Modeling of Hidden Fire Smoke Signature in Aircraft

A CASE STUDY OF OVERHEAD AREA

Ezgi Öztekin*

*Technology and Management International (TAMI) LLC, Toms River, NJ

Fire Safety Branch (ANG-E21)
Aviation Research Division,
FAA William J. Huges Technical Center, NJ

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Outline

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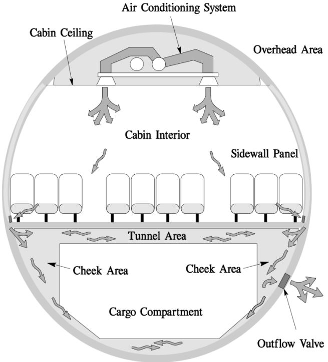
Introduction

Hidden fires

- FAA Advisory Circular (AC) 120-80, In-Flight Fires, 2004.
- **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:** Overhead area, cheek area, sidewall panel.



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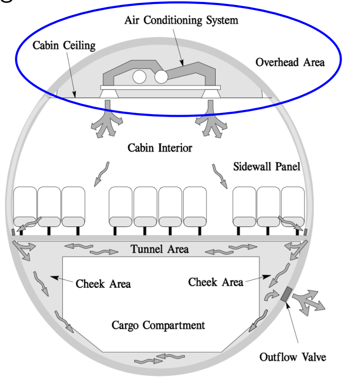

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Overhead area of **B747 SP** Test article

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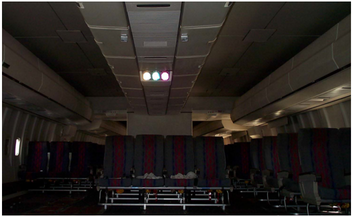
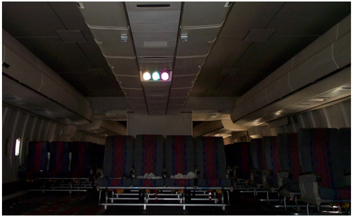


Courtesy of T. Marker

Introduction

Overhead area of **B747 SP** Test article



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Outline

Introduction

Fire source

- The FAA Tech Center Aircraft Fire Safety group has adopted the polyurethane foam block as the standard fire-threat for in-flight fires*,†,‡.
  - $4 \times 4 \times 9$ inch^3 in size,
  - 49 kW/m^2, 781 ^{o}C,
  - Total burn time $\geq$ 10 minutes, active burn time $\approx$ 1 minute.

Fire source‡

Courtesy of R. Ochs

*Development of repeatable hidden fire source, S. Le Neve, Toulouse Aeronautical Test Centre (CEAT), 2009.

†Development of an improved fire test method and criteria for aircraft electrical wiring, J.W. Reinhardt, FAA Tech Report, 2010.

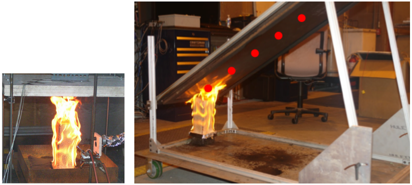
‡Composite structure flame propagation test method development, R.I. Ochs, FAA Tech Center, 2012.

Outline

Methodology

Steps followed in a fire test:

- Determine
  - fire threat (fuel selection),
  - test configuration
  (geometry, location of fire source, additional combustibles, ambient conditions, etc),
  - instrumentation
  (heat flux gauges, thermocouples, pressure transducers, etc),
- Build test set-up
- Run tests (data collection) and analyze.



Courtesy of S. Le Neve and R. Ochs

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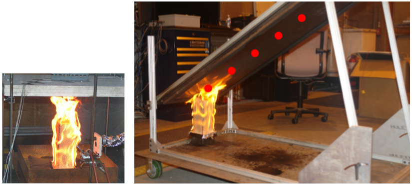
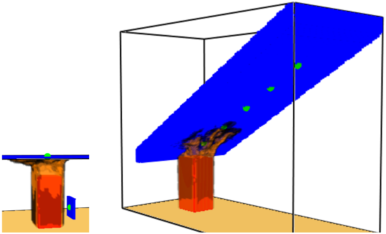


Courtesy of S. Le Neve and R. Ochs

Steps followed in a fire modeling study:

- Determine
  - fire threat (fuel selection),
  - test configuration
  (geometry, location of fire source, additional combustibles, ambient conditions, etc),
- Build test set-up
  (fuel characterization, CAD model, computational mesh)
- Run simulations (data collection) and analyze.



Outline

Methodology

Solver selection and model set-up

Two computational fluid dynamics (CFD) packages are employed:

1- Fire Dynamics Simulator **(FDS)***, developed by National Institute of Standards and Technology (NIST), and

2- **fireFOAM**†, developed by FM Global.

FDS is faster and requires less computational resources, while fireFOAM is more flexible to apply in complex geometries.

General solver set-up

- Subgrid-scale turbulence is modeled either with the WALE (Wall Adapting Local Eddy viscosity), or the dynamic Smagorinsky models,
- Combustion (fire) is modeled assuming infinitely fast chemistry,
- Thermal conduction to the outer skin is assumed to be one-dimensional,
- Simulations are second-order accurate in time and space,
- Radiation is modeled using the finite volume discrete ordinates method.

* https://code.google.com/p/fds-smv/

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

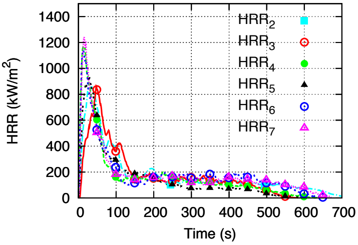
Outline

Methodology

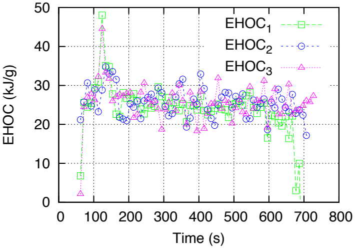
Fire source - Characterization

- The rates of **heat release** and **mass loss** are measured in bench-scale tests,
- The **heat of combustion** is calculated from the experimental data (cone calorimeter),
- The stoichiometry and the radiative fraction for the fire source are still unknowns. The selected values for these parameters will affect the simulation results.
  - Radiative fraction is assumed to be 0.335,
  - Stoichiometry is decided based on the known heat of combustion value.

Heat release rate (HRR)



Effective heat of combustion (EHOC)



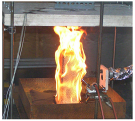
Methodology

Fire source - Characterization

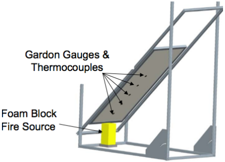
Various test cases are simulated where foam block is placed under:

- **Case 1** a horizontal ceiling 9 inches away from the top of the foam block[*]
- **Case 2** an inclined panel with different orientations[†]
- **Case 3** an inclined panel in a chimney configuration[†]
- **Case 4** a curved surface, representative of an aircraft skin, inspired by earlier intermediate-scale tests[‡], except the block is placed farther away from the ceiling

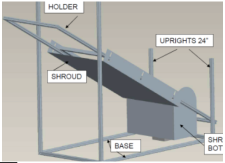
Test case 1[*]



Test case 2[†]



Test case 3[†]



Test case 4[‡]

[*] Development of repeatable hidden fire source, S. Le Neve, Toulouse Aeronautical Test Centre (CEAT), 2009.

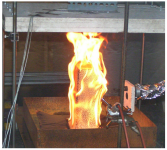
[†] Composite structure flame propagation test method development, R.I. Ochs, FAA Tech Center, 2012.

[‡] Development of an improved fire test method and criteria for aircraft electrical wiring, J.W. Reinhardt, FAA Tech Report, 2010.

Methodology

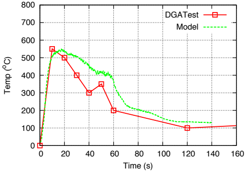
Fire source - Characterization

- Maximum temperature measured, at 20s, is ≈ 823 Kelvin,
- In spite of the uncertainties in the model parameters, predicted temperature range is close to that measured in the experiments*

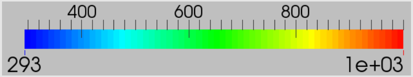


Test case 1*

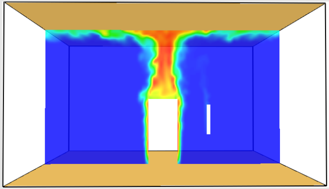
Temperature



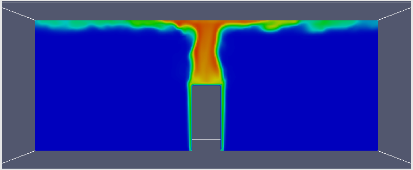
Contourplots of instantaneous temperatures at t=20s



FDS results



fireFOAM results



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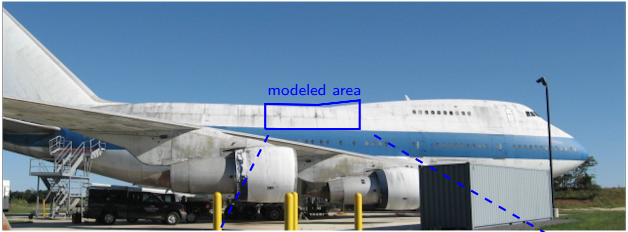
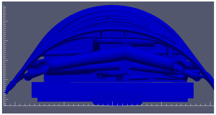
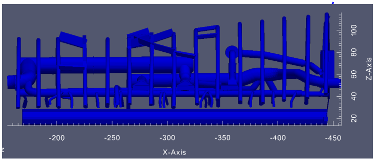
Overhead area of B747 SP Test article

Bench-scale tests $\mapsto$ full-scale tests







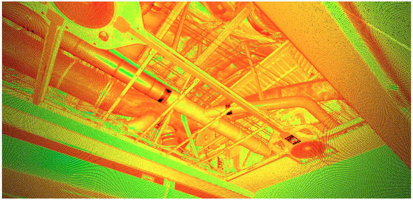
$\longleftarrow$ $5.5m$ $\longrightarrow$ $\longleftarrow$ $7.5m$ $\longrightarrow$

Methodology

CAD model for the B747 overhead area

LIDAR (Light Detection and Ranging) technology is used in the determination of the internal dimensions of the overhead area of 747SP test article.

LIDAR point cloud data

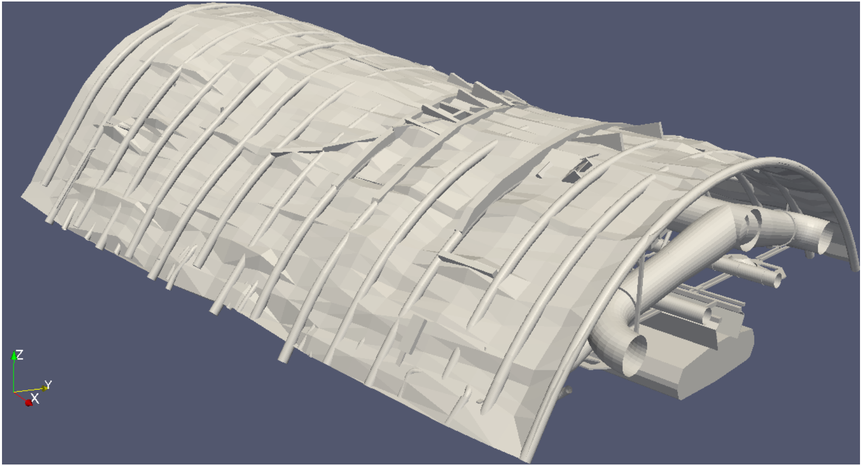


Scanned real geometry

Methodology

CAD model for the B747 overhead area

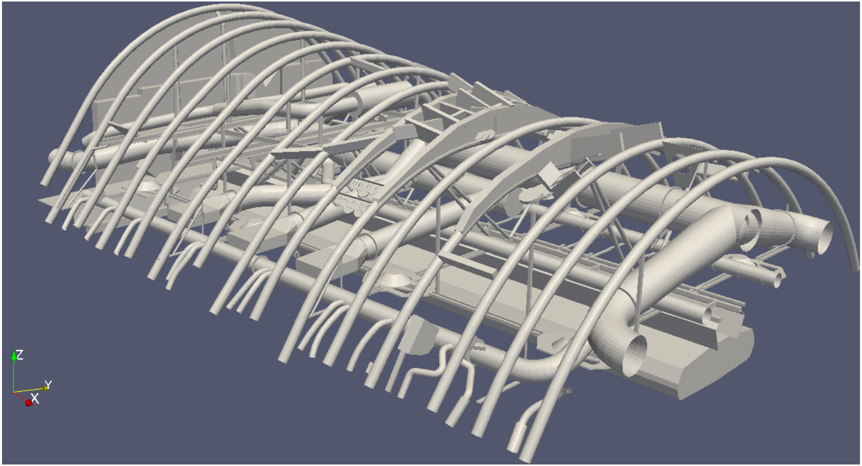
3D model



Methodology

CAD model for the B747 overhead area

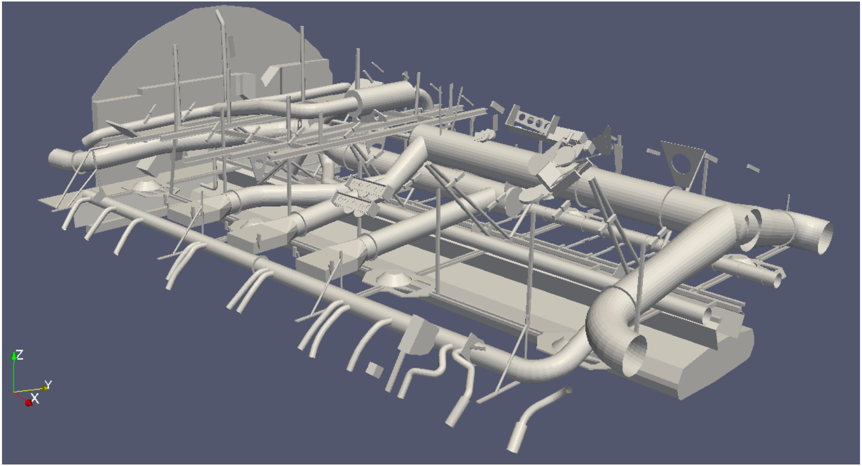
3D model without the insulation



Methodology

CAD model for the B747 overhead area

Inside the 3D model



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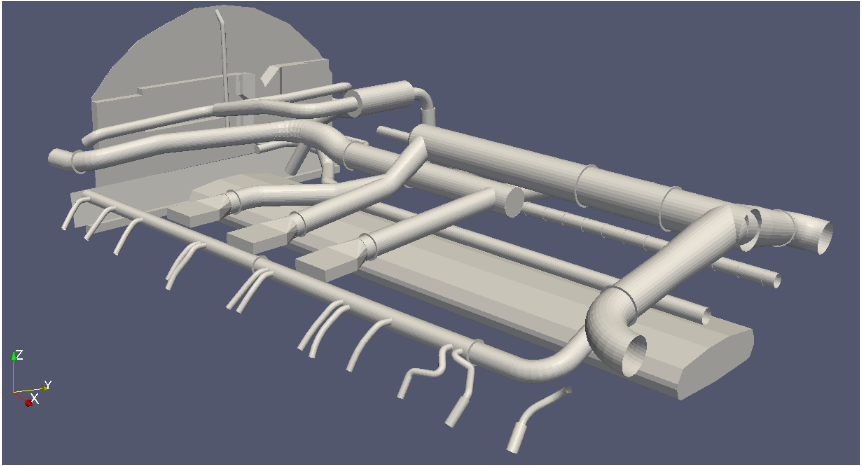
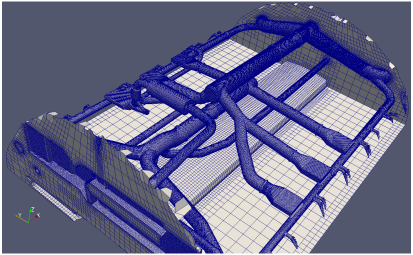


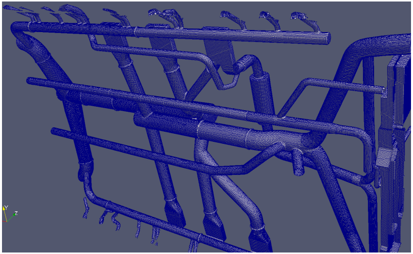
Outline

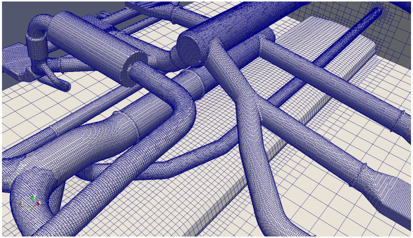
Methodology

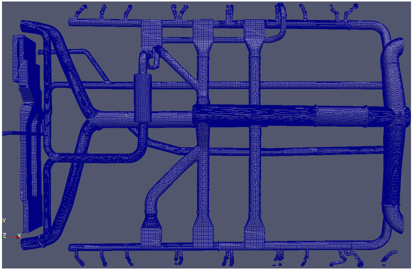
Mesh for the B747 overhead area

Small features, such as droppers on each end, require finer resolutions with an increase in the total number of grid points.









Summary and Future Work

- ✓ Selection of a CFD solver .... **[Done]**
- ✓ Characterization of the fire source .... **[Done]**
- ✓ CAD model for the B747 overhead area .... **[Done]**
- ▶ Mesh generation for the modeled geometry .... **[In progress]**
- ▶ Acquiring computational resources .... **[In progress]**
- ▶ Solution and analysis .... **[Next in line]**