ME – PhD Thesis Defense

"Single and twin liquid jet injection in crossflow: Influence of Mach number and jet spacing"

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ABSTRACT

Supersonic air-breathing engine development towards hypersonic vehicles is challenging as the incoming crossflow air enters the combustor at supersonic speeds, which significantly limits the time scales for the fuel-air mixing. The transverse injection of a liquid fuel jet into the crossflow is one of the commonly employed fuel injection techniques under these conditions. The liquid jet atomization and spray formation are strongly governed by various flow processes seen in the interactions between the jet and the supersonic crossflow, namely the jet penetration in the transverse direction, the dynamics of bow shock formed upstream of the jet, the interaction between the bow shock with the crossflow wall boundary layer, and flow unsteadiness. The thesis study experimentally investigates the flow and atomization characteristics of transversely injected twin liquid jets into supersonic crossflow of air with free stream Mach number, $M_\infty=2.5$.

The first part of the thesis investigates a single liquid jet interaction with the crossflow over a wide range of M_∞, from 0.2 to 2.5. With increase in M_∞, the jet breakup morphology transitions from bag breakup at low $M_\infty=0.2$ to catastrophic breakup at high $M_\infty=2.5$. The instability wavelength on the jet windward surface, driven by Rayleigh-Taylor instability, decreases with the increase in M_∞, highlighting an enhanced jet breakup at higher M_∞. The variation of Sauter Mean Diameter (SMD), measured at downstream locations, shows a decreasing trend with increasing M_∞ due to the enhanced breakup. The second part of the thesis deals with the twin liquid jet injection into supersonic crossflow of $M_\infty=2.5$ by distributing a single jet injection mass flow rate into two identical liquid jets. The flow and atomization characteristics of transversely injected twin liquid jets separated by different streamwise distance, s_x are presented. The streamwise twin liquid jet's penetration height is found to be higher compared to that of the equivalent single jet due to the upstream jet shielding on the downstream jet from the incoming crossflow. At $s_x=10D$ (D is the jet diameter), the spray plume exhibits highest penetration with least unsteadiness, lower shock-induced pressure losses (with losses of 17.4% compared to 31.3% for the single jet), and smallest mean droplet size. Similar investigations of twin jet injection into supersonic crossflow with different spanwise distance, s_z is carried out. A variations in s_z alters the effectiveness of interaction between the jets. Smaller s_z results in stronger interaction between the jet and bow shocks, leading to corrugated shock structures. Unsteadiness in spray plume characteristics dominantly observed in both single jet and twin jet injections. To shed more lights on the source behind the flow unsteadiness, the thesis further investigates the characteristics of an elevated transversely injected liquid jet into the supersonic crossflow.

The thesis study demonstrates the significant influence of crossflow Mach number, wall boundary layer interactions, and twin jet spacing on the liquid jet atomization and downstream spray plume characteristics. The reported findings provide insights into optimizing liquid jet injection strategies for supersonic crossflow applications, with implications for propulsion, combustion, and other high-speed flow systems.

ABOUT THE SPEAKER

Kukkarasi Ramana is a PhD student in the Dept. of Mechanical Engineering, IISc Bangalore. He obtained his B.Tech degree in Mechanical Engineering from the RGUKT, IIIT Idupulapaya in 2015 and M.Tech degree in Mechanical Engineering (Cryogenics & Vacuum Technology) from NIT, Rourkela in 2018. His areas of research interest are multiphase flows, spray & atomization, and high-speed aerodynamics.