# Towards the Enhancement of Aircraft Cargo Compartment Fire Detection System Certification using Smoke Transport Modeling

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FAA Technical Center

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Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed-Martin Company,
for the United States Department of Energy under Contract DE-AC04-94AL85000.

# Project Purpose

## Provide a reduction in the cargo compartment false alarm rate (currently 200:1)

**Direct Costs of Diversion**

- **Estimated at $30,000- $50,000**

**Indirect Cost of False Alarms**

- **Increased risk due to landing at unfamiliar or less adequate airports**
- **Loss of confidence in detection systems**
- **Risk of passenger or crewmember injuries during evacuation**

Information and image provided by David Blake of the FAA Technical Center

# Project Collaborators

FAA Technical Center

- Define standard fire sources for detection.
- Conduct cone calorimeter experiments to characterize fire source and full scale experiments for model validation.

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- Develop computational fluid dynamics simulation tool to predict the transport of heat, smoke and gases throughout an aircraft cargo compartment.


- Develop miniature gas sensors for use in fire detectors.
- Provide funding for CFD model development and validation.

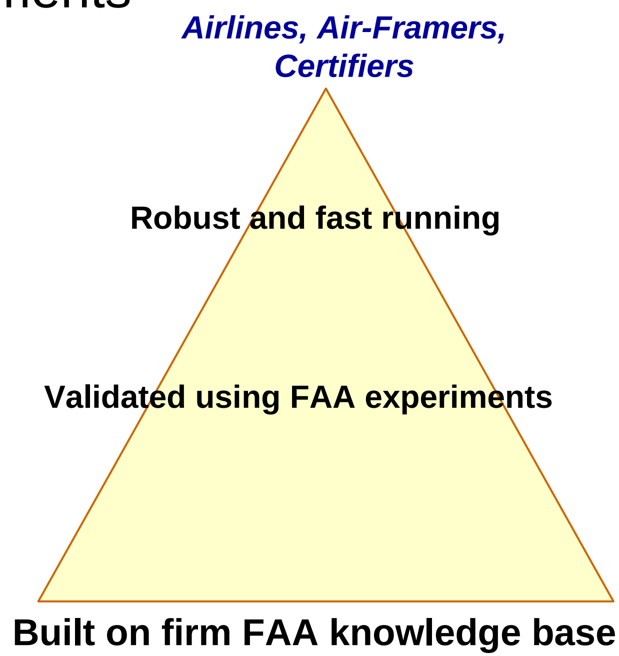
NIST
National Institute of Standards and Technology

- Evaluate the response of existing aircraft smoke detectors to actual fires and to nuisance alarm sources.
- Recommend sensor combinations and alarm algorithms to discriminate between the two.

# Modeling Smoke Transport in Aircraft Cargo Compartments

Goal: Develop a CFD-based simulation tool to predict smoke transport in cargo compartments

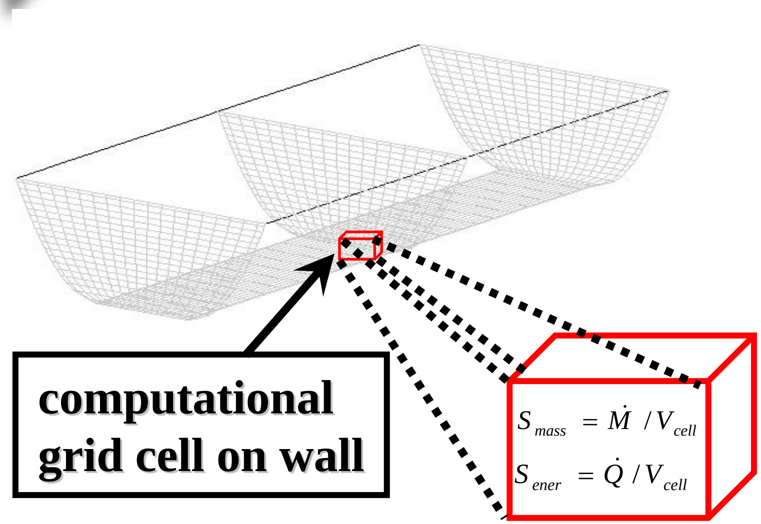
- Improve the certification process
  - Identify optimum smoke detector locations
  - Specify sensor alarm levels
  - Identify most challenging fire locations
  - Reduce the number of flight tests
- Fast running
- Suitable for non-expert users
- Experimental data for source term characterization from FAA experiments
- Validated using FAA full-scale experiments

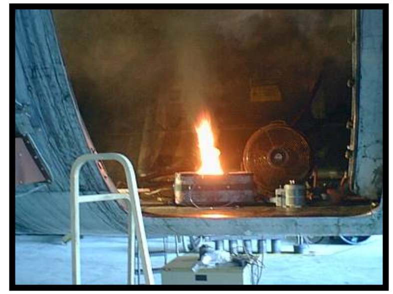


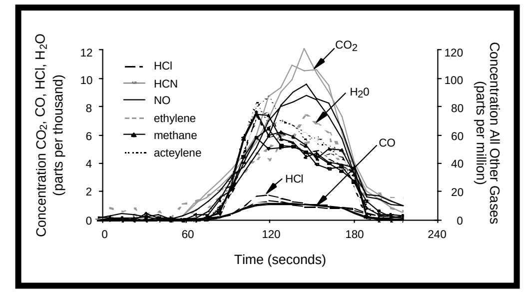
# Sandia National Laboratories Team Members

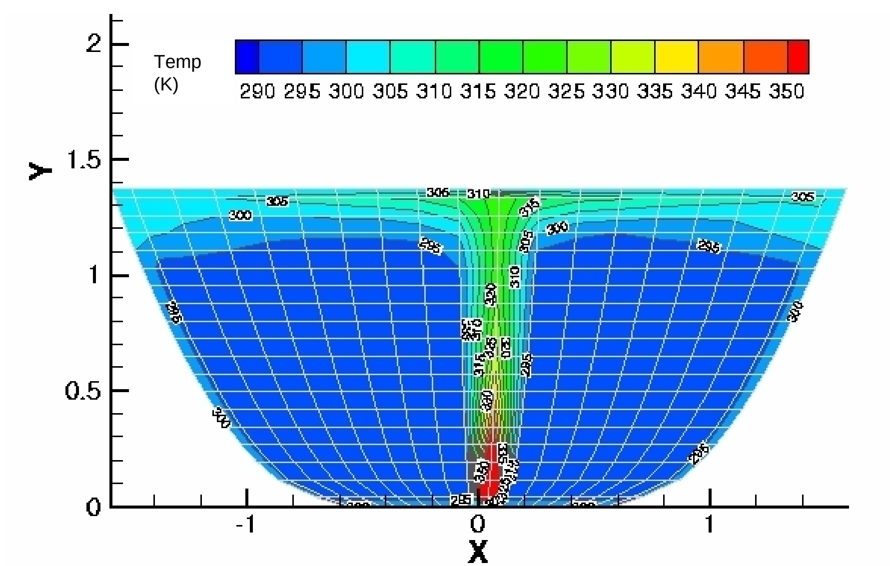
- Experimental
  - Walt Gill and Jill Suo-Anttila
- Code Development
  - Anay Luketa-Hanlin, Jim Nelsen, and Stefan Domino
- Graphical User Interface and Code Development
  - Carlos Gallegos

# Smoke Transport Analysis Code






- Curvature of compartment is resolved on grid
- HRR, MLR are time varying inputs (as measured in FAA experiments)
- Species tracking: presently soot, CO, and $CO_2$ but addition of more or different species possible
- Simulation time = 1 hour per minute of real time
- Validated using FAA full-scale experiments

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# Verification via the Method of Manufactured Solutions

***Navier Stokes Equations***

This section introduces the momentum and continuity equations as they are implemented in the FAA code. The momentum equations are assumed to have the form,

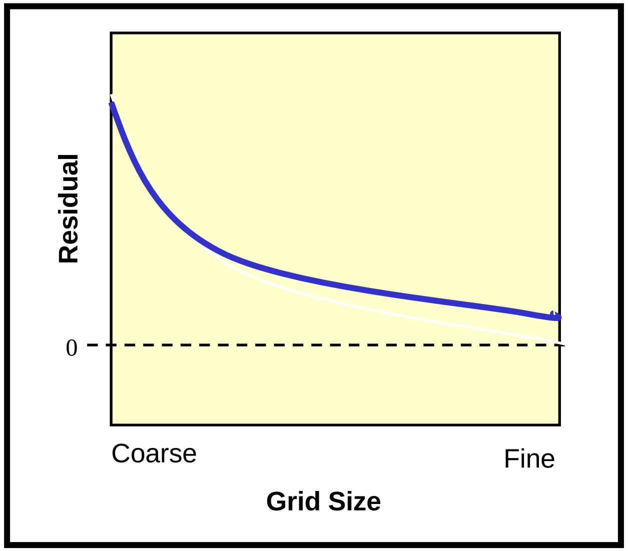
$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left\{\mu(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\right\}+S_{mom,i}\,.$$

The continuity equation has the form,

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u_i)}{\partial x_i}=S_{cont}\,.$$

***Calculations***

A solution to the equations is assumed (u, v, w, P) and the source term required so that the solution satisfies the equations is derived. The Navier-Stokes Equations are solved with the source term added  and the solutions should converge to the assumed solution if the numerics are correct.



# Verification of the Smoke Transport Model

***Source Terms***

This section introduces the momentum and continuity source terms that are required so that the manufactured solution,

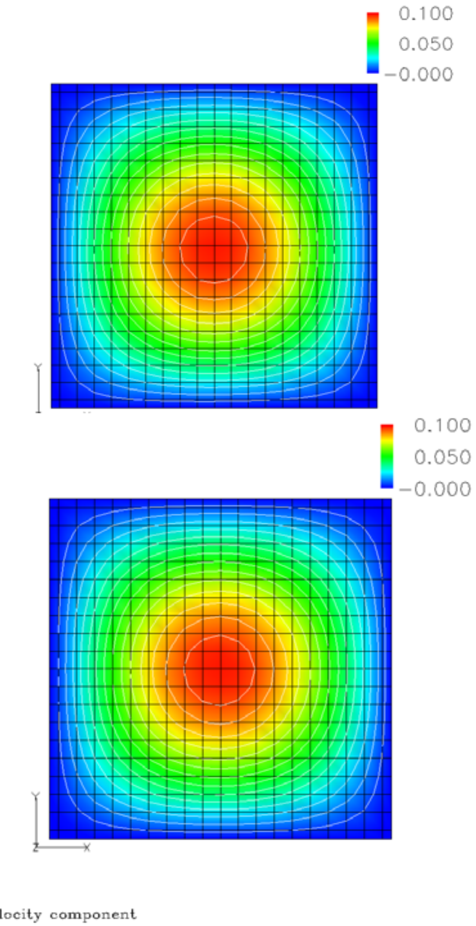
$$u(\mathbf{x},t) = U_0 t^2 \cos(\kappa x)\sin(\kappa y)\sin(\kappa z)$$

$$v(\mathbf{x},t) = U_0 t^2 \cos(\kappa x)\sin(\kappa y)\sin(\kappa z)$$

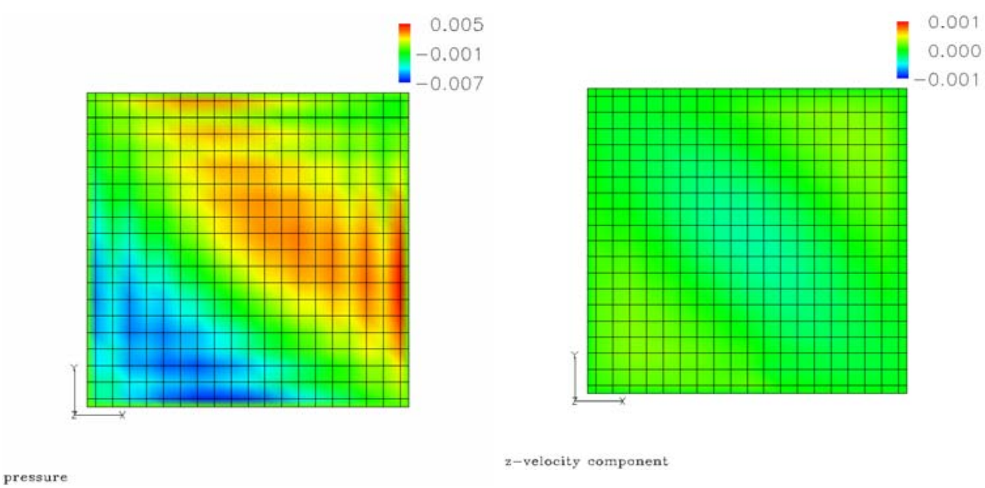
$$w(\mathbf{x},t) = 0$$

$$P(\mathbf{x},t) = 0$$

satisfies the laminar Navier Stokes equations as programmed in the FAA code.
(simulations performed by Tom Voth)

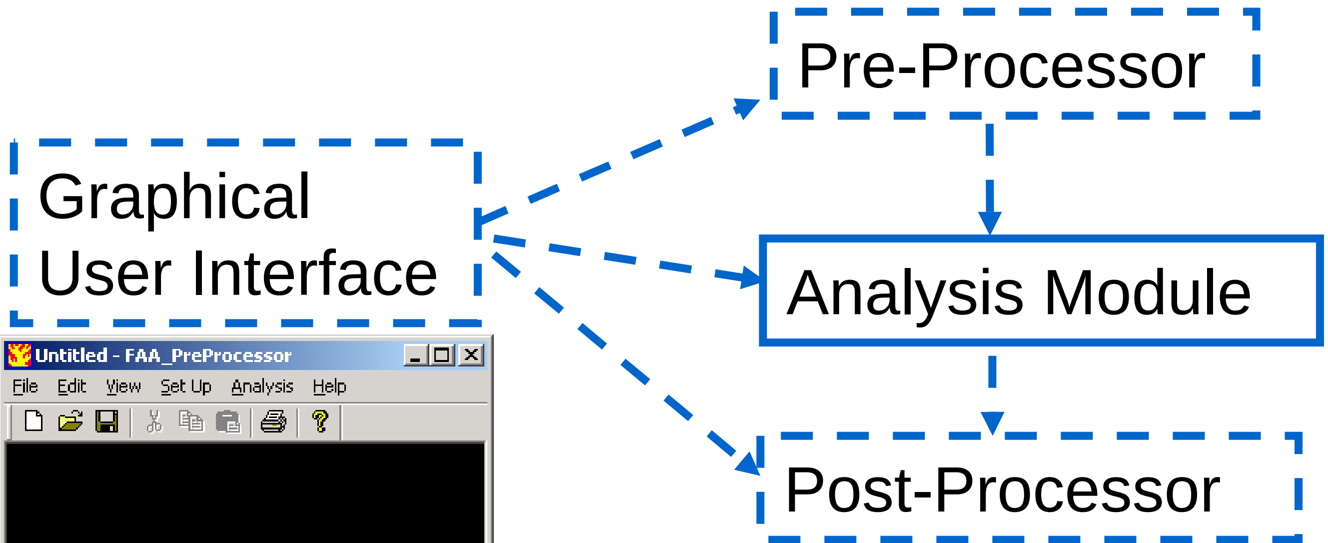


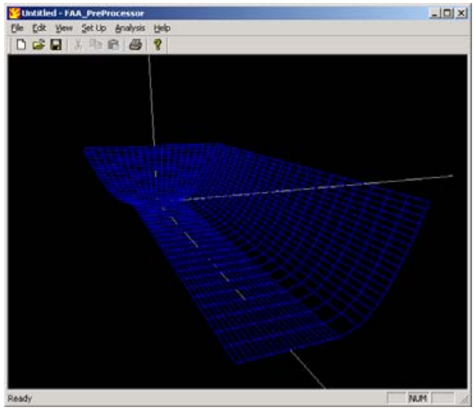

Predicted x and y-velocity components



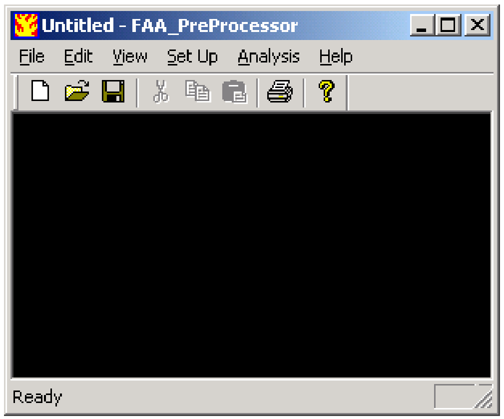

Predicted pressure and z-velocity component at time = 1, Uo=0.1

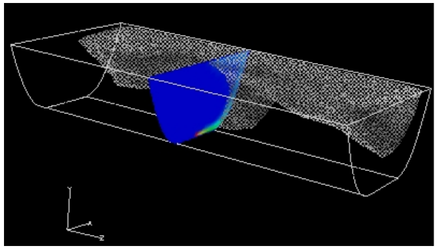
# Software Design



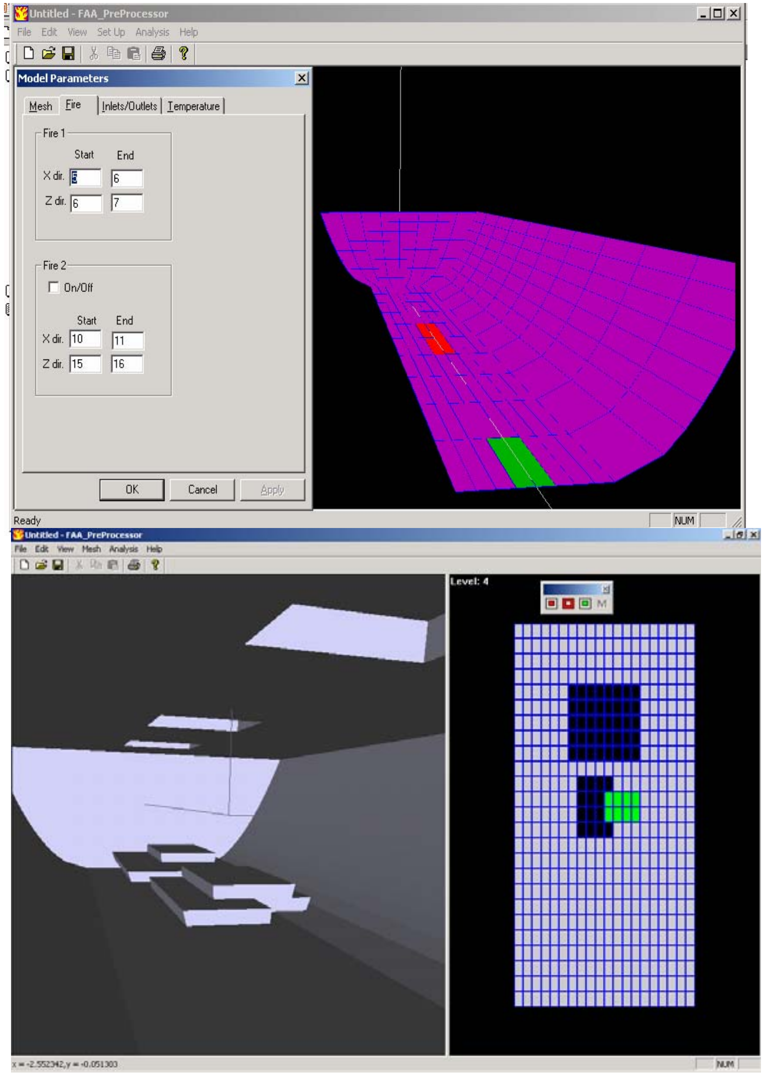
$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = S_m^p$$



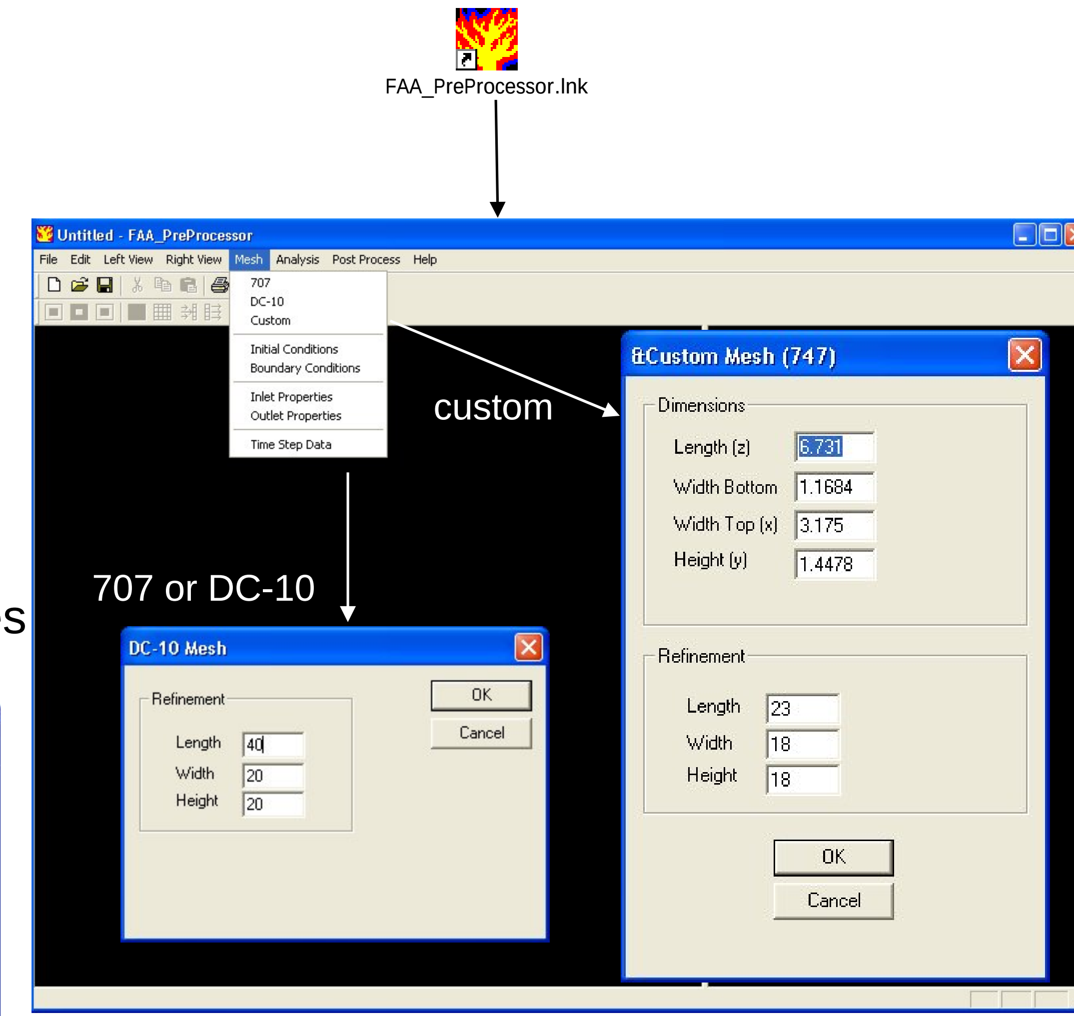
# Pre-Processor Overview

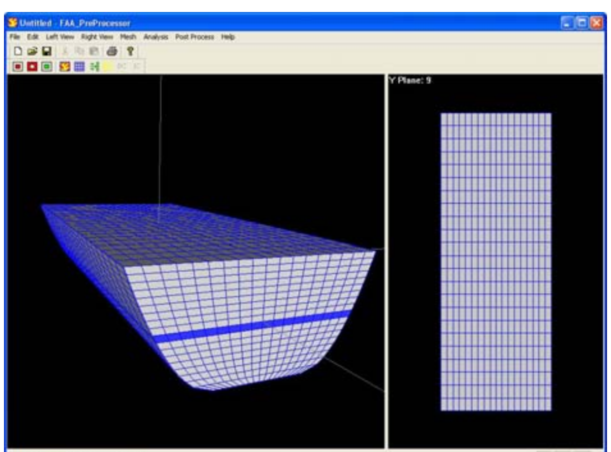
- Provide models for different aircraft
  - Boeing 707
  - DC8, DC10
  - User defined (curved or straight walls)
- Capabilities
  - Refine mesh
  - Enter fire(s) location and type
  - Enter ventilation velocities and locations
  - Enter compartment temperature and pressure
  - Add obstacles and recessed areas
- Instantaneous visual feedback



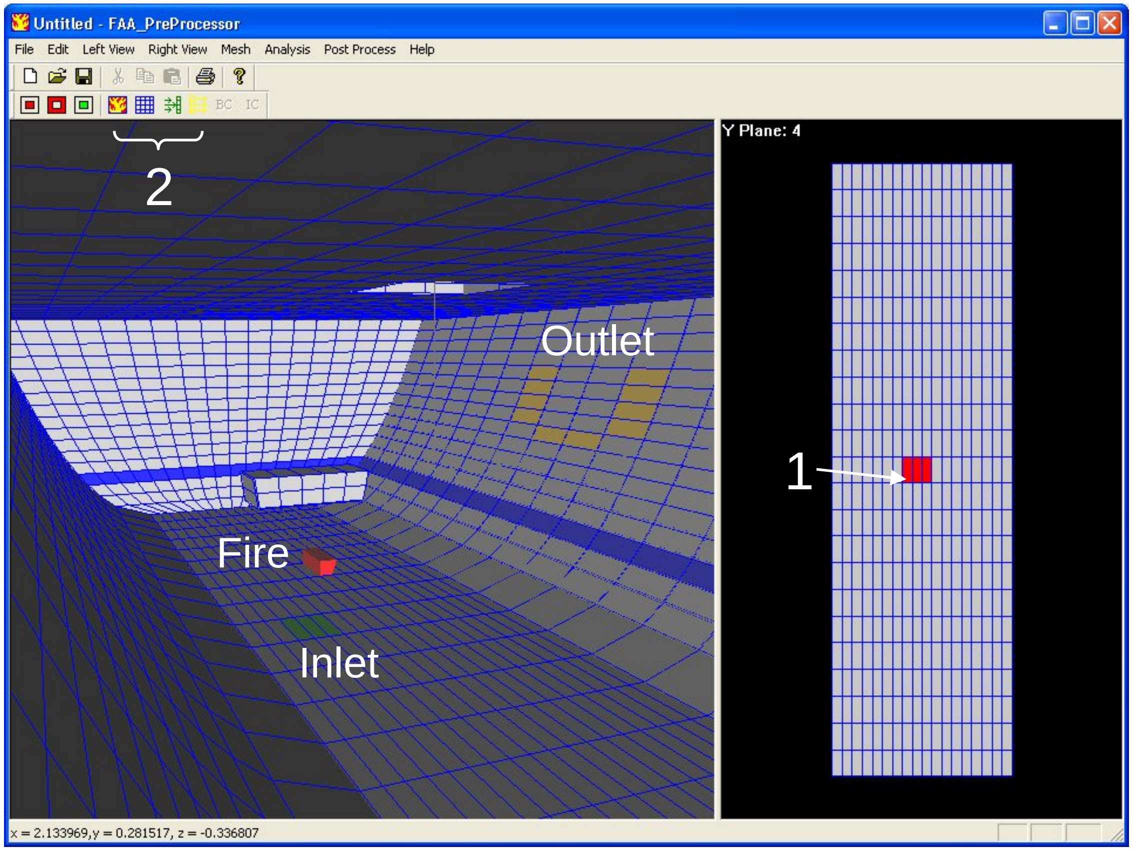
# Running a Simulation
# Compartment and Mesh Specification

- Execute the Pre-Processor
- Select the type of compartment
  - 707
  - DC-10
  - User Defined
- Input the dimensions
- Enter the mesh size - # of nodes
- Refine, add features and obstacles

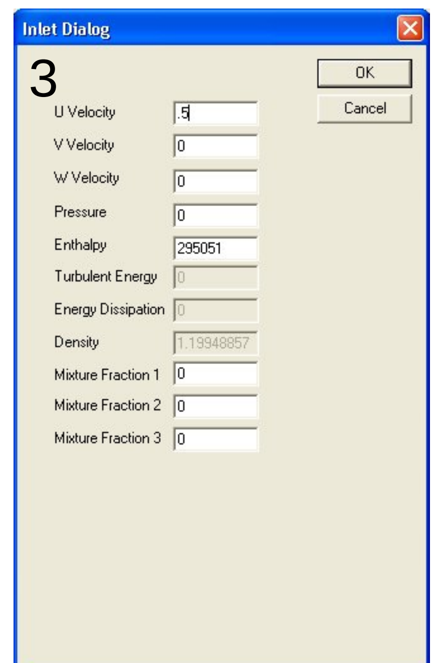


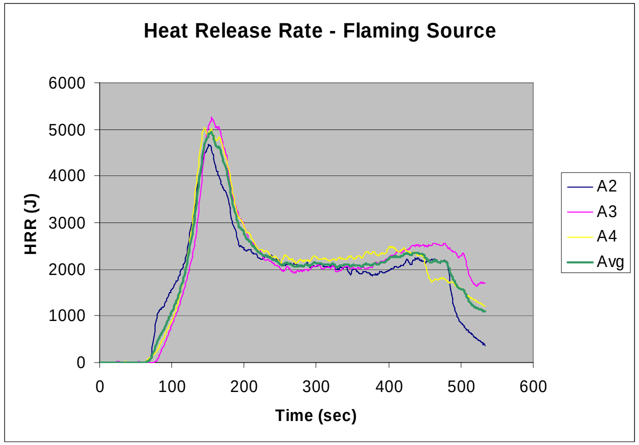
# Running a Simulation
# Ventilation and Fire Specification

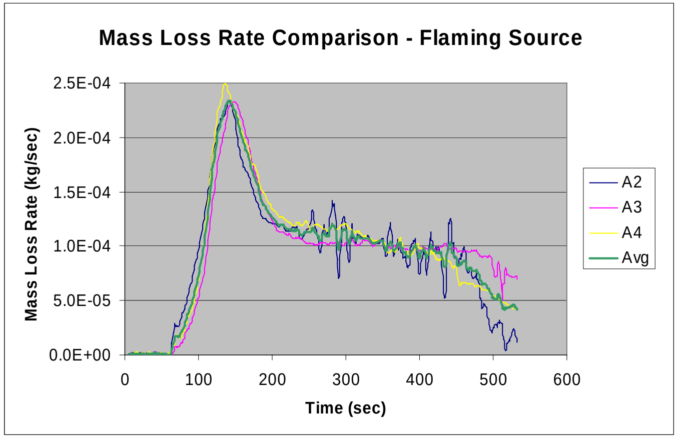


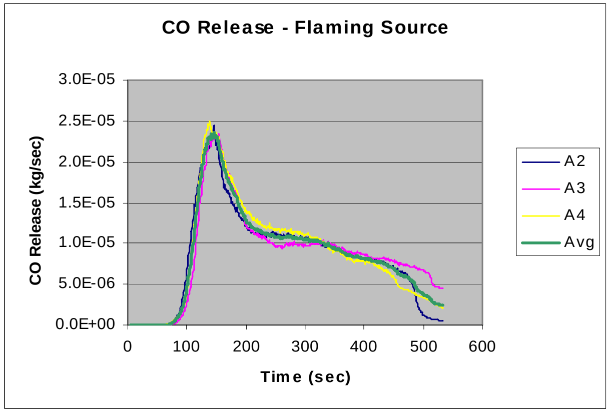

1. Select cells
2. Enter type of cell (inlet, outlet, fire) – cell colored to denote type
3. Use table to enter ventilation properties
4. Fire properties in file

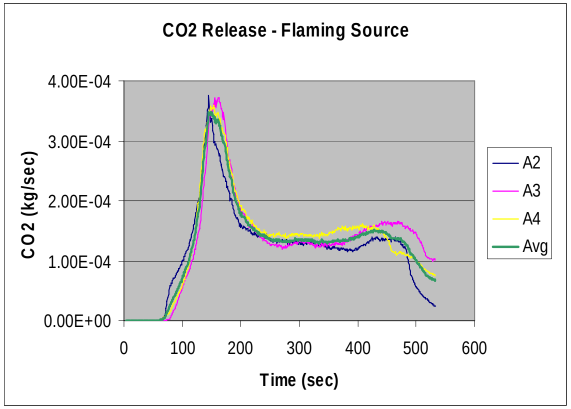


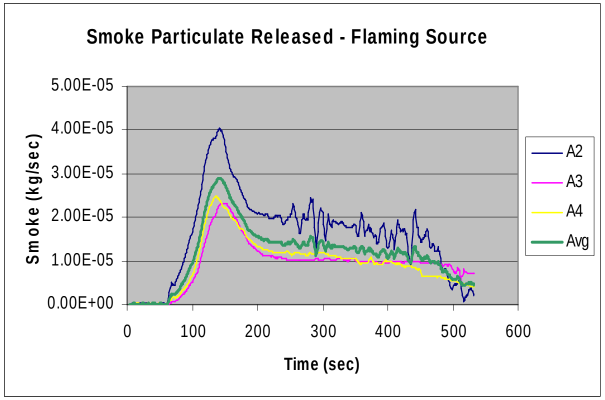
# Flaming Source Characterization



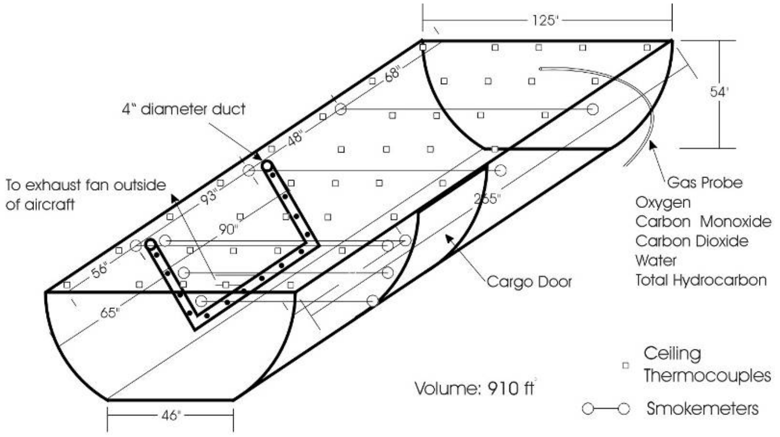



# FAA Full-Scale Validation Experiments

- **Validation Experiments**

| Factor | Number of Levels | Specification |
|---|---|---|
| Fire location | 3 | Center, Curved Wall, Corner |
| Ventilation | 2 | None, forced |
| Geometry | 2 | 707, DC10 lower |

- **Baseline (center, 707, no ventilation)**
- **Instrumentation**
  - **40 ceiling thermocouples**
  - **3 gas analyzer locations**
  - **6 smokemeters**

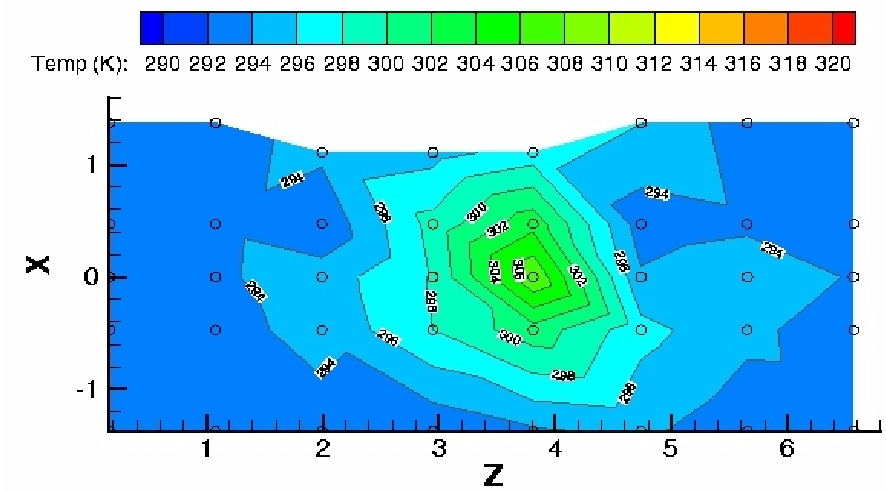


# FAA Full-Scale Validation Experiments

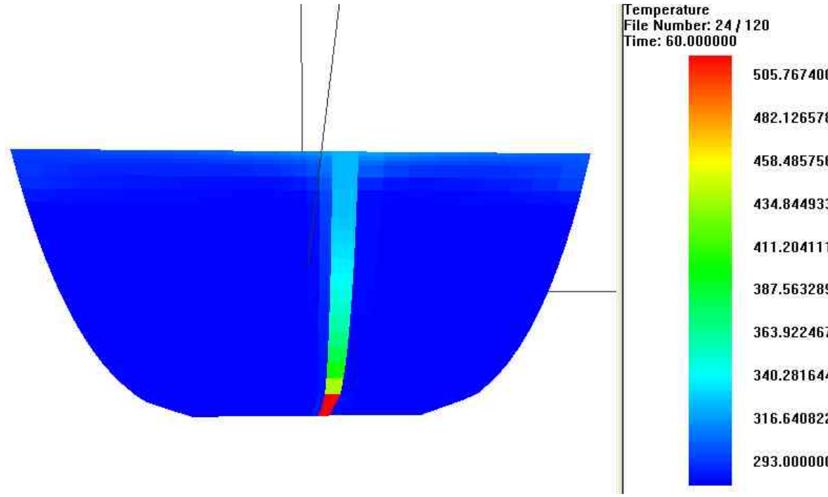
- 707 experiments
  - Baseline – center fire
  - Attached – sidewall fire
  - Corner – corner fire
  - Determined leakage ventilation had no impact on data
  - All 707 experiments were conducted without ventilation
- DC-10 experiments
  - Forced ventilation

# Code Validation Metrics (707)

- Thermocouple temperature rise
  - 0 - 60 seconds
  - 0 -120 seconds
  - 0 -180 seconds
- Light transmission
  - 30 and 45 sec (ceiling and vertical)
  - 60 sec (vertical - high, mid, low)
  - 120 sec (vertical - mid and low)
  - 180 sec (vertical - mid and low)
- Gas species concentration rises
  - 0 - 60 seconds
  - 0 -120 seconds
  - 0 -180 seconds



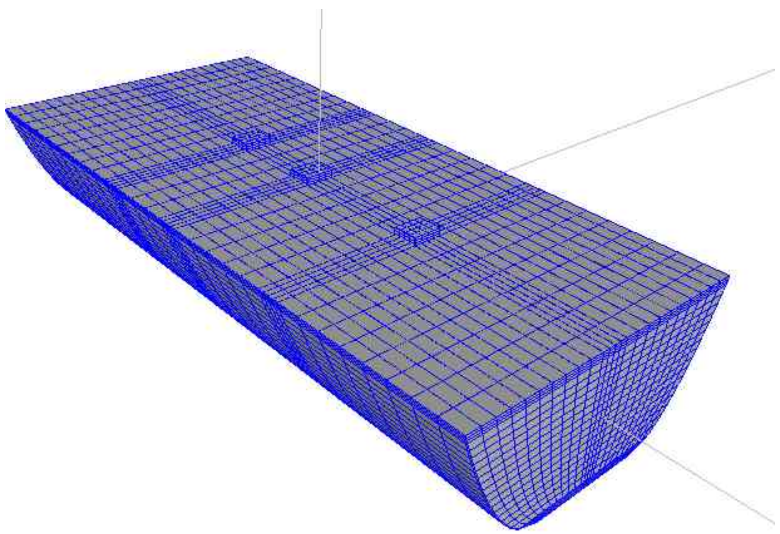

Experimental ceiling temperature distribution at 60 sec



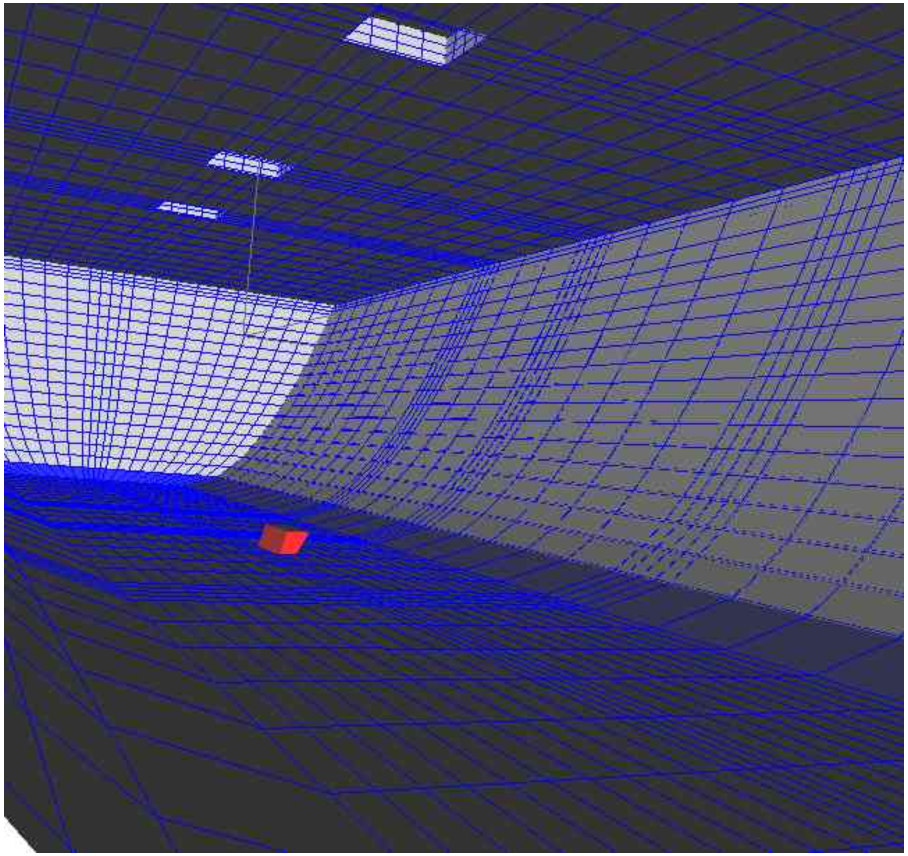

Computational temperature distribution at 60 sec

# 707 Validation Simulations

- Interface described used to create mesh and run simulation
- Example results and comparisons follow
- All comparisons documented in final validation report included with release

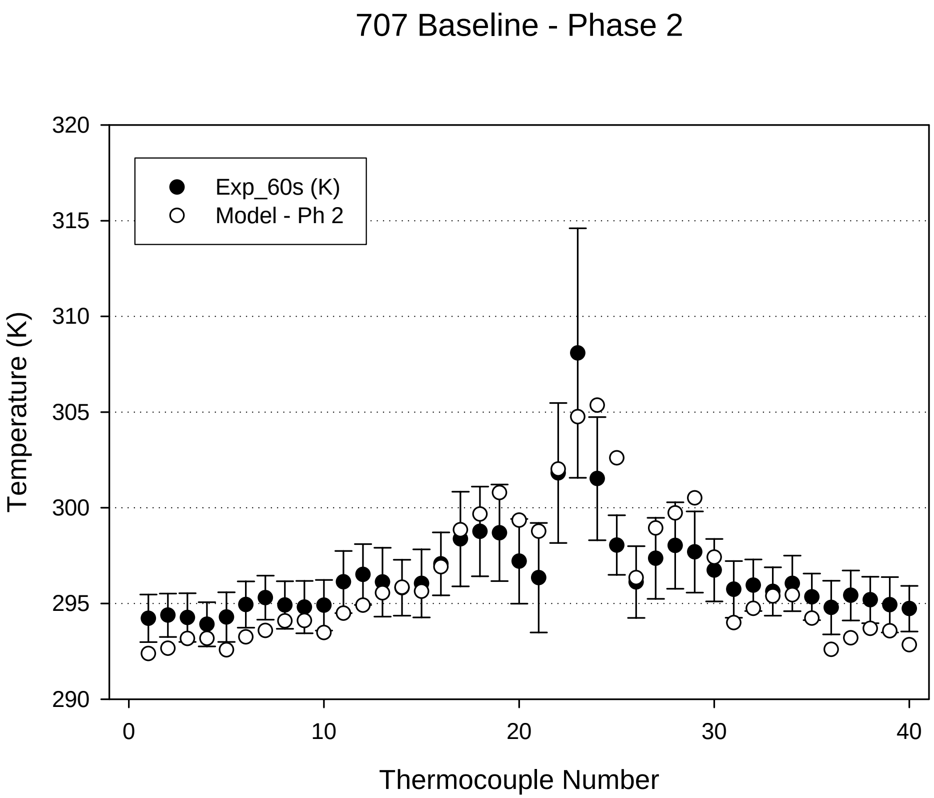


707 Baseline computational mesh

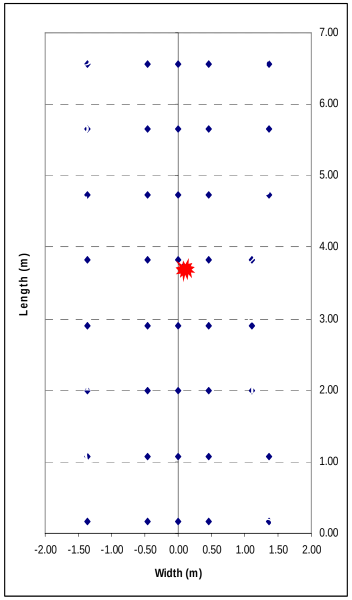


Internal view (showing fire and recessed areas) of 707 computational domain

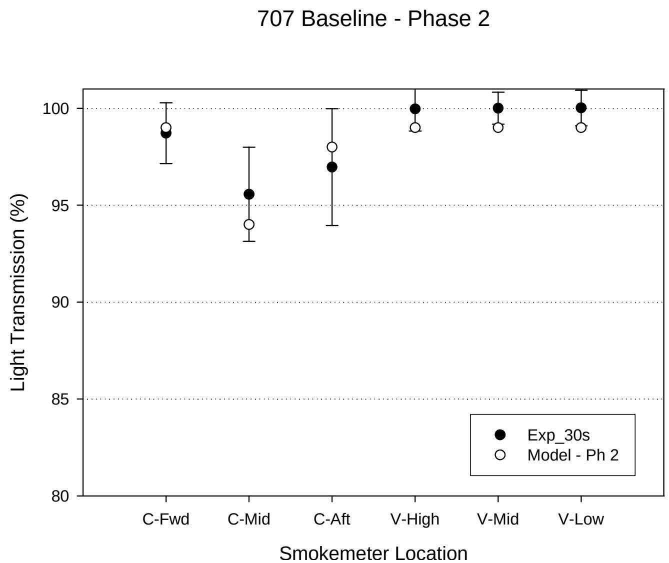
# 707 Validation – Temperatures

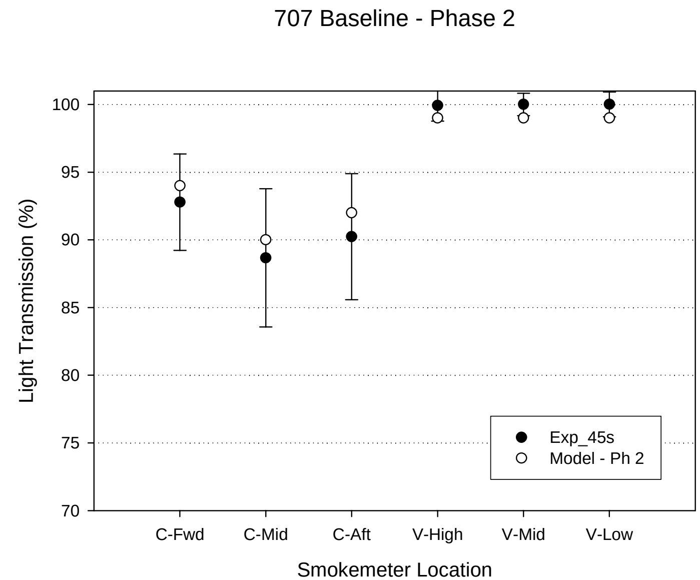


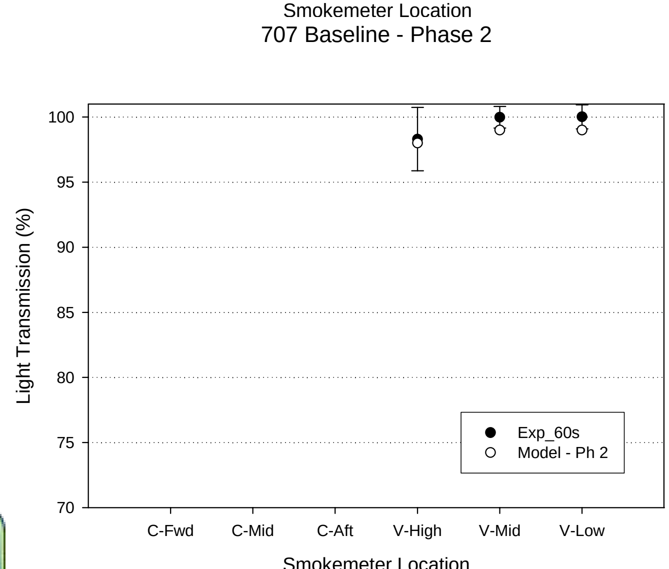

- Baseline 707 experiments
  - center fire
  - 40 thermocouples
  - Model including heat transfer to the ceiling and walls
  - h=7 $W/m^2K$ in model



# 707 Validation – Light Transmission

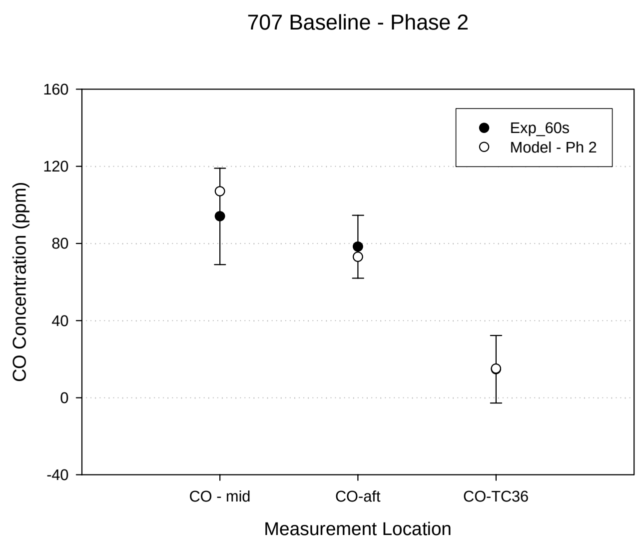


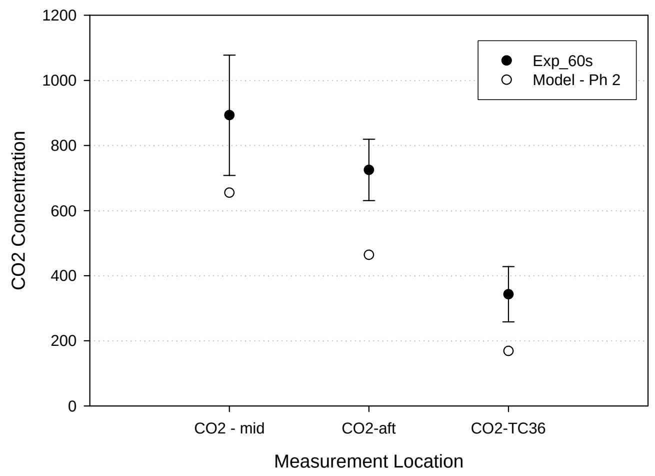




- Baseline 707 experiments
  - center fire
  - 6 smoke meters
- Comparison
  - Good agreement in trends and magnitudes
  - Best at 60 seconds and before (alarm required < 60 seconds)

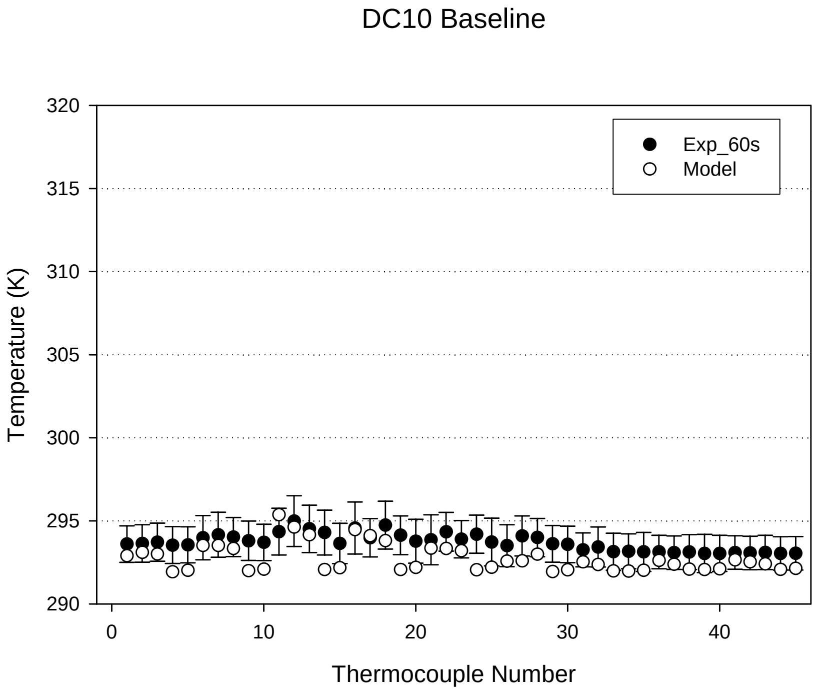
# 707 Validation – Gas Concentrations



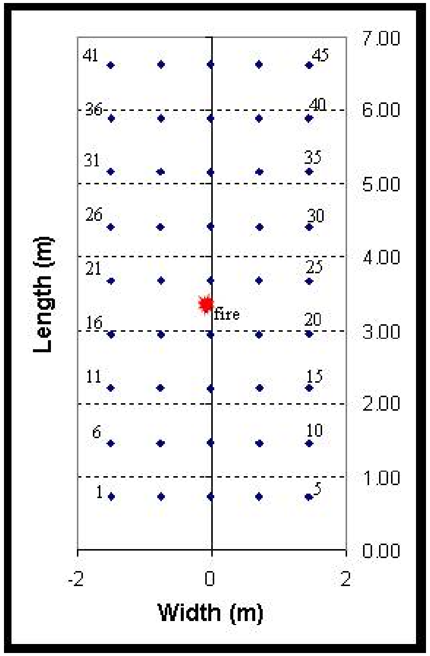




- Baseline 707 experiments
  - center fire
  - 3 gas analyzer positions
- Comparison
  - Good agreement in trends and magnitudes for CO
  - Magnitudes slightly low for CO2, although trends are good

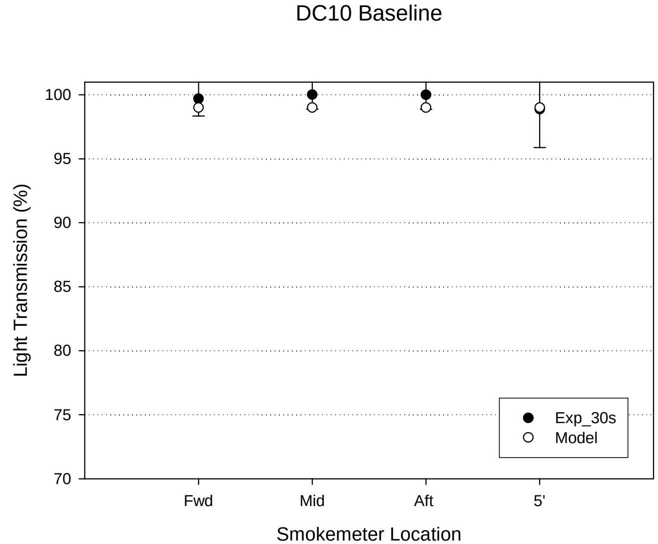
# DC10 Validation – Temperatures

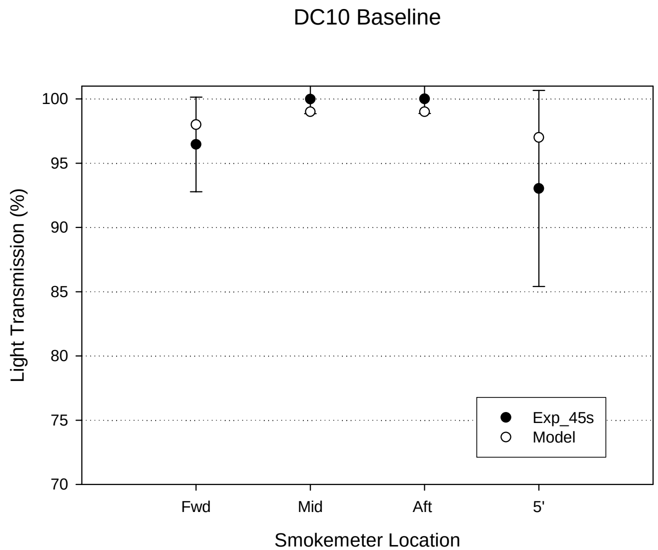


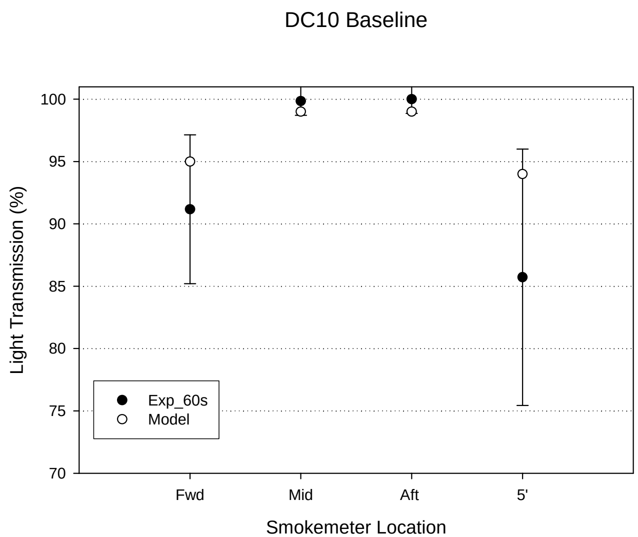

- Baseline DC10 experiments
  - center fire
  - 40 thermocouples
  - Model including heat transfer to the ceiling and walls
  - h=7 $W/m^2K$ in model
  - Small increase in temperatures



# DC10 Validation – Light Transmission

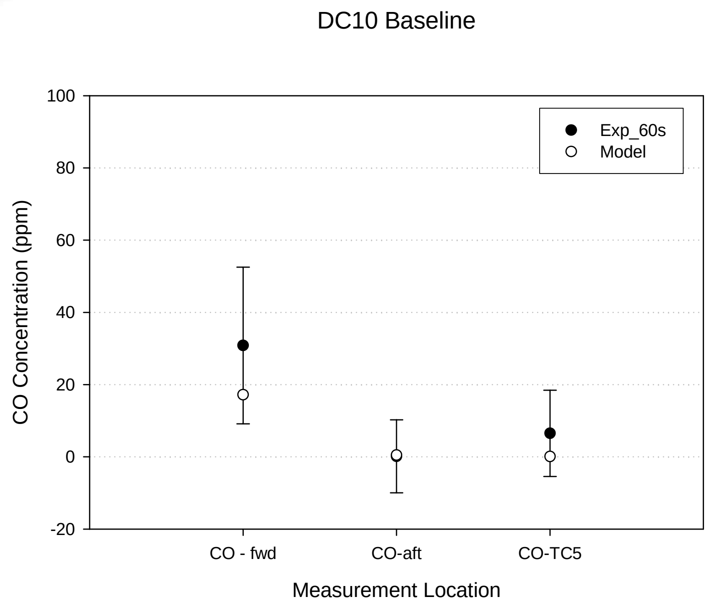


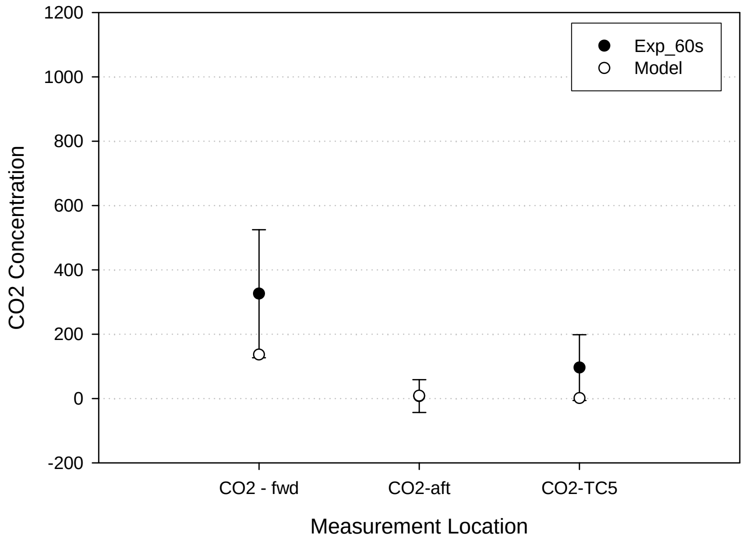




- DC10 experiments
  - center fire
  - 6 smoke meters
- Comparison
  - Good agreement in trends and magnitudes
  - Best at 60 seconds and before (alarm required < 60 seconds)

# DC10 Validation – Gas Concentrations




- DC10 experiments
  - center fire
  - 3 gas analyzer positions
- Comparison
  - Good agreement in trends and magnitudes for CO and CO2

# Code Release Website

- http://www.esc.sandia.gov/faa-stc/index.html
- Included documentation downloaded with the code
  - Theory and users manual
  - Verification and validation manual
  - Tutorial presentation
  - Example simulation