Supersonic Mixing and Combustion of Gaseous and Liquid Hydrocarbon Fuels using Curved Pylons

A thesis submitted

in partial fulfillment for the award of the degree of

Doctor of Philosophy

by

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February 2025

Abstract

The effects of curved pylons on the supersonic mixing and combustion of gaseous, liquid, and aerated secondary jets were explored in this study. A total of four pylon configurations, with one conventional pylon and three curved pylons with different bottom curvature angles, were considered. Numerical simulations were carried out with extensive experimental validation for the mixing studies of ethylene jet. The experiments were carried out with the freestream Mach number of 1.65 and total pressure and temperature of 4 bar and 300 K, respectively. The commercially available solver was validated using experimental results such as wall pressure, shockwave structures from Schlieren visualization, velocity data from particle image velocimetry, and number density from planar laser-induced fluorescence. Even though the mixing efficiencies were similar among different pylons, curved pylons produced higher penetration height and flammable plume area. The total pressure loss was also lower in the cases with curved pylons than the standard pylon. The results were also compared with the conventional transverse injection, and results suggest that the complete mixing would be achieved in the pylon cases with a shorter combustor and a lower loss than the transverse injection. The atomization and mixing of liquid and aerated jets were assessed using droplet velocity from fluorescence-based particle image velocimetry, penetration height from high-speed Shadowgraph, and plume area from cross-sectional planar laser-induced fluorescence. Two liquid flow rates and two gas-to-liquid ratios were considered in this study. The aerated jets with curved pylons produced high droplet velocities, indicating a better atomization quality than the standard pylon. When the liquid flow rate was low, the difference in the penetration height was considerable among pylon cases, whereas it became minimal at a high liquid flow rate and for aerated jets. The growth of the plume area along the flow direction was higher for the curved pylon cases that employed aerated jets than the standard pylon. The dynamic mode decomposition of images obtained from the high-speed Shadowgraph revealed three distinct flow features: convective mode, flapping mode, and shear-induced breakup mode. The improved performance of curved pylons with aerated jets was attributed to flapping and shear-induced breakup modes. The reactive flow simulations were carried out for the pylon-cavity configuration with different pylons placed upstream of the cavity. The reacting flow solver was validated using experimental wall pressure and CH^* chemiluminescence from the literature. The simulation

results were also compared with the conventional transverse injection case. The flame stabilization occurred mainly inside the cavity for all cases. The high heat release rate was observed in three regions, one in the central portion of the combustor and the other two near the sidewalls for pylon cases. In contrast, it was only observed in the central portion for the transverse injection. The Takeno Flame Index was used to distinguish premixed and non-premixed combustion modes. The premixed combustion occurred primarily inside the cavity, and the non-premixed combustion occurred in the shear layer for all the cases. The premixed combustion produced a higher heat release rate than the non-premixed combustion. Even though mixing efficiencies were higher for the pylon cases than the transverse injection, it produced the highest combustion efficiency and heat release power, followed by the curved pylon with the lowest curvature angle. The curved pylon with the lowest curvature angle produced vortices close to the wall, which helped in the entrainment of fuel, leading to the highest combustion efficiency among other pylon cases. The turbulent flame regimes were plotted using the Damköhler number and turbulent Reynolds number, and it was found that the high heat release rate occurred in the perfectly stirred reactor/laminar chemistry regime for all cases. This was due to the high chemical time scales of ethylene combustion. The mixing and reactive flow studies showed that the mixing studies alone are insufficient to predict supersonic combustion performance. The heat loss through the walls, the fuel selection and the associated chemical time scales of the fuel were found to be defining parameters in supersonic combustion. Overall, curved pylons produce better atomization, mixing, and combustion than the standard pylon. Therefore, the curved pylon with a low curvature angle would be a preferable option for the supersonic combustion of hydrocarbon fuels.