Variable Valve Actuation for Advanced Mode Diesel Combustion

(DOE Award # DE-FC26-05NT42483)

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Acknowledgements: DOE, GM, ORNL

DOE Peer Review
February 25-28, 2008

Outline

- Goals and Objectives
- Previous Review Comments (N/A)
- Barriers
- Approach
- Performance Measures and Accomplishments
- Technology Transfer
- Publications/Patents
- Collaborations/Interactions
- Plans for Next Fiscal Year
- Summary

Purpose of Work

- VVA project initiated to support FCVT Advanced Mode Diesel Combustion Enabling Technology.
- **Design, build and test a practical, production worthy VVA system that can have widespread use across many engine platforms.**

Project consists of two main tasks/phases :

- Phase 1 - Feasibility Study / Proof of Principle:
  - Benchmark VVA concepts from patents to production
  - Select target engine, develop engine models
  - Determine functional and performance requirements
  - Propose design options
  - Select candidate system

- Phase 2 - Development and Demonstration:
  - Design and detail single cylinder components
  - Using FEA and dynamic modeling refine design
  - Iterate with OEM for best packaging options
  - Build hardware and test fixtures
  - Test on engine stand to verify performance

Variable Valve Actuation – Project Objectives and Deliverables

Phase 1 Feasibility Study / Proof of Principle

Oct 2005 | January 2006 | August 2006 | De 20 | ar 08

1.1 Identify Preliminary Functional Requirements and Candidate Engine
- Identify target engine
- Obtain or build an engine model
- Calibrate engine model using dyno data
- Define representative points of the drive cycle

1.2 Detailed VVA Functional Requirements
- Identify optimal valve profiles to maximize 1. fuel economy, 2. low-speed torque and 3. light load exhaust temperatures using the engine model
- Quantify associated NOx and HC generation
- Identify required mechanism analysis tools (Adams, AMESim, etc.)
- Identify performance constraints of leading VVA mechanisms using identified analysis tools
- Evaluate available VVA analysis systems with engine model

1.3 Selection of Candidate VVA System
- Select most appropriate VVA system based on key selection criteria

1.4 Project Management
- Manage scope, cost and schedule
- Provide updates and final topical report

2.1 Detailed Candidate VVA System Design & Analysis
- Design and detail single-cylinder VVA hardware for motored head testing
- Develop actuator and control system for motored head application

2.2 Virtual verification testing of the final VVA system
- Refine the design with dynamic analysis and FEA modeling
- Iterate design to fit target application & verify predicted engine performance

2.3 Procurement and Shakedown
- Build VVA hardware
- Build required test fixtures
- Machine targeted cylinder head to accept VVA hardware
- Install in cylinder head and conduct initial shakedown

2.4 Experimental Fixture Testing
- Examine high speed videos, accelerometer traces and strain gage data to establish correlation with various FEA models
- Adjust design of VVA hardware to reflect above

2.5 Virtual Engine Testing
- Demonstrate and document single cylinder VVA mechanism performance
- Identify mechanism limitations
- Model actual mechanism performance in the engine model
- Recommend future design direction

2.6 Project Management
- Manage scope, cost and schedule
- Provide updates and final report

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Responses to 2007 Reviewers' Comments

- Not Applicable

Barriers Addressed

- The advantages of Variable Valve Actuation is well known in the industry. Research papers by universities, independent and government labs, and most OEMs indicate fuel savings and reduced emissions.
- Typical hardware used for testing is generally laboratory grade, electro-hydraulic, or electro-mechanical devices. However, these suffer from high cost, bulky, limited life, high power, and generally cannot be implemented into a production engine.
- By using sophisticated design tools: dynamics, statics, engine models, and OEM input, Delphi will produce a mechanical system that is reasonably priced, reliable, and can be incorporated into an OEM engine.
- Accelerated hardware testing in our laboratory will verify the modeling results and assure the required performance and durability.
- A productive mechanism will enable implementation of AMDC and HCCI in future production engines.

The best system in the world is useless if it is never put into production.

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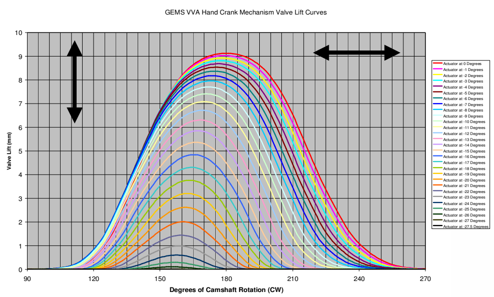
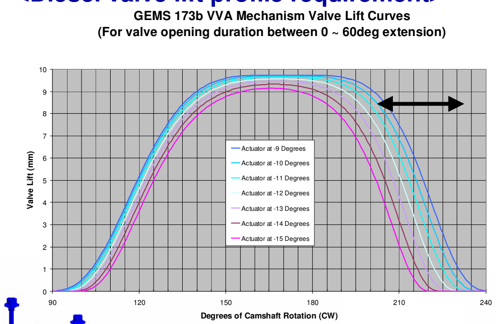
VVA Concept - Overview

►VVA concept will permit adjustment of lift and/or duration

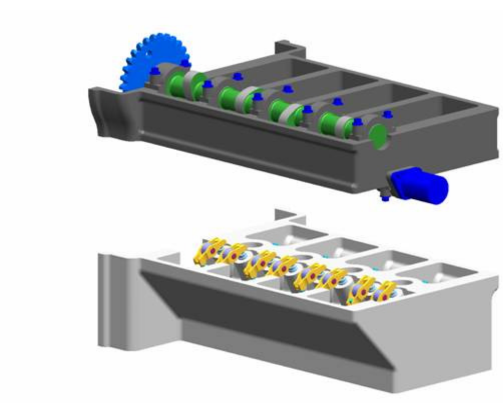
<Gasoline valve lift profile requirement>

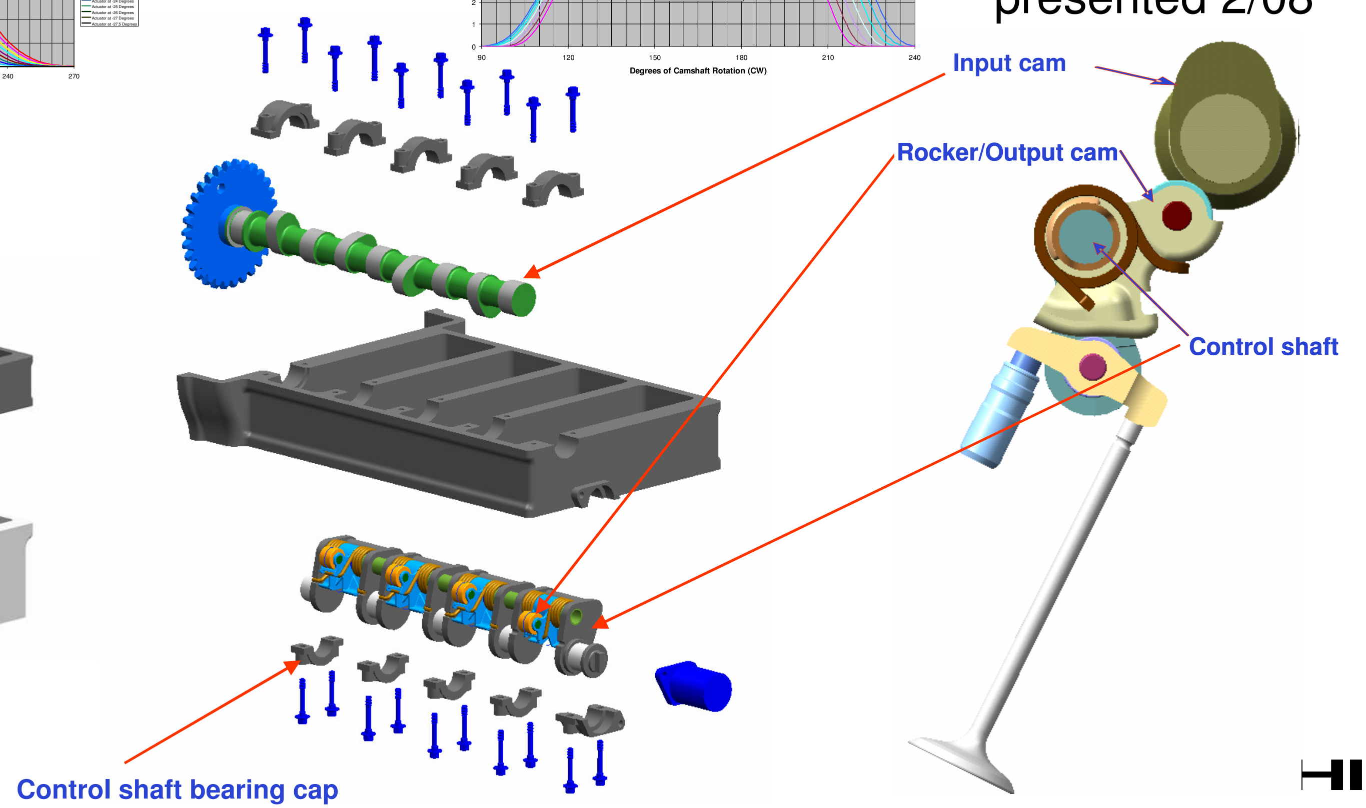


<Diesel valve lift profile requirement>



Further details and animation will be presented 2/08





Approach

- Benchmarking
- Engine Selection
- Determine Functional and System Requirements
- Concept Development
- Concept Selection
- Mechanism Analysis
- Sub component development
- Component build
- Test and verification

Accomplishments / Summary

- Completed engine selection matrix and selected engine
- Completed benchmarking analysis
- Developed suite of design tools for rapid concept development
- Proposed alternative concepts and selected best one
- Prepared engine model for CFD work and began initial runs
- Completed mechanism dynamic and static analysis
- Sub-component development completed
- Hardware built and installed on single cylinder engine
- Testing in progress on motored head stand

Technical Accomplishments

25 Engines Evaluated.

			Engine configuration					Model avaiablity			
			Engine type (L4/L6/V6/V8)	Valve train type	DOHC or SOHC	US market availablity	Available packaging envelope	GT-Power model	3D In-Cylinder flow/combustion model (Star-CD or Kiva)	Engine CAD model	Emission regulation compliance
Points			L4/L5/L6: 2 V6/V8: 1	Type 2,3: 2 Type 1,4,5: 1	DOHC: 2 SOHC: 1	Yes: 2 No: 1	Yes: 2 No: 1	Yes: 2 No: 1	Yes: 2 No: 1	Yes: 2 No: 1	Euro5/US Tier 2 Bin5: 2 Euro4: 1
Weight factor			**2**	**3**	**3**	**1**	**3**	**3**	**2**	**3**	**2**
Criticality							**1**	**1**		**1**	
OEM	**Model**	**Liters**									
		6.0	1	1	2	2	1	2	2	2	1
		3.5, 4.	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
		2.2	2	2	2	1	2	1	1	1	1
		2.7	1	2	2	1	2	1	1	1	1
		1.9	2			1		1	1	1	1
		3.2	2	1	2	2	1	1	1	1	1
		3.0	1	2	2	1	2	1	1	1	1
		1.9	2	2	2	1	2	1	1	1	1
		2.4	2	2	2	1	2	1	1	1	1
		1.3	2	2	2	1	2	1	1	1	1
		3.0	2	2	2	1	2	1	1	1	1
		2.7	2	2	2	1	2	1	1	1	1
		4.2	1	2	2	1	2	1	1	1	1
		3.0	2	2	2	1	2	1	1	1	1
		4.4	1		2	1		1	1	1	1
		2.0	2		1	1					1
		2.9	2		2	1					1
		1.9	2	2	2	1	2	1	1	1	1
		2.2	2	2	2	1	2	1	1	1	1
		1.6	2		2	1		1	1	1	1
		2.0	2		2	1		1	1	1	1
		2.2	2	2	2	1	2	1	1	1	1
		2.2	2	2	1	1	2	1	1	1	1
		2.4	2	2	2	1	2	1	1	1	1

Type 1: Direct Acting, Overhead Cam

Type 2: End Pivot Rocker Arm, Overhead Cam

Type 3: Center Pivot Rocker Arm, Cam-in-Head

Type 4: Center Pivot Rocker Arm, Cam-in-Head with Lifter

in-Block Rod)

5 Types of Valvetrain systems

(Data chart will expand when double clicked)

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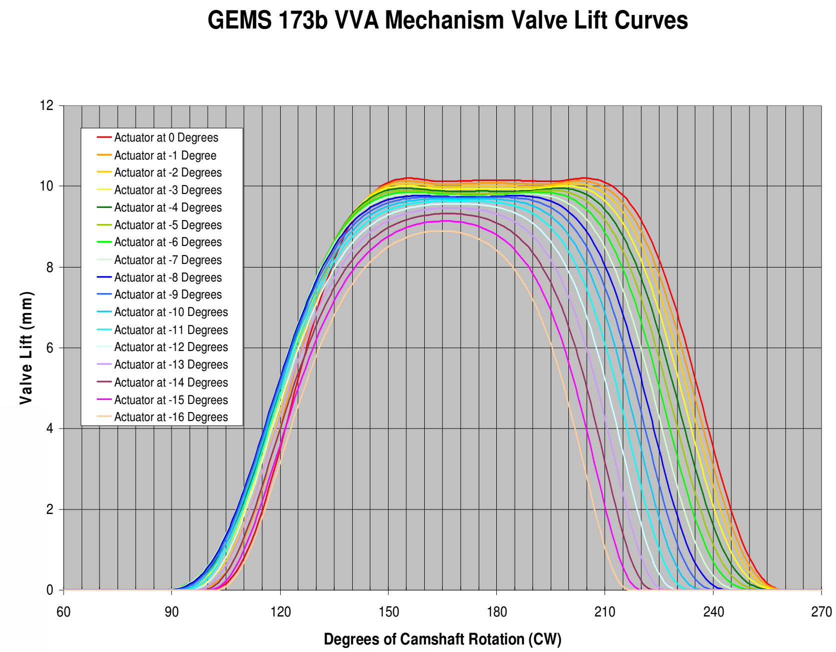
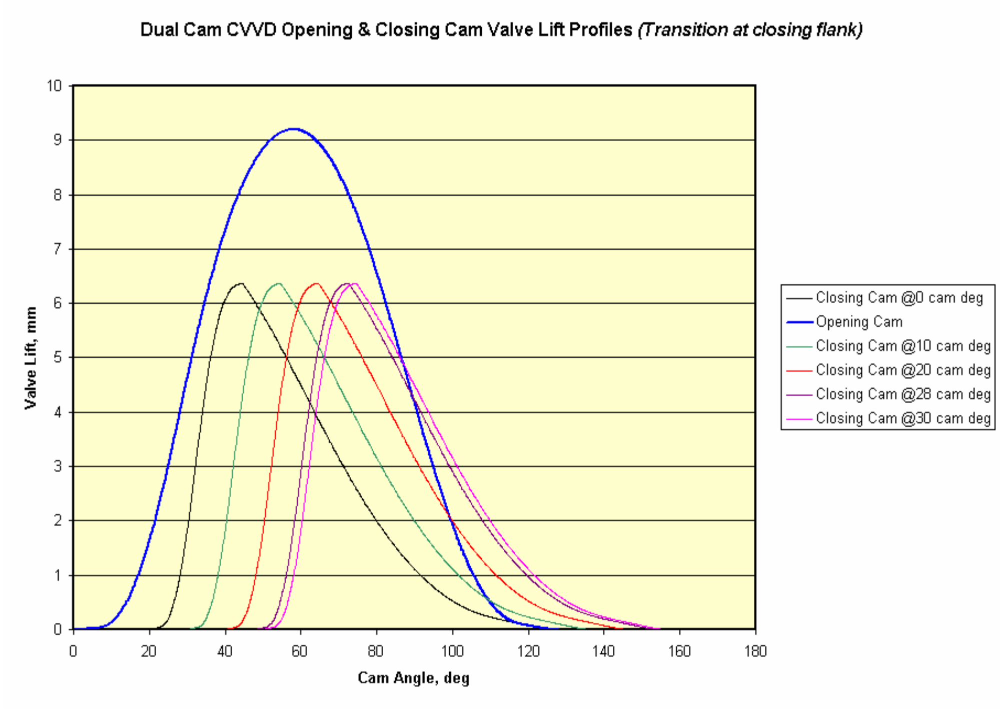
Technical Accomplishments

Range of potential valve motions with single and dual cam designs.

(Figures will be detailed during presentation 2/08)



Range of valve lift vs. Cam angle.
Extended Duration



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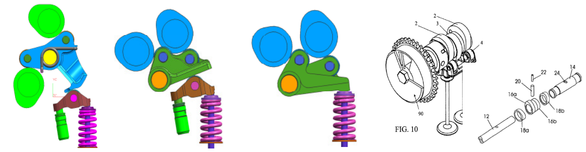
Technical Accomplishments

Multiple design options for dual cam design

Note
Hydraulic cam phaser is assumed for estimating the system



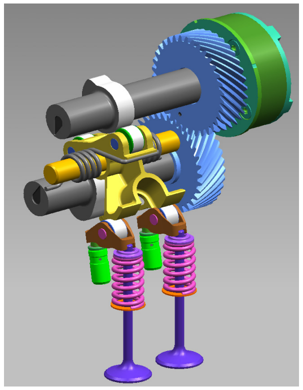
Comparison metric	Delphi GEMS	Delphi CVVD Design "A"	Delphi CVVD Design "B"	Delphi CVVD Design "C"	Double layer camshaft
Packaging Width	+	-	o	o	+
Packaging Height	o	-	+	+	+
Diesel Requirement Compliance	-	+	+	+	+
OEM Assembly Ease	+	+	+	o	-
Friction	o	o	o	o	-
Serviceability	+	+	+	o	-
System Manufacturing Cost	-	o	o	+	-
	-Electric motor actuator needed, with phaser -Output cam grinding needed	-Concern with packaging H and W -Output cam grinding needed	-Concern with phaser gear size for durability -Advantage in packaging	-Concern with phaser gear size for durability -Low cost design (need to re-design cylinder head)	nner & outer)

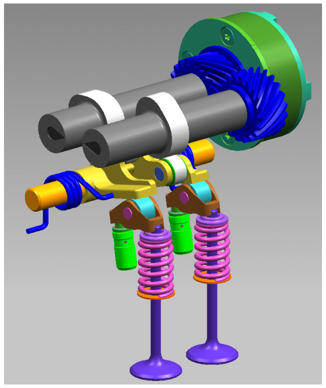
Concept Selection Matrix

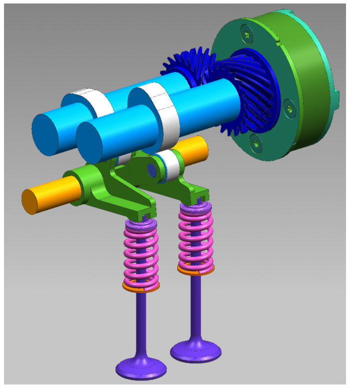
Design "A"
- Easy attachment of cam phaser
- Balanced rocker motion with easy roller bearing application

Design "B"
- Low packaging height
- Can avoid costly output cam grinding
- Concern about insufficient contact length on output cam

Design "C"
- Most cost effective design if OEM plans to re-design the cylinder head
- HEA can be added between rocker arm and valve stem







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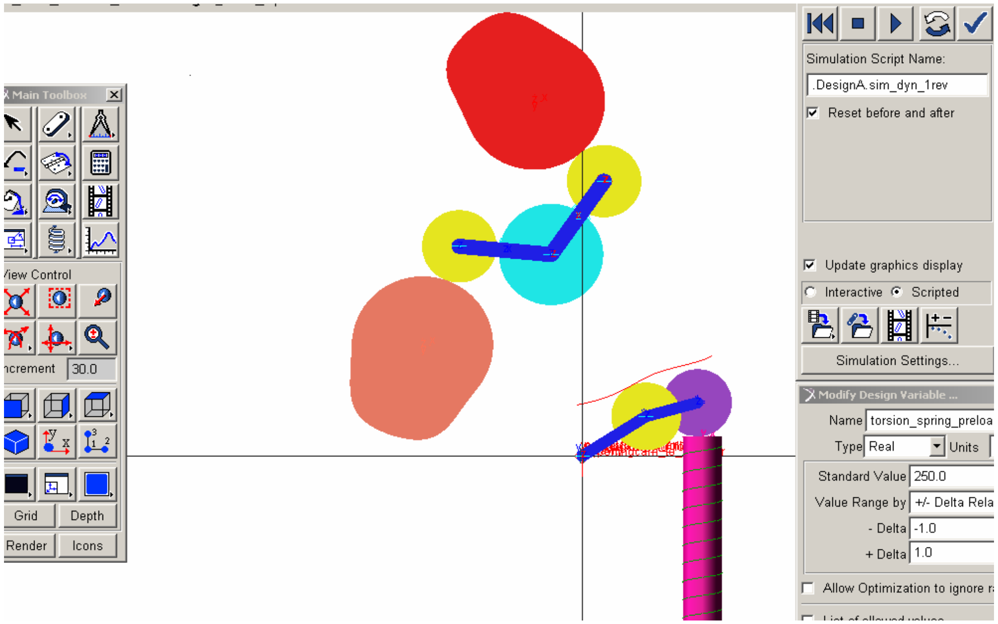
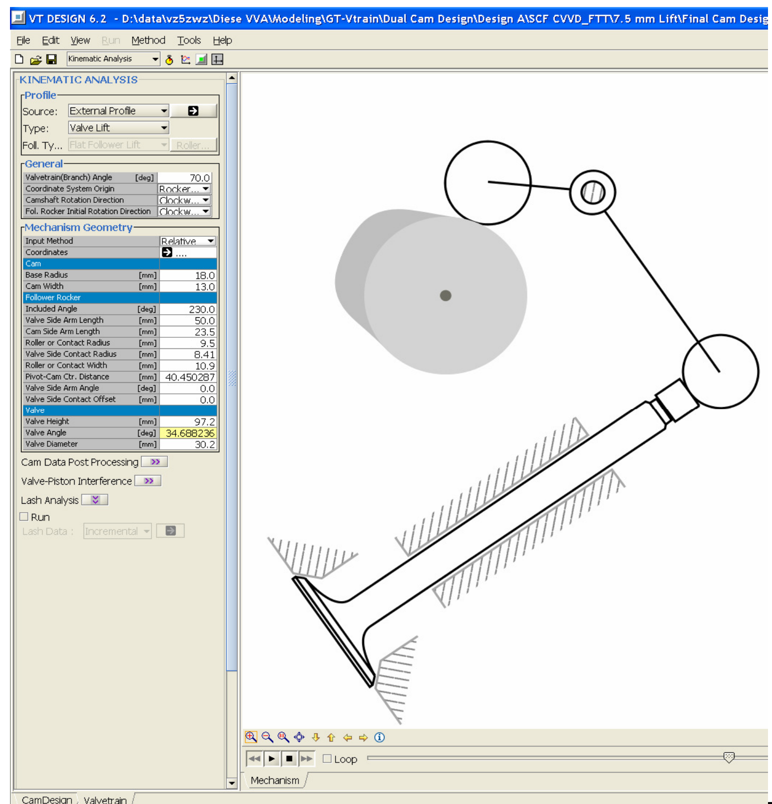
Technical Accomplishments



ADAMS rigid body dynamics simulation

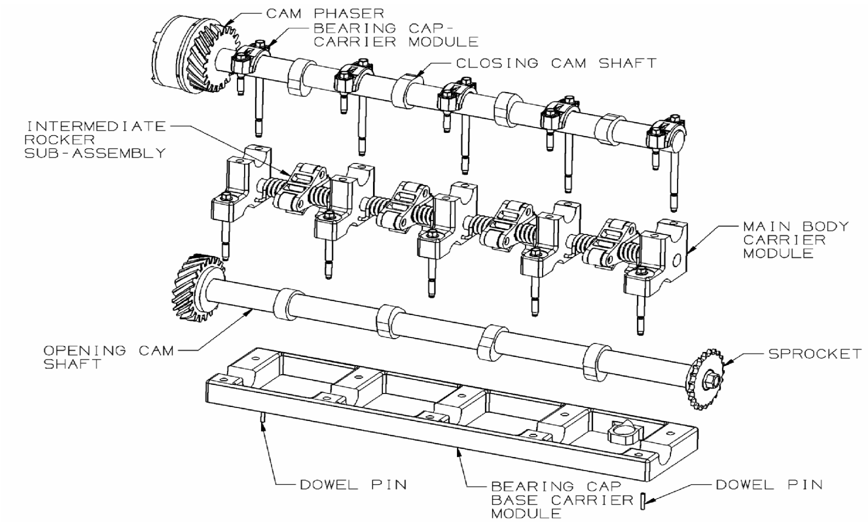
(ADAMS Animation)

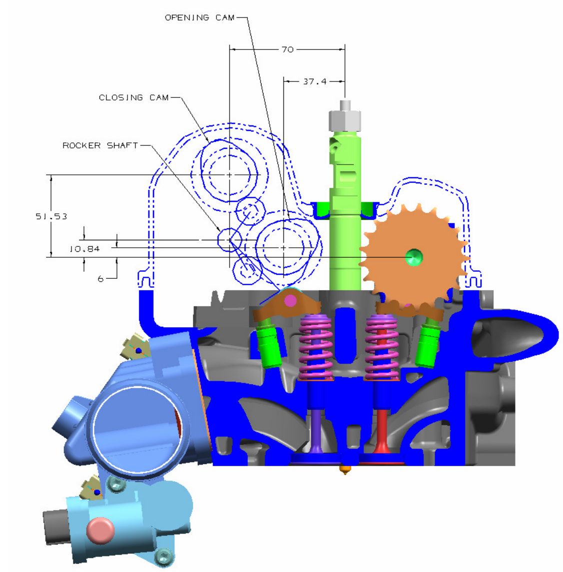
GT Valvetrain used for cam profile design

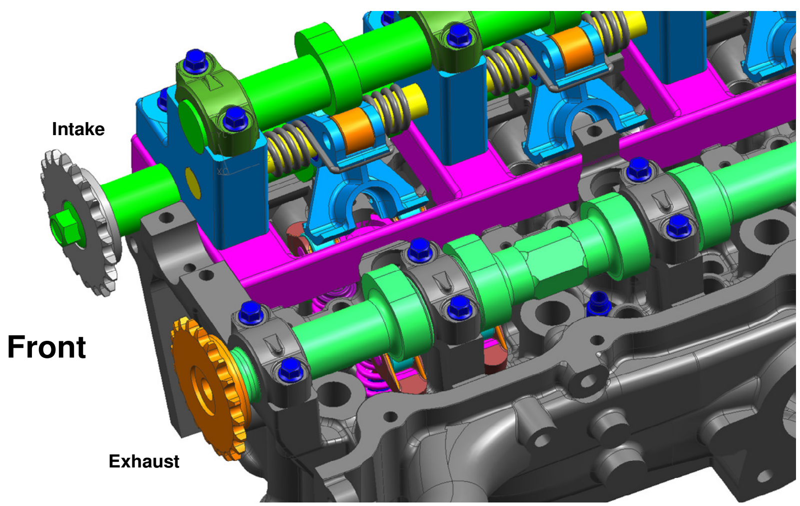


Technical Accomplishments

Cradle Design







Typical Installation envelope

Mechanism Packaging

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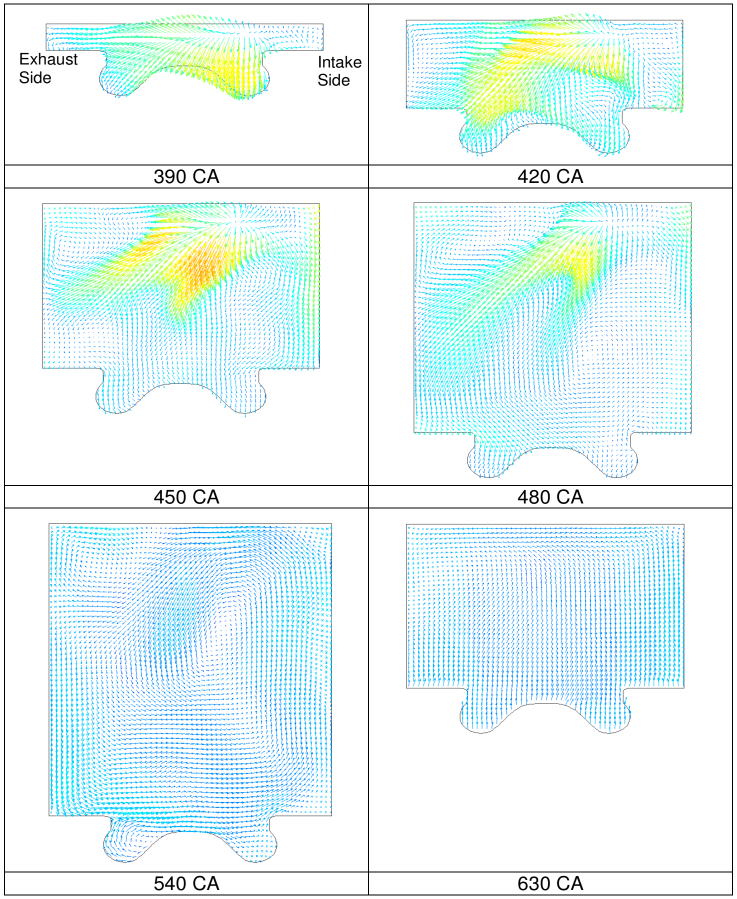
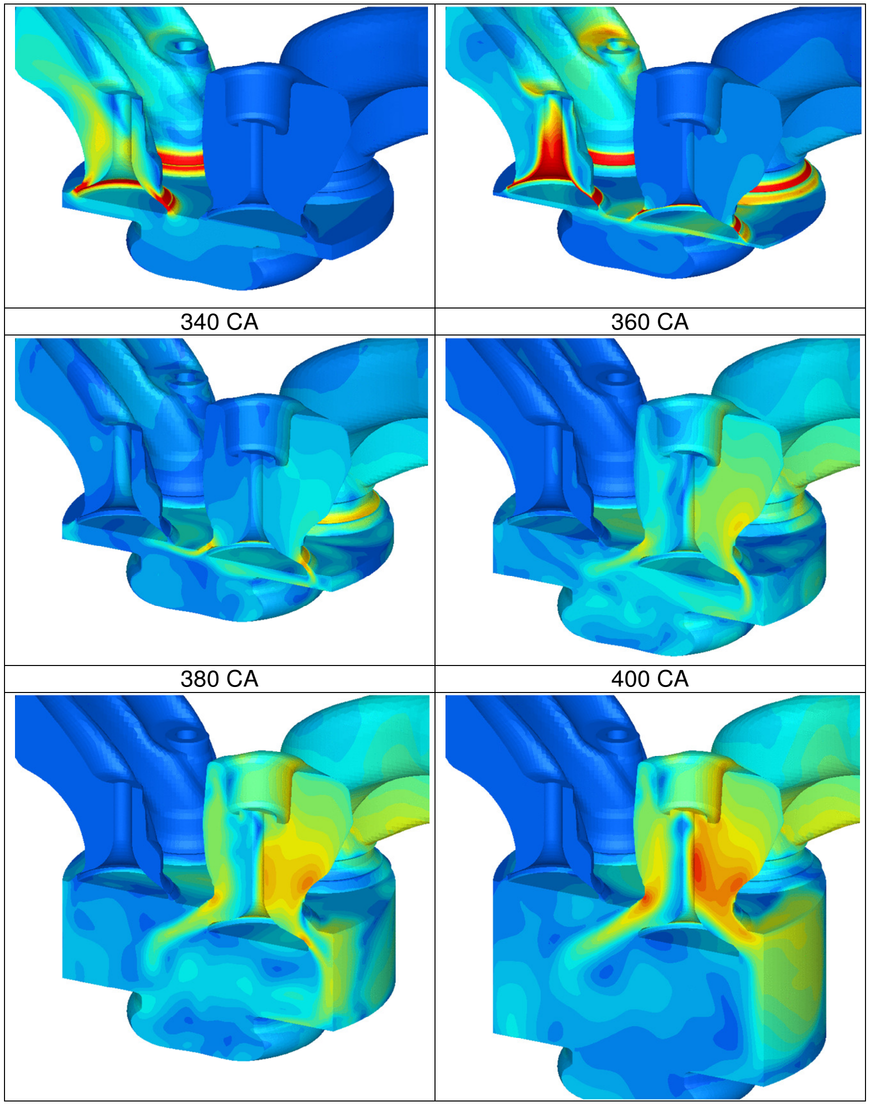
Technical Accomplishments

CFD Model is used to evaluate mechanism lift profile family compatibility with engine.





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Publications, Presentations, Patents

- Patents
  - 3 Granted for mechanism design
  - 2 Filed for control system and design
  - 3 In process for dual cam designs
- Presentations to potential OEMs and ORNL

Collaborations / Interactions

- Numerous meetings with OEM Advanced Powertrain, R&D, and Production Design Groups. On-Site visits and conference calls
- OEM supplied overall engine packaging and environmental requirements and design guidelines
- OEM provided a range of desired valve lift curves derived from dyno testing
- Two recent CRADAs with ORNL initiated incorporating variable valve actuation.
  - Ignition Control for HCCI by Spark Augmentation and Advanced Controls
  - Enhanced Ethanol Engine and Vehicle Efficiency

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Activities for Next Fiscal Year

- Complete hardware test on single cylinder test fixture
- Test mechanism for dynamic and performance requirements
- Verify desired lift curves and mechanical loads
- Develop realistic diagnostics and controls for mechanism
- Collaborate with OEM to install on multi-cylinder engine.

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Summary

- Relevance to DOE objectives
  - A production feasible VVA will allow widespread implementation of Advanced Mode Diesel Combustion, reducing petroleum use and reducing emissions.
- Approach to research
  - Modeling is used whenever possible to reduce cost and turnaround time
    - » Engine models
    - » Dynamic and static models are used extensively to optimize design and test before cutting metal.
- Technical Accomplishments
  - Modeling results and preliminary hardware indicate high confidence of design.
  - Patents: Granted - 3, Filed - 2, In process - 3
- Collaborations/Interactions
  - Working with OEM to implement design on production engine
  - 2 CRADAs with ORNL signed. VVA is key enabler for HCCI and Ethanol operation
- Next Year Activities
  - Complete single cylinder testing
  - Verify performance of design on test stand
  - Complete diagnostics and controls for system
  - Partner with OEM to install on multi-cylinder engine

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