Title: Numerical Investigation of Reacting Jet-in-Crossflow at High Pressure

In this dissertation, the operational map of a lean reacting jet-in-crossflow situation has been explored with Computational Fluid Dynamics (CFD) and an axially staged combustor experiment at pressures of five atmospheres to aid scaling to gas turbine engine conditions applied industrially. The optically accessible test section features three side windows, allowing local flow and flame analysis with PIV and CH* chemiluminescence along with pressure, temperature and species measurements. The research objective was to reveal nitrogen oxide kinetics with a CFD model developed and experimentally validated in-house. For a 12.7mm axial jet, the matching result of turbulence-governed finite-rate modelling was compared with a laminar flame chemistry overprediction. The full GRI Mech 3.0 was computed with detailed chemistry to avoid any loss of accuracy that would occur by applying Flamelet chemistry or reduced methane mechanisms. Simulated jet trajectories show excellent agreement with the data which is described by an elliptic curvature to compensate for the poor far-field prediction of existing correlations. A nitrogen oxide benefit was proven at elevated operating pressures due to the transition from shear layer burning to jet core flame burning. Optimizing the axial fuel split to 25% utilized a lean headend with a slightly rich jet equivalence ratio. Impaired fuel-air premix conditions in the axial fuel line resulted in an ignition point further downstream and reduced reaction rates. This delay can affect a NO benefit paired with relatively rich headend equivalence ratio, reducing the residence time of the reacting axial jet without exceeding spatial limitations. Dependencies of axial NO emission on the key influence parameters temperature, pressure and residence time were proposed. For a 4mm axial jet, variation of main stage ($\phi = 0.575 - 0.73$) and jet equivalence ratio ($\phi = 1.1 - ?$) have been investigated. The premixed flames were found to be controlled by the crossflow temperature before ignition and the crossflow oxygen level during axial combustion. Analysis of the flame shape and position for the rich premixed operating points describes an upstream stabilized flame along with a highly lifted windward flame branch. Control of added jet fuel amount as well as headend temperature and coupled oxygen level were critical to attain a compact flame body and allow combustion at sufficient reaction rate. Delayed combustion event with overshooting, spatially divided flames was observed for the axial jet equivalence ratios $\phi = ?$ and $\phi = 8$ combined with at a relatively rich main stage $\phi = 0.73$ due to the lack of available oxidizer.

Major: Mechanical Engineering

Educational Career:
Bachelor's of Chemical Engineering, BS, 2015, Friedrich-Alexander-Universität, Erlangen, Germany
Master's of Chemical Engineering, MS, 2017, Friedrich-Alexander-Universität, Erlangen, Germany

Committee in Charge:
Kareem Ahmed, Chair, Mechanical & Aerospace Engineering
Jayanta Kapat, Mechanical & Aerospace Engineering
Samik Bhattacharya, Mechanical & Aerospace Engineering
Scott Martin, Embry-Riddle Aeronautical University

Approved for distribution by Kareem Ahmed, Committee Chair, on June 10, 2020.

The public is welcome to attend.