

Medium-Duty Diesel Combustion (ace136)

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June 11, 2019

Timeline

- December 2017-present: medium-duty diesel research
- Ongoing project with continual guidance from AEC MOU industrial partners and reviewers
- Research priorities for MCCI:
 - Reduced engine-out NOx and particulates
 - Reduced cold-start emissions

Budget

FY18: \$750k
 FY19: \$900k

Barriers & technical targets

- Lack of quantitative engine combustion databases precludes collaborative model verification and validation
- Inadequate understanding of fuel injection, air motion, and combustion chamber geometry effects on combustion and pollutant formation
- Research priorities for MCCI:
 - Reduced engine-out NOx and particulates
 - Reduced cold-start emissions

Partners

 Technical advice, regular meetings and teleconferences; Supplier of new engine

 Wisconsin Engine Research Consultants RANS 3D-CFD simulations; Model development and evaluation

Relevance

- Improving MCCI combustion system efficiency and emissions behavior will require improved understanding of how spray-wall interactions can promote rapid fuel-air mixing
- Clean catalyst heating operation is critical to enable fuel efficient diesel engines to comply with new CARB regulations (e.g. 0.02 g/bhp-hr NOx)

Objectives for this period

- Test hypotheses about the mechanisms responsible for decreased vortex formation with the stepped-slip piston at near-TDC injection timings
- Develop a modified piston bowl to enhance spray-wall interactions associated with a stepped-slip piston to improve fuel-air mixing
- Develop injection strategies and perform engine performance and emissions testing to understand how post/main quantity and split ratio impact pollutant emissions and heat release behavior
- Begin the design and fabrication of a new, medium-duty diesel research engine

Milestones

FY19

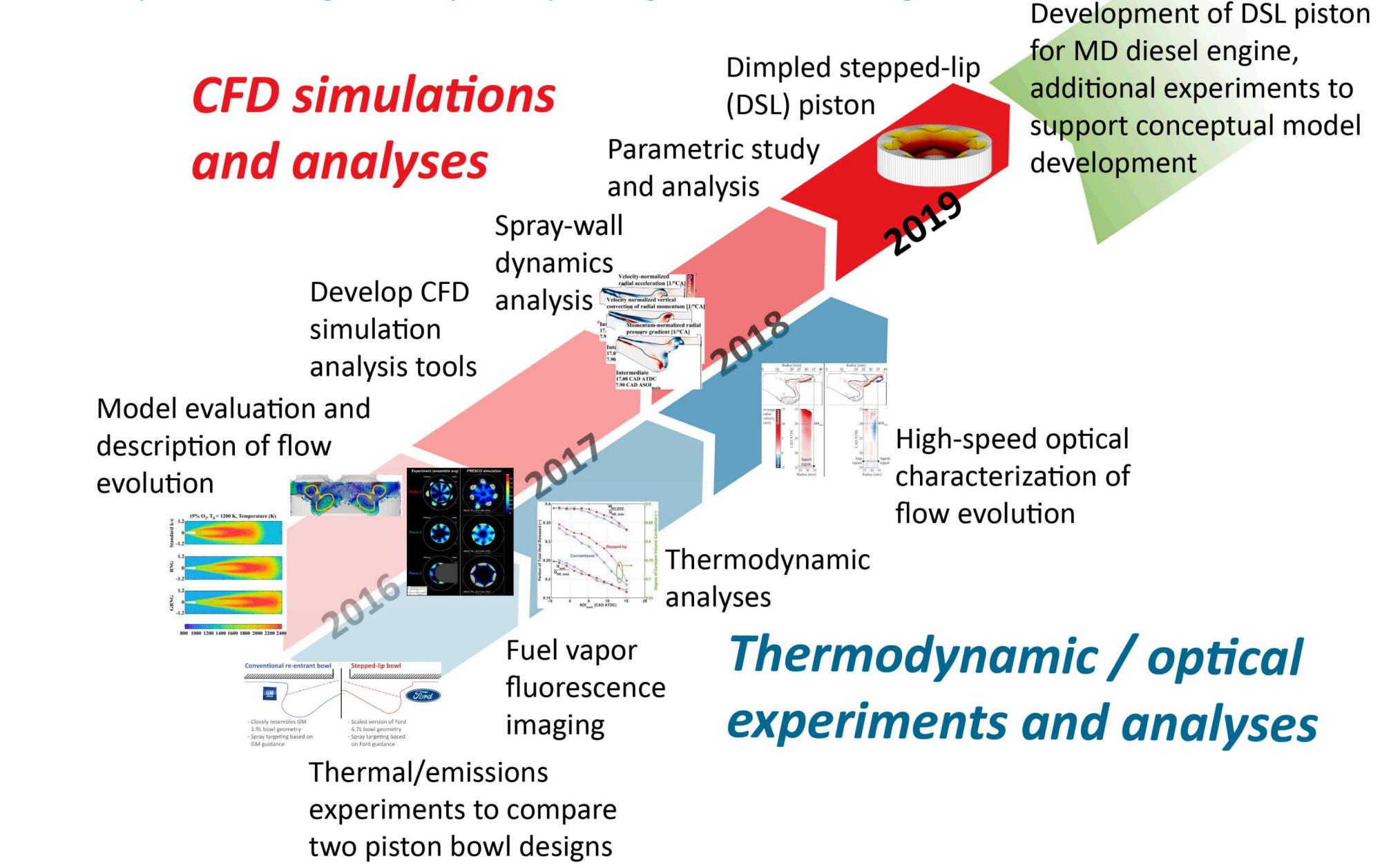
- Q2: Initial performance and emissions measurements with cat heating operation (small-bore)
- Q3: High-speed vis/IR imaging experiments w/ catalyst heating operation (small-bore)
- Q4: First operation of new medium-duty diesel engine (thermal configuration) in lab

FY20

- Q1: Complete shakedown testing of new medium-duty diesel engine
- Q3: Tradeoffs between pollutant emissions and exhaust temperature/heat flux in catalyst heating operation

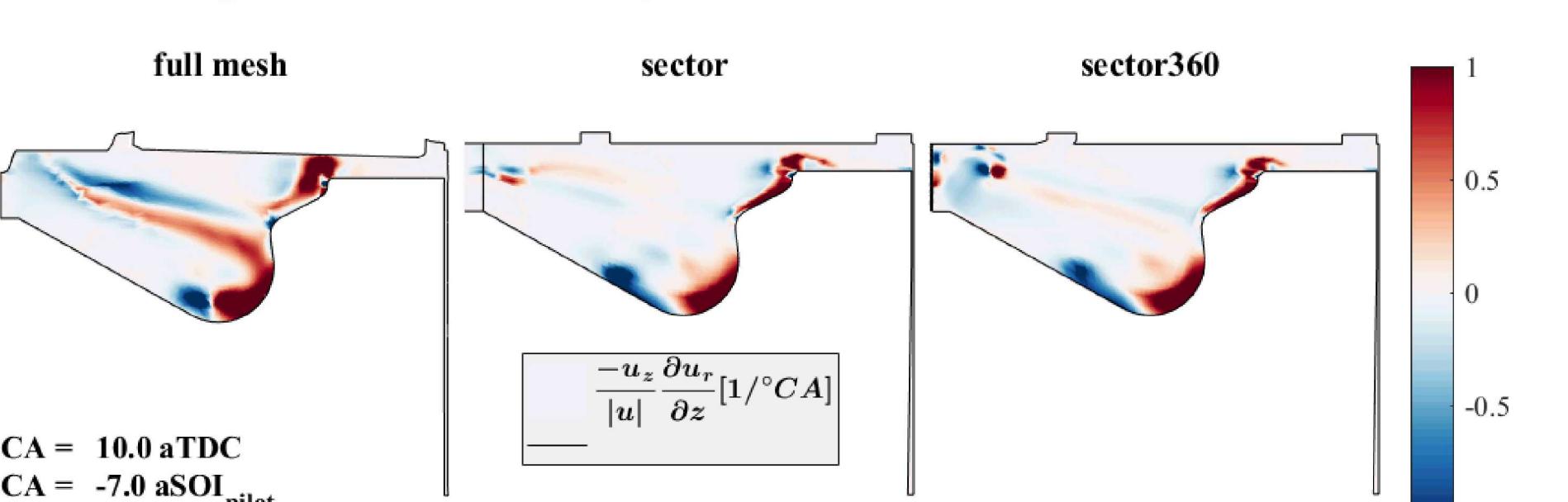
Approach: piston bowl geometry study

Unique thermodynamic optical experiments and in-depth analyses of simulation results to provide new insight into the role of piston bowl geometry in improving turbulent mixing



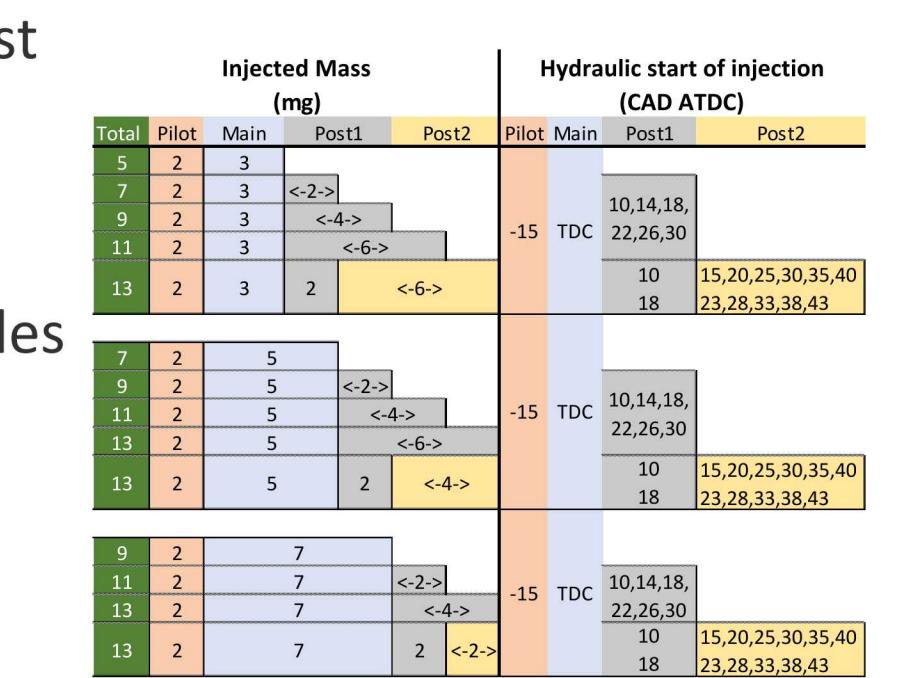
TA: simulation methodology (sector vs. full) impacts prediction of spray-wall interactions

- CFD simulations for the bowl geometry study have been performed on full engine meshes that preclude large parametric studies
- Can a sector mesh capture the spray-wall interactions in manner consistent with experimental predictions?
- Vertical convection of radial momentum is not accurately predicted with a sector mesh or 360° axisymmetric mesh; vortex dynamics in the squish region are only consistent with experimental data with the full mesh.



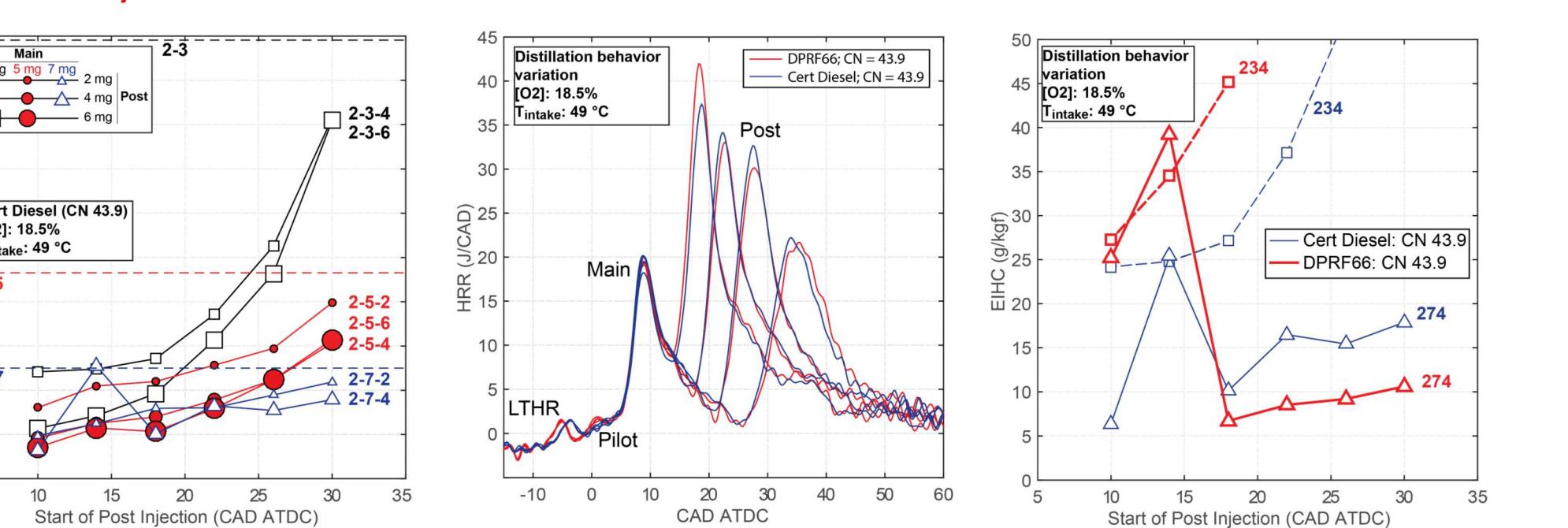
Approach: catalyst heating operation study

- Long term goal: conceptual models describing injection, mixture formation, combustion, and pollutant formation mechanisms for multiple injection, catalyst-heating operation
- Address complexity of catalyst heating operating strategies by focusing on simplified subsets; current focuses:
 - Post/main injection quantity/split ratio and timing
 - Fuel boiling range and cetane number
- Develop a family of well-characterized injection schedules with constant pilot, main, and post injection masses
- Perform engine performance and emissions testing using these various injection schedules
- High-speed liquid- and vapor-phase fuel imaging, natural luminosity imaging
 - Provide insight into mixture formation, ignition, and combustion processes



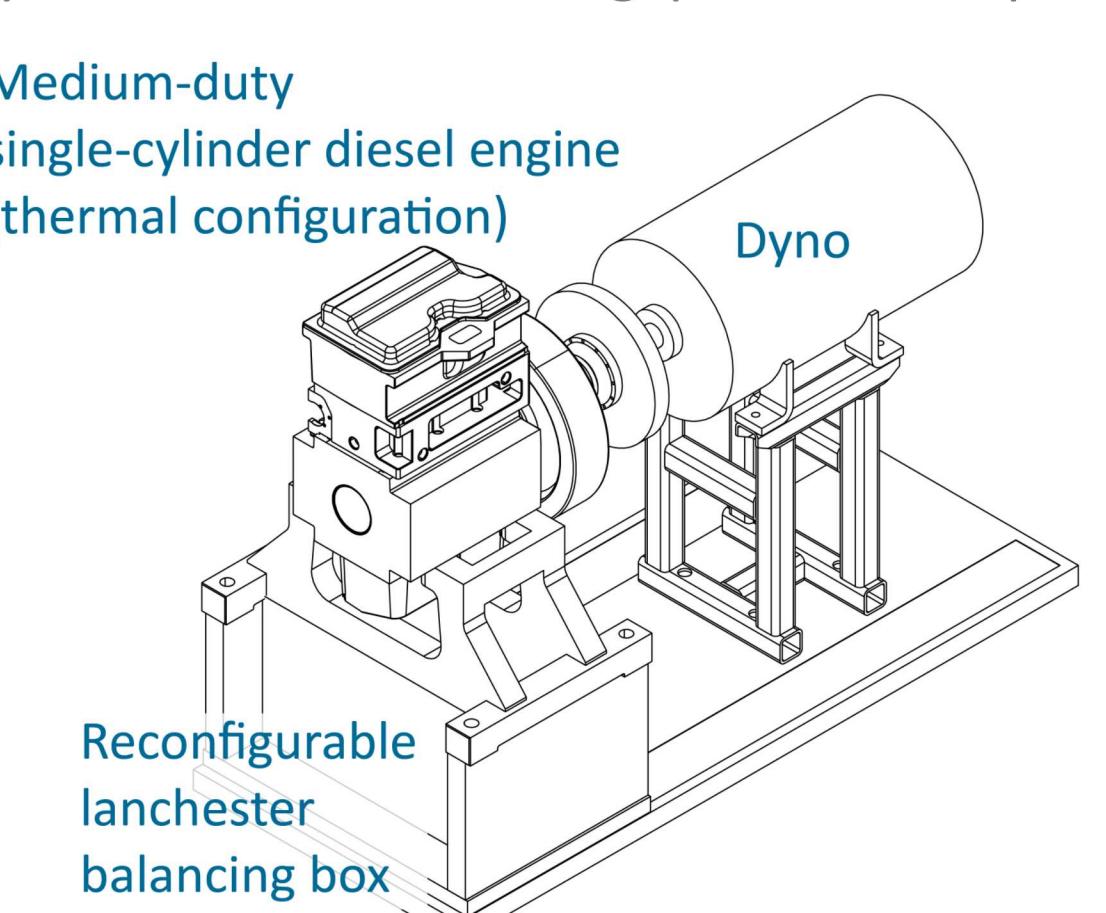
TA: post injections reduce unburned hydrocarbon emissions in catalyst heating operation

- Preliminary testing for a wide range of injection schedule calibrations
 - Variations of EGR rate, intake temperature, cetane number, and distillation behavior
- Adding the first post injection decreases hydrocarbon emissions, but retarding post injections increases them
- Fuel distillation behavior has a very small impact on post injection heat release, but the full boiling range diesel typically results in significantly lower hydrocarbon emissions



Progress on new medium-duty research engine

- Conception phase of dual-configuration thermal/optical engine: complete
- Single cylinder short block to be provided by Ford
 - 6.7L Power Stroke® diesel combustion system
- Cylinder heads and liners: fabrication complete
- Dry sump oil cart: fabrication complete, system ready for installation
- Reconfigurable belt-driven balancing box: May 2019 delivery
- Final assembly and shakedown testing: planned completion Fall 2019



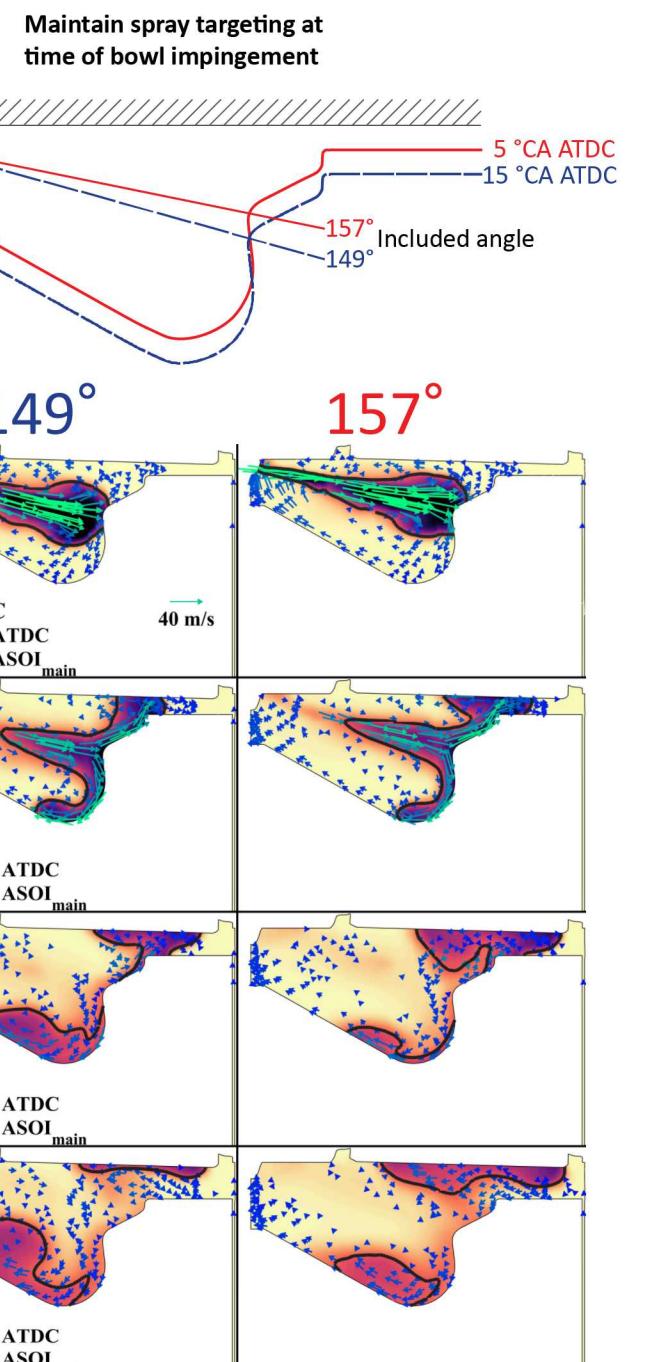
Responses to reviewer comments

- More work should be done to understand the influence of piston speed and load on flow evolution with the stepped-slip piston.
 - We would very much like to better understand these effects, and hope to do so once the new engine geometry is approved for CFD studies.
- Experimental work to better understand spray-wall interactions should continue with the new medium-duty platform as they are critical for mixing-controlled combustion systems.
 - We would welcome the opportunity to continue this work and engage with industry professionals to maintain the value of the research.
- The development and building up of the new medium-duty engine platform may reduce the ability to perform catalyst heating research.
 - This has indeed been a challenge. However, the results from the initial catalyst heating study with the small-bore engine have provided valuable insights. The ongoing analysis of high-speed imaging data will help build understanding of post injection ignition and combustion processes.
- Devoting attention to scaling key measurements/parameters will be helpful when developing engineering-level conceptual models.
 - Parametric studies included in this year's results are a start in this direction. As time and experimental capabilities permit, we are considering experiments designed to inform conceptual models for spray-wall interactions and cat heating operation.

VTO program management: Gurpreet Singh, Michael Weismiller

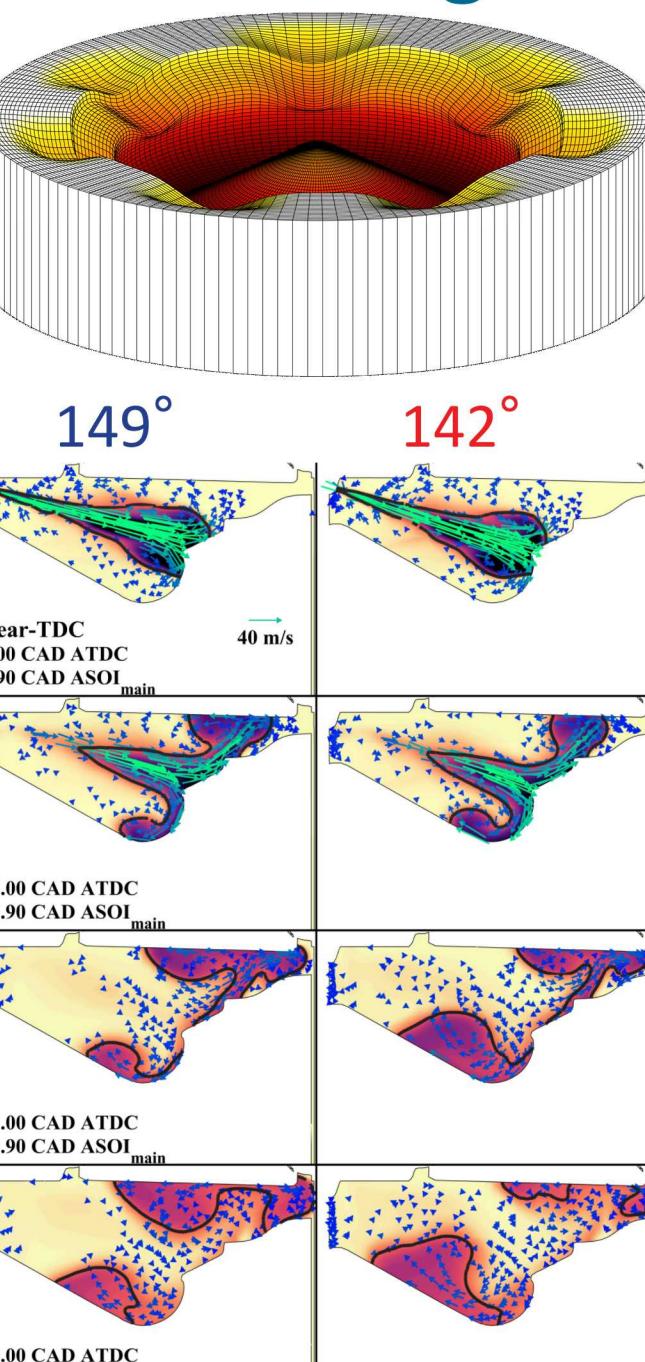
TA: spray targeting alone cannot improve vortex formation with the stepped-slip bowl

- Hypothesis: spray targeting at later injection timings promotes vortex formation in the squish region
- Test: adjust spreading angle for near-TDC injection so spray targeting matches the later injection case
 - Nozzle holes cannot be translated vertically by this amount due to interference with the head
- Spray targeting affects fuel mass and momentum splitting, but cannot restore the formation of long-lived vortices at near-TDC injection timings
- Space between the piston and head must play a key role in vortex formation in the squish region



TA: dimpled stepped-slip (DSL) piston promotes vortex formation at near-TDC injection timings

- Hypothesis: more space for each spray in the squish region will enhance vortex formation at near-TDC injection timings
- Test: proposed dimpled stepped-slip (DSL) piston design, CFD simulations with two included angles
 - Intake pressure increased to simulate identical compression ratio
- Providing more space between the piston and cylinder head can promote vortex formation in the squish region at near-TDC injection timings
 - Spray targeting and depth of dimples influence fuel mass/moment splitting



Remaining challenges / future research

Bowl geometry study

- Is enhancing vortex formation (e.g., with the DSL piston) a means to:
 - Increase mixing-controlled heat release rates?
 - Improve thermal efficiency?
 - Improve the soot-NO_x tradeoff?
- If enhancing vortex formation is important, what geometric aspects of stepped-slip bowl geometry can support this?
- What causes load and speed sensitivities with stepped-slip bowls, and how might this be mitigated?

Catalyst heating operation study

- What is the mechanism by which post injections ignite, and how does it depend on injection timing?
- What is the source of unburned hydrocarbons / formaldehyde emissions? What role does post injection timing/quantity play?