A Common Engine Platform for Engine LES Development and Validation

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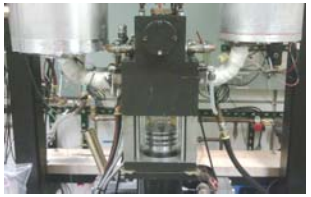
Introduction

- Goal: Predictive, physics-based CFD tools for IC engine design & optimization
  - Understand and minimize undesired cyclic variation
- Approach: LES as a compromise between full detail and practicability
  - Achieve the highest accuracy for the lowest cost
  - Develop and understand best practices for using LES on engine simulation
  - Use a range of LES modeling approaches to evaluate requirements for proper use
  - Validate and advance with optical engine experiments

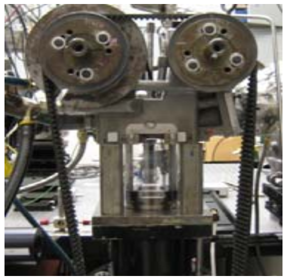
Approach

- Bring together researchers with common interests but complementary specialties

- Define a common platform to work on to maximize synergy and compatibility of results
  - Two optical engines at The University of Michigan to investigate:
    - Turbulence
    - Boundary layers
    - Sprays
    - Mixing
    - Combustion
    - ….

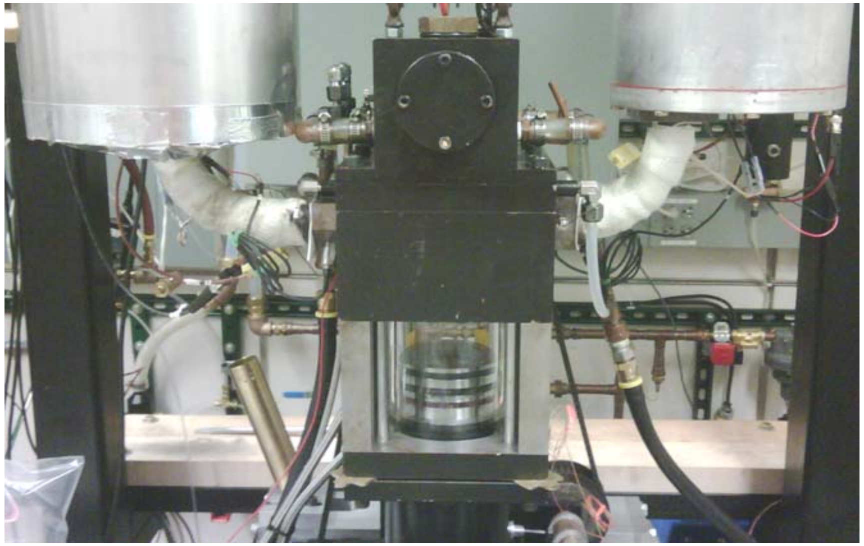


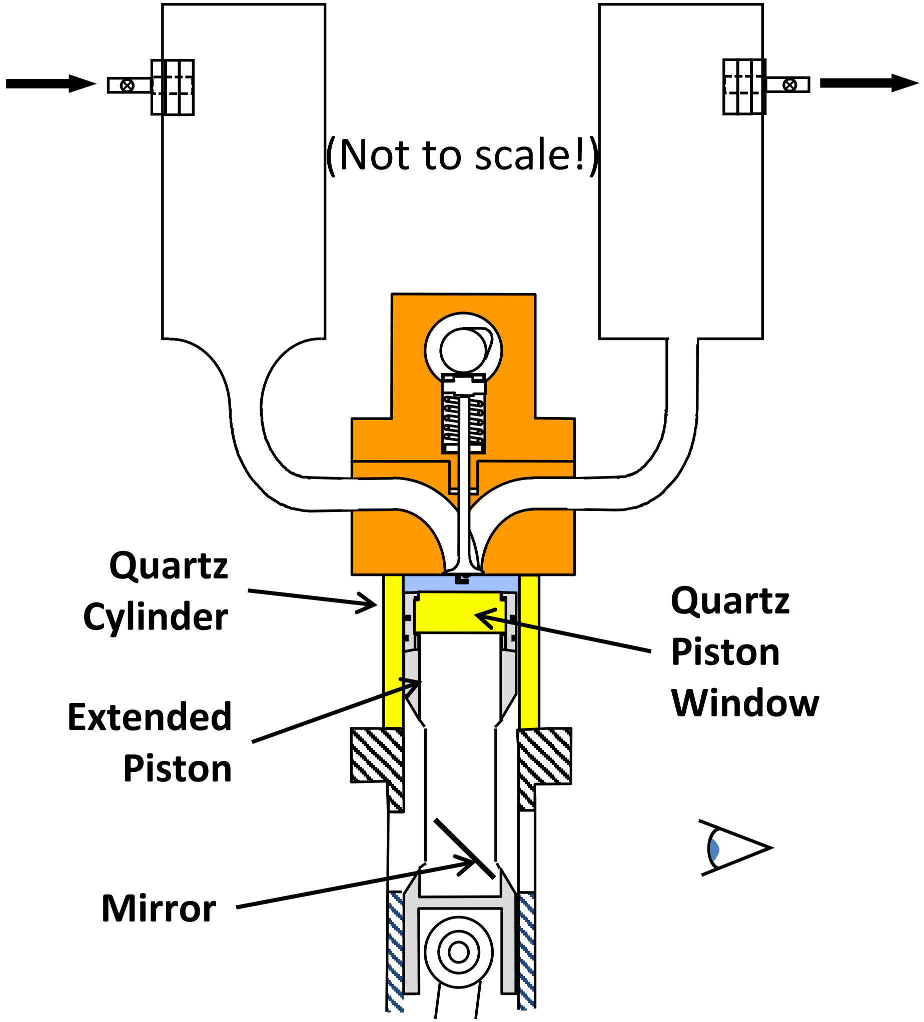
TCC two-valve flat head optical engine



Four-valve pentroof optical engine

The platform: TCC Optical Engine



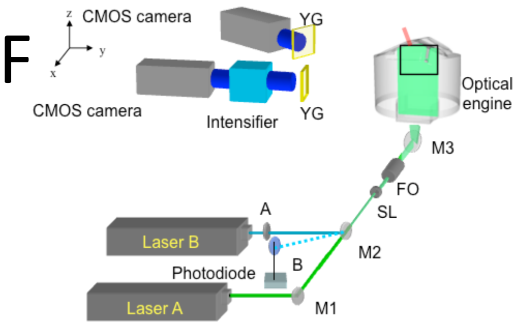


Features
Designed for:
- Best CFD compatibility
- Best optical access
- Comprehensive instrumentation

Reuss, Kuo, Khalighi, Haworth, and Rosalik, (1995), "PIV in a high-swirl engine for evaluation of CFD calculations." SAE Paper 952381
Haworth (1999), "Large-eddy simulation of in-cylinder flows." Oil & Gas Sci. and Tech., IFP, 54(2), 175-185.
Reuss (2000), "Cyclic variability of large-scale turbulent structures in directed and undirected IC engine flows." SAE Paper 2000-01-0246.

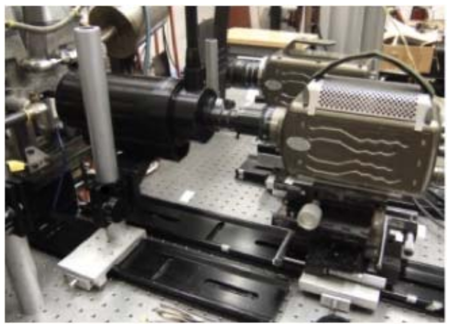
High-speed imaging diagnostics

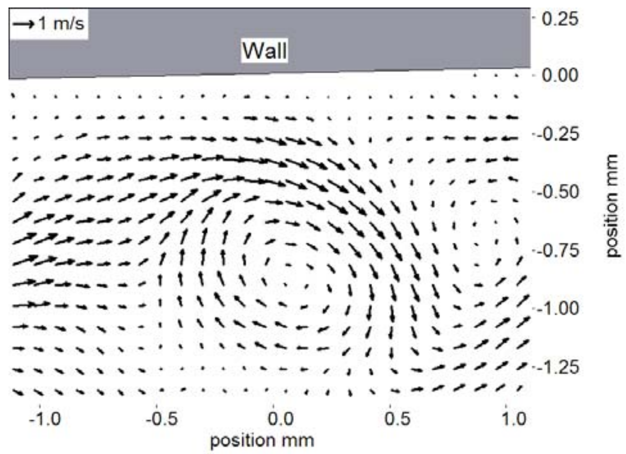
- Crank-angle resolution for temporal details
  - High-speed PIV and PLIF



Peterson, Reuss, Sick, ProCI 33, 2010

- Microscopy for spatial details
  - High-speed μ-PIV and PLIF





Alharbi & Sick, Exp. In Fluids, 2010

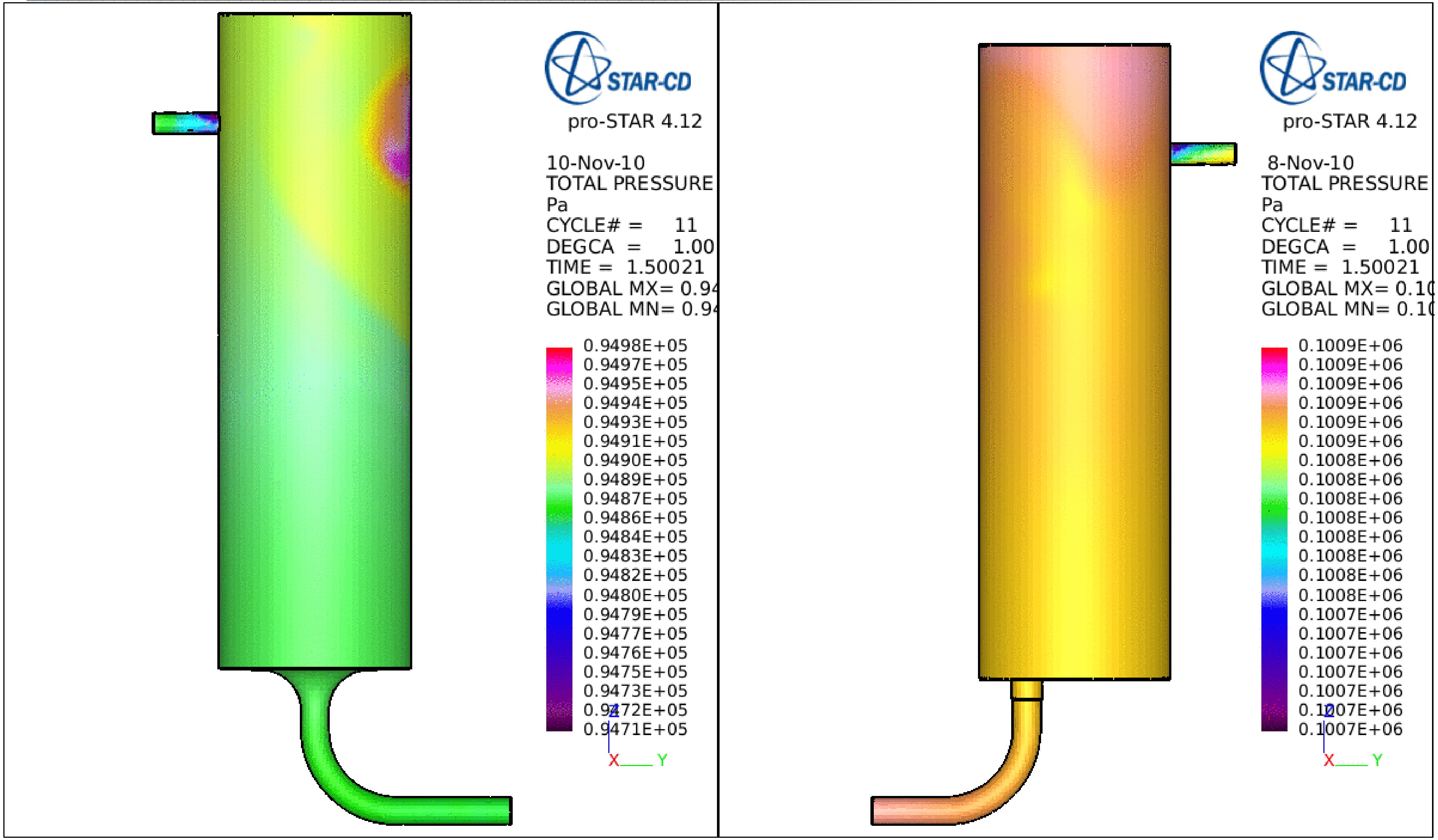
LES approaches

- **High-resolution** (minimal subgrid-scale modeling, approaching DNS; >10^8 cells per cylinder) for physics discovery and model development/validation.

- **Low-resolution** (RANS-like resolution; currently 10^5-10^6 cells per cylinder) for engineering development and applications.

- **Medium-resolution** (currently 10^6-10^7 cells per cylinder) will bridge these two extremes.

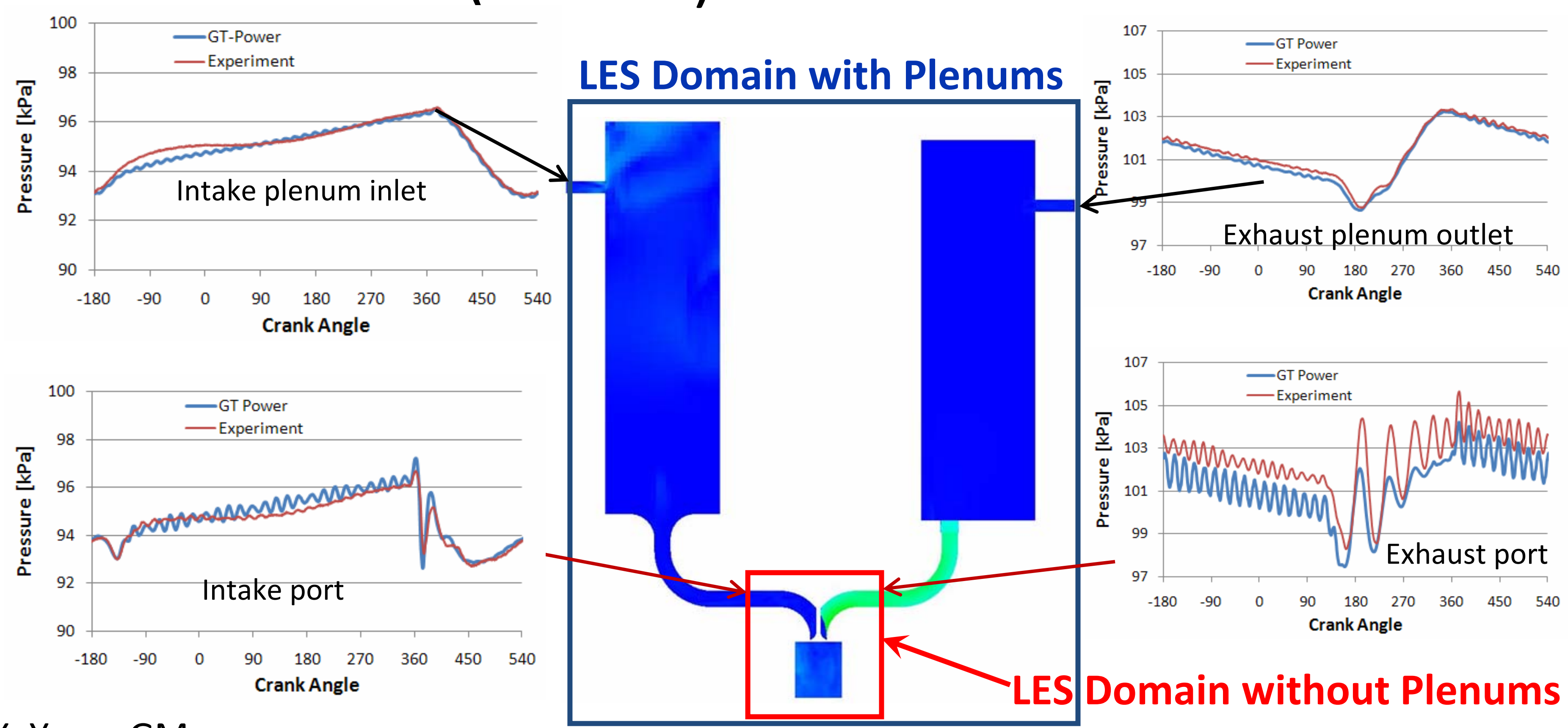
Boundary conditions



Liu & Haworth, PSU

Computational Domains

- GT Power to determine boundary conditions for smaller (=faster) LES domain?

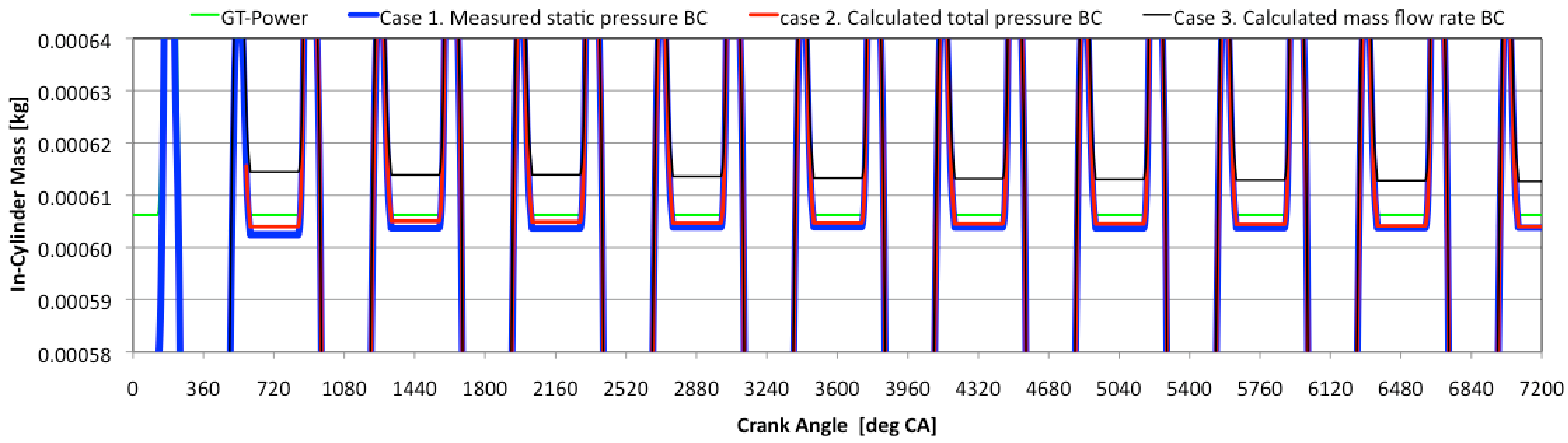


X. Yang, GM

Impact of initial conditions

- How many cycles are needed to be independent of initial conditions?
- How should those be chosen?

Trapped mass for measured and calculated boundary conditions

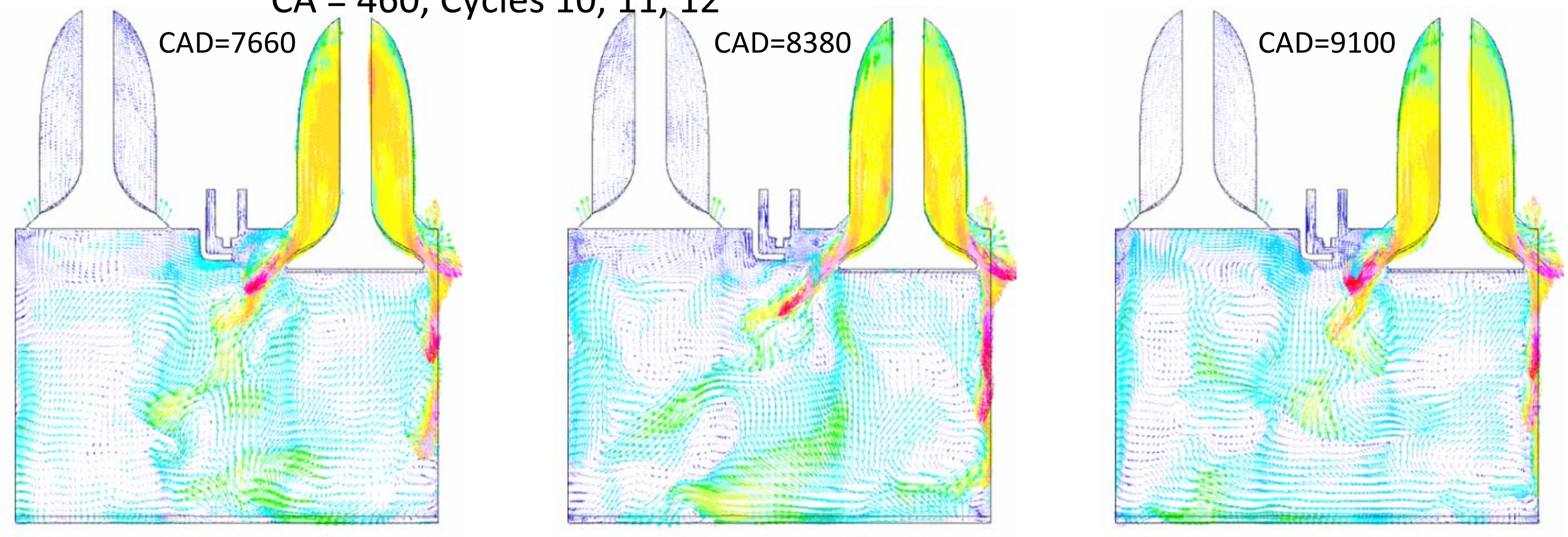


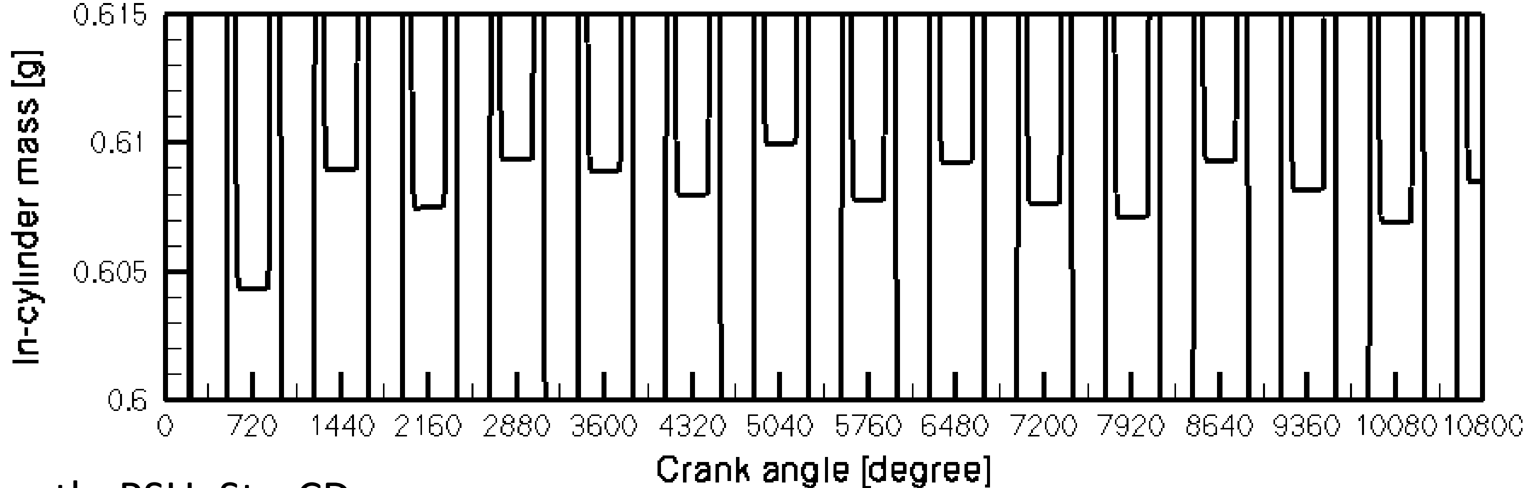
LES calculation of UM TCC Engine Using CONVERGE, X. Yang, GM; One-Equation Viscosity Model

Cycle-to-cycle variations

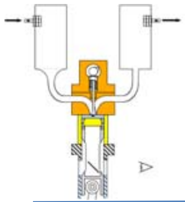
CA = 460, Cycles 10, 11, 12

~ Peak intake valve lift





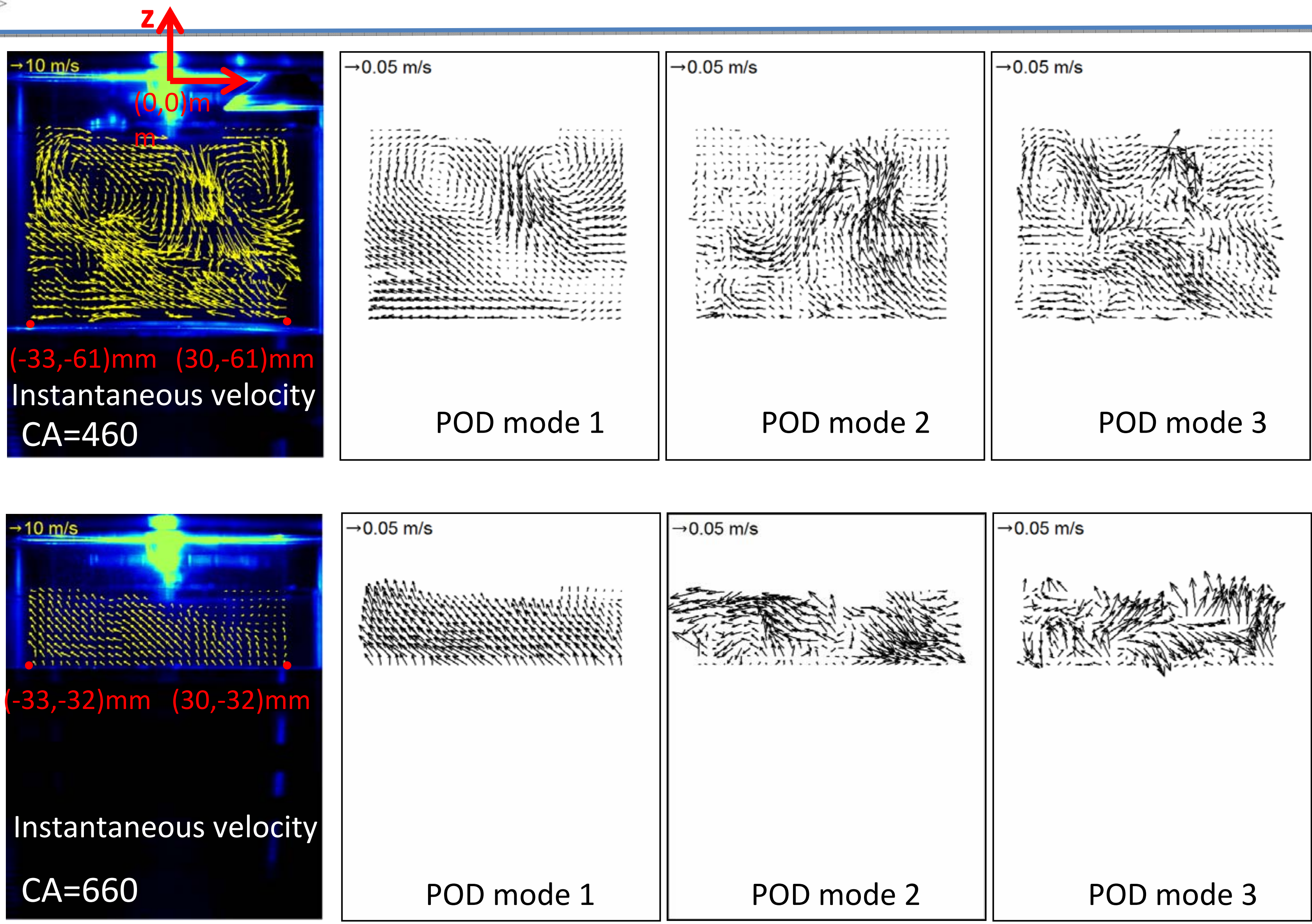
Liu & Haworth, PSU, StarCD



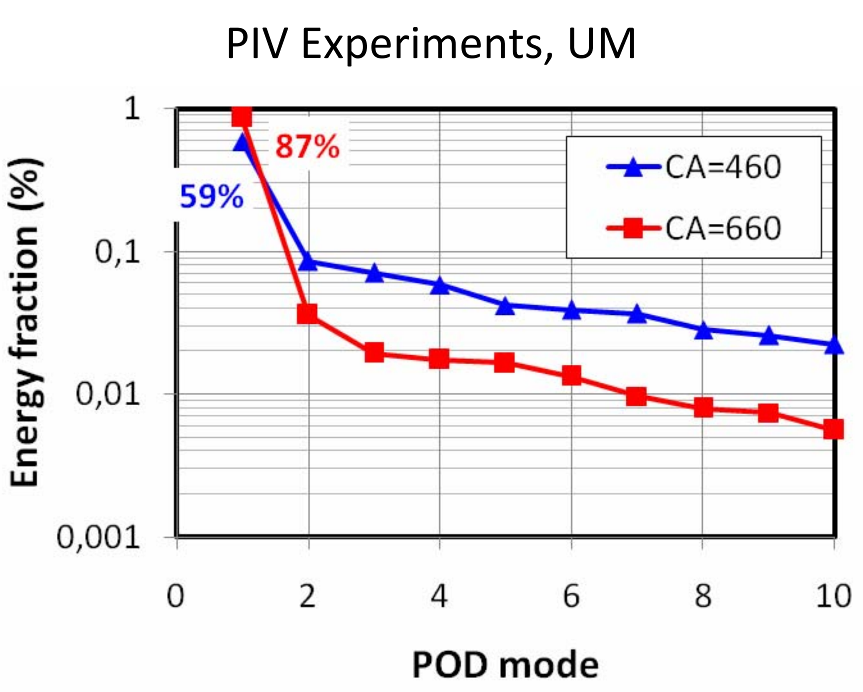
PIV examples and POD analysis

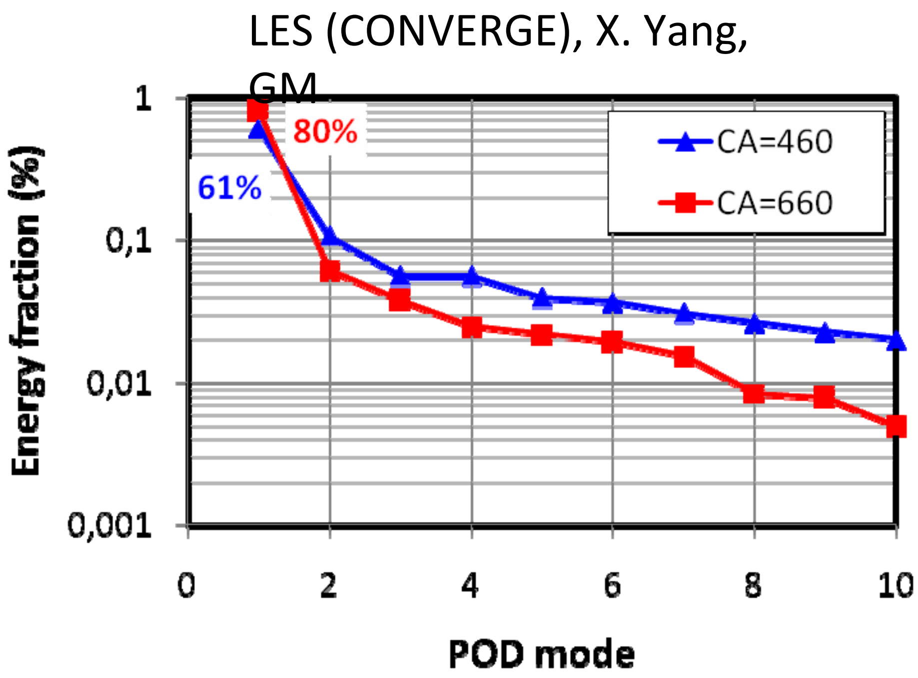
~ peak intake valve opening

during compression



POD analysis of PIV and LES

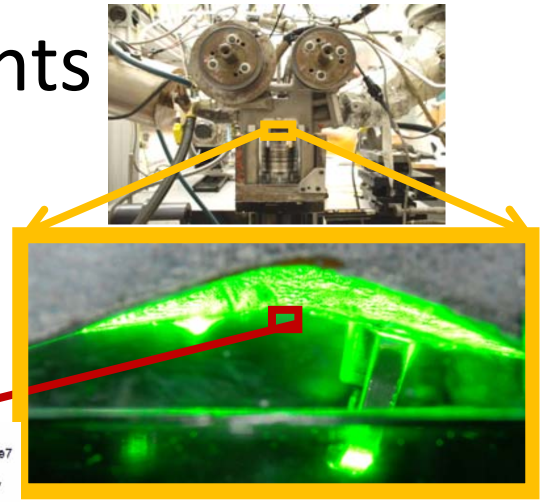




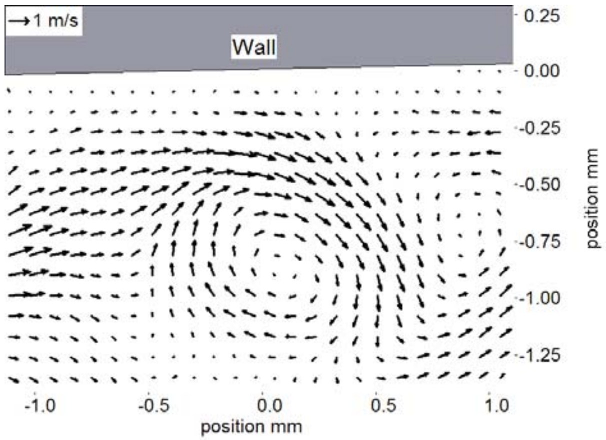
- Experimental data from 10 consecutive cycles
- LES 19 cycles

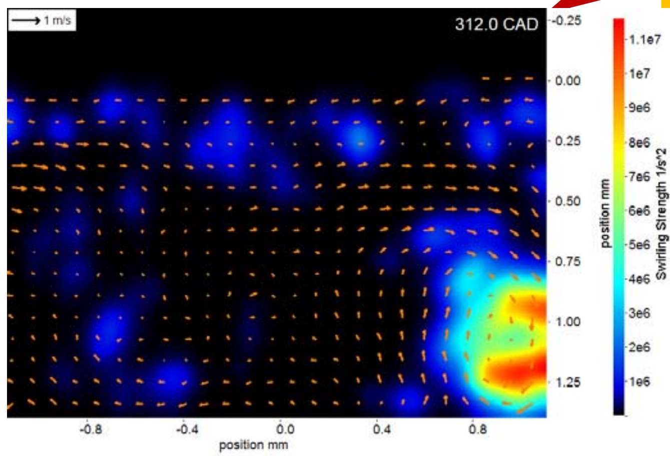
Boundary Layer Flow

- High-resolution μ-PIV measurements



- Examples from four-valve engine



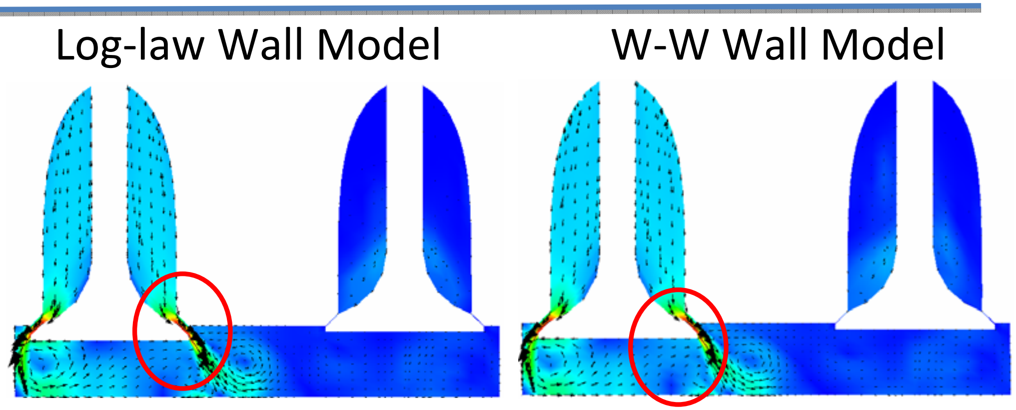


- Agreement with law of the wall is poor

Alharbi & Sick, Exp. In Fluids, 2010

Wall function model testing

- Test Werner-Wengle wall function model
- Developed for LES
- Power law profile



Maximum velocity of the intake flow:
Log-law: 94 m/s
Werner-Wengle: 102 m/s

20° ATDC

Log-Law Model (Standard KIVA)

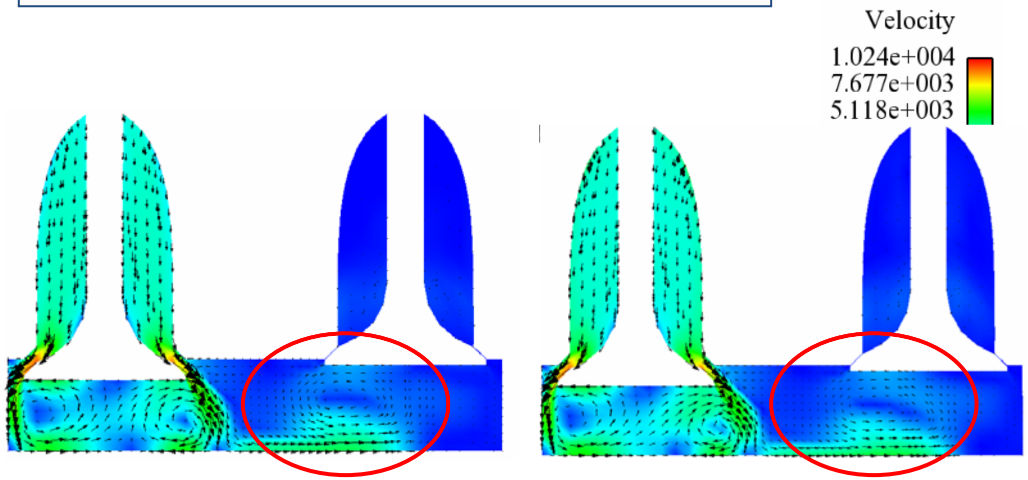
Viscous sublayer: $U^{+} = y^{+}$

Log-Law Layer: $U^{+} = 2.5 \times \ln(y^{+}) + 5.5$

Werner-Wengle (W-W) Model

Viscous sublayer: $U^{+} = y^{+}$

Outer layer: $U^{+} = A \times (y^{+})^{B}$



Slightly stronger swirl eccentricity with Werner-Wengle model

30° ATDC

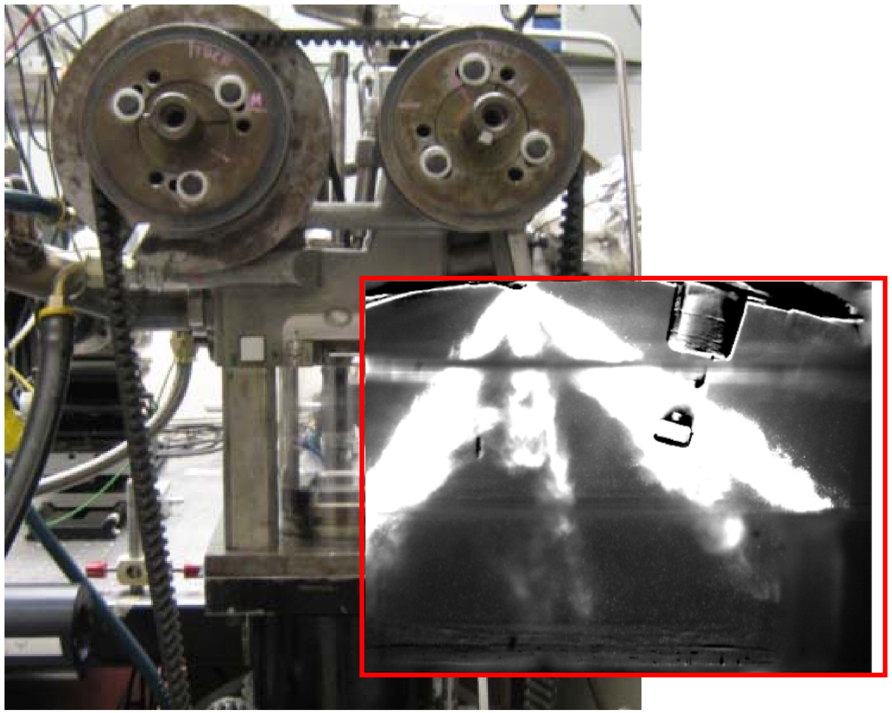
Zhang & Rutland, UW, KIVA

Summary

- Consortium effort to address needs and opportunities for developments in predictive, physics-based engine LES design tools for industrial applications
- Defined and implemented a common engine platform
- Dual optical engine facility and high-speed imaging diagnostics
- First focus on practical aspects
  - Boundary conditions
  - Data analysis methods
  - Best practices for comparison of experimental and simulation results

Outlook

- Comprehensive comparison of PIV and LES results
  - POD analysis
  - Sub model assessment
    - Boundary layers
    - ….
- Combustion studies
  - TCC engine
  - Four-valve DI engine



Engine details

Valves	1 intake, 1 outlet
Spark plug	Central
Compression ratio	10 (geom.), 8.1 (eff.)
Speed	<4000 RPM
Air supply	Critical orifice air control
Fuel supply	Premixed (future)
Bore/stroke	92 mm / 86 mm