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Central States Section of the Combustion Institute

Chemiluminescence measurements in a combustor using a 7-point lean direct injector array configuration for gas turbine engine applications

Tyler G. Capil, NASA Glenn Research Center
Kathleen M. Tacina, NASA Glenn Research Center
Yolanda R. Hicks, NASA Glenn Research Center

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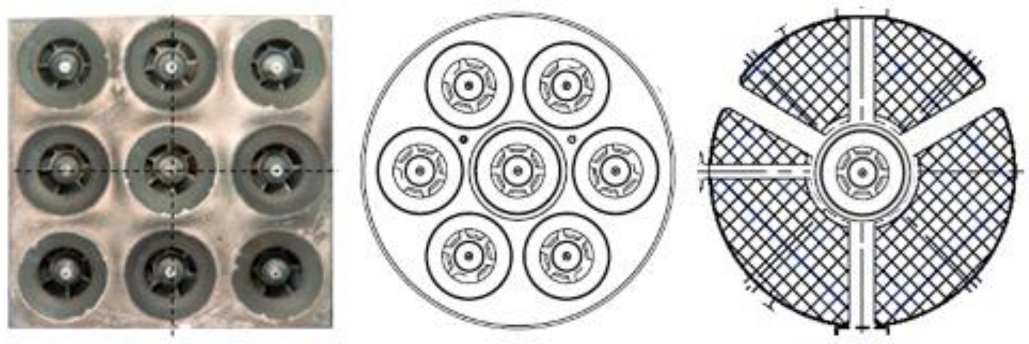
Outline

- Motivation
- LDI hardware
- Objectives for present work
- Recent history
- Optical diagnostics setup
- Results from LDI

The motivation for Lean Direct Injection (LDI) was proposed as a technique to reduce aircraft NOx emissions

- Fuel directly injected into combustor
- Fine atomization and rapid fuel-air mixing
- Multiple, smaller fuel injectors instead of single injector



Performs well at high power but sometimes suffers unstable flame at low power conditions

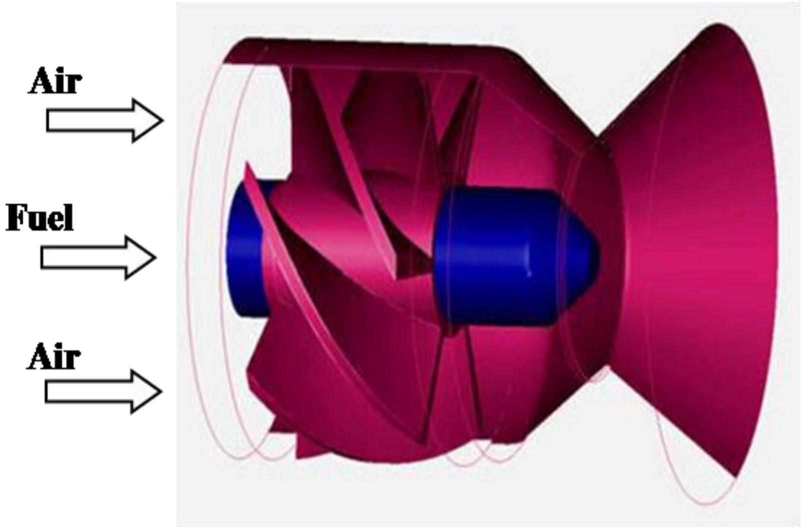
Lean combustion prone to pressure dynamics leading to instabilities

LDI Hardware

The baseline element of the LDI hardware consists of a converging-diverging venturi throat

Simplex fuel nozzle placed at tip of venturi throat

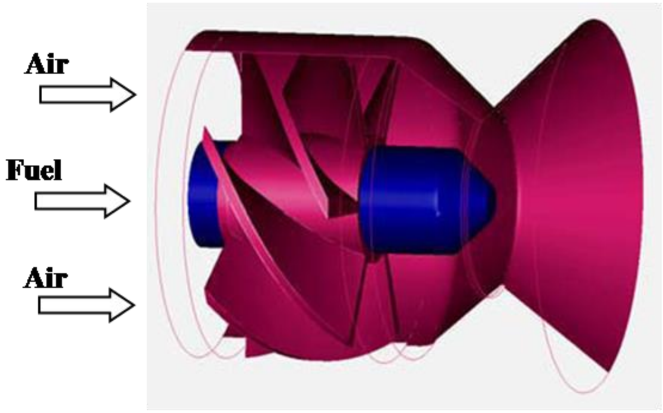
Six helical blades guide the air flow path
Typical swirlers used are 45˚, 52.5˚, 60˚



LDI Hardware

Seven elements arranged to form 7-point array where spacing between elements is 23.8 mm

Center element acts as pilot and injector tip can be offset in upstream direction



Objective of this work was to provide a comparison of flame structure from two different configurations of the 7-point LDI hardware

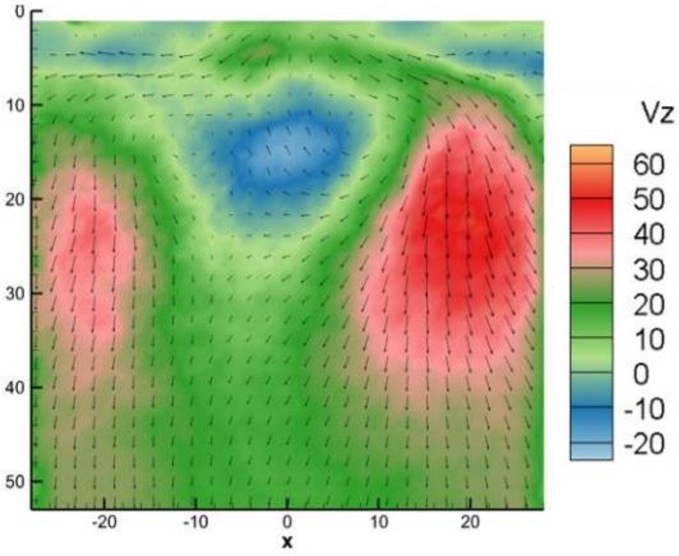
1. Co-swirling configuration
   Center pilot swirler: RH 60˚
   Outer swirler: RH 52˚

2. Counter-swirling configuration
   Center pilot swirler: LH 60˚
   Outer swirlers: RH 52˚

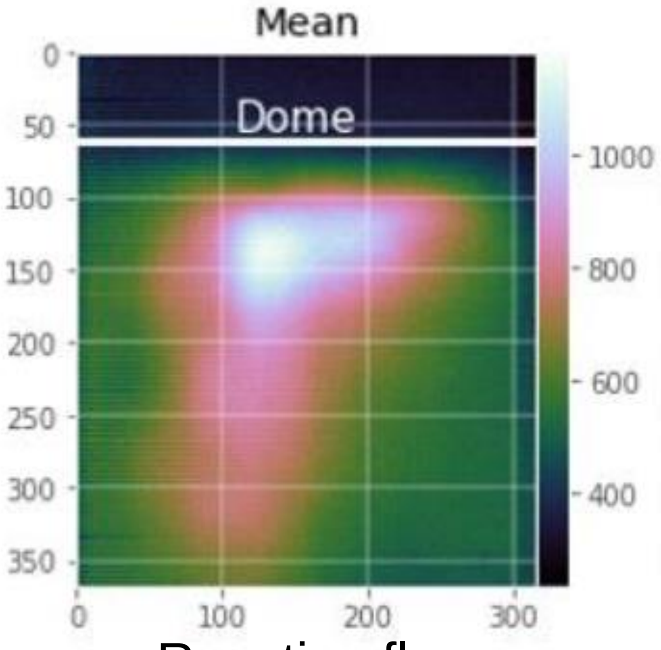
Recent studies reported for 7-point LDI for both non-reacting and reacting conditions

- Parametric studies to observed effect of swirler angle, clocking, and center offset
- Non-reacting cases studied formation of recirculation zones
- Combustion tests examined flame structure and combustion dynamics

Flow Direction



Non-reacting flow

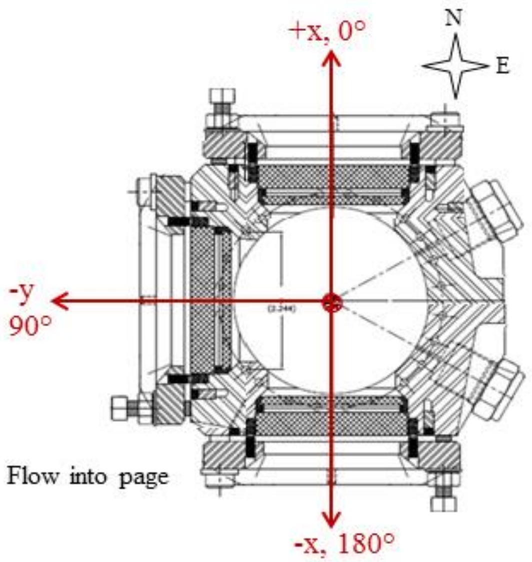


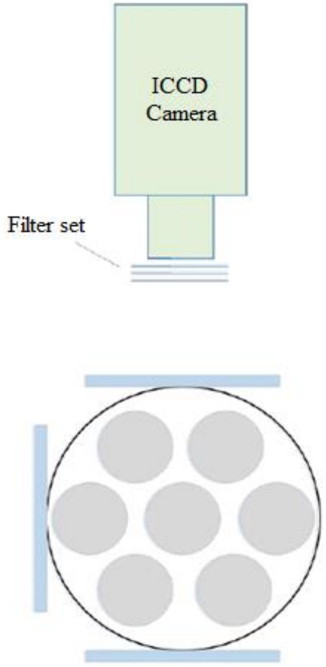
Reacting flow

Optical measurements for combustion were acquired through chemiluminescence

Combustion tests captured chemiluminescence through intensified CCD (ICCD) camera, PI-Max 3, at 25 Hz frame rate

Chemiluminescence species of C_2^* and CH^* spectrally isolated using narrow bandwidth filters





Several inlet test conditions were used to observe the effect of varying equivalence ratio and reference velocity

P_3 psia	T_3 ˚F	u_{ref} m/s	Φ	Φ_c	Φ_o
75	800	10.7	0.450	0.450	0.450
75	800	10.7	0.480	0.480	0.480
75	800	10.7	0.500	0.500	0.500
75	800	12.2	0.450	0.450	0.450

Optical measurements for non-reacting flows were acquired through water-seeded PIV

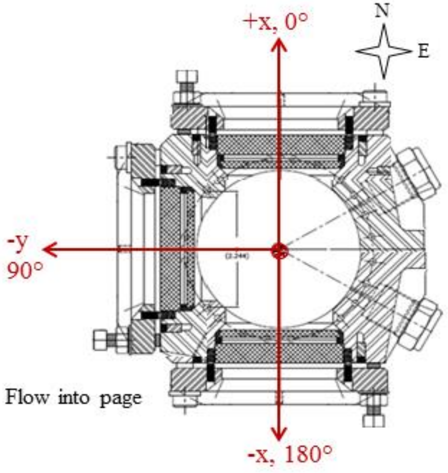
Cold flow testing was done by spraying water into the center nozzle

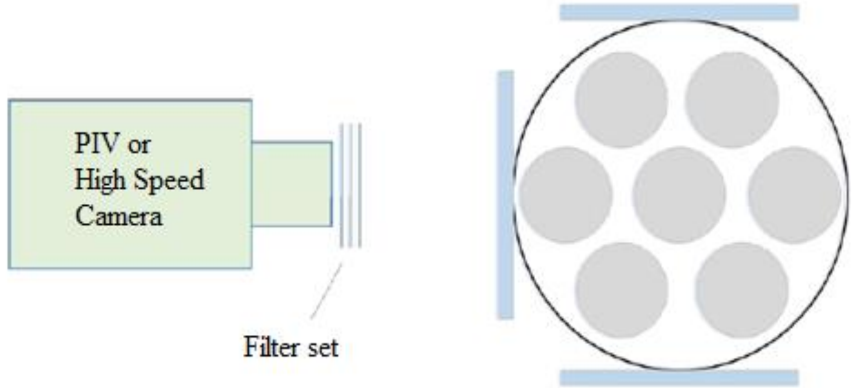
15 Hz, dual head, Nd:YAG laser was used to scatter light off water droplets

500 image pairs captured by interline transfer, CCD camera

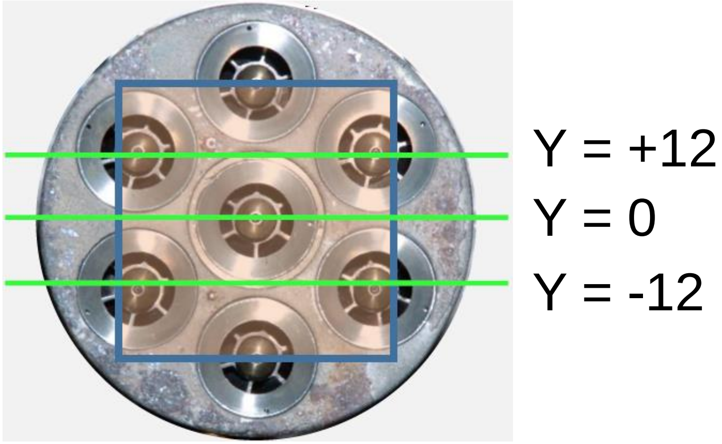
Traverse laser sheet along y-coordinate from -24 mm to 24 mm

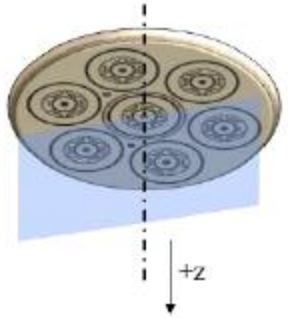
Inlet air conditions: 75 psia, 800 F, 22.9 m/s

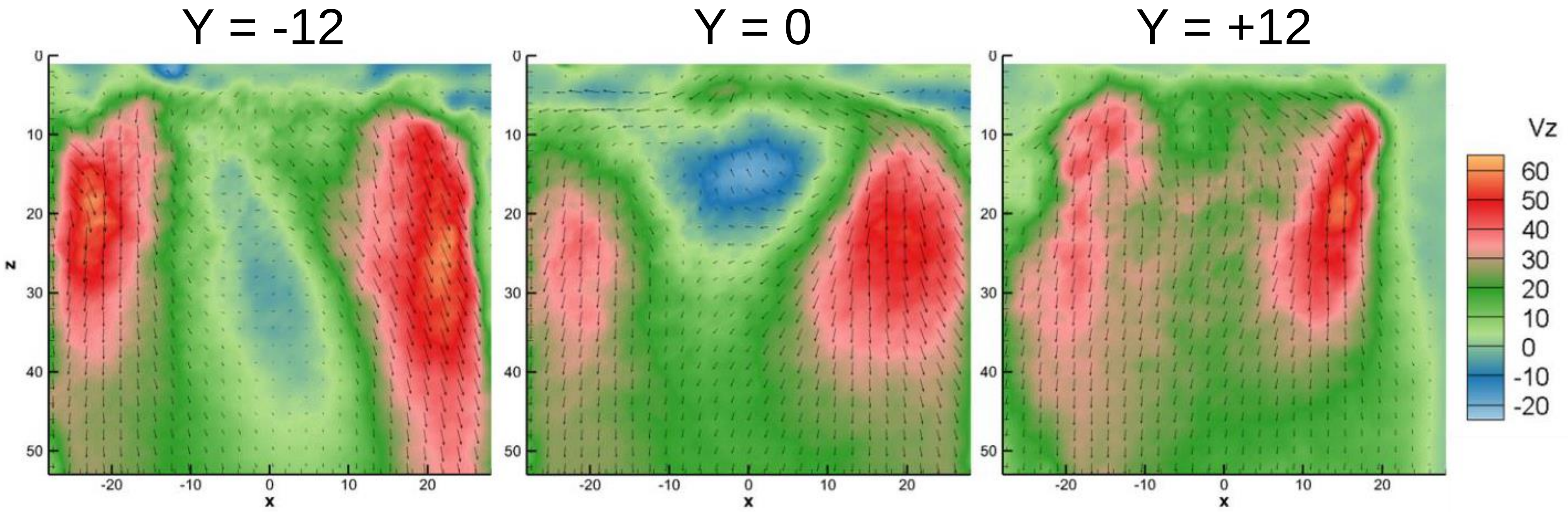




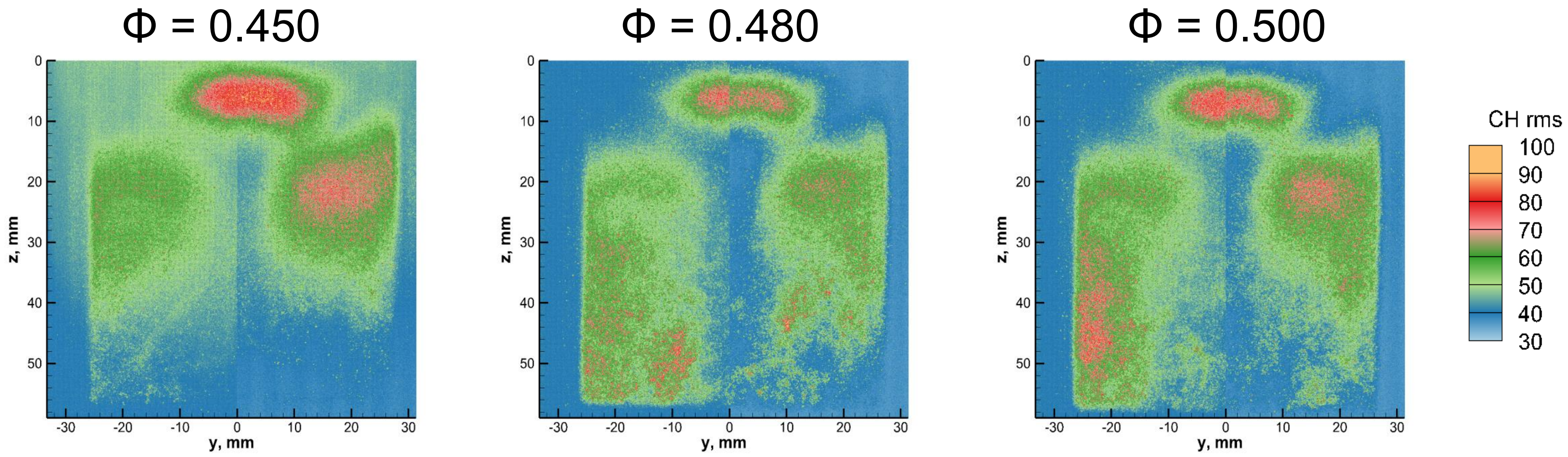
Average x-z velocity field for non-reacting, co-swirl showed an elongated central recirculation zone (CRZ)

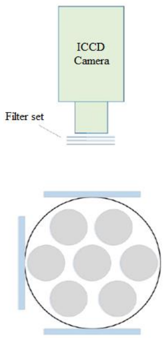






Co-swirl CH* chemiluminescence showed flat shape near pilot and rough symmetry from outers





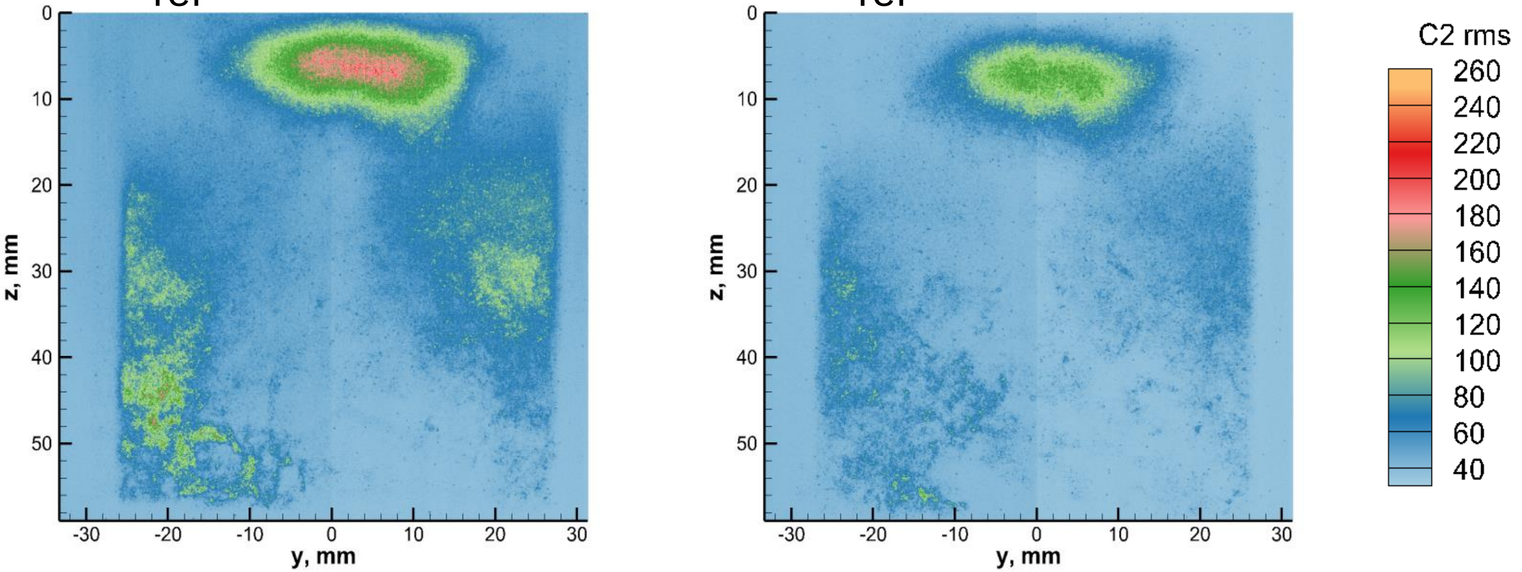
CH* tended to increase as equivalence ratio increased

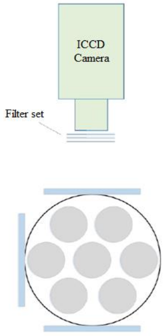
Hollow region of lower CH* downstream of pilot similar shape to CRZ

Co-swirling C_2^* chemiluminescence decreased as reference velocity increased

u_{ref} = 10.7 m/s u_{ref} = 12.2 m/s

Φ = 0.450



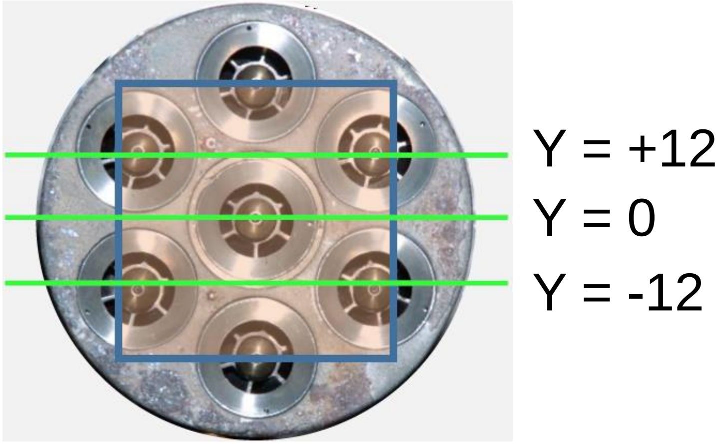


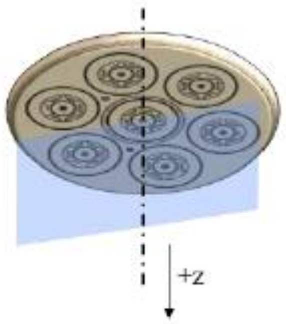
Increased reference velocity means:

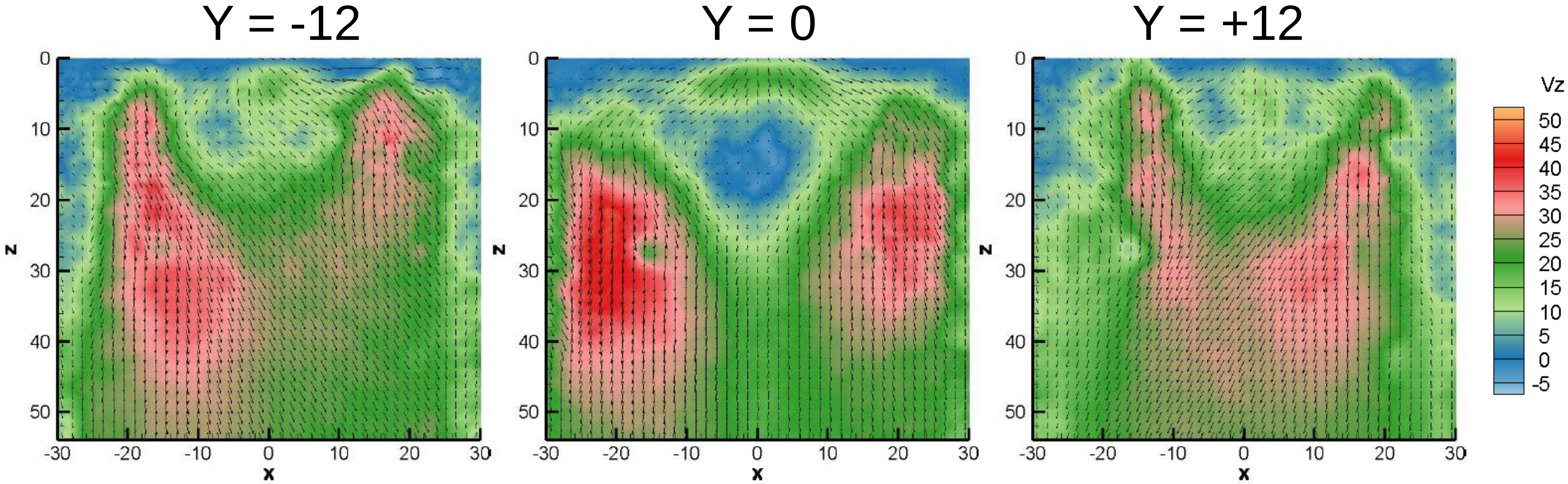
- Higher pressure drop across nozzle results in finer atomization
- Smaller fuel drops vaporize better
- Increased turbulence with higher velocity means enhanced mixing

∴ Weaker chemiluminescence

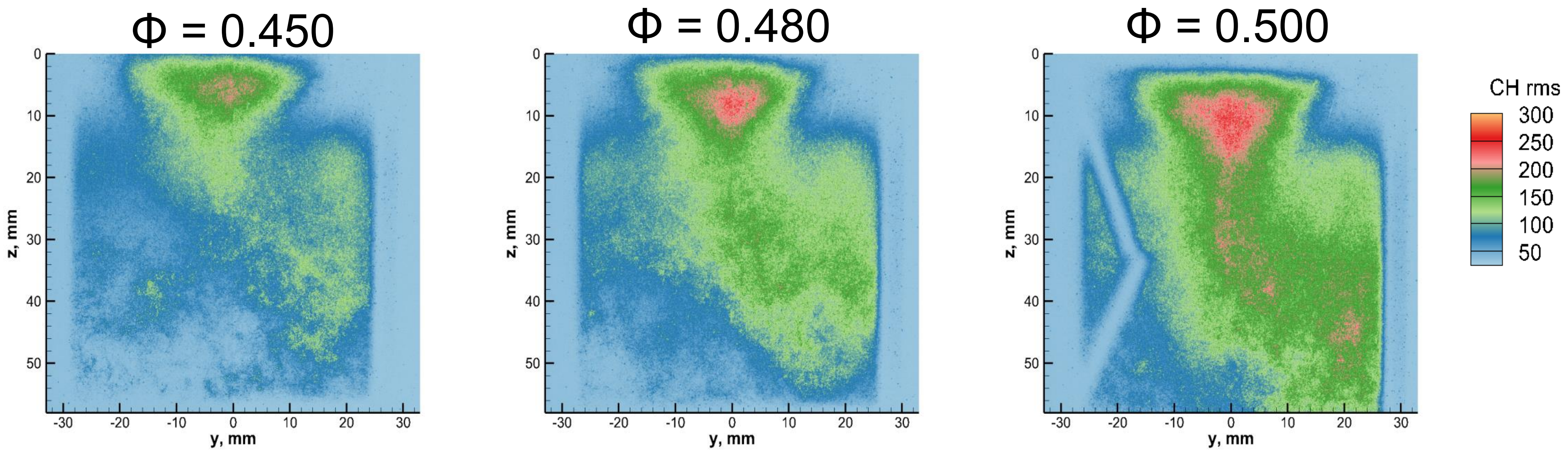
Average x-z velocity for non-reacting, counter-swirl hints at weak recirculation zone

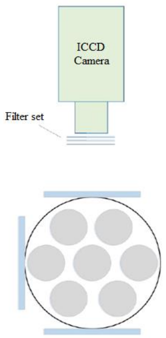






Counter-swirl CH^* chemiluminescence displayed a triangular shape from pilot and overall asymmetry





Triangular shaped pilot similar in shape to weak CRZ

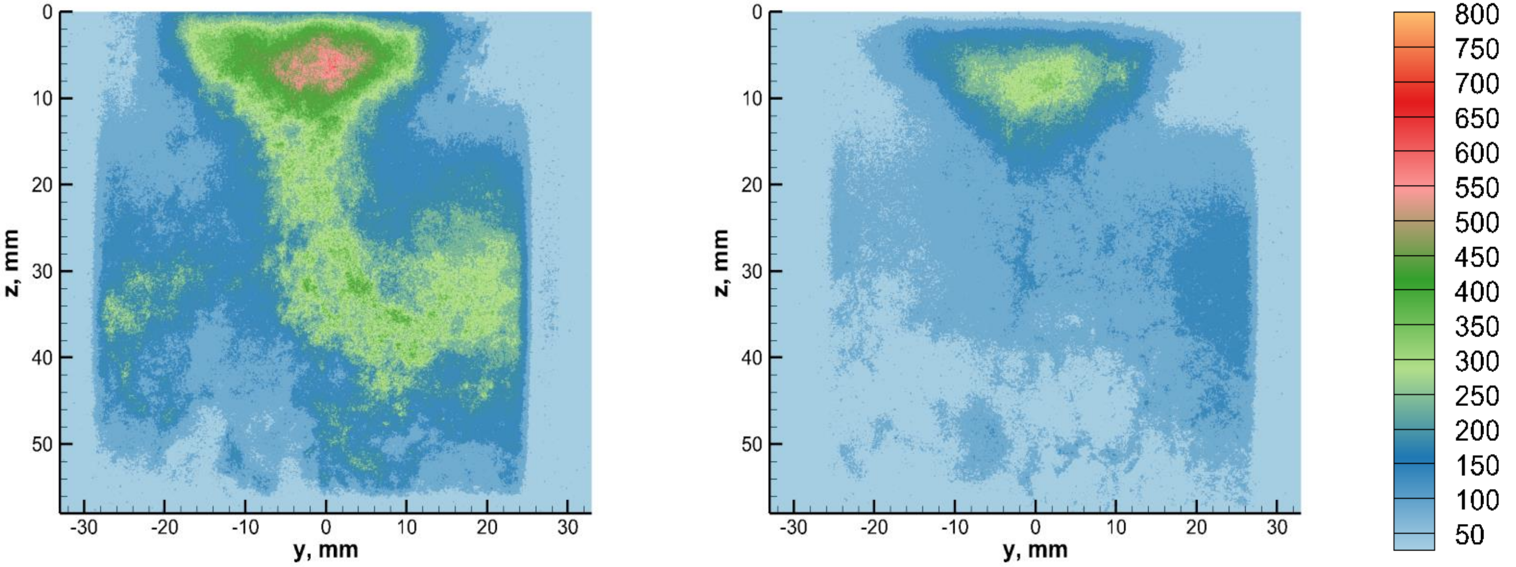
Asymmetry could be result of downstream swirl

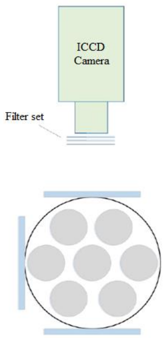
Chemiluminescence approaching camera could “forward scatter”

Counter-swirl C_2^* chemiluminescence also showed weaker chemiluminescence with increased velocity

u_{ref} = 10.7 m/s u_{ref} = 12.2 m/s

Φ = 0.450





Increased reference velocity means:

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∴ Weaker chemiluminescence

Summary

A comparison of co-swirling and counter-swirling configurations was examined

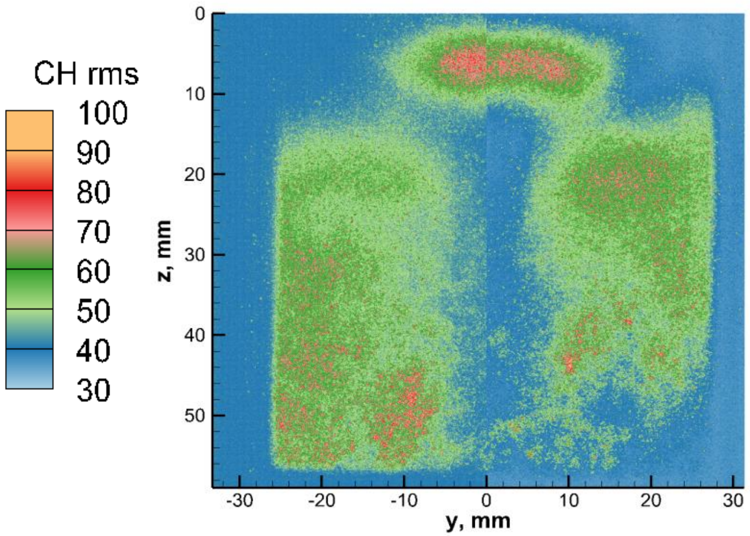
Co-swirling configuration

- Flat, round pilot
- Symmetry observed with outers
- Weak region of CH^* seemed to coincide with CRZ

Counter-swirling configuration

- Triangular, pilot
- Asymmetry showed most signal concentrated right-handed

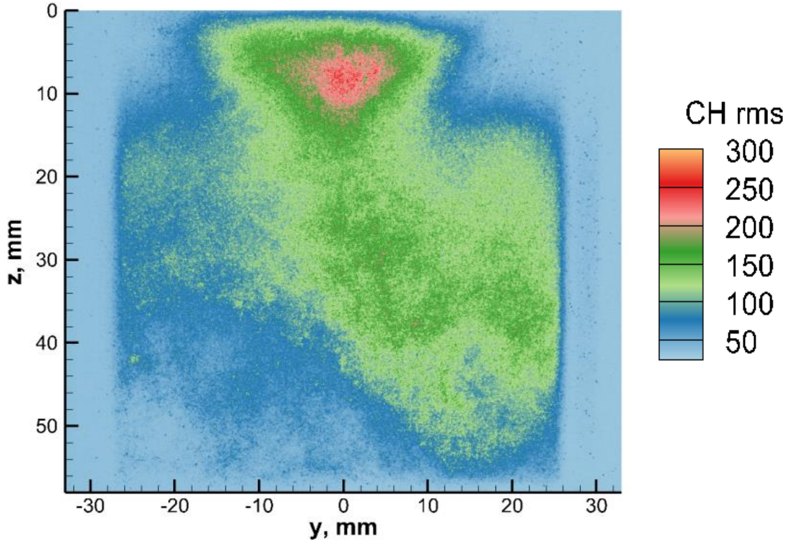
Φ = 0.480



Both configurations showed:

- Increased chemiluminescence as equivalence ratio increased
- Decreased chemiluminescence as reference velocity increased

Φ = 0.480



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