Low-Temperature Combustion for High-Efficiency, Ultra-Low Emission Engines

University Consortium

University of Michigan
Massachusetts Institute of Technology
Stanford University
University of California, Berkeley

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12th Diesel Engine-Efficiency and Emissions Research (DEER) Conference
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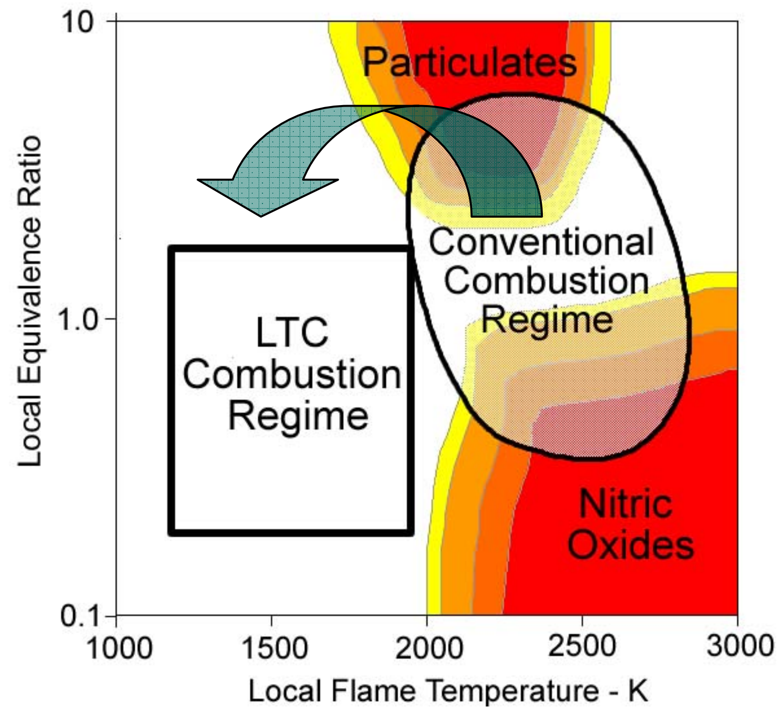
Big Picture

- HCCI university consortium concentrated on
  - developing workable control systems
  - obtaining experimental data
  - developing analytical tools to optimize and assess implementation ideas
- LTC university consortium will focus on
  - extending the practical operating range of LTC engines at both low and high load
  - improve <u>system</u> fuel economy benefits
  - include PPCI engines and alternate fuels

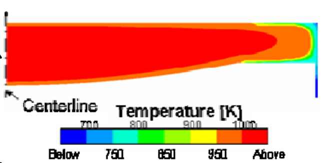
Low Temperature Combustion

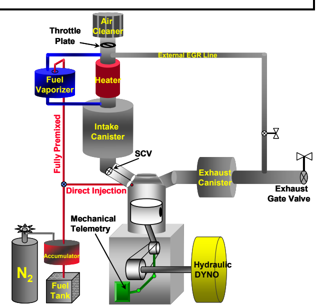
Precisely Control Combustion
to Expand LTC Operating Range

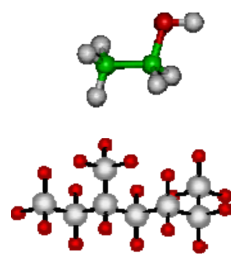
- Maintain High Thermal Efficiency
- Avoid pollution forming regimes



Physics ⟷ **Experiments Modeling** ⟷ **Chemical Kinetics**





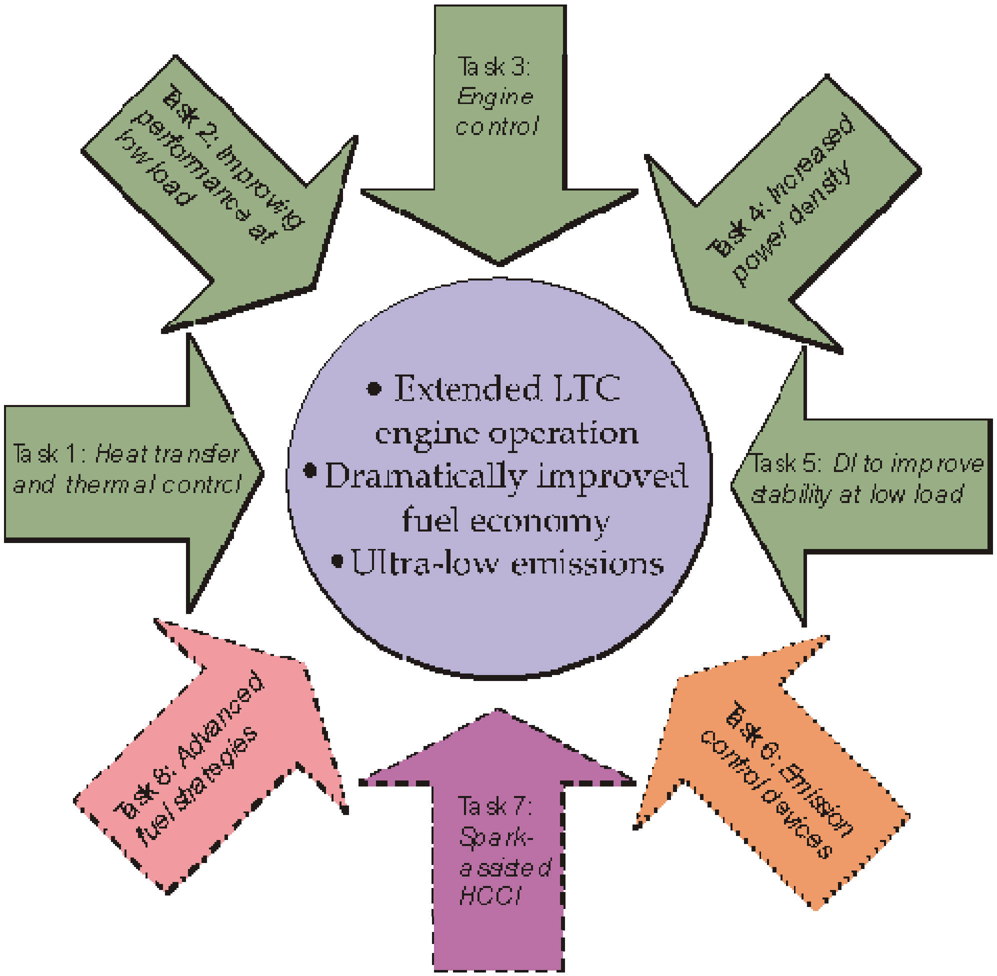


Engine System Management: Boosting; Thermal ⟷ **In-cylinder measures: Fuels, Injection; Assisted Ignition**

LTC University Consortium

LTC Consortium Tasks

1. Thermal management (UM)
2. Combustion stability at low load (UM)
3. Engine control for extended operation (MIT)
4. Increased power density (UCB)
5. DI studies for low load (SU)
6. Emission control devices for PPCI (UM)
7. Spark assisted HCCI (UM)
8. Ignition properties of alternative fuels (UM)

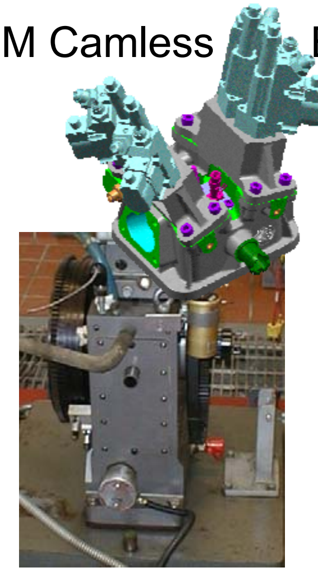


Engine University Consortium Set-Ups

UM Optical Engine

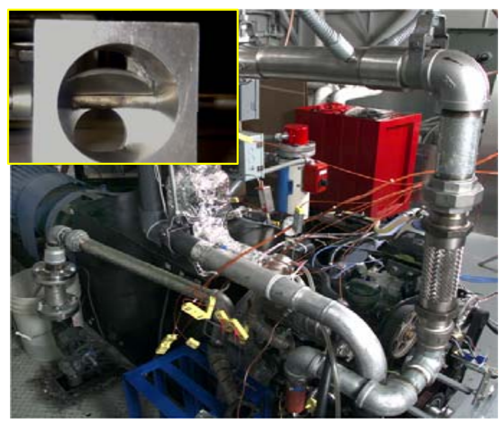
UM Heat Transfer Engine

UM Camless Engine

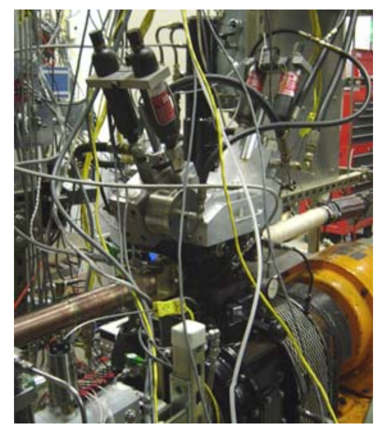


MIT Camless Engine

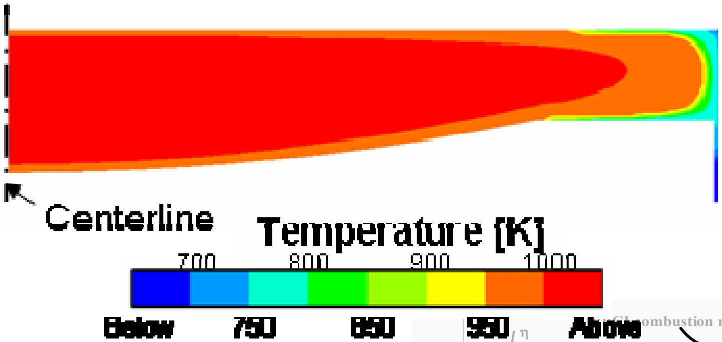
UCB Multi-cylinder engine

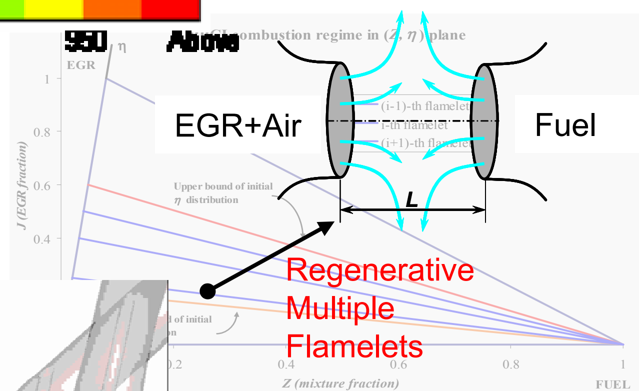


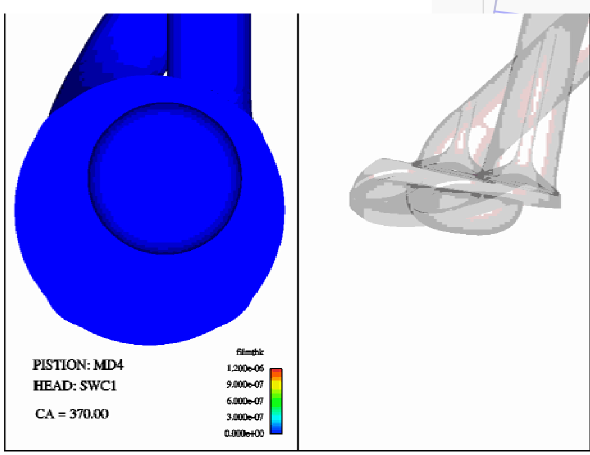
Stanford Camless Engine



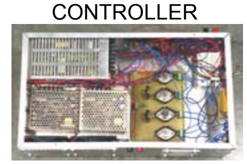
Thermal and Compositional Stratification: Near-wall Conditions and Mixture Preparation



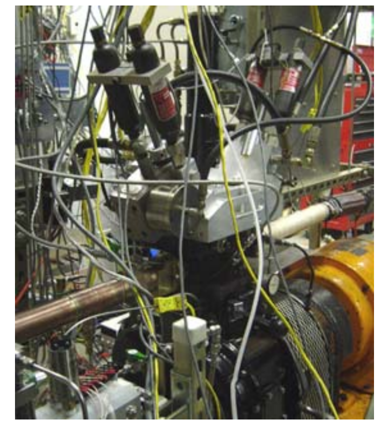




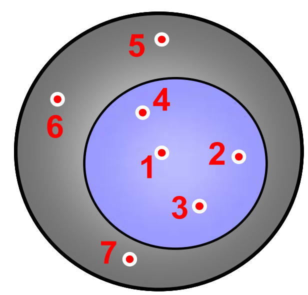
CONTROLLER

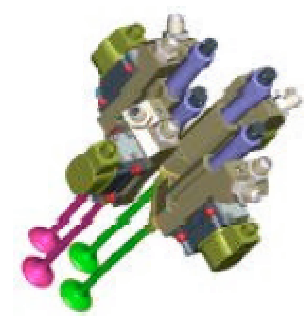


Stanford VVA engine



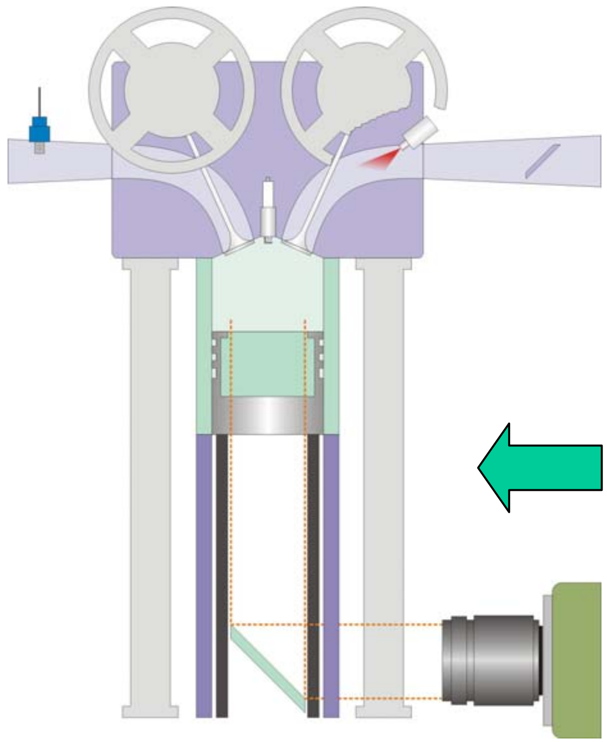
UM Heat Transfer and VVA Engine





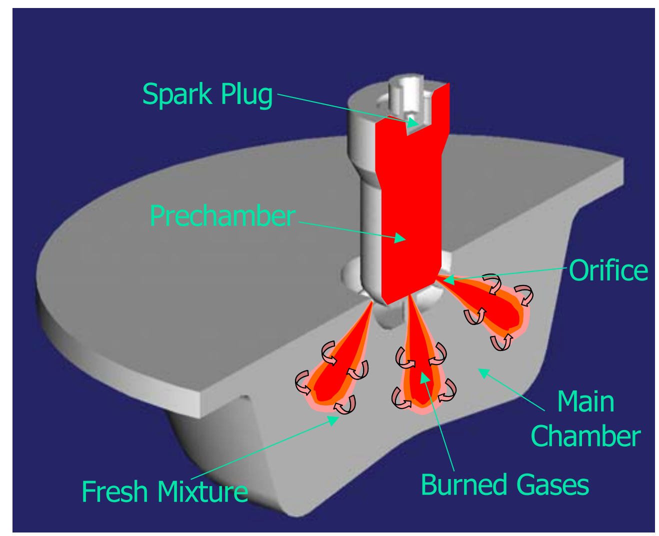
Spark-Assisted Concepts: Expand the LTC Operating Range

SA-HCCI Open Chamber

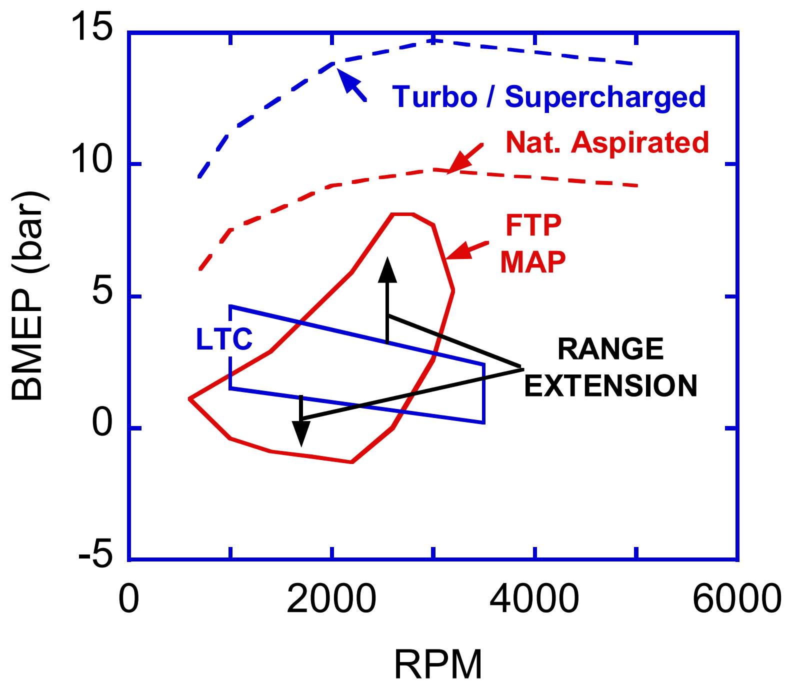


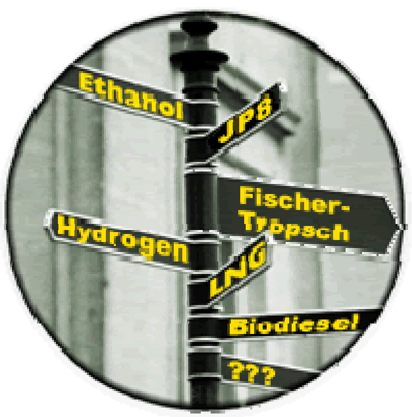
UM Optical Engine

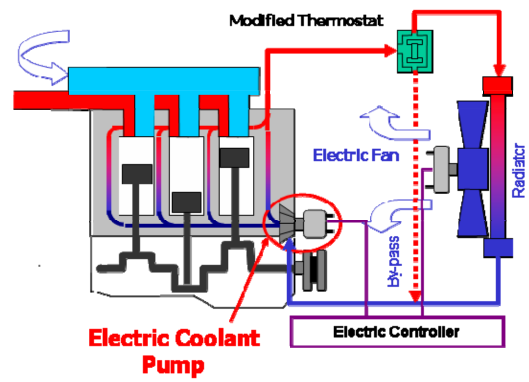
SA-Prechamber Concept



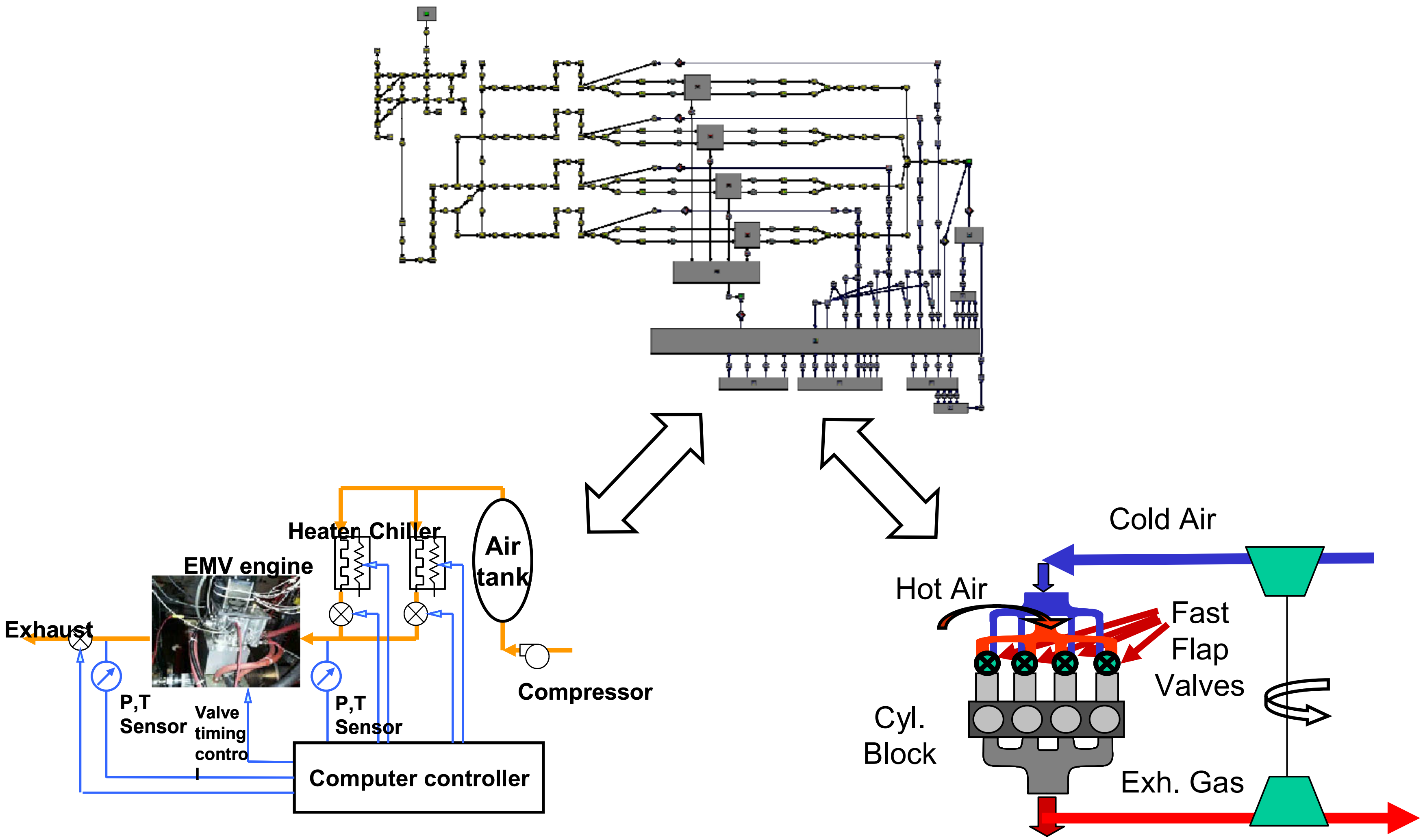
From In-cylinder to Systems





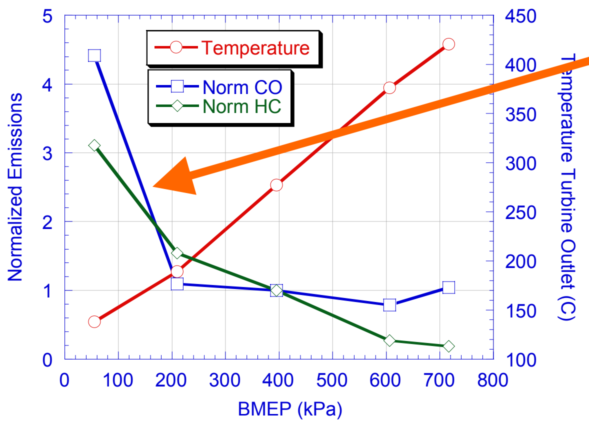


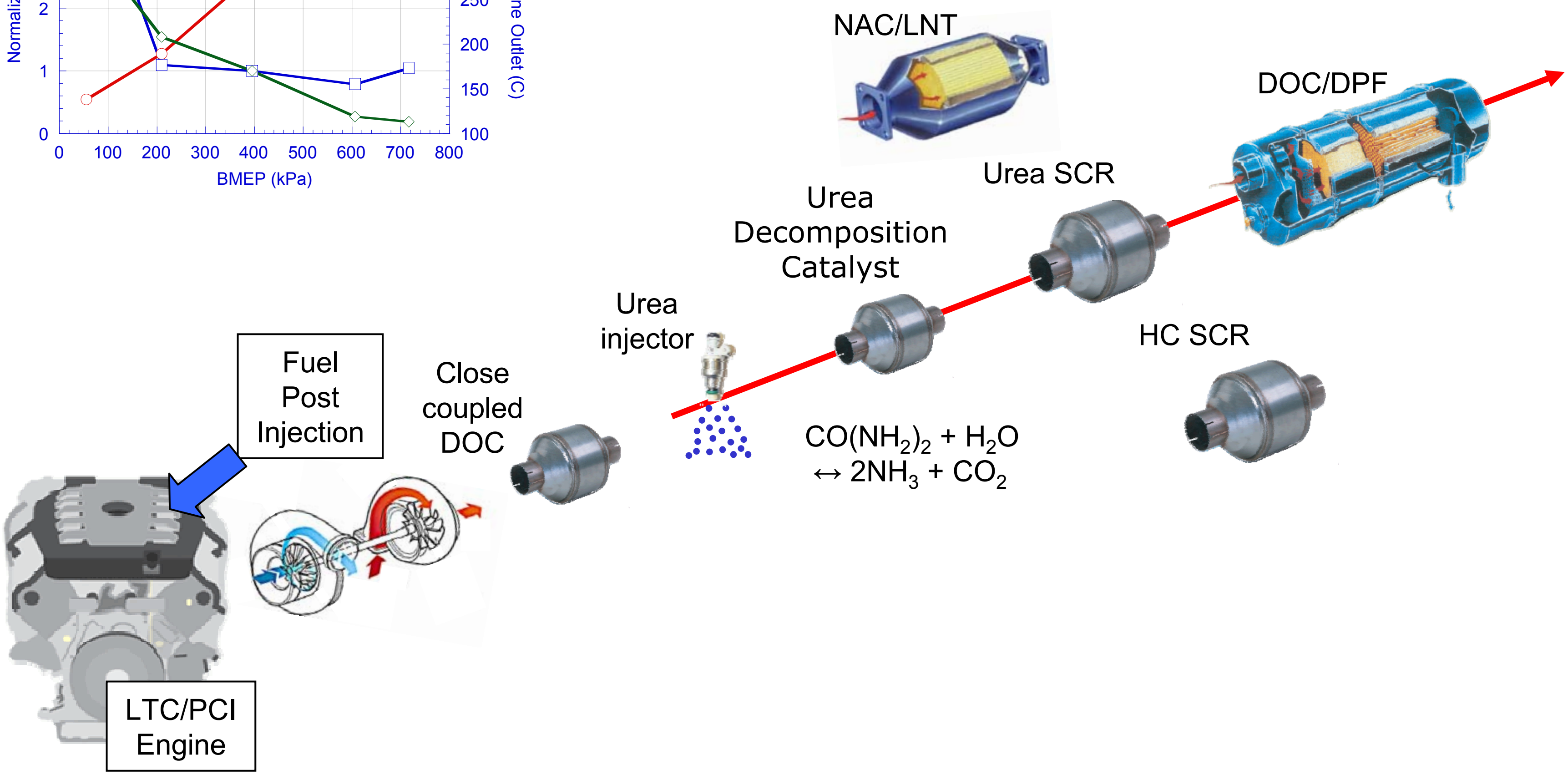
Expanding the LTC Range:
Turbo-charging and Exhaust Heat Recuperation



Aftertreatment Options for LTC Engine

Low Temperature Combustion leads to higher HC, CO

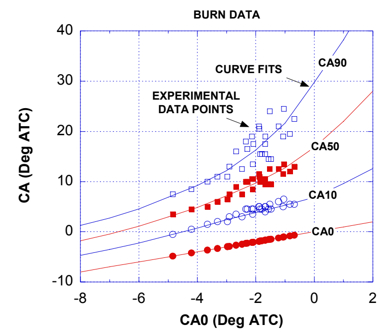




Thermal Management:
Predictive HCCI Engine System Simulation

Auto-ignition delay expression

$$\int (1/\tau_{ign})dt = 1.0 \qquad \tau_{ign} = 1.3\cdot 10^{-4}\cdot P^{-1.05}\cdot \phi^{-0.77}\cdot y_{O2}^{-1.41}\cdot \exp(33700/R\cdot T)$$



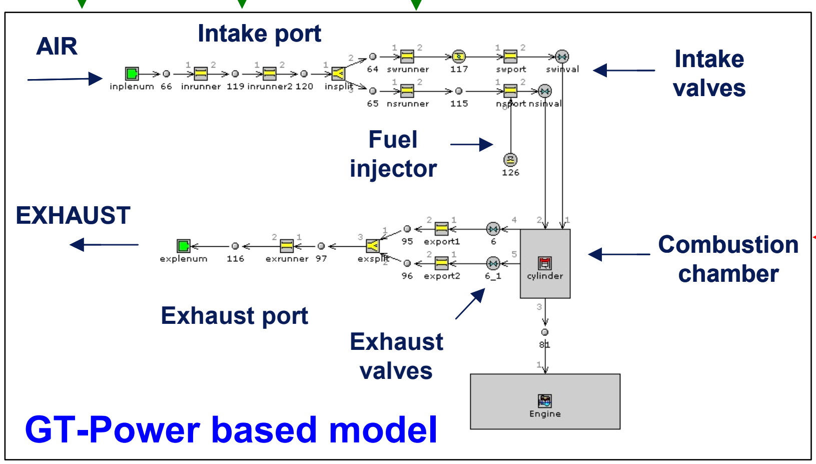
Combustion efficiency and Burn rate correlation

$$C_{eff}(\%) = \min[95.5, 92.5 - 1.1\cdot(CA0) - 0.06\cdot(CA0)^2]$$

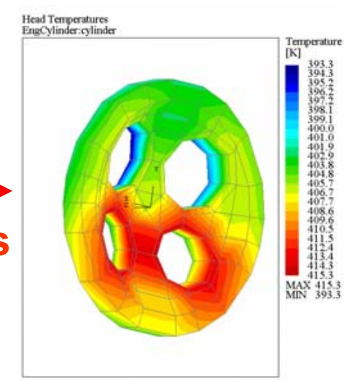
$$x = C_{eff}\cdot[1-\exp(-(\frac{CA-CA0}{\Delta\theta})^{w+1})]$$

Heat Transfer correlation

$$h(t) = \alpha_{scaling}\cdot L(t)^{-0.2}\cdot P(t)^{0.8}\cdot T(t)^{-0.73}\cdot W(t)^{0.8} \qquad W(t) = C_1 S_p + \frac{C_2}{6}\frac{V_d T_r}{P_r V_r}(P - P_{mot})$$

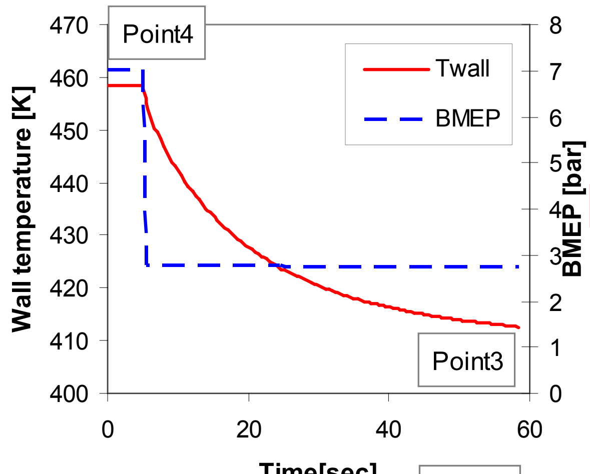


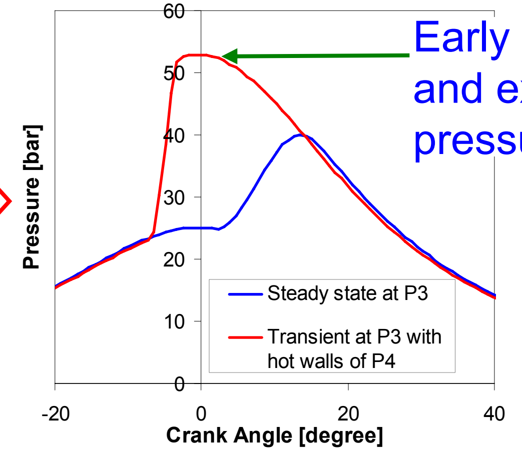
Finite Element Analysis of Wall Temperatures



Thermal Management: Wall Temperature Effects

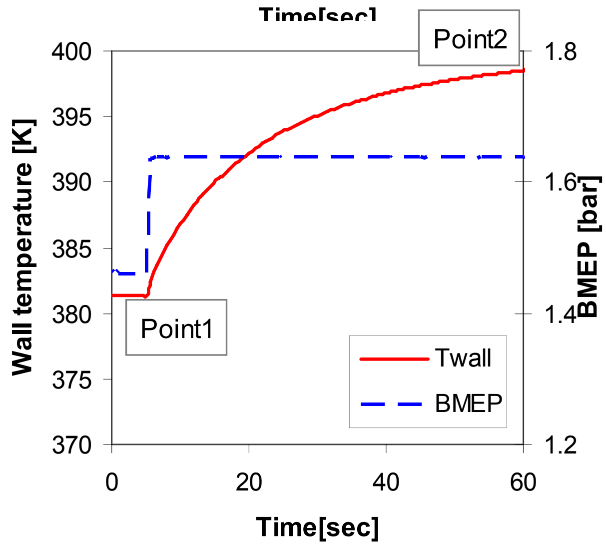
Hot to cold





Early ignition timing and excessive pressure rise rate

Cold to hot



Misfire

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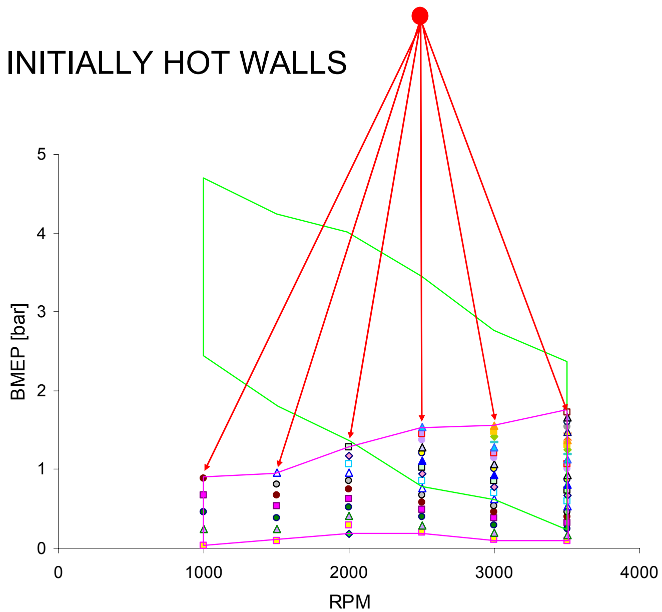
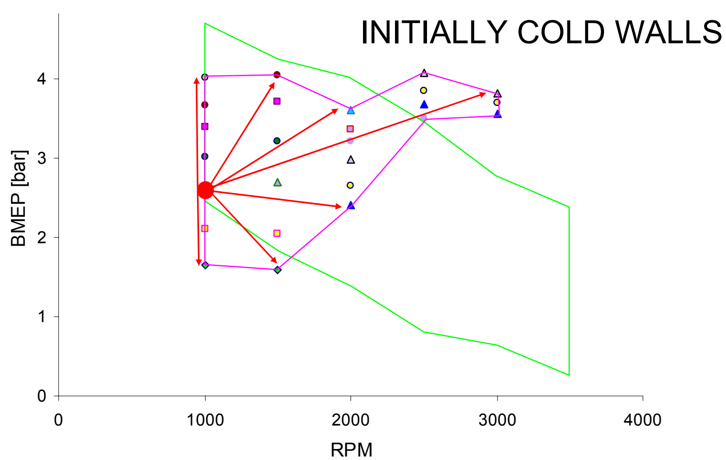
HCCI operation depends on load history: Transient wall temperatures affect the range

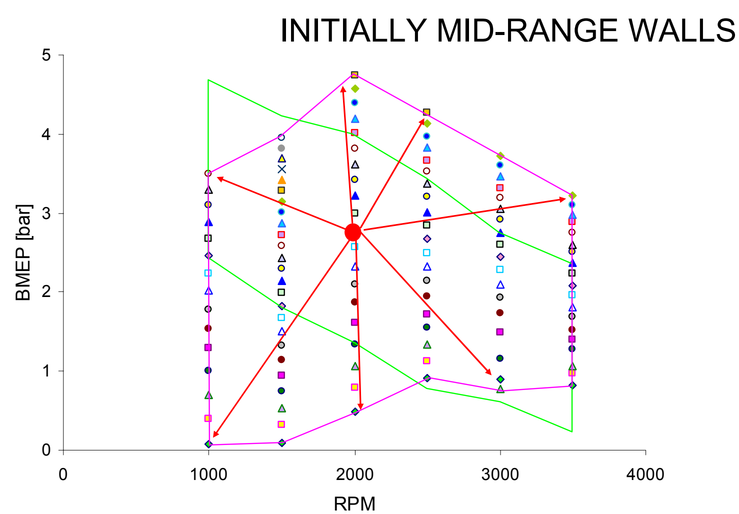
- Engine with rebreathing:
  - Residual fraction adjusted for optimal combustion
- Compression ratio = 12.5



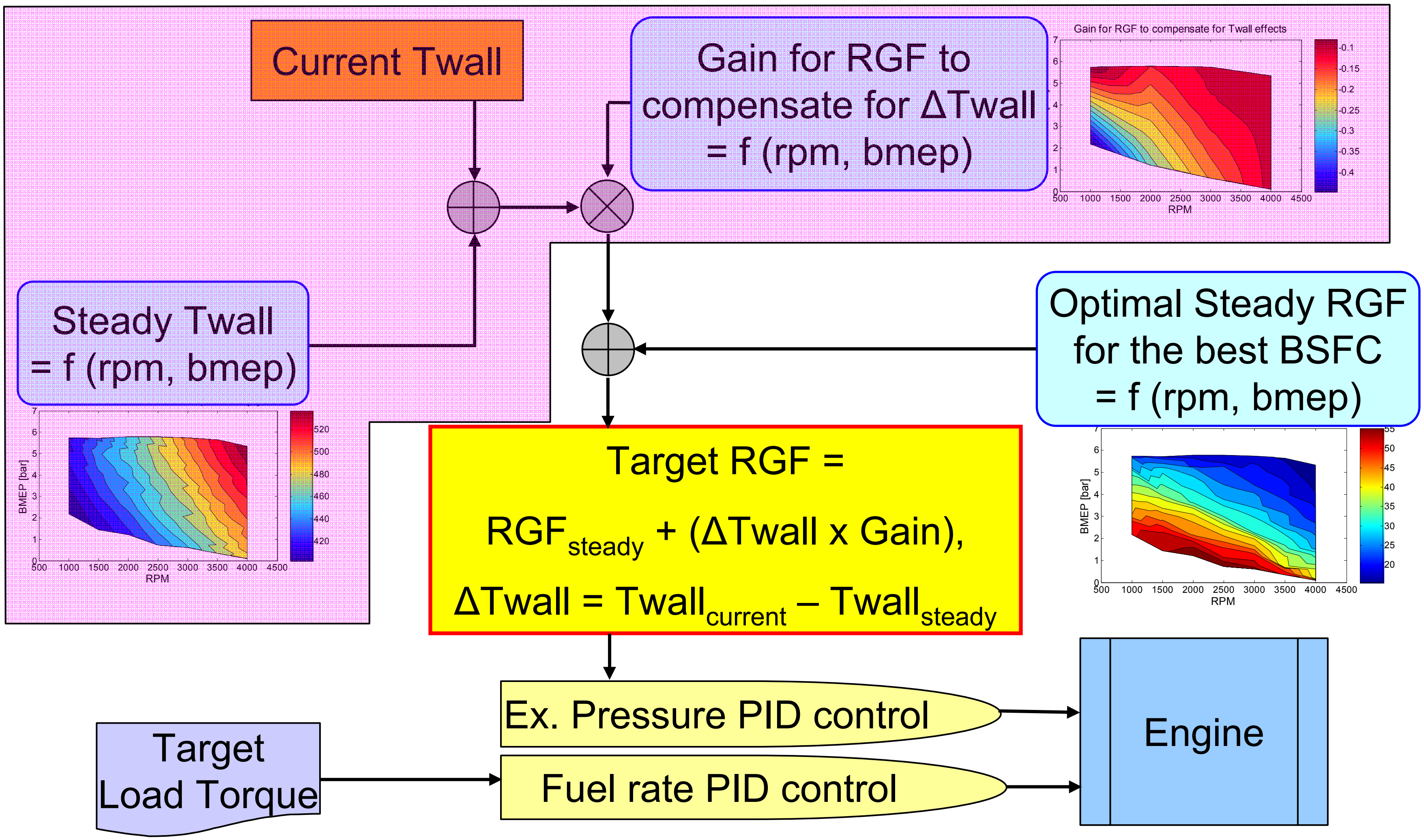
RANGE WITH STEADY STATE WALL TEMP

RANGE WITH TRANSIENT WALL TEMP



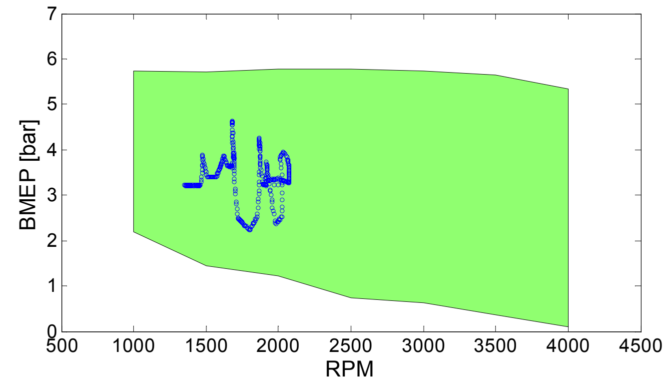


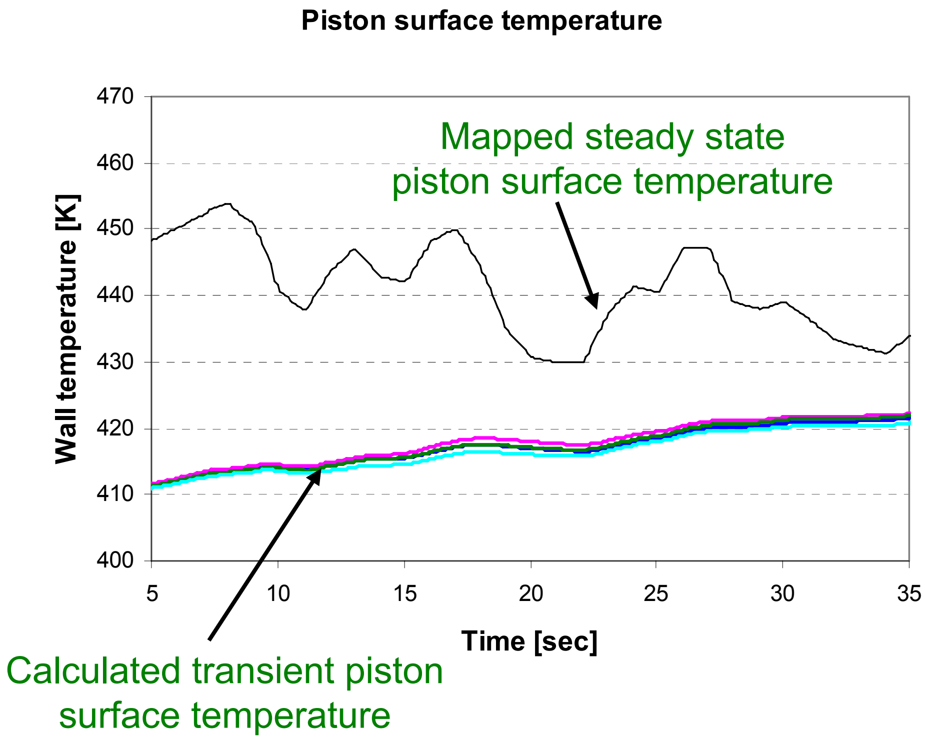
Schematic Diagram Twall Compensation

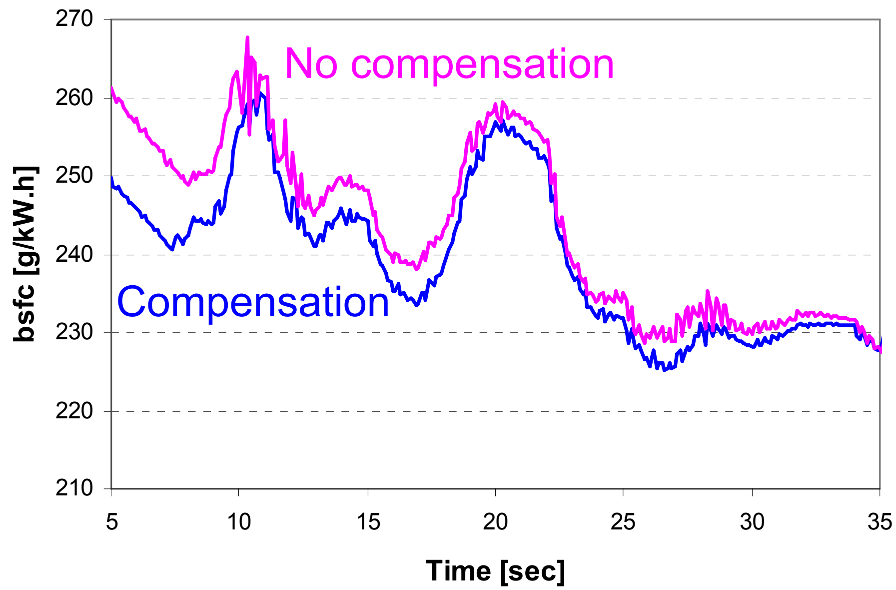


Transient Simulation in HCCI Regime – Cold Walls

- Brake specific fuel consumption
  - Overall better BSFC with compensation for the cold Twall







Acknowledgements

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Thank you!