

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

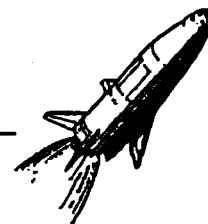
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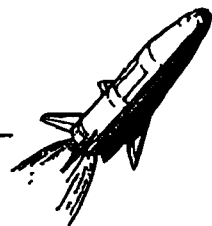
Outline

Reusable Cryogenic Tanks



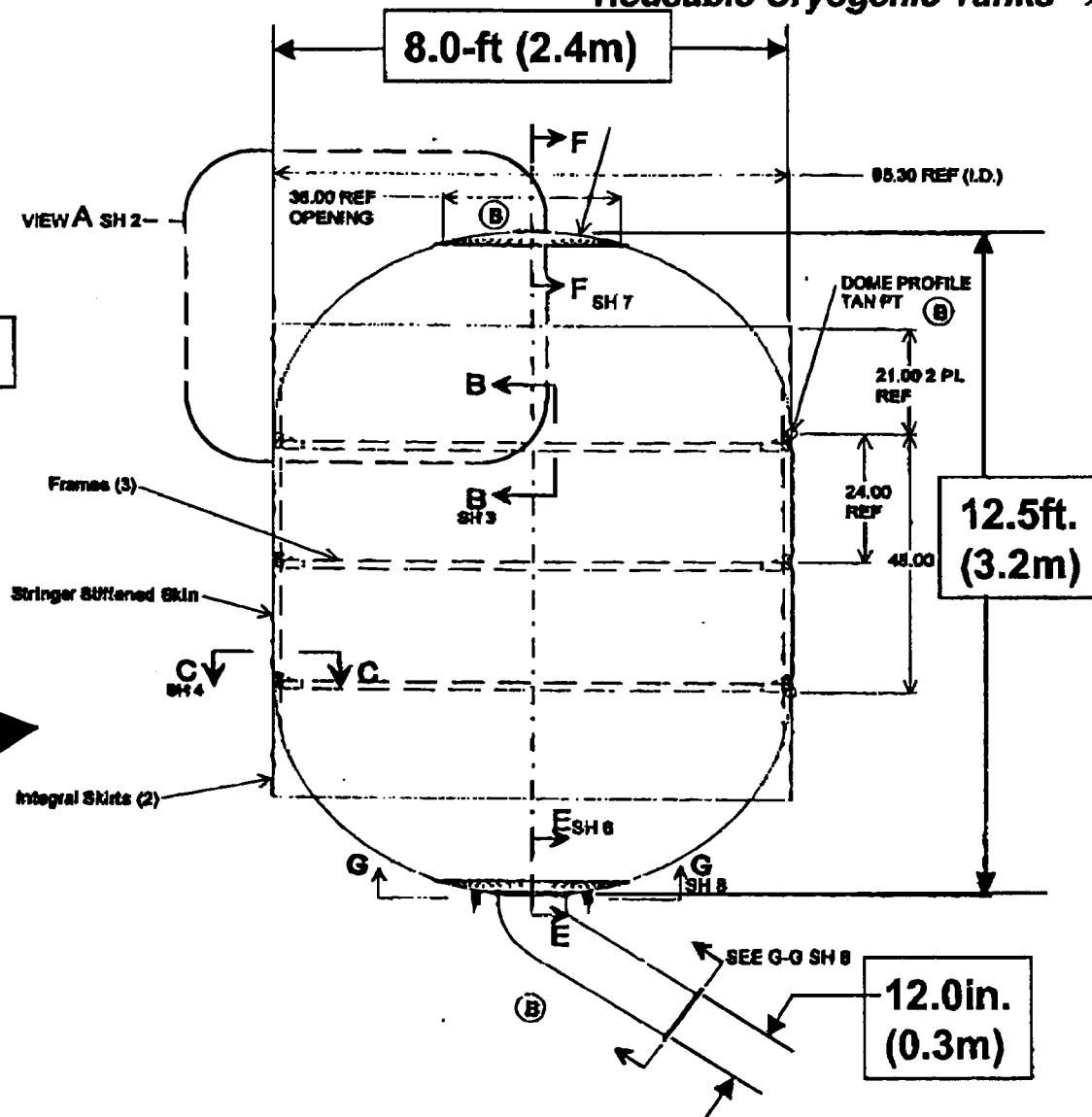
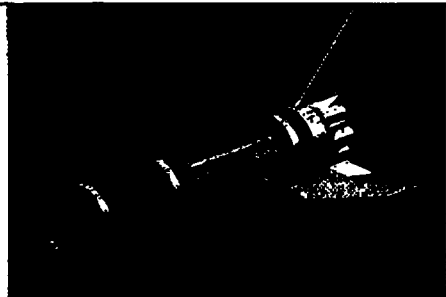
- **Tank Test Article**
- **MSFC Test Facility**
- **Test Plan**
- **LN2 Pre-test series**
- **LH2 Cyclic Test**
- **Repair**
- **Burst Test**
- **Post-Test Evaluation**

Tank Structural Configuration



Reusable Cryogenic Tanks

Heritage Rockwell SSTO



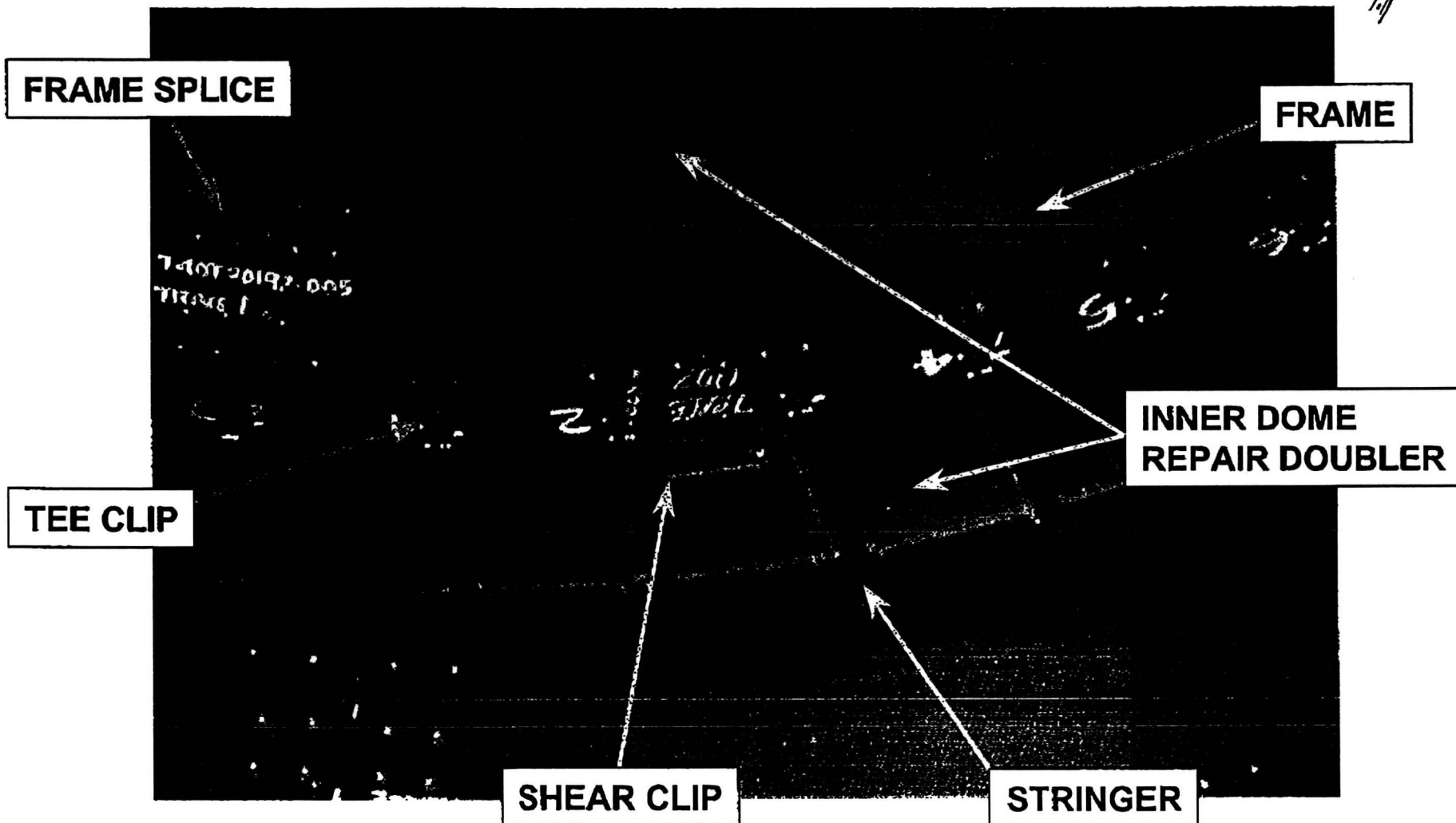
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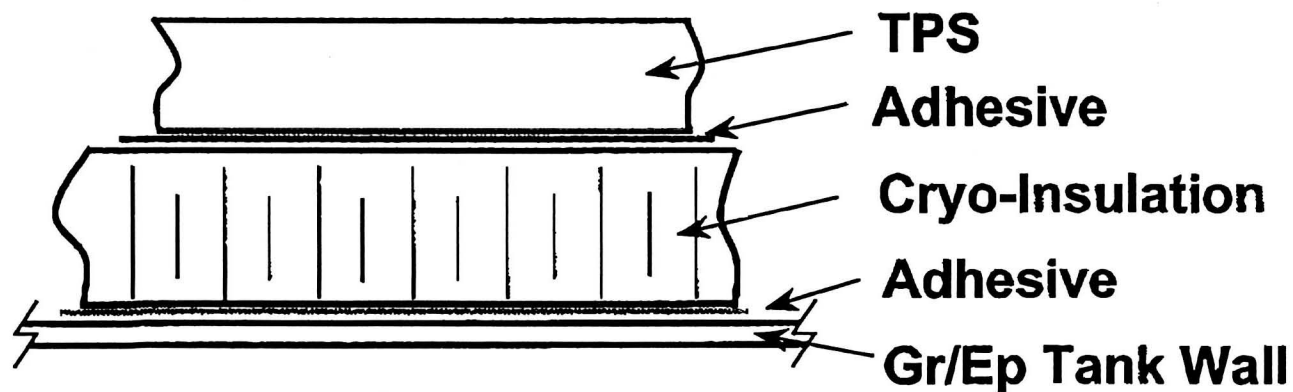
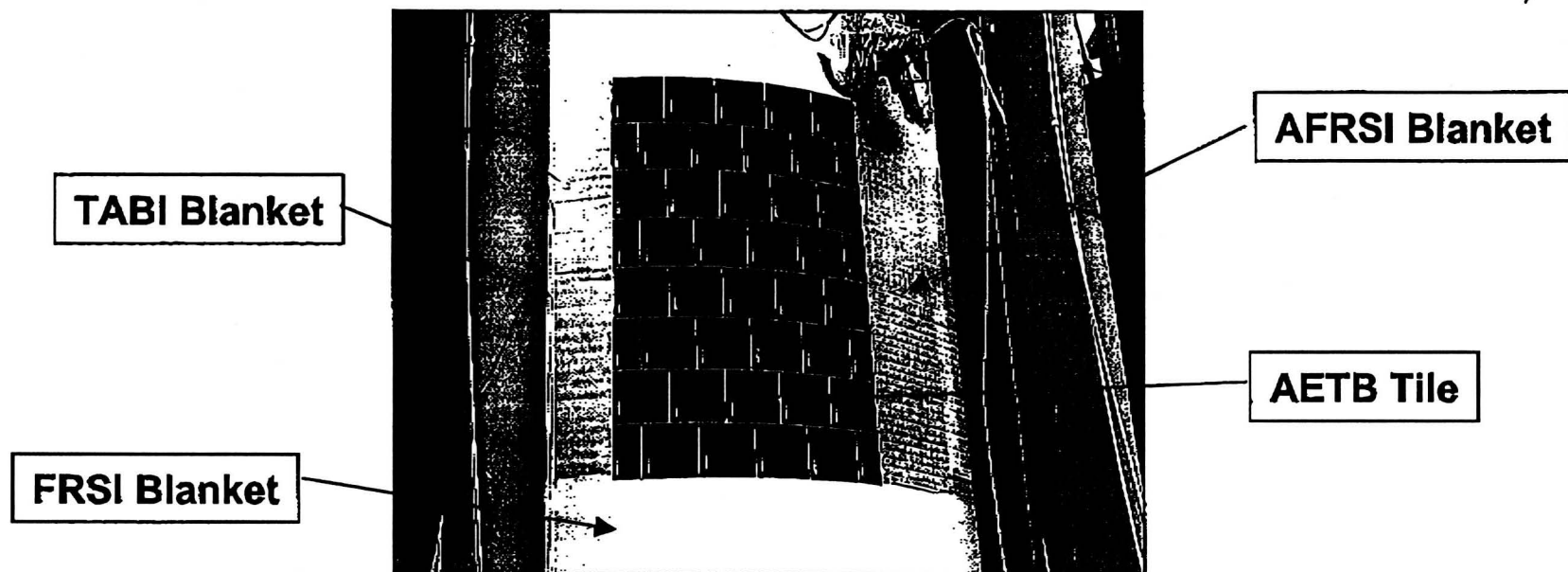
As-Built Internal Details of Structure

Reusable Cryogenic Tanks



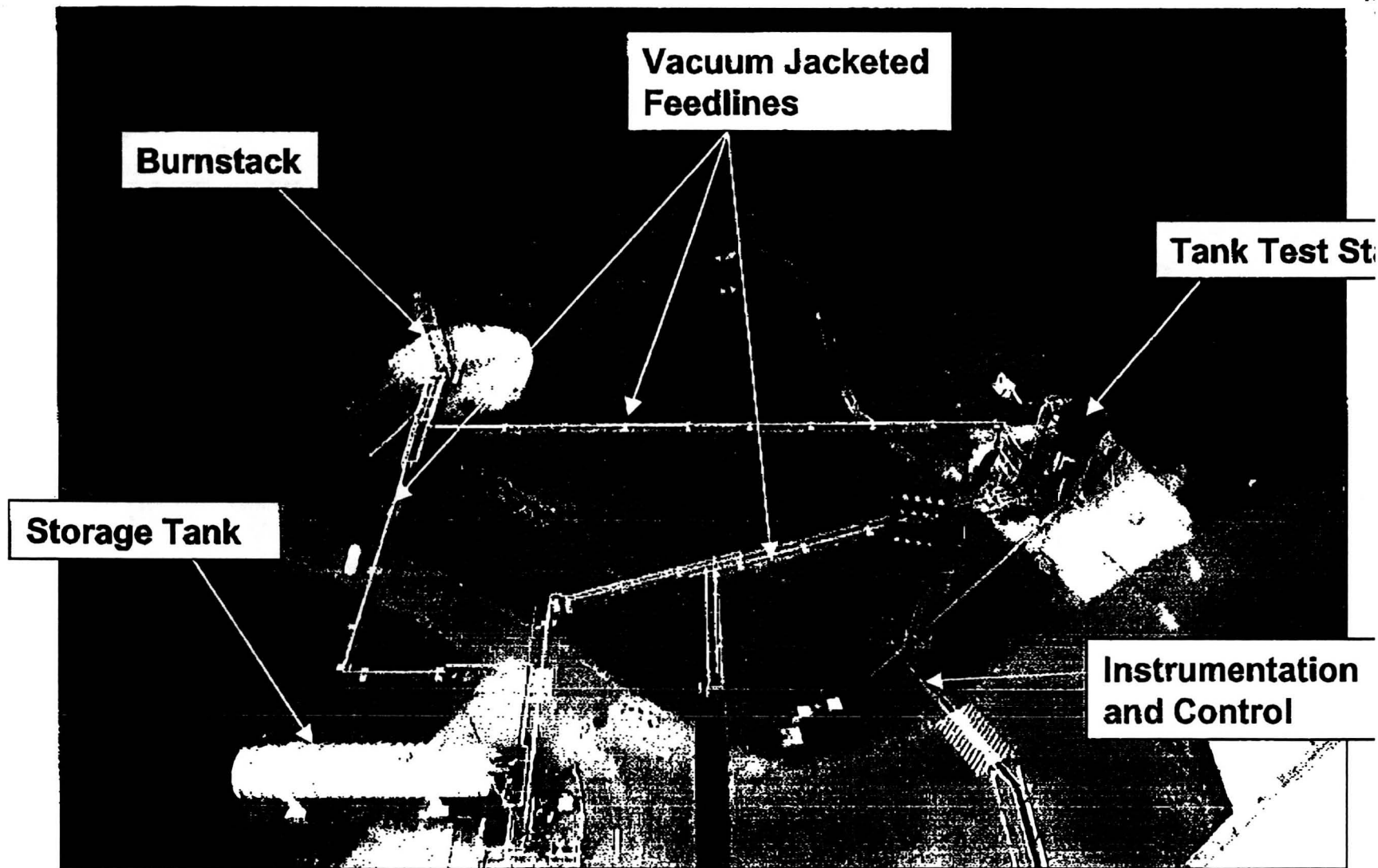
TPS Arrangement In Heated Area of Tank Wall

Reusable Cryogenic Tanks



MSFC Cryogenic Structure Test Facility

Reusable Cryogenic Tanks

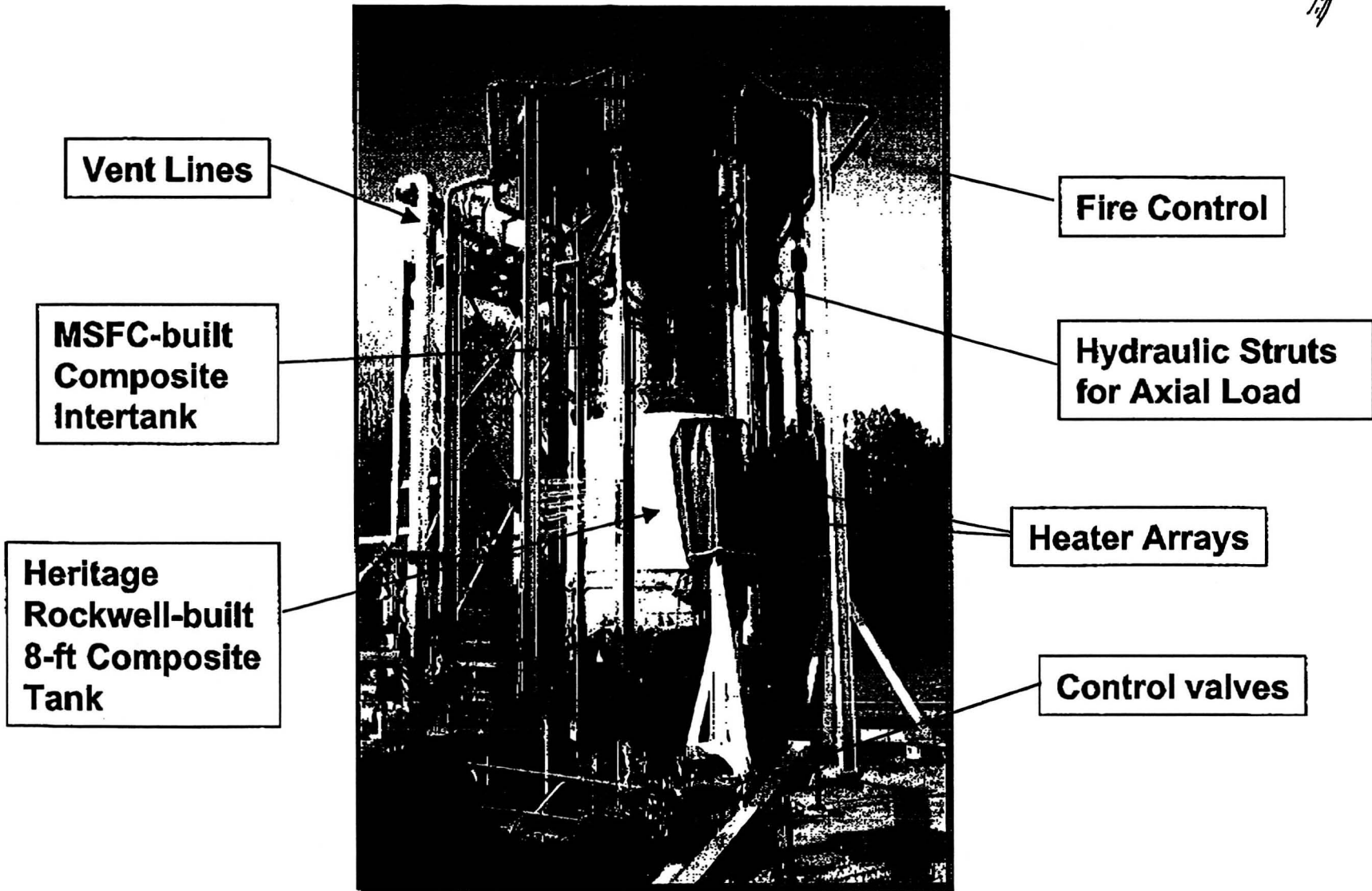
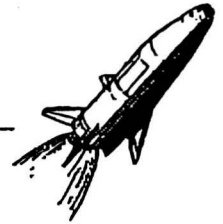


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8-ft Tank Test Setup

Reusable Cryogenic Tanks

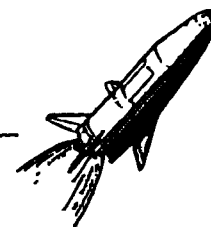


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Cyclic Test Plan and Accomplishments

Reusable Cryogenic Tanks



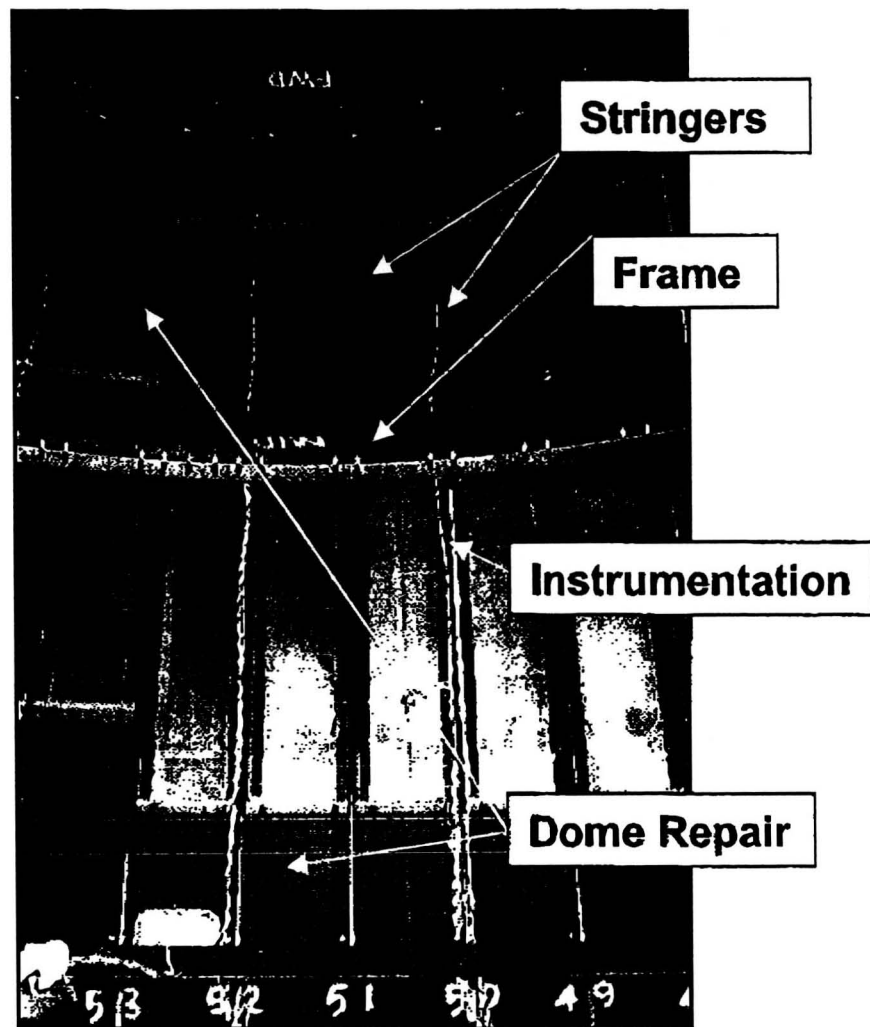
- **Eight LN2 Pre-tests completed**
 - **Cold shock**
 - **Proof pressure (LN2)**
 - **Ascent axial load**
 - **Landing axial load**
 - **10 simulated LN2 cycles**
- **26 of 200 LH2 Test cycles completed**
 - **Fill and pressurize to over 40 psi**
 - **Apply over 600 lb/in axial launch load**
 - **Reduce pressure and load**
 - **Apply heat to TPS surface (Entry)**
 - **Apply over 800 lb/in axial landing load**
 - **Repeat**

Visual Inspection Of Tank Interior After 5 Cycles

Reusable Cryogenic Tanks



- 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

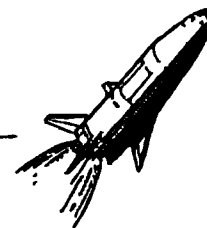


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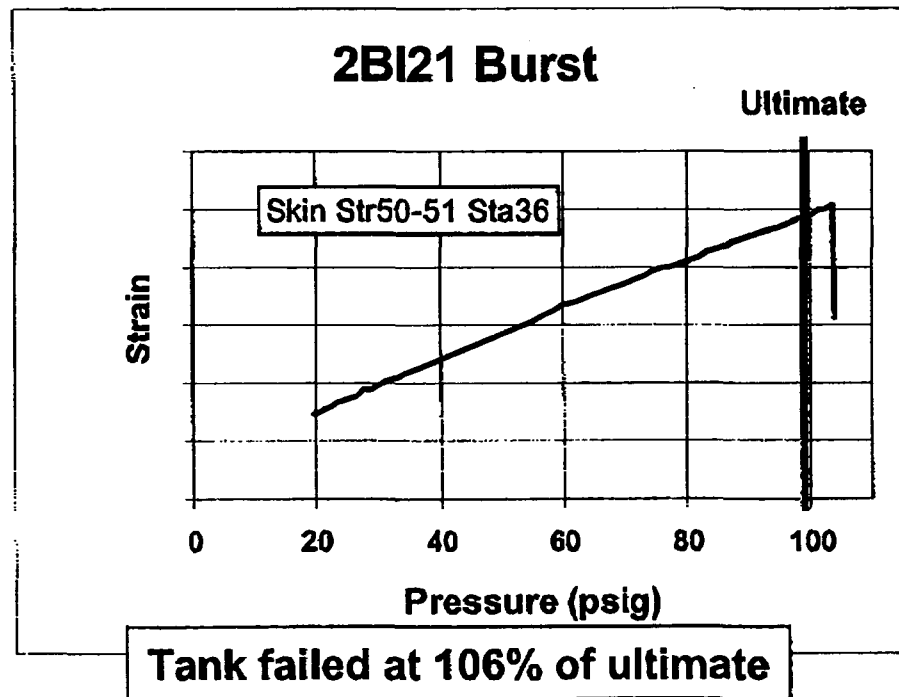
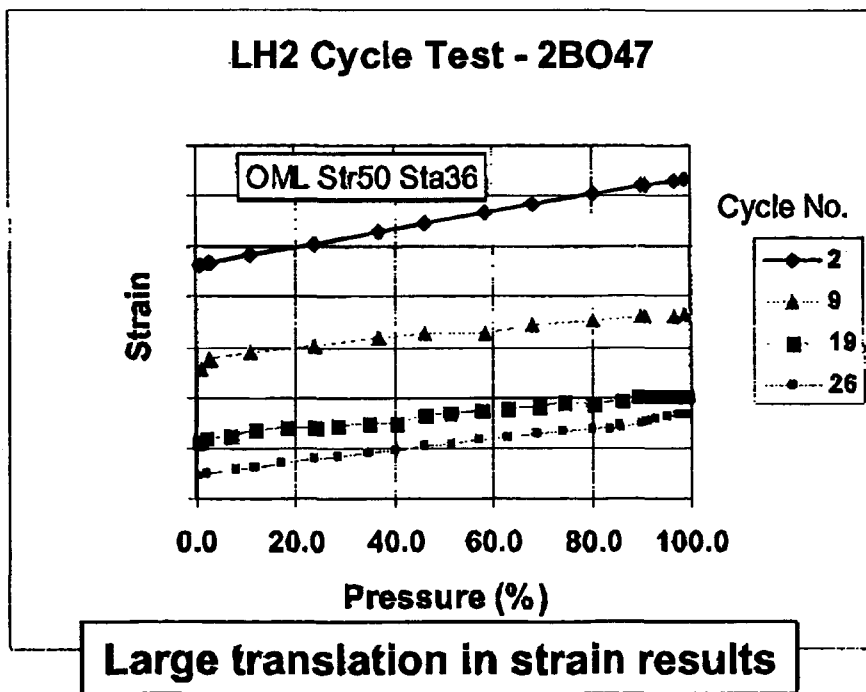
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Strain Data

Reusable Cryogenic Tanks

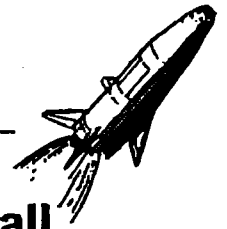


- Large translation of the strain data was observed from some gages but not others, but since the data was linear, the behavior was concluded to be a gage or calibration issue rather than a structural problem
- Only four gages survived through all 26 LH2 cycles and burst test

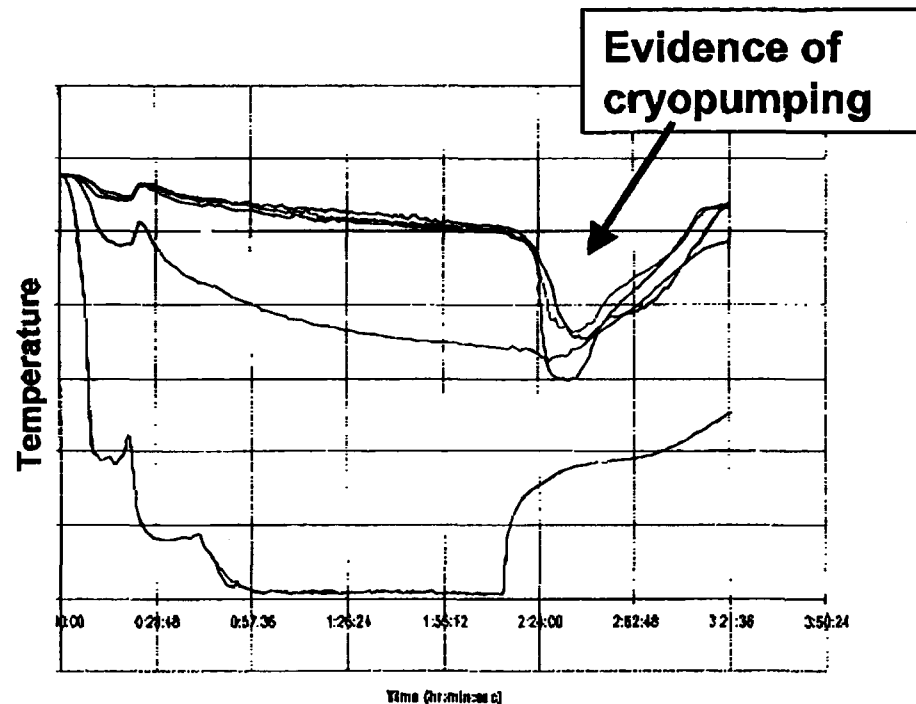
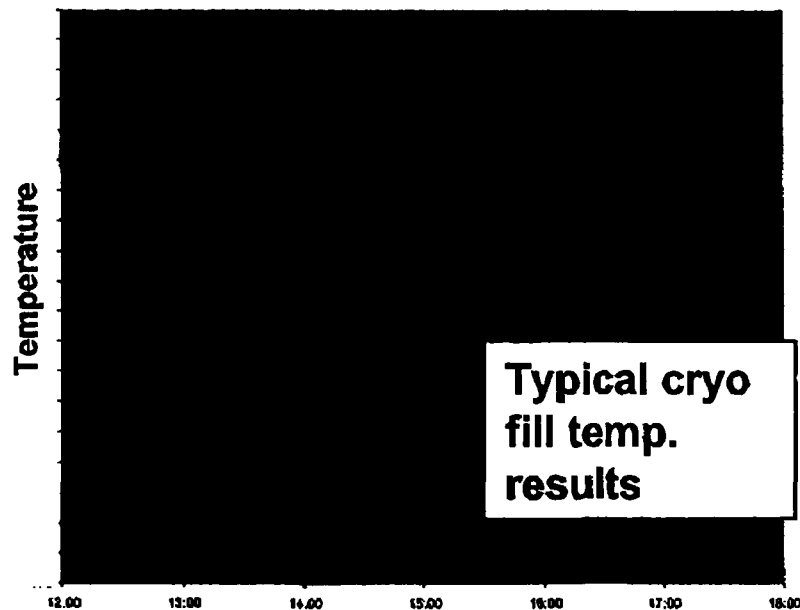


TPS Temperature Data

Reusable Cryogenic Tanks

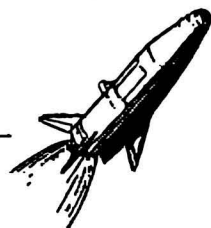


- Thermal data obtained on wall, within TPS, within insulation, and at all interfaces
- Adhesive bondline temperatures generally remained within established maximum and minimum limits
- Cryopumping, caused by liquid air evaporating away from the tank wall surface and blowing through the insulation, was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



Acoustic Emission Data

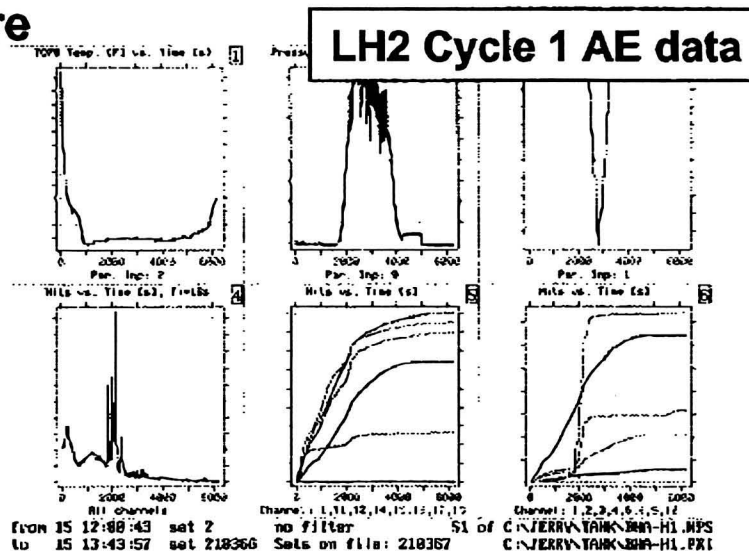
Reusable Cryogenic Tanks



- 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



Leak Detection and Repair

Reusable Cryogenic Tanks



Bubbles Indicate
Leak Location



Vacuum bag being removed
from external patch along
stringer 51.

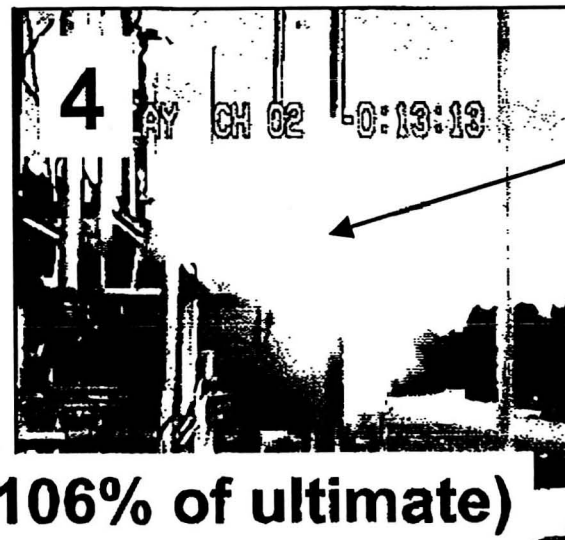
LN2 Pressure Load Burst Test

Reusable Cryogenic Tanks



TOTAL P.16

Burst
location at
stringer 51



Expanding
Nitrogen
Cloud

Burst occurred at 106% of ultimate)

Ultimate Load Test Failure Location

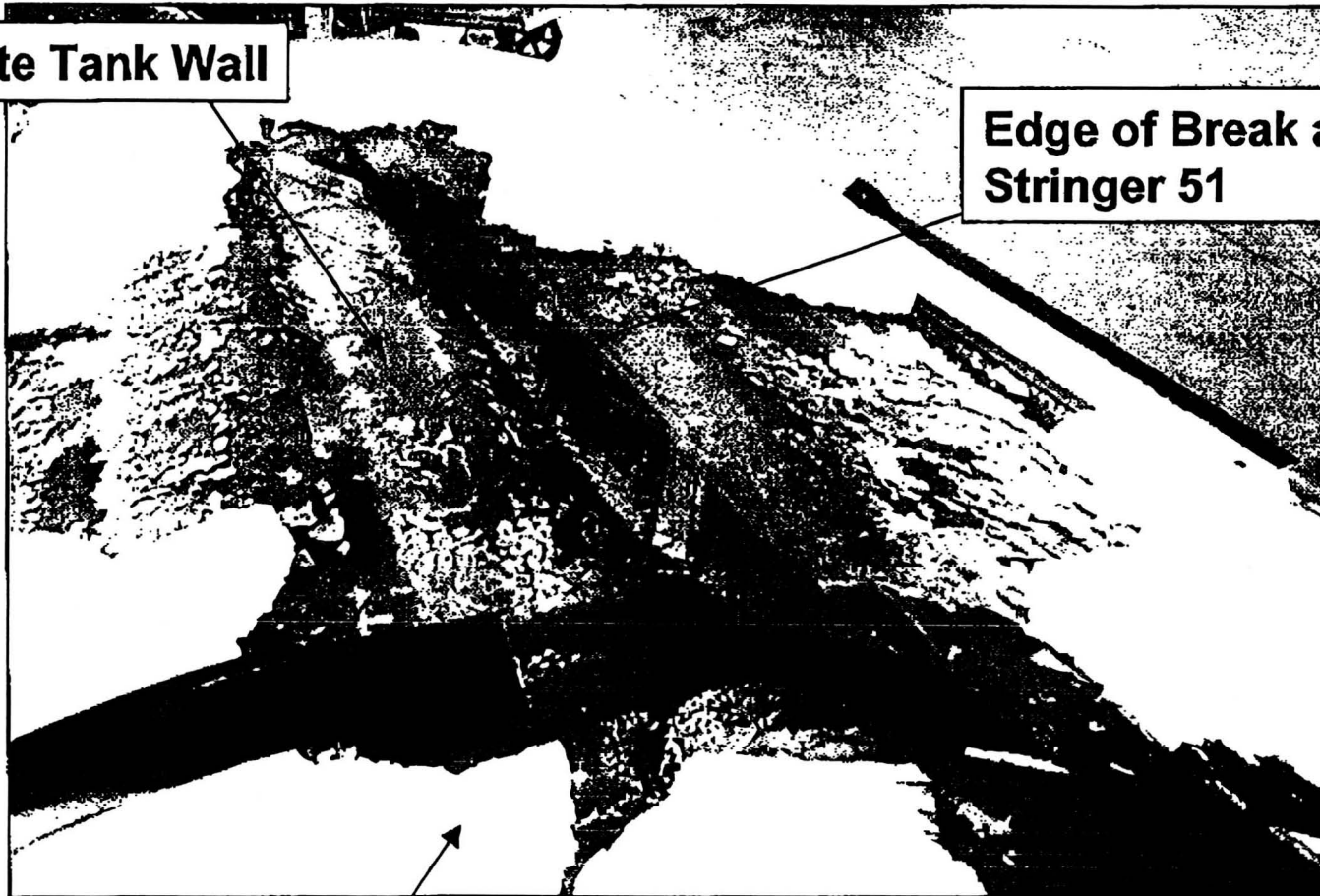
Reusable Cryogenic Tanks



TOTAL P.02

Composite Tank Wall

Edge of Break at
Stringer 51

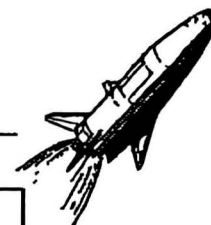


Cryoinsulation

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Tank Dissection for Post-test Analysis

Reusable Cryogenic Tanks



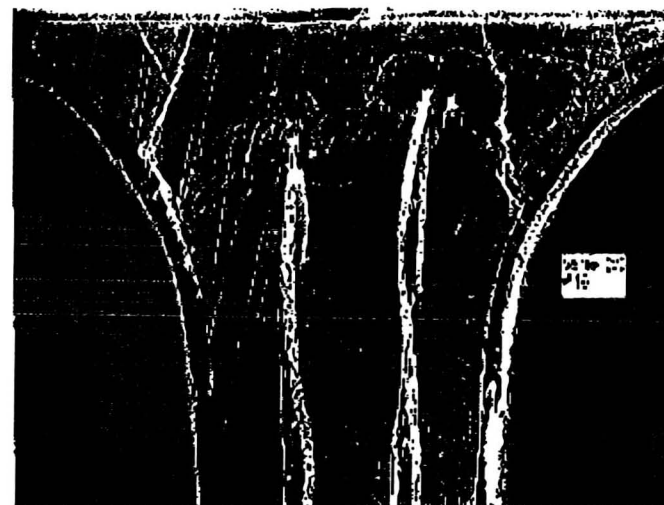
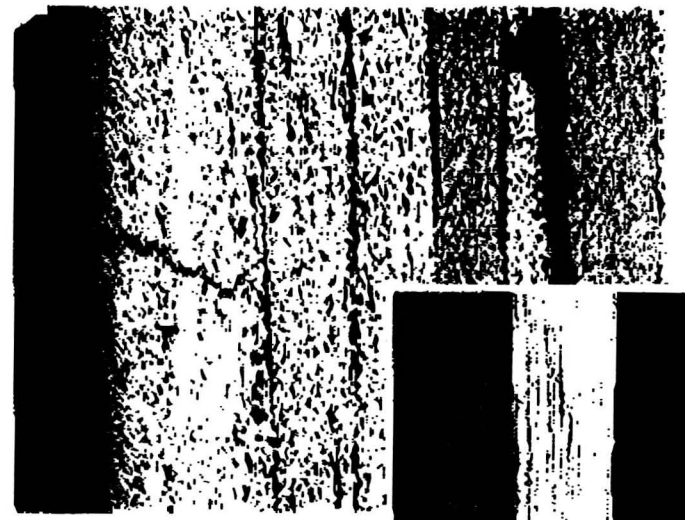
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Post-test Evaluation

Reusable Cryogenic Tanks



- 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)



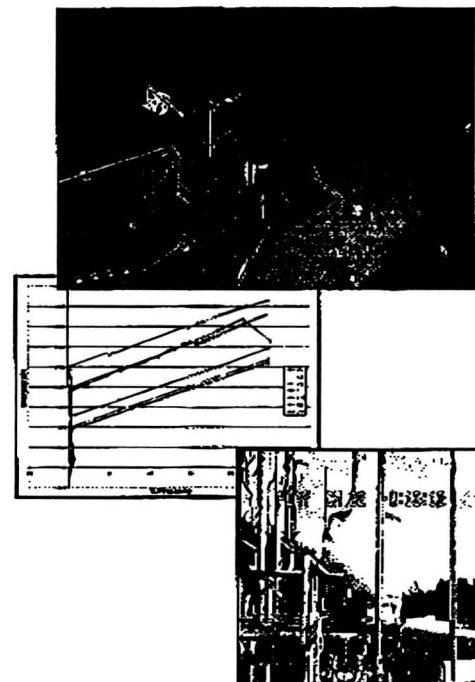
Conclusion and Recommendations

Reusable Cryogenic Tanks



TOTAL P.04

- 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*