Simulation of complex geometry in FDS

Marcos Vanella[a,b], Randall McDermott[b], Glenn Forney[b], Emanuele Gissi[C], Kevin McGrattan[b]

[a] *University of Maryland, College Park, MD*
[b] *National Institute of Standards and Technology, Gaithersburg, MD*
[c] *Corpo Nazionale dei Vigili del Fuoco, Italy*

Fire and Evacuation Modeling Technical Conference 2018,
Gaithersburg, Maryland, USA. October 1-3, 2018.

- Modeling fire dynamics for Complex Geometry.
- Treatment of FDS physics units.
- Defining geometries in FDS. Restrictions on GEOM input.
- The CATF input namelist.
- Workflow showcase through validation case.
- Summary.

FDS for Complex Geometry

The Fire Dynamics Simulator* (FDS) is used in:

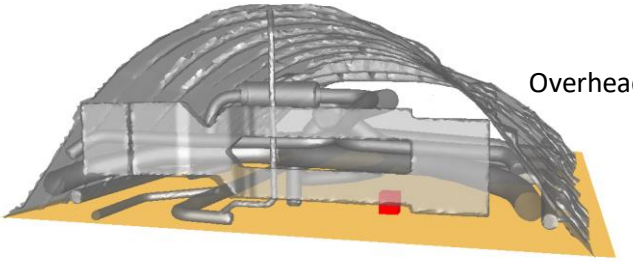
- performance-based design,
- forensic work,
- Simulation of wild land fire scenarios.

- In 3D it employs structured, rectilinear grids.
- Defines "lego-block" geometries for internal boundaries.

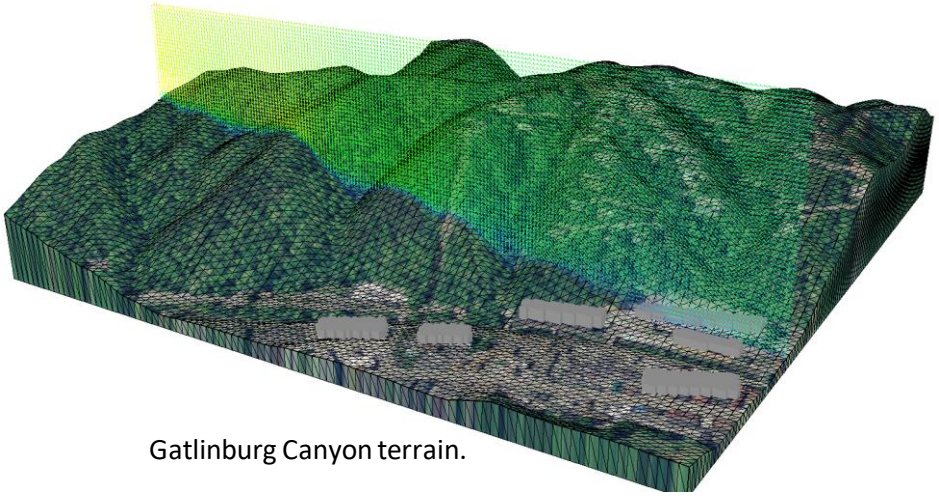
NFRL 20 MW calibration burner.

Objective:

Add on : Develop an efficient, conservative numerical scheme for complex geometry within FDS.



Overhead compartment model, Guo H., FAA.



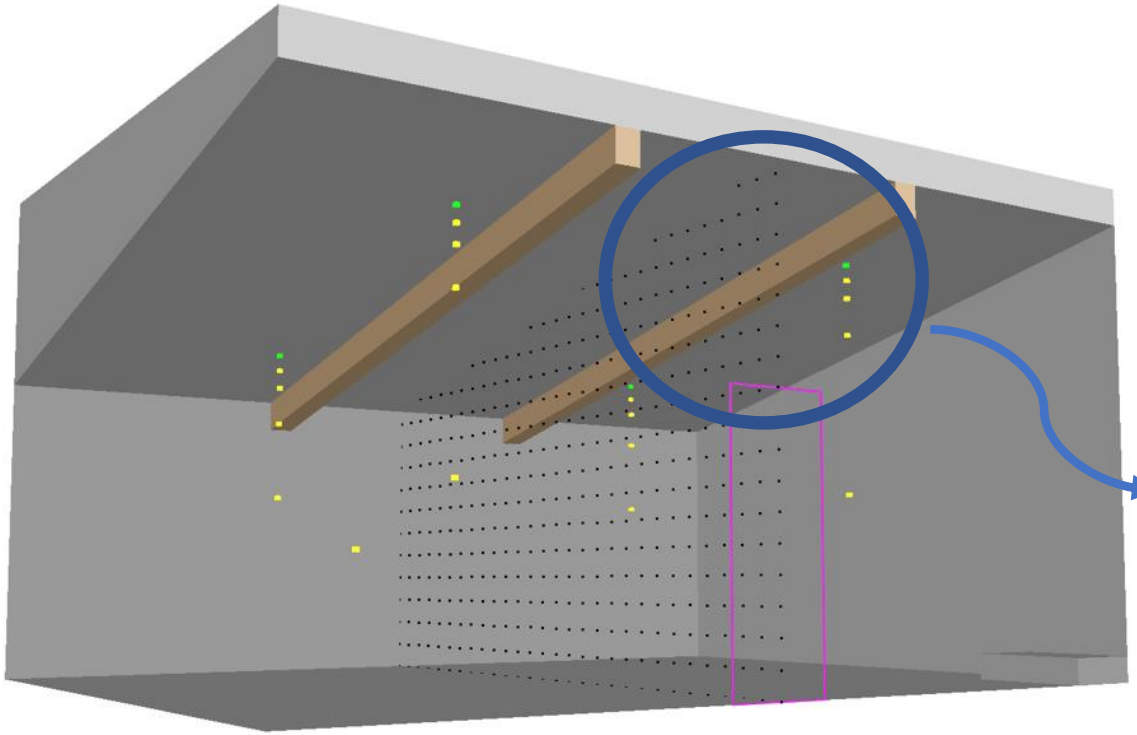
Gatlinburg Canyon terrain.

* K. McGrattan et al. Fire Dynamics Simulator, Tech. Ref. Guide, NIST. Sixth Ed., Sept. (2013).

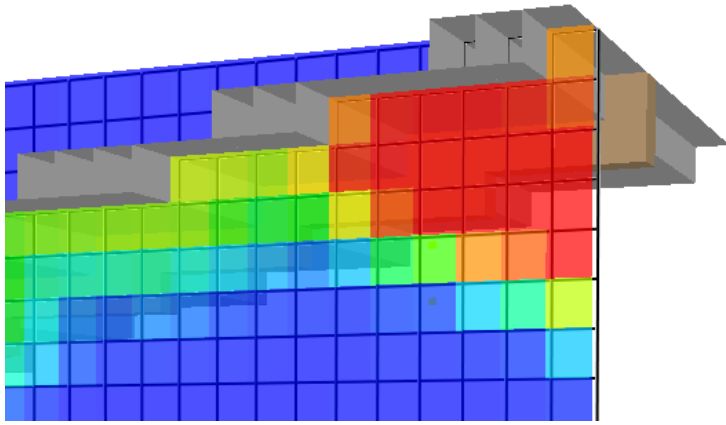
FDS for Complex Geometry

FDS Modifies the geometry keeping the fluid mesh:

- The geometry shape is changed to conform (”snap to”) to the fluid mesh.



Fire on sloped compartment. R. L Vettori, NISTIR 7079 (2003).

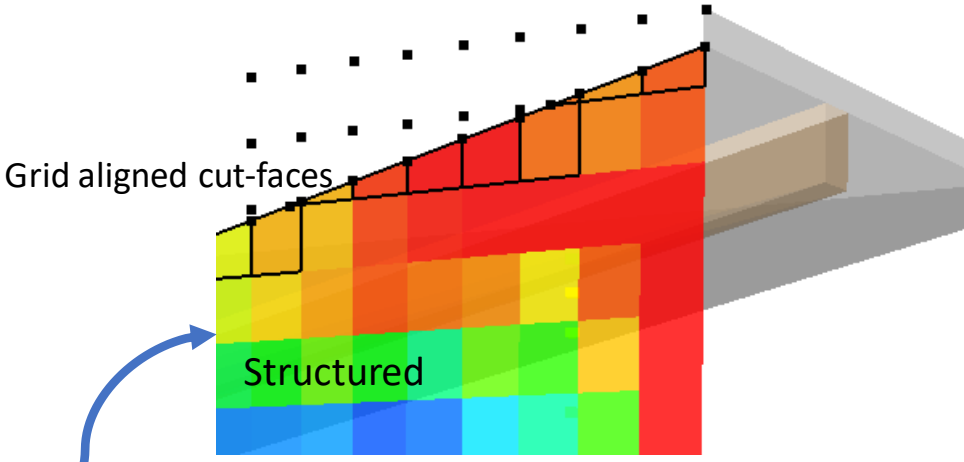


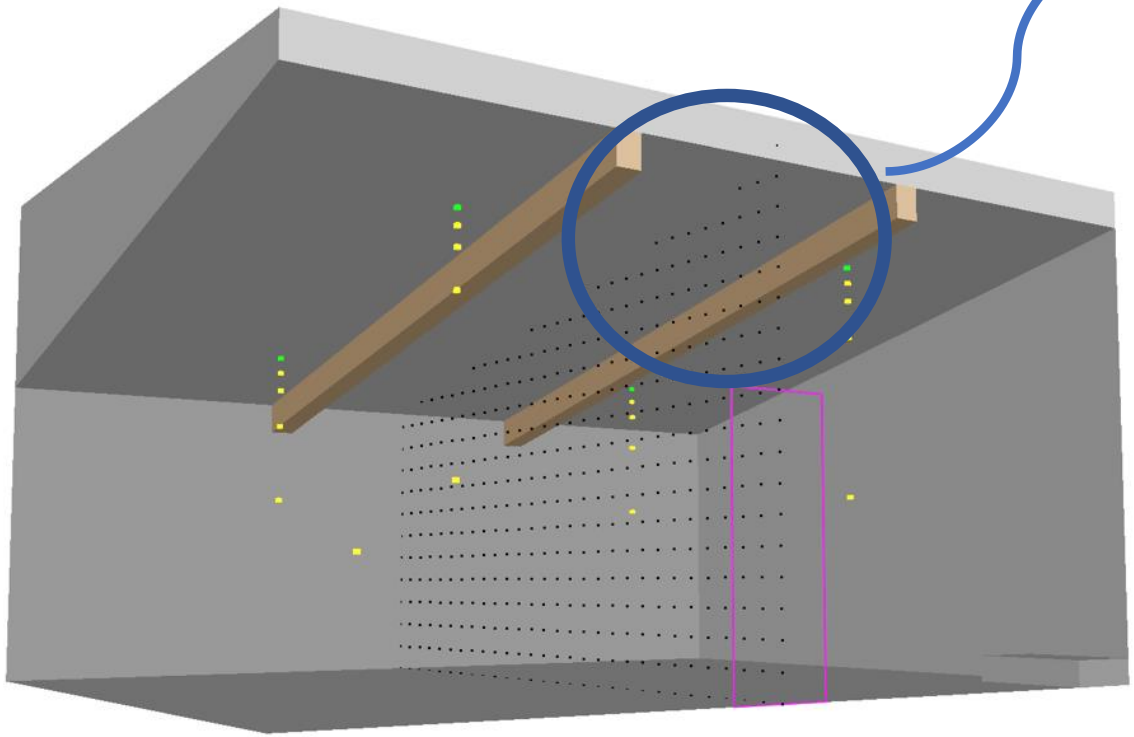
Cuboid obstacles

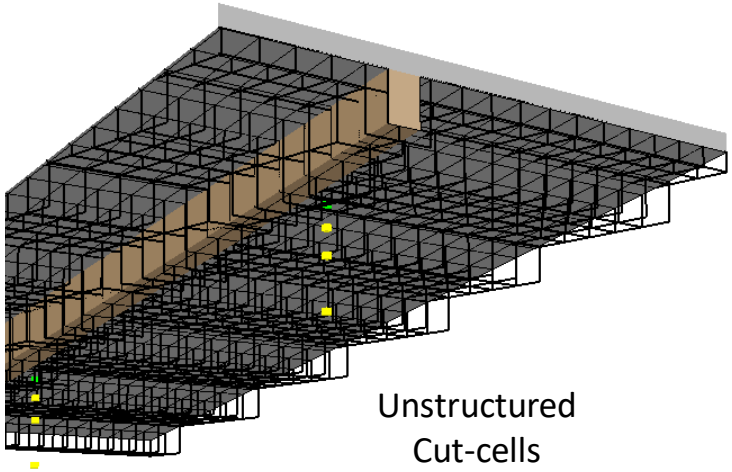
FDS for Complex Geometry

Modifying the fluid mesh, keeping geometry shape:

- The FDS meshes are modified to conform to the geometry definitions.
- Computational geometry engine.







Fire on sloped compartment. R. L Vettori, NISTIR 7079 (2003).

FDS physics units

- **Scalar transport:**

Spatial and temporal discretization on cut-cell region.

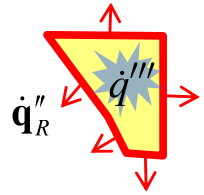
Scalar transport

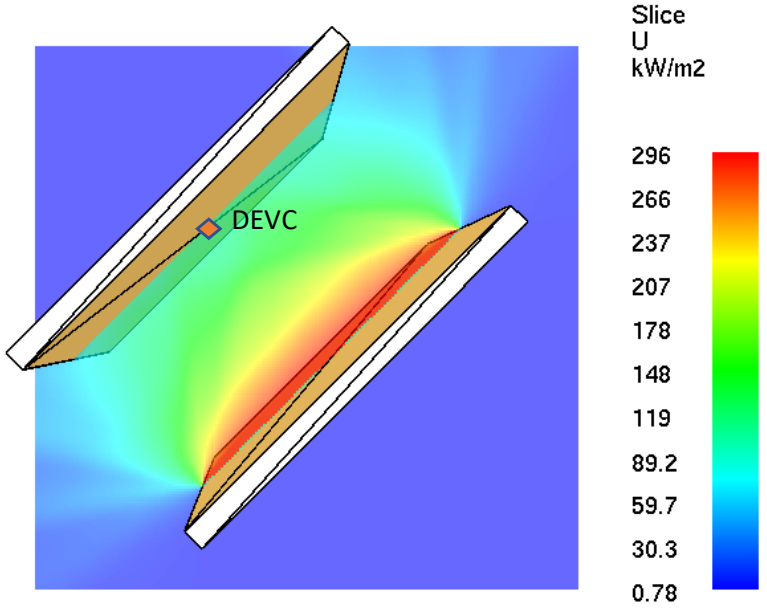
$$\frac{\partial \rho Y_\alpha}{\partial t} + \nabla \cdot \left(\rho Y_\alpha \mathbf{u}\right) = -\nabla \cdot \left(-\rho D_\alpha \nabla Y_\alpha\right) + \dot{m}_\alpha''' \longrightarrow r^{n+1}, Y_a^{n+1}$$

- **Combustion, Radiation:**

Different cell volumes, boundary cut-faces as source of Radiation FVM.

Combustion, Radiation





- **Energy:**

Unstructured FVM discretization, BCs.

Divergence Constraint*

$$\nabla \cdot \mathbf{u} = \frac{1}{\rho h_s}\left[\frac{D}{Dt}\left(\bar{p} - \rho h_s\right) + \dot{q}''' - \nabla \cdot \dot{\mathbf{q}}''\right] \longrightarrow \left(\nabla \cdot \mathbf{u}\right)^{n+1}$$

* R. J. McDermott. J. Comput. Phys. 274, pp. 413-431 (2014); + E. A. Fadlun et al. J. Comput. Phys. 161, pp. 35-60 (2000).

FDS physics units

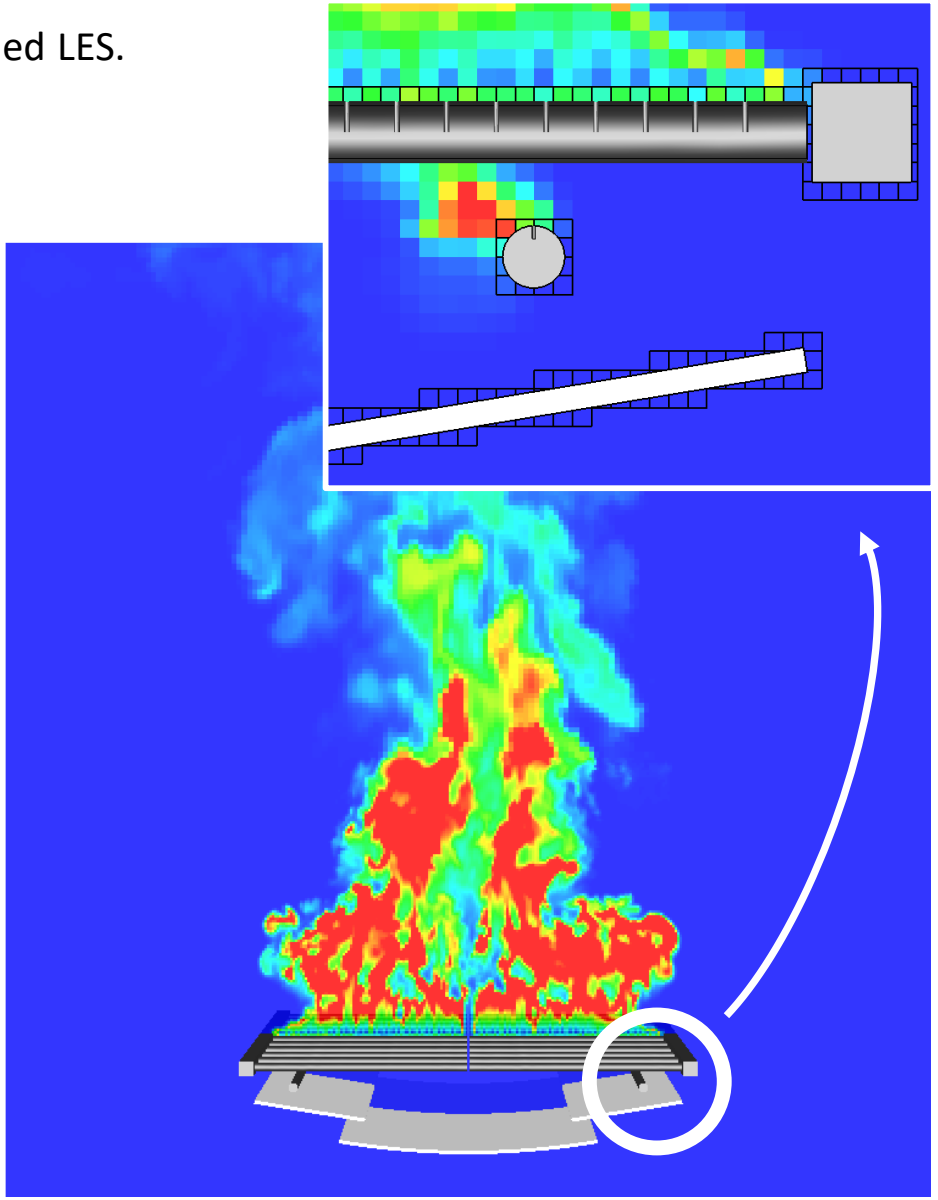
- **Momentum Coupling:**

Add presence of boundary through IBM, wall modeled LES.
Respect continuity through divergence equivalence.

$$\begin{cases} \text{Compute source } \mathbf{F} \longrightarrow \mathbf{F}_{IB} = -\left(\dfrac{\partial \mathbf{u}}{\partial t}\right)_D \\ \dfrac{\partial}{\partial t}(\nabla\cdot\mathbf{u}) \approx \dfrac{(\nabla\cdot\mathbf{u})^{n+1} - \nabla\cdot\mathbf{u}^n}{\Delta t}, \quad \Delta H = -\left[\nabla\cdot\mathbf{F} + \dfrac{\partial}{\partial t}(\nabla\cdot\mathbf{u})\right] \\ \dfrac{\partial \mathbf{u}}{\partial t} = -(\mathbf{F} + \nabla H) \longrightarrow \mathbf{u}^{n+1}\ \Delta H^n \end{cases}$$

- **Post Processing:**

SMV SLCF, BNDF, devices, etc.

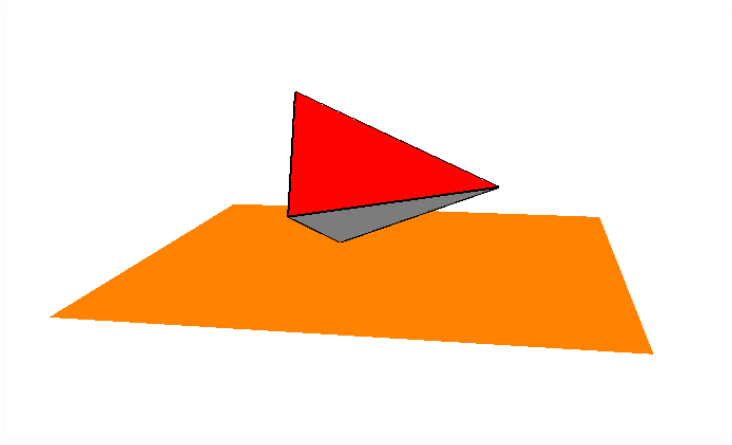


NIST calibration burner, 8MW.
Temperature: 20°C (blue) to 1400°C (red).

Defining geometries

Defining a geometry with &GEOM:

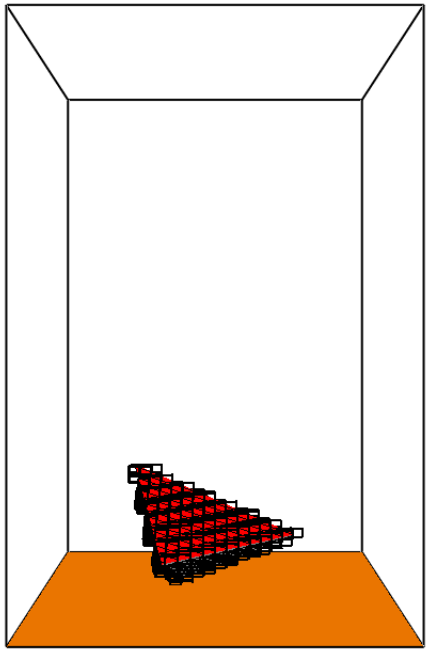
```
&SURF ID='BURNER', HRRPUA=300., COLOR='RED' /
&SURF ID='WALLS TETRA', COLOR='GRAY 60', ADIABATIC=T, DEFAULT=T /

# Geometries:
&GEOM ID='TETRA'
      SURF_ID='WALLS TETRA','BURNER'
      VERTS=0.0, 0.0, 0.0,
            1.0, 0.0, 0.0,
            0.0, 1.0, 0.0,
            0.0, 0.0, 1.0,
      FACES=1, 2, 4,   1,
            1, 3, 2,   1,
            1, 4, 3,   1,
            2, 3, 4,   2,
      GAXIS=-1.,1.,0.
      GROTATE=30.
      SCALE=2.5,2.5,2.5
/
```



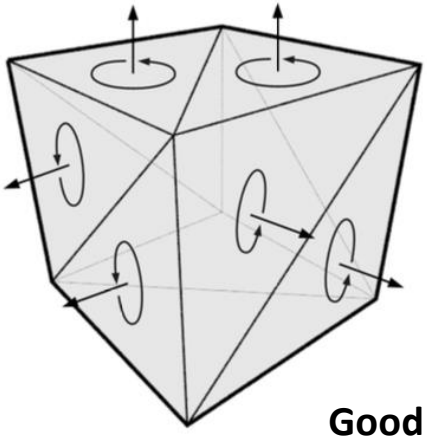
Defining geometries

Defining a geometry with &GEOM:

```
&SURF ID='BURNER', HRRPUA=300., COLOR='RED' /
&SURF ID='WALLS TETRA', COLOR='GRAY 60', ADIABATIC=T, DEFAULT=T /

# Geometries:
&GEOM ID='TETRA'
      SURF_ID='WALLS TETRA','BURNER'
      VERTS=0.0, 0.0, 0.0,
            1.0, 0.0, 0.0,
            0.0, 1.0, 0.0,
            0.0, 0.0, 1.0,
      FACES=1, 2, 4,   1,
            1, 3, 2,   1,
            1, 4, 3,   1,
            2, 3, 4,   2,
      GAXIS=-1.,1.,0.
      GROTATE=30.
      SCALE=2.5,2.5,2.5
/
```



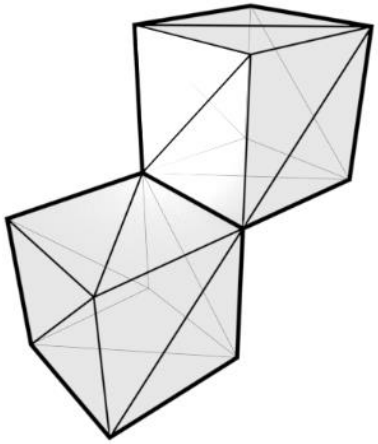
Restrictions on GEOMs



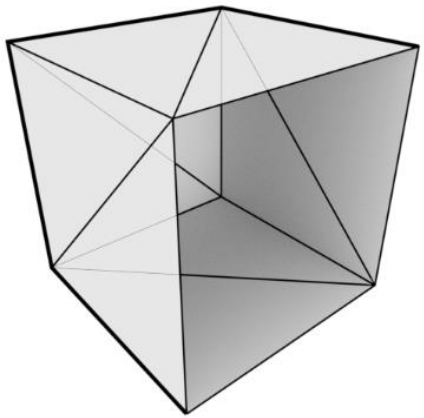
Good GEOM

- Unique non-degenerate **VERTS**.
- All edges of non-zero length, connecting two faces.
- **FACES** of non-zero area, not intersecting others.
- Local **VERTS** numbering follows right hand rule outside.
- GEOMs define unconnected volumes through surfaces. They don't intersect, self intersect.

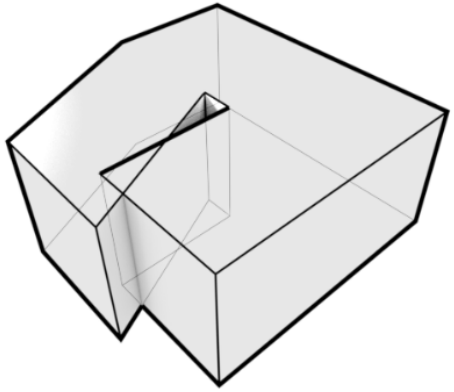
Bad GEOMs



Non manifold, intersecting



Open surface



Self intersecting

CATF Namelist

- **CATF** : Concatenate input files.
- Include information from different text files into an FDS input file.
- Allows us to employ a large &GEOM (or other Namelists) on several input files.

```
&HEAD CHID='tetra_demo', TITLE='Complex Geometry: Test tetrahedron burner.' /

# 1 MESH:
&MESH IJK=30,30,60, XB=-2.5,4.0,-2.5,4.0,0.0,10.0, /

# Time and Misc:
&TIME T_END=15. /
&MISC SIMULATION_MODE='LES', CONSTANT_SPECIFIC_HEAT_RATIO=T /

# Reaction:
&REAC FUEL='PROPANE', SOOT_YIELD=0.02 /

# BCs:
&VENT MB='XMIN', SURF_ID='OPEN' /
&VENT MB='XMAX', SURF_ID='OPEN' /
&VENT MB='YMIN', SURF_ID='OPEN' /
&VENT MB='YMAX', SURF_ID='OPEN' /
&VENT MB='ZMIN', SURF_ID='FLOOR' /
&VENT MB='ZMAX', SURF_ID='OPEN' /
&SURF ID='FLOOR', COLOR='ORANGE', ADIABATIC=T, DEFAULT=T /

# Tetra GEOM:
&SURF ID='BURNER', HRRPUA=300., COLOR='RED' /
&SURF ID='WALLS TETRA', COLOR='GRAY 60', ADIABATIC=T, DEFAULT=T /
&CATF OTHER_FILES='tetra.geom' /

&TAIL /
```

tetra_demo.fds

```
# Geometries:
&GEOM ID='TETRA'
      SURF_ID='WALLS TETRA','BURNER'
      VERTS=0.0, 0.0, 0.0,
            1.0, 0.0, 0.0,
            0.0, 1.0, 0.0,
            0.0, 0.0, 1.0,
      FACES=1, 2, 4, 1,
            1, 3, 2, 1,
            1, 4, 3, 1,
            2, 3, 4, 2,
      GAXIS=-1.,1.,0.
      GROTATE=30.
      SCALE=2.5,2.5,2.5
/
```

tetra.geom

CATF Namelist

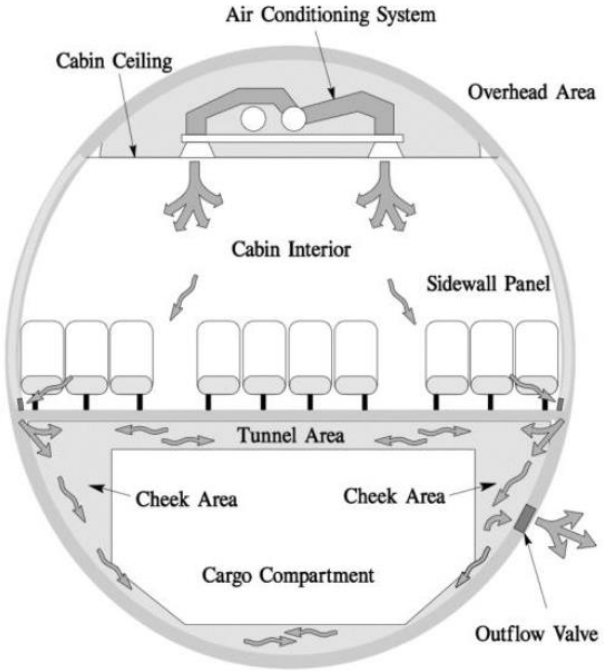
Executing FDS produces an input file `tetra_demo_cat.fds` at startup that is used in the run.

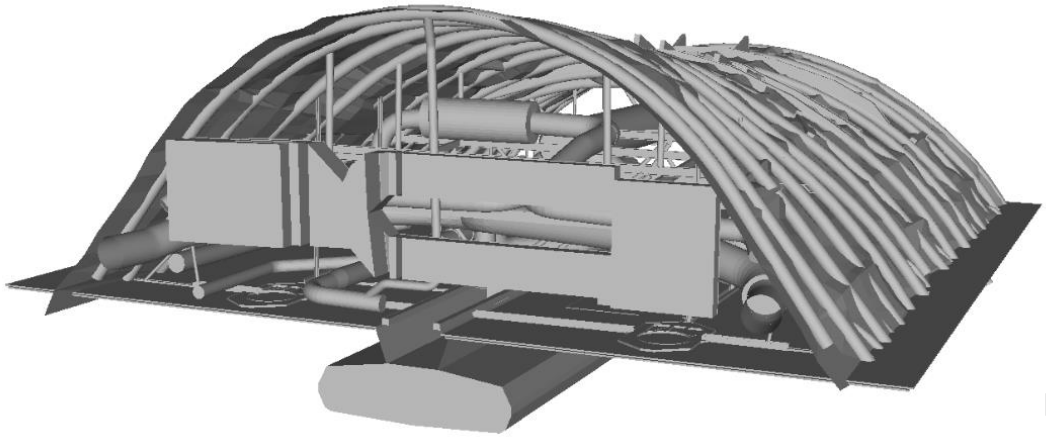
```
16:37 $ /Users/mnv/Documents/FIREMODELS_FORK/fds/Build/mpi_gnu_osx_64/fds_mpi_gnu_osx_64 tetra_demo.fds
Reading input file ...

 Fire Dynamics Simulator

 Current Date     : September 28, 2018  16:37:36
 Revision         : FDS6.7.0-661-g855702a-dirty-master
 Revision Date    : Thu Sep 27 15:21:32 2018 -0400
 Compiler         : Gnu gfortran GCC
 Compilation Date : Sep 28, 2018  10:34:36

 MPI Enabled;    Number of MPI Processes:       1
 OpenMP Disabled

 MPI version: 3.1
 MPI library version: Open MPI v3.0.0, package: Open MPI brew@Sierra.local Distribution, ident: 3.0.0, repo

 Job TITLE        : Concatenated : Complex Geometry: Test tetrahedron burner.
 Job ID string    : tetra_demo_cat

 Time Step:      1, Simulation Time:      0.10 s
 Time Step:      2, Simulation Time:      0.20 s
 Time Step:      3, Simulation Time:      0.30 s
 Time Step:      4, Simulation Time:      0.40 s
 Time Step:      5, Simulation Time:      0.50 s
 Time Step:      6, Simulation Time:      0.60 s
 Time Step:      7, Simulation Time:      0.69 s
 Time Step:      8, Simulation Time:      0.79 s
 Time Step:      9, Simulation Time:      0.89 s
 Time Step:     10, Simulation Time:      0.99 s
 Time Step:     20, Simulation Time:      1.63 s
 Time Step:     30, Simulation Time:      1.98 s
```

Workflow Showcase

FAA fire on B747 overhead cargo compartment test:

- Hidden area fire on Boeing 747 overhead compartment.



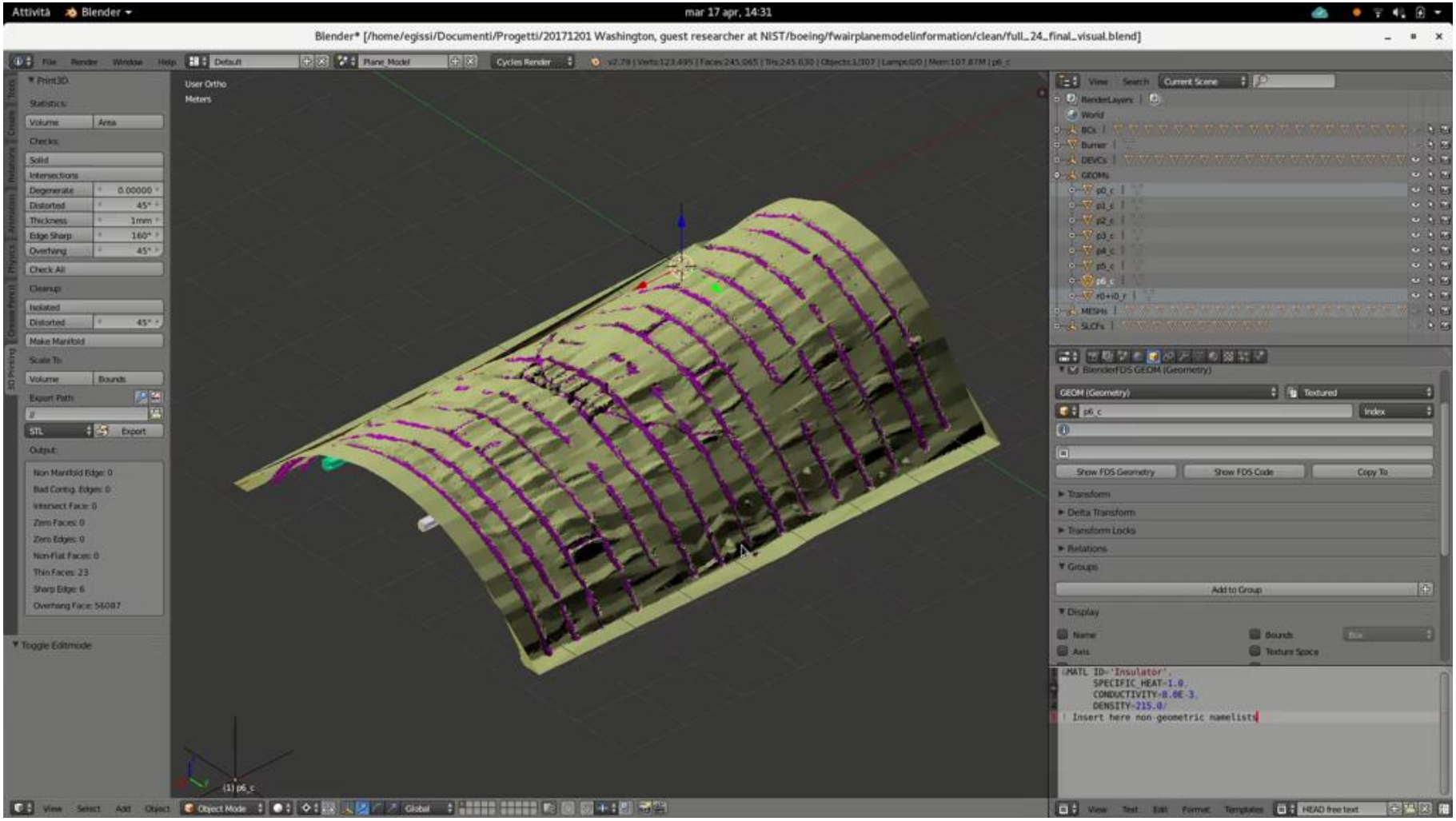


LIDAR generated 3D
CAD model.
Propane Burner 11KW

Guo H. et al., FAA Technical Report DOT/FAA/TC-18/14 (2018).

Workflow Showcase

- CAD model imported to preprocessor (PyroSim, Blender FDS). Objects must be made consistent. Surface triangle sizes and simulation parameters, including FDS meshes required, are defined here.



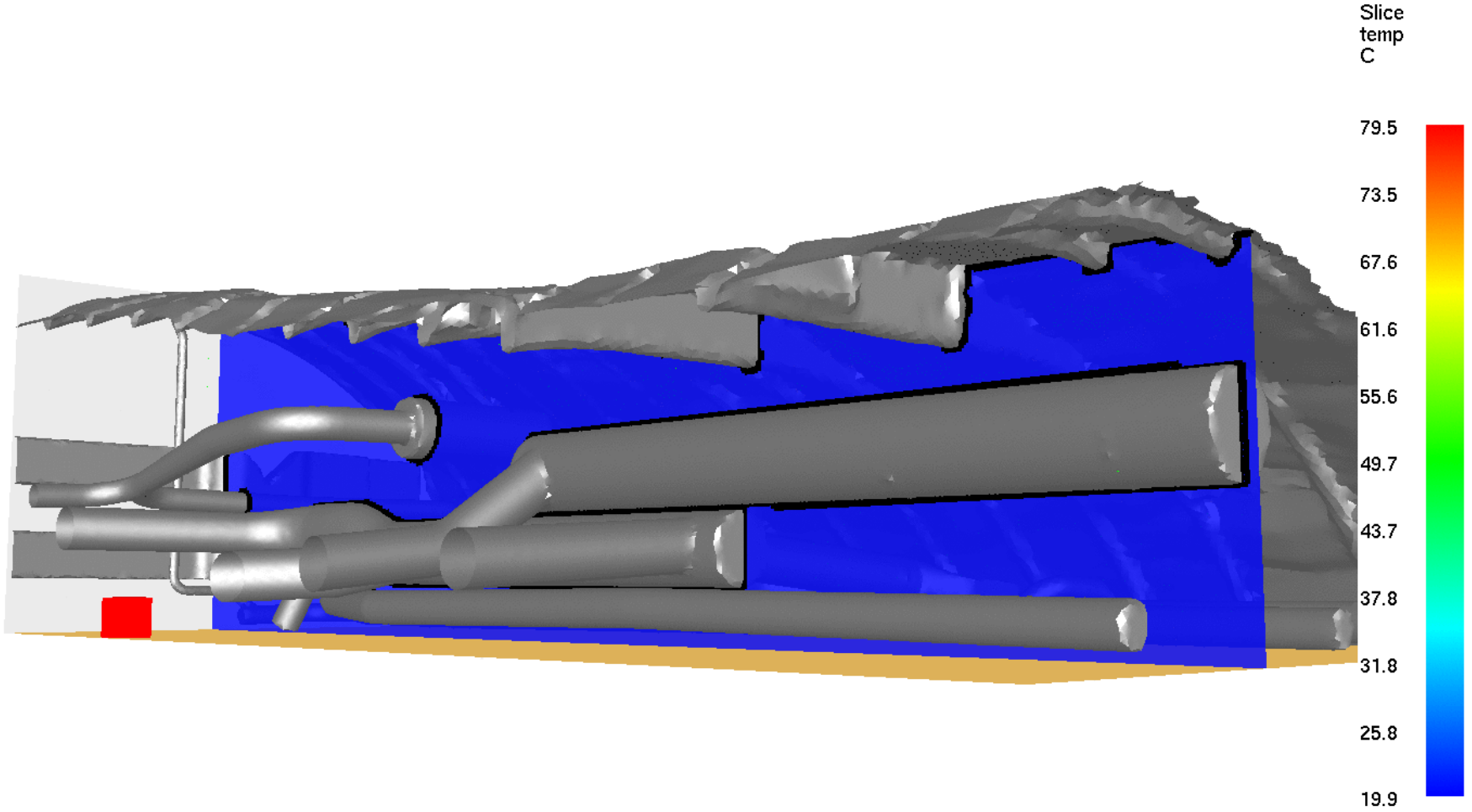
Workflow Showcase

- From preprocessor an FDS input file (and files to be included through &CATF) is generated.

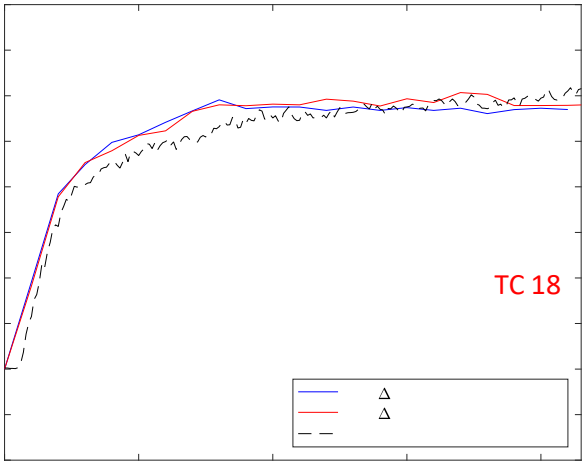
```
&HEAD CHID='FAA_B747_geom_2cm', TITLE='Guo et al. (2018) Modeling of Hidden Fire in Aircraft Overhead Area'/

! Mult Mesh, 144 Meshes:
&MULT ID='mesh multiplier', DX=0.84, DY=0.6, DZ=1.0, I_UPPER=7, J_UPPER=8, K_UPPER=1 /
&MESH IJK=42,30,50, XB=-0.01,0.83,0.01,0.61,0.0,1.0, MULT_ID='mesh multiplier' /

&TIME T_END=300.0 /
&DUMP DT_HRR=10, DT_DEVC=10, GET_CUTCELLS_VERBOSE=.TRUE. /

&MISC P_INF=100000, SIMULATION_MODE='LES' / ! Ground level simulation, cabin overhead area set to 1 bar.
&PRES VELOCITY_TOLERANCE=0.0005, MAX_PRESSURE_ITERATIONS=50 /

&REAC ID='Reaction1',
      FYI='RADIATIVE_FRACTION=0.30 by default for propane',
      FUEL='PROPANE',
      SOOT_YIELD=0.02,
      CRITICAL_FLAME_TEMPERATURE=1327.0,
      HEAT_OF_COMBUSTION=4.636E4/

&SURF ID='Burner',
      FYI='11 kW',
      COLOR='RED',
      HRRPUA=343.4/

&SURF ID='ADIABATIC',
      COLOR='GRAY 80',
      ADIABATIC=.TRUE./

 ...
 ...

&CATF OTHER_FILES='../../../../cad/FAA_Cargo_Compartments/FAA_B747_geometry.dat' /
&CATF OTHER_FILES='../../../../cad/FAA_Cargo_Compartments/FAA_B747_thermocouples.dat' /
```

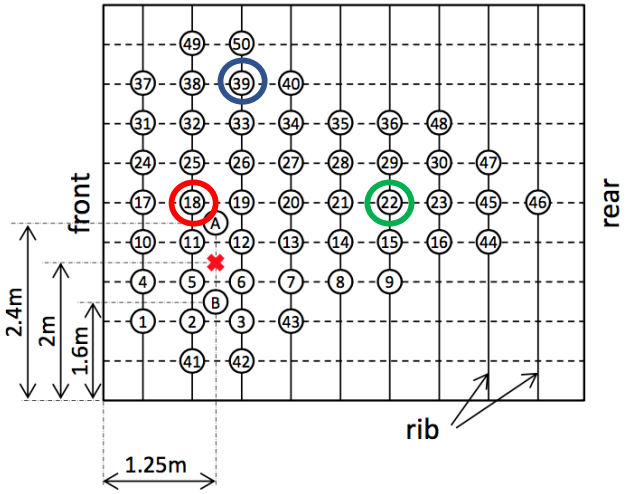
Workflow Showcase

- FDS defines the cut-cell regions near the geometries surfaces.
- The burden of defining the grid next to the object is on the computational geometry module of FDS.

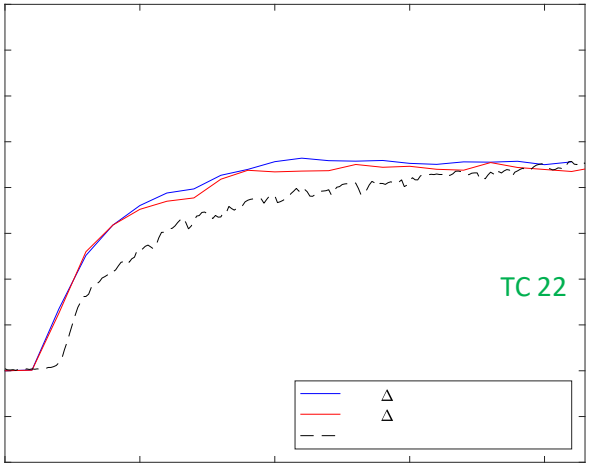


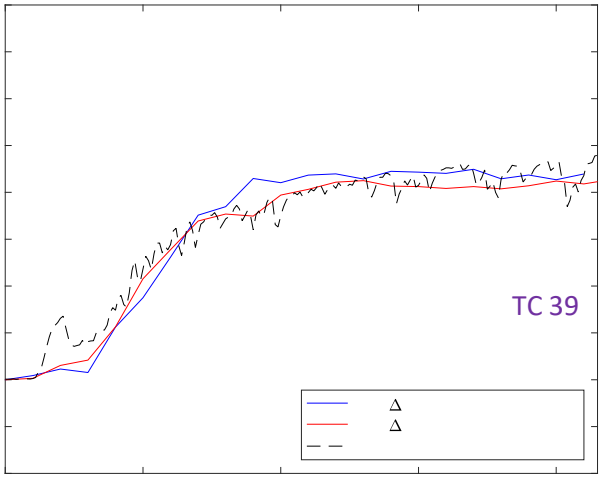
Workflow Showcase





Thermocouple layout*, 5 cm from ceiling insulation.

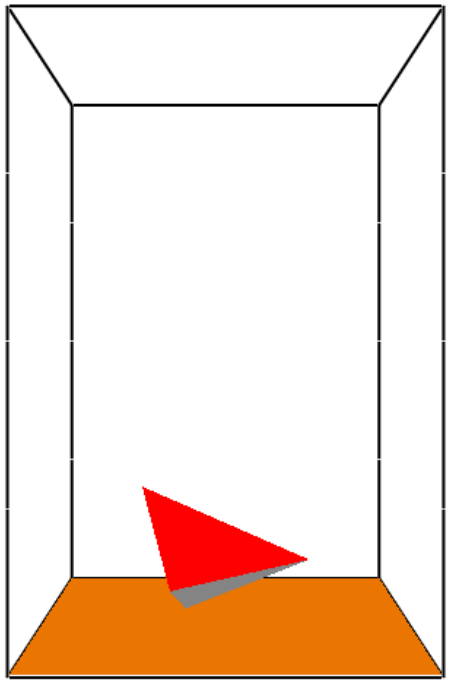




*Guo H. et al., FAA Technical Report DOT/FAA/TC-18/14 (2018).

Summary

- An add on to FDS, but requires rewriting on most code units.
- Allows to impose triangulated boundary surfaces on fluid grid.
- Ongoing validation and verification.
- Ongoing implementation of radiation, mass/heat flux BCs, LES wall models, and others.
- GEOMs (in Beta) will be released in FDS 7.



Time: 0.0

Thank you