Effects of Spent Cooling and Swirler Angle on a 9-Point Swirl-Venturi Injector

Zhuohui He, K. M. Tacina, Chi-Ming Lee
NASA Glenn Research Center
Robert R. Tacina
Retired, NASA Glenn Research Center
Fei Phil Lee
Woodward, FST

Outline

- Background
  - Nitrogen Oxides
  - Aircraft engine combustors
  - Lean Direct Injection (LDI)
  - Swirl-Venturi LDI
- Methods
  - Flametube measurements
  - Experimental hardware
- Results
- Conclusion

Background: Nitrogen Oxides

- Subsonic aircraft
  - Targets landing-takeoff (LTO) NOx
  - Reduce cruise NOx

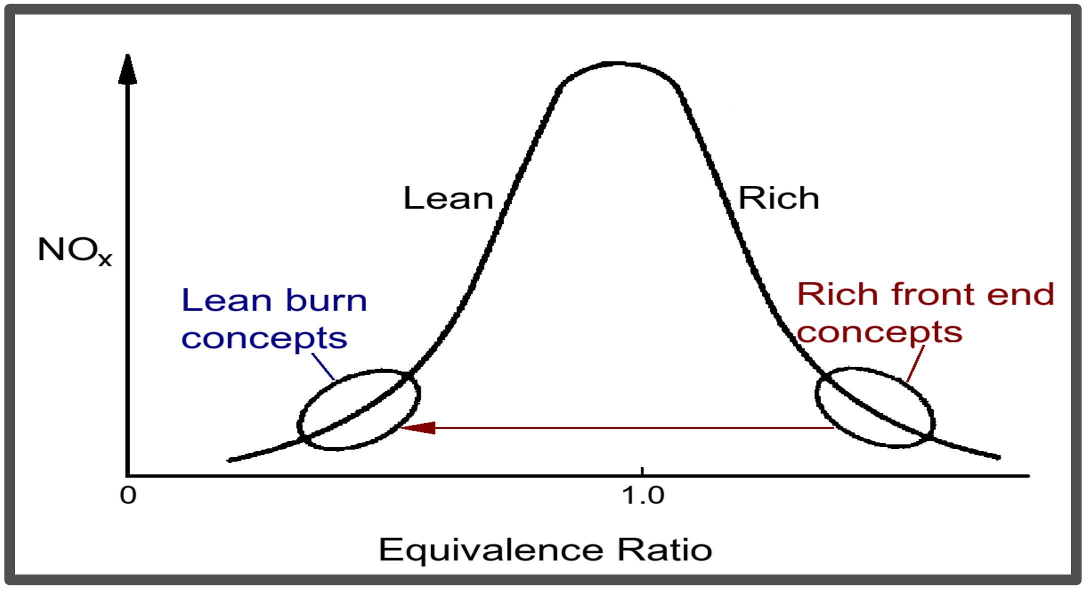
Source: NASA

- Supersonic aircraft
  - High altitude emissions
  - Targets cruise
  - Protect ozone layer
  - Decreased by stratospheric NOx emissions

Supersonic cruise conditions are targeted here

Background: Low NOx concepts

Avoid high-NOx stoichiometric burning!



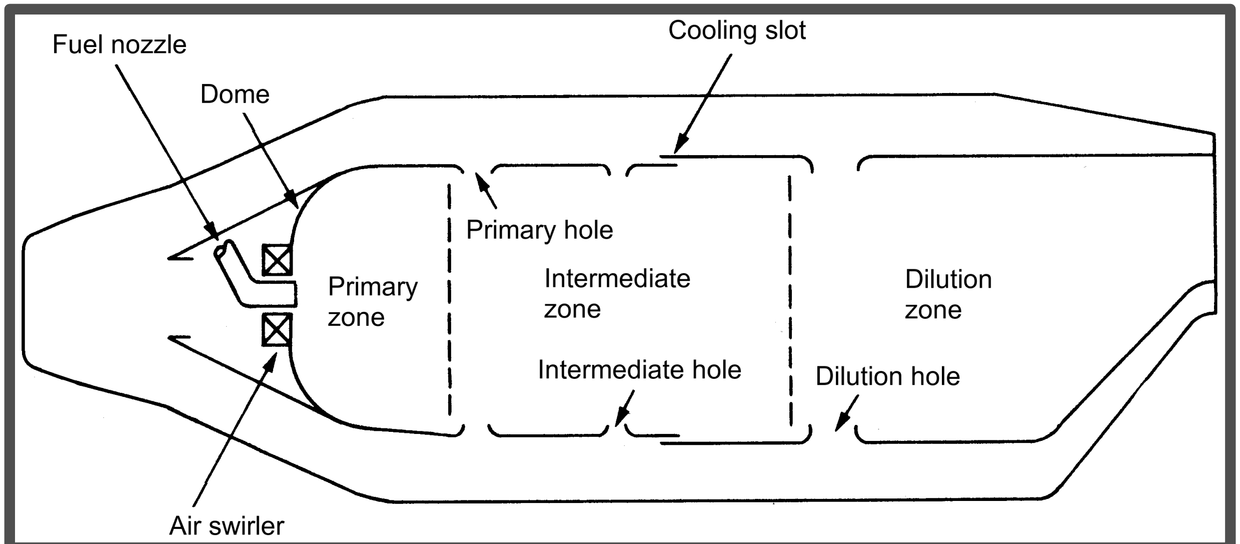
Lean burn concepts

- Lean, premixed, prevaporized (LPP)
- Lean partially premixed
- Lean direct injection (LDI)

Rich front end concepts

- Rich burn—quick quench—lean burn (RQL)
- Rich front end

Background: Aircraft Engine Combustors



Source: Lefebvre, Gas Turbine Combustion, 1st ed

Source: GE

Lean Direct Injection

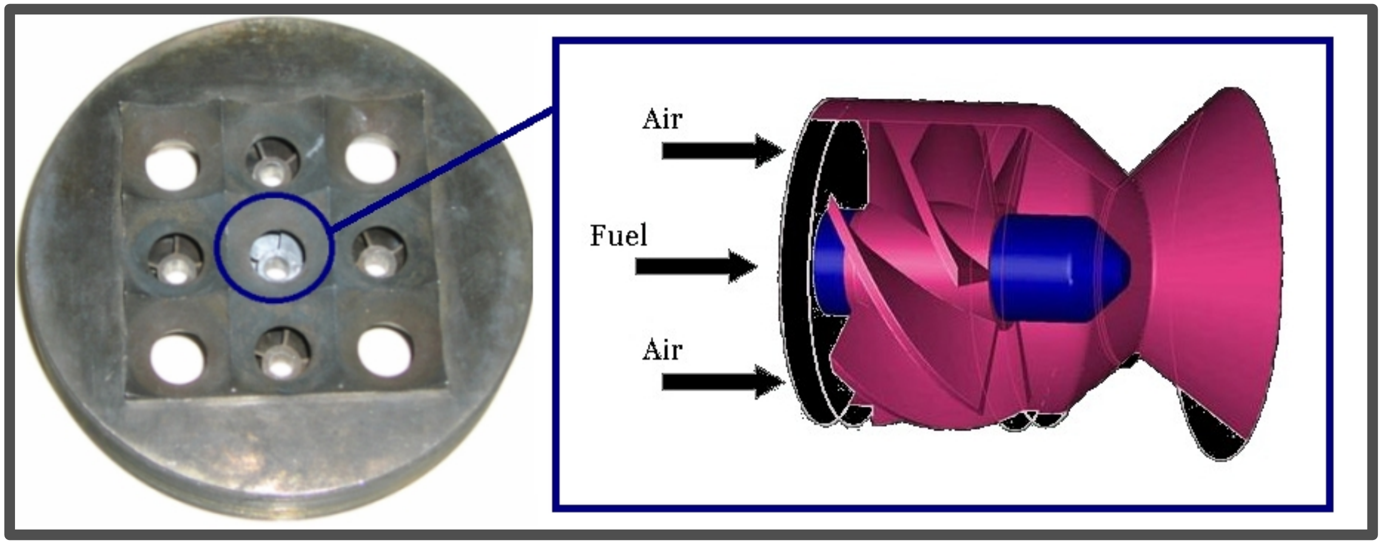
- Fuel lean: no rich front end
  - All *combustion* air enters through the dome

- Fuel is injected directly into the flame zone
  - Reduces problems with autoignition, flashback.

- Fine atomization and rapid, uniform fuel/air mixing

9-Point-Swirl-Venturi Injector

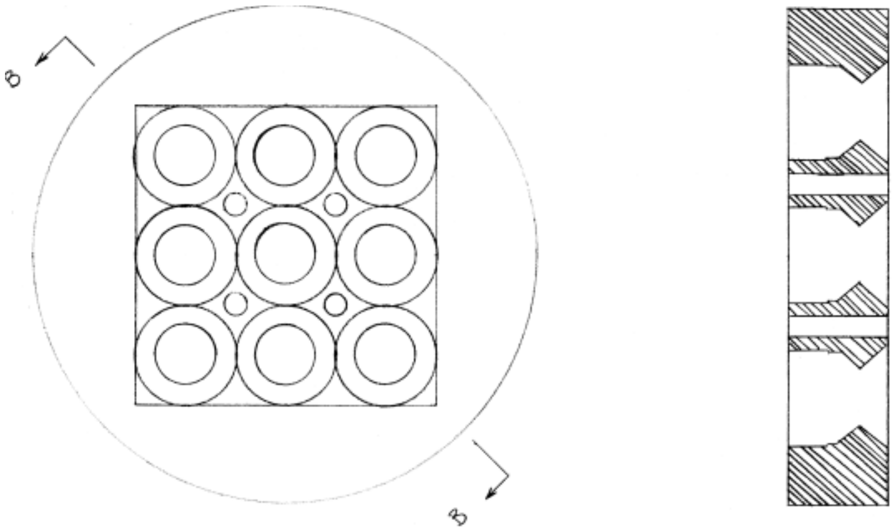
High Speed Research(HSR) program



- 5-bladed, helical air swirler
- Converging-diverging venturi

- Simplex fuel injectors
- Fuel injector tip at venturi throat

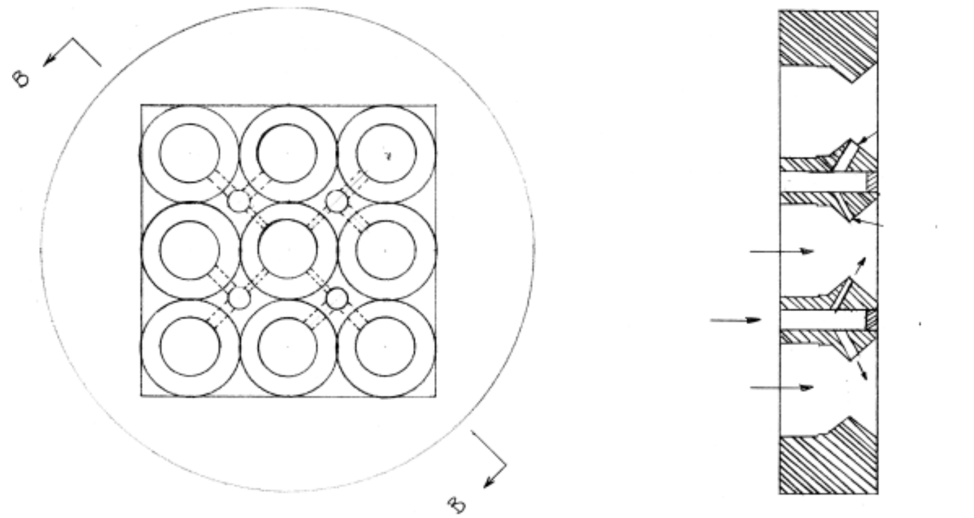
Effects of Cooling air



Back View
(upstream looking downstream)

Section B-B

Straight through spent cooling (ST)



Back View
(upstream looking downstream)

Section B-B

Cooling at the venturi throat (AT)

- Combustor inlet conditions
- Prevent hardware damage.

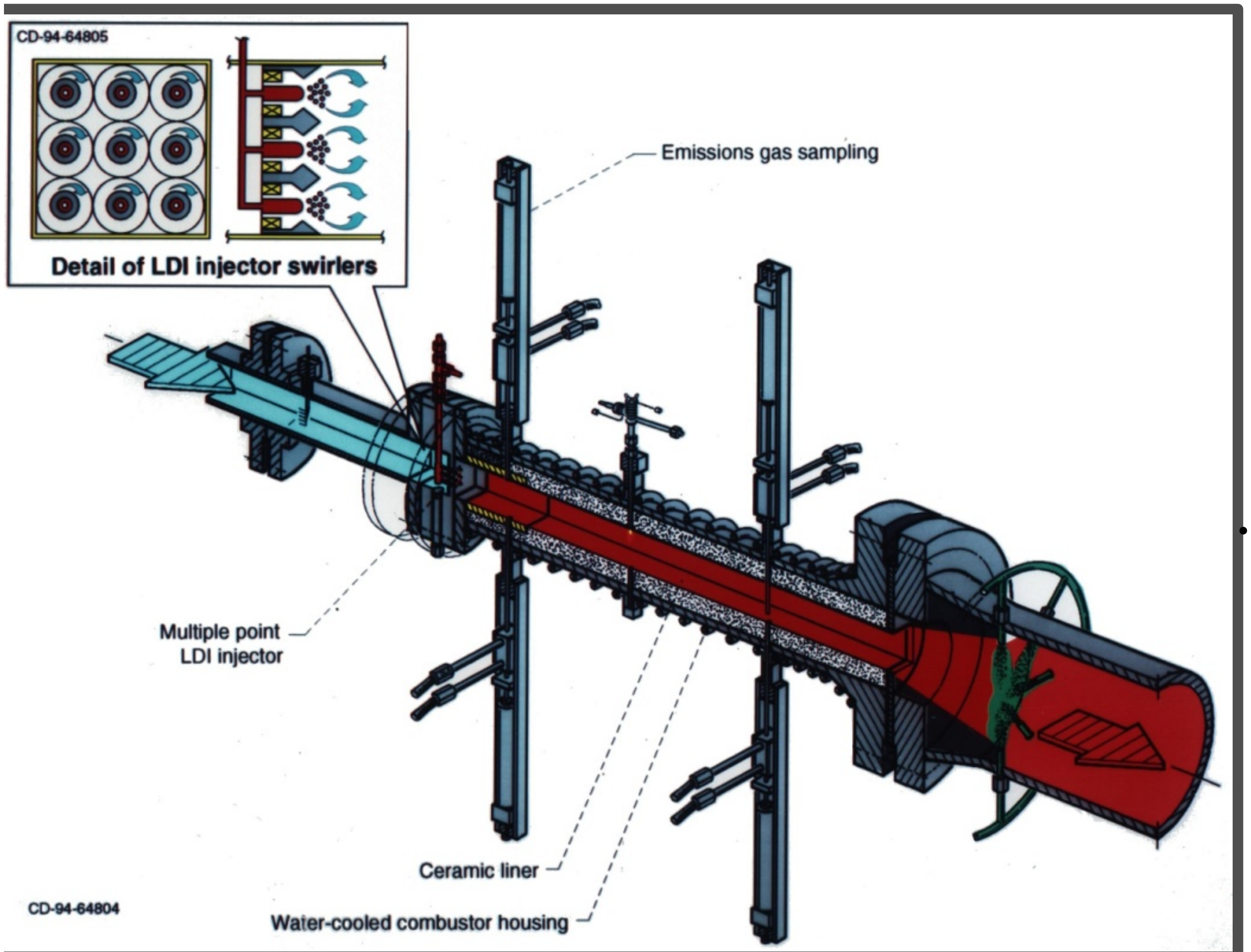
Other comparing parameters

- Swirler angle
  - 45°
  - 60°

- Compare to similar 9-point SV injector(no cooling)
  - ultra-efficient engine technology (UEET) program

Method

Flametube



- No air cooling
- Capabilities
  - 840 K inlet temp
  - 1500 kPa
- 76.2-mm by 76.2-mm square cross section

- Standard gas bench
  - SAE 1533
  - CO_2, CO, O_2
  - UHC
  - NOx: Chemiluminescence

UEET correlation equations

- For the UEET configuration
  (Source:ISABE-2005-1106)

  - with 45º swirlers

(1) $$EINOx = 0.11 * {P_3}^{0.59} * e^{\frac{T_3}{194}} * \Phi^{5.07} * (\frac{\Delta P}{P}\%)^{-0.56}$$

  - with 60º swirlers:

(2) $$EINOx = 0.013 * {P_3}^{0.59} * e^{\frac{T_3}{194}} * \Phi^{1.69} * (\frac{\Delta P}{P}\%)^{-0.56}$$

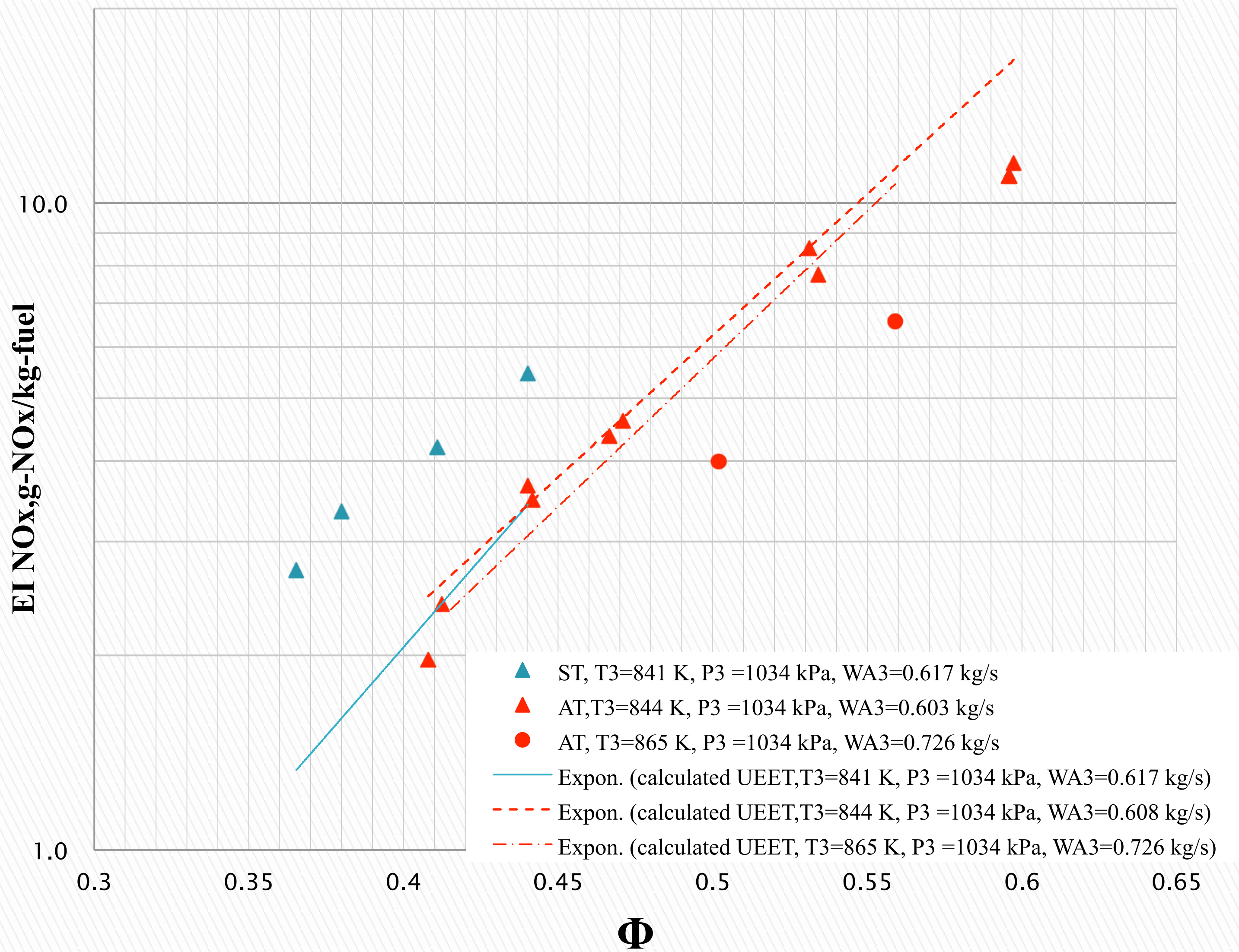
Results

Effective area (ACd) and Flow number

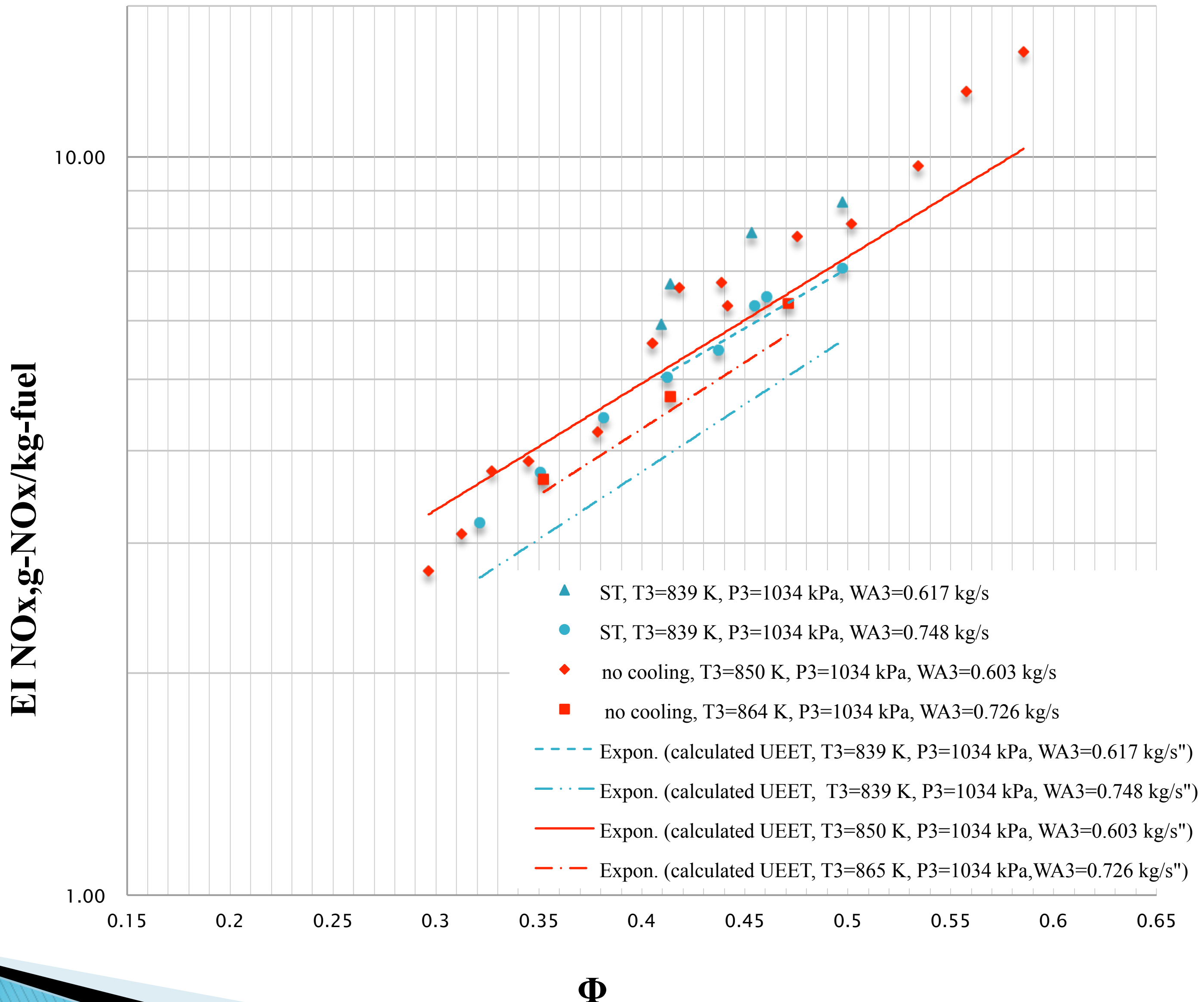
	HSR 45^o /ST	HSR 45^o /AT	HSR 60^o /ST	HSR 60^o/no cooling	UEET 45^o (no cooling)	UEET 60^o (no cooling)
ACd	1.745	1.644	1.477	1.37	1.48	1.35
FN(total)	17.9	17.16	18.49	18.24	26.1	26.1

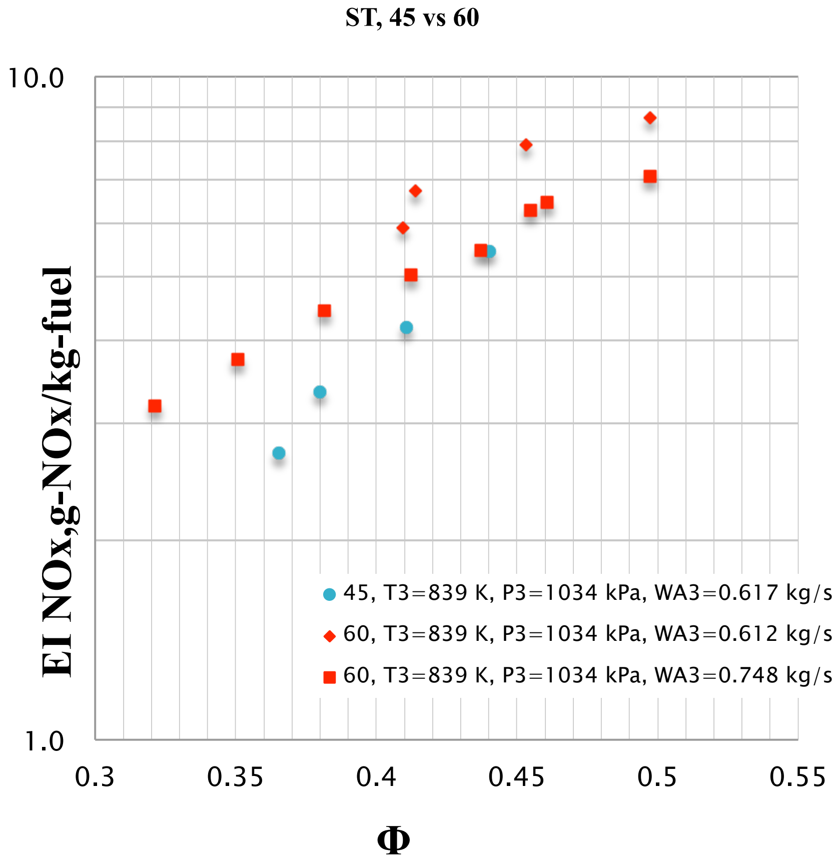
- ACd= air mass flow rate / sqrt (ΔP)
  - NOx emission increase when air pressure drop decrease
  - ST > AT >no cooling
  - 45^o > 60^o
  - HSR 60^o similar ACd with UEET 60^o
- FN=fuel mass flow rate/sqrt(ΔP).
  - high ΔP, lower fuel drop size
  - FN=18 for HSR configurations
  - FN=26.1 for UEET configurations
  - 40% higher flow number will result about 30% higher fuel drop sizes

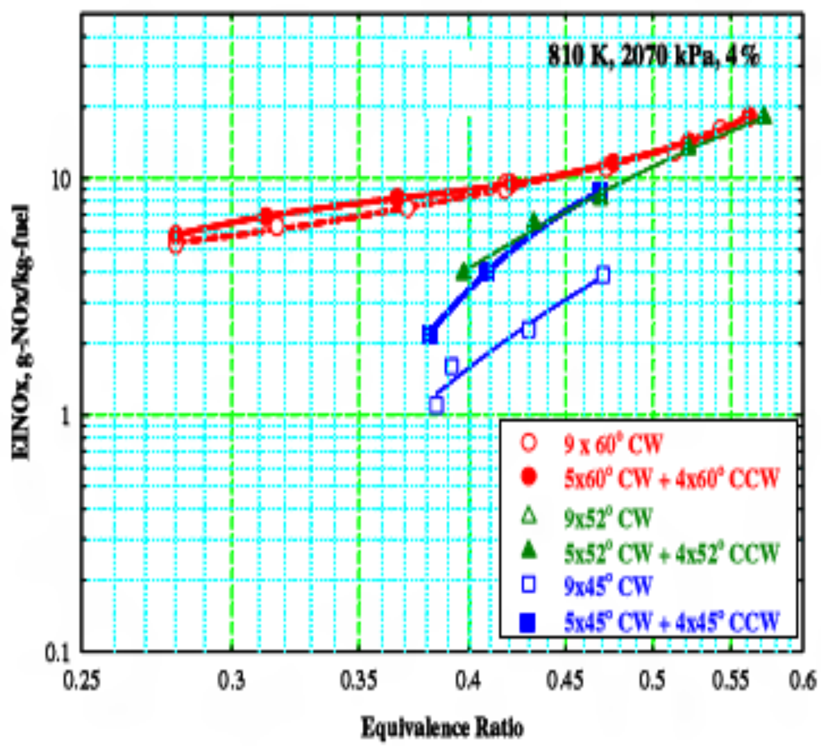
45º swirler ST vs AT



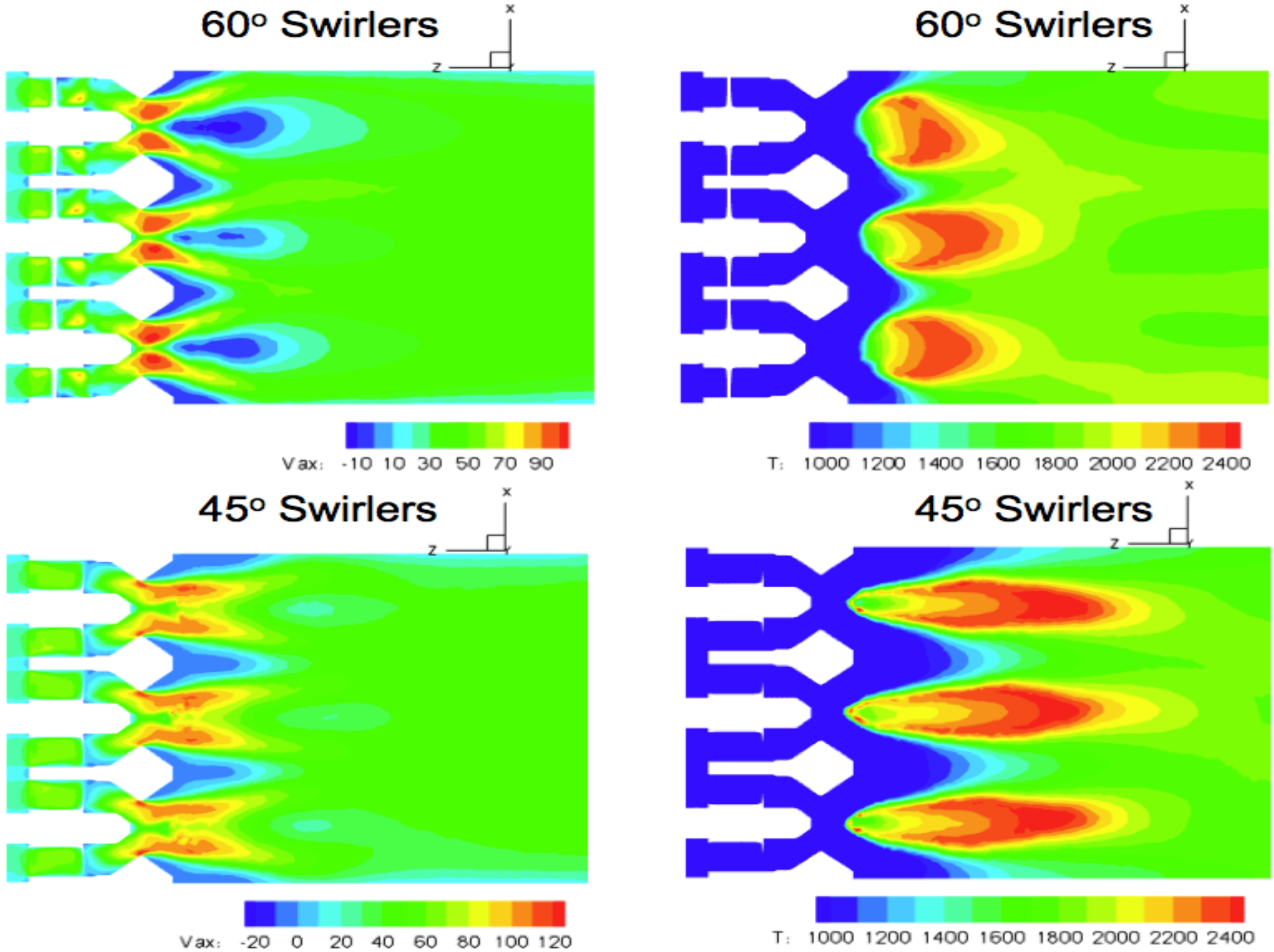
60° swirler, ST vs no cooling




ST, 45 vs 60
10.0
1.0
0.3
0.35
0.4
0.45
0.5
0.55
EI NOx,g-NOx/kg-fuel
Φ
45, T3=839 K, P3=1034 kPa, WA3=0.617 kg/s
60, T3=839 K, P3=1034 kPa, WA3=0.612 kg/s
60, T3=839 K, P3=1034 kPa, WA3=0.748 kg/s

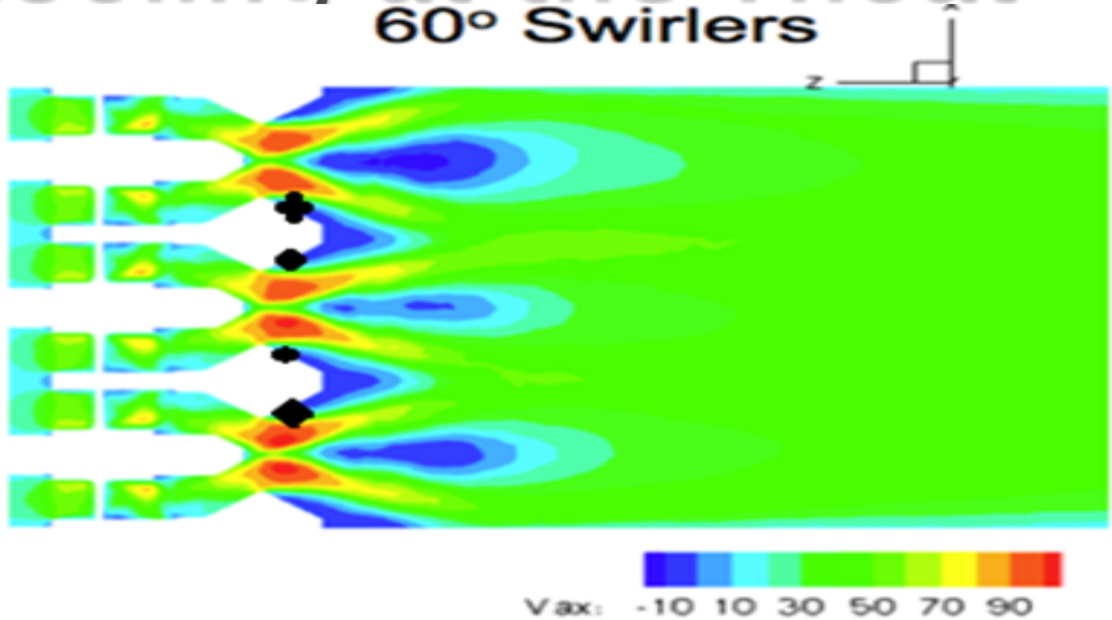

810 K, 2070 kPa, 4%
EINOx, g-NOx/kg-fuel
10
1
0.1
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
Equivalence Ratio
9 x 60° CW
5x60° CW + 4x60° CCW
9x52° CW
5x52° CW + 4x52° CCW
9x45° CW
5x45° CW + 4x45° CCW

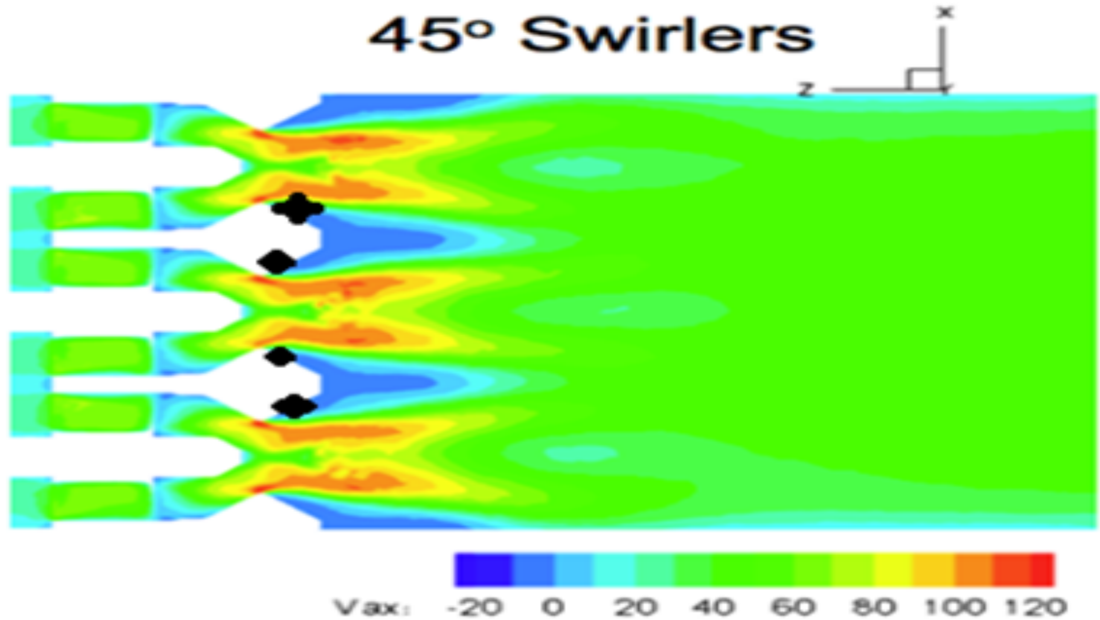
Cfd picture



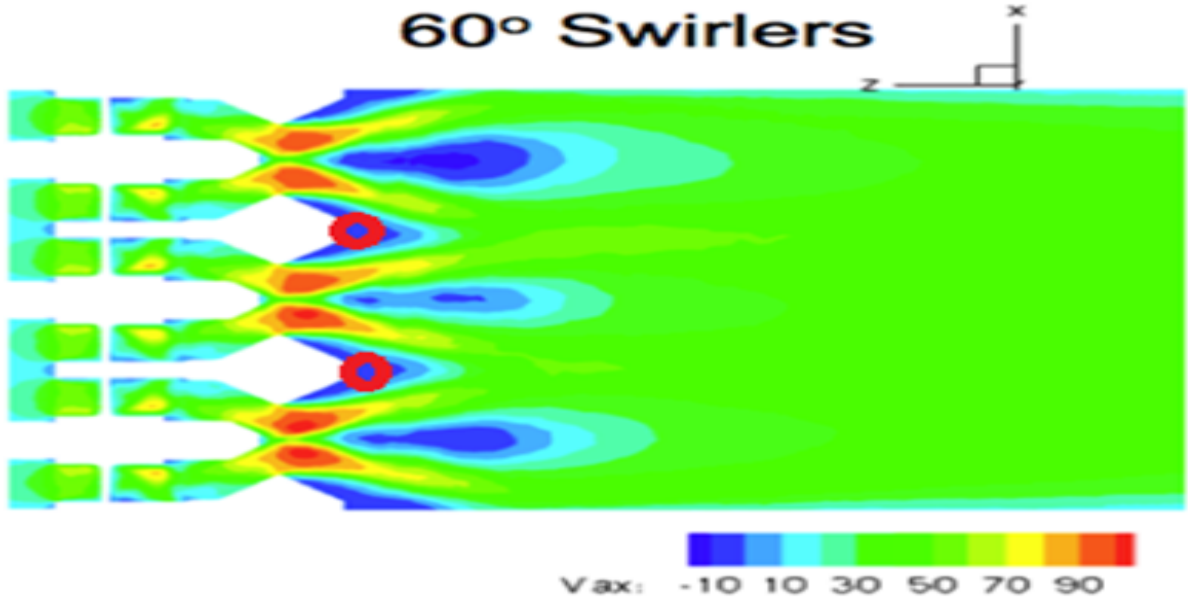
Source: **Ajmani, ASME GT2013-95669**

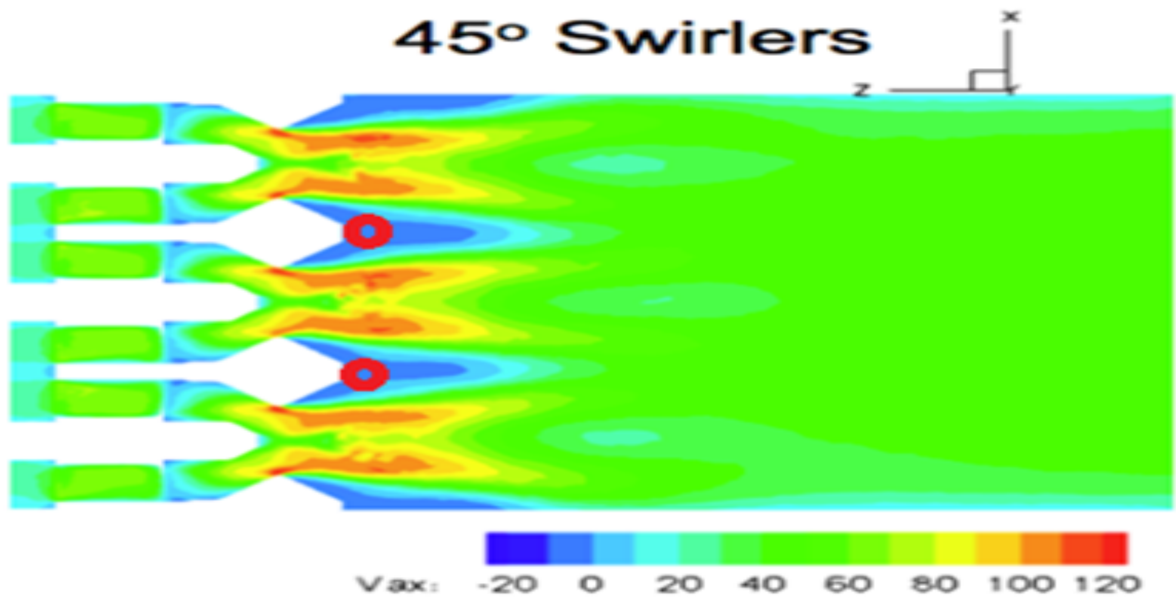
Spent cooling at the Thoat





Straight through Spent cooling





Conclusion

- Cooling air is unnecessary for the current designs, but might be important in future SV-LDI designs.
  - post-testing visual inspection showed no damage on the injector hardware.
  - spent cooling might be needed at the higher inlet pressures of next generation aircraft engines and when using Alt fuel with short ignition delay time
- The effects of spent cooling depend on spent cooling location, swirler angle, and test conditions.

Acknowledgements

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- Robert Tacina and Phil Lee collaborated on the SV-LDI designs
- Chi-Ming Lee and Robert Tacina ran the flametube tests
- Robert Tacina did preliminary data analysis

- Questions…