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

University Consortium

University of Michigan
Massachusetts Institute of Technology
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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 system 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 Combustion Regime

- Conventional Combustion Regime
- Nitric Oxides
- Particulates

### Local Flame Temperature - K

- Local Equivalence Ratio

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**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

Stanford VVA engine

UM Heat Transfer and VVA Engine
Spark-Assisted Concepts: Expand the LTC Operating Range

SA-HCCI
Open Chamber

SA-Prechamber
Concept

UM Optical Engine
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

- Fuel Post Injection
- Close coupled DOC
- LTC/PCI Engine
- NAC/LNT
- Urea SCR
- DOC/DPF
- \[ \text{CO(NH}_2\text{)}_2 + \text{H}_2\text{O} \leftrightarrow 2\text{NH}_3 + \text{CO}_2 \]
Thermal Management: Predictive HCCI Engine System Simulation

Auto-ignition delay expression
\[ \int \left( \frac{1}{\tau_{\text{ign}}} \right) dt = 1.0 \]
\[ \tau_{\text{ign}} = 1.3 \cdot 10^{-4} \cdot P^{-1.05} \cdot \phi^{-0.77} \cdot Y_{O_2}^{-1.41} \cdot \exp(33700/R \cdot T) \]

Combustion efficiency and Burn rate correlation
\[ C_{\text{eff}}(\%) = \min[95.5, 92.5 - 1.1 \cdot (CA0) - 0.06 \cdot (CA0)^2] \]
\[ x = C_{\text{eff}} \cdot [1 - \exp\left(-\frac{(CA - CA0)}{\Delta \theta}\right)^{w+1}] \]

Heat Transfer correlation
\[ h(t) = \alpha_{\text{scaling}} \cdot L(t)^{-0.2} \cdot P(t)^{0.8} \cdot T(t)^{-0.73} \cdot W(t)^{0.8} \]
\[ W(t) = C_1 S_p + \frac{C_2 V_d T_r}{6 P_{\text{mot}}} (P - P_{\text{mot}}) \]

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
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

INITIALLY HOT WALLS

INITIALLY COLD WALLS

INITIALLY MID-RANGE WALLS
Target RGF = 
\[ RGF_{\text{steady}} + (\Delta T_{\text{wall}} \times \text{Gain}) \]

\[ \Delta T_{\text{wall}} = T_{\text{wall, current}} - T_{\text{wall, steady}} \]

Engine

Ex. Pressure PID control

Fuel rate PID control

Target Load Torque

Steady Twall = f (rpm, bmep)

Current Twall

Gain for RGF to compensate for \( \Delta T_{\text{wall}} \) = f (rpm, bmep)

Optimal Steady RGF for the best BSFC = f (rpm, bmep)
Transient Simulation in HCCI Regime – Cold Walls

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

Mapped steady state piston surface temperature

Calculated transient piston surface temperature

No compensation

Compensation
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