SMOKE TRANSPORT MODELING: VALIDATION STUDY

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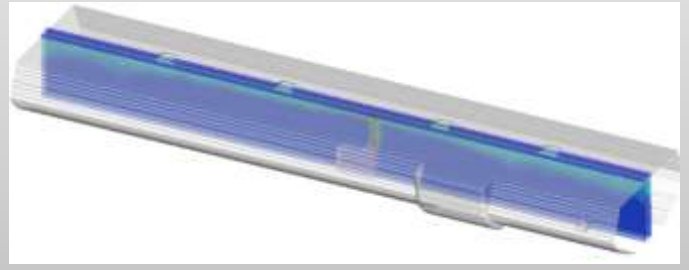
DETECTION SYSTEM DESIGN TOOL DEVELOPMENT

OBJECTIVE:

DEVELOP A MODEL-BASED TOOL TO AUGMENT DETECTION SYSTEM DESIGN AND STREAMLINE CERTIFICATION PROCESS

Cargo Bay Detection System Design Tool



Benefits:

Virtual tests

Parametric variations

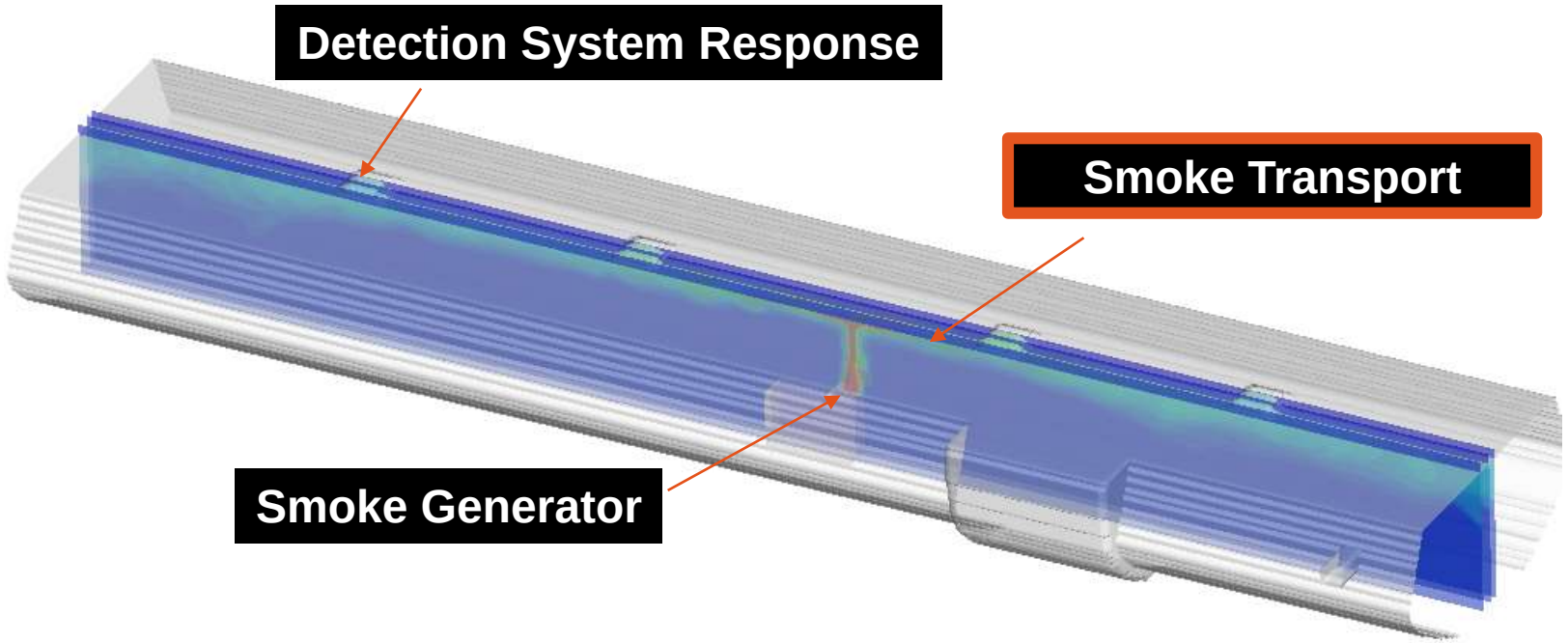
Physical insight

Accelerate design & development

Reduce number of flight certification tests

Reduce cost of certification

COMPONENTS OF THE MODEL-BASED DESIGN TOOL

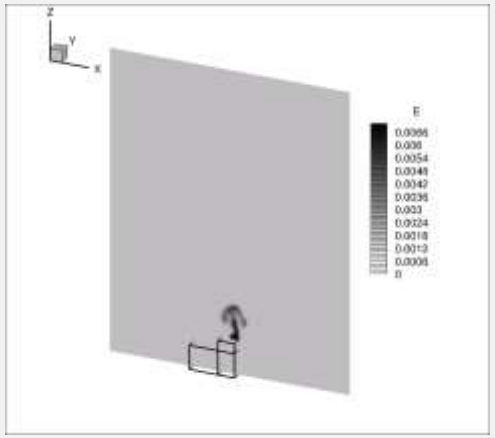


Smoke transport takes up a large portion of the detection system response time.

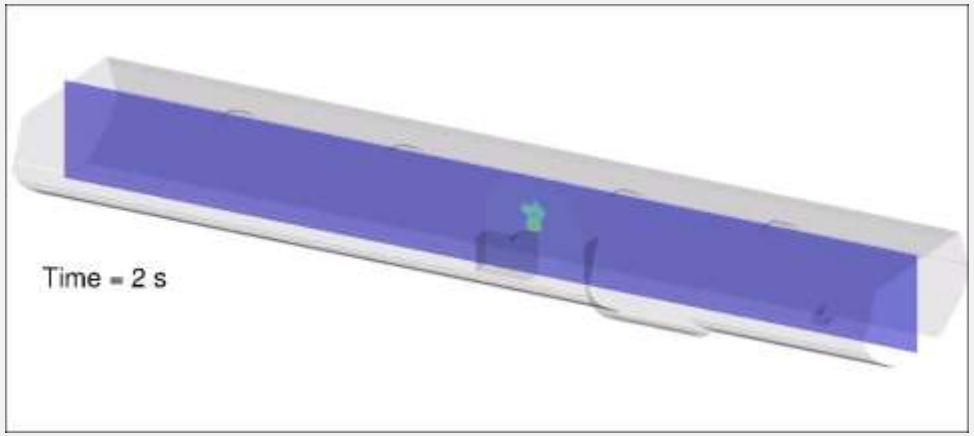
Predicting smoke transport accurately is key to the design tool robustness.

DESIGN TOOL DEVELOPMENT STATUS

May 2018: Developed approach to model smoke generator dispersion



Nov 2018: Demonstrated method to simulate smoke transport and predict alarm times in a cargo bay



Today's focus:

1) **<u>Validate</u> development of buoyant plume from the smoke generator**
2) **Investigate the effect of ceiling height on the buoyant plume and ceiling jet**

SMOKE GENERATOR CHARACTERIZATION SET-UP

UTRC Multiphase Injection Lab

Enclosed room

Option to turn ventilation off during tests

Smoke Generator (SG) Placement

Ground SG

Ceiling height comparable to cargo bay with high ceilings

Raised SG

Ceiling height comparable to cargo bay with low ceilings

TEST METHODS

Vane anemometer cross-checked with hot film anemometer

- One set of smoke generator settings tested
- Velocity and temperatures measured at multiple increments along plume centerline
- Multi-channel data acquisition system sampled at 10 Hz
- Tests repeated on different days
- Experimental error within 10%

Detailed characterization methodology used to acquire data sets for model validation

CFD MODEL SET-UP

Fire Dynamics Simulator (FDS)

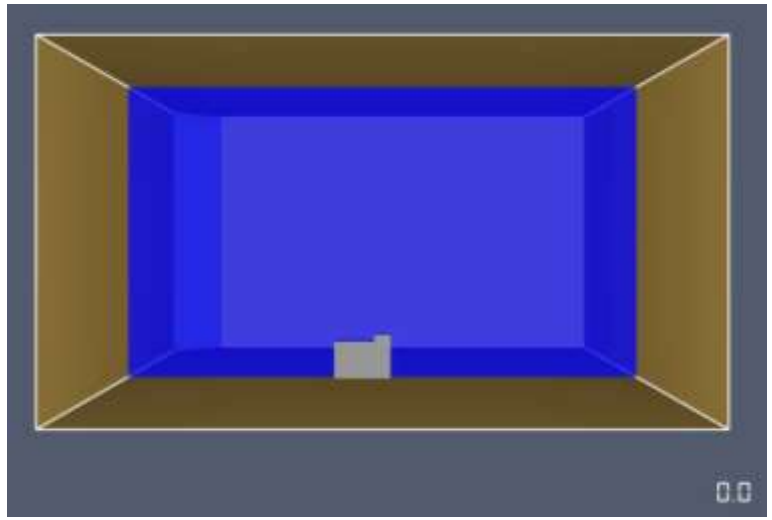
3-D, unsteady solver from NIST (version 6.6.0)

Large Eddy Simulation (LES)

Parametric Study

- Mesh size and distribution
- SG exit plane boundary conditions
- Turbulence intensity
- Turbulence model

Simulation Settings



Average number of hexahedral cells: 40 million

Non-uniform sized mesh

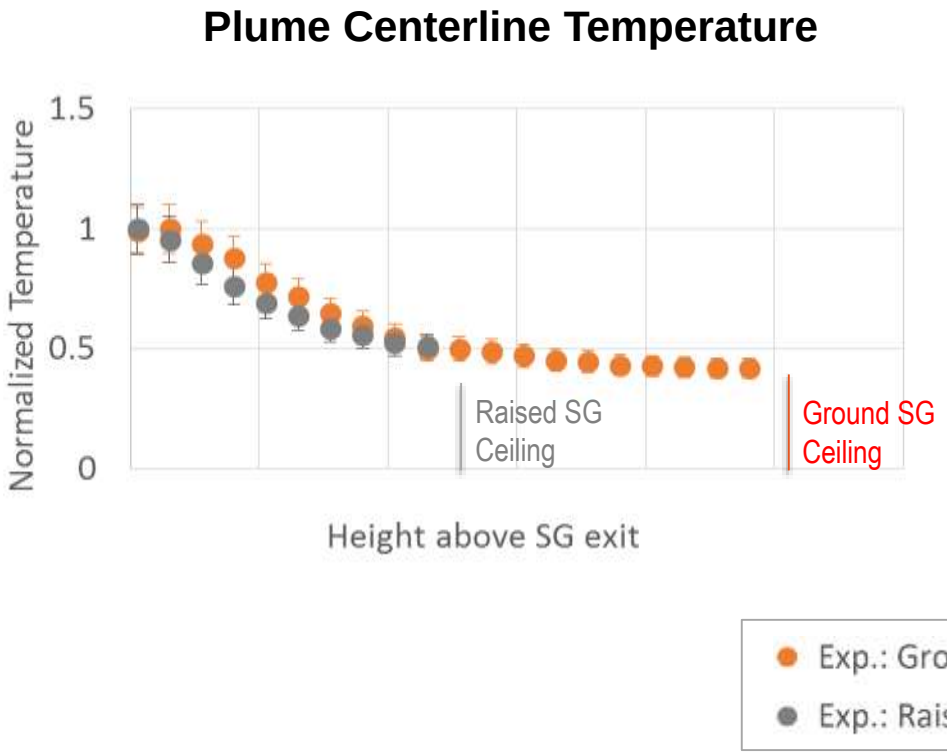
Input conditions: measurements at SG exit plane

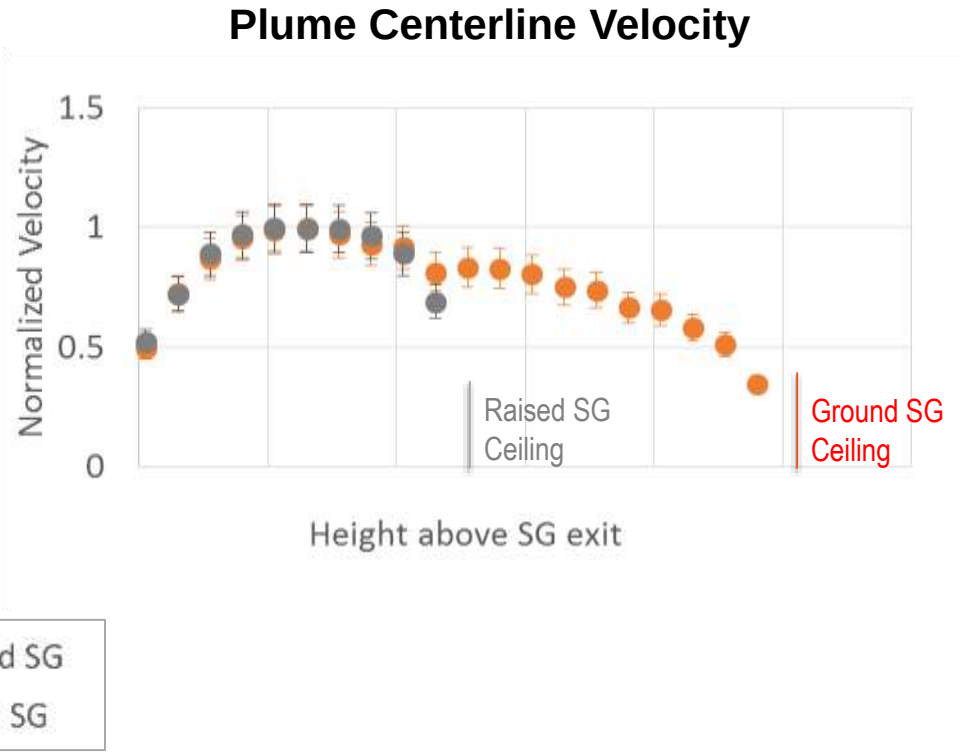
Parallel computing cluster: ~60 cores

Wall clock time: 80 hours

Over 30 simulations conducted to identify best methodology to simulate buoyant plume

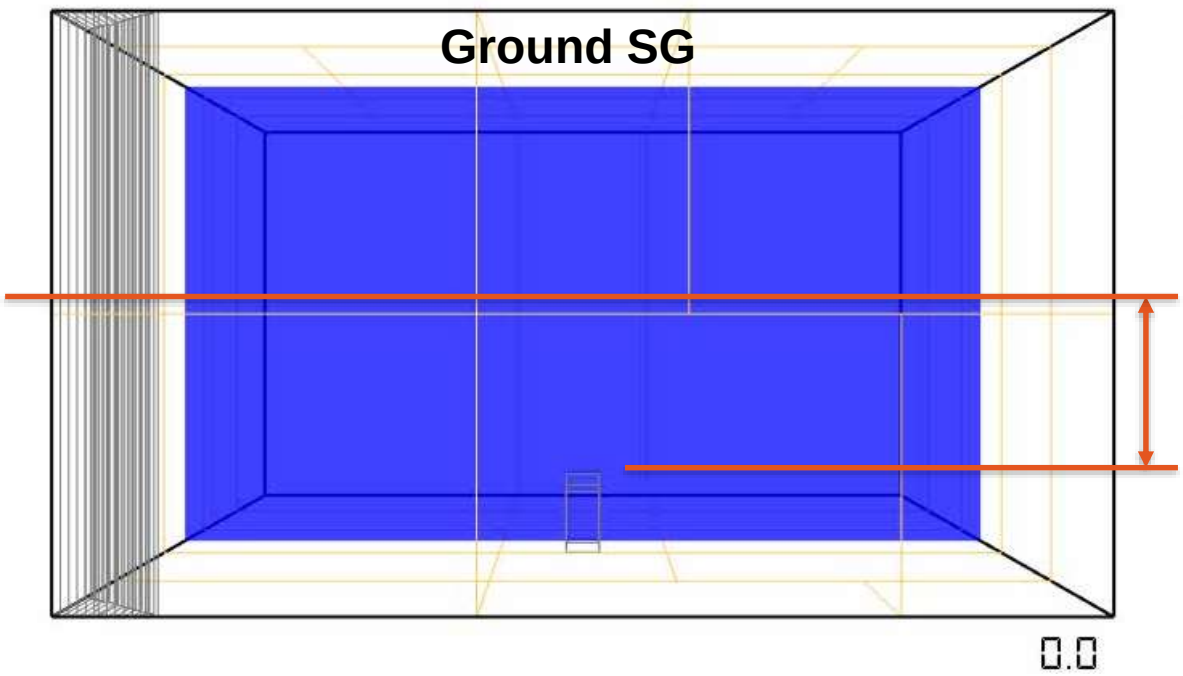
MEASUREMENTS: PLUME CENTERLINE

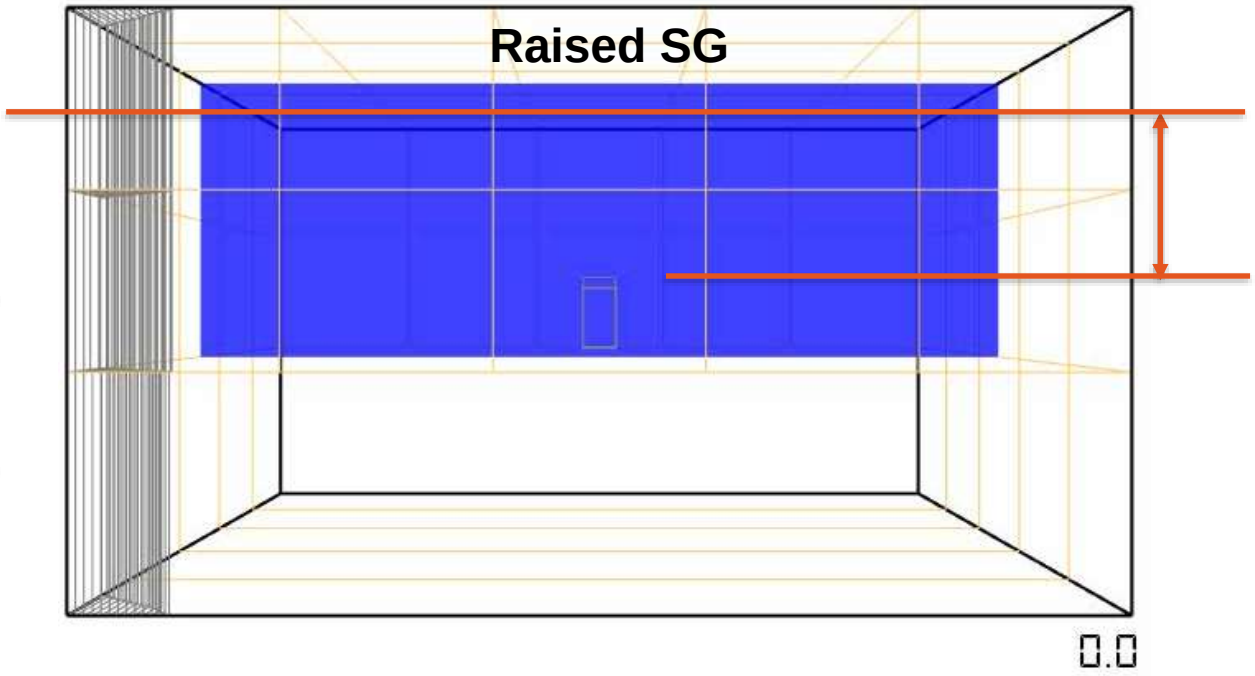




Similar plume centerline profiles obtained for the two ceiling heights

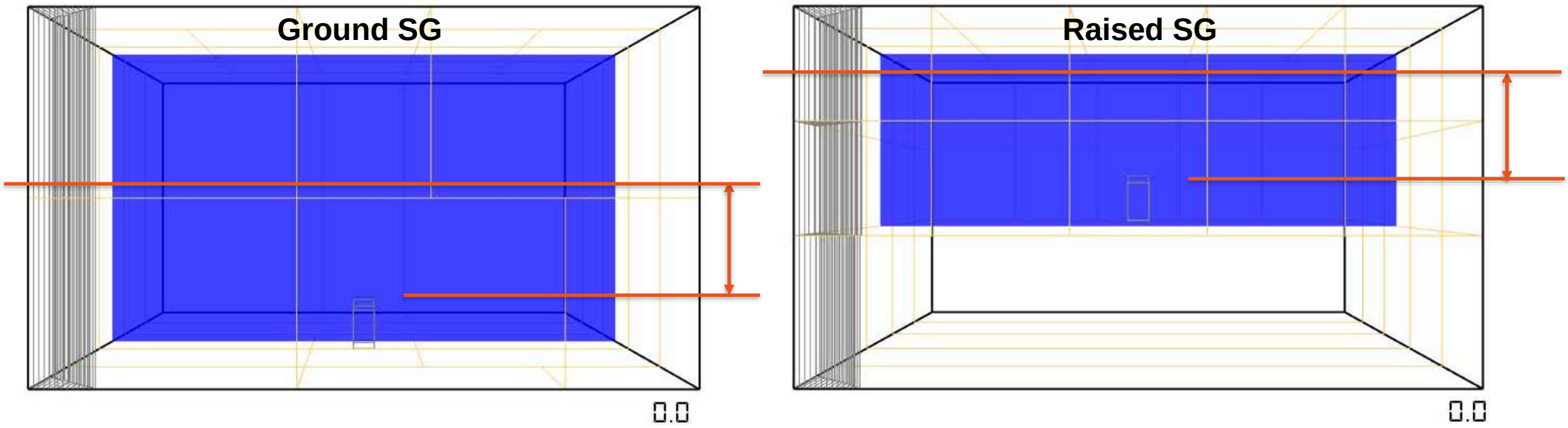
CFD: CENTERLINE TEMPERATURE MOVIES





Similar temperature profiles along the plume centerline at same comparable heights

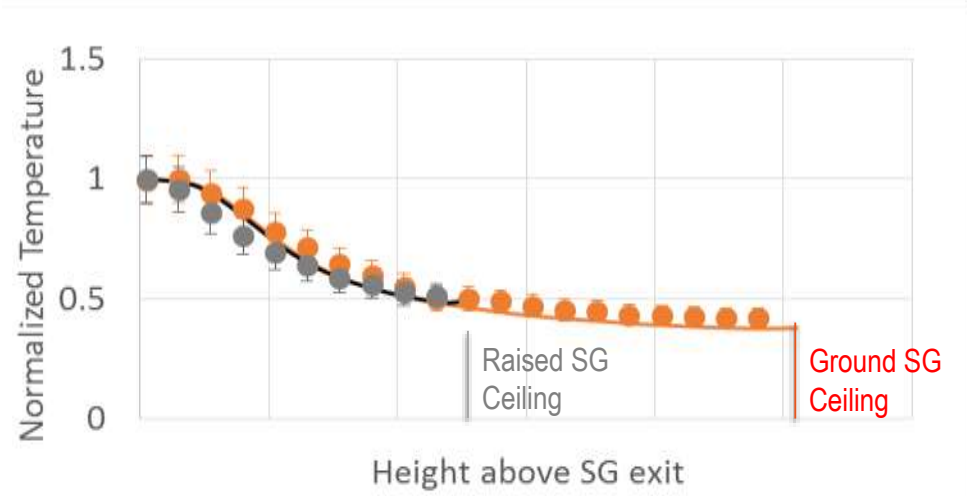
CFD: TOTAL VELOCITY MAGNITUDE MOVIES



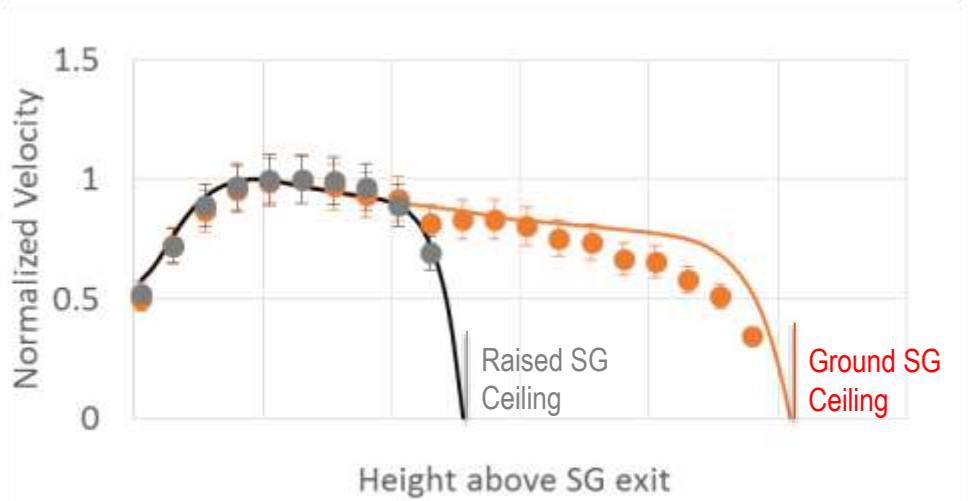
Similar velocity profiles along the plume centerline at same comparable heights

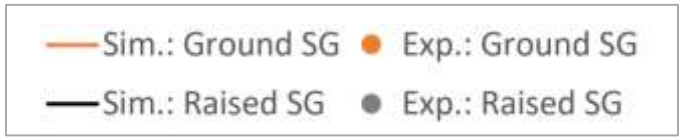
CFD VALIDATION: PLUME CENTERLINE

Plume Centerline Temperature



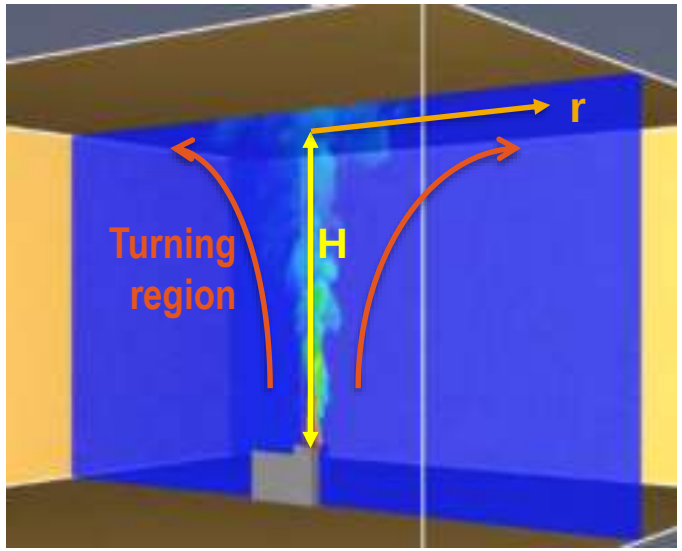
Plume Centerline Velocity





CFD accurately predicts the measured centerline data for both plume heights

CEILING JET CORRELATION



Experimentally-derived correlations for ceiling jet flow*

(beyond the turning region at the ceiling)

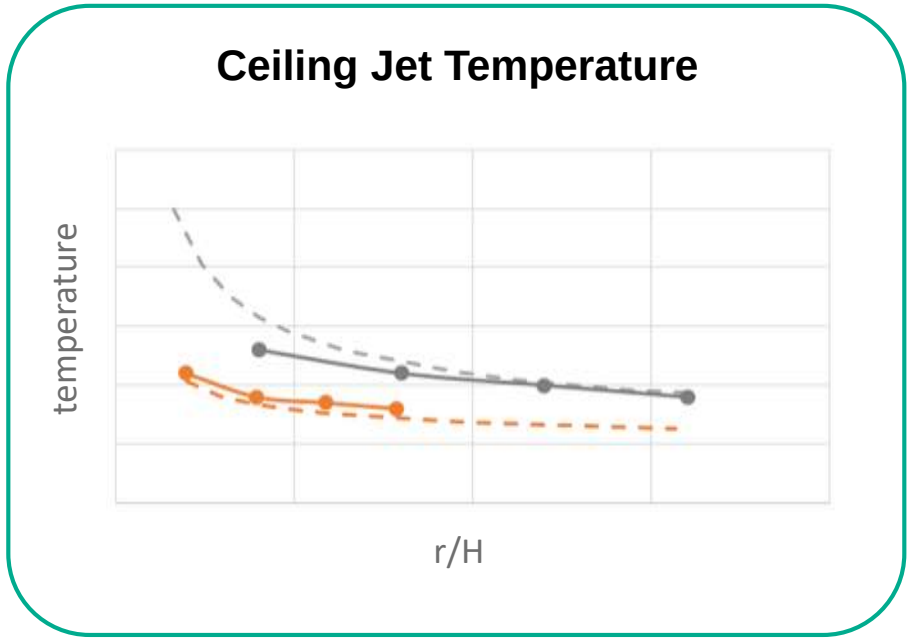
$$T - T_\infty \propto \frac{\left(\dot{Q}/r\right)^{2/3}}{H} \qquad \text{For } r/H > 0.18$$

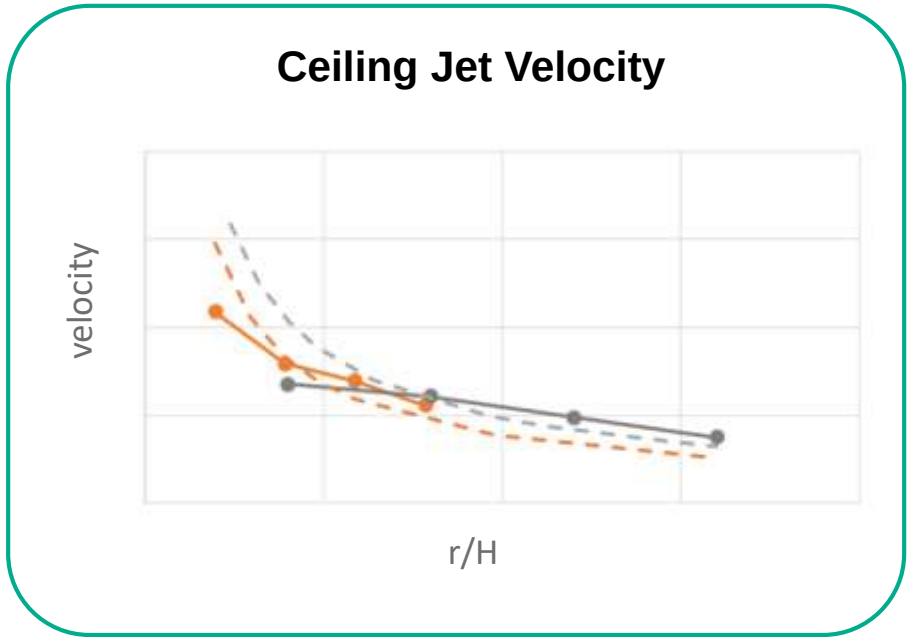
$$U \propto \frac{\dot{Q}^{1/3} H^{1/2}}{r^{5/6}} \qquad \text{For } r/H > 0.15$$

Where $\dot{Q}$ is the total energy release rate in kW
T is the temperature in ℃
U is the velocity in m/s
r, H are the radial position and plume height in meters

*Alpert, R.L., *Fire Tech.*, **8**, 181 (1972)

CFD & CORRELATION COMPARISON: CEILING JET TEMPERATURE AND VELOCITY





CFD results: Ground SG
CFD results: Raised SG
Correlation: Ground SG
Correlation: Raised SG

CFD simulations confirms correlation trends for ceiling jet temperatures and velocities

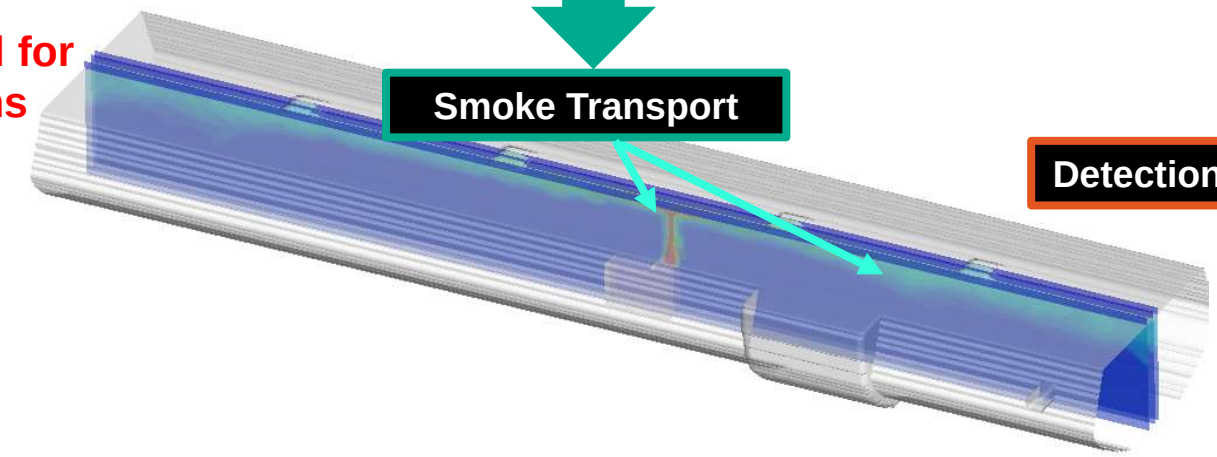
DETECTION SYSTEM DESIGN TOOL DEVELOPMENT

SUMMARY Developed CFD simulation / test methodologies to simulate and validate the buoyant plume

Validated CFD simulations of buoyant plumes under two ceiling heights for:

Plume centerline temperatures & velocities *Ceiling jet temperatures & velocities*

Predictive modeling tool for smoke detection systems



NEXT STEP

Validate the detector alarm times predicted by the tool with acquired test data

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