

# Medium-Duty Diesel Combustion (ace136)

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#### Timeline

- December 2017-present: medium-duty diesel research
- Ongoing project with continual guidance from AEC MOU industrial partners and reviewers

#### 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



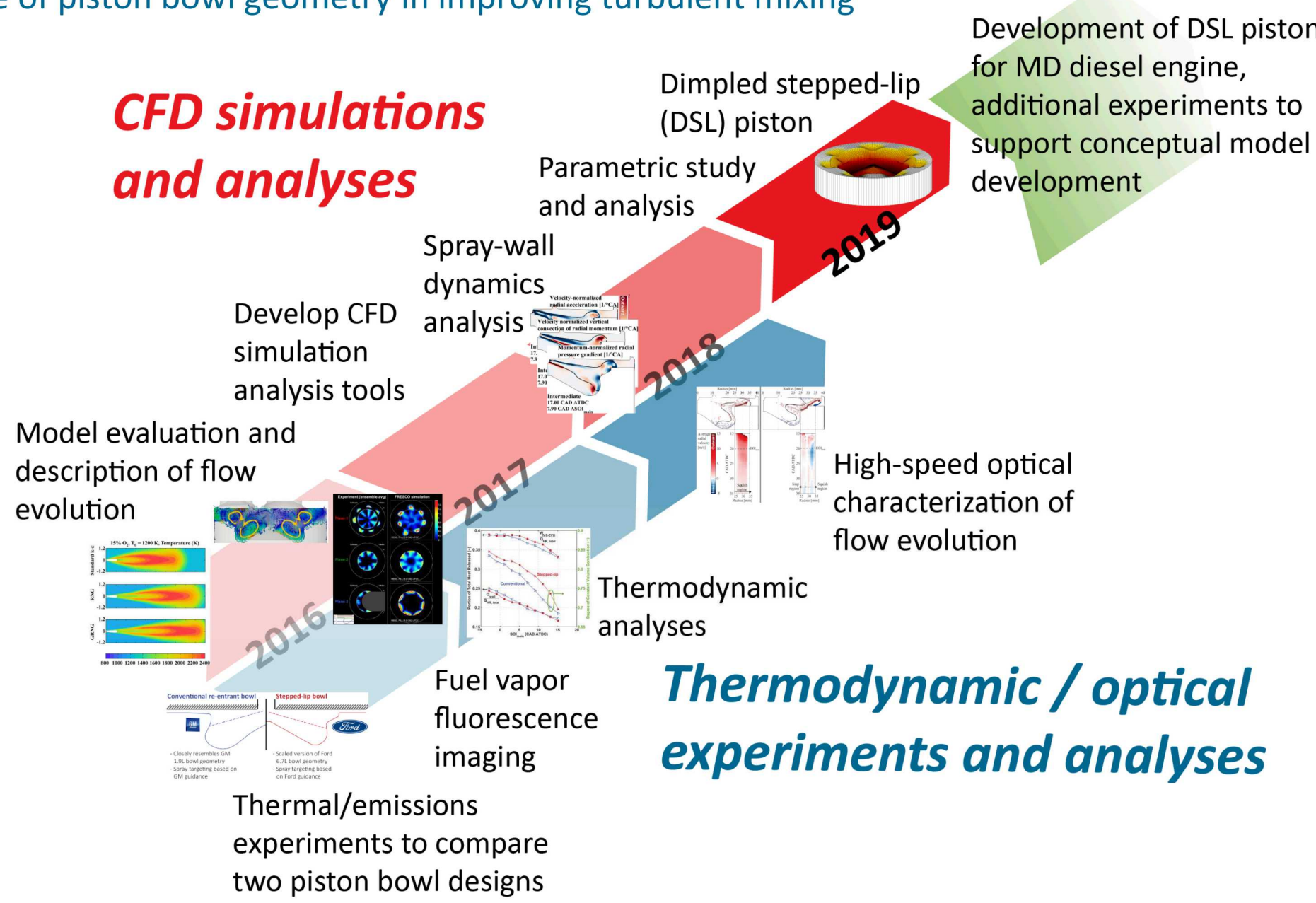
Technical advice, regular meetings and teleconferences; Supplier of new engine



RANS 3D-CFD simulations; Model development and evaluation

#### 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



#### 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-lip piston at near-TDC injection timings
- Develop a modified piston bowl to enhance spray-wall interactions associated with a stepped-lip 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

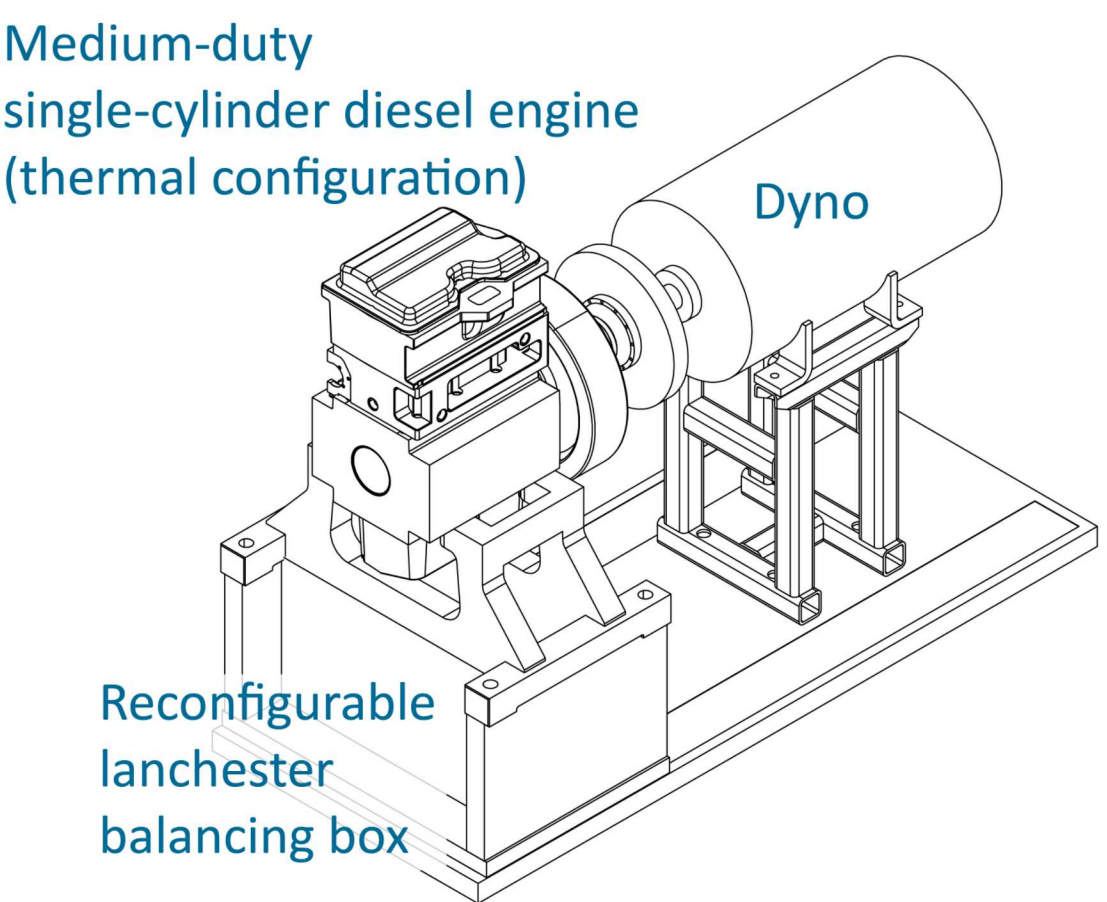
#### Approach: catalyst heating operation study

- 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

Injected Mass (mg)					Hydraulic start of injection (CAD ATDC)				
Total	Pilot	Main	Post1	Post2	Pilot	Main	Post1	Post2	
5	2	3							
7	2	5	<0.2		-15	TDC	10,14,18		
9	2	7	<0.4				22,26,30		
11	2	9	<0.6				10,14,18		
13	2	11	<0.8				22,26,30		
15	2	13	<1.0				10,14,18		
17	2	15	<1.2				22,26,30		
19	2	17	<1.4				10,14,18		
21	2	19	<1.6				22,26,30		
23	2	21	<1.8				10,14,18		
25	2	23	<2.0				22,26,30		
27	2	25	<2.2				10,14,18		
29	2	27	<2.4				22,26,30		
31	2	29	<2.6				10,14,18		
33	2	31	<2.8				22,26,30		
35	2	33	<3.0				10,14,18		
37	2	35	<3.2				22,26,30		
39	2	37	<3.4				10,14,18		
41	2	39	<3.6				22,26,30		
43	2	41	<3.8				10,14,18		
45	2	43	<4.0				22,26,30		

#### 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

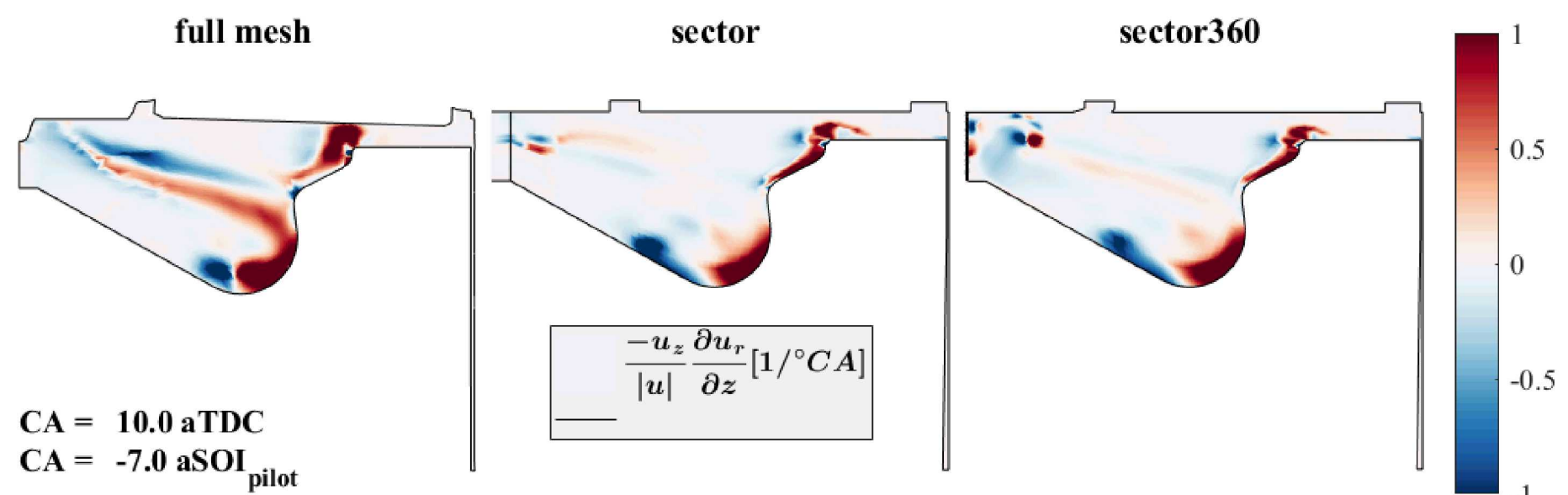


## VTO program management: Gurpreet Singh, Michael Weismiller

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

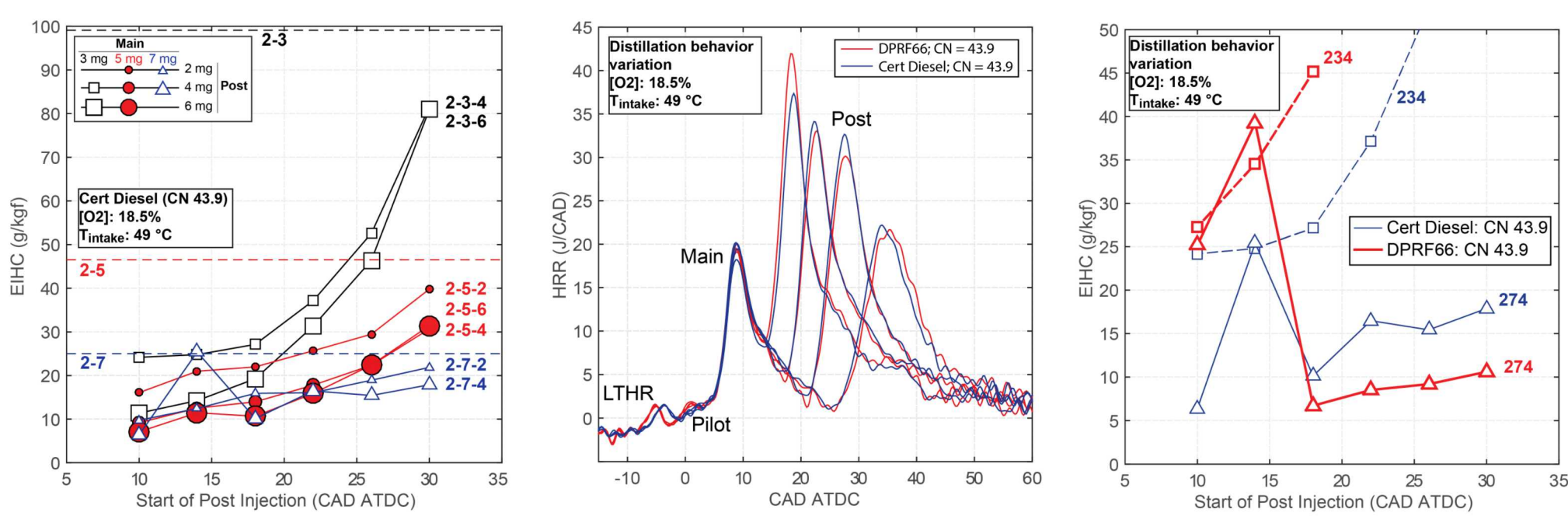
- CFD simulations for the bowl geometry study have been performed on full engine meshes that preclude large parametric studies
- Can a sector mesh capture the spray-wall interactions in manner consistent with experimental predictions?

- 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.



#### 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



#### Responses to reviewer comments

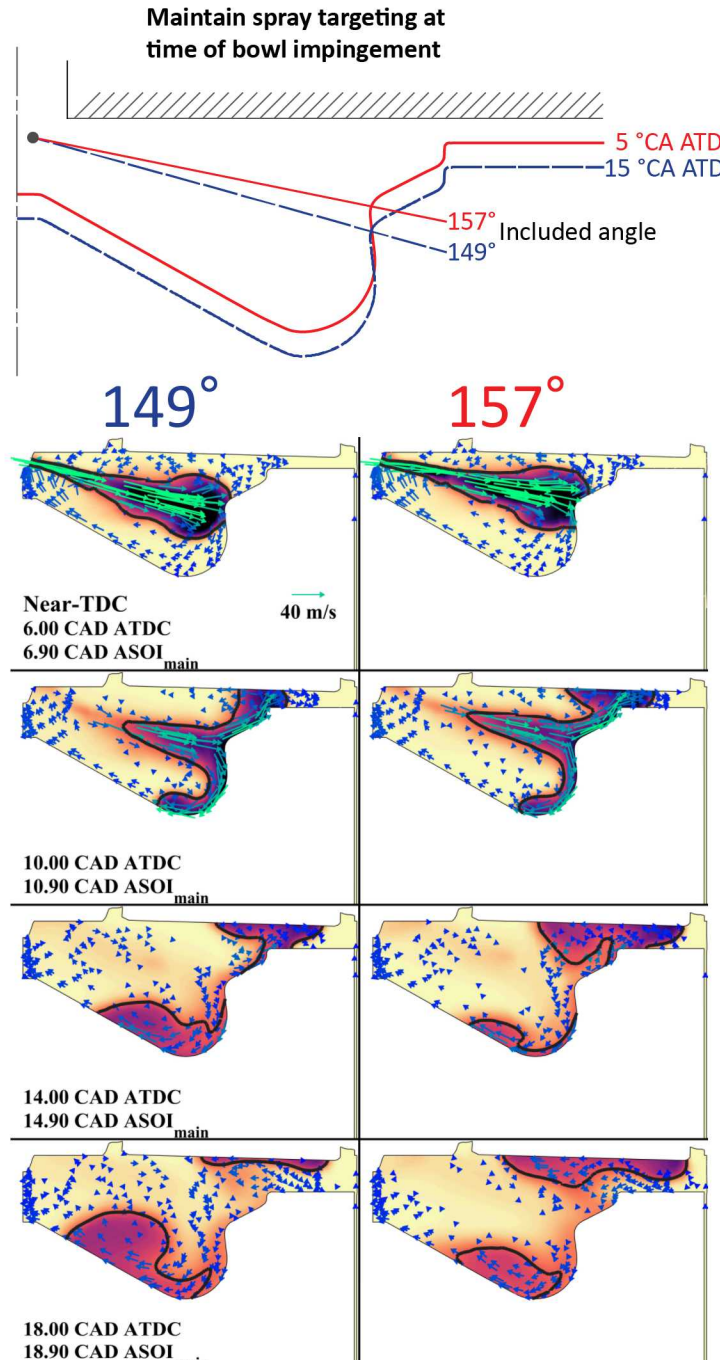
- More work should be done to understand the influence of piston speed and load on flow evolution with the stepped-lip piston.
  - We would very much like to better understand these effects, and hope to do so once the new engine geometry is approved for CFD studies.
- Experimental work to better understand 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.

#### TA: spray targeting alone cannot improve vortex formation with the stepped-lip 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

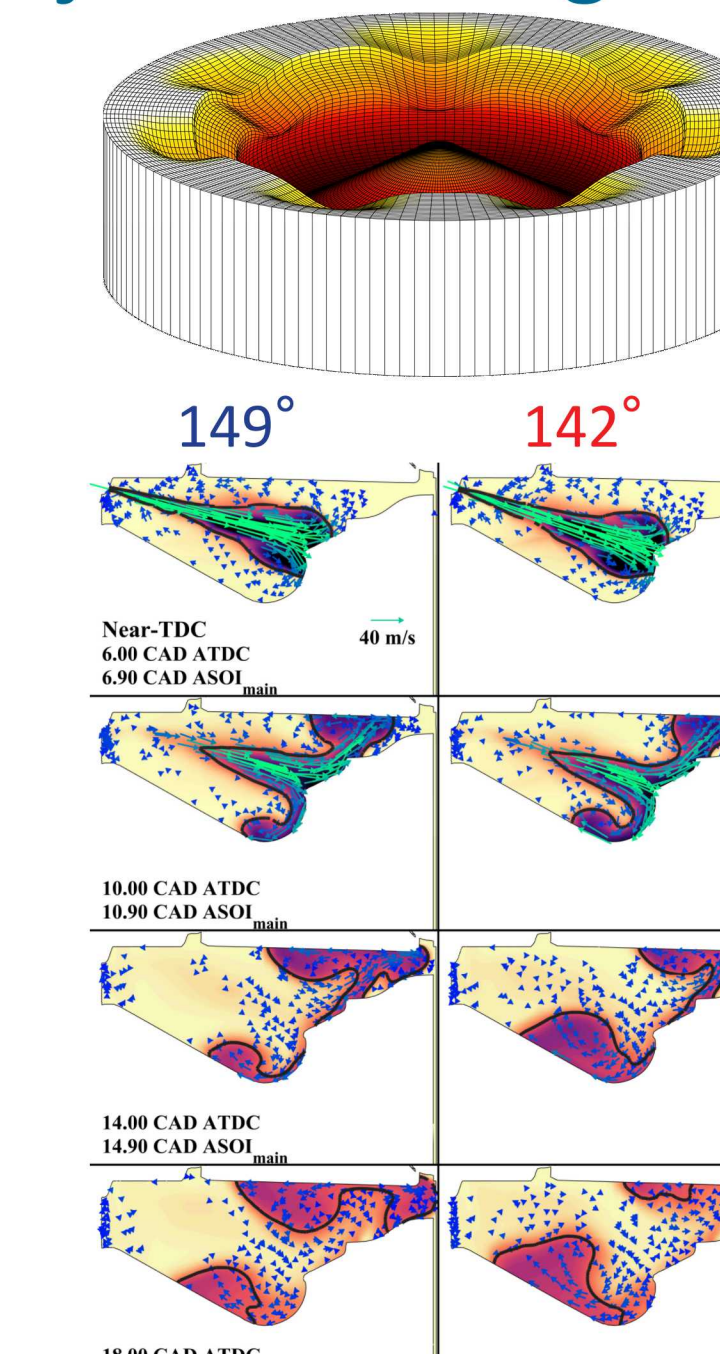


#### TA: dimpled stepped-lip (DSL) piston promotes vortex formation at near-TDC injection timings

- Hypothesis: more space for each spray in the squish region will enhance vortex formation at near-TDC injection timings
- Test: proposed dimpled stepped-lip (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/momentum splitting



#### 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

#### 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-NOx tradeoff?

- If enhancing vortex formation is important, what geometric aspects of stepped-lip bowl geometry can support this?

- What causes load and speed sensitivities with stepped-lip 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?