Numerical modelling of 2-stroke marine engines for future fuels applications:

Ammonia and Methanol dual-fuel combustion system development

Ludovico Viglione
2S Future Fuels Team

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Outline

Scope of Work

CFD Model and Methodology

CFD Model Calibration & Combustion simulation

Nozzle Tip Design

Conclusions and Next Steps

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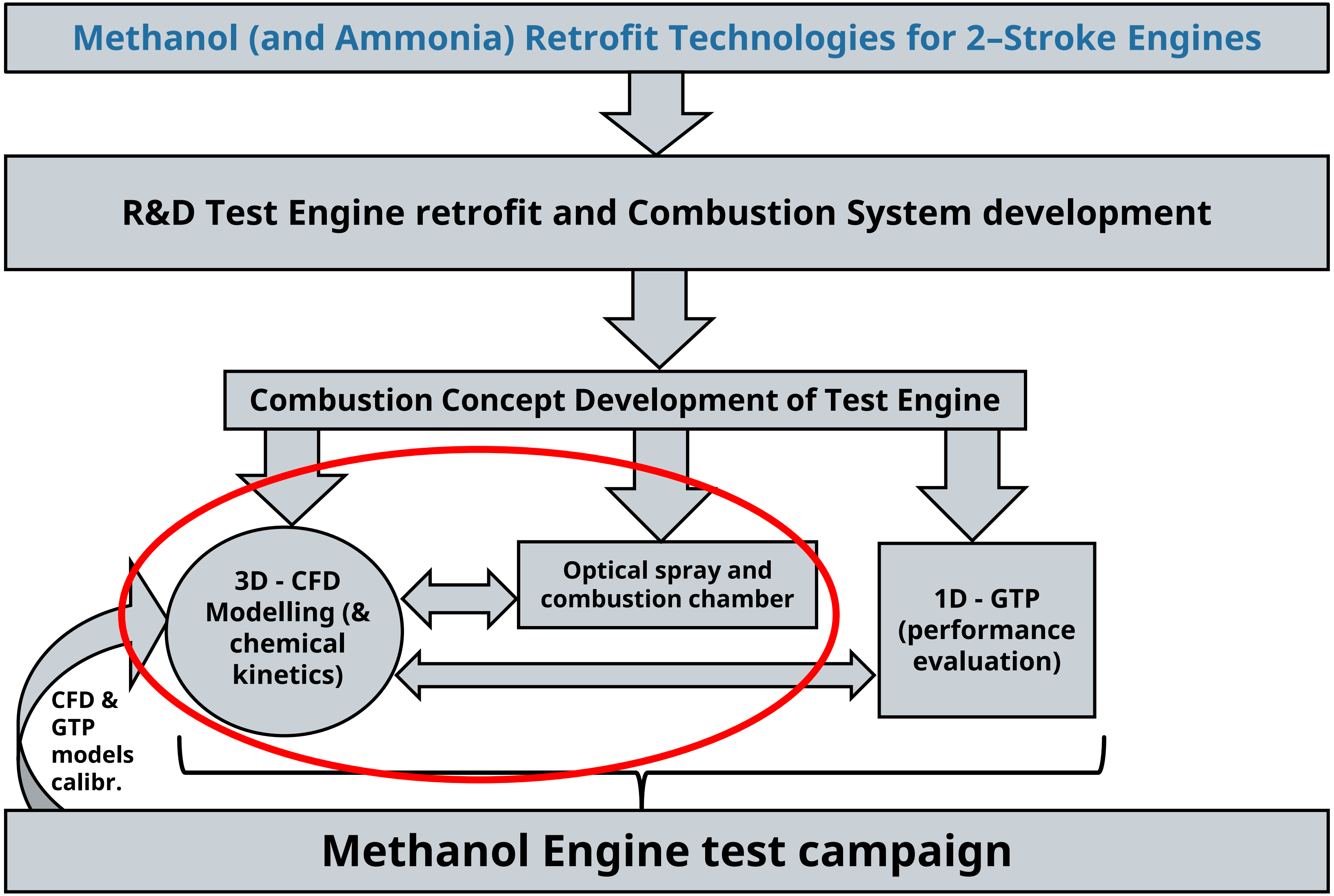
Workflow Overview



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CFD Model and Methodology

Model Development and Gas Exchange simulation

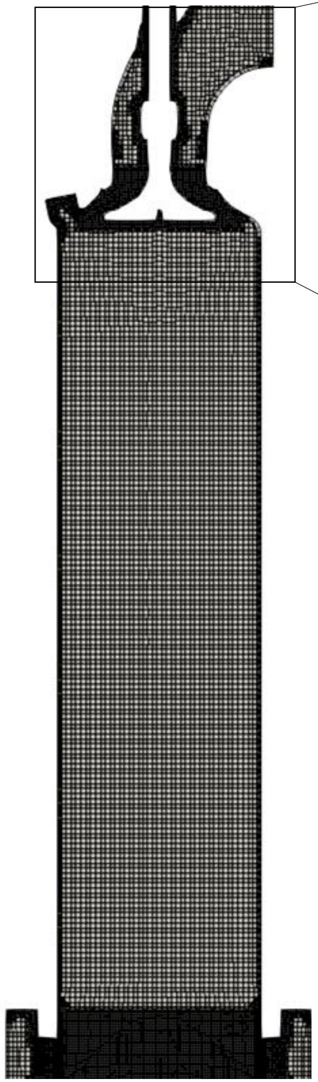
OpenFoam v8

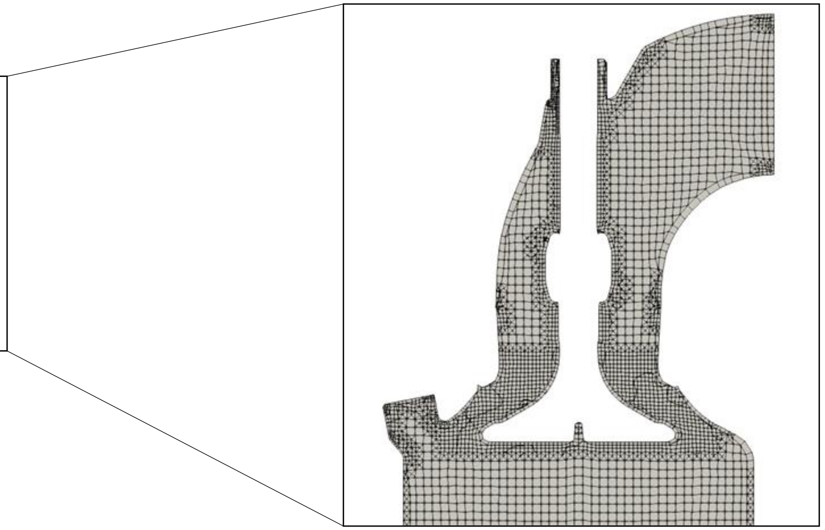
+

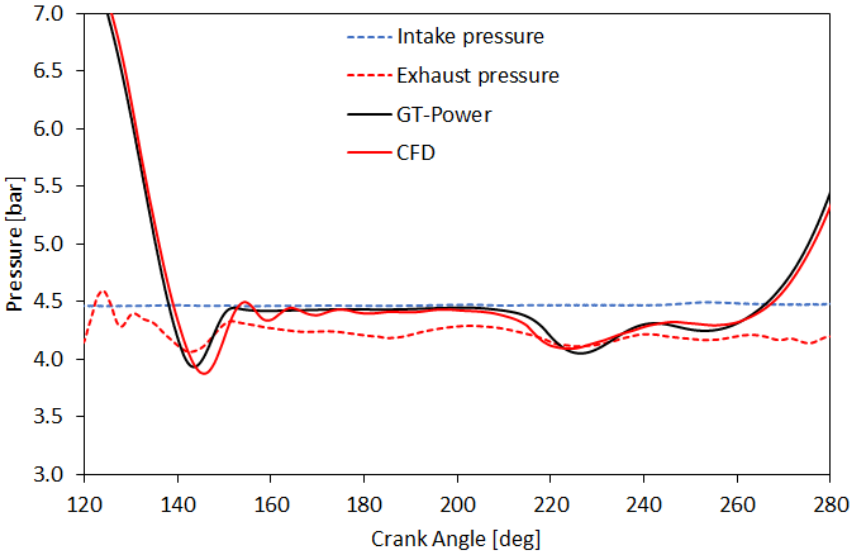
“LibICE” libraries

(from Politecnico di Milano)

- RANS simulation (k/epsilon)
- Tabulated chemistry
- Dual Fuel chemical kinetics



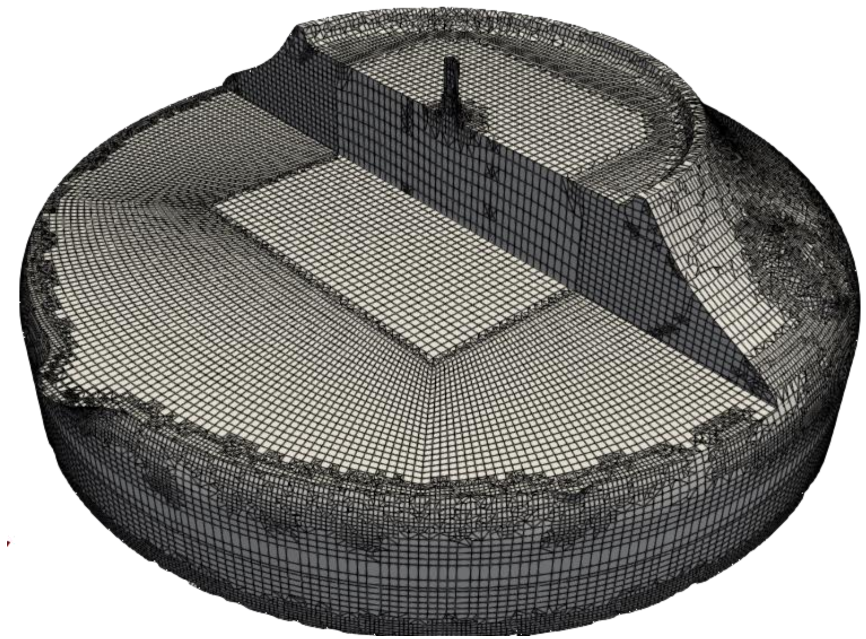




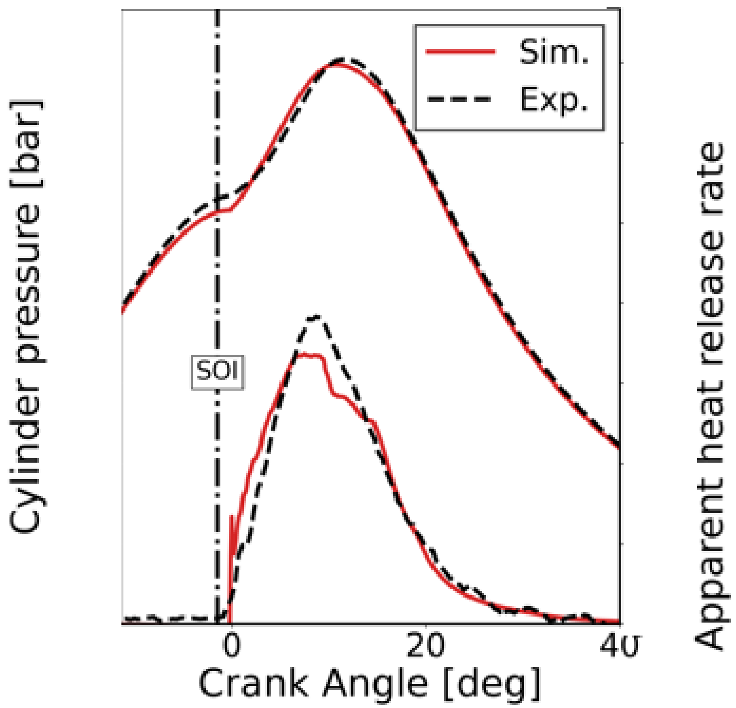
CFD Model and Methodology

Engine Model Validation – Diesel data comparison

- Combustion simulation managed with separate mesh
- Lagrangian injection : KH-RT breakup model
- Fixed wall temperature



Mesh information Combustion mesh	
Minimum n° of cells	≈ 0.5 M
Mean cell size	0.4 mm
Simulation Time	≈ 20 h



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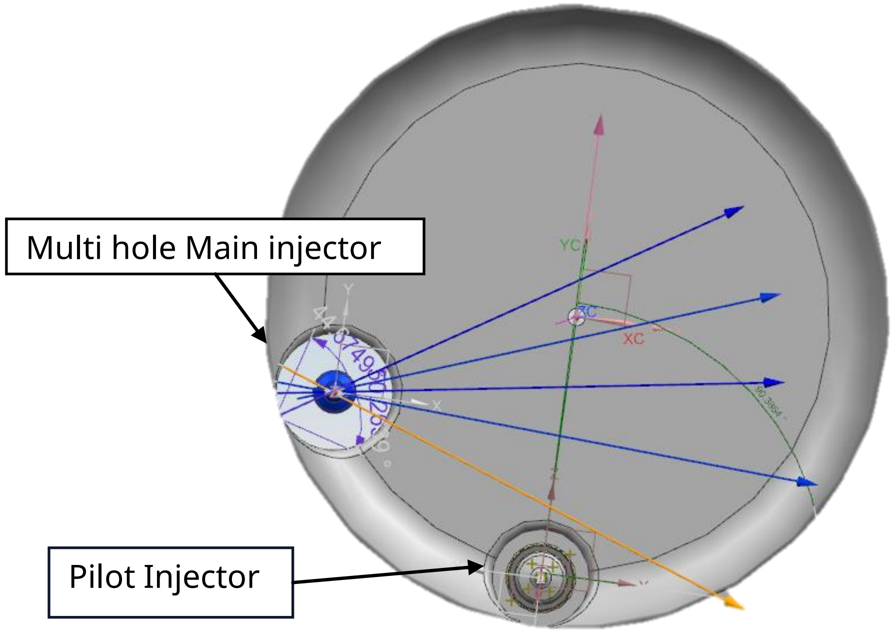
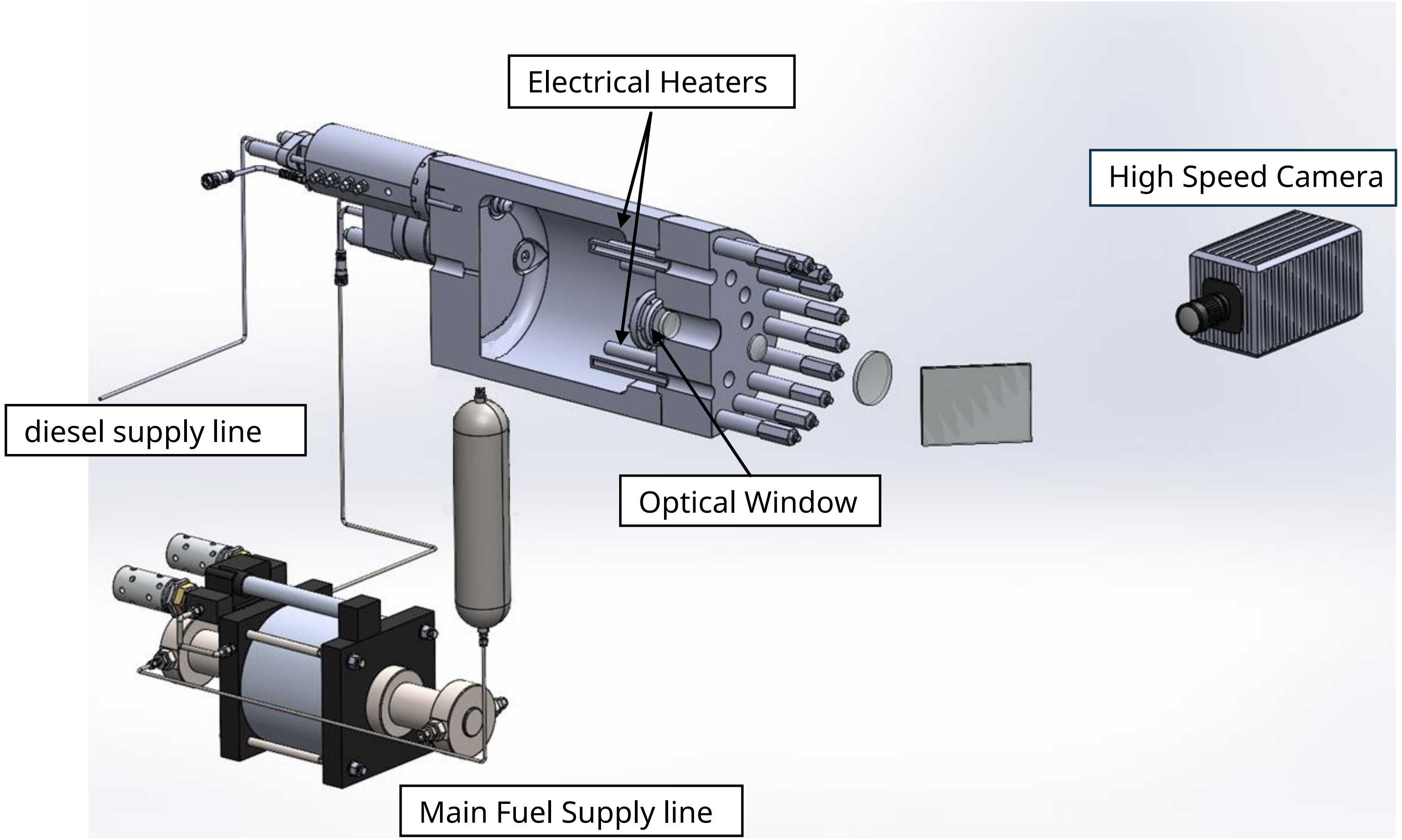
CFD Model Calibration & Combustion simulation

Optical spray chamber - Setup

Chamber Volume	3000 cm3
Diameter	320 mm
Max Pressure	100 bar
Max heating Temp.	550 °C
Max Structure Temp.	> 700 °C





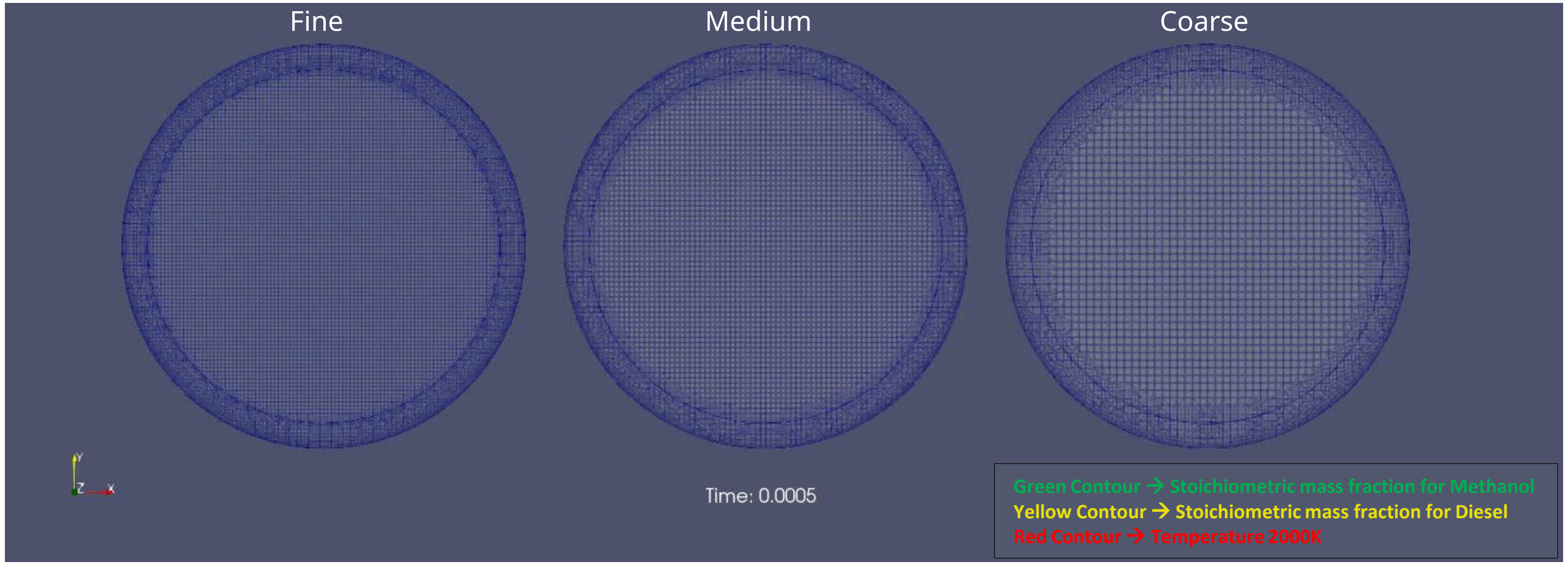
CFD Model Calibration & Combustion simulation

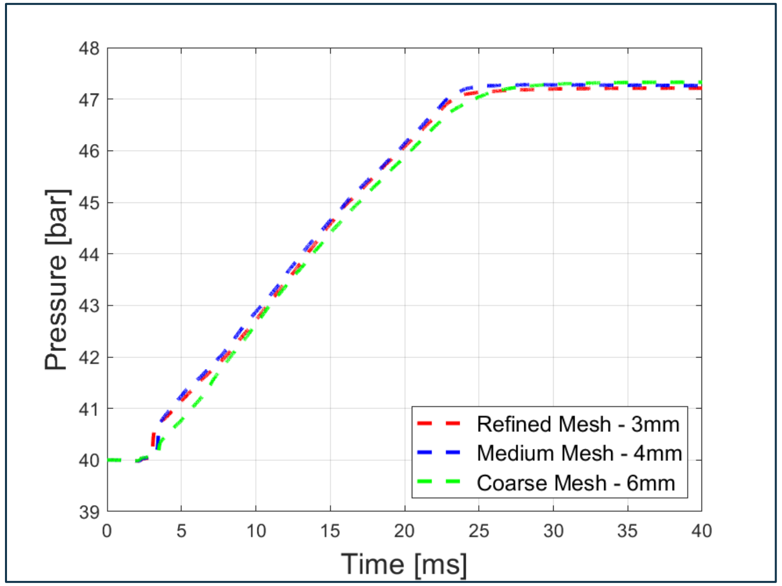
Optical spray chamber model – Description and mesh Independence test

- No pressure trace difference between medium and fine mesh
- Better flame wrinkling and spray induced turbulence with the Fine Mesh

Mesh Size and Computational time

	Cell Count (x 10^3)	base mesh [mm]	Simulation time [h]
Coarse	~ 109	6	~3
Medium	~ 323	4	~9
Refined	~ 745	3	~20





CFD Model Calibration & Combustion simulation

Optical spray chamber model – Chemical Kinetic Model Sensitivity

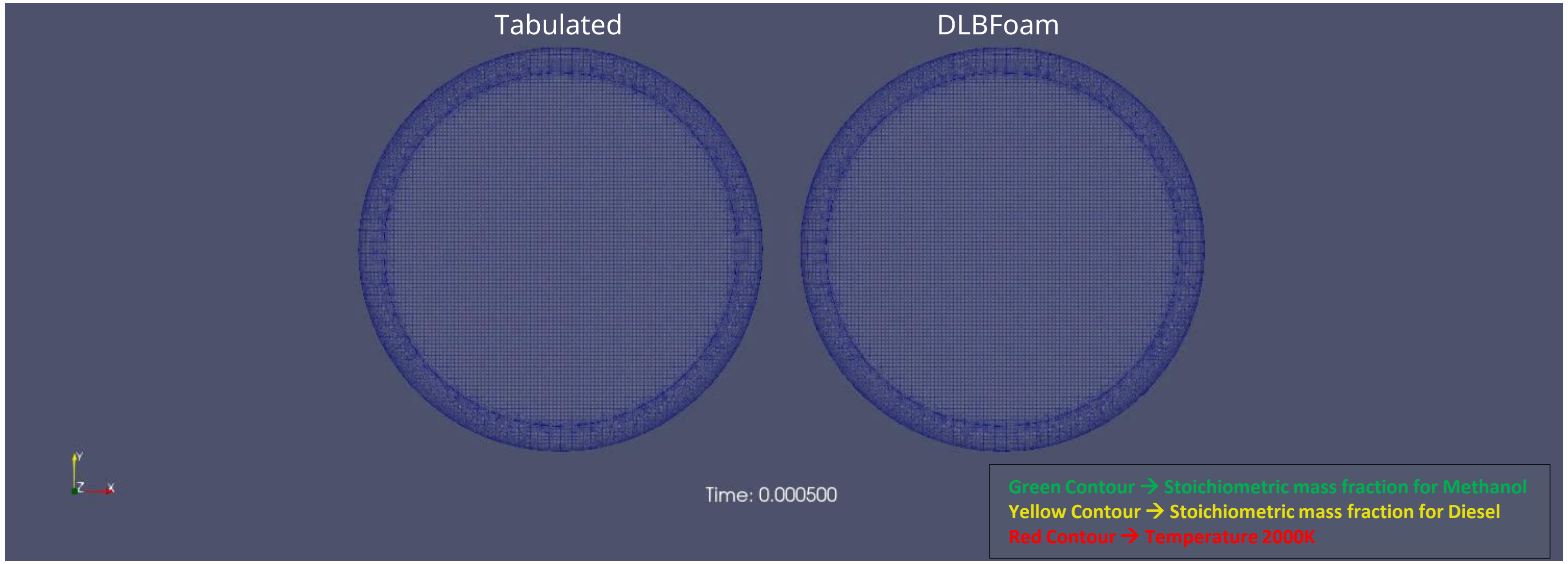
Tabulated Kinetic and direct kinetic approach comparison:

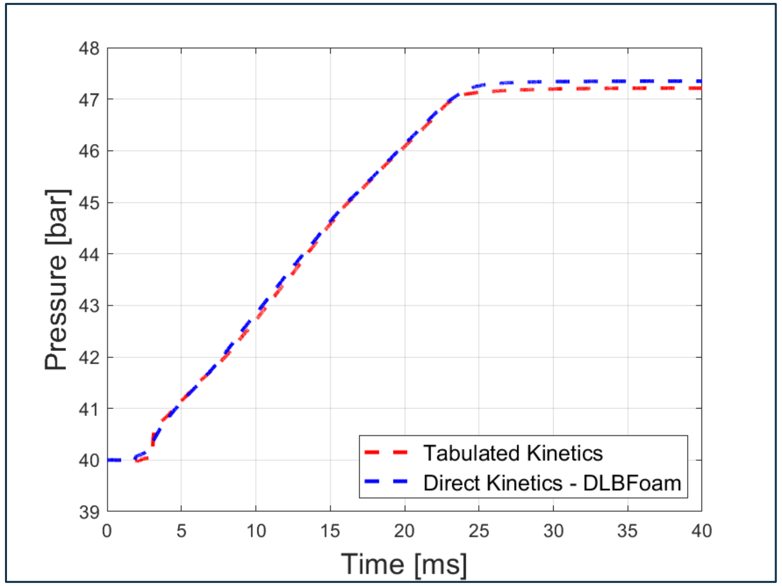
- No major difference on pressure traces
- Smoother combustion transition with direct kinetic
- Slightly different flame interaction and evolution
- Comparable time frames using *DLBFoam & pyJac*(*) for direct kinetics

Both the approaches are applicable to the full scale model with different focuses

Mesh Size and Computational time

	Cell Count (x 10^3)	base mesh [mm]	Simulation time [h]
Tabulated Kinetic	~ 745	3	~20
Direct Kinetic (**DLBFoam**)*	~ 745	3	~33



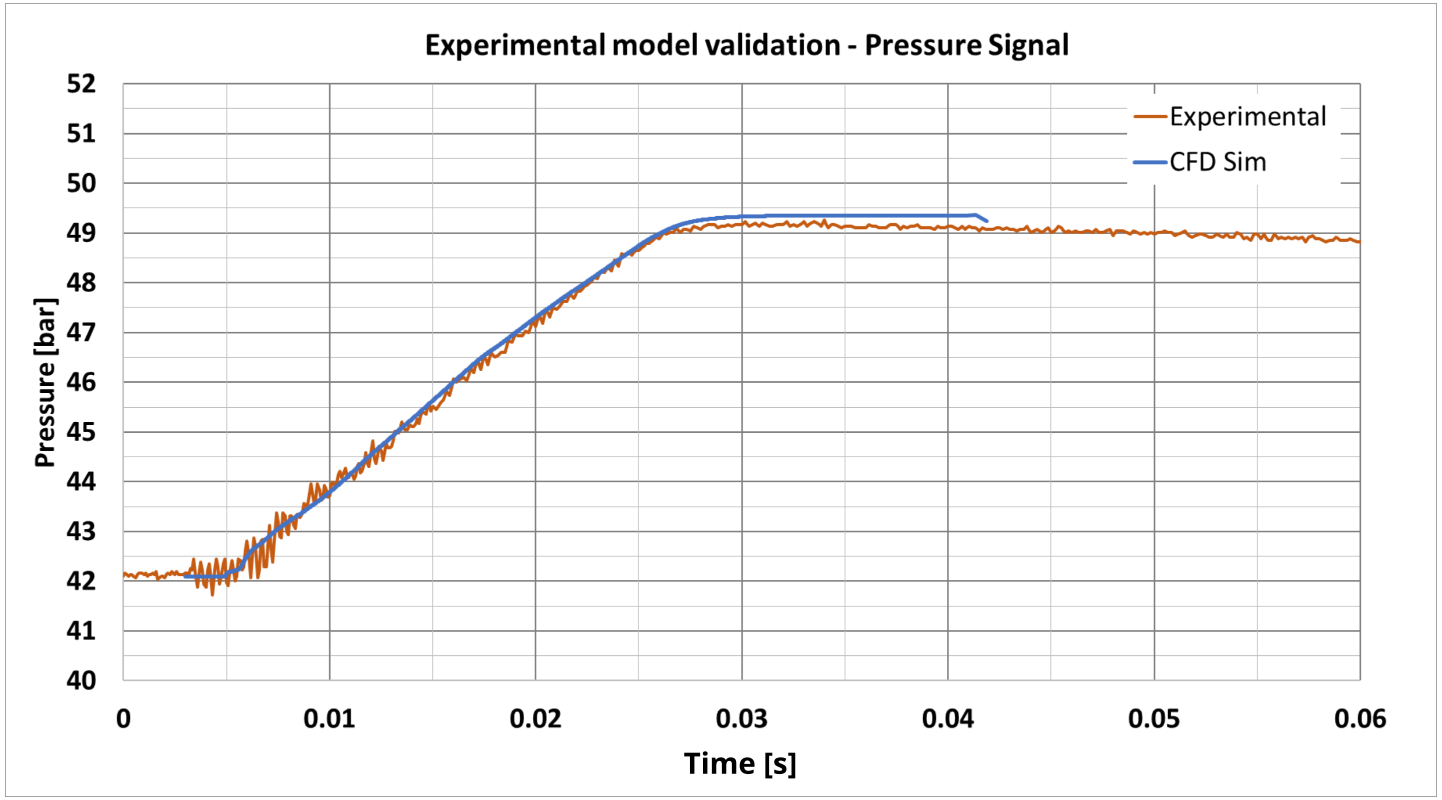


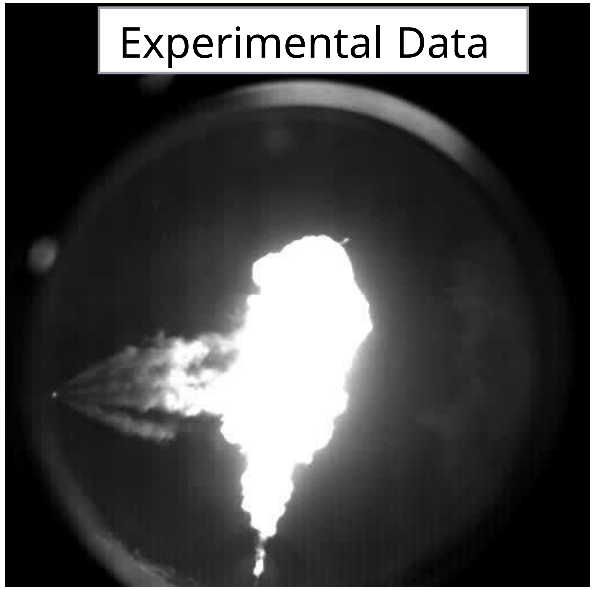
* **B. Tekgül, P. Peltonen, H. Kahila, O. Kaario, V. Vuorinen,** DLBFoam: An open-source dynamic load balancing model for fast reacting flow simulations in OpenFOAM, Computer Physics Communications, Volume 267, 10.1016/j.cpc.2021.108073 (2021).
I. Morev, B. Tekgül, M. Gadalla, A. Shahanaghi, J. Kannan, S. Karimkashi, O. Kaario, V. Vuorinen, Fast reactive flow simulations using analytical Jacobian and dynamic load balancing in OpenFOAM, Physics of Fluids 34, 021801, 10.1063/5.0077437 (2022).

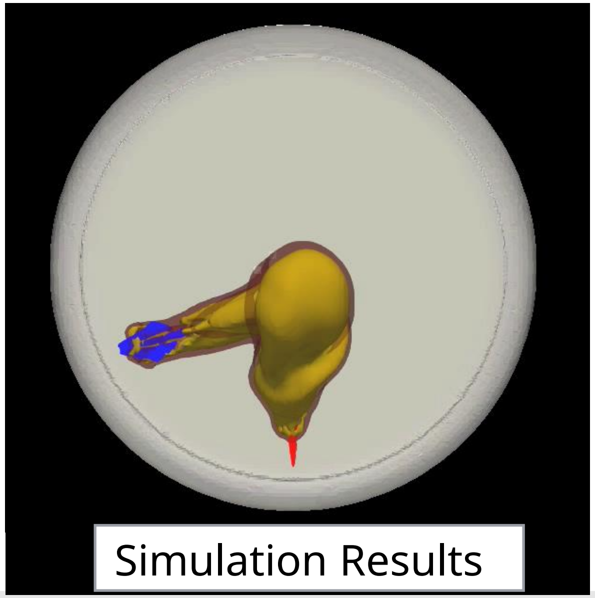
CFD Model Calibration & Combustion simulation

CFD Model Validation

- ✓ Very good correlation between Simulation and Experimental results
- ✓ Proof of good performance of chemical/combustion model

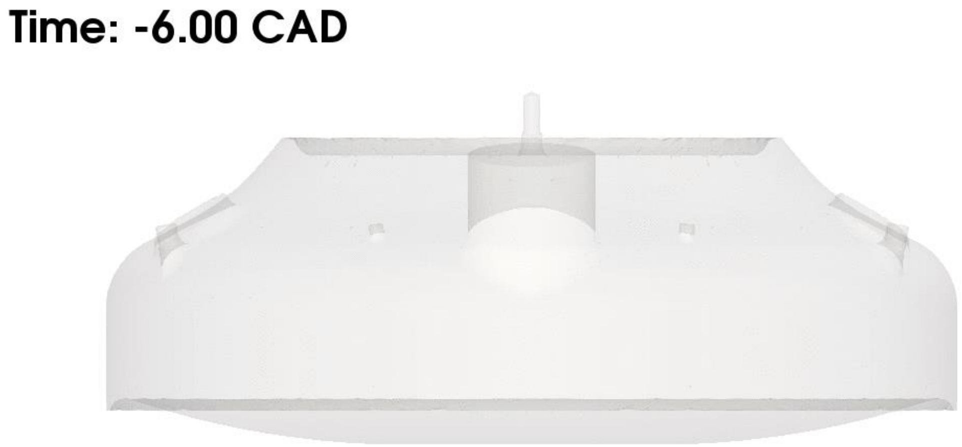






CFD Model Calibration & Combustion simulation

Diesel pilot ignited methanol – RTX5 Engine configuration



Diesel = red
Methanol = blue
Iso-contour at T 2000 K = yellow

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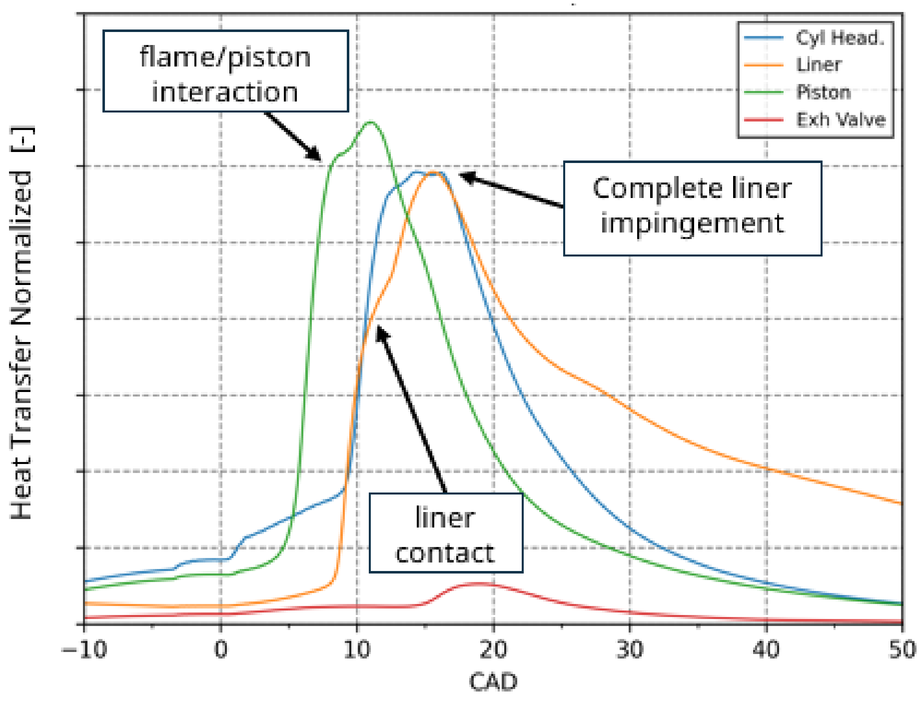
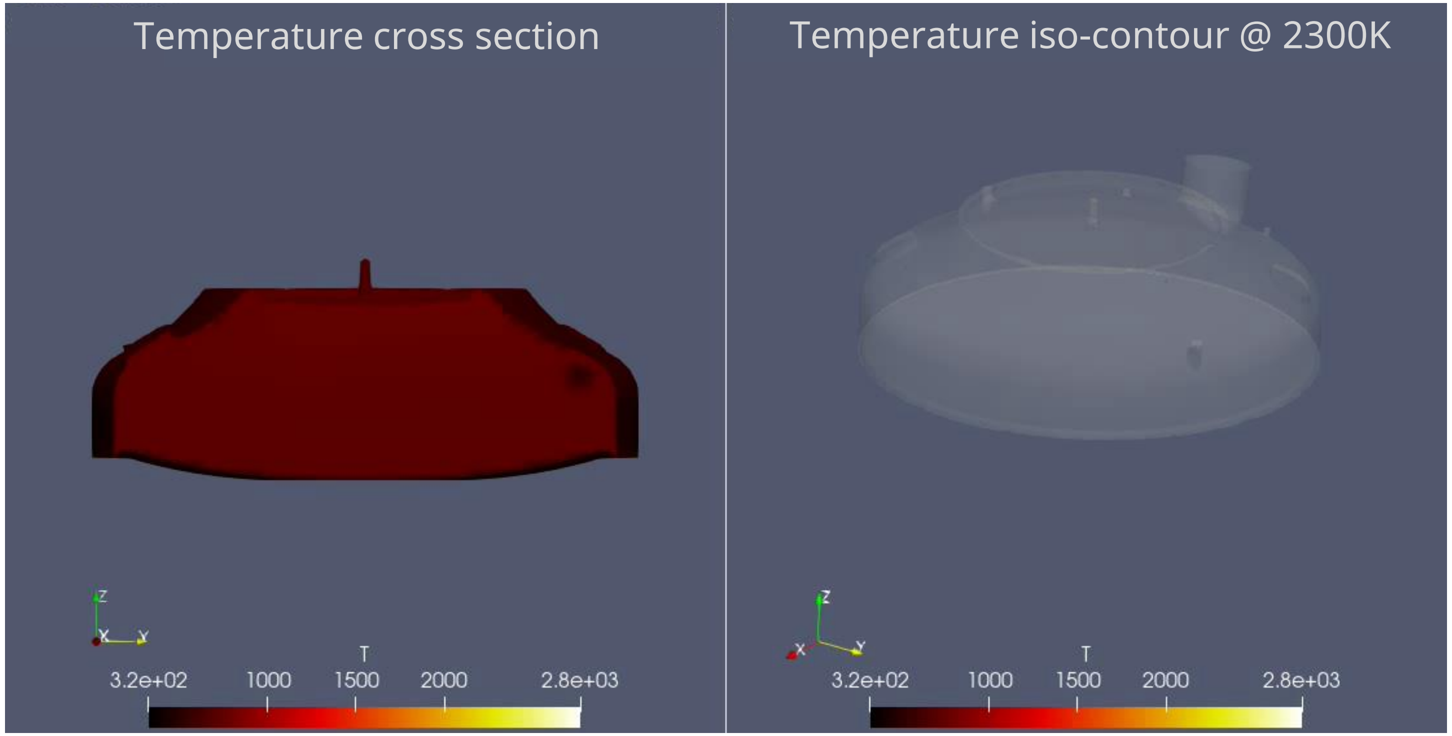
Nozzle Tip Design (Main Injector)

Selection Criteria - Flame Wall Interaction and Spray orientation

- Use of standard nozzle tip for (evaluated as a first step)

➢ Significant amount of Methanol injected causes deep jet penetration, with high risk of flame / wall interaction

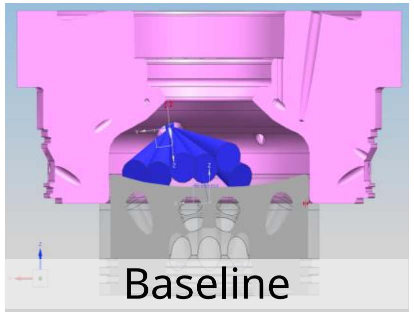


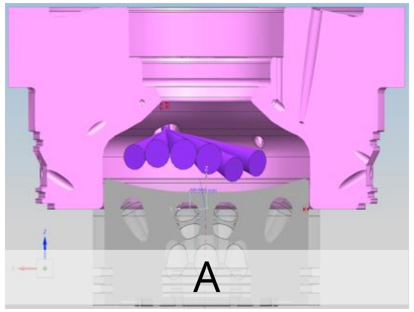


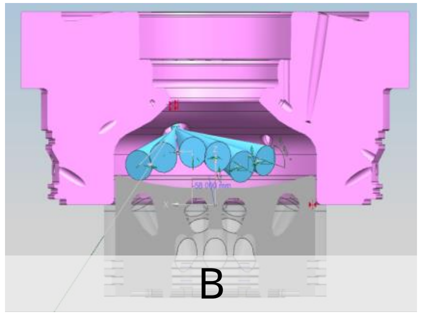
Nozzle Tip Design (Main Injector)

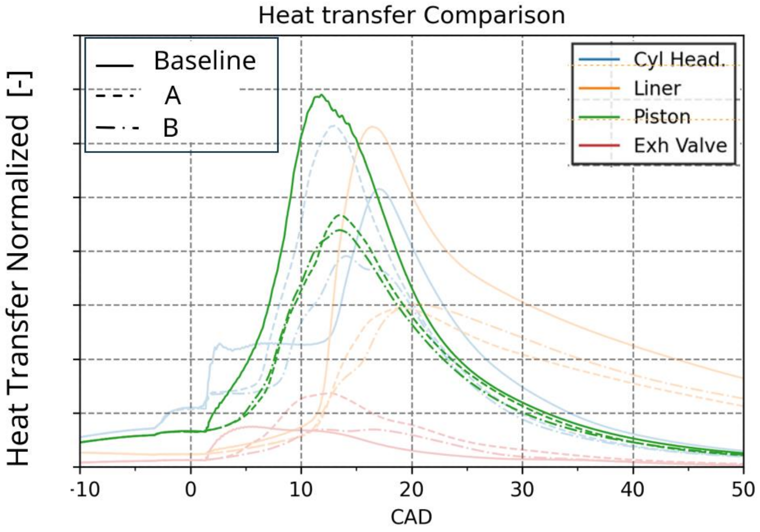
Selection Criteria - Heat Transfer and Flame/Wall interaction

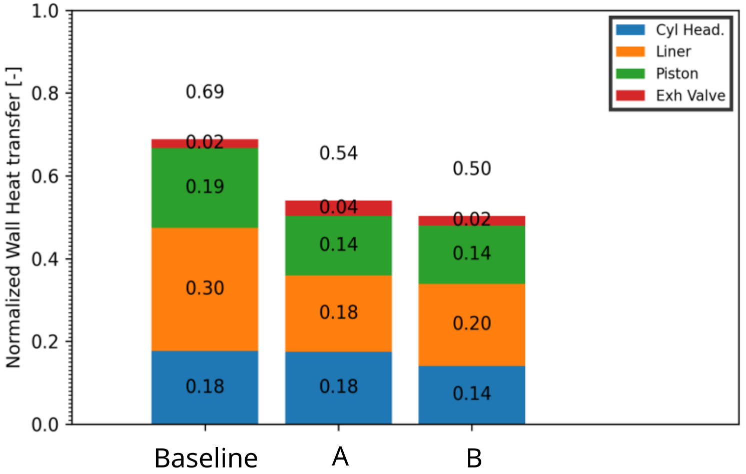
- ✓ 30% reduction of heat rejected
- ✓ Improved IMEP and efficiency
- ✓ Better air entrainment and flame development



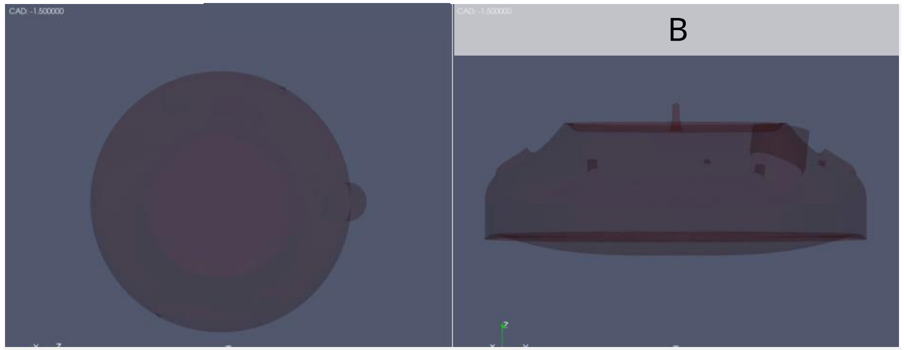








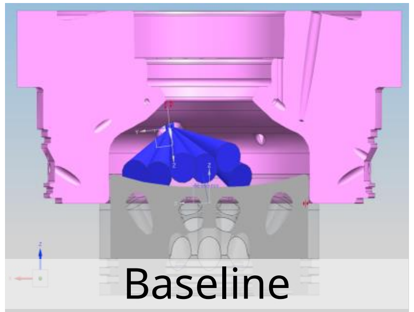
Stochiometric Mixture Fraction Contour

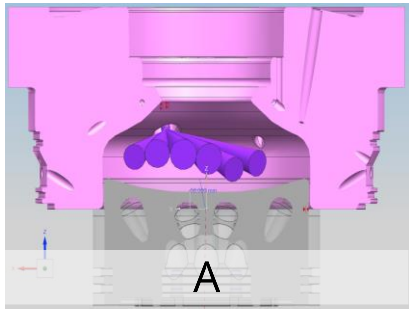


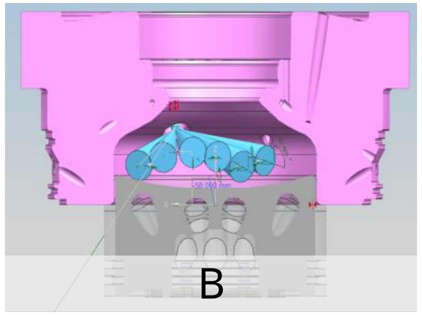
Stochiometric Mixture Fraction Contour

Nozzle Tip Design (Main Injector)

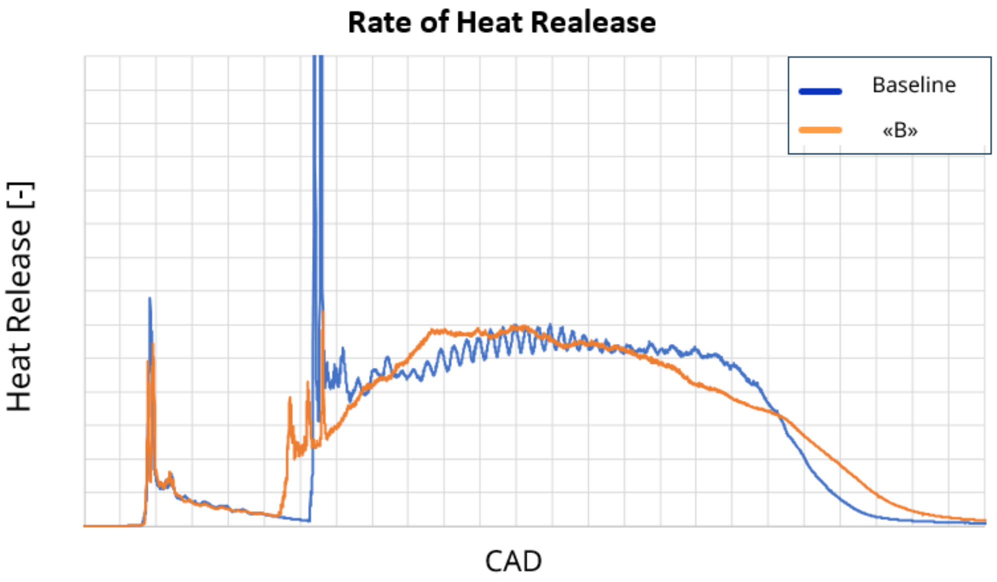
Selection Criteria - Heat release and Combustion efficiency

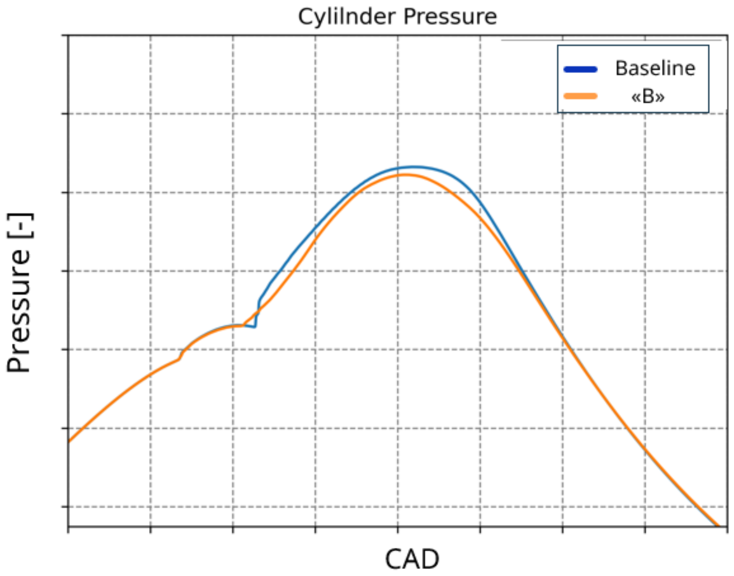






- ✓ 30% reduction of heat rejected
- ✓ Improved IMEP and efficiency
- ✓ Better air entrainment and flame development





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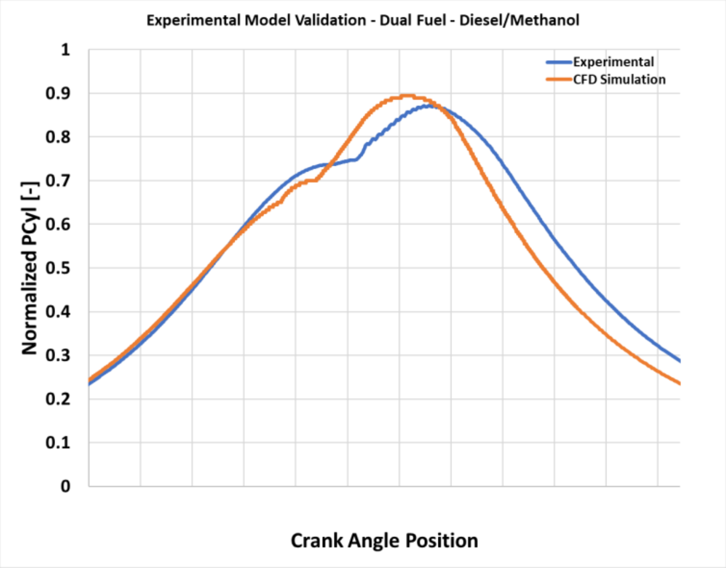
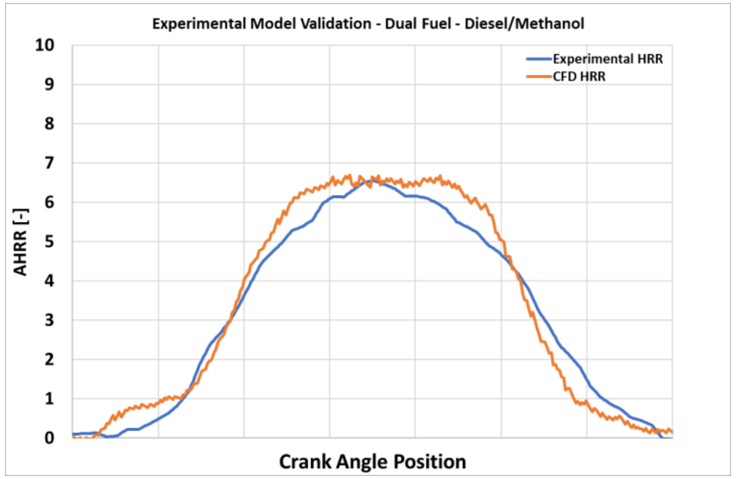
Model Validation: Dual Fuel LFO/CH_3OH - Experimental Case



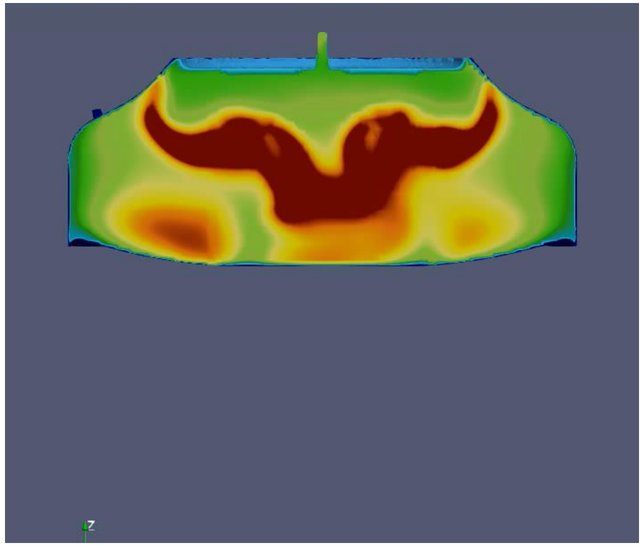


Model Validation:

- ✓ Good pressure and HRR matching
- ✓ Satisfactory prediction on Engine load and parameter sweep

Next Steps:

- Heat transfer model calibration/improvement



Conclusions and Next Steps

- Methanol Diffusive combustion concept successfully evaluated by CFD and experiments on spray chamber
- CFD Model successfully validated against Experimental results on test Engine
- CFD results used for defining Spec/Requirements of Future Fuels Injection technology

Next

- ➢ Further model validation and Development
  - Evaluation of different combustion concepts
  - Introduction of CHT modelling
- ➢ CFD modelling of dual fuel Diesel/Ammonia combustion
- ➢ Extension of current validated model on several 2-Stroke Engines

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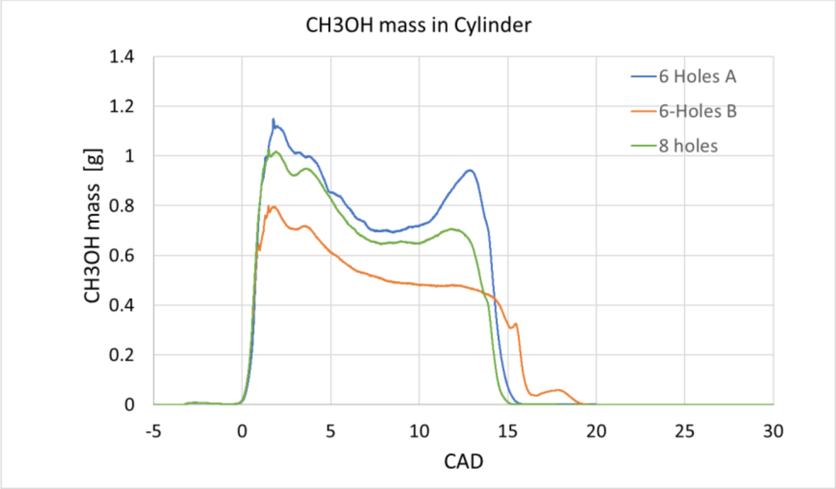
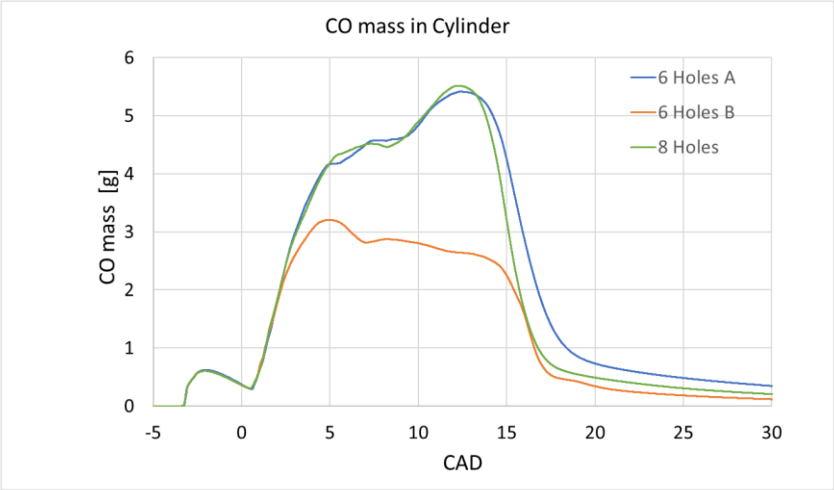
Supporting slides

Nozzle selection

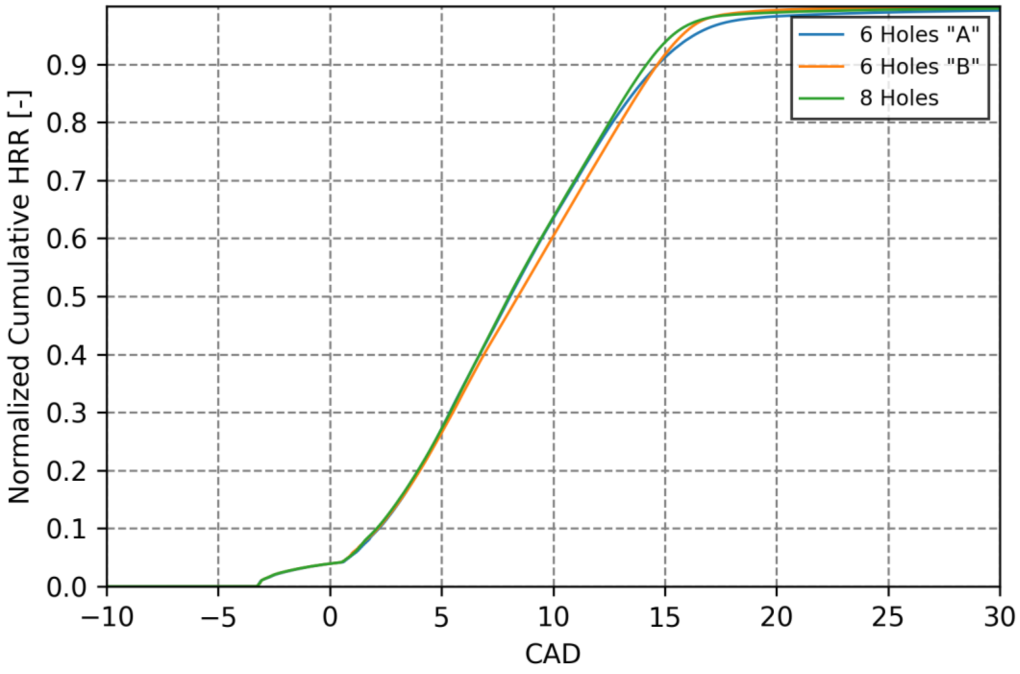
Combustion and Emissions





6 Holes B (justification of selection):

- Less interaction with opposing spray
- Better air entrainment
- Possible better combustion



Selected Nozzles

Formaldehyde formation