FLAME WHIRLING CHARACTERISTICS

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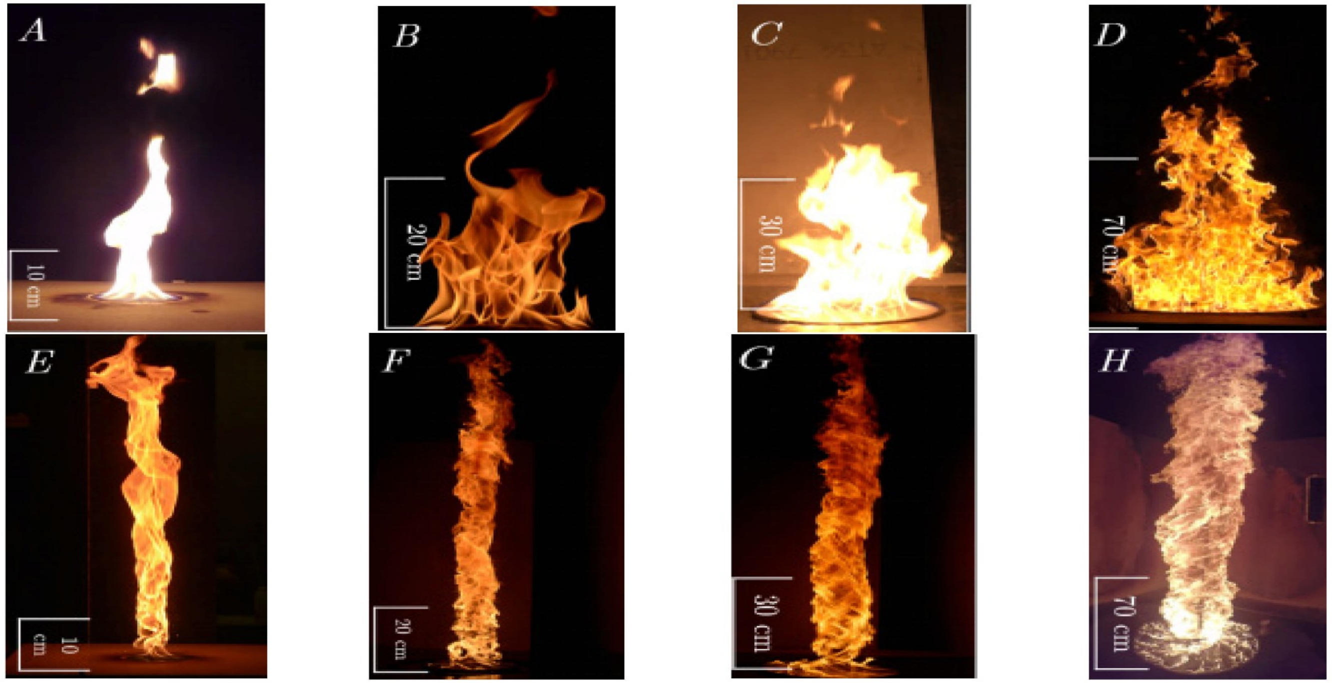
How a Fire Whirl form?

A fire whirl is induced by the interaction between the long fire front and the cross wind, which was typically characterized by its flame moving behavior.

In our project we reports on initial fire whirl simulations done with a large eddy simulation (LES) model called FDS.



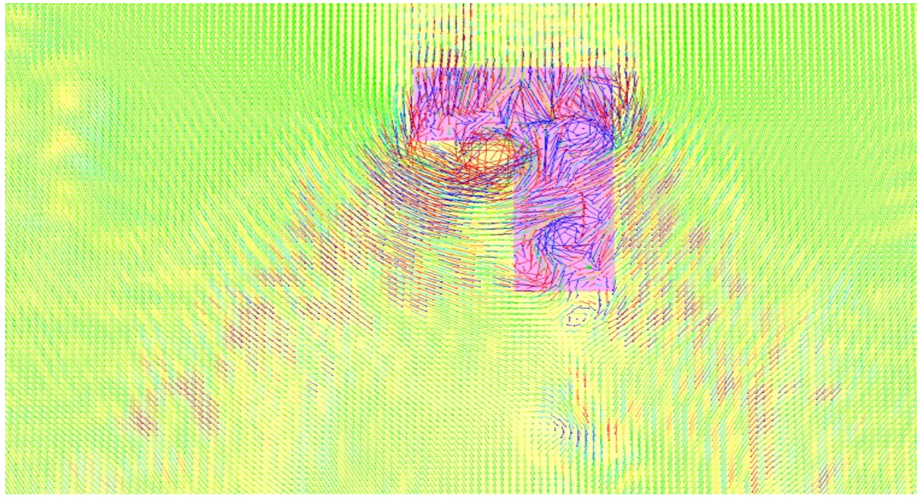
Source- Google Images

3 essential conditions for the fire whirl formation

1) Generating eddy

2) A fluid sink located within the eddy- Flame

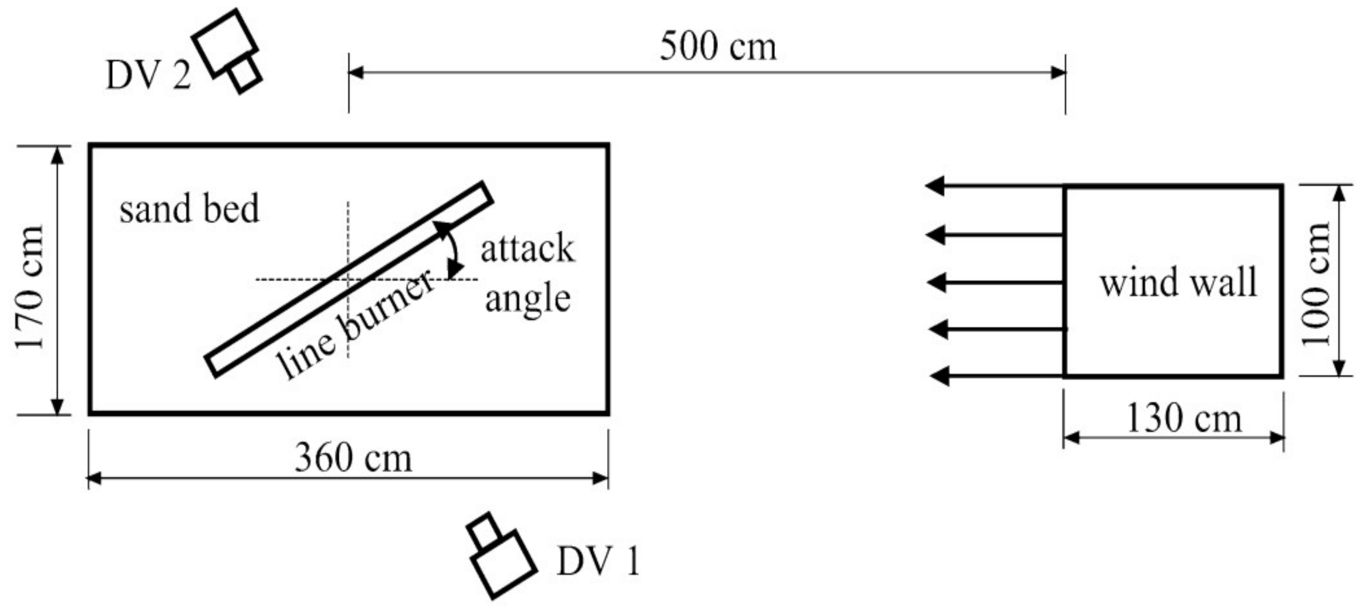
3) Some friction or drag offered to the movement of air in the ground of the eddy



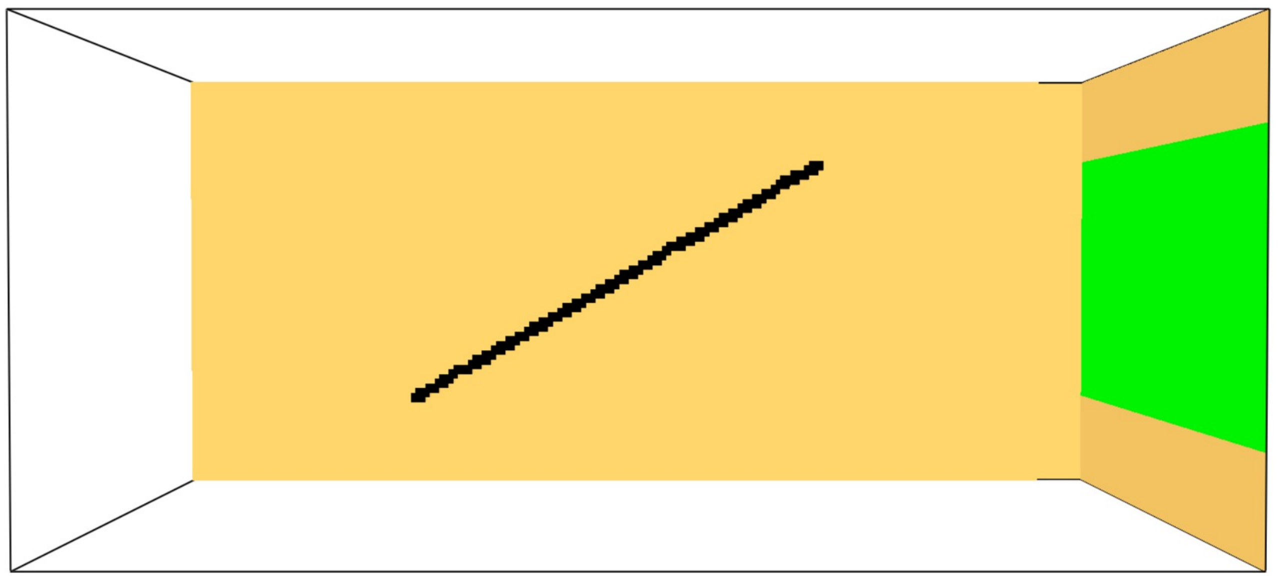
Velocity vector slice file from Z Axis [1]

Setup

Experimental Setup



Simulation Setup



Relationship b/w Attack Angle & Critical Speed

$$U_c \sin\theta \Big/ \sqrt{gw} \sim \dot{Q}_l^{1/3} \Big/ \left(\rho_\infty c_{p,\infty} T_\infty g^{0.5} w^{1.5}\right)^{1/3}$$

Critical wind speed range between 0.24 to 0.49m/s

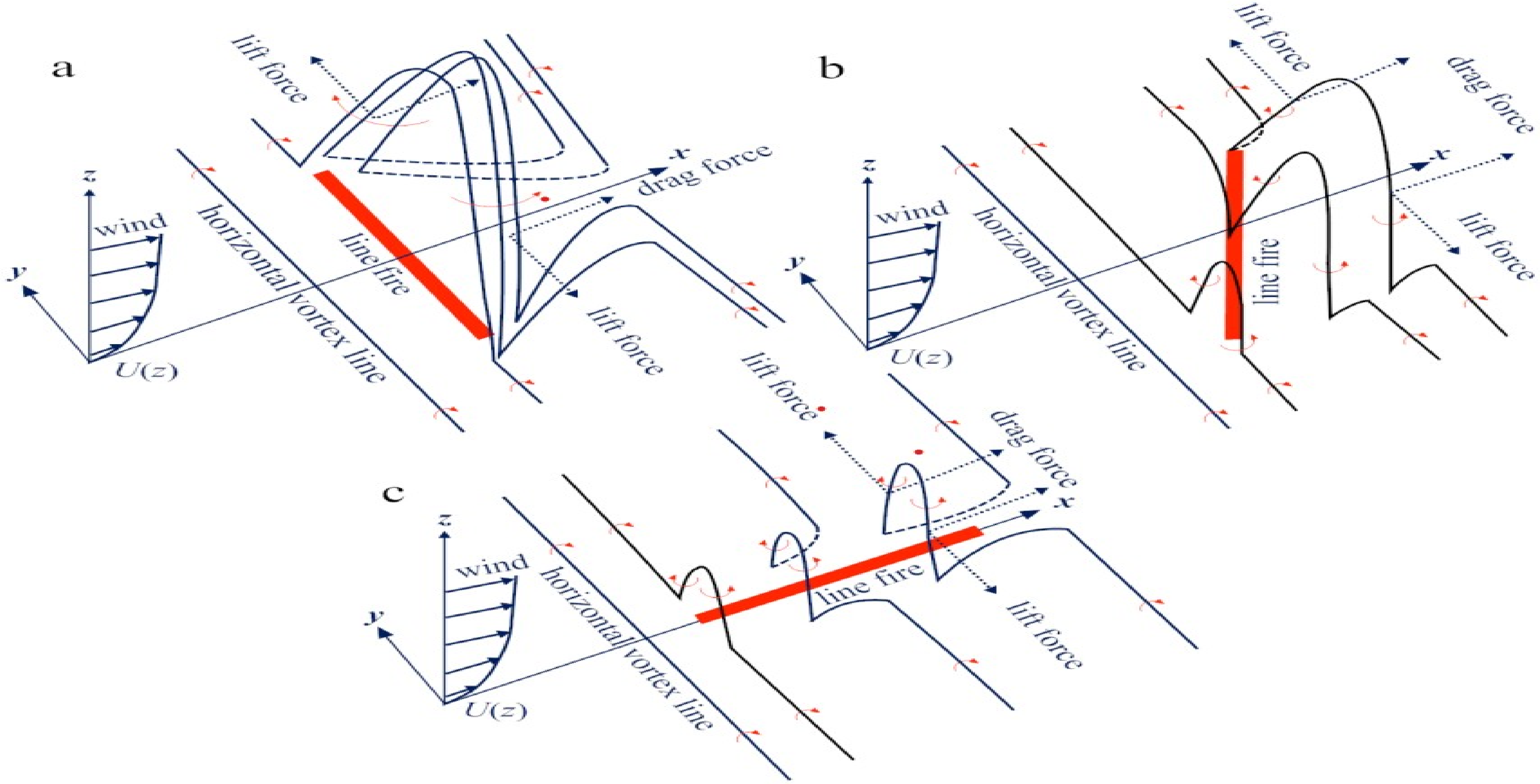
Ambient Temperature (C) is 20.00

Ambient Density (kg/m^3) is 1.195

Spec. Heat (J/kg/K) Ambient for 293 K is1.08E+03

The Effect of Attack Angle

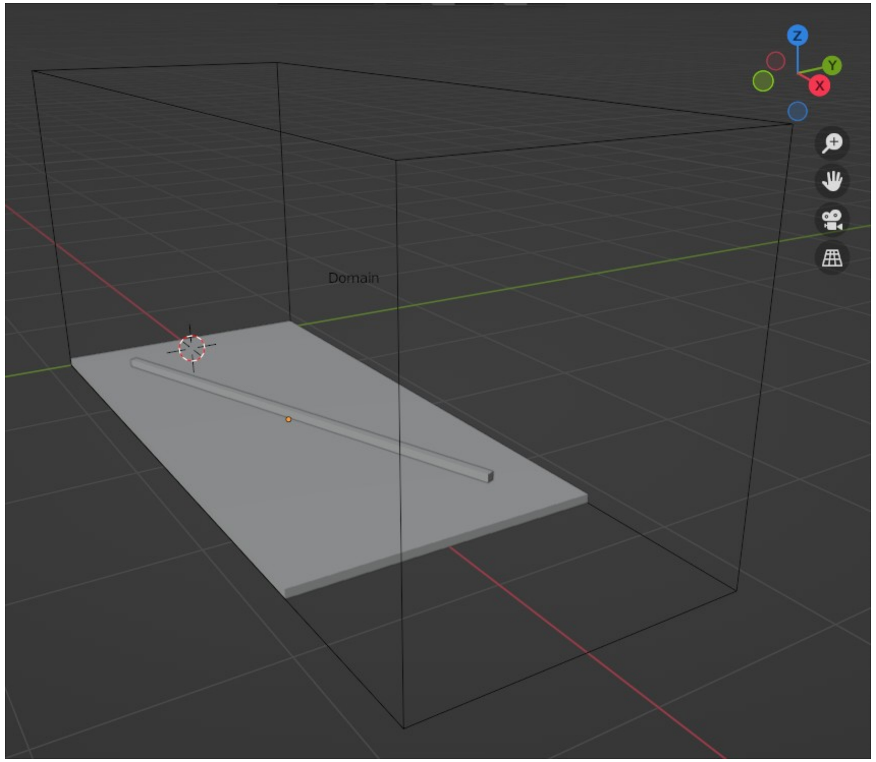
Fire whirl results from the interaction of concentrated vortex and upward fire plume.

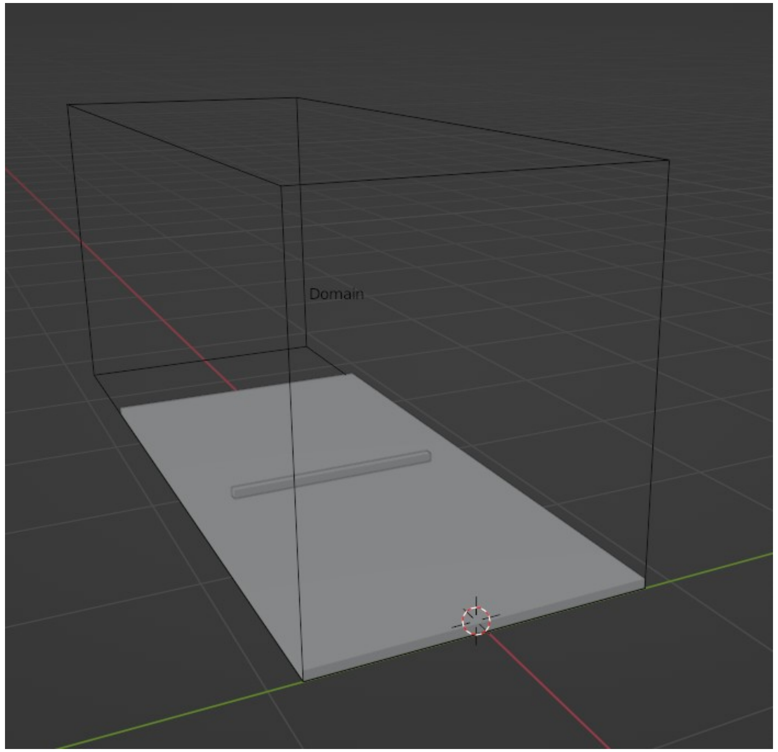


- Making the Simulation Model

Using Blender to Make the Geometry

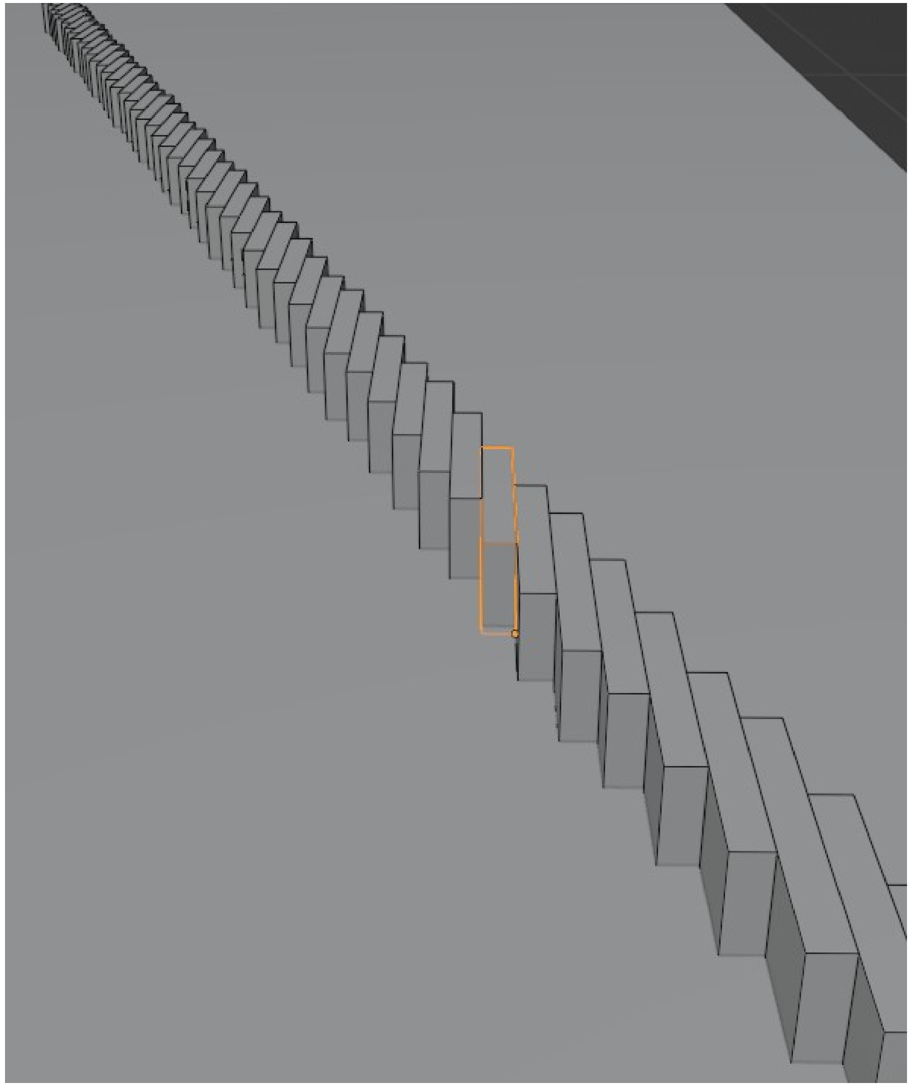
- Decided with 4 models
  - 200cm with 30°
  - 300cm with 20°
  - 120cm with 90°
  - 100cm with 90°

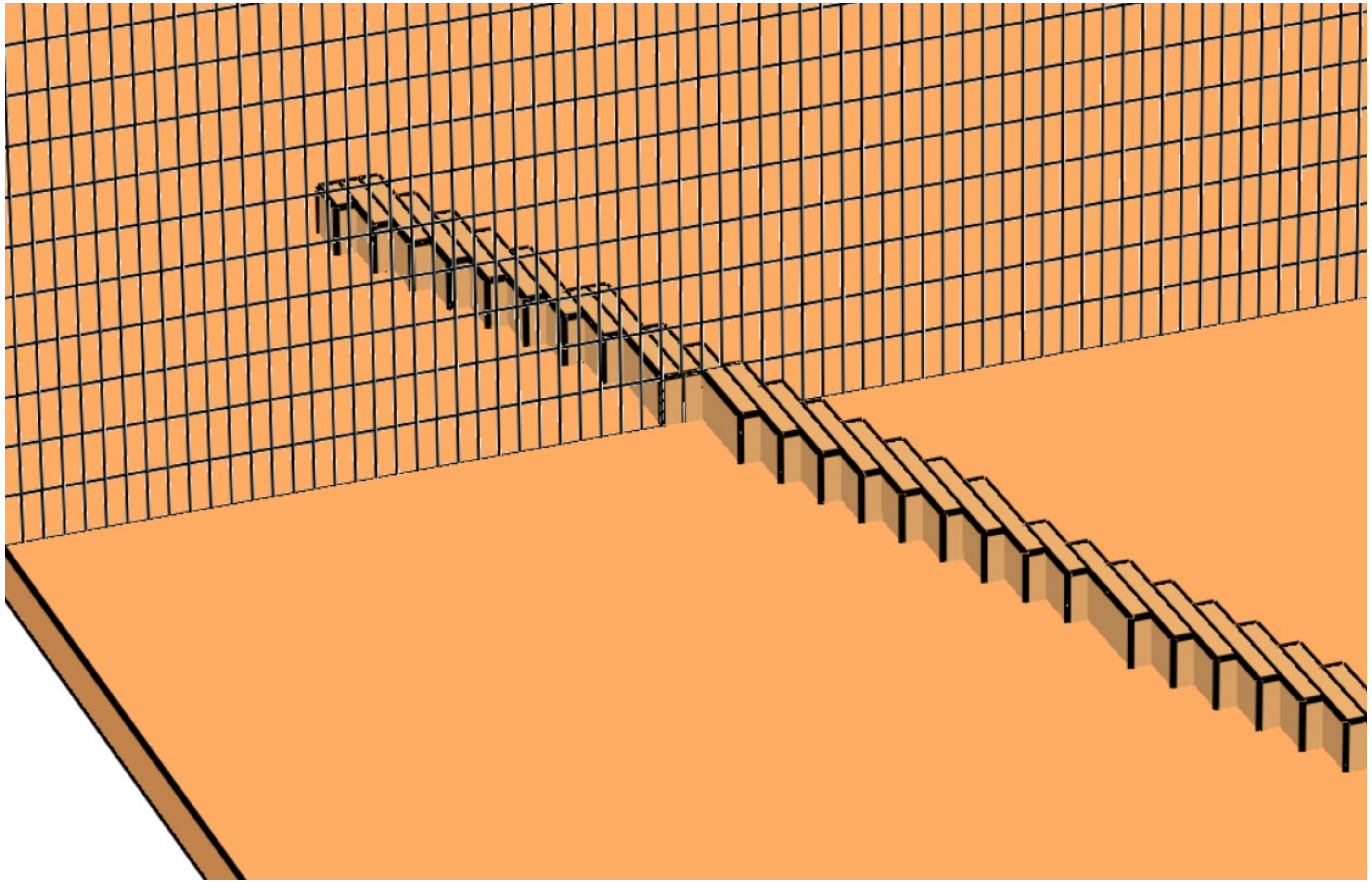




- Issues with rendering angled geometries
  - Need for Voxels
  - Slices Files cannot be made at an angle (Along the Burner)

- Determining Voxel Size (for y-dimension) and Resulting Mesh
  - 1 cm Voxel Size leads to a very fine Mesh
    - 680 x **170** x 50
    - Is removed for coarser meshes.
  - 2 cm Voxel Size is also computationally expensive
    - 680 x **85** x 50



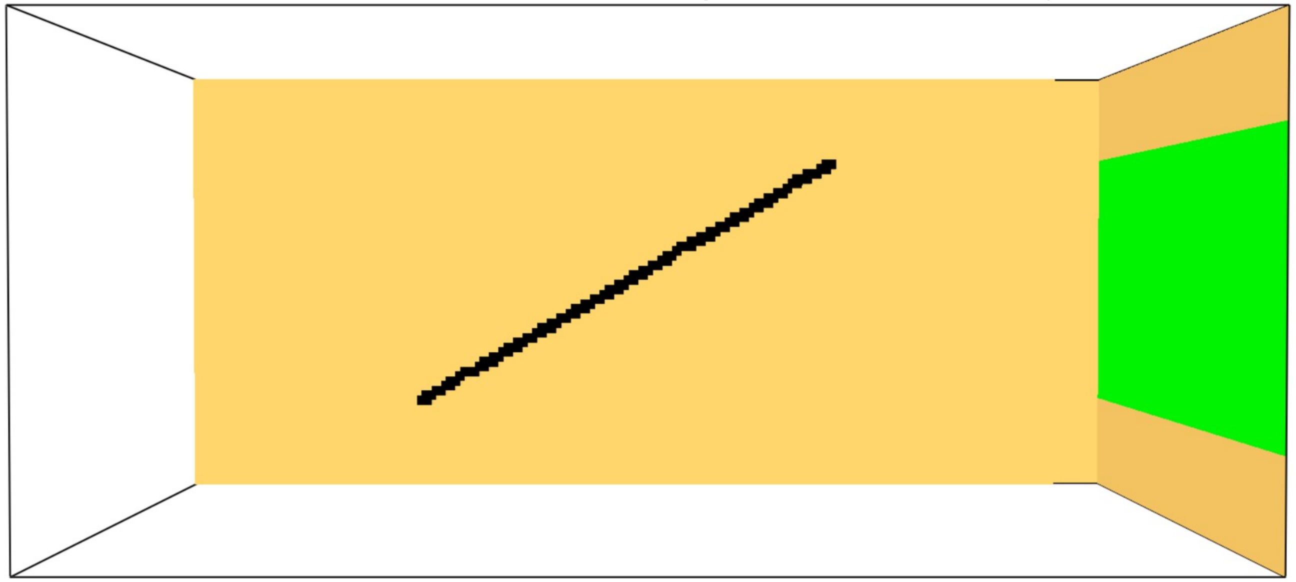


Voxels Rendered in Blender are independent of the applied mesh

Small Voxel are clipped for coarser meshes

- Deciding the Mesh and Decreasing the Domain
  - 2cm on each dimension would've resulted in a large cell count
    - 340 x 85 x 100 cells
  - Two Options:
    - Either create multiple meshes with Fine grid near the line burner, and Coarse grid everywhere else
      - Problematic due to overlapping meshes
    - Or Reduce the Domain Size
      - Simpler approach
      - The constant wind allows to reduce the distance between Sandbed and Windwall
- Resulting mesh
  - **190 x 85 x 40 cells**
  - 2cm x 2cm x 5cm cell size.

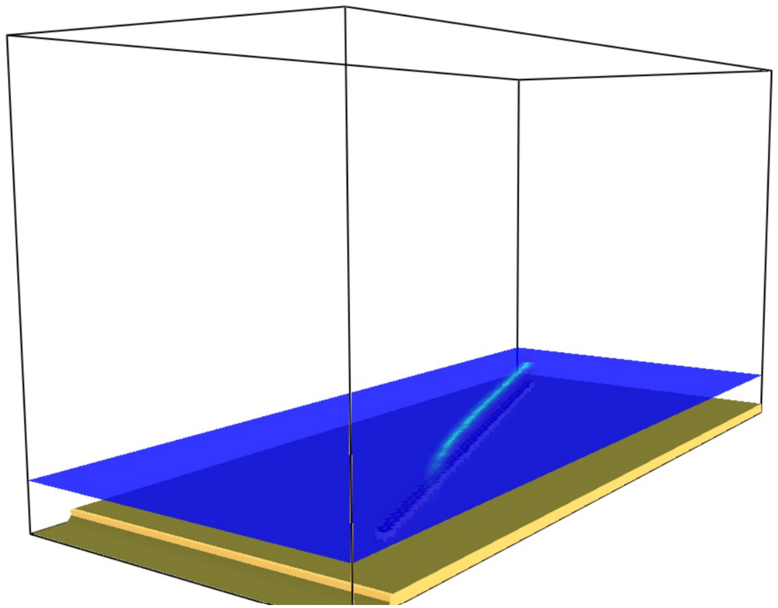
Our Working Geometry

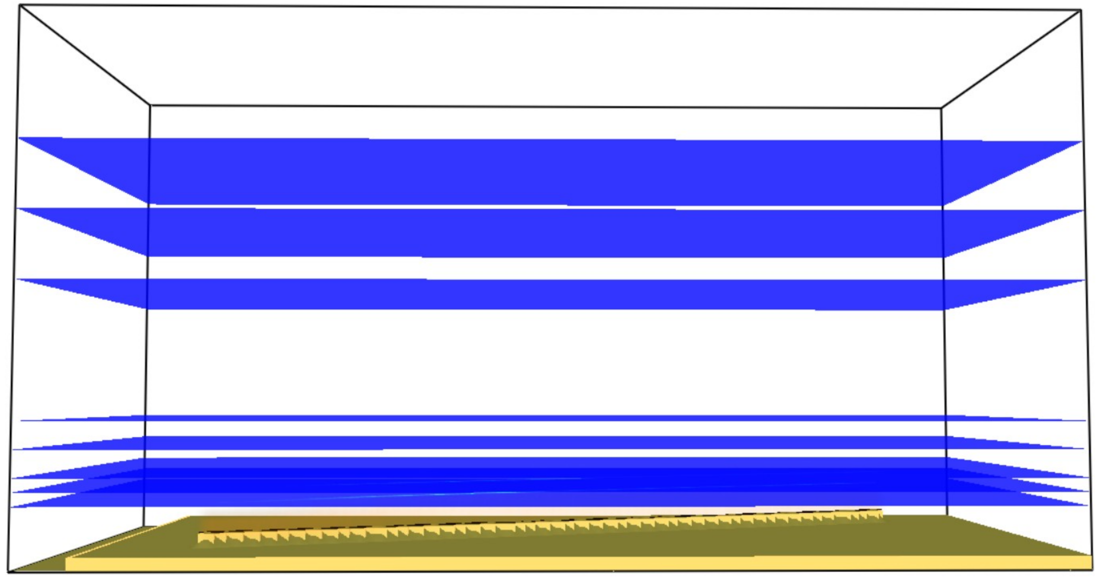


Approach to Identify Fire Whirls

- Use SLCF for HRRPUV at different heights
- Use velocity profiles to check for spins
- Use vorticity to check for spins

FDS cannot produce angled SLCF





- 90° Geometries were much easier to work with
  - Only one voxel
  - SLCF along the burner

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&SURF ID='line_burner', HRRPUA=800., COLOR = 'BLACK' /
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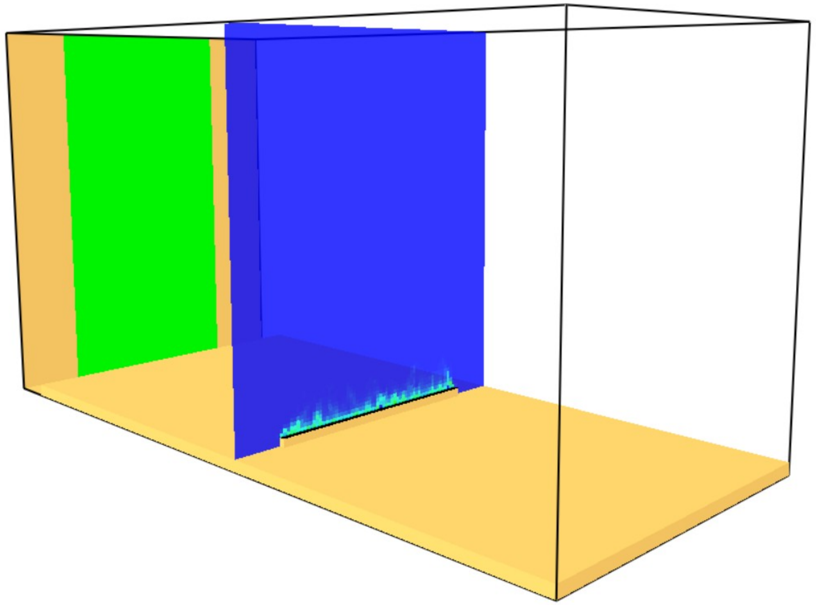

For Angled Geometries

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&OBST XB=3.110 3.210 0.490 0.510 0.045 0.105 /
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&OBST XB=2.230 2.370 0.170 0.190 0.045 0.105 /
&OBST XB=2.170 2.310 0.150 0.170 0.045 0.105 /
```

and so on ...

- Parameters used
  - HRRPUA = 800 kW/m^2
  - Sand Bed, to induce roughness and no-slip
  - Angles
  - Velocity = $0.24 \le Uc \le 0.49$

No Fire Whirl

$$U_c \sin\theta / \sqrt{gw} \sim \dot{Q}_l^{1/3} \Big/ \left(\rho_\infty c_{p,\infty} T_\infty g^{0.5} w^{1.5}\right)^{1/3}$$

Uc = 2.07 m/s

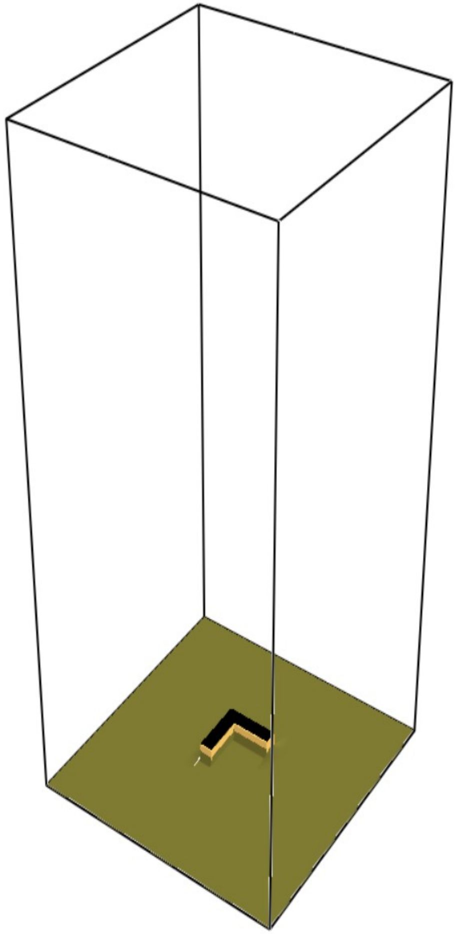
No Fire Whirl
… yet again

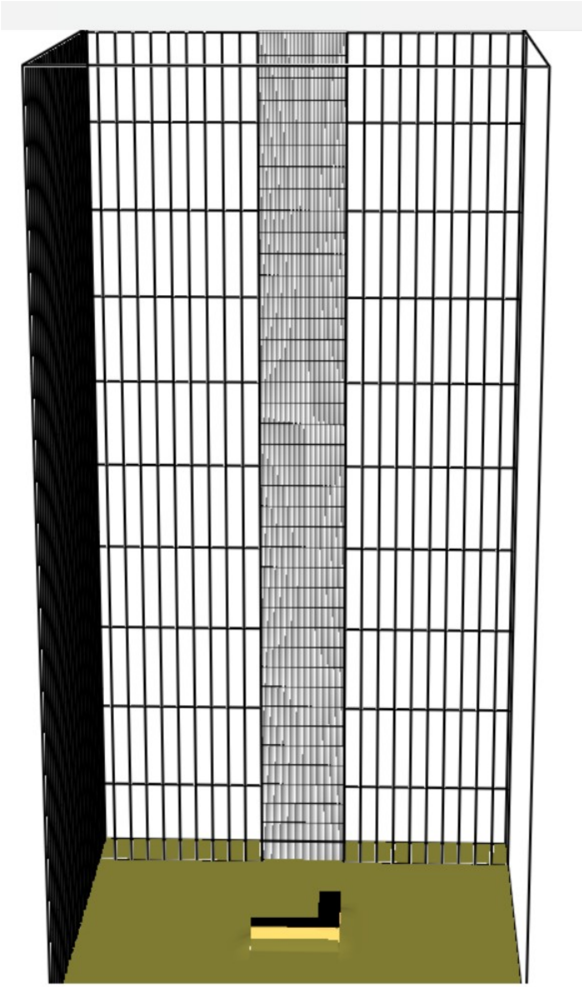
- Doubts on Formula
  - We circled back to Uc = 0.24 or 0.49 m/s

- Fire Whirl may be generated on an even finer mesh.
- But the current geometry is quite large to implement such a mesh

- Next Approach: New Geometry
  - We decided to produce a secondary model with small geometry
  - The only purpose of this model is to force it to produce a fire whirl
  - Hence, it wasn't bounded by the conditions of the first geometry

- Characteristics
  - L-Model
  - Composite Mesh
  - 100 x 100 x 200 cm^3 domain
  - 0.5 x 0.5 x 5 cm^3 cell size





References

[1] INVESTIGATING CAUSES OF LARGE SCALE FIRE WHIRLS USING NUMERICAL SIMULATION, Jason Forthofer*, Kyle Shannon, and Bret Butler, USDA Forest Service, Rocky Mountain Research Station, Missoula, MT.

[2] Effect of Wind on Fire Whirl Over a Line Fire, Kuibin Zhou, Naian Liu* and Xieshang Yuan

[3] Fire Whirl due to Interaction between Line Fire and Cross Wind, KUIBIN ZHOU, NAIAN LIU