Flex Fuel Optimized SI and HCCI Engine

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Michigan State University

Project ID #: ACE021

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Overview

- **Timeline**

  Phase 1: 10/01/09 ~ 05/31/10
  Phase 2: 06/01/10 ~ 05/31/11
  Phase 3: 06/01/11 ~ 03/31/12
  Phase 4: 04/01/12 ~ 09/30/12

  Phase 1: 80% complete by 04/10

- **Budget**

  Total Project Funding (all phases)
  - DOE $1,401,299
  - Recipient $ 584,240

  DOE funding obligated/budgeted
  - FY 10 $444,172/$444,172
  - FY 11 $ /$517,638
  - FY 12 $ /$439,489

- **Barriers**
  - Target: Demonstrate a SI and HCCI dual combustion mode engine for a blend of gasoline and E85 for the best fuel economy
  - Development of a cost effective and reliable dual combustion mode engine
  - Development of a model-based SI and HCCI mode transition control strategy for smooth mode transition

- **Partners**
  - Michigan State University
    Harold Schock
  - Chrysler Group LLC*

*** Chrysler Group LLC's participation in this program as industrial partner is contingent upon MSU and Chrysler entering into a mutually satisfactory Cost Sharing Agreement.**

Objectives

Smooth mode transition between SI and HCCI combustion is the key technology for dual-mode combustion engines operated under a blend of gasoline and ethanol.

Resulting technology will be commercially VIABLE

- Demonstrate a SI and HCCI dual-mode combustion engine, that is commercially viable, for a blend of gasoline and E85.
- Develop control oriented hybrid combustion model to study SI and HCCI mode transition characteristics
- Develop and demonstrate model-based combustion mode transition between SI and HCCI combustion
- Utilize closed loop combustion control to minimize efficiency degradation with low engine out exhaust emissions when any blend of gasoline and E85 are used.

Objectives During Review Period

Phase 1 - Applied Research

- Confirmation of target SI and HCCI dual combustion mode engine design and specifications
- Engine simulation and analysis
    - GT-Power simulation for SI and HCCI combustion
    - GT-Power simulation for SI and HCCI mode transition
    - Numerical simulation of injector flow and spray dynamics
- Control oriented engine model development
- Single cylinder optical engine design
- Optical engine fabrication

Milestones

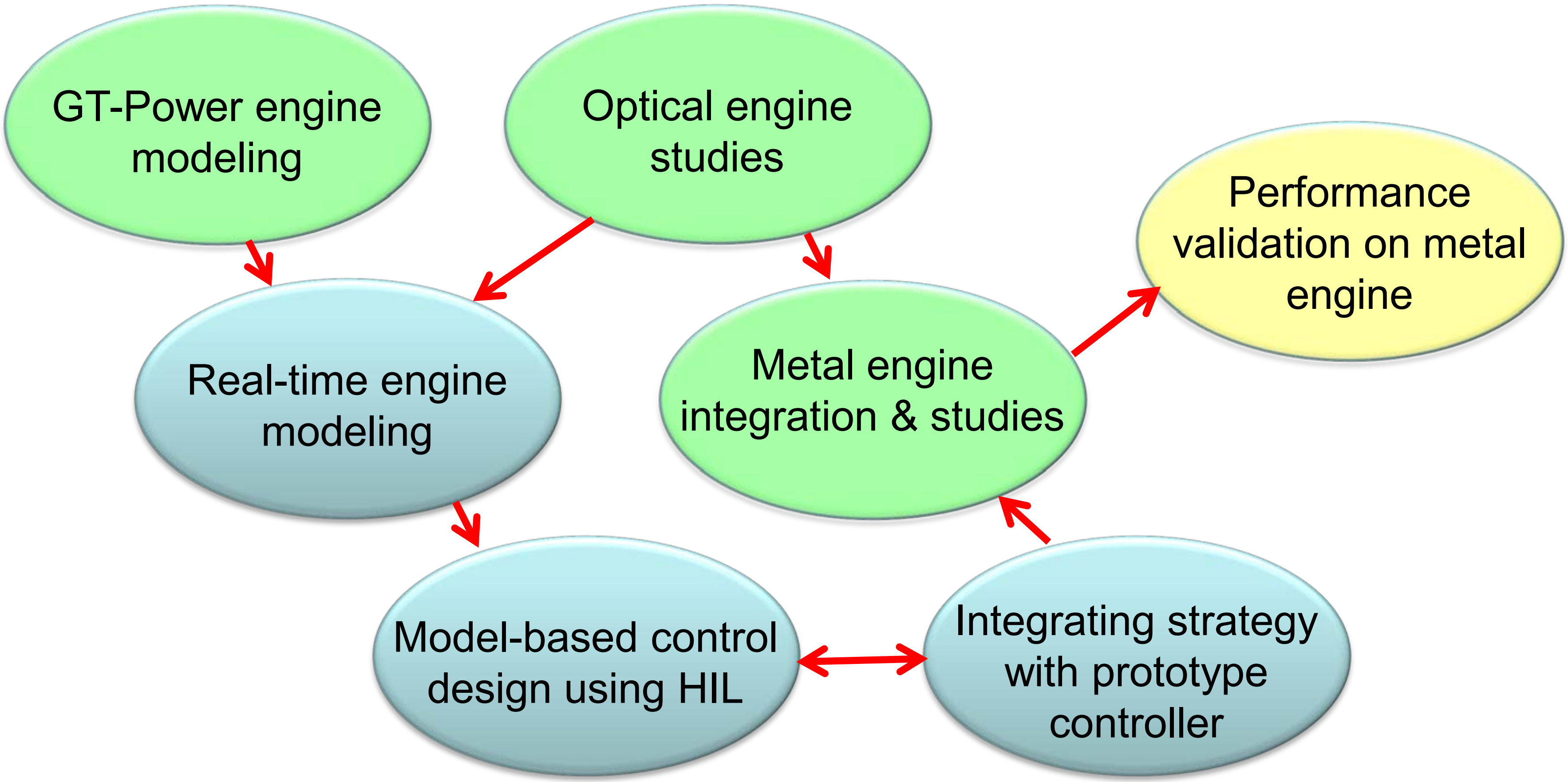
- **Phase I Milestones 05/31/10**
  - Confirmation of SI – HCCI dual combustion engine design and specification ✓
  - Engine simulation and analysis (70%)
  - Control oriented real-time engine model development and validation (90%)
  - Optical single cylinder engine design✓
  - Optical single cylinder engine fabrication (70%)
  - Go/No-go decision point
- **Phase II Milestones 05/31/11**
  - Optical engine tests including spray/flow and combustion tests
  - Two-step valve lift and electrical variable valve timing (VVT) actuation implementation
  - Ionization ignition system development for combustion feedback
  - Engine subsystem integration complete
  - Engine prototype control fabrication and implementation
  - Go/No-go decision point
- **Phase III Milestones 03/31/12**
  - SI and HCCI dual-mode combustion engine fabrication
  - CL combustion control development
  - HCCI CL combustion control dyno validation and tests
  - SI and HCCI mode transition control strategy development and validation on HIL (Hardware-In-the-Loop) simulator.
  - Go/No-go decision point
- **Phase IV Milestones 09/30/12**
  - Determine HCCI operational range in dyno
  - Final performance development and validation in dyno for different blends of gasoline and ethanol
  - SI and HCCI dual combustion model transition validation in dyno
  - Final project report

Approach

Using a combination of optical and metal engine experiments, engine modeling, and closed loop combustion control, develop a comprehensive SI and HCCI combustion mode transition strategy for a flex fuel engine.

- **Real-time engine modeling and model-based control**: study SI and HCCI combustion mode and the hybrid SI-HCCI combustion mode during combustion mode transition; and develop closed loop combustion control strategy for hybrid combustion mode and SI-HCCI combustion transition under blends of gasoline and ethanol.
- **Optical engine study**: detailed investigation of in-cylinder flow, mixing, and combustion processes to understand/optimize HCCI and SI-HCCI hybrid combustion process.
- **HIL based control strategy development:** develop model-based mode transition control strategy using HIL simulations for reduced cost
- **System integration on the metal engine**: validate the developed control strategy on the metal engine for smooth mode transitions between SI and HCCI combustion modes for blends of gasoline and ethanol
- **Technology transfer:** work with our industrial partner, during the project period to ensure smooth technology transfer to industry

Approach (cont'd)



Partner to provide target engine and engine modification design, engineering support on GT-Power engine modeling, and engine performance specifications

Technical Accomplishments:
Target SI and HCCI dual combustion mode engine

- **Target Engine**
  2.0L four cylinder, DOHC, direct injection, and turbocharged

- **Modification to be made**
  Cam and valve subsystem will be modified to use two-step valve lift with electrical variable valve timing

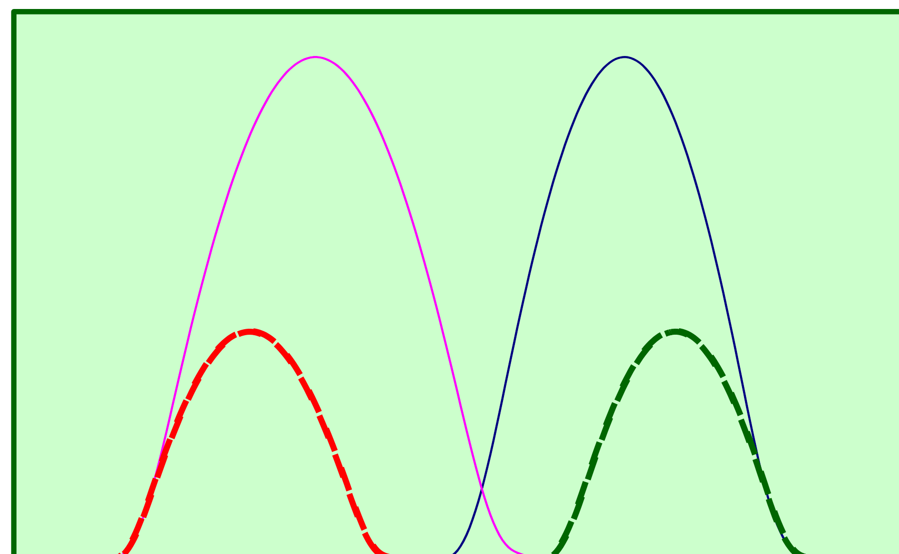
  The range of variable valve timing will be extended to allow NVO or recompression

  Compression ratio will be increased to around 11.5 for HCCI combustion

  Cool EGR loop will be added for HCCI combustion control

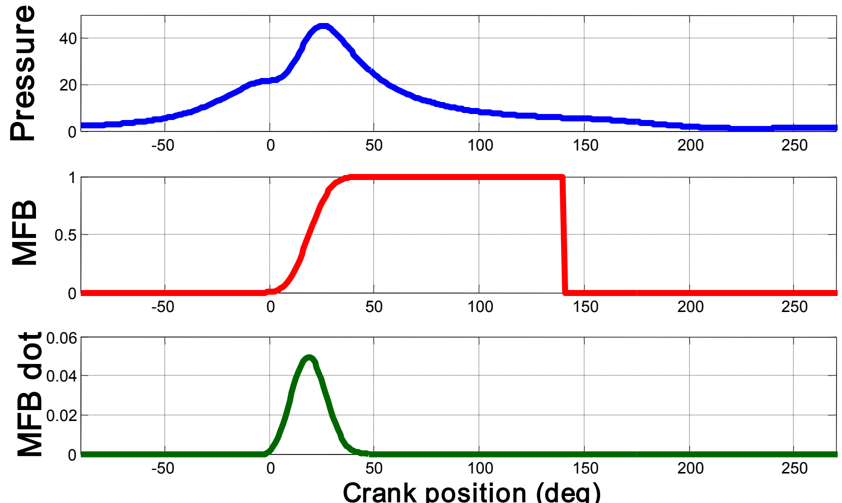
Cylinder Head

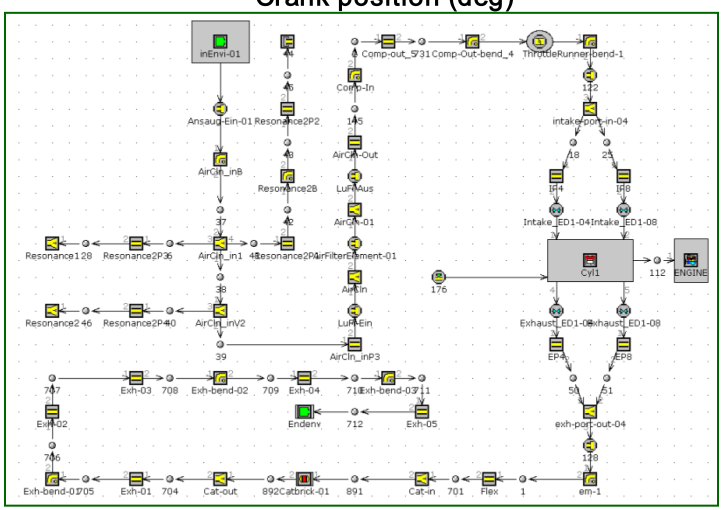
Two-step valve actuator study



Technical Accomplishments:
GT-Power engine and injector modeling

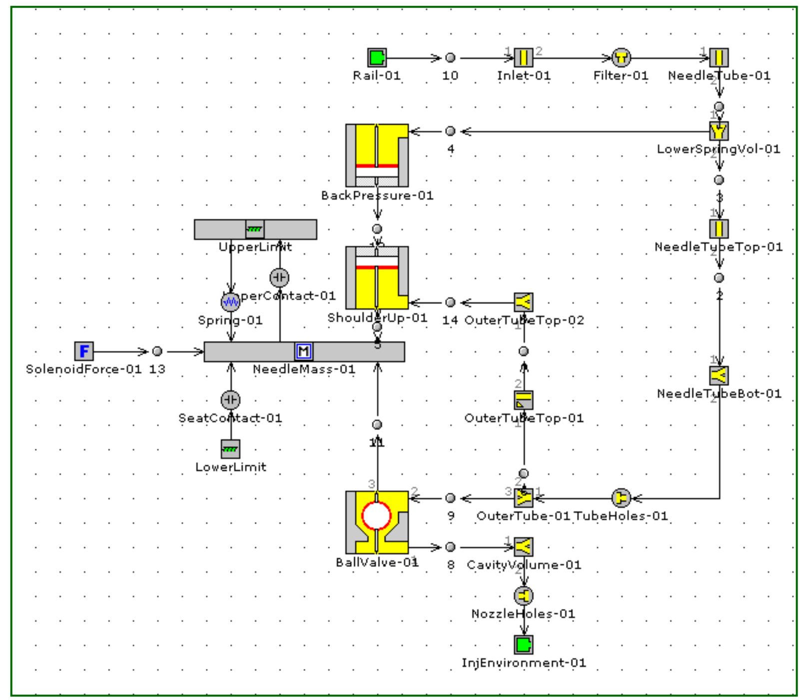
- **GT-Power engine modeling**
  Single cylinder engine model





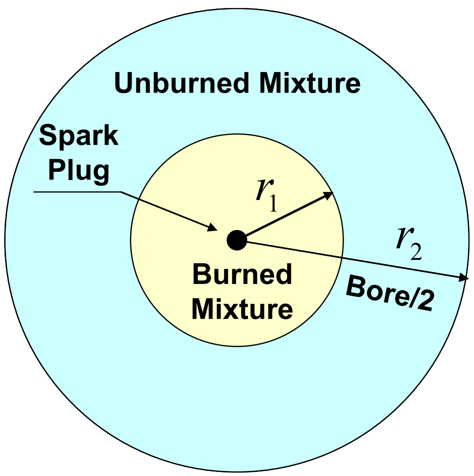
- **Injector spray and flow modeling**
  GT-Power Injector model was developed to simulate injector flow dynamics

GT-Power injector model

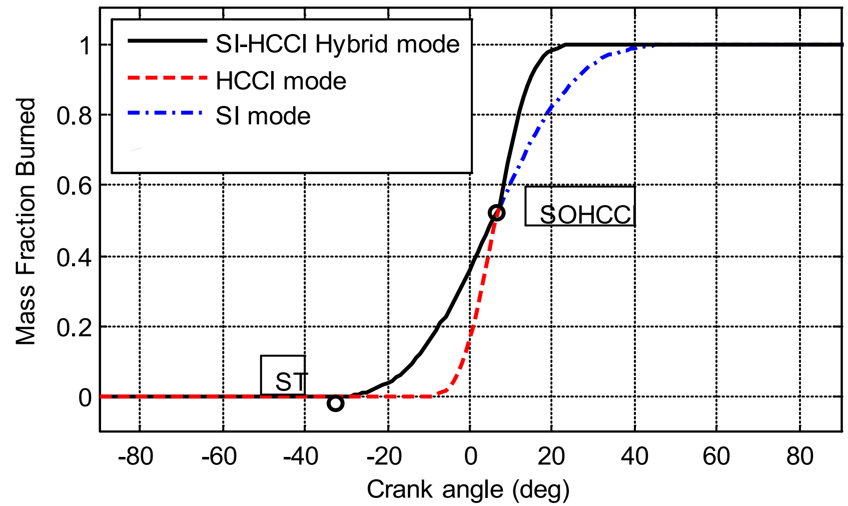


Technical Accomplishments:
Real-time SI-HCCI hybrid combustion modeling (1)

SI-HCCI Hybrid Combustion Modeling for combustion mode transition:

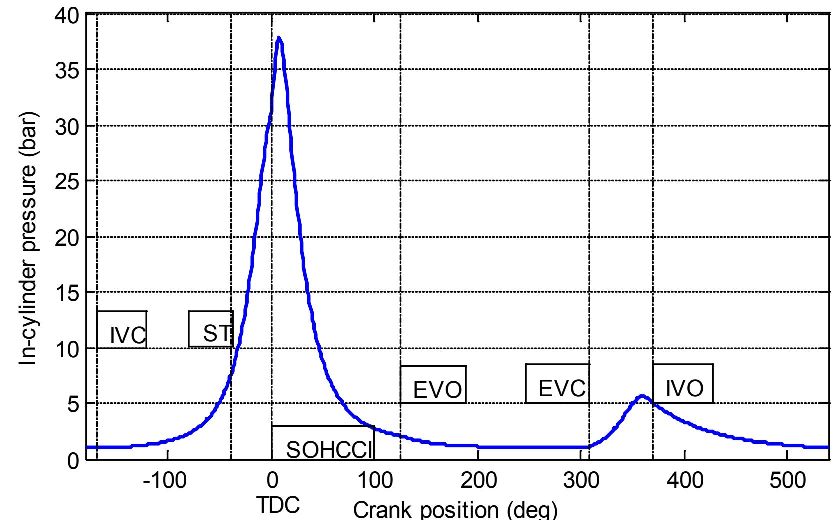


SI and HCCI combustion in one engine cycle

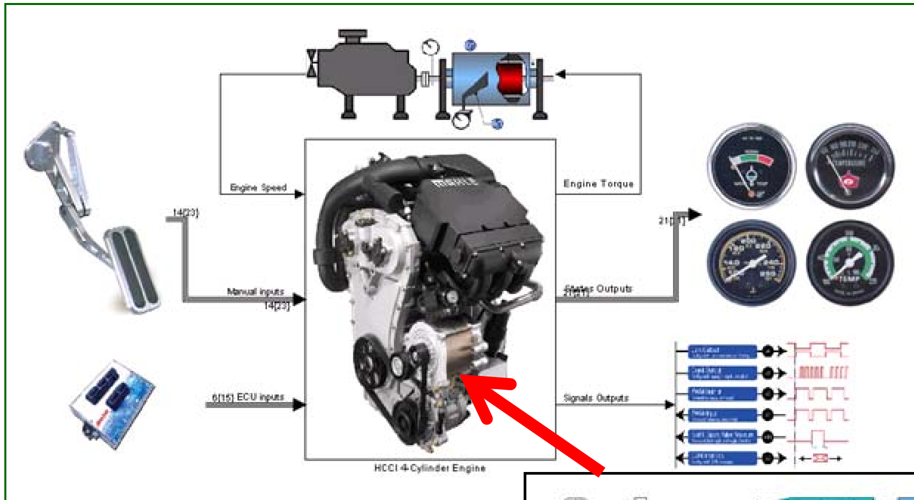


Six combustion phases modeled

- **IVC**: intake valve closing
- **ST**: spark ignition timing
- **SOHCCI**: start of HCCI combustion
- **EVO**: exhaust valve opening
- **EVC**: exhaust valve closing
- **IVO**: intake valve opening



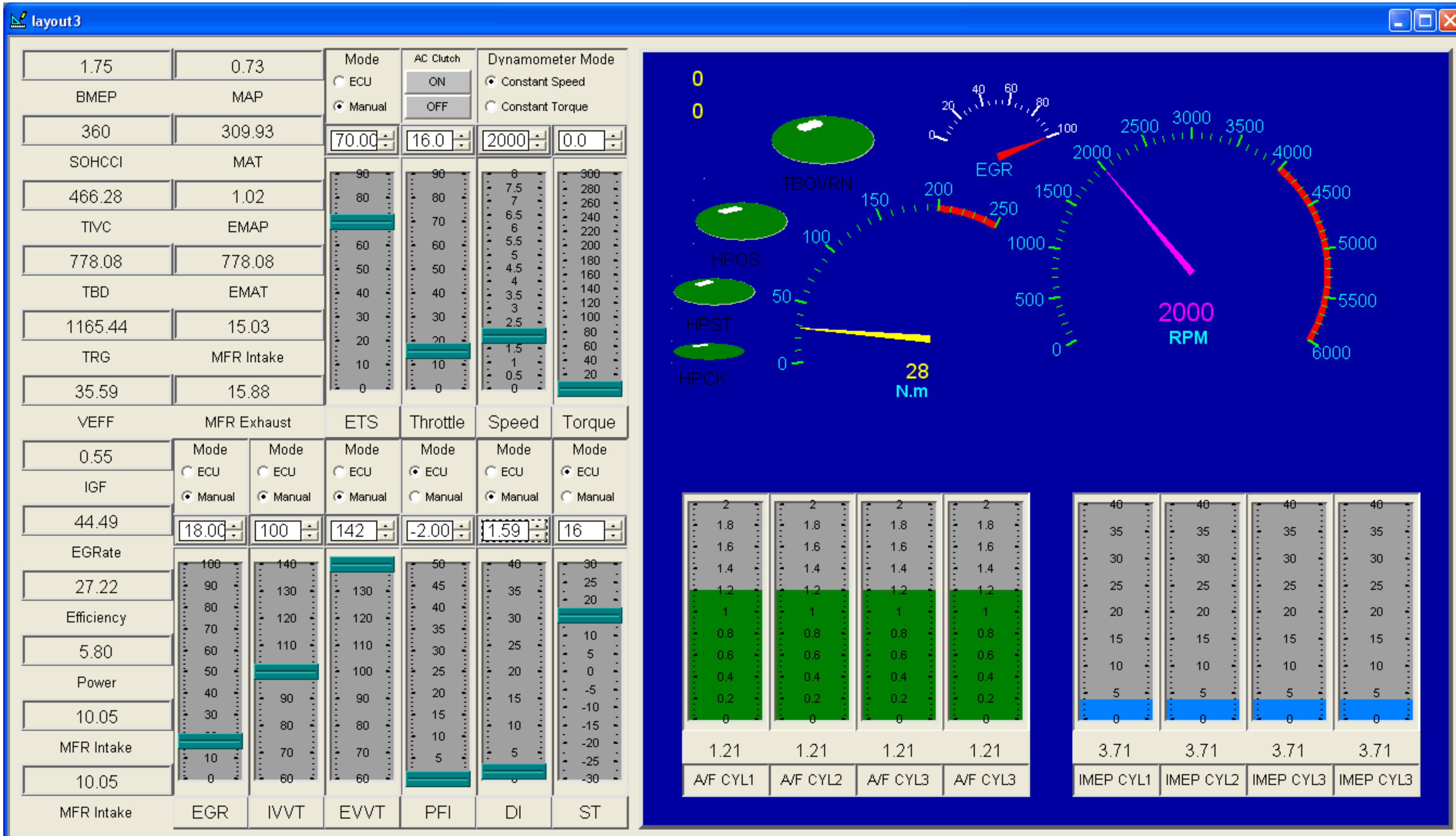
Technical Accomplishments:
Real-time SI-HCCI hybrid combustion modeling (2)



Real-Time Model Simulink Diagram

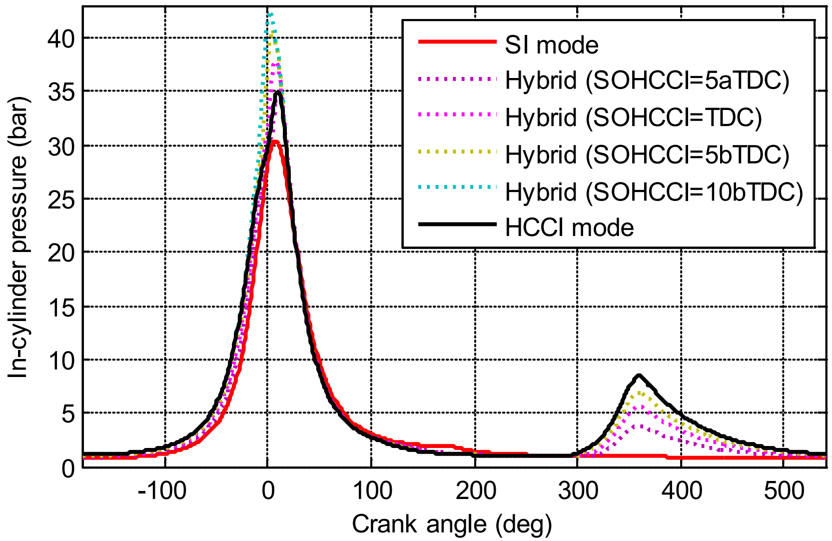
Technical Accomplishments: Real-time SI-HCCI hybrid combustion modeling (3)

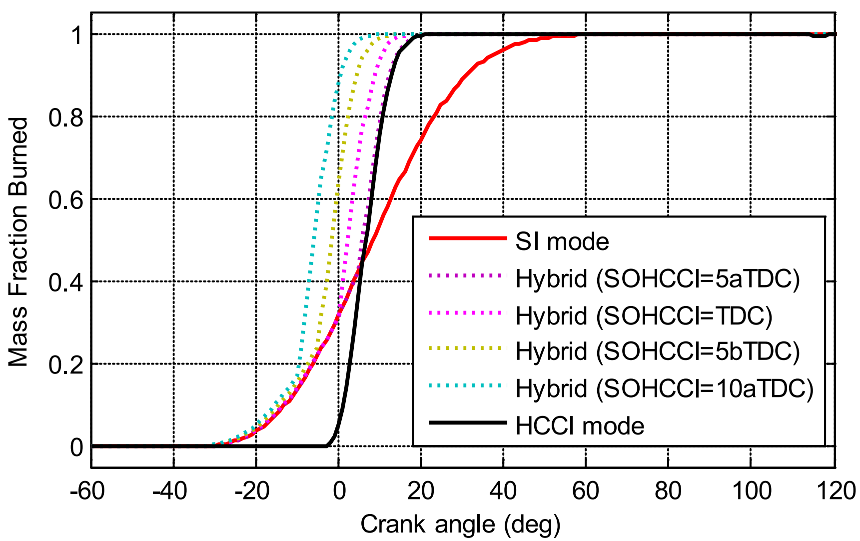
HIL Simulation Environment (GUI)

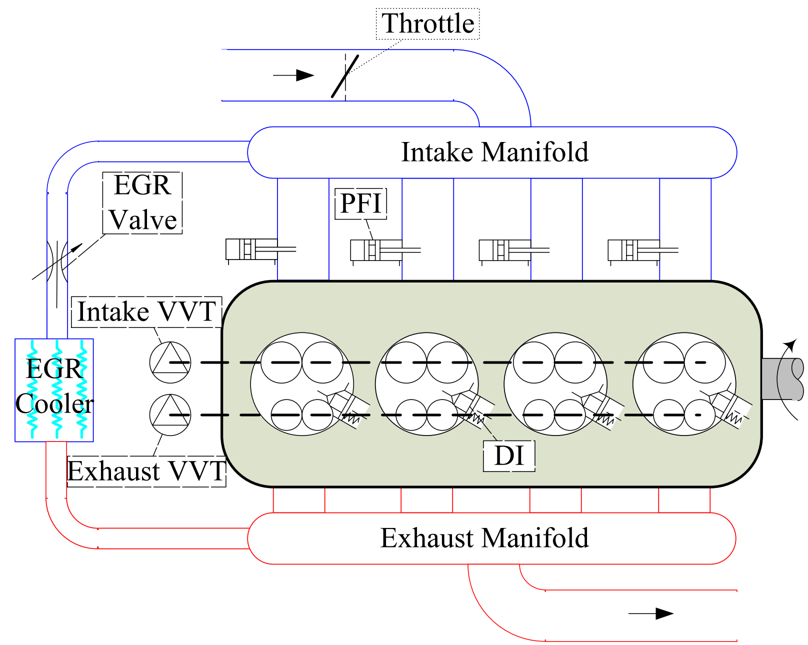


Technical Accomplishments:
Real-time SI-HCCI hybrid combustion modeling (4)

Preliminary modeling and simulation results





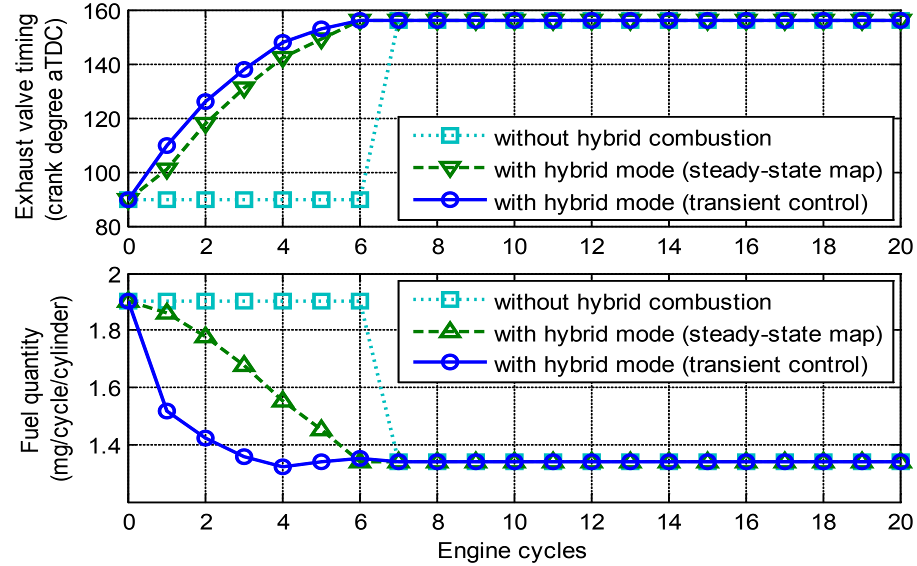


Parameter	Model value
bore/stroke/con-rod length	88mm/82.2mm/132mm
compression ratio	11:1
intake valve opening duration	180 crank degree
exhaust valve opening duration	180 crank degree
intake/exhaust manifold volumes	2.5L/2.3L

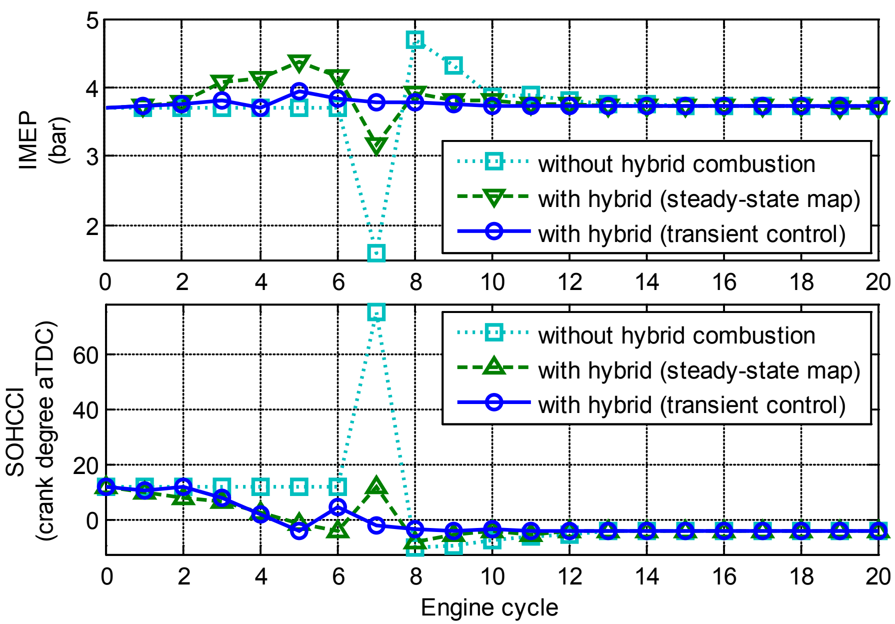
RPM=2000; Throttle=16deg; EGR_valve=18;
MAP=0.73bar; EMAP=1.02bar; IMEP=3.7bar

Technical Accomplishments:
Real-time SI-HCCI hybrid combustion modeling (5)

- **SI-HCCI combustion mode transition simulation**
  - without hybrid combustion mode
  - with hybrid combustion using steady state control parameters
  - with hybrid combustion using transient control parameters

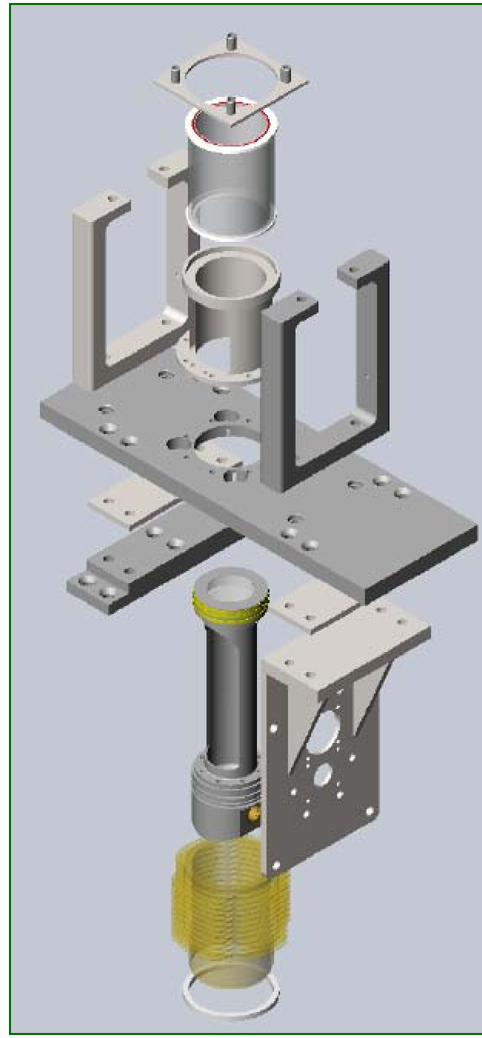


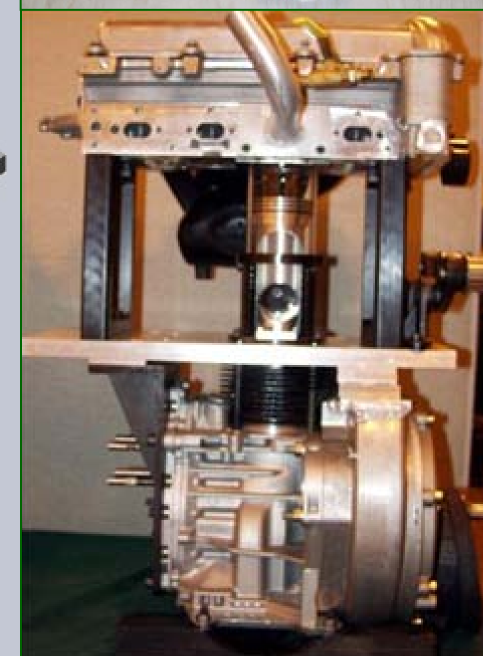
- **Conclusions from simulation**
  - Hybrid combustion mode is capable of improving combustion mode transition between SI and HCCI combustions
  - Steady state operational parameters are NOT optimized for transient control and model-based combustion mode transition control is necessary for a smooth mode transition



Technical Accomplishments: Optical engine design and fabrication

- **Optical engine design complete**
  - Hatz crank shaft design and modification complete
  - Connect rod design and fabrication complete
  - Optical liner design and fabrication complete
  - Optical piston under design





- **Physical Test Planned**
  - Cold flow test for fuel injection optimization with optical piston and liner
  - Combustion tests for SI, HCCI and SI-HCCI hybrid combustion with optical piston and metal liner

Collaborations

- **Industrial partner**

  Support for current phase includes

  – Design services to determine base engine platform.
  – GT Power support: providing base model for simulation studies
  – Engineering support for hardware procurement and modifications

  Future support includes

  – Design service for packaging HCCI actuator and sensing subsystems in the target multi-cylinder engine
  – Hardware modification for multi-cylinder HCCI component adaptation
  – Review of control oriented modeling and closed loop combustion control strategies

Collaborations (cont'd)

Technology Transfer

- A production viable control system for gasoline HCCI combustion
  - Smooth combustion mode transition between SI and HCCI operation through control of hybrid combustion
  - Closed loop combustion control strategy developed based on 1D engine model and validated in HIL (Hardware-In-the-Loop) environment, and Simulink based control algorithms that are portable to production software
- Feasibility study results of the ignition system with ionization combustion feedback vs. in-cylinder pressure sensing for
  - Start of combustion and combustion duration
  - Ethanol concentration

Future Work (Next Fiscal Year – Phase II)

Phase II – Subsystem Development

- Optical engine tests
  - Injector spray and flow visualization tests and optimization
  - Combustion visualization tests
- Two-step valve lift and electrical VVT actuation implementation
  - Cylinder head modification to fit two-step valves
  - Modification for electrical variable valve timing subsystem
  - Integration and bench tests for two-step electrical VVT system
- Ionization based ignition system with combustion feedback
  - Ignition system selection (energy and voltage requirement)
  - Ionization detection system for the high energy ignition system
- Integration of real-time engine model into a HIL simulator
- Prototype engine controller specification and fabrication

Summary

Relevance: Improvements in Ethanol blend flex fuel engine technologies for SI and HCCI dual combustion engines are being developed to provide smooth combustion mode transition between SI and HCCI combustions

Approach: Using a combination of optical and metal engine experiments, along with engine modeling and closed loop combustion control, to develop a comprehensive SI and HCCI combustion mode transition strategy

Key Enablers: Two-step lift electrical VVT, closed loop combustion control, model-based combustion mode transition, hybrid combustion mode control

Collaboration: Michigan State University (project lead), Chrysler Group LLC* (industrial partner).

Technical Accomplishments:

- ❑ Finalized target SI and HCCI dual combustion engine design and specifications by working with Industrial Partner .
- ❑ Single cylinder GT-Power model of the target engine has been delivered and simulations of SI and HCCI combustion are underway
- ❑ Real-time control oriented SI, HCCI, and SI-HCCI hybrid combustion engine model has been developed, preliminarily calibrated using the GT-Power simulation results, and implemented into a dSPACE HIL simulator.
- ❑ Optical engine design is completed and fabrication underway.
- ❑ Hybrid combustion mode is capable of improving combustion mode transition between SI and HCCI combustions. Study shows that steady state operational parameters are NOT optimized for mode transient control and model-based control is necessary for a smooth combustion mode transition