam integrity and surface temperature
Load & Temperature Vs Time

- **Load (lbs)**: The graph shows a fluctuating load with multiple peaks and troughs over time.
- **Temperature (K)**: The temperature data is indicated by a green line, showing a smoother trend compared to the load data.

The graph demonstrates the dynamic interaction between load and temperature over time, highlighting the substrate integrity testing for cryogenic propellant tanks.
TPS Cracking
Typical TPS Failures

Knit line of two insulating layers

Aluminum Substrate

Frost Propagation from crack

Ablative layer

Crack through both layers

Crack across outer surface layer
Crack Detection/Observation

- Ability to actively monitor specimen during the test is critical
- Acoustic emissions indicate crack formation and propagation and enhance data reliability.

Crack while actively cooling

Same Crack at room temperature; almost invisible
Conclusions

- CTD’s Cryoflex test system demonstrates the ability to use LHe to achieve an intermediate cryogenic temperature of a metallic substrate and ambient temperature exposure to SOFI foam, while allowing mechanical loads to be applied to the substrate.
- The system accurately simulates actual conditions in the fill, pressurization, and draining of a cryogenic fuel tank used in aerospace applications.
- Allows direct monitoring of the condition of the foam and the foam/substrate interface to immediately locate and identify a disjuncture within the foam or the foam to substrate bond.
- Reducing the safety precautions by using LHe (as opposed to the use of more volatile cryogens) results in additional cost savings.