Analyzing Airwaves: Navigating Turbulence with Pitot Tubes

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Abstract

To characterize a turbulent jet, an experiment was conducted to measure the velocity of a stream of air at different distances. Using an experimental setup that consists of a steady flow of air and a pitot tube, a mechanism was created to sweep out the planer area of the turbulent jet cone and output numerical data at different distances. The data was then inputted into a LabVIEW sub-VI and converted from the sample voltage to velocity in units of m/s. The model hypothesis states that at "sufficiently large Reynolds numbers (i.e. $\geq 10^4$), turbulence reaches a universal state where local flow dynamics depend only on local conditions". For this experiment, the Reynolds number was calculated as 18000 ± 100 at a distance of 1D. This confirms the hypothesis that the flow exhibits turbulent behavior consistently across subsequent regions (5D, 7D, 9D). Presenting a turbulence intensity plot reveals that at 1D, within the potential core, laminar flow is evident. Thus, it was predicted from the hypothesis that at 5D the fully turbulent region was displayed. To characterize the turbulent flow, a self-similar region was plotted where the turbulent flow at different distances universally matched and when normalized, plotted on top of each other. Using the self-similar plot, by interpolation it was possible to predict the turbulent region at any distance.

Experimental Setup

- 2 axis control
- Sweep out a planer area of our turbulent jet cone
- Characterize and compare to the hypothesis to understand the numerical values in self-similarity

Is It a Turbulent Jet?

- At “sufficiently large Reynolds numbers (i.e. ≥ 10^4), turbulence reaches a universal state where local flow dynamics depend only on local conditions”

- Assuming at 25 C, U_{max} = 15.028147 m/s, and Kinematic viscosity = 1.562 x 10^{-5} m^2/s

- Re = 18000 ± 100

- Yes! Interactions are occurring between the streamlines

“Edge, Engineers. “Viscosity of Air, Dynamic and Kinematic.” *Engineers Edge - Engineering, Design and Manufacturing Solutions*, www.engineersedge.com/physics/viscosity_of_air_dynamic_and_kinematic_14483.htm. Accessed 20 Feb. 2024.”

The Story: Raw Data (Unnormalized Plot)

- Displays the turbulent jet and its various regions

- As D goes up, velocity reduces

- Velocity will eventually reach zero

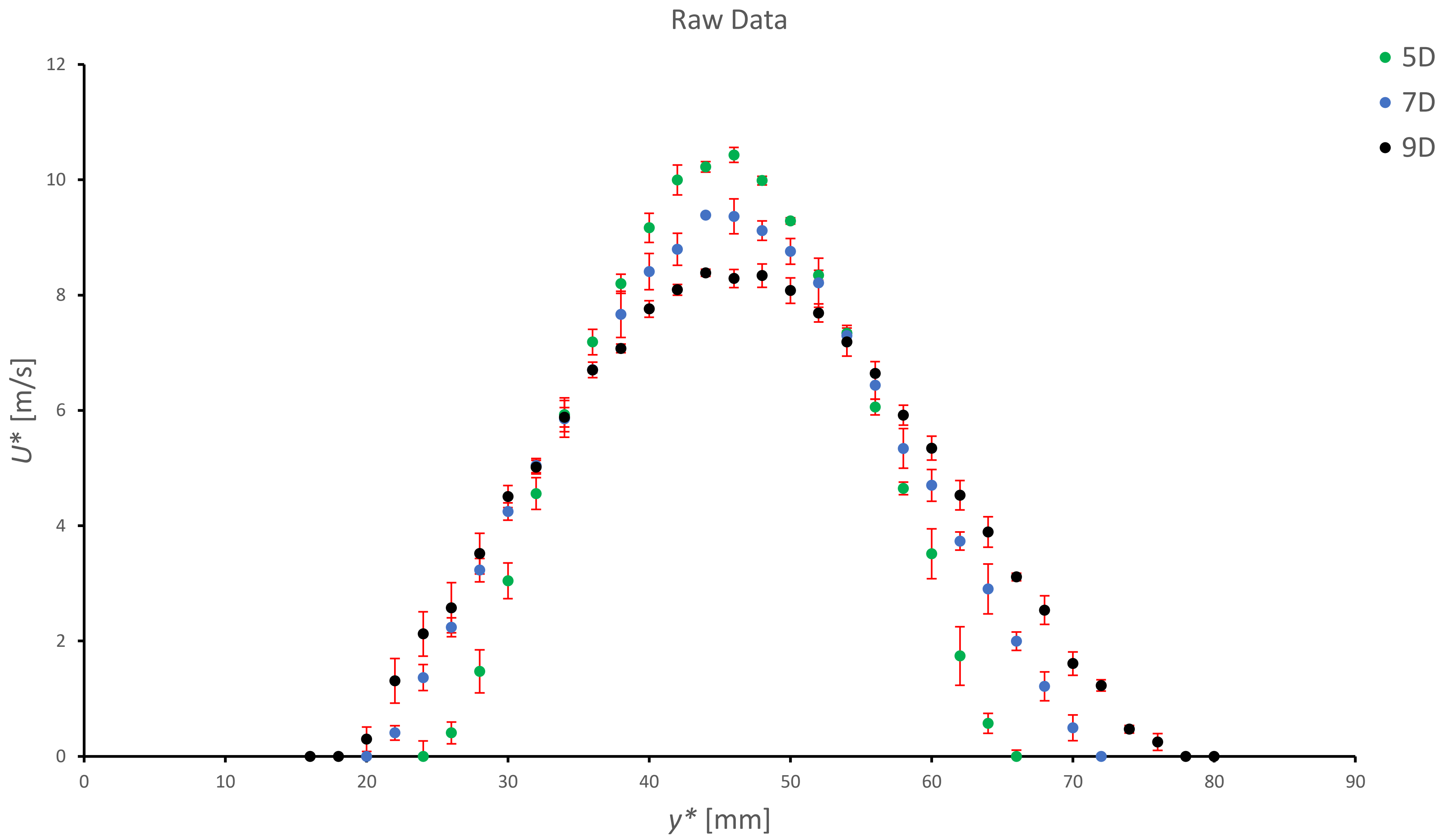

Figure 1 – Unnormalized data displaying the velocity profiles at each distance. This characterizes the reduction in velocity the further way the pitot tube is from the air source.

Normalized Plot: Self-Similar Region

- Investigating the universal state of turbulent flow

- The potential core ended at 5D

- We see that with uncertainty the collapsed data falls on top of each other (matches)

- Means that we can predict future D's

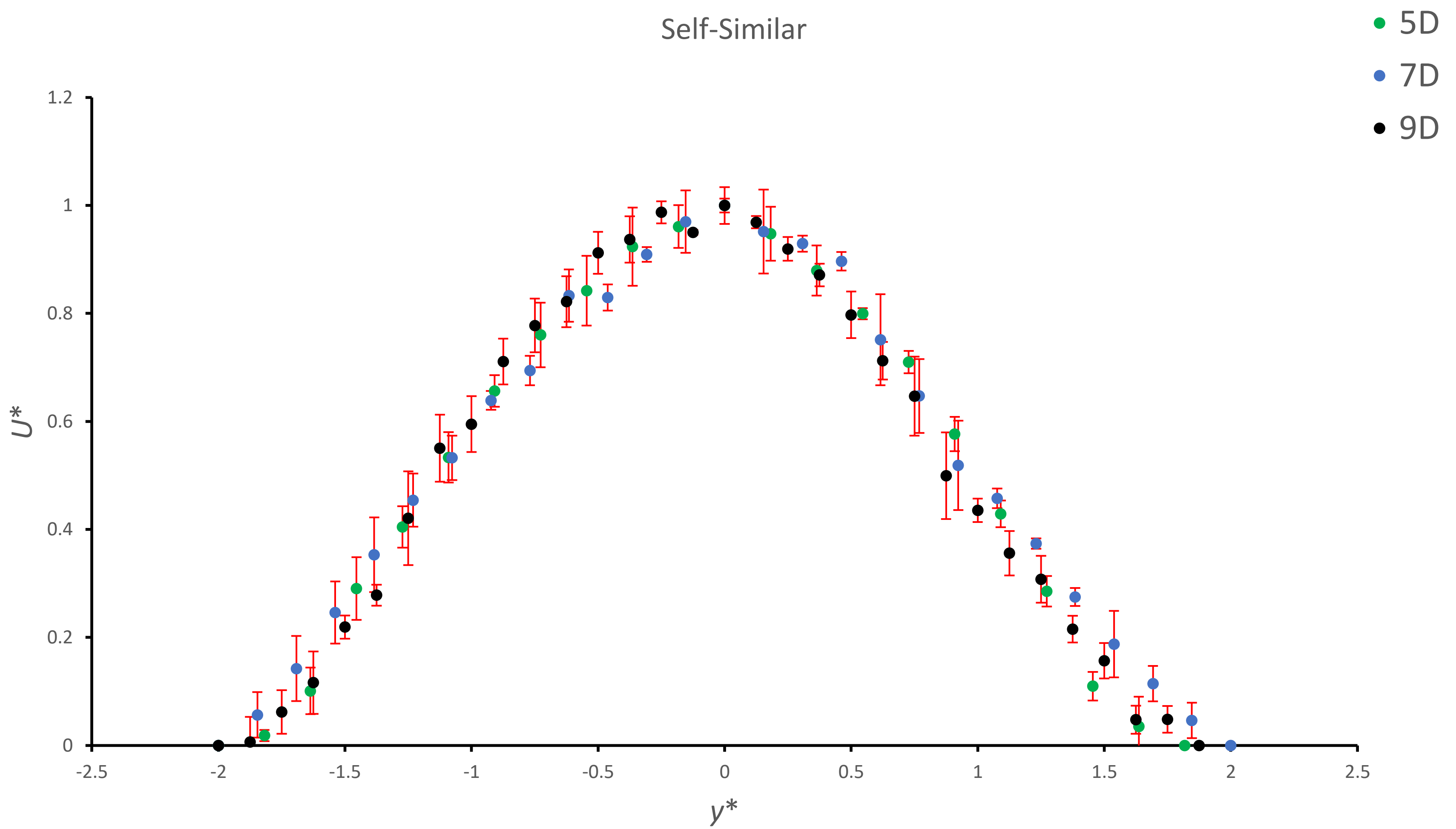

Figure 2 – Self-similar normalized plot where the collapsed data showcases the shared relationship between turbulent flows at different distance regions.

Normalized Plot: Represented Trace

- A represented trace is displayed to showcase the normalization process

- This is done by, dividing the velocities by the max velocity to get U^*

- Finding the half distance of the trial (y)

- Dividing y by $\frac{1}{2}$

- Divide y by $y\frac{1}{2}$ to get $y*$

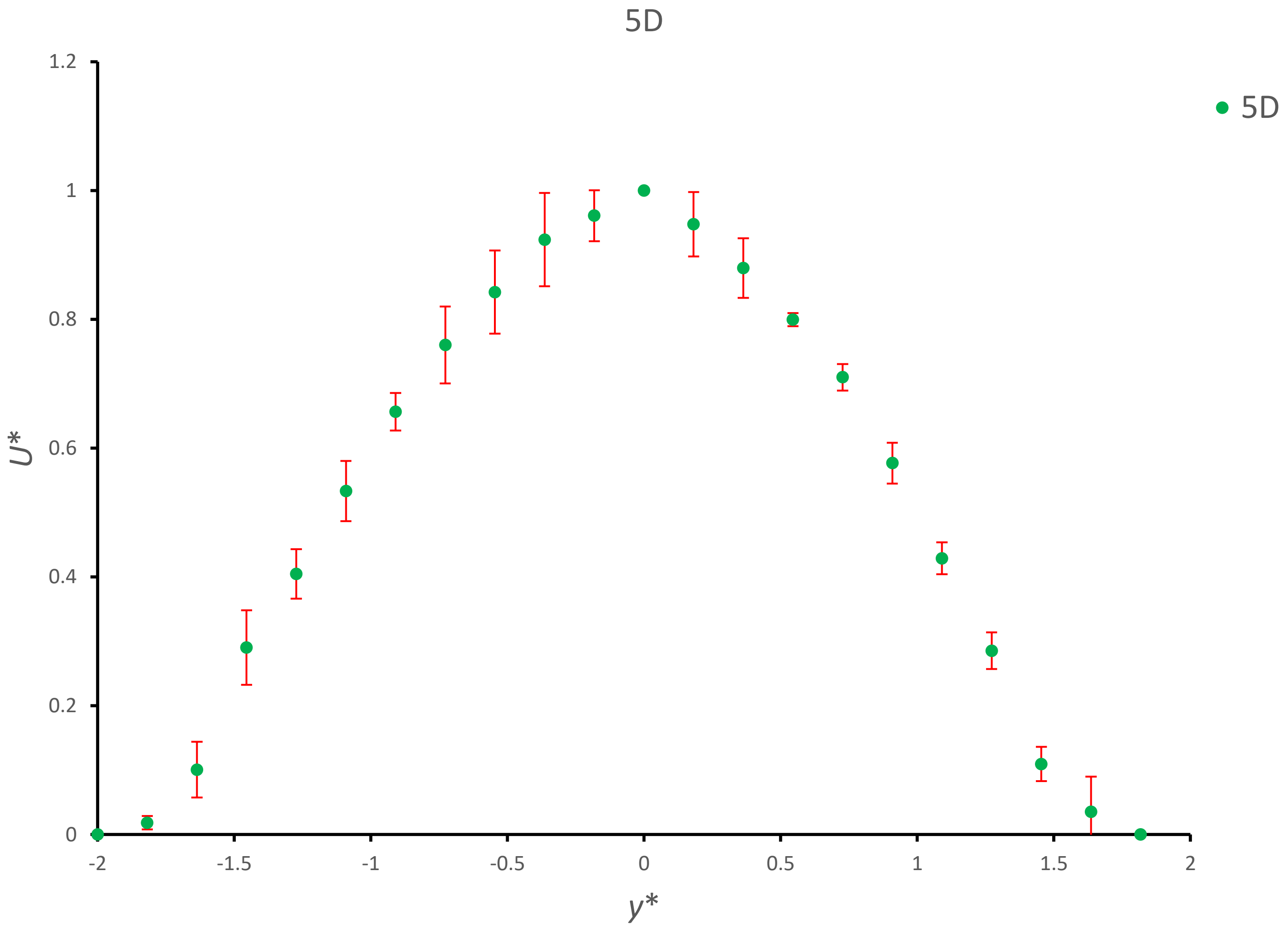

Figure 3 – Represented trace from self-similarity plot of 5D. Data was normalized, and uncertainty was calculated using three separate trails (std.) multiplied by the t-estimator for a confidence window of 95%.

Turbulent Jet Profile

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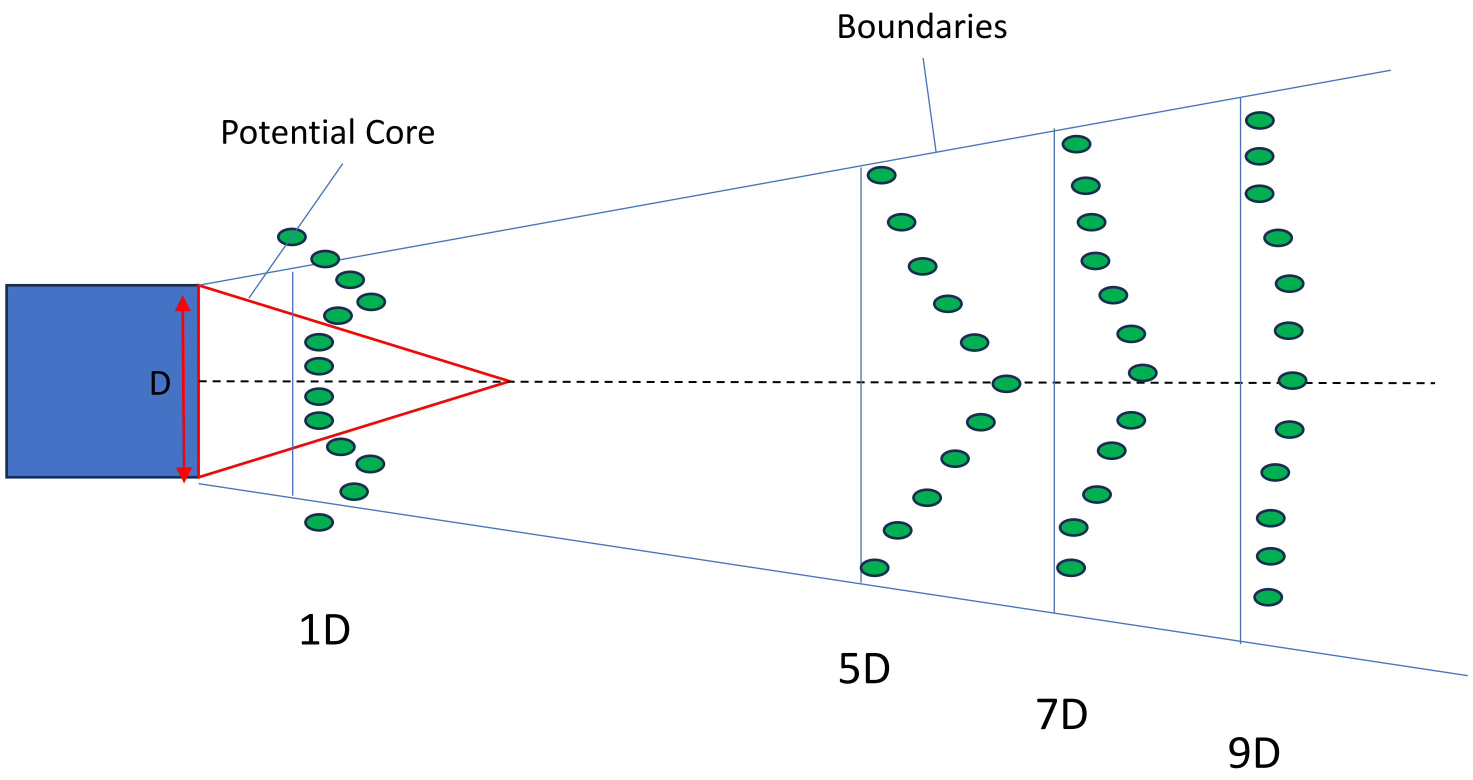

Figure 4 – Plotted turbulence will showcase the laminar flow on the potential core and subsequently display turbulent flow in the self-similar region

Developed Zone (Turbulent Flow)

Turbulence Intensity

- Not much, but there is laminar flow at the potential core at 1D

- We can see this within uncertainty

- Flow is turbulent according to self-similar region and according to Reynolds number

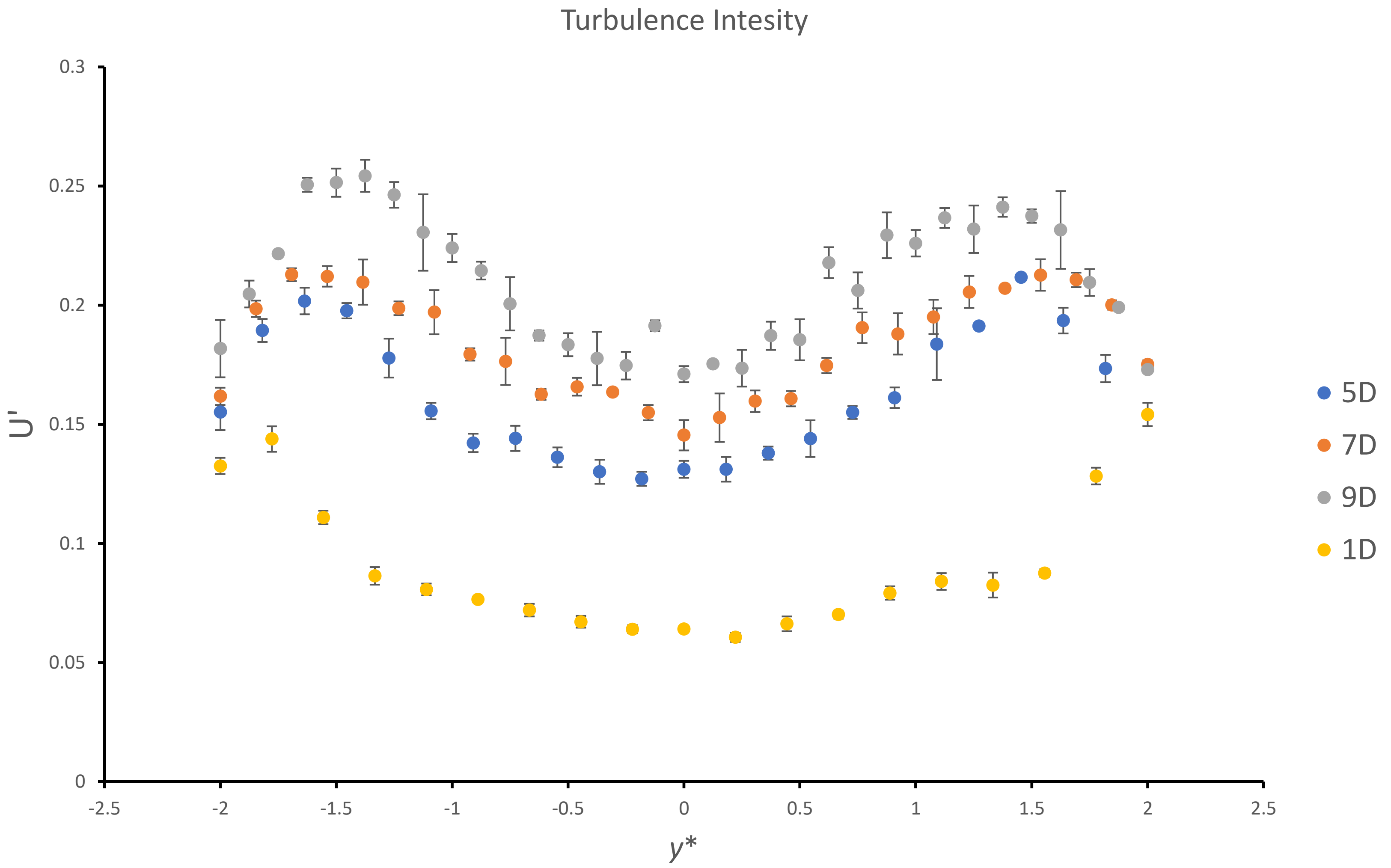

Figure 5 – At the potential core, 1D, there is laminar flow at the bottom of the curve where there is a straight line. The laminar flow is not easily visible but, within uncertainty there is laminar flow

Conclusion

- The model hypothesis was correct
- Reynolds number predicted turbulent flow
- The turbulence intensity plot displays laminar flow in the potential core
- Self-Similarity data allows us to predict the behavior of the turbulent flow using interpolation for further D values