Smoke transport in an aircraft cargo compartment

Ezgi Öztekin[*], Dave Blake[**] and Richard Lyon[**]

[*] Technology and Management International (TAMI), LLC

[**] Federal Aviation Administration (FAA) William J. Hughes Technical Center

International Aircraft Systems Fire Protection Working Group

May 11-12, 2011

Koeln, Germany

Motivation

- FAA Federal Aviation Regulations (FAR) Part 25, Section 858:

  "If certification with cargo or baggage compartment smoke or fire detection provisions is requested, the following must be met …

  a. The detection system must provide a visual indication to the flight crew within one minute after the start of fire.

  …

  d. The effectiveness of the detection system must be shown for all approved operating configurations and conditions."

- Smoke detectors have high false alarm rates.
- Standardization of certification process is necessary.
- Ground and in-flight tests required for the certification process are costly and time consuming.

Objective

- FAA aims to
  - Allow for improved detector alarm algorithms, thereby the reliability of the smoke detectors,
  - reduce the total number of required tests,

by integrating computational fluid dynamics (CFD) in the certification process.

- The objective of the present study is to
  - assess predictive abilities of available CFD solvers for smoke transport when applied to aircraft cargo compartments.

Methodology

- CFD solver candidates:
  - Commercial solvers:
    - Fluent, …
  - Open source solvers:
    - FAA Smoke Transport Code
    - Fire Dynamics Simulator (FDS)
    - Code-Saturne
    - Jasmine
    - Sophie
    - FireFOAM-OpenFOAM
    - …

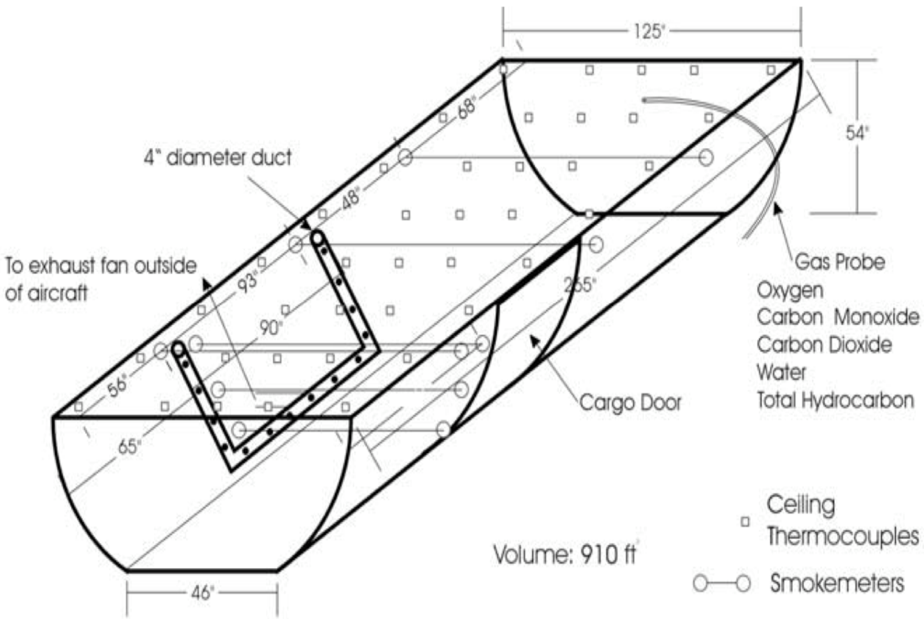
- Our criteria:
  - Reliable
  - Accessible
  - Robust
  - Fast turnaround time
  - User-friendly (pre/post–processing, installation, maintenance)
  - Free or available at a small cost
  - Inexpensive to use/maintain
  - Gradual learning curve

Methodology

- Fire Dynamics Simulator (FDS) developed at National Institute of Standards and Technology (NIST),
  - solves Navier-Stokes equations for low Mach number thermally-driven flow, specifically targeting smoke and heat transport from fires,
  - has a companion visualization program Smokeview (SMV),
  - have been verified/validated for a number of fire scenarios.
- Validation
  - FDS will be validated for three fire scenarios in an empty compartment: baseline, attached-sidewall, attached-corner.
  - Results will be compared with the full-scale FAA test measurements on two types of aircraft cargo compartments: Boeing-707, DC-10.

Methodology

- Type of Aircraft: Boeing-707

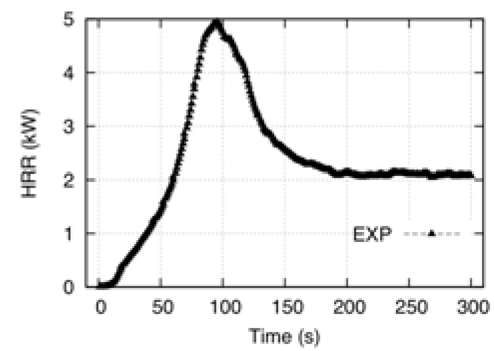


Ground test measurements: 15 tests with

- 40 thermocouples
- 6 smoke meters
- 3 gas analyzers

<u>Fire source:</u> Compressed plastic resin block

- when burned yielding combustion products similar to actual luggage fires,
- with imbedded nichrome wire to enable remote ignition,
- with cone calorimetry test data (HRR, MLR, CO_2, CO, and soot).

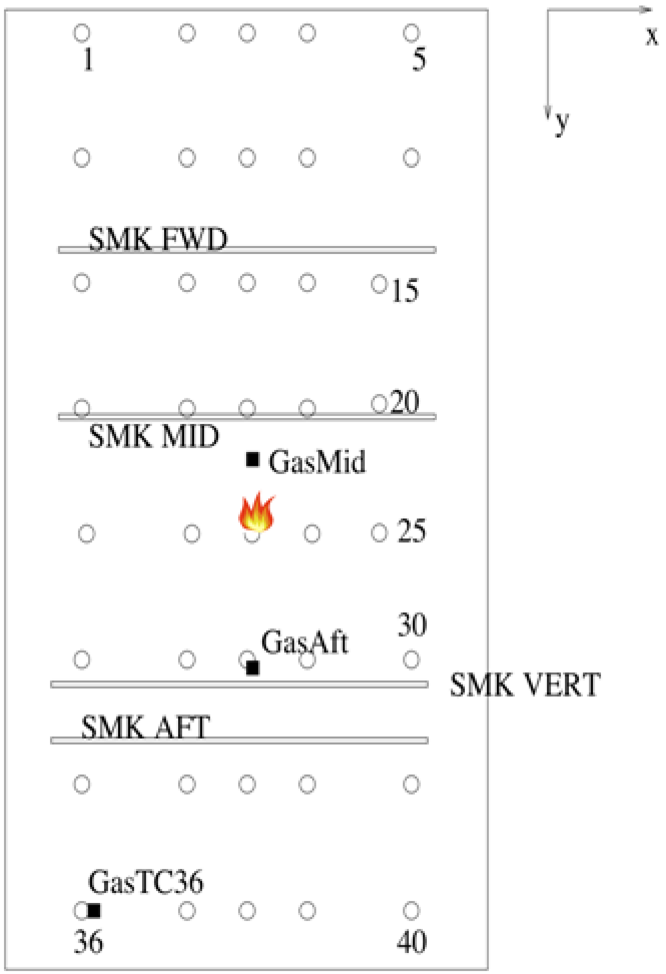


Methodology

- <u>Validation Metrics</u>
  A. Thermocouple temperature rise
    - from 0 to 60 seconds
    - from 0 to 120 seconds
    - from 0 to 180 seconds

  B. Light transmission
    - at 30 and 50 seconds (ceiling and vertical)
    - at 60, 120 and 180 seconds (vertical – high, mid and low)

  C. Gas species concentration rise
    - at 60, 120 and 180 seconds



Methodology

- <u>Model set-up</u>

  Geometry, grid and materials:

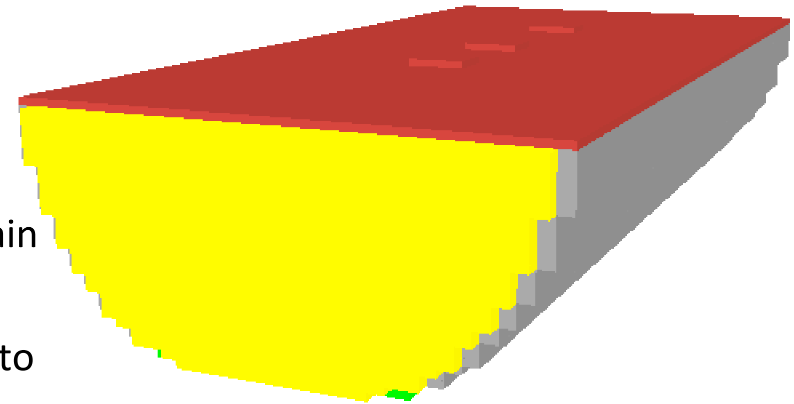
  - Rectilinear grids, single-domain solution
  - Recessed areas are included in the flow domain
  - Grid dimensions: 36x72x36 for 3.6x7.3x1.7m, maximum grid size = 0.1m, chosen according to

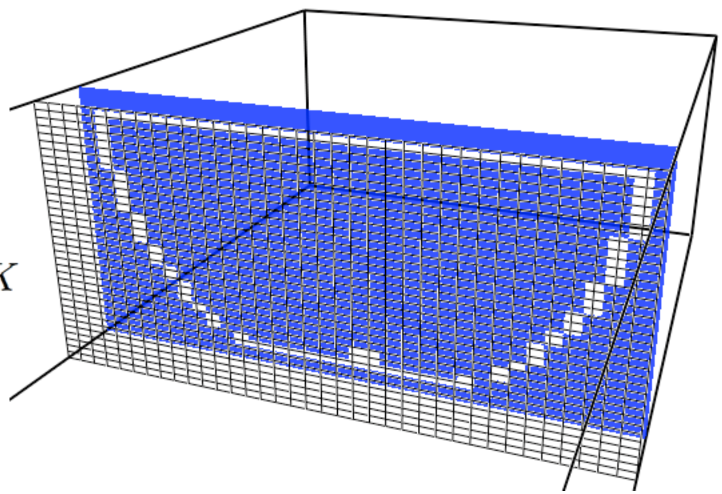
    $$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{2/5}$$

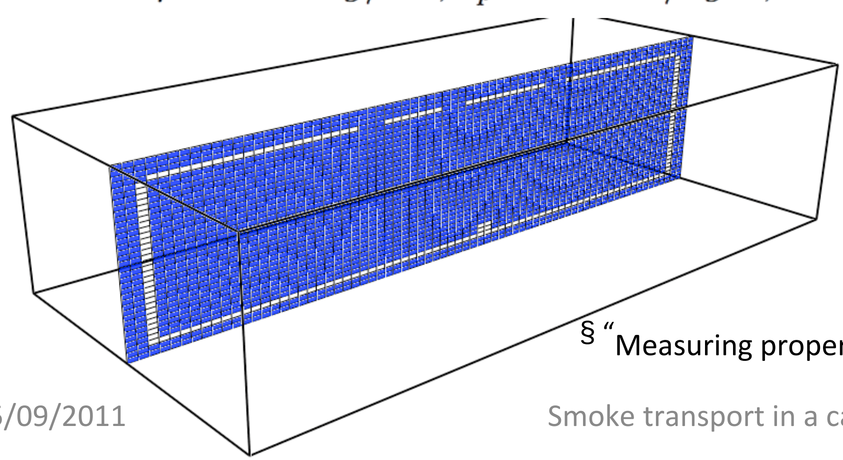
    where D* is the characteristics fire diameter.
  - Fiberglass epoxy resin:

    properties of woven glass with 30% vinyl ester§

    $\rho = 1683\ kg/m^3,\ c_p = 1200\ J/kgK,\ k = 0.3\ W/mK$







§ "Measuring properties for Material Decomposition Modeling", C. Cain and B. Lattimer

Methodology

- <u>Model set-up</u>

  Model parameters:

  - Fire source: flaming resin block, no ventilation,
  - Radiation modeling, radiative fraction: 0.40,
  - Turbulence modeling: dynamic Smagorinsky,
  - Scalar transport using Superbee flux limiter.

Reaction with a made up fuel using known yields of soot, CO, and CO_2.

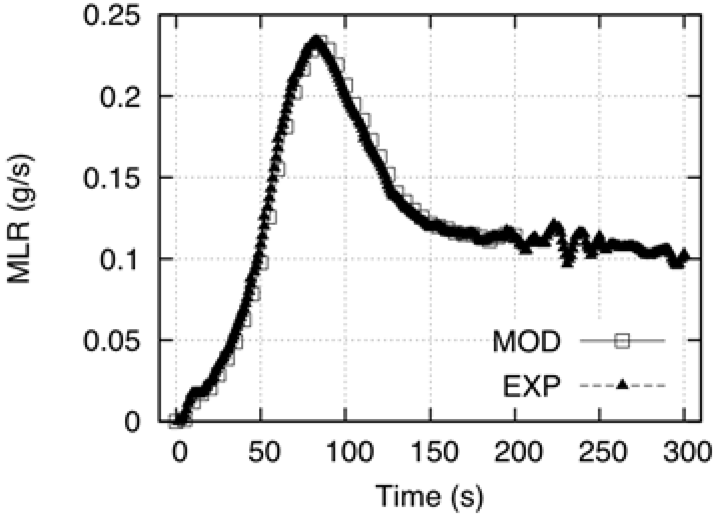
Heat of combustion = 21000 kJ/kg from known cone calorimetry data (MLR and HRR).

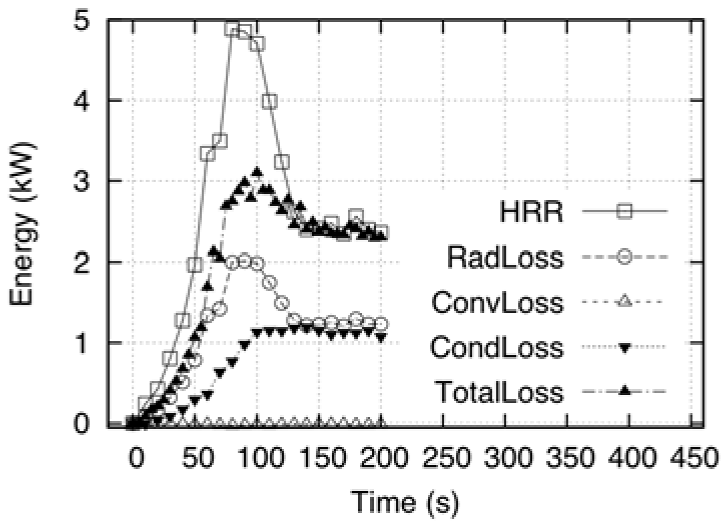
Extinction coefficient = 8700 m^2/kg (FDS default).

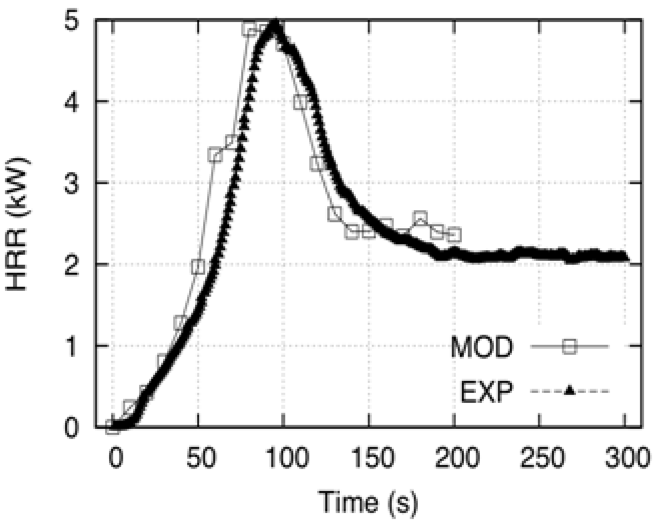
Results

B707 Baseline Fire

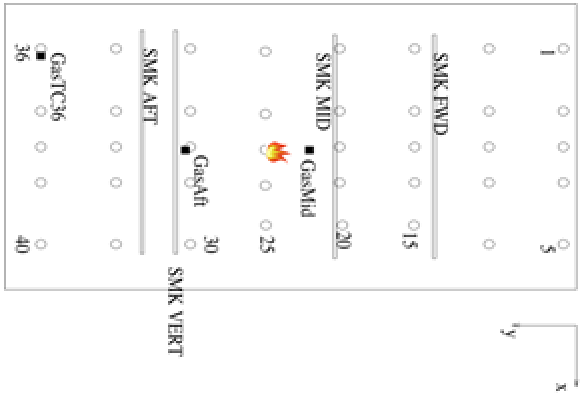
- Cone calorimetry data for mass loss rate (MLR) is used to represent the fire source in the model.
- Calculated heat release rate (HRR) is in agreement with the experimental data.
- Energy Budget shows the contribution of radiative and conductive heat losses.







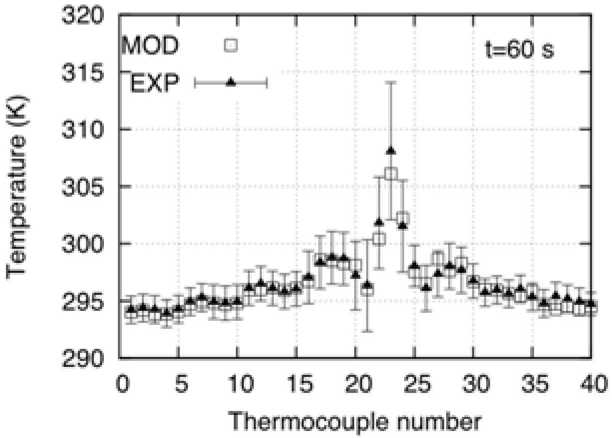
Results

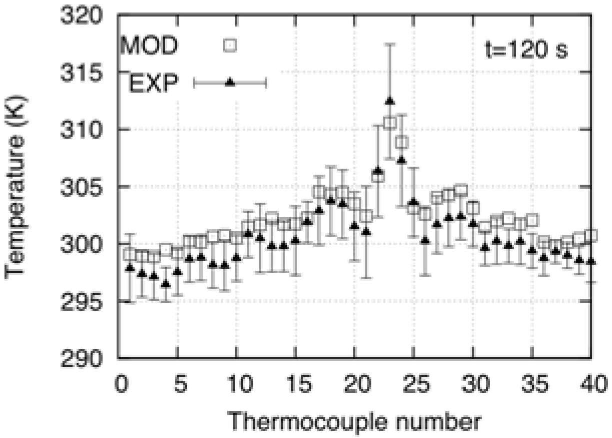


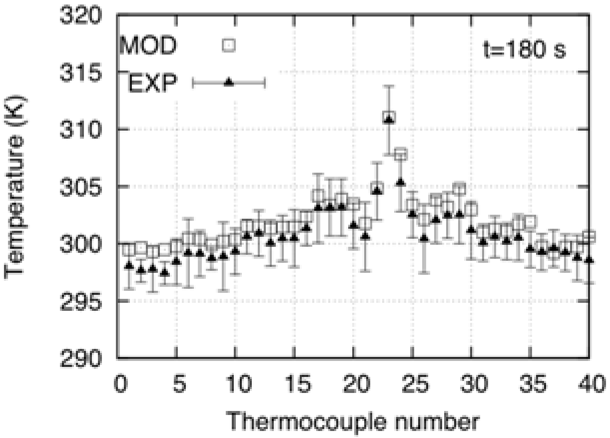
B707 Baseline Fire

A. Temperature comparisons

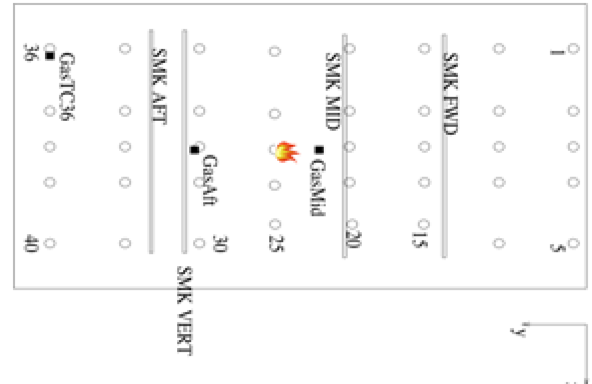
- Experimental uncertainty is ~6 ^{o}C close to the fire source, and ~2 ^{o}C away from the fire source.
- Temperature predictions are higher than the experimental mean but still within the experimental uncertainty.
- The difference between model estimates and measurements increases in time.







Results

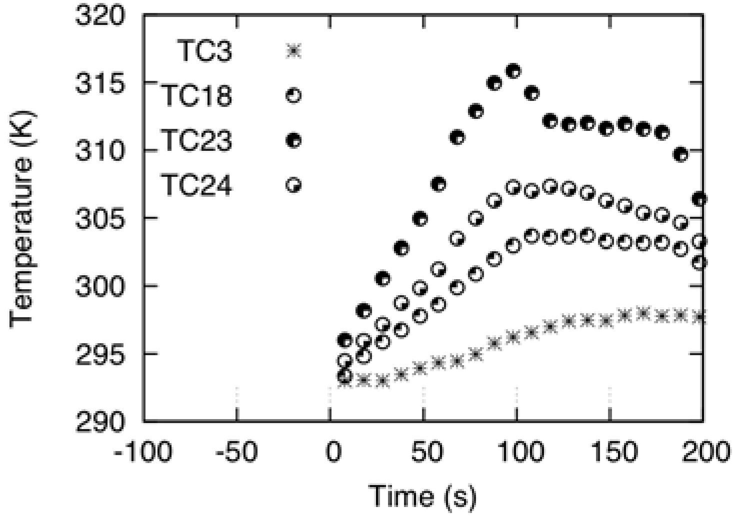


B707 Baseline Fire

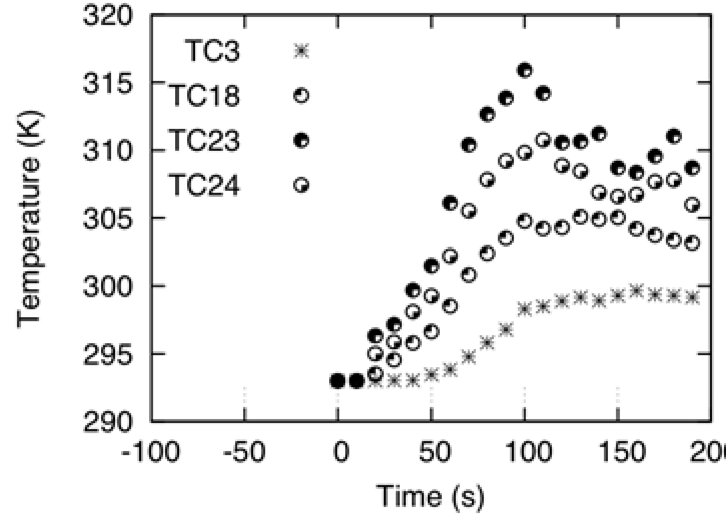
A. Temperature comparisons

- The difference between model estimates and measurements is the same everywhere (~3 ^{o}C).

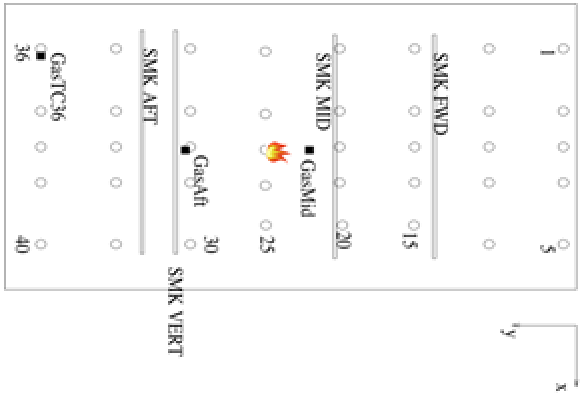
Measurements



Model



Results

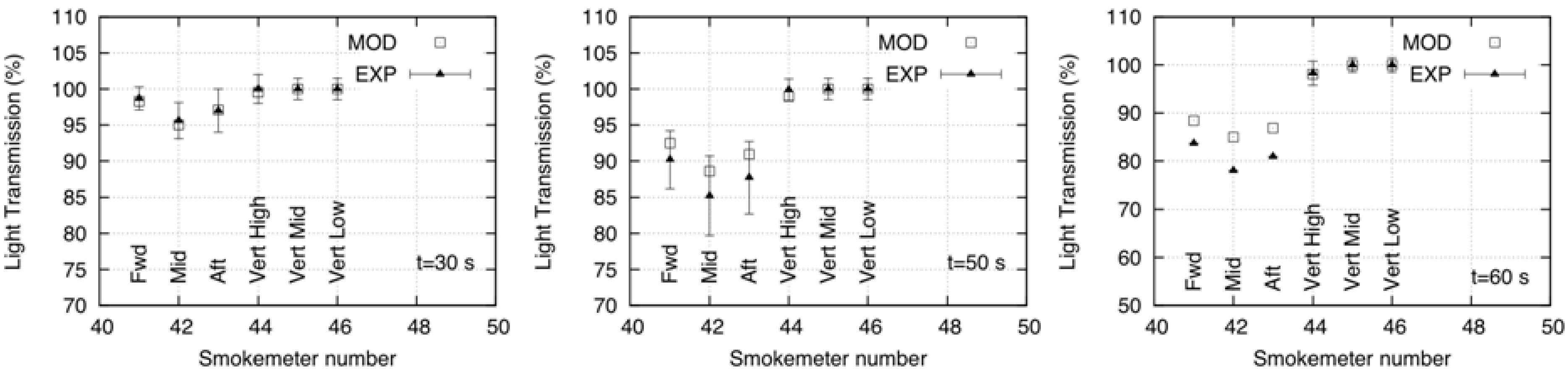


B707 Baseline Fire

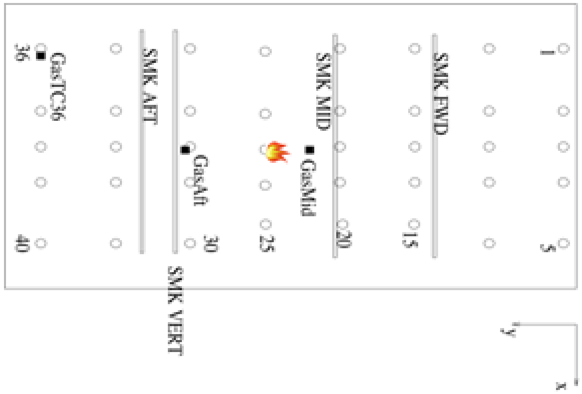
B. Light transmission

$$LT = exp(-K_m \sum_{i=1}^{N} \rho_{soot,i} \Delta x_i) \times 100\ (\%)$$

- Light transmissions are predicted within 5% of measurements for the first 60 seconds of fire initiation.
- There is less smoke in the model (at Fwd, Mid and Aft smoke meter regions).



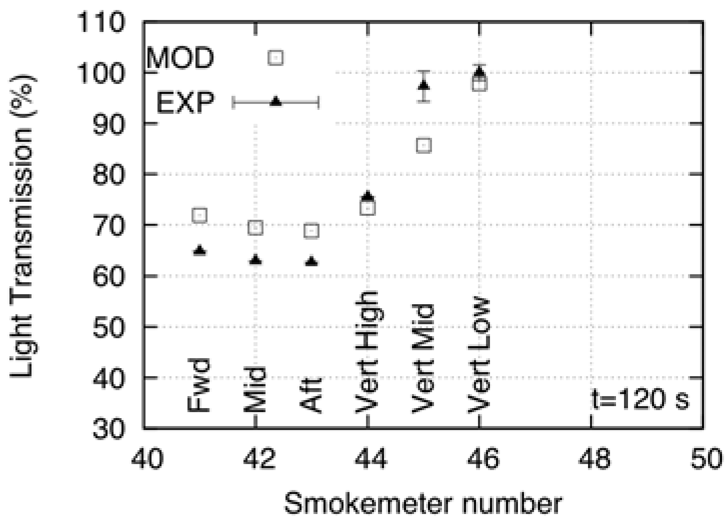
Results

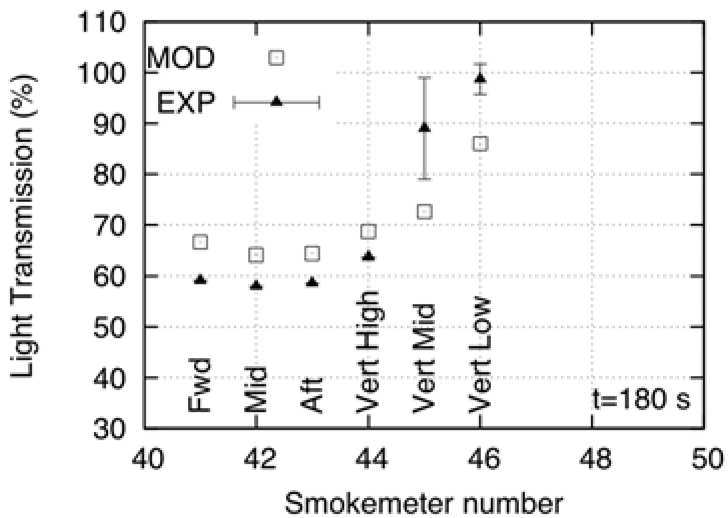


B707 Baseline Fire

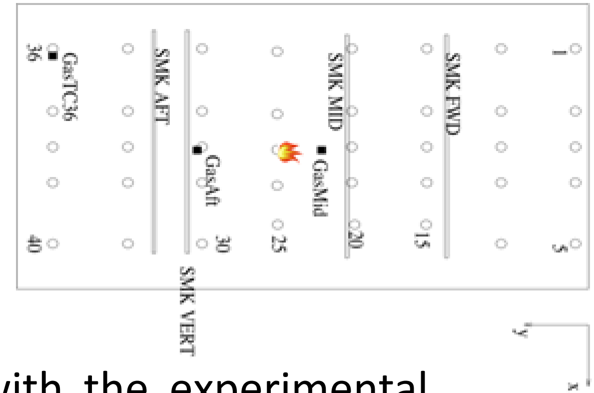
B. Light transmission

- Model predicts 5% less smoke at Fwd, Mid, Aft smoke meter regions at 120 and 180 seconds.
- Model vertical smoke meters at low and mid stations show 20% more smoke compared to the experiments.





Results

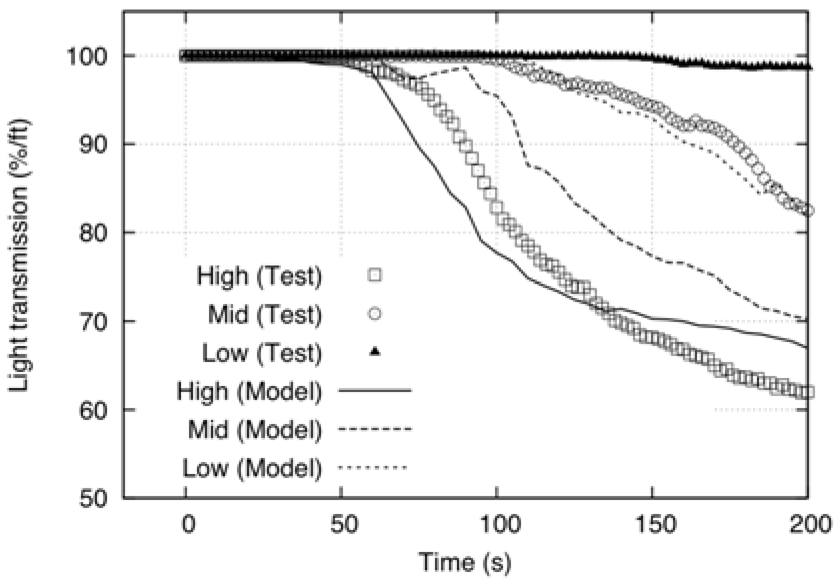


B707 Baseline Fire

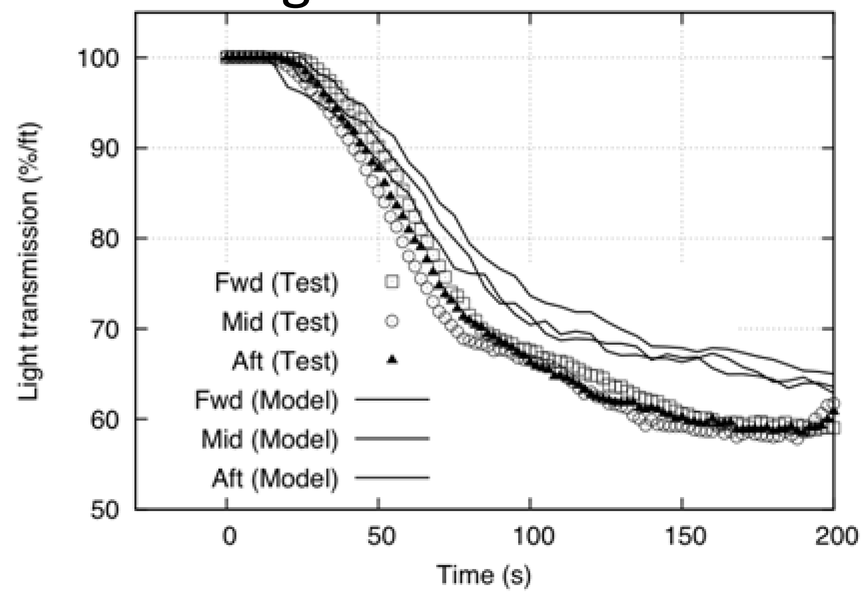
B. Light transmission

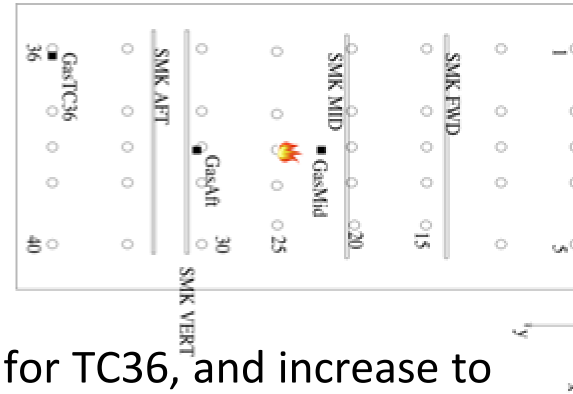
- Vertical distribution of smoke is not in agreement with the experimental data.
- Ceiling smoke distribution is within 5% of the experiments.

Vertical meters



Ceiling meters



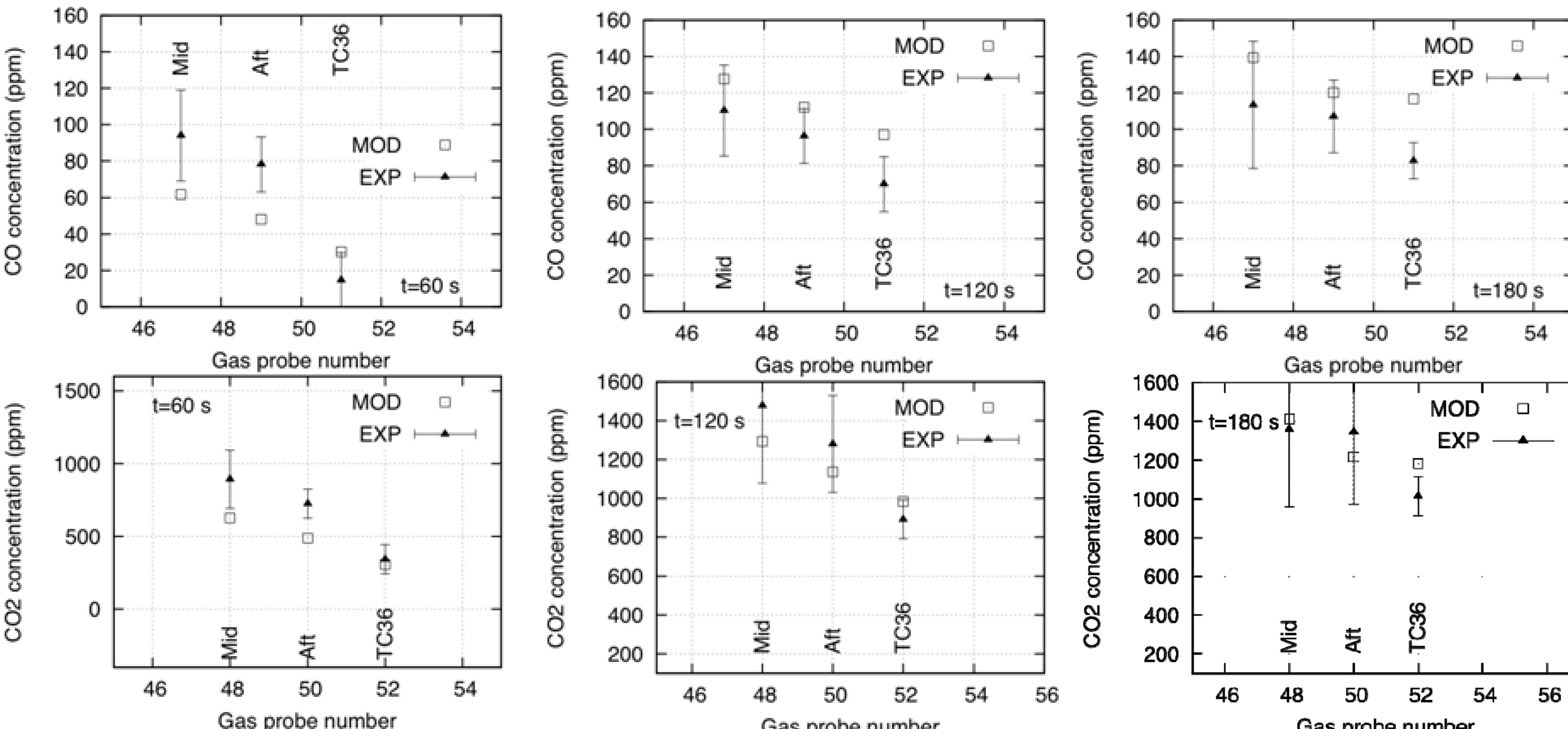


Results

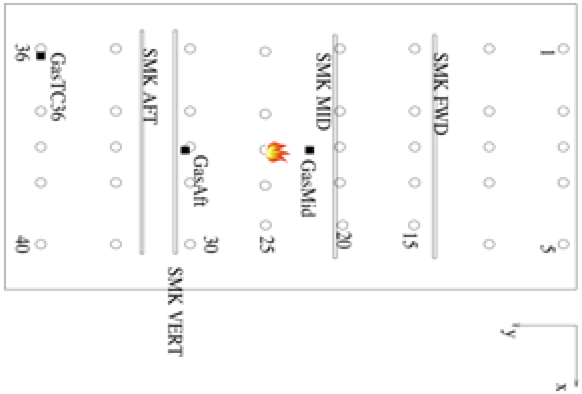
B707 Baseline Fire

C. Gas Species concentration

Both CO and CO_2 concentrations are low at t=60 s except for TC36, and increase to experimental values at t=120, 180 s.



Results

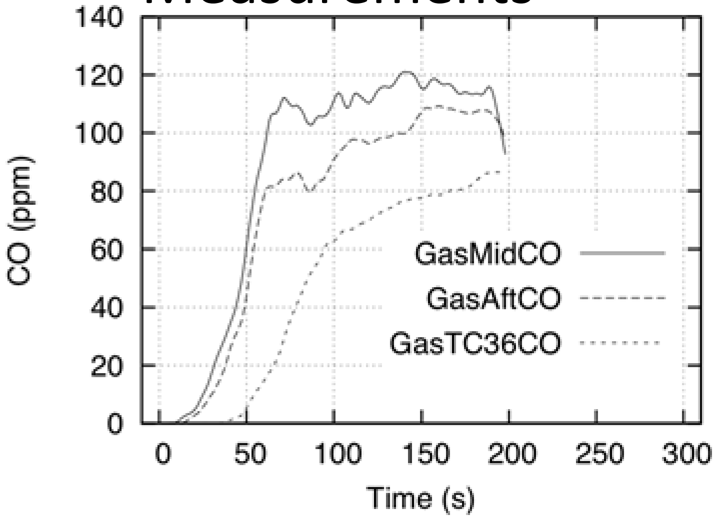


B707 Baseline Fire

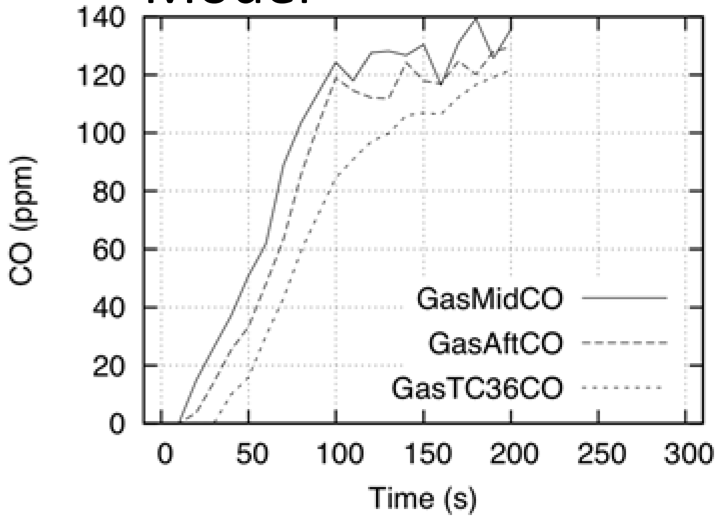
C. CO concentration

- The time lag for CO concentration at TC36 is almost 20 seconds.

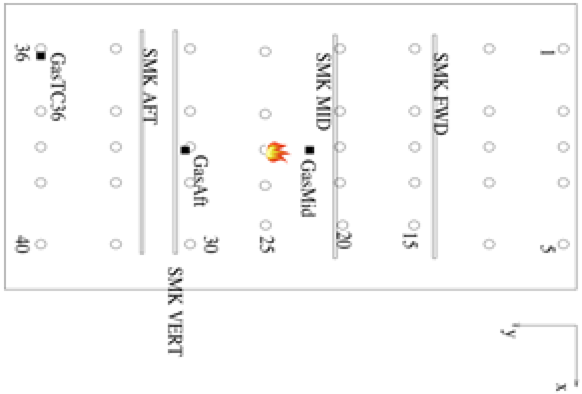
Measurements



Model



Results

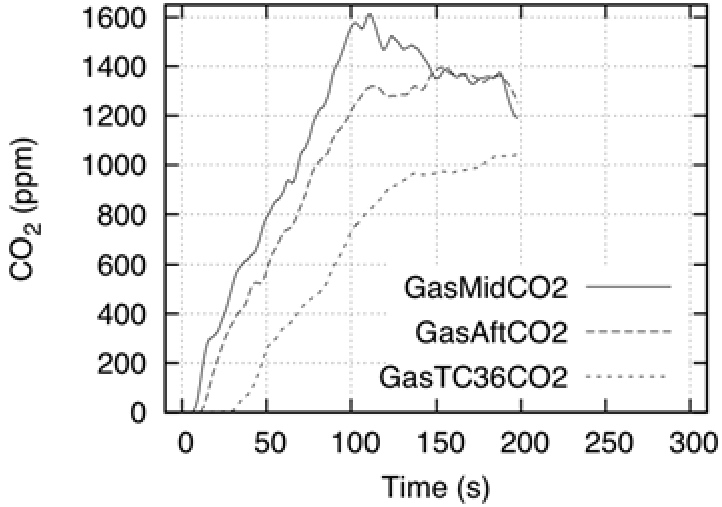


B707 Baseline Fire

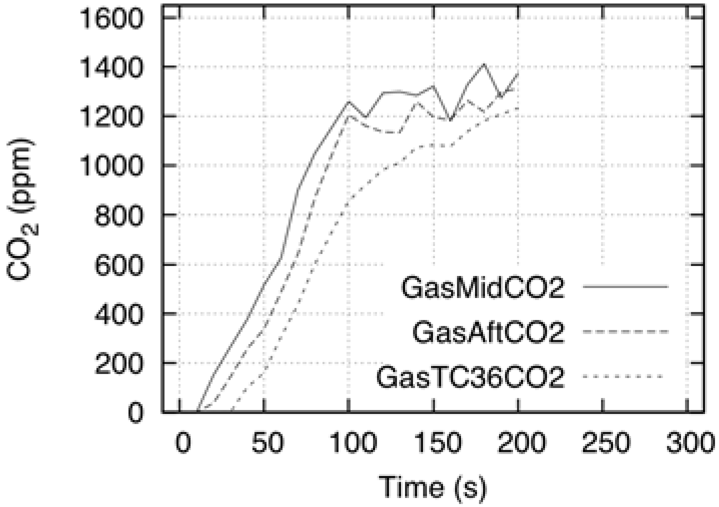
C. CO_2 concentration

- Model data has a more gradual increase in the first 60 seconds.

Measurements



Model



Conclusions

- Our preliminary results show:
  - Temperature
    - Temperatures are predicted within experimental uncertainty, however, heat losses must be examined further.
  - Smoke
    - Light transmissions are predicted within 5% close to the ceiling but 20% off in the lower regions and agreement deteriorates in time.
  - Gas concentrations
    - CO and CO_2 concentrations are predicted within experimental uncertainty, however, mass checks show added CO_2 to be well above that of the experiment.

Future Work

- Further examination and in-depth analysis is required,
  - check for energy and mass conservation, use of more accurate material properties.
- Model parameters must be examined
  - for radiation and turbulence modeling.
- Numerical error analysis must be done.
- If B707 baseline fire scenario is found to be successful,
  - Continue code validation for other B707 scenarios: attached-corner and attached-sidewall cases, and for DC 10 cargo compartment with all three fire scenarios.