Combustion model for engine concept simulation

Arne Andersson; Bincheng Jiang

Volvo Global Trucks Technology

Karin Fröjd; Simon Bjerkborn; Lars Seidel

Michał Pasternak; Andrea Matrisciano; Fabian Mauss

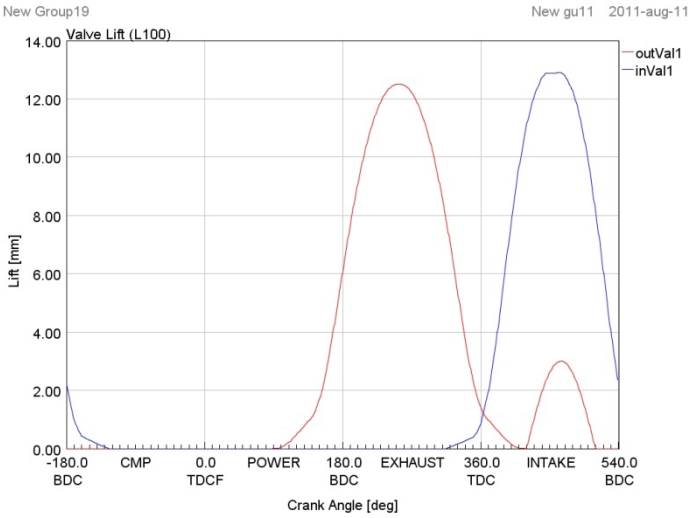
Lund Combustion Engineering – LOGE AB

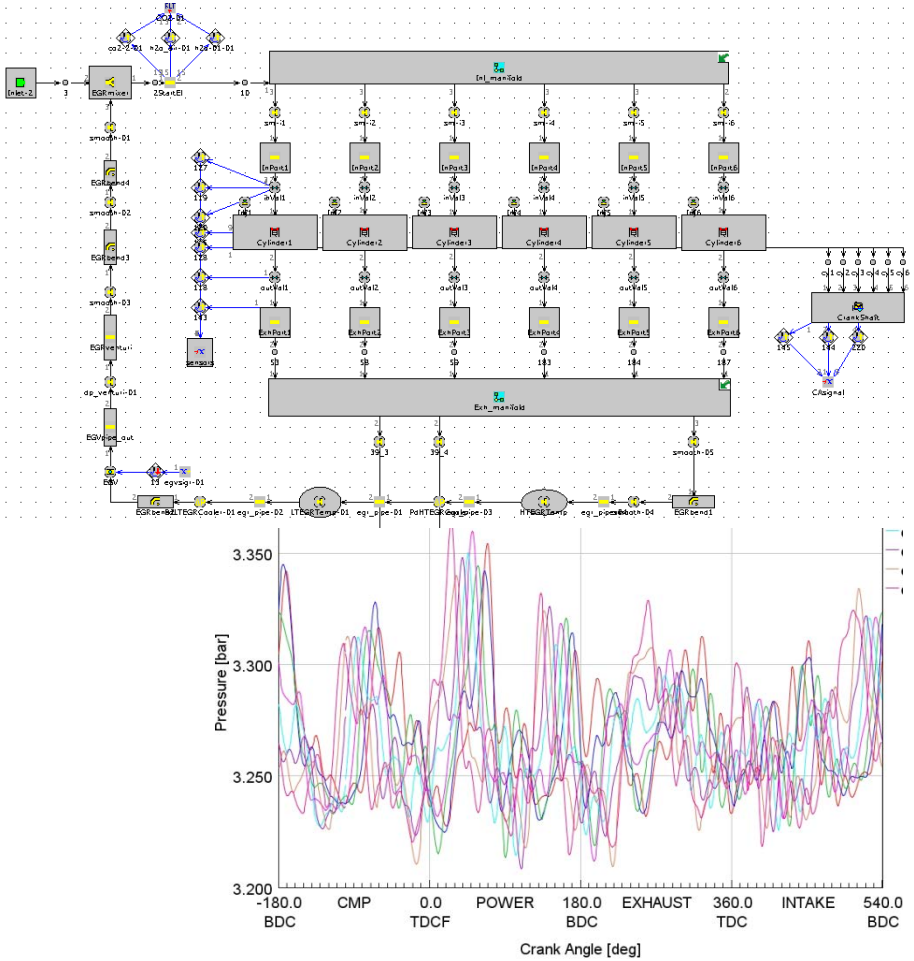
DEER 2012 Conference

Combustion model needed for advanced combustion in engine concept development

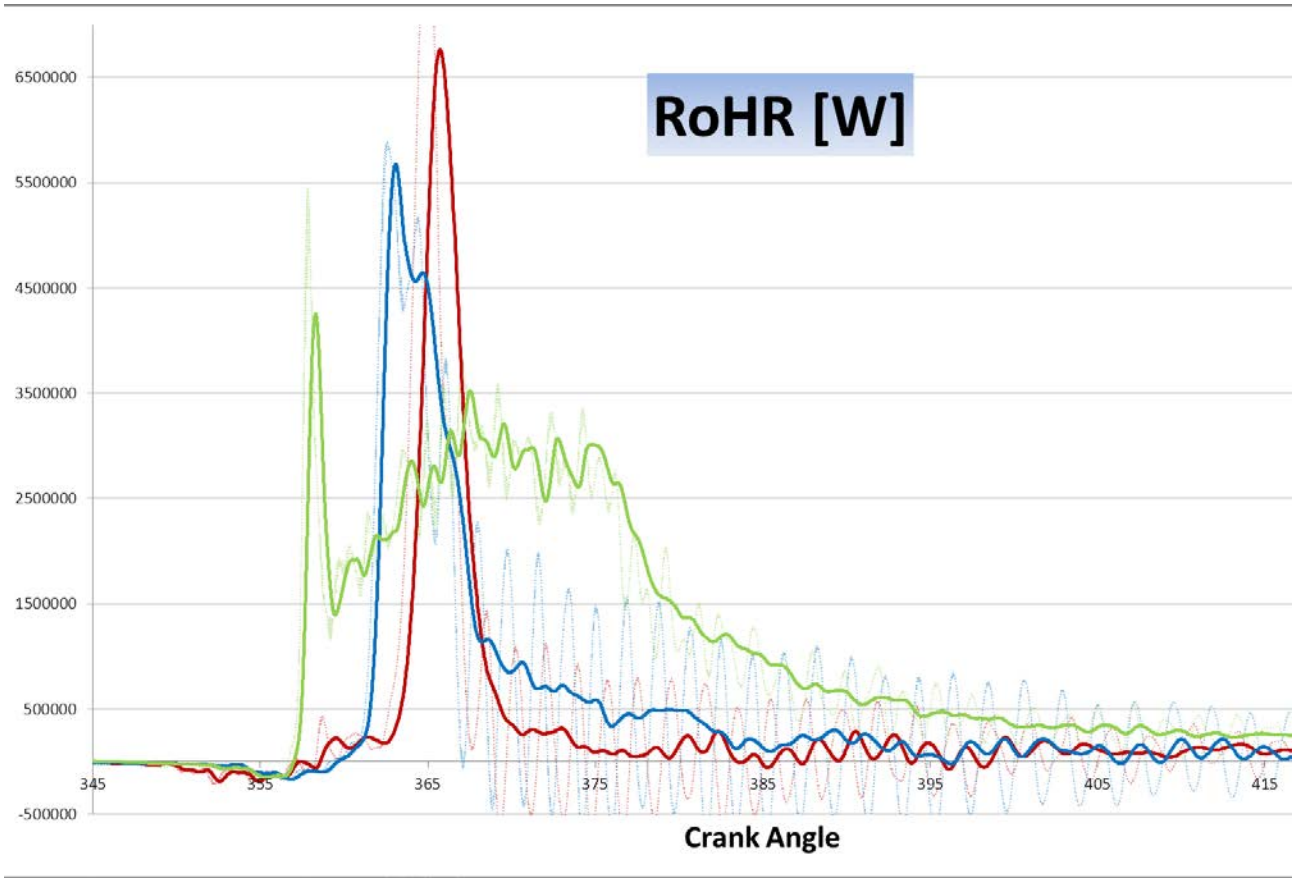
Systems approach is needed

Integration with GT-Power





PPC is challenging to model
A wide span of combustion modes in a load sweep

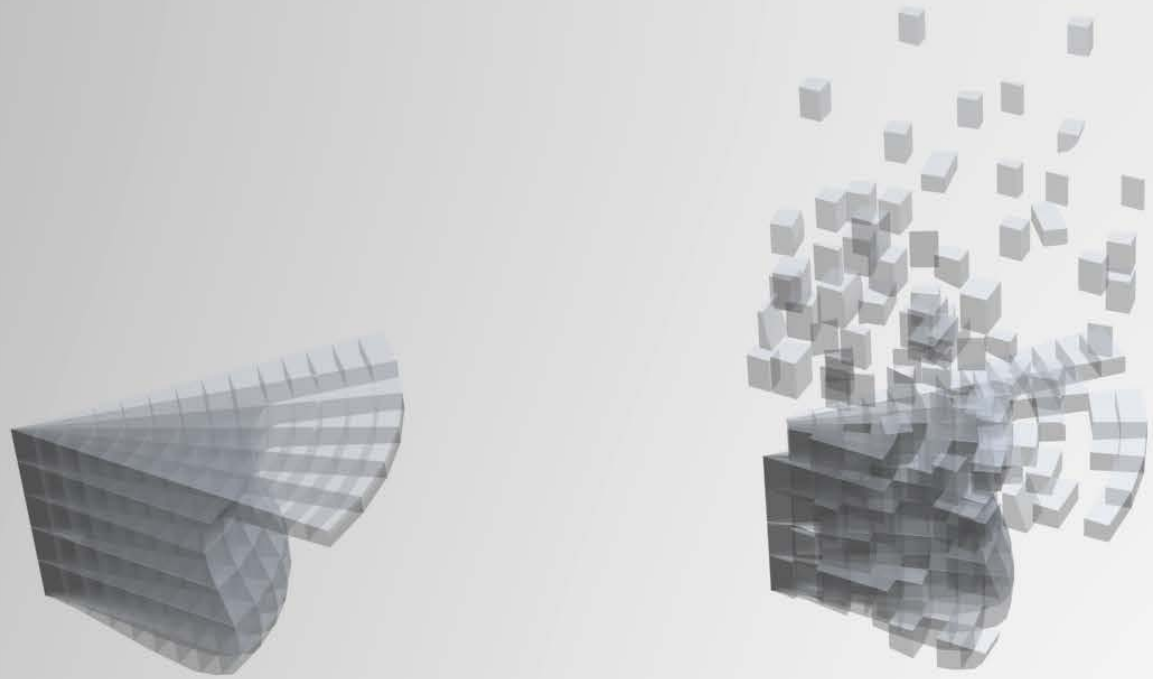


IMEP 8 bar
Like HCCI

IMEP 12 bar
PPC

IMEP 26 bar
Diffusion combustion

The Stochastic Reactor Model (SRM)

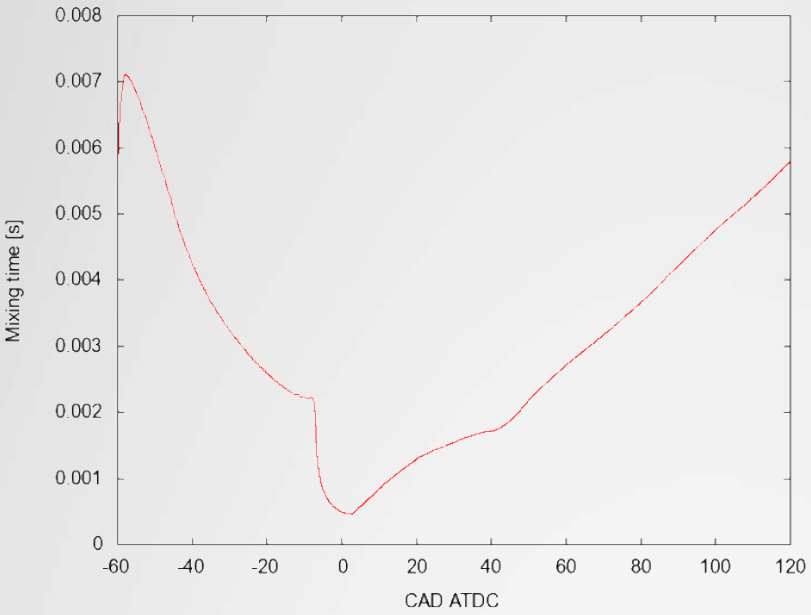


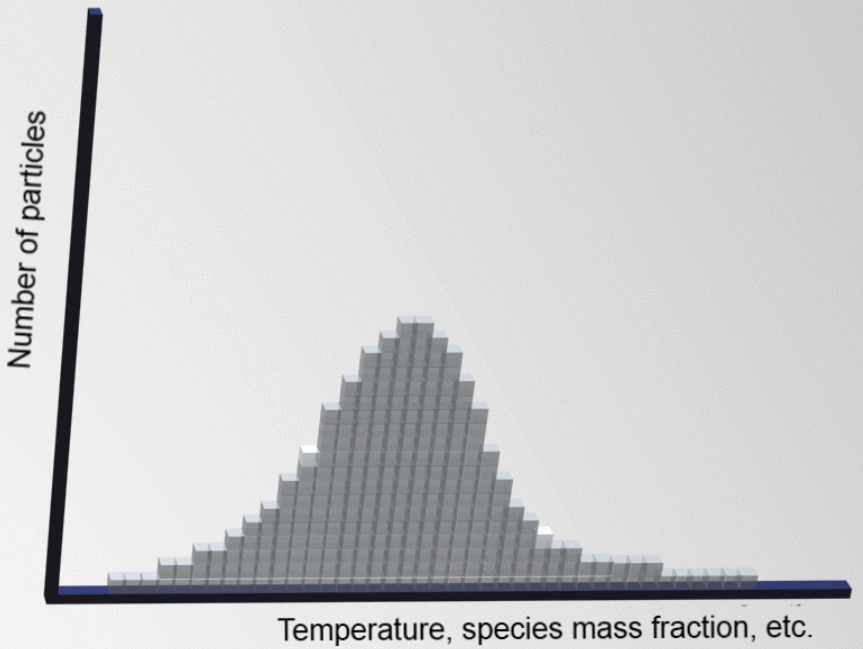
The in-cylinder processes (temperature, species concentrations) are statistically described by a probability density function (PDF).

The evolution of the PDF is governed by turbulent mixing and detailed chemistry.

VOLVO

The Stochastic Reactor Model (SRM)





Mixing is modeled as a stochastic process: Particles are randomly selected to interact with each other. Both temperature and chemical composition is exchanged.

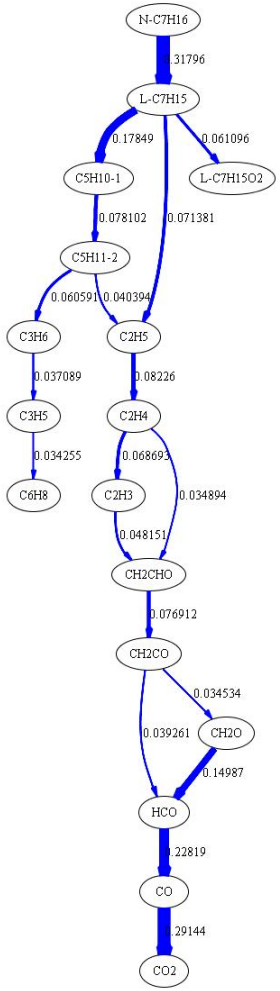
The frequency of mixing events is determined by the turbulent mixing time τ

Chemistry

The SRM model makes use of detailed chemistry.

Three different mechanisms were evaluated:

- 33-species Tsurushima mechanism
- 200-species NICE mechanism
- 477-species Toluene Reference Fuel (TRF) mechanism

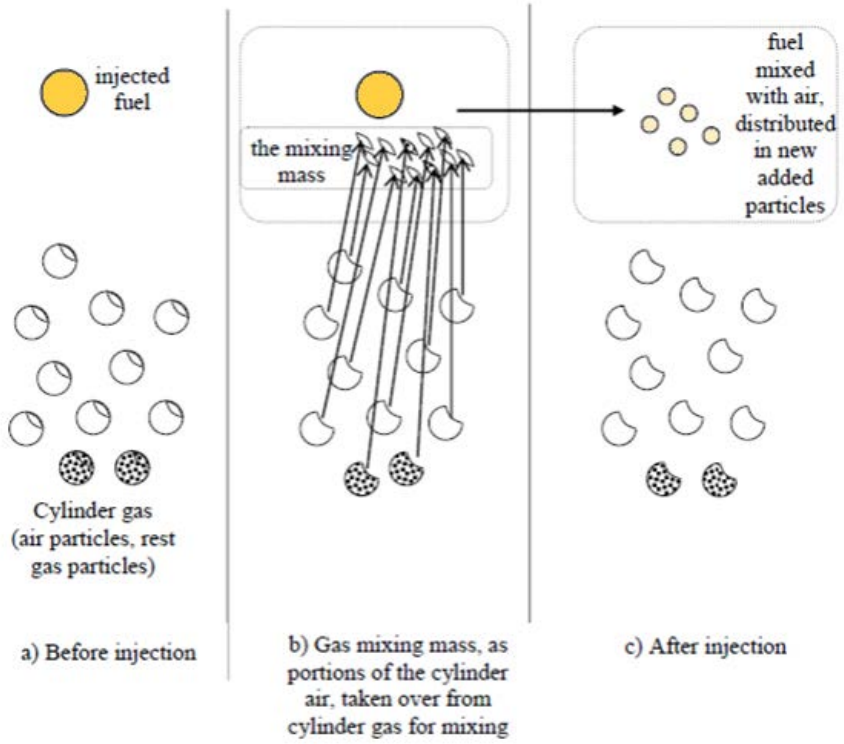


The 33-species mechanism was found to yield unrealistic ignition timing, whereas the differences between the 200-species mechanism and the 477-species mechanism were negligible.

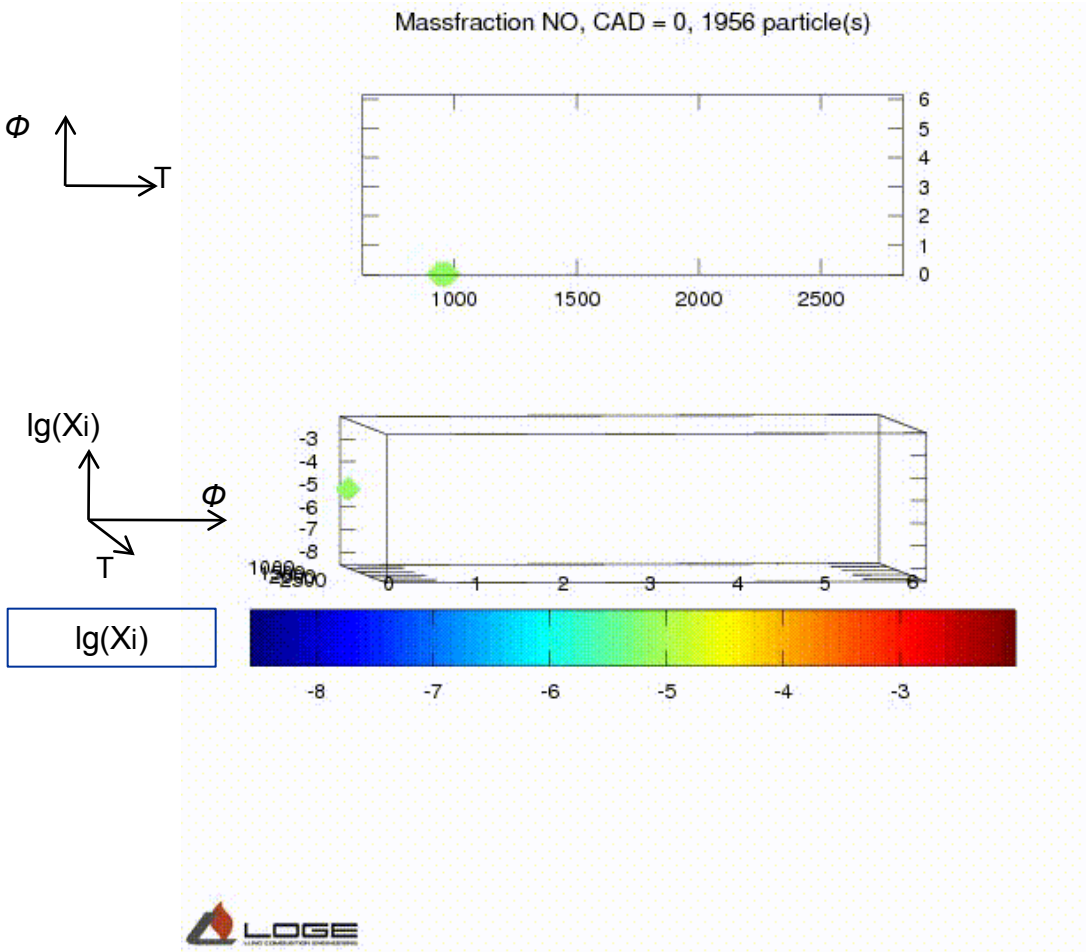
The 200-species NICE mechanism has been used for all simulations in this presentation.

Fuel injection

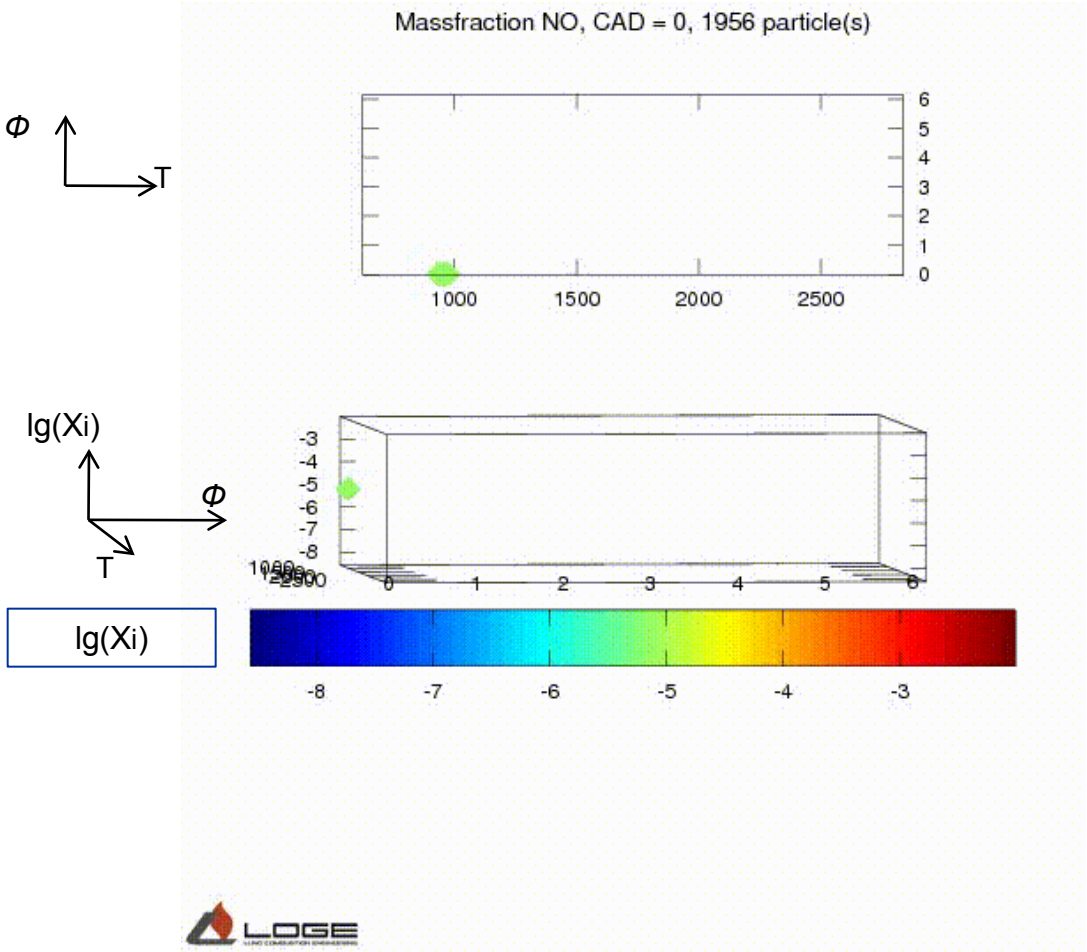
- Vaporized fuel is introduced as new particles in the SRM.
- These particles are mixed with the background gas (air and EGR) according to the turbulent mixing time.



Example: Vaporized cold fuel mixing with background gas and igniting

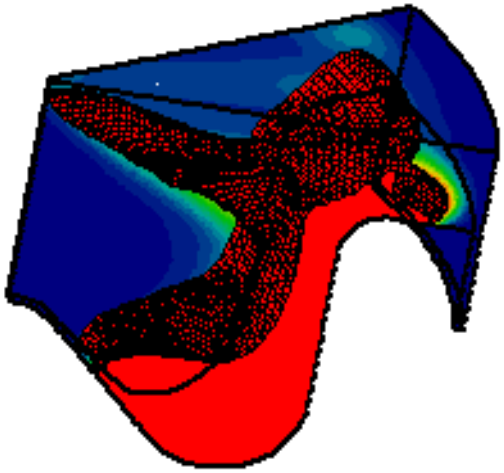


Example: Vaporized cold fuel mixing with background gas and igniting



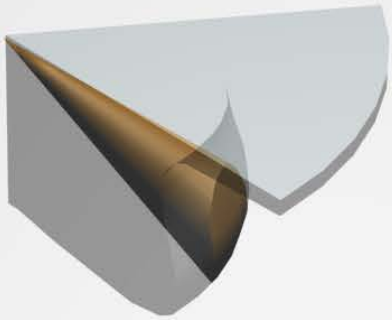
PPC modeling with the SRM

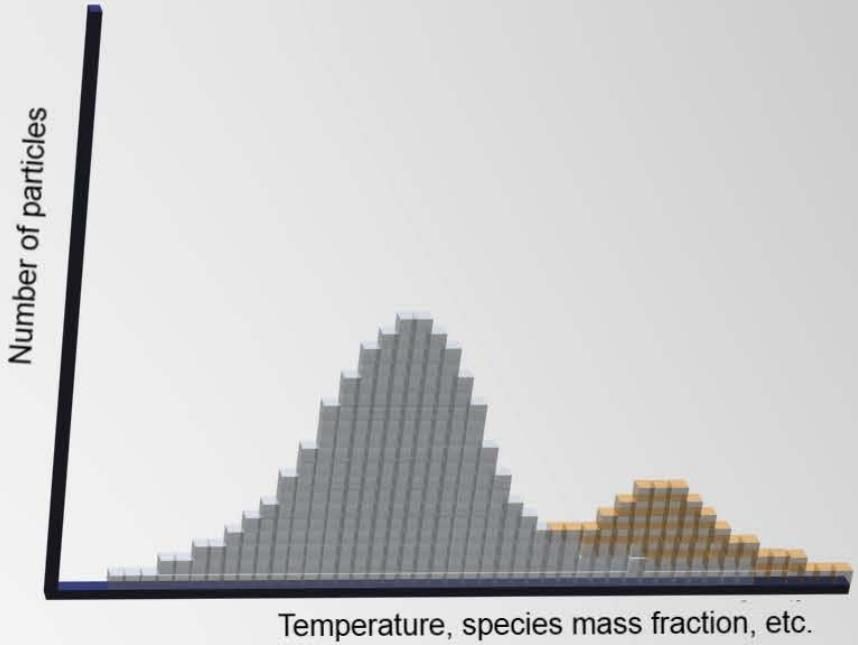
Problem: While the SRM model presumes statistical homogeneity in the combustion chamber, this assumption is not true for the PPC. At the point of ignition, much fuel is still concentrated in a rich zone



Solution: Divide the background gas in the SRM into two distinct zones. Let the injected fuel be introduced into one of the zones. Mix predominantly within each zone to capture the effects of stratification.

PPC modeling with the SRM

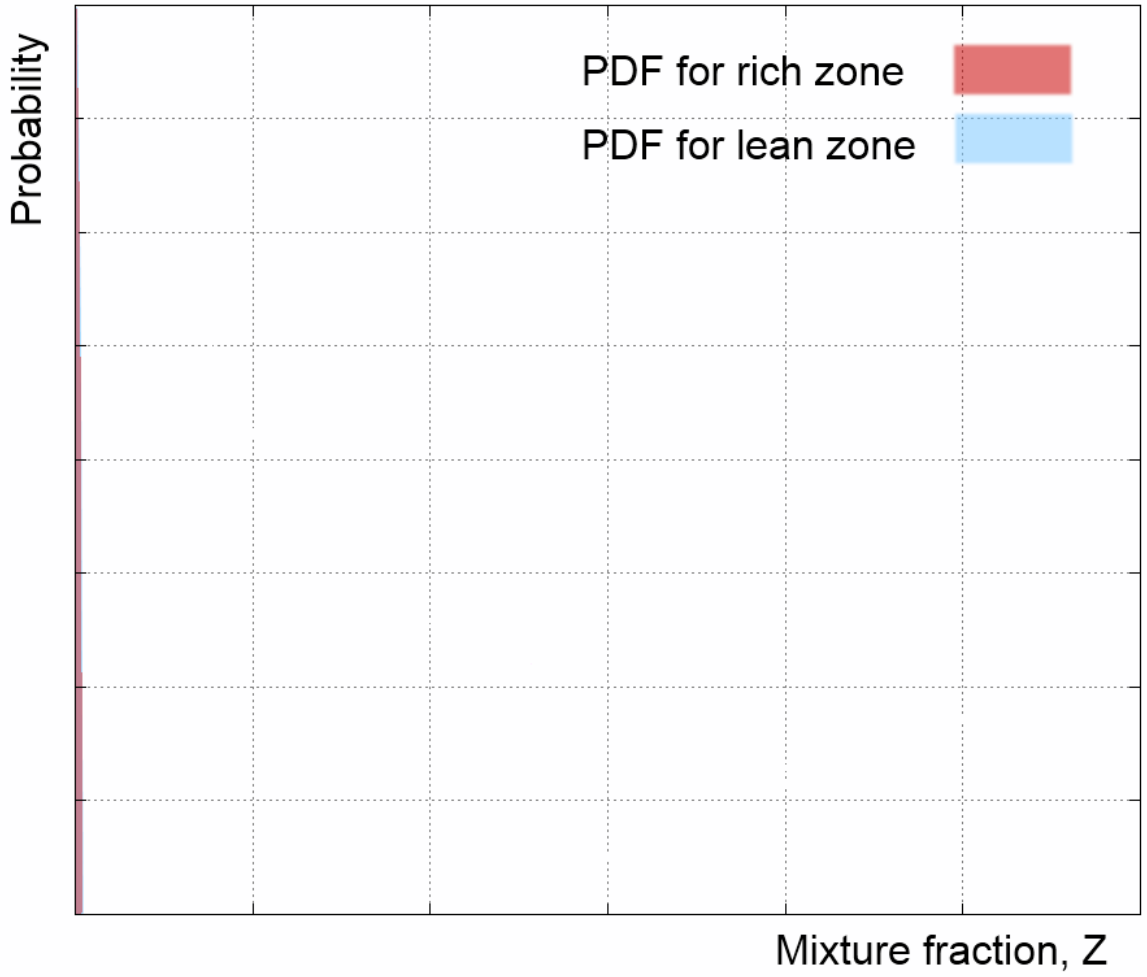




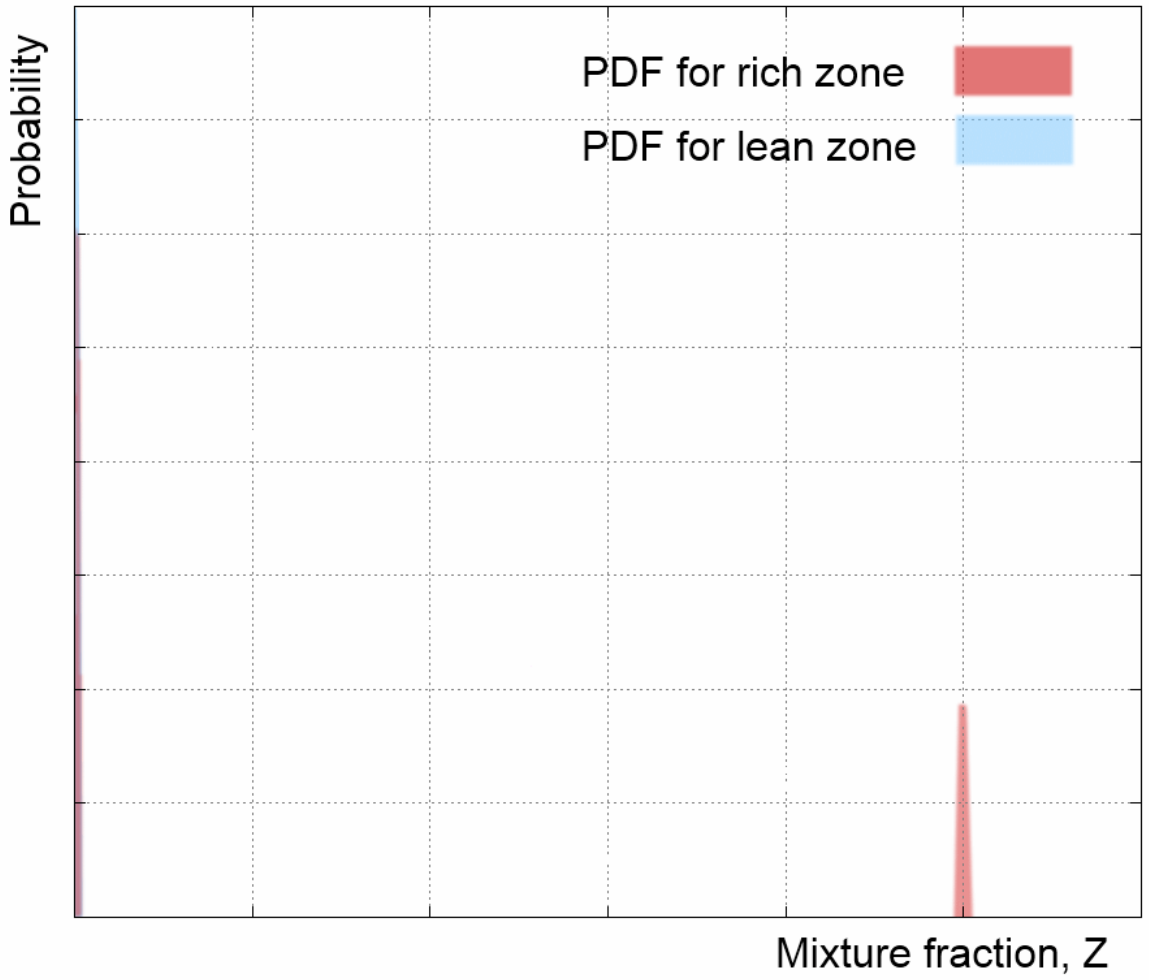
With the two-zone approach, each property of the gas is described by two superimposed PDF:s.

The total mass of background gas to be allocated into the fuel-rich zone is a user parameter, as is the scale factor for the amount of mixing between the zones.

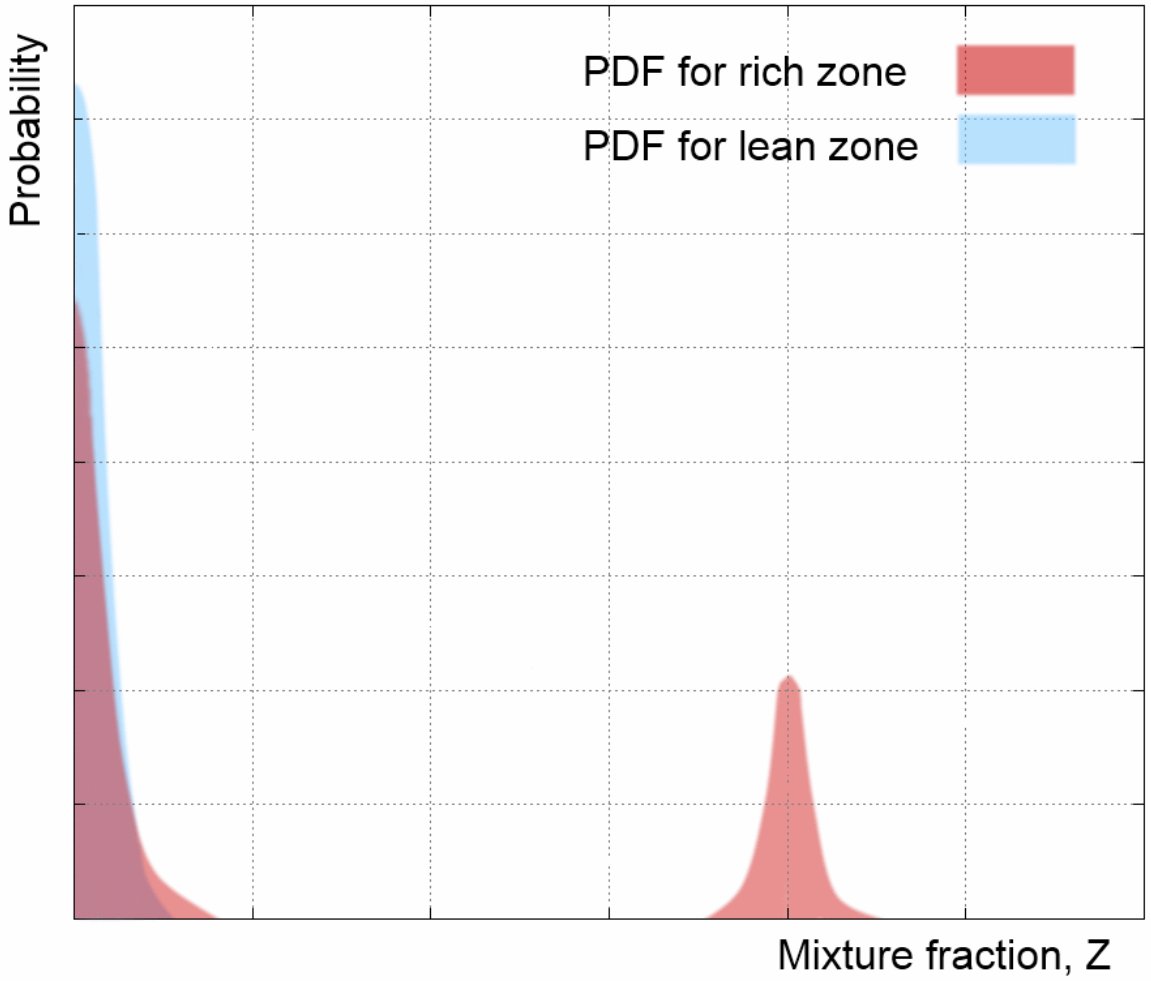
Two-zone PDF development



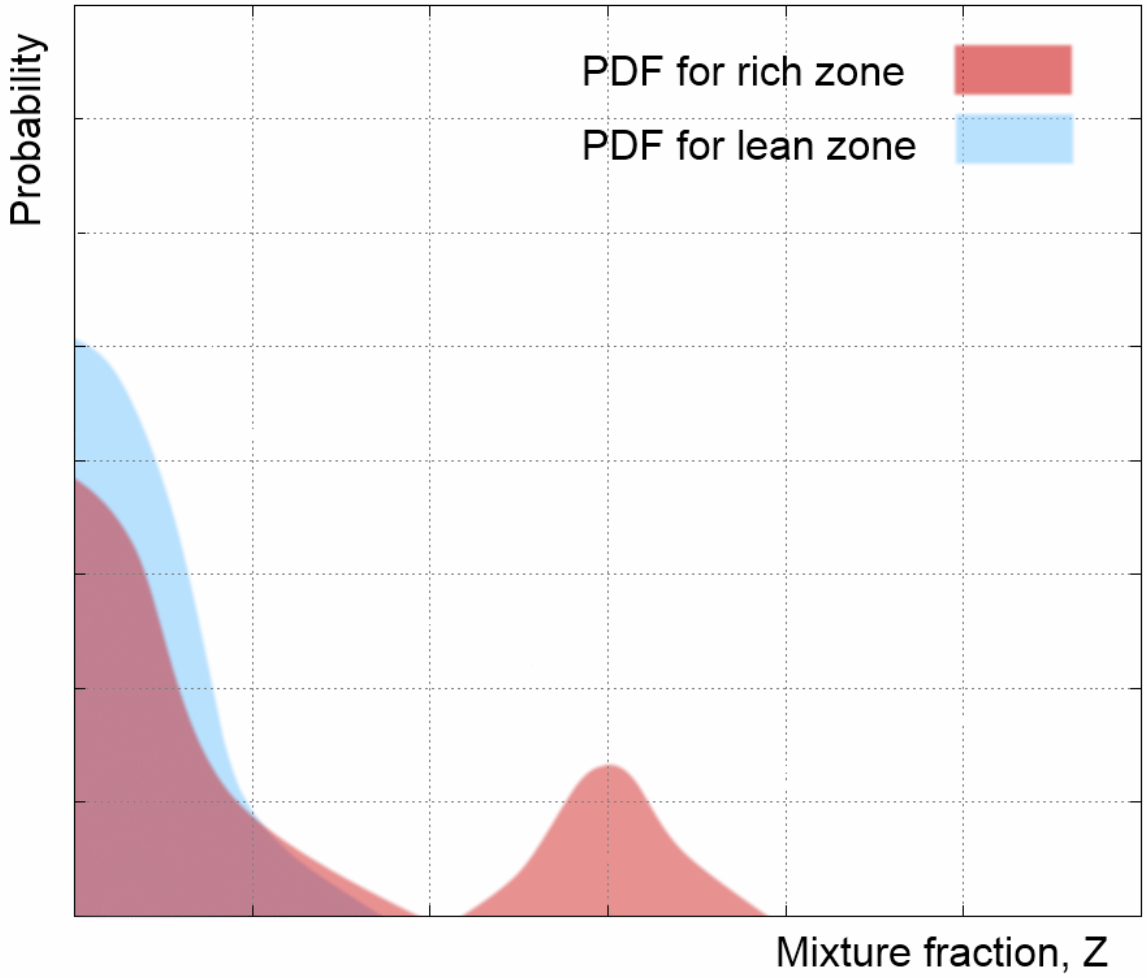
Two-zone PDF development



Two-zone PDF development

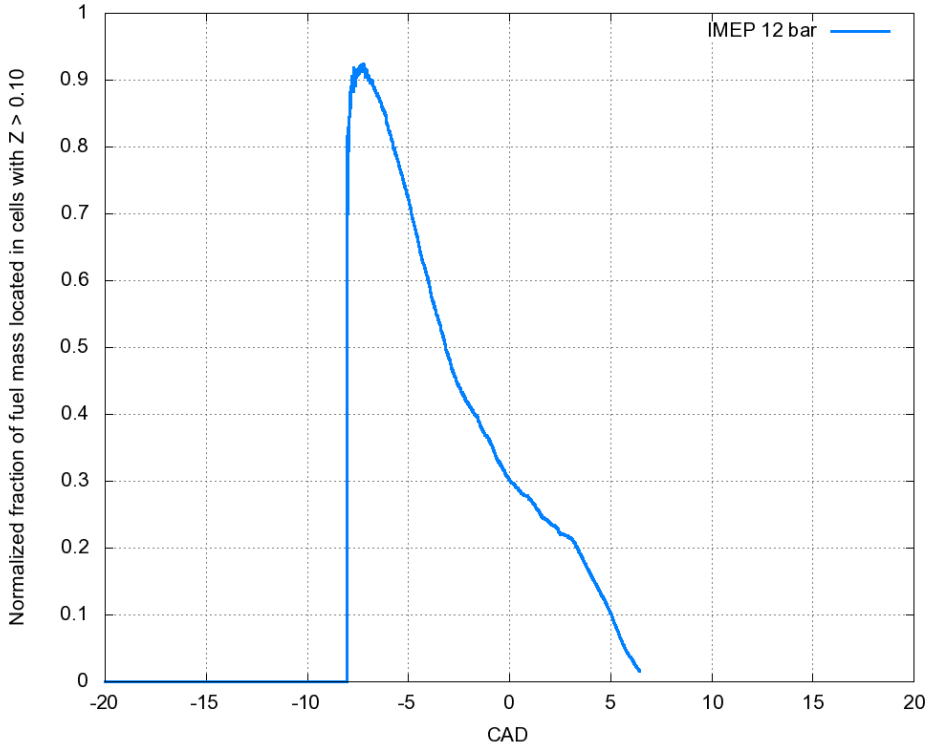


Two-zone PDF development



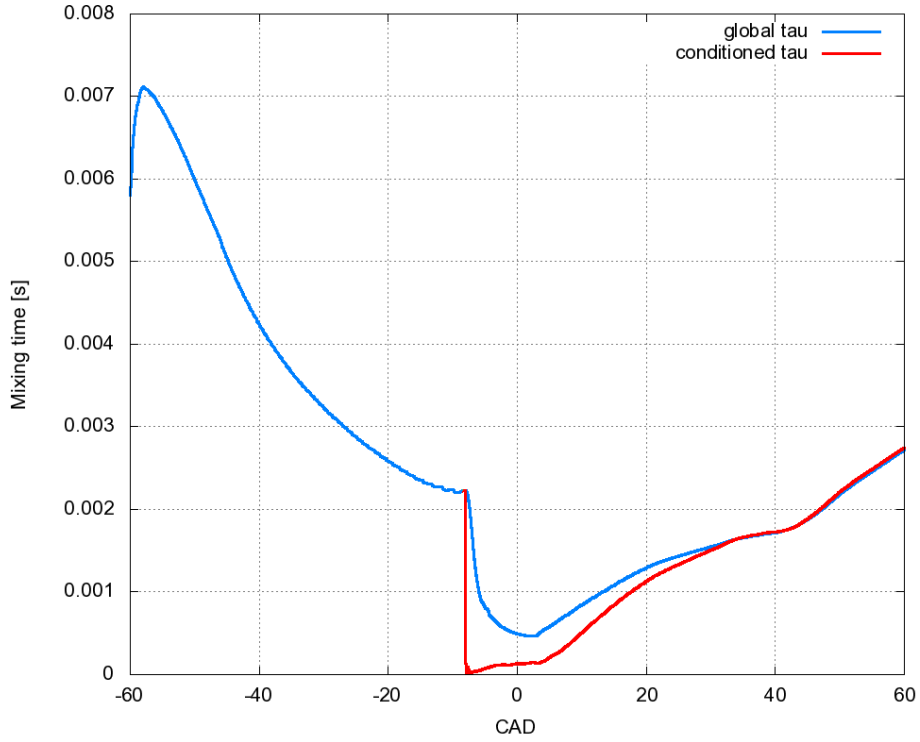
Fuel density distribution from CFD calculations

CFD calculations support the notion that a portion of the fuel is found in a localized rich zone for a significant amount of time after EOI. Zone volumes for the different operating points were approximated based on the Z distribution.



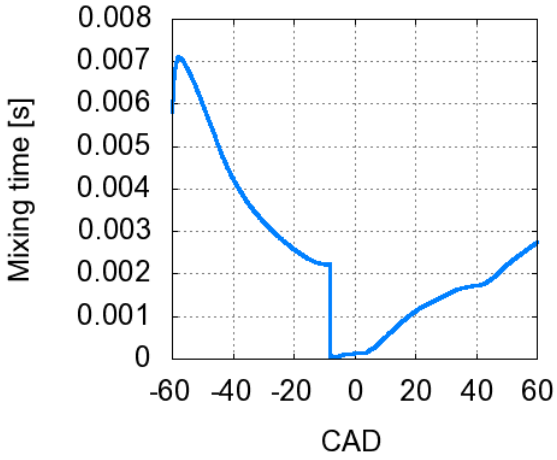
Turbulent mixing time from CFD calculations

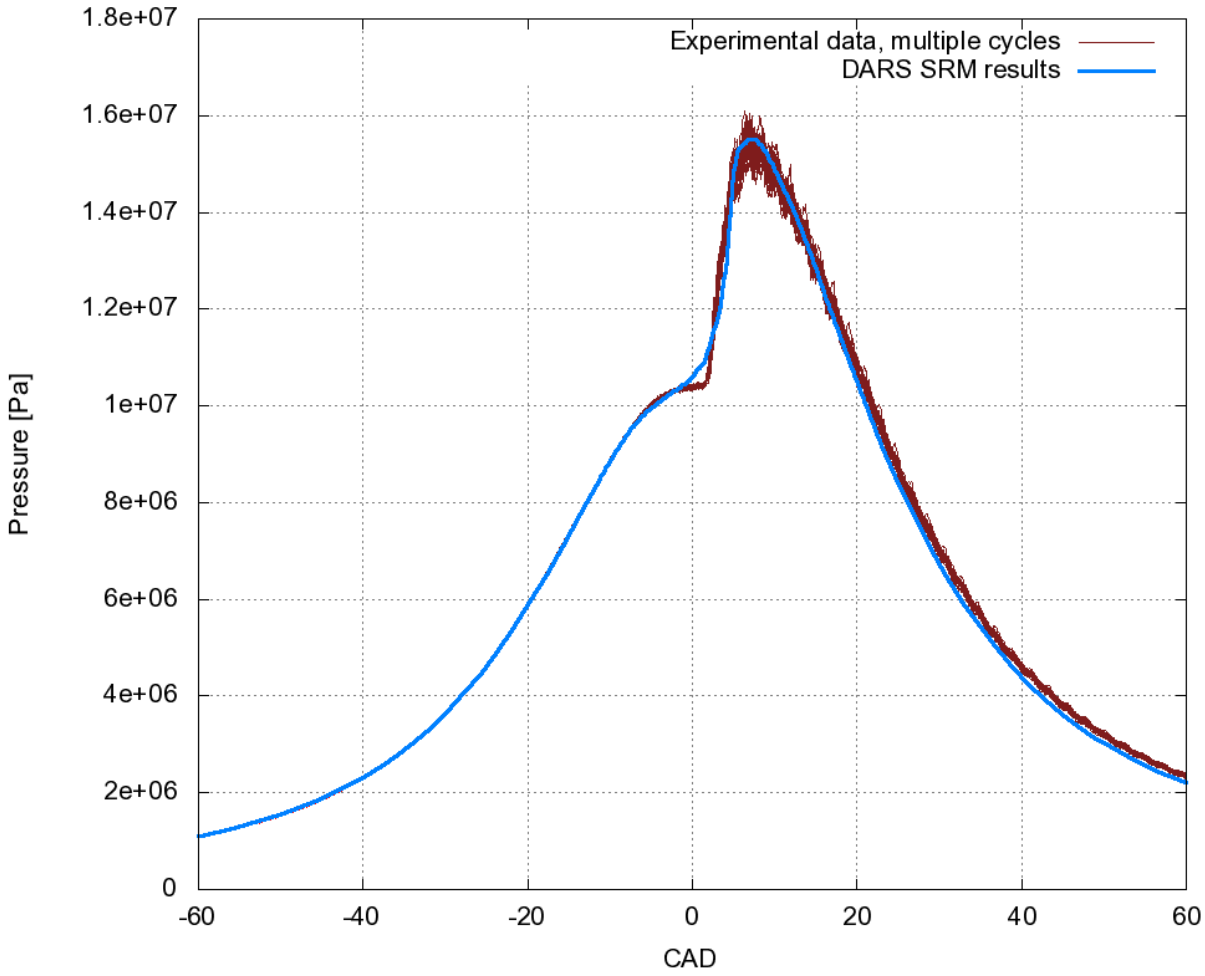
The mixing time is taken from CFD calculations for each respective operating point. In order to model the mixing within the rich zone, tau profiles conditioned on mixture fraction 0.06 to 0.08 were used.



Case 1 – IMEP 12 bar

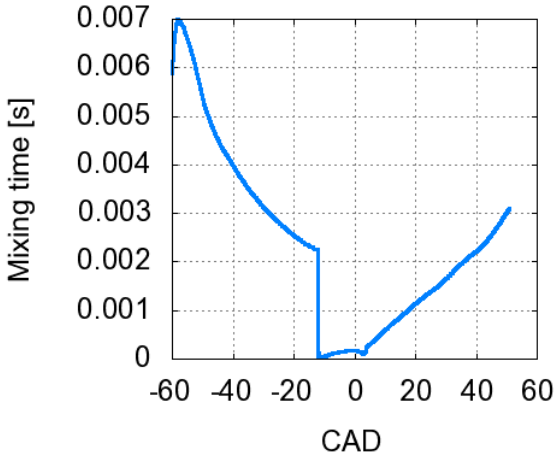
A good agreement was found using the CFD provided mixing time.

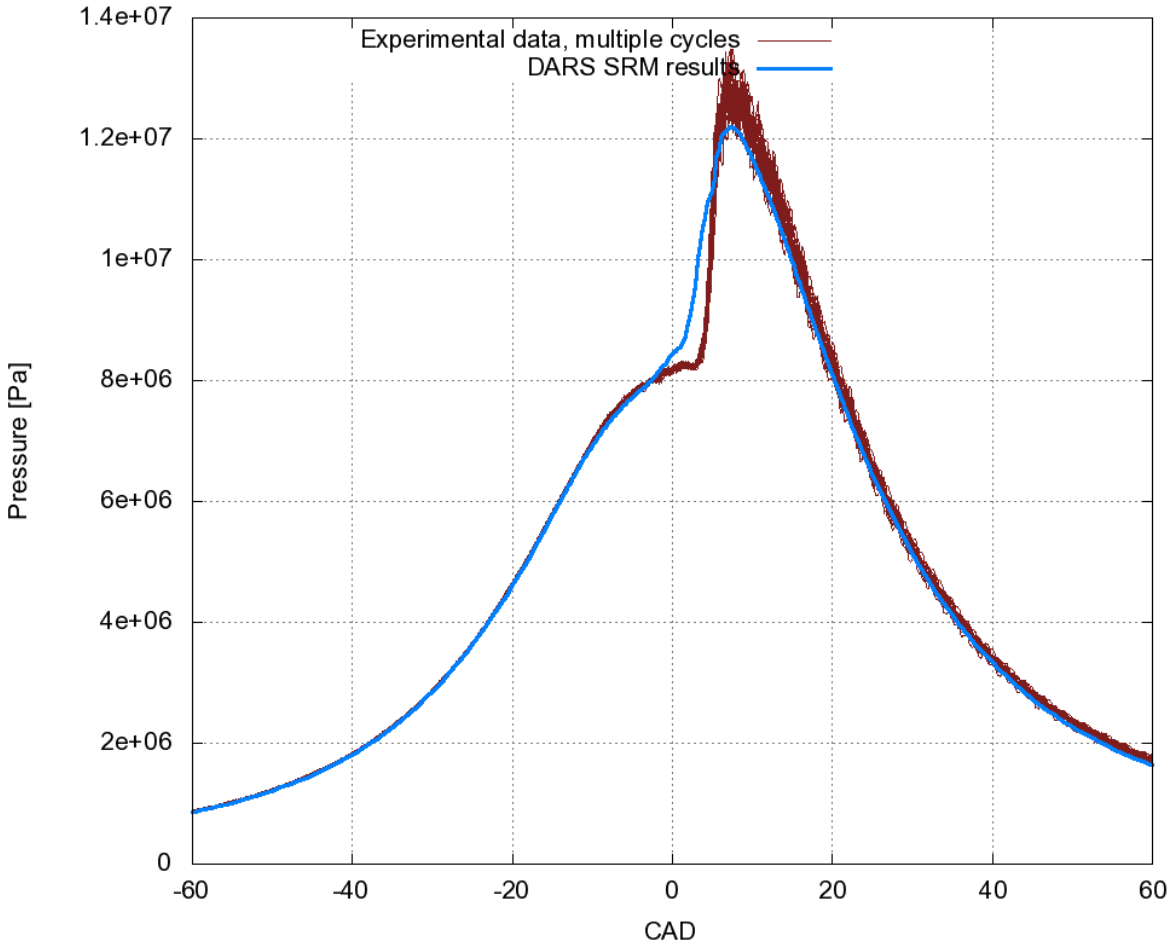




Case 2 – IMEP 8 bar

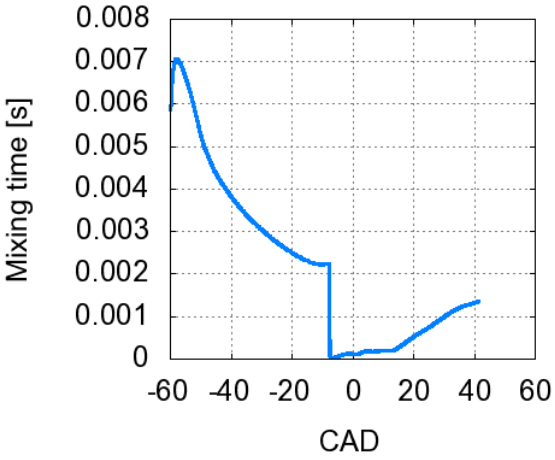
All relevant parameters except the turbulence profile and zone volume was kept constant between the cases.

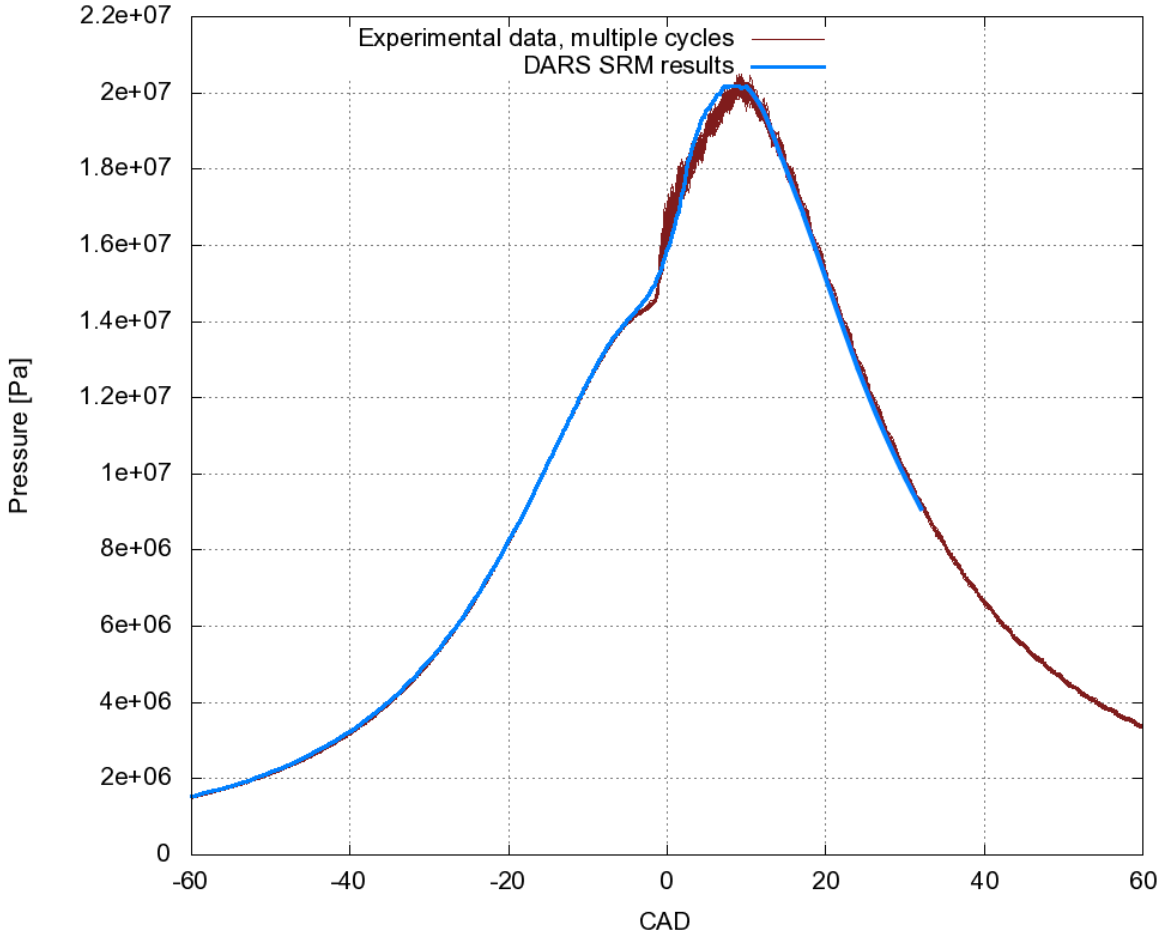




Case 3 – IMEP 26 bar

All relevant parameters except the turbulence profile and zone volume was kept constant between the cases.





Sum up and conclusions

3D combustion CFD generate statistical input data for the 0D combustion model

- **With the right statistical parameters we can create a 0D combustion model capable of PPC simulation**
- **A 2-zone stocastic approach is required to match CFD data**
- **The Stocastic approach enables the use of big enough kinetic mechanisms**
- **The stocastic approach enables the combustion model integration in GT-Power**

Acknowledgements

This material is based upon work supported by

- Department of Energy National Energy Technology Lab under Award Number DE-EE0004232
- Department of Energy National Energy Technology Lab under Award Number DE-FC26-07NT43222