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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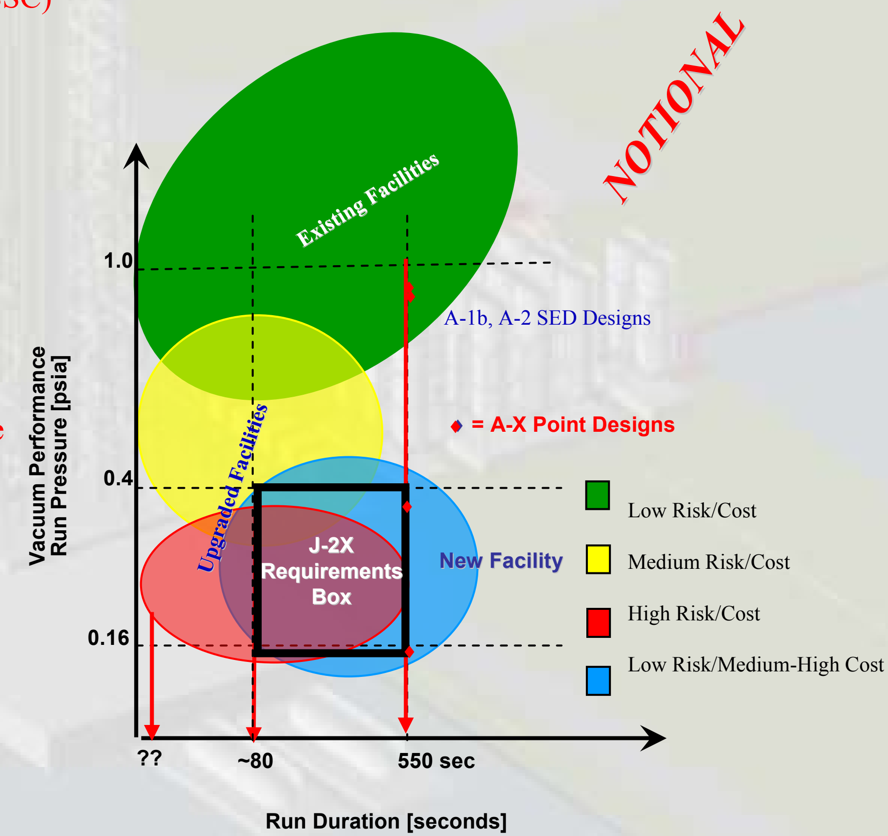
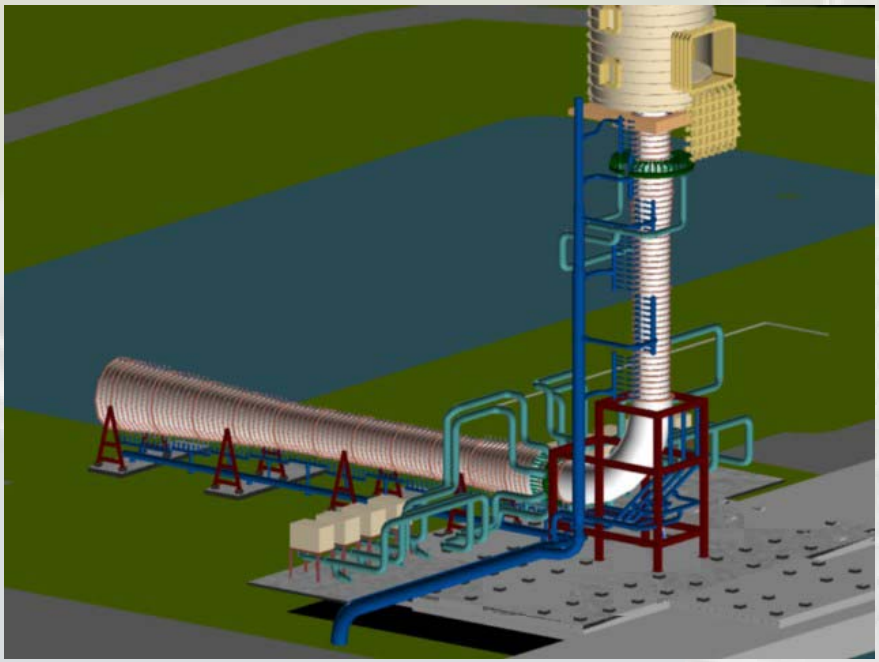
New Exploration Objectives

- **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 at a Single Location

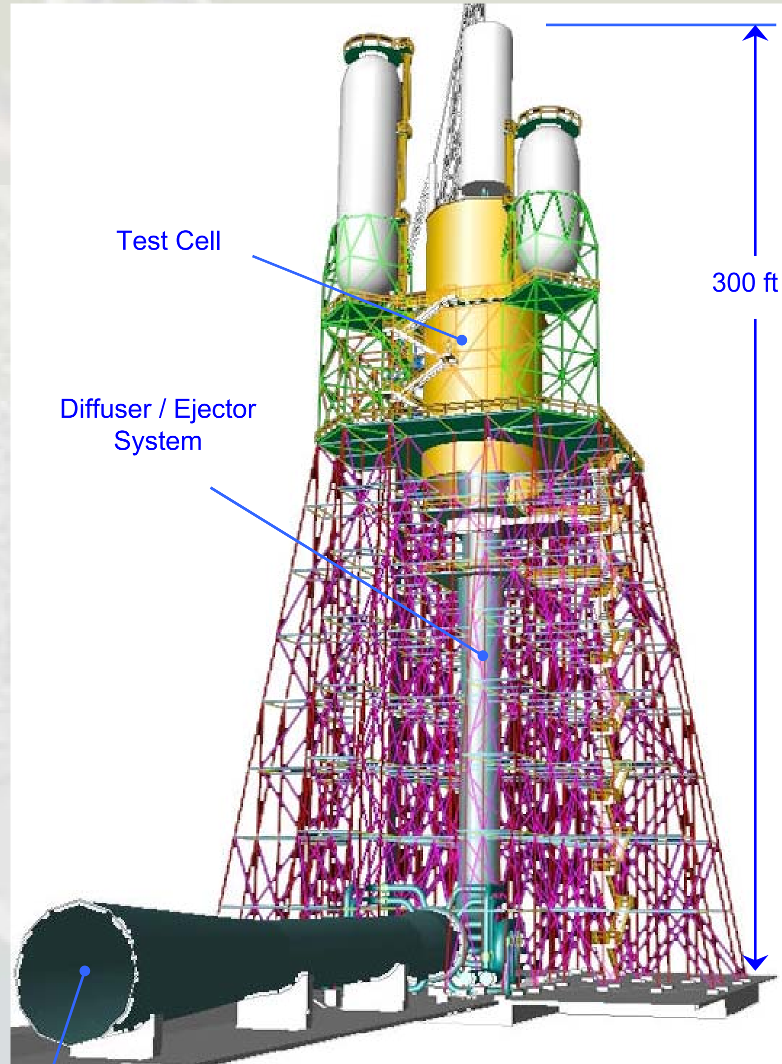
Vacuum Performance Requirements Impact



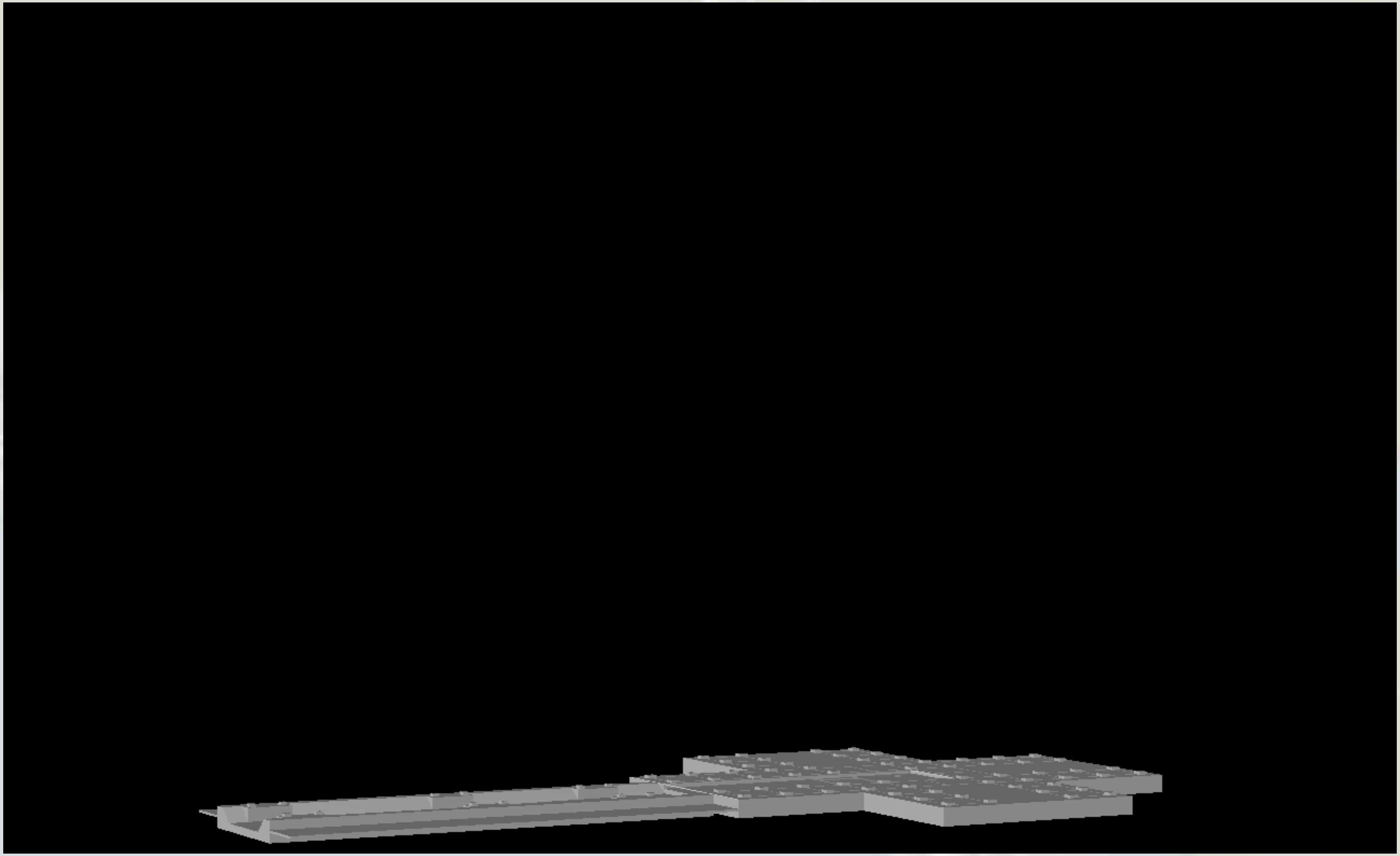
A3 Test Stand



A3 Test Stand

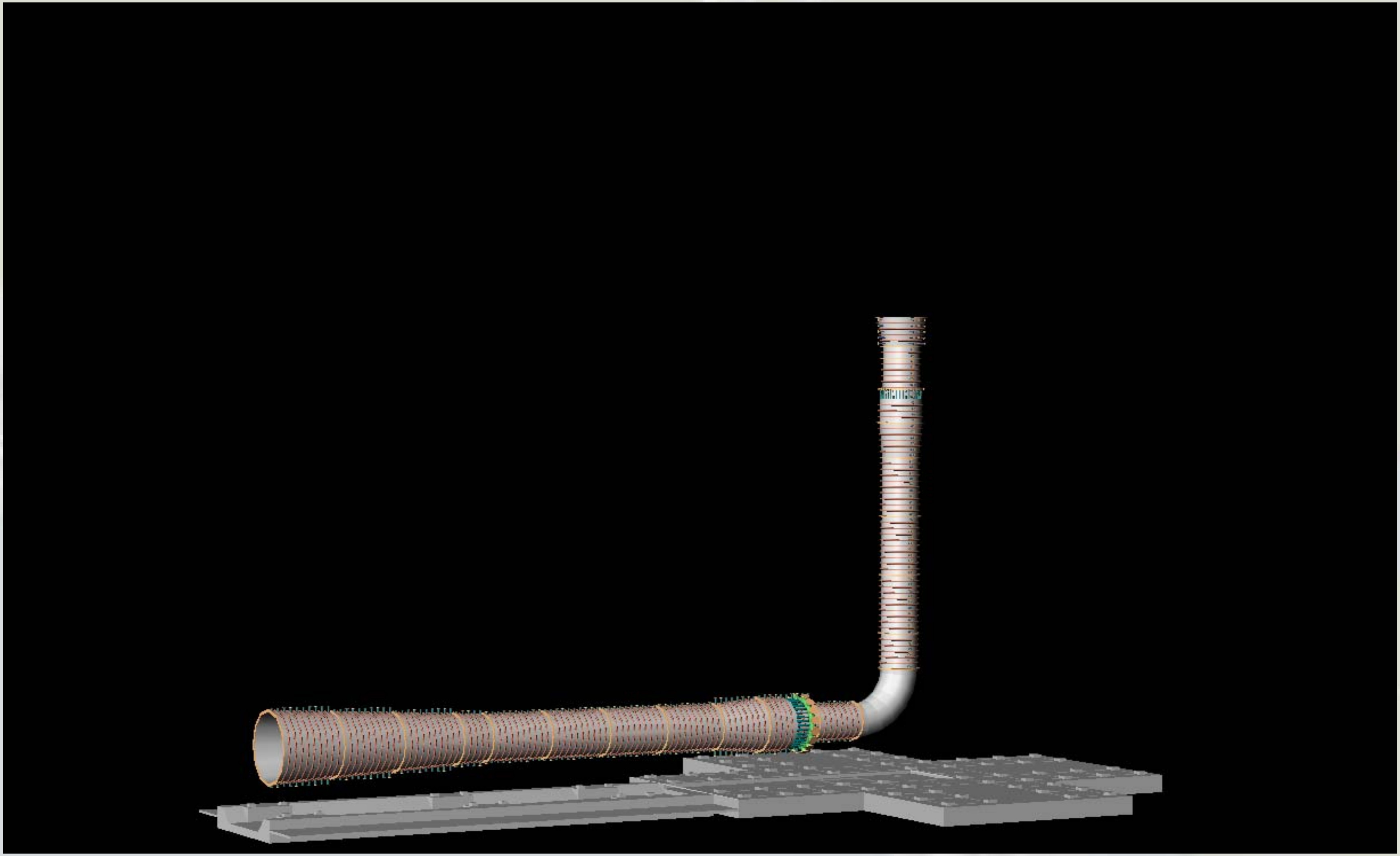


A-3 Test Stand 3-D Layout
Foundation



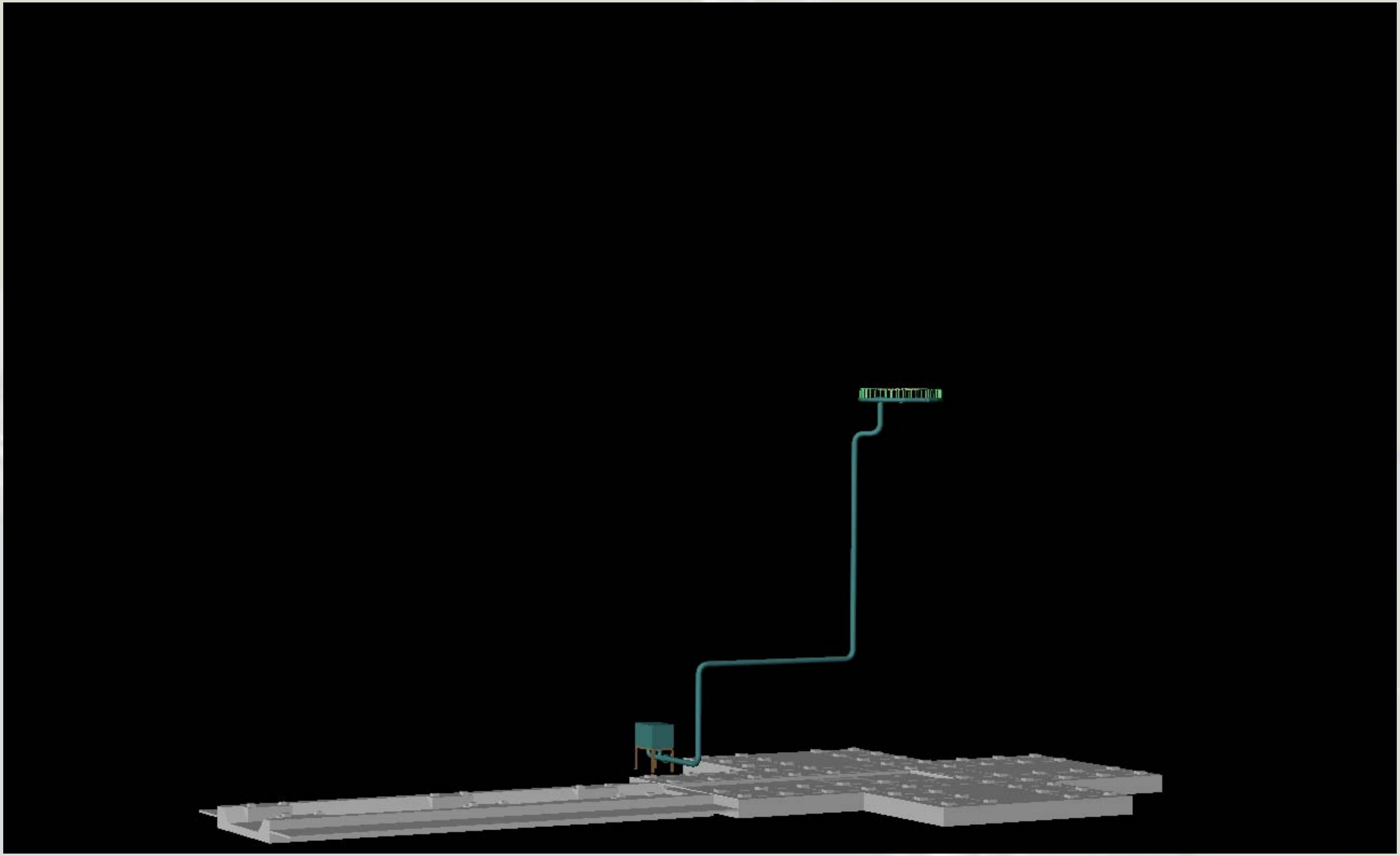
A-3 Test Stand 3-D Layout

Diffuser and Exhaust Train



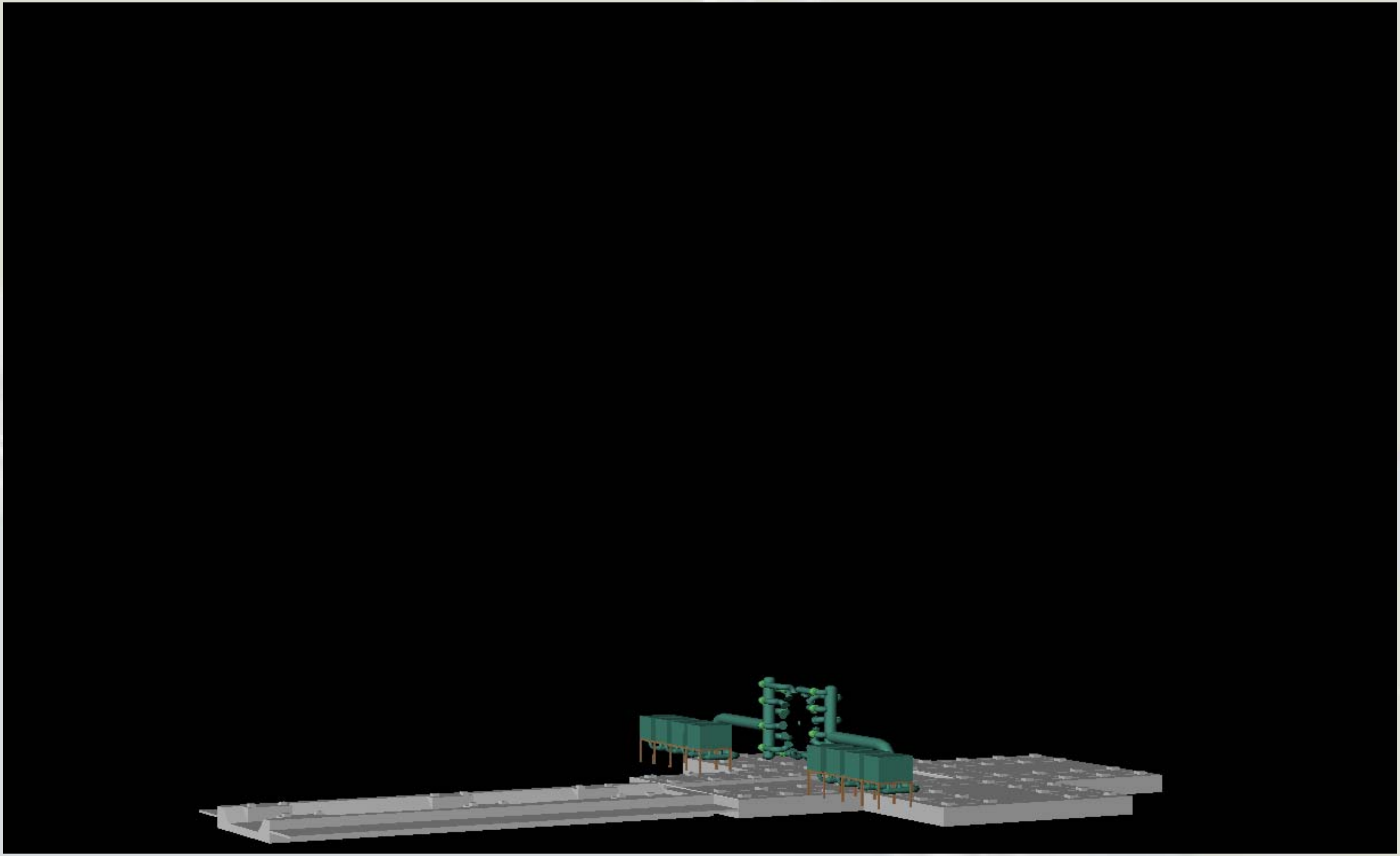
A-3 Test Stand 3-D Layout

1st Stage Steam Ejector



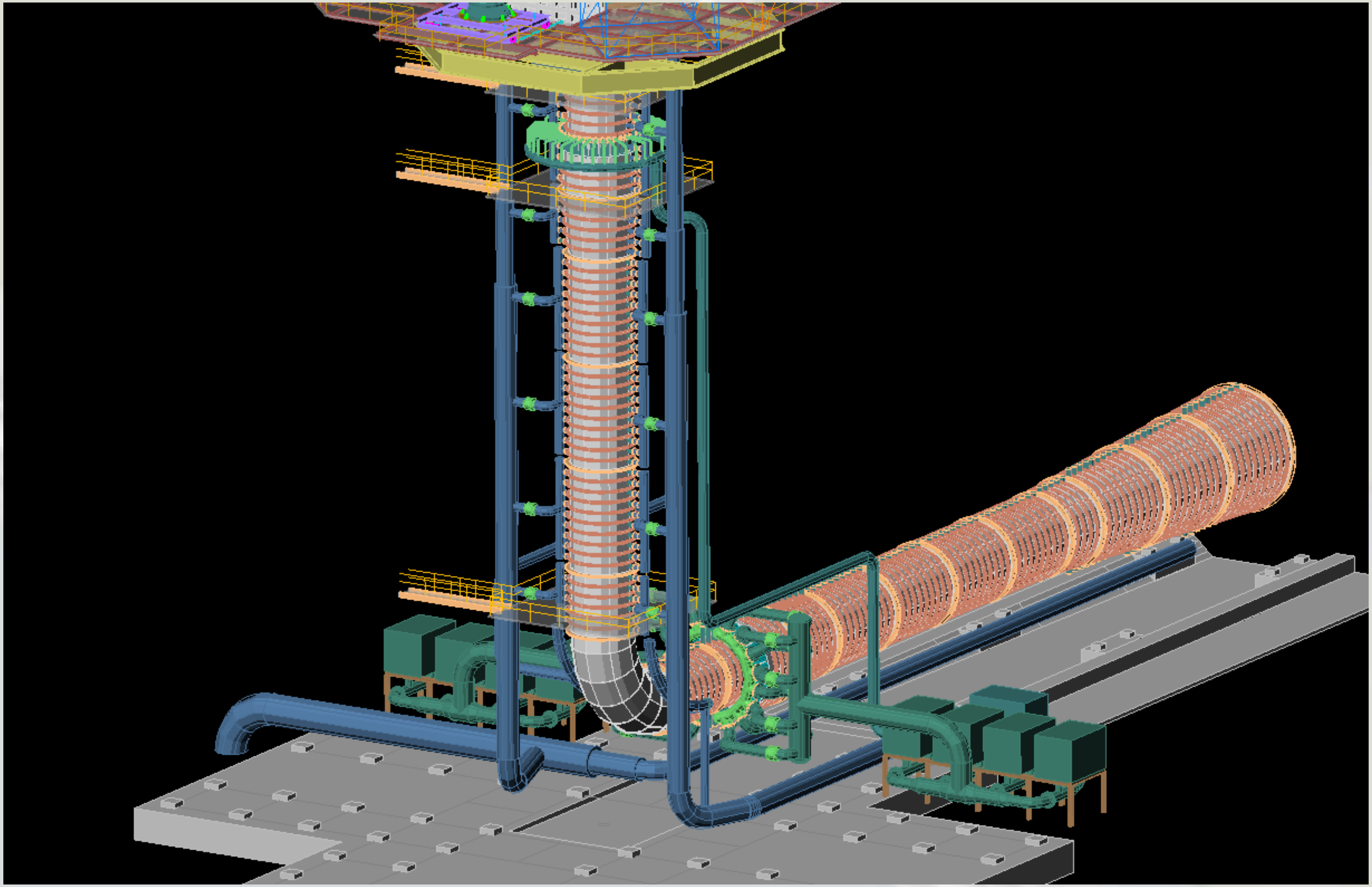
A-3 Test Stand 3-D Layout

2nd Stage Steam Ejector



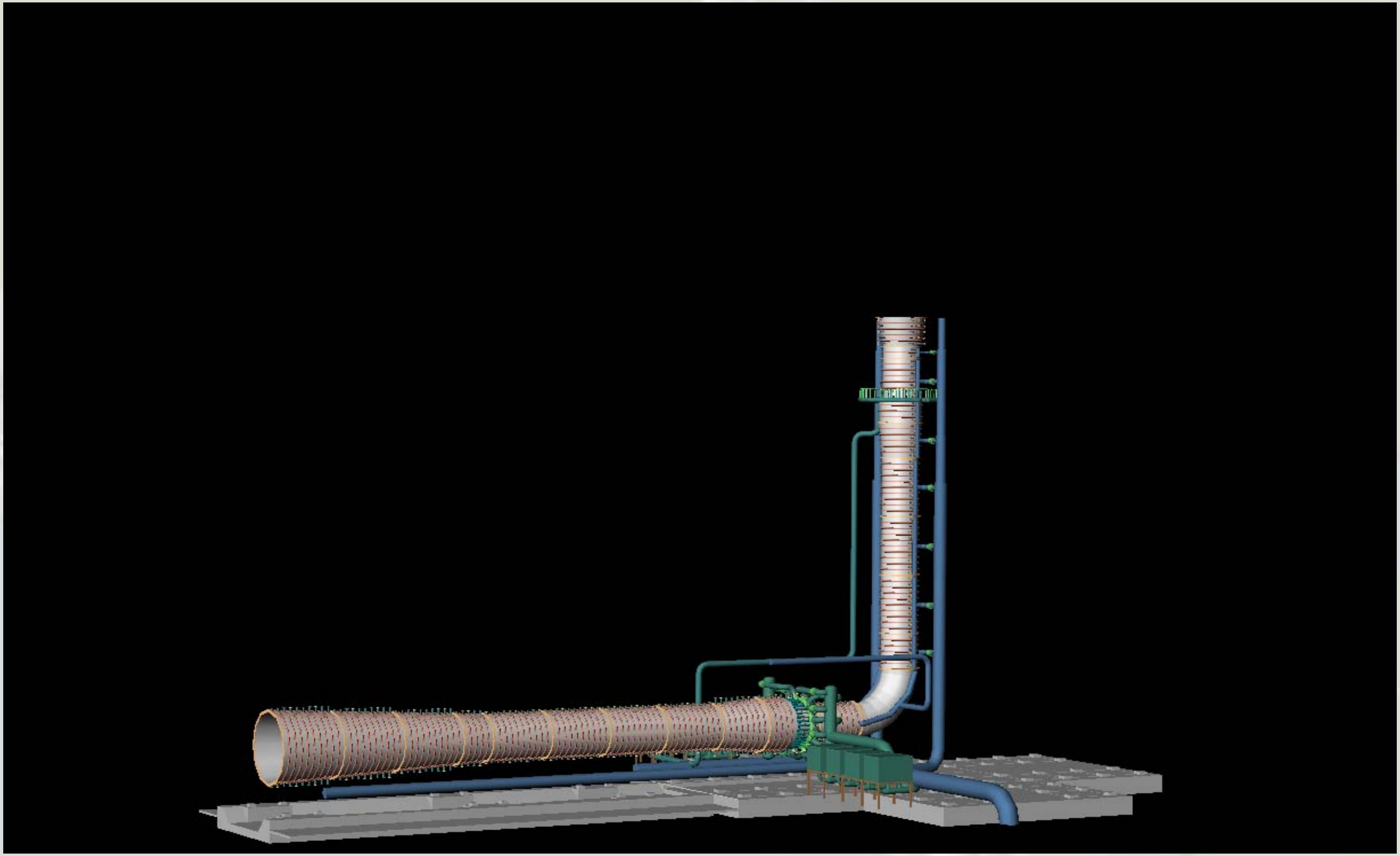
A-3 Test Stand 3-D Layout

Cooling Water



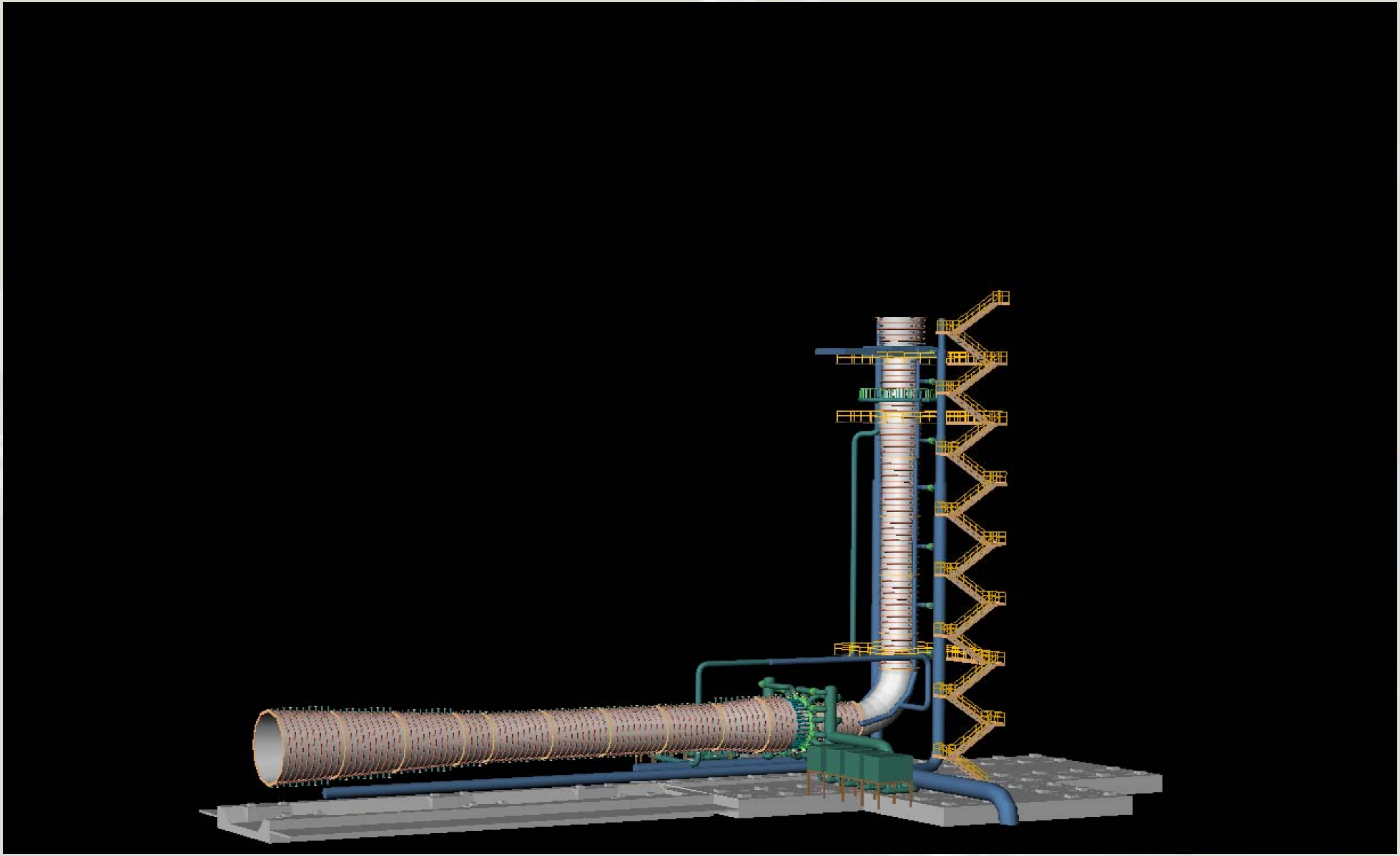
A-3 Test Stand 3-D Layout

Diffuser, Cooling Water and Ejectors



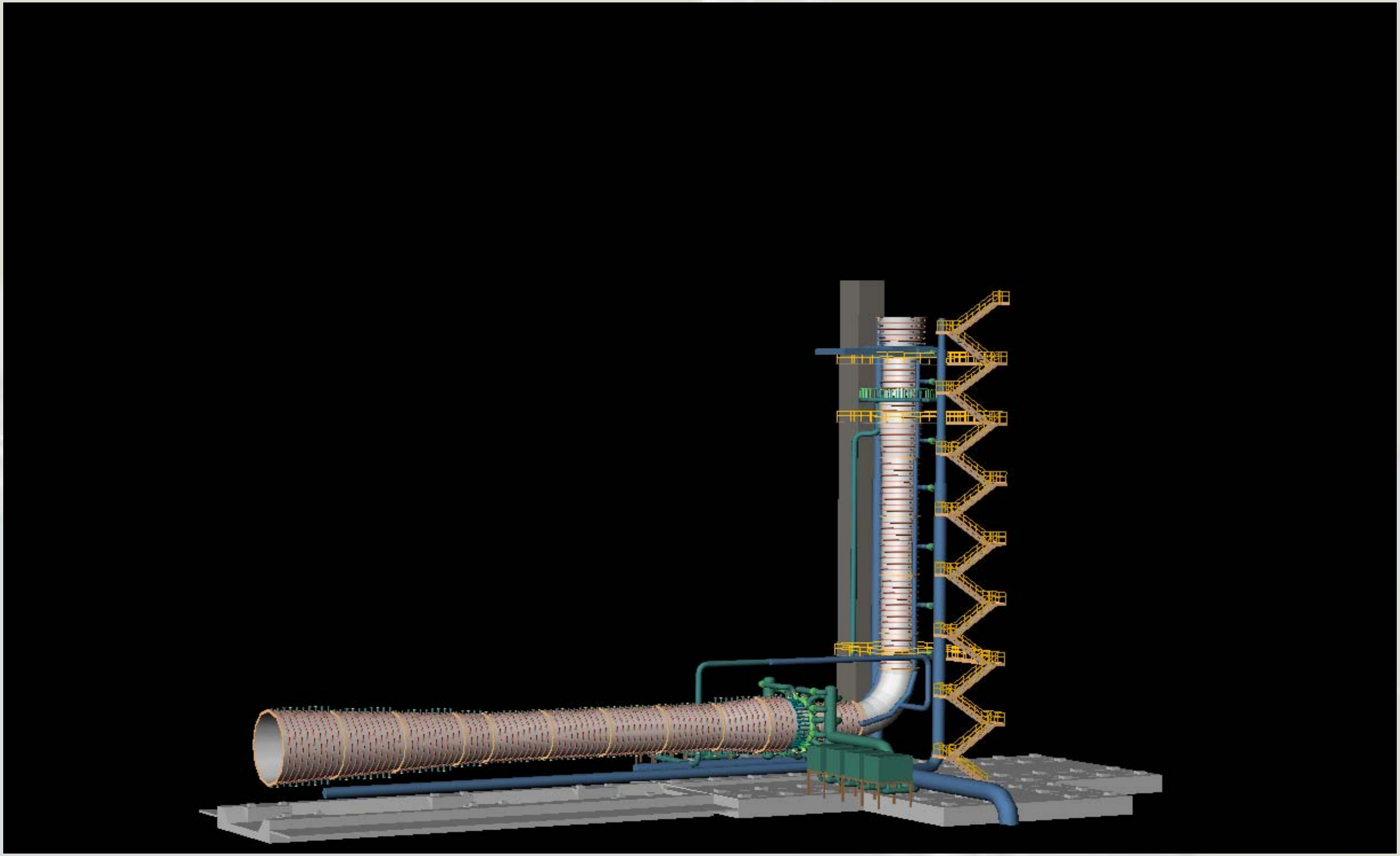
A-3 Test Stand 3-D Layout

Access Stairs and Platforms



A-3 Test Stand 3-D Layout

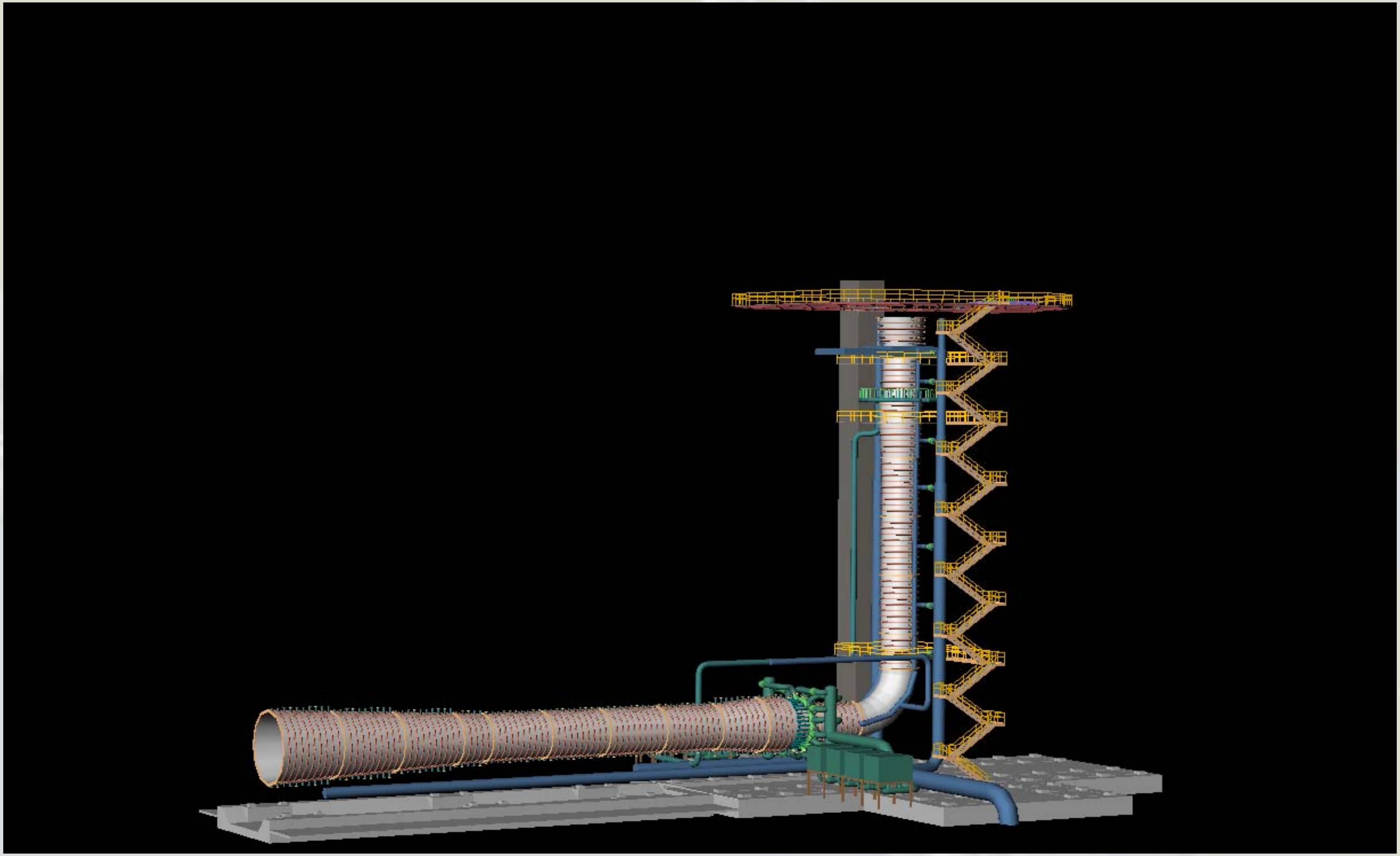
Elevator



RELEASED - Printed documents may be obsolete; validate prior to use.

A-3 Test Stand 3-D Layout

Engine Work Deck



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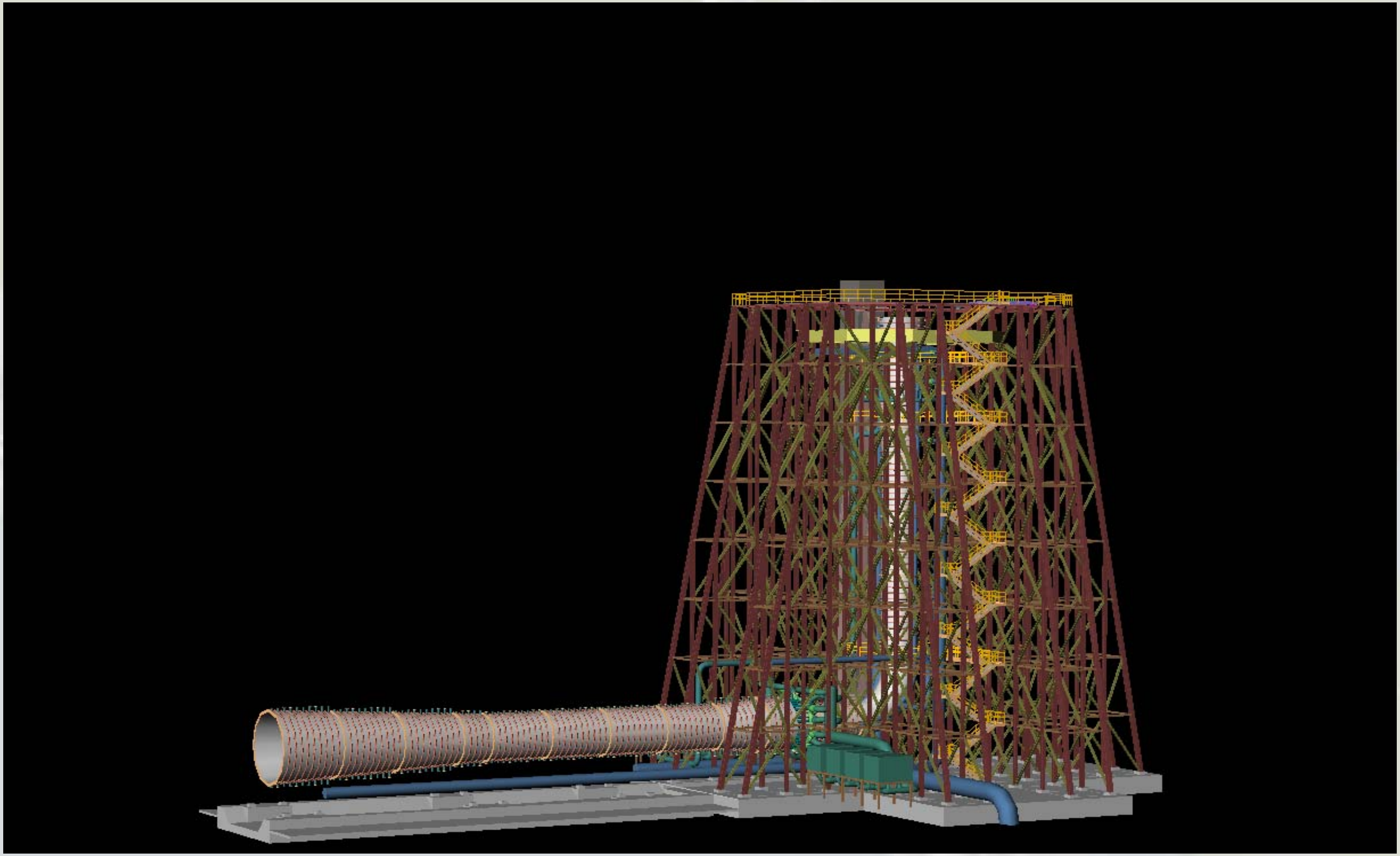
A-3 Test Stand 3-D Layout

Structural System



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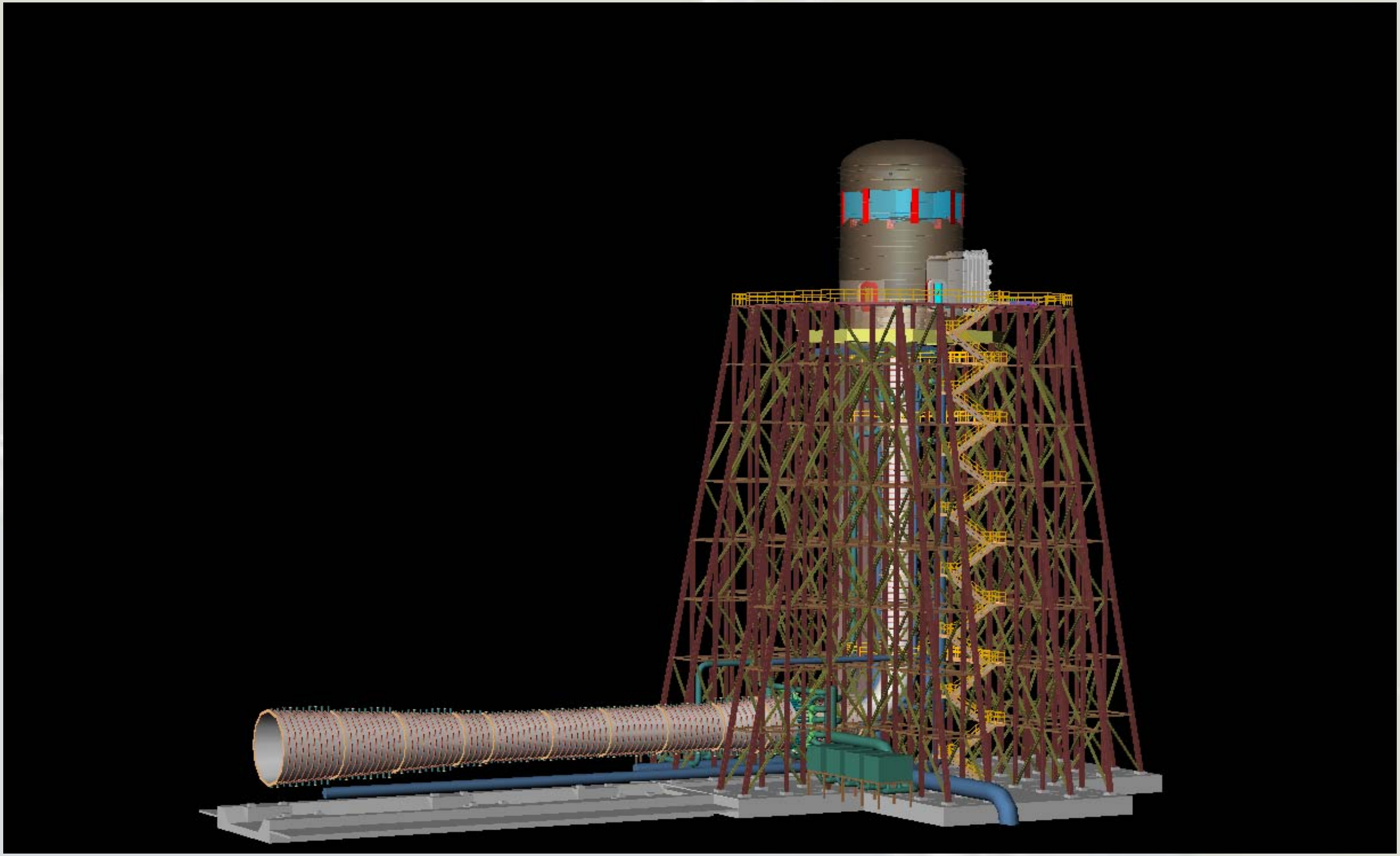
A-3 Test Stand 3-D Layout

Test Cell and Thrust Takeout



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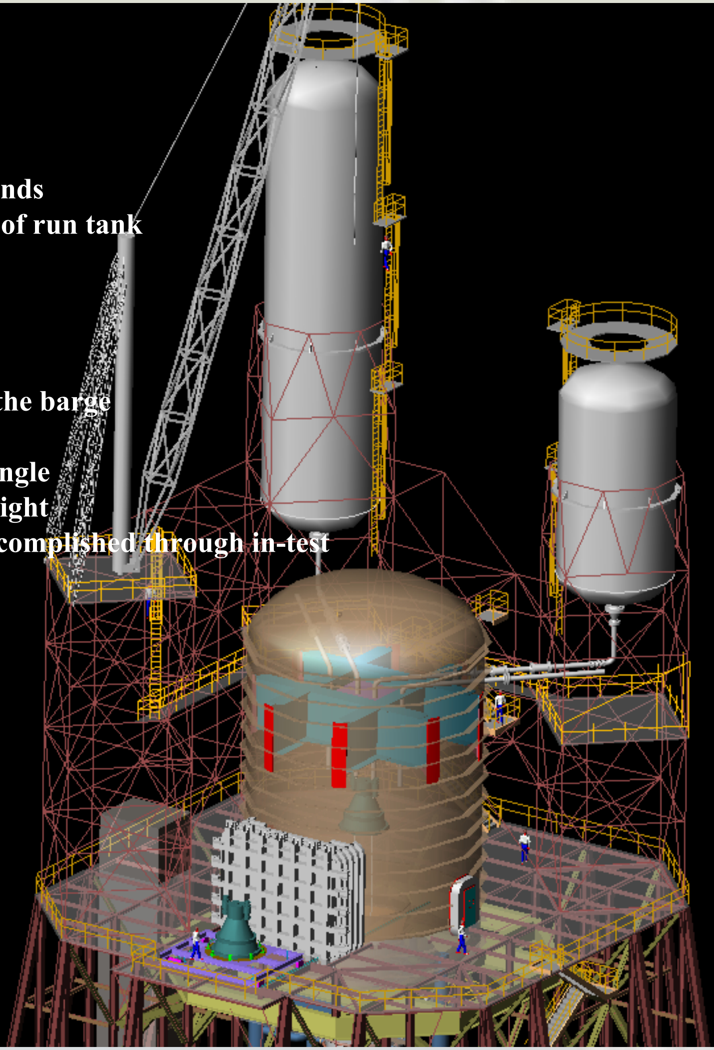
A-3 Test Stand 3-D Layout

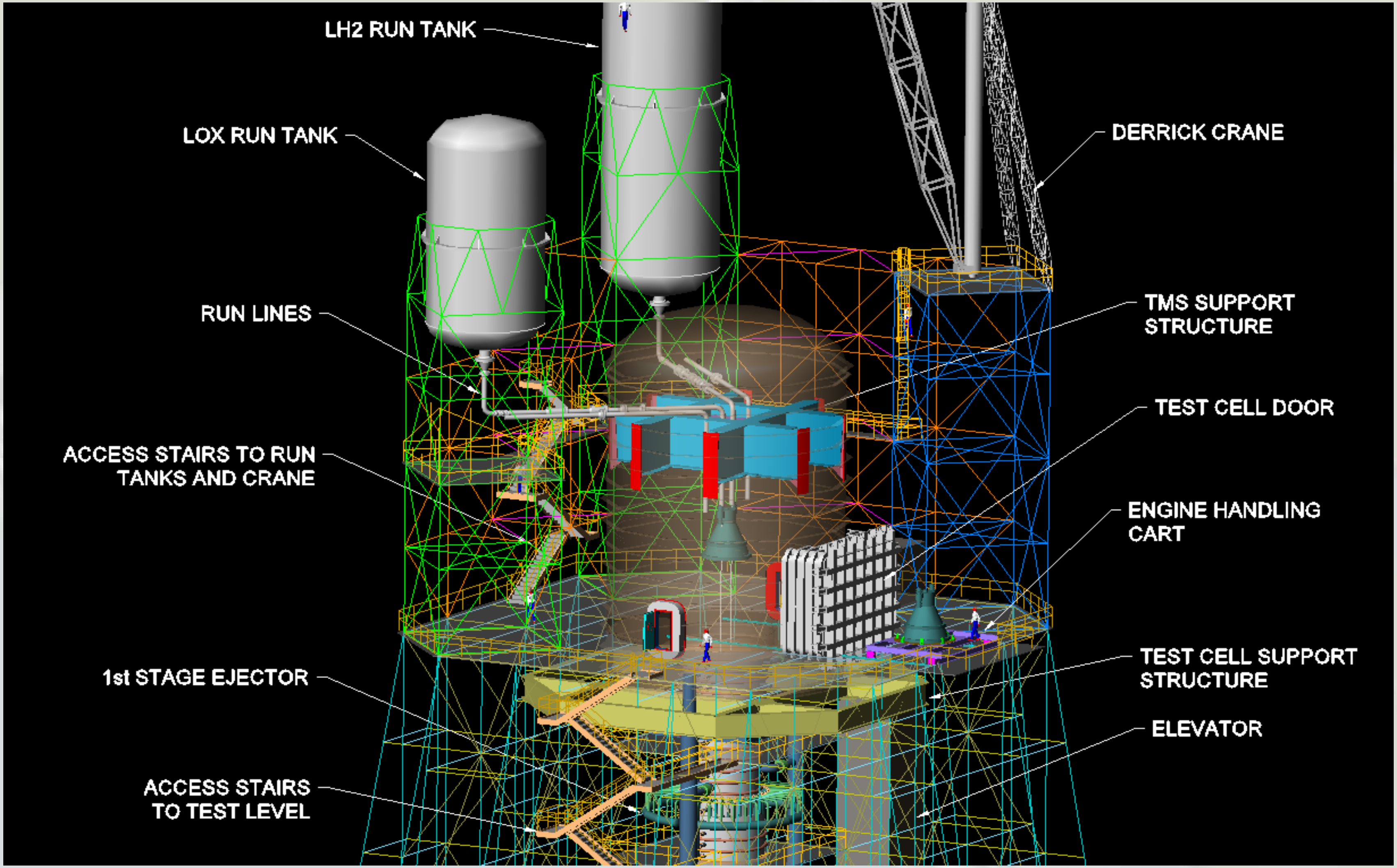
Test Cell and Thrust Takeout

- 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.



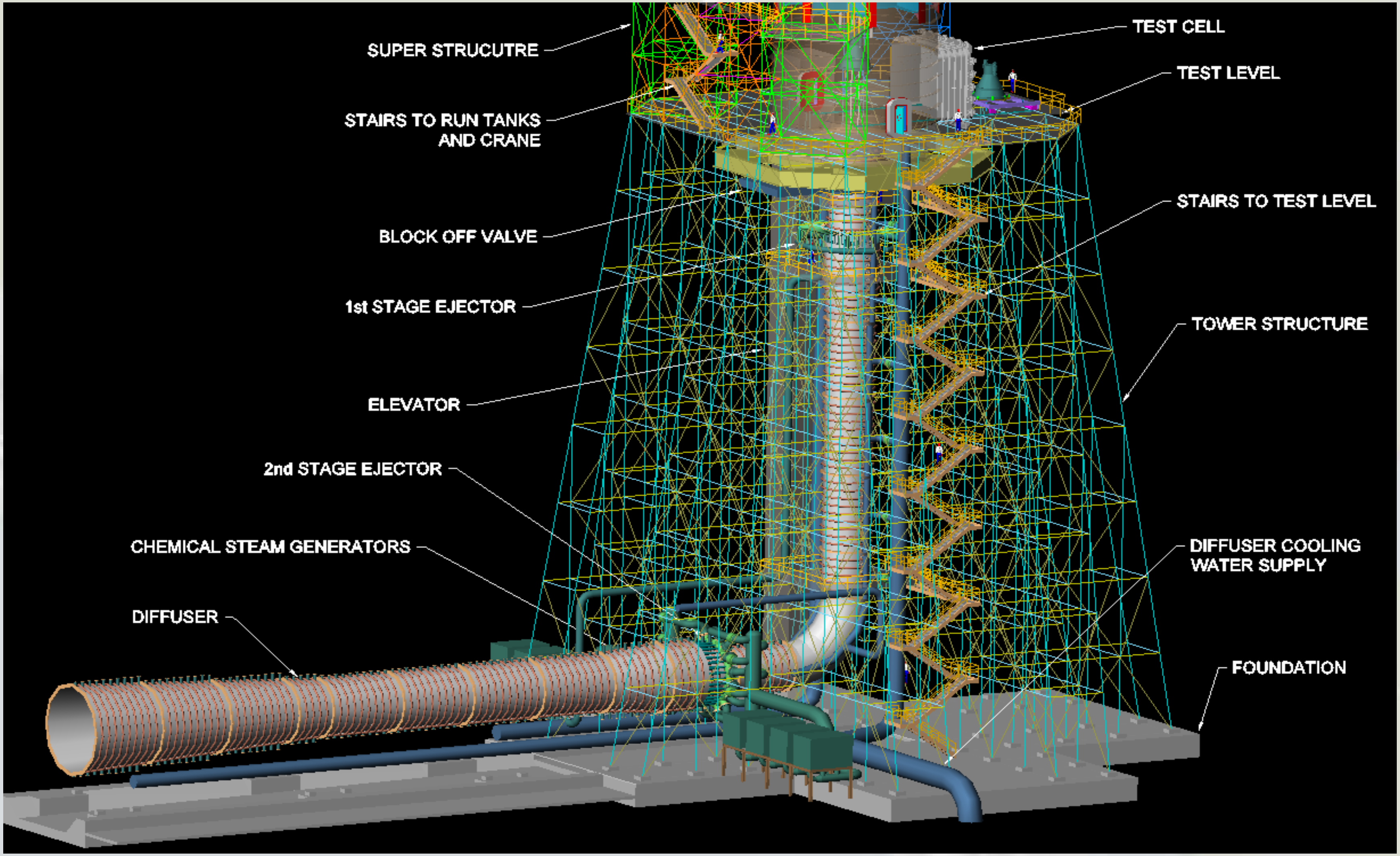
A-3 Test Stand 3-D Layout

Engine Deck and Superstructure



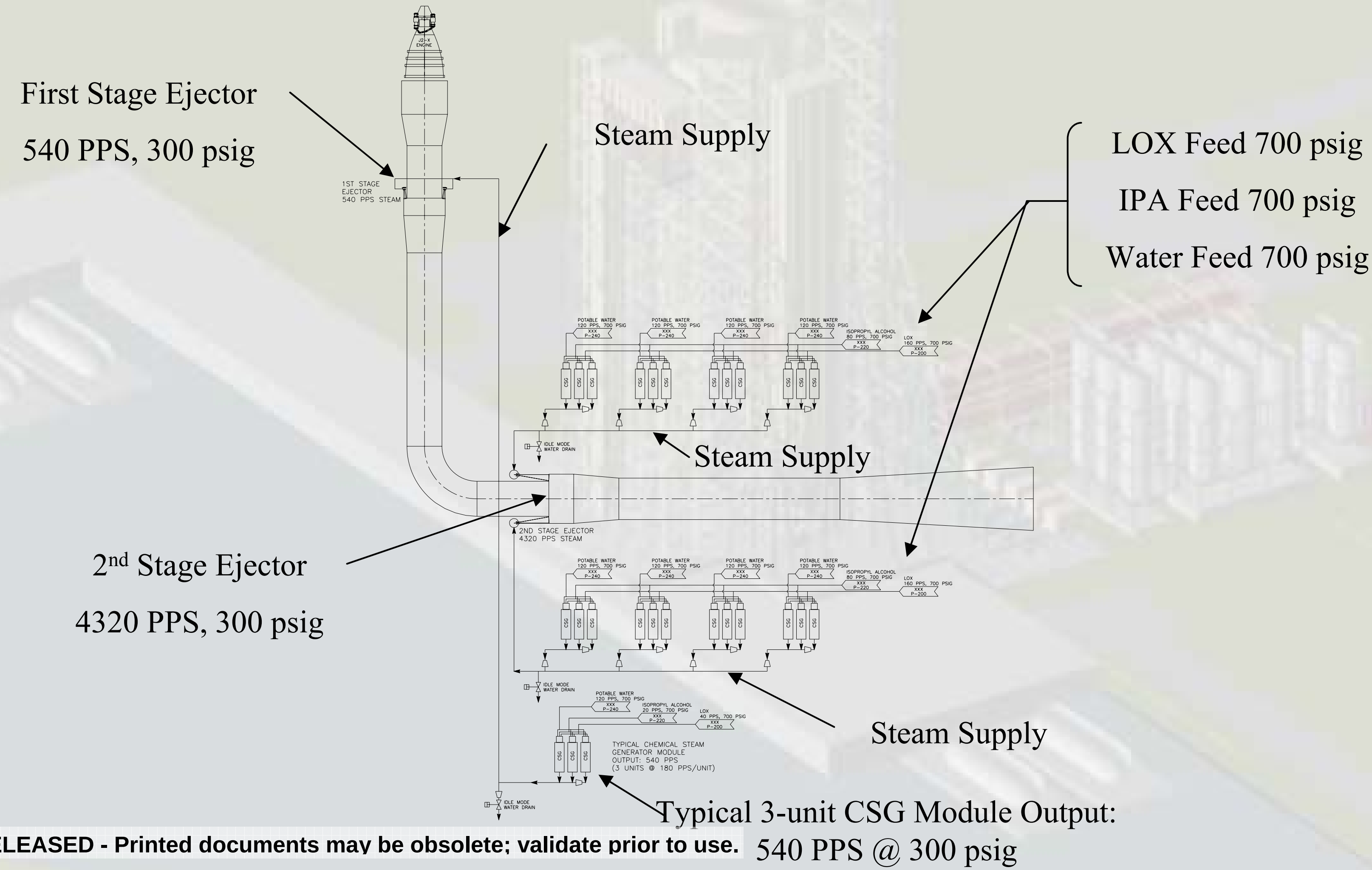
A-3 Test Stand 3-D Layout

Structure and Altitude Support Systems

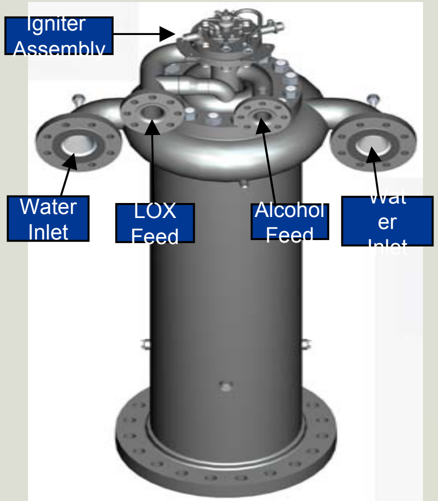


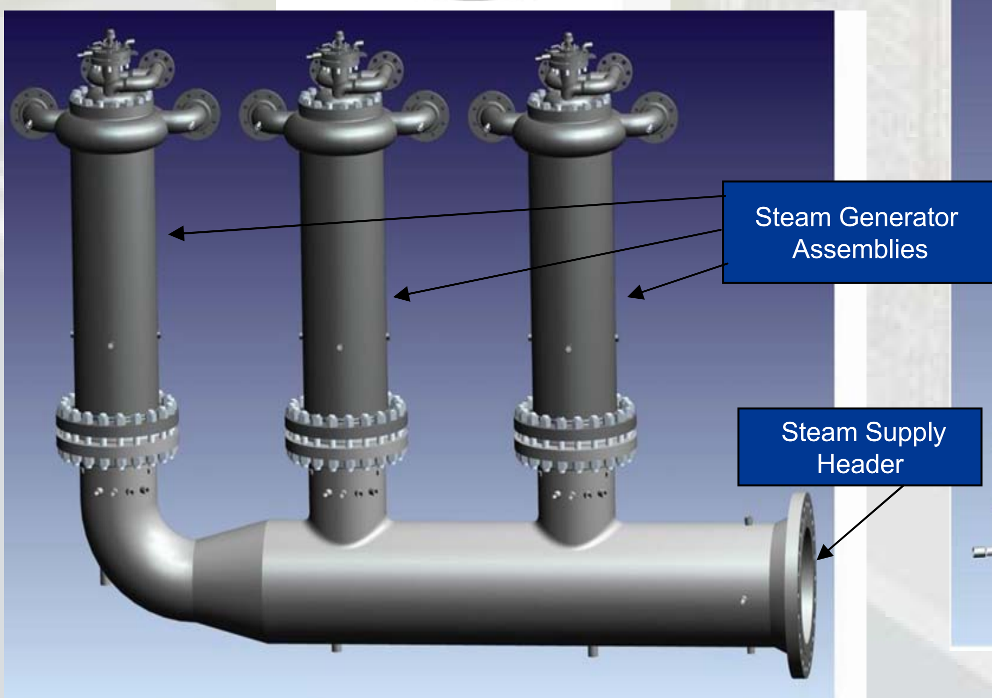
Steam System

- A-3 Steam System Schematic Diagram



Chemical Steam Generators



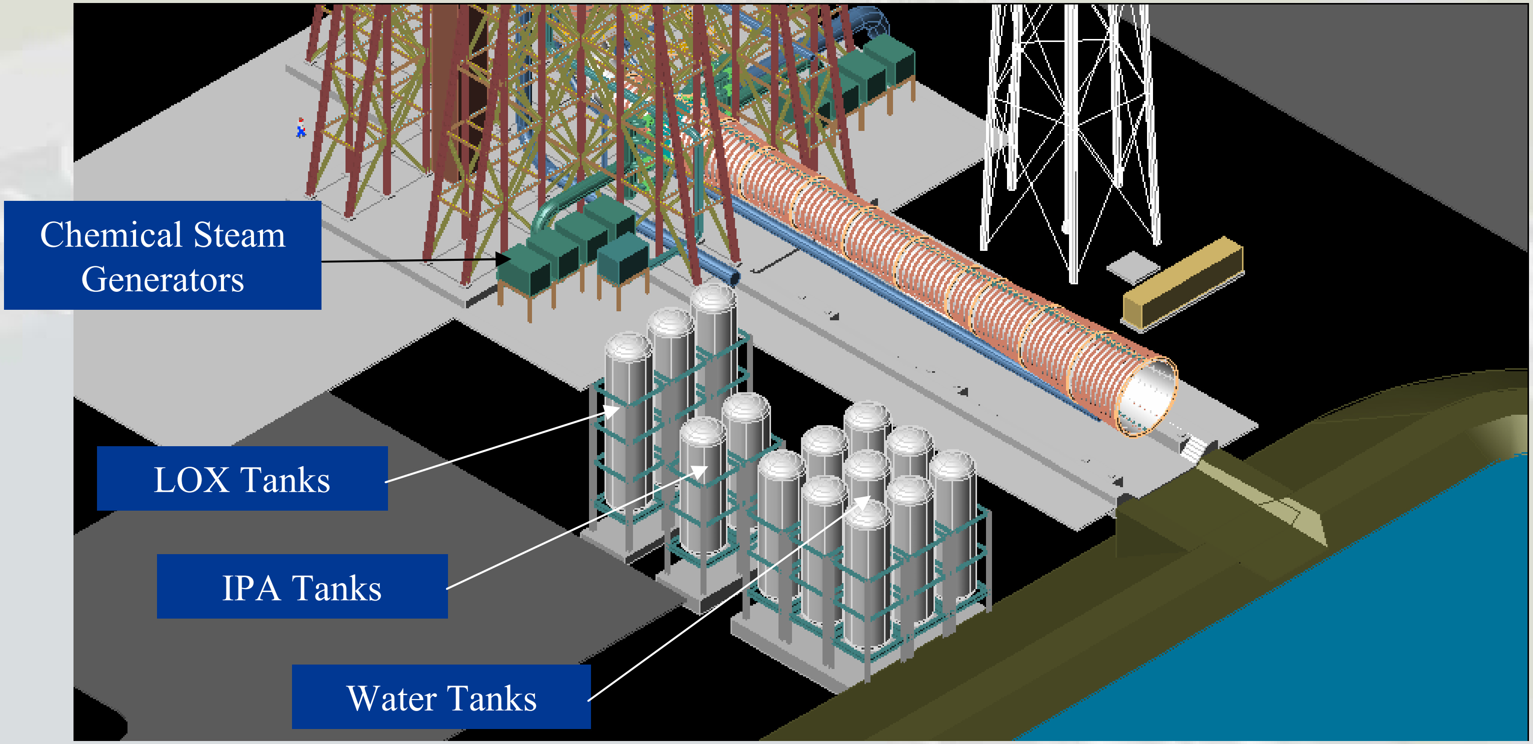


Steam Generation System

AX Steam System Propellant Feed/Storage requirements

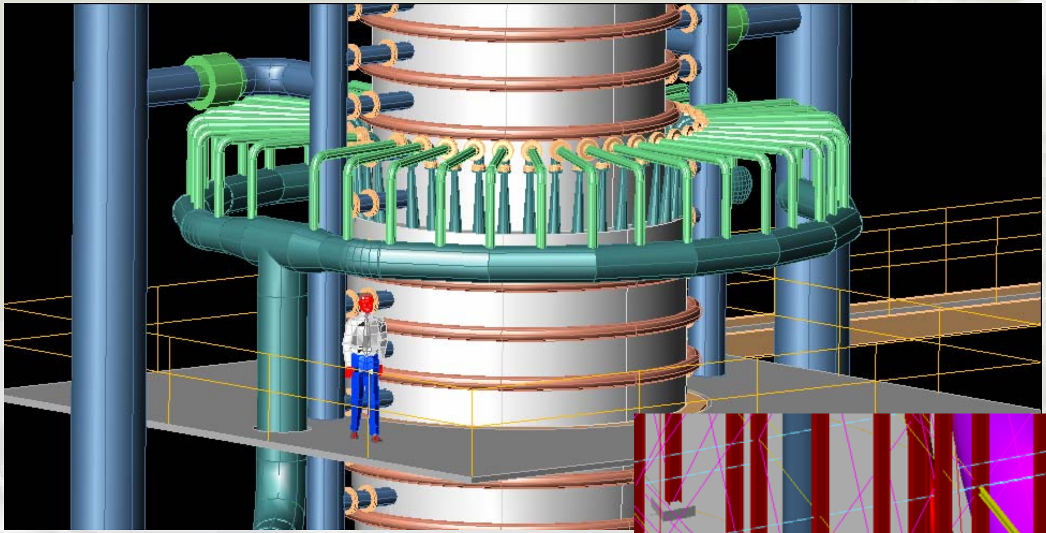
LOX: 89,609 gallons

- **IPA: 62,478 gallons**
- **H2O: 277,670 gallons**

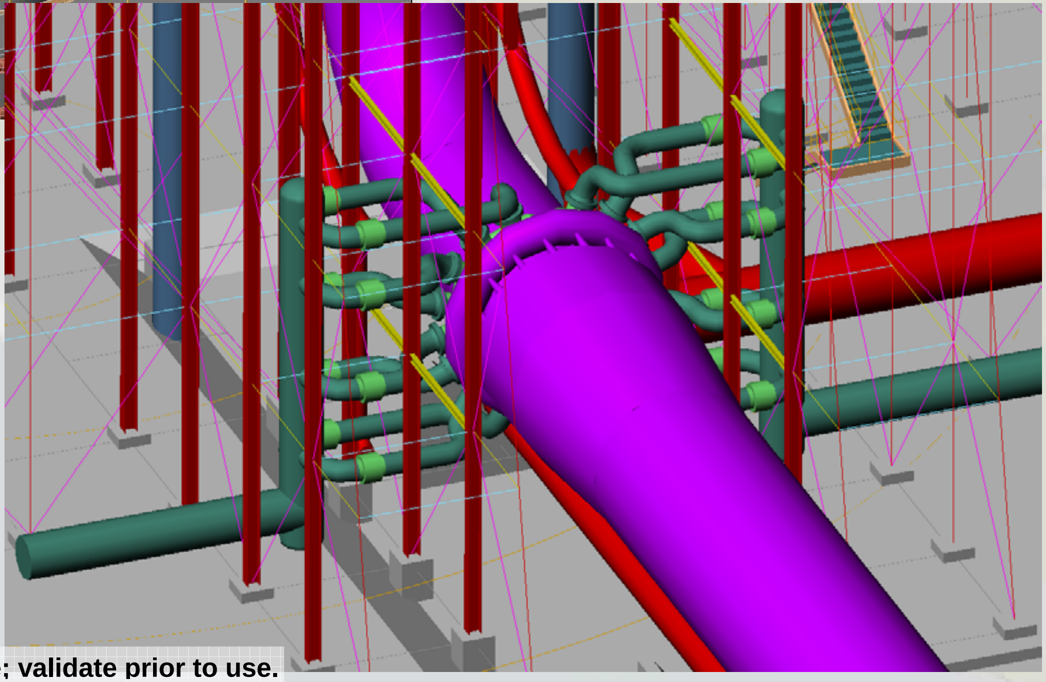


Steam Ejectors

1st Stage Ejector: Conical Nozzles, 460 PPS

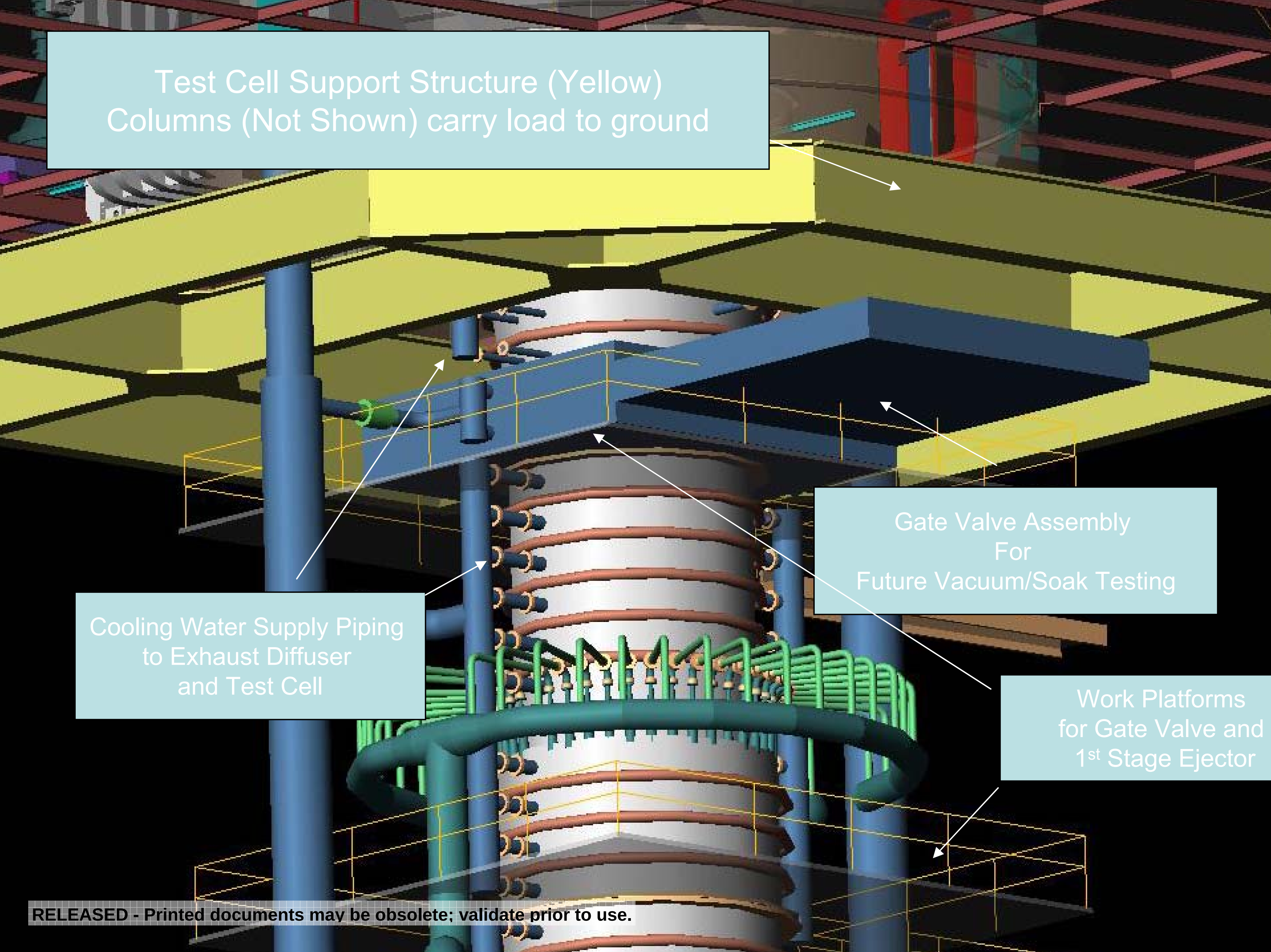


2nd Stage Ejector: Flat-Plate, 4380 PPS



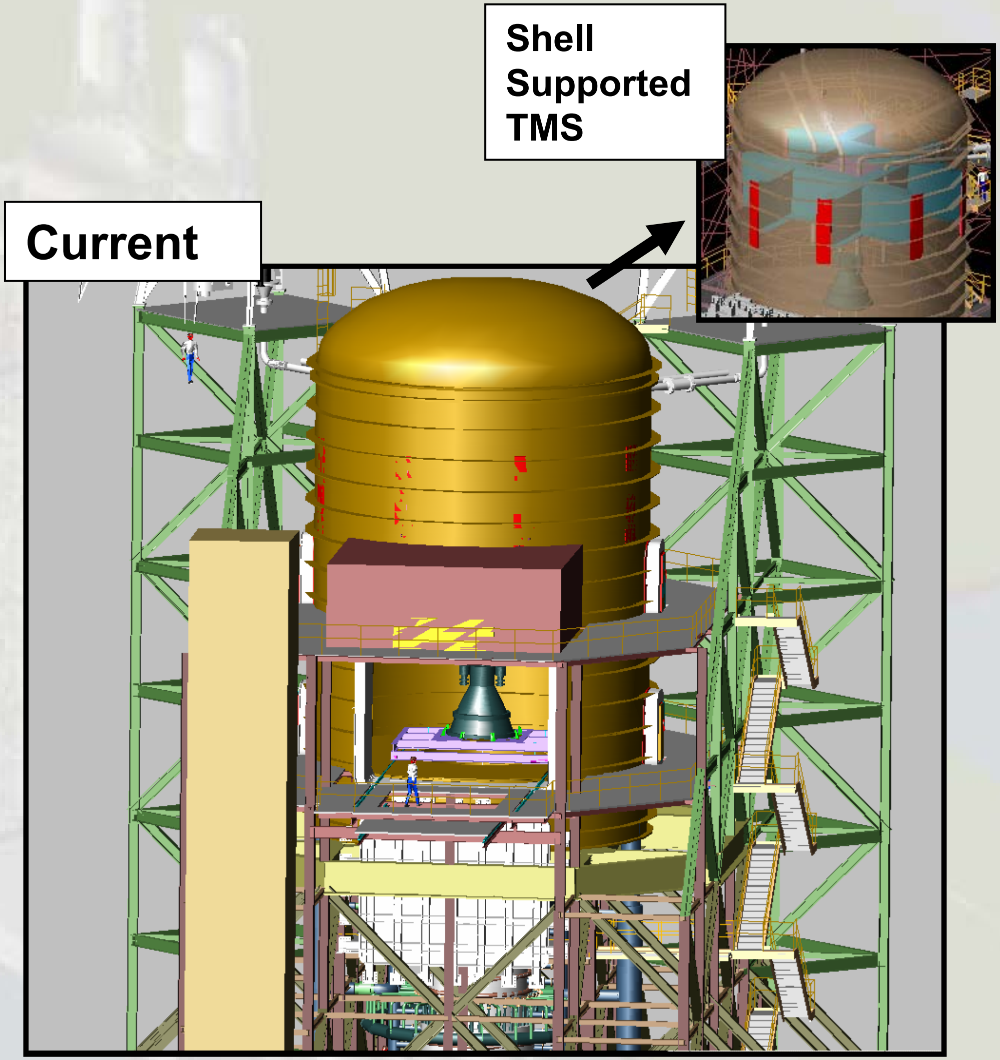
Sliding Gate Valve

- 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

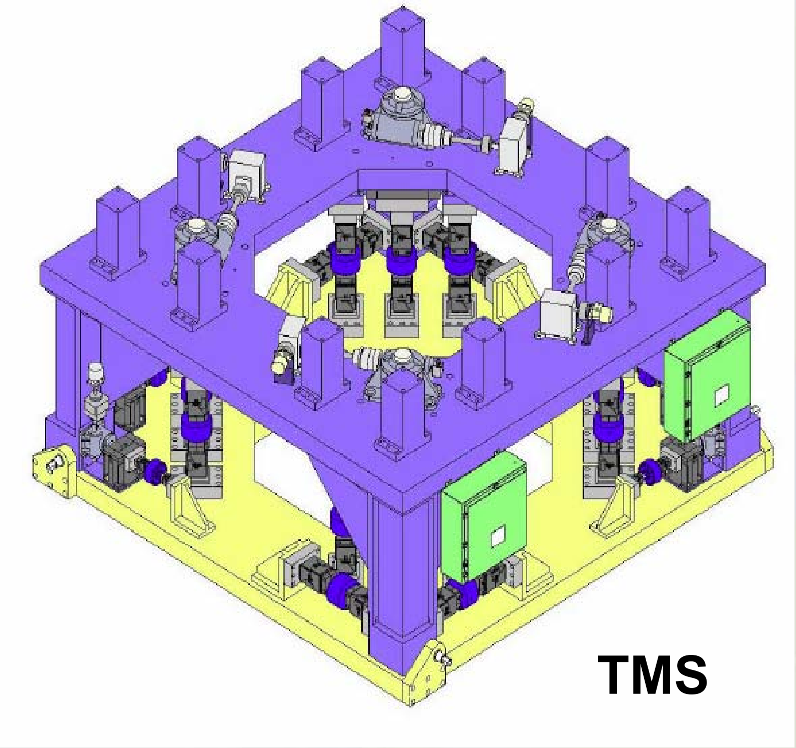
Test Cell Configuration

- 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



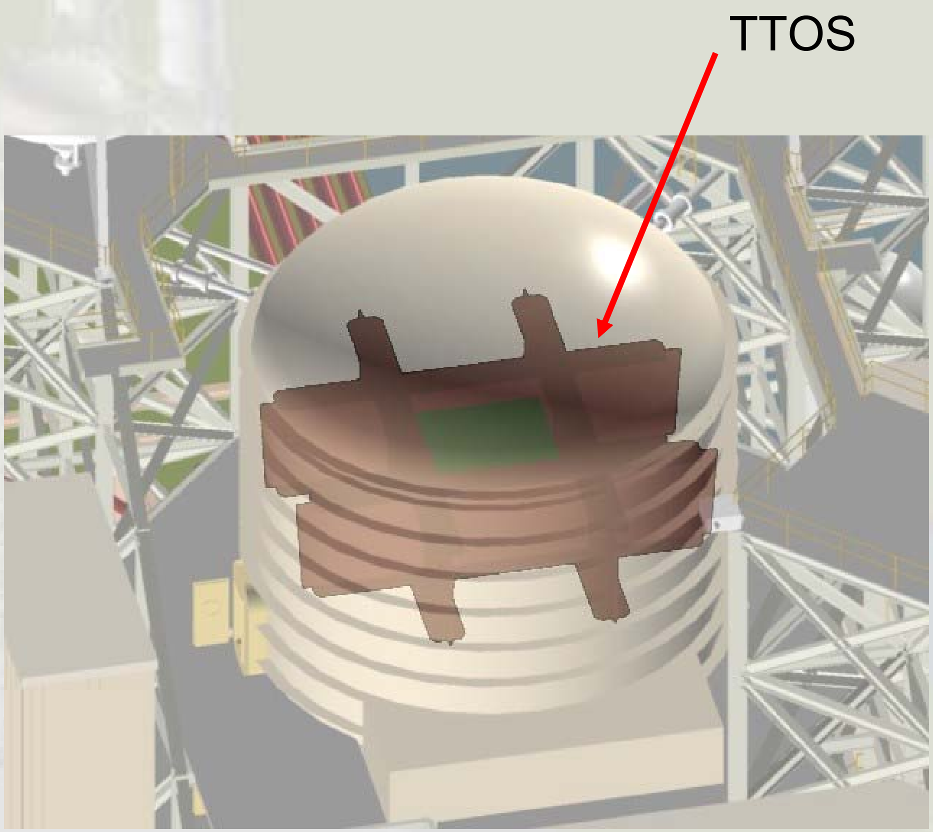
Thrust Measurement System

- 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.



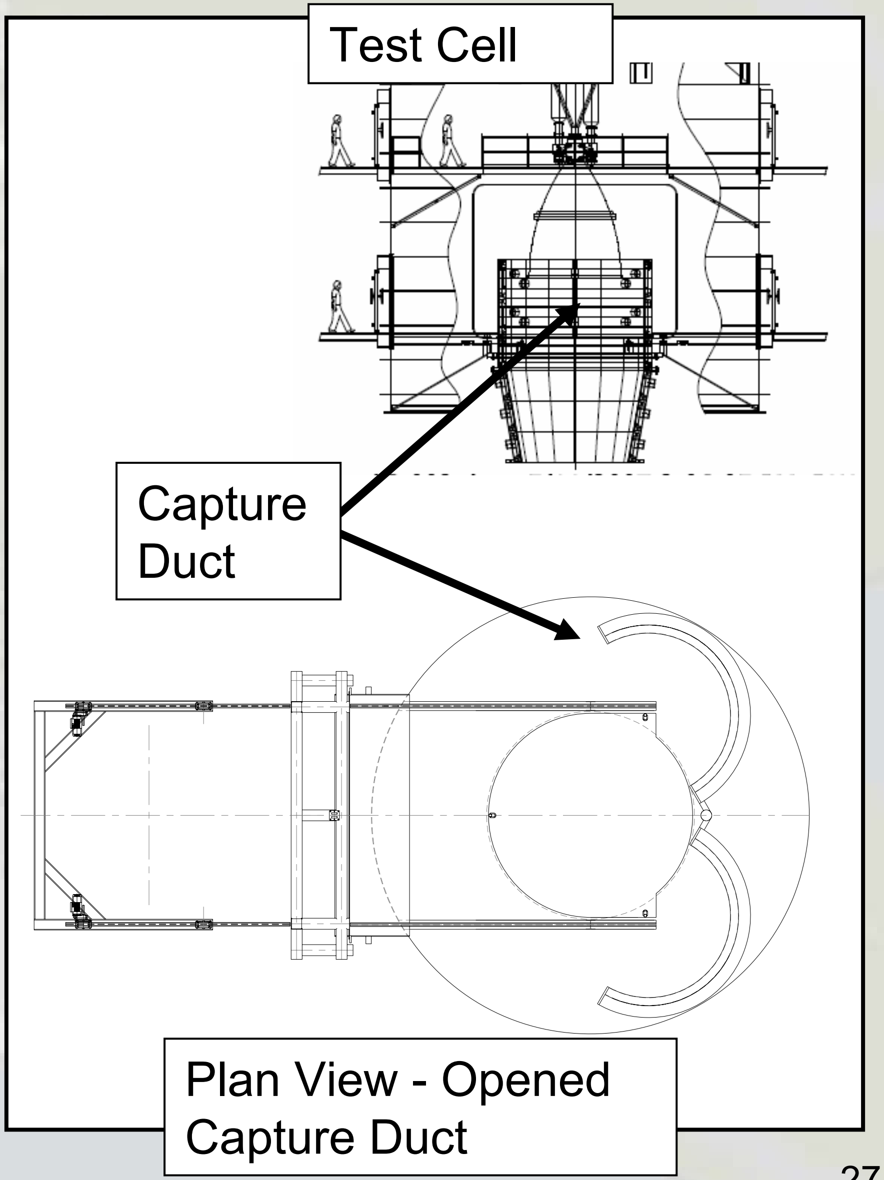
Thrust Takeout Structure

- 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



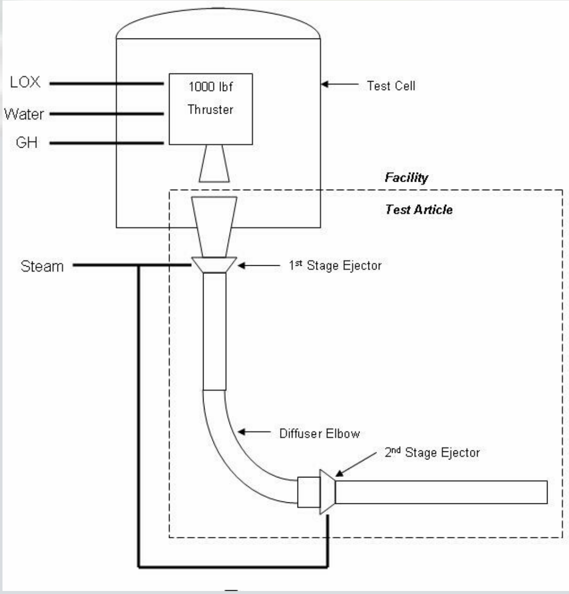
A-3 Risk Mitigation – Subscale Diffuser

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)

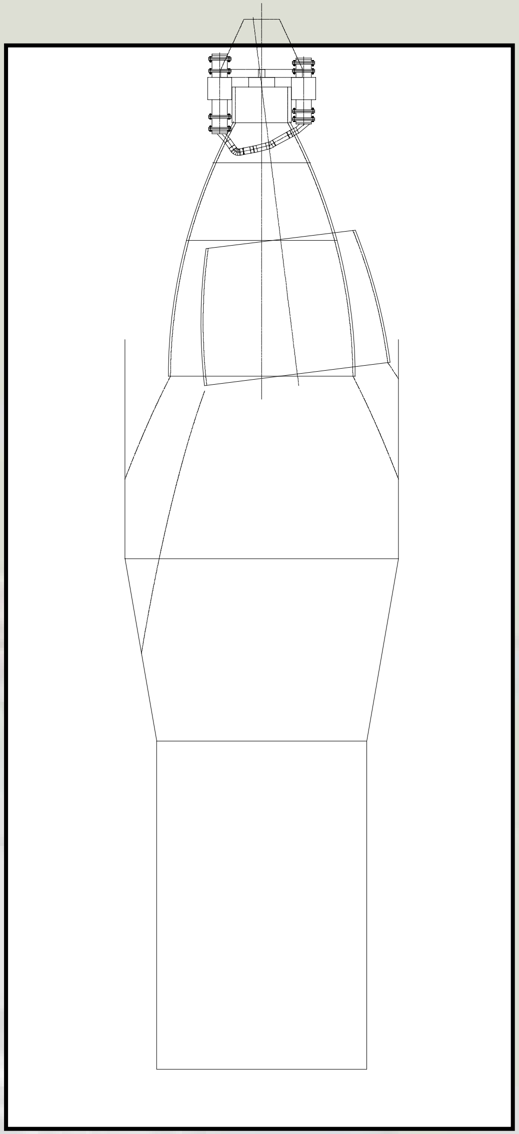
- Ignite and characterize steam combustor (modified thruster)
- Integrate steam combustor with water injector system

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



November


January


December

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