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BUOYANCY EFFECTS ON FLOW STRUCTURE AND INSTABILITY OF LOW-DENSITY GAS JETS

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ABSTRACT

A low-density gas jet injected into a high-density ambient gas is known to exhibit self-excited global oscillations accompanied by large vortical structures interacting with the flow field. The primary objective of the proposed research is to study buoyancy effects on the origin and nature of the flow instability and structure in the near-field of low-density gas jets. Quantitative rainbow schlieren deflectometry, Computational fluid dynamics (CFD) and Linear stability analysis were the techniques employed to scale the buoyancy effects.

The formation and evolution of vortices and scalar structure of the flow field are investigated in buoyant helium jets discharged from a vertical tube into quiescent air. Oscillations at identical frequency were observed throughout the flow field. The evolving flow structure is described by helium mole percentage contours during an oscillation cycle. Instantaneous, mean, and RMS concentration profiles are presented to describe interactions of the vortex with the jet flow. Oscillations in a narrow wake region near the jet exit are shown to spread through the jet core near the downstream location of the vortex formation. The effects of jet Richardson number on characteristics of vortex and flow field are investigated and discussed.

The laminar, axisymmetric, unsteady jet flow of helium injected into air was simulated using CFD. Global oscillations were observed in the flow field. The computed oscillation frequency agreed qualitatively with the experimentally measured frequency. Contours of helium concentration, vorticity and velocity provided information about the evolution and propagation of vortices in the oscillating flow field.

Buoyancy effects on the instability mode were evaluated by rainbow schlieren flow visualization and concentration measurements in the near-field of self-excited helium jets undergoing gravitational change in the microgravity environment of 2.2s drop tower at NASA John H. Glenn Research Center. The jet Reynolds number was varied from 200 to 1500 and jet Richardson number was varied from 0.72 to 0.002. Power spectra plots generated from Fast Fourier Transform (FFT) analysis of angular deflection data acquired at a temporal resolution of 1000Hz reveal substantial damping of the oscillation amplitude in microgravity at low Richardson numbers (~0.002). Quantitative concentration data in the form of spatial and temporal evolutions of the instability data in Earth gravity and microgravity reveal significant variations in the jet flow structure upon removal of buoyancy forces. Radial variation of the frequency spectra and time traces of helium concentration revealed the importance of gravitational effects in the jet shear layer region.

Linear temporal and spatio-temporal stability analyses of a low-density round gas jet injected into a high-density ambient gas were performed by assuming hyper-tan mean velocity and density profiles. The flow was assumed to be non parallel. Viscous and diffusive effects were ignored. The mean flow parameters were represented as the sum of the mean value and a small normal-mode fluctuation. A second order differential equation governing the pressure disturbance amplitude was derived from the basic conservation equations. The effects of the inhomogeneous shear layer and the Froude number (signifying the effects of gravity) on the temporal and spatio-temporal results were delineated.

A decrease in the density ratio (ratio of the density of the jet to the density of the ambient gas) resulted in an increase in the temporal amplification rate of the disturbances. The temporal growth rate of the disturbances increased as the Froude number was reduced. The spatio-temporal analysis performed to determine the absolute instability characteristics of the jet yield positive absolute temporal growth rates at all Fr and different axial locations. As buoyancy was removed ($Fr \rightarrow \infty$), the previously existing absolute instability disappeared at all locations establishing buoyancy as the primary instability mechanism in self-excited low-density jets.