Modeling Smoke Transport in Aircraft Cargo Compartments

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**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 worst case 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

*Validated using FAA experiments*

*Built on firm FAA knowledge base*

*Robust and fast running*
Insight into Physical Processes

- FAA experiments helped identify four classes of cargo compartment fire scenarios
- Model capable of assessing these scenarios (curvature and packing issues addressed)
FIRE SIGNATURES

• Characterization of particulate emitted from potential sources (flaming, smoldering, simulated)

• FAA calorimeter experiments for source heat release, mass loss, and species information

TRANSPORT

• Full-scale facility for validation experiments
Smoke Transport Code Features

- Curvature of compartment is resolved on grid
- Arbitrary ventilation inlets and outlets can be specified
- Location and type of fire can be selected
- HRR, MLR are time varying inputs (as measured in FAA experiments)
- Species tracking: presently soot, CO, and CO\textsubscript{2} but addition of more or different species possible
- Simulation time on the order of hours

\[ S_{\text{mass}} = \frac{\dot{M}}{V_{\text{cell}}} \]
\[ S_{\text{ener}} = \frac{\dot{Q}}{V_{\text{cell}}} \]
Smoke Transport Code Demonstration Calculations

• Buoyant Plume
  – 10 sec flaming fire in the center of sealed compartment

• Attached Flow
  – 120 sec flaming fire near wall of sealed compartment

• Dual Fire
  – arbitrary fire and ventilation locations
Smoke Transport Code Demonstration Calculation
Buoyant Plume Scenario

- Total flaming experiment time of 300 seconds
- Flaming heat release data (top)
- CO/CO2 composition (bottom)
  - Near constant uniform split
    \[ Y_{\text{CO}_2} = 10 \times Y_{\text{CO}} \]
- CFD simulation performed with time-varying heat, mass, and compositions completed for data points between 180 and 190 s
- Maximum HRR of 2.5 KJ/s
 Smoke Transport Code Demonstration Calculation
Buoyant Plume Scenario

- Ten second simulation (1.7 hours of compute time for 10K grid points; Sun Ultra²).
- Temperature profiles shown; walls are adiabatic
- No specified ventilation
- HRR, MLR are time varying as measured in FAA experiments
- Species concentrations (CO, CO₂, soot) - aids in sensor selection and placement
Smoke Transport Code Demonstration Calculation

Buoyant Plume Scenario

probe location
Smoke Transport Code Demonstration Calculation
Attached Flow Scenario

- Flaming source in forward in 707 cargo bay - attached flow
- Flaming experiment time of 120s
- CFD simulation performed with time-varying heat, mass, and compositions
- Maximum HRR of 4 kJ/sec

[Graphs showing Heat Release Rate, Mass Release Rate, and Species Mass Fractions]
Smoke Transport Code Demonstration Calculation
Attached Flow Scenario

- 120 second simulation (~9 hours of compute time for 10K grid points; Sun Ultra²).
- Walls are adiabatic
- No specified ventilation
- HRR, MLR are time varying as measured in FAA experiments
- Species concentrations (CO, CO₂, soot) - aids in sensor selection and placement

Soot Concentration
Smoke Transport Code Demonstration Calculation
Attached Flow Scenario - Temperature

![Graph showing temperature distribution over time for Corner and Center Probes.](image)
Smoke Transport Code Demonstration Calculation
Attached Flow Scenario - Species

- CO/CO2 tracking could aid in sensor threshold selection and placement
- Soot concentration provides insight into particulate detectors
Smoke Transport Code Demonstration Calculation
Dual Source with Ventilation
Future Activities

• Finalize plan to verify and validate the smoke transport code

• Implementation of clutter model for tightly packed compartments

• Verification and validation of the code using:
  – Method of manufactured solutions
  – Experimental data in literature
  – FAA full-scale experiments

• Release of alpha version (Oct ‘02)