Lean Miller Cycle System Development for Light-Duty Vehicles

2015 U.S. DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation
Meeting - Arlington, VA
June 11, 2015

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General Motors Powertrain

Project ID #
ACE093

OVERVIEW

Timeline

Start Date: January, 2015

End Date: December, 2019

Project Duration: 5 years

Completion: 5%

Budget

Total funding for 5 years

- $ 8,268,881 DOE Share
- $12,403,320 GM Share
- $20,672,201 Total

DOE funding for FY15: $ 681,129

Goals

35% Fuel economy over baseline vehicle

Barriers

- Advanced dilute combustion regimes for gasoline engines
- Emission control challenges for advanced combustion concepts
- Effective engine controls for advanced gasoline engines

Project Lead

General Motors LLC

Supplier Support

- AVL – single cylinder development
- Other suppliers being aligned

RELEVANCE - Objectives

- Develop and demonstrate a vehicle achieving:
  - 35% fuel economy improvement (over 2010 baseline Chevrolet Impala)
  - EPA Tier 3 emission limits (30mg/mi NMOG+NOx; 3mg/mi PM)
  - DOE Thermal Efficiency goals:

Modeled efficiency improvements required to meet fuel economy goals							
	2010 Baselines				2020 Stretch Goals		
	Peak efficiency	Efficiency at 2bar BMEP, 2000 rpm	Efficiency at 2000 rpm and 20% of peak load	2000 rpm peak load	Peak efficiency	Efficiency at 2bar BMEP, 2000 rpm	Efficiency at 2000 rpm and 20% of peak load
Gasoline	38	25	24	9.3	46	30	29
Gasoline	36	24	24	10.9	43	29	29
Gasoline	36	22	29	19	43	26	35
Diesel	42	26	34	22	50	31	41
Green Highlighted cell represents most relevant operating point for that technology pathway.							

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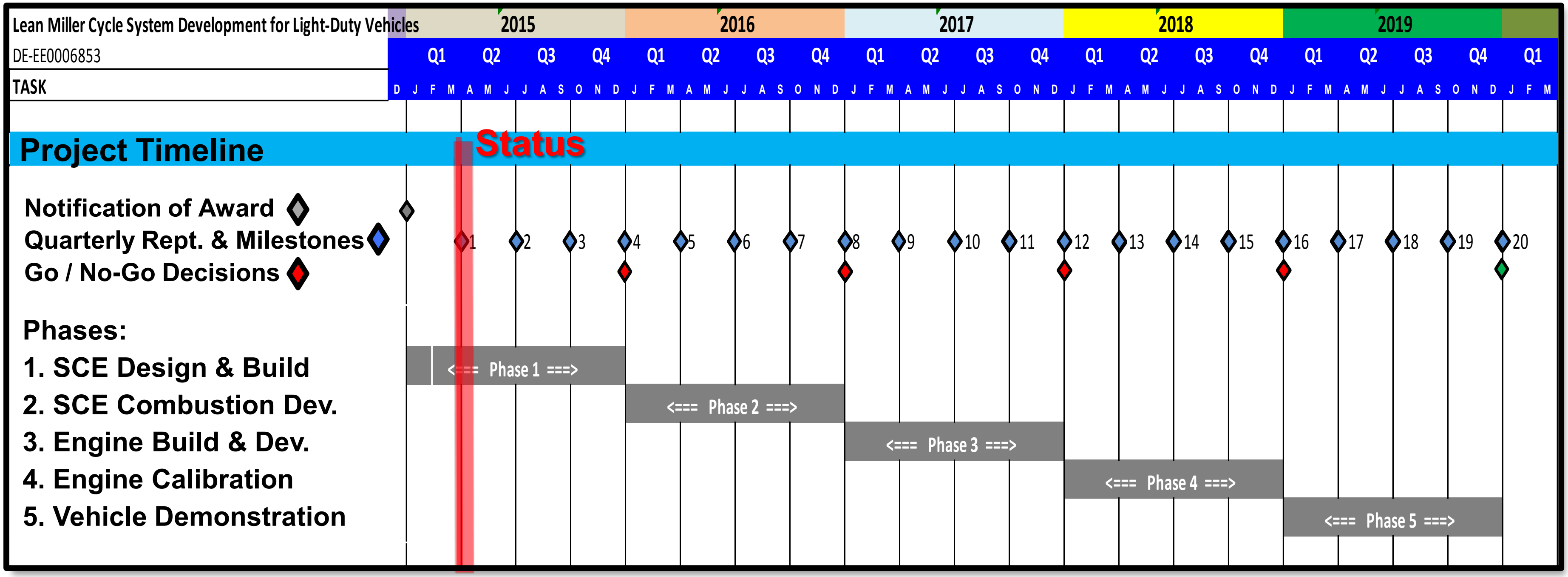
APPROACH – Overall Milestones

- ❑ **4 Annual Go / No-Go Decision Reviews**
  1. Dec. 2015 Baseline SCE Design & Testing
  2. Dec. 2016 Lean Miller Cycle Assessment
  3. Dec. 2017 Multicylinder Efficiency vs. Targets
  4. Dec. 2018 Full Dyno Assessment – FE / Performance / Emissions
- ❑ **Project Completion**
  5. Dec. 2019 Final Vehicle Demonstration



APPROACH – 2015 / 2016 Milestones

Includes Annual Decision Points

Task Number	Task Title or Subtask Title	Milestone or Go/No-Go Decision Point	Milestone or Go/No-Go Decision Point Number	Milestone Description (Go/No-Go Decision Criteria)	Milestone Verification Process (What, How, Who, Where)	Anticipated Date (Months from Start of Project)	Anticipated Quarter (from Start of Project)
1.2	Initial 1D/3D Simulations	Milestone	M1.2	Complete Initial 1D/3D Simulation	GM - Analysis Simulation	3	1
1.3	Single Cyl Hardware Design	Milestone	M1.3	Complete Single Cylinder Designs	GM - Design Data (External Supplier)	6	2
1.4	Procure Single Cyl Hardware	Milestone	M1.4	Procured Single Cylinder Hardware	GM - Build Data (External Supplier)	9	3
1.5.1	Baseline SCE Design	Milestone	M1.5.1	SCE Engine Fired on Dyno	GM - Dyno Data (External Supplier)	12	4
1.5.1	**Baseline SCE Design**	**Go/No-Go Decision Point**	**GNG #1**	**Baseline SCE Testing Complete**	**GM - Dyno Data (External Supplier)**	**12**	**4**
1.5.2	Multi-Hole Inj Head Design	Milestone	M1.5.2	Multi-Hole Inj Head Design #1 Completed	GM - Dyno Data (External Supplier)	15	5
1.5.3	Piezo Inj Head Design	Milestone	M1.5.3	Piezo Inj Head Design #1 Completed	GM - Dyno Data (External Supplier)	18	6
1.5.4	Piston, Inj, Plug Optimization	Milestone	M1.5.4	Single Cylinder Optimization Completed	GM - Dyno Data (External Supplier)	21	7
1.5.5	Final Single Cyl Design	Milestone	M1.5.5	Final Single Cylinder Design Completed	GM - Dyno Data (External Supplier)	24	8
1	**LMC Single Cylinder Testing**	**Go/No-Go Decision Point**	**GNG #2**	**Lean Miller Cycle Assessment**	**GM - Dyno Data (External Supplier)**	**24**	**8**

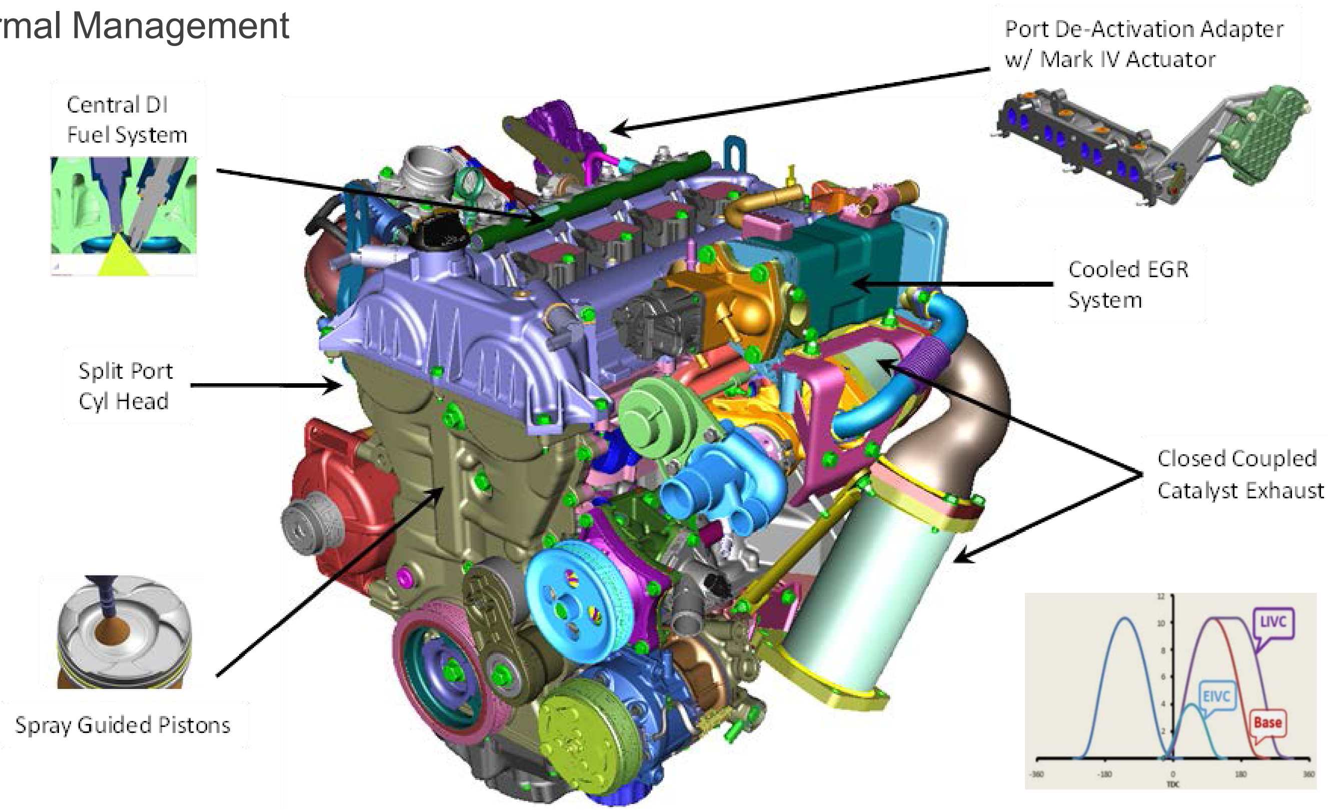
APPROACH – 2017 / 2018 /2019 Milestones

Task Number	Task Title or Subtask Title	Milestone or Go/No-Go Decision Point	Milestone or Go/No-Go Decision Point Number	Milestone Description (Go/No-Go Decision Criteria)	Milestone Verification Process (What, How, Who, Where)	Anticipated Date (Months from Start of Project)	Anticipated Quarter (from Start of Project)
2.3.1	Engine Build #1	Milestone	M2.3.1	Engine #1 Build Completed	GM - Build Data (External Supplier)	27	9
3.2	Install & Debug Engines	Milestone	M3.2	Engine #1 Fired on Dyno	GM - Dyno Data (External Supplier)	30	10
3.3.1	Lean Miller Development	Milestone	M3.3.1A	LMC preliminary efficiency status	GM - Dyno Data (External Supplier)	33	11
3.3.2	Adv Boost & ATM Development	Milestone	M3.3.2	ATM preliminary efficiency status	GM - Dyno Data (External Supplier)	36	12
3.3	**Dynamometer Development**	**Go/No-Go Decision Point**	**GNG #3**	**Meet DOE Efficiency Targets**	**GM - Dyno Data (External Supplier)**	**36**	**12**
3.3.1	Lean Miller Development	Milestone	M3.3.1B	FE Projections > 15% Improvement	GM - Dyno Data (External Supplier)	39	13
3.3.1	Lean Miller Development	Milestone	M3.3.1C	FE Projections > 20% Improvement	GM - Dyno Data (External Supplier)	42	14
3.4	Final Calibration DOE	Milestone	M3.4	FE Projections > 25% Improvement	GM - Dyno Data (External Supplier)	45	15
3.5	Cal Verification	Milestone	M3.5	FE Projections = 28% Improvement	GM - Dyno Data (External Supplier)	48	16
3	**Calibration & Controls Dev**	**Go/No-Go Decision Point**	**GNG #4**	**Full Dyno Assessment (FE, Perf, Emission)**	**GM - Dyno Data (External Supplier)**	**48**	**16**
4.4.1	Veh A LMC Integration	Milestone	M4.4.1A	Vehicle FE > 10% Improvement	GM - Veh Data (MPG)	51	17
4.4.1	Veh A LMC Integration	Milestone	M4.4.1B	Vehicle FE > 20% Improvement	GM - Veh Data (MPG)	54	18
4.4.1	Veh A LMC Integration	Milestone	M4.4.1C	Vehicle FE > 30% Improvement	GM - Veh Data (MPG)	57	19
4.5	**Final Vehicle Demonstration**	**Milestone**	**M4.5**	**Vehicle FE = 35% Improvement**	**GM - Veh Data (MPG)**	**60**	**20**

APPROACH / Strategy

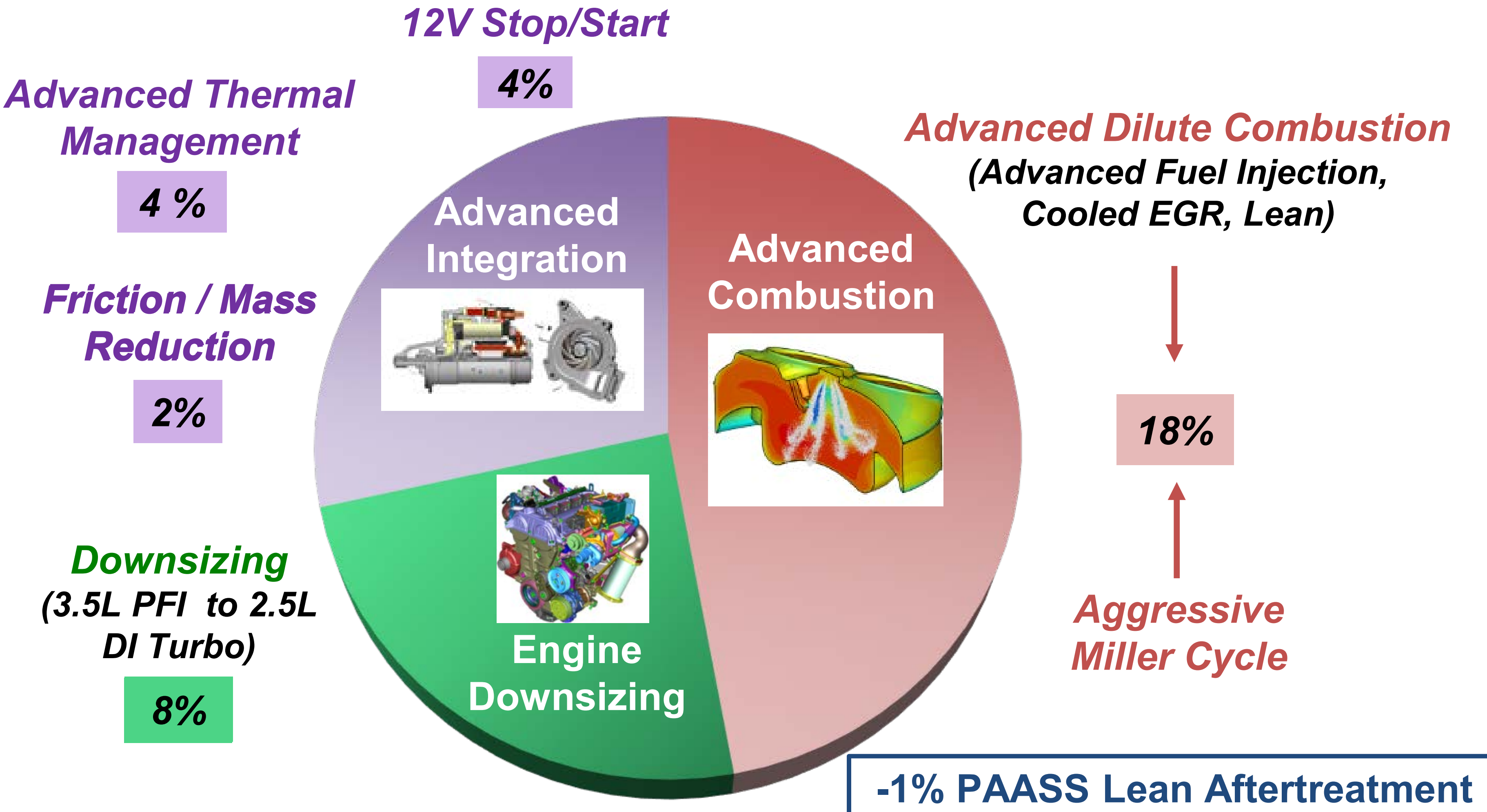
<u>Lean Miller Cycle Integration</u>

- ❑ Lean Stratified Spray Guided with Miller cycle into one combustion system
- ❑ Optimized engine sizing and minimized friction
- ❑ Optimized high pressure fuel system, piston geometry, valvetrain, and EGR
- ❑ Passive-Active Ammonia SCR lean NOx aftertreatment system
- ❑ Advanced Thermal Management
- ❑ 12V Stop/Start



APPROACH / Strategy

Targeted Efficiency Improvements



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

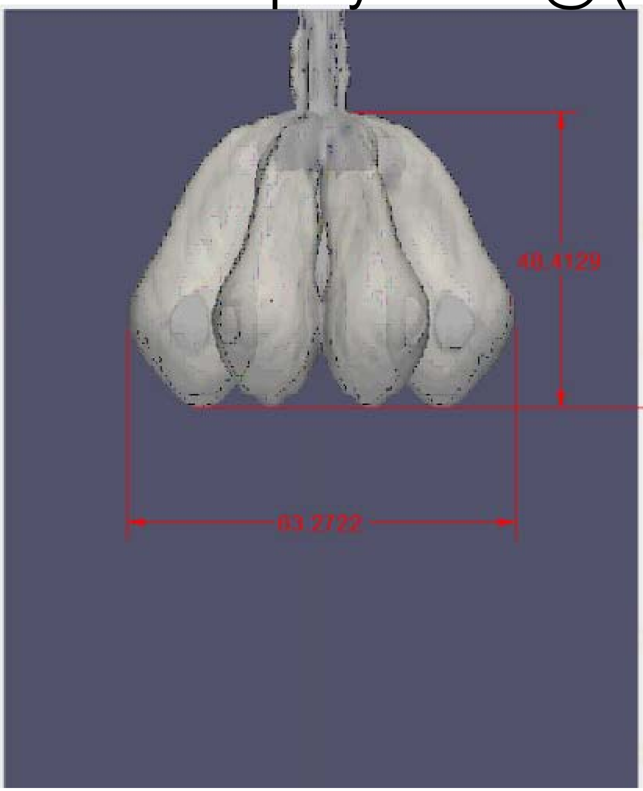
- Project kick-off January, 2015
- AVL selected for single cylinder testing
- Initial 1D and 3D modeling started
- Initial tasks identified:
  - Optimizing displacement for best lean stratified / downsizing balance
  - Optimizing piston bowl design for both high load Miller and light load stratified performance

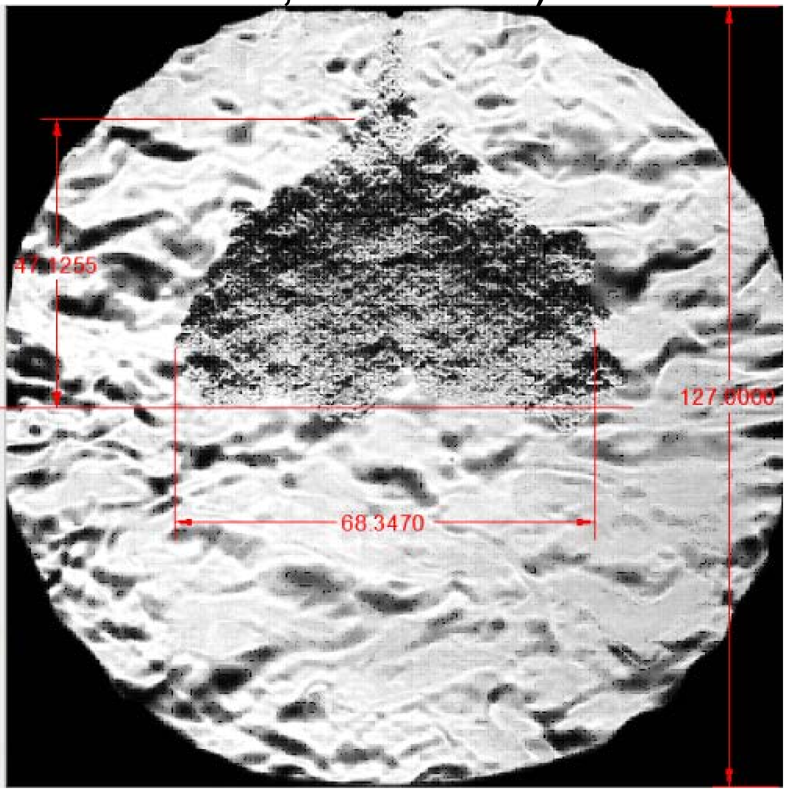
This will be the focus of analysis and single cylinder design and development

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

3D Simulation – Spray Calibration – Vapor Phase

Comparing dimensions of CFD and experimental vapor plume
Spray Bomb @ (P = 10.6 bar, T = 600 k)





CFD **Experimental**

Example: match of vapor spray penetration and cone between CFD and Schlieren spray imaging

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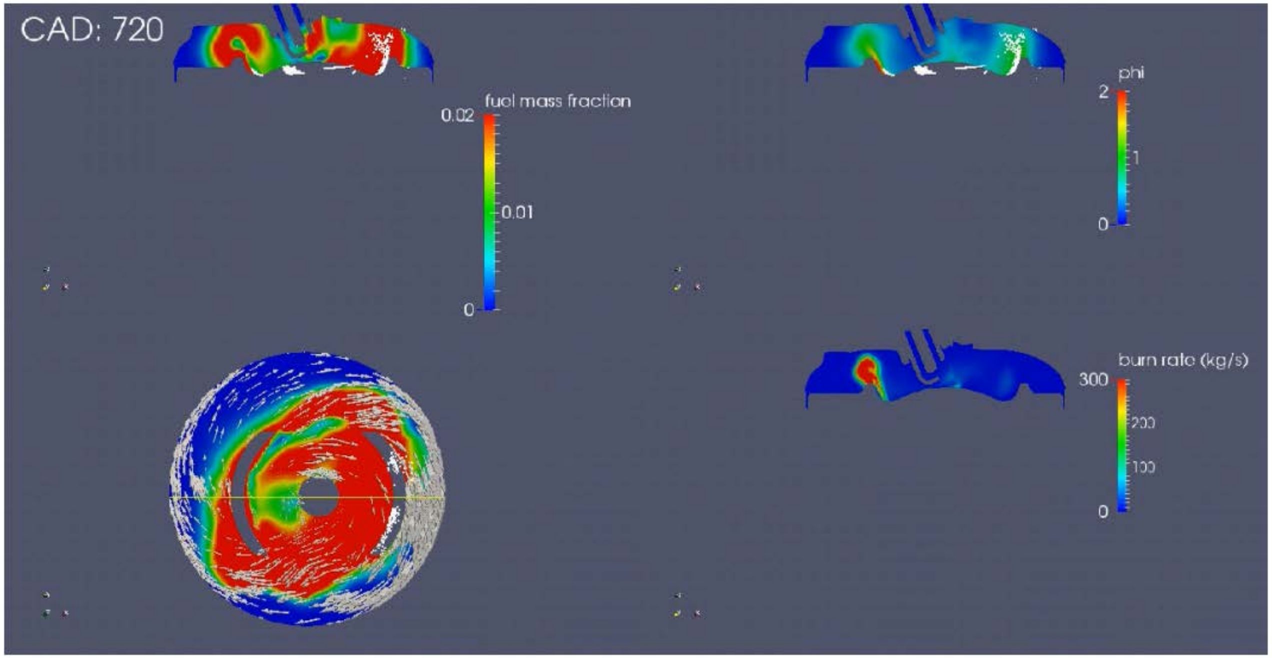
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Light Load Combustion Animation



1333 RPM / 2.4 Bar

- CFD is identifying key features of the physics of the fuel injection, stratification and mixing process
- Being used to design and analyze various piston bowls and spray shapes to arrive at an optimum across the speed-load range

Responses to Previous Year Reviewer's Comments

- New project – not reviewed last year

Collaboration and Coordination

- AVL – Single cylinder testing subcontractor
  - Hardware design support
  - Engine builds
  - Engine testing
- Surveying several additional system suppliers
  - Fuel injection
  - Ignition
  - Boost
  - Aftertreatment

Challenges (Near-Term)

- Select displacement for best lean stratified / downsizing balance
- Optimize piston bowl design for both part-load stratified and high-load Miller performance

  Tradeoffs between effective compression ratio vs. knock limit, surface to volume, mixing

Proposed Future Work

FY 2015

- Develop combustion system hardware designs using 1D and 3D modeling
- Implement single cylinder for optimization and complete baseline testing in homogeneous mode

FY 2016

- Investigate Miller cycle strategies (LIVC, EIVC) along with compression ratio to optimize fuel consumption
- Optimize lean stratified combustion system on single cylinder engine – piston bowl, spray patterns, mixture motion, dilution strategies

Summary

Lean Miller Cycle System Development

- New project – kicked off January, 2015
- Initial 1D and 3D modeling work is underway
- Started designing and analyzing piston bowls for operation across speed load range
- Work is moving on track to meet 2015 milestones

THANK YOU!

Technical Back-Up Slides

Lean Gasoline System Development

Accomplishments – Phase 3: Vehicle Fuel Economy Projections

Summary from Previous Phase 1 GM/DOE Project

Targeted Efficiency Improvement

- ✓ Downsizing 7-8 %
- ✓ Dilute & Lean Combustion 12-13%
- ✓ Total from Engine 19-21 %
- ✓ 12V Stop/Start & Active Thermal Management 5 %

FE Projections: PFI to NA Lean to Lean Downsize Boost

				BSFC Improvement	
		Speed (RPM)	Load (n-m)	PFI to Lean NA	PFI to LDB
Urban	Idle	700	19	0%	0%
	Zone 2	1335	27	17%	30%
	Zone 3	1565	28	19%	31%
	Zone 4	1805	29	18%	35%
	Zone 5	1530	95	-1%	7%
	Zone 6	1821	80	3%	9%
	Zone 7	2250	101	0%	7%
Highway	Zone 8	1410	51	18%	16%
	Zone 9	1669	60	9%	14%
	Zone 10	1461	114	0%	3%
	Zone 11	1692	100	0%	6%

	Projected FE Improvement	
City	12%	26%
Highway	8%	12%
Combined	10%	21%

➔ The LDB engine in combination with 12V Stop/Start and Active Thermal Management is projected to meet the 25% fuel economy improvement target