Particle Image Velocimetry of Transverse Jets in Cross Flow

Jesse Tsai[1], Kayla Kuzmich[2], David Forliti[2], Nils Sedano[2], Kriss Vanderhyde[2]

1: STEM Teacher and Researcher, San Francisco State University

2: Aerospace Systems Directorate, AFRL, Edwards Air Force Base

Introduction

The goal of this experimental study was to determine the effectiveness of the scaling parameter *B*, for the jet in cross flow (JICF). Establishing *B*'s effectiveness will provide a reliable base model for the optimization of the mixing and the homogeneity of fluids using JICF.

Background

Jet in cross flow (JICF) is the interaction between fluids entering a cross flow from a transverse jet. The vortical structures, namely the counter-rotating vortical pairs (CVP) play a significant role in the entrainment between the cross flow and transverse jet. The JICF can be used to predict impacted areas from pollutants in smoke plumes.

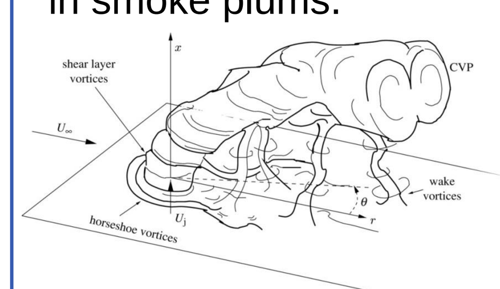


Fig 1: Structure of the JICF[1]

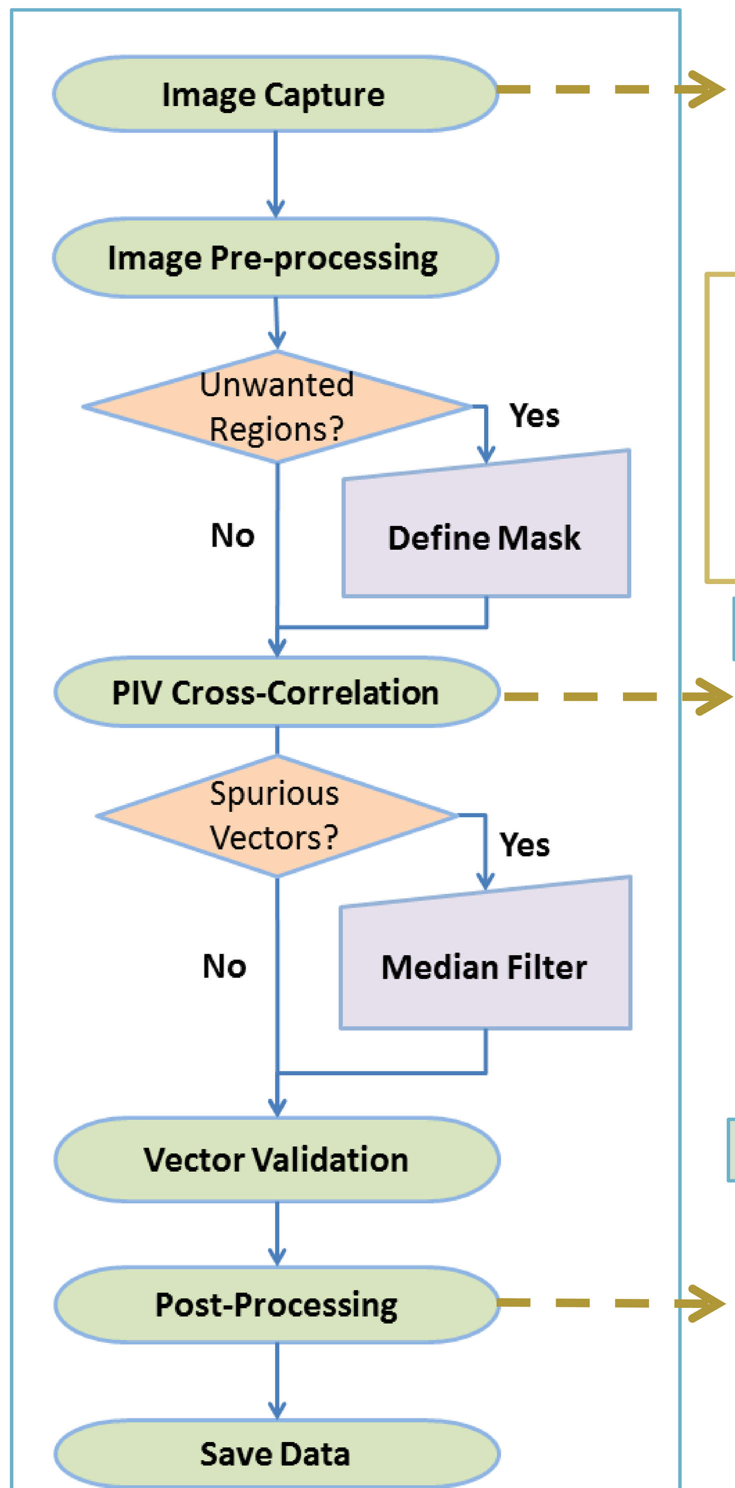
Fig 2: JICF in smoke plumes

Particle image Velocimetry (PIV) is a method of tracking fluid motion through the use of small tracer particles by determining their location at two instances of time. Our goal is to compare the effectiveness of the **trajectory scaling law** *B* in comparison to the currently used velocity ratio *R*. *B* accounts for the densities, drag, and entrainment of the fluids.

$$B = \frac{J}{\frac{2C_D}{\pi} + C_e J^{1/2}} \qquad R = \frac{v_{jet}}{v_{cf}}$$

Where v_{jet} is the velocity of the jet, v_{cf} is the velocity of the crossflow, J is the momentum flux ratio of the jet to crossflow, C_D is the drag coefficient, and C_e is the entrainment coefficient.

Particle Image Velocimetry Pipeline



Initial Data

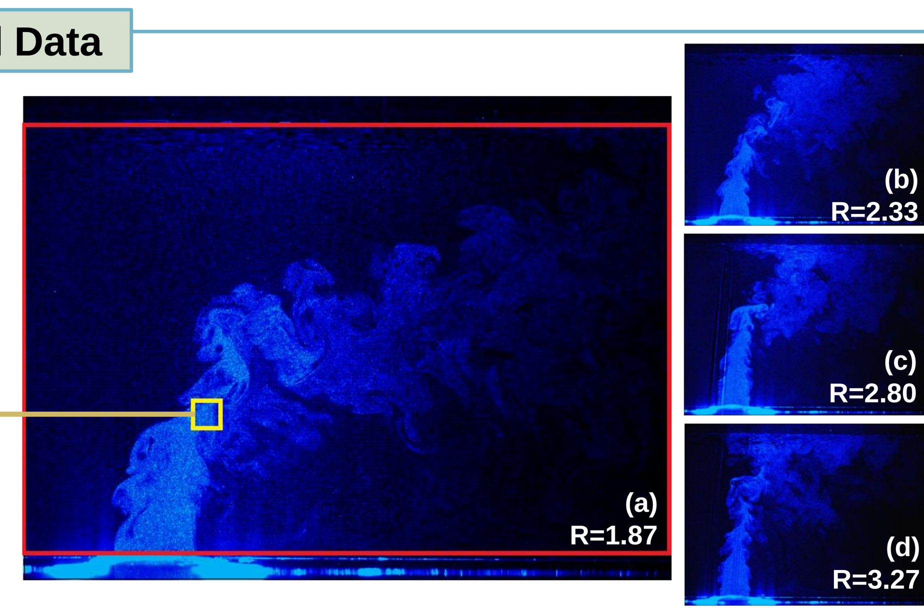
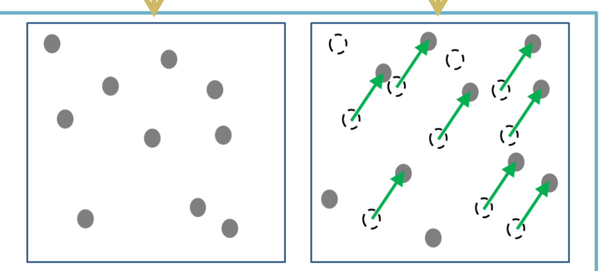


Fig 5: Instantaneous images when velocity ratio is (a) 1.87, (b) 2.33, (c) 2.80, (d) 3.27, against a constant crossflow.

PIV Cross-Correlation

Image pairs use interrogation regions to compute the average displacement within each region. The average velocity can then be calculated using the average displacement and the time Δt.



(a) initial time *t* (b) later time $t+\Delta t$

Fig 6: The grey dots are the particles at time *t* and time $t+\Delta t$. In a small enough region, the particles will travel in a nearly linear direction.

Final Image and Expected Results

After scaling the displacement in pixels to millimeters, a velocity vector field was then determined by averaging the velocity vectors from all the instantaneous images to obtain the average flow of the JICF. As the jet velocity increased, the jet penetrated further into the cross flow.

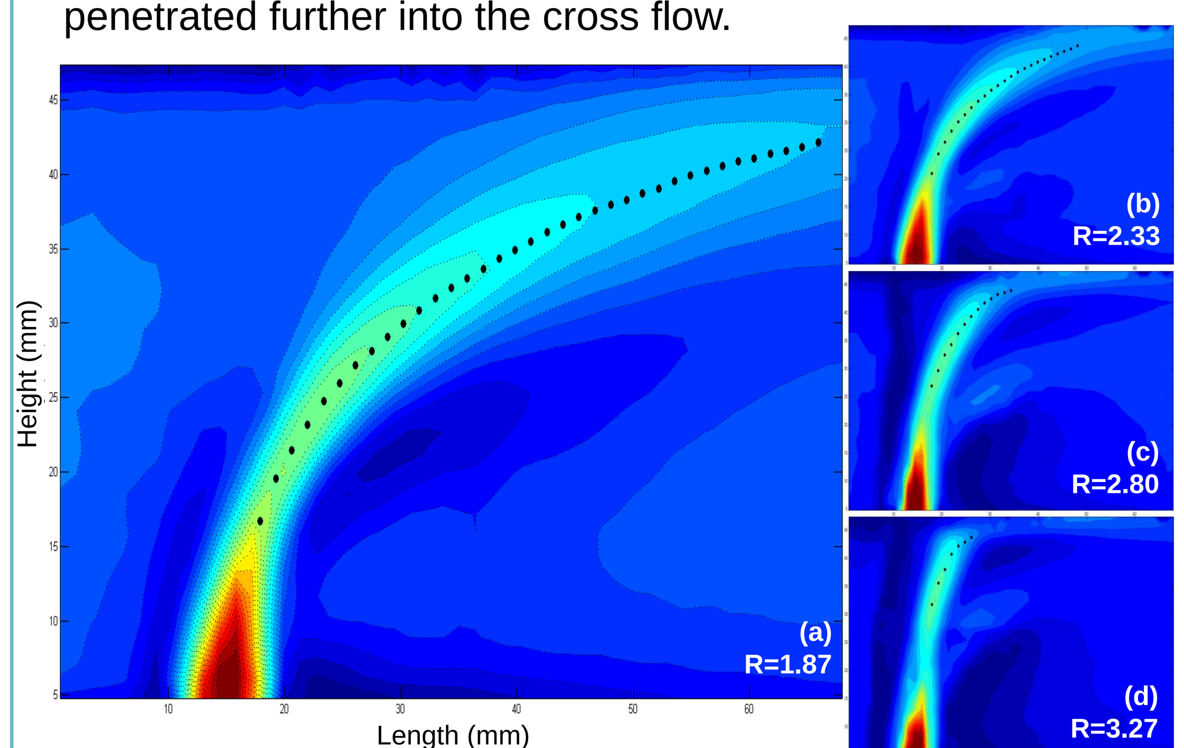


Fig 7: The vector field with a contour for the four different jet flow rates of (a) 1.87, (b) 2.33, (c) 2.80, (d) 3.27. Note that the increased jet velocity resulted in the impact against the opposite wall.

Experimental Setup

Tracer particles consisted of aerosolized olive oil. The transverse jet entered the test section perpendicular to the crossflow. The laser emitted a pulse that was formed into a sheet, and then scattered by the tracers that was then captured by the camera.

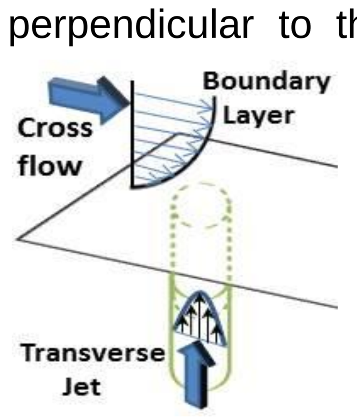


Fig 3: Components to form the JICF.

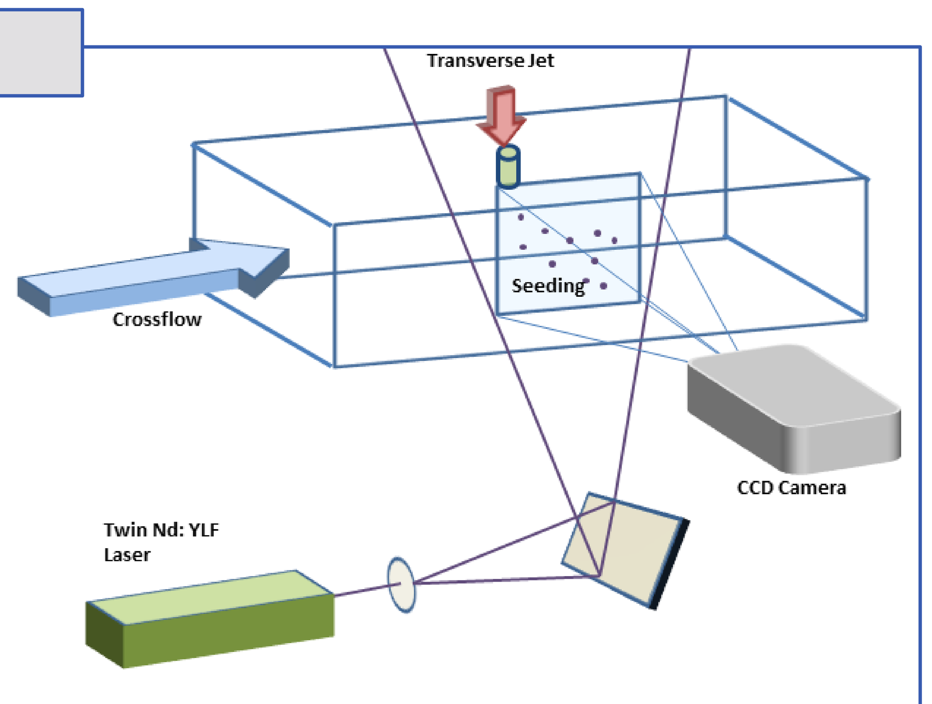


Fig 4: Schematic representation of imaging set-up for the experiment.

Analysis of Results

The final velocity vector fields for the different jet velocities are shown with their corresponding Reynolds number, *Re*, and scaled to the different trajectory scaling values of (a) RD_j, (b) R^2D_j, and (c) BD_j. Upon inspection of the results, RD_j does not collapse the jet centerlines as well as R^2D_j or BD_j. R^2D_j and BD_j appear to show good collapse of the centerlines onto a central curve.

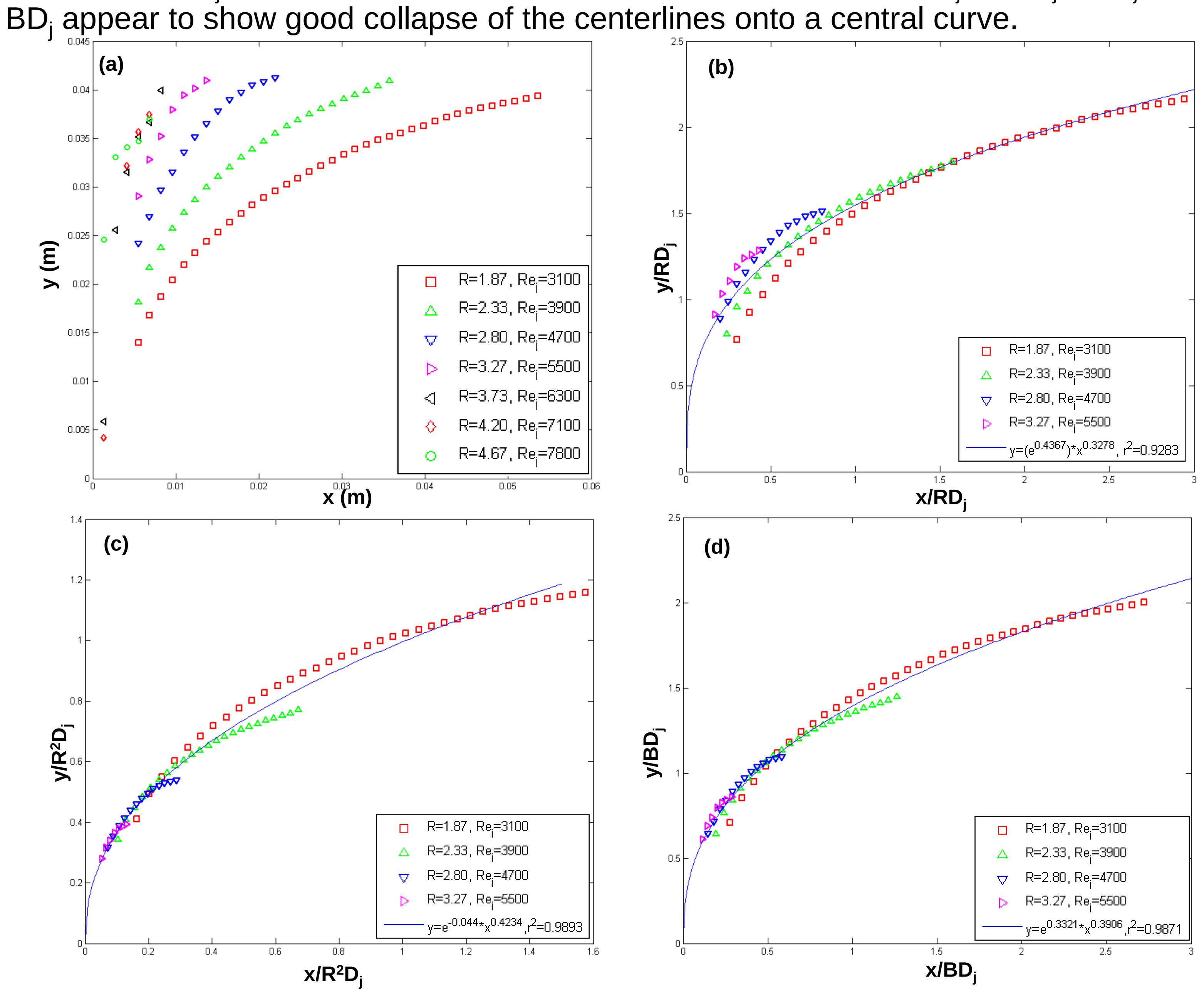


Fig 8: Transverse jet trajectories scaled with (a) no scaling, (b) RD_j, (c) R^2D_j, and (d) BD_j.

Conclusions

The results plotted in respect to the different scaling laws RD_j, R^2D_j, and BD_j displayed a general collapse of data to a central curve. It can be argued that either R^2D_j or BD_j show similar results with $r^2=0.9893$ for R^2D_j and $r^2=0.9871$ for BD_j. Even so, BD_j can be modified to show a better collapse of the data, while R^2D cannot.

Future Work

The BD_j parameter will need to be verified under different parameters and conditions. One such experiment would be to use fluids of different densities for the jets. Another experiment could explore higher temperatures and higher pressures. Further research into the JICF will prove to be invaluable for future designs of combustion devices.

References

[1] Fric, T. and Roshko, A., "Vorticity Structure and Evolution in a Transverse Jet," *Journal of Fluid Mechanics,* Vol. 352, 1997, pp. 27-64.

[2] Kiger, K. "Introduction to Particle Image Velocimetry," *Burgers Program for Fluid Dynamics,* University of Maryland.

Acknowledgements

Special thanks go to National Science Foundation and the STAR program for making this collaboration possible. Other individuals also recognized are David V. Salazar, and Jorel Estrada for their help and assistance at the Edwards Air Force Base. And a special thank you to the other STAR affiliates that have assisted with the research: Yvonne Campos, Sean Phillips, Ilian Rojas, Samantha Bell, and Madani Khan.

This material is based upon work supported by the S.D. Bechtel, Jr. Foundation, the National Marine Sanctuary Foundation, the Carnegie Corporation of New York, and/or the National Science Foundation under Grant Nos. 0952013 and 0833353. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funders. The STAR program is administered by the Cal Poly Center for Excellence in Science and Mathematics Education (CESaME) on behalf of the California State University.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited. PA Release # 14428