A University Consortium on High Pressure, Lean Combustion for Efficient and Clean IC Engines
(UM - lead, MIT, UCB)

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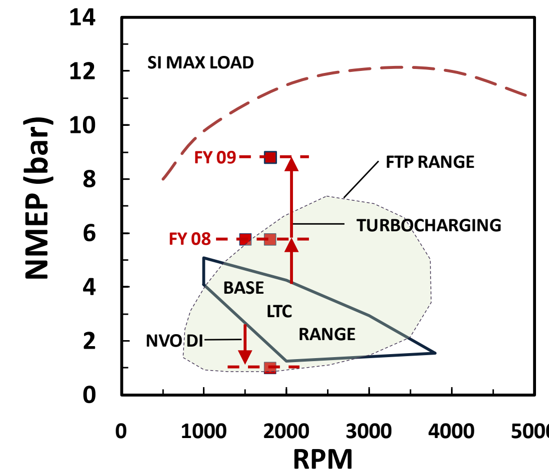
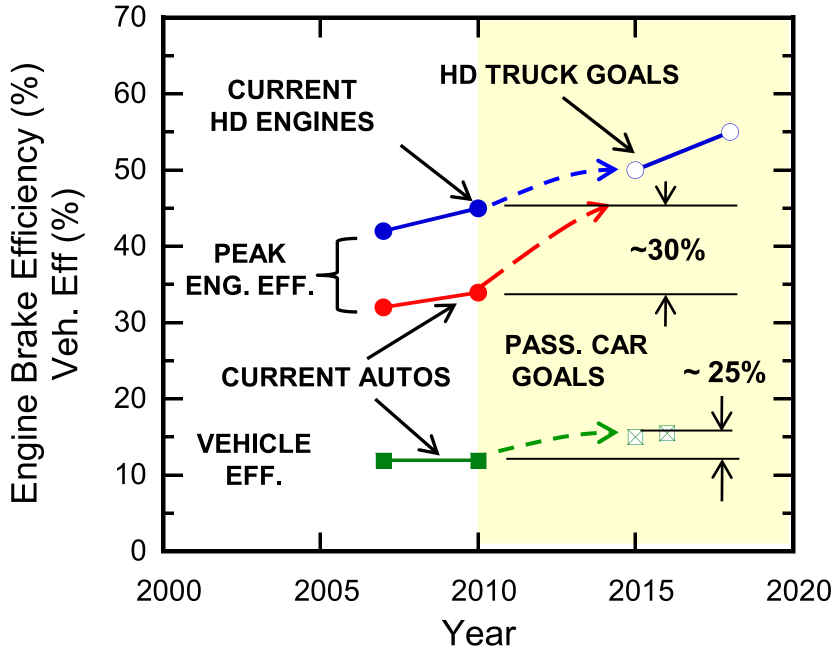
The Big Picture

HPLB University Consortium

- LTC university consortium extended the practical operating range of LTC engines at both low and high load
- HPLB consortium aims to demonstrate path to achieve 30% peak engine efficiency gain, with 25% vehicle FE improvement.
- Explore new combustion modes, advantages of stratification, and novel fuels in high pressure, lean burn engines.





Approach

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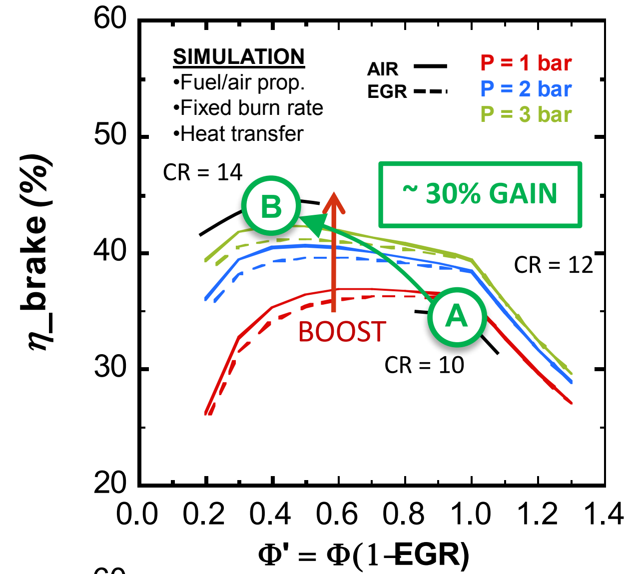
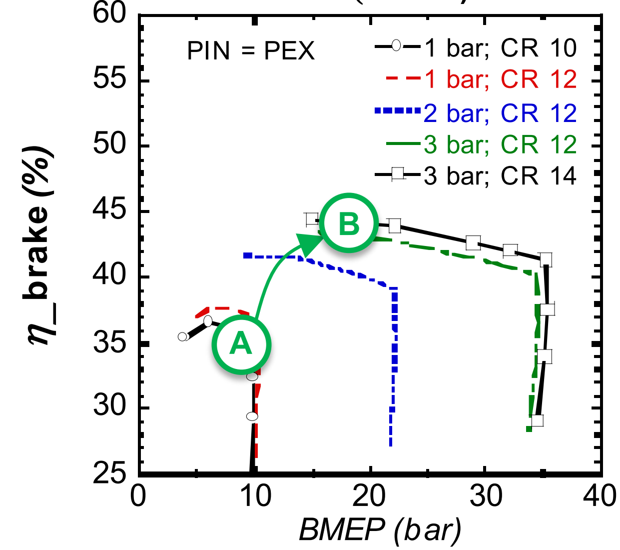
- Focus on <u>*High Pressure – Lean Burn*</u> path toward engine fuel economy gain of 30%
  - Application to downsized and boosted, high compression ratio engines
  - Lean burn and high unburned temperature for thermodynamic gains
  - Multi-mode combustion (Spark Assisted Compression Ignition – SCDI, SACI, HCCI)



- Assess <u>*final, in-vehicle fuel economy*</u> results; (goal: 25% gains).
  - Downsizing, load shifting, start stop alternators, hybrids, increasing electrification



Tasks

ANALYTICAL TOOLS

MODELS, EXPERIMENTS

TASK 1.

Fuel Efficiency of Advanced HPLB Cycles (UM)

- Develop models of engines and engine-vehicle cycles in advanced combustion modes
- Make ongoing assessment of potential FE gains

TASK 2.

Charge Stratification (UM, MIT)

- Explore fuel and thermal stratification and its interaction with fuel properties and heat transfer (RCM at MIT, CFD at UM)

TASK 3.

Multi-Mode Combustion (UM, UCB)

- Carry out SACI metal and optical engine experiments (UM)
- Continue CFD model development of SACI (UM)
- Carry out MWASP experiments and modeling (UCB)

TASK 4.

Fuel Chemistry Opportunities (UM, MIT)

- Explore fuel/stratification interactions in RCM and RCF.
- Assess novel fuel opportunities for improved efficiency in modified diesel engine: Gasoline/diesel/ethanol blends

In-vehicle FE improvement

Consortium Experimental Facilities

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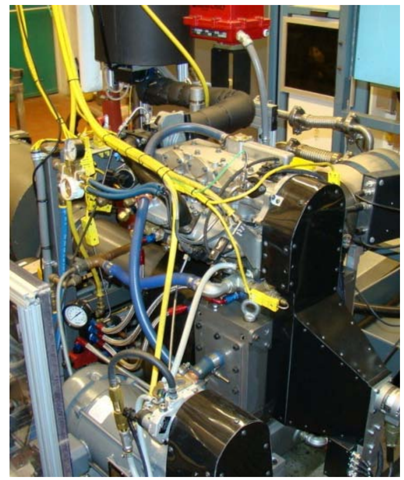
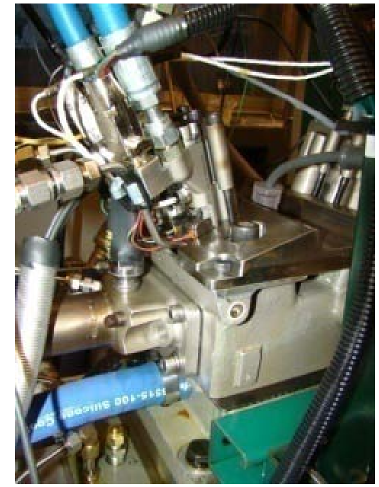
UM optical engine
(SA-HCCI and fuels)

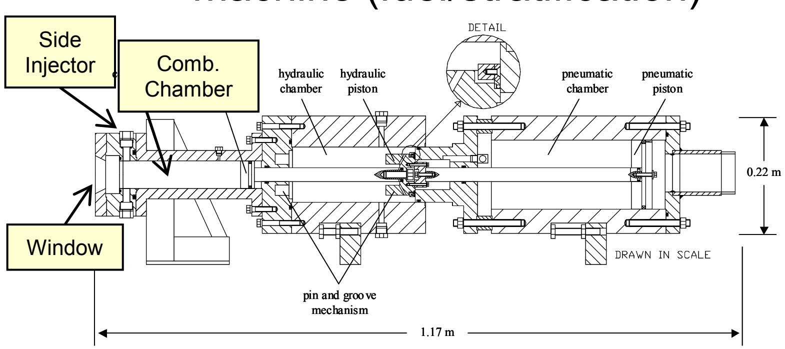
UM diesel engine
(fuels/thermal stratification)



UM camless FFVA engine
(multi-mode combustion)



MIT rapid compression
machine (fuel/stratification)



UCB single cyl. engine
(MWASP)

UM rapid compression
facility (ign. chemistry)

Demonstrated Framework For "Engine-in-Vehicle" Fuel Economy Assessment

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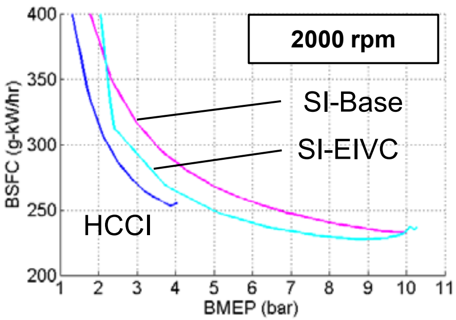
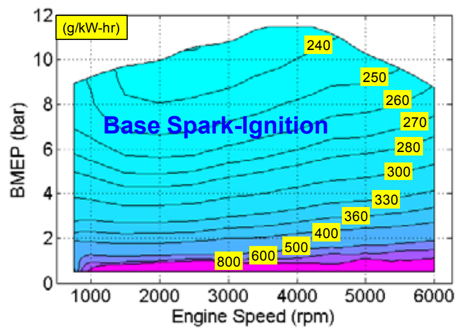
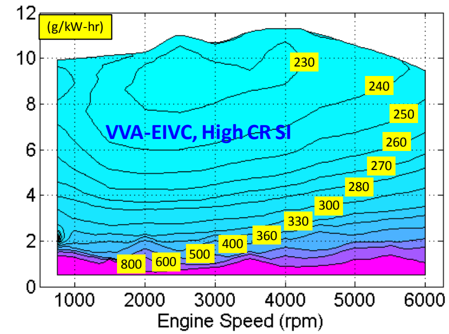
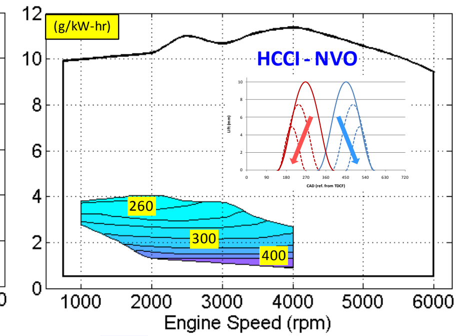


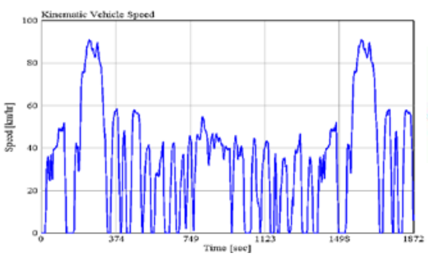






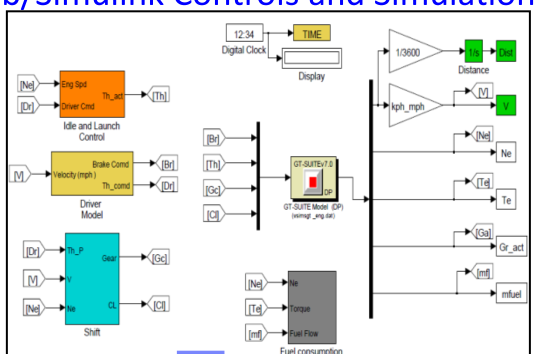
Matlab/Simulink Controls and Simulation

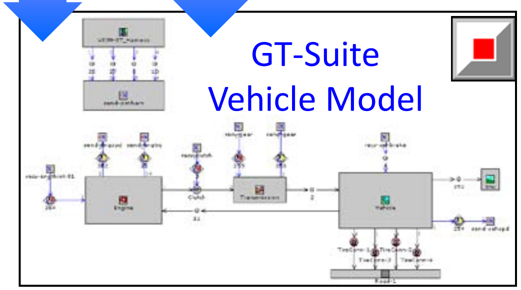
Drive-Cycle

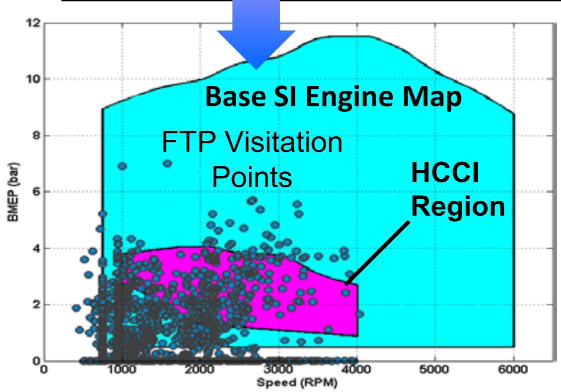


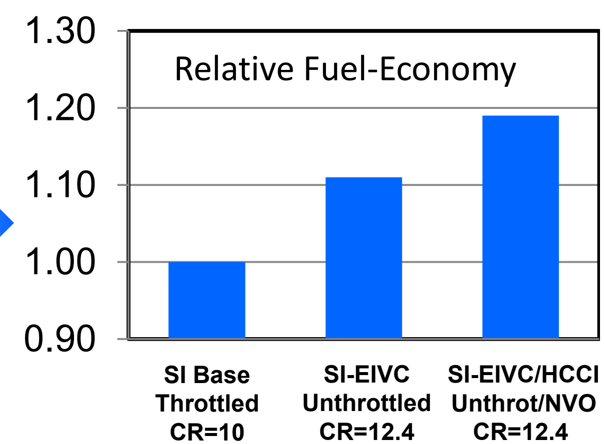
Vehicle Parameters

Mid-Size Sedan
2.5L Engine, 3285 lb
6-Speed A/T (w/o TC)









Demonstrated SI, SACI and HCCI operation in Multi-Mode Combustion (MMC) Engine

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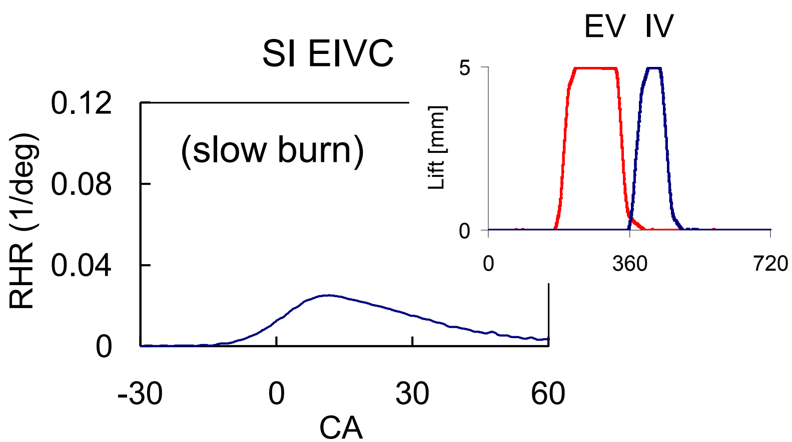
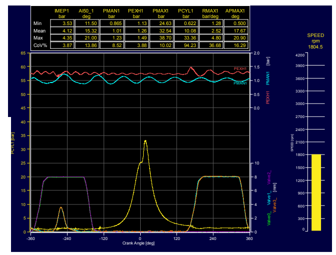
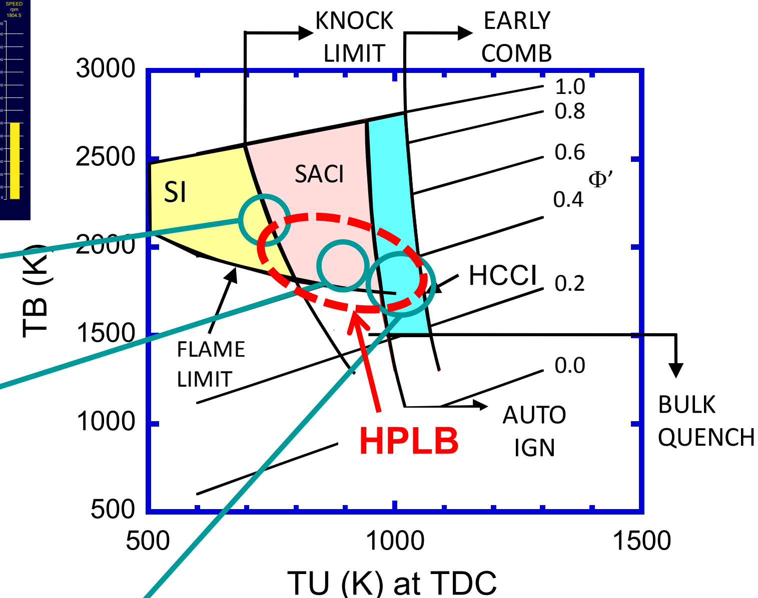
- Constant NMEP = 3.5 bar



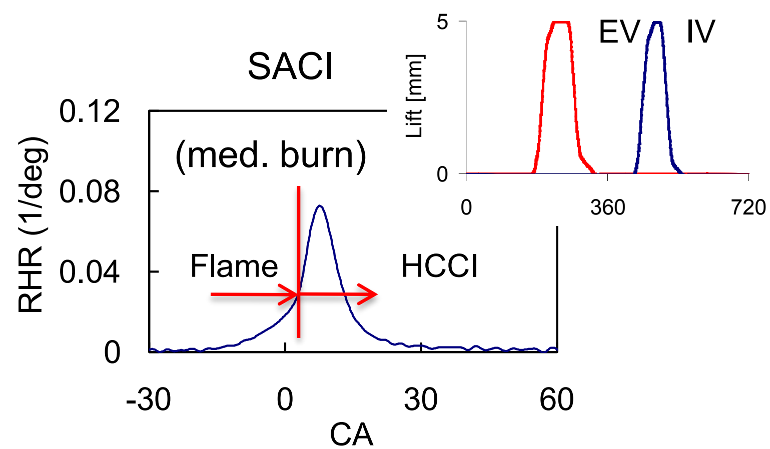
FFVA valve lift display

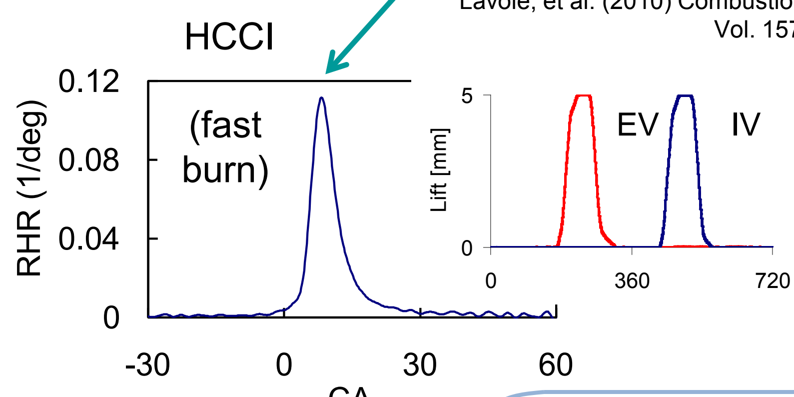


Multi-Mode Combustion Diagram*



* Lavoie, et al. (2010) Combustion and Flame, Vol. 157 No. 6, 1106

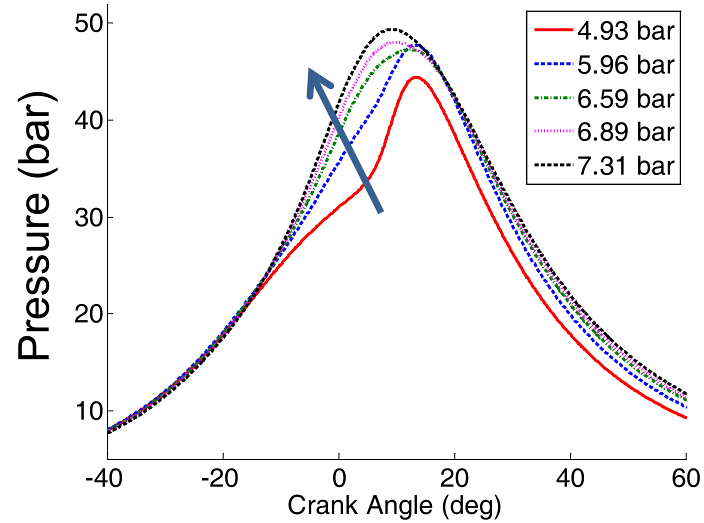


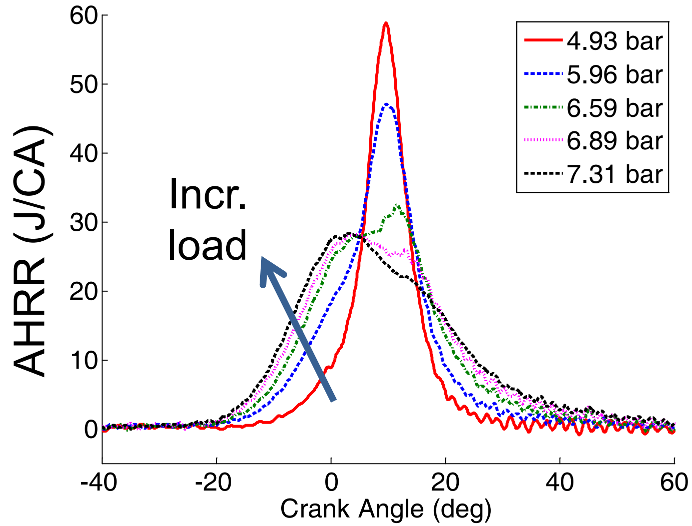


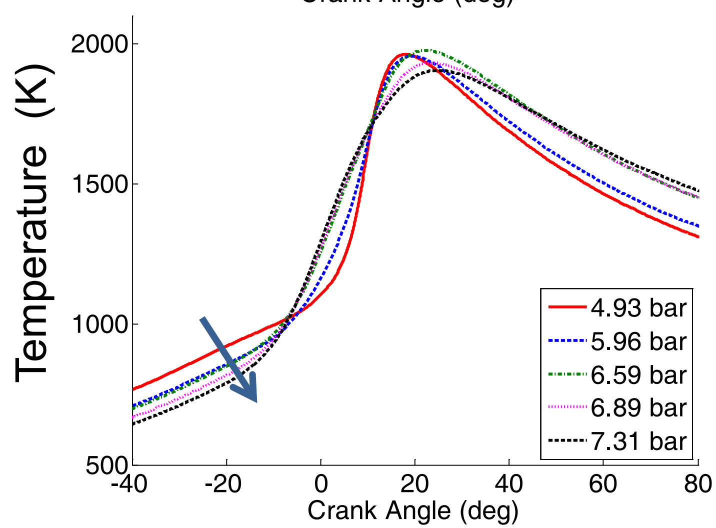
SACI Extends Load Limit

- Increase load by adding fuel and reducing trapped residual gas at Φ = 1
- Reduce charge temperature by reducing internal EGR (reduce NVO)
- Control phasing with spark timing
- SACI extends combustion duration and reduces peak heat release

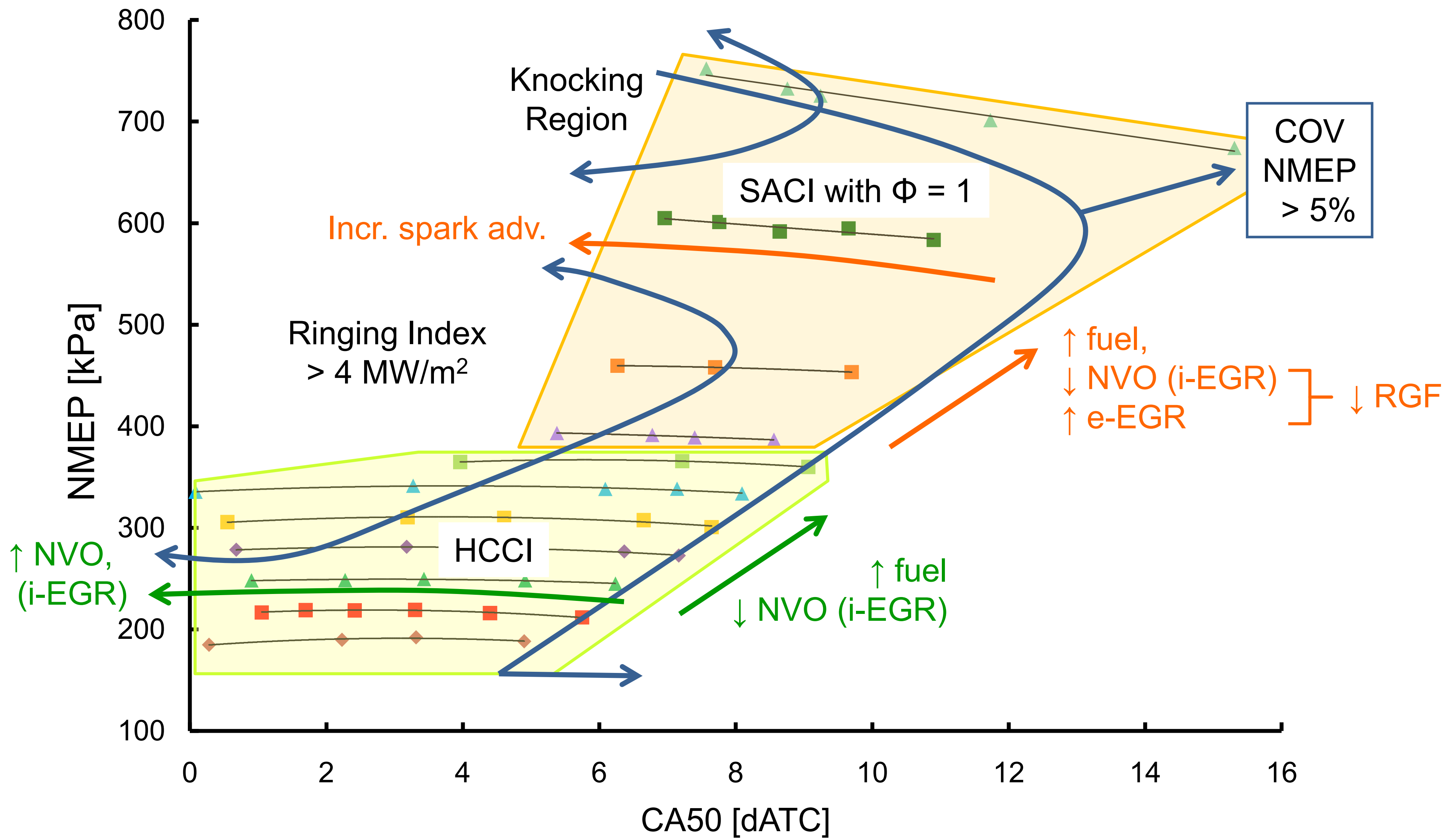
CA50 = 10 deg ATC







Extending the High Load Limit with SACI in FFVA Engine at 2000 rpm



Developed Coherent Flamelet Multi Zone (CFMZ) Model of SACI

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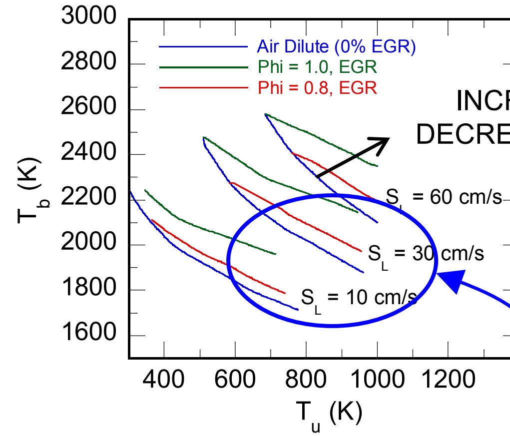
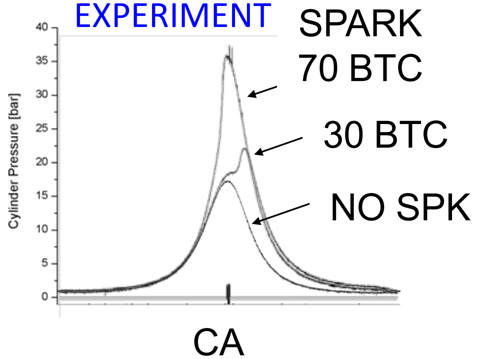
- Extended laminar flame speed data with 1-D unsteady simulations (HCT) and showed that
  - Ultra-lean laminar flames are viable provided the unburned temperature is high enough
  - EGR dilution requires higher T_U than air dilution for same flame speed (higher Cp)

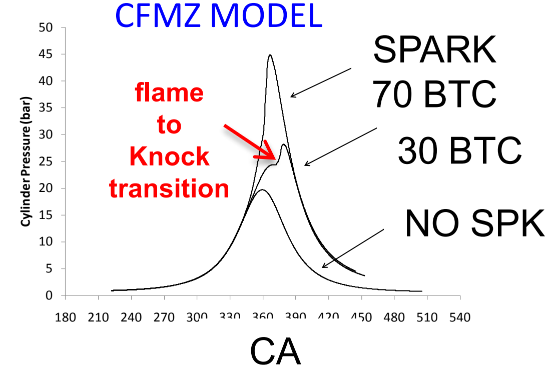
MODELED LAMINAR FLAME SPEED CONTOURS



Extended LTC regime Lean/dilute; high T_U

- Developed Coherent Flamelet Multi Zone model (CFMZ) using extended laminar flame dataset
  - Initial results with CFMZ capture the deflagration and knocking combustion seen in previous SACI experiments at UM.





Compared CFMZ Model Predictions to Optical Engine Images

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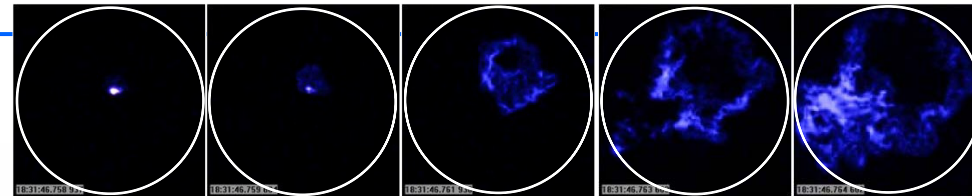
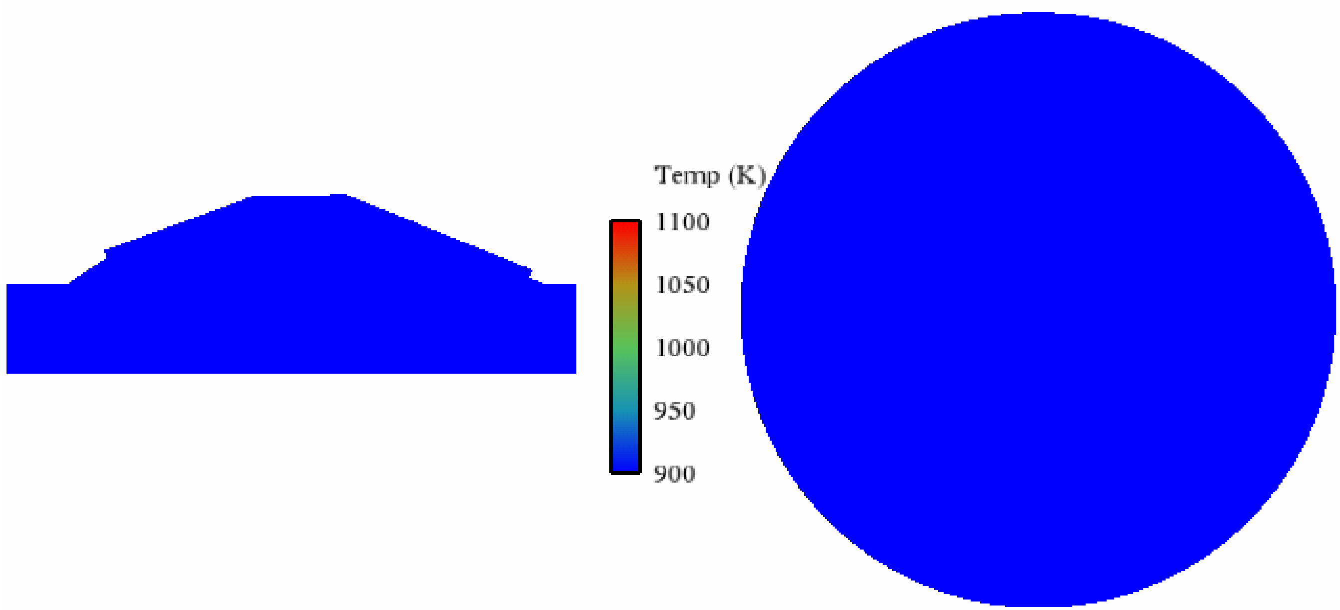
UM Optical engine image sequence



CFMZ model

Crank = 685 deg

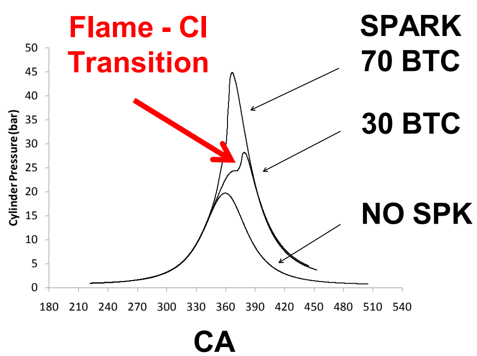


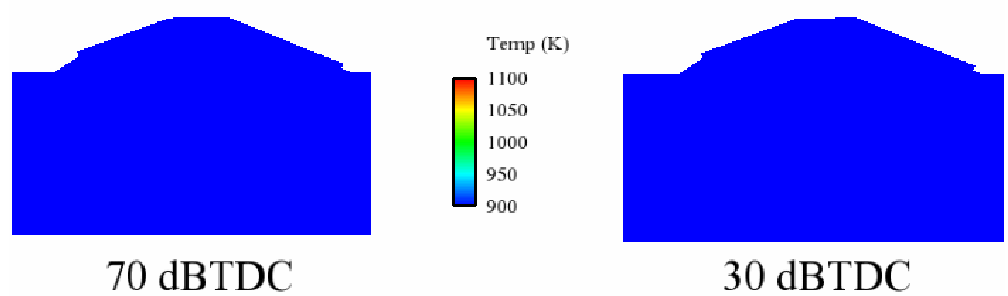
(700 RPM, Φ = 0.45, Tintake = 520 K, SPARK AT 30 dBTDC)

SACI Provides Control of Phasing by Spark Timing

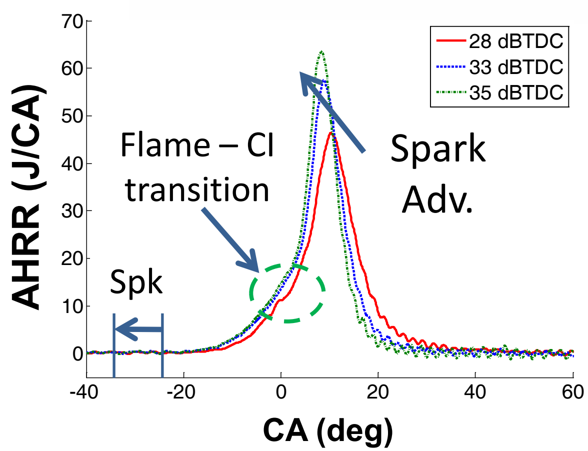
CFMZ Model

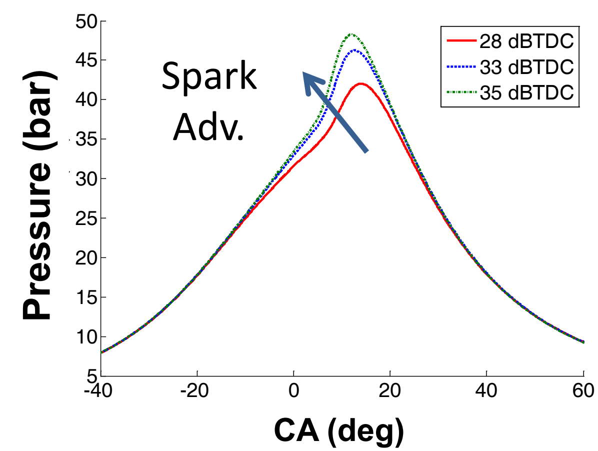
Crank = 650 deg





Experimental (FFVA engine)





Exploring Microwave Assisted Spark Plug (MWASP) to Extend the Lean Limit

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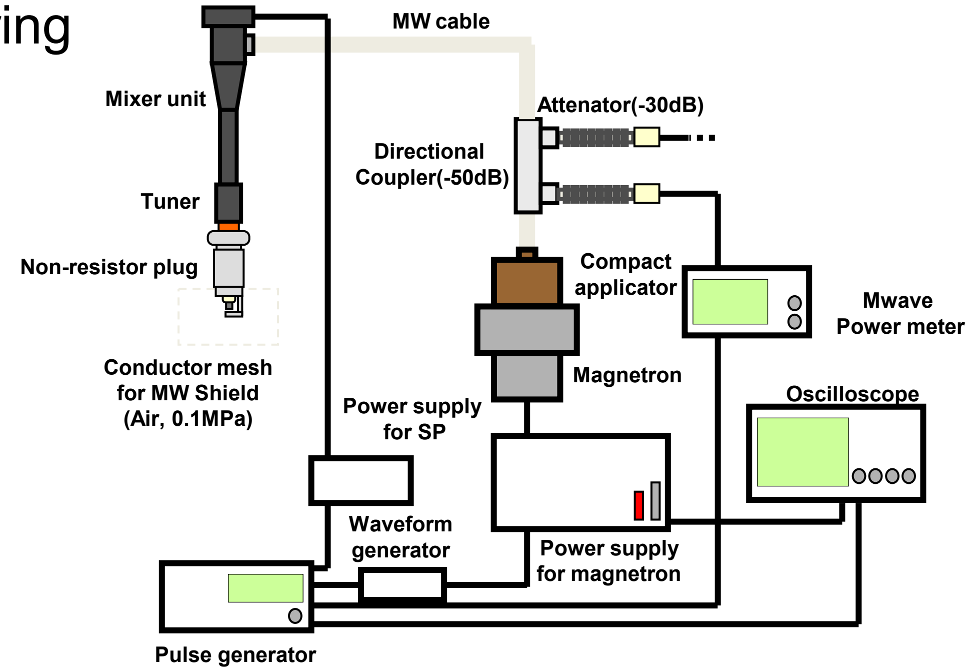
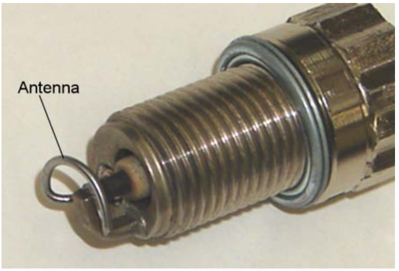
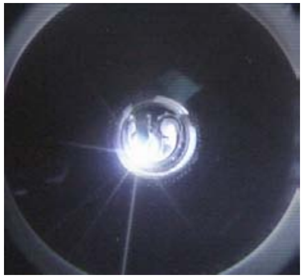
- Tests with igniter from Imagineering Inc.
- CFR engine
  - 1200 rpm / WOT
  - T intake = 25 C
  - Gasoline CR = 7, 9
  - Methane CR = 10
  - MW energy = 0, 0.1, 0.75, 1.5 J
- Stability was improved near lean limit (Φ ~ 0.65)
- Under SACI conditions (high preheat) MWASP should permit more dilute operation and wider range of control.



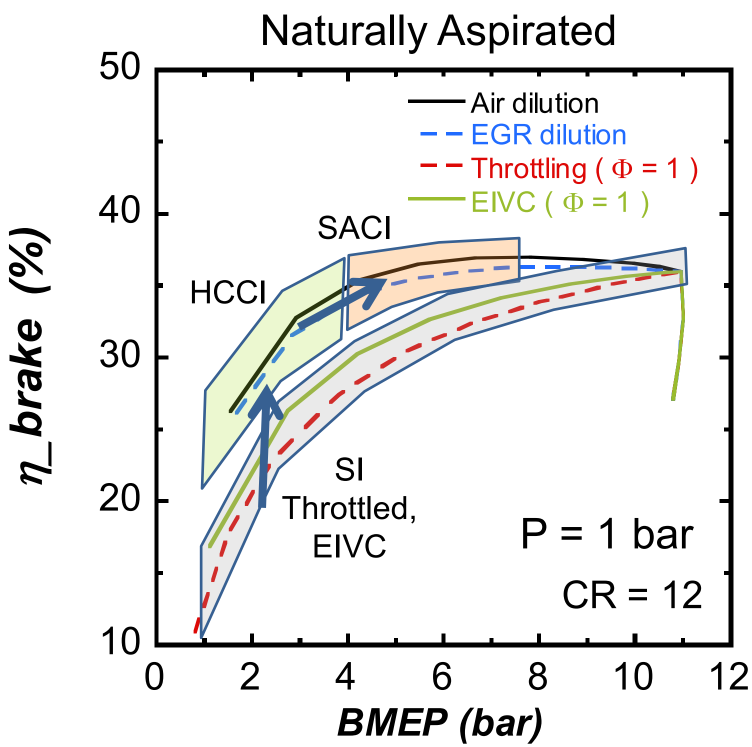
MW Assisted Spark Plug

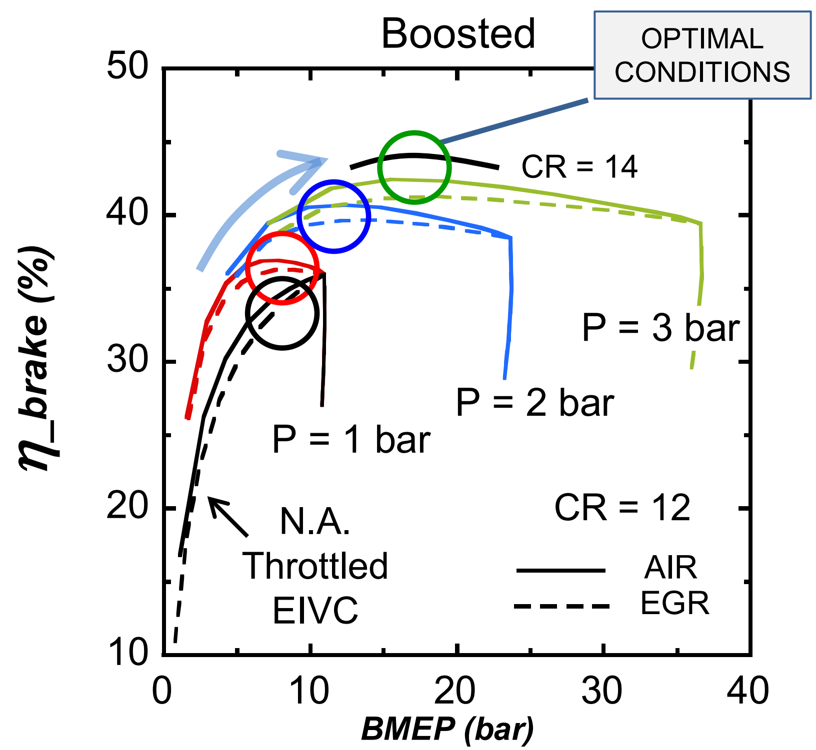


MW Plasma spark



Roadmap Toward 30% Light Duty Engine Efficiency Gains





- Higher CR, boosted engines (expect better turbo machinery)
- Downsize, down speed to maintain high BMEP and peak efficiency
- Lean / dilute (EGR) combustion regimes for low thermodynamic benefit
- New modes of ignition (SACI, MWASP)
- Fuel evaporation and octane; thermal and compositional stratification

Collaborations

- Initiated four year partnership with Bosch, AVL and Emitec to develop advanced control strategies for multi-mode combustion and associated aftertreatment
- Studying sensitivity of spark-assisted HCCI engines to range of market fuels; with BP and Ford.
- Working on boosted single cylinder HCCI studies with GM
- Working with Microwave Enhanced Ignition device supplied by Yuji Ikeda, Imagineering, Inc., Japan
- Collaborating on SACI and combustion stability with Robert Wagner (ORNL)
- Supplied engine maps for HCCI to Argonne National Labs
- Collaborated with C. K. Westbrook and Bill Pitz (LLNL) on validating reaction mechanisms for long chain alkanes, small esters
- Currently working with Ford on the next steps towards changing our optical engine to direct injection.
- Working with Jacqueline Chen (Sandia National Laboratories), Ramanan Sankaran (ORNL), Mauro Valorani (University of Rome, La Sapienza), Chris Rutland (UWisc) on mixing effects on HCCI combustion.

Acknowledgements

Consortium team members:

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