Extension of LSI Functionality for Gas Turbine Applications

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1 Introduction

Low swirl injector (LSI) technology is being evaluated for use in gas turbine (GT) engines. The LSI is a lean premix (LP) combustion technology originally developed for fundamental studies of flames [1-5]. It operates differently than traditional high swirl LP GT injection systems, which utilize a bluff body or an aerodynamic recirculation zone to stabilize flames. The LSI utilizes a divergent flow to stabilize a flame by exploiting the turbulent displacement flame speed of propagating LP flames. The flame burns in a region where the turbulent flame speed matches the decreasing flow velocity as it diverges from the injector exit.

Modern GTs, designed to run on pipeline quality natural gas (NG), must meet strict pollutant emission limts. The formation of NO_x, a major criteria pollutant, is dependent upon flame temperature and subsequently the equivalence ratio ϕ, Engines are primarily operated by burning LP fuel/air mixtures to satisfy these limits, NG fueled LSI GT engines have achieved NO_x emissions levels less than 5 ppm @ 15% O_2 [6, 7]. Extending the lean blow-off (LBO) limit to a lower ϕ would increase the funcitonality of a LSI based GT combustion system by futher reducing NO_x emissions. The LBO limit can be altered by operating at different operating conditions (pressure and temperature) or by stabilizing the weak LP flame by reducing flow field disturbances. One source of flow disturbance is the transition from the injector to combustor dump plate. This transition results in a corner recirculation zone with large vortex structures that can perturb the LP flame. In order to reduce the LBO limit for NG engines the impact of these vortices must be reduced.

There is considerable interest in the use of syngas, derived from gasified coal, as a primary fuel for large utility-sized GT engines in Integrated Gasification Combined Cycle (IGCC) power plants. LSI combustor systems are being developed for use with high hydrogen fuel (HHF) [8-10]. Coal derived syngas, after treatment by a water shift reaction to oxidize CO to CO_2 for sequestration and storage, is a HHF with hydrogen content ranging between 80 and 90%. In the case of this study, HHF is comprised of 90% H_2 and 10% CH_4. HHF burns with

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higher flame temperatures than NG flames for a given ϕ. For practical use in GT engines, thermal output levels must be on par with NG flames. However, due to the highly reactive nature of hydrogen, operation with HHF at the same thermal outputs as natural gas poses a high risk of flame flashback. The use of HHF syngases in commercial GT engines necessitates the design and development of modified or alternative combustion systems that can burn this fuel without the potential of flashback, while producing an adequate level of thermal output. Extending the flashback limit of the LSI combustor would benefit development of a HHF GT engine.

This study reports on efforts to extend the functionality of LSI based combustors to meet the operability needs of both NG and HHF fueled GT engines. A flare quarl has been designed to promote flame stability by reducing corner recirculations and to provide the naturally diverging flame a structure to align with.

2 Experimental Setup

The LSI consists of a shallow angle vane swirler surrounding an open, non-swirled, center-channel (figure 1) [2]. Key to the stabilization of the LSI flame, the center flow promotes flow divergence and inhibits vortex breakdown. A screen, located in the central non-swirling section, is used to balance the flow split between the swirled and non-swirled sections of the injector. When correctly balanced, a lifted flame stabilizes downstream of the injector exit plane where the local displacement turbulent flame speed matches the local injector exit flow velocity.

The LSI used in this study was configured for the DOE National Energy Technology Laboratory's (NETL) SimVal high pressure experimental facility [8]. Key dimensions are: Li = 6.8 cm, Lc = 2.2 cm, Ls = 2.8 cm, Ri = 2.8 cm, and Rc = 1.9 cm. This LSI has 16 aerodynamically shaped thickened blades with a 37^{o} discharge angle. The center screen contains 37, 3.66 mm diameter holes arranged in three concentric circles surrounding a center hole. This center screen permits approximately 30% of the reactants to pass through the un-swirled center portion, with the remainder passing through the swirl vane annulus.

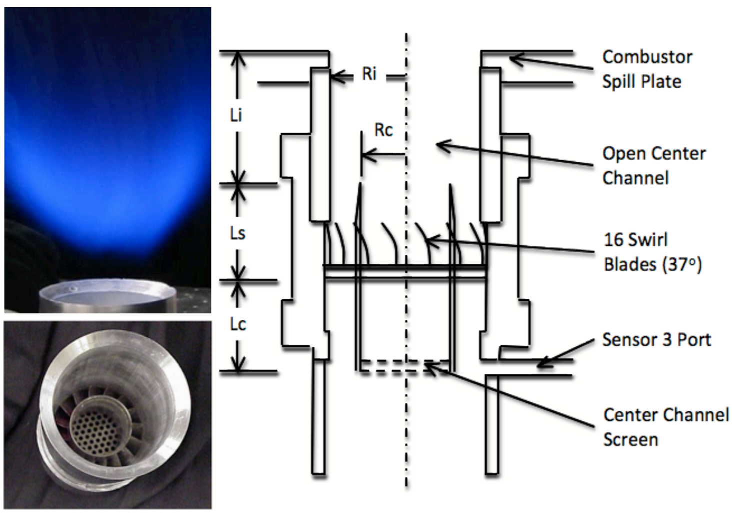

Figure 1. Photos and schematic of the LSI.

The test stand (figure 2a) is comprised of a venturi mixing tube which premixes fuel and air before being fed into a cylindrical settling chamber. The LSI assembly is mounted on top of the settling chamber and contains a 5.6 cm diameter swirler. Mounted at the exit of the LSI, and on top of the combustor dump plane, is a removable combustion chamber, 18 cm in diameter and 32 cm tall, creating a 3.2:1 dump plane to injector diameter ratio. The experimental setup is an atmospheric system supplied by a fan-blower. In this testing, fuel/air flow rates were established resulting in LSI exit bulk flow velocity of 15 m/s. Fuel flows are supplied through computer-controlled mass flow controllers upstream of the mixing tube. Reactants are assumed to be well-mixed.

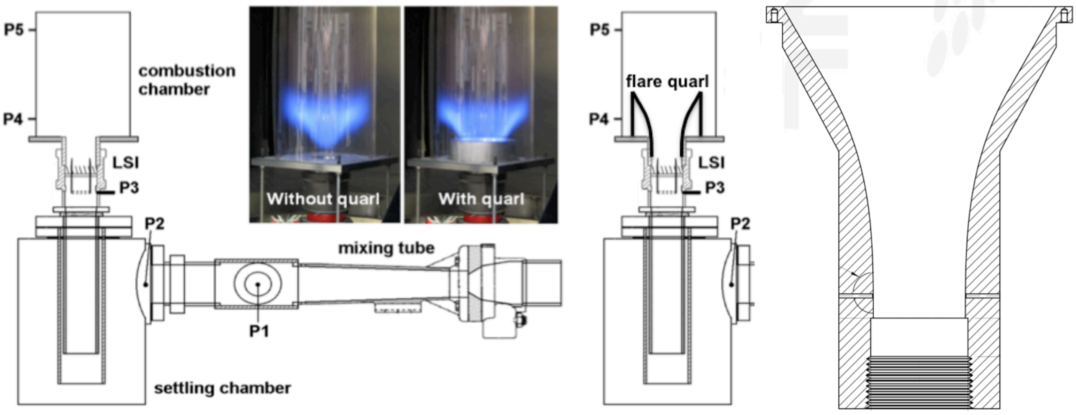

Figure 2. (a) Schematic and photos of the LSI installed in the flow system with and without the flare quarl. (b) Detail of the flare quarl. LSI mounts in lower threaded section.

The baseline combustor configuration is without the flare quarl as shown in Fig 2a to the left. An engineered flare quarl (figure 2b) has been designed to fit in the exit of the LSI. The expansion of the quarl was designed to match the natural divergance angle of the flow produced by the LSI. The quarl provides the diverging flow with a physical structure to follow and fills the combustor corner volume, discouraging the formation of recirculation structures that may perturb the reacting flow field.

3 Results

Compared to the baseline configuration of a 90 degree sudden expansion dump plane, the flare quarl increased the operability of the LSI by reducing NG LBO and increasing HHF flashback limts. A summary of dump plate and flare quarl functionality limits is presented in table 1.

Table 1: Summary of LSI functionality extensions due to flare quarl

Fuel	Functionality Measure	Limit w/o Quarl	Limit with Quarl
100% CH_4	LBO	0.46	0.44
HHF 90% H_2 - 10% CH_4	Flashback	0.40 (1380 K)	0.55 (1700 K)

Use of the flare quarl also extends the LBO operability range of the LSI with NG fuel. Images of the LSI NG flame, with and without the flare quarl, are seen in figure 3. The two flames were generated with the same inlet conditions, U_0 = 15 m/s and ϕ = 0.47. Figure 3a shows the methane flame burning above the dump plate. The LSI produces a lifted flame that burns weakly due to the low amount to fuel being supplied. In figure 3b, the quarl is encased in refractory material, used to fill the space between the quarl and the enclosure wall. With the quarl not in place, the flame would extinguish at the LBO limit of ϕ 0.46. With the quarl, the LBO limit decreases to ϕ 0.44. This decrease in NG LBO could potentially be used to reduce LP GT NO_x emissions. Additionally, the quarl does not heat up because the flame is not in contact with its inner wall.

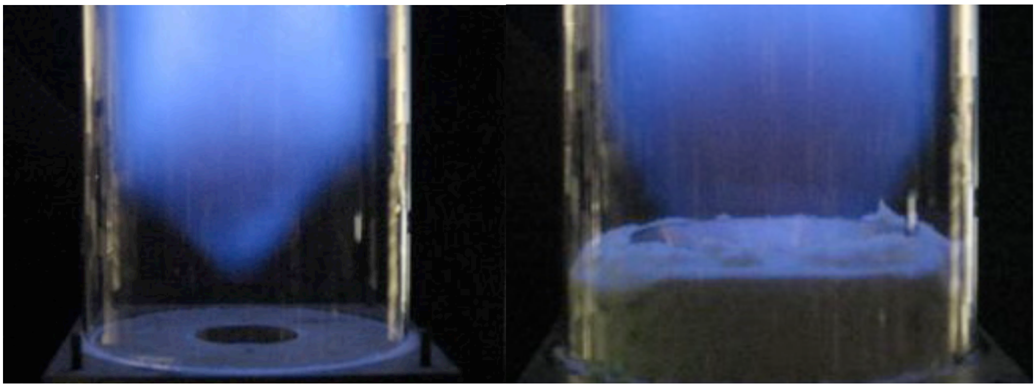

Figure 3. Images of 100% CH_4 flames, U_0 = 15 m/s, ϕ = 0.47. (a) dump plate (b) flare quarl.

The flare quarl also increased operability of the LSI combustion system with HHF by raising the flashback limit. Increases in the flashback limit allows for the use of higher tempreature flames in LP GT engines. As ϕ is raised, flame speed increases and the flame structure shifts from being lifted to burning in the outer shear layer of the diverging flow, creating a crown shaped flame. The flame continues to burn closer to the injector exit until it attaches to the dump plate transition as seen in figure 4a. The image of the flame in figure 4a is taken with U_0 = 15 m/s and ϕ = 0.40. Further increases in ϕ results in the flame flashing back and either attaching the the injector or to the upstream fuel source. Use of the flare quarl alows for HHF flames of ϕ 0.55, as seen in figure 4 (b). The increase in ϕ elevates the adiabatic flame temperature from 1380 K to 1700 K, a temperature commonly used in gas turbine engines to meet thermal output requirements.

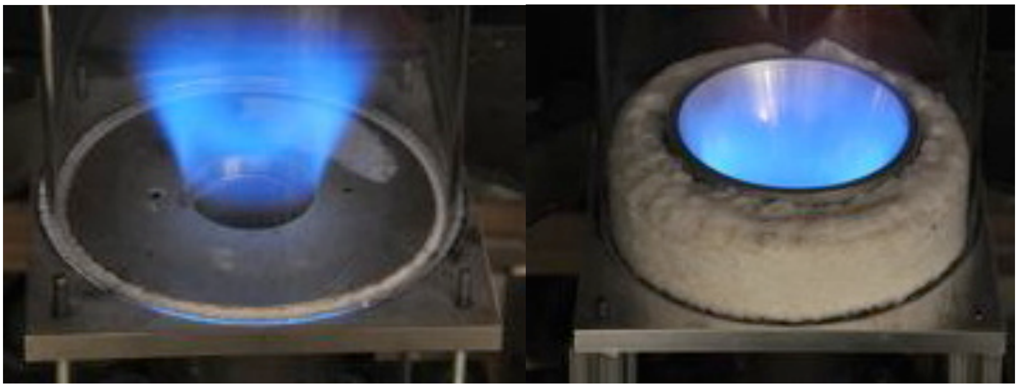

Figure 4. Images of HHF flames, U_0 = 15 m/s. (a) ϕ 0.40 with dump plate (b) ϕ 0.55 with flare quarl.

4 Discussion

A flare quarl was designed to increase the operability of NG and HHF LSI combustors for GT engines. Its main purpose is to provide a solid boundary for guiding the naturally diverging LSI flow field and to remove flow field instabilities that may develop due to corner recirculations. Use of the flare quarl extended NG LBO limit from 0.46 to 0.44 and increaesd the HHF flashback limt from 0.40 to 0.55. The results show that flare quarl can achieve these operability increases.

5 Future Work

The flare quarl is successful at reducing NG LBO and increasing the flashback limit for HHF at atmospheric conditions. Before testing the effectiveness of the quarl in a gas turbine engine, the quarl will be tested in a laboratory with high-pressure and preheat capabilities. A 3.81 cm diameter burner and quarl assembly has been fabricated and installed at the UCI Combustion Laboratory. The LSI will be tested with and without the quarl with both NG and HHF at gas turbine light off conditions to investigate LBO and flashback limits.

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