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Piston Geometry Effects on In-cylinder Swirl Asymmetry in a Light-Duty Optical Diesel Engine

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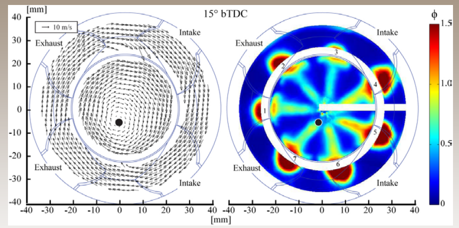
Motivation

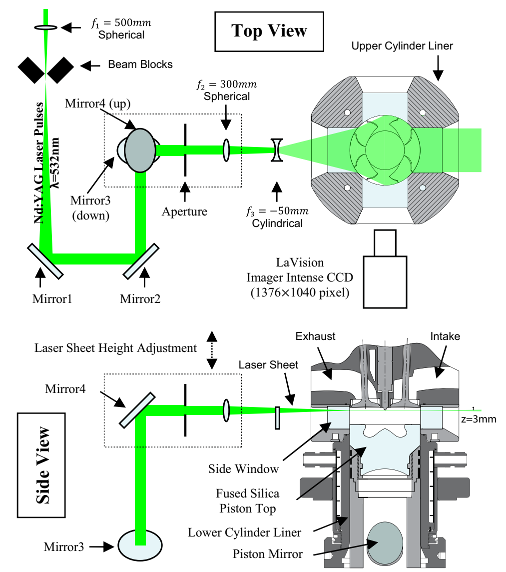
For direct-injection, swirl-supported light-duty Diesel engines, asymmetrical in-cylinder flow topologies prior to fuel injection can lead to an asymmetrical mixture preparation process. **Reducing these asymmetries is considered as one strategy to reduce unburned hydrocarbon (UHC) emissions under Low-Temperature Combustion (LTC) conditions.** In order to faithfully reproduce in-cylinder swirl asymmetries present in production light-duty Diesel engines, a transparent piston top with near-production bowl geometry is employed in a single-cylinder optical Diesel engine. Planar particle image velocimetry (PIV) measurements are performed to characterize the in-cylinder flow in several horizontal (swirl) planes.



Petersen, B., Miles, P., and Sahoo, D., "Equivalence Ratio Distributions in a Light-Duty Diesel Engine Operating under Partially Premixed Conditions," *SAE Int. J. Engines* **5**(2):526-537, 2012, doi:10.4271/2012-01-0692.

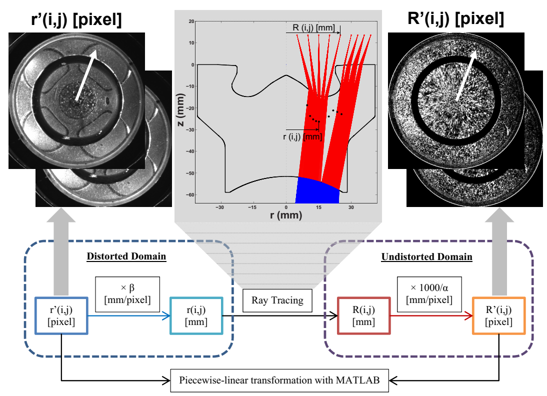
Experimental Setup

- Optical access is provided by a classic Bowditch piston extension with a fused-silica piston top. All PIV data are acquired while the engine is motored at 1500 rpm with no fuel injection.
- A **slit imaging approach** is implemented to achieve a thin laser sheet inside the combustion chamber (laser waist diameter = 450μm at chamber center, 800μm near the wall).
- **Porous SiO_2 powder** (d_p = 2μm, true density ρ_p = 600kg/m³) is used as tracer. The **Stokes number is less than 0.1** throughout the full compression stroke.

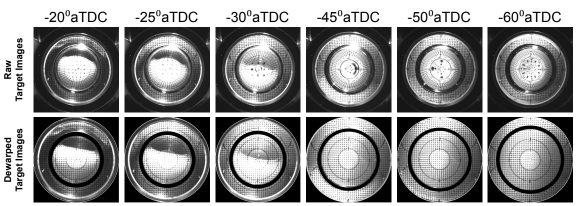


Optical Distortion Correction

- To ensure reliable measurement of particle displacements, **optical distortions (spatially and temporally variant)** caused by the piston geometry must be corrected.
- **Ray tracing and manual image registration** provide a full dewarping transformation with any given laser plane position (z) and piston location (CAD).

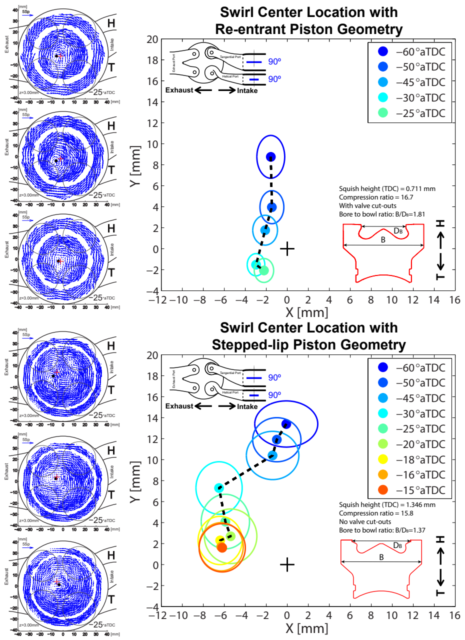


- Evaluation of optical distortion correction with uniformly spacing target mounted in the laser plane



Results

- Comparison of swirl center locations for two different geometries: a conventional **re-entrant bowl** and a **stepped-lip bowl**.
- Laser plane: z=3mm for CAD <= -25°aTDC; z=squish height/2 for CAD >= -20°aTDC.



Black dots show the swirl center location for each instantaneous velocity field. Red crosses mark the swirl center mean locations. S_p stands for mean piston speed (4.51m/s). "H": helical port, "T": tangential port. Each ellipse indicates one σ of swirl center location away from the mean position.

Future Work

- Comparison with 3D numerical simulation (UW-Madison, ERC) to understand the extent to which piston bowl geometries can affect flow asymmetry (i.e. bore to bowl ratio, valve cut-outs, etc.).

Conclusions

- In the late compression stroke, in-cylinder swirl in the stepped-lip piston case is more eccentric from chamber center and cyclic variability is larger than the re-entrant case. This is the joint effect of piston geometry change and increased squish height.

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More detailed information is included in Zha, K., Busch, S., Miles, P. C., Wijeyakulasuriya, S., Mitra, S. and Senecal, P. K., "Characterization of Flow Asymmetry During the Compression Stroke Using Swirl-Plane PIV in a Light-Duty Optical Diesel Engine with the Re-entrant Piston Bowl Geometry," *SAE Int. J. Engines* **8** (4), 2015, doi: 10.4271/2015-01-1699.