Hydrogen and Storage Initiatives at the NASA JSC White Sands Test Facility

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Aerial View Looking North
Introduction

- WSTF Hydrogen Initiatives
- WSTF Storage Initiatives
- Hydrogen Group Contact Information
Hydrogen Initiatives

• NASA WSTF Hydrogen Activities
  – Aerospace Test
  – System Certification & Verification
  – Component, System, & Facility Hazard Assessment
  – Safety Training

• Technical Transfer
  – Development of Voluntary Consensus Standards and Practices
  – Support of National Hydrogen Infrastructure Development
Hydrogen Initiatives

• Research and Development
  – Combustion Hazard Characterization
  – Component Development
  – Safety Research
    • Gaseous Leaks & Detection
    • Liquid Hydrogen Spills
    • Electrolyzer/Fuel Cell Test Bed
Storage Initiatives

Composite Overwrapped Pressure Vessels (COPV)
  – Effects of Wear and Handling
  – Effects of Aging
• Standards Development
• Inspection Training
Aerospace Test

- Delta Clipper
- Hydrogen Tank Boiloff tests

DC-X Executes Vertical Landing at WSMR

Static Firing of DC-X with 4 LOX/Hydrogen RL10-A5 Engines
System Certification & Verification

- Shuttle Flow Control Valve
- Shuttle LHRP
- PRSA

View of 6000 PSIA Tube Storage Bank for Flow Control Valve

Power Reactant Storage Assembly
Combustion Hazard Characterization

- Flammability & Ignition
- Fire, Deflagration, & Detonation
- Blast & Explosion

Explosion of 50 lb. LOX/LH2 at High Energy Blast Facility

Tank Drop Test -- 75-ft-Dia Fireball from Explosion of 2,200 lb. LOX/LH2

1500 Gal LH2 Spill, 3 MPH Wind
Combustion Hazard Characterization

- Combustion Hazard Handbooks
  - Fuel Hand Book
  - Combustion White Paper

Insert Image of H-O Vertical Det tube

Hydrogen-Oxygen Ignition Test
with
Dry Catalyst, Small Particle
Component, System, Facility Hazard Assessment
Safety Training

- Hydrogen Safety Course [14 hrs]
- Operators Course [4 hrs]

WSTF Support of the NASA Safety Training Center
Development of Voluntary Consensus Standards & Technology Transfer

- Aerospace Hydrogen Consensus Standards Managed with AIAA

- Support Review of ISO Commercial Standards for Hydrogen Systems
  - ISO/TC 197 Hydrogen Technologies
  - Member of US Technical Advisory Group to ANSI
Development of Voluntary Consensus Standards & Technology Transfer

**Phase I**
- **Initiation**: NASA identifies WSTF as lead for transfer of specific standards to VC.

**Phase II**
- **Development**: NASA and VCOs agree to transfer, with WSTF participation in technology transfer activities.

**Phase III**
- **Completion**: VCOs establish and maintain worldwide VC standards.

- **Hazardous Fluids, Material, and Component R & D**
- **Hazards Analyses**
- **Safety Courses**
Support of National Hydrogen Infrastructure Development

- DOE National Hydrogen Infrastructure Assessment – Sandia Labs Livermore
  - Unintended Releases
  - Materials Compatibility
- DOE Safety Panel
- Peer Review of Papers

1.4 kg GH2 at 5000 PSI in COPV
Bonfire Test with No Pressure Relief
Composite Overwrapped Pressure Vessels (COPV)

• COPVs are high-strength, light-weight containers for storing fuels and pressure media.

• COPVs use a thin metal or non-metal liner over-wrapped with a high modulus fiber and cured with an epoxy matrix.
Detrimental Effects to COPV Strength

- Mechanical Damage - cut or broken fibers on surface or sub-surface.
- Manufacturing Defect - misaligned damaged tow, buckled liner, etc.
- Stress Rupture - catastrophic failure due to long term sustained loading.
Standards Development

- AIAA S-081A: Space Systems - Composite Overwrapped Pressure Vessels (COPVs)
  - Working group member
- NGV-2: Compressed Natural/Hydrogen Gas Vehicle (NGV/HGV) Fuel Containers
  - Technical advisory group member
COPV Visual Inspection Training

• Meets requirement in AIAA S-081A to have trained visual inspectors.
• Trains personnel to visually inspect the surface of composite pressure vessels (mainly carbon fiber) for indications of mechanical damage. The 2-day course also explains the importance of positively identifying mechanical damage by the use of secondary NDE techniques.
Cycle/Burst COPV

- Hydraulic Cycle Testing Up to 15K PSI
- Hydraulic Burst Testing of a Kevlar COPV
- High and Low Flow Rates at Various Volumes
- Axial Displacement, Strain Measurement (Conventional and Fiber Optic Bragg Grating), Load Measurement, Acoustic Emissions, Eddy Current, and Digital Image Correlation
Stress Rupture

• Long-term, High-stress Sustained Load Testing
• Numerous Fiber Systems on Experimental Test Bottles
• Dampened Pressure Systems Up to 6K PSI
• Ambient Temperature to -40 °F
CO
PV An
alysi
s and T
est V
erifi
cation

• Integrated Composite and Structural Analysis (GENOA-PFA)
• Allows Complex Composite Ply Definition
• Filament Winding Routines for Overwrapped Vessels
  – Cylindrical
  – Spherical
• Verified Via Test and Evaluation (ASTM, WSTF, …)
• Combined Macro and Micromechanics Code
Numerical Analysis of Complex Composite Structures

- Nonlinear Static & Dynamic
- Creep
- Low and High Cycle Fatigue
- Impact Simulation
- Progressive Failure Analysis
  - Damage Tracking
  - Failure Mechanisms
Global and Local Analysis

Figure 1.0.1-1. GENOA, Parallel Processing Software For Structural Analysis of Polymer Matrix Composite, Exploits Hierarchical Multi-Level on Macro and Micro Scales
Fracture Pattern Processing to Structural Failure (Equilibrium Solution)

- Longitudinal Tensile Failure Pattern (Fiber Breaks)
- 7720 psi
- Model ’11’
- Ply 3 next to liner
- Damage progression out towards surfaces

Stress at Cycle 212 (5980 psi)

Non-Equilibrium Solution of Failure of Structure
Damage Evolution: Final fracture at 61.5 Mpa
(Design Burst Pressure = 62 Mpa) (AlphaSTAR)

Failure Mechanisms

Damage Initiation
Damage Propagation
Final Fracture = 11,200 Psi
Facilities and Resources

• Expertise
  – Resource for Proper Hydrogen Practice
  – Systems Hazard Analysis
  – Hydrogen Safety Training
  – Standards Development
  – Multidisciplinary Force

• Facility Resources
  – Material Test
  – Cleanroom
  – Chemical Analysis
  – System & Component Testing (concrete test cells (800 area))
  – High Energy Blast Facility (<2000 lbs TNT eq. 700 area)
  – Liquid & Gaseous Hydrogen Supply (250 area)
Hydrogen Group Contact Information

NASA Program

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Contractor Support

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