ME: PhD Thesis Defense

Evaluation of Air Blast Swirl Injector: Flow-Field Hybrid RANS-LES Studies and Coupling with RANS Spray Characterisation Colligating Global Combustor Characteristics-A Novel Exploration

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The injector plays a critical role in combustion efficiency, flame stability, ignition, and combustor exit profile. Protocol of designing future engines meeting requirements of lower emissions, noise, use of multi fuel, green hydrogen, renewable fuels may lead to increase in research in combustion system. The incipient requirements of the flow field downstream of the injector in terms of uniform mixing and spray characteristics are paramount. Existing calculations for injector performances include empirical calculations, uncertainty in boundary conditions, and a lack of a proper framework to predict spray performances from first principles. Hence, modeling and simulation are performed to realize injector performance and reduce design cycle time and costs. In this research work, the flow field and spray of the air blast swirl injector are studied using ANSYS Fluent code, exploring finally, how spray non-uniformity at the injector level is a contributory factor for the combustor pattern factor, which is the manifestation of high non-uniformity in the combustor exit temperature. The study is divided into two parts: flow-field and spray characterization.

For Flow-Field Characterization, Steady-state flow-field RANS-based studies are conducted and validated with experimental data. The analysis explored geometry, grid types, boundary conditions, and turbulence models (Realizable k-epsilon (rke) and Reynolds Stress Model (RSM)). RSM was found to be better at capturing local turbulence phenomena, while rke to be suitable for global mean flows. However, both models have limitations in capturing unsteady flow features. Hybrid RANS-LES simulations address these limitations, dividing the computational domain into RANS and LES zones. RANS zones supply the boundary conditions to the LES region, covering dynamics of prime importance in an integrated manner. This approach improved accuracy in capturing unsteady phenomena like Processing Vortex Core (PVC) and shear layer instabilities, while balancing computational cost and time. Results obtained from the Hybrid RANS-LES showed close agreement with experimental data, including turbulence kinetic energy, sound pressure levels, and POD (Proper Orthogonal Decomposition) eigen mode energy levels. The study has been extended to predict the flow field at off-design conditions, such as high-pressure and high-temperature conditions, showing reduced mean velocity and increased TKE fields.

For Spray Characterization, a twin swirler injector is evaluated under atmospheric conditions using the Discrete Phase Model in ANSYS Fluent, with Lagrangian tracking of the sprays in the Eulerian flow field. The unsteady tracking was performed on the steady-state flow field generated using the RSM model at the atmospheric condition at a better cost and time. Both cold and hot spray conditions are analyzed. Droplet injection parameters are derived using innovative methodologies, including FFT and POD mode analysis. Droplet diameter is determined through a series of methodologies (single phase, multiphase VOF (Volume of Fluid), Linear stability analysis) of the fuel and airstream. Hot spray conditions showed evaporation effects, leading to larger droplet sizes due to the evaporation of many smaller droplets in cold spray. Spray uniformity was quantified based on the circumferential distribution of droplet number density and mean velocity downstream of the injector. Instantaneous r-θ variation of droplet size D32 and droplet number density at location x/D=1.68 (emerged as sweet spot on the field) captured as peak fuel pocket (maximum values of number density distribution) located circumferentially at a point/region, finally responsible for higher pattern factor in the combustion chamber, and a correlation is also devised. The position of the localized value of the fuel pocket is related to the local vorticity field. RSM simulations are satisfactory for injector-level analysis, while LES simulations are preferred for understanding overall combustion chamber physics. The study concludes that the developed methodologies can serve as practical design tools for evaluating injector performance at the design stage, reducing costs and time while ensuring accurate predictions of combustion system behavior.

ABOUT THE SPEAKER

Rampada Rana is working as Scientist F at Gas Turbine Research Establishment at DRDO. He is pursuing PhD at the Mechanical Engineering Department at the IISc under the esteemed Prof. Saptarshi Basu, and Dr. N. Muthuveerappan as external supervisor, with research focus on numerical studies of flow field, atomization, and spray. He holds BE in Mechanical Engineering from NIT, Durgapur. He had worked in electronic cooling, thermodynamic cycles of gas turbines, LCF life test evaluation; also having interest in cooling, FSI, rotodynamic, experiment and SCM.