Reusable Cryogenic Tanks

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

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For
44th AIAA/ASME/ASCE/AHS/ASC Structure, Structural Dynamics, and Material Conference
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

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Heritage Rockwell SSTO

Frames (3)

Stringer Stiffened Skin

Integral Skirts (2)

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Boeing

3
As-Built Internal Details of Structure

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FRAME SPLIC

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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TPS
Adhesive
Cryo-Insulation
Adhesive
Gr/Ep Tank Wall

AFRSI Blanket
AETB Tile

TABI Blanket
FRSI Blanket
MSFC Cryogenic Structure Test Facility

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

- Vent Lines
- Fire Control
- MSFC-built Composite Intertank
- Hydraulic Struts for Axial Load
- Heritage Rockwell-built 8-ft Composite Tank
- Heater Arrays
- Control valves

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Phantom Works
Cyclic Test Plan and Accomplishments

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- 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
Visual Inspection Of Tank Interior After 5 Cycles

- 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

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- 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.

LH2 Cycle Test - 2BO47

2BI21 Burst

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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
Acoustic Emission Data

- 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

Sensor and installation in cryoinsulation

LH2 Cycle 1 AE data
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

Burst location at stringer 51

Expanding Nitrogen Cloud

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

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Composite Tank Wall

Edge of Break at Stringer 51

Cryoinsulation

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Tank Dissection for Post-test Analysis

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Post-test Evaluation

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- 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

Reusable Cryogenic Tanks

- 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