Bifurcation and Stability Analysis of a Jet in Crossflow

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ABSTRACT

Jets in crossflow arise when fluid is injected through a nozzle into a spatially developing boundary layer. We study Direct Numerical Simulations (DNS) of a jet in crossflow at low values of the jet-to-crossflow velocity ratio R. Evidence has been presented ([3]) that the flow dynamics is dominated by an interplay of three common instability mechanisms - Kelvin-Helmholtz shear layer roll-up, elliptic instability of the counter-rotating vortex pair, and a von Kármán type of instability near the wall. The stability analysis of [1] established that the dominating instability is of the anti-symmetric elliptic type at $R = 3$. We observe that, starting from much lower values of R, at which the flow is stable, the first instability to arise as R is increased is the Kelvin-Helmholtz type symmetric shear layer roll-up resulting in the shedding of hairpin vortices (see Fig. 1). Anti-symmetric instabilities arise at higher values of R, before the flow finally becomes turbulent ([3], [2]).

The observed shedding of hairpin vortices just above the first bifurcation is linked to a possible existence of a local absolute instability in the region of separated flow immediately donwstream of the nozzle that results in a shear layer instability. We perform a linear stability analysis for a few values of R near the bifurcation and determine that the unstable mode indeed corresponds to a shear layer instability with spanwise symmetry. We also compute the adjoint global eigenmodes, and find that the overlap of the direct and the adjoint eigenmode, also known as a 'wavemaker', provides additional evidence that the most sensitive region of the flow is the shear layer associated with the separated flow downstream of the jet nozzle.

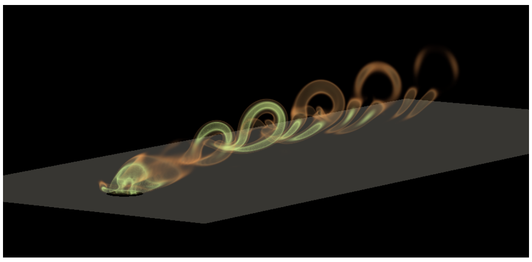

Figure 1: A snapshot of the limit cycle at $R = 1$, showing volume rendering of the λ_2 vortex identification criterion. The near-field downstream of the nozzle is steady, while the far-field eventually synchronizes with the shedding frequency of the hairpin vortices. Levels of high magnitude of λ_2 are colored yellow to indicate vortex 'cores'.

References

[1] S. Bagheri, P. Schlatter, Peter J. Schmid, and Dan S. Henningson. Global stability of a jet in cross-flow. *Journal of Fluid Mechanics*, 624:33–44, 2009.

[2] Miloš Ilak, Philipp Schlatter, Shervin Bagheri, Mattias Chevalier, and Dan S. Henningson. Stability of a jet in crossflow. *arXiv:1010.3766v1*, October 2010.

[3] Philipp Schlatter, Shervin Bagheri, and Dan S. Henningson. Self-sustained global oscillations of a jet in crossflow. *Theoretical and Computational Fluid Dynamics*, (online), 2010.