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Design for Fractal Grid Generated Turbulence

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Grid Design for Fractal Generated Turbulence

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Objective

- Design a set of passive grids with fractal geometry to be placed at the entrance of a wind tunnel, acting as an inflow condition.
- Quantities of interest are mean velocities, turbulence intensities, turbulence decay, energy dissipation rate, anisotropy/isotropy, and the formation of vortices.

The observations obtained can contribute to the understanding of flow mixing by manipulating inflow conditions. Practical applications of this knowledge could include energy efficient mixing, heat dissipation techniques in electronics, forced convection.

Background & Motivation

Fluid flow is a dynamic system and it's development is reliant on initial conditions. Turbulent flow often displays intermittency, or periodic phases, and self similar patterns. A fractal is a infinitely repeating self similar pattern. Kolmogorov's theory used the idea of self-similarity to develop the statistical theory described by the energy cascade in turbulent flow.

Figure 1: Self similar patterns can visually be seen when pouring coffee into your milk.

In Kolmogorov's energy cascade theory, the Reynold's number based on Taylor microscale increases proportionally to the ratio of the integral length scale, L, to the Taylor microscale, λ. The Reynolds number, Re_λ, is the ratio of inertial forces to viscous forces.

$$Re_\lambda = \frac{V\lambda}{\nu}$$

V = Incoming velocity
λ = Taylor microscale
υ = Kinematic viscosity

The Taylor microscale, λ, is calculated by:

$$\lambda = \frac{\langle u(t)^2 \rangle}{\left\langle \left(\frac{\partial u(t)}{\partial t}\right)^2 \right\rangle}$$

u = Instantaneous velocity
t= Time

Previous studies for fractal generated turbulence using square grids have been performed by Hurst *et. al* (2007), Seoud *et. al* (2010), Gomes-Fernandes *et. al* (2012). In these studies they observed unusual behavior in turbulence, they found a constant ratio of integral scale to Taylor microscale as a function Reynolds number. In addition, turbulence intensities increased in the stream wise direction as the thickness ratio increased.

Design Process

1) **Geometry**: Four fractal patterns were two-dimensionally sketched in AutoCad. The open center grid was selected first for ease of design compared to the center space filled.

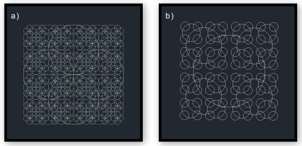

Figure 2: (a) Center space filled grid and (b) open center space grid

2) **Properties**: Values for length ratios, thickness ratio, and blockage ratio were chosen. The fractal dimension was determined based on the geometry of the design and describes the complexity of the shape.

$$D_f = \frac{\log(N)}{\log(r)}$$

r = ratio of scale
N = number of copies
D_f = Dimension

$$L_j = R_L * L_0$$

L_j = Outer radius at iteration j
R_L=Length Ratio
L_0 = Initial outer radius

$$t_r = \frac{t_{max}}{t_{min}}$$

t_r = Thickness ratio
t_{max} =Thickness of thickest bar
t_{min} = Thickness of thinnest bar

$$\sigma = \frac{A_{grid}}{A_{tunnel}}$$

t_r = Thickness ratio
t_{max} =Thickness of thickest bar
t_{min} = Thickness of thinnest bar

3) **Dimensions**: Based off of the selected properties and the dimensions of the wind tunnel cross-section, the diameters of the circles were determined using an iterative process until all properties were met.

4) **Fabricating & Material Considerations**: Baltic birch plywood was chosen because of its stiffness and low comparable costs to other materials.

Results

Grid properties:

- Fractal Dimension = 2
- Length Ratio = 8
- Thickness Ratio = 2.5
- Blockage Ratio = 25% ± 0.5

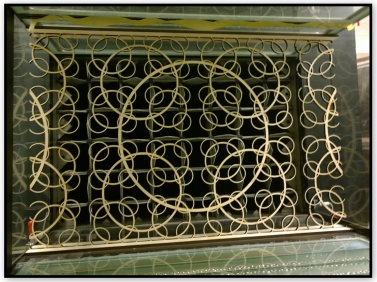

Figure 3: Full scale grid tested in the wind tunnel for a fit check and vibrational observation.

Conclusion

- Circular geometry was chosen to design the grids to study the behavior of the induced flow from a fractal grid since previous studies have been done with square and I-beam patterns that contain mainy sharp edges.
- The fractal dimension of the circular fractal geometry was determined using the radius for the ratio of scale.
- The desired blockage ratio and thickness ratio were achieved by adjusting the inner diameters in a iterative design process.
- Material selected to build the bridge was baltic birch plwood and the grid was fabricated using a laser cutter.
- The grid succesfully showed little to no visual vibrations under desired incoming velocities.
- As the thickness ratio increases the thinnest bars will become thinner. It is recommended when doing so to look into stiffer materials in order to significant vibrations do not occur.

Moving Forward

Next steps that need to be taken to meet the goal of the project are:

- Create a set of fractal grids with thickness ratios of 5 & 8, while keeping blockage ratio, length ratio, and fractal dimension constant.
- Create a center space filled grid, example reference fig. 2(a).
- Collect data using Particle Image Velocimetry (PIV).

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