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

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Constellation Program

Develop a new space transportation system to travel beyond low Earth orbit, establish a sustained human presence on the moon, and then go on to Mars.
SSC will test and certify the Ares I and Ares V upper stage engines...

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

Crew Launch Vehicle

Cargo Launch Vehicle

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J2X Engine

- 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

- 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

**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

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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 (H₂O, CO₂, CO, trace hydrocarbons)
  - 31,853 kg (35.1 tons) CO predicted to be released during each 650 second test

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Emission Estimates

- Lewis Model
- Emissions data from WSTF from circa 1980

<table>
<thead>
<tr>
<th>Component</th>
<th>% by Volume</th>
<th>% by Mass</th>
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<tbody>
<tr>
<td>Methane</td>
<td>0.176</td>
<td>0.14</td>
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<tr>
<td>Ethylene</td>
<td>0.035</td>
<td>0.05</td>
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<tr>
<td>Acetylene</td>
<td>0.049</td>
<td>0.06</td>
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<tr>
<td>Ethane</td>
<td>0.007</td>
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<td>Propane</td>
<td>0.014</td>
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<td>Propane</td>
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<tr>
<td>Isopropanol</td>
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<tr>
<td>Other Hydrocarbons</td>
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<tr>
<td>CO2</td>
<td>6.65</td>
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<td>CO</td>
<td>1.52</td>
<td>2.09</td>
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<tr>
<td>H2</td>
<td>1.06</td>
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<td>O2</td>
<td>3.86</td>
<td>6.05</td>
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<tr>
<td>N2</td>
<td>0.74</td>
<td>1.02</td>
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<tr>
<td>H2O</td>
<td>85.71</td>
<td>75.69</td>
</tr>
</tbody>
</table>

- 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

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Located in Existing Test Complex

Stennis Space Center

Stennis Space Center
A3 Test Stand

A1 Stand
A2 Stand
A3 Project Site
High Pressure Industrial Water Facility
E Complex
Canal
B1/62 Stands

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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 2nd 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
CO Modeling

- 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

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CO Model Results

- 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

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