Effect of Operating Conditions on a Liquid Jet in Swirling Crossflow

OVERVIEW

Jet in swirling crossflow (JISC) is a fuel injection strategy utilized in liquid fired gas turbine engines. Optimization of JISC can lead to reduced emissions, greater efficiency and improved operability. Previous work has largely ignored swirl and concentrated on a more elegant problem of a liquid jet injected into a uniform crossflow. Moreover, research and development is often conducted at reduced pressure and temperature or scaled conditions due to the expense of recreating actual gas turbine conditions. This study focuses on establishing a relationship between fuel plume characteristics and operating conditions. The area, centerline distance, angle of rotation, plume unmixedness, responsible unmixedness, average Sauter mean diameter (SMD) and SMD standard deviation were investigated using planar fluorescence and light scattering techniques. The image data were collected using a 16 bit CCD camera. The plume characteristics were extracted with an image analysis script and correlations were formulated to predict the behavior.

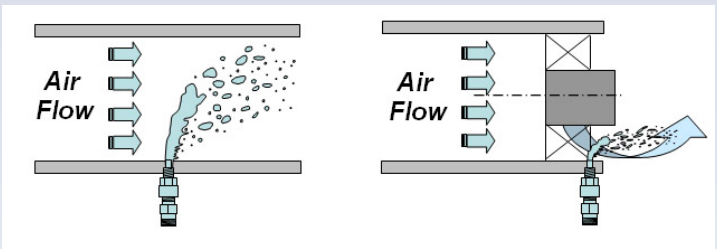

Figure 3. Bottom view of premixing module

Figure 4. Side view of fuel injector

GOALS

1. Develop mixing performance characteristics and a method to predict their behavior
2. Develop a test matrix to investigate mixing behavior for a variety of test conditions
3. Analyze the results in order to:
   - Develop a design tool
   - Develop a mechanistic model that characterizes performance

RESULTS

The test hardware consisted of an axial swirl premixing module with a plane fuel injector mounted flush with the outer test hardware .

Figure 3. Bottom view of premixing module

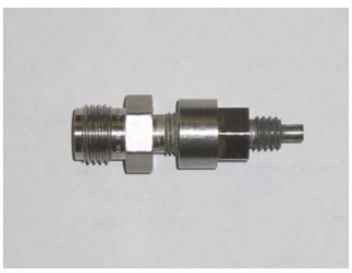

Figure 4. Side view of fuel injector

Shakedown tests were initially conducted to establish the operable ranges of the test hardware and develop the characteristic extraction methodology. In addition the repeatability and uncertainty of the experimental setup was established.

Once completed, two test matrices were constructed based on (1) primitive parameters: pressure, temperature, air pressure drop and fuel flow and (2) nondimensional parameters: momentum flux ratio, Weber number and liquid Reynolds number.
Two different types of models were formulated to predict the atomization behavior. The first used a statistical approach and the primitive parameters while the second employed a least squares regression utilizing nondimensional parameters in the form:

$$Aq^{b}We^{c}Re^{d}$$

Initial observations of fuel plume behavior dependency on a single operating parameter were investigated. With this information the linear regression was carried out with only the most influential parameters.
With the exception of average SMD and SMD standard deviation, the models were able to accurately predict the mixing characteristics as a function of operating conditions.

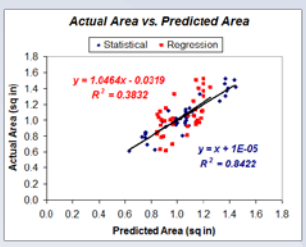

Figure 5. Correlation predictability comparison for plume area

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In addition, the implications of the correlations on gas turbine design through scaling of conditions was investigated by extrapolating the results to practical conditions found in a medium size industrial gas turbine.
The main conclusions of the project were:

- Laser sheet drop sizing requires the simultaneous minimization of numerous error sources from multiple individual measurements and methods
- Conservation of momentum flux ratio and air momentum are able to scale plume area, plume unmixedness and responsible unmixedness to extrapolated practical values with less than 1% error
- Accurate prediction of JISC behavior is possible and can thereby air in the design of devices that take advantage of this fuel injection scheme

PUBLICATIONS

MIXING OF A PLANE JET INTO A SWIRLING CROSSFLOW (2008). Proceedings of the 21st Annual Conference on Liquid Atomization and Spray Systems, Orlando, FL. May 18-21, 2008. Masuda, B.J. and V.G. McDonell.

PERSONNEL

Investigators: Professor. G.S. Samuelsen and Dr. V.G. McDonell
Staff: Richard L. Hack
Graduate Students: Brandon J. Masuda

Project Sponsors: Solar Turbines