FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT ELECTROMECHANICAL, SYSTEMS & METAL ENGINEERING
SUSTAINABLE THERMO-FLUID ENERGY SYSTEMS RESEARCH GROUP

COUPLED TABULATED KINETICS AND FLAME PROPAGATION MODEL FUMIGATED DUAL-FUEL ENGINES

Gilles Decan

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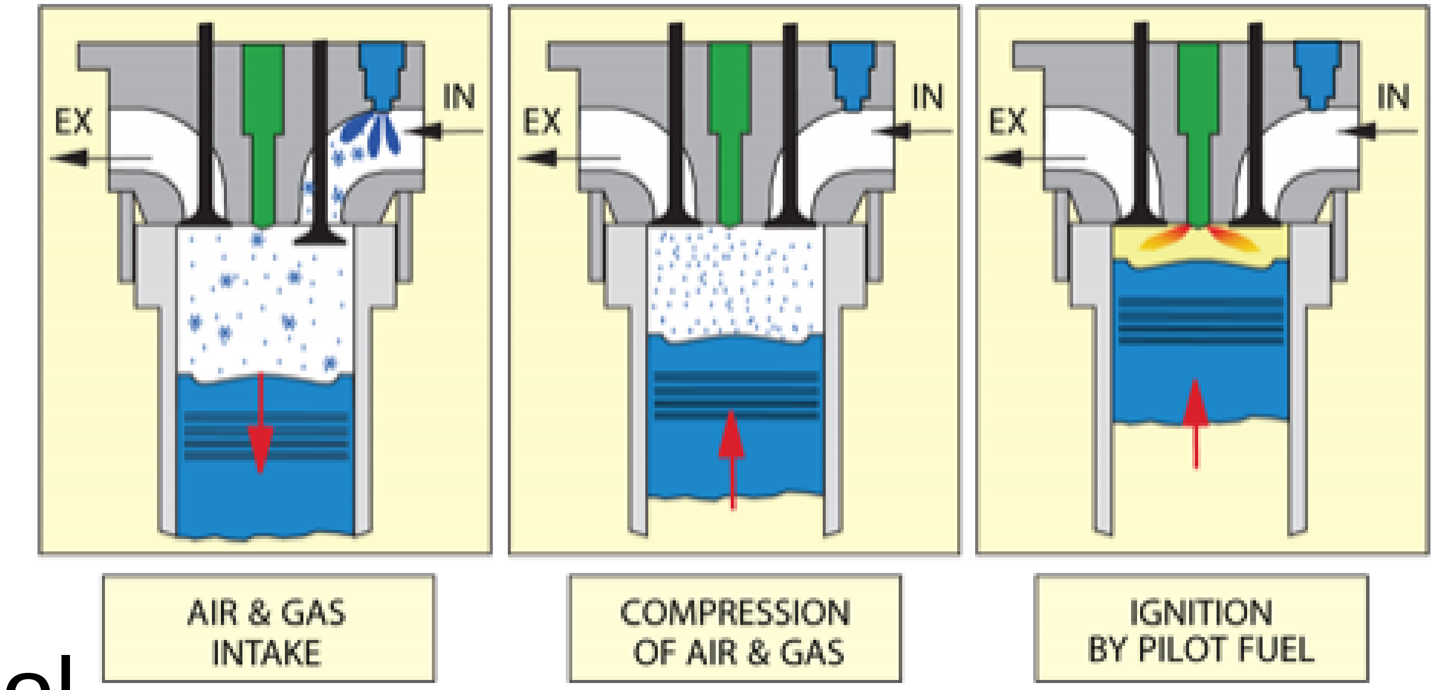
FUMIGATED DUAL-FUEL ENGINE

- Marine industry
  - Mainly powered by CI diesel engines

- Fumigated dual-fuel engine
  - Replace main diesel with CNG/Methanol
  - Small diesel pilot to ignite mixture
  - Reduce NO_x, soot and CO_2
  - Easy retrofit
  - Introduction renewables



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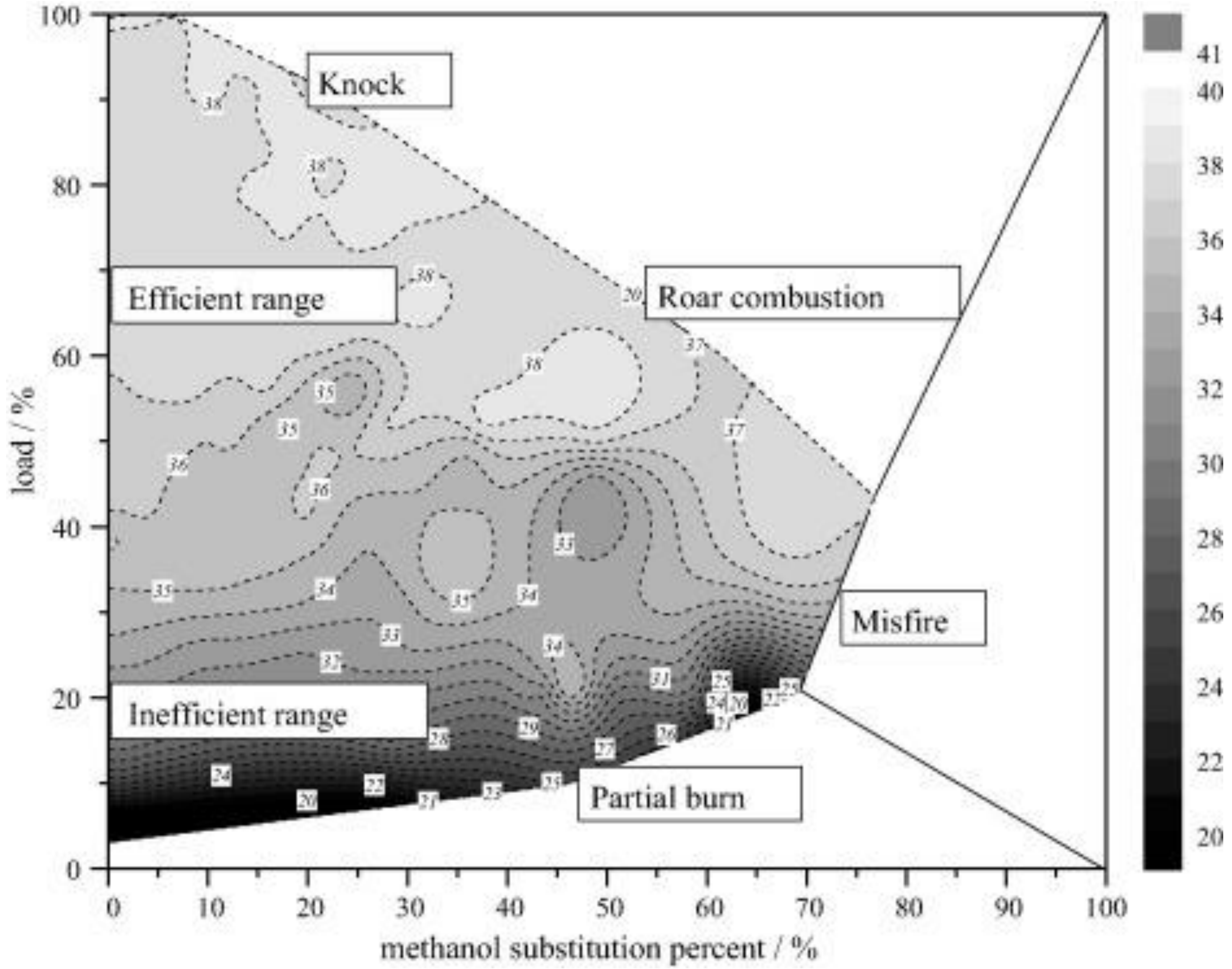
DUAL-FUEL OPTIMIZATION

OpenFOAM simulations helping engine development

- Optimization needed
  - Low & high load
  - Lean & rich limits
  - Optimized SR
  - Avoid misfire and knocking



Stable combustion model

- Fumigated dual-fuel operation
  - Diesel pilot injection
  - Diesel auto-ignition
  - Flame propagation

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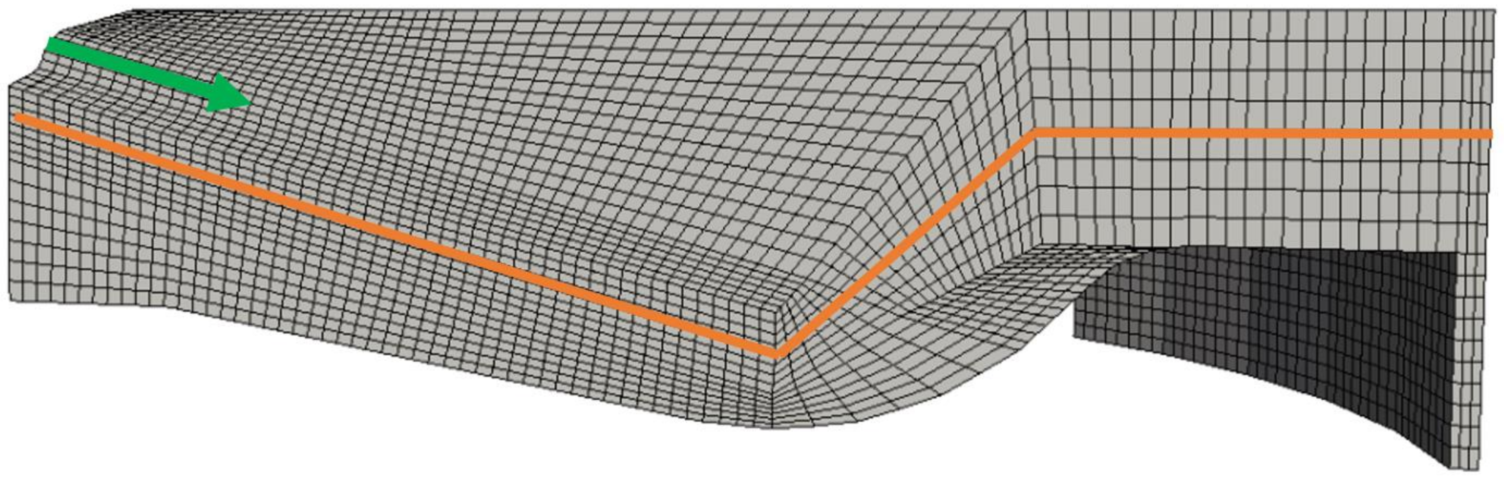
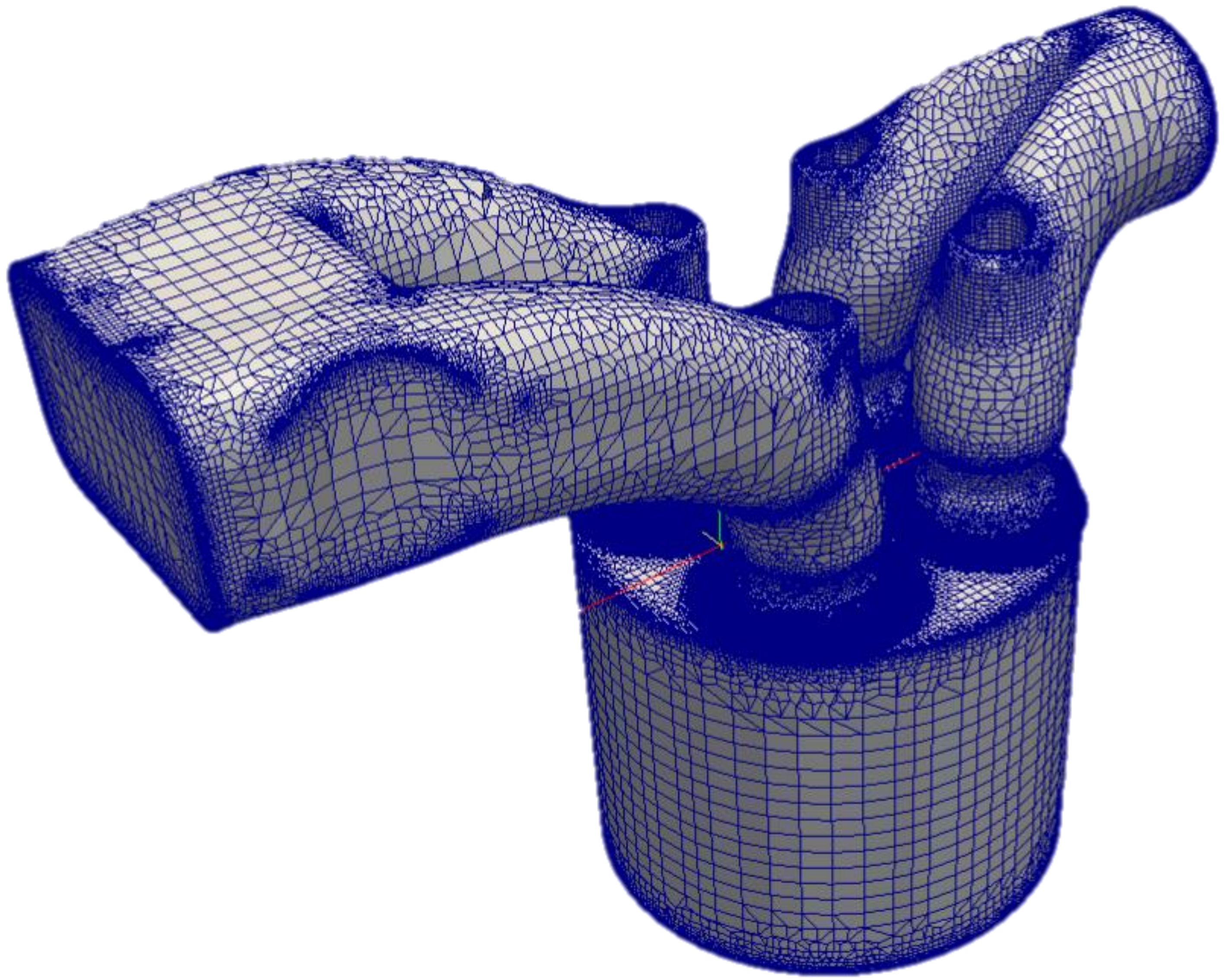
SPRAY-ORIENTED SECTOR MESH

- RANS simulations
  - 40° sector for single spray

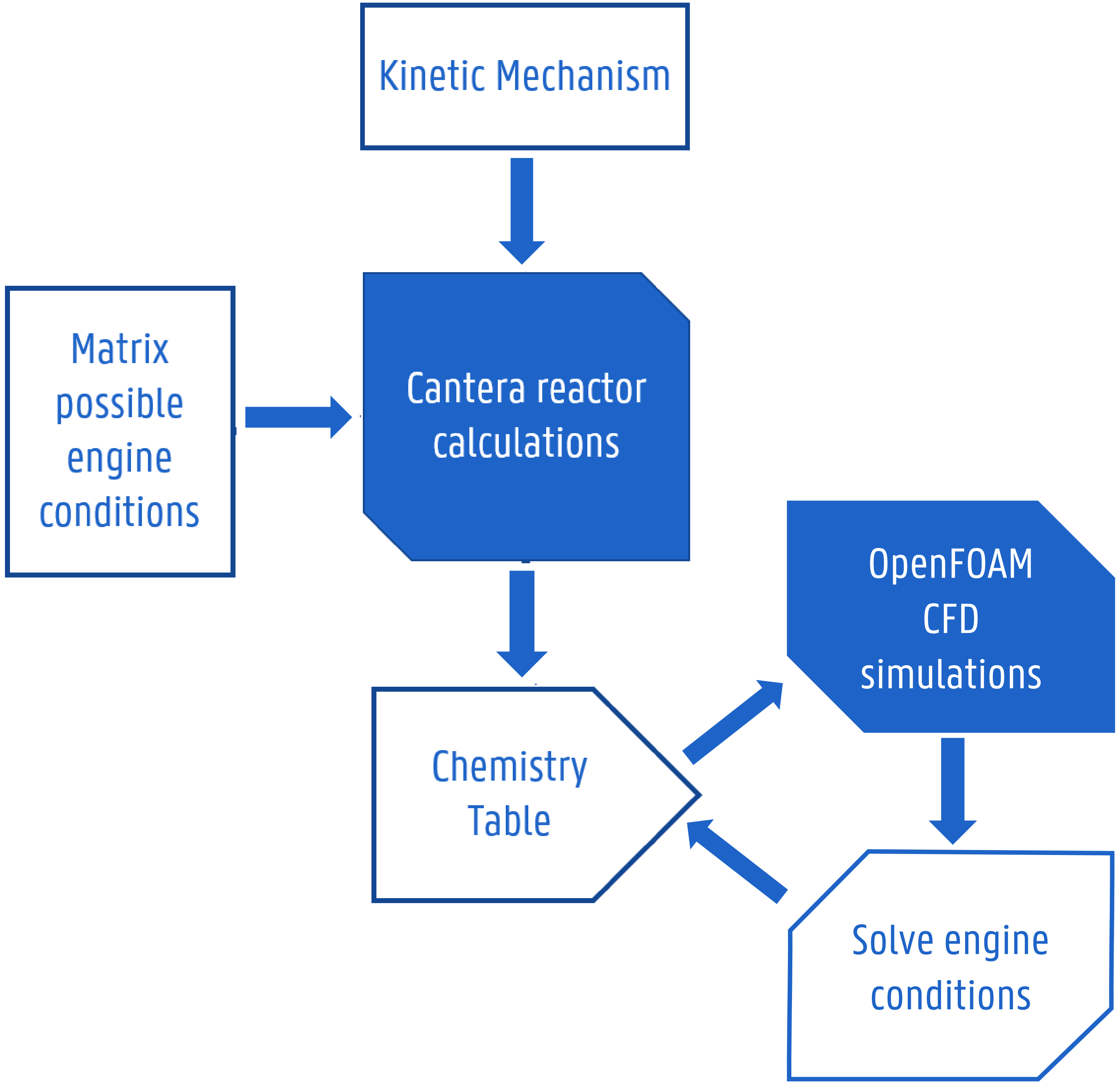
- Initialization
  - Experimental data
  - Gas dynamics simulations





Bore	0.24 m
Stroke	0.29 m
CR	12.1
RPM	630 – 1000
IVC	-112° ATDC

TABULATED KINETICS



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TABULATED KINETICS

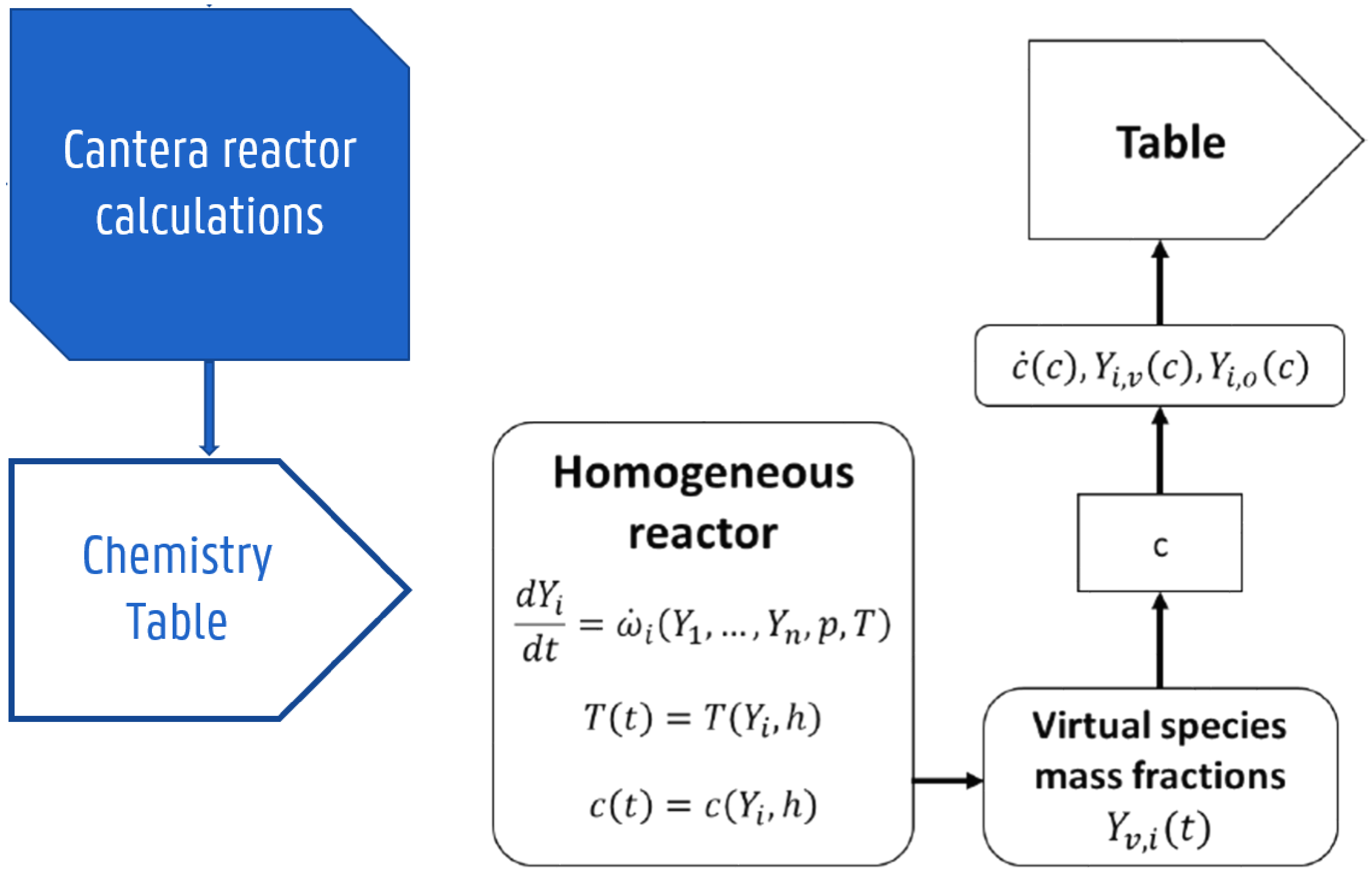
Kinetic Mechanism

$C_7H_{16}/CH_4/CH_3OH$ scheme

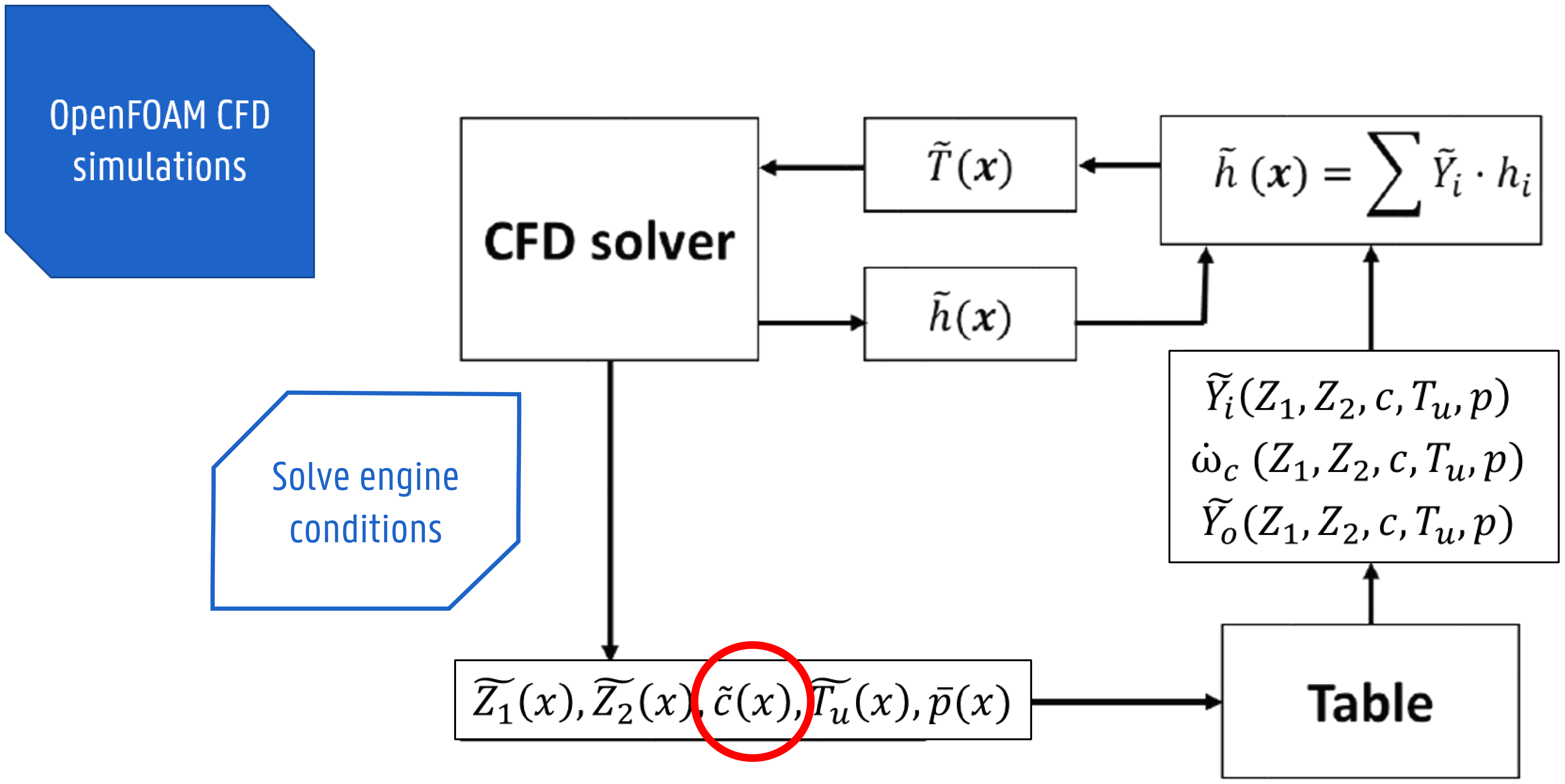
156 species & 3370 reactions

Matrix possible engine conditions

P [bar]	20	…	160
T [K]	600	…	1250
Φ_diesel	0.3	…	5.0
Φ_fuel	0.3	…	5.0



TABULATED KINETICS



WELLER FLAME SURFACE WRINKLING

- Diesel pilot auto-ignition

$$\frac{\partial \rho C}{\partial t} + \nabla(\rho U C) - \nabla\left(\frac{\mu_t}{Sc_t}\nabla C\right) = \rho \dot{C}$$

C > 0.9 ?

% ignited > 0.4-0.5*DEF ?

- From progress variable C to regress variable b
- Flame propagation

$$\frac{\partial \rho b}{\partial t} + \nabla(\rho U b) - \nabla\left(\frac{\mu_t}{Sc_t}\nabla b\right)$$

$$= -\rho_u S \Xi \nabla b + \frac{C_s \rho_u b}{\Delta t_{ign}}$$

+

- Knock modeling vs ign. delay

Knock Modeling

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COHERENT FLAME MODEL

- Diesel pilot auto-ignition

$$\frac{\partial \rho C}{\partial t} + \nabla(\rho U C) - \nabla\left(\frac{\mu_t}{Sc_t}\nabla C\right) = \rho\dot{C}$$

C > 0.5 ?

- Combined flame propagation and non-premixed combustion

$$\frac{\partial \rho C}{\partial t} + \nabla(\rho U C) - \nabla\left(\frac{\mu_t}{Sc_t}\nabla C\right) = (1-\xi)\rho\dot{C} + \xi\rho_u S\Sigma(c_{max} - c_0)$$

% ignited > DEF ?

$$\frac{\partial \rho C}{\partial t} + \nabla(\rho U C) - \nabla\left(\frac{\mu_t}{Sc_t}\nabla C\right) = \rho_u S\Sigma(c_{max} - c_0)$$

+ Knock Modeling

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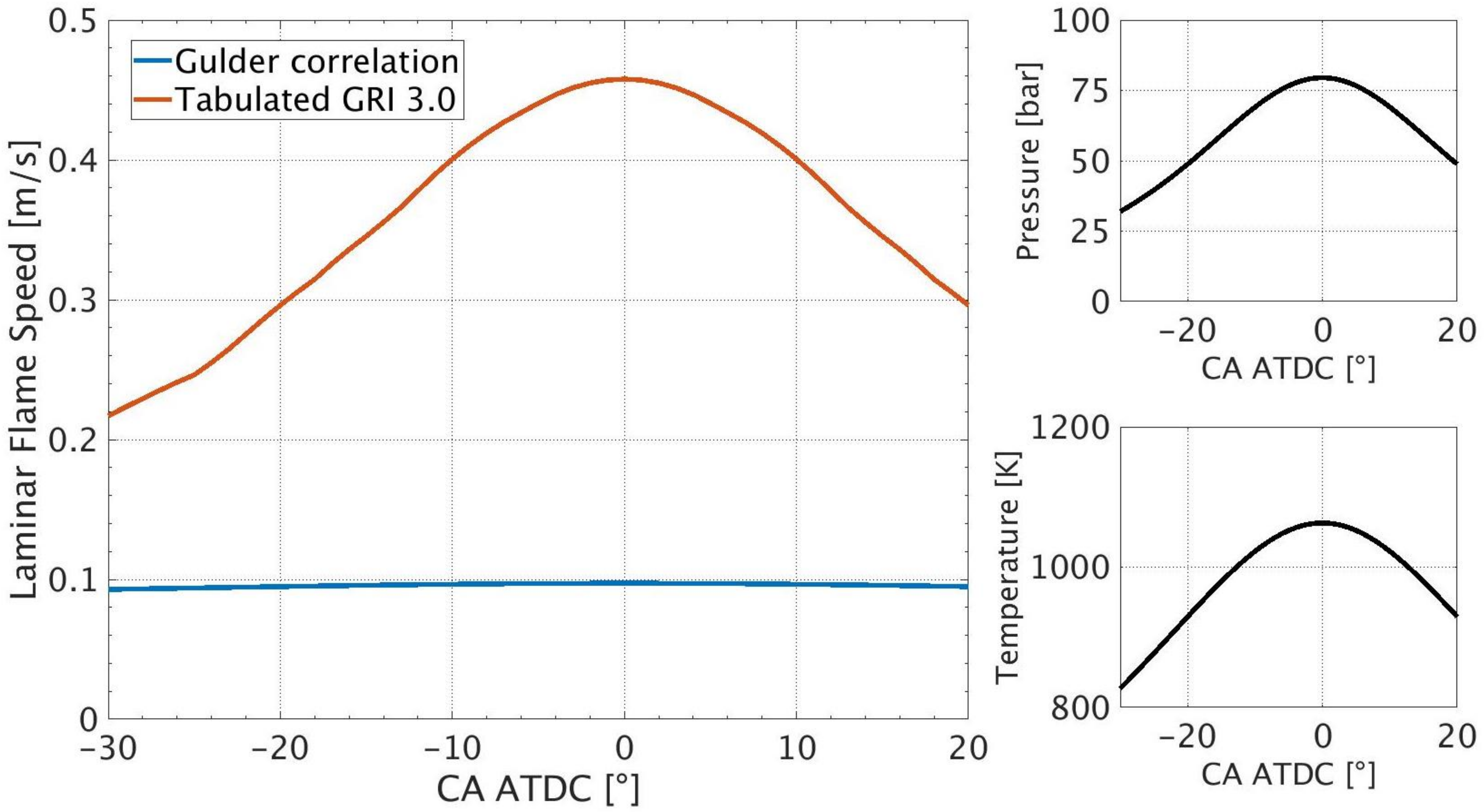
LAMINAR FLAME SPEED

- Tabulated LFS values
- More realistic under engine conditions



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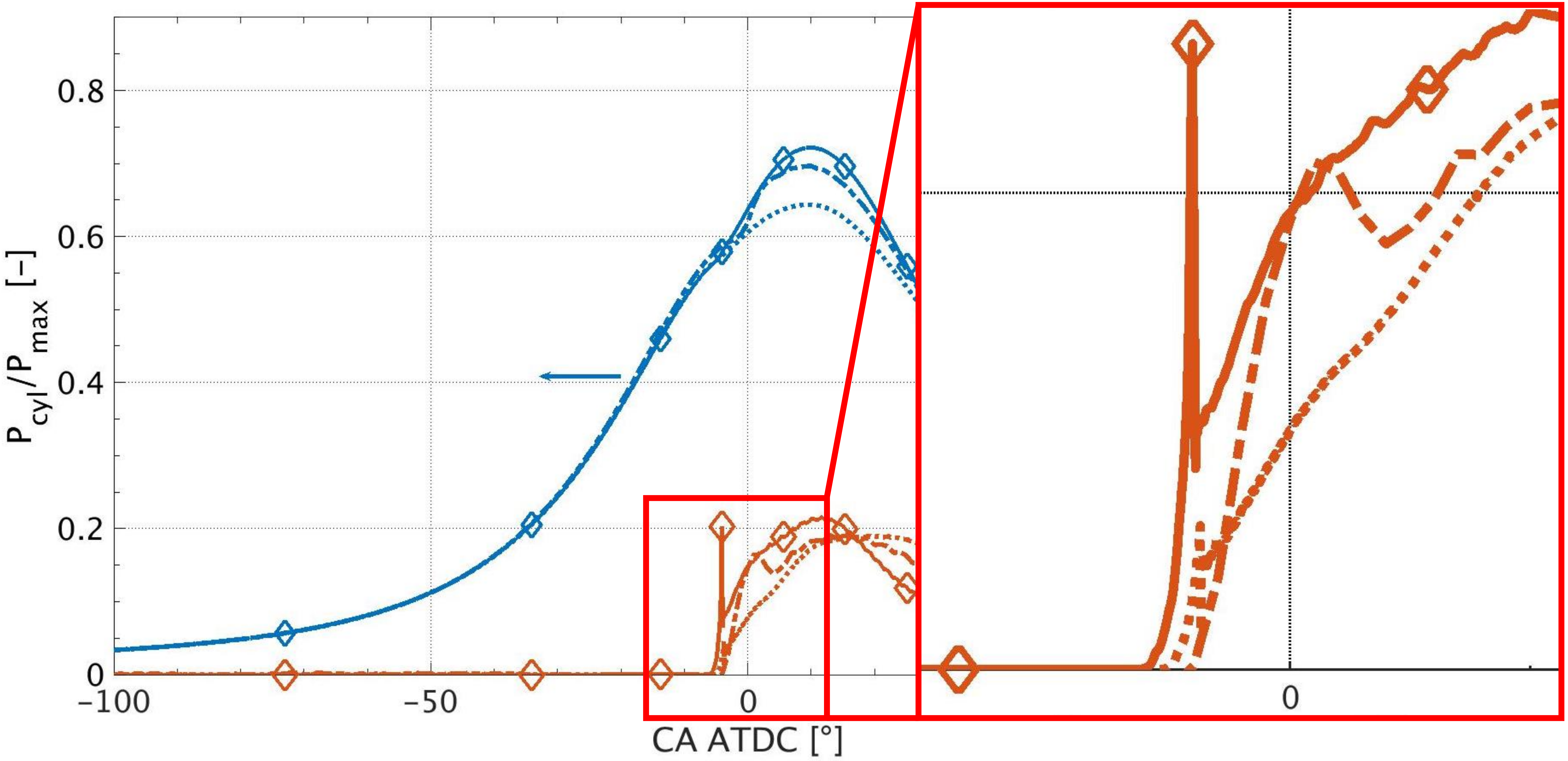
RESULTS – CH_4 - WELLER



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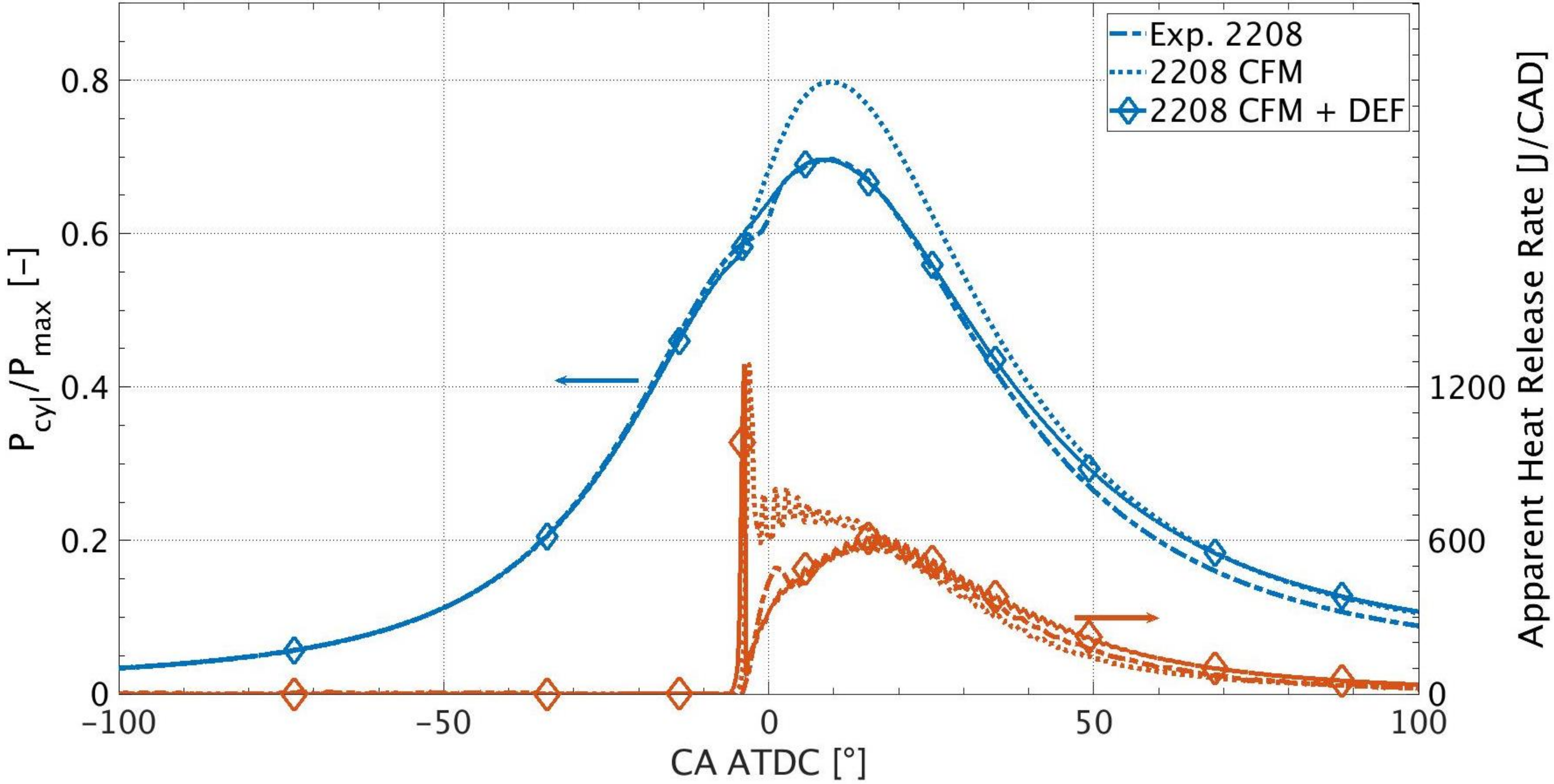
RESULTS – CH_4 - CFM



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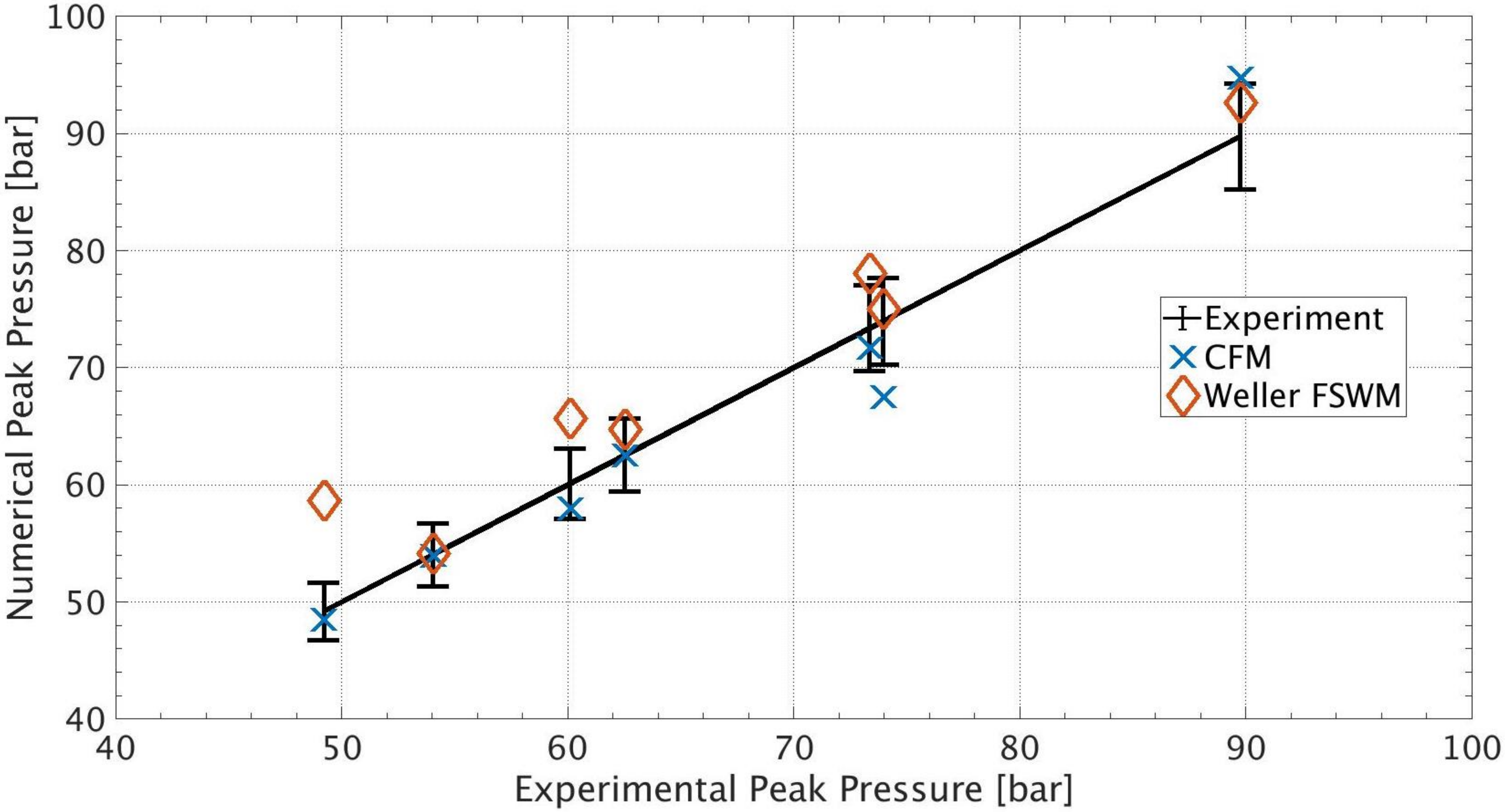
RESULTS – CH_4



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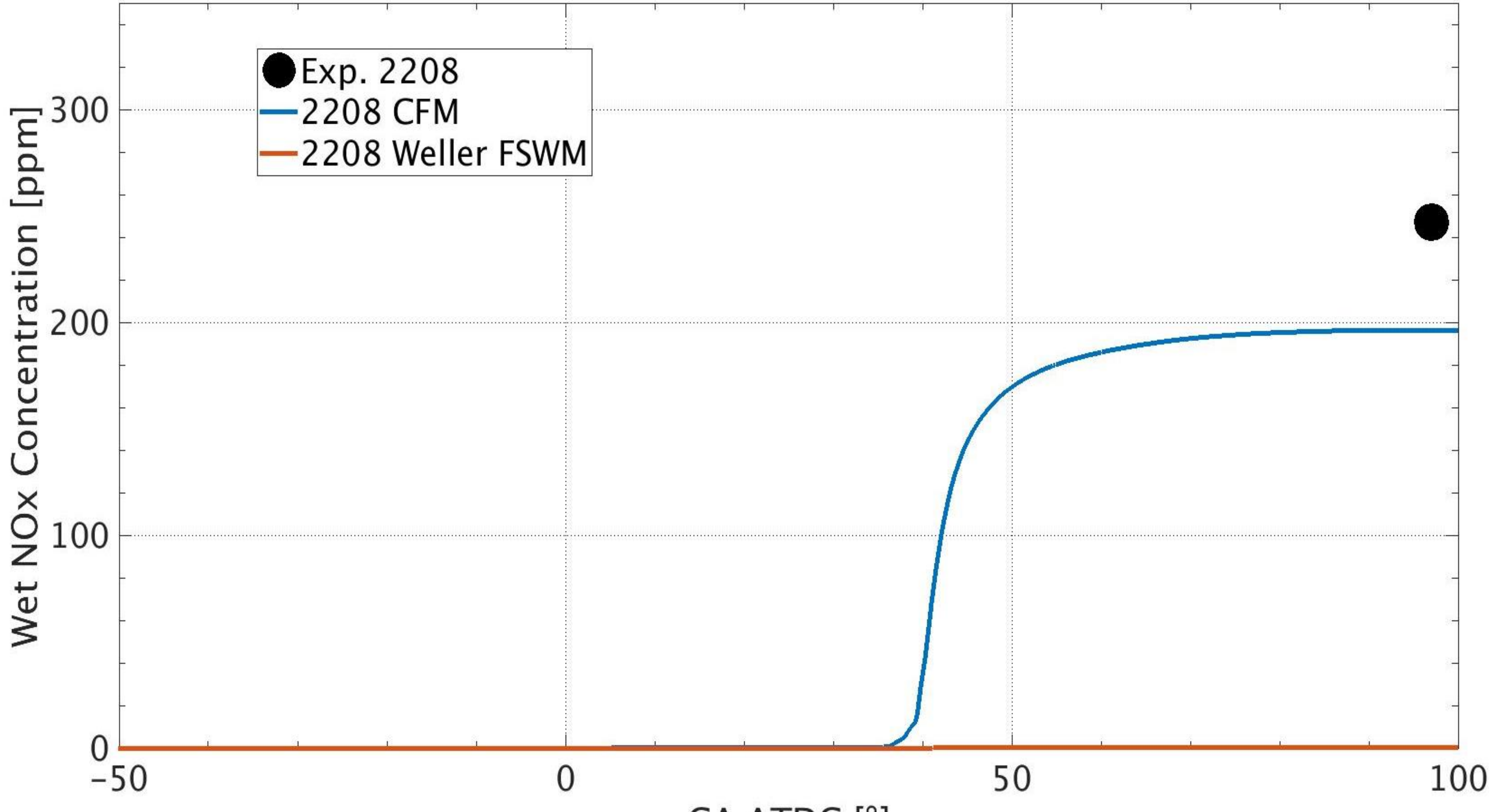
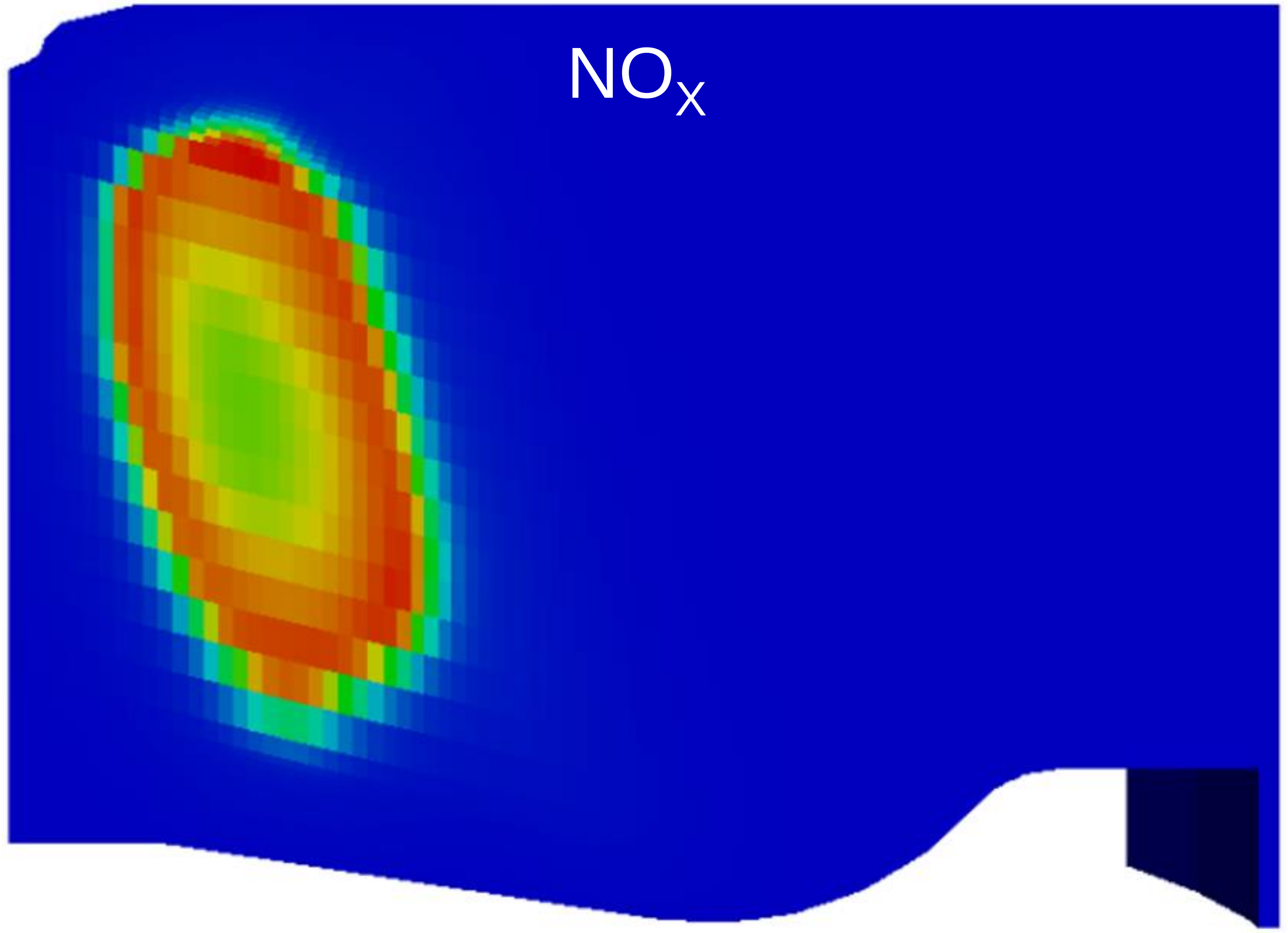
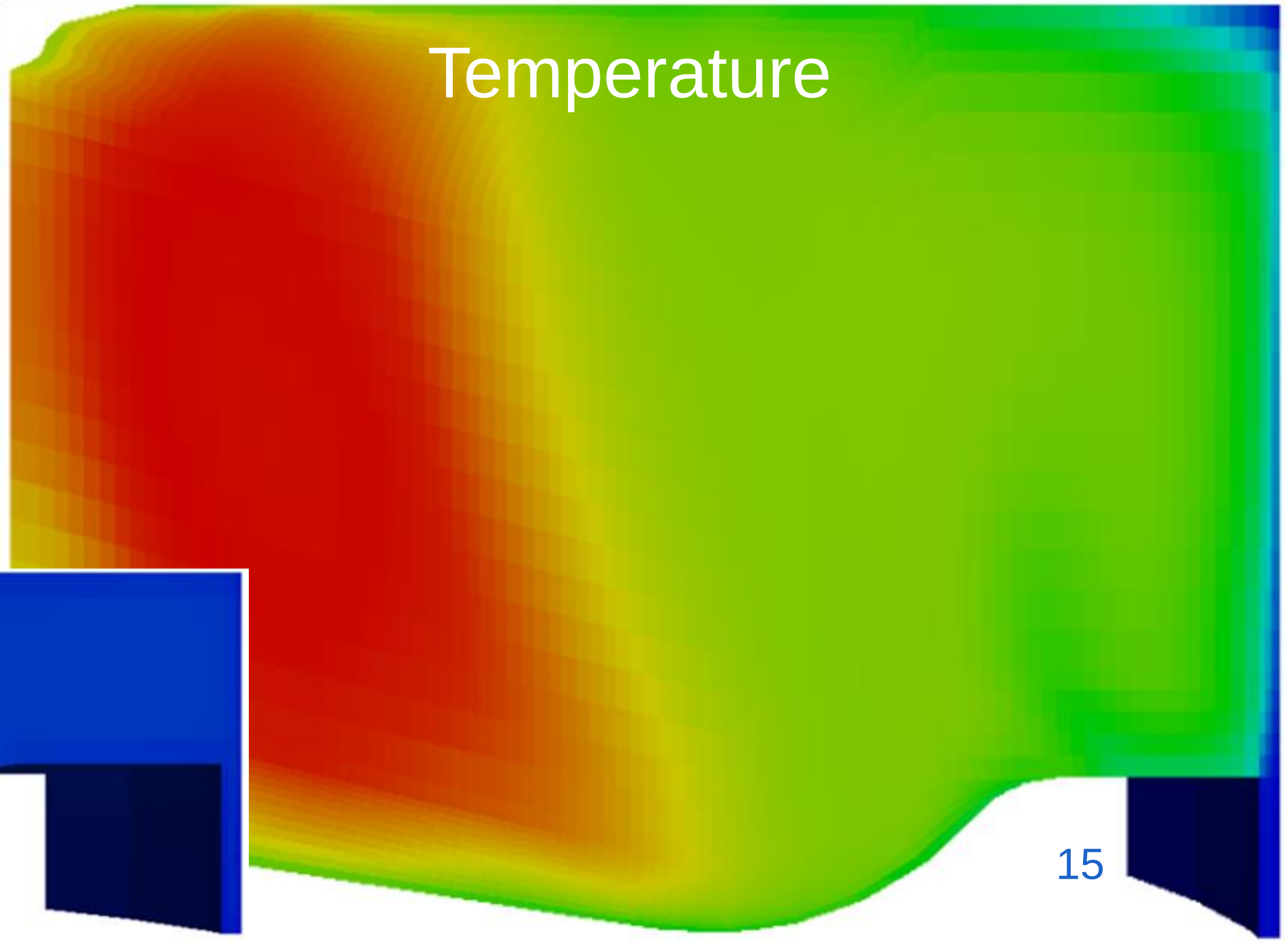
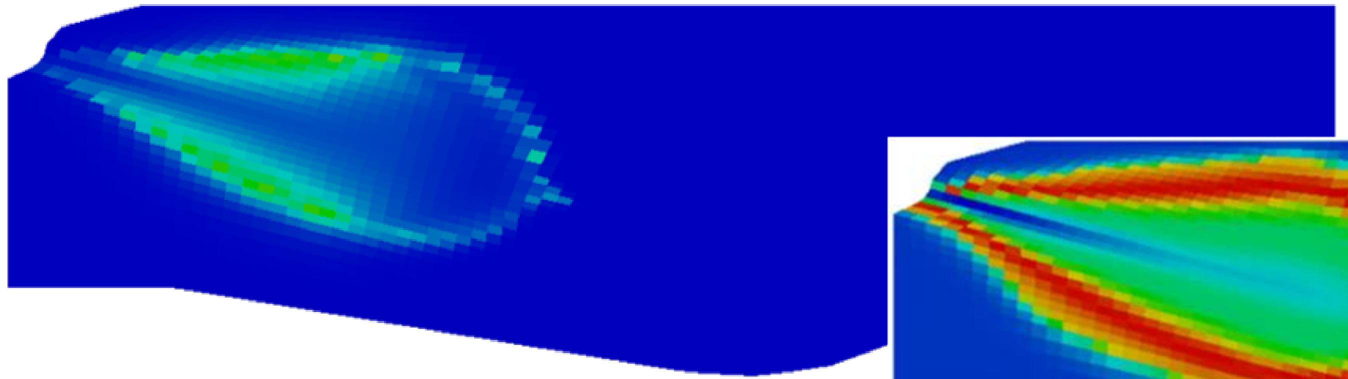
NOX PREDICTION



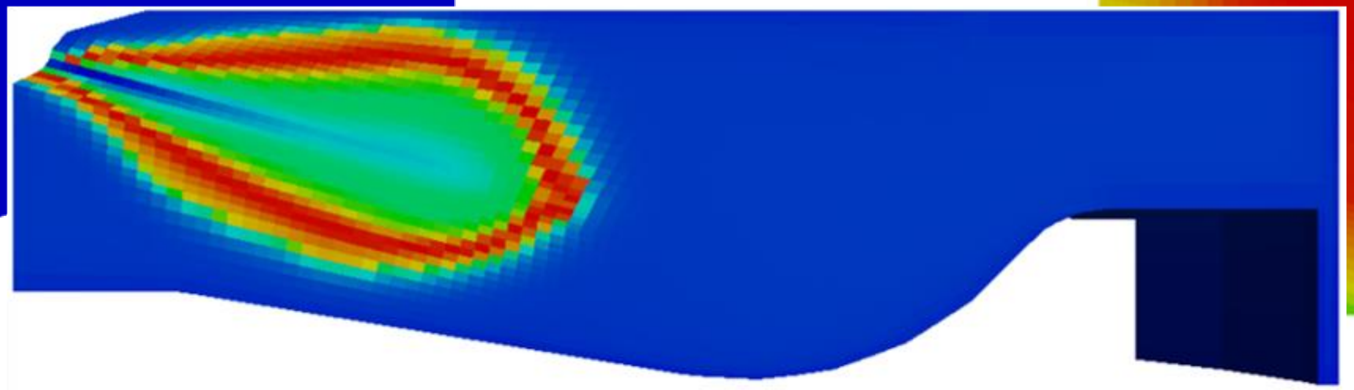




NO_X



Temperature



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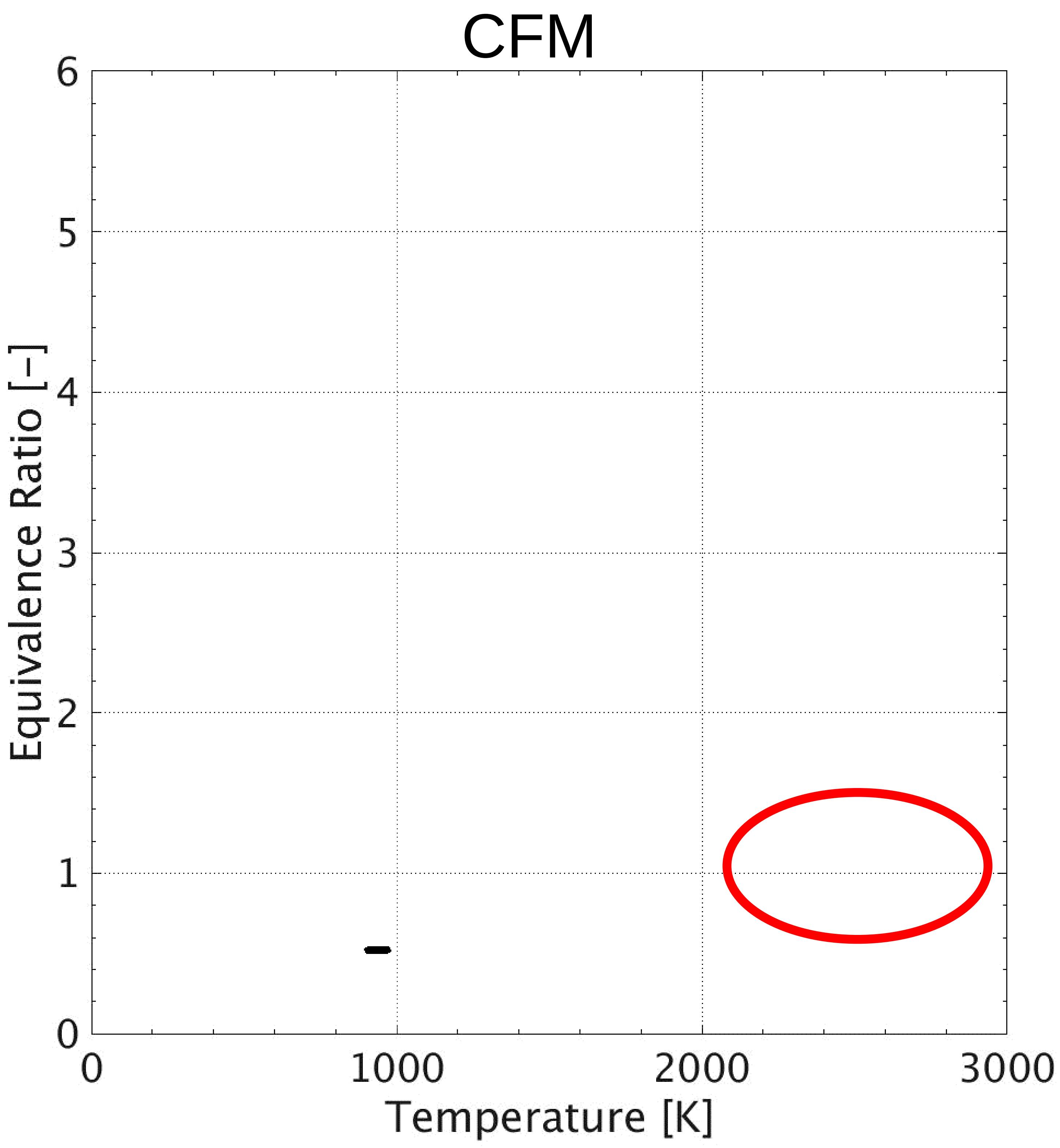

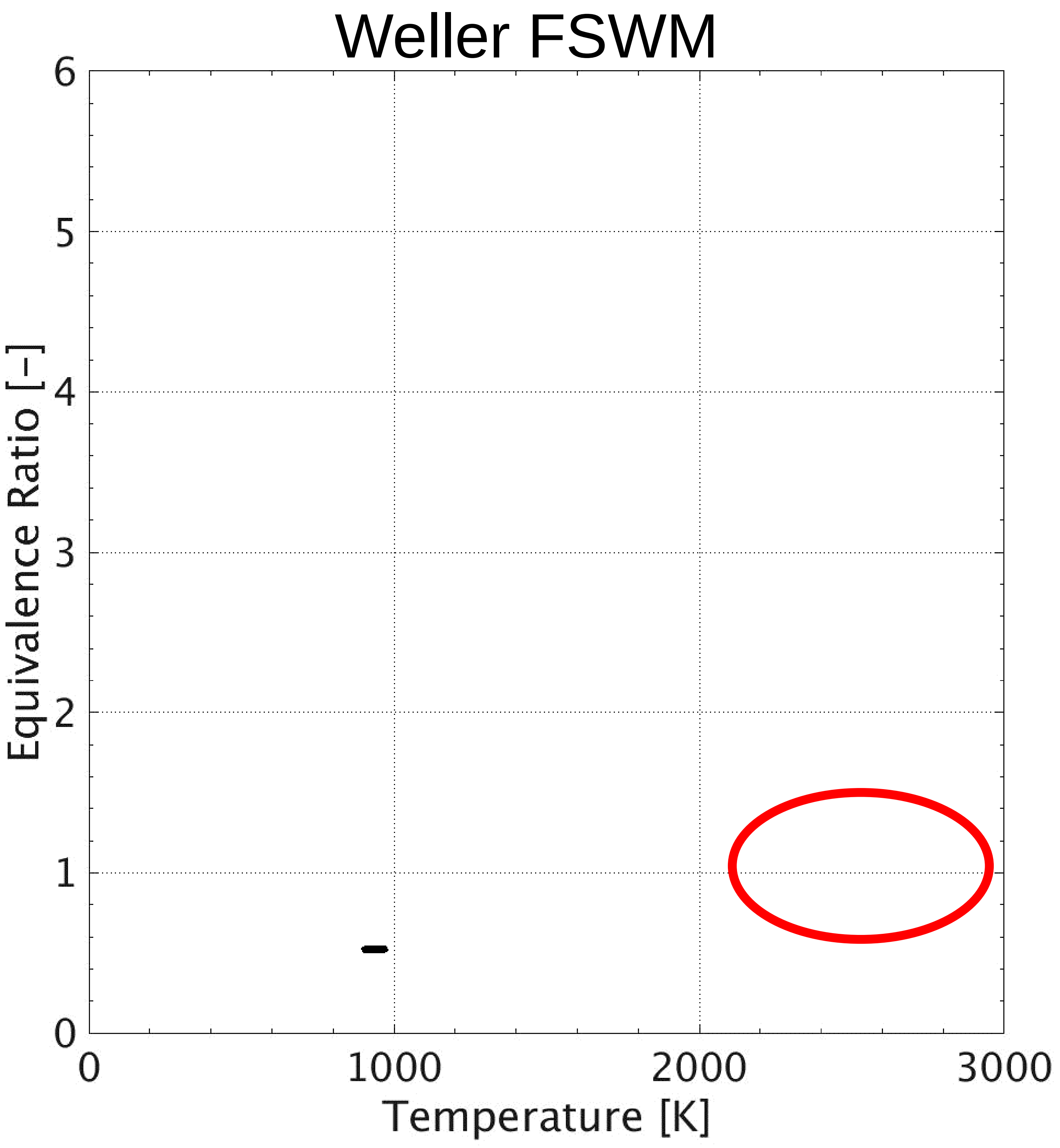

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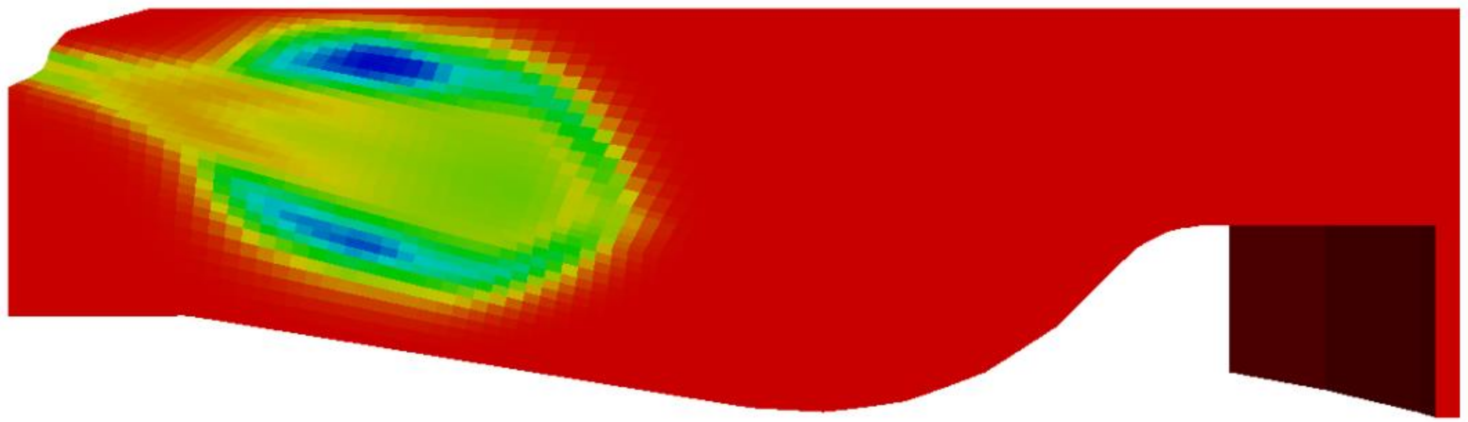
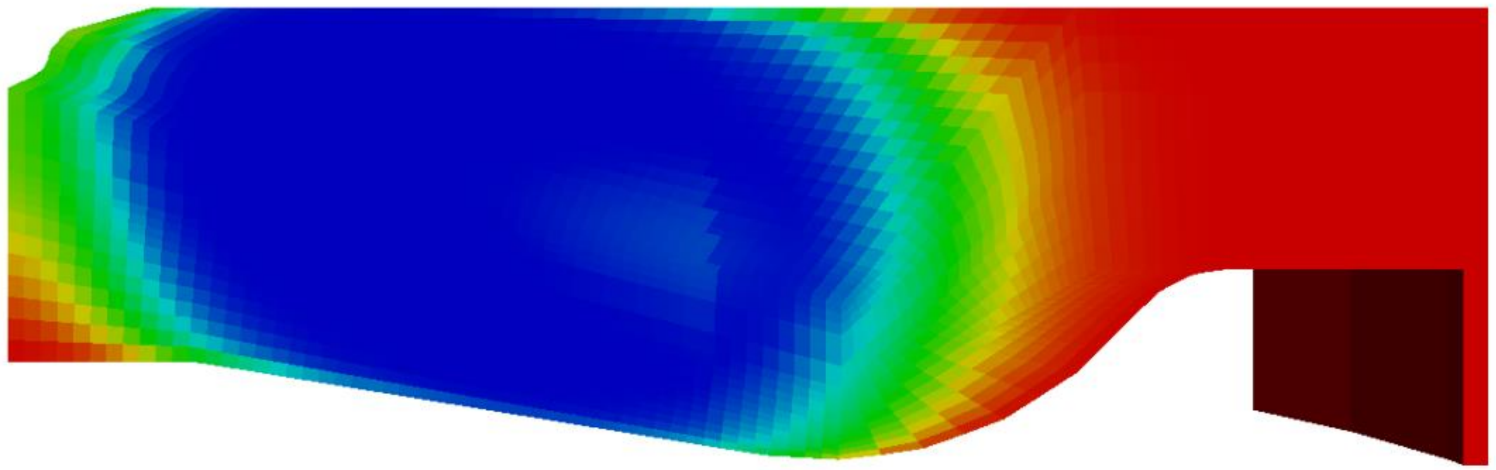
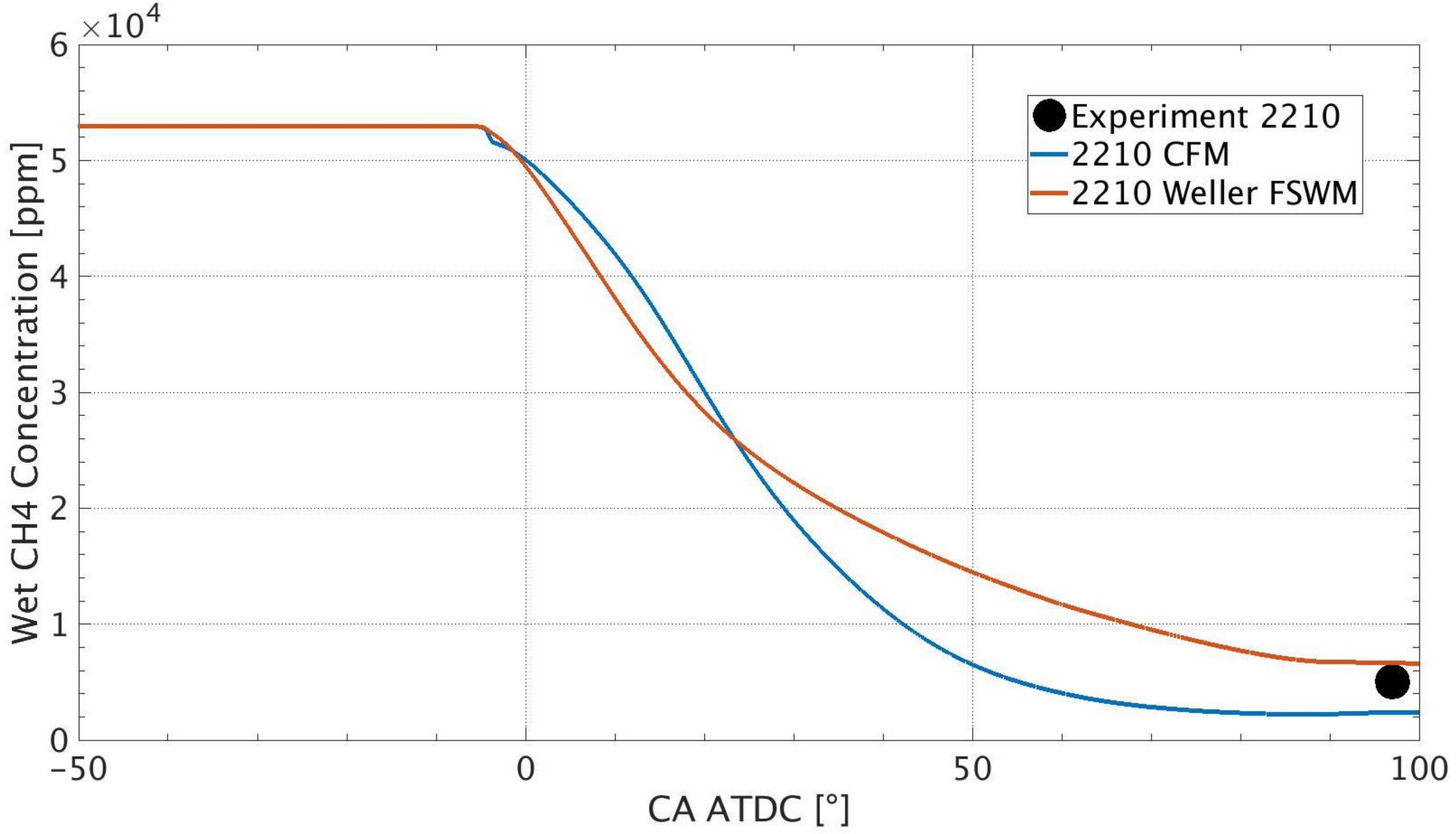
UNBURNED METHANE

-2° ATDC

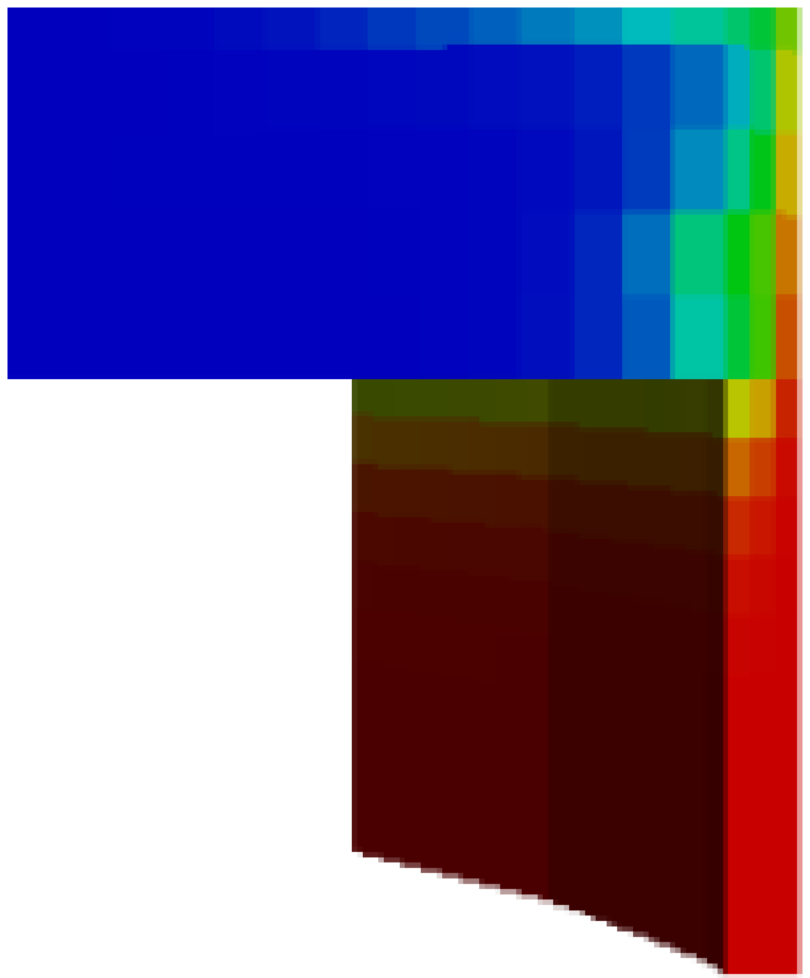


11° ATDC

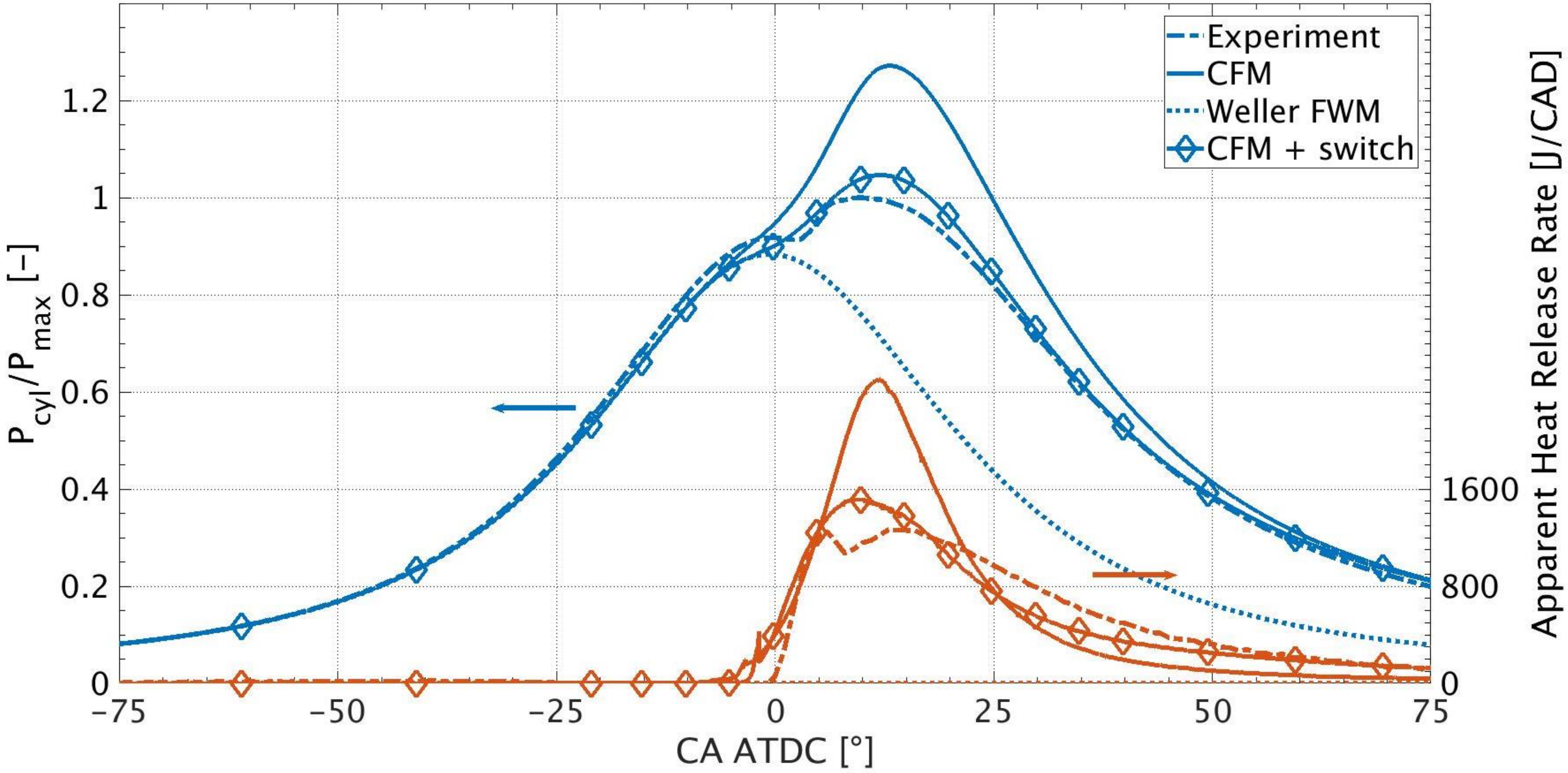




EVO



RESULTS – CH_3OH



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CONCLUSIONS

- Fumigated dual-fuel engine
  - Reduce pollutant emissions and CO_2
- Dedicated combustion model for optimization
  - Tabulated kinetics
  - 2 flame propagation models

- Weller FSWM
  - Include longer ignition necessary
- CFM
  - Reduce the timing of ignition necessary

- Further investigation of pollutants and methanol operation
- Improved ignition model like TFPV or RIF

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