Implementation of a 0D/3D process for heat release prediction of an engine in the early development stage

LOGE User Conference

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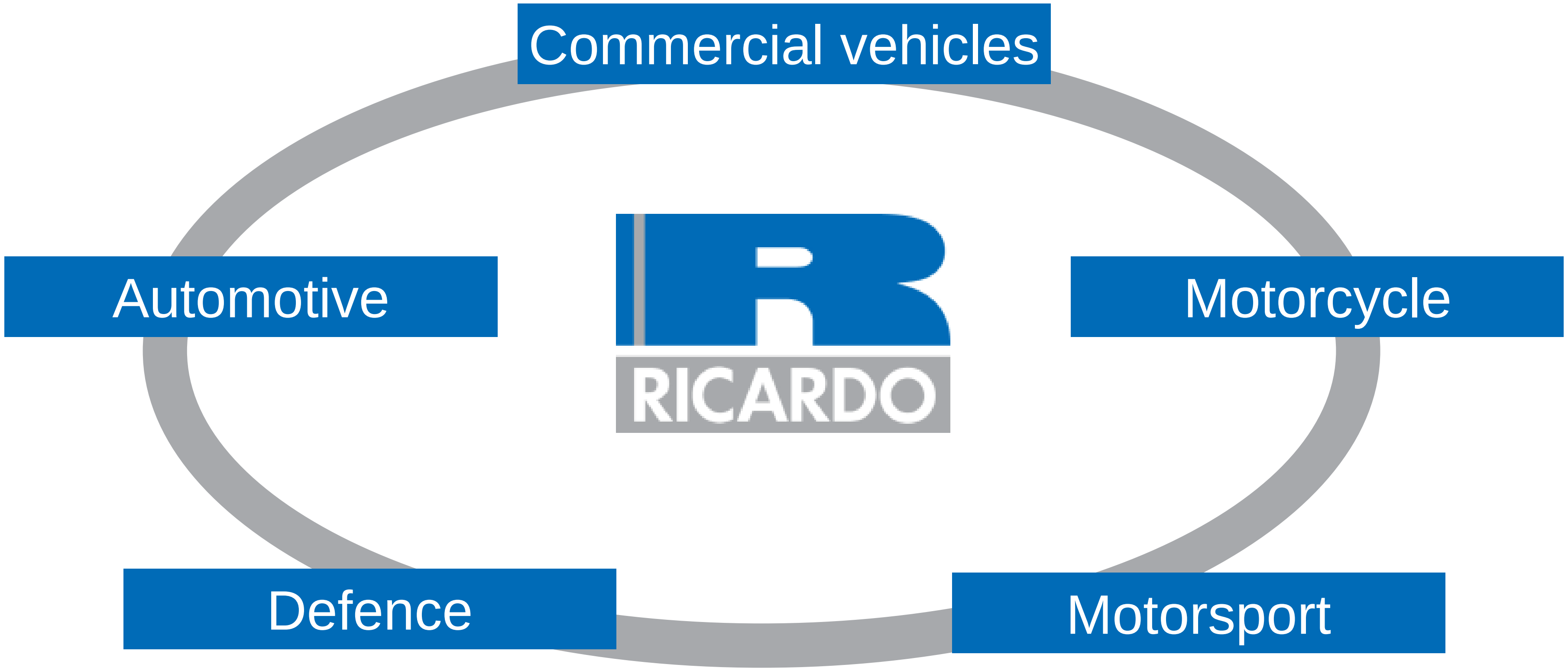
Christian Rota
Rob Morgan
Nick Winder
Kenan Mustafa

Agenda

- **Introduction & Challenges**
- Proposed process
- Investigation setup
- Combustion prediction for different loads
  - Injector comparison
- Combustion prediction for different Starts of Injection
- Conclusion

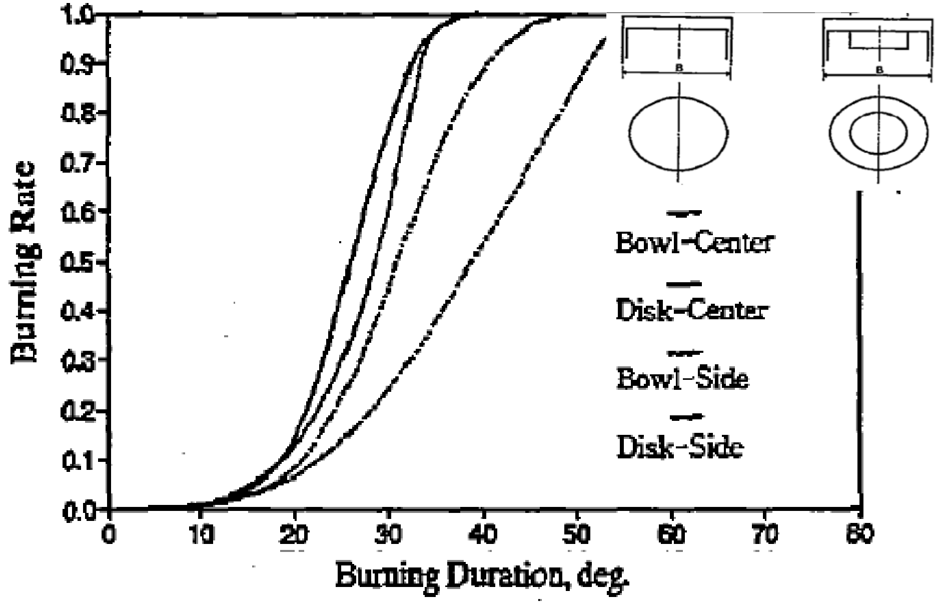
Early stages of engine hardware screening and calibration development for combustion systems is completed virtually, therefore engine models need to offer realistic responses for combustion rate

- Typical engine characteristics investigated in an engine development process
  - Engine size
  - Ports and manifolds designs (air motion)
  - Boosting strategies
  - Fuel injection strategy
  - Valves strategy
  - EGR & charge dilution



For predictive virtual engine development we need to capture more of the physics influencing the combustion rate.

- The combustion rate and duration can be drastically changed by air motion, fuel-air mixing, charge dilution, fuel properties, ignition, etc…
- Experience has taught us how to adjust combustion rate models to accommodate the changes in physics, but this is **postdictive**
- For virtual development of new engine concepts we need to be **predictive**
- For confidence, response of the following to changes in hardware / strategies**:**
  - Burn angles prediction, **(1 – 2 degrees accuracy)**
  - Detonation Border Line, **(1 – 2 degrees accuracy)**



The Effect of Combustion Chamber Geometry in a SI Engine SAE 972996

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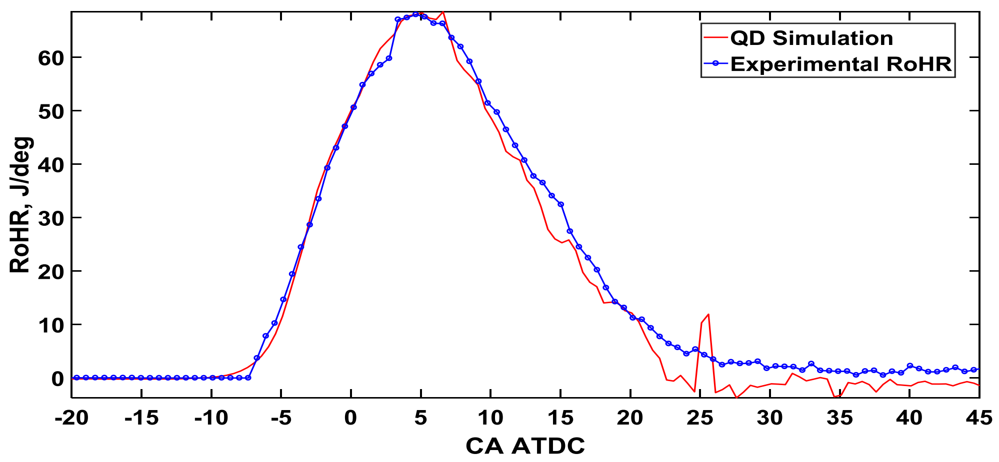
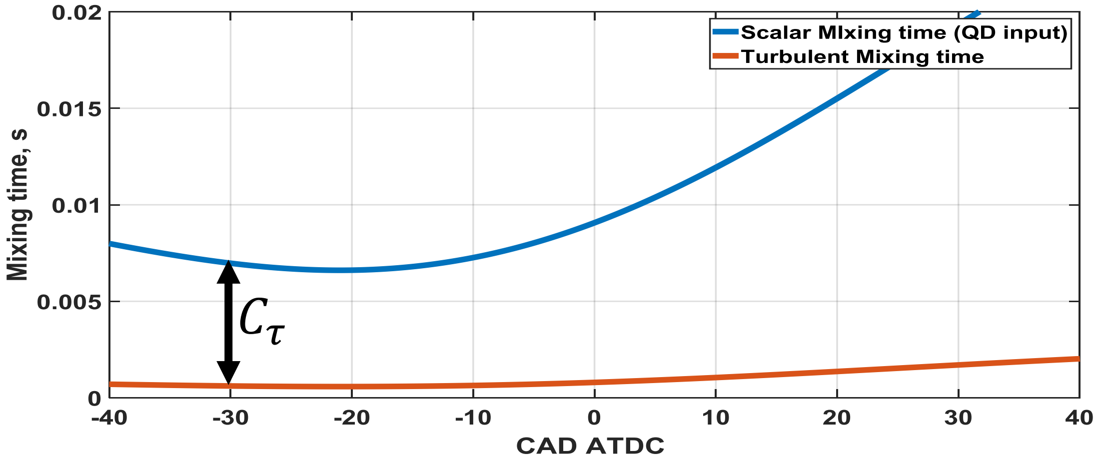
The Stochastic Reactor Model (SRM) accounts for the in-cylinder air motion and charge species distribution as it calculates combustion rate. SRM coupled with 3D CFD could therefore be predictive.
Phase1 – Cold 3D CFD to tune the scalar mixing time for a baseline engine





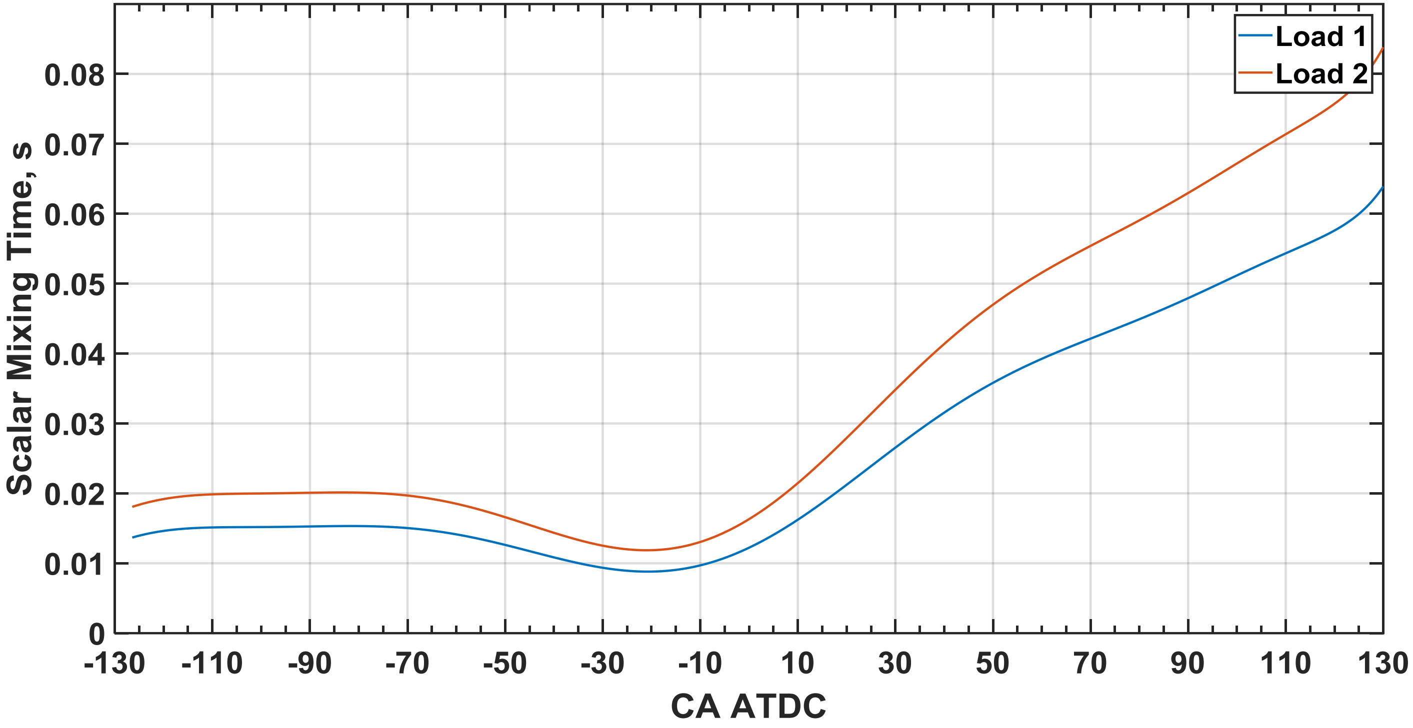
QD Combustion Model
(Heat Release calculation)

1-D Engine Gas Dynamics model
(Engine performance assessment)

Cold 3D CFD
(Scalar mixing time assessment)

- $Turbulent\ Mixing\ Time, \tau_{CFD} = \left(\frac{k}{\epsilon}\right)$
- $Scalar\ Mixing\ Time, \tau_{QD} = \left(\frac{\tau_{CFD}}{C_\tau}\right)$ *[Pasternak, 2015]*

Stochastic Reactor Model (SRM) coupled with 1D and 3D cold CFD could deliver predicted Heat Release curve for different potential designs
Phase2 – Engine Update



QD Combustion Model
(Heat Release calculation)

1-D Engine Gas Dynamics model
(Engine performance assessment)

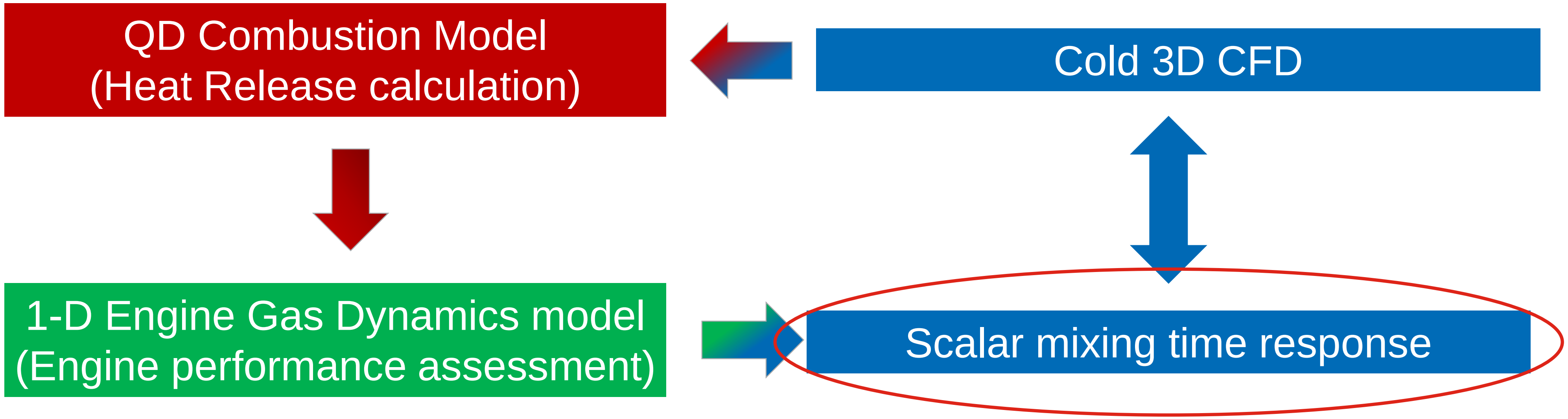
Scalar mixing time response

Injector, Load, Speed, SOI, Valve Timing, etc.

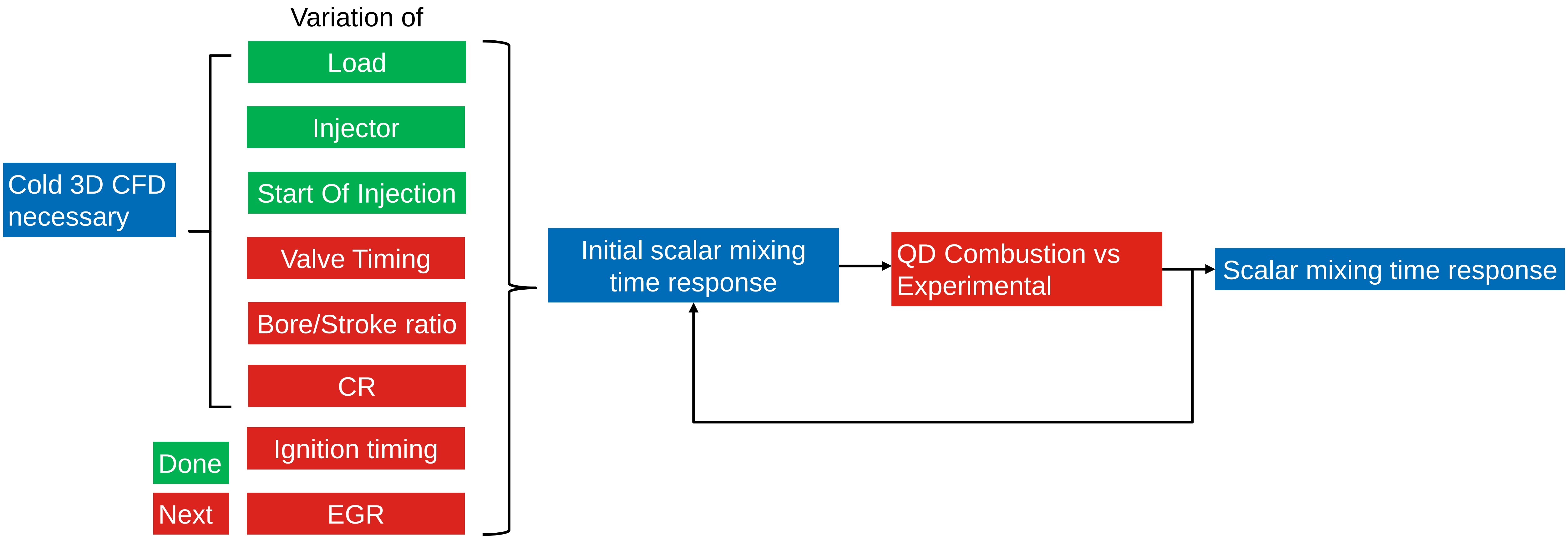
To be explained later

Stochastic Reactor Model (SRM) coupled with 1D and 3D cold CFD could deliver predicted Heat Release curve for different potential designs
Phase3 – New Engine

Design A vs Design B



The in-cylinder turbulence variation to different operating condition has to be investigated to correctly predict the engine combustion rate
Multiple CFD runs are therefore necessary to build a reliable mixing time correlation



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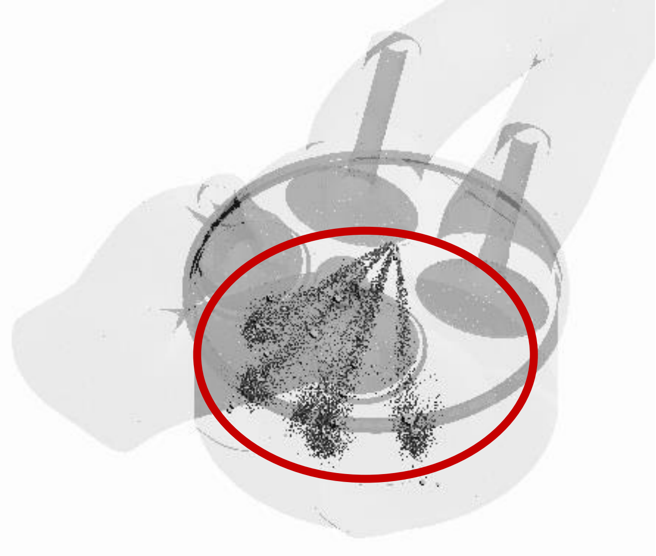
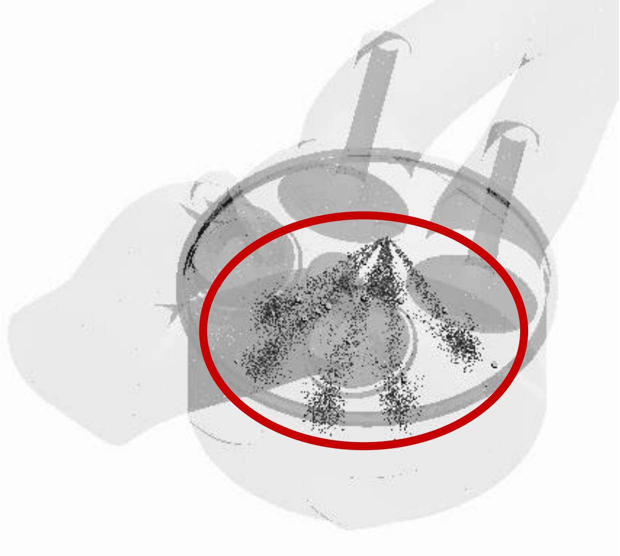
A single cylinder GDI Ricardo engine was used.
Injector A – Holes designed to maximise in-cylinder tumble motion
Injector B – Wider and more homogeneous spray pattern

Injector A



Injector B



Engine Parameters	Value
Bore	84 mm
Stroke	90 mm
Displacement	0.5 L
Compression ratio	10.2:1
IVC	-124.4 °CA ATDC
EVO	139.6 °CA ATDC
CFD Parameters	**Value**
Software	VECTIS
Turbulence Model	K-Epsilon
Wall Function	Isothermal

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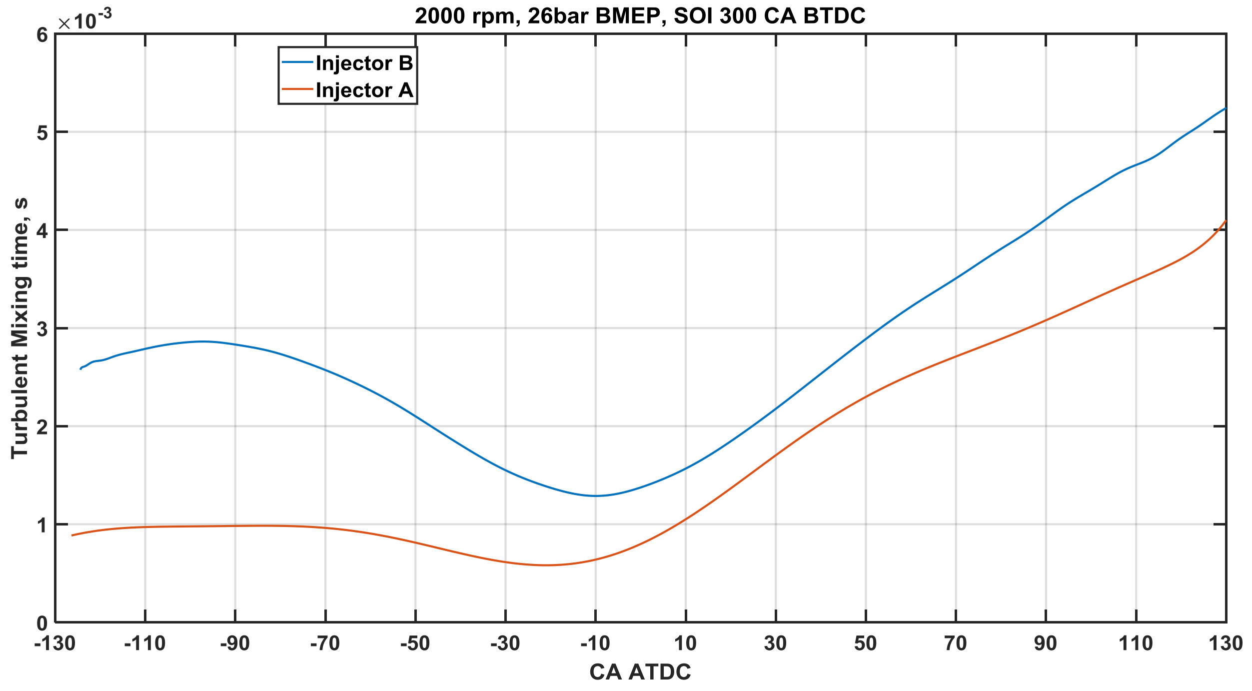
Scalar mixing time response to load – SRM run matrix
Full load CFD used as baseline the developed mixing time response

Run	Kp	Injector	Fuel Pressure	SOI [CABTDC]
1	2000 rpm 2 bar BMEP (PL)	Injector A	150 bar	300
2	2000 rpm 8 bar BMEP (PL)	Injector A		300
		Injector B		300

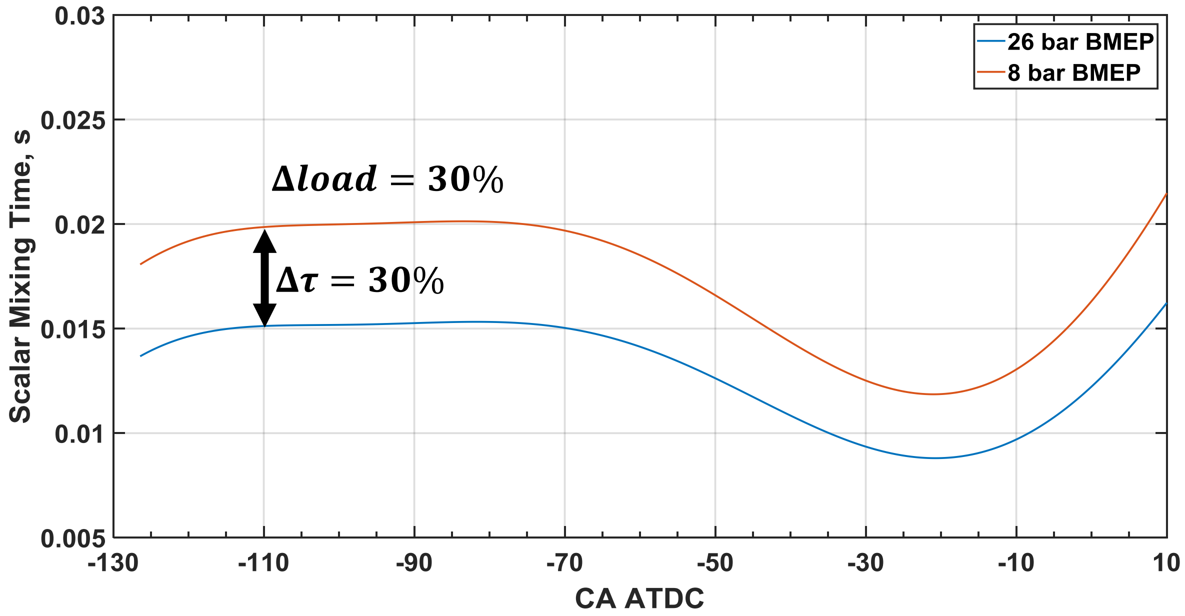


Scalar mixing time response to load – Single CFD run at full load was used to predict the combustion at different loads

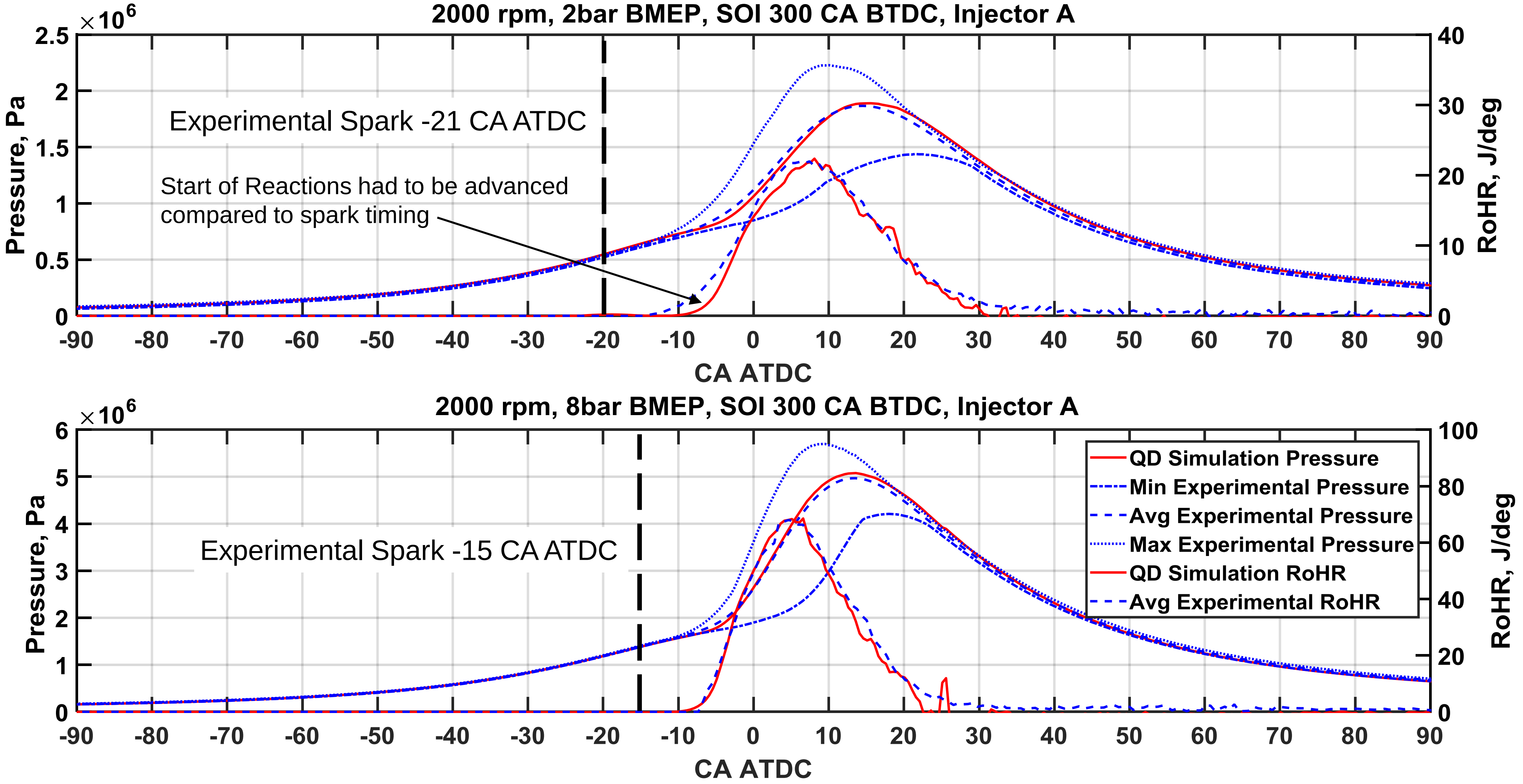
Assumptions

- Constant integral length scale
- Scalar mixing time shape profile does not change for different loads
- **Linear** load vs turbulent mixing time correlation *[Pasternak, 2015]*

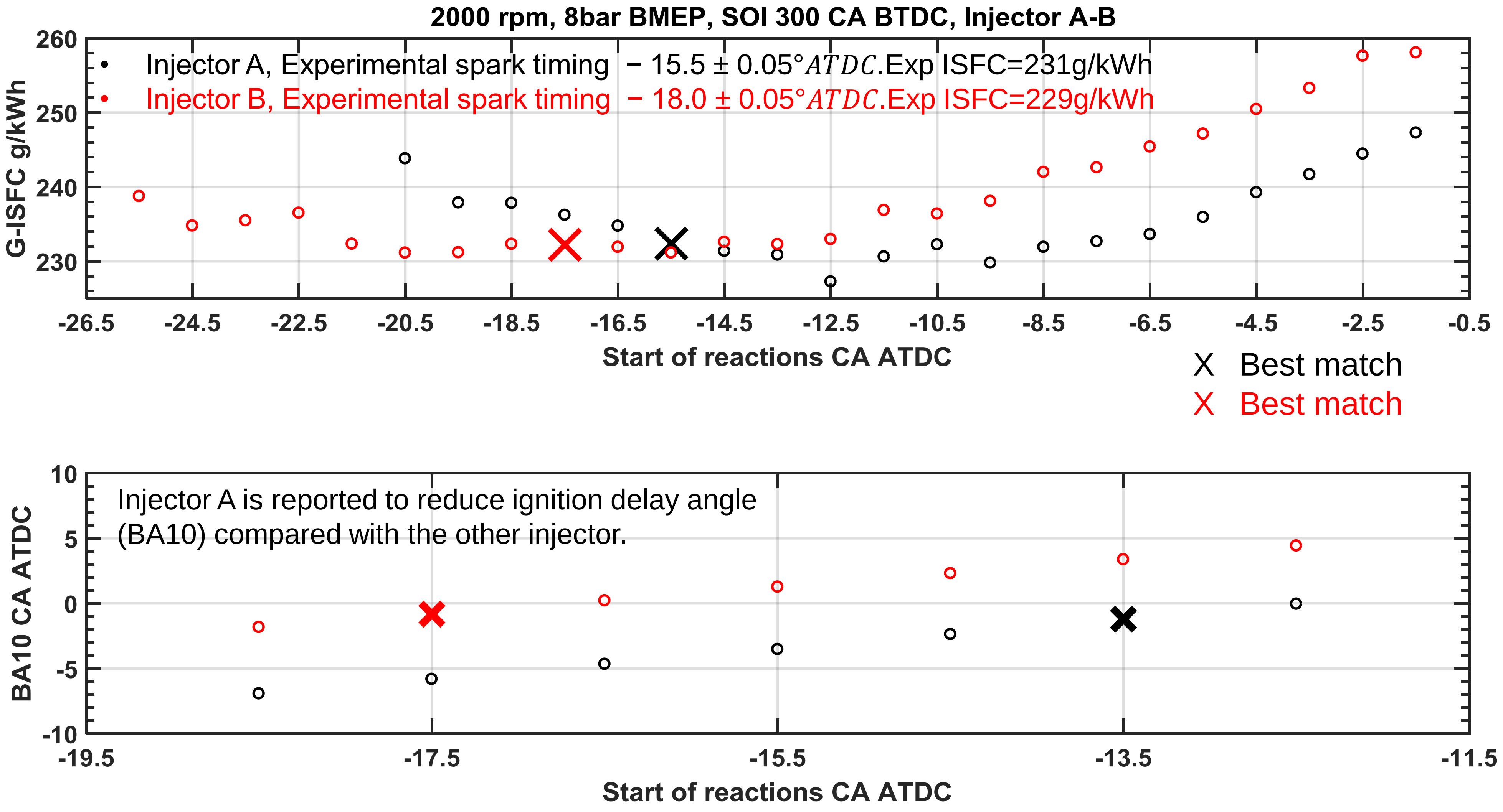
- $Turbulent\ Mixing\ Time, \tau_{CFD} = \left(\frac{k}{\epsilon}\right)$
- $Scalar\ Mixing\ Time, \tau_{QD} = \left(\frac{\tau_{CFD}}{C_\tau}\right)$



Scalar mixing time response to load – A single cold CFD at full load is enough to correctly predict combustion behaviour at different loads
Predicted pressure and RoHR traces



Injector Comparison – Both injectors ran at the same condition except for the scalar mixing time profile. Expected fuel consumption trend predicted by the model. Injector with less turbulence resulting in slower combustion.



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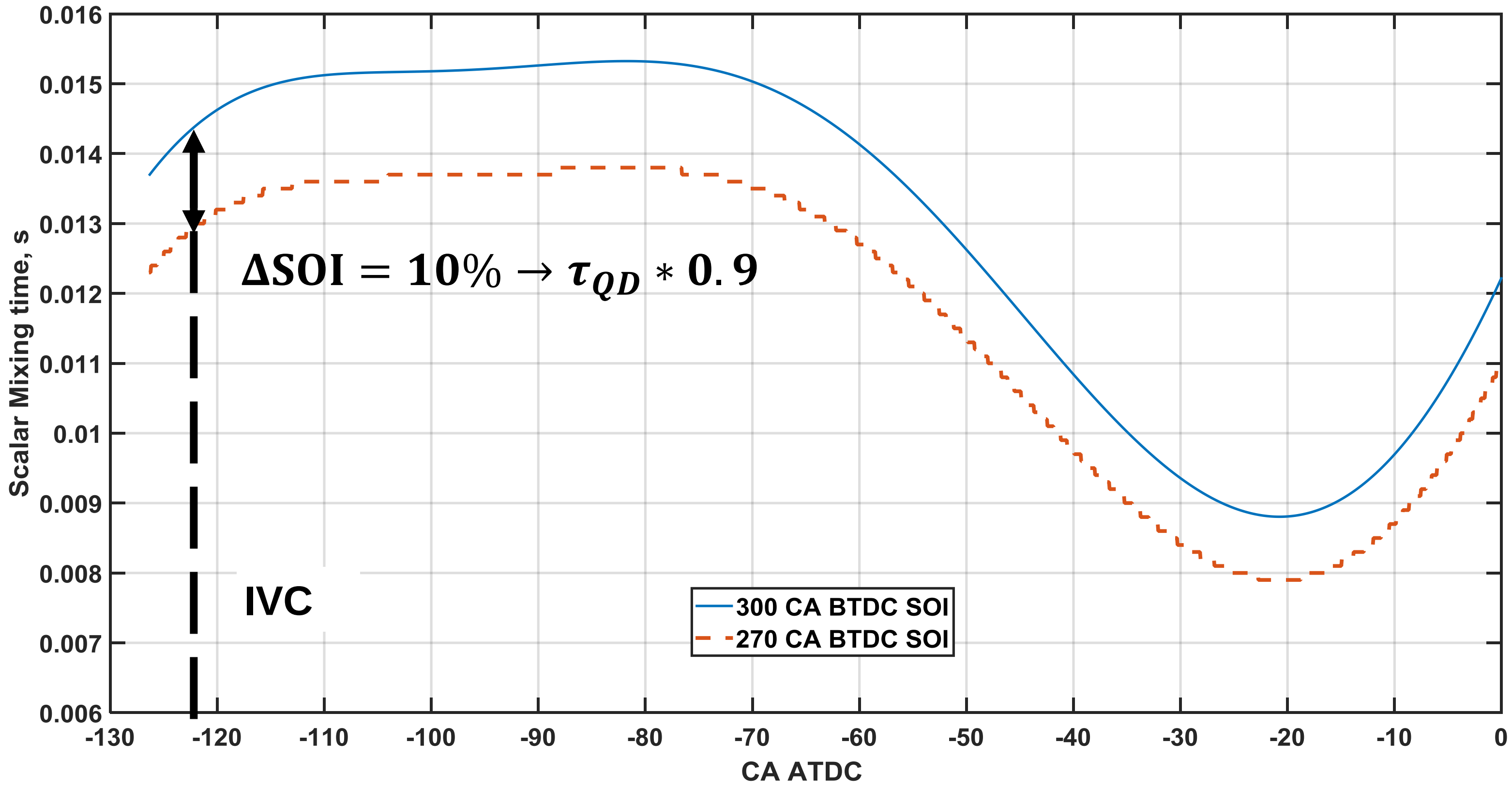
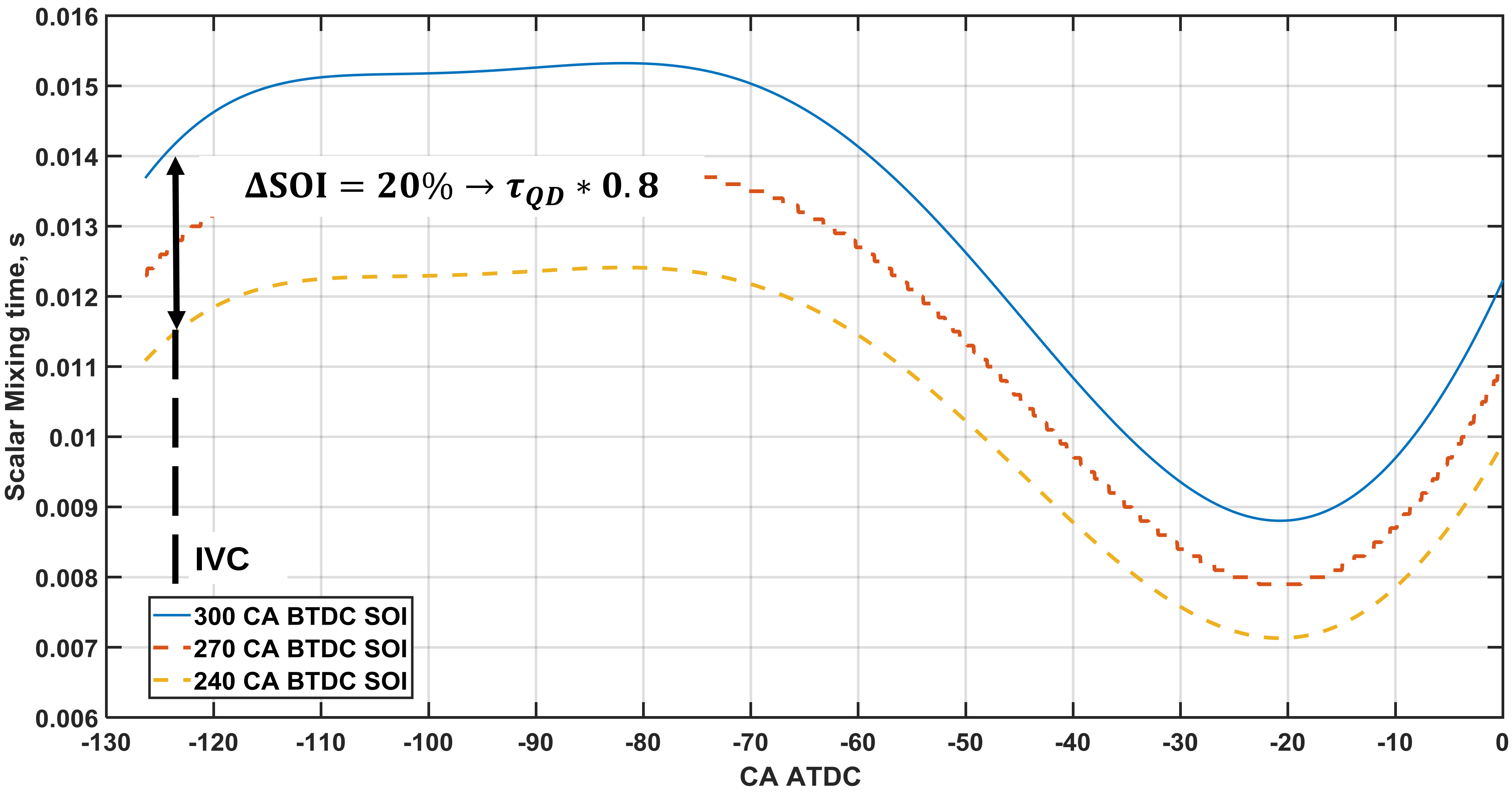
Scalar mixing time response to Start Of Injection (SOI) – Single CFD run at SOI 300 CA BTDC was used to predict the combustion at different SOI times

Assumptions

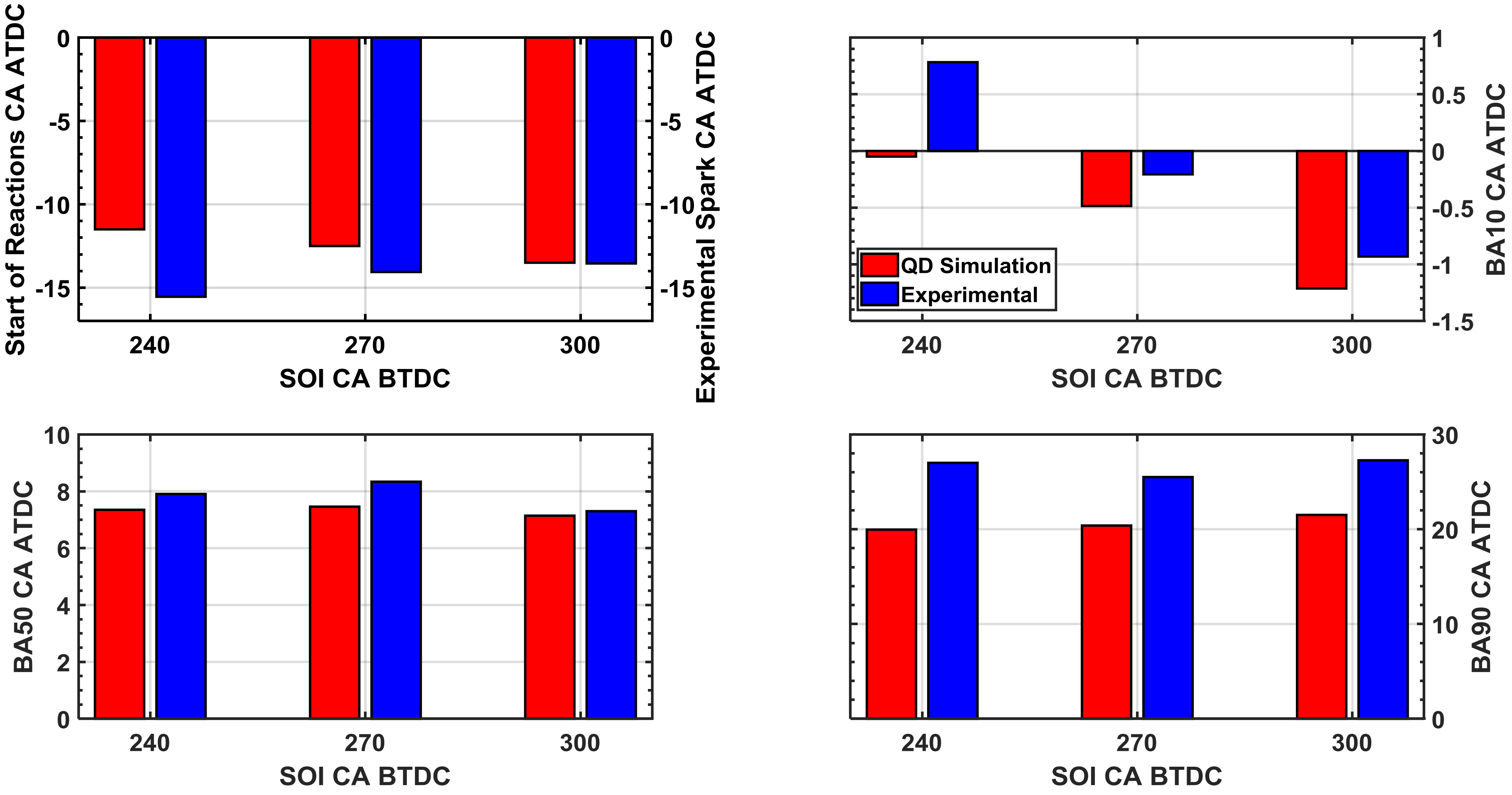
- Scalar mixing time at IVC linearly depends from SOI
- All previous assumption



Scalar mixing time response to SOI – Single CFD run at SOI 300 CA BTDC was used to predict the combustion at different SOI times



Scalar mixing time response to SOI – Single CFD used to predict combustion at different SOI. Assumed correlation seems to produce good results



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The developed mixing time response has shown good results for the conditions investigated. Further development has to be carried out to verify the proposed process predictive capabilities

Proposed process together with the developed mixing time response has shown good results

- ✓ Combustion rate correctly predicted
- ✓ Little experimental data used
- ✗ QD combustion model performs well **only if** the mixing time is the correct
- ✗ Cold CFD not always available during concept selection

Future steps:

- Mixing time response to be further developed
  - VVT, bore/stroke, different tumble ratios to be investigated
- Test the process with different fuels
  - Natural gas
  - Water injection

Thank you for your attention!

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Any questions?