Homogeneous Charge Compression Ignition (HCCI) R&D

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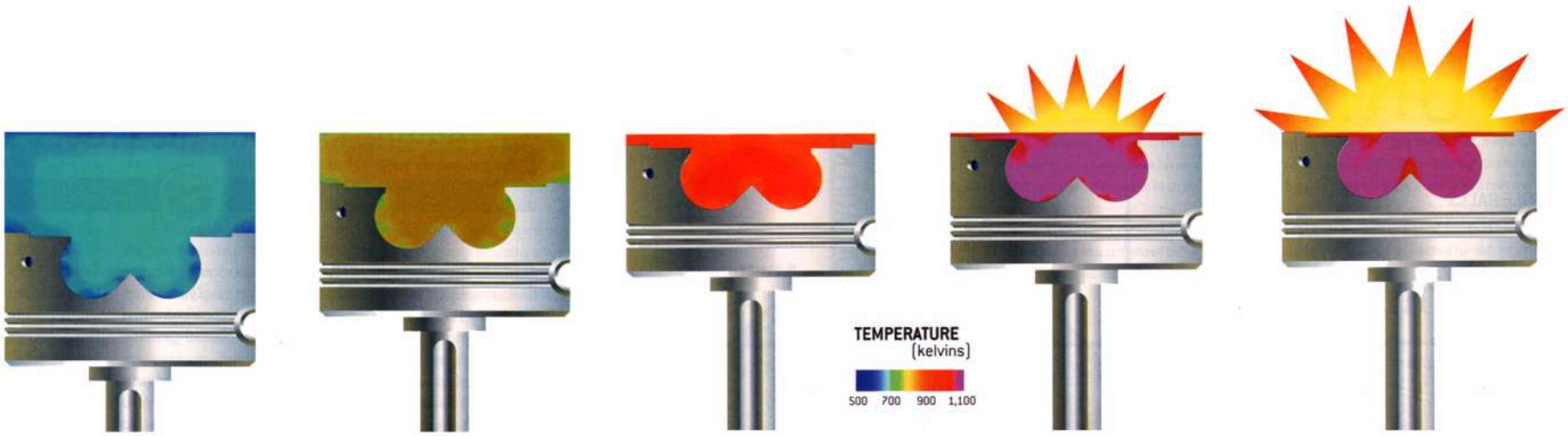


LLNL HCCI combustion simulation results for thermal autoignition of the fuel during compression.

Scientific American, June 2001

Objectives:

Develop a new combustion system that can provide the high efficiency and durability of diesel engines with very low NOx and particulate matter emissions.

Plans:

Find inexpensive, practical solutions for the problems of HCCI engines:

- **control**
- **multi-cylinder balancing**
- **high HC and CO emissions**
- **low power output**
- **startability**

We are addressing the problems of HCCI combustion through a combination of analysis and experiments

Control:

- Detailed analysis of possible control strategies
- Experimental testing
- Additives

Multi-cylinder balancing:

- Achieved balanced combustion in VW TDI engine

High HC and CO emissions:

- Detailed analysis for optimized engine geometry

Low power output:

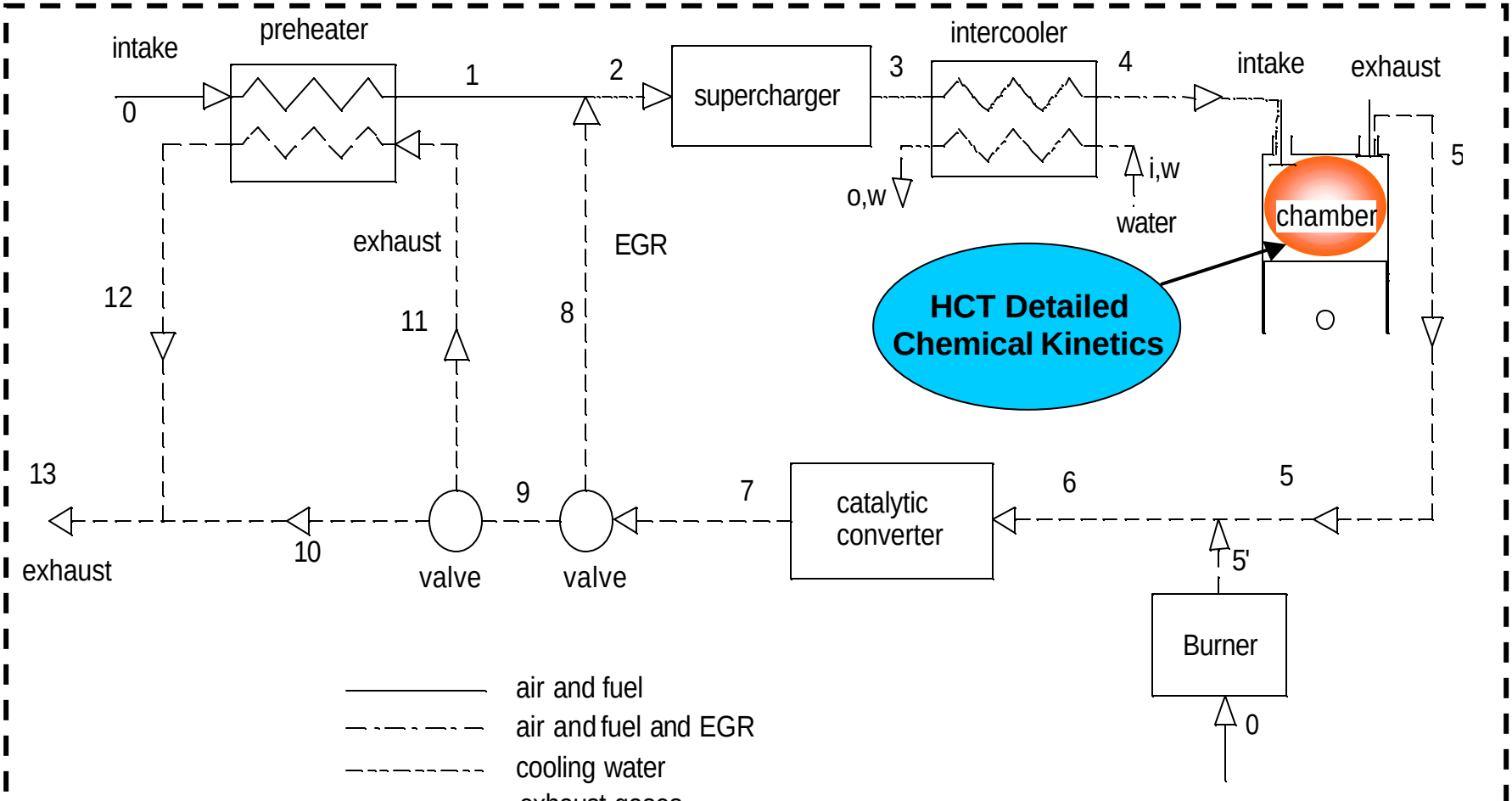
- Optimization of engine performance map
- Transition to SI/CI combustion

Startability:

- Analysis of transition between SI/CI and HCCI combustion

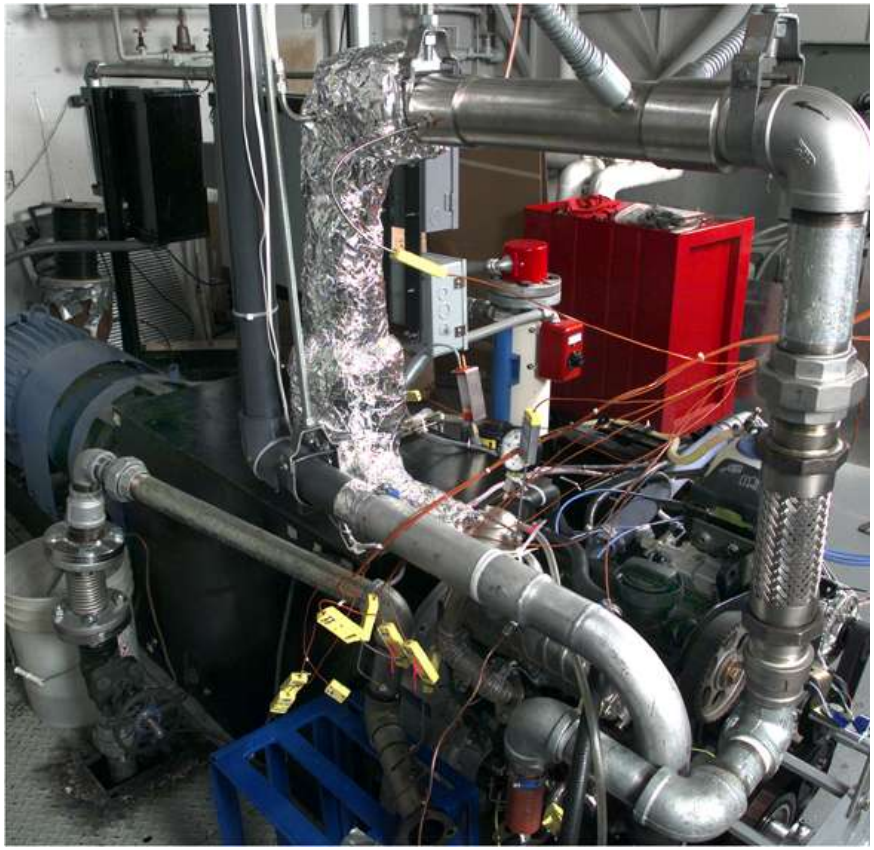
We have analyzed potential methodologies for control of HCCI combustion (SAE 2000-01-2869)

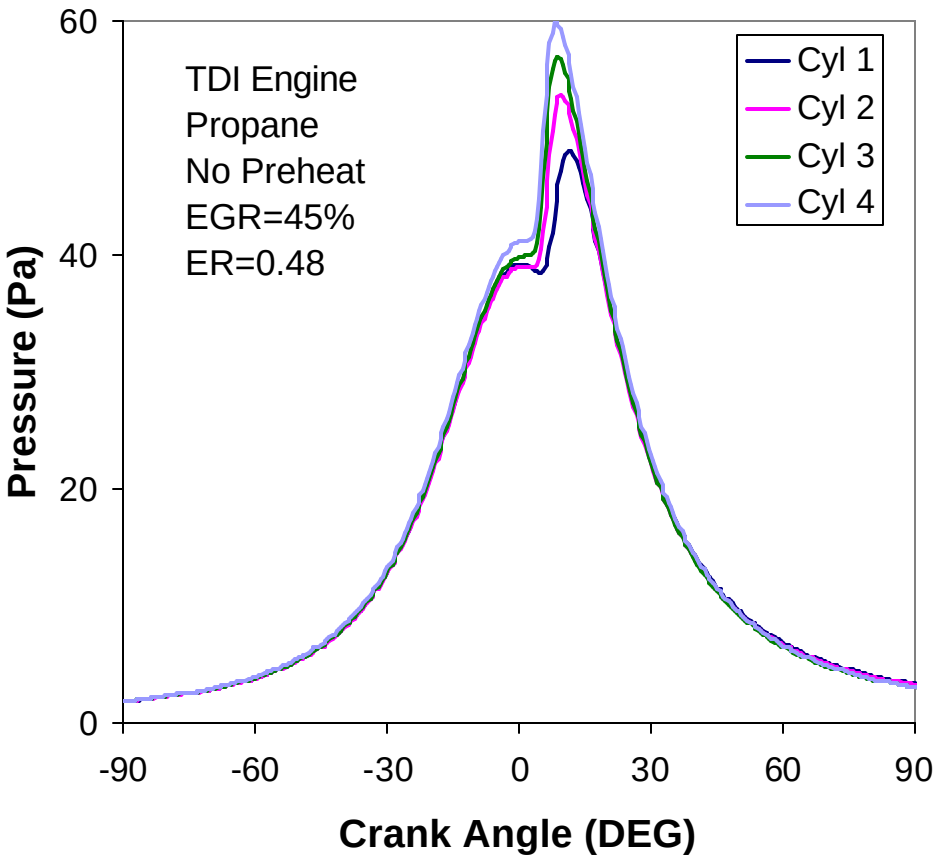
Example of thermal control system



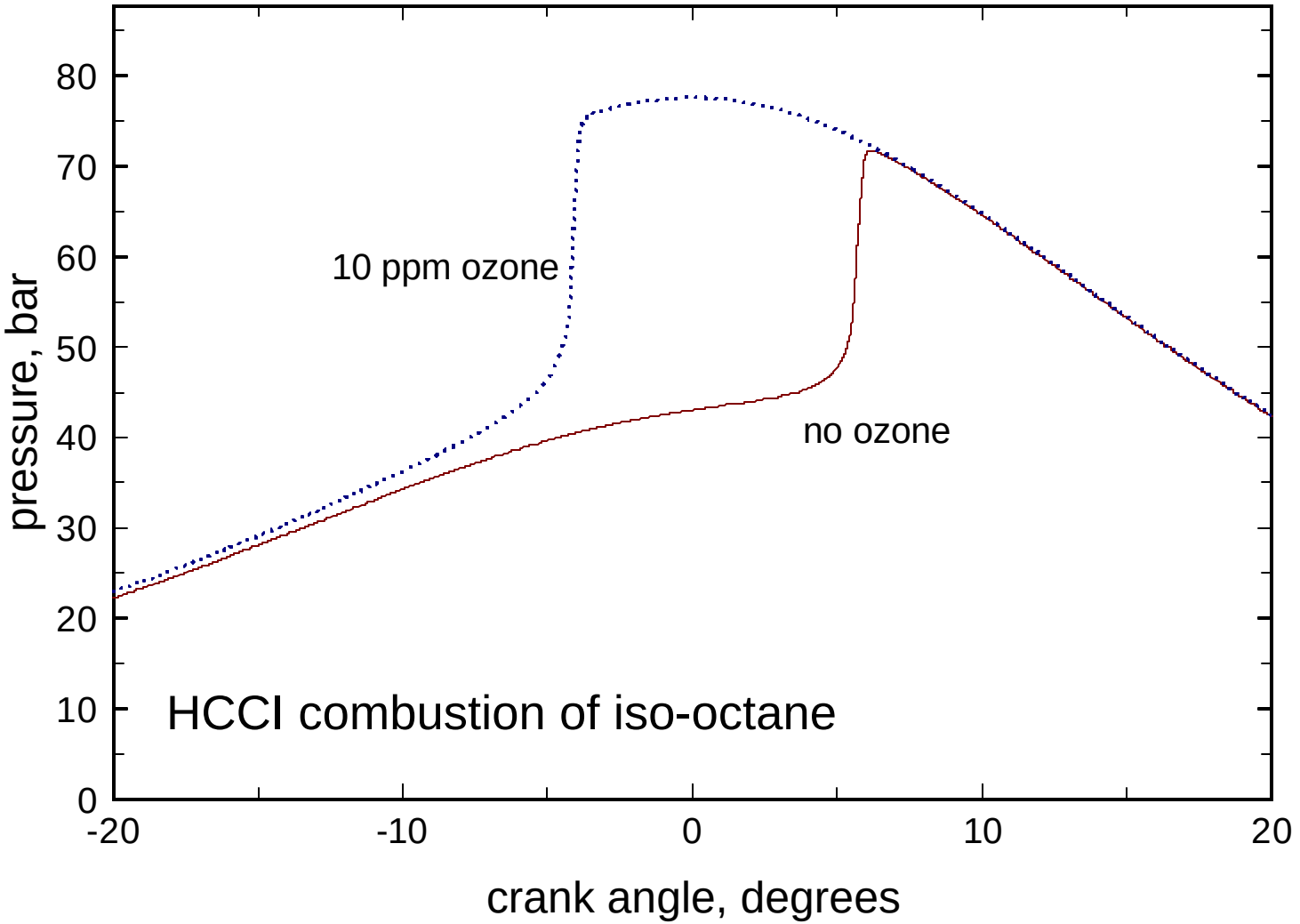
SuperCode Optimization

We have successfully operated the TDI engine with an EGR-equivalence ratio control with no intake heating

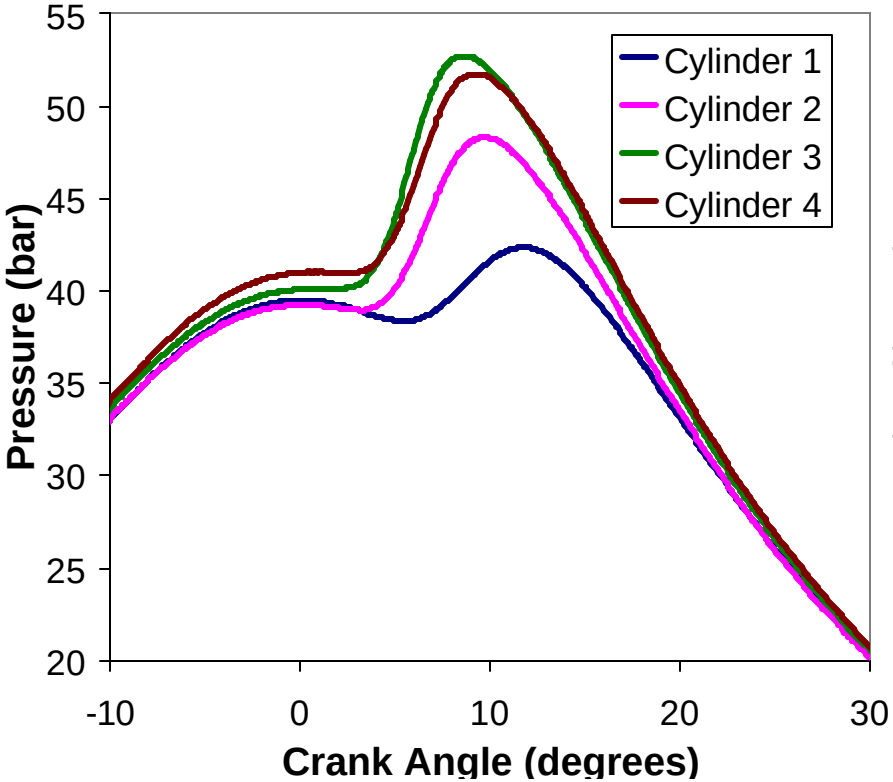


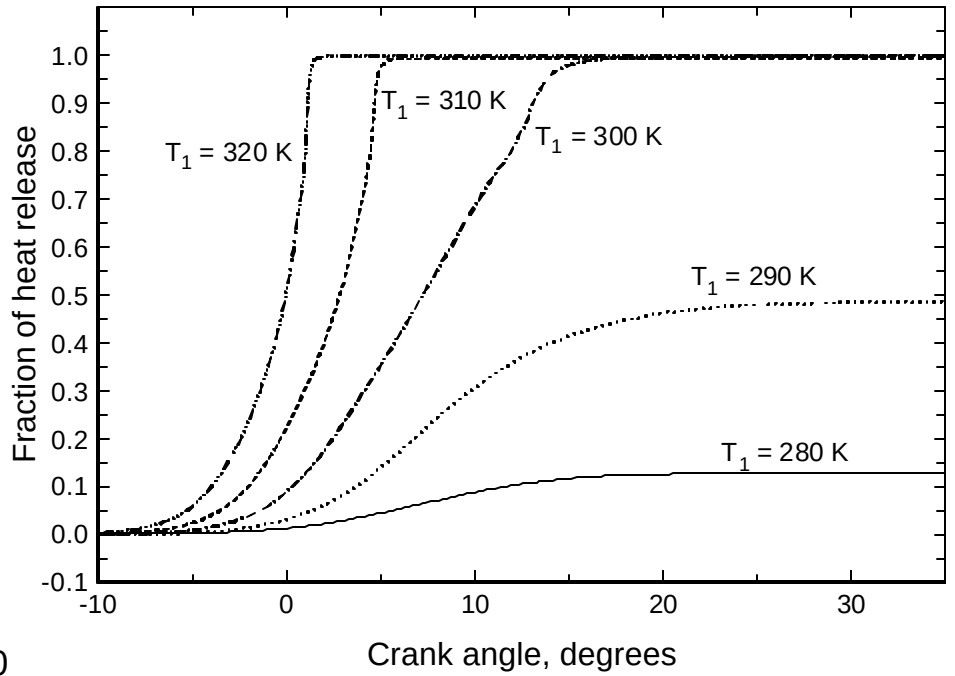


We are looking at the use of additives for control of HCCI engines



Control of multi-cylinder HCCI engines is a challenge

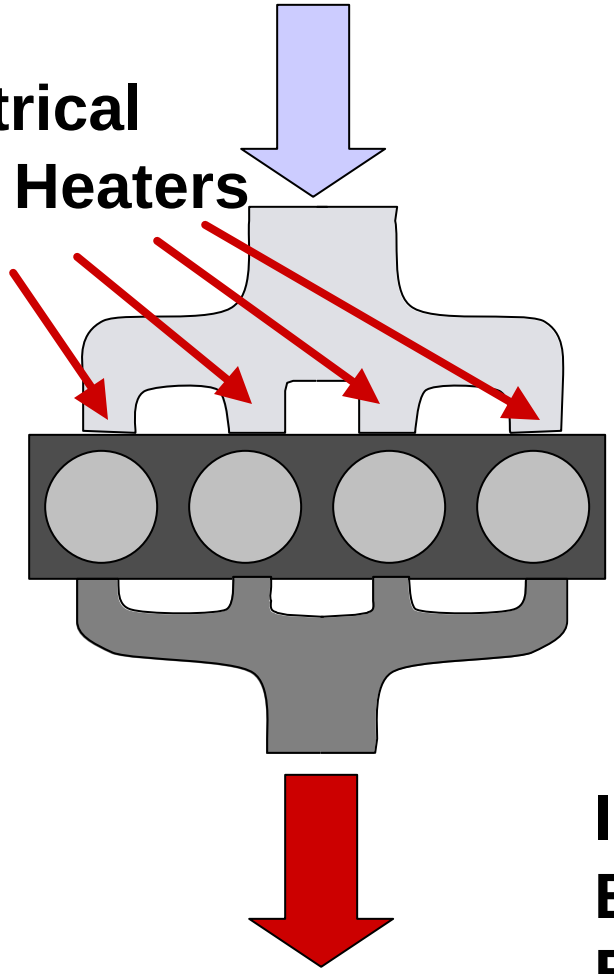


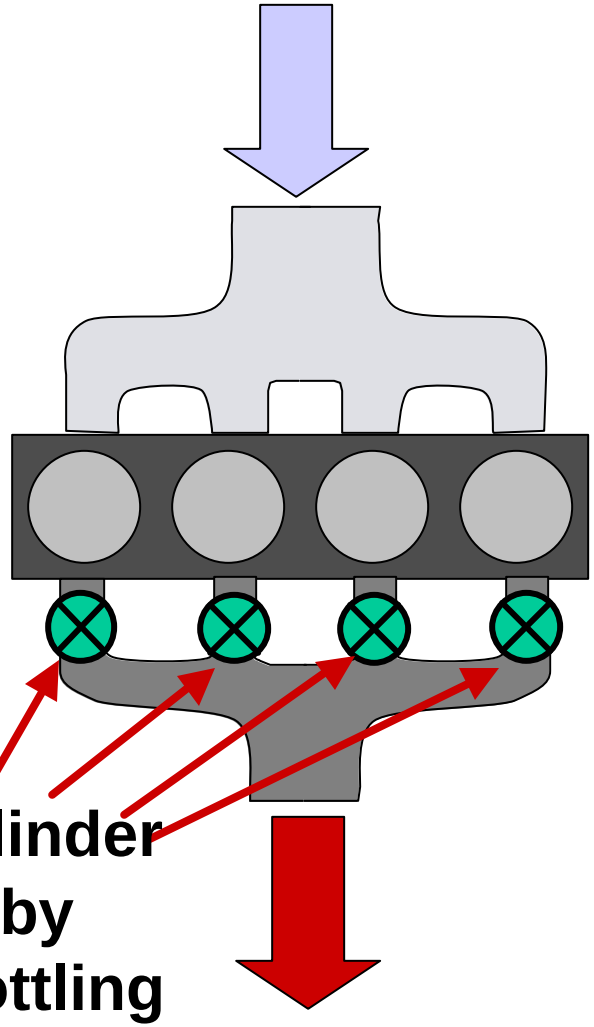


We are exploring many means of cylinder-by-cylinder timing control

Control systems are being implemented for two generic, low cost control options:

Electrical Trim Heaters

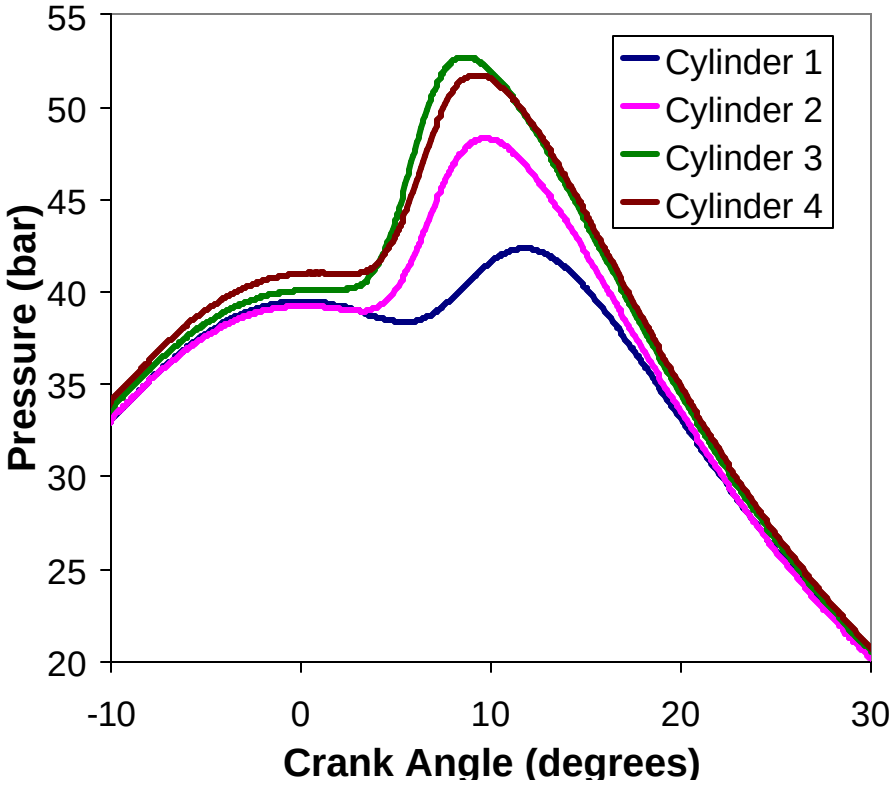




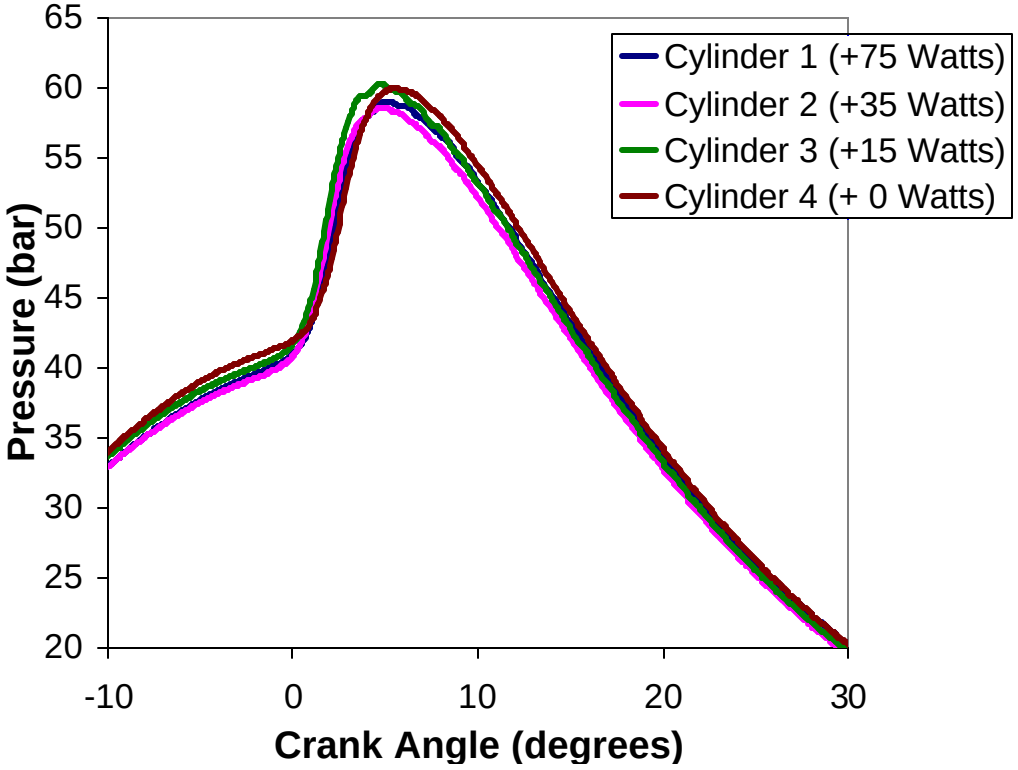
Individual cylinder EGR Control by Exhaust Throttling

Multi-cylinder engine operation requires balancing of combustion timing between cylinders

Trim heaters using less than 1% of mechanical energy output can effectively balance the cylinders in steady operation

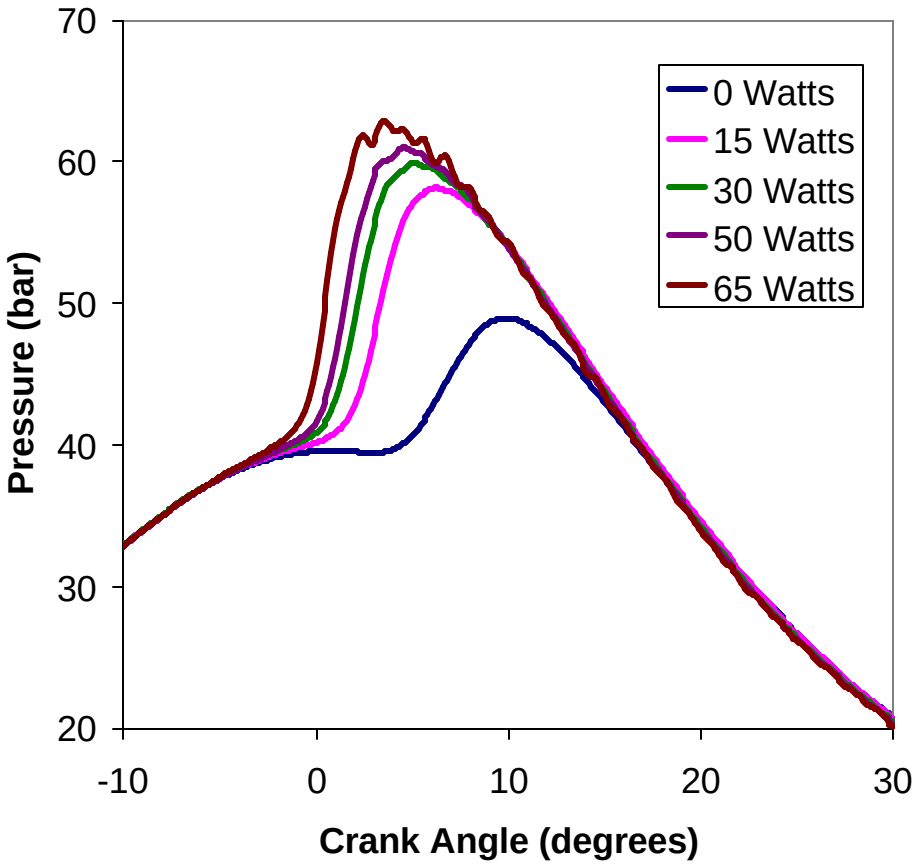


Unbalanced

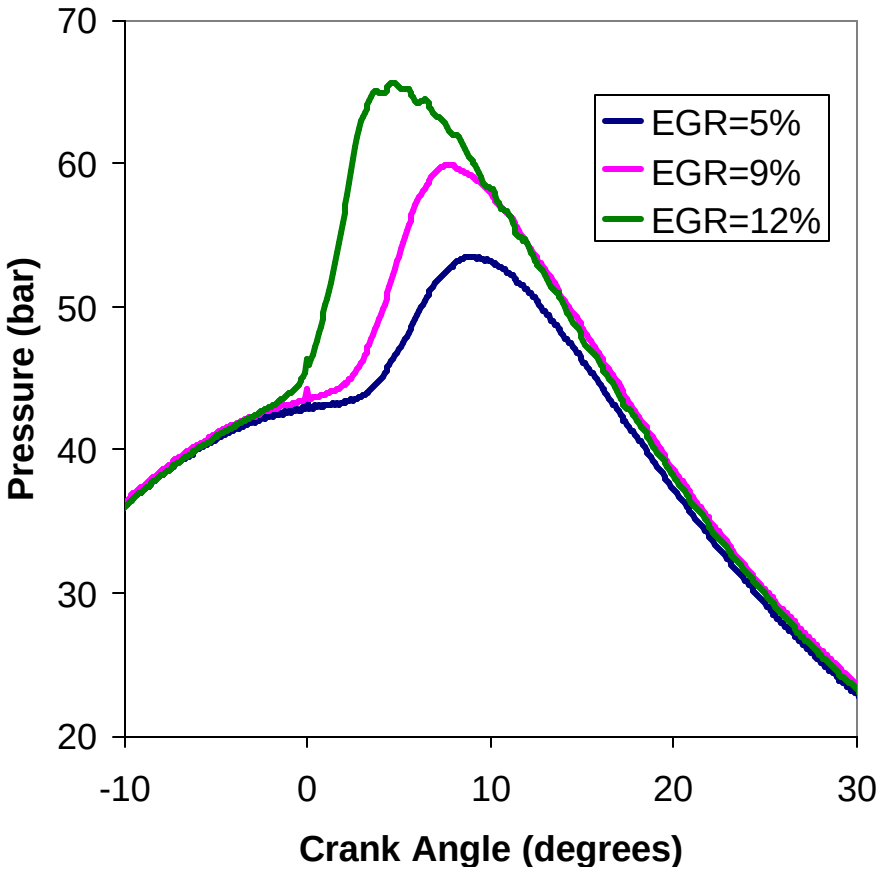


Balanced

We have successfully demonstrated two possible means of individual cylinder combustion timing control

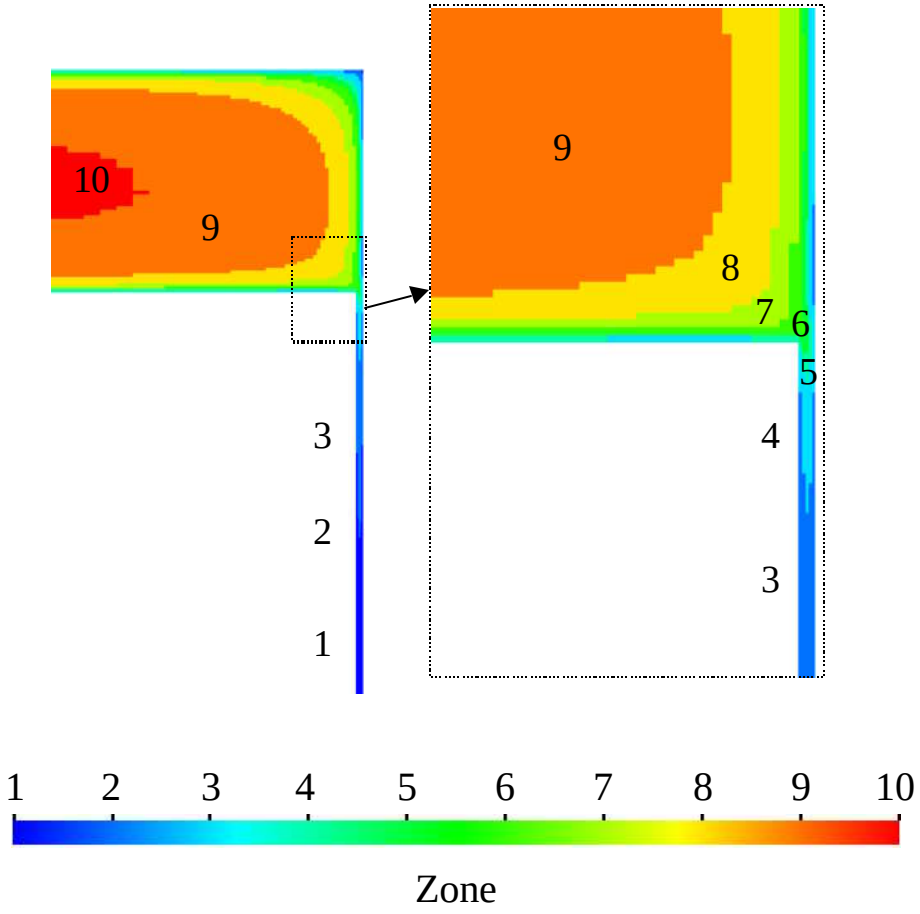


Timing Control with Trim Electrical Heater

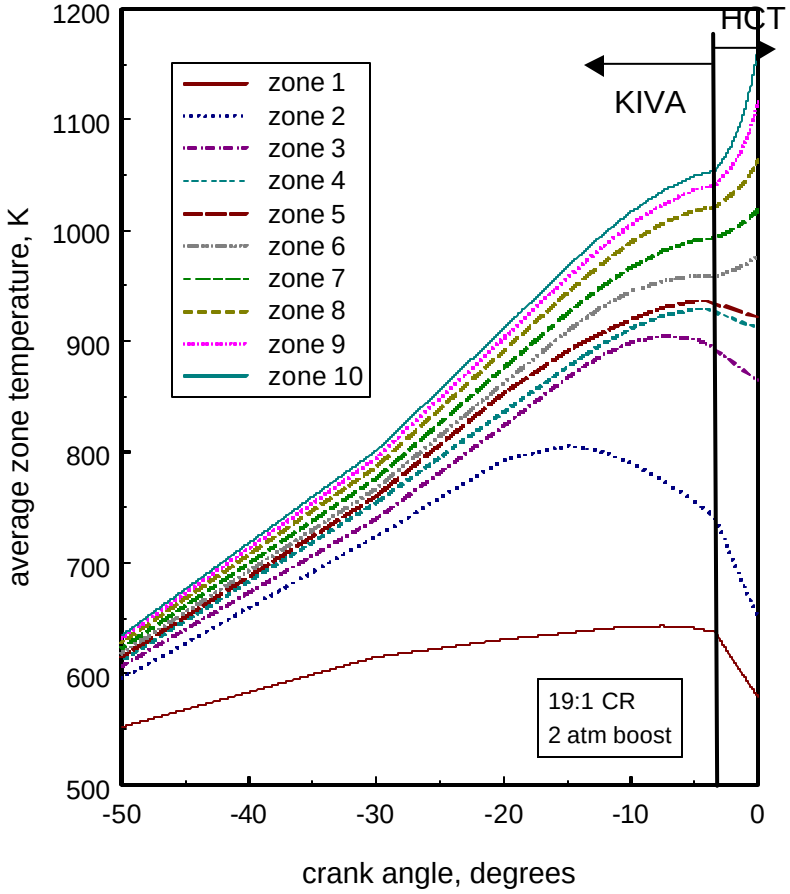


Timing Control with Exhaust Throttle EGR

Our multi-zone methodology can successfully predict geometry effects on HC and CO emissions



Location of isothermal zones in cylinder (SAE 2000-01-0327)



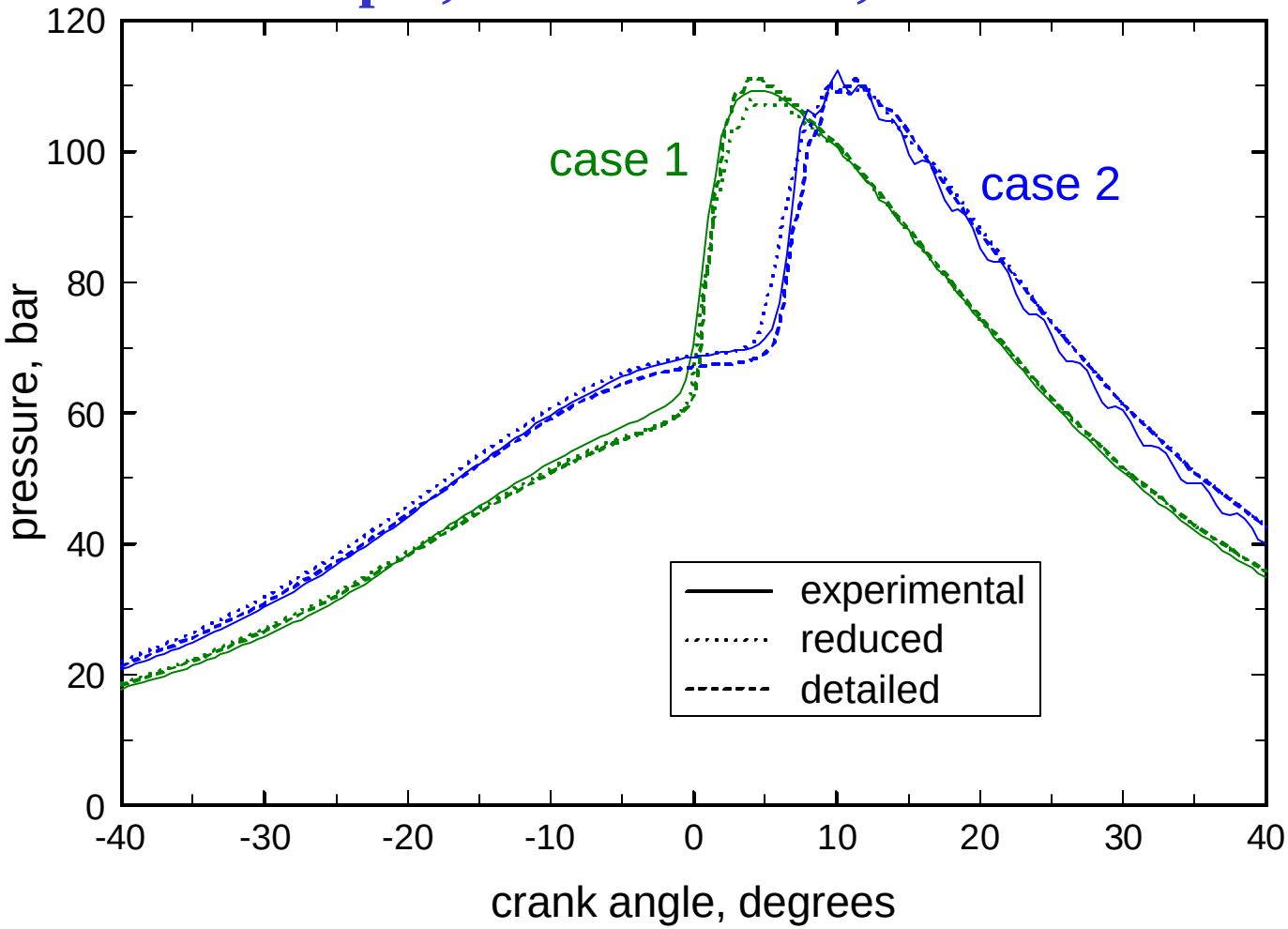
Temperature history of 10 zones during compression stroke

Our multi-zone model generates accurate predictions for HCCI combustion

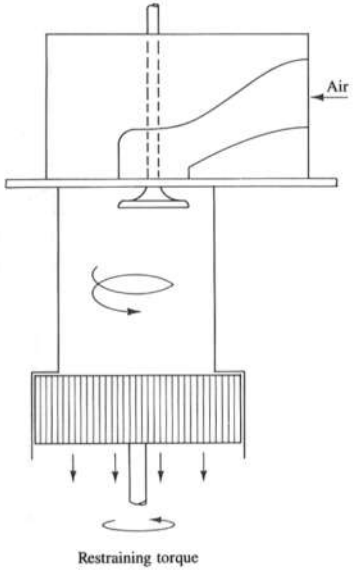
Iso-octane data from Cummins

Case 1: 1010 rpm, 2.41 bar intake, f=0.346

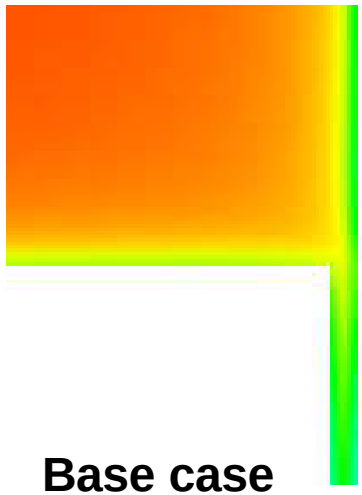
Case 2: 2007 rpm, 3.11 bar intake, f=0.348



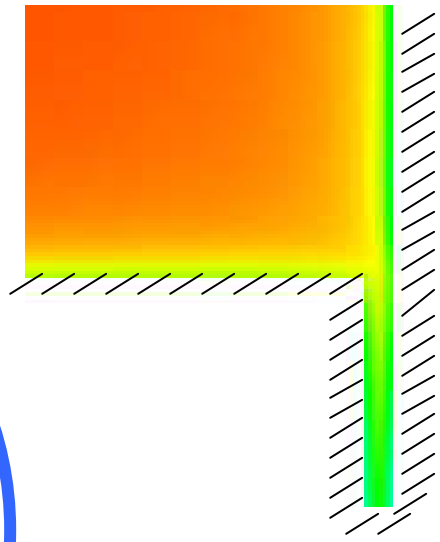
We have applied the multi-zone methodology to four engine designs to evaluate their effect on emissions



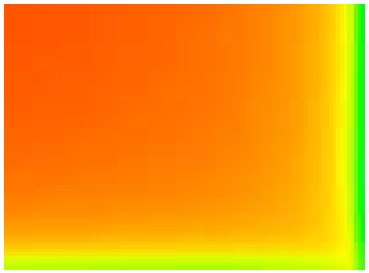
Low swirl
(0.43 vs. 4.3)



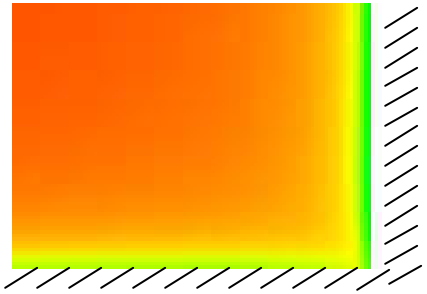
Base case



Hot wall (600K)

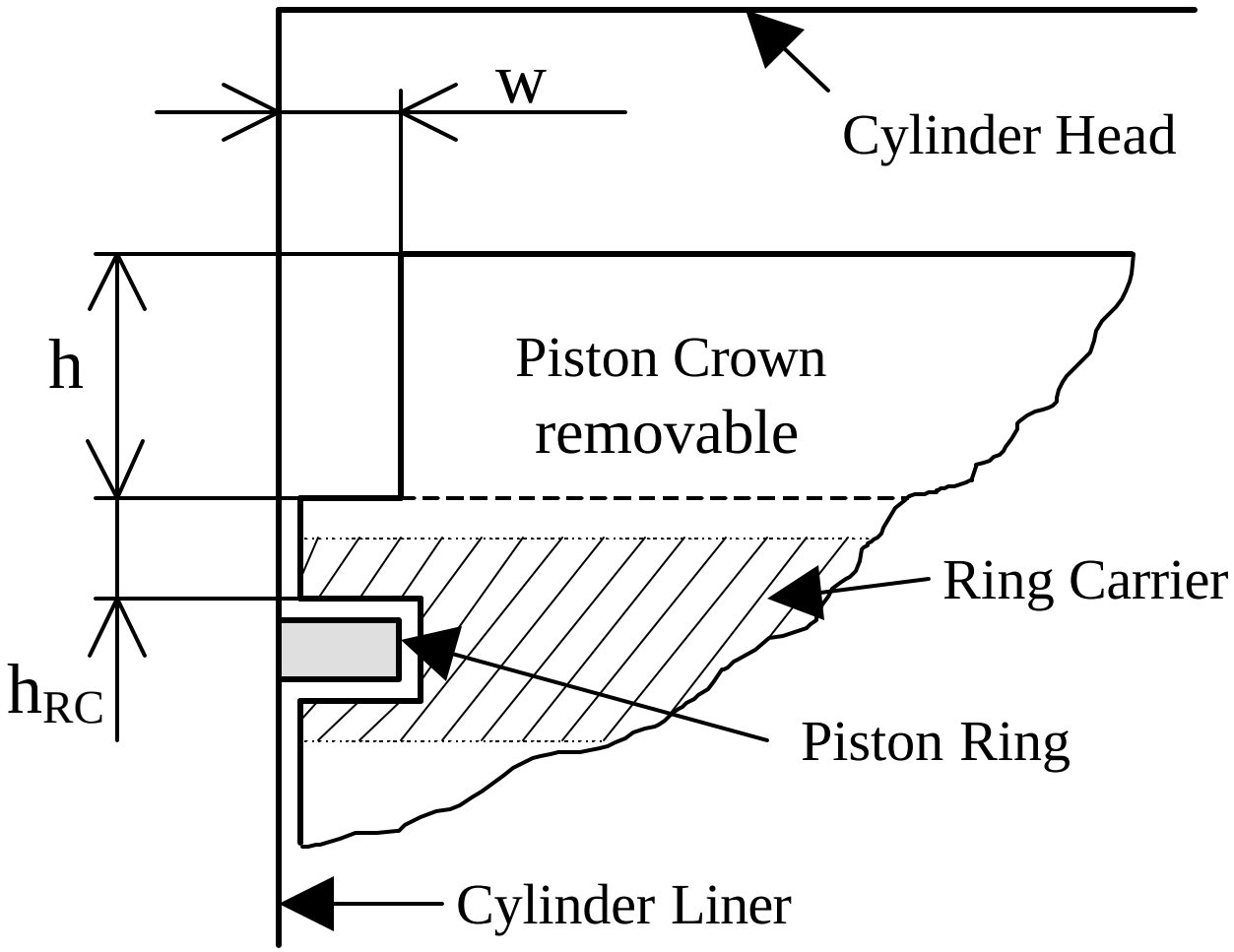


No crevice



All — Low swirl, hot wall, no crevice

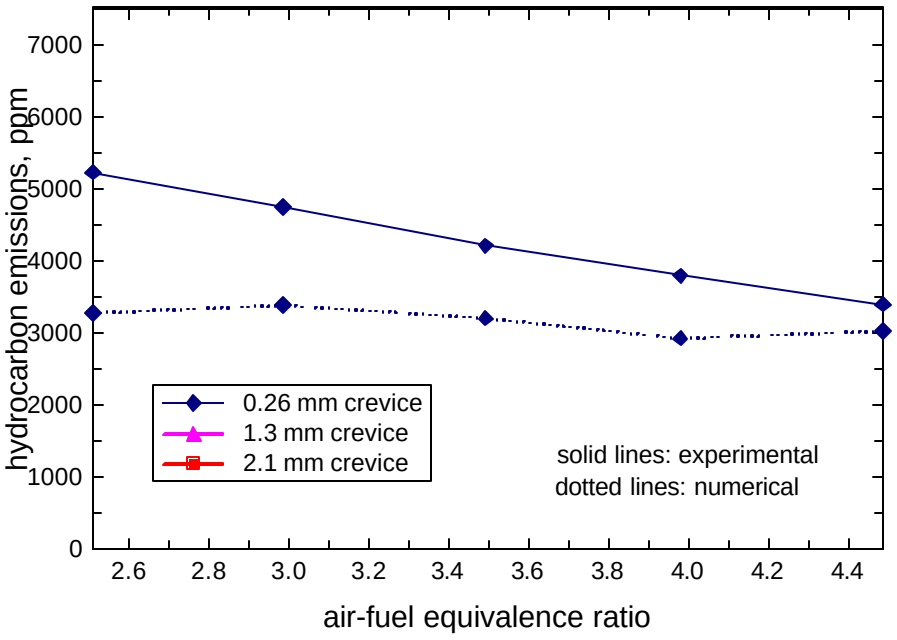
We have analyzed three engine geometries experimentally tested at the Lund University

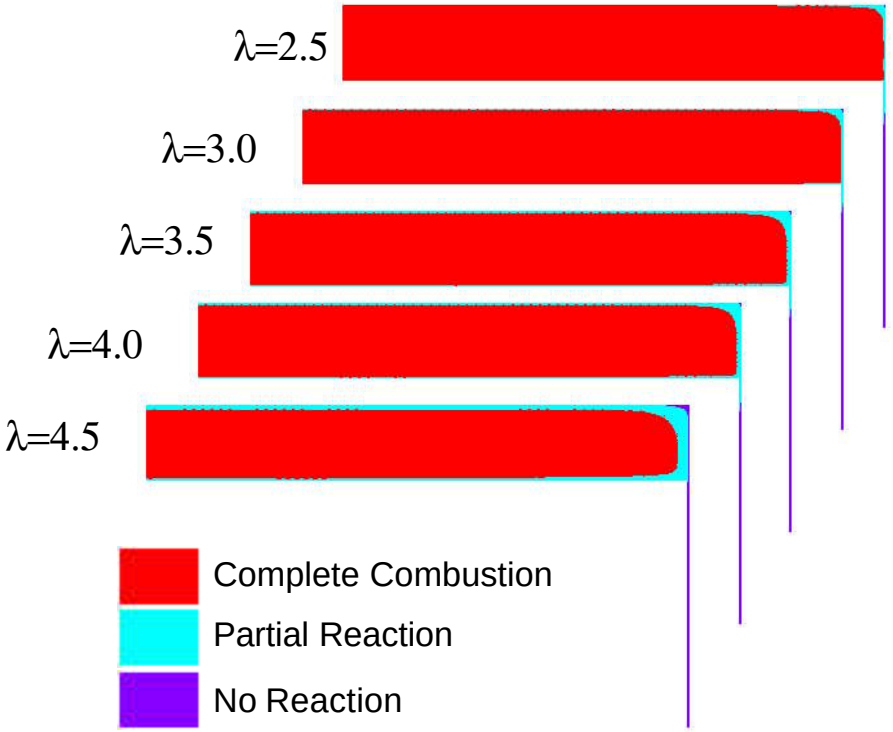


Crevice width w=0.26 mm, 1.6 mm and 2.1 mm

Constant compression ratio 17:1

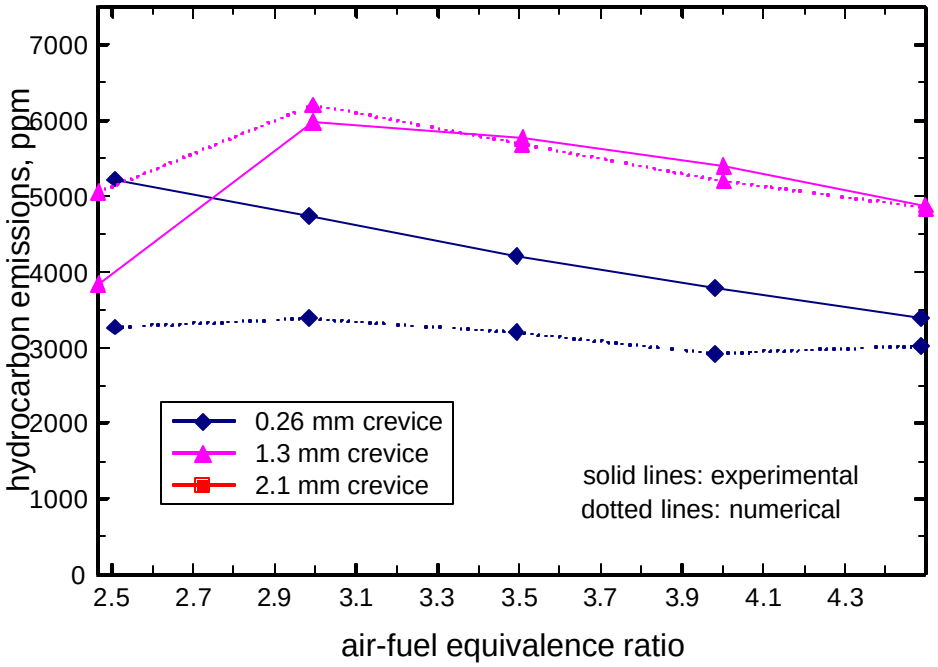
Our analysis can explain the non-monotonic behavior in HC emissions as a function of equivalence ratio

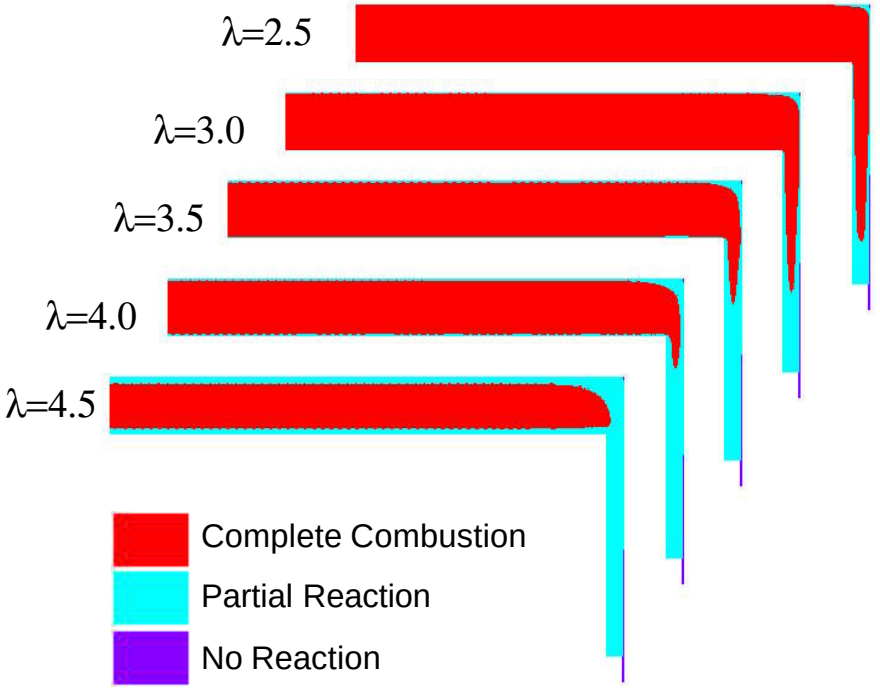




Engine with narrow crevice
0.26 mm

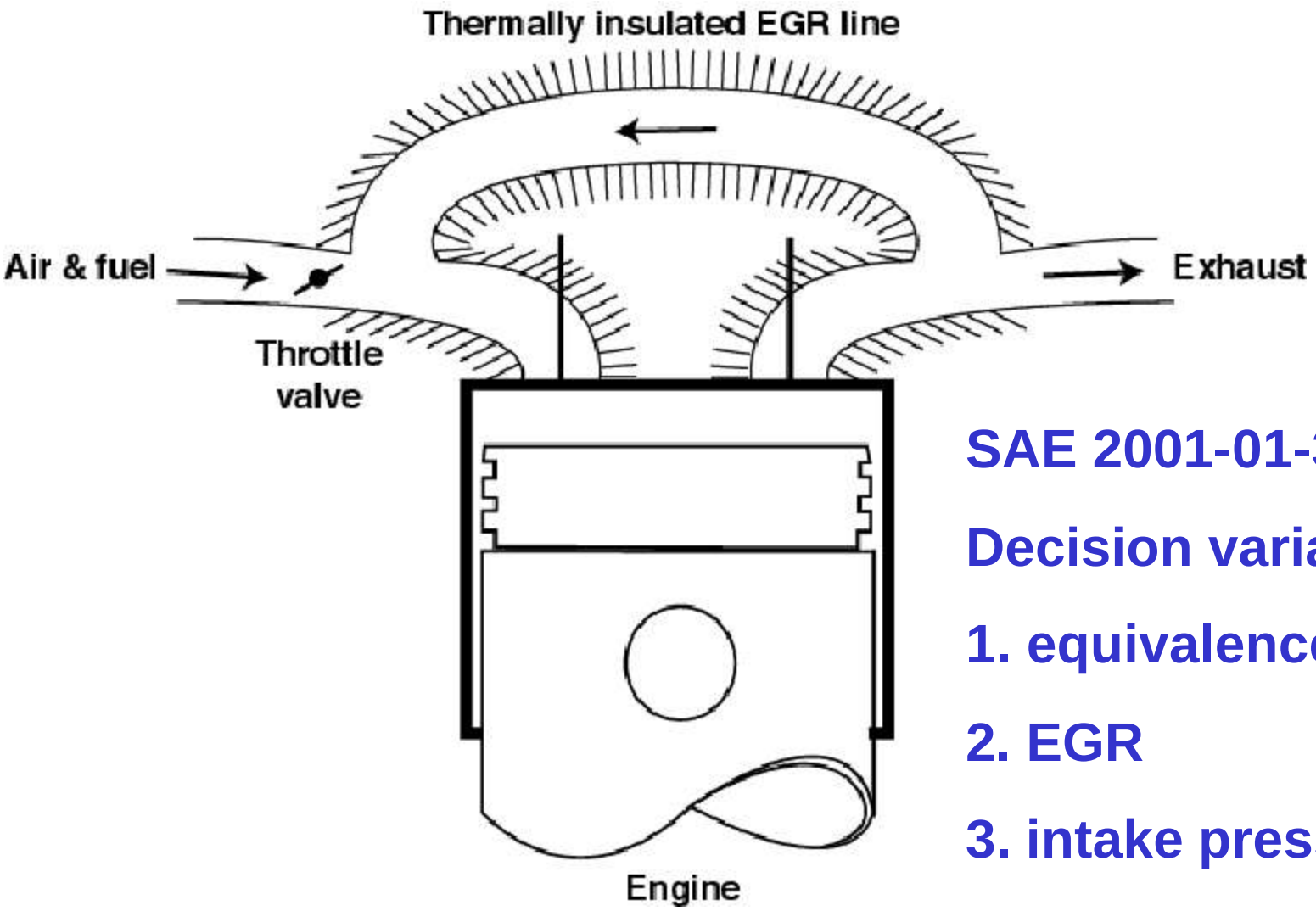
Our analysis can explain the non-monotonic behavior in HC emissions as a function of equivalence ratio





Engine with wide crevice

We have applied the system simulation and optimization tool to evaluate transition between HCCI and SI ignition



SAE 2001-01-3613

Decision variables:

1. equivalence ratio

2. EGR

3. intake pressure

We are collaborating with multiple industrial and academic partners

LUND UNIVERSITY

- **Cummins**
  - 2-year long CRADA, 2 joint papers
  - working on establishing a new CRADA
- **Caterpillar**
  - donated experimental engine 3401
- **Sandia National Laboratories**
  - detailed analysis of experimental data
- **Lund Institute of Technology**
  - 2 joint papers, collaboration on analysis
- **University of Wisconsin**
  - joint work on KIVA analysis
  - 3 joint papers
- **UC Berkeley**
  - joint experimental and numerical work, 18 joint papers
  - four graduate students obtaining degrees on HCCI

HCCI roadmap