Low Swirl Injector Testing in Gas Turbine Operating Environments

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Gas Turbine Need

- Growing environmental concerns leading to stricter emissions regulations for gas turbines
  - Single digit NOx levels in some areas
- Combustion technology is a simple, safe, and cost effective way to achieve these goals without exhaust cleanup

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Objectives

- Assess the viability of the Low Swirl Injector (LSI) as a combustion technology of the future for ultra-low NOx emissions in industrial gas turbine engines
- The aims of this project were to:
  - Evaluate the emissions characteristics of the LSI injectors over a wide range of conditions that simulate those of gas turbine operation
  - Examine the performance at different pilot fuel flows to better understand lean blow out limits and flame stability
  - Test the exit temperature profile and pattern factor produced by a full set of injectors at atmospheric pressure and preheated conditions

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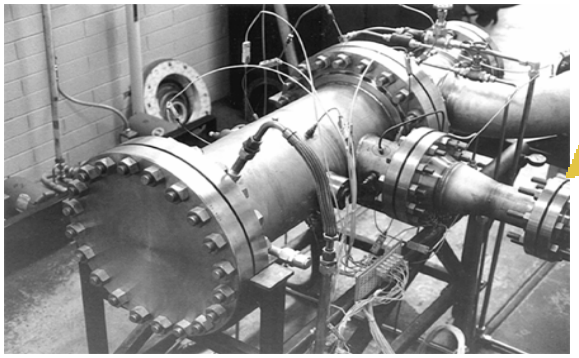
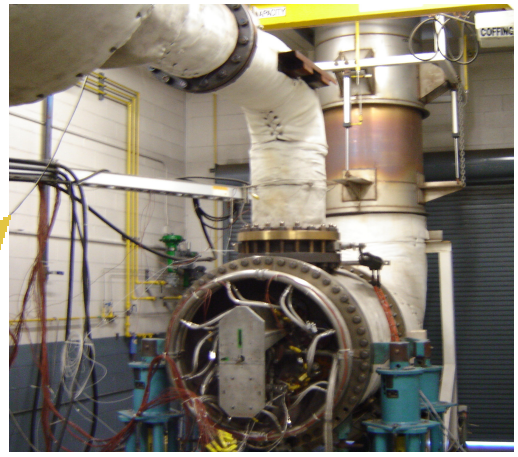
Approach

- Conducted single injector atmospheric tests to evaluate fuel/air mixing profile using methane analyzer
- Tested single injectors in Solar's high pressure single can rig to examine emissions levels at various inlet temperatures, pressures, flame temperatures and pilot fuel flows
- Conducted high pressure thermal paint tests to assess temperatures and thermal stresses of the injector during normal operation



Solar's high pressure single can injector test rig

Solar's full annular atmospheric test rig with preheat



- Tested 12 injector set in full annular combustor liner with preheated air at atmospheric pressure to get emissions and combustor exit temperature profile and pattern factor

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Single Injector Test Results

Atmospheric Mixing Rig

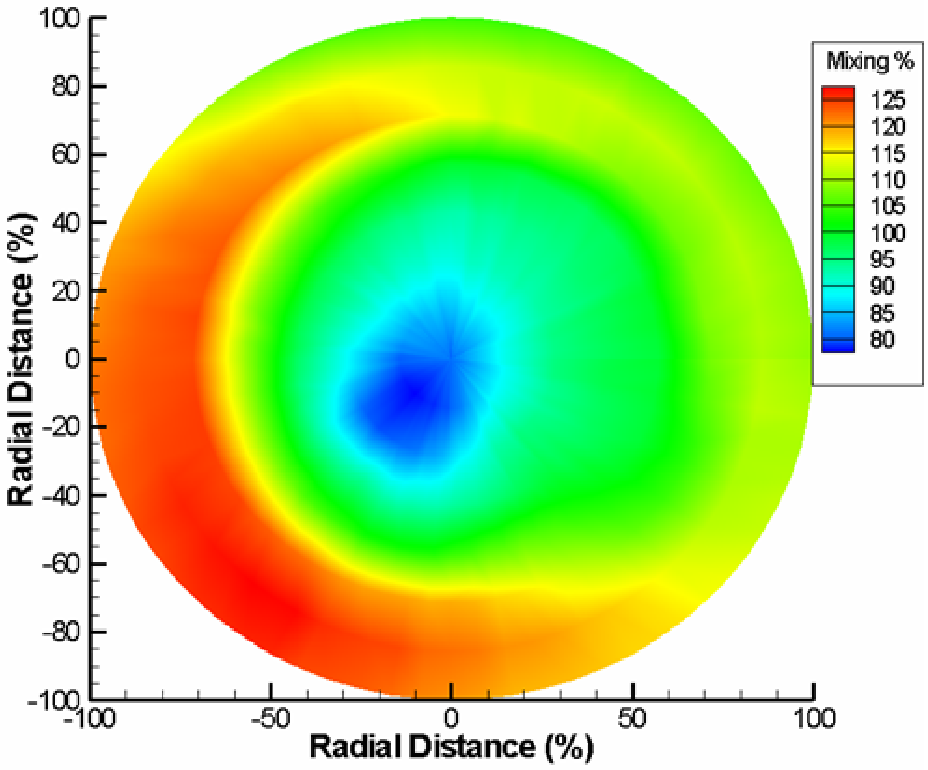
Test Conditions: Fixed design point fuel and air flows at atmospheric temperature and pressure

Measurement Apparatus: Specially designed rake with 8 probes spanning the radius rotated 360 degrees at exit plane, taking fuel-to-air ratio measurements every 5 degrees

Results:

- Overall mixing profile acceptable
- Lean region in center due to no pilot fuel flow during test
- Rich region on outside suggests improvements still possible if needed

LSI Fuel/Air Mixing Profile



(Mixing % plotted as % deviation from mean)

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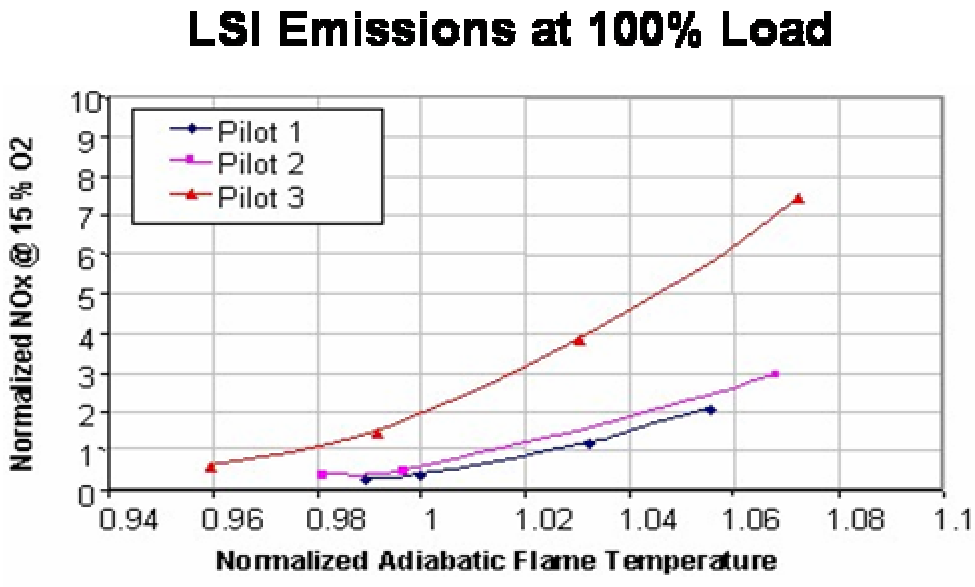
Single Injector Testing, cont'd.

High Pressure Single Can Rig Results

- Emissions gathered at high pressure engine conditions for various pilot fuel flows at simulated full and half load conditions
- All the data has been normalized with design point conditions
- Low NOx emissions seen over wide temperature range
- Emissions behavior consistent between different injectors tested



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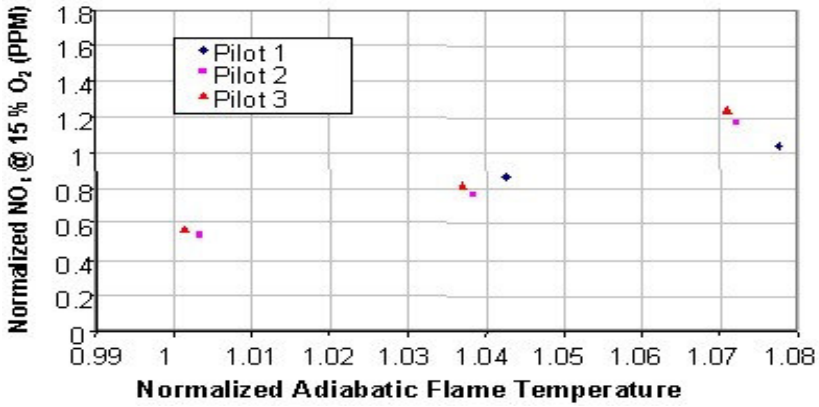
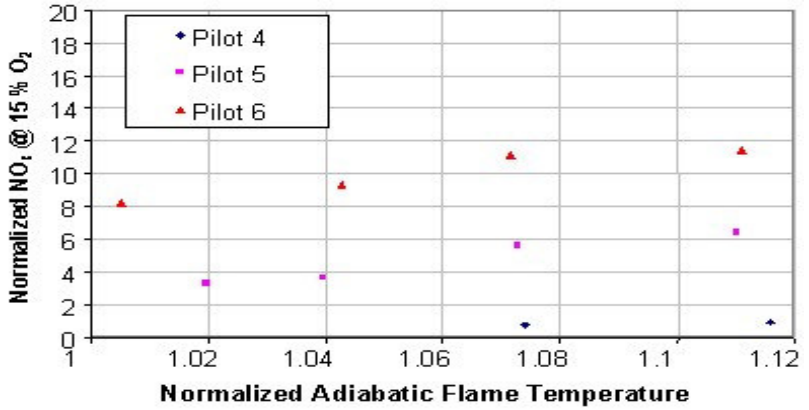
Full Annular Test Results

- Full set of injectors installed in annular combustor
- Tests run at simulated 100% and 50% load conditions with preheated air at atmospheric pressure
- Pilots used in 50% Load tests higher than those used in 100% Load tests
- Results exhibited similar trends when compared to single injector high pressure tests

Emissions at 100% Load



Emissions at 50% Load



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Full Annular Test Results, cont'd.

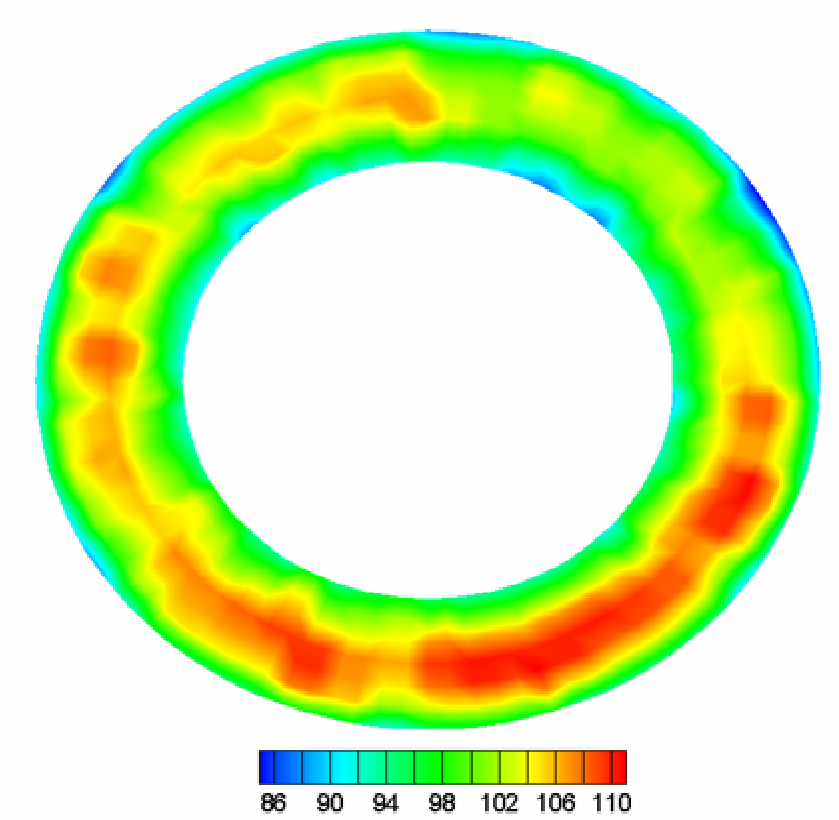
Test Conditions: Simulated full load fuel and air flows at engine preheat levels and atmospheric pressure. Pilot fuel flows varied.

Measurement Apparatus: Custom rig with four rakes 90 degrees apart, each with 7 thermocouples spanning the combustor liner exit annulus

Results:

- Exit profile consistent for all three pilots tested
- Temperature profile and pattern factor within engine specifications

Combustor Exit Temperature Profile



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Project Summary and Conclusions

- Preliminary tests indicate that LSI technology is a viable low emissions and low cost alternative to exhaust gas cleanups
- Single injector mixing tests demonstrate acceptable fuel/air uniformity at the exit plane
  - Design changes may be able to improve premixing
- Low pilot fuel flows offer same low emissions as 0% pilot flow while extending lean blow out limits and improving flame stability
- Full scale atmospheric tests showed same emissions trend while demonstrating an exit temperature profile meeting engine specifications

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