Reusable Cryogenic Tanks

Thermal-Mechanical Cyclic Test of a Composite Cryogenic Tank for Reusable Launch Vehicles

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Special Session: Cryogenic Propellant Tanks and Integrated Structures for a Next Generation Reusable Launch Vehicle
Outline

Reusable Cryogenic Tanks

- Tank Test Article
- MSFC Test Facility
- Test Plan
- LN2 Pre-test series
- LH2 Cyclic Test
- Repair
- Burst Test
- Post-Test Evaluation
Tank Structural Configuration

Reactive Cryogenic Tanks

8.0-ft (2.4m)

VIEW A SH 2

Frames (3)

Stringer Stiffened Skin

Integral Shells (2)

Heritage Rockwell SSTO

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As-Built Internal Details of Structure

Reusable Cryogenic Tanks

FRAME SPLICE

FRAME

INNER DOME REPAIR DOUBLER

TEE CLIP

SHEAR CLIP

STRINGER

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TPS Arrangement In Heated Area of Tank Wall

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AFRSI Blanket

AETB Tile

TPS

Adhesive

Cryo-Insulation

Adhesive

Gr/Ep Tank Wall

TABI Blanket

FRSI Blanket
MSFC Cryogenic Structure Test Facility

Reusable Cryogenic Tanks

- Burnstack
- Storage Tank
- Vacuum Jacketed Feedlines
- Tank Test Station
- Instrumentation and Control
8-ft Tank Test Setup

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Vent Lines

MSFC-built Composite Intertank

Heritage Rockwell-built 8-ft Composite Tank

Fire Control

Hydraulic Struts for Axial Load

Heater Arrays

Control valves

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Cyclic Test Plan and Accomplishments

Reusable Cryogenic Tanks

- Eight LN2 Pre-tests completed
  - Cold shock
  - Proof pressure (LN2)
  - Ascent axial load
  - Landing axial load
  - 10 simulated LN2 cycles
- 26 of 200 LH2 Test cycles completed
  - Fill and pressurize to over 40 psi
  - Apply over 600 lb/in axial launch load
  - Reduce pressure and load
  - Apply heat to TPS surface (Entry)
  - Apply over 800 lb/in axial landing load
  - Repeat
With the sump cover off, an inspection of the inside of tank was performed.

No visually apparent anomalies were observed in the tank skin.

A "tap test" of the bond of each of the 60 stringers from the lower end to the mid frame revealed no obvious soft areas or disbonds.

Visual inspection of each of the tension and shear clips common to the lower frame showed no clip or fastener failures or apparent movement.

While not conclusive of tank health, no change in tank appearance was evident through 5 cycles.
**Strain Data**

- Large translation of the strain data was observed from some gages but not others, but since the data was linear, the behavior was concluded to be a gage or calibration issue rather than a structural problem.
- Only four gages survived through all 26 LH2 cycles and burst test.

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**LH2 Cycle Test - 2BO47**

- Large translation in strain results

**2BI21 Burst**

- Tank failed at 106% of ultimate
TPS Temperature Data

- Thermal data obtained on wall, within TPS, within insulation, and at all interfaces
- Adhesive bondline temperatures generally remained within established maximum and minimum limits
- Cryopumping, caused by liquid air evaporating away from the tank wall surface and blowing through the insulation, was evident locally

Evidence of cryopumping

Typical cryo fill temp. results

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Acoustic Emission Data

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- Significant number of AE signals recorded during each LH2 or LN2 filling due to cold shock induced thermal stresses
- Tank pressurization (tension membrane load) caused a large number of AE hits
- Matrix cracking or crazing monitored at the beginning of the test series, with no structural integrity damage
- Fewer AE signals were detected during each subsequent equivalent cycle (Kaiser effect)
- A distinct peak of AE hits occurred when the pressure increased from the cyclic test pressure to burst pressure
Leak Detection and Repair

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Bubbles Indicate Leak Location

Vacuum bag being removed from external patch along stringer 51.

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LN2 Pressure Load Burst Test

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Burst location at stringer 51

Expanding Nitrogen Cloud

Burst occurred at 106% of ultimate
Ultimate Load Test Failure Location

Composite Tank Wall

Edge of Break at Stringer 51

Cryoinsulation

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PHANTOM WORKS
Tank Dissection for Post-test Analysis

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Post-test Evaluation

- Microscopy and C-scans revealed good tank wall consolidation
- Minimal microcracking (max. 2-ply depth) in the tank wall were found
- Blade-stringers were cracked in noodle area (probably due to thermal stresses)
- Some stringer flanges dis-bonded from the tank wall (probably due to burst test)
Conclusion and Recommendations

- Designed, built, and cyclic tested flight-weight graphite/epoxy LH2 tank under NASA MSFC Cooperative Agreement
- Integrated structure, cryo-insulation and TPS system with SHM instrumentation successfully demonstrated
- Eight LN2 Pretest Series tests completed
- 26 LH2 simulated mission cycles completed
- Burst test demonstrated robust design

- Next building block in development of composite cryotanks for RLVs is fabrication and cyclic test of an even larger tank, with integrated wing and thrust structure, to demonstrate low-cost producibility and operability, and long-life, complex-loading capability