Experimental Analysis of Jets in Crossflow and Shear Layer Instabilities

UCLA Samueli School of Engineering
SUMMER UNDERGRADUATE RESEARCH PROGRAM

Energy & Propulsion Research Laboratory
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Introduction

Transverse jets or jets in crossflow (JICF) are used in various engineering applications to enhance mixing, such as in fuel injection for propulsion. When a jet issues into a crossflow, it forms complex vortical structures and instabilities. Of particular interest is the upstream shear layer, which can transition from **convective to absolute** or (globally) unstable as the jet-to-crossflow momentum flux ratio (J) decreases. Understanding this transition is critical for predicting and controlling jet penetration and scalar diffusion.

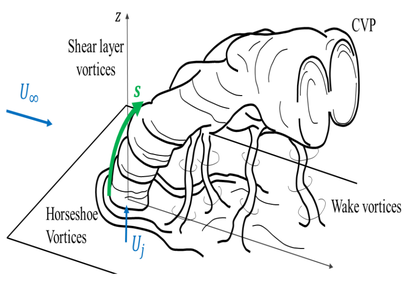


Figure 1.A Adapted from Fric & Roshko, JFM (1994)

Motivation

This project aims to experimentally investigate the behavior of instabilities in the upstream shear layer of a jet in crossflow, focusing instabilities transition from convective to absolute as the jet-to-crossflow momentum flux ratio (J) decreases. By using hot-wire anemometry we obtain and identify dominant modes and their frequency and comparing them across various flow conditions, we seek to validate the proposed analogy between the upstream shear layer and a counter-current shear layer. These insights contribute to the lab's broader goal of improving our ability to predict and control jet penetration and scalar diffusion in engineering applications.

Figure 1. A Film cooling for turbine blades (Image from werthinc.com)

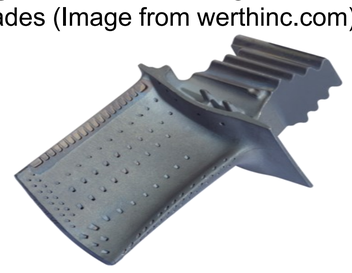
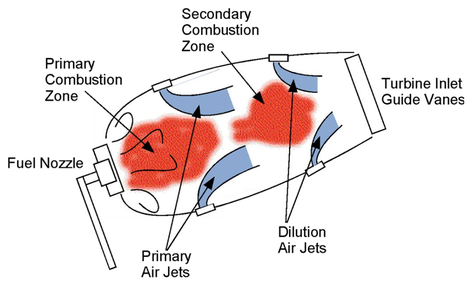
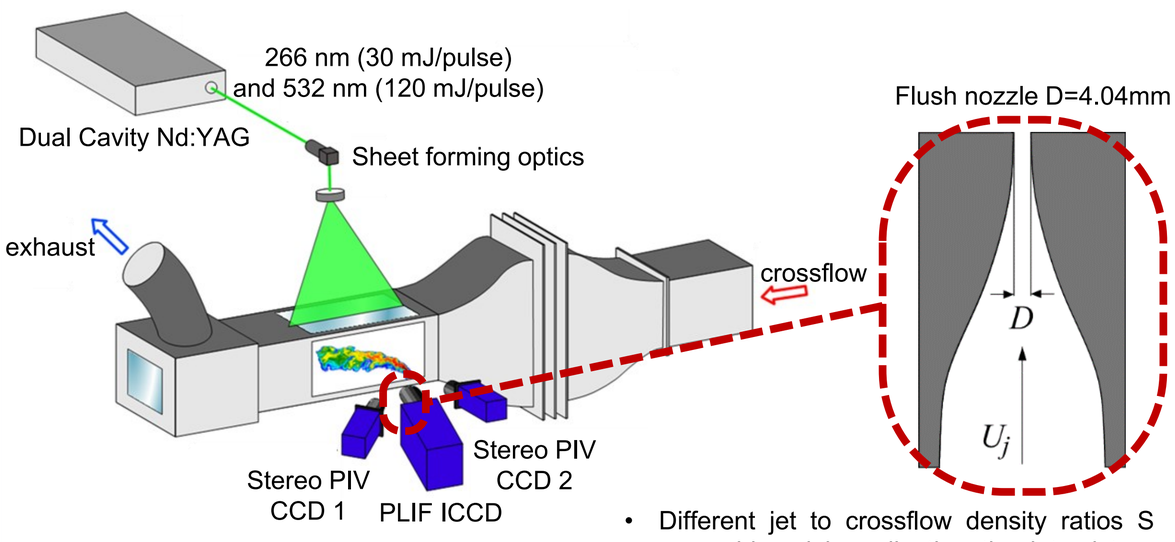


Figure 1.B Dilution air jets in gas turbine engines



Methods

In the present experiments, the gaseous jet issues perpendicularly into the wind tunnel test section via a 4 mm nozzle situated flush with respect to the injection wall. Optical access enables laser diagnostics including simultaneous stereo particle image velocimetry (PIV) and planar laser-induced fluorescence (PLIF) to capture detailed measurements at the center plane as well as across the cross-section of the JICF.



Flow conditions for current PIV/PLIF setup	
Jet Reynolds number	$Re_j = 1900$ (constant)
Jet-to-crossflow density ratio	$S = 1$ to 1.1
Jet-to-crossflow momentum flux ratio	$J = 3$ to 20
Jet constituents / crossflow	Ar, N_2, He, Acetone / air

- Different jet to crossflow density ratios S are achieved by adjusting the jet mixture composition, which leads to variations in jet velocity and viscosity while maintaining a fixed jet Re for various momentum flux ratios J.
- By varying J, the experiments capture the transition from convectively unstable (CU) to absolutely unstable (AU) flow, highlighting the evolving instability mechanisms in the shear layer. These may be compared with equidensity studies, for which a critical $J_{crit} \approx 10$[1,2] and related low density studies[3,4].

Results & Experimental Improvements

Hot Wire data

Hot wire anemometry was used to capture velocity fluctuations along the transverse jet's upstream shear layer, revealing frequency shifting associated with hotwire tonal interaction with instabilities except at low J.

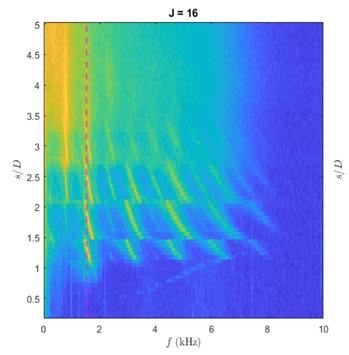


Figure 2.A
At momentum flux ratio **J = 16,** frequency shifting and the presence of a subharmonic and higher harmonic modes suggest **CONVECTIVE INSTABILITY**

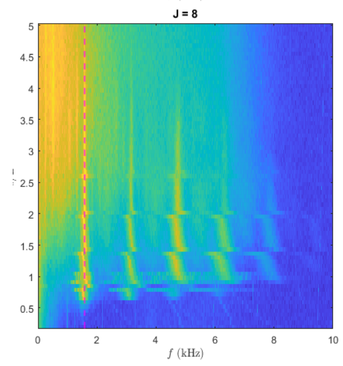


Figure 2.B
At momentum flux ratio **J = 9,** a strong pure-tone instability, diminished frequency shifting and higher harmonic modes suggest **ABSOLUTE INSTABILITY**

Designed and Fabricated Components using CAD

Several new components were designed and fabricated using CAD to help aid calibration of the hot wire, laser sheet thickness, and camera position for PIV and PLIF experiments, which will be analyzed together with the hot wire-determined frequencies in the jet's upstream shear layer.

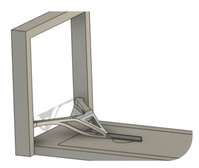


Figure 3.A
Visual Laser Alignment tool

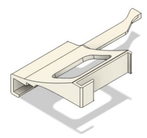


Figure 3.B
Aligner for calibration plate

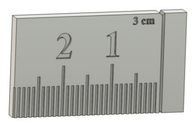


Figure 3.C
Swapable Rulers

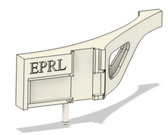


Figure 3.D
Ruler Holder

Piping and Instrumentation Diagram (P&ID)

We created the P&ID for the flow system and wind tunnel.
Created naming conventions and physical labels to standardize procedures.

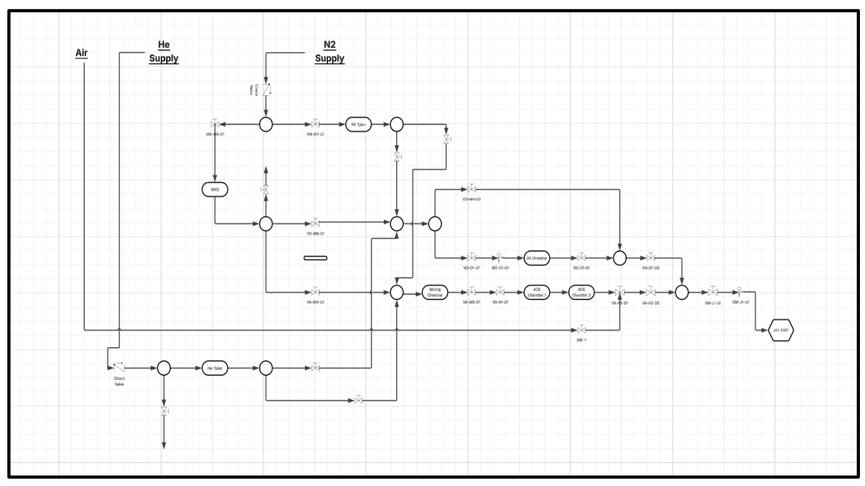


Figure 4
P&ID showing oil and acetone tracer lines used in separate experiments as well as venting procedures, providing a reference for setup, and improving procedure safety.

Conclusions

Our work this summer assisted in advancing research performed in the Energy and Propulsion Laboratory with the JICF Experiment.

- Designed and fabricated 4 new components to optimize efficiency and data collection
- Created a schematic for the plumbing system to improve procedures.
- Collected dominant upstream shear layer instability data from hot wire anemometry for future analysis and comparisons with laser diagnostics

We also plan on using hot wire and laser based data to implement the Ginzburg-Landau (GL) equation as a model for jet transition dynamics, in collaborative efforts with UFF (Brazil), led by Prof. Leonardo Alves.

References

[1] Megerian et. al., **JFM**, 2007
[2] Getsinger et. al., **JFM**, 2014
[3] Gevorkyan et. al., **JFM** 2016
[4] Shoji et. al., **JFM**, 2020

Acknowledgements

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