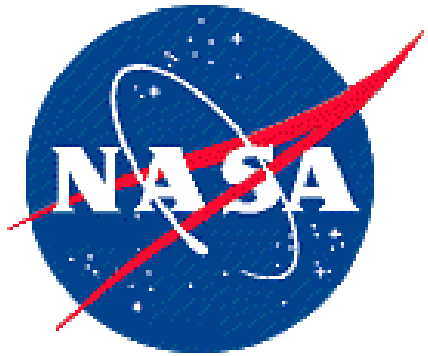


*John C. Stennis Space Center*

# Modeling Potential Carbon Monoxide Exposure Due to Operation of a Major Rocket Engine Altitude Test Facility Using Computational Fluid Dynamics

Michael Blotzer, MS, CIH and Jody Woods

NASA John C. Stennis Space Center

# Constellation Program

*Stennis Space Center*

# Constellation Launch Vehicles

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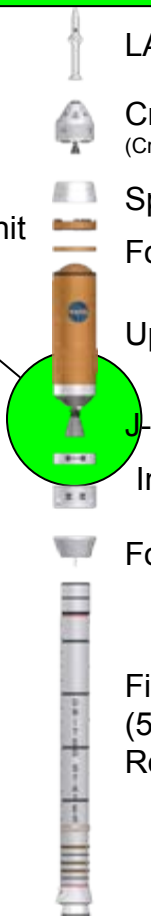
**SSC will test and certify the Ares I and Ares V upper stage engines…**



LAS

Crew Exploration Vehicle (CEV)
(Crew Module / Service Module)

Spacecraft Adapter

Instrument Unit

Forward Skirt

Upper Stage

J-2X Upper Stage Engine

Interstage

Forward Frustum

First Stage
(5-Segment Reusable Solid Rocket Booster (RSRB))

**Crew Launch Vehicle**

Composite Shroud

LSAM

EDS Stage
LOx/LH2
One J2S+ Engine
Al-Li Tanks/Structures

**…and the Ares V Core Stage and RS-68 engines.**

Core Stage
LOx/LH2
Five RS-68 Engines
Al-Li Tanks/Structures

Two 5-Segment RSRBs

**Cargo Launch Vehicle**

# J2X Engine

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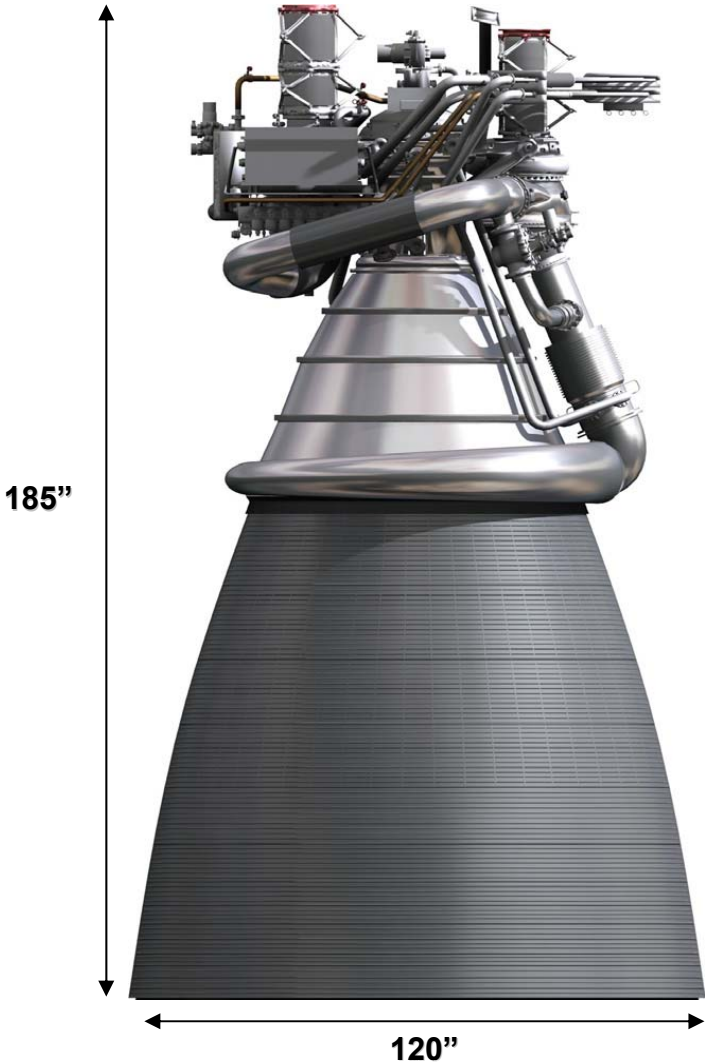


- Weight: 5,450 lbs
- 294,000 lbs of thrust primary mode for Ares I low-Earth orbit
- 242,000 lbs of thrust secondary mode for Ares V Earth departure stage

# A-3 Test Stand

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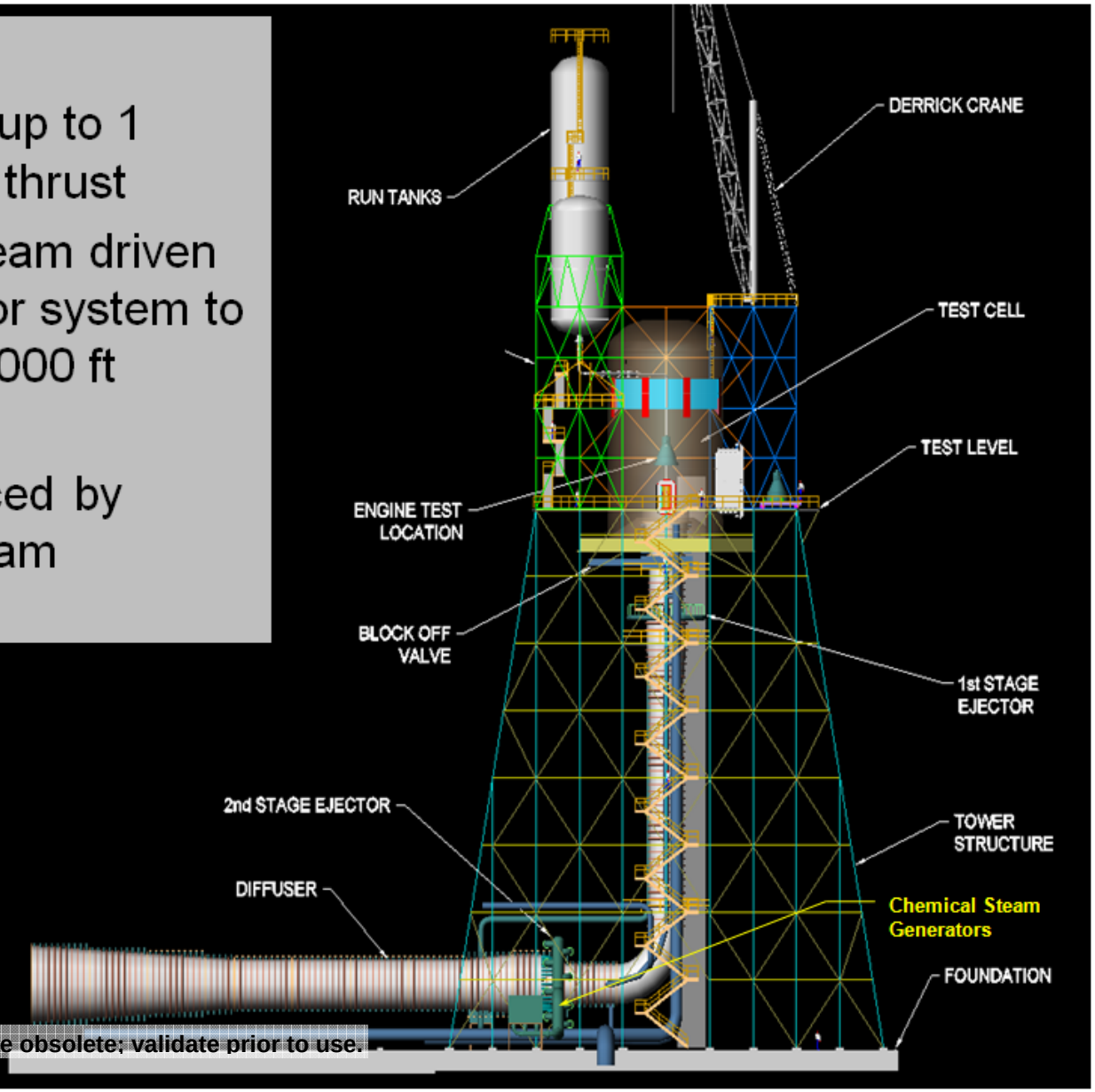
- 300 feet tall
- Test engines up to 1 million pound thrust
- Two-stage steam driven diffuser-ejector system to simulate 100,000 ft altitude
- Steam produced by Chemical Steam Generators



# Chemical Steam Generators

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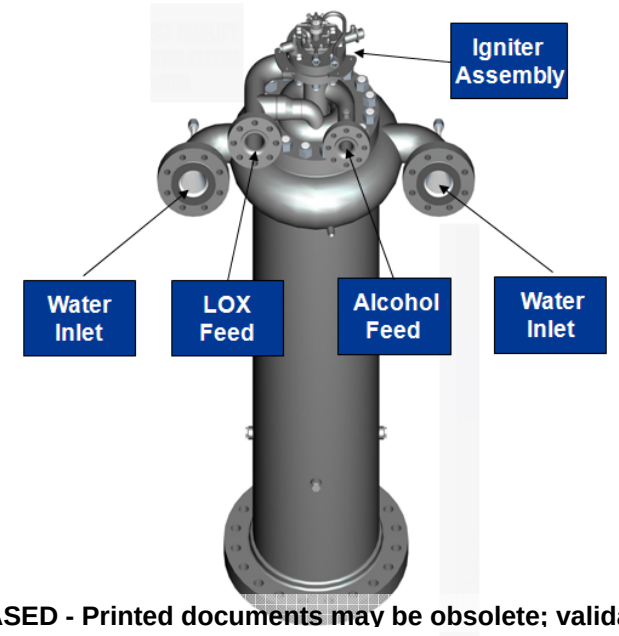
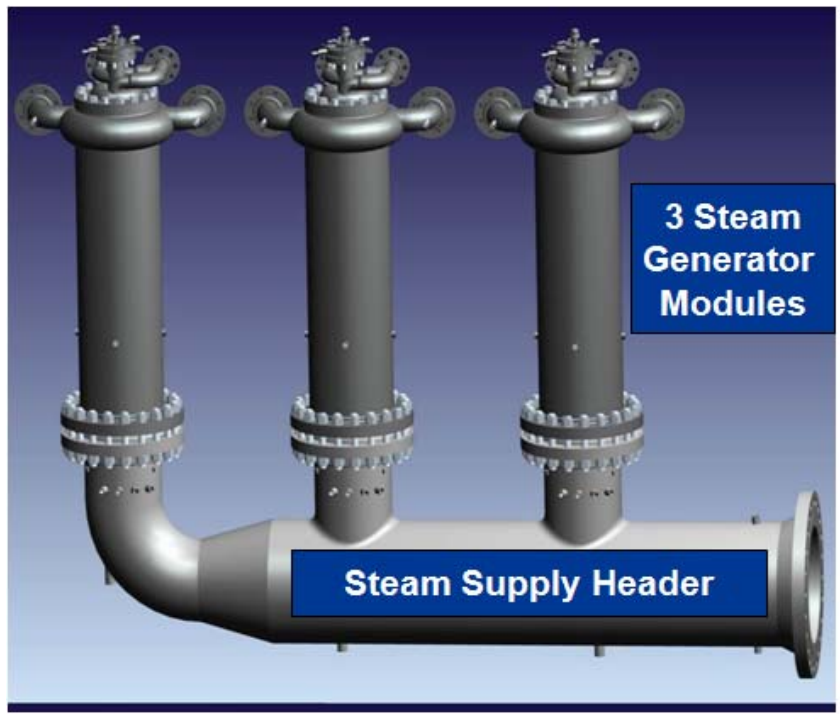
## CSG Module

- 27 chemical steam generator (CSG) modules
- Each module consumes
  - 42 lb/sec Liquid Oxygen
  - 21 lb/sec Isopropyl Alcohol
  - 124 lb/sec Water




## CSG Unit

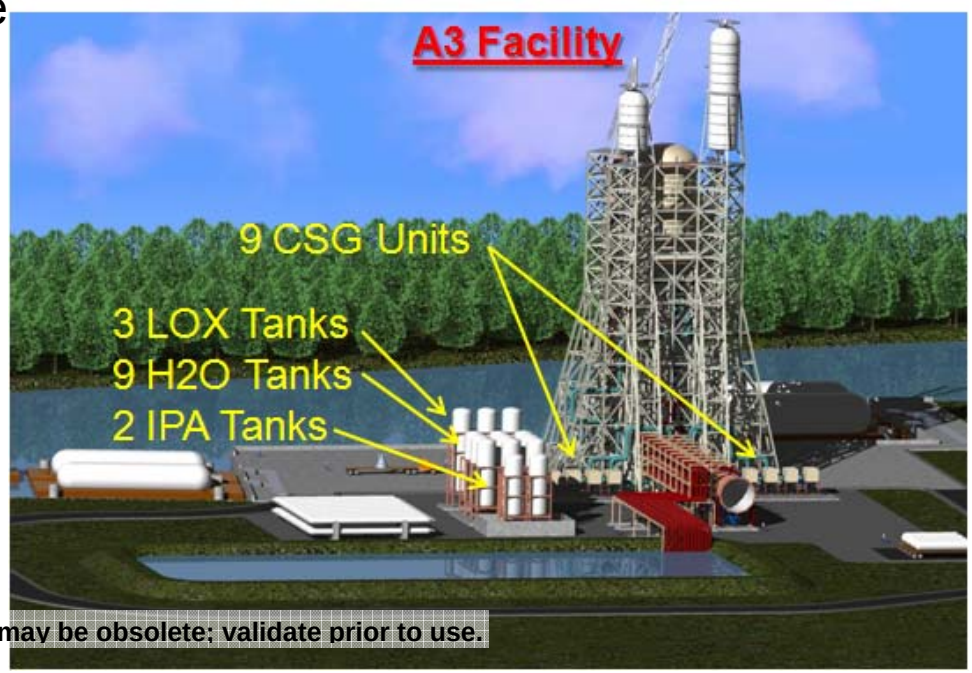
- CSG modules arranged in 9 groups (units) of 3 modules each



# Chemical Steam Generators



- Chemical steam generation system supplied by:
  - Two 35,000 gal isopropyl alcohol tanks
  - Three 35,000 gal liquid oxygen tanks
  - Nine 35,000 gal water tanks
- Chemical steam generation system produces:
  - 2,290 kg (5000 lbs) steam product per second ($H_2O$, $CO_2$, CO, trace hydrocarbons)
  - 31,853 kg (35.1 tons) CO predicted to be released during each 650 second te



# Emission Estimates



- Lewis Model
- Emissions data from WSTF from circa 1980

| | Composition | |
|---|---|---|
| **Component** | **% by Volume** | **% by Mass** |
| Methane | 0.176 | 0.14 |
| Ethylene | 0.035 | 0.05 |
| Acetylene | 0.049 | 0.06 |
| Ethane | 0.007 | 0.01 |
| Propylene | 0.014 | 0.03 |
| Propane | 0.0006 | 0.00 |
| Isopropanol | 0.136 | 0.40 |
| Other Hydrocarbons | 0.007 | 0.01 |
| CO2 | 6.65 | 14.35 |
| **CO** | **1.52** | **2.09** |
| H2 | 1.06 | 0.10 |
| O2 | 3.86 | 6.05 |
| N2 | 0.74 | 1.02 |
| H2O | 85.71 | 75.69 |

- AEDC Measurements using latest got gas sampling technology during CSG Risk Mitigation testing to confirm WSTF data
  - Testing with measurements just underway
  - Preliminary results consistent with WSTF data

# Located in Existing Test Complex

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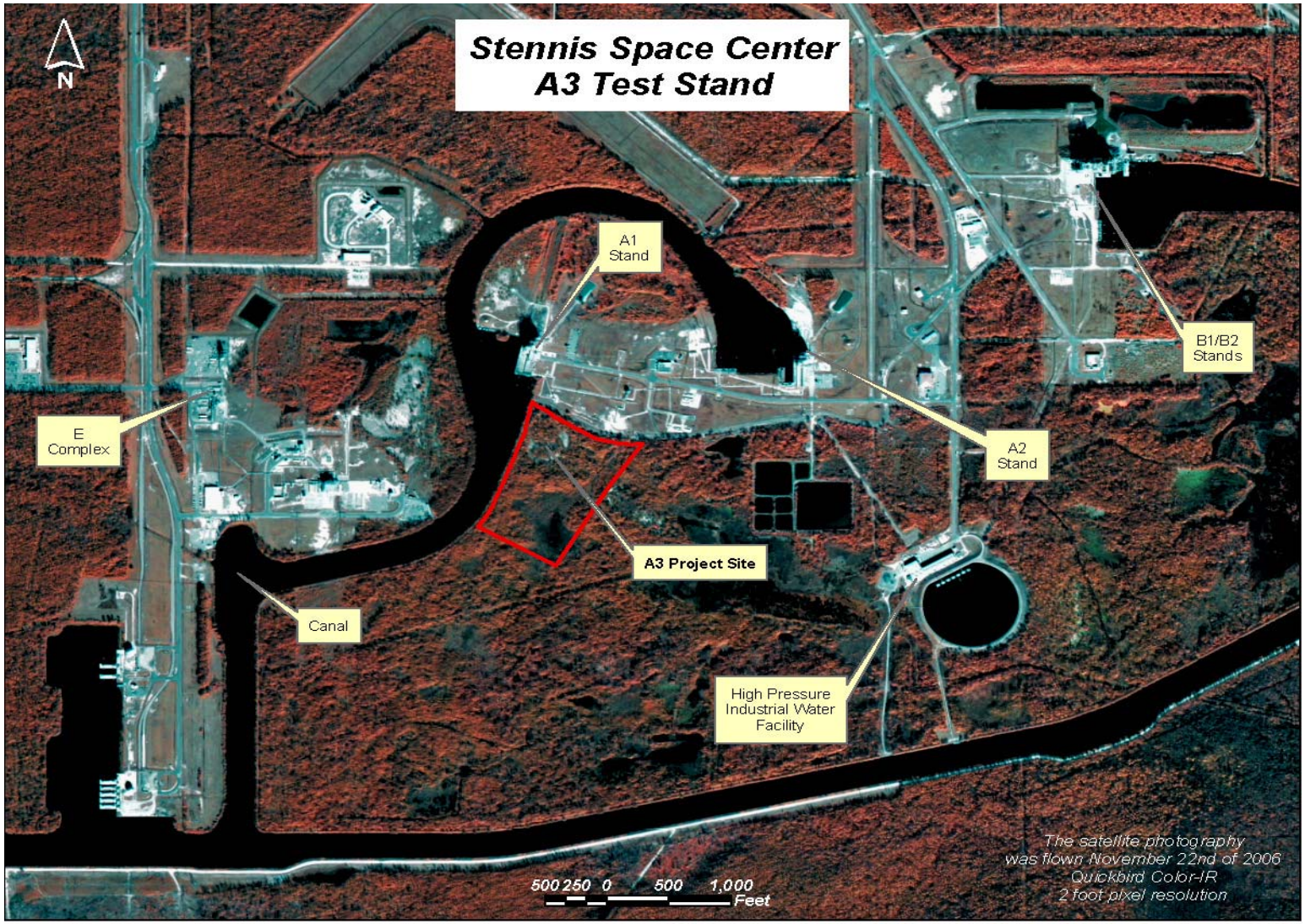


# Computational Fluid Dynamics



- Computational Fluid Dynamics (CFD) used to model the evolution of the exhaust plume generated by operation of the A3 facility and predict dispersion of CO
- Unsteady Reynolds Averaged Navier Stokes Equations solved in 3 dimensions using finite volume method given the specified boundary conditions with $2^{nd}$ order implicit time and space accuracy
  - Nine Steady State cases and one Transient
- Buoyancy terms included in momentum equations
- Variable composition mixture model with N2, O2, CO2, CO, H2, H2O species

# Computational Tools



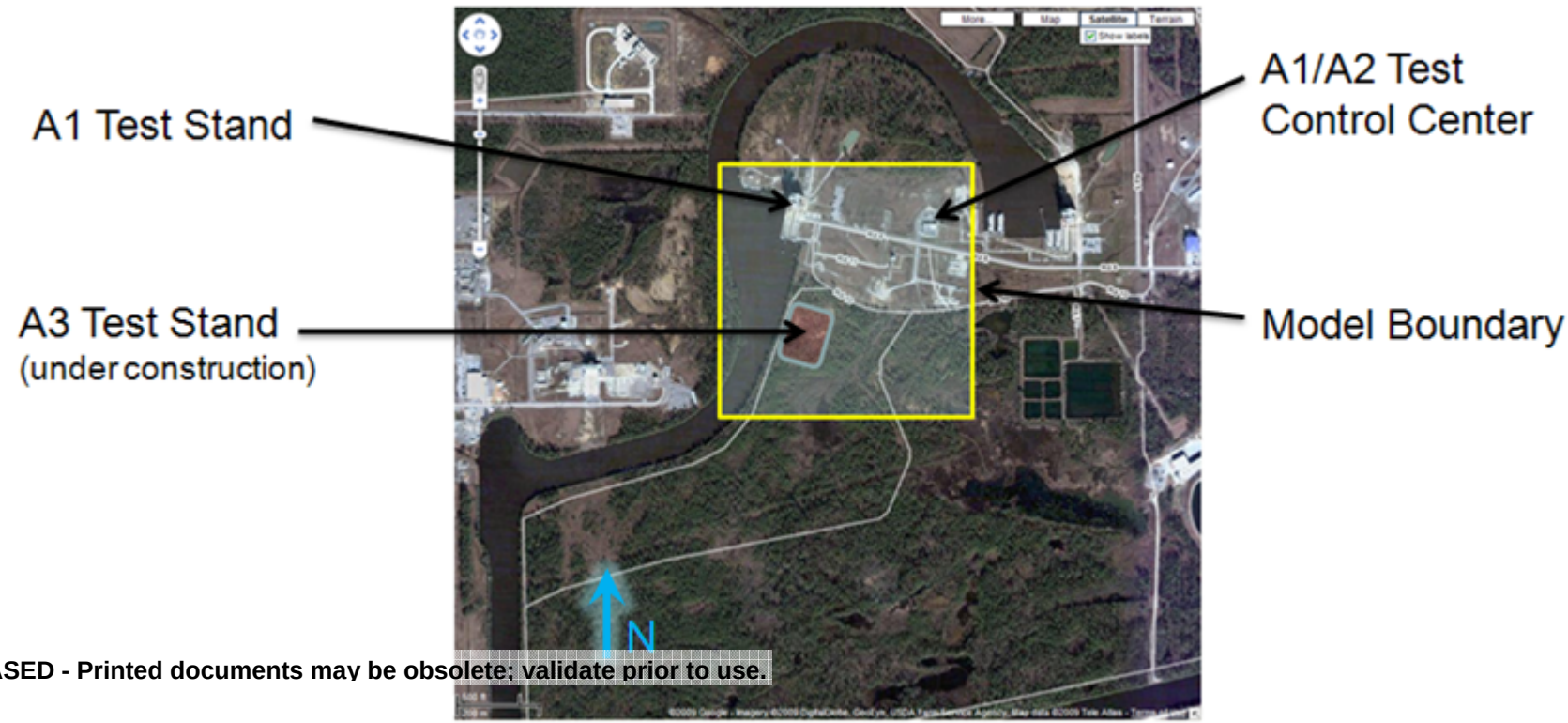
- ANSYS CFX v11 computational fluid dynamics software used for analyses
- Problem setup and post-processing done on high-end desktop PC
  - Approximately 3 man weeks effort expended
- Solutions obtained on 32 processors of a 96 processor LINUX computational cluster
  - Approximately 4 weeks of run time for all cases (9 steady state and 1 transient solution)

# CO Modeling



- **A 2000ft(L) x 2000ft(w) x 1000ft(h) volume within the A3 Test Complex was included in the plume dispersion model**
- **Model included A1 Test Stand and the A1/A2 Test Control Center since they are locations that people may occupy during testing at A3**

## Aerial View of Test Complex



# CO Modeling

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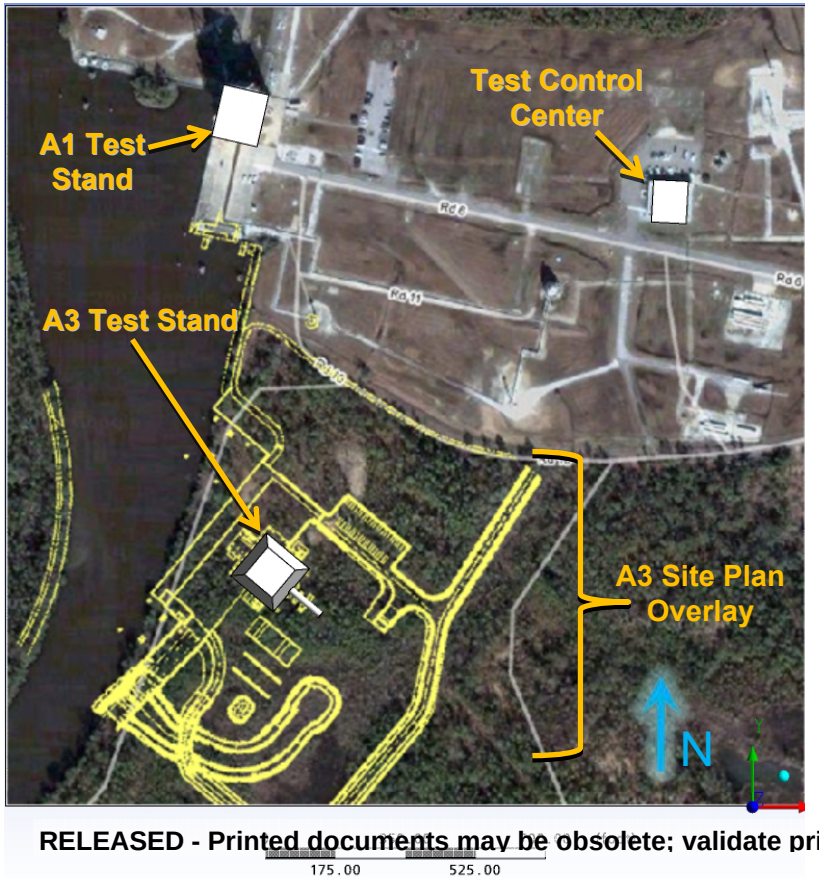
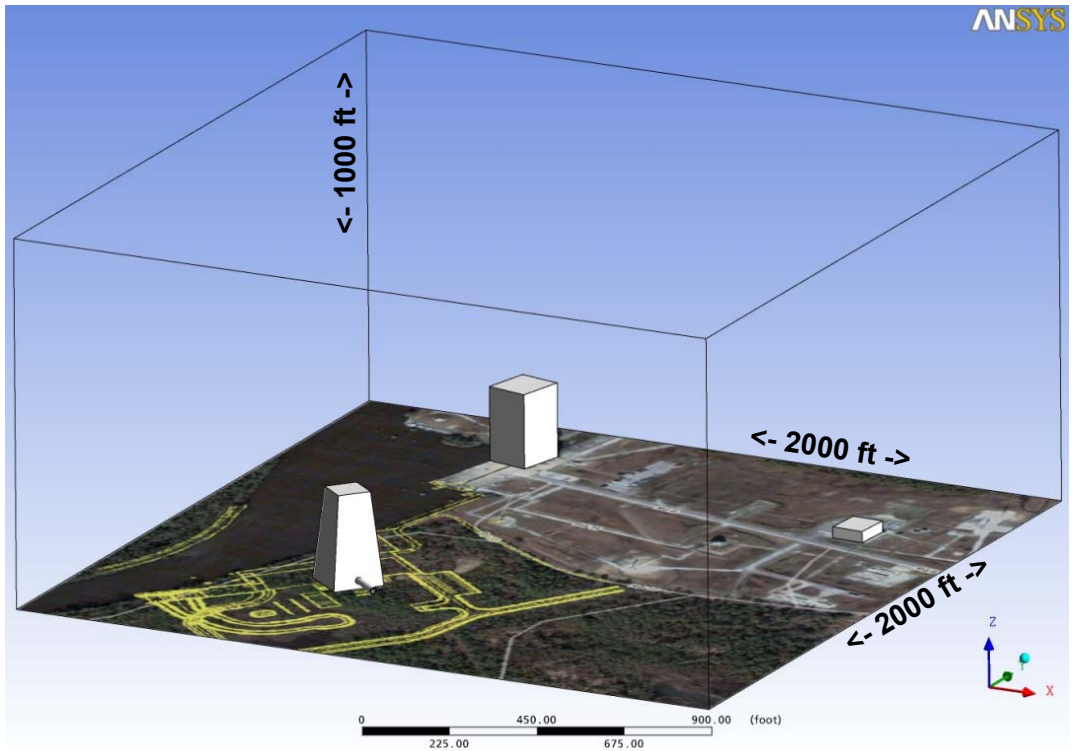
- **Steady State analyses completed for 9 wind conditions**
  **(No wind & 35 mph N, NE, E, SE, S, SW, S, & NW)**
- **Transient analysis completed for southerly 35 mph wind**

## Model Plan View




## Model Isometric View



# CO Model Results

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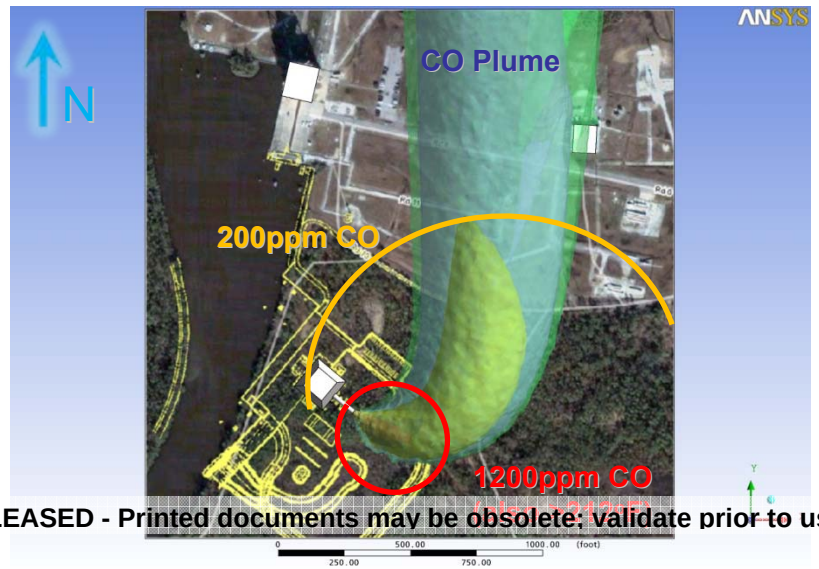
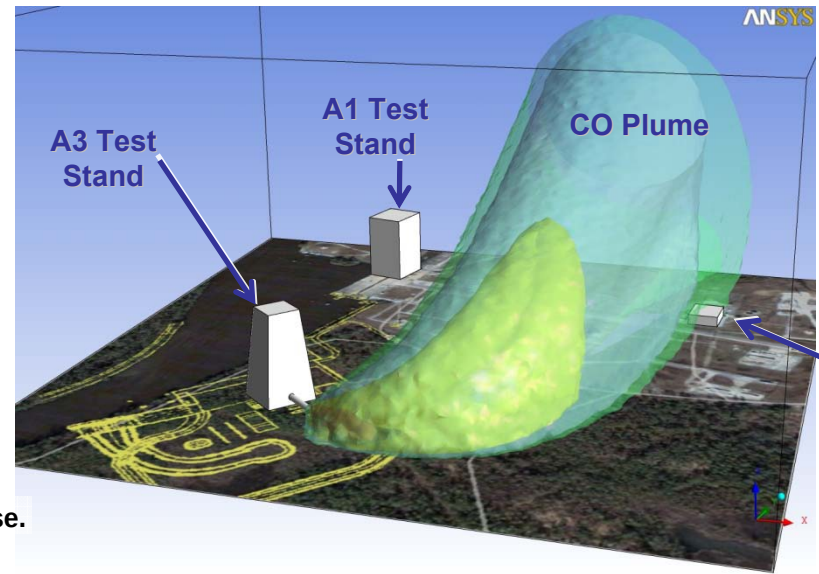
- Simulation results post processed to reveal CO Isosurfaces at specified parts per million levels

25ppm : ACGIH 8 Hour Average Limit
50ppm : OSHA 8 Hour Average Limit
200ppm: NIOSH No exposure Ceiling
1200ppm : Immediate Danger to Life

- Plots below show steady state results for 35mph South wind
  - Orange and red arcs on figure to left show maximum extent of 200ppm and 1200ppm concentration with varying wind direction at 35mph wind speed
- Animation shows transient results for 300 second test

  (maximum planned duration 650 seconds)



# Next Steps



- Simulation results used to determine exclusion zones during testing and possible modifications to other facilities

- Model verification by environmental monitoring (subscale diffuser)

# Conclusions



- Computational Fluid Dynamics proved to be a valuable tool for modeling dispersion of the CO plume from operation of A3 Test Stand
- CO levels may be between 50ppm and 200ppm in the occupied areas given the right wind conditions
- Max test duration is less than 11 min and CO then disperses rapidly (less than 1 minute)
- 8 Hour time weighted average exposure less than 5ppm