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C2Or4B-03: Particle Levitation Velocimetry for boundary layer measurements in high Reynolds number liquid helium turbulence

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Understanding boundary layer flows in high Reynolds number (Re) turbulence is essential for advancing fluid dynamics across a range of critical applications, from enhancing aerodynamic efficiency in aviation to optimizing energy systems in industrial processes. Accurate characterization of turbulence, including scaling laws for mean velocity and turbulence intensity, is vital for developing robust predictive models. However, generating such flows typically demands large-scale, power-intensive facilities. Furthermore, conventional measurement tools, such as hot wires and pressure sensors, often introduce disturbances due to intrusive support structures, thereby compromising measurement fidelity. In this paper, we discuss a new method that leverages the vanishingly small viscosity of liquid helium to produce high Re flows, combined with an innovative Particle Levitation Velocimetry (PLV) system for precise, non-intrusive flow-field measurements. The PLV system utilizes magnetically levitated superconducting micro-particles as flow sensors to capture near-wall velocity fields in liquid helium. We present the detailed design of the PLV system, which employs four coaxial coils to create a trapping zone with strong transverse energy gradients, allowing for particle trapping even in the presence of high Re flows. Through comprehensive theoretical analysis, we demonstrate that the PLV system enables quantitative measurements of the velocity boundary layer over a wall unit range of $44 \leq y^+ \leq 4400$, with a spatial resolution that, depending on the particle size, can reach down to about 10 μm. This non-intrusive, high-resolution measurement capability represents a significant advancement in the study of wall-bounded flows, with profound implications for both fundamental turbulence research and practical engineering applications.

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