Altitude Testing of Large Liquid Propellant Engines

For

The 26th AIAA Aerodynamic Measurement Technology and Ground Testing Conference

Development of Test Facilities Session

Presenters
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New Exploration Objectives

- Provided by J2-X Program Elements at MSFC
- Re-analyze Altitude Capability for J2-X
- RPTMB provided further guidance in AR 2006-MB-0351-1 in Feb 2006 for A1-b concept
- Low Cost/Low Risk Alternative to Altitude Testing
  - Exploits Existing/Proven Commercially Available Industrial Systems
  - Exploits Existing/Proven Design and Analysis Expertise (JE and SSC)
  - Exploits Existing/Proven A-1 Test Facility Infrastructure
    - Propellant Run Systems
    - Propellant Storage and Transfer Systems
    - Data Acquisition, Control, and Instrumentation Systems
    - Structures
    - TMS
    - Engine Specific Systems, Interfaces, Avionics, Assembly, and Maintenance
  - Exploits Existing/Proven (and Recent) SSC Test Team Experience
    - Experience Testing Complex LOX/LH2 Engines (e.g., SSME, RS-68, Aerospike)
    - Diffuser Test Operations Experience
  - Design Modularity Enables Optimization/Tailoring to Test Requirements and Program Resources
  - Enables Anytime/Interference-Free Testing
  - Enables Synergistic Sea-Level and Altitude Testing to Single Location

Vacuum Performance Requirements Impact

- Low Risk/Cost
- Medium Risk/Cost
- High Risk/Cost
- Low Risk/Medium-High Cost

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A3 Test Stand

Test Cell

Diffuser / Ejector System

Steam Discharge to Atmosphere

300 ft
A-3 Test Stand 3-D Layout

Diffuser and Exhaust Train

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A-3 Test Stand 3-D Layout
1st Stage Steam Ejector

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A-3 Test Stand 3-D Layout

Cooling Water
A-3 Test Stand 3-D Layout
Diffuser, Cooling Water and Ejectors
A-3 Test Stand 3-D Layout

Elevator
A-3 Test Stand 3-D Layout

Engine Work Deck
A-3 Test Stand 3-D Layout
Test Cell and Thrust Takeout
• 80,000 gallon LH tank
• 35,000 gallon LOX tank
• Volume includes:
  – 10% ullage
  – Test duration: 350 seconds
  – 10% remaining in heel of run tank
• Volume included:
  – Chill down of run line
  – Fill run line
  – Chill test article
• Tank will be topped off from the barge after chilling and filling
• Preferred option because of single tank and limitation of tank height
• Additional Run Time will accomplished through in-test propellant transfer.
A-3 Test Stand 3-D Layout
Engine Deck and Superstructure

LH2 RUN TANK
LOX RUN TANK
RUN LINES
ACCESS STAIRS TO RUN TANKS AND CRANE
1st STAGE EJECTOR
ACCESS STAIRS TO TEST LEVEL
DERRICK CRANE
TMS SUPPORT STRUCTURE
TEST CELL DOOR
ENGINE HANDLING CART
TEST CELL SUPPORT STRUCTURE
ELEVATOR

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A-3 Test Stand 3-D Layout
Structure and Altitude Support Systems

SUPER STRUCTURE
STAIRS TO RUN TANKS AND CRANE
BLOCK OFF VALVE
1st STAGE EJECTOR
ELEVATOR
2nd STAGE EJECTOR
CHEMICAL STEAM GENERATORS
DIFFUSER

TEST CELL
TEST LEVEL
STAIRS TO TEST LEVEL
TOWER STRUCTURE
DIFFUSER COOLING WATER SUPPLY
FOUNDATION

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Steam System

- A-3 Steam System Schematic Diagram

First Stage Ejector
540 PPS, 300 psig

2nd Stage Ejector
4320 PPS, 300 psig

Typical 3-unit CSG Module Output:
540 PPS @ 300 psig

Steam Supply

LOX Feed 700 psig
IPA Feed 700 psig
Water Feed 700 psig

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Chemical Steam Generators

- Igniter Assembly
- Water Inlet
- LOX Feed
- Alcohol Feed
- Water Inlet

- Steam Generator Assemblies
- Steam Supply Header
- Water Cooling and Injection Spray Tubes
- Steam Outlet
Steam Generation System

AX Steam System Propellant Feed/Storage requirements

LOX: 89,609 gallons
  - IPA: 62,478 gallons
  - H2O: 277,670 gallons
Steam Ejectors

1st Stage Ejector: Conical Nozzles, 460 PPS

2nd Stage Ejector: Flat-Plate, 4380 PPS
Sliding Gate Valve

- Adverse pressure waves, differential pressures across the nozzle, and steam on hot engine components can be avoided with a valve in the diffuser upstream of the 1st stage ejector.

- A sliding gate valve in the diffuser would be closed after test to prevent shutdown effects from reaching the engine.

- This valve would negate the option of using a high flow rate GN purge in the test cell.
Test Cell Support Structure (Yellow)
Columns (Not Shown) carry load to ground

Gate Valve Assembly
For
Future Vacuum/Soak Testing

Cooling Water Supply Piping
to Exhaust Diffuser
and Test Cell

Work Platforms
for Gate Valve and
1st Stage Ejector
Test Cell Configuration

- 40’ diameter cylindrical shell
- Ellipsoidal head
- Inverted conical floor
- Raised floor with embedded cart rails
- Main hatch: Vertical translation of a flat door
- Cylindrical shell used to support the TTOS/TMS
Thrust Measurement System

- TMS structural assembly consists of the ground frame and live bed.
  - Capable of 740K lbf axial thrust
- TMS Calibration System
  - 350K lbf in y – axis
  - 31K lbf in x- and z- axes
- TMS Measurement System
  - Total Measurement Uncertainty:
    - 0.25% along vertical axis
    - 0.85% along lateral axis
- TMS Hydraulic Pump Skid located near the Test Cell under a covered area.
Thrust Takeout Structure

- Upper surface of the TMS ground frame is supported by the TTOS.
- TTOS designed for 600K lbf static vertical thrust / 900K lbf dynamic vertical thrust.
- Stiffness of the TTOS shall be, as a minimum, .005” deflection at 600,000 lbs vertical & .005” deflection at 125,000 lbs lateral.
- Holes for attaching TMS structural assembly to TTOS drilled per TMS bolt hole template (TMS Vendor).
- TMS/TTOS installation requires simultaneous lift after attaching both pieces together.
- Bolted to Test Cell Wall: Remove for future stage testing.
Diffuser Capture Duct

- The portion of the diffuser extending inside of the test cell must accommodate pre-test and post-test operations including engine installation.
- The top of the diffuser shall extend above the bottom of the nozzle extension – This allows a smaller diffuser diameter and lower steam flow requirements than if the diffuser was shorter.
- The diffuser must be split into at least two pieces to retract without striking the nozzle extension.
- Accommodate high heat flux 170 Btu/ft^2 sec.
A-3 Risk Mitigation – Subscale Diffuser

Background
- A-3 Test Facility risk mitigation are efforts funded via a technical task agreement with MSFC.
- E3 Test Facility Cell 1 for subscale diffuser testing
- E3 Test Facility Cell 2 for DTF-type thruster (STE) characterization tests as well as steam generation activities

Summary of Task Objectives
Characterize the performance of the subscale diffuser at ~6% scale and obtain data to support design and analysis efforts for the A-3 test facility.

Phase I – DTF Firing (completed 9/24/2007)
- Successfully ignite the DTF thruster at sea-level and shut down safely (Cell 2)
- Verify repeatability of startup
- Provide performance data regarding the operation

Phase II – Steam Generation (completed 12/12/2007)
- Ignite and characterize steam combustor (modified thruster)
- Integrate steam combustor with water injector system

Phase III – Subscale Diffuser Performance
- Ignite and characterize J-2x simulator (modified thruster) at sea-level (1/8/2008)
- Integrate subscale diffuser and steam generator and characterize (12/13/2008)
- Perform J-2x simulator altitude hotfire tests with subscale diffuser (1/11-18/2008)
- Completed 01/18/08
Rocket Diffuser Design

- Rocket Diffuser (size reduced by using clamshell style capture duct and moving diffuser inlet lip above the NEP)
Pictorial History

August

August

September

January

December

November

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Summary

• Altitude Testing of the J2-X engine at 100,000 feet (start capability)
• Chemical Steam Generation for providing vacuum
• Project Started Mar’ 07
• Test Stand Activation around Late 2010
• J-2X Testing around early 2011