Lambda 1 High Load Operation via Water Injection

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Outline

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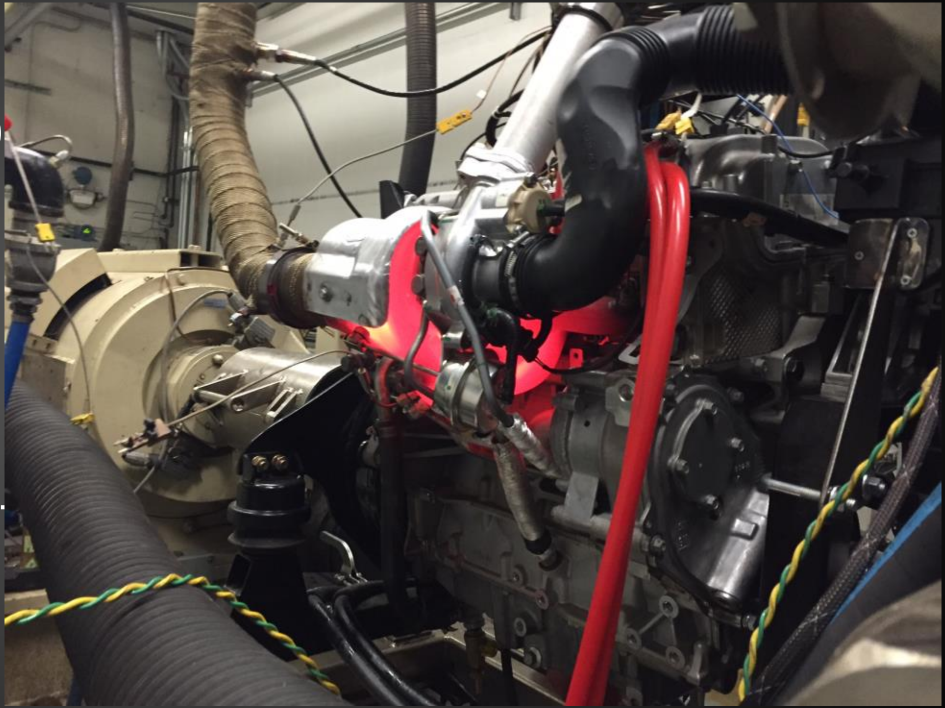

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Motivation

- Avoiding this!
- Enabling the next generation of high efficiency engines

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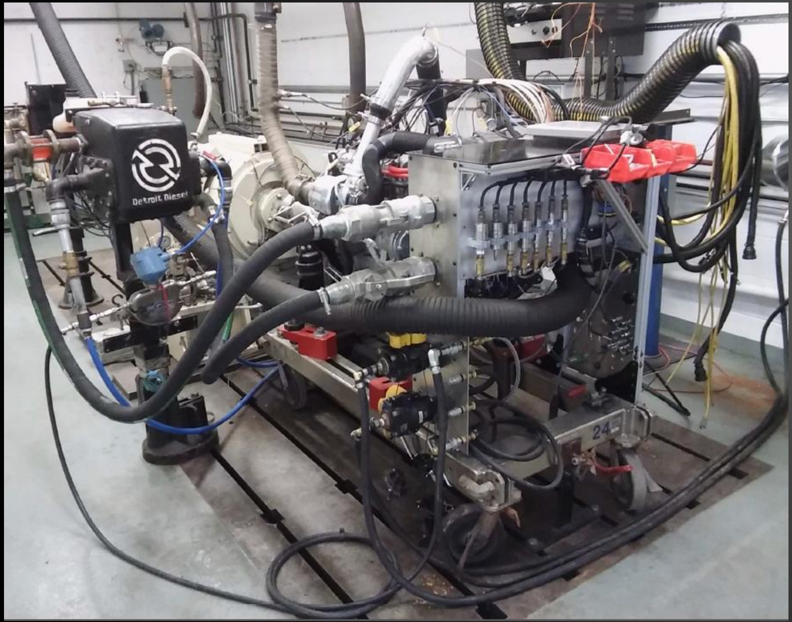
Motivation

- Despite increasing popularity, engine "downsizing" does not delivery dramatic real-world fuel economy benefits.
- Downsized engines must be operated at higher loads, often into regions where spark retard and/or over fueling is used to control knock.
- Maximum engine output in SI engines is limited by knock (auto-ignition)
- Mitigation of knock is an enabler for aggressive downsizing AND increased performance

Experimental Setup

Baseline Engine

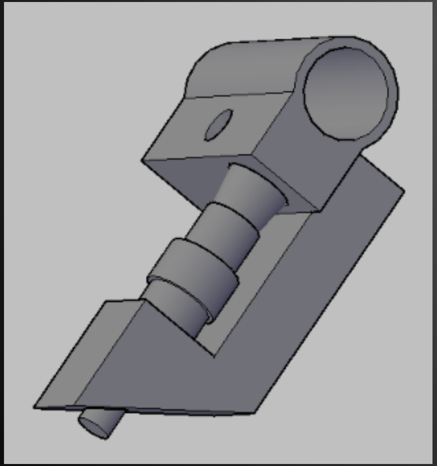
- SIDI 2.0L GM Ecotec LTG
- Twin Scroll Turbocharger
- Dual Independent Cam Phasing
- Large Aftermarket Support

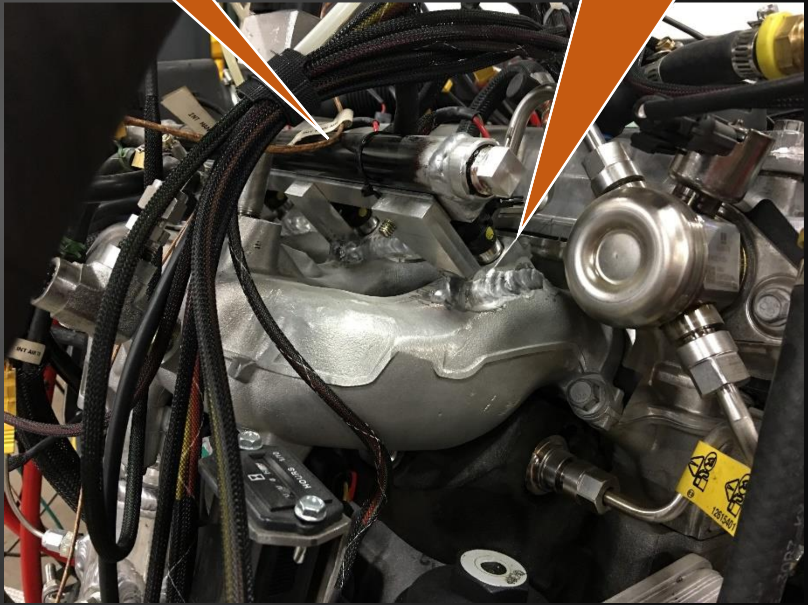


Engine Specifications		
Base Engine	Displacement	2.0L
	Bore	86.0 mm
	Stroke	86.0 mm
	CR	9.2:1
Instrumentation	Dynamometer	350 kW AC
	Combustion	A&D CAS, AVL GH15D Pressure Transducers, BEI Optical Encoder
	Flow	Laminar Flow Element for Air Coriolis Meter for Fuel Coriolis Meter for Water
	General	Gauge & Absolute Pressures, Type K Thermocouples, Electronic Data Acquisition

Experimental Setup – Water Injection

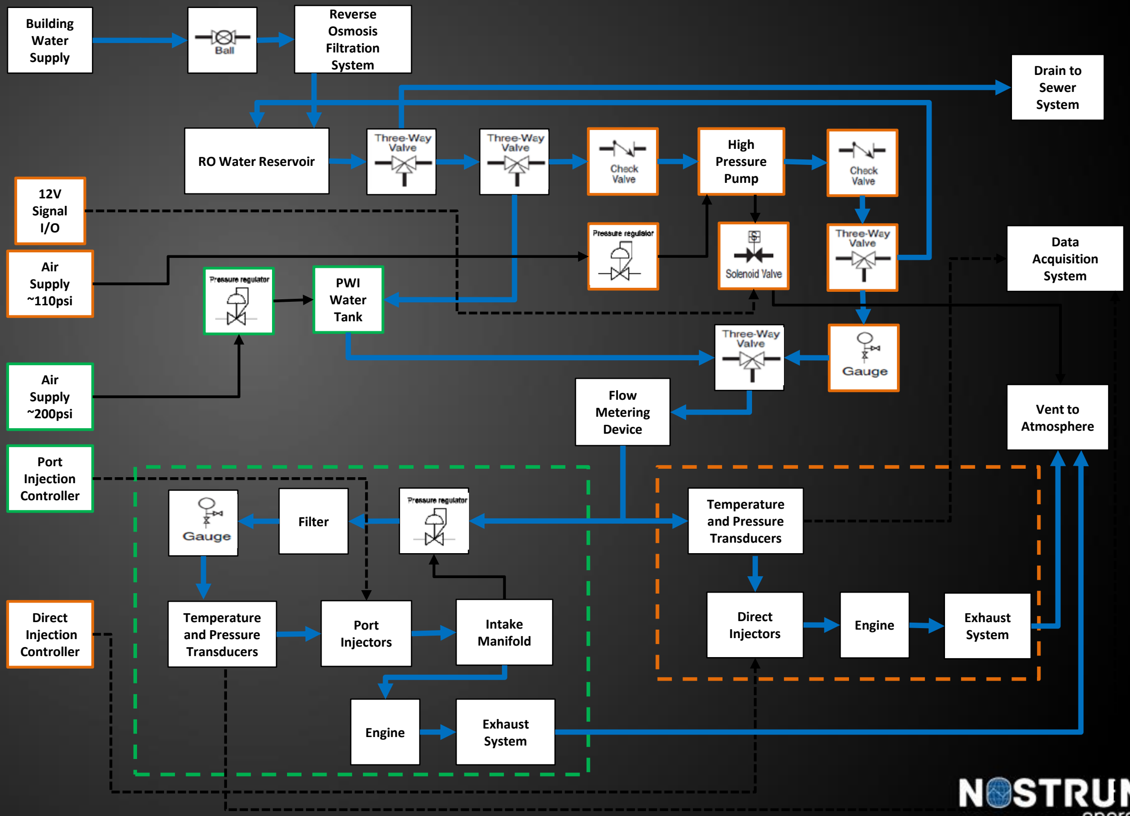
- Injectors installed in intake manifold
- Direct Injection also an option





Experimental Setup – Water Injection

- Test water is generated through Reverse Osmosis
- High Pressure supply (250 bar) for Direct Injection testing
- Low Pressure supply (10 bar) for Port Injection testing
- Flow measured with Coriolis meter



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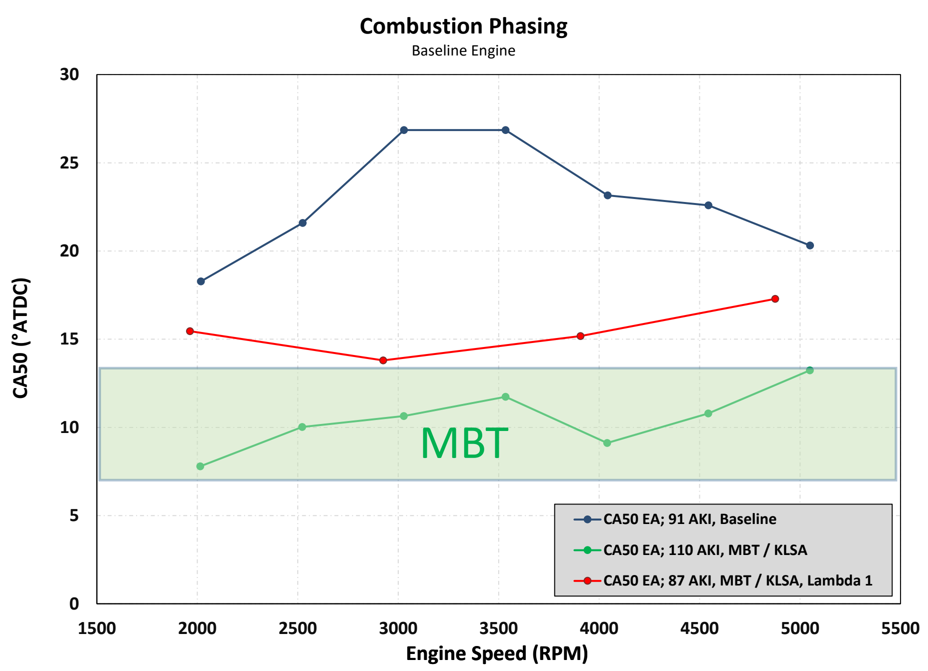
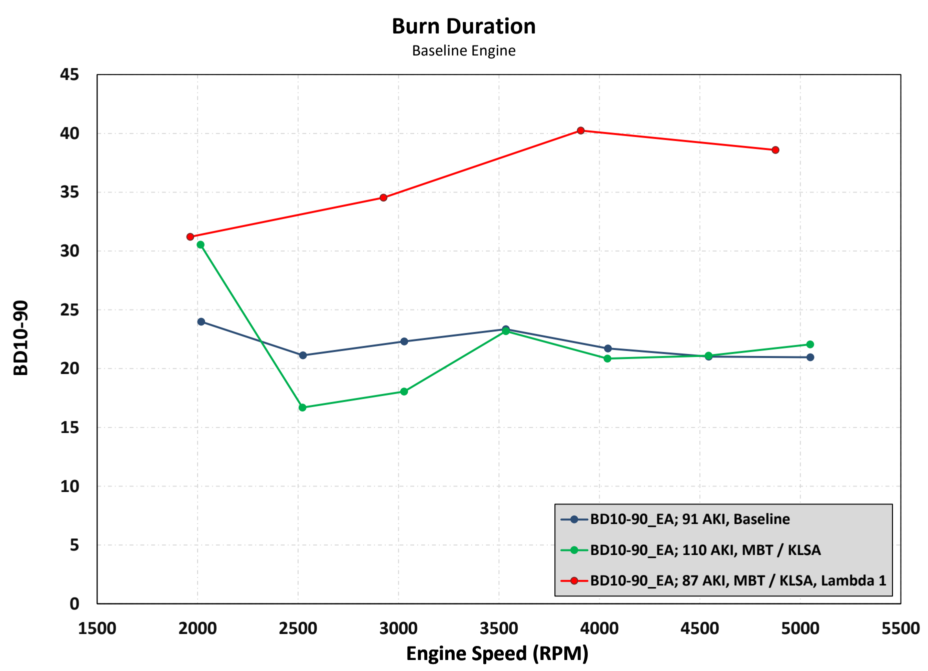
Experimental Tests To Be Discussed

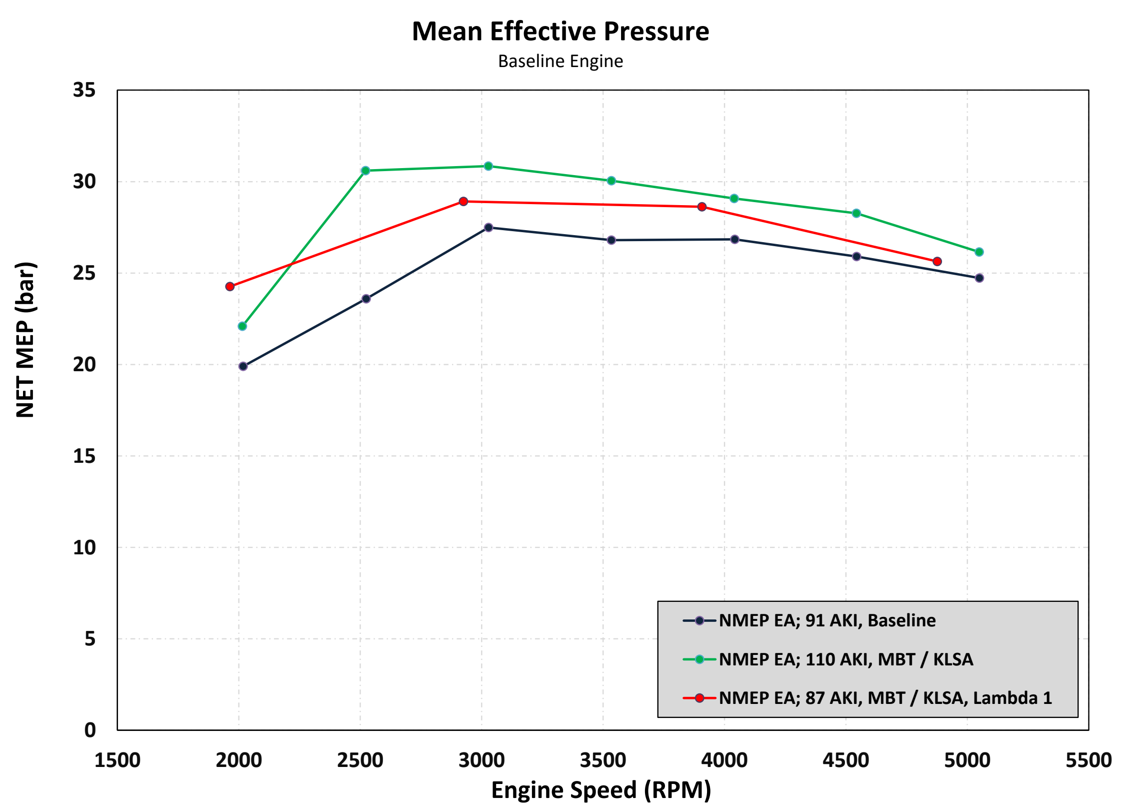
Test Number	Fuel	Water Injection	Spark Timing / Combustion Phasing	I-Cam	E-Cam	Lambda
Test 1	91 AKI (Engine manufacturer req.)	None	Production	Production	Production	Production
Test 2	110 AKI	None	10° CA50 or KLSA*	Production	Production	Production
Test 3	87 AKI	Port Injection	10° CA50 or KLSA*	Production	Production	1.0

Experimental Results: Combustion





Experimental Results; Output



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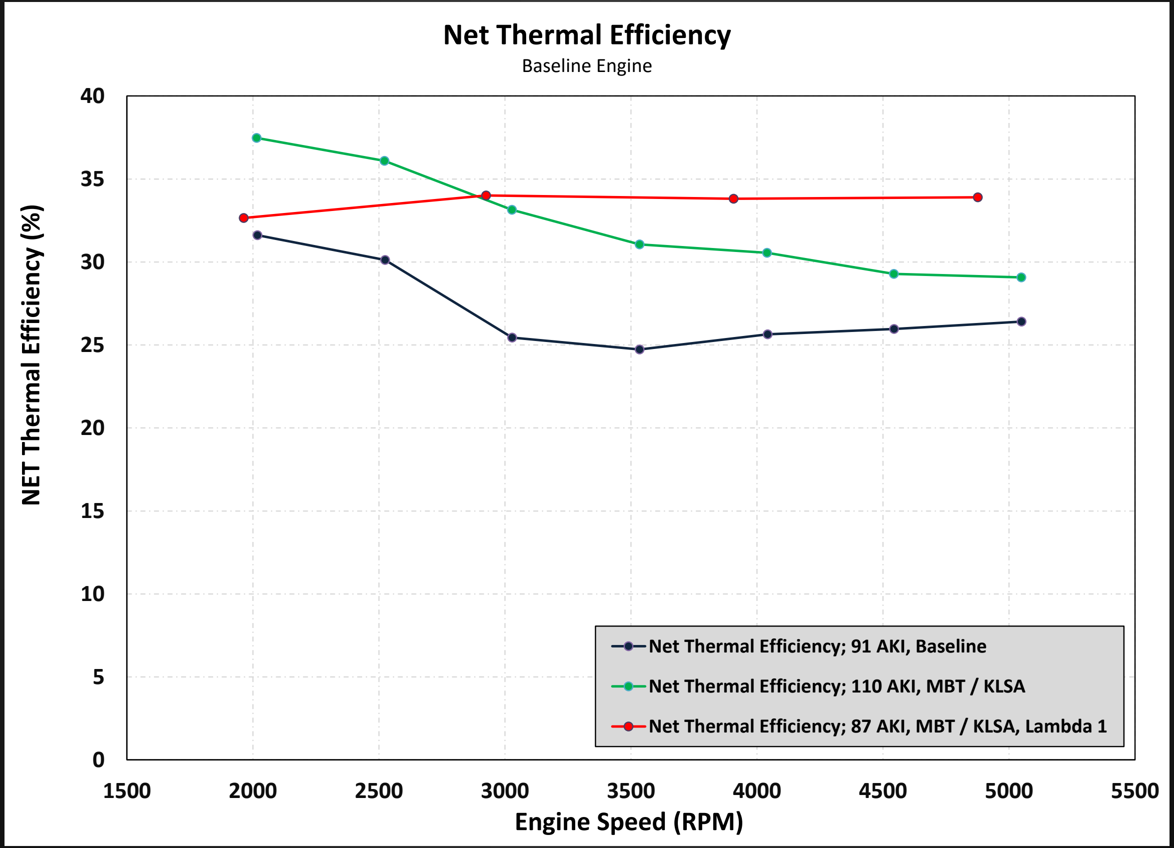
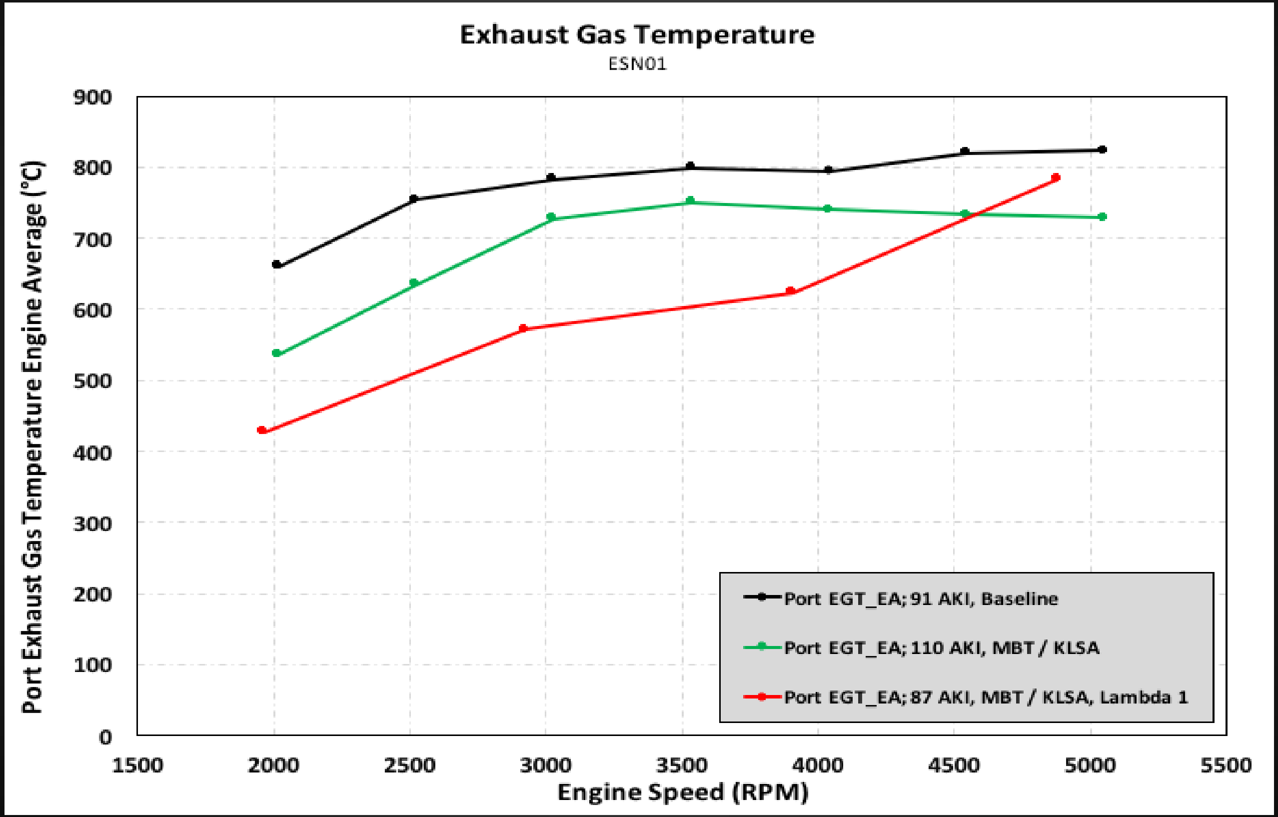
Experimental Results; Efficiency



Experimental Results: Exhaust Gas Temperatures



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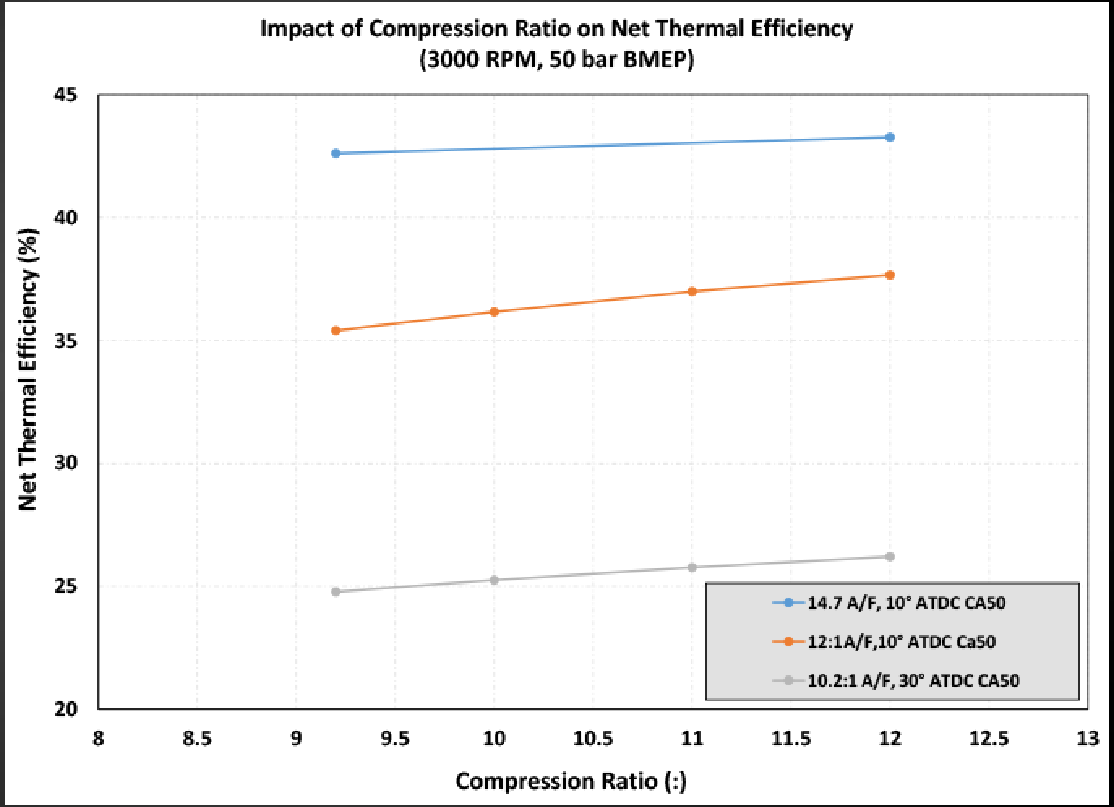
Simulation

- 1D Engine Simulation was utilized to scope the High BMEP Build (Target 50 bar BMEP)
  - Determination of required air pressure and flow
  - Investigation of peak cylinder pressure over a range of compression ratios
  - The same simulation model will be used to evaluate the impact of water injection

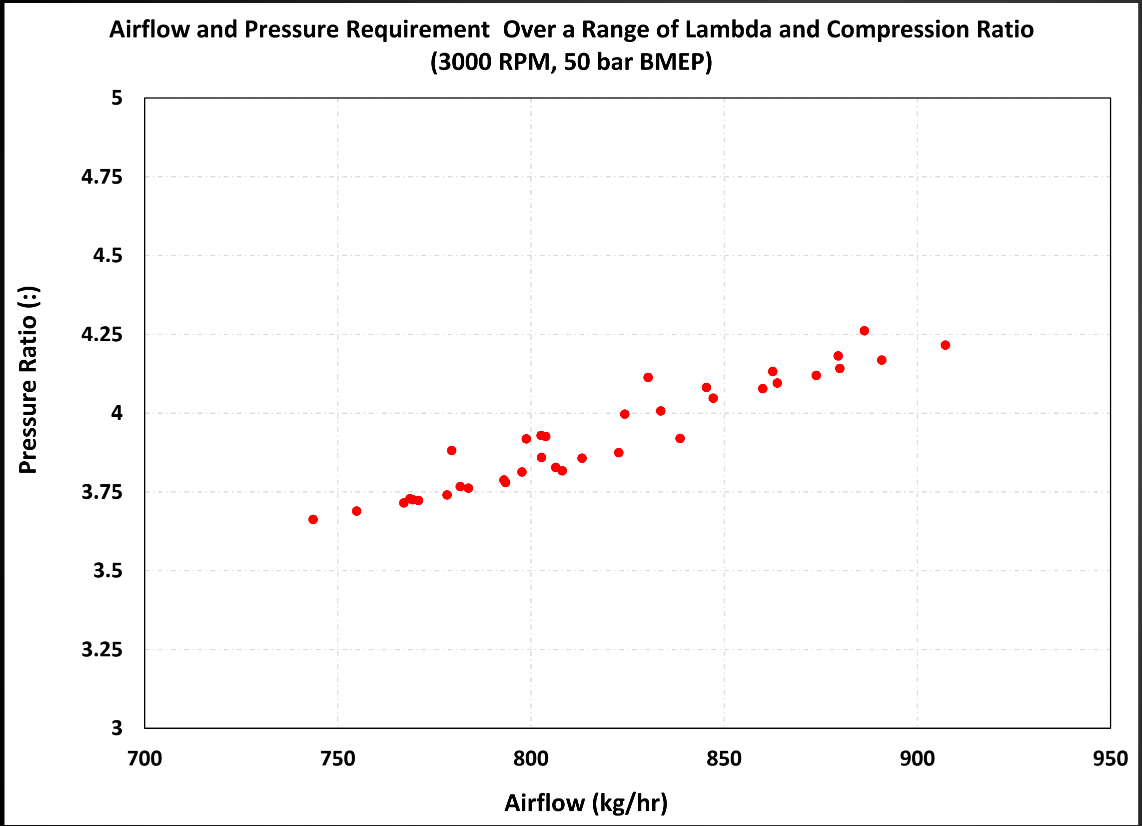
Simulation Results

- Fuel Enrichment and Combustion Phasing both have large impact on Net Thermal Efficiency

- Good opportunity for efficiency improvements



Simulation Results



- Required P/R and mass flow are challenging for a single compressor
- Boost pressure is currently supplied via an external compressor
- Good candidate for alternative boosting systems (multi-stage, compounded)

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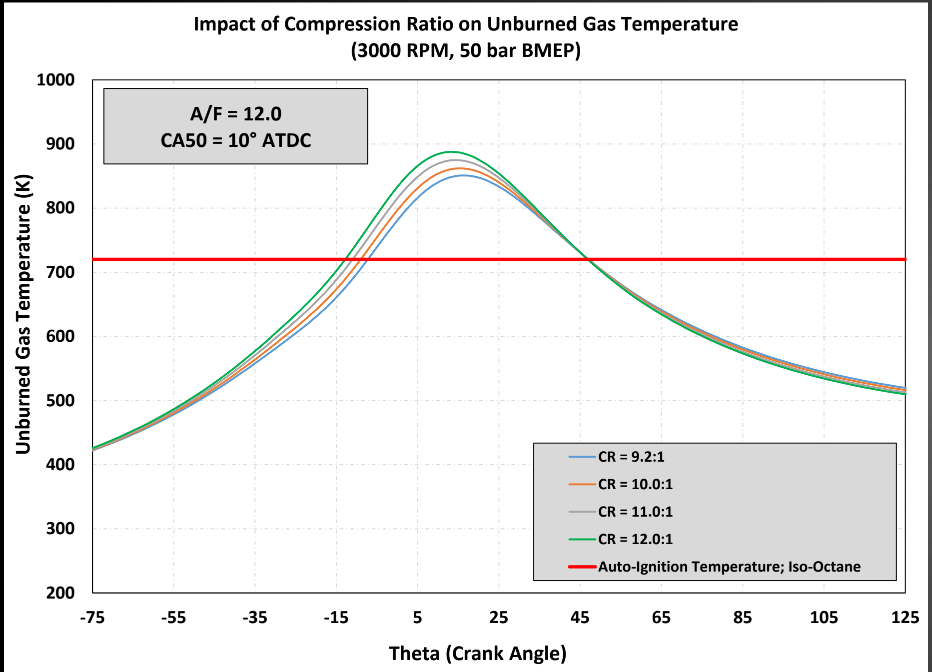
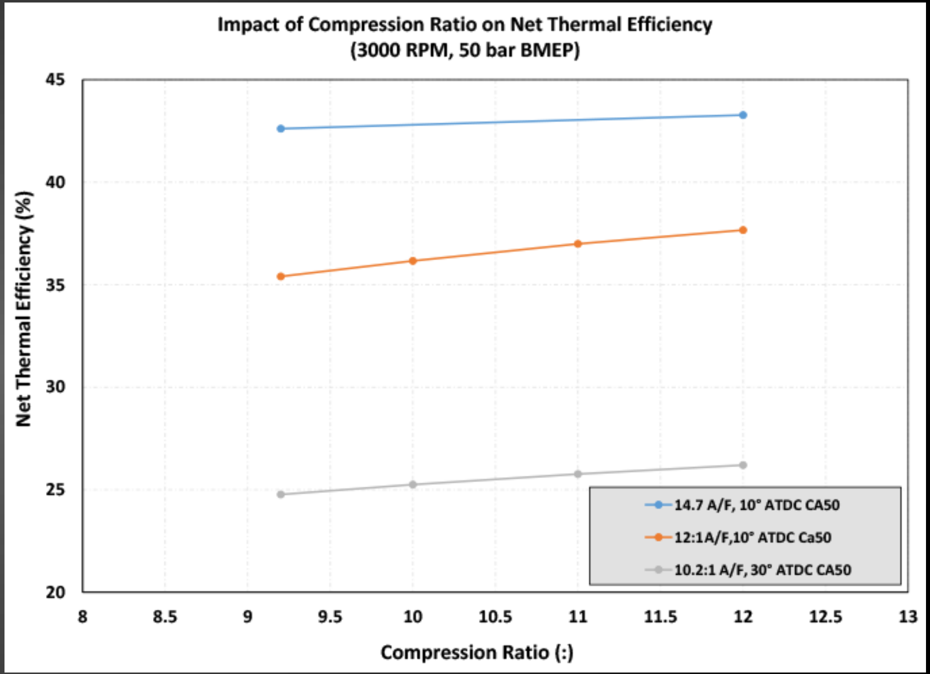
Simulation Results





11.0:1 chosen as a compromise between efficiency, peak cylinder pressure, and unburned gas temperature (knock propensity)

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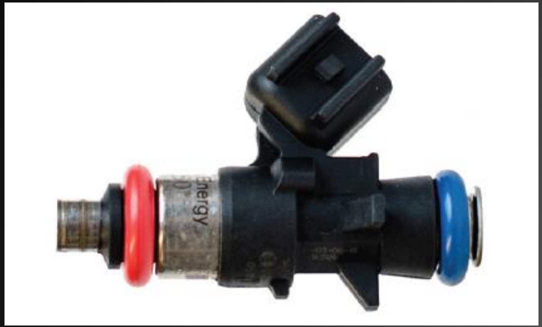
Water Injectors

- Patented jet-to-jet collision breakup mechanism
- Reduced spray penetration and improved liquid atomization allow faster water vaporization rates

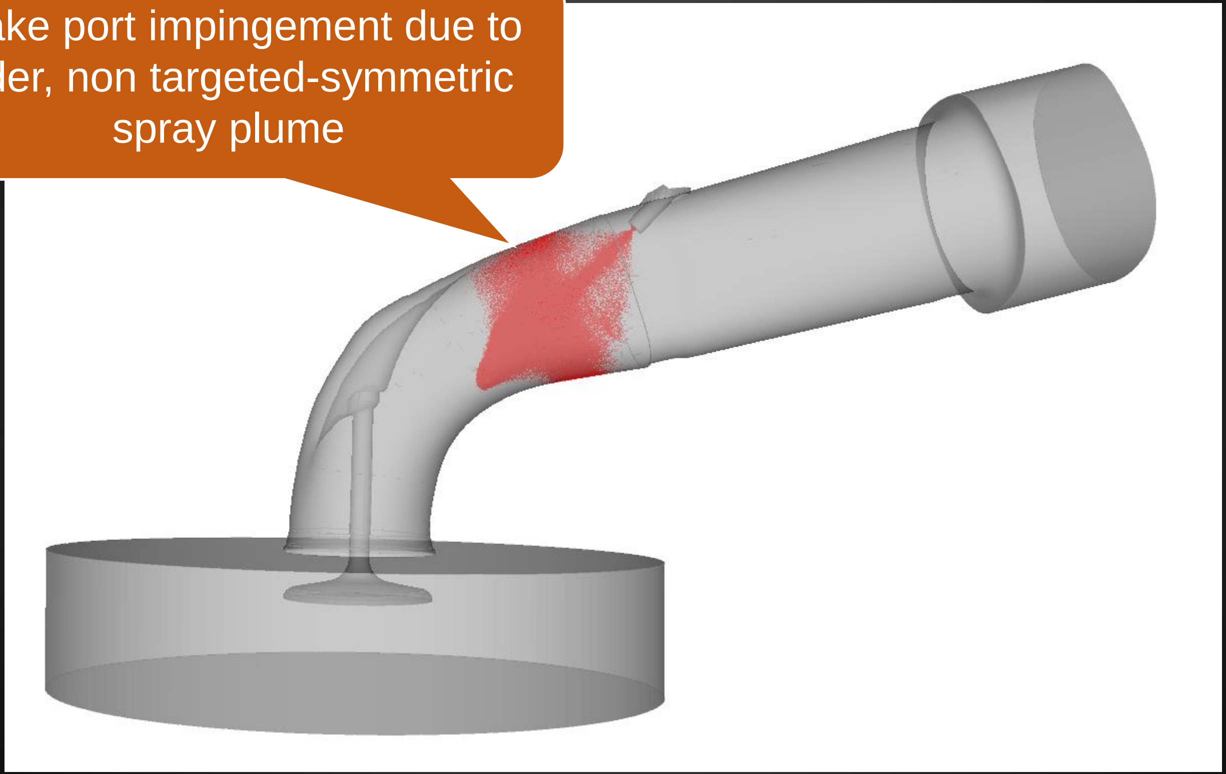
Water Injectors used on this project



- Spray Targeted Nostrum KiWi; Kinetic Water Injector
- Nostrum Water DI injector (next phase)

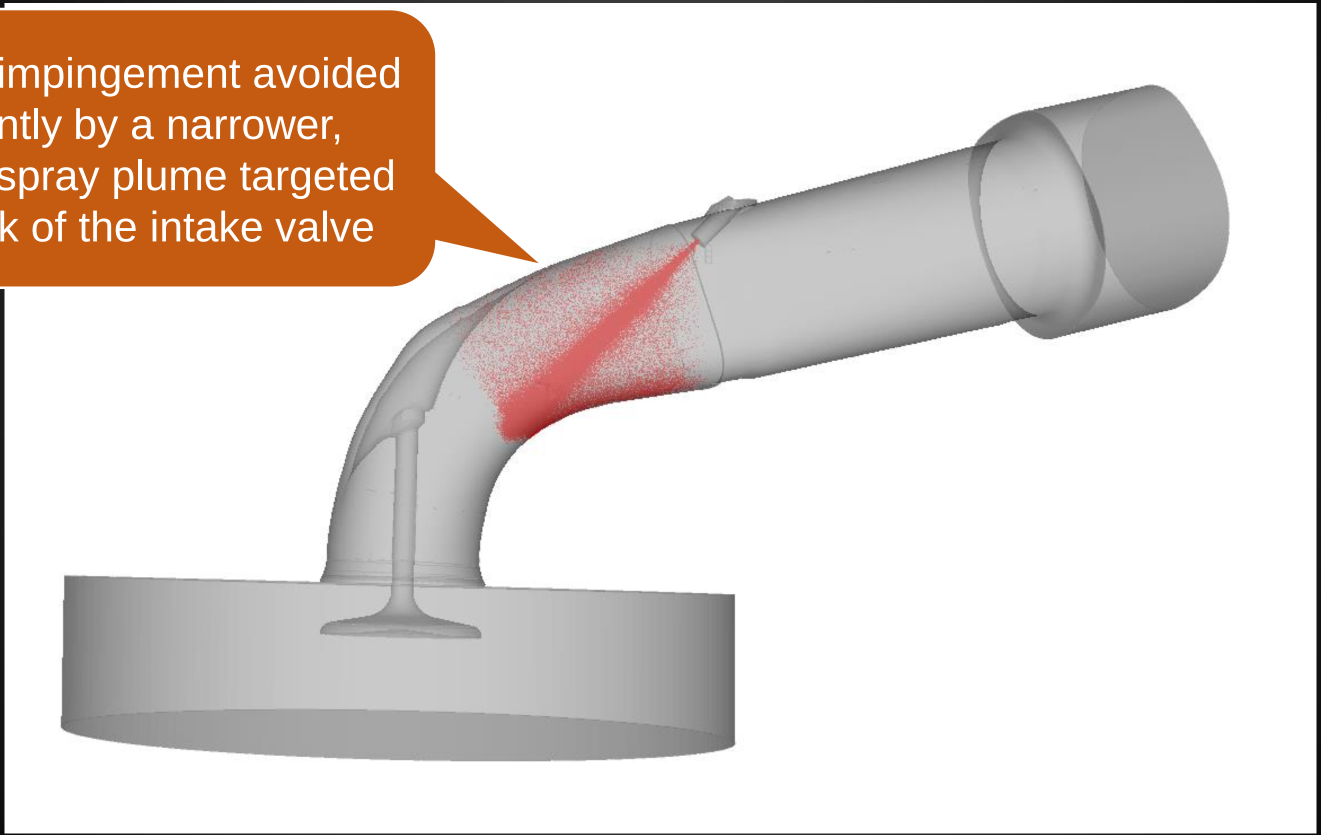
PFI Spray Targeting – Symmetric Spray

Intake port impingement due to wider, non targeted-symmetric spray plume

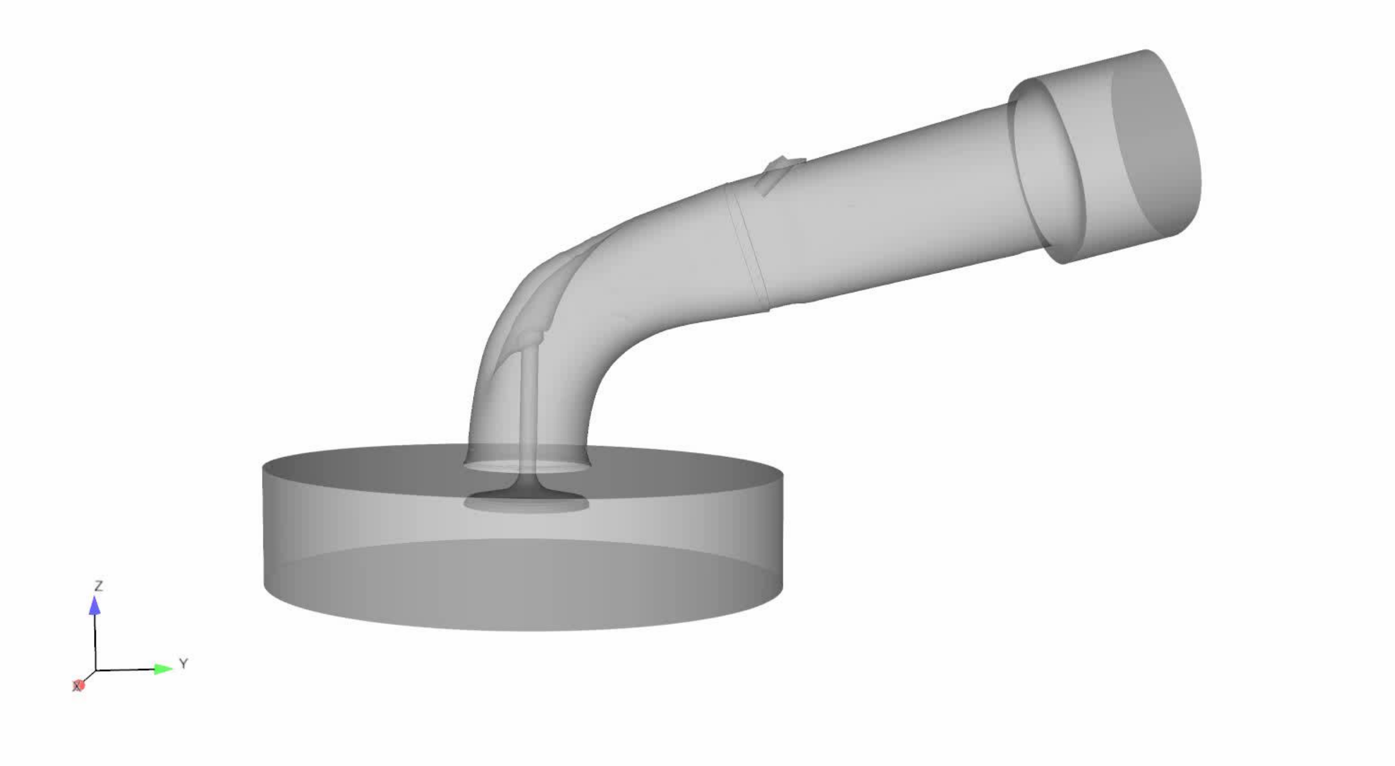


PFI Spray Targeting – Directional Spray

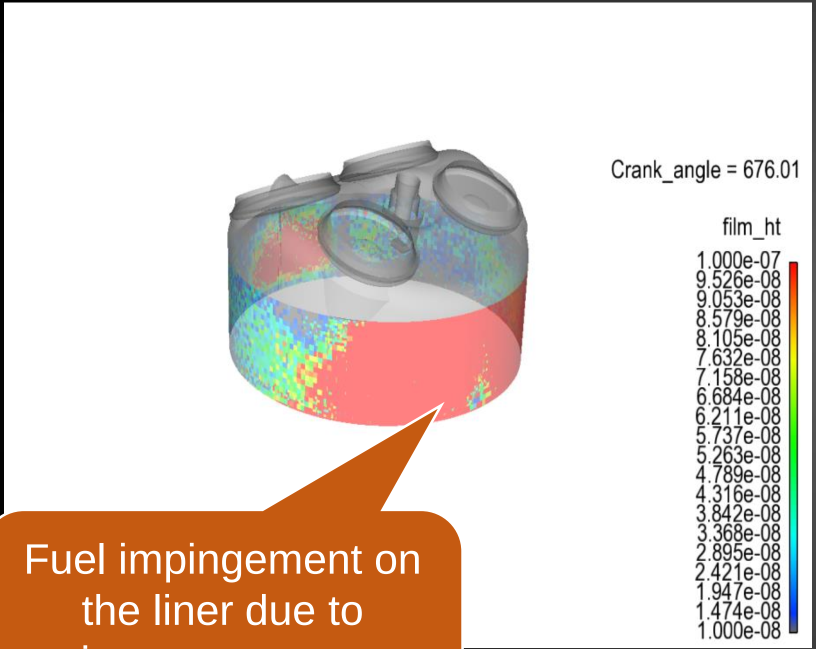
Intake port impingement avoided significantly by a narrower, directional spray plume targeted to the back of the intake valve



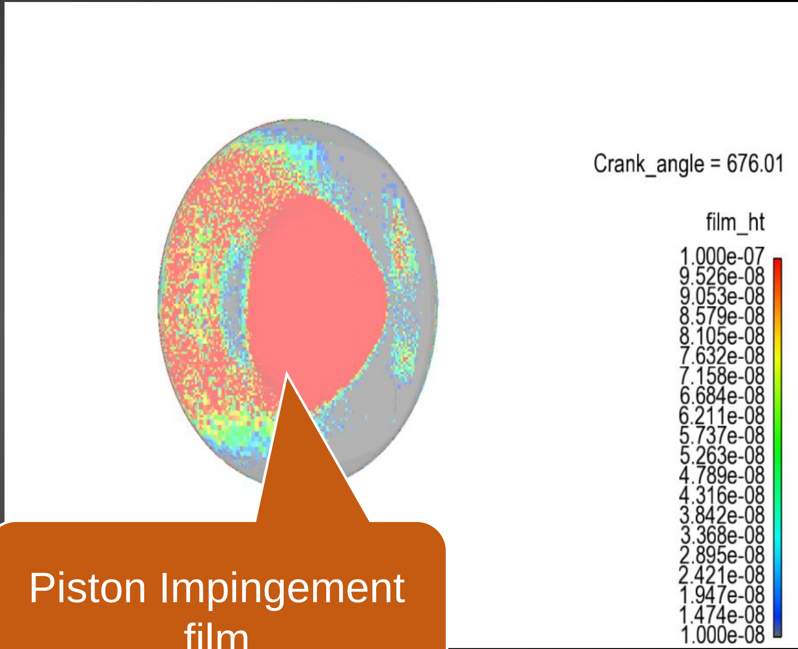
PFI Spray Targeting – Directional Spray Movie



Liner & Piston Impingement



Fuel impingement on the liner due to improper spray targeting



Piston Impingement film

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Conclusions

- Port water injection has been successfully demonstrated near current production best in class full load levels (~27 bar BMEP)
  - Enabled ***near MBT Combustion Phasing*** (water flow limited by instrumentation) on “Regular” 87 AKI Fuel and ***stoichiometric operation***
  - Resulted in a significant increase in Net Thermal Efficiency over production across all speeds
    - 34% @ 3000 RPM
  - Resulted in a significant increase in NMEP over production across all speeds
    - 5.1% @ 3000 RPM

Next Steps (Near Term)

- Evaluate water injection at higher levels of BMEP
- Evaluate water injection at increased compression ratio
- Compare Direct Water Injection to Port Water Injection
- 1D Simulation of Water Injection
- Reduce water usage though spray targeting and reduction in droplet size

High BMEP Engine Components

- Currently no production engine at this cylinder pressure
- Production intent
  - Forged Pistons & Connecting Rods
  - High Strength head studs
  - 10W40 High ZDDP Synthetic Oil
  - Increased valve lift
  - Increased valve spring stiffness
  - Larger High Pressure Fuel Pump
    - 83% increase in fuel flow

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Q&A

For full powerpoint

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