Investigation of Liquid Fuel Refill Dynamics in a Rotating Detonation Combustor using Megahertz Planar Laser-Induced Fluorescence

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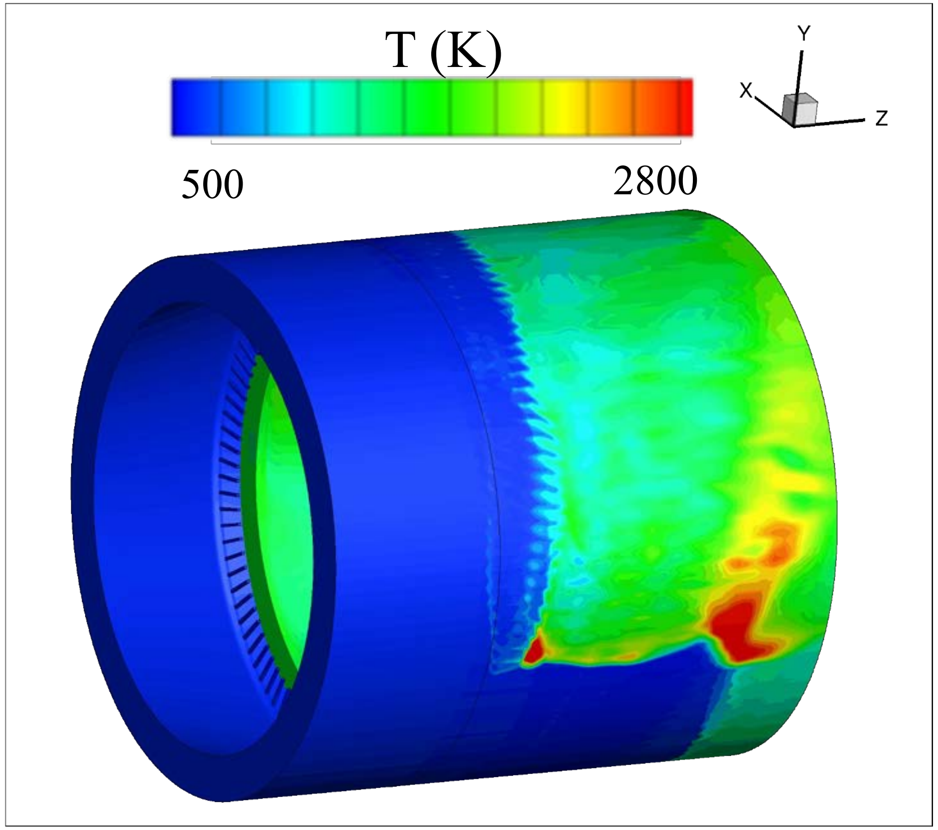
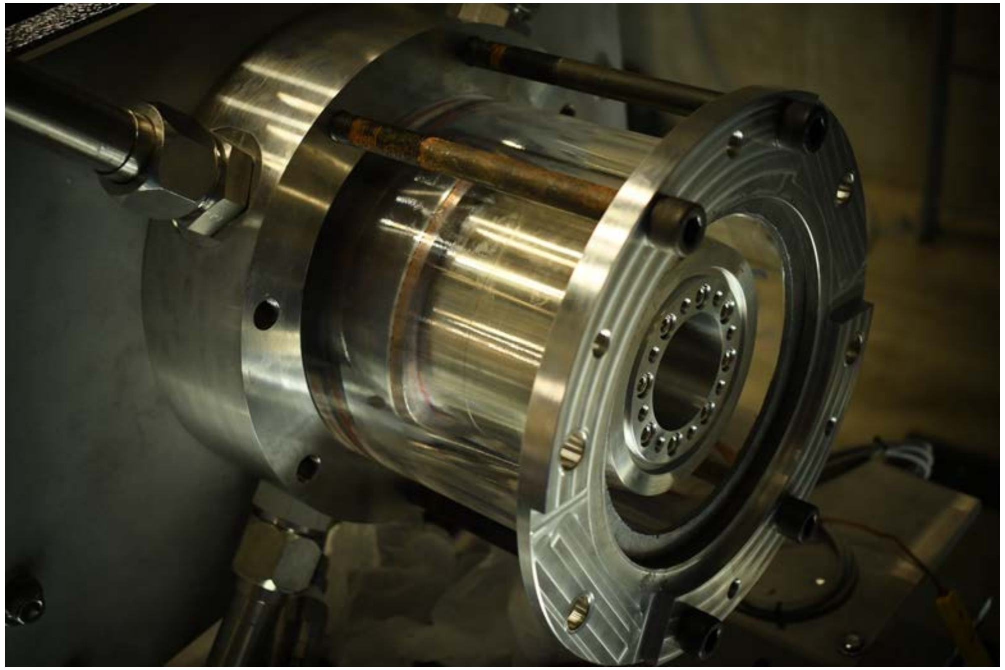
Motivation

- Potential performance benefits of RDEs highly desired
- Many real-world propulsion systems operate with liquid propellants
- Liquid spray breakup in an RDE had never been directly measured



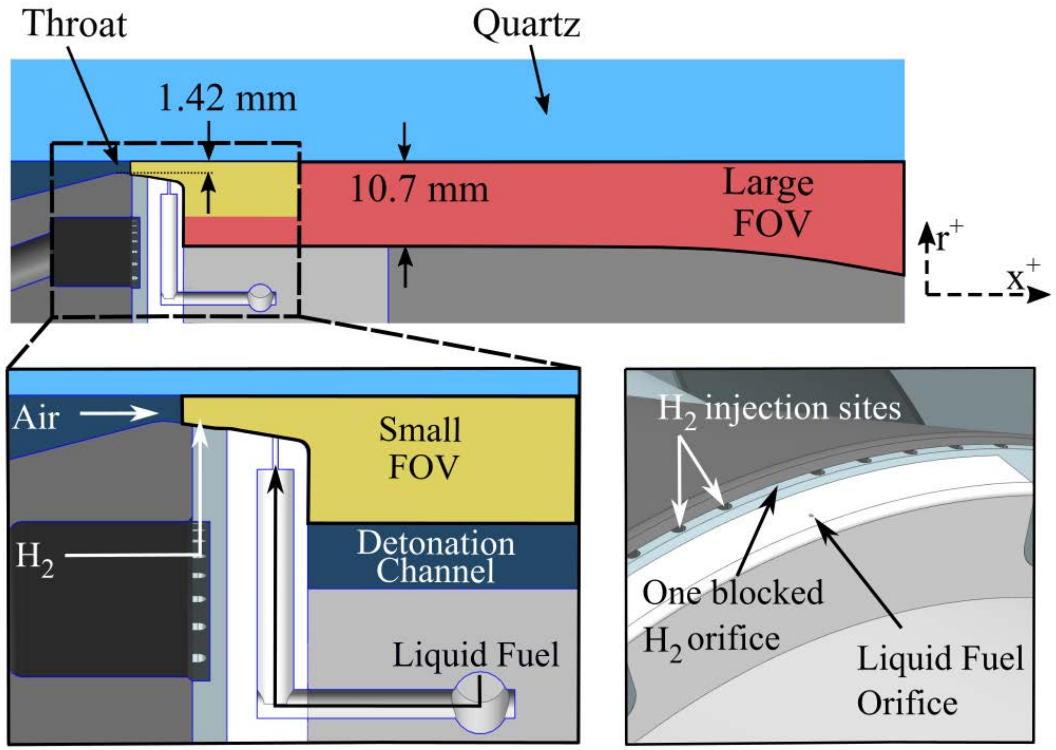
Test Platform Overview

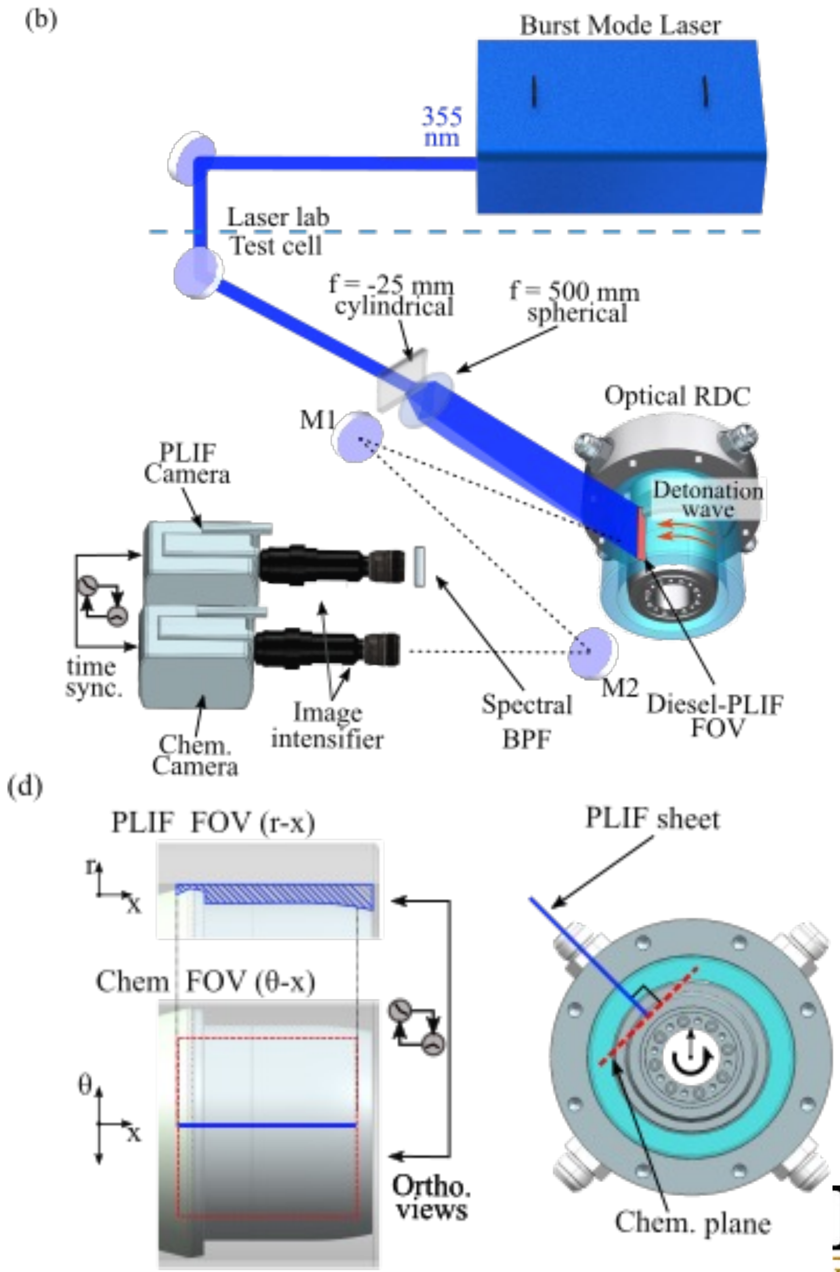
- 120 mm nominal chamber diameter with optical access
- Operates with Hydrogen/Air
- The RDE platform is well studied and characterized for a plethora of operating conditions
- For this work, RDE acts as a detonation driver to investigate liquid fuel spray breakup
- Other capabilities include use of various fuels, heated air, modular geometry



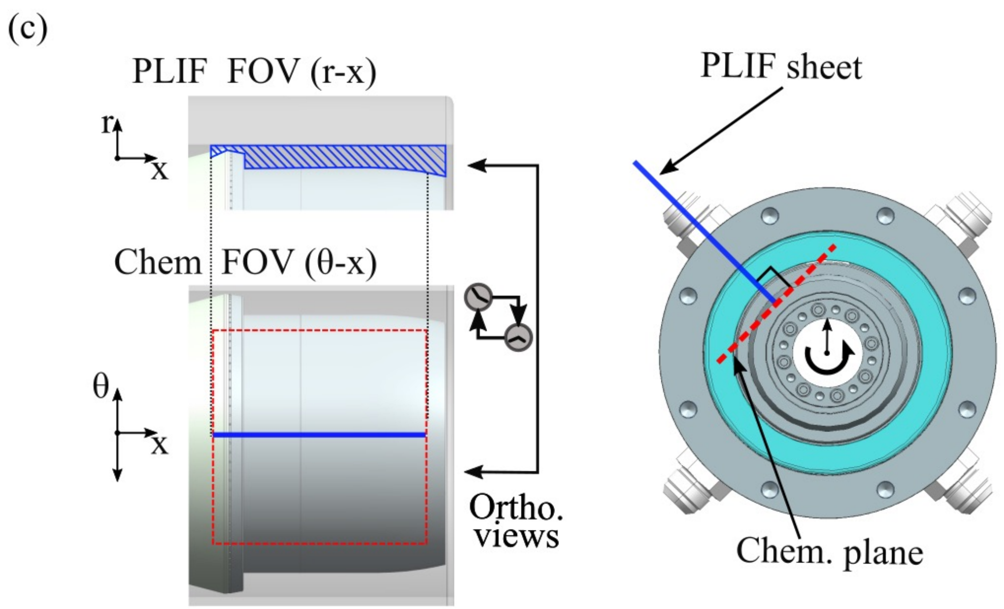
Experimental Setup

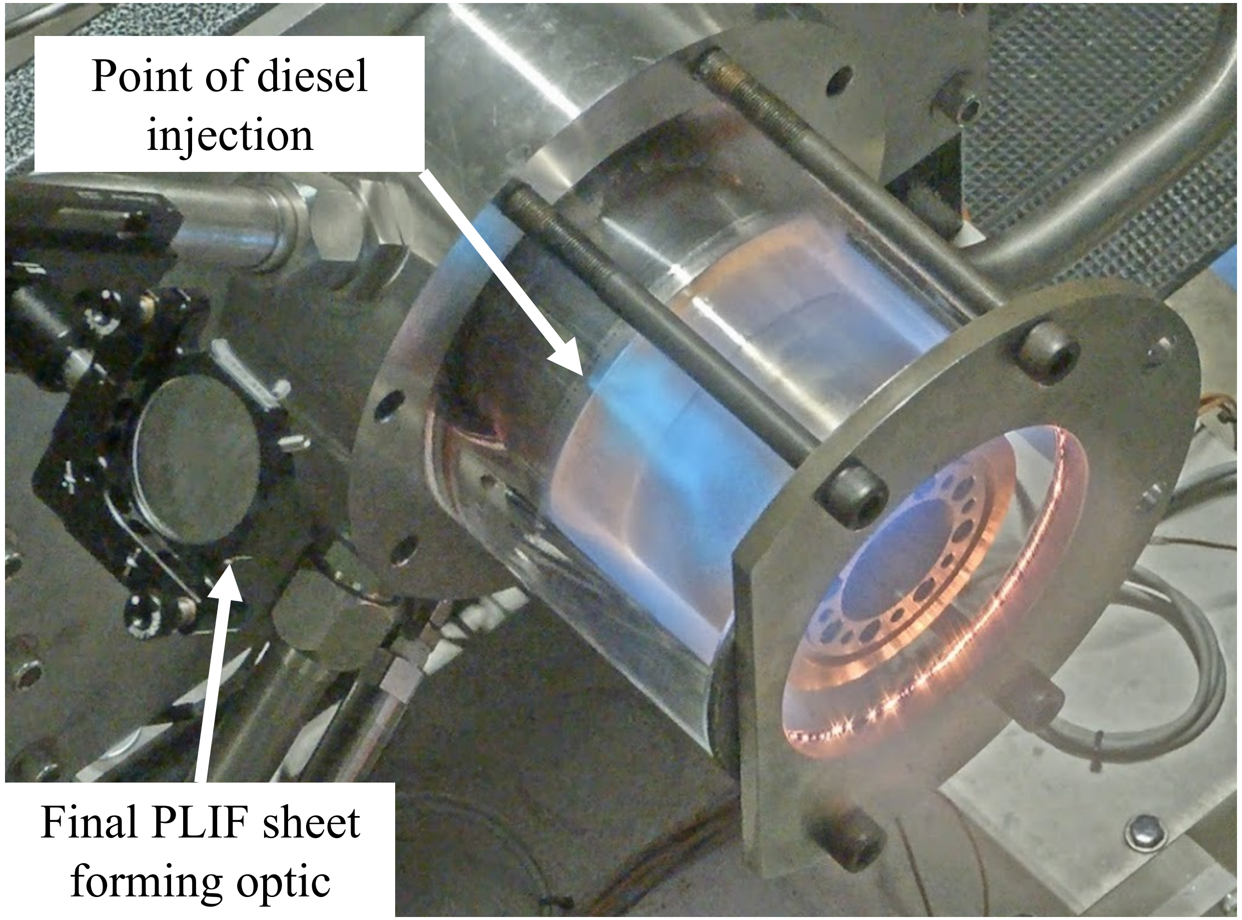
- Fuel injector was modified to have one H2 orifice replaced with a liquid fuel orifice
- Liquid fuel orifice diameter of 0.3 mm (0.012 in.)
  - Diesel flow rates between 0.2-1.5 gram/s
  - Momentum flux ratios between 0.01-0.1





Diesel Injection During Hot Fire





Reported Test Conditions

Test Condition	Flow Rates			Equiv. Ratio [-]	Momentum Flux Ratio [-]	Liquid Fuel Inj. Pressure [bar]	Nom. Wave Speed [m/s]	Nom. Cycle Freq. [kHz]
	Air [kg/s]	Hydrogen [kg/s]	Liquid Fuel [gr/s]					
1	0.46	0.012	0.92	~1	0.06	15.2		
2			0.62		0.03	8.5		
3			0.45		0.015	4.3		
4	0.23	0.006	0.65		0.06	7.5		
5			0.44		0.03	4.3		
6			0.31		0.015	2.6		

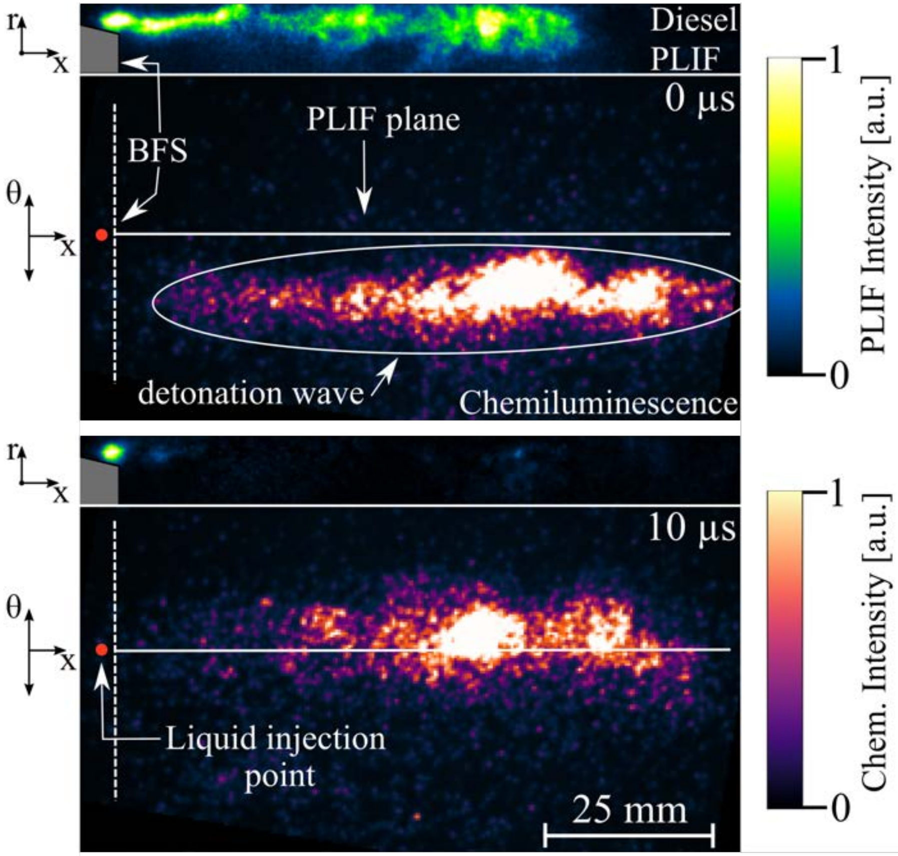
Varied chamber mass flux

Varied momentum flux ratio

Liquid Spray - Detonation Interaction at a Glance

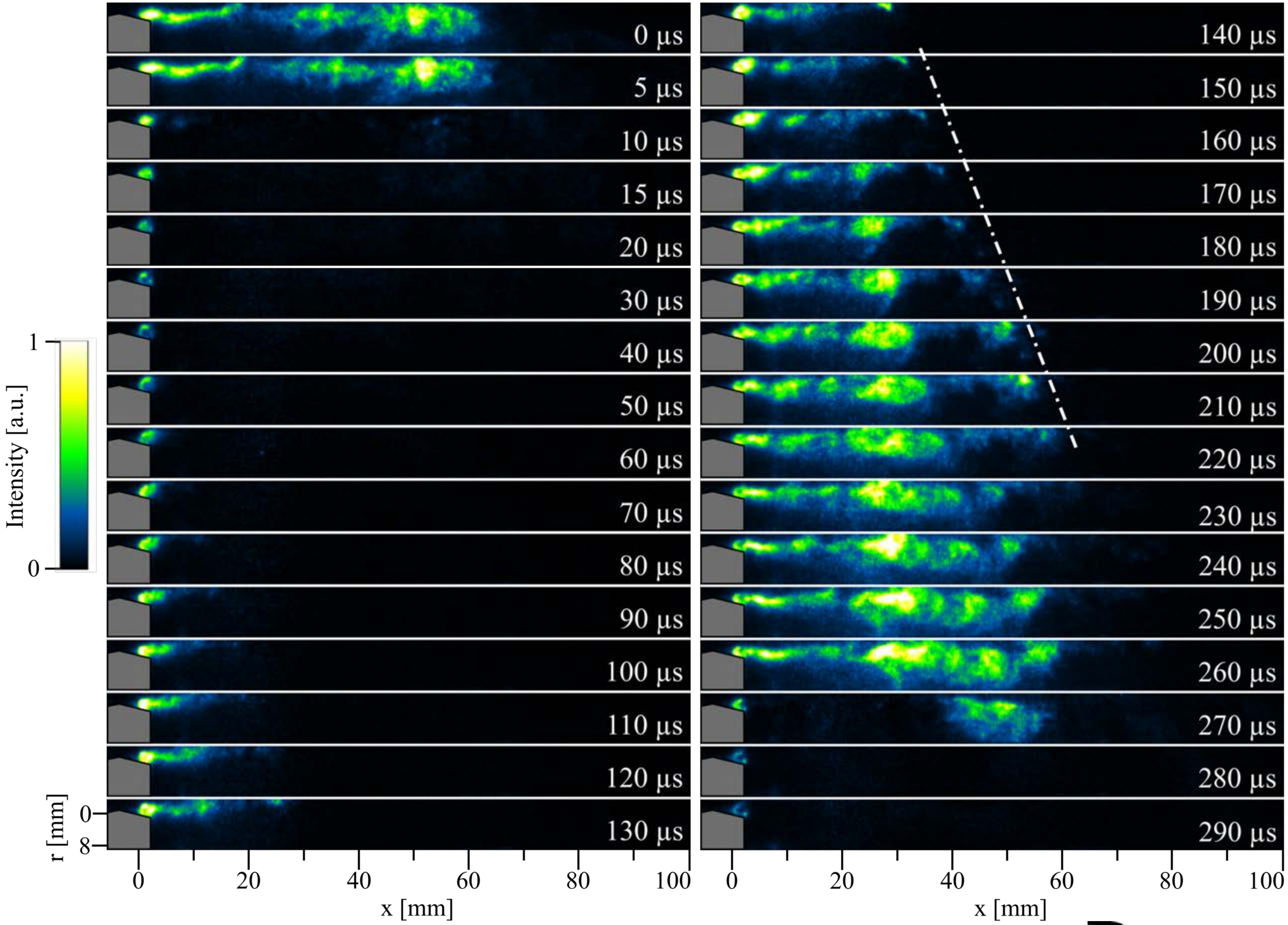
95 mm

- All diesel PLIF signal is removed from image plane within one frame
- Diesel does not encompass entire height of channel until about halfway down the channel
- Diesel injector element does not appear to turn off



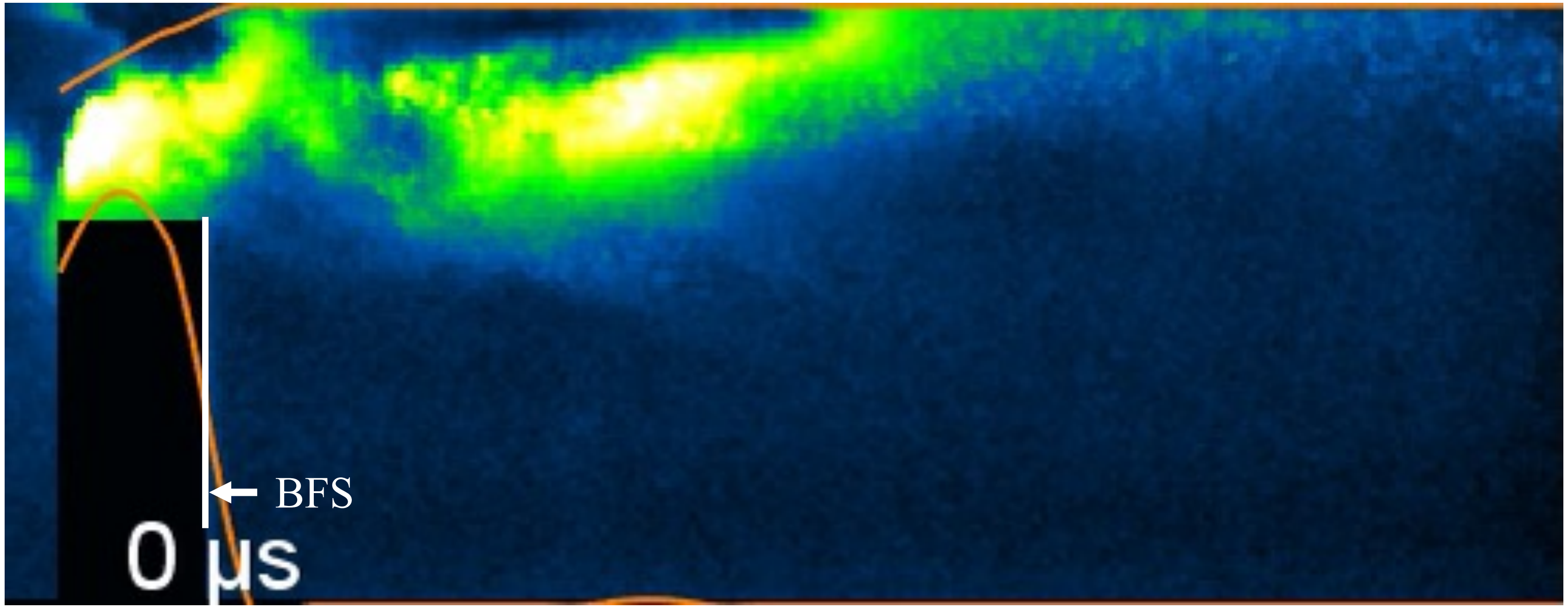
Liquid Spray - Detonation Interaction at a Glance

- There is a significant period where diesel is not being issued into the channel
- Diesel injector element does not appear to turn off
- Diesel injector recovers within one detonation period



1 MHz PLIF – Small FoV

- Previous data necessitated a test case that can monitor near-field jet response
- Key take-aways:
  - Significant out of plane motion
  - Leading edge jet response lags behind spray breakup

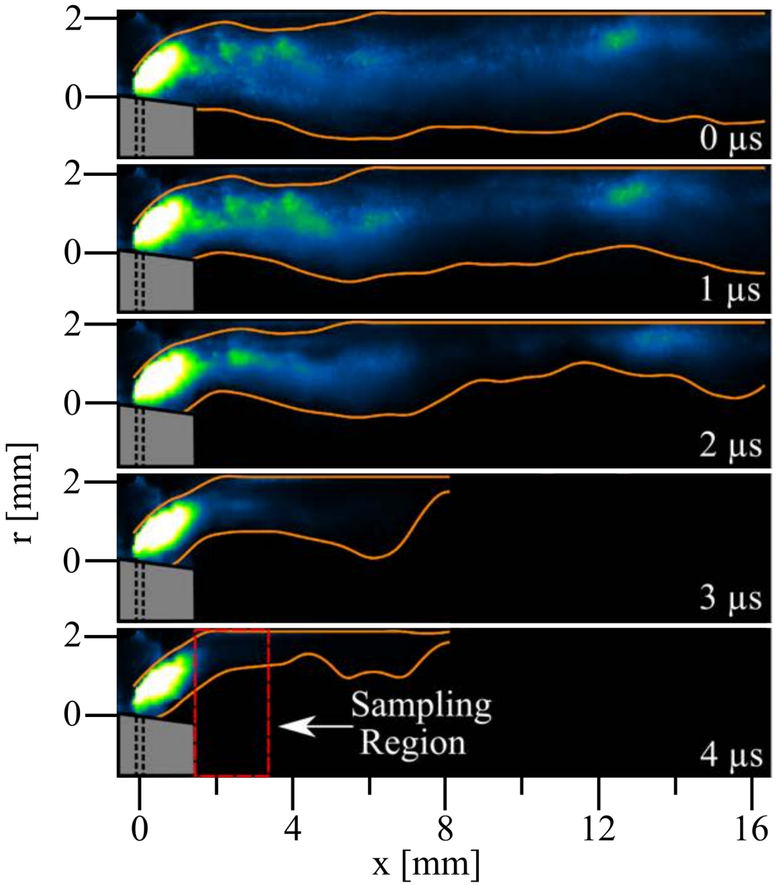


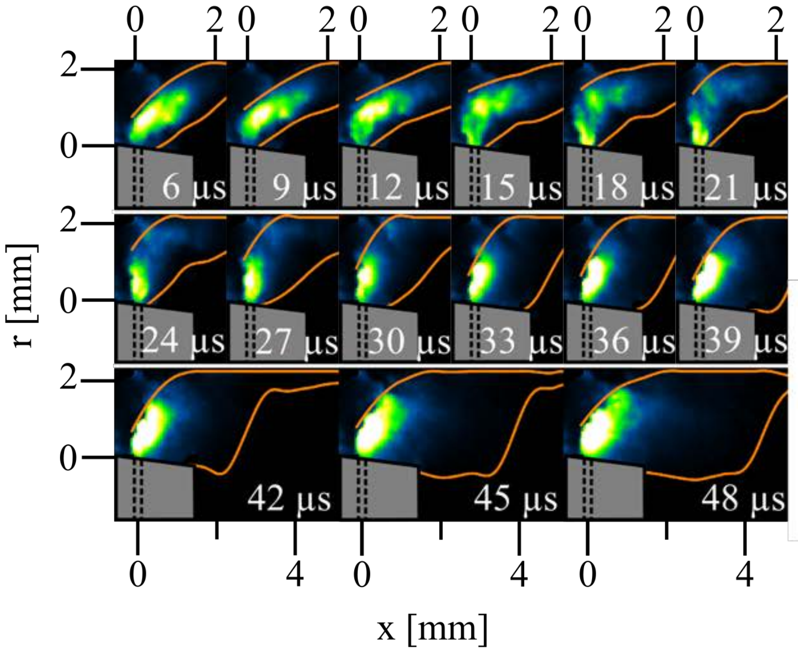
Orange curves represent spray boundary

Liquid Spray - Detonation Interaction at a Glance

- Liquid fuel is completely consumed or displaced from the channel within a few microseconds

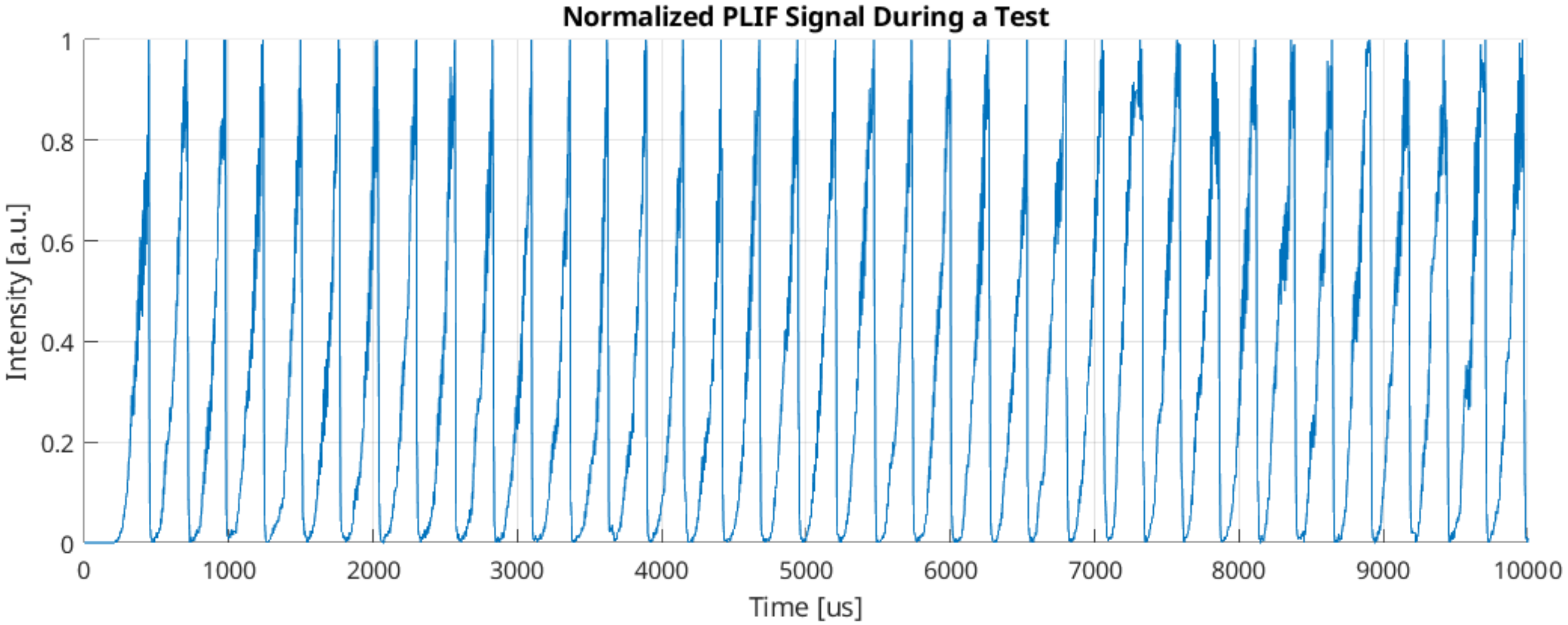
- There is a significant dwell period where liquid fuel is not being issued

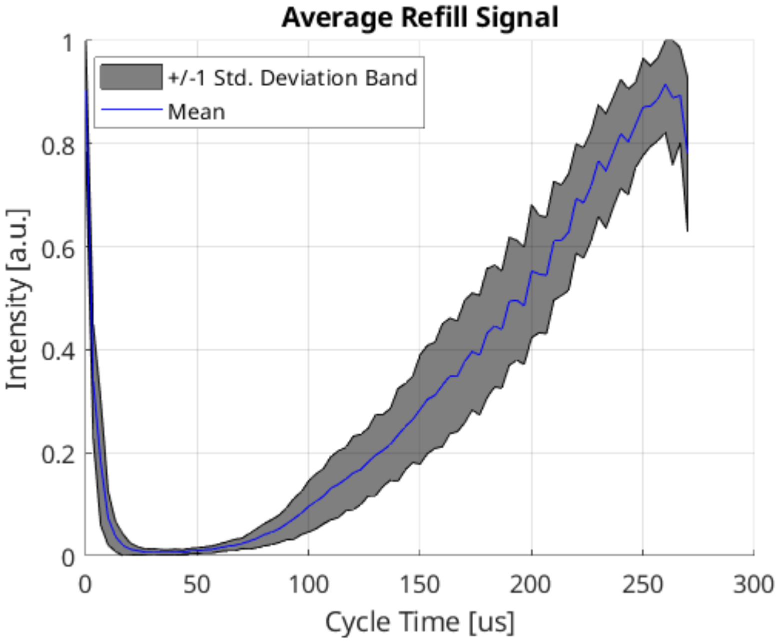




Spray Refill Analysis

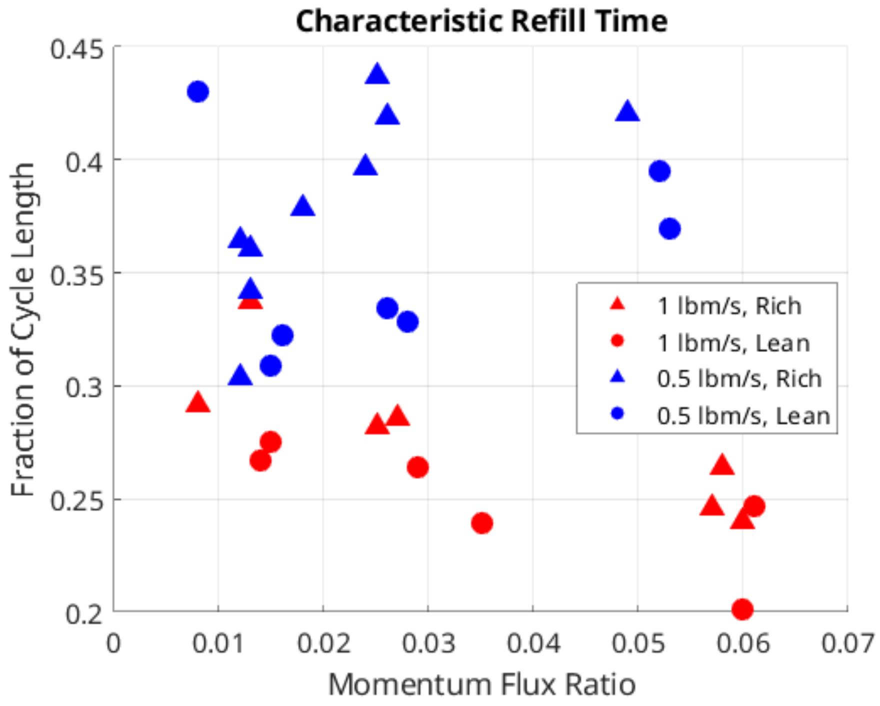
- Sampled PLIF signal immediately downstream of the BFS to monitor refill dynamics
- Averaging 30-40 cycles per test to produce Refill Signal
- Characteristic refill time defined as point where intensity achieves 10%

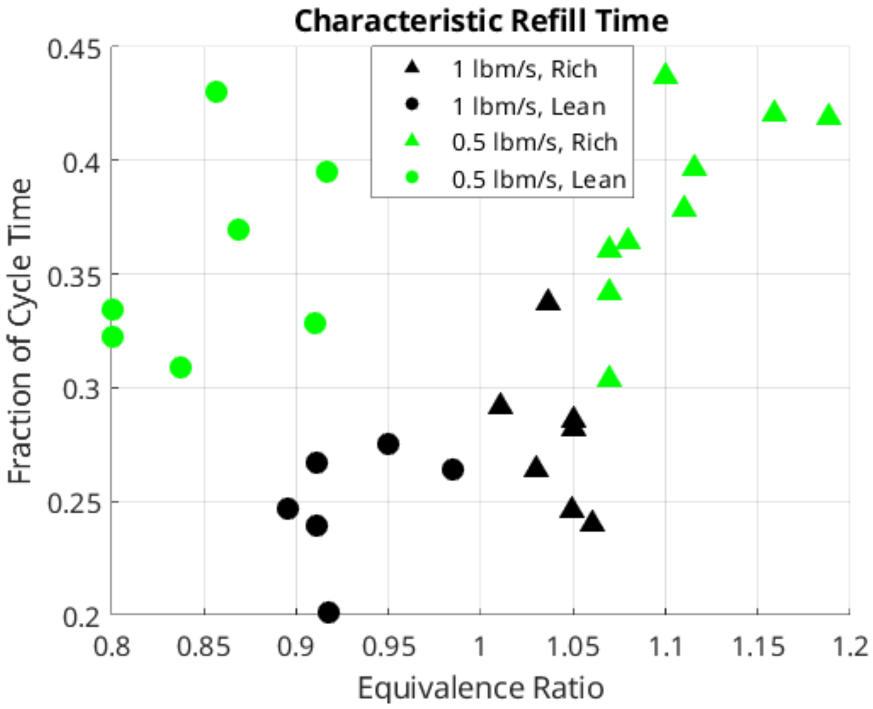




Spray Refill Analysis

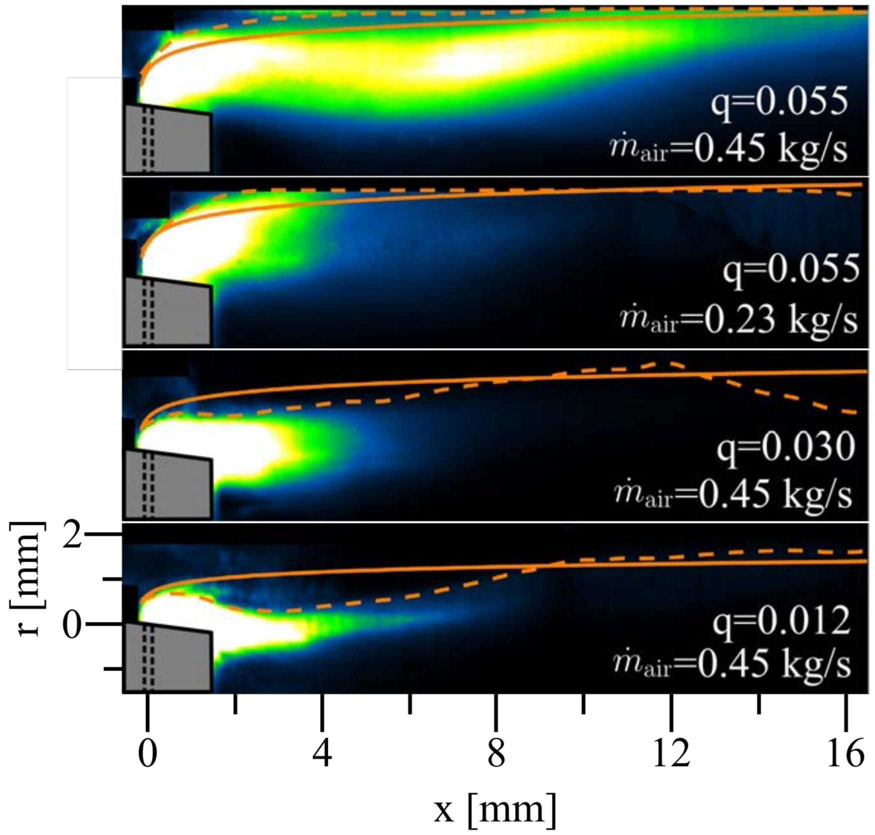
- Refill time of the liquid fuel strongly depends on the mass flux of the incoming air stream
- No apparent dependence on mass flux of liquid fuel





Liquid Fuel Spray Characteristics

- Despite the extreme unsteadiness, the fuel sprays resemble canonical jet in crossflows
- Time series averaged jet trajectories (dashed) resemble an empirical correlation (solid) for some conditions
- Backwards facing step influences spray trajectory for low momentum flux ratios



Summary

- Liquid fuel PLIF has been directly measured in an RDE for the first time
- Within one detonation period, the liquid fuel spray has sufficient time to recover and nearly refill the channel
- Liquid fuel refill time strongly coupled to incoming mass flux
- Experimental jet trajectories resemble canonical correlations for some conditions
- Additional detail in publication