Pool Fire Stability Downstream of Circular Cylinders in an Engine Nacelle Environment

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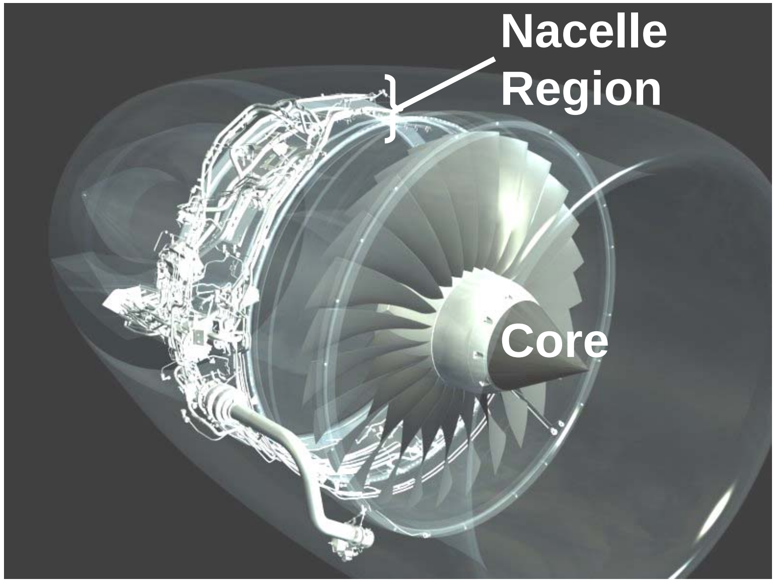
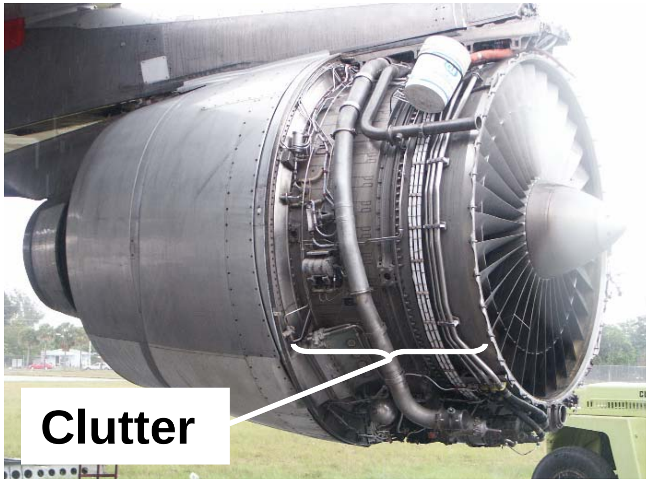
Introduction

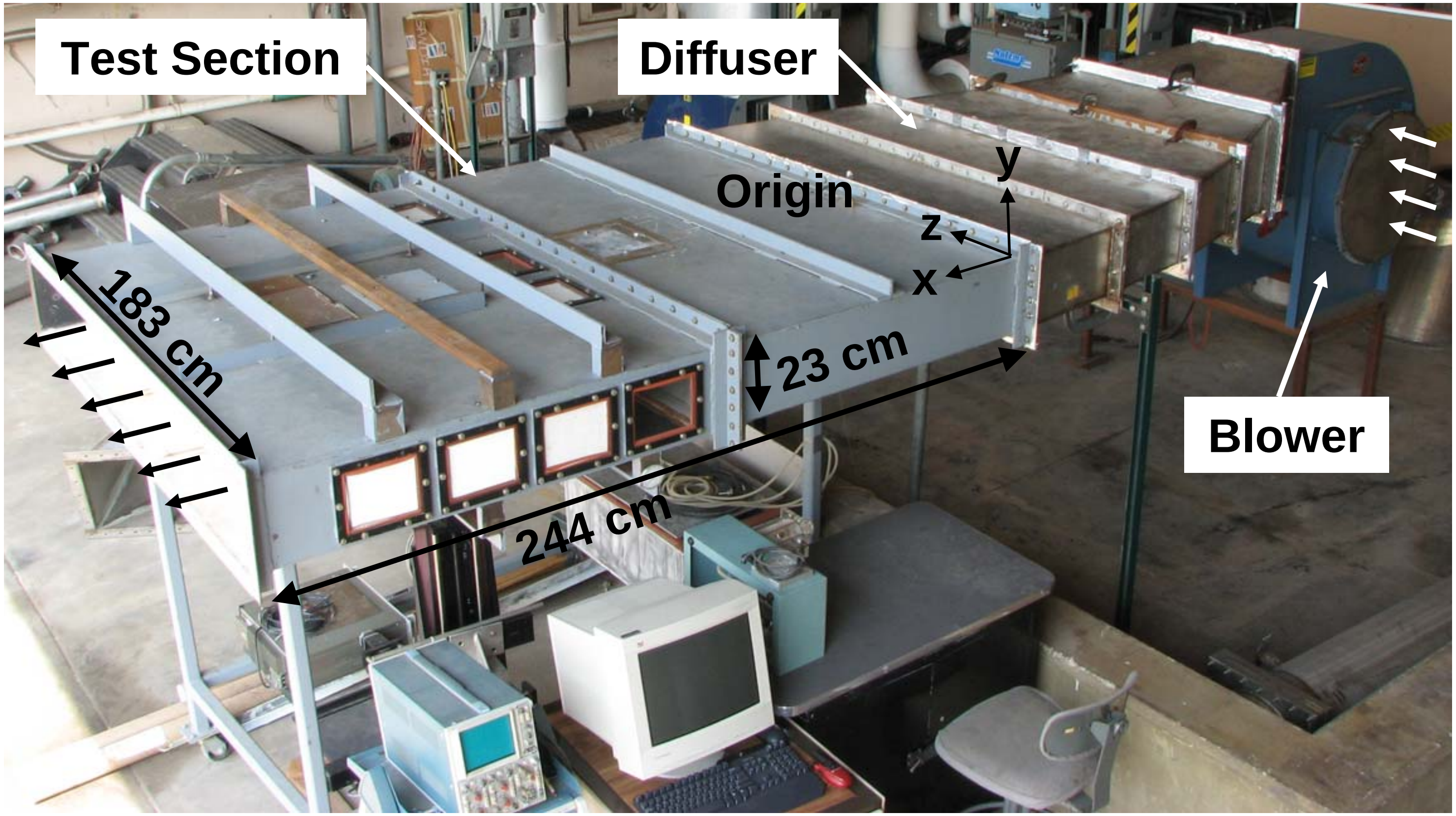
- Aircraft engine nacelles are typically highly cluttered environments
  - Difficult fire zones to protect.
- The T&E community uses simulators as geometrical representations of actual platforms
- Simulator cost is directly related to geometric detail.
  - Small obstructions often omitted.





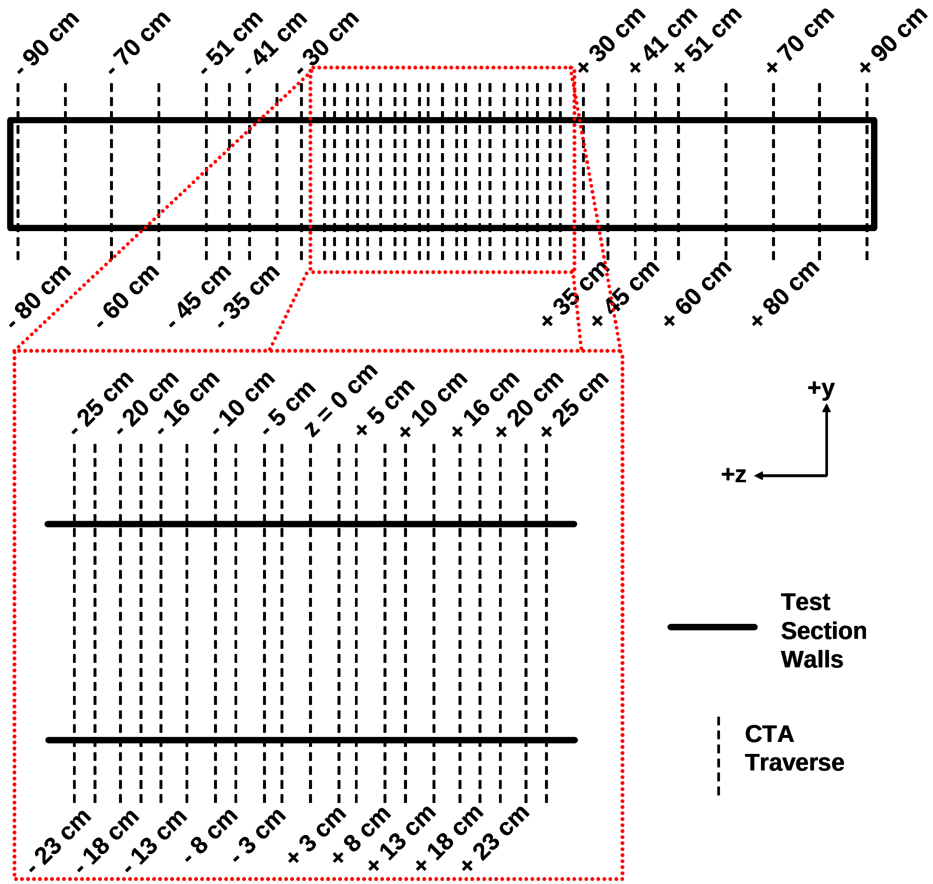
Experimental Facility

- 5, 10, 20, and 40 mm diameter cylinders examined within a representative aircraft engine nacelle airflow.



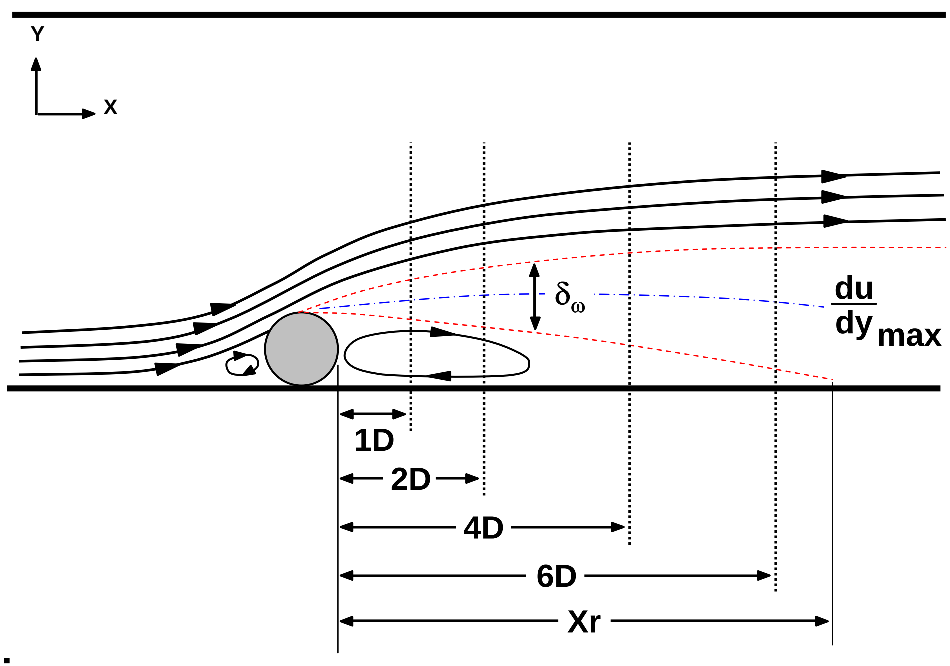
Inlet Airflow Characterization

- Temperature corrected Constant Temperature Anemometry (CTA) utilized to acquire all velocity and turbulence measurements
  - 5 µm tungsten hot-wire.
  - 25 kHz for 18 sec.
- Freestream airflow measured at 1158 positions across the test section width at x = 112 cm.



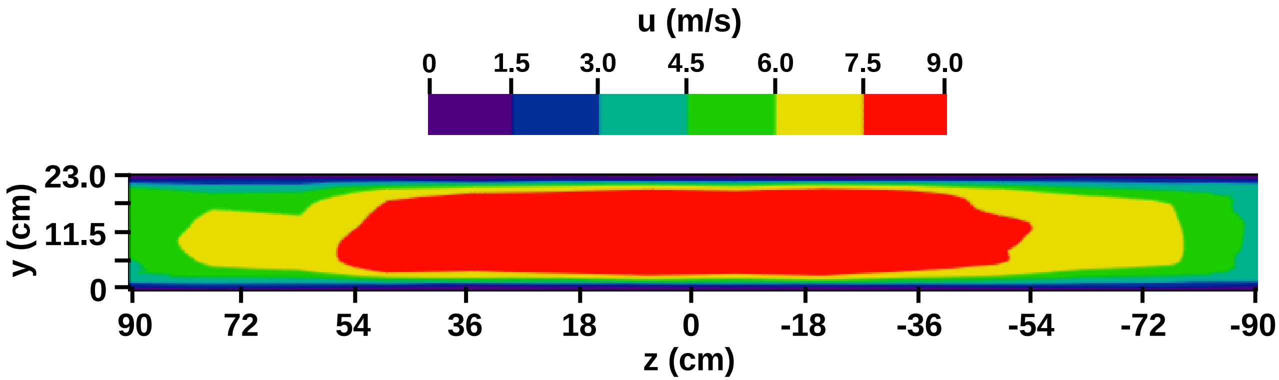
Shear Layer Measurements

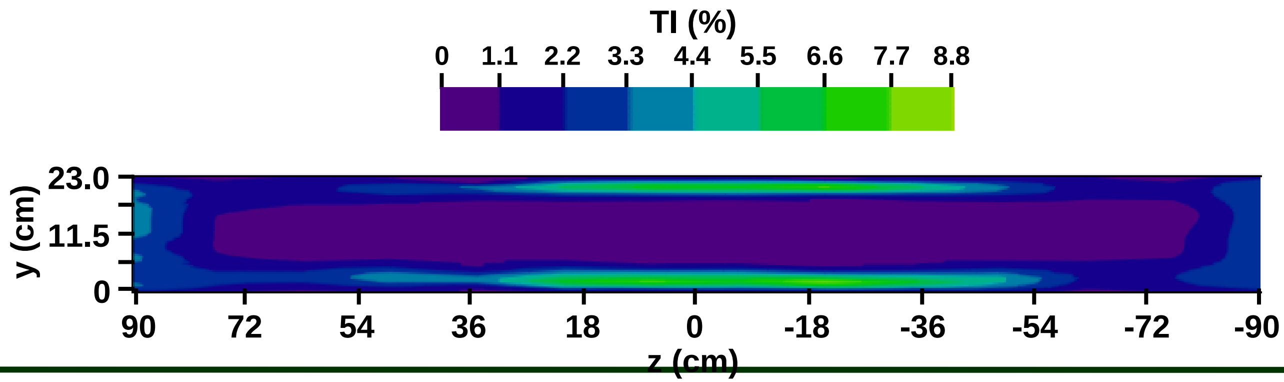
- Boundary layer measurements acquired at 4 streamwise positions along test section centerline.
  - Without clutter.
  - Two-dimensionality also checked at 5 spatial locations.
- Shear layer measured at 4 streamwise positions downstream of each clutter.
- For all shear layer measurements
  - Initial probe position at y = 0.25 mm.
  - 90 variably spaced locations.



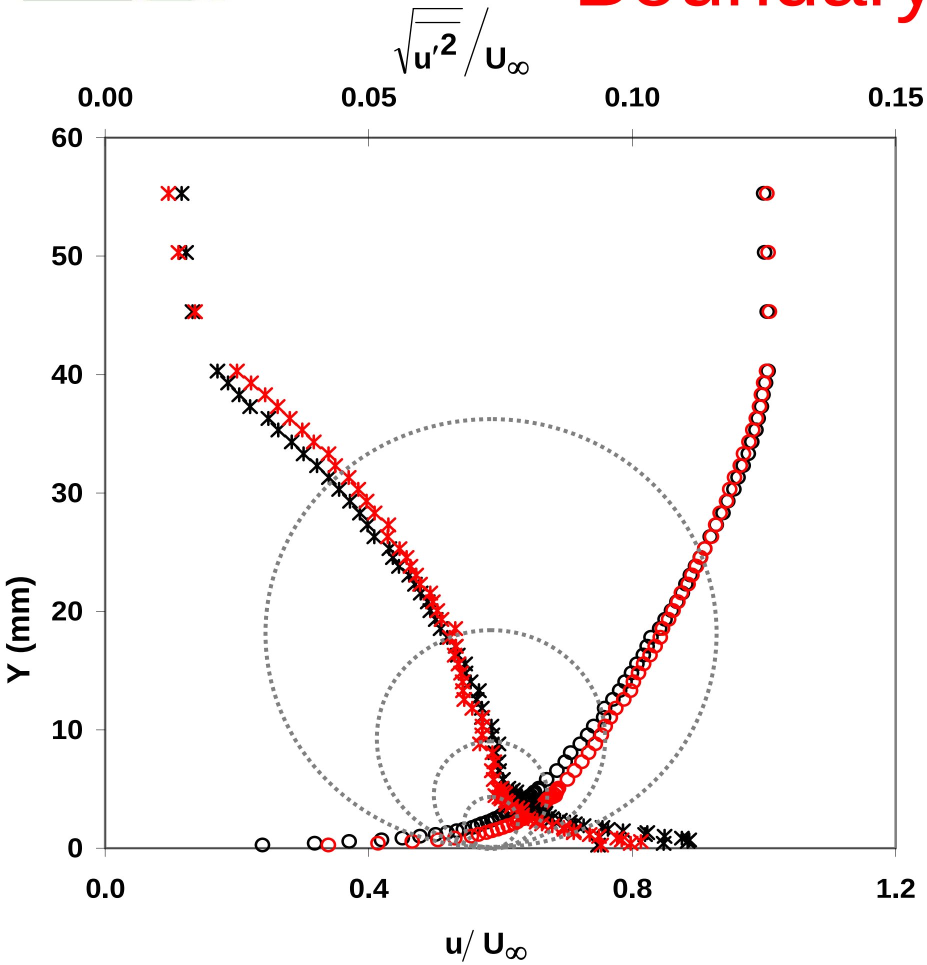
Inlet Airflow Characterization

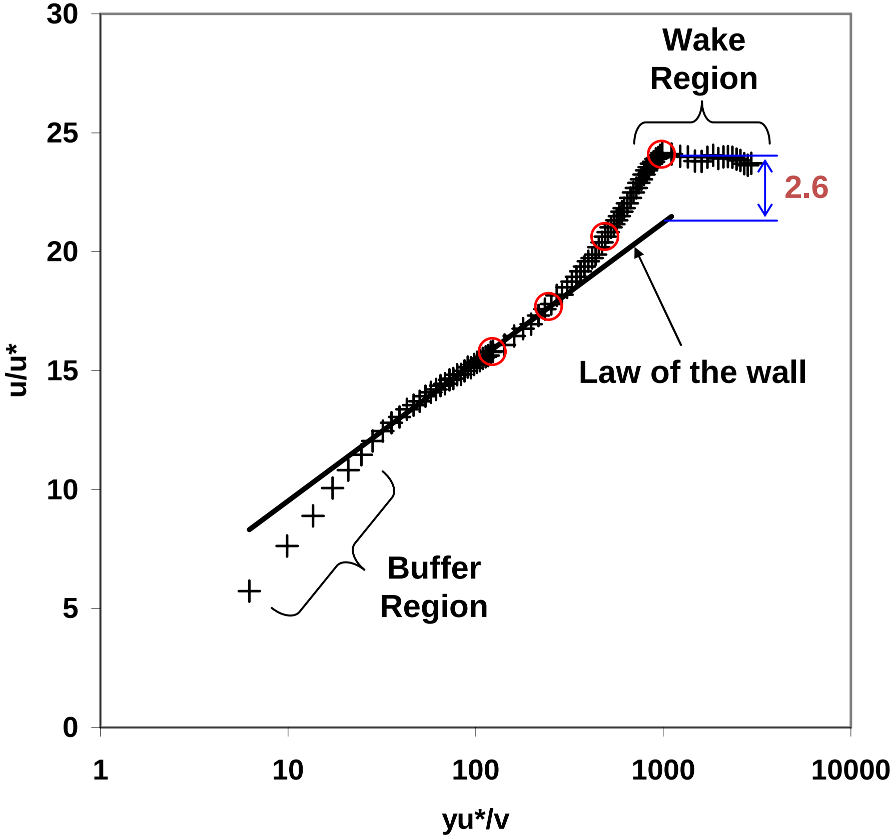
- Velocity measured within +/- 6% across center 55% of test section.
- Freestream velocity and TI of 8.4 m/s and 1%





Boundary Layer Profiles





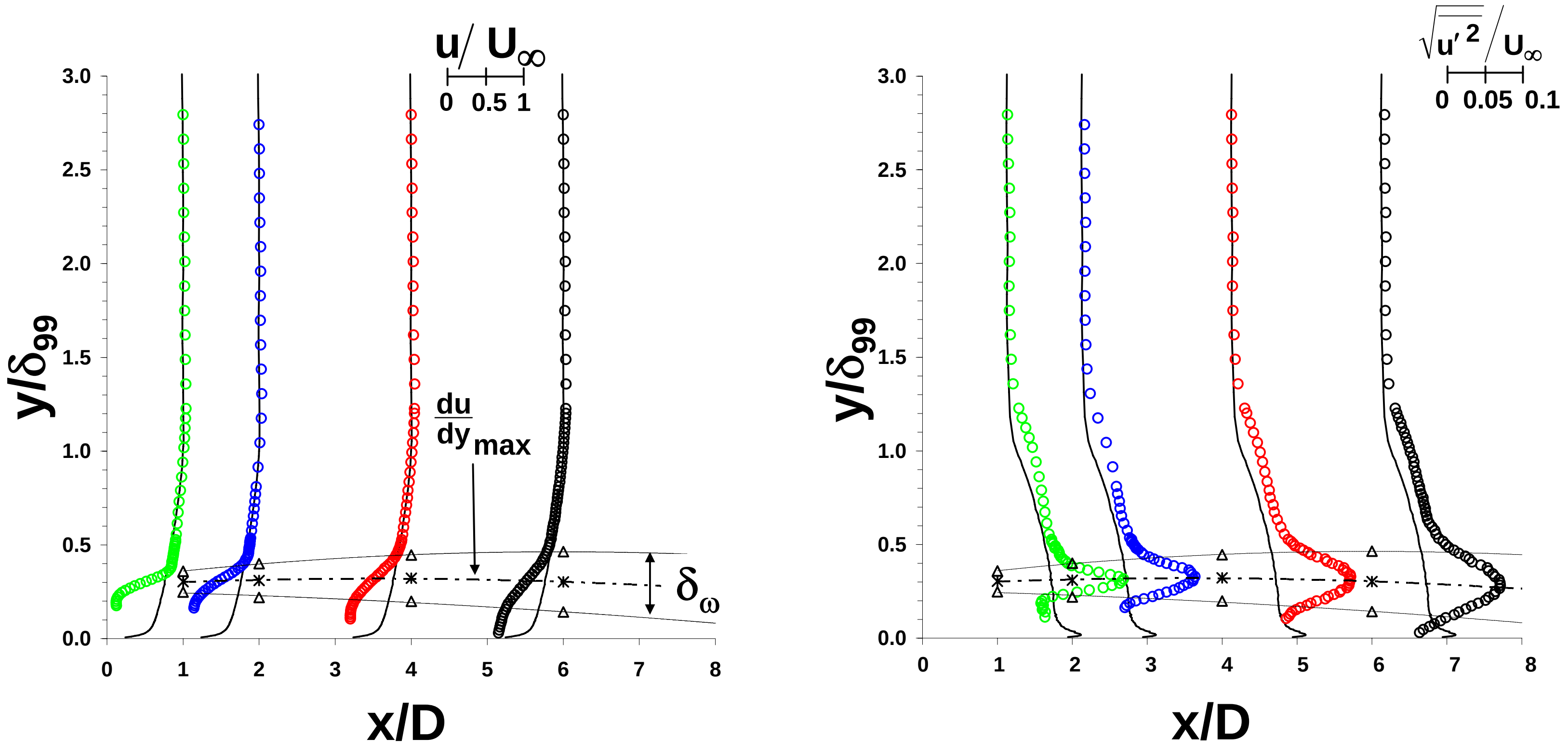
x (cm)	z (cm)	δ_{99}(mm)	δ^* (mm)	θ (mm)	H	c_f	u* (m/s)
120	0	38.3	6.9	5.0	1.38	0.0035	0.37
144	0	39.3	6.7	5.0	1.34	0.0032	0.32

Flow Visualization

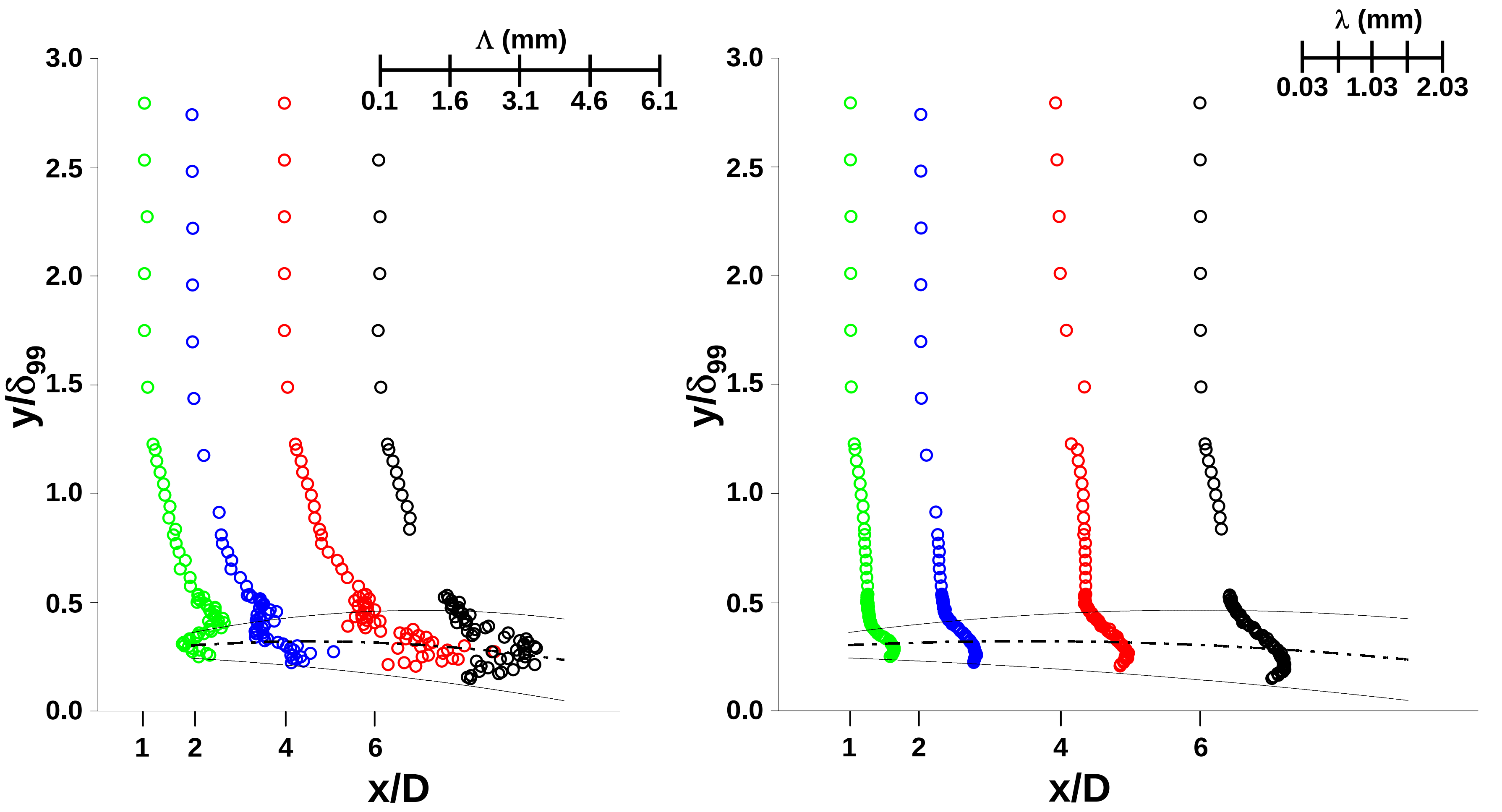
- Helium bubbles were injected into the flow upstream of the clutter elements.
- Bubbles were illuminated with off-axis light and the traces recorded using a high speed video camera with a side-view perspective.

- Video shows He bubbles injected upstream of the 20 mm diameter clutter.
  - Recirculation region clearly observed.

Velocity and TI Profiles

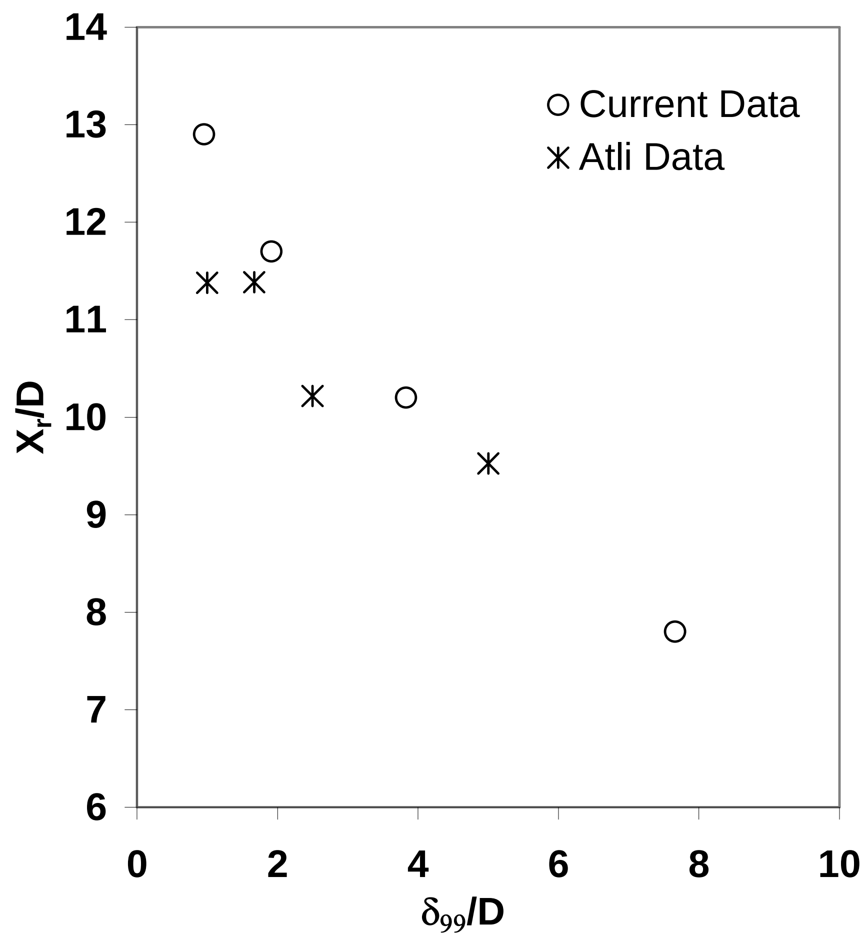


Turbulence Length Scales



Recirculation Length

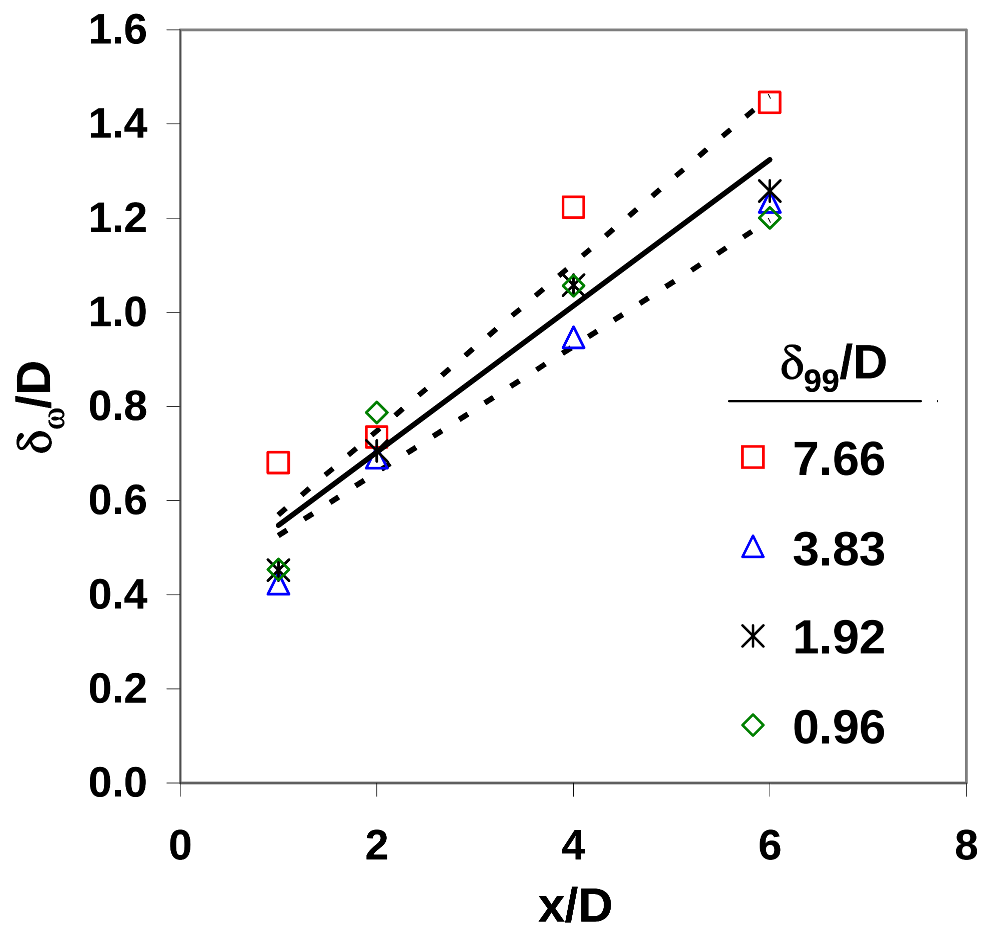
- The recirculation length was measured using cotton tufts and Helium bubble flow visualization.
- The length of the downstream recirculation region, X_r, was observed to be linearly dependant on the ratio δ_{99}/D.
  – Comparable to previously reported fence flow data.



*Atli, V., "Subsonic Flow over a Two-Dimensional Obstacle Immersed in a Turbulent Boundary Layer on a Flat Surface," Jo. Of Wind Eng. And Ind. Aero., Vol. 31, No. 2-3, 1988, pp. 225-239.

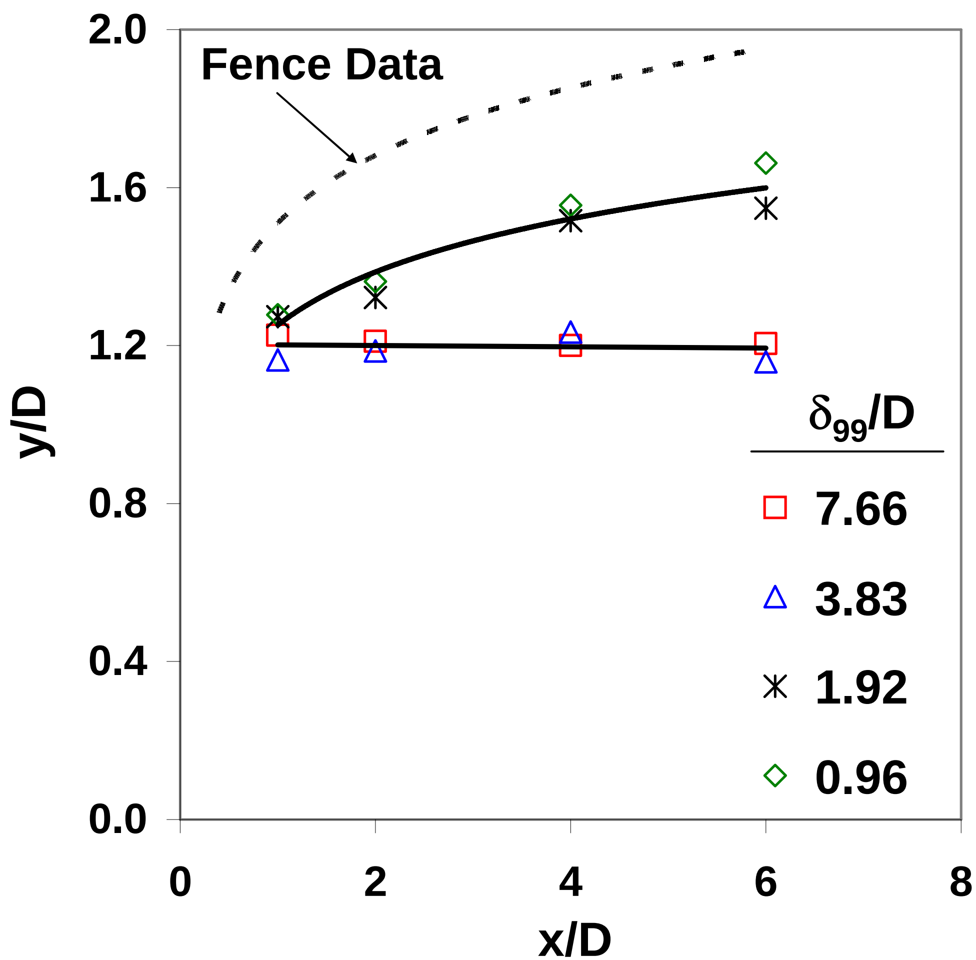
Free Shear Layer Spread Rate

- The spread rate of the free shear layer was observed to linear.
  - Slope of 0.156 δ_ω/x
- Comparable to other free shear flows.
  - Previously reported backward step data displayed as red dashed lines.



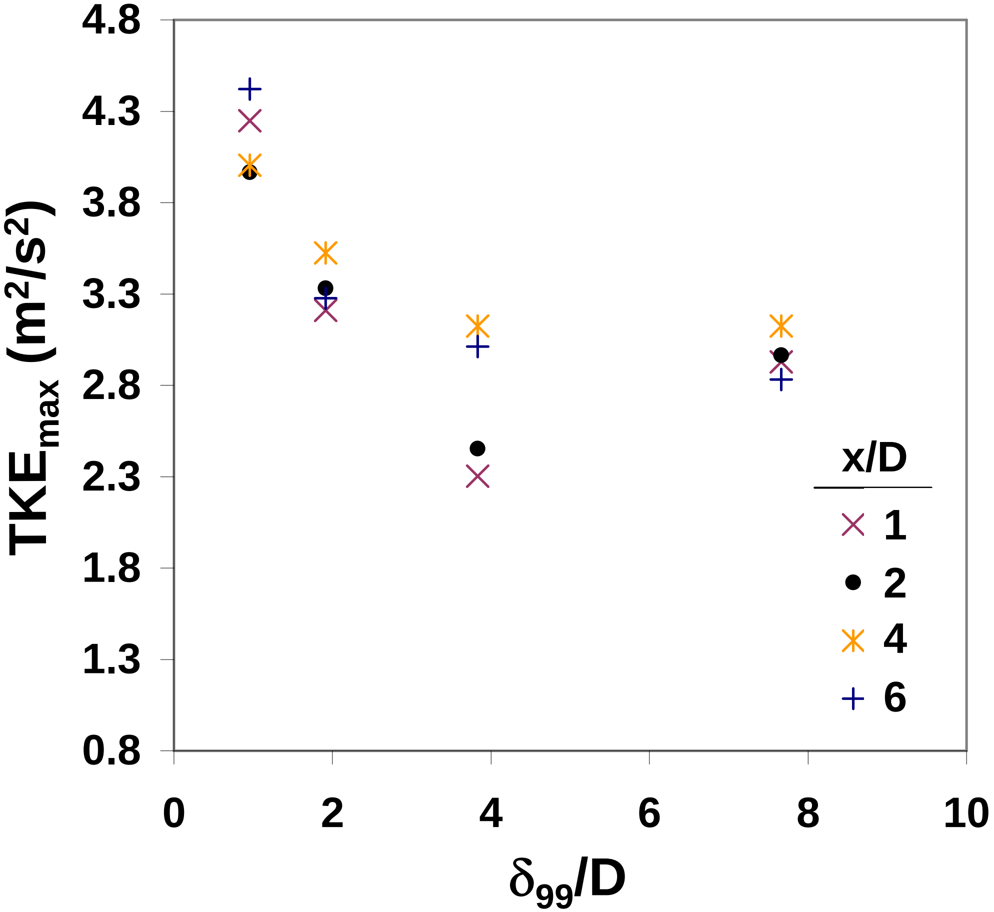
Free Shear Layer Trajectory

- The trajectory of the shear layer was observed by measuring the location of the shear center at each downstream location.
- Two different trajectories were observed:
  - Previously unreported for any shape obstruction.

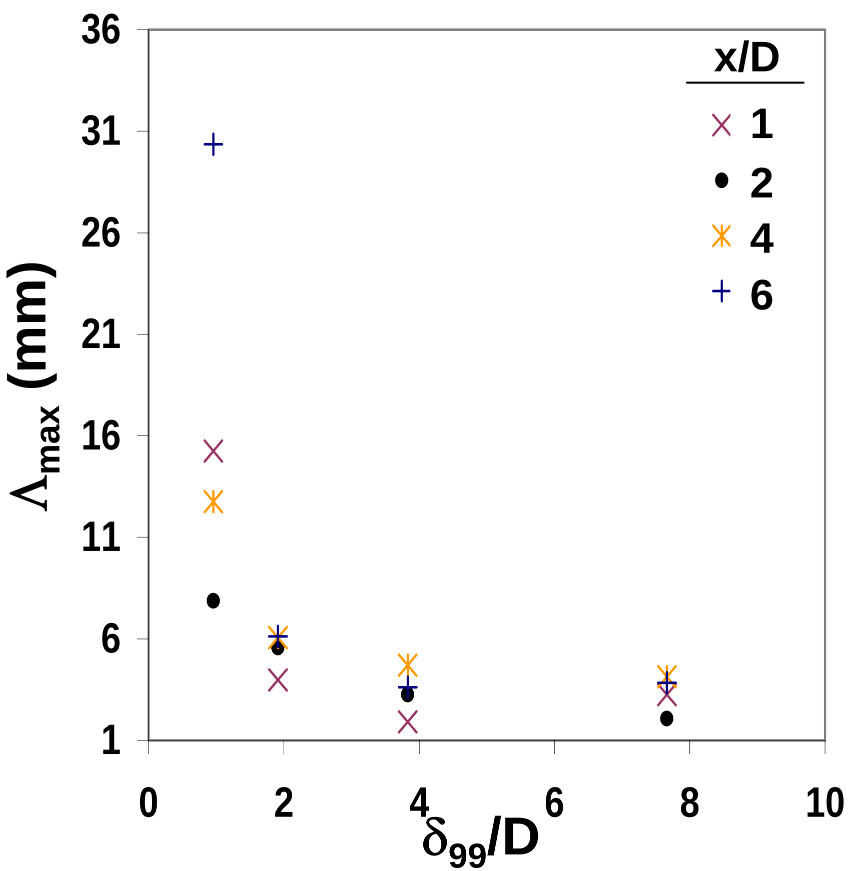


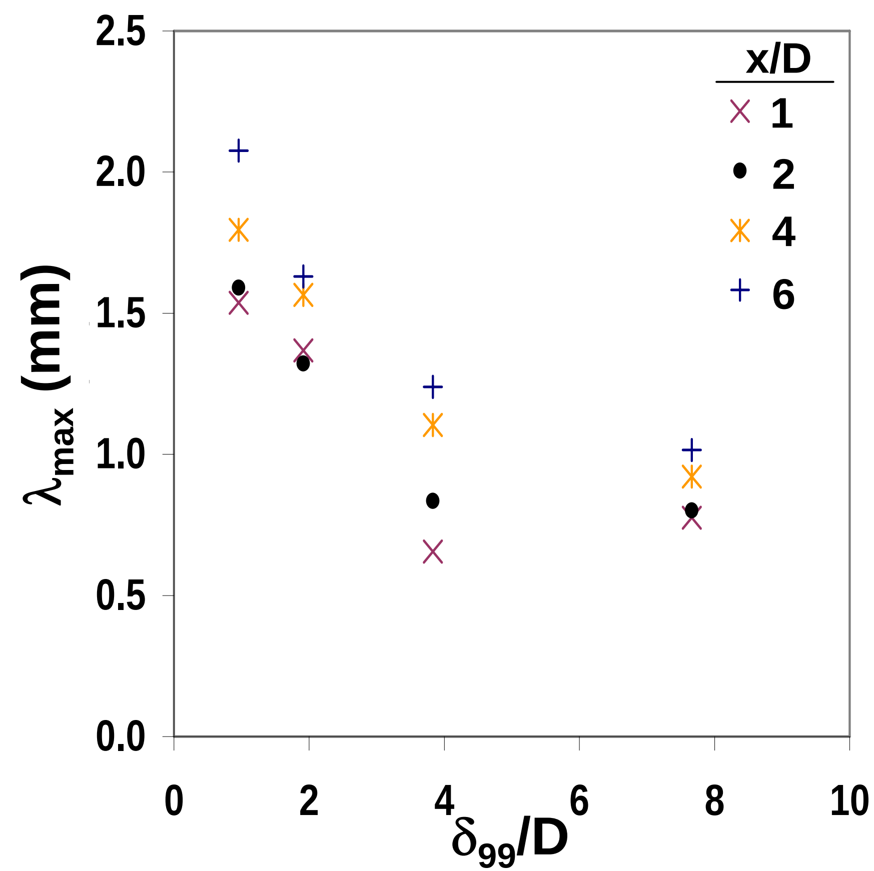
Effect of Clutter Size on TKE

- The TKE was also observed to be dependant on the δ_{99}/D ratio.
- As δ_{99}/D increased, max. TKE decreased.
- Again, TKE appears to approach an asymptotic value.



Effect of Clutter Size on Turbulence Length Scale





Fire Test Videos

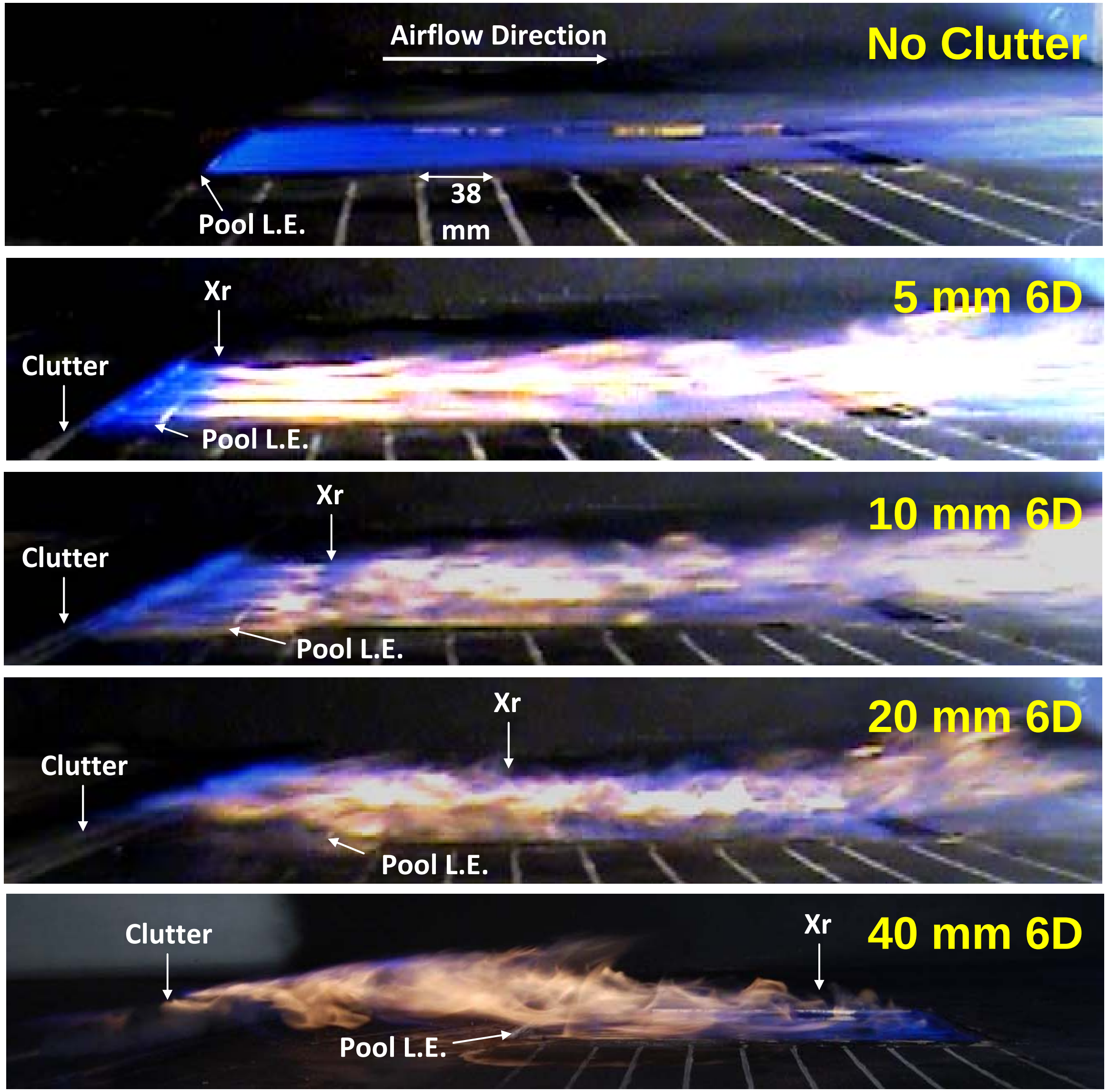
No Clutter (Baseline)

5mm Clutter 6D Upstream

40mm Clutter 6D Upstream

Color Fire Test Video Analysis

- Baseline condition
- Rim-stabilized wrinkled flame.
- Rim-stabilized wrinkled flame.
- Transitional flame.
- Wake-stabilized flame.



Summary

- The free shear layer separated from the clutter was observed to reside within a residual shear region from the upstream boundary layer flow.
  - However, the free shear layer spread rate was observed to be similar to other free shear flows.
- Evidence of a cut-off δ_{99}/D was observed.
  - On the order of $\delta_{99}/D = 4$.
- When the clutter is reduced below 1/4th of δ_{99}
  - The free shear layer will maintain a constant height.
  - TKE, Λ, and λ will maintain constant levels.

Summary

- The 40 mm clutter ($\delta_{99}/D < 4$) was observed to create a wake-stabilize flame within the confines of its downstream recirculation region.
- In contrast, the 5 and 10 mm clutter ($\delta_{99}/D > 4$) was observed to create a rim-attached wrinkled flame.
- The 20 mm clutter was observed to create a transitional flame.
- Therefore, it appears that when $\delta_{99}/D > 4$, the cylinder acted as a bluff body, whereas, for $\delta_{99}/D < 4$, the clutter sufficiently increased the turbulence scales enough to create a stable flame region deep within the boundary layer flow.

Acknowledgements

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