Project ID: ace163

Ducted Fuel Injection and Cooled Spray Technologies for Particulate Control in Heavy-Duty Diesel Engines

PI: Adam Klingbeil, PhD

2021 DOE Vehicle Technologies office annual merit review

Wabtec CORPORATION

Project Overview

Timeline

- Start: October 2020
- End: September 2023
- ~10% complete

Partners

- Sandia National Laboratories
- Southwest Research Institute

Budget

- Total Project Funding: $3.1MM over 3 years
  - DOE: $2.4MM
  - Wabtec: $641k
- Total project funds for Year 1: $1.2MM

Barriers

- Off-road vehicles use complex emission control devices to meet regulations.
- Technologies are needed that increase efficiency and/or reduce cost, complexity and energy penalty associated with emissions control over a typical drive cycle.

Relevance

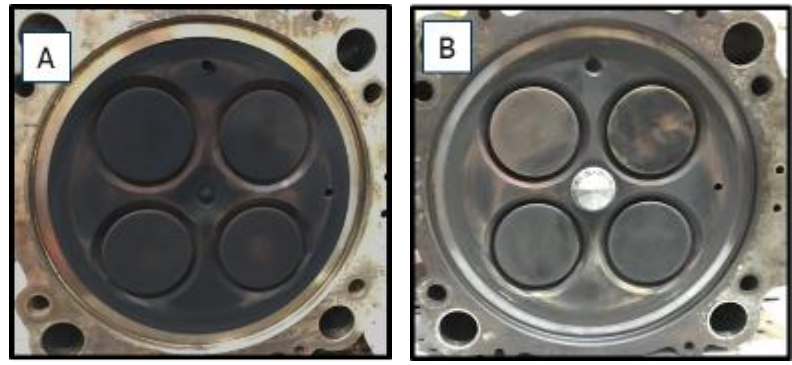
Impact

- Ducted fuel injection (DFI) has yielded nearly sootless combustion at low load
- Cooled spray (CS) has shown >70% particulate matter reduction at a full load condition
- **Question**: What is the potential performance benefit?

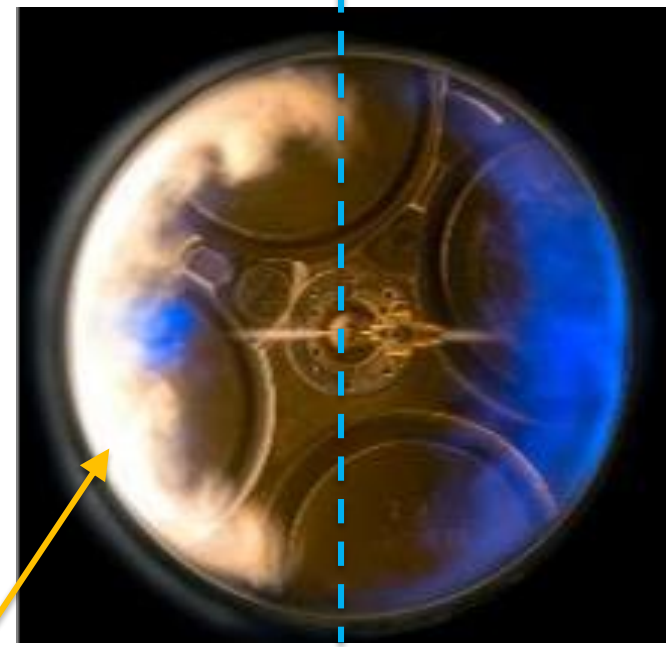
Objectives

- 75% Particulate Matter reduction over operating range using CS technology
- Develop scaling rules to apply DFI/CS to small and large engines

Conventional Diesel Combustion | With Cooled Spray



Conventional Diesel Combustion | Ducted Fuel Injection



Yellow Flame
➔Soot

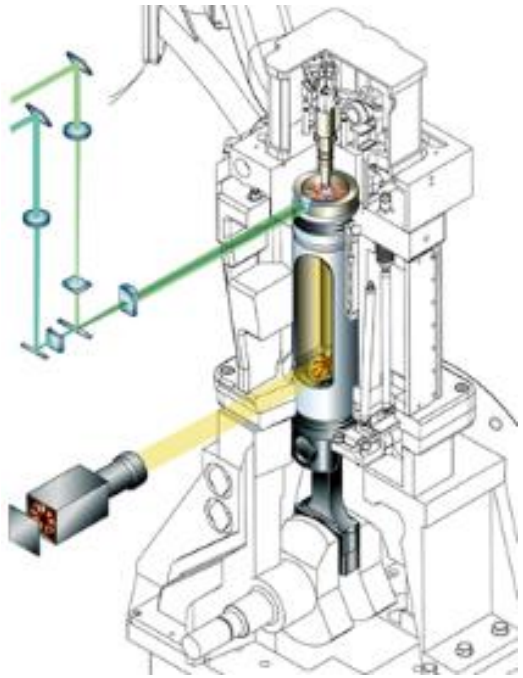
Milestones

Date	Status	Description
Dec, 2020	Complete	Operating conditions and boundary conditions will be defined for both engines. Range of DFI and CS design parameters (e.g., duct length) will be defined.
Mar, 2021	Complete	Design of head modification for testing Cooled Spray hardware on metal engine.
June, 2021	1-Month Delay	Characterize performance for base engine design with and without EGR at key operating conditions.
Sep, 2021	On Schedule	Fuel injector and custom nozzles, custom cylinder head, DFI components and CS blanks designed and procurement initiated.
Dec, 2021	On Schedule	DFI evaluated in the optical engine for the new hardware.
Mar, 2022	On Schedule	Generate updated CS geometries for metal engine testing based on previous metal and optical engine tests.
June, 2022	On Schedule	Performance test results in at least 2 updated CS designs for at least 3 conditions.
Sep, 2022	On Schedule	Downselection of CS hardware and broad performance sweep using CS.
Dec 2022	On Schedule	Evaluation of CS design in optical engine and comparison to DFI completed.

Approach

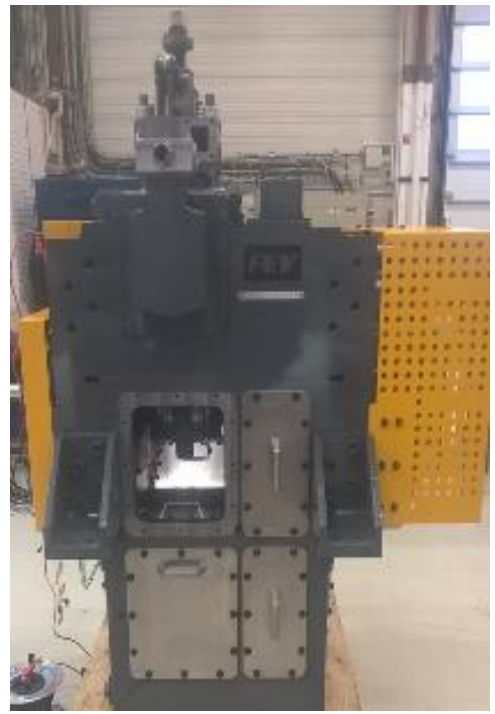
Optical Engine: Develop scaling rules for DFI/CS

- Vary injector hole size over wide range
- Characterize DFI/CS geometry sensitivity
- Up to 200 bar cylinder pressure



Metal Engine: 75% Particulate Matter (Soot) reduction

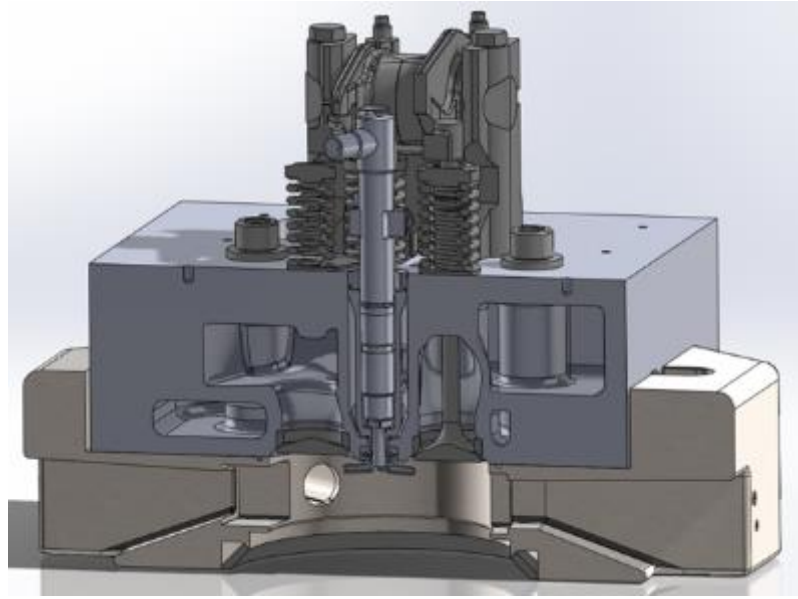
- Cooled Spray in single-cylinder engine
- Design features guided by optical engine results
- Evaluate over engine map



Technical accomplishments and progress

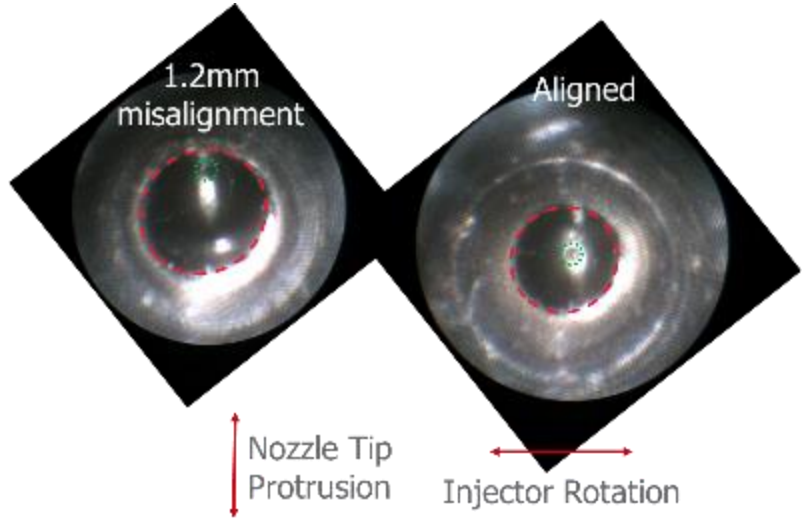
Optical Engine

- Optical piston designed, procurement initiated
- Design of cylinder head with rotating mounting stage nearly complete
- Injector selection nearing completion
- High-speed data-acquisition system procured



Metal Engine

- Designed modifications for Cooled spray inserts, cylinder head, injector sleeve and sealing washer
- Prototype hardware built
- Initial test fit complete ➔ small modifications required before testing
- New alignment procedure developed using fiber optic borescope



Collaboration with other institutions

- **Sandia National Labs (C. Mueller, C. Nilsen, N. Harry, D. Biles)**
  - Optical engine design modifications
  - Optical engine testing, diagnostics
- **Southwest Research Institute (T. Tinar, S. Ellis)**
  - Metal engine testing
  - Combustion and emissions data collection
- **Key Suppliers:**
  - FEV: Single-Cylinder Engine
  - Bosch: Fuel injection equipment

Proposed future research

FY 21: Acquire baseline data

- Evaluate engine performance without Cooled Spray over engine map
- Quantify benefit of initial Cooled Spray design at select conditions

FY 22: Technology Characterization

- Baseline optical engine measurements with DFI
- Evaluate multiple Cooled Spray designs on metal engine
- Downselect Cooled Spray geometry and test over engine map
- Optical engine measurements for Cooled Spray compared to DFI

Any proposed future work is subject to change based on funding levels

Summary Slide

- **Significant design work completed for metal and optical engines**
- **Design of optical engine hardware is nearing completion and PO's are being issued**
  - On track to have optical engine measurements by Dec 2021
- **First prototypes of Cooled Spray hardware have been inspected and will be ready to test**
  - Expect to have engine test data without cooled spray by July, 2021
  - …with cooled spray results by October, 2021

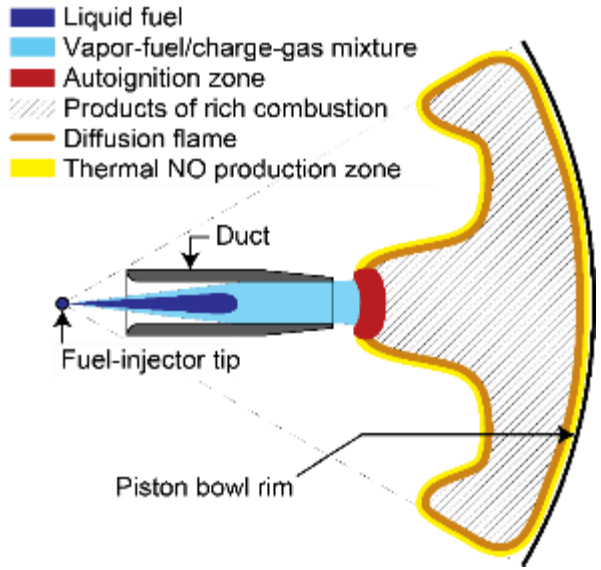
Technical Backup Slides (Optional, maximum of 5 slides)

Relevance: What are the technologies?

Cooled Spray/Ducted Fuel Injection for Reduced Diesel Particulate Matter

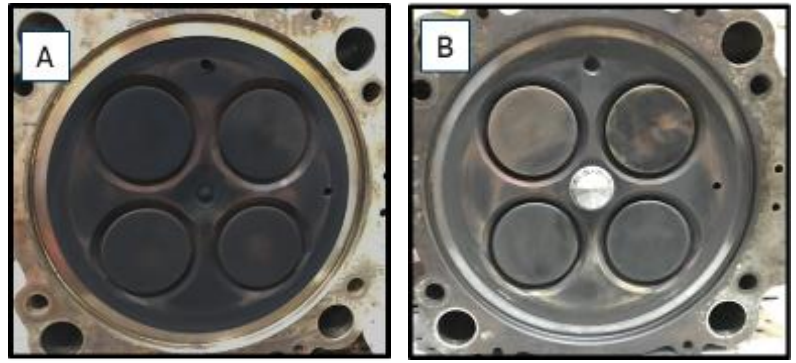
Ducted Fuel Injection:

- Ducts placed outside of fuel injector nozzle orifice delay start of combustion
- Extend liftoff length
- Reduce formation of particulate matter



Cooled Spray:

- Monolithic insert installed in cylinder head
- Multiple fuel and air passages manage mixing of fuel and air
- Leads to lower particulate matter

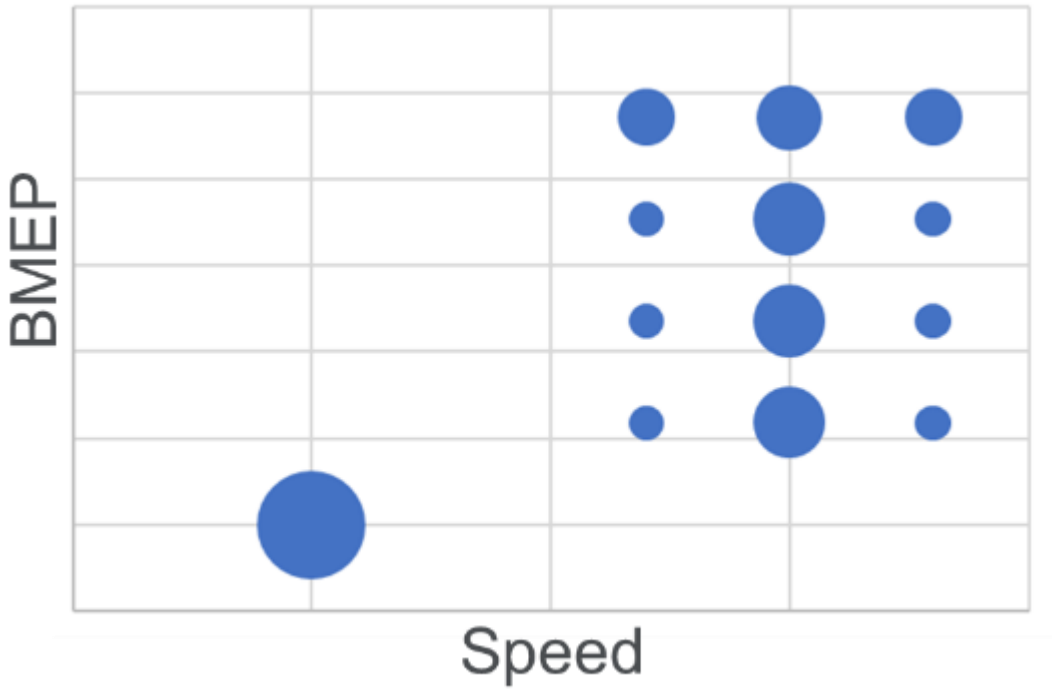


Compare Wabtec and Sandia Engines

Objective: Combustion in optical engine should be representative of combustion in the metal engine

		Sandia Optical Engine	Wabtec Metal Engine
Bore	Mm	125	168
Stroke	Mm	140	198
Compression Ratio		12.5	16
Displacement	L	1.72	4.4
Rated Speed	RPM	1800	1800
Rated Power	kW/Cyl	~52	155
Fuel System		Common Rail	Common Rail

13-Mode Supplemental Engine Test (SET)



Operating Conditions

- >20bar BMEP
- 1200, 1500, 1800RPM
- Engine boundary conditions being determined from GT-Power
- EGR: TBD based on engine performance with EGR (expect ~25-30%)