Effect of Surface Features on the Drag of a Tethered Sphere Flow Measurement Device

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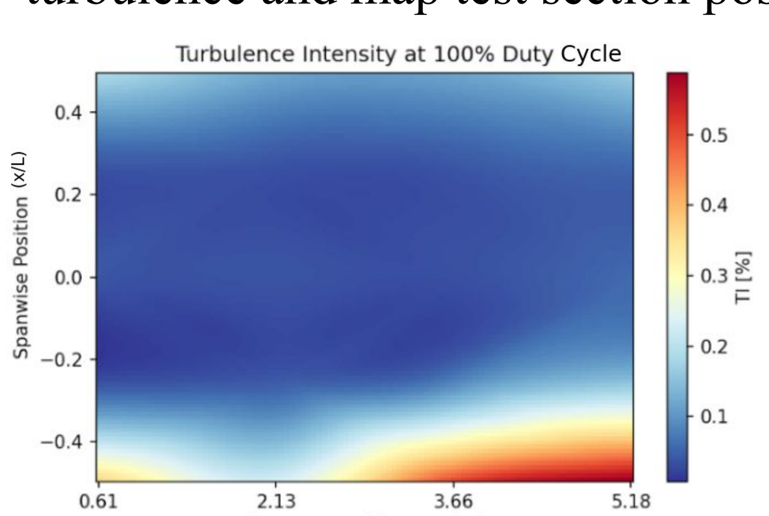
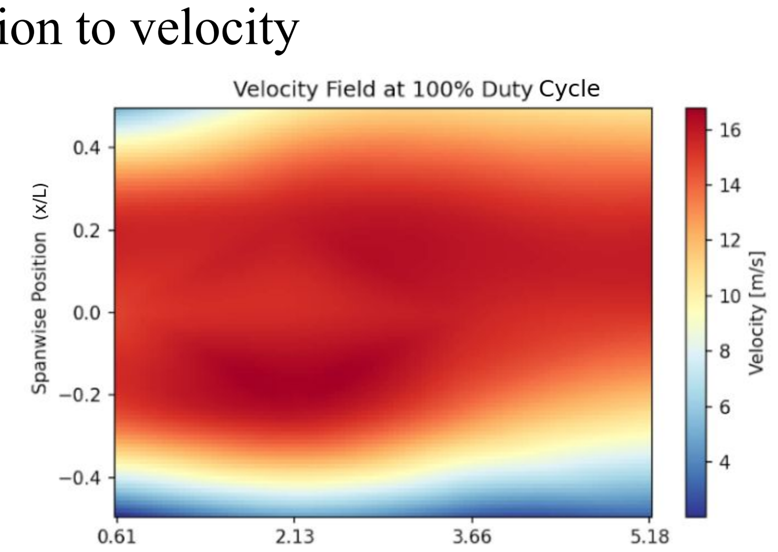
Motivation

An important part of the field of environmental science and engineering is understanding the **fluid mechanics** behind **environmental flows,** specifically in the atmosphere, rivers, and oceans. Measuring these flows can be difficult, however, because of the large length scales they span; the **motivation** behind this project is to develop **cost-effective flow sensors** to provide flow maps with high accuracy. How our project specifically aims to do this is by utilizing the **dynamics of tethered spheres** by designing and **3D printing different roughness elements** and protrusions of different sizes and types to vary on a sphere, increasing the roughness on a sphere and encouraging the transition of the **boundary layer** from **laminar** to **turbulent**. This experiment is a step forward towards developing cost-effective flow sensors. Our experiment involves placing spheres in a wind tunnel and analyzing the corresponding flow data to observe the effect of large roughness elements on **vortex-induced vibration** and the drag coefficient drop off and recovery seen during the **drag crisis** at critical Reynolds numbers.

Wind Tunnel Characterization

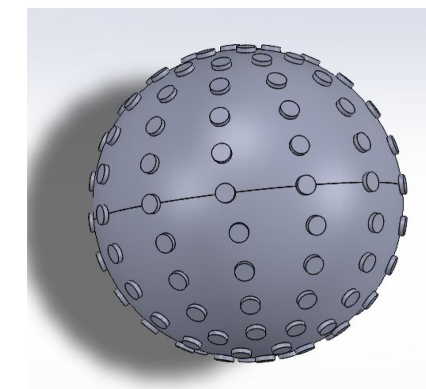
- Testing was run using a WindShaper fan array of 1.5m in length
- Allowed for modular control over wind speeds up to 15 m/s
- We used an anemometer to measure the **wind velocity** and **turbulence intensity** at an array of points in the test section
- A flow conditioner was used to reduce turbulence
- This allowed us to select a point with minimal turbulence and map test section position to velocity





Procedure

- Several configurations of 3d printed **conical** and **cylindrical** surface features with varying height and number were selected
- For each configuration, the features were evenly distributed around a the surface of a 12 inch(0.3048 m) diameter styrofoam sphere
- The sphere was then mounted on a **sting** attached to a load cell to measure the drag forces on the sphere
- This setup was placed on a stand center of the test section 12 ft(3.5676 m) downstream from the windshaper
- Using anemometer wind speed data, we selected a range of duty cycles from 10%-70% corresponding to a Reynolds number range of about 30,000 - 180,000 to sweep over
- A LabView script collected the load cell readings, allowing us to extract **drag force** and **drag coefficient** data

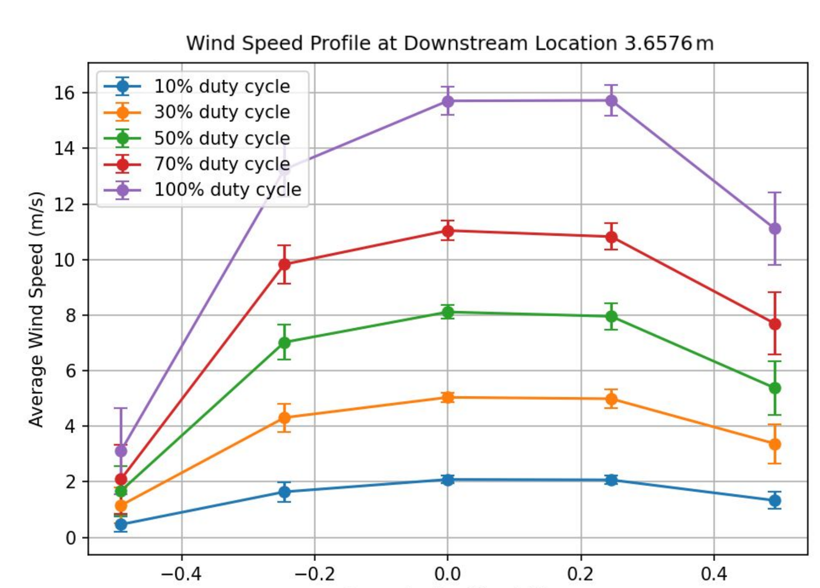


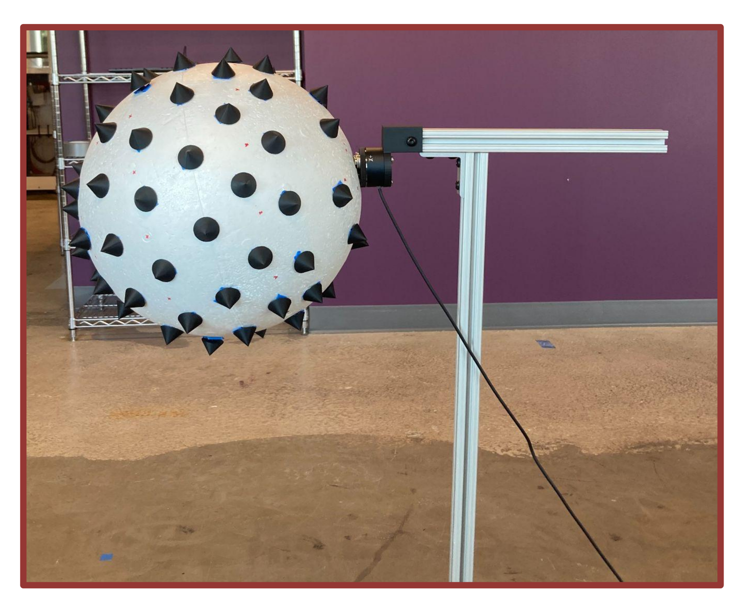
$$\mathrm{Re} = \frac{\rho u L}{\mu}$$

Re = Reynolds Number
ρ = fluid density
u = flow speed
L = characteristic linear dimension
μ = dynamic viscosity of the fluid

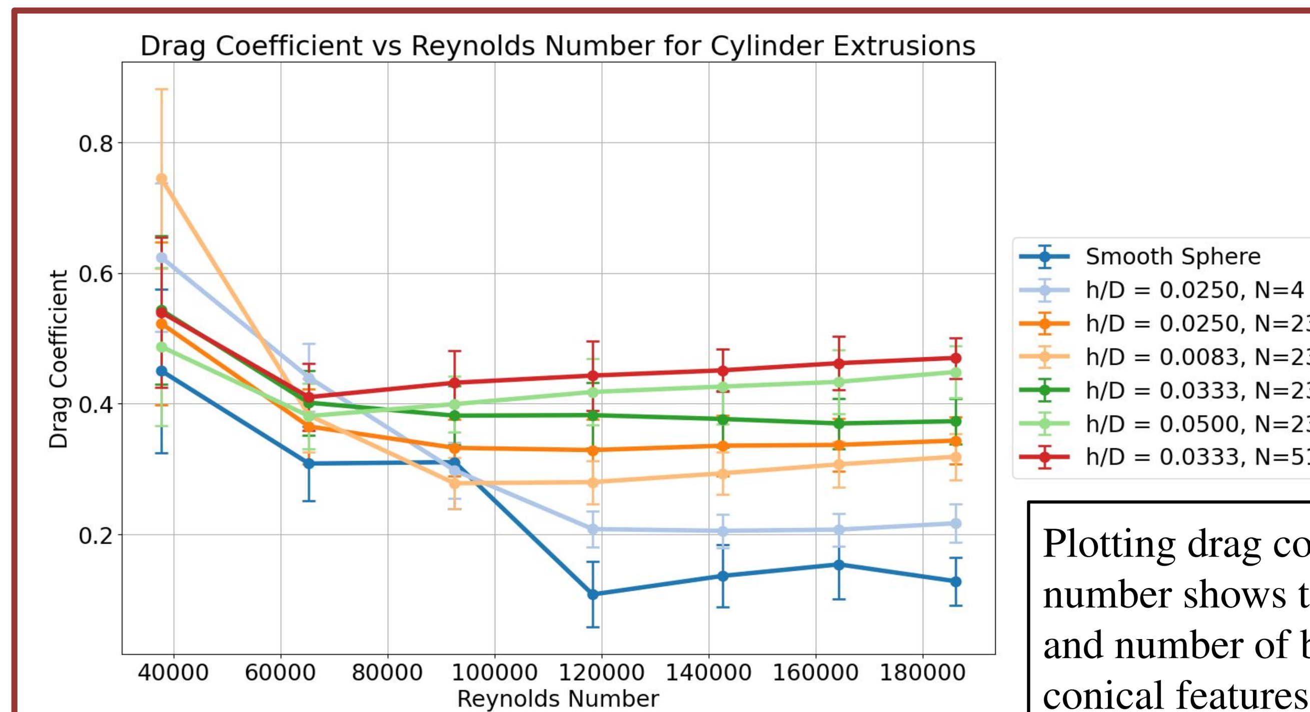
$$c_d = \frac{2F_d}{\rho u^2 A}$$

c_d = drag coefficient
F_d = drag force
ρ = fluid density
u = flow speed
A = reference area

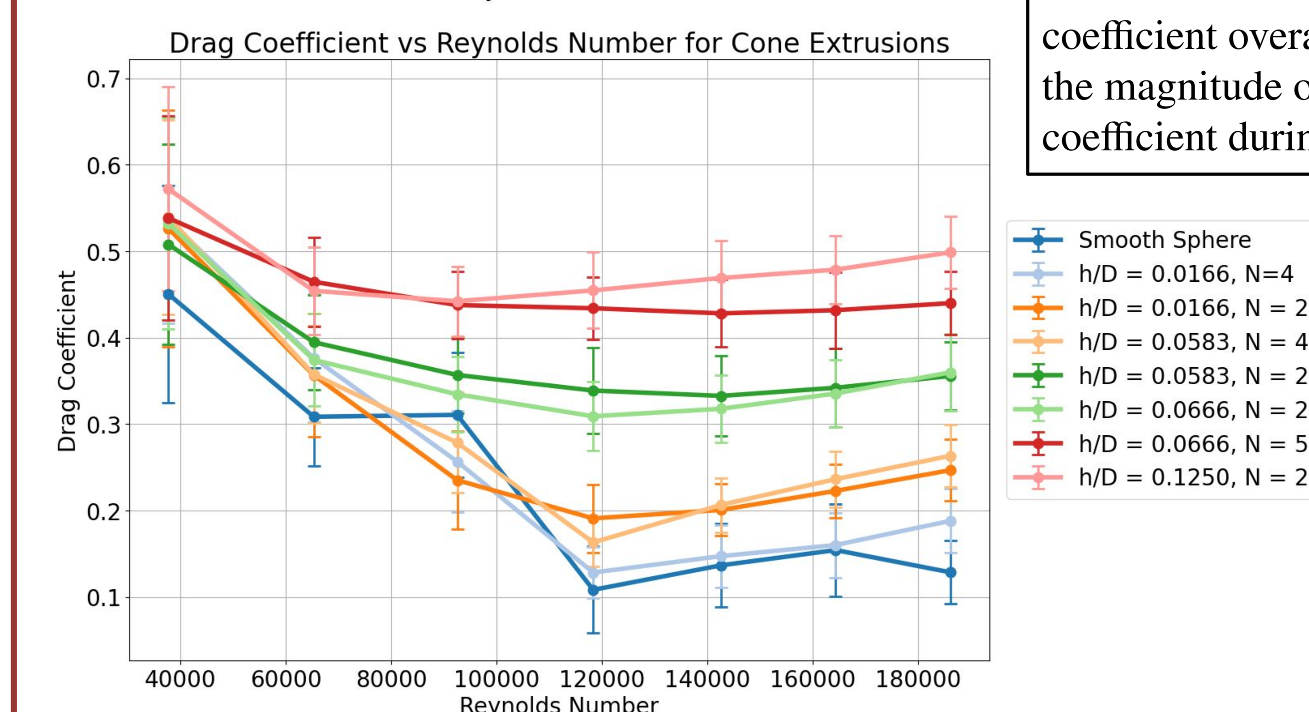




Results



Plotting drag coefficient vs Reynolds number shows that increasing the size and number of both cylindrical and conical features increases drag coefficient overall, but also reduces the magnitude of the drop off in drag coefficient during the drag crisis



Conclusions and Future Work

- **Large scale** surface protrusions achieved the effect of both **smoothing out the drag crisis**, making wind speed measurements easier to resolve as well as **increasing overall drag,** increasing the signal to noise ratio in drag force measurements.

Future work:

- Further investigation into how other types of attachments could reduce vortex induced vibration
- Testing of the effects of varying levels of inflow turbulence

Acknowledgements

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