TOWARDS IMPROVED SPRAY MODELS FOR HANDLING COMPLEX ENGINE GEOMETRIES

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Acknowledgements

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Summary - Motivation

- Internal injector scales can differ from combustion engine scales by 2-3 orders of magnitude

- Realistic engine geometries require non-axial grids and the limited flow field resolution near the injector can affect spray simulations

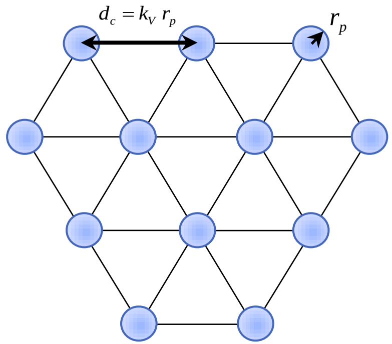
Reduce the dependency of spray predictions on grid resolution through an improved sub-grid-scale representation of the spray jet flow field

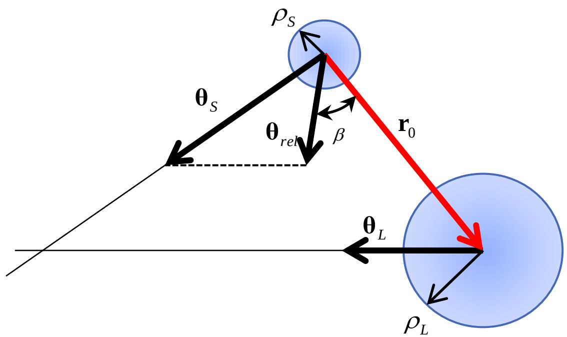
Improve the computational efficiency of the methodology to adopt more realistic numbers of particles

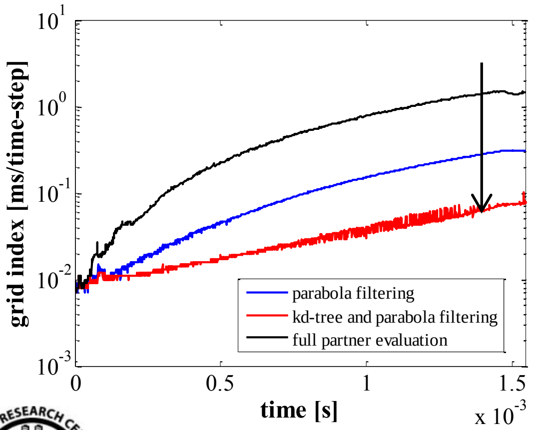
Long-term goal: Predictive multi-physics modeling of ICE flows, sprays, and combustion

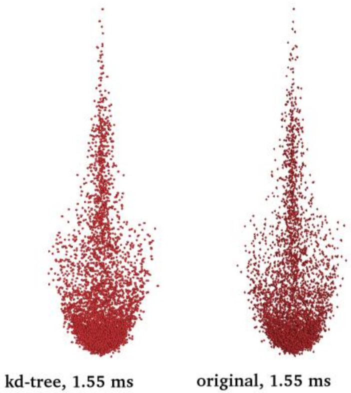
Efficient grid-independent collision modeling

- Tetrahedralization of the drop-in-parcel representation for fast ROI calculation
- Deterministic collision parameter estimation allows efficient pre-processing using data-mining techniques









Non-vaporizing, no-breakup simulation time

reduced by 2 o.m.

'full blob' case with 21k parcels

Sub-grid scale modeling of transient gas-jet

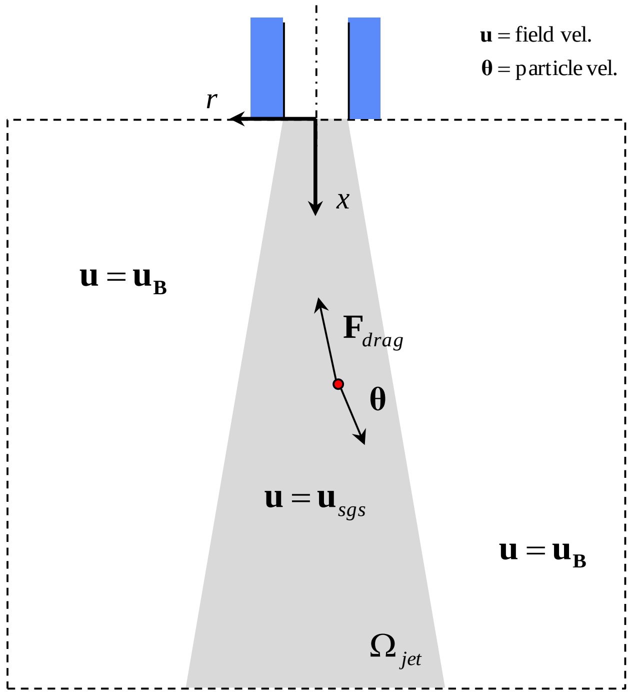
- A time-resolved sub-grid scale gas-jet model to cope with underresolved grid near the nozzle

$$\begin{cases}\boldsymbol{\theta}_B = \dfrac{\boldsymbol{\theta}'_n + \Delta t\, d_{p,sgs}\left(\boldsymbol{\theta}_t + \mathbf{u}_{sgs}\right)}{1+\Delta t\, d_{p,sgs}} \\ \left(m_B + S_{uvw}\right)\mathbf{u}_B - m_n \mathbf{u}_n = \mathbf{E} - \mathbf{r}_\mathbf{u}\end{cases}$$

$$\downarrow$$

$$S_{uvw} = \sum_{p \in i4} \begin{cases} \dfrac{4}{3}\pi \rho_p N_p r_B^3 \dfrac{\Delta t\, d_p}{1+\Delta t\, d_p}, & \mathrm{p} \notin \Omega_{\mathrm{jet}} \\ 0, & \mathrm{p} \in \Omega_{\mathrm{jet}} \end{cases}$$

$$\mathbf{r}_u = \sum_{p \in i4} \begin{cases} \dfrac{4}{3}\pi \rho_p N_p \left(r_B^3 \dfrac{\boldsymbol{\theta}'_n + \Delta t\, d_p \boldsymbol{\theta}_t}{1+\Delta t\, d_p} - r_n^3 \boldsymbol{\theta}'_n \right), & \mathrm{p} \notin \Omega_{\mathrm{jet}} \\ \dfrac{4}{3}\pi \rho_p N_p \left(r_B^3 \dfrac{\boldsymbol{\theta}'_n + \Delta t\, d_p \left(\boldsymbol{\theta}_t + \mathbf{u}_{sgs}\right)}{1+\Delta t\, \mathrm{d_p}} - r_n^3 \boldsymbol{\theta}'_n \right) & \mathrm{p} \in \Omega_{\mathrm{jet}} \end{cases}$$



Solution within the jet region provided by the analogy

$$\frac{f_v x}{u} = Strouhal \approx Stokes = \frac{\tau_I}{\tau_p}$$

Sub-grid scale modeling of transient gas-jet

- Transient turbulent gas-jet velocity field of Abani and Reitz, PoF2007

$$\mathbf{u}_{axis}(x,t)=\mathbf{u}_{inj}(t_0)+\int_{t_0}^{t}\left[1-\exp\left(-\frac{\tau-t_0}{St\left(x-x_{inj}\right)}\left\|\mathbf{u}_{inj}(\tau)\right\|\right)\right]\frac{\partial\mathbf{u}_{inj}(\tau)}{\partial\tau}d\tau,$$

$$\mathbf{u}_{sgs}(x,r,t)=\frac{f_{entr}(x)\mathbf{u}_{axis}(x,t)}{\left(1+\frac{12r^2}{x^2K_{entr}^2}\right)^2}$$

$\downarrow$

Model parameters

- **St** = Stokes number = spatial response time
- $\mathbf{K_{entr}}$ = Entrainment constant = turbulent dispersion due to viscosity
- $\mathbf{f_{entr}}$ = how much of the momentum actually transfers to the gas phase

GA study of spray model constants

- Multiple interacting spray models → hard to isolate the effects of each model
- Hard to validate each of these isolated phenomena against experiments
- May be aided by future DNS simulations

↓

A GA optimization to answer these questions:

→ What **parameter regions** should we move in?

→ When we used to calibrate the spray constants, how much were we **tweaking the gas-phase** prediction too?

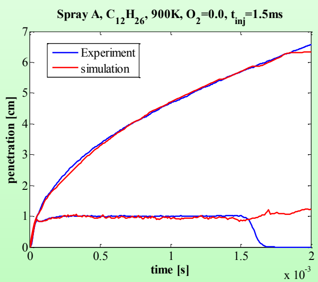
→ Is there an **optimal calibration set**, and, does this include "historically used" values or does it suggest new ones, which better fit the newest and highly confident Sandia experiments?

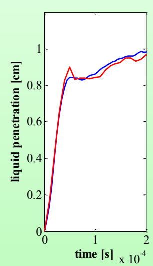
GA study of spray model constants

6 model variables

Variable	name	std value	range	to
RT time constant	C_{RT}	1.0	0.05	50.0
RT wavelength cnst.	$C_{\Lambda RT}$	0.1	0.01	10.0
KH decay timescale cnst.	B_1	40.0	10.0	100.0
Gas-jet Stokes number	St	3.0	0.1	5.0
Gas-jet entrainment cnst.	K_{entr}	0.45	0.3	3.0
Max gas-jet velocity frac.	γ	0.6	0.2	0.9

5 Spray A objectives

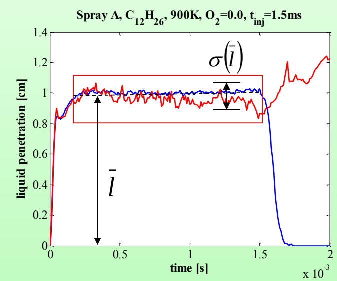


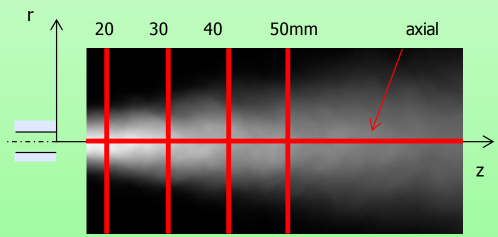


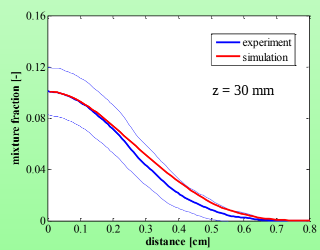
← Vapor penetration

← Liquid transient

S.S. liquid penetration & std. →



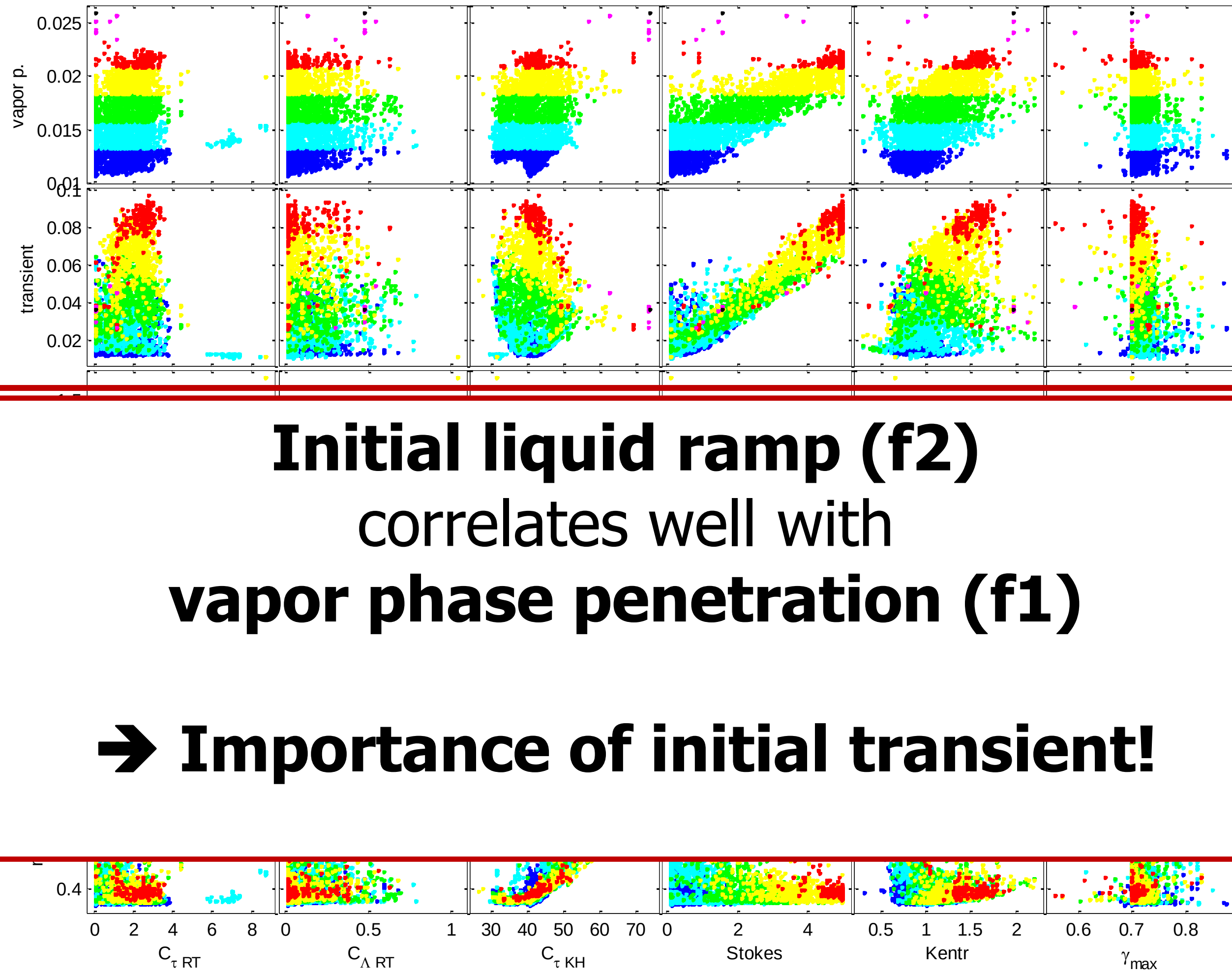




Mixture fraction distribution at 5 locations (4 radial + axis)

Pareto visualization – colored by vapor penetration merit

Merit functions



Initial liquid ramp (f2)

correlates well with

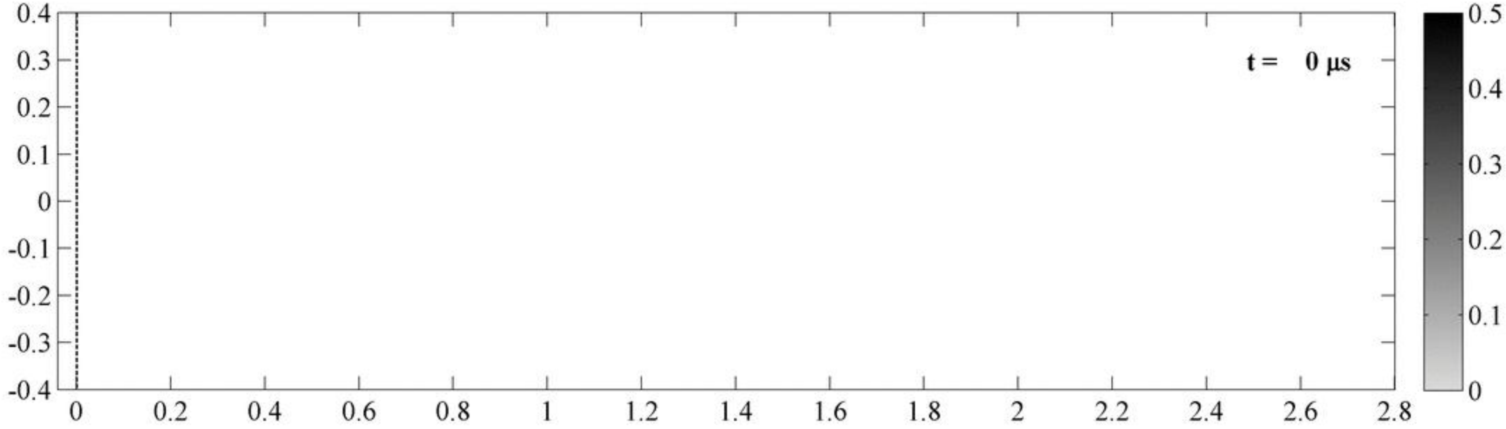
vapor phase penetration (f1)

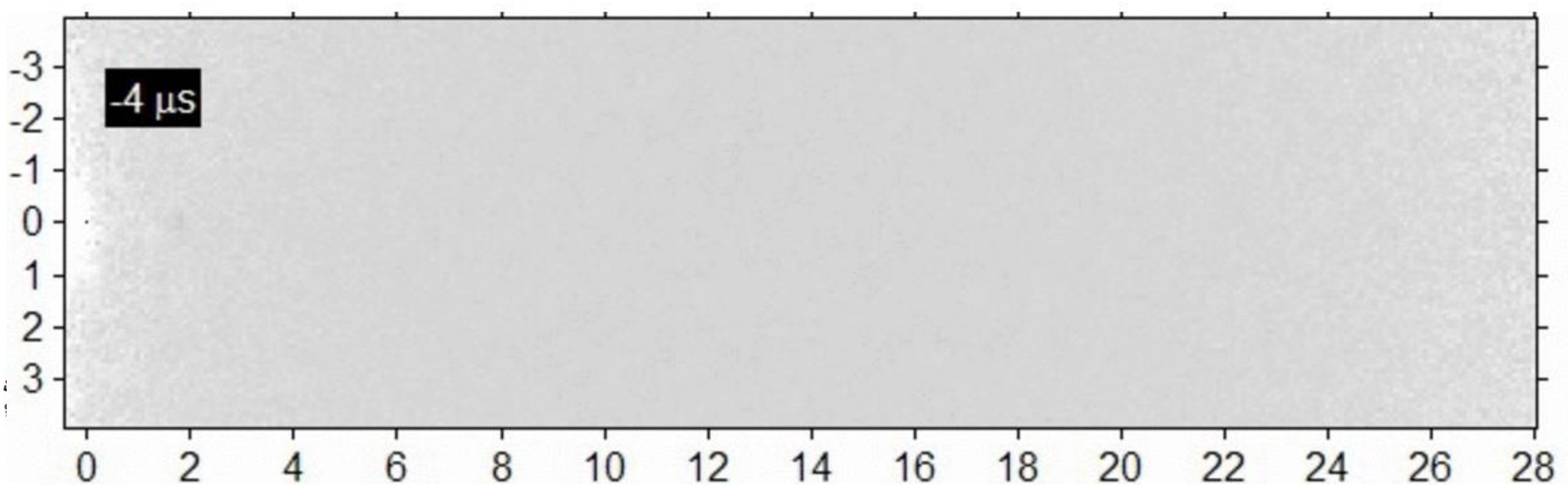
➔ Importance of initial transient!

Spray model constants

Liquid phase development

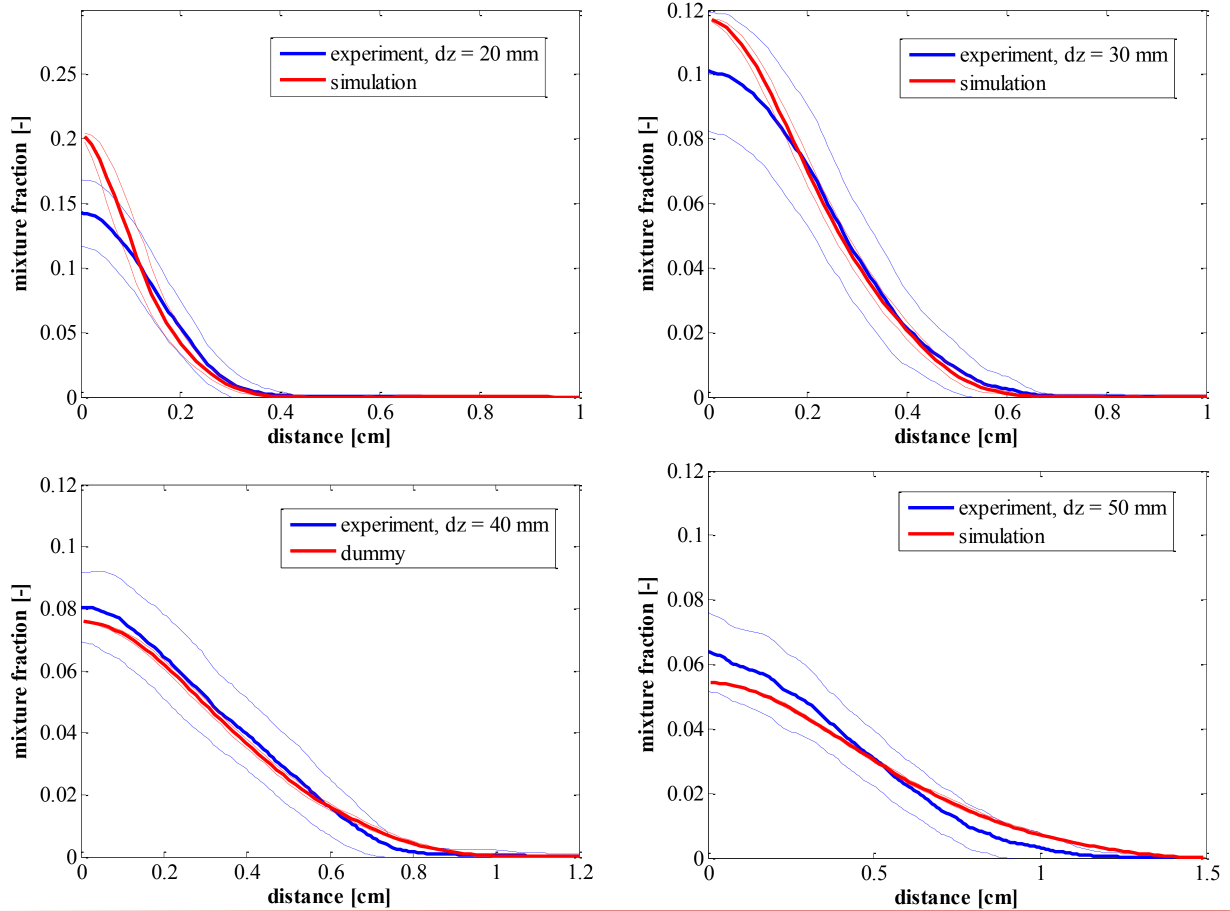
- How correctly are we comparing measured and simulated liquid length?
  - Exp datasets: Dashed line = penetration (Pickett et al., SAE2011-01-0686); Movie: Manin et al., COMODIA 2012
  - How to distinguish between tiny droplets after catastrophic breakup and gas phase at the tip?





Mixture fraction distribution

- k-epsilon turbulence models suffer from jet over-dispersion (Pope, 1978)
- GA has tuned spray parameters to compensate for this → good mixing downstream and far from axis



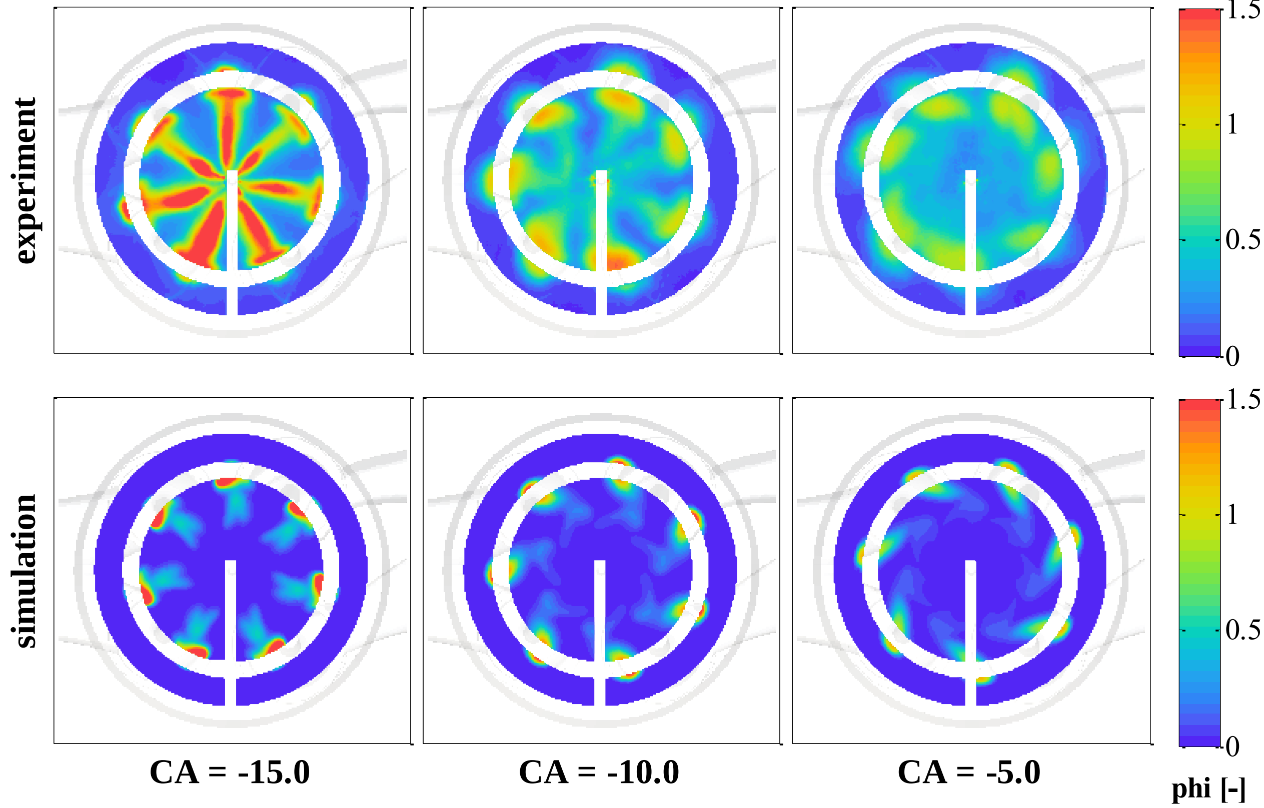
Mixture preparation in the SNL light-duty engine

■ Acknowledgements! ➔ Paul C. Miles, Dipankar Sahoo, Kan Zha, Stephen Busch

far from calibration injection pressure

p_{inj} = 500 bar

Squish plane



Mixture preparation in the SNL light-duty engine

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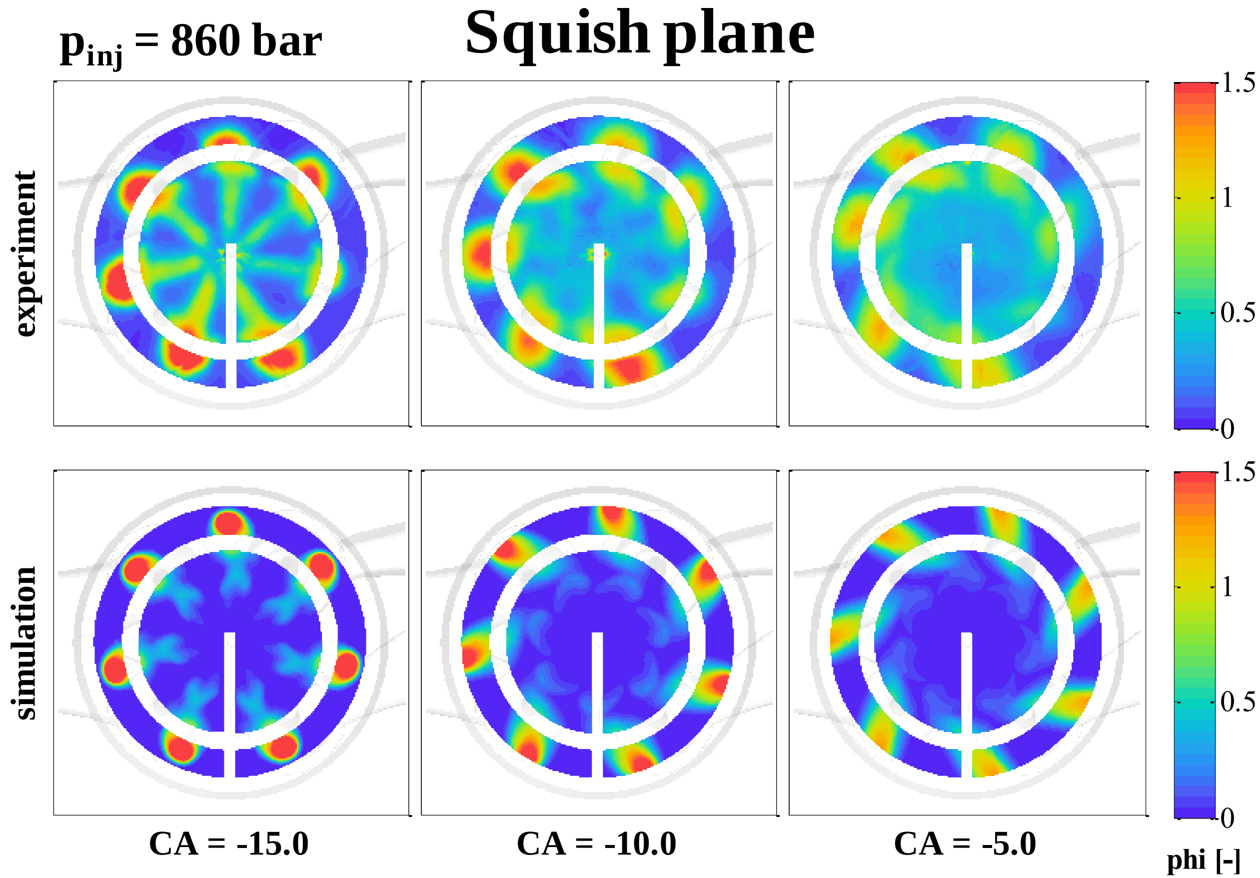
closer to calibration injection pressure



Mixture preparation in the SNL light-duty engine

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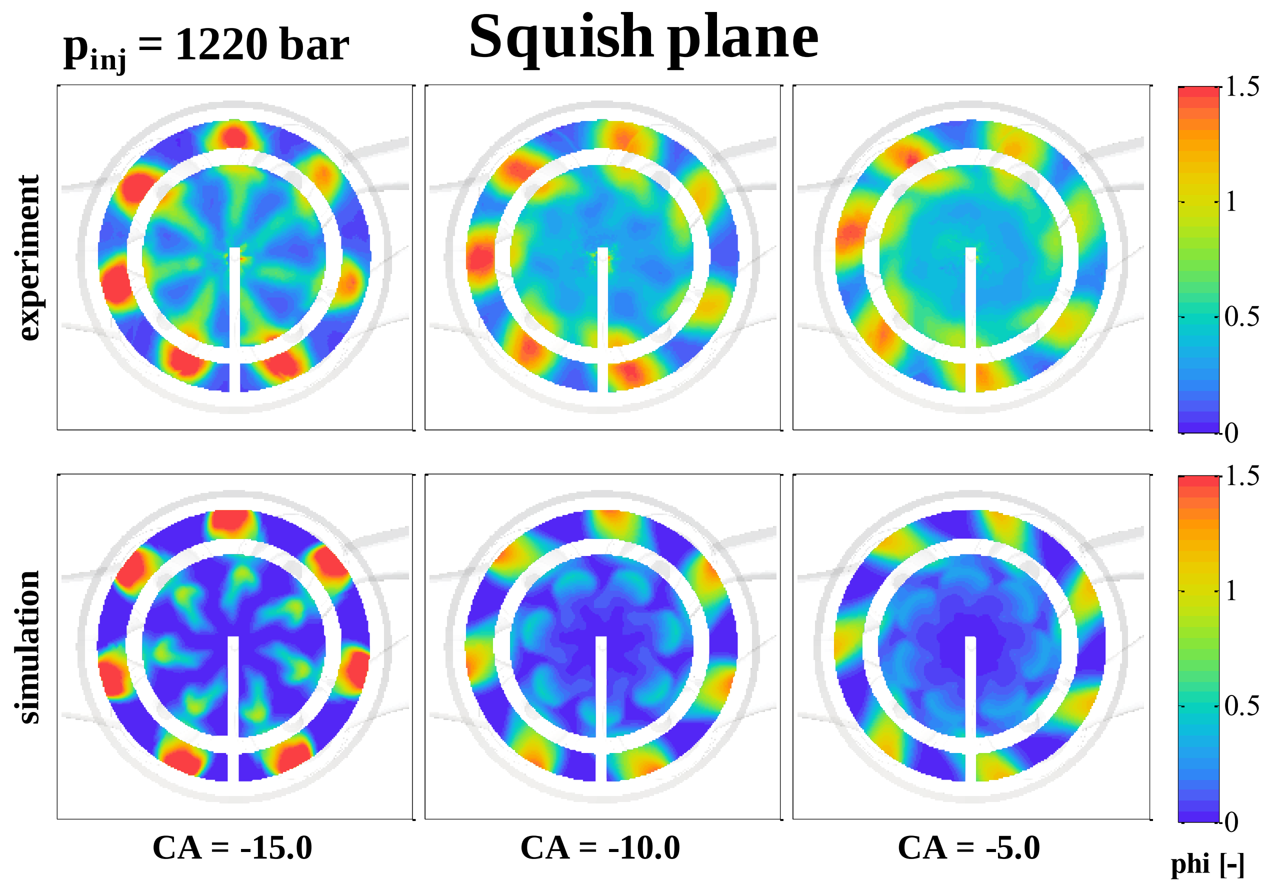
closest to calibration injection pressure

p_{inj} = 1220 bar



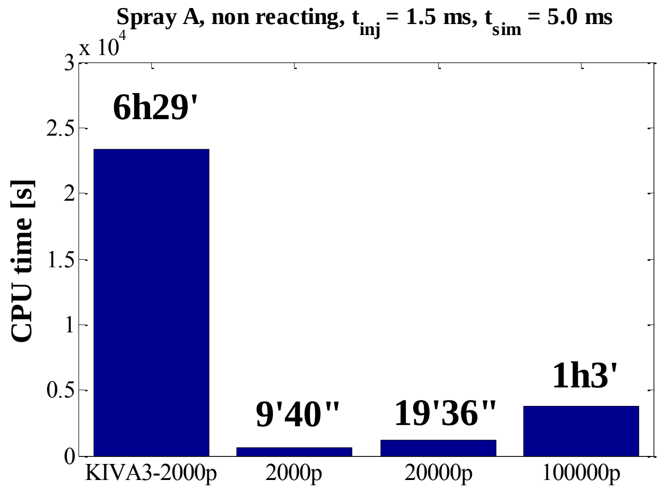
Conclusions

- Advanced spray models implemented and validated in structured geometries

- Still room for improvement
  - Reduction of numeric constants in the gas-jet model ← Extension of the gas-jet theory
  - Reduction of numeric constants in the atomization model ← We range extension of the KH-RT model

Now need to apply the validated models in more comprehensive modeling of local flow field and thermal quantities
→ full engine geometry and full (multiple) cycle simulations

- The model seems to be fast enough for it



References

Perini, F. and Reitz, R.D.,

"Improved atomization, collision and sub-grid scale momentum coupling models for transient vaporizing engine sprays"

Int J Multiphase Flow, submitted, 2015

see you at SAE…

PFL140 Fluid flow Measurement & Analysis

Wed Apr 22, 1:00 PM, Room 413 A

Perini, F., Zha, K., Busch, S., Miles, P.C., and Reitz, R.D.,

"**Principal Component Analysis and Study of Port-Induced Swirl Structures in a Light-Duty Optical Diesel Engine**"

SAE paper 2015-01-1696