Toward Optical Measurements of Stratified Jets

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A modular jet facility has been developed to enable optical measurements of both unstratified and stratified jet flows; however, stratified measurements remain challenging due to refractive index variations that distort velocity and scalar fields. These mismatches bend and scatter light rays, leading to image distortion and particle displacement errors in Particle Image Velocimetry (PIV) (McDougall, 1979). Consequently, refractive index matching (RIM) is a critical tool for experimental studies of liquid-phase stratified turbulence.

RIM has been widely adopted in laboratory studies of stratified liquid flows to enable optical flow measurements (Clément et al., 2018). Successful implementation of RIM requires precise measurement of the refractive index, yet such instruments can be costly and may not be readily accessible in all laboratory settings. To address this limitation, we propose a simple prism-based refractometer to provide reliable refractive index measurements with sufficient precision for RIM applications.

The performance of the prism-based refractometer was evaluated to assess its accuracy and suitability for RIM applications. Refractive index measurements were conducted using aqueous NaCl and ethanol solutions, with independently varied solute concentrations up to 50 g/L, spanning normalized density differences $\Delta\rho = (\rho_{\text{salt}} - \rho_{\text{ethanol}})/\rho_{\text{salt}}$ between 0–2% and matched refractive indices in the range 1.3329–1.3359. Preliminary measurements suggest that the proposed method is capable of achieving the high precision required for RIM applications, at a fraction of the cost of commercial refractometers. In parallel, PIV measurements of the unstratified jet at $Re = U_0 D/\nu = 8200$ were conducted to validate the performance of the experimental facility, investigating the development of the exit velocity profile and its downstream evolution toward canonical self-similar behaviour under neutrally buoyant conditions. These results establish a baseline for future stratified jet experiments, where the proposed refractometer will be used in conjunction with RIM to enable accurate optical measurements.

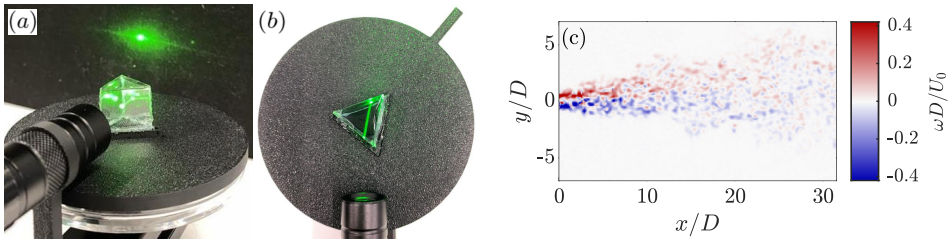

Figure 1: (a, b) Schematic of the prism refractometer used to measure refractive index via beam deviation, (c) instantaneous vorticity field for the neutrally buoyant jet at $Re = 8200$.

References

Clément, S. A., Guillemain, A., McCleney, A. B., & Bardet, P. M. (2018). Options for refractive index and viscosity matching to study variable density flows. *Experiments in Fluids*, 59(2), 32.

McDougall, T. J. (1979). On the elimination of refractive-index variations in turbulent density stratified liquid flows. *Journal of Fluid Mechanics*, 93(1), 83–96.

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