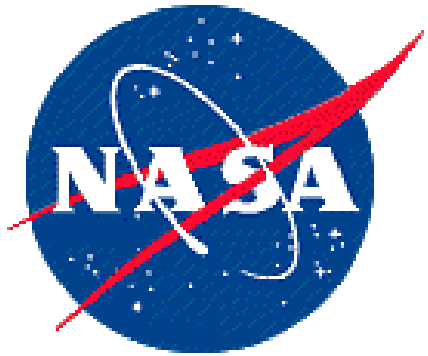


John C. Stennis Space Center

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

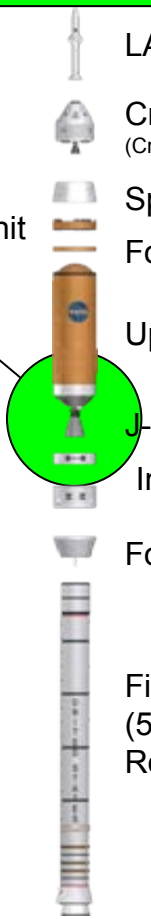
Constellation Program

Stennis Space Center

Constellation Launch Vehicles

Stennis Space Center

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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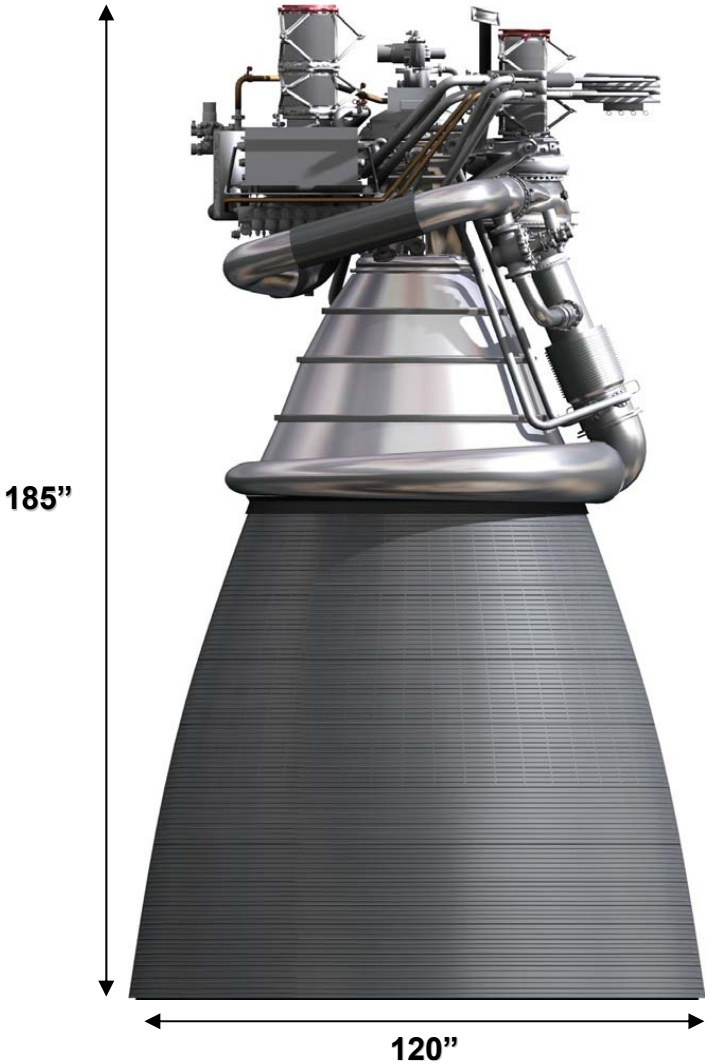

- Weight: 5,450 lbs
- 294,000 lbs of thrust primary mode for Ares I low-Earth orbit
- 242,000 lbs of thrust secondary mode for Ares V Earth departure stage

A-3 Test Stand

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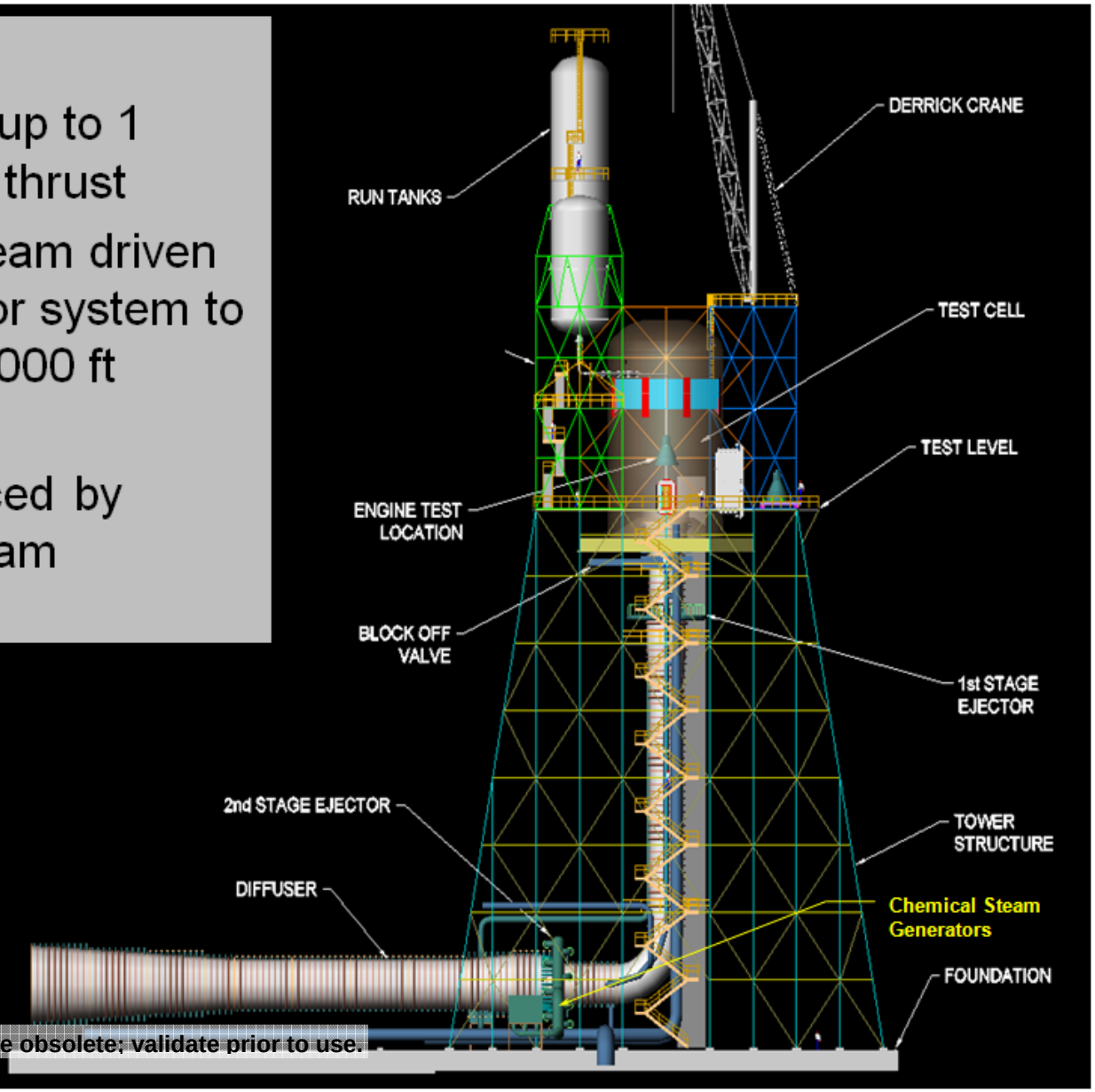
- 300 feet tall
- Test engines up to 1 million pound thrust
- Two-stage steam driven diffuser-ejector system to simulate 100,000 ft altitude
- Steam produced by Chemical Steam Generators



Chemical Steam Generators

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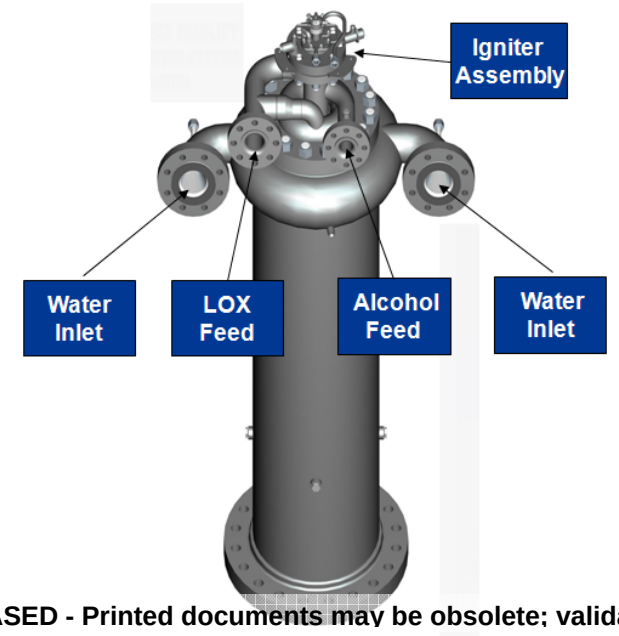
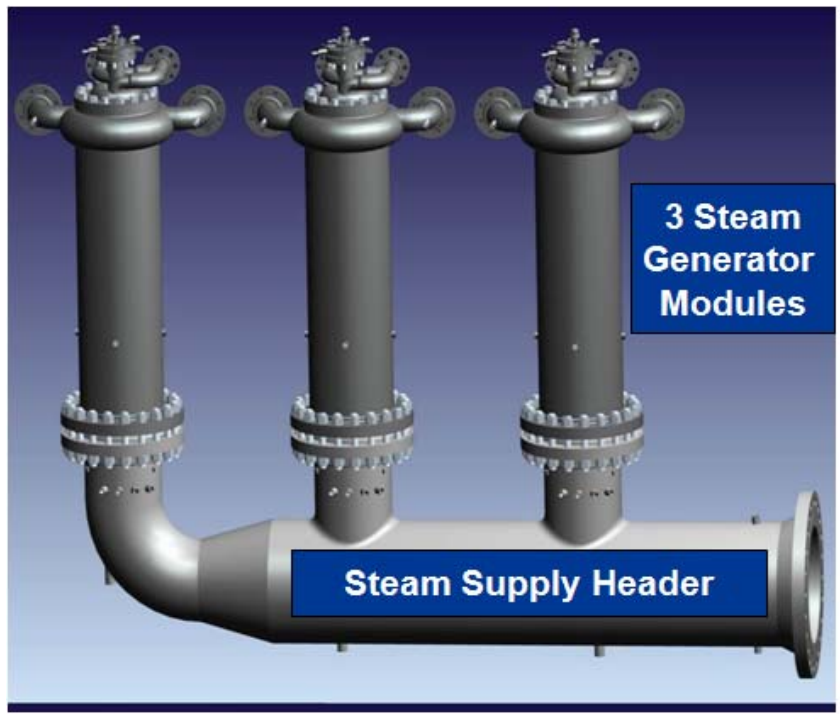
CSG Module

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



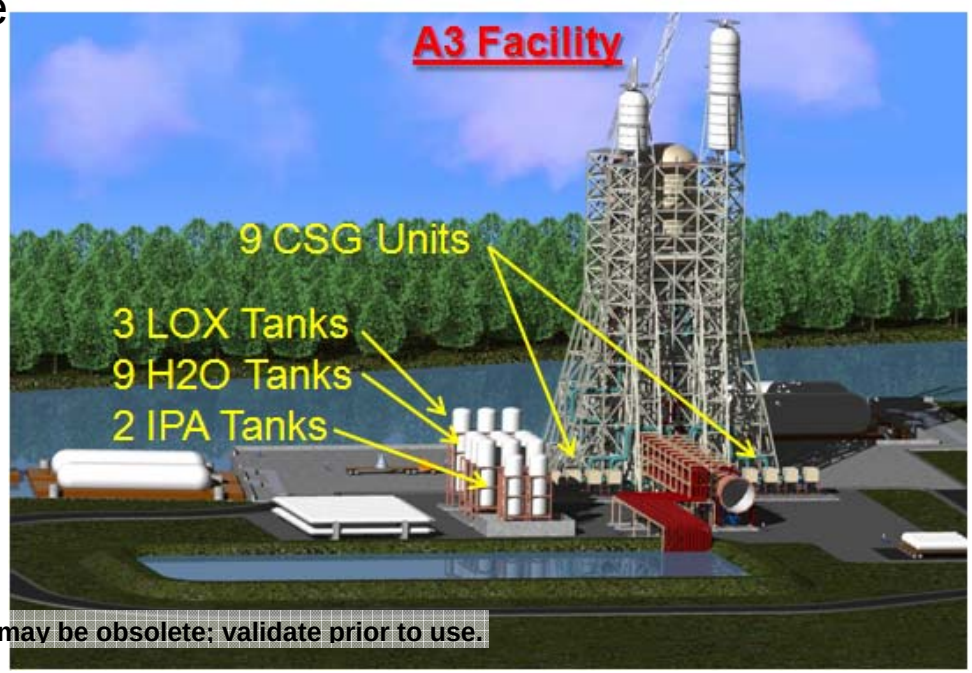
CSG Unit

- 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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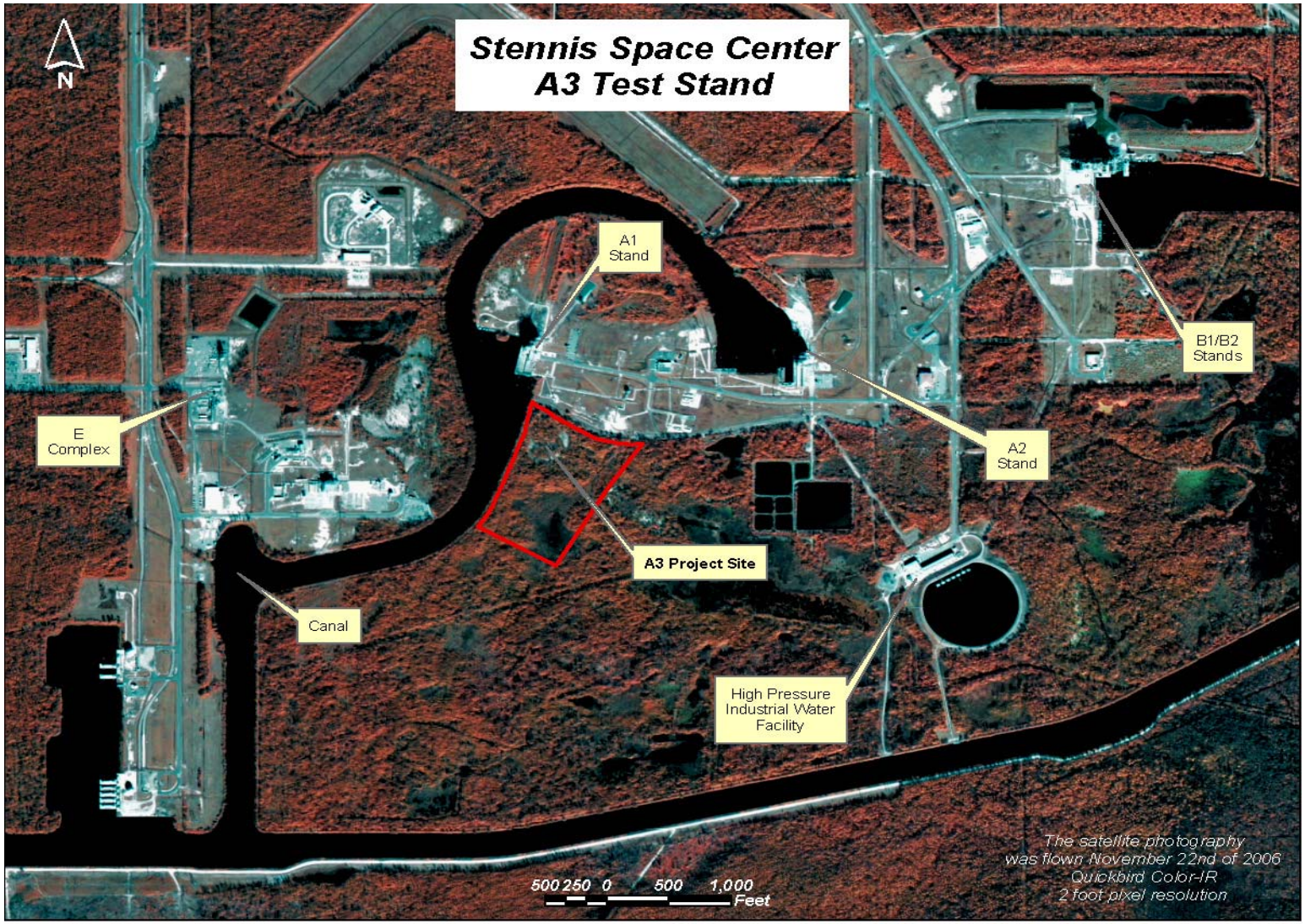


Computational Fluid Dynamics

- 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

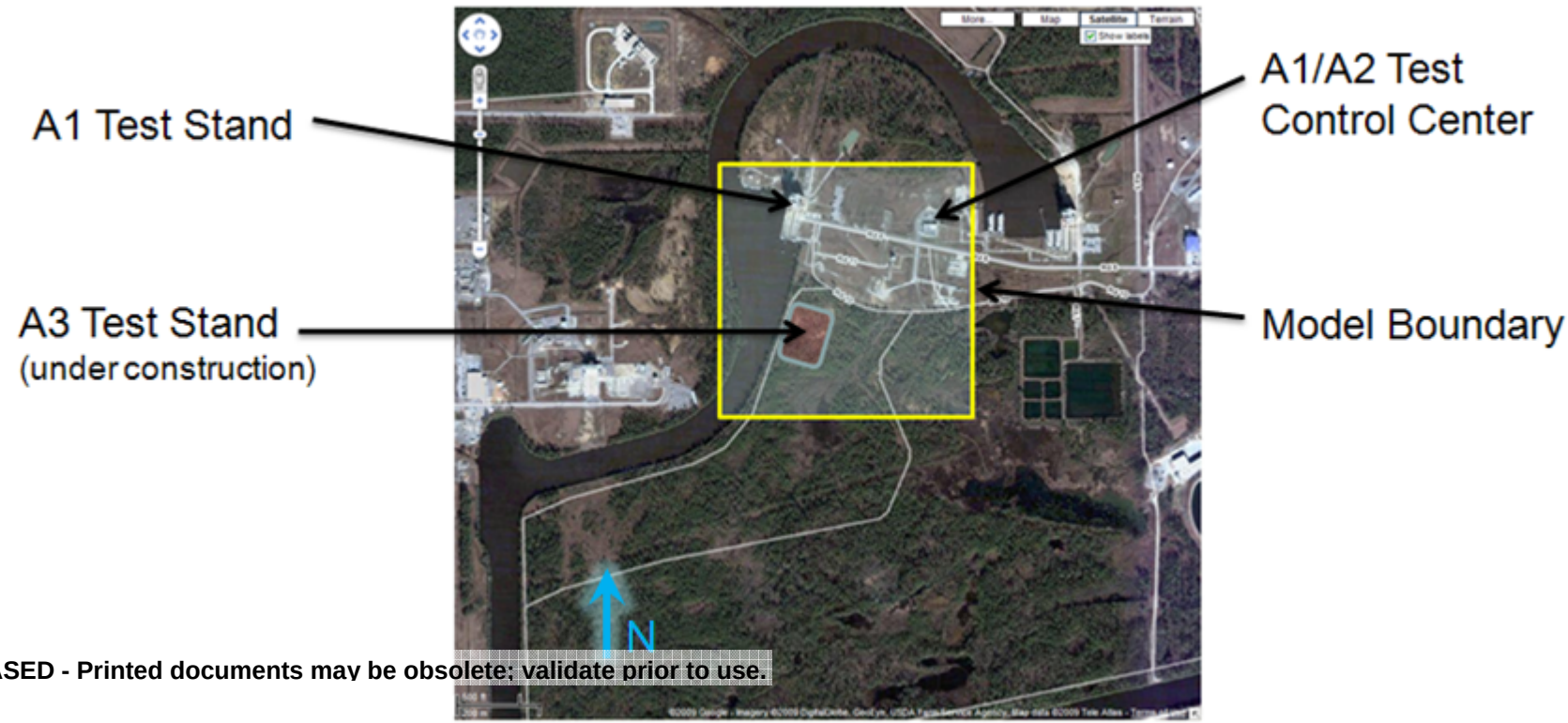
Computational Tools

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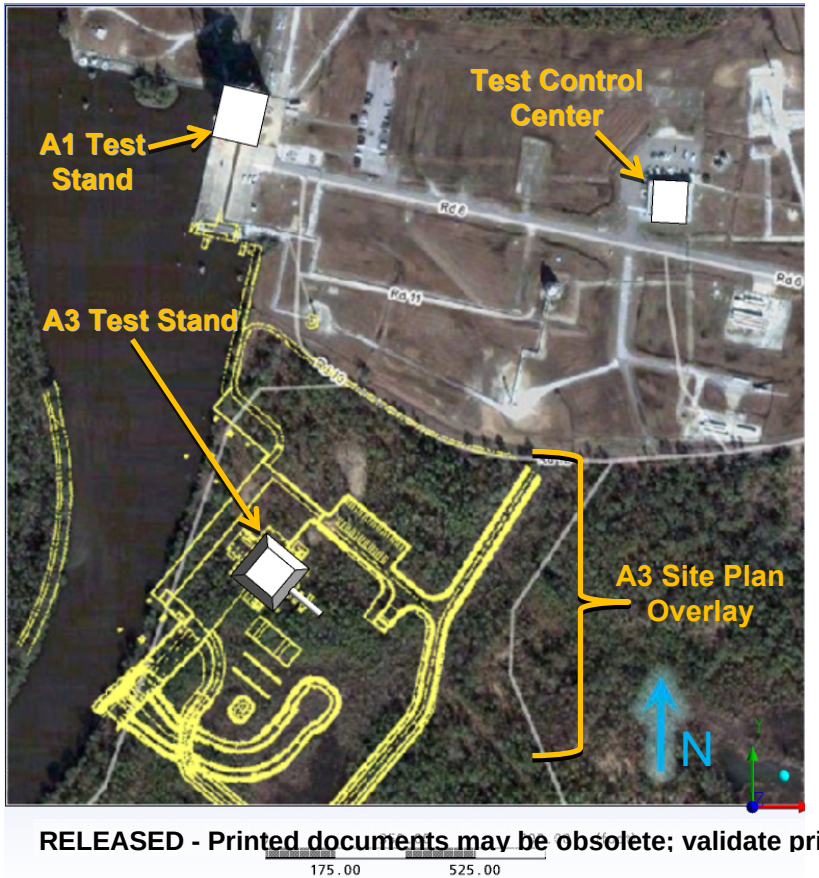
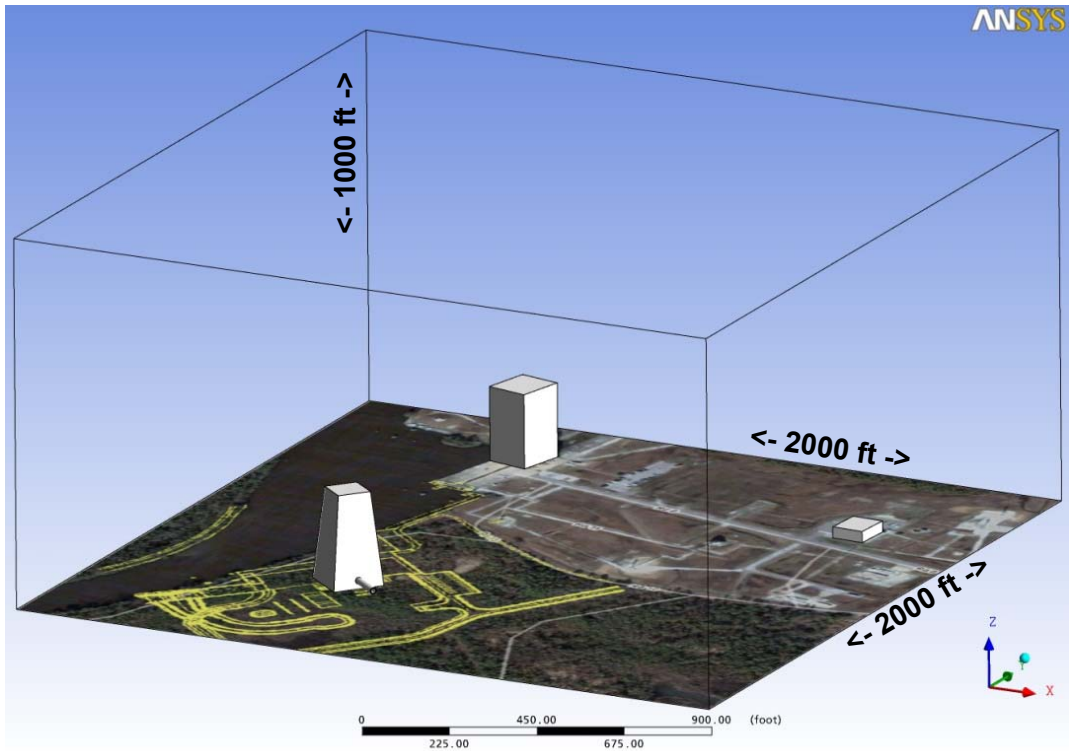
- **Steady State analyses completed for 9 wind conditions**
  (No wind & 35 mph N, NE, E, SE, S, SW, S, & NW)
- **Transient analysis completed for southerly 35 mph wind**

Model Plan View



Model Isometric View



CO Model Results

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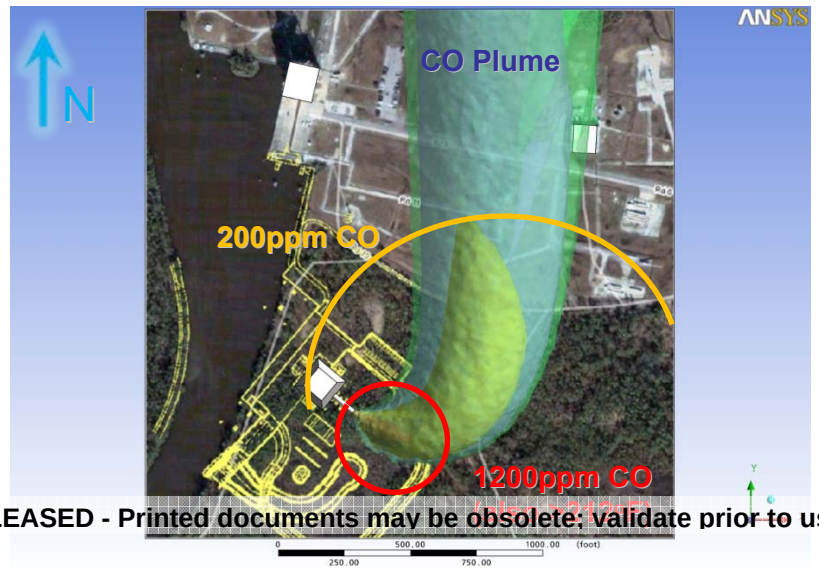
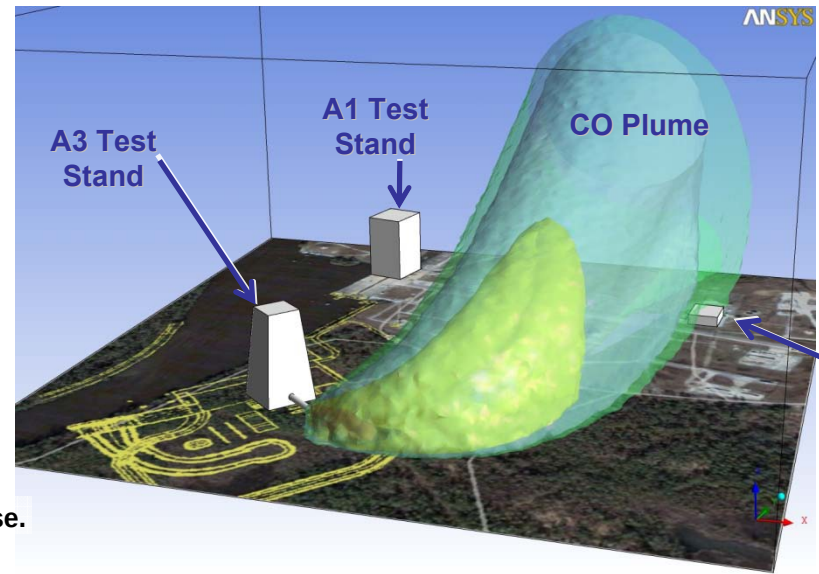
- Simulation results post processed to reveal CO Isosurfaces at specified parts per million levels

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