POLITECNICO DI TORINO

Dipartimento Energia

Effect of CNG-H_2 blends and turbulence on EGR tolerance in SI engine

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Outline

- Objective
- Methodology
  - Simulation setup
  - Validation
  - Mesh Dependency
- Assessment of effect of EGR addition
- Assessment of effect of hydrogen addition
- Conclusion

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Objective

- To study the effect of hydrogen addition with CNG on combustion
- To study the effect of EGR on combustion

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Methodology

ENGINE 1

Experiments
- With CNG, HCNG15, HCNG25, w/o EGR

Simulation calibration
- For CNG with user defined flame tables (GRI Mech 3.0)

Calibration validation
- HCNG15, HCNG25 with respective UD flame tables

Prediction
- For EGR limits

ENGINE 2

Experiments
- With CNG, EGR %

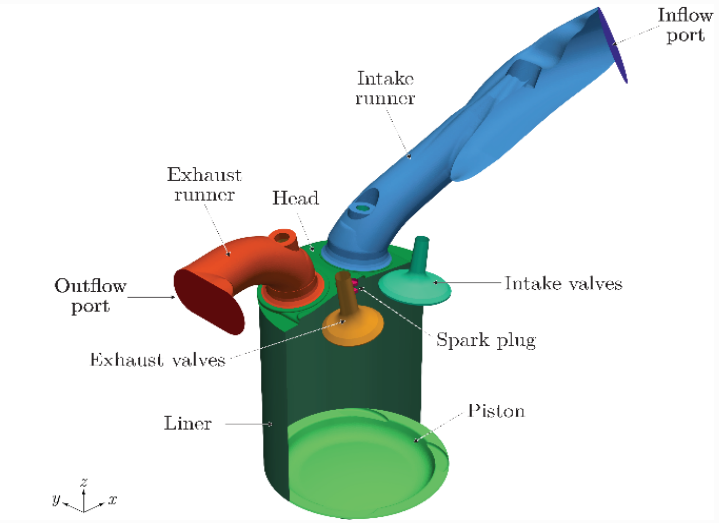
Simulation calibration
- For CNG with user defined flame tables (GRI Mech 3.0)

Calibration validation
- With EGR %

Prediction
- For HCNG15 and HCNG25

Simulation setup and Model validation

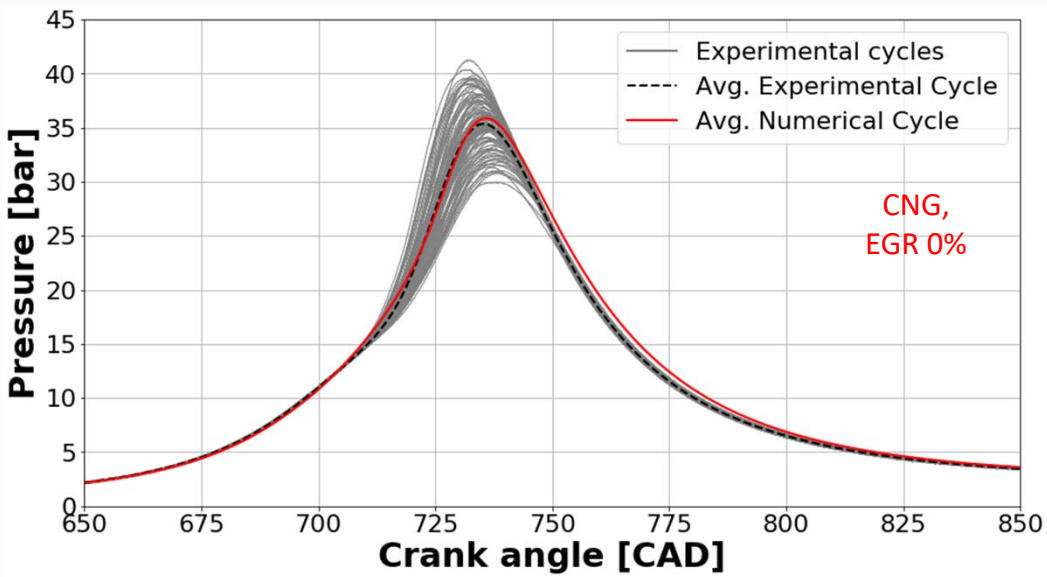
ENGINE 1



Cylinder displacement	342 cm³
Bore / Stroke	72 mm / 84 mm
Compression Ratio Valves per cylinder Combustion chamber Intake valve	9.8:1 4 Pent-roof Opening duration = 250CAD / maximum lift = 7.5mm
Exhaust valve	Opening duration = 244 CAD / maximum lift = 7 mm
Injection system	Port Fuel injection
Turbocharger	Wastegate-controlled, fixed geometry turbine

Numerical Setup	
Flow	Compressible
Gas Simulation	Redlich Kwong model
Numerical method	Implicit method
Turbulence model	RNG k-ϵ
Combustion model	ECFM
Heat transfer model	Angelberger

Base grid [mm]	4*4*4
Cylinder Region	
Fixed embedding	scale = 1
AMR - Velocity	sub-grid criterian = 1 m/s Scale = 3
AMR - Temperature	sub-grid criterian = 5 K Scale = 3
Fixed Embedding - spark plug area	scale = 5



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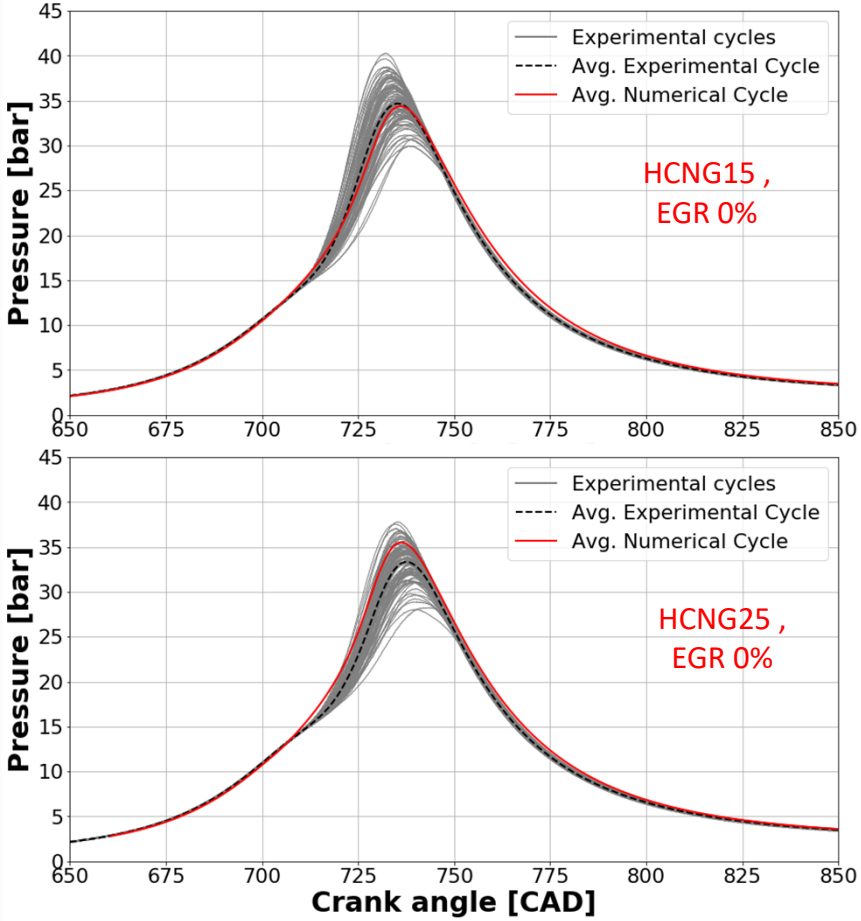
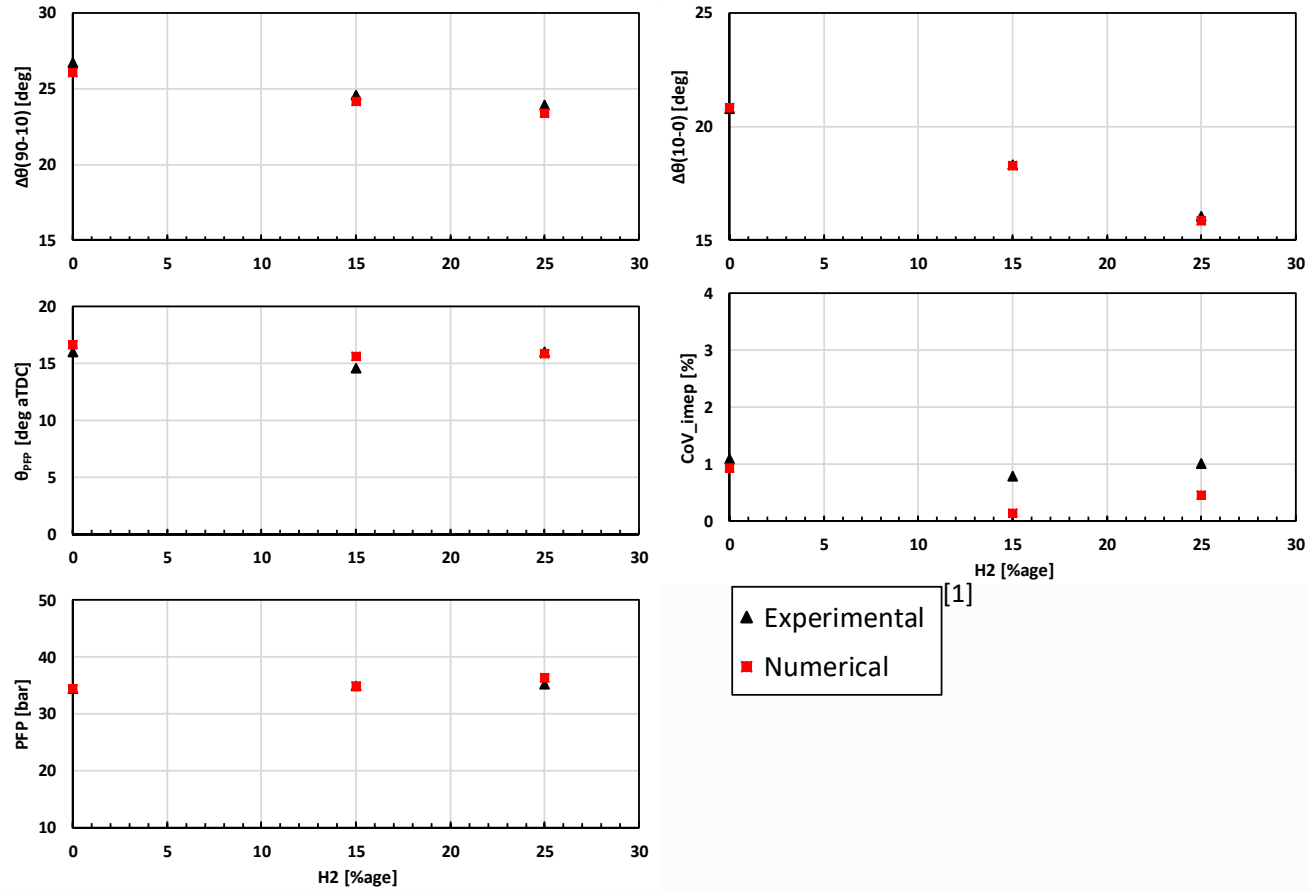
Model validation

ENGINE 1





[1]

[1]. BARATTA, M., D' AMBROSIO, S., MISUL, D., & SPESSA, E. (2014). EFFECTS OF H_2 ADDITION TO COMPRESSED NATURAL GAS BLENDS ON CYCLE-TO-CYCLE AND CYLINDER-TO-CYLINDER COMBUSTION VARIATION IN A SPARK-IGNITION ENGINE. JOURNAL OF ENGINEERING FOR GAS TURBINES AND POWER, 136(5), 051502. DOI:10.1115/1.4026163

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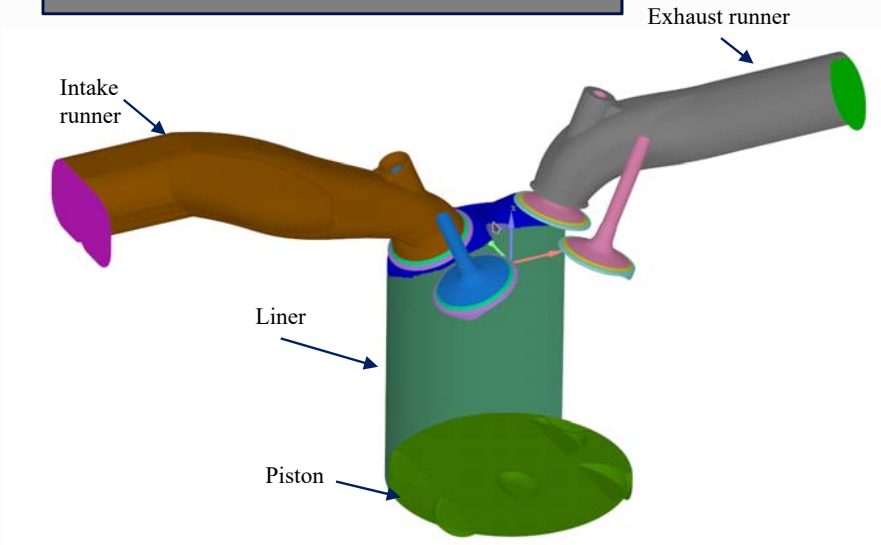
Simulation setup and Model validation

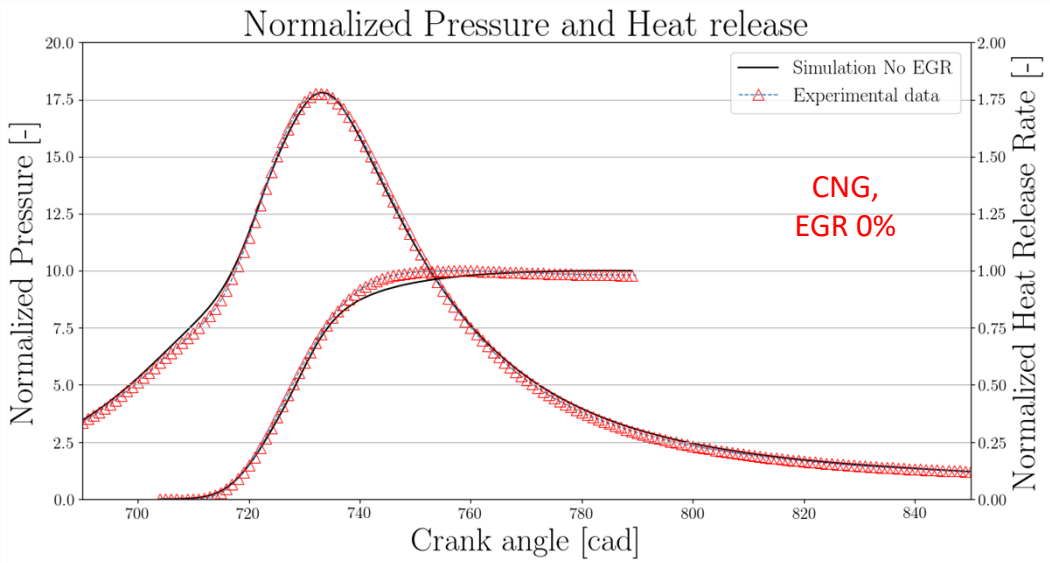
ENGINE 2



Engine displacement	405 cm^3
Bore / Stroke	80 mm / 80.5 mm
Compression ratio	13.4:1
Piston	Central shallow bowl
Ignition system	Mercedes Coil (90 mJ) NGK spark plug (ILZKR8A)
Intake valve	Opening duration = 169 CAD / maximum lift = 8.5 mm IVO = -6 ATDC / IVC = -5 ABDC
Exhaust valve	Opening duration = 200 CAD / maximum lift = 8.5 mm EVO = +38 BBDC / EVC = -18 BTDC

Numerical Setup	
Flow	Compressible
Gas Simulation	Redlich Kwong model
Numerical method	Implicit method
Turbulence model	RNG k-ϵ
Combustion model	ECFM
Heat transfer model	Angelberger

Base grid [mm]	4*4*4
Cylinder Region	
Fixed embedding	scale = 2
AMR - Velocity	sub-grid criterian = 1 m/s Scale = 3
AMR - Temperature	sub-grid criterian = 2.5 K Scale = 3
Fixed Embedding - spark plug area	scale = 5



[2]

[2]. BARATTA, M., MISUL, D., GOEL, P., LAURENZANO, D. ET AL., "EXPERIMENTAL AND NUMERICAL ANALYSIS OF DILUTED COMBUSTION IN A DIRECT INJECTION CNG ENGINE FEATURING POST- EURO-VI FUEL CONSUMPTION TARGETS," SAE TECHNICAL PAPER 2018-01-1142, 2018, HTTPS://DOI.ORG/10.4271/2018-01-1142.

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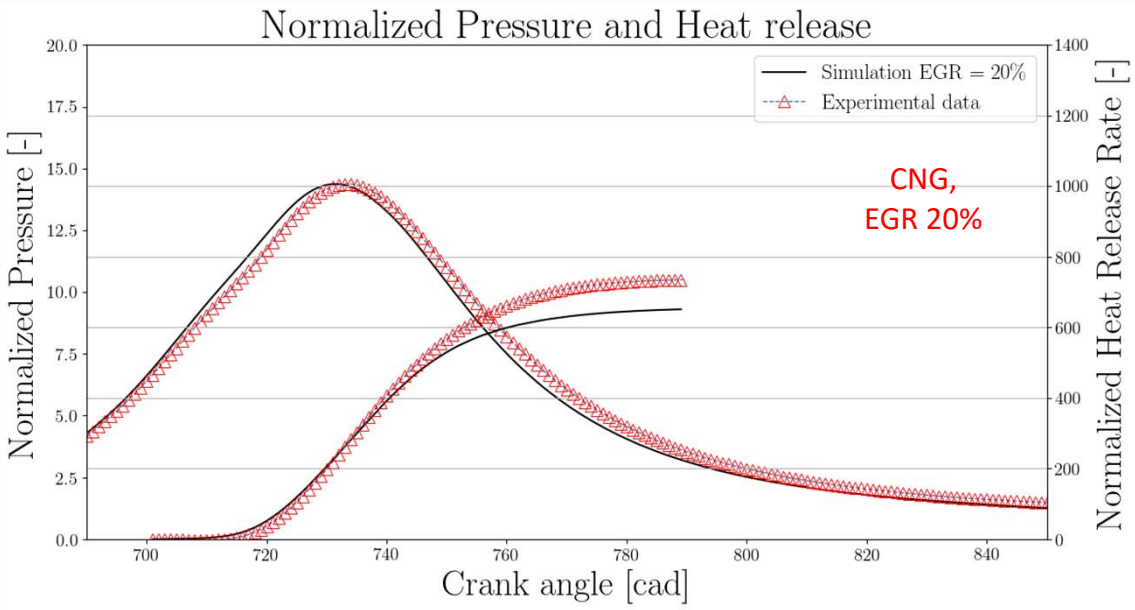
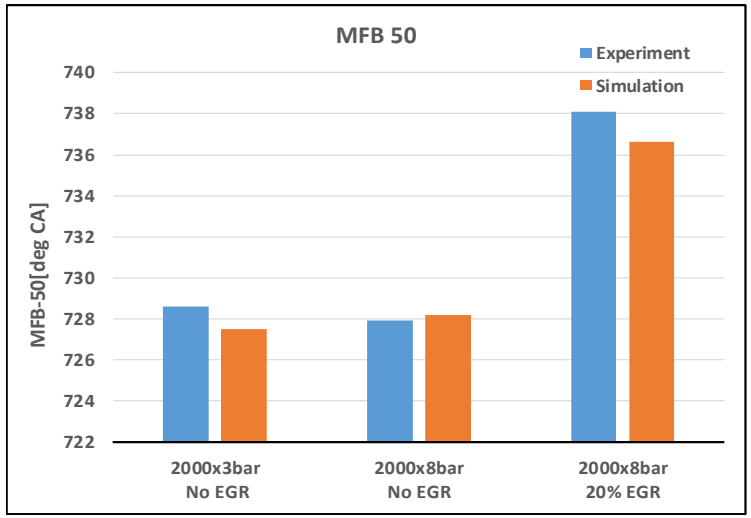
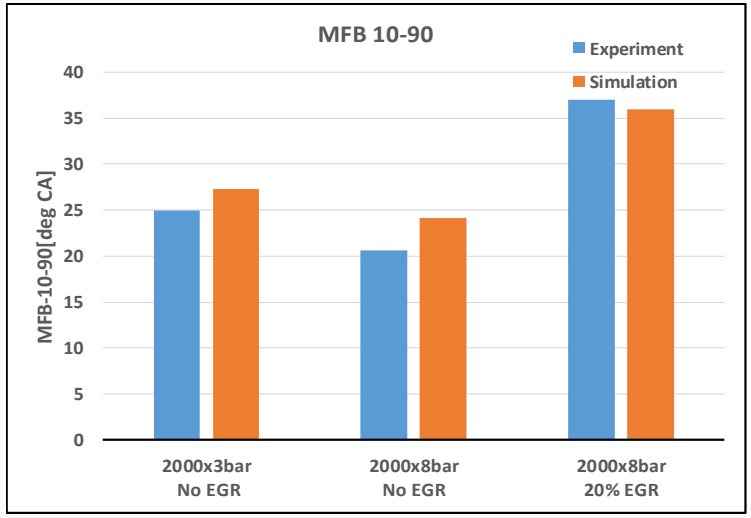
Model validation

ENGINE 2







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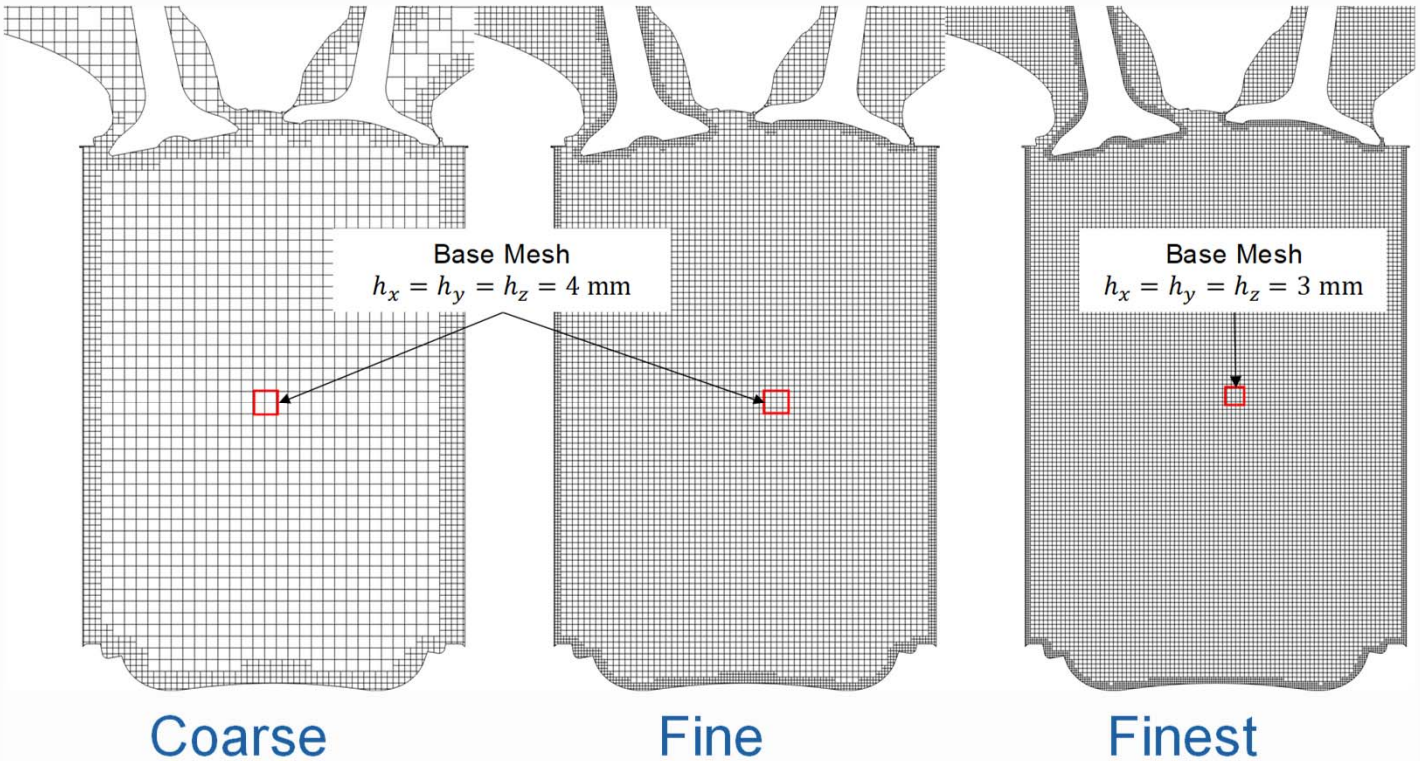
Mesh dependency



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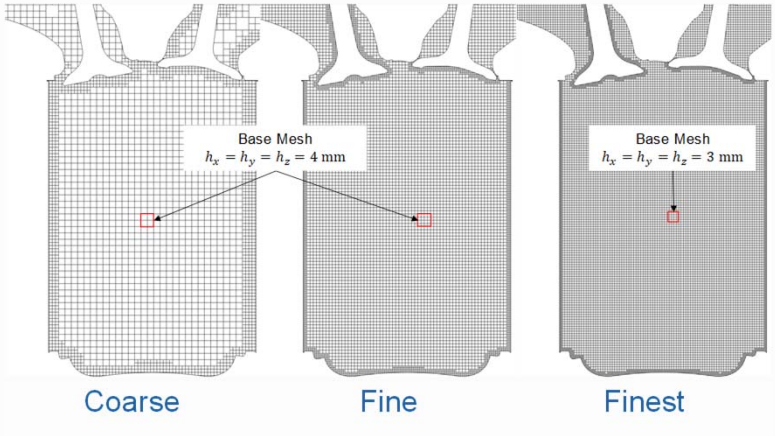

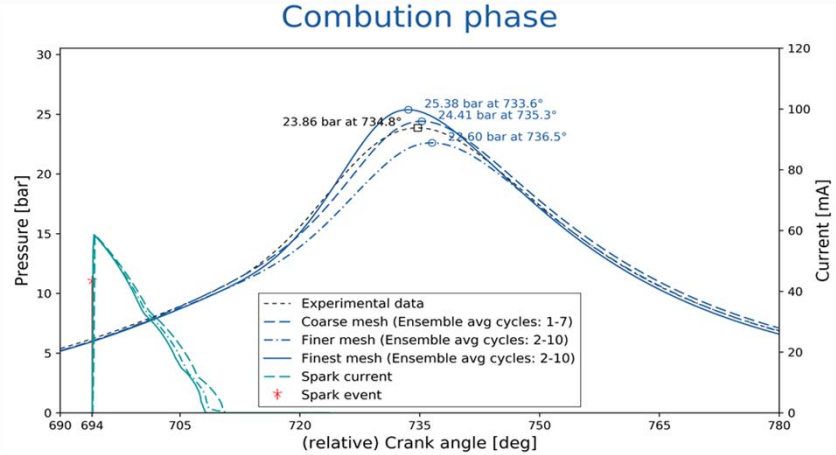

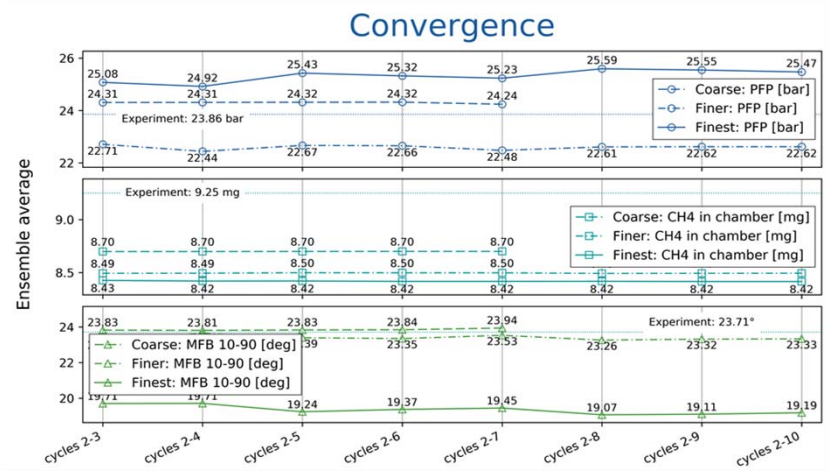

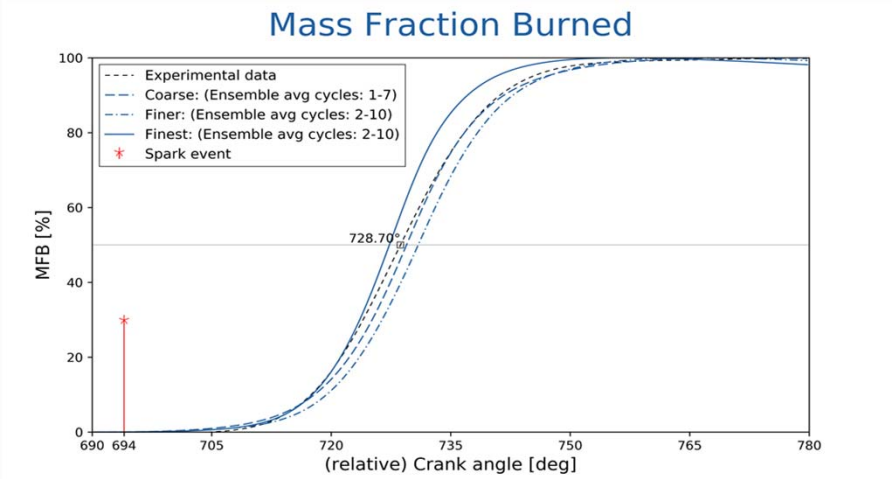

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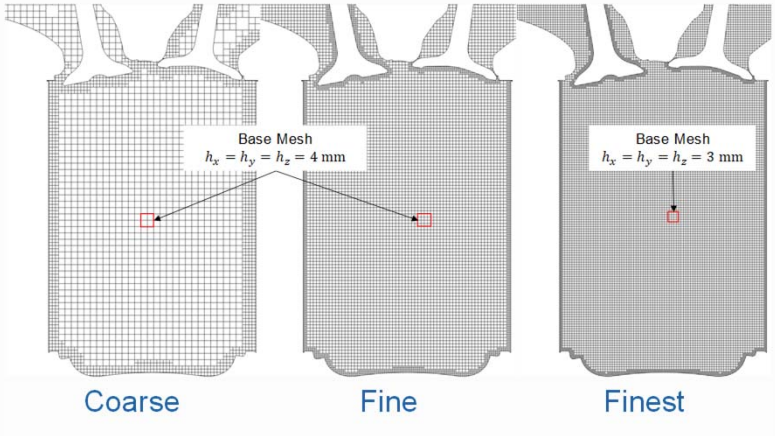
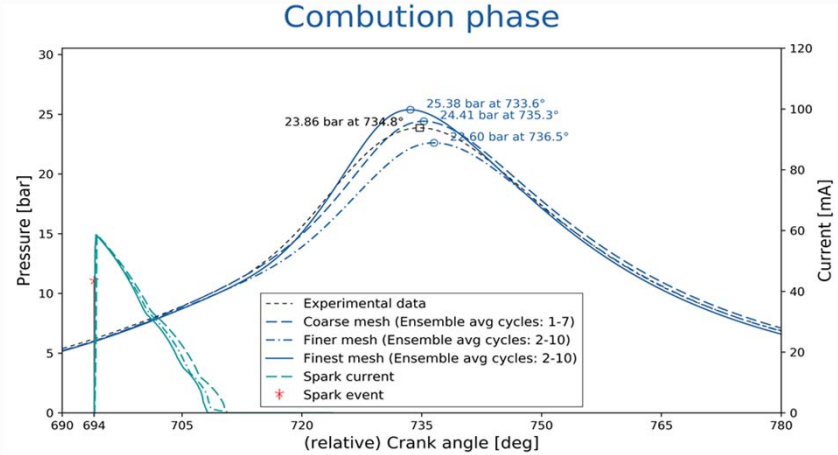
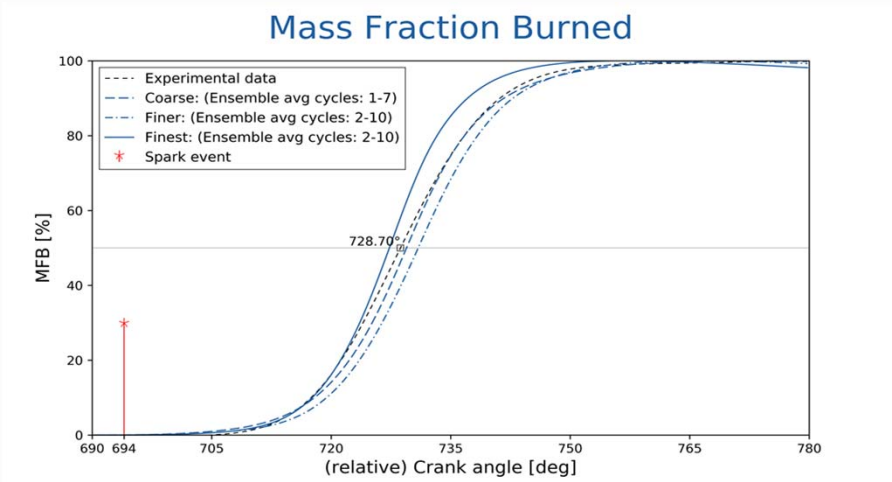
Mesh dependency





	Course	Finer	Finest
Base grid [mm]	4*4*4	4*4*4	3*3*3
Cylinder Region			
Fixed embedding	scale = 1	scale = 2	scale = 3
AMR - Velocity	sub-grid criterian = 1 m/s Scale = 3	sub-grid criterian = 1 m/s Scale = 3	sub-grid criterian = 1 m/s Scale = 3
AMR - Temperature	sub-grid criterian = 5 K Scale = 3	sub-grid criterian = 2.5 K Scale = 3	sub-grid criterian = 2.5 K Scale = 3
Fixed Embedding - spark plug area	scale = 5	scale = 5	scale = 5
CoV_Peak pressure (Experiment = 4.37%)	0.86%	3.12%	3.85%
Simulation Time	18hrs/cycle on 22 cores	32hrs/cycle on 22 cores	42hrs/cycle on 22 cores



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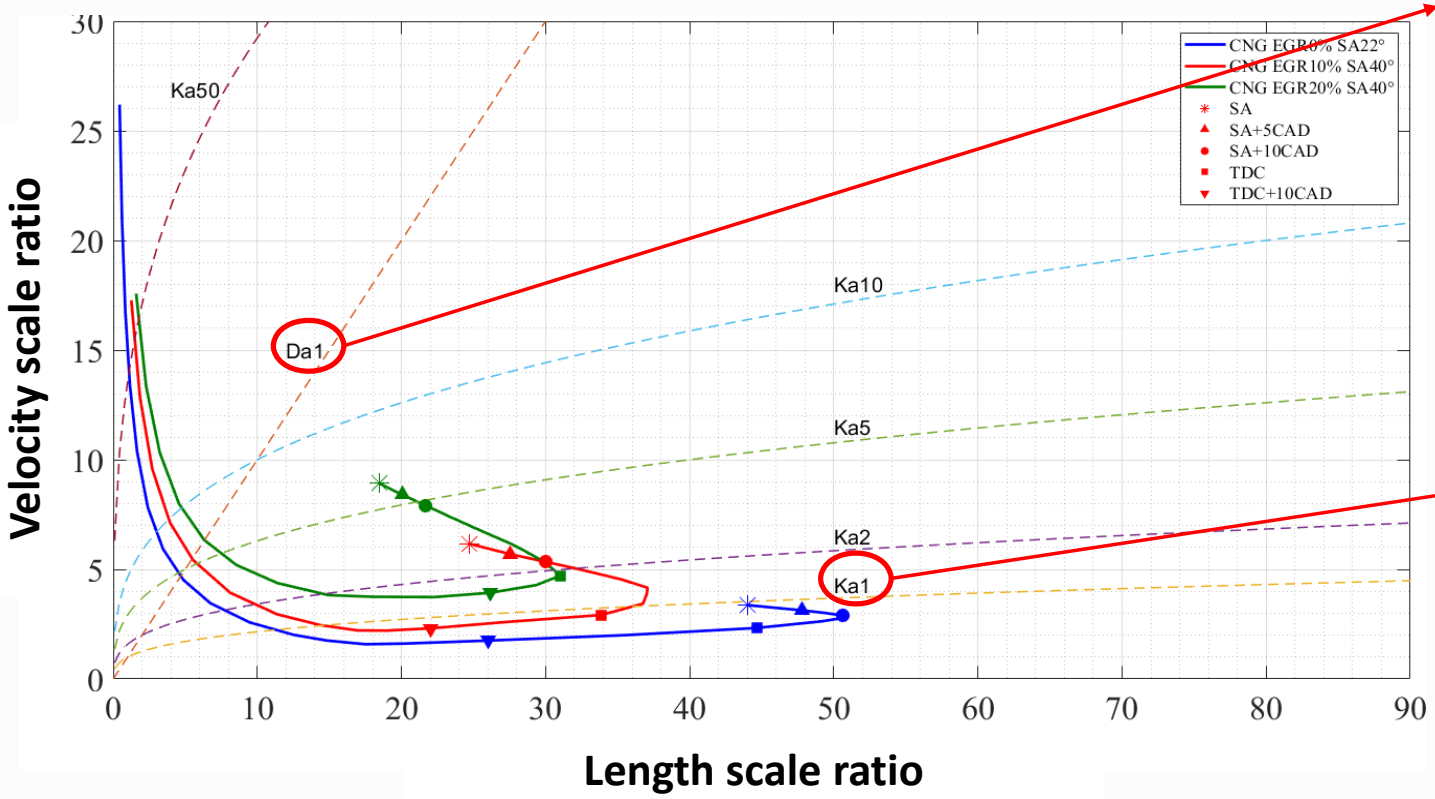
Definition of parameters used in Borghi plots



$$Da = \frac{Residence\ time}{Chemical\ time} = \frac{L_i}{L_F}\frac{S_L}{u'}$$

$$Ka < 1$$

$$L_F < \eta;\ u_\eta < S_L$$

$$Ka = \frac{(L_F)^2}{(\eta)^2} = \frac{(u_\eta)^2}{(S_L)^2}$$

where,

L_F = Laminar flame thickness [m]

L_i = Turbulent length scale [m]

u' = Turbulent intensity [m/s]

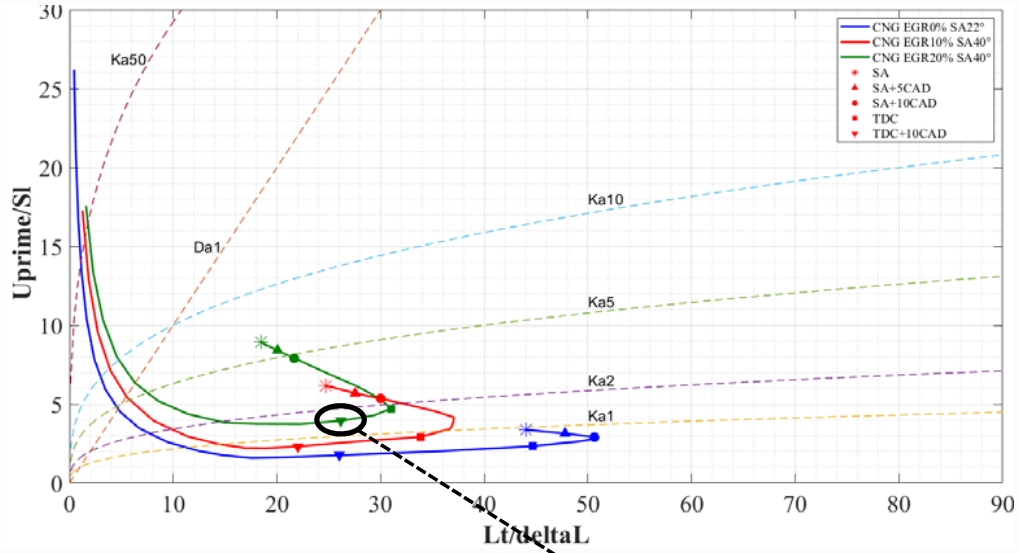
S_L = laminar flame speed

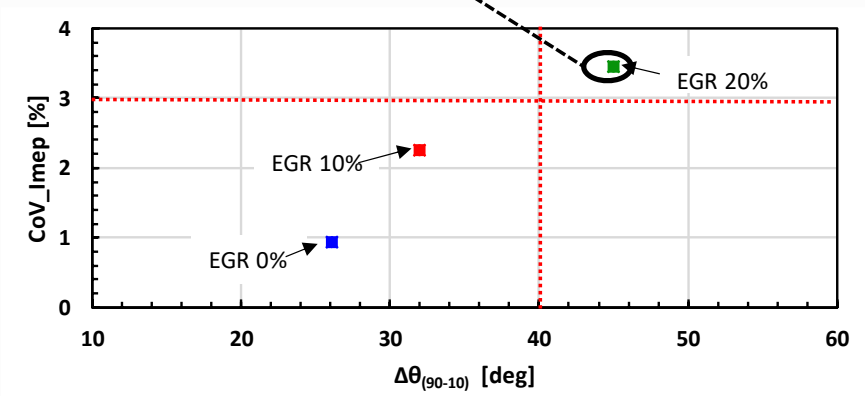
η = Kolmogorov length scale

U_η = Kolmogorov velocity scale

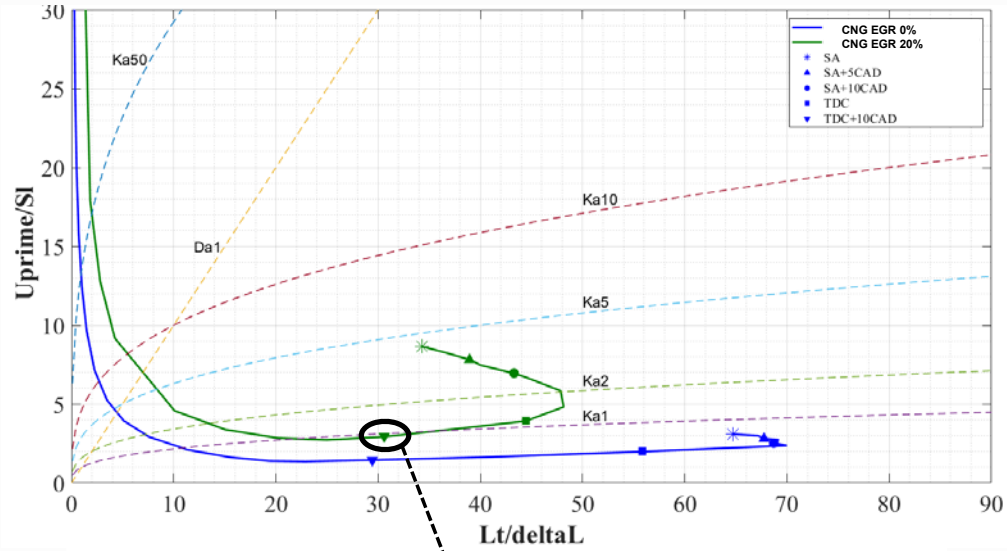
Effect of EGR addition

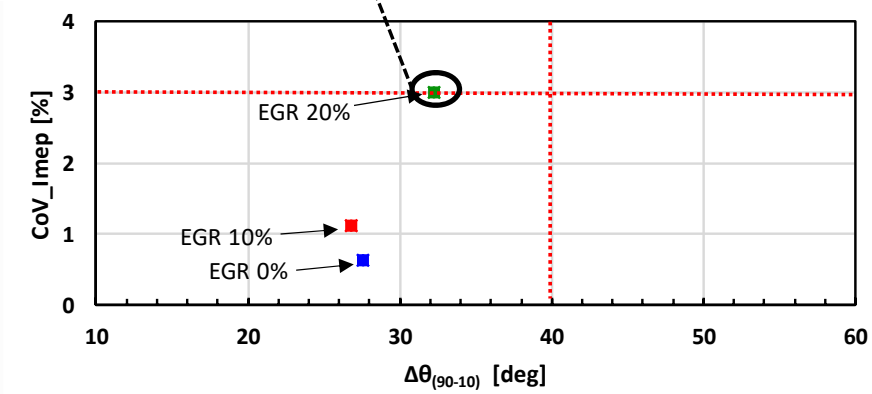
ENGINE 1





ENGINE 2





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Effect of Hydrogen addition

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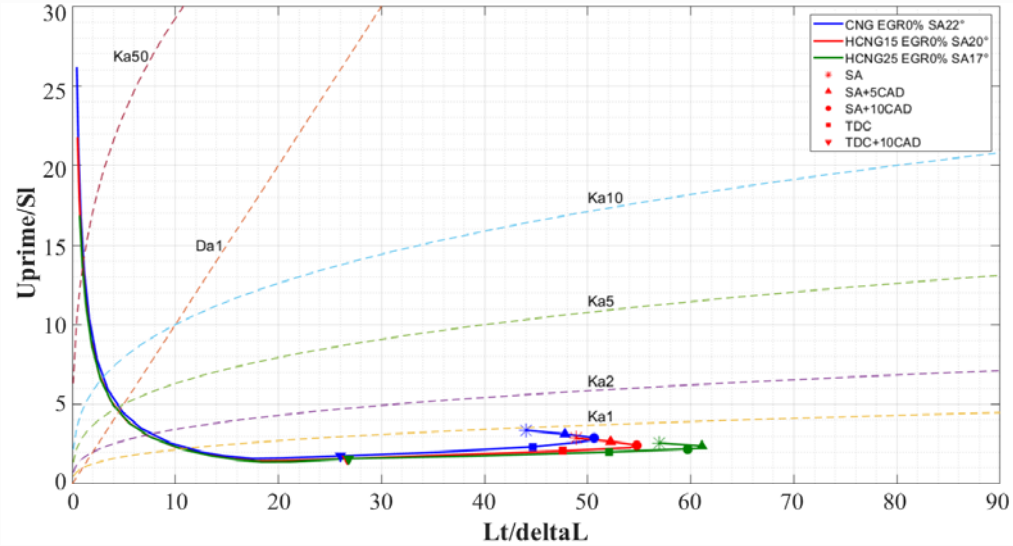

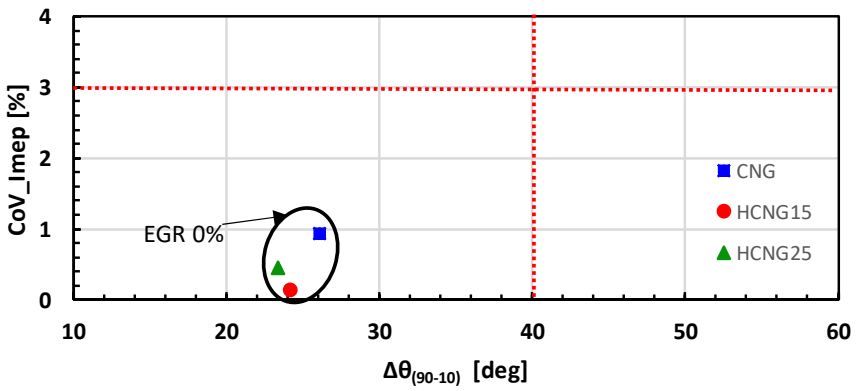

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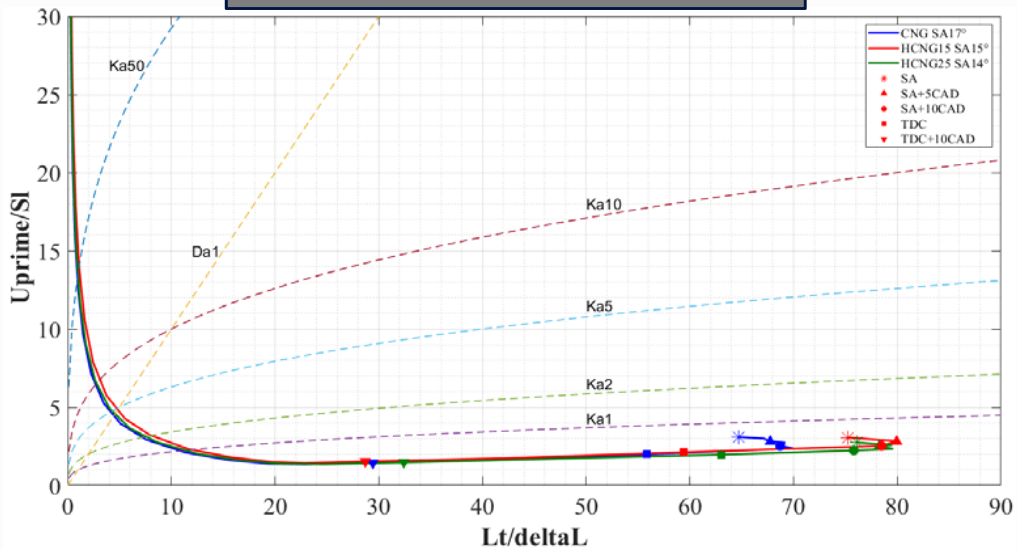

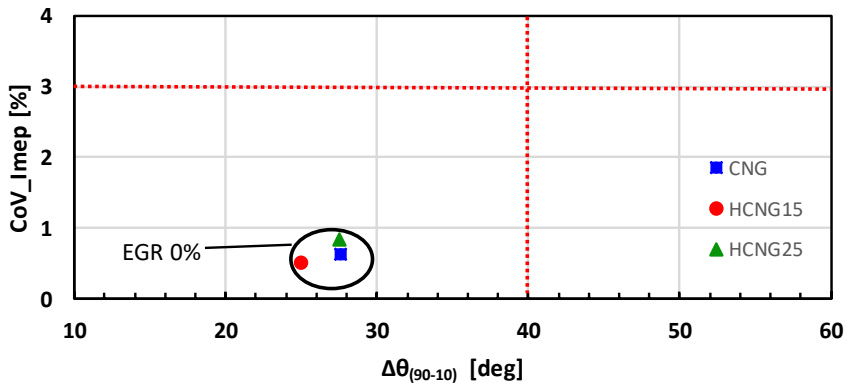

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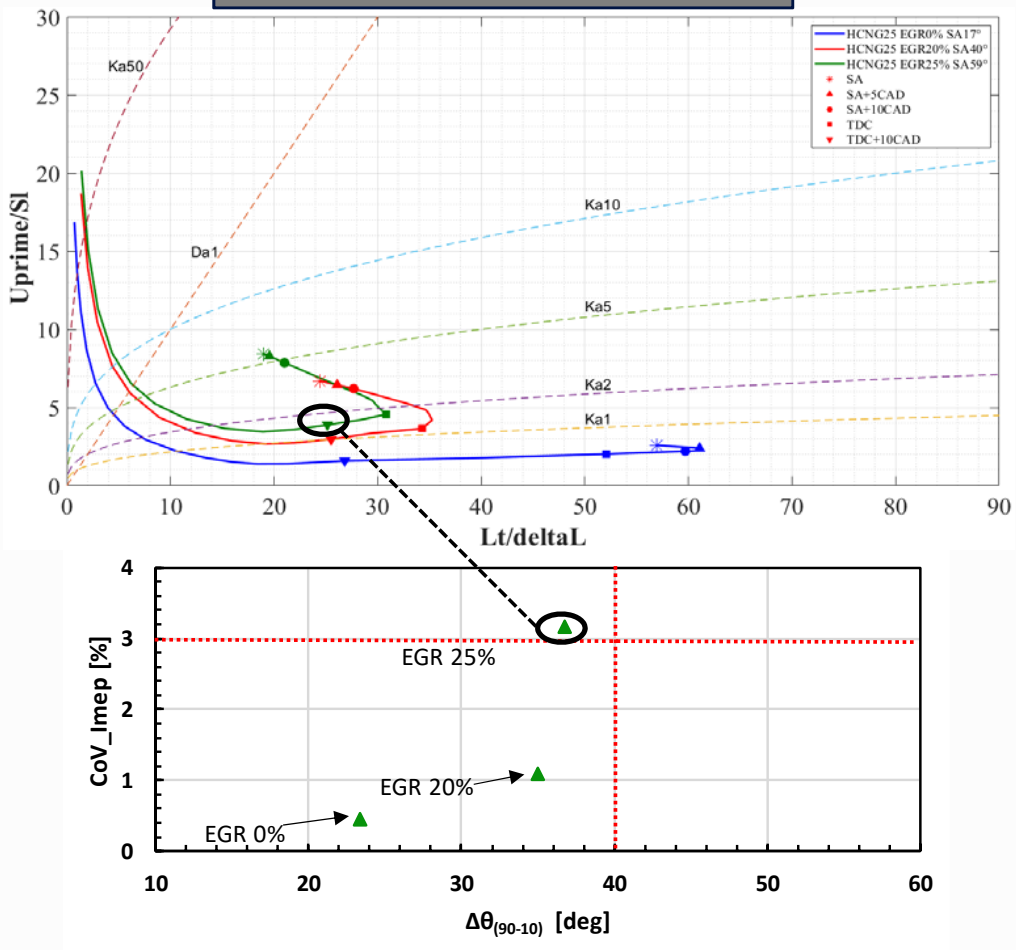
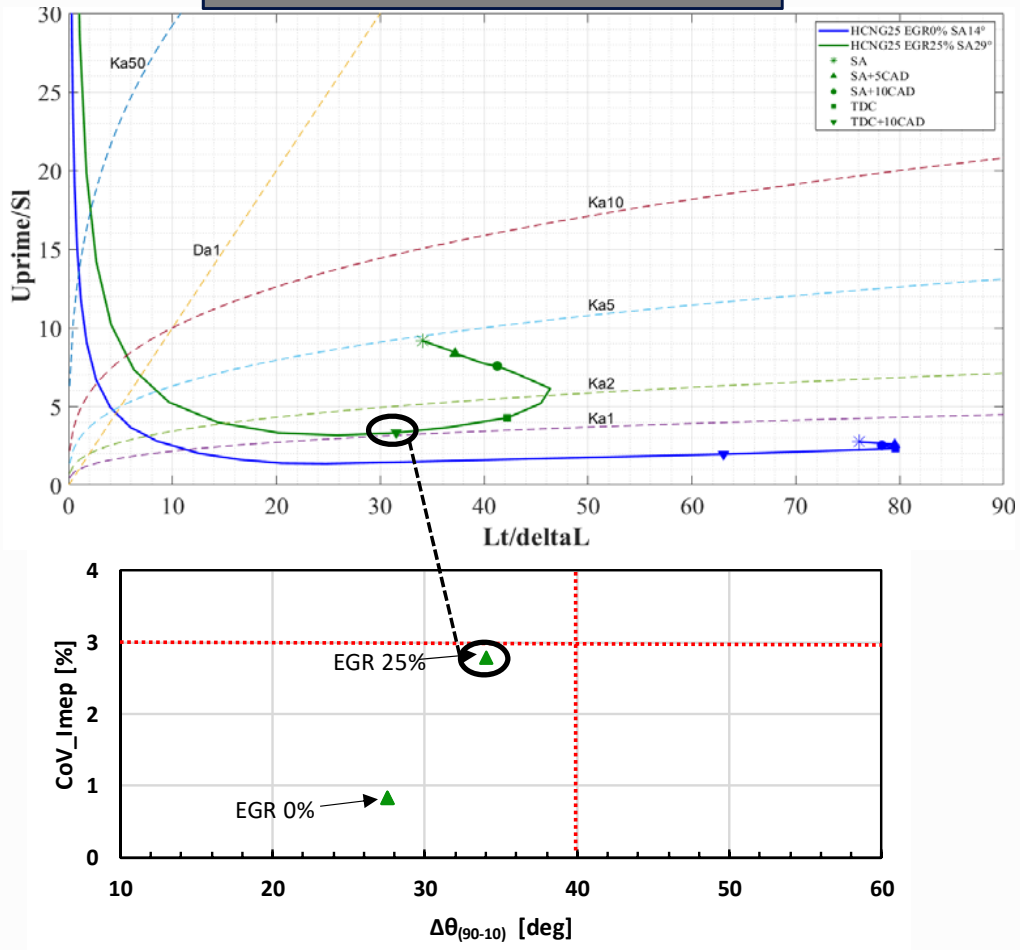
Effect of Hydrogen addition on EGR Tolerance

ENGINE 1



ENGINE 2



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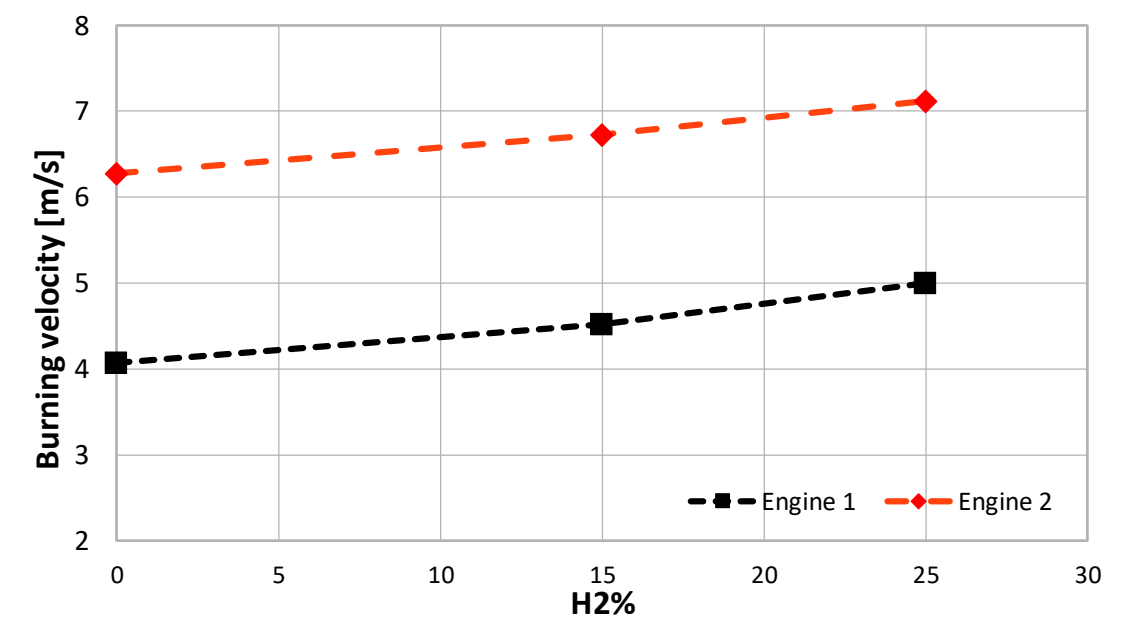
Conclusion



Difference due to turbulent intensity:

$\approx f(\frac{1}{Da}) = f(\frac{L_F}{L_i}\frac{u'}{S_L})$

where,
Da = Damköhler number
L_F = Laminar flame thickness [m]
L_i = Turbulent length scale [m]
u' = Turbulent intensity [m/s]
S_L = laminar flame speed

Future Work

- To check this function's validity with EGR cases and different load points

Acknowledgment

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CONVERGE CFD SOFTWARE

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Thank you!!!