Chapter 4
Conclusion

The work and results presented in this thesis, illustrate the successful development of a facility for the evaluation of a hydrogen-air mixer. In all, three experiments are developed and two are used to conduct mixer measurements. Mie scattering and schlieren flow visualization techniques are fully implemented to qualitatively evaluate: relative fuel concentration uniformity and spatial distribution, overall swirl angle, and general geometric features of the flow. These geometric features include: recirculation and wake regions, mixing boundaries, and 2-D jets. Also, a Laser Doppler Velocimetry (LDV) system is developed, to a trial stage, for the measurement of mean velocities. Results from the two flow visualization experiments, discussed in Chapter 3, illustrate the effectiveness of the established facility. When the results from the Mie scattering experiment are processed and overlaid on the CFD results, many similarities are found.

During the analysis of Nozzle J, the simulation consistently captures the main geometric flow features of the nozzle flow including the size and location of the primary and secondary wake regions behind the center body. The simulation also captures the swirl well via matching of the swirl angle. At and beyond one nozzle diameter downstream, agreement is found on the fuel concentration uniformity and spatial distribution. The main disagreement between the computational and experimental Mie scattering and schlieren results is over the fuel concentration in the primary wake and the neck behind the center body. These results indicate that the CFD model accurately predicts most of the nozzle flow characteristics of Nozzle J. The results also indicate that the experimental flow is entraining more ambient air into the center body wake than the computational flow, leading to more lean concentrations than predicted. However, further investigation is required to determine whether the experiment or model is in error.

Comparisons drawn between the Nozzle D experimental and computational results are similar to those of Nozzle J in the agreement of swirl pattern and intensity, as well as the location and size of the center body primary and secondary wakes. However, the Nozzle D results show less agreement on the other geometric features of the flow.

The Nozzle D comparisons also show poorer fuel concentration predictions than for Nozzle J, likely due to Mie scattering experimental resolution. Agreement is reached at and downstream of two nozzle diameters from the outlet, but agreement of both fuel concentration uniformity and spatial distribution is poor within two diameters. These results indicate that the model predicts the swirling fuel-rich regions to stay together as they swirl downstream, and not mix with the ambient air as effectively as seen in the experimental results.

While the Mie scattering results are inconclusive concerning fuel concentration within one nozzle diameter of the outlet, the results and comparisons of the schlieren flow visualization experiment provide some insight. Schlieren results for Nozzle J indicate that a uniform fuel concentration exists across the annulus of the nozzle outlet, showing that fuel and air within the nozzle have mixed completely by the time they reach the outlet. The results also show that by one nozzle diameter downstream, the mixture effluent from the nozzle has fully mixed with the ambient air. The schlieren results appear to indicate superior mixing performance compared to the results of the Mie scattering experiment, which may be due to the averaging inherent to the schlieren technique. The Mie scattering experiment looks at a 2-D slice of the nozzle flow, while the schlieren experiment indicates an average of the 3-D flow along the axis of the light beam. Along with fuel concentration insight, the schlieren results also illustrate some of the geometric flow features revealed in the Mie scattering results. The flow necking as well as primary and secondary wake regions are observed. They also match the same features in the centerline Mie scattering results providing further validation of the CFD predictions. Schlieren results from Nozzle D do not provide the same geometric flow insight, but indicate the same mixing characteristics as with Nozzle J. Nozzle D results show a fully premixed flow out of the nozzle, which fully mixes with the ambient air within one nozzle diameter.

As a result of this thesis work, significant progress is achieved with the RFL LDV system. All of the LDV optics and the laser head are relocated to a new optical table to enhance the mobility of the system and minimize the occasional drift motion of the primary mirrors. New high gain, high bandwidth, and low noise PMT amplifiers are constructed and implemented to reduce noise in the PMT signals. A pair of TSI Inc.

counter timer processors is implemented to replace the complex original processing electronics package, whose functionality is un-trusted. New LabVIEW software is written to sample and process the LDV signals for each velocity component. In conclusion of the LDV work, tests are conducted on a standard flow to evaluate the ability of the LDV to measure two components of mean velocity. These tests indicate that LDV measurements of the mean green velocity component contain only 4.5% error, and are repeatable with a deviation of only ±1.4%. The tests also show that LDV measurements of the blue velocity component contain higher error, 19%, but are also repeatable with a higher deviation of ±6.4%.

This study presents the development of a facility that contributes to the technology of hydrogen combustion in gas turbine engines, increasing the overall ability of the combustion community to evaluate the effectiveness of new nozzle designs. Development of hydrogen-air mixing technology leads to improved lean premixed hydrogen combustor design, providing lower emissions and increased efficiency over combustors burning traditional fuels. Also, the capability to validate mixer CFD simulations using simple methodologies and economical experiments is invaluable for the development of modern combustor technologies.