ASME
ICEF 2024
The ICE Forward Conference

Modeling Dual Fuel Combustion in a Heavy-Duty Diesel Engine Fueled with Diesel and Natural Gas

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Introduction & Motivation

In this project, we developed a CFD model to simulate dual fuel low temperature combustion (DFLTC) on a heavy-duty single-cylinder research engine (SCRE) based on the PACCAR MX-11 series platform using the Converge CFD software. As discussed in the workflow, the existing engine geometry was upgraded significantly to include details of intake and exhaust manifold geometries.

DFLTC has been demonstrated to defeat the soot-NOx trade-off in diesel engines with little compromise in thermal efficiency [2].

A distinct feature of DFLTC as in Fig. 1 is the presence of low temperature heat release (LTHR) from diesel combustion [3,4]. The validated CFD model is used to test the hypothesis that at early injection timings the injected diesel fuel has sufficient time to disperse into the natural gas – air mixture. This results in localized distributed autoignition, which further consumes the natural gas – air mixture as combustion proceeds and leads to low engine-out oxides of nitrogen emissions. Additionally, the overall lean combustion results in near-zero soot emissions.

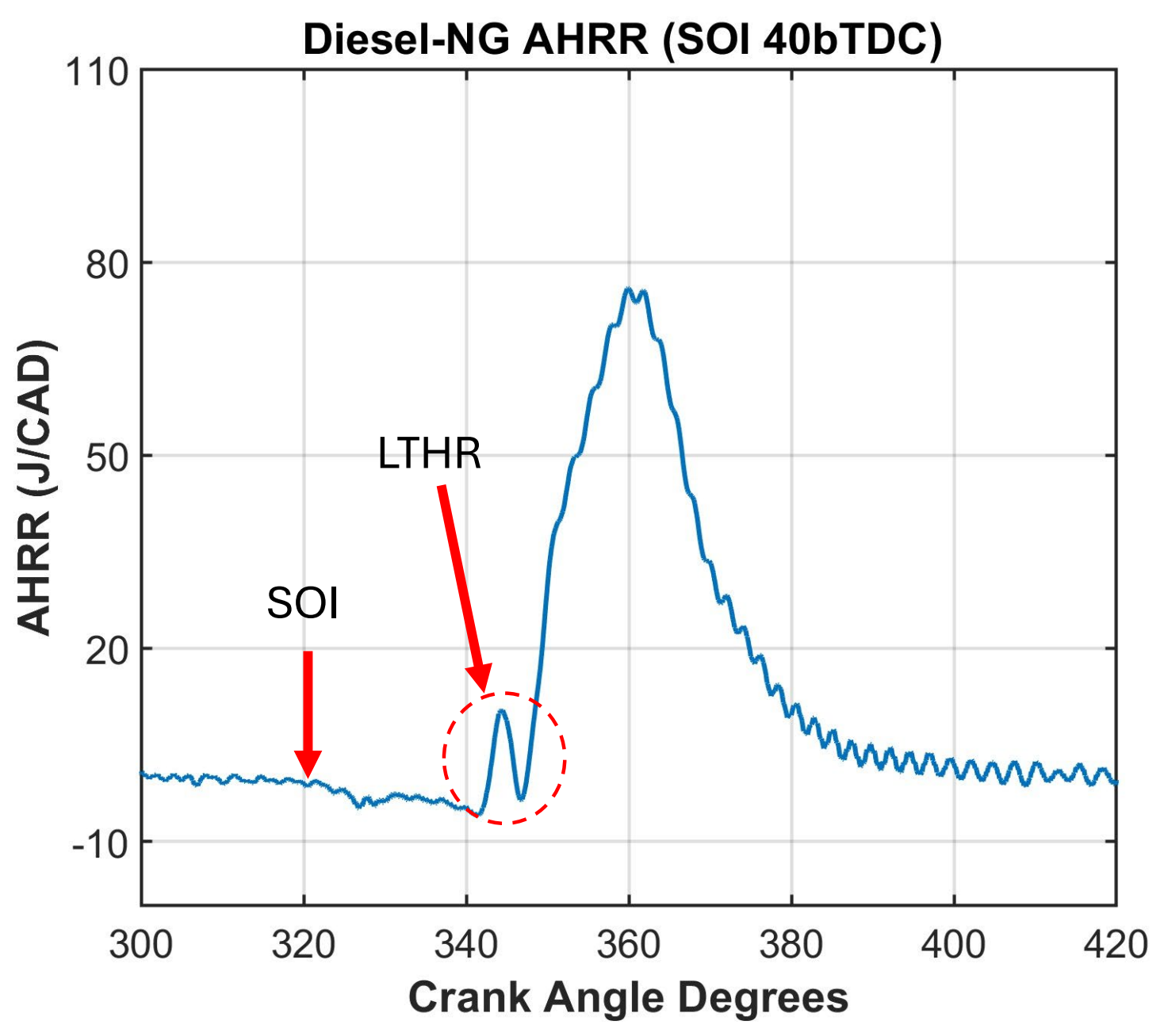
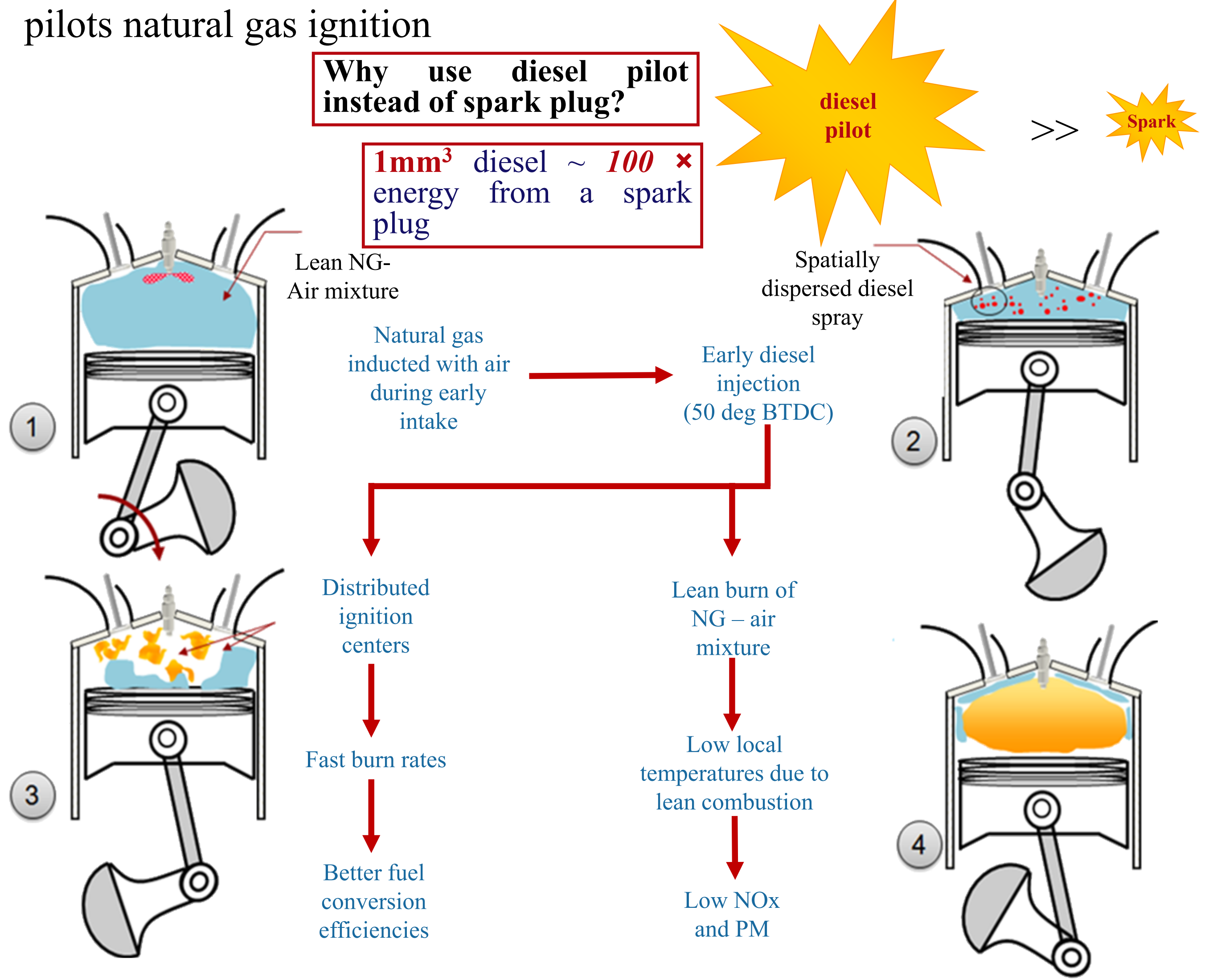


Figure 1

Hypothesis

- ❖ Dual Fuel Diesel and Natural Gas
- ❖ Natural gas – highly resistant to autoignition (hard to burn)
- ❖ Diesel – higher propensity to autoignite than natural gas
- ❖ ***Hypothesis*** – localized autoignition of diesel at beginning of heat release pilots natural gas ignition



Engine Specifications

Table 1: Single cylinder research engine specifications [2]

Parameter	Value
Bore	123 mm
Stroke	152 mm
Connecting rod	243 mm
Compression ratio	18.5:1
Combustion chamber geometry	Mexican hat
Diesel injection system	Delphi DFP5
Injector nozzle hole diameter	0.1905 mm
Number of nozzle holes	7
Maximum engine speed	2200 rpm

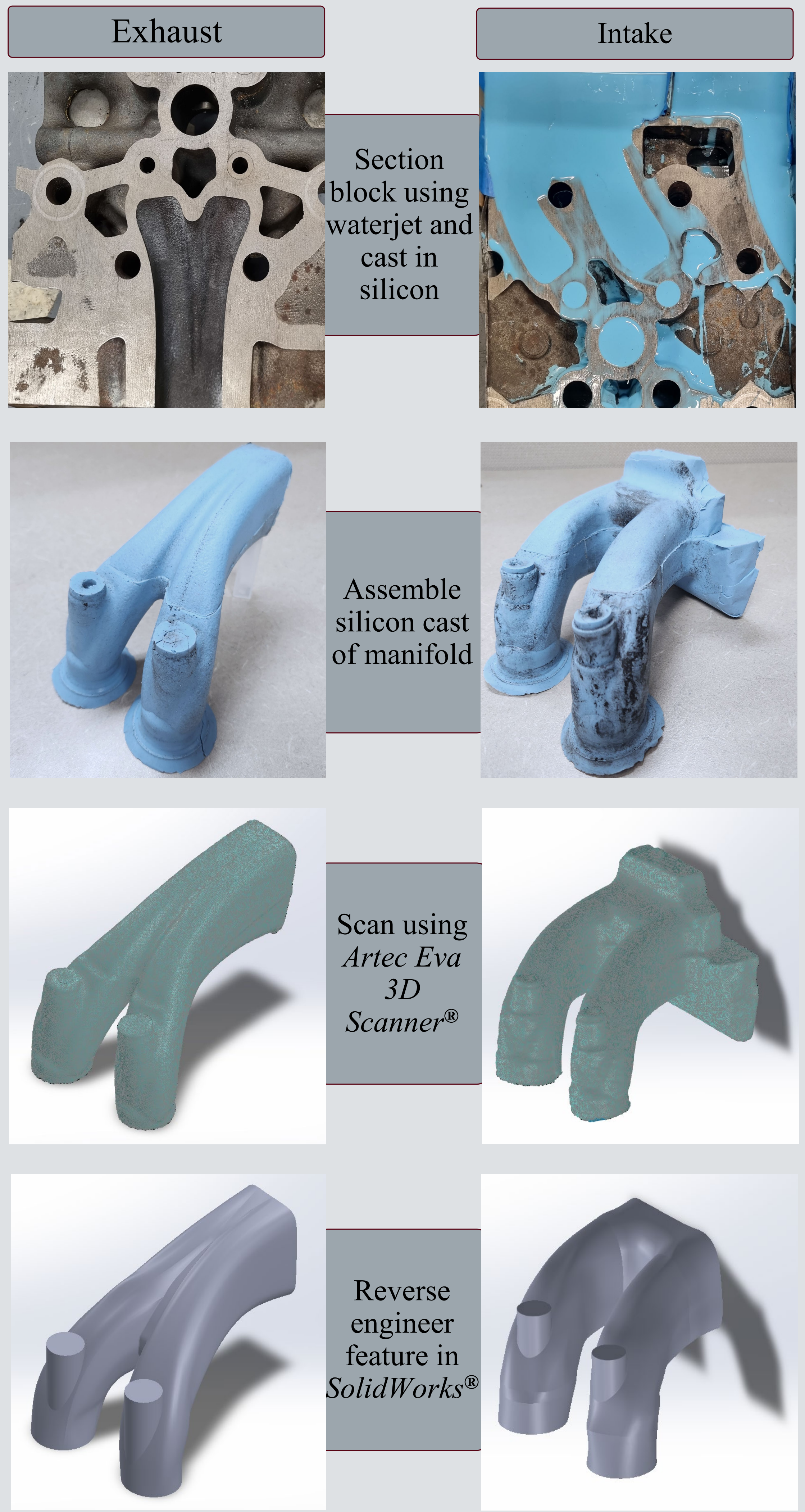
Table 2: Dual fuel specifications.

Fuel	Model Fuel	Auto Ignition	Intake Method
Diesel	Dodecane	High	High pressure liquid spray
Natural Gas	Methane	Low	Fumigated premixed with air

Converge CFD Workflow

- ❖ Current simulation uses cylinder volume without intake and exhaust manifolds and uses average boundary flow conditions at intake and exhaust
- ❖ Addition of intake and exhaust manifold geometry realizes turbulent flow at these locations.
- ❖ Return to CAD model phase to improve boundary accuracy

Create CAD Model
Model Import and clean
Case Setup & run model on HPC cluster
Compare with engine experiments
Parameter Tuning
Model Validation
Visualization *Tecplot360®*



Exhaust
Intake

Section block using waterjet and cast in silicon

Assemble silicon cast of manifold

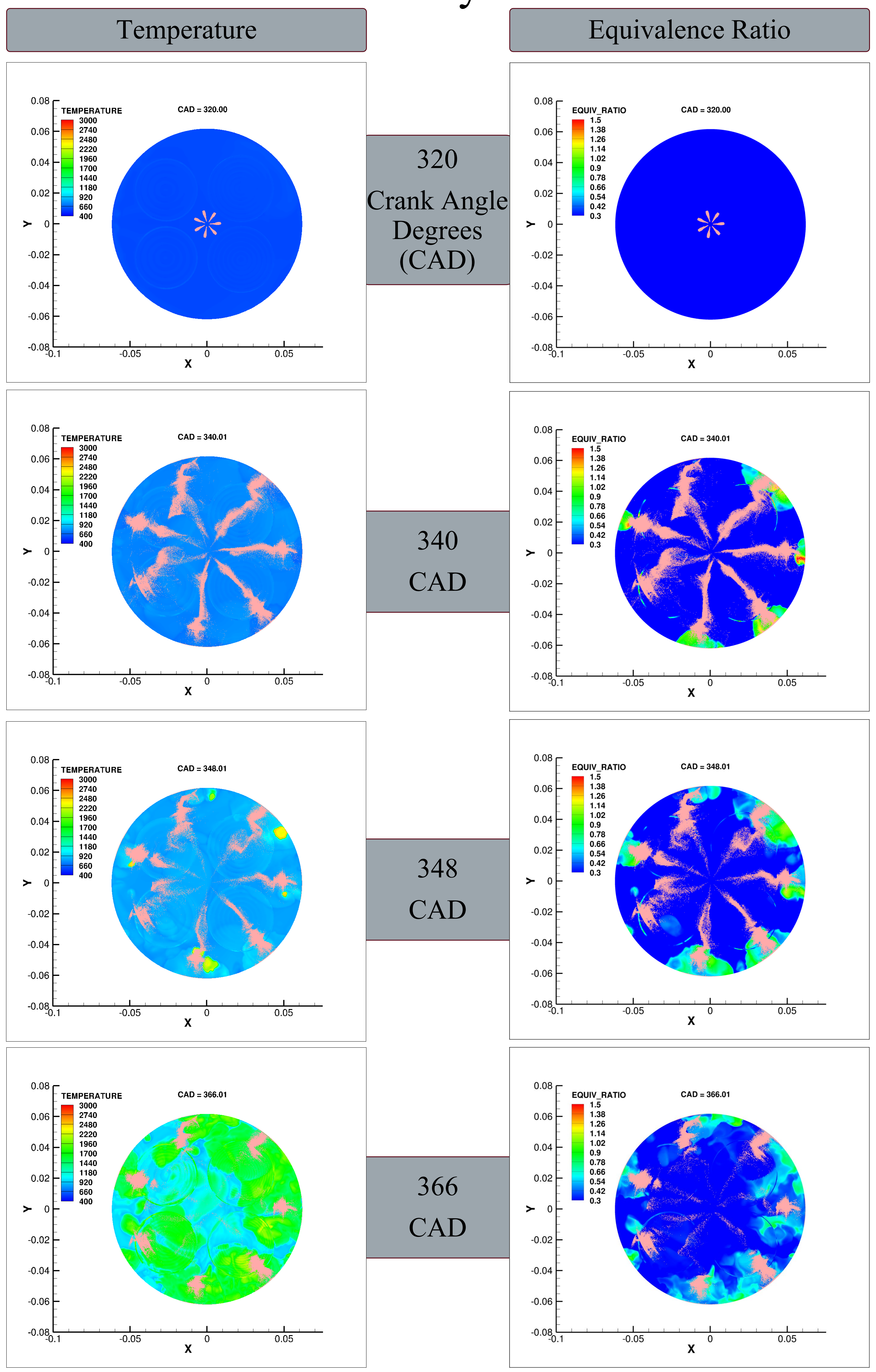
Scan using *Artec Eva 3D Scanner®*

Reverse engineer feature in *SolidWorks®*

Conclusions

- ❖ CFD model captures the high-pressure diesel spray evolution accurately and shows the spatial dispersion of diesel droplets in combustion chamber before start of combustion validating our hypothesis
- ❖ CFD model captures diesel autoignition and start of first-stage energy release from subsequent diesel combustion, which burns faster than natural gas due to its greater autoignition propensity
- ❖ Validated model demonstrates distributed localized diesel autoignition leading to low temperature natural gas combustion well below the threshold temperature (>2000 K) to form nitrogen oxide emissions

Preliminary Results



Temperature
Equivalence Ratio

320
Crank Angle Degrees (CAD)

340
CAD

348
CAD

366
CAD

Future Work

- ❖ Apply new intake and exhaust geometry to capture turbulent boundary flow
- ❖ Re-validate combustion model against experiments with new geometry
- ❖ Validate local autoignition with highspeed photography from single cylinder engine
- ❖ Extend the model to investigate zero carbon fuels such as hydrogen and ammonia, and renewable oxygenated fuels like dimethyl ether

Acknowledgement

The author would like to thank The University of Alabama Office for Undergraduate Research, Honors College, and Randall Research Scholars Program for sponsoring conference travel.

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