Implementation of UW-ERC Spray and Combustion Models to STAR-CD for Engine Simulations

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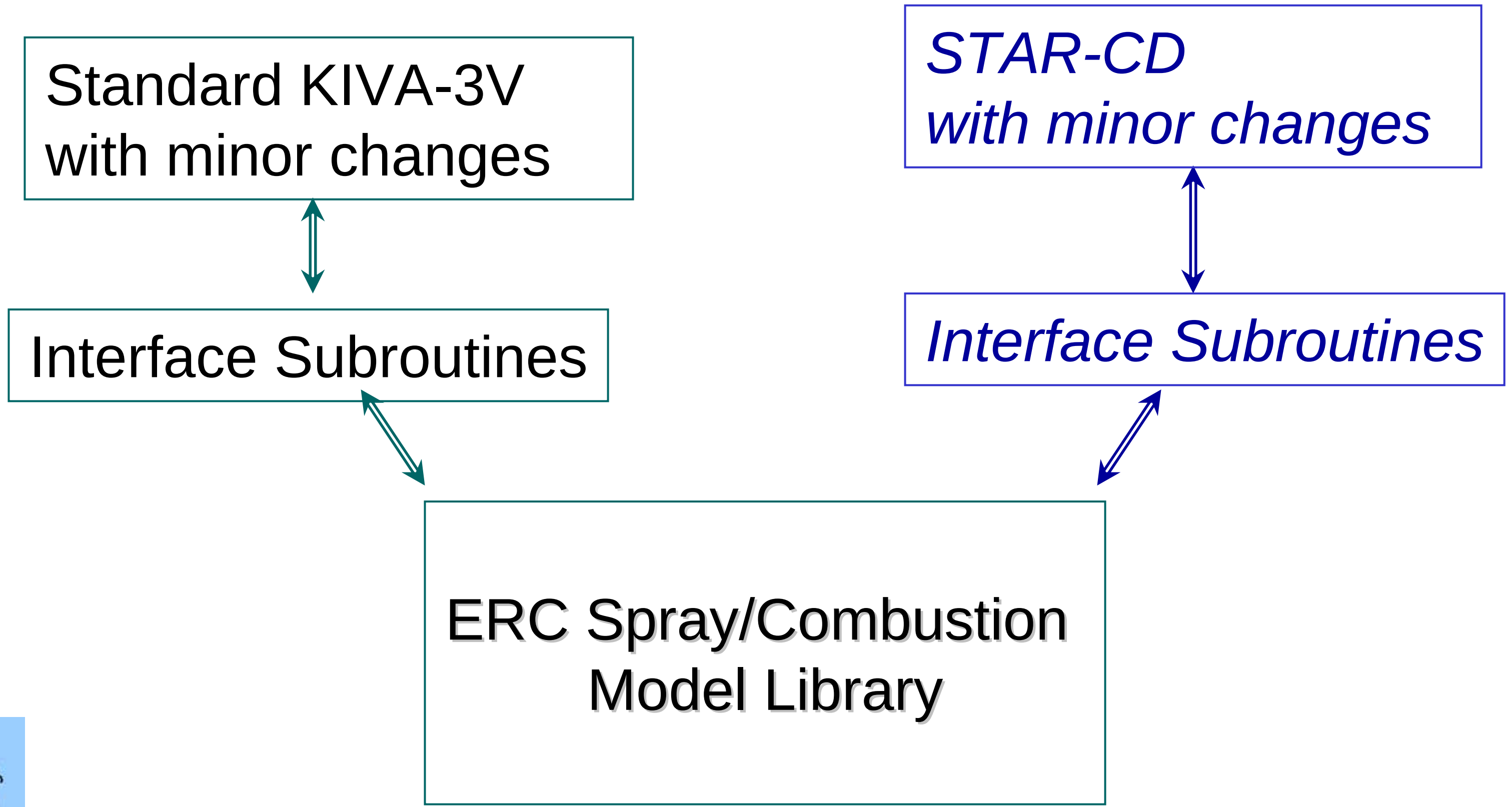
Background

- Provide alternative models to STAR for engine simulations
- Implement ERC models to STAR-CD
    - at the current stage, models include:
        - fuel atomization
        - ignition and combustion
        - soot and NOx emission models
- Minor code modifications are needed to use ERC models.

Model Formulation

- ERC models were originally developed with KIVA
- Proper interface subroutines are needed to use the ERC models



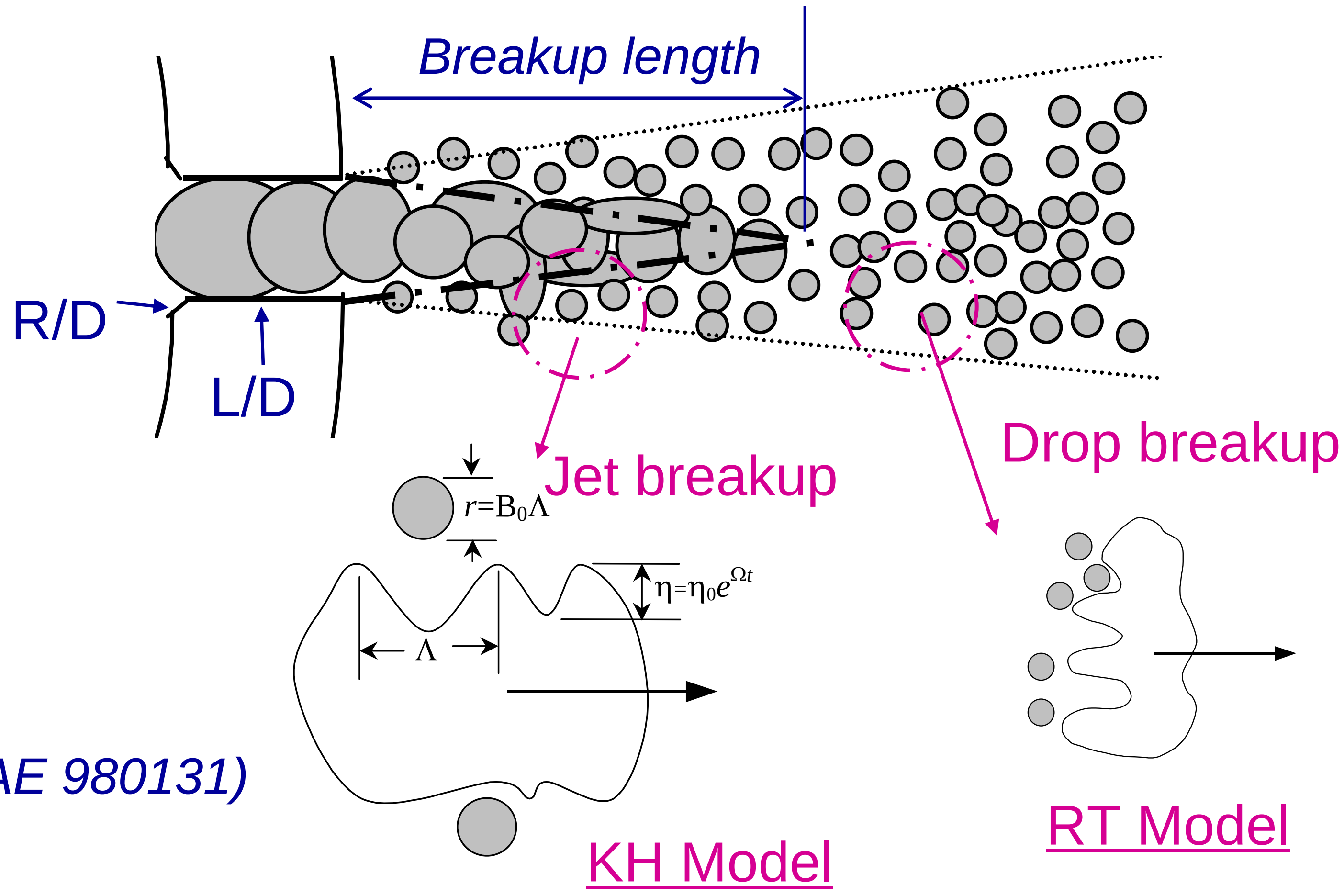
Model Implementation

- Available ERC Models

Process—Model	Current Implementation to STAR
Fuel injection—Nozzle flow cavitation model	
Fuel atomization—KH-RT drop breakup model	●
Fuel vaporization—Multi-component	
Spray/wall interaction	
Wall film—Liquid film model	
Auto-ignition—Shell Model	●
Combustion—Lam-turb-char-timescale model	●
Soot—formation vs. oxidation	●
NO*x*—Extended Zel'dovich	●
Other Combustion Model: PDF model, Flamelet model, Detailed chemistry model	
Heat transfer—unsteady wall heat flux	
Crevice flow model	
Gasoline hollow cone spray model	
Gasoline flame-kernel ignition model	

Spray Atomization Model

- Breakup induced by unstable surface wave
- Different types of breakup mechanism in different regimes
- Injection Schematic:



(SAE 980131)

Chemistry Models

- Shell Ignition Model
  - Generic species and generic reactions for HC fuels
  - Consider low-temperature chemistry
- Combustion Model
  - Use of laminar and turbulent characteristic timescales
  - Seven reactive species: fuel , O_2, N_2, CO_2, H_2O, CO, H_2
  - Compute equilibrium concentrations for species
  - Reaction rate: $$\frac{dY_i}{dt} = -\frac{Y_i - Y_i^*}{\tau_{lam} + f\tau_{turb}}$$

(SAE 950278, SAE 960633)

Emission Models

- Soot Model
  - Competing formation and oxidation rates
  - Consider two different reactive sites on soot surface for oxidation
  - Net soot formation rate: $dM_{net}=dM_{form} - dM_{oxid}$
- NOx Model
  - Extended Zeldovich mechanism
  - Account for OH radicals in the formation process

(SAE 950278, SAE 960633)

Engine Experiments

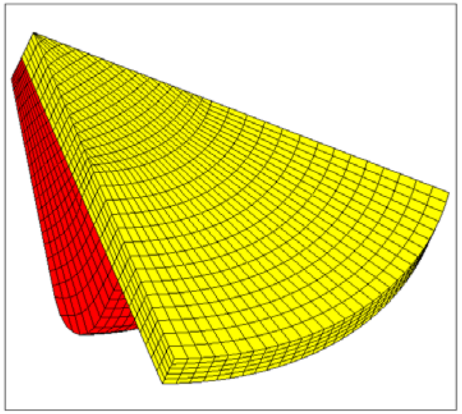
- Caterpillar 3400 Engine
  - single-cylinder; V_D=2.34 liters; CR=15.6
- Operating Conditions

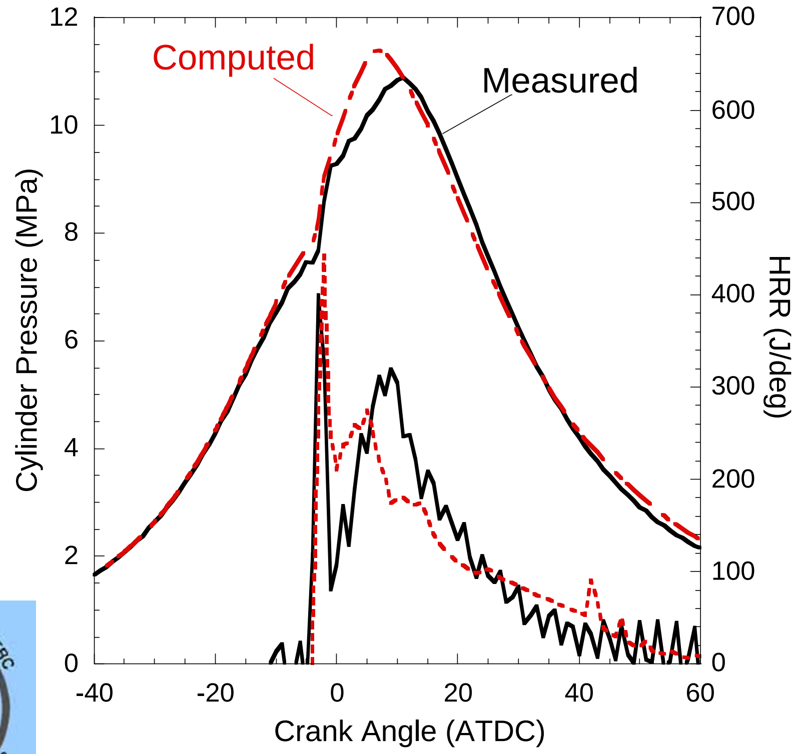
	load	rpm	injection scheme	SOI (atdc)
Baseline	75%	1600	single	-9
High load	75%	1600	single	-7, -4, -1, +2, +5
High load	75%	1600	split 12-(6)-13	-7, -4, -1, +2, +5
Low load	25%	1690	single	-9, -6, -3, +0, +3
Low load	25%	1690	split 9-(8)-5.25	-9, -6, -3, +0, +3

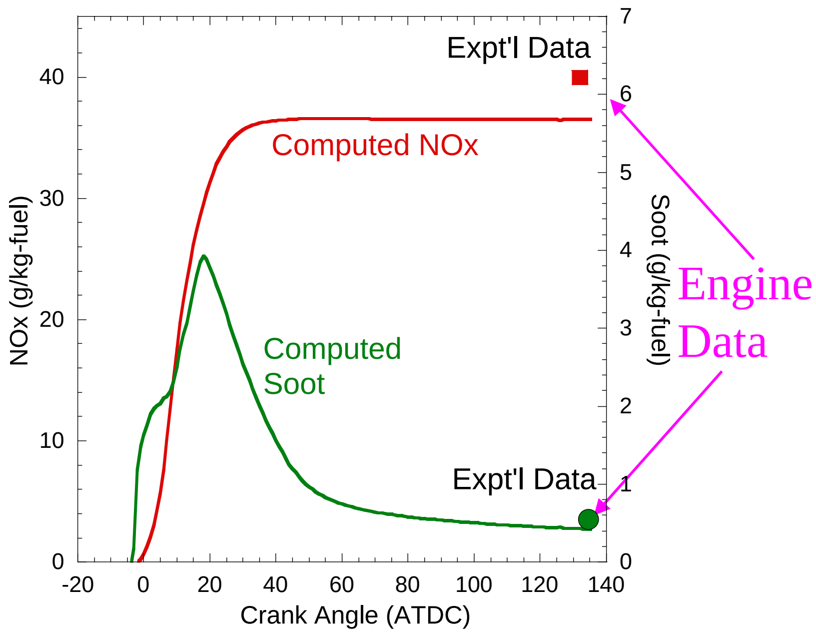
- Same model constants were used for all cases.

Baseline: Cylinder Pressure, HRR and Emissions

- 3-D, 60-degree sector mesh
- High Load (75%), Single Injection, SOI= -9 ATDC
- Baseline case to determine model constants

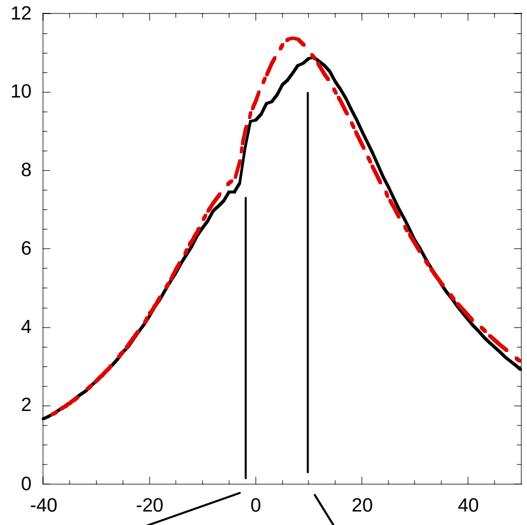






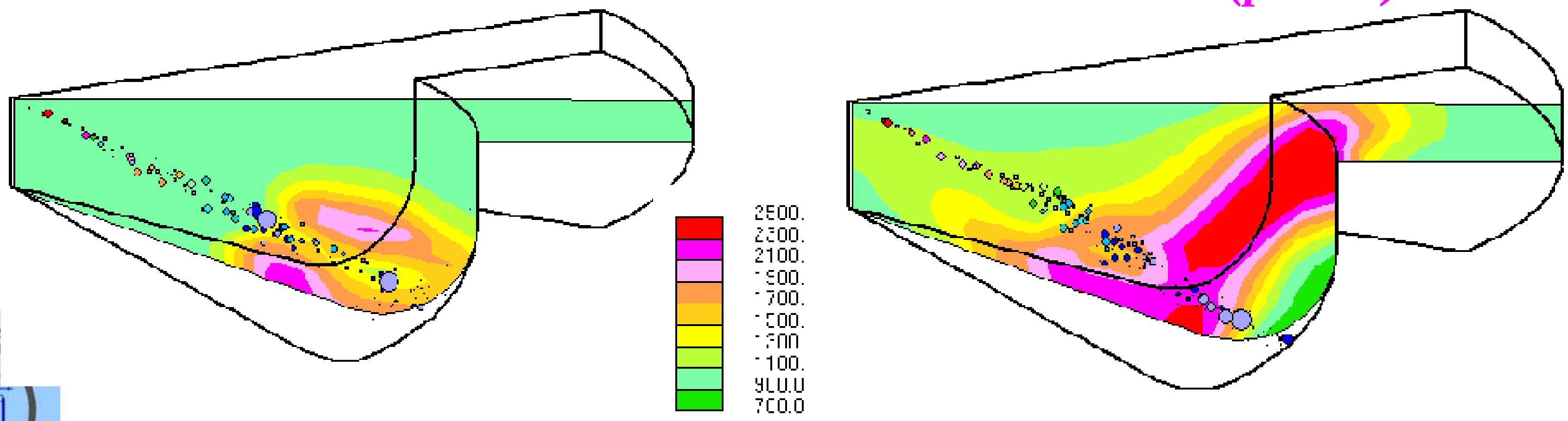
Baseline: Spray and Temperature

- Spray drop distribution
- Temperature contours on the middle plane



-2 ATDC (ignition)

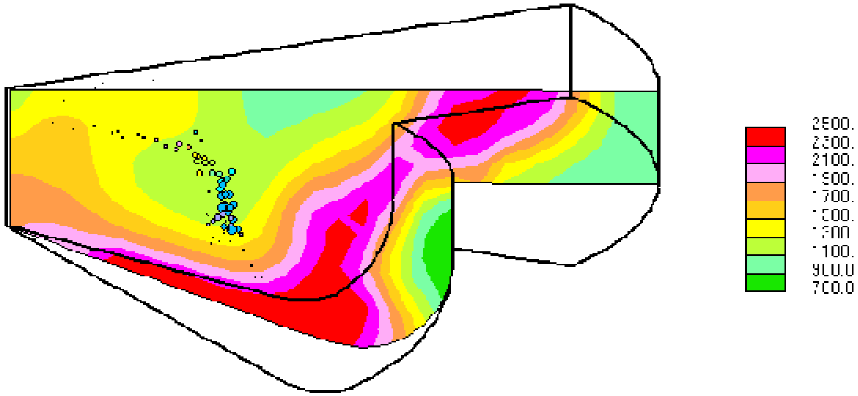
10 ATDC (peak P)



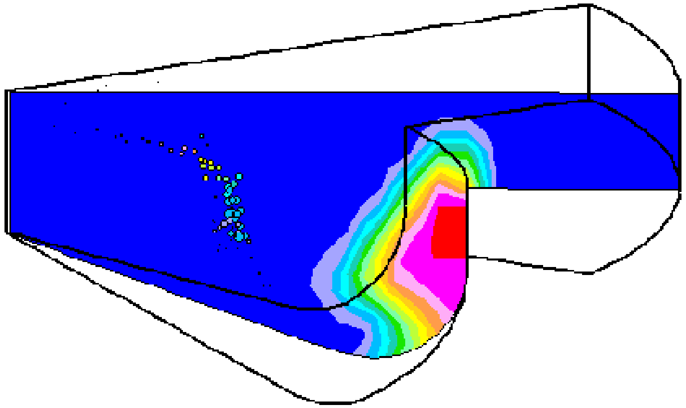
Baseline: Temperature and Emissions

- 20 ATDC

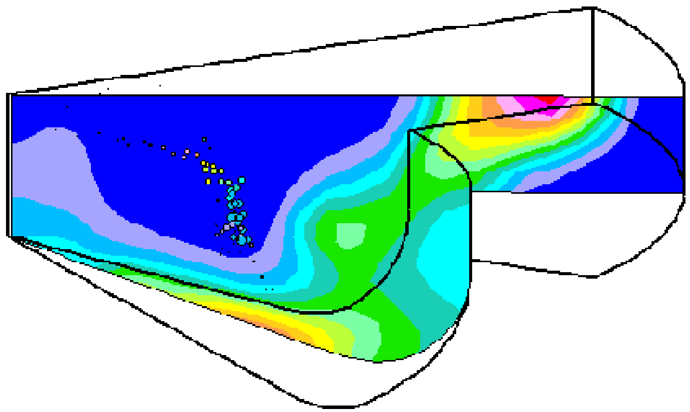
Temperature contours



Soot distribution



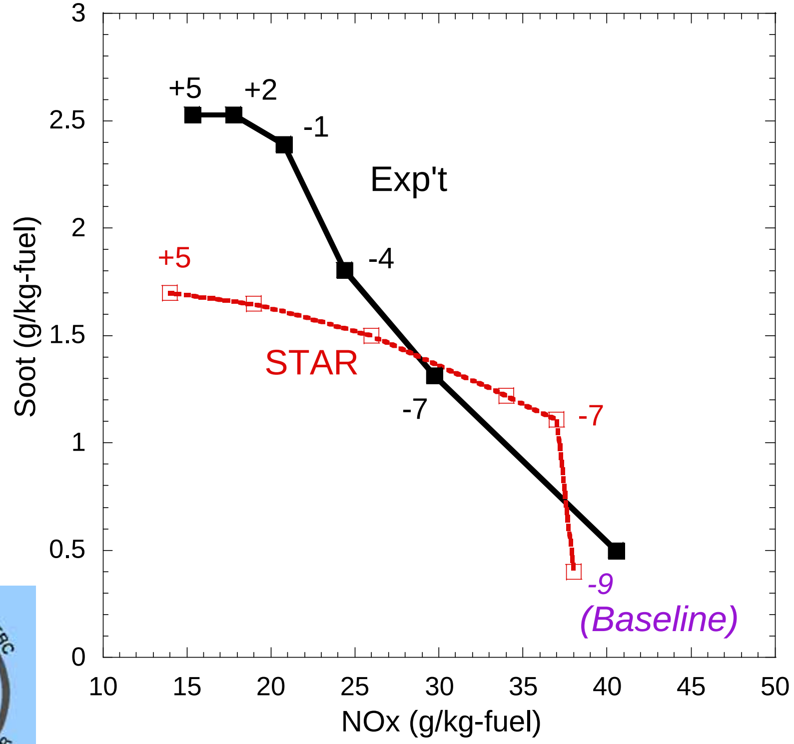
NO distribution



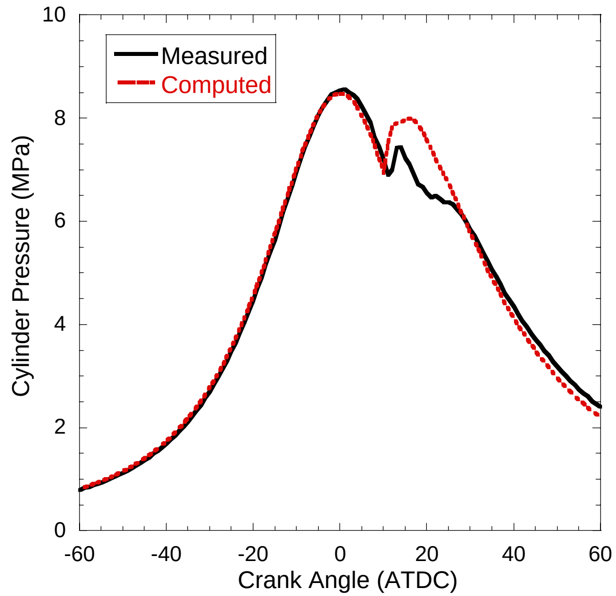
High Load, Single Injection

- SOI= -7, -4, -1, +2, +5 ATDC
- Injection duration 19.75 CAD
- Consistent model constants for all cases

Soot-NOx Results



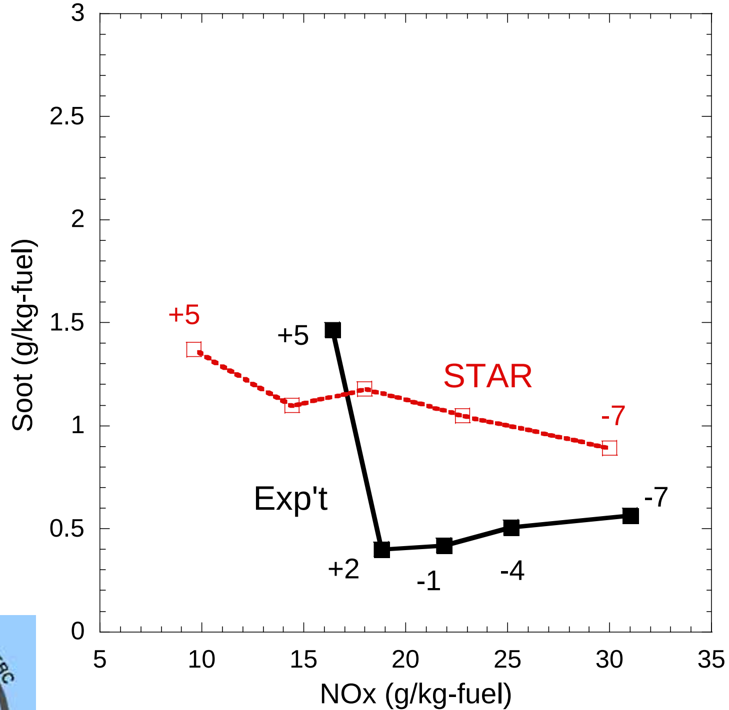
Example: SOI= +5.0
Cylinder Pressure



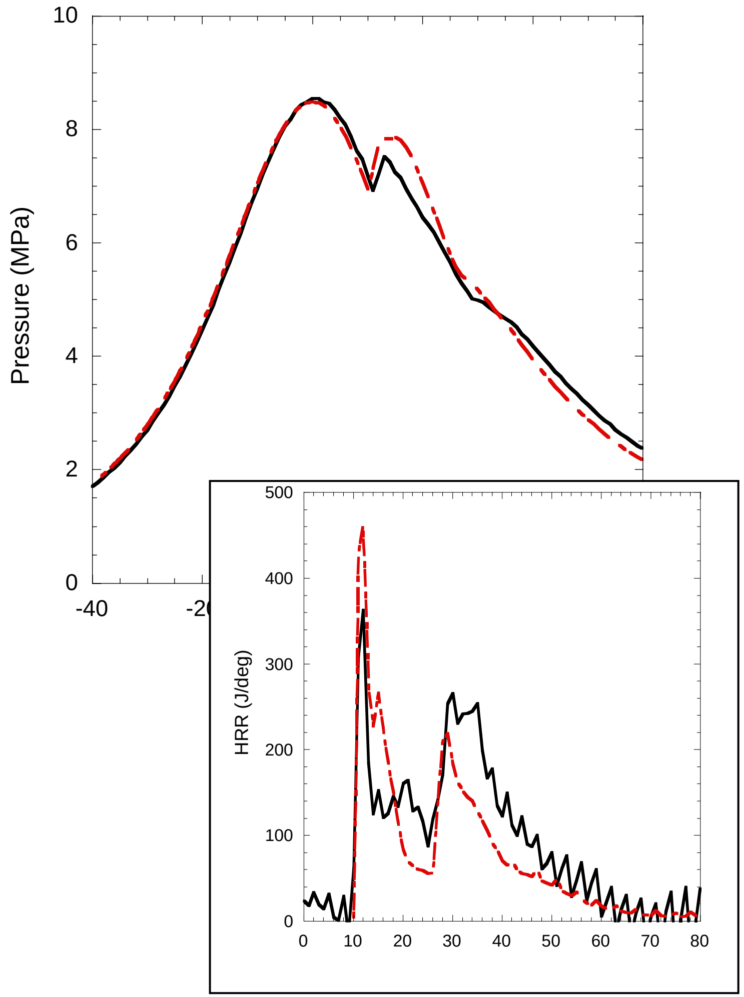
High Load, Split Injection

- SOI= -7, -4, -1, +2, +5 ATDC
- Injection Scheme: 12-(6)-13

Soot-NOx Results

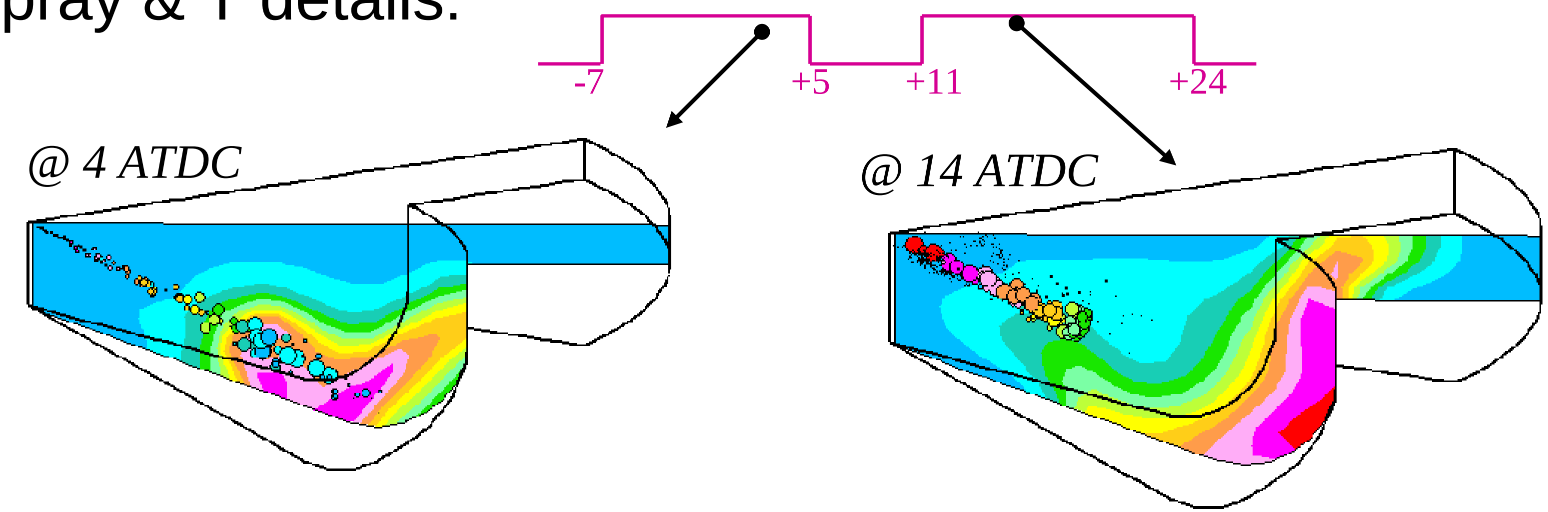


Example: SOI= +5.0
Cylinder Pressure & HRR

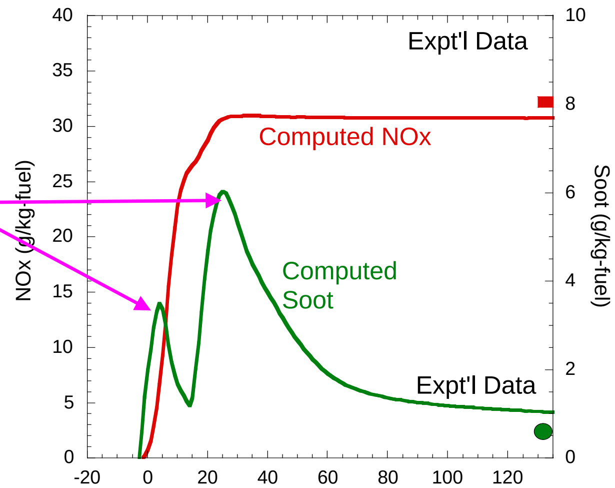


High Load, Split Injection

- Example: SOI= -7 atdc; Rate Shape: 12-(6)-13 deg.
- Spray & T details:



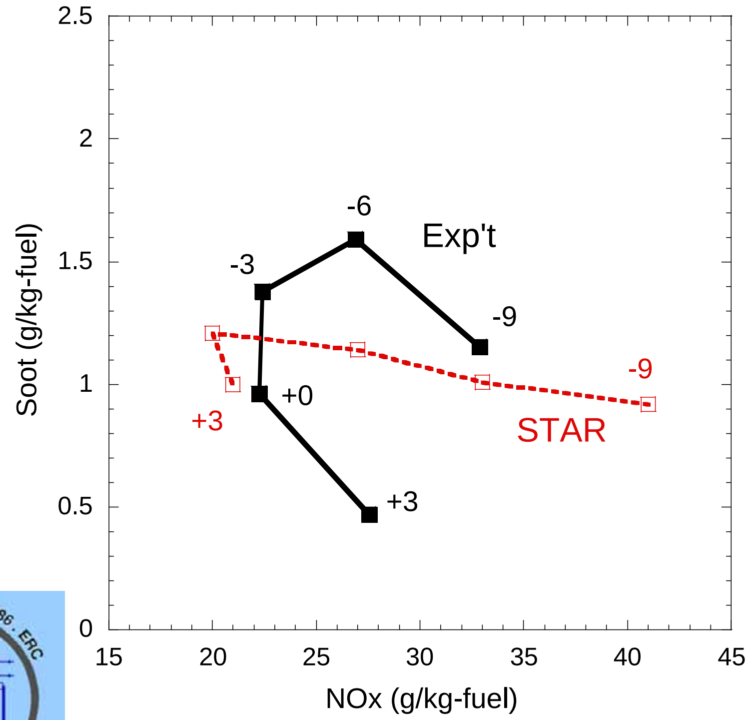
- Soot-NOx Evolutions
  - two peaks of soot
  - from two injection pulses



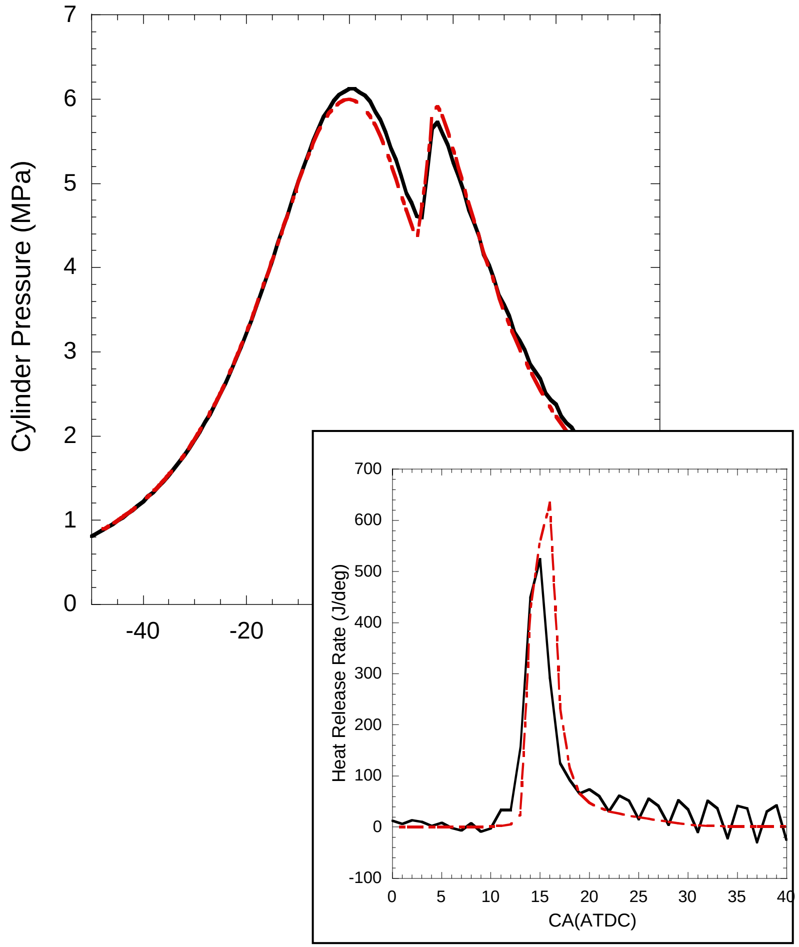
Low Load, Single Injection

- SOI= -9, -6, -3, +0, +3 ATDC
- Injection Duration: 9.75 CAD

Soot-NOx Results



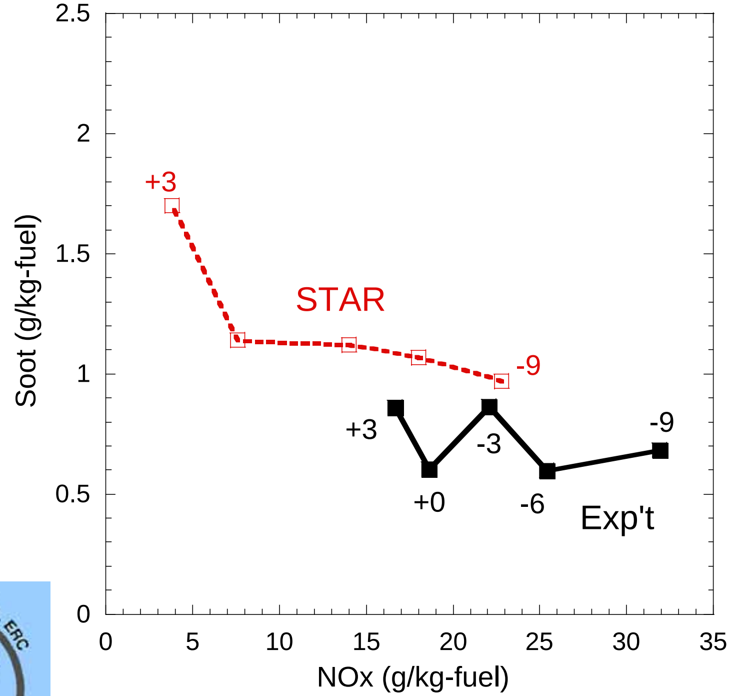
Example: SOI= +3.0
Cylinder Pressure & HRR



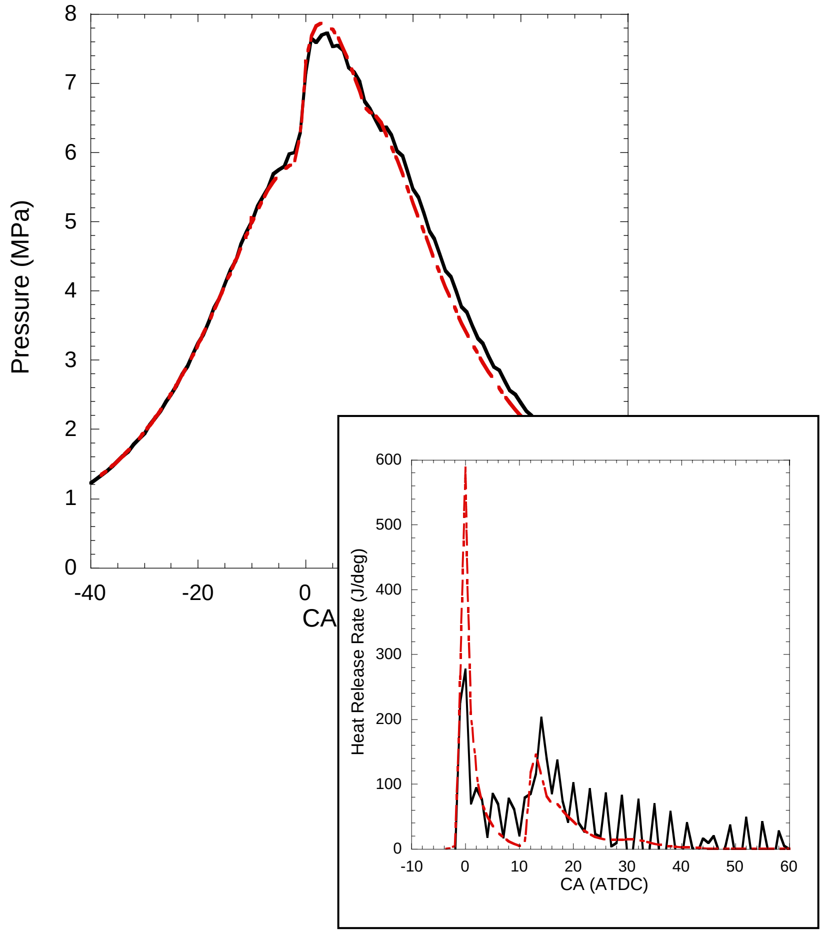
Low Load, Split Injection

- SOI= -9, -6, -3, +0, +3 ATDC
- Injection Scheme: 9-(8)-5.25

Soot-NOx Results



Example: SOI= -9.0
Cylinder Pressure & HRR



Conclusions

- Reasonable results by using ERC models with STAR
- Implementations of other models are under investigation
  – Other type of combustion models: PDF, Flamelets ...
  – Spray/wall impingement, wall-film models
  – Hollow-cone spray model for GDI engines
  – GDI ignition/combustion models
  – other models