Modeling of Hidden Fire Smoke Signature in Aircraft

A CASE STUDY OF OVERHEAD AREA

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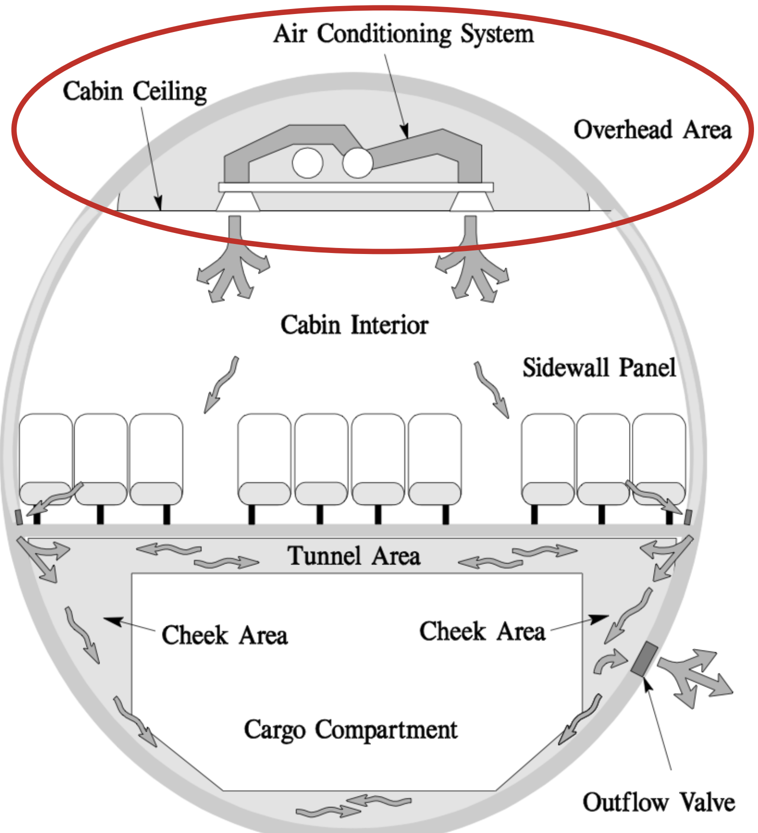
Introduction

Hidden-area fires*

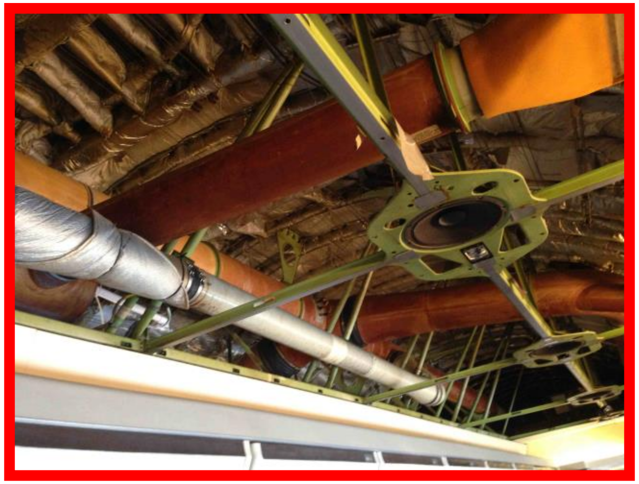
- **Definition of hidden in-flight fires:** "*Fires that are "hidden" are not readily accessible, may be difficult to locate and are more challenging to extinguish.*"
  - *examples:* fires behind sidewall paneling or in overhead areas.
- **Potential causes:**
  - Wiring failures, electrical component failures, lightning strikes, hot temperature bleed air leaks, faulty circuit protection.
- **Indications:**
  - Abnormal operation or disassociated component failures, circuit breakers, hot spots, odor, visual sighting – smoke.
- **Locations of interest:**
  - Cheek area, overhead area, sidewall panel.

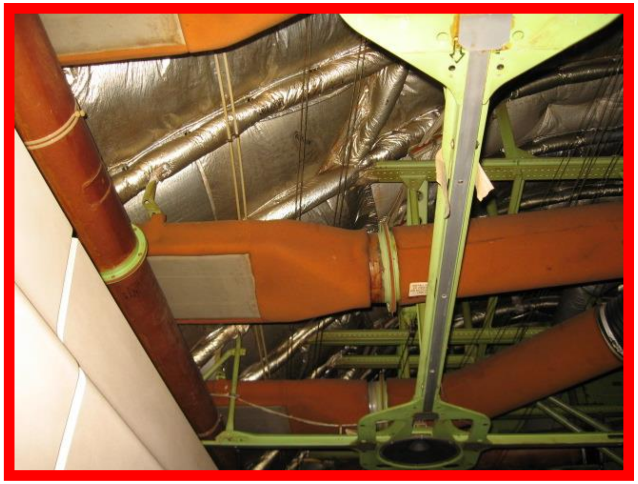


* FAA Advisory Circular (AC) 120-80, In-Flight Fires, 2004.

Introduction

Selected overhead area of the B747-SP test article

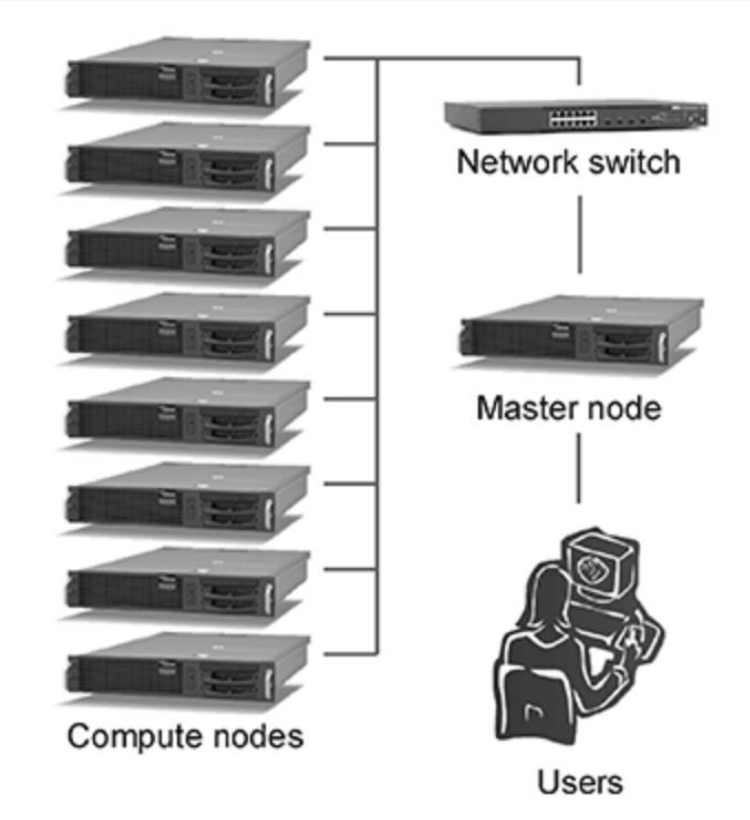




Introduction

High performance computing (HPC) system

- An in-house high performance computing (HPC) system has been built under the Aviation Research division of FAA WJHTC.
- Nine (one master + eight compute) nodes with dual-processors having fourteen cores adding up to 252 cores:
  - *(2) Intel Xeon E5-2695 v3 (Haswell) 2.3GHz, 35M Cache, 14 core processors, 120W,*
  - *512 GB RAM via (32) 16GB up to 2133MT/s RDIMMs, dual rank,*
  - *(16) 1.2TB 10K RPM SAS 6Gbps Hard drive,*
  - *Mellanox ConnectX-QDR InfiniBand HCA*



Schematic from http://www.inspace.re.kr/high-performance-computing.html

- Allows massively-parallel computations, significantly reduces the computational time.

Introduction

Light Detection and Ranging (LIDAR)

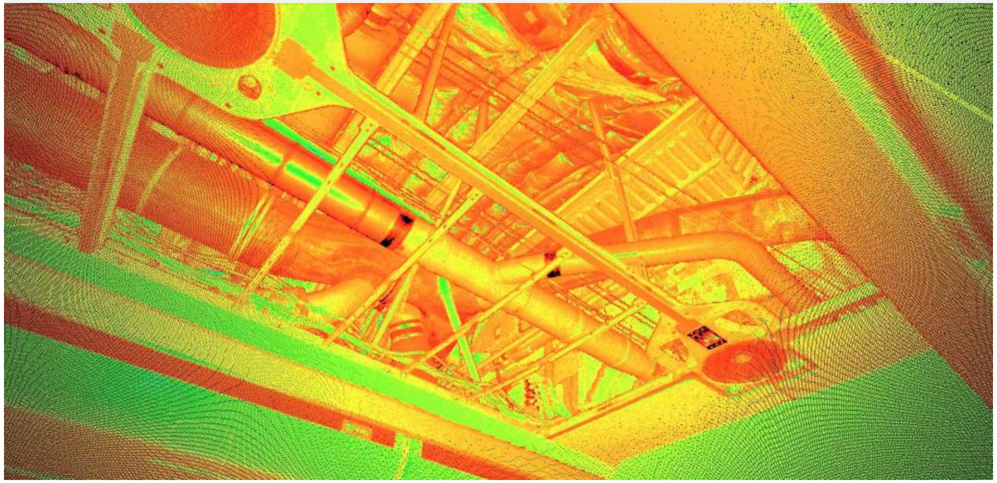
In order to produce the three-dimensional CAD model of the overhead area Light detection and ranging (LIDAR) technology is employed.

REAL GEOMETRY → POINT CLOUD DATA → 3D CAD MODEL

LIDAR equipment

real geometry

point cloud data



Introduction

Controllable burner

A DIFFUSION GAS BURNER

- repeatable/reproducible tests,
- controllable and safe
  - monitored mass flow,
  - shut-off switch,
  - remotely-controlled ignition,
- propane-fueled,
- range: 2.5kW up to 60kW.

Adjustable HRR

9.2 kW

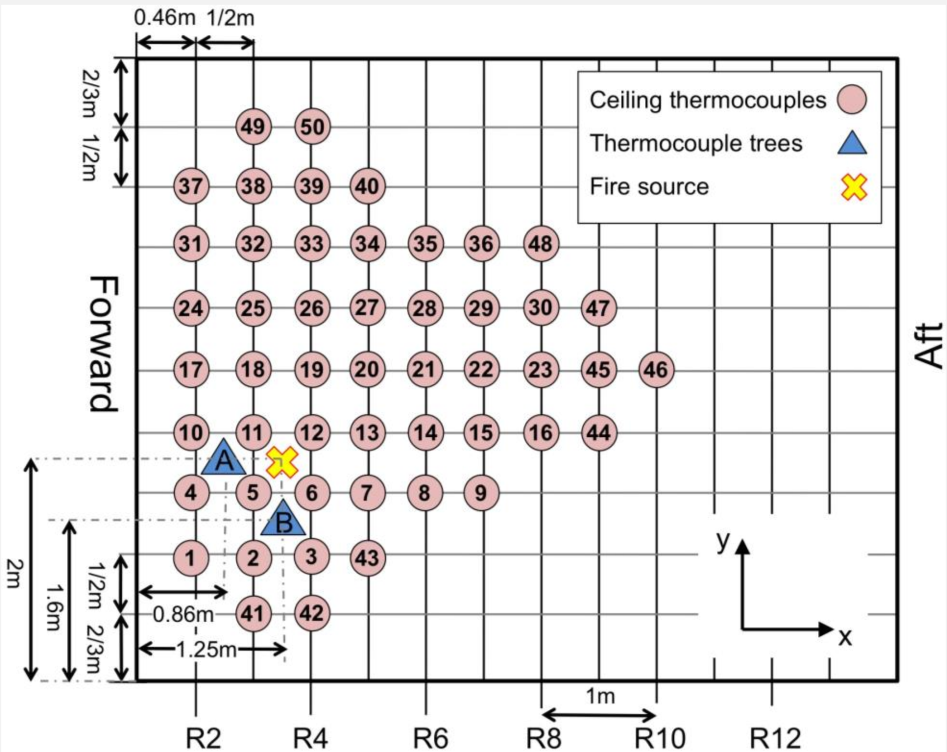
2.5 kW

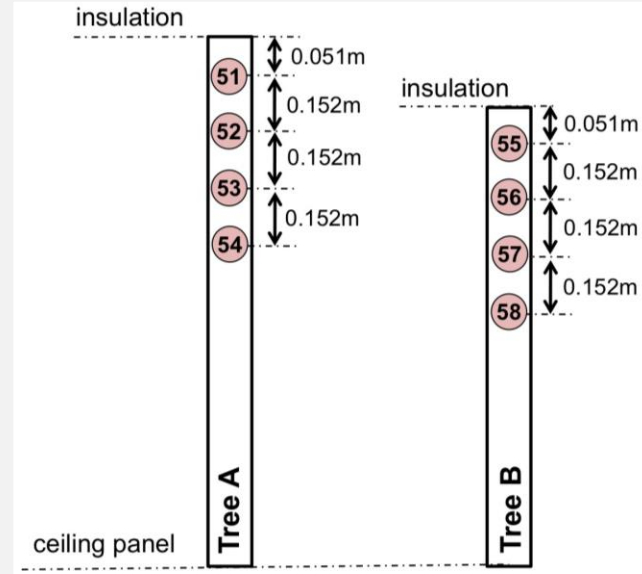
Methodology

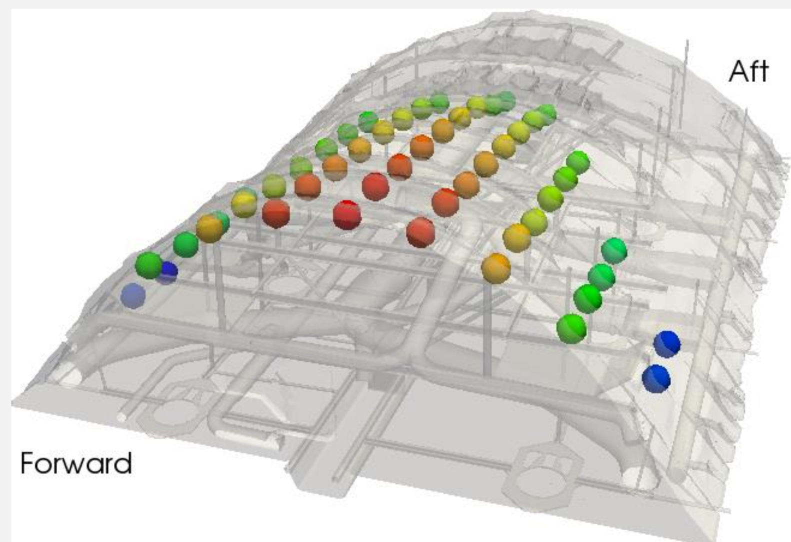
Experimental section – Instrument locations

Selected overhead region was equipped with fifty-eight thermocouples:

- fifty ceiling TCs from 1 to 50
- eight tree TCs from 51 to 58







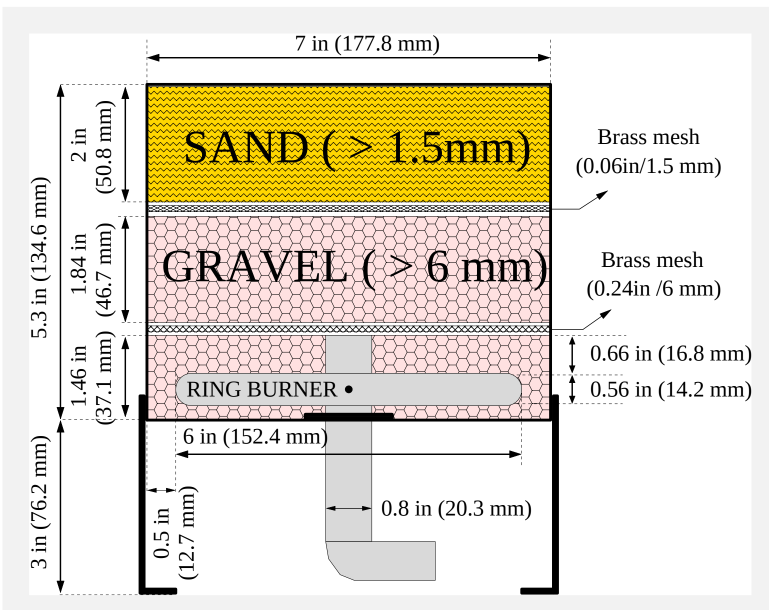
Methodology

Experimental section – Fire source

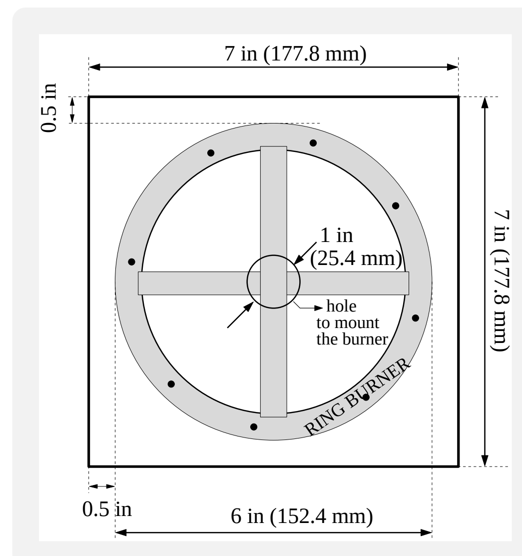
A propane gas burner was built following ISO 9705[¶] international standards.

- 7x7 in^2 (0.18x0.18 m^2) surface area,
- chemical HRR equivalent to the maximum HRR of the FAA's standard fire source for inflight fires (polyurethane foam block).

Looking from side



Looking from top



[¶] ISO 9705:1993(E), "Fire tests - Full-scale room test for surface products", International Organization for Standardization, Geneva, Switzerland, 1993.

Methodology

Numerical section – Flow solver §

Numerical simulations are performed using FireFOAM, an open-source computational fluid dynamics (CFD) solver for fire growth and suppression modeling.

FireFOAM has been developed by the Factory Mutual Research Corporation and built upon OpenFOAM** general purpose toolbox.

Solver set-up

- Subgrid-scale turbulence is modeled with the WALE (**W**all **A**dapting **L**ocal **E**ddy-viscosity) model,
- Combustion (fire) is modeled assuming infinitely fast chemistry,
- Thermal conduction is assumed to be negligible,
- Radiation is not modeled,
- Simulations are second-order accurate in time and space.

§ https://code.google.com/p/firefoam-dev/

** https://www.openfoam.org/

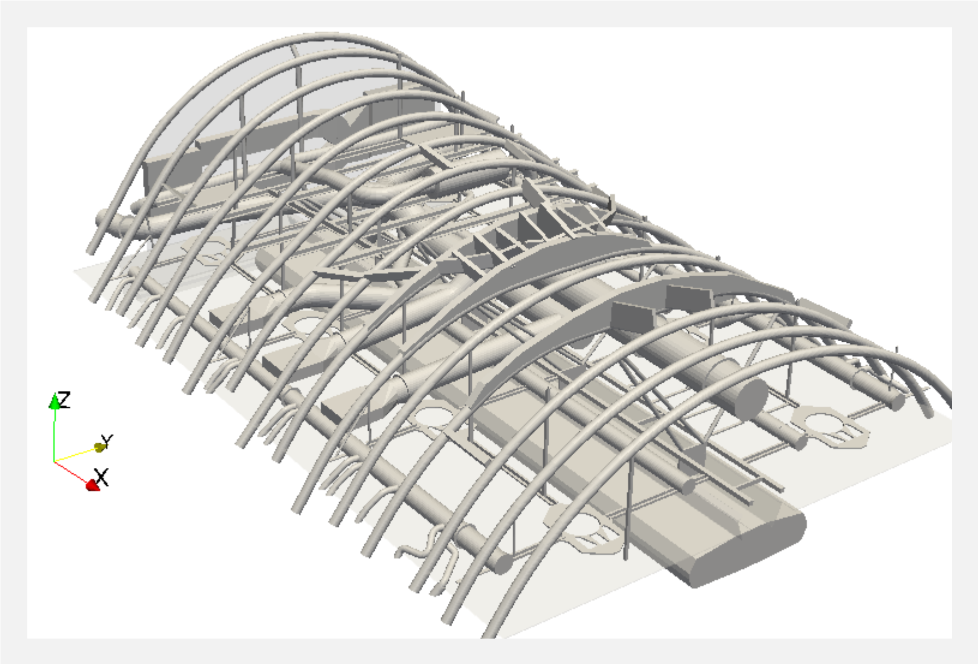
Methodology

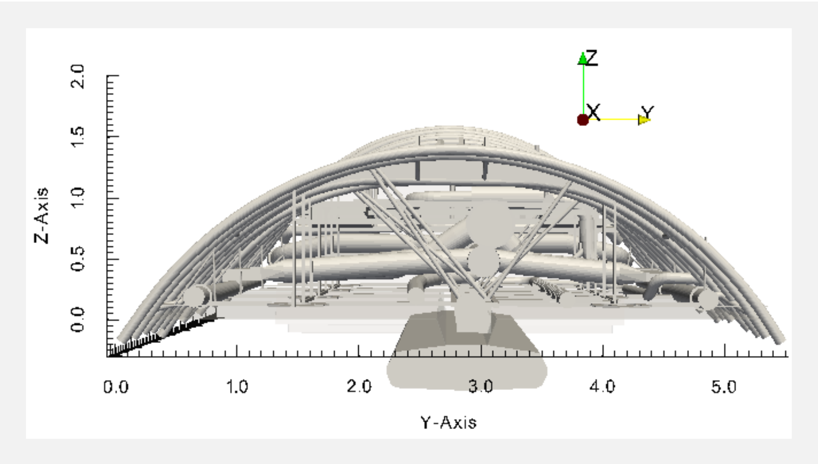
Numerical section – Geometry

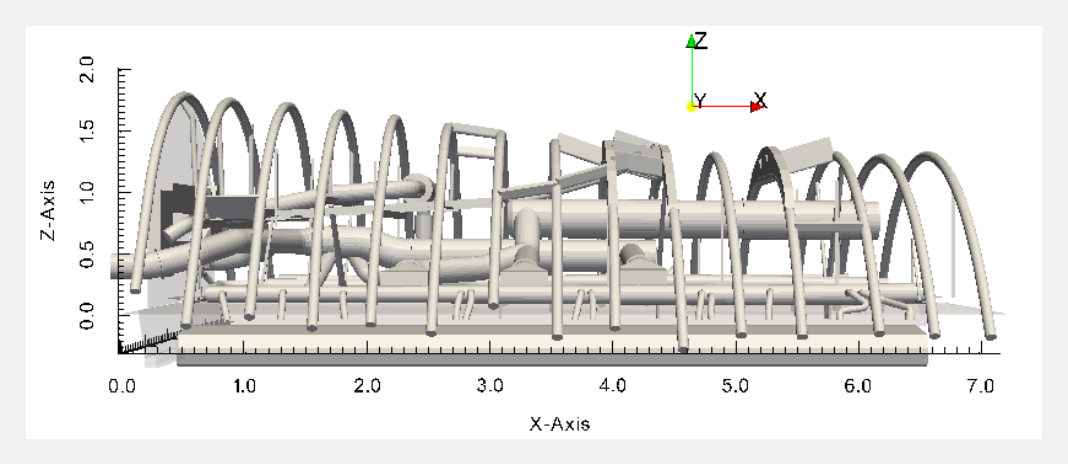
Three-dimensional CAD model includes air-distribution ducts, support structures, storage bin, etc.

Modeling is done for 6.5 m long x 5.2 m wide, 1.8 m tall (21 x 17 x 5.9 ft^3) region.

Insulation is not shown, ceiling panels on the bottom and forward-end wall are shown transparent.





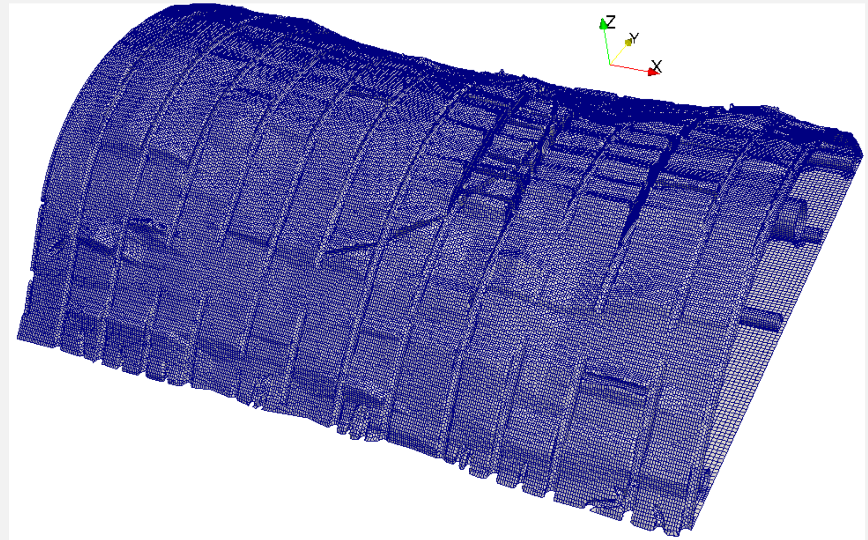


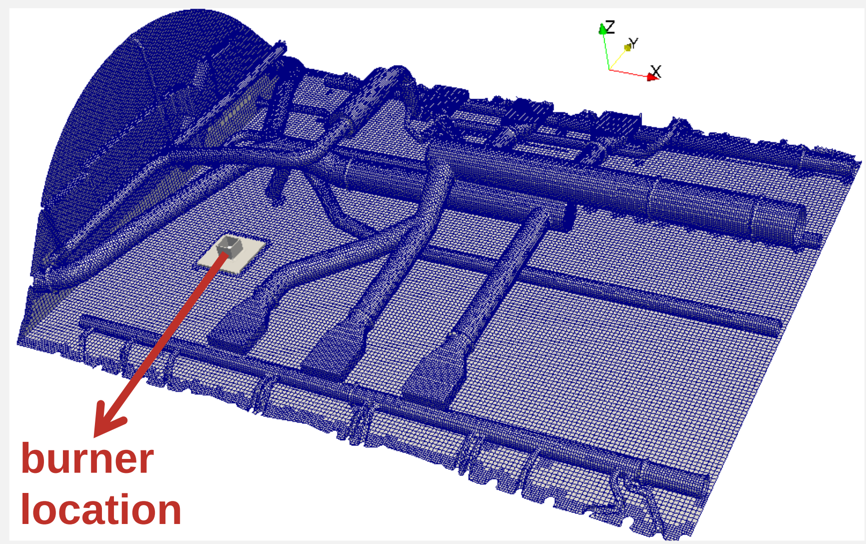
Methodology

Numerical section – Grid

- Total number of cells, composed mostly hexahedra, is 1.4 millions.
- Finest resolution is placed close to the burner and 0.01 m. This corresponds to characteristic fire diameter to cell size of 16 ($D^*/\delta = 16$).
- Mesh parameters:
  - Maximum aspect ratio ≈ 11
  - Maximum skewness ≈ 4
  - Maximum nonorthogonality ≈ 65

Grid distribution close to obstructions

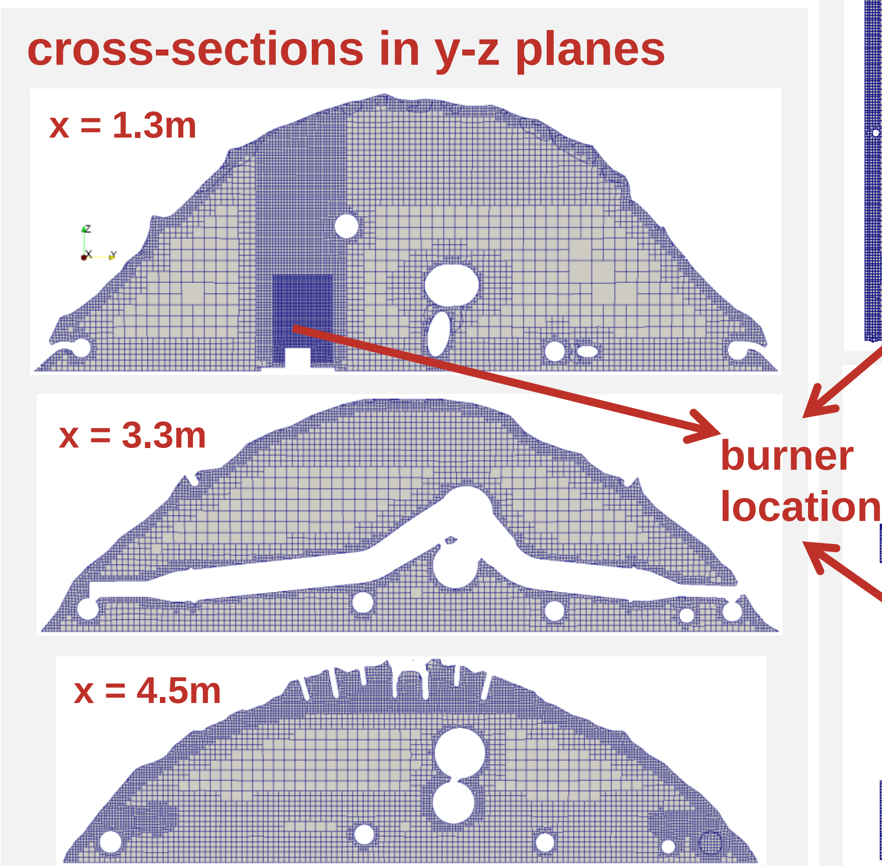


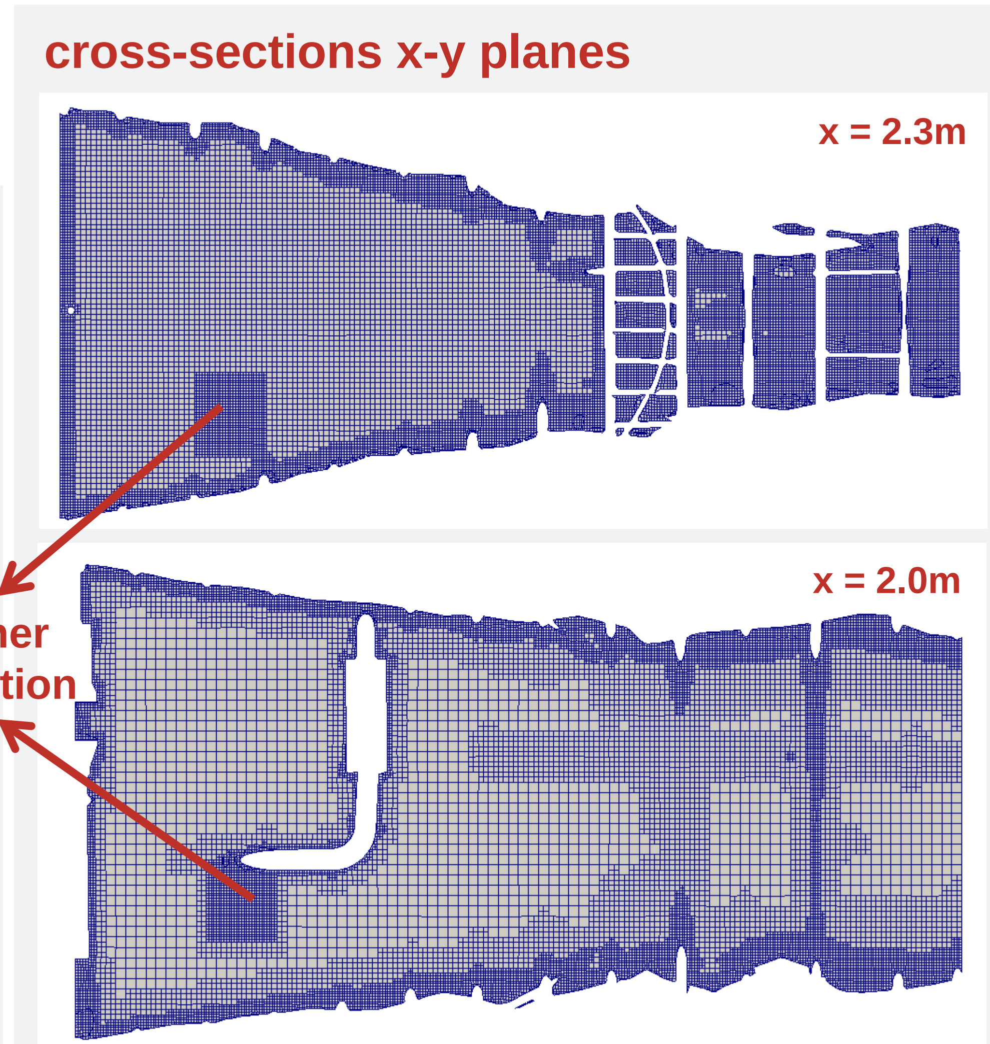


Methodology

Numerical section – Grid

Finer grid resolutions are used close to the fire source and obstructions.



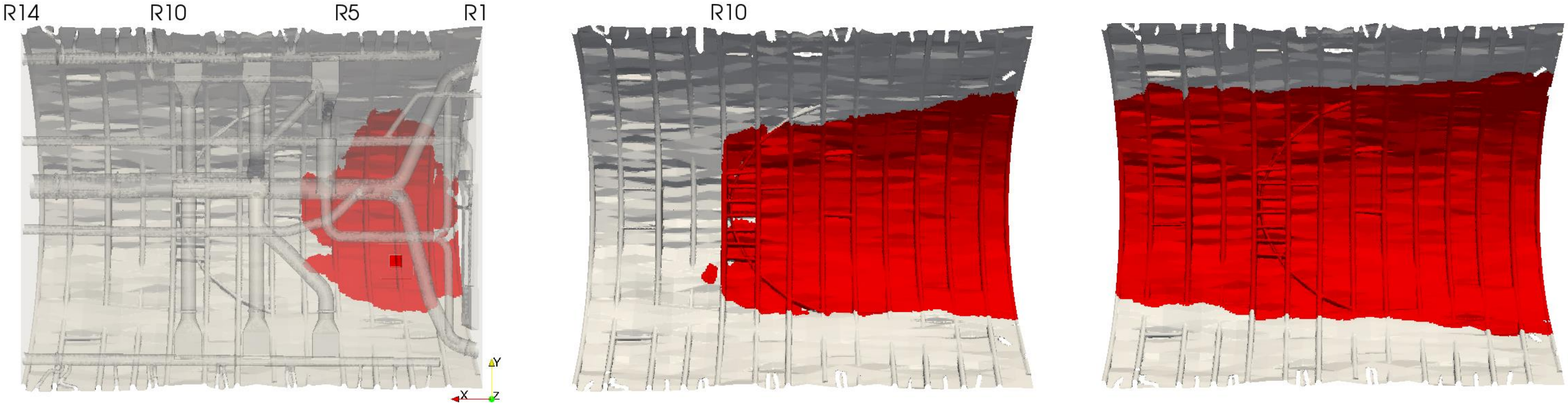


Results

Gas temperatures – Spread rate

- Region of very small temperature change, 0.5K, above ambient is shown to indicate the front of hot gases in successive time steps starting from 5 to 45 seconds into fire initiation.
- At 45 seconds, the hot gases cover the entire length of the overhead region studied.

Looking from the cabin below to the overhead area



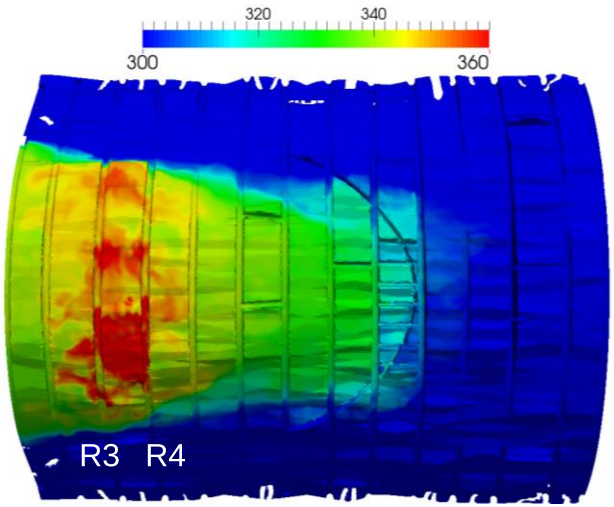
5 seconds **20 seconds** **45 seconds**

Results

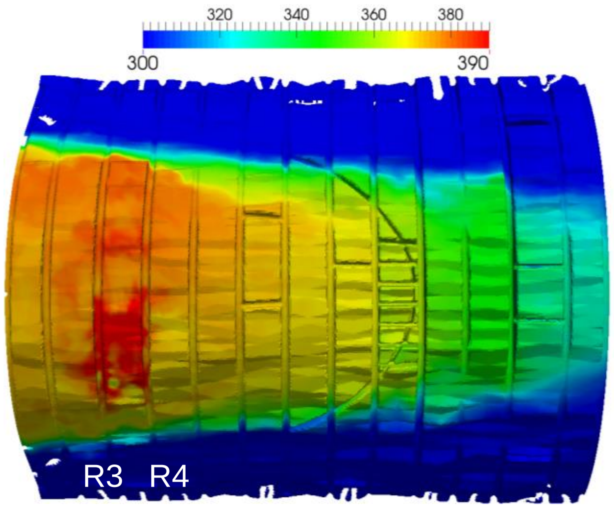
Instantaneous gas temperatures at 30, 90, 120 seconds

- **At 30 seconds:** the channeling effect of rib numbers 3 and 4 (R3 and R4) is noticeable with the high temperatures locally concentrated between these two ribs not only above the burner but in the channel.
- **By 120 seconds:** more uniform temperature distribution in the taller side of the insulated ceiling except for local maximums above the burner.

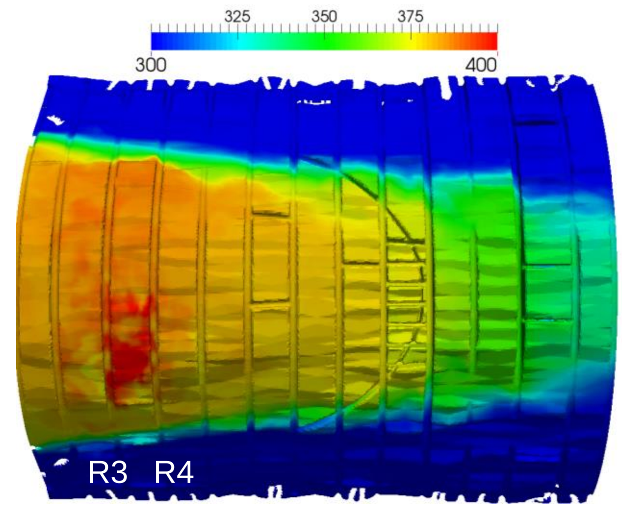
Looking from top to the overhead area



30 seconds



90 seconds



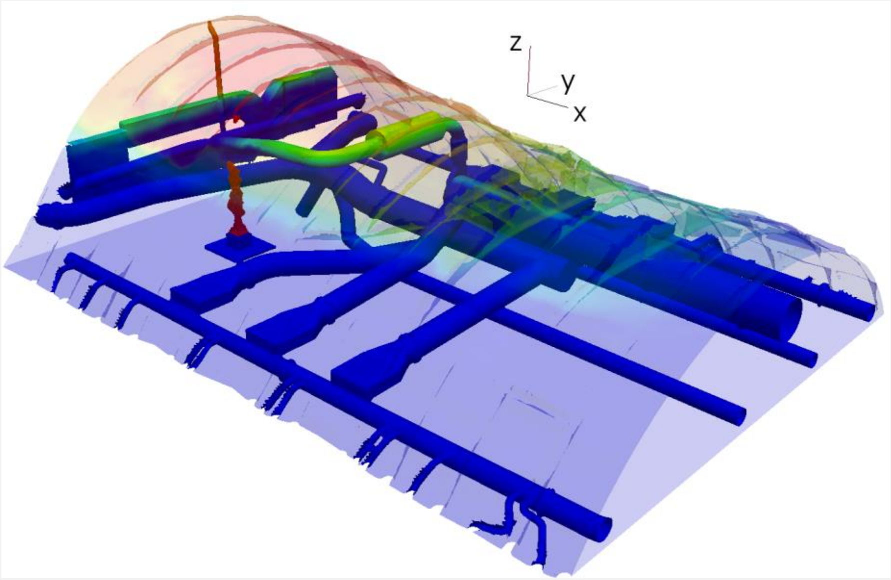
120 seconds

Results

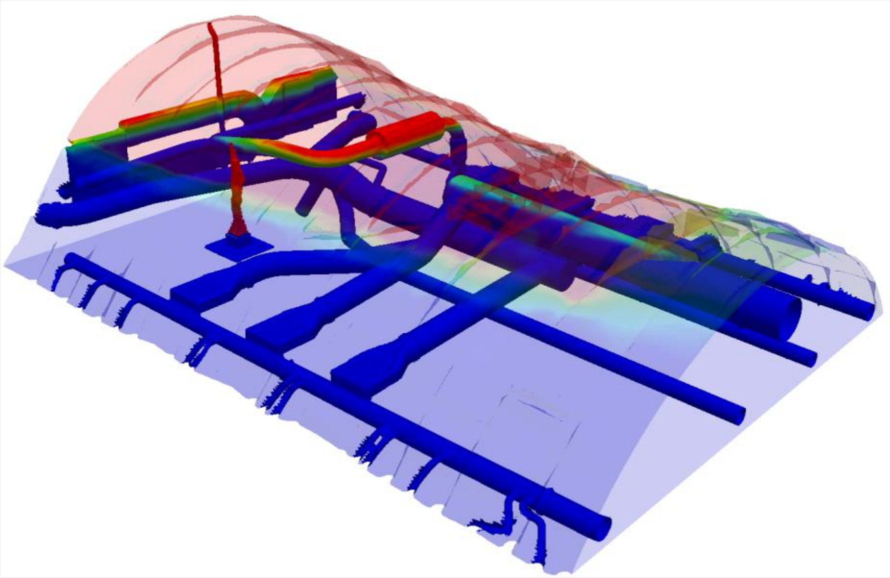
Gas temperatures – close to the obstructions

- Gas temperatures of only a few objects changed: the upper part of the forward bulkhead, the muffler-shaped duct, and the duct relatively at a higher location.
- There is a clear increase in gas temperatures around these objects from 30 to 120 seconds (Temperatures between 300 Kelvin (blue) to 380 Kelvin (red)).

30 seconds



120 seconds

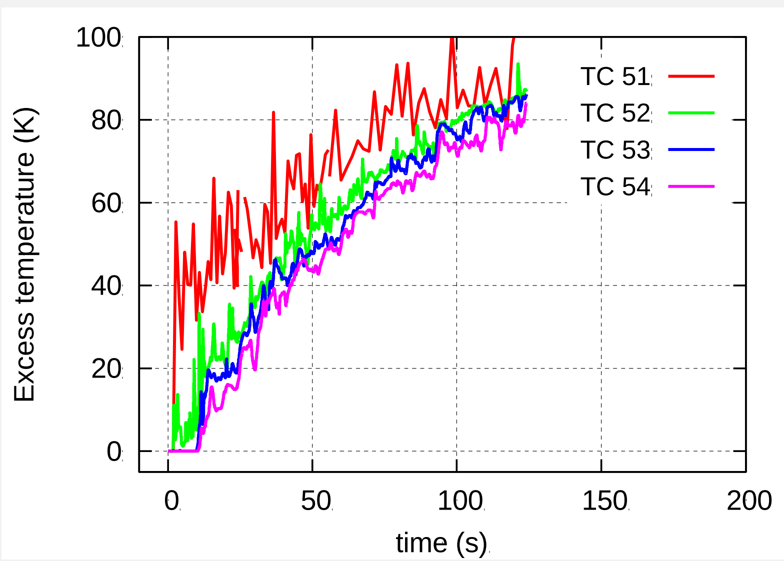


Results

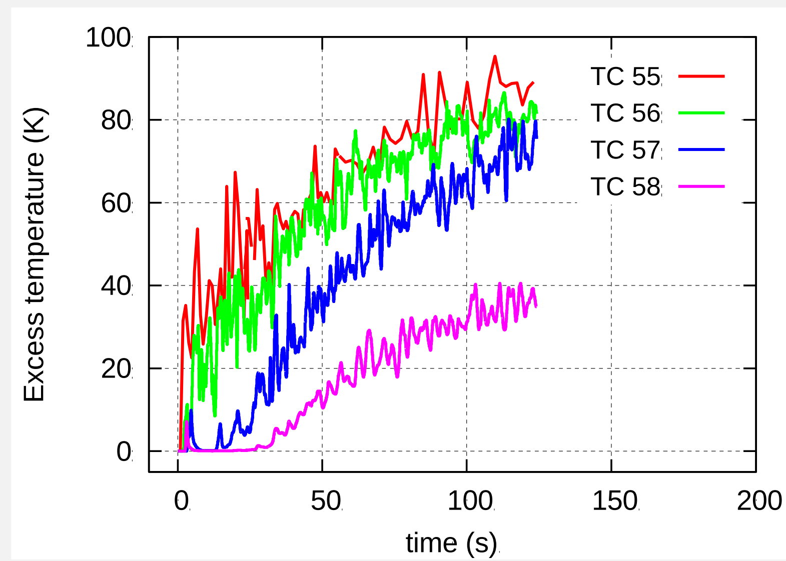
Gas temperatures – at thermocouple locations

- Maximum temperatures are close to the fire source and on the taller side of the insulated ceiling.
- Although both thermocouple trees are at the same distance to the fire source, one on the taller ceiling side reads higher temperatures even 50 cm (20 in) below.

TC tree on the taller side



TC tree shorter side



Conclusions

Summary and Future Work

The preliminary conclusions can be summarized as follows:

- The cross-sectional variation of the overhead region has more dominant influence on the transport than the clutter,
- The obstructions close to the ceiling, especially the ribs, hinders the transport and enhances turbulence,
- The preferred direction of the gas transport is along the ribs and towards the taller side of the insulated ceiling,
- The maximum predicted temperature (380 Kelvin) is higher that that obtained from the ceiling jet correlations (350 Kelvin).