Combustion Commonality and Differences Between HSDI and Heavy Duty Truck Engines

Rong Chen, Adedejo Oladipo, Brian Bolton, Nabil Hakim

Experimental understanding of the diesel spray and combustion process at the fundamental level has helped advance the virtual lab simulation tools. The computational fluid dynamics (CFD)-based simulation has been globally verified in many engines, providing substantial credibility to the use of this technology in advanced engine development.

This paper highlights the common aspects and differences between the small-bore HSDI and the larger displacement heavy-duty truck engine spray and combustion processes. Implications for combustion system strategies will be delineated. Detroit Diesel integrated “Wired” approach will be explained with pointers towards future tool enhancements.

DETROIT DIESEL CORPORATION

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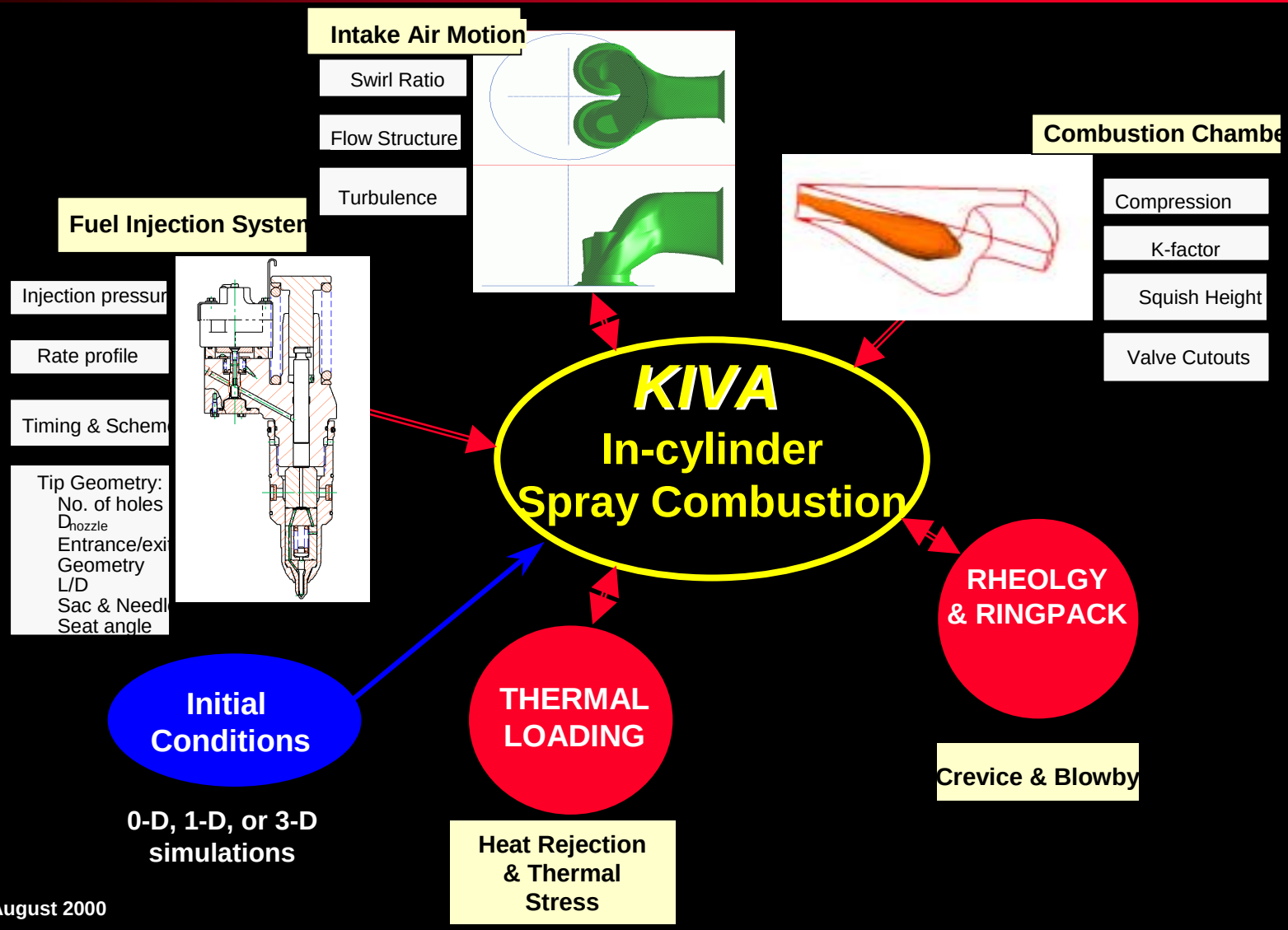
Outline

- Diesel Combustion Virtual-Lab Testing
- HSDI Vs. HD Engine Characteristics
- HSDI Vs. HD Combustion Characteristics
- Spray and Combustion Comparison
- Concluding Remarks

Diesel Combustion Virtual-Lab

- Integrated Toolbox for Thermofluids Simulation
- Virtual Hardware Testing at Selective Engine Operating Conditions
- Local Combustion Optimization with Experimental Validation

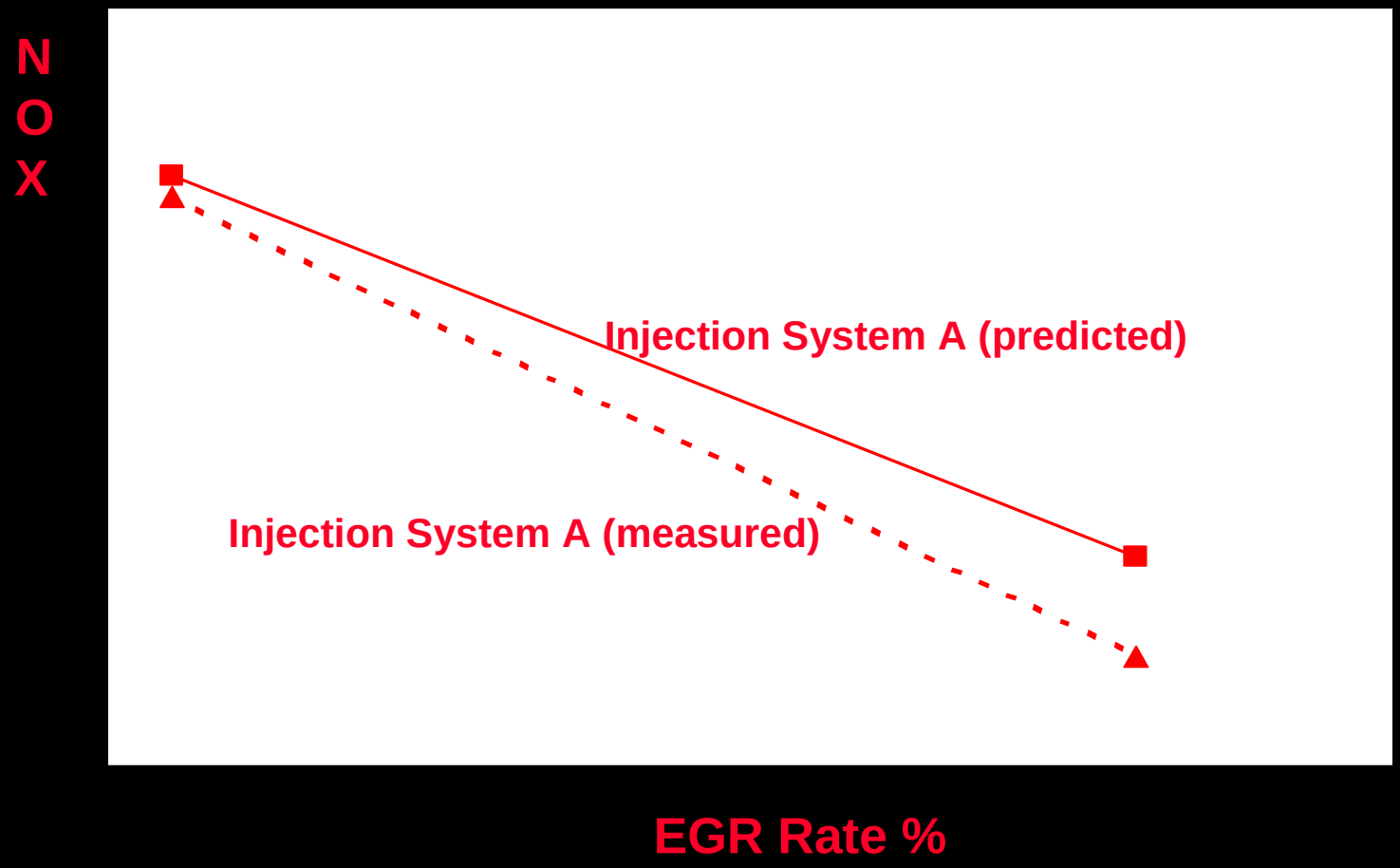
Integrated Virtual-Lab Toolbox for Diesel Spray and Combustion Simulation



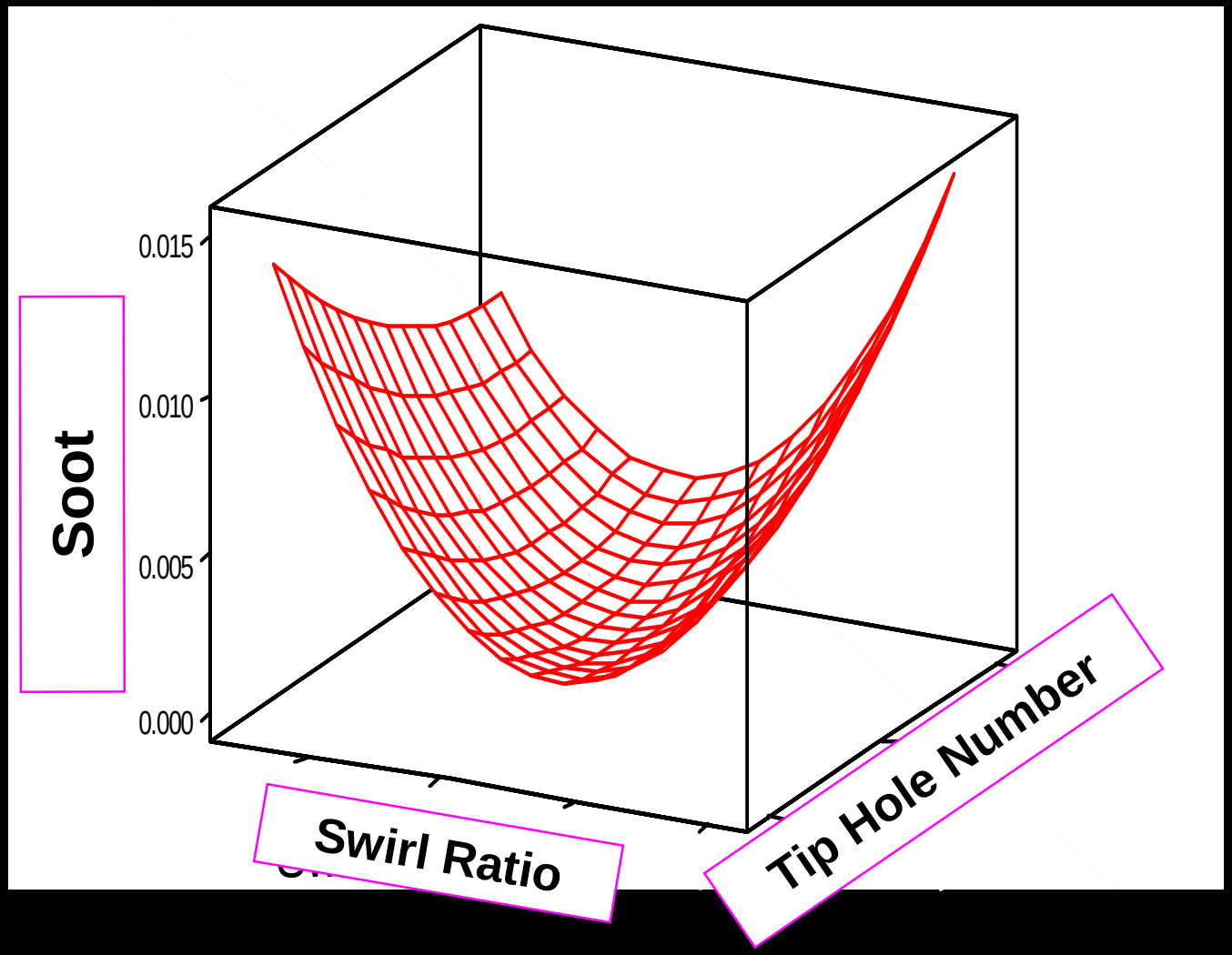
Application Examples to Combustion System Design

- NOx Reduction Efficiency with EGR
  - Effect of Fuel Injection System on EGR Combustion
- Optimization of Coupled Parameters
- Comparison of Computed and Measured Rate of Heat Release

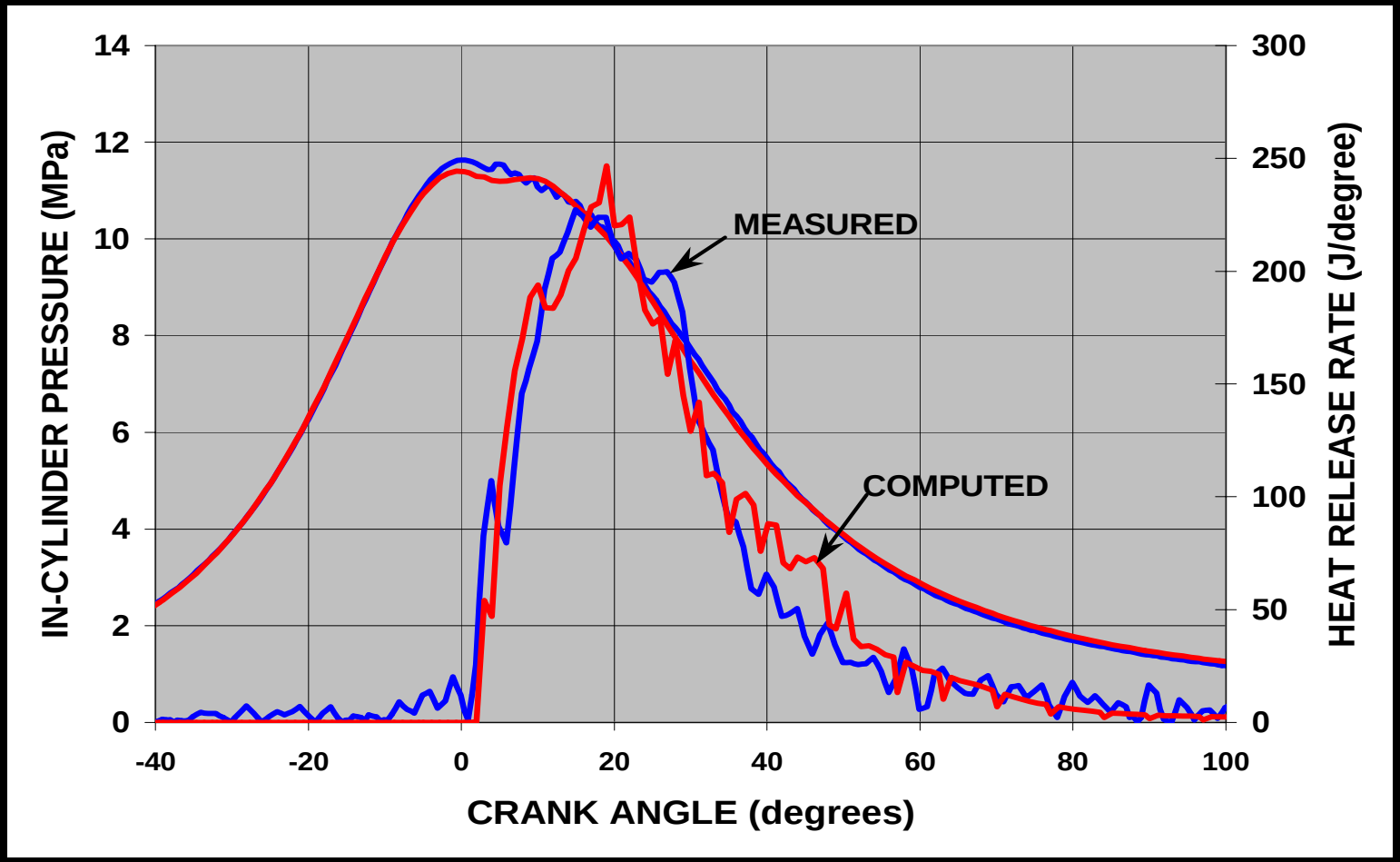
Screening NOx Reduction Efficiency



Example of Local Optimization



Heavy Duty Heat Release Studies



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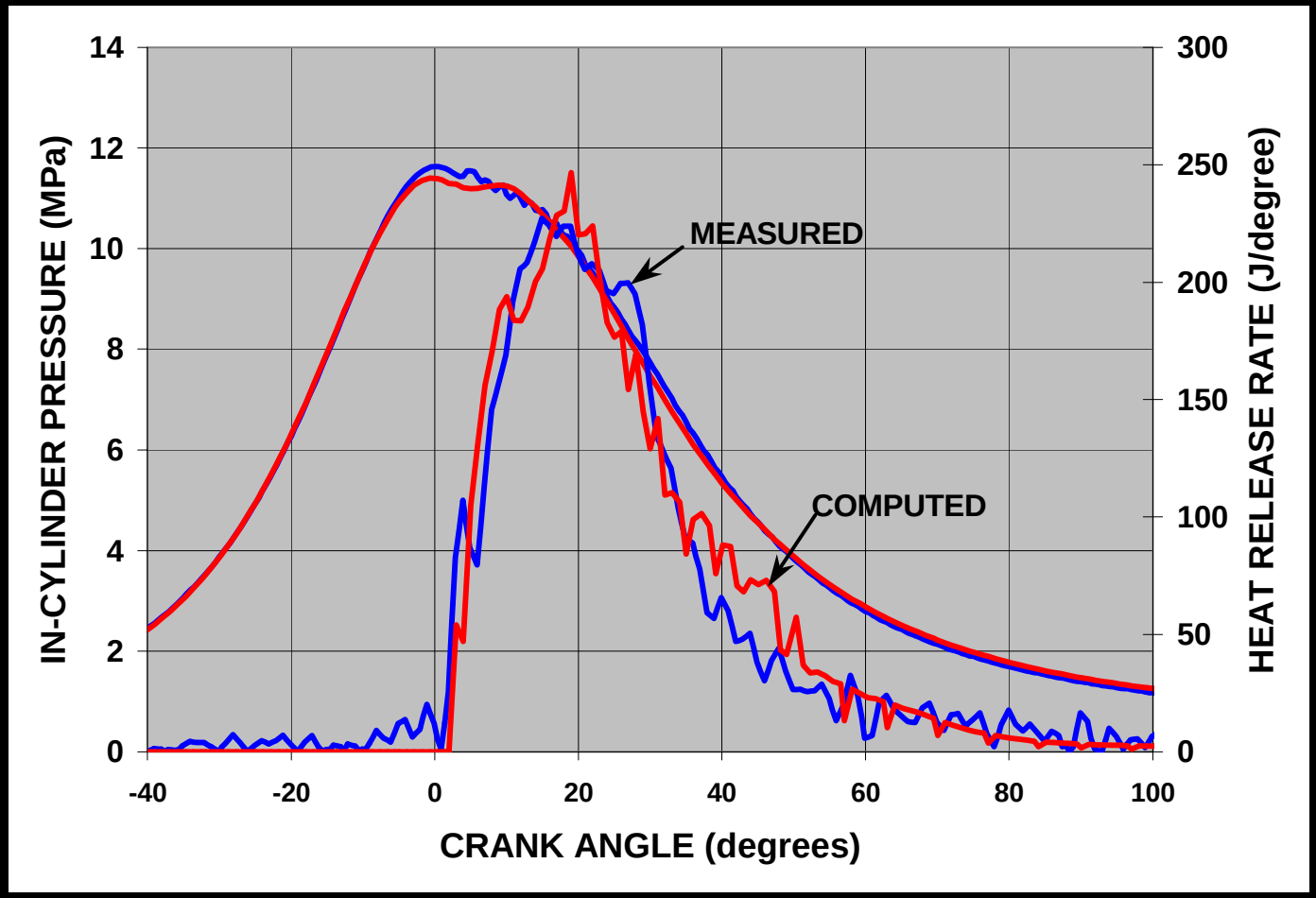
HSDI Vs. HD - Engine Characteristics

	HSDI	Heavy Duty
Application	*Personal Transportation*	*HD Truck*
Duty Cycle	Low speed/light load	Wider range
Rated Speed	~ 4200 r/min	~ 2100 r/min
Emission Cert	Vehicle based	Engine based
Power Density	Higher	High
BMEP	Medium	Higher
Thermal Load	Lower	Higher
FIE	CR	CR/EUI/EUP
EGR Rates	Higher	Lower
Swirl	Higher	Lower

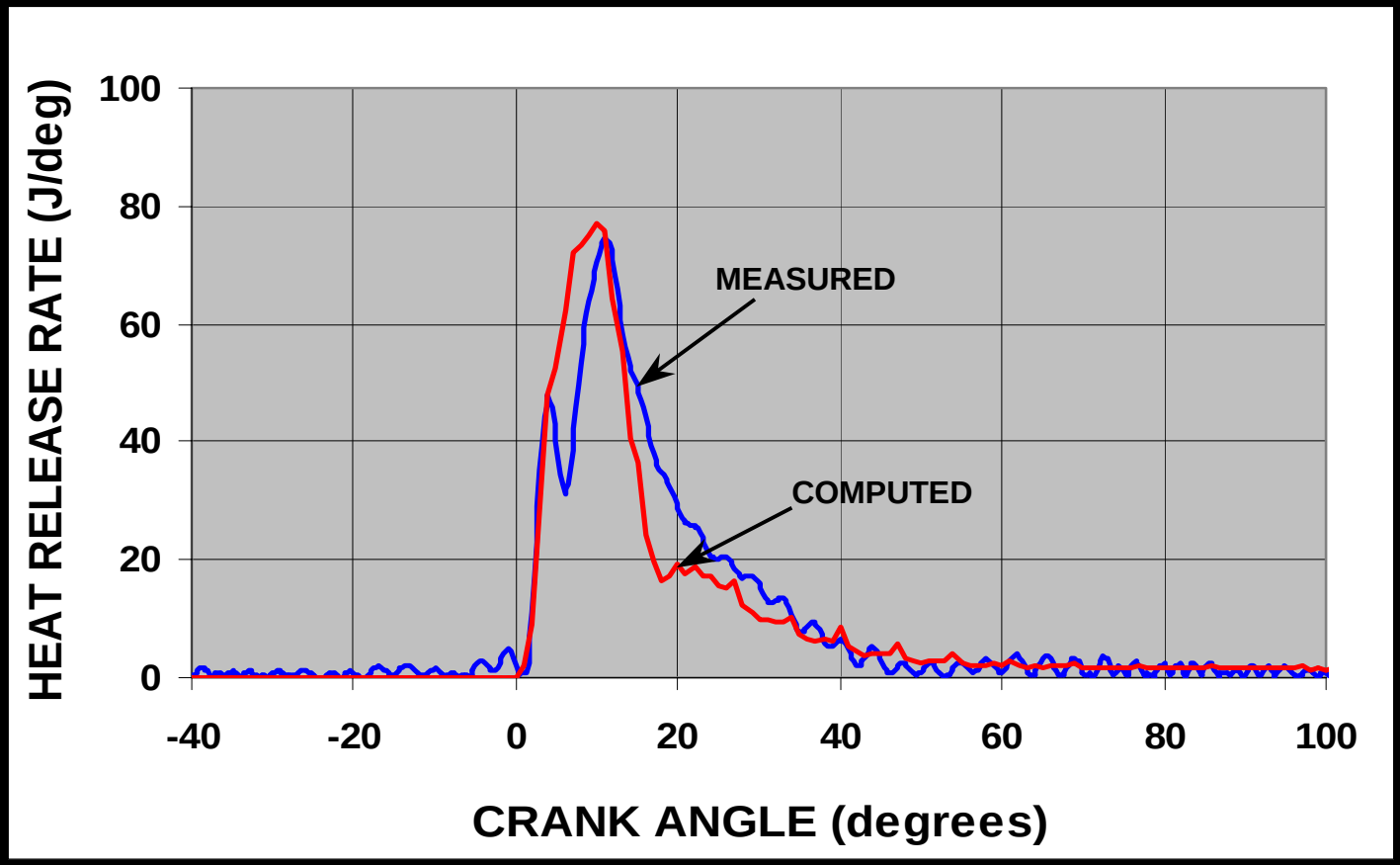
Heavy Duty Heat Release (HD)



Injection Spray Predominant, Model Calibration Is Accomplished

HSDI Heat Release

KIVA Prediction with HD Sub-models



Spray Injection and Air Motion Are Equally Important

➔ Model Calibration Is More Complex

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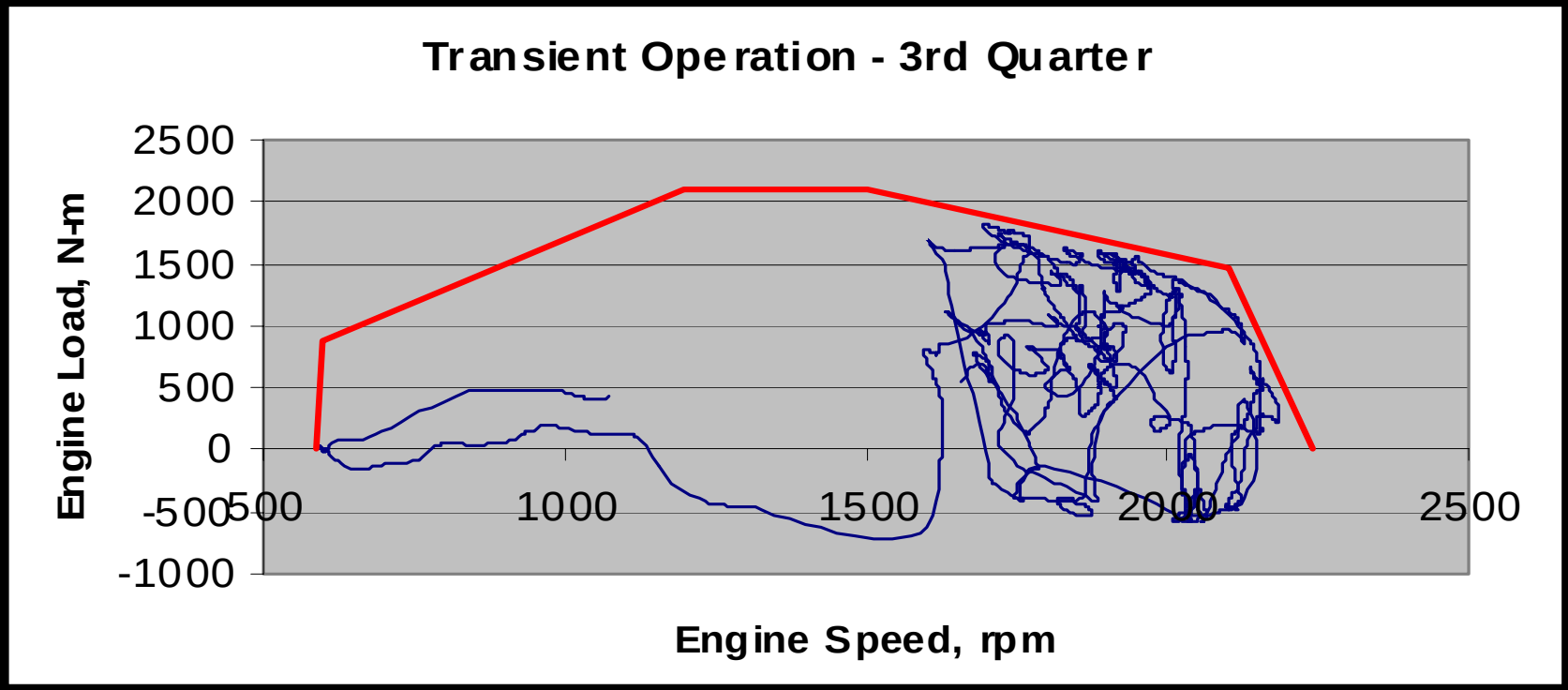
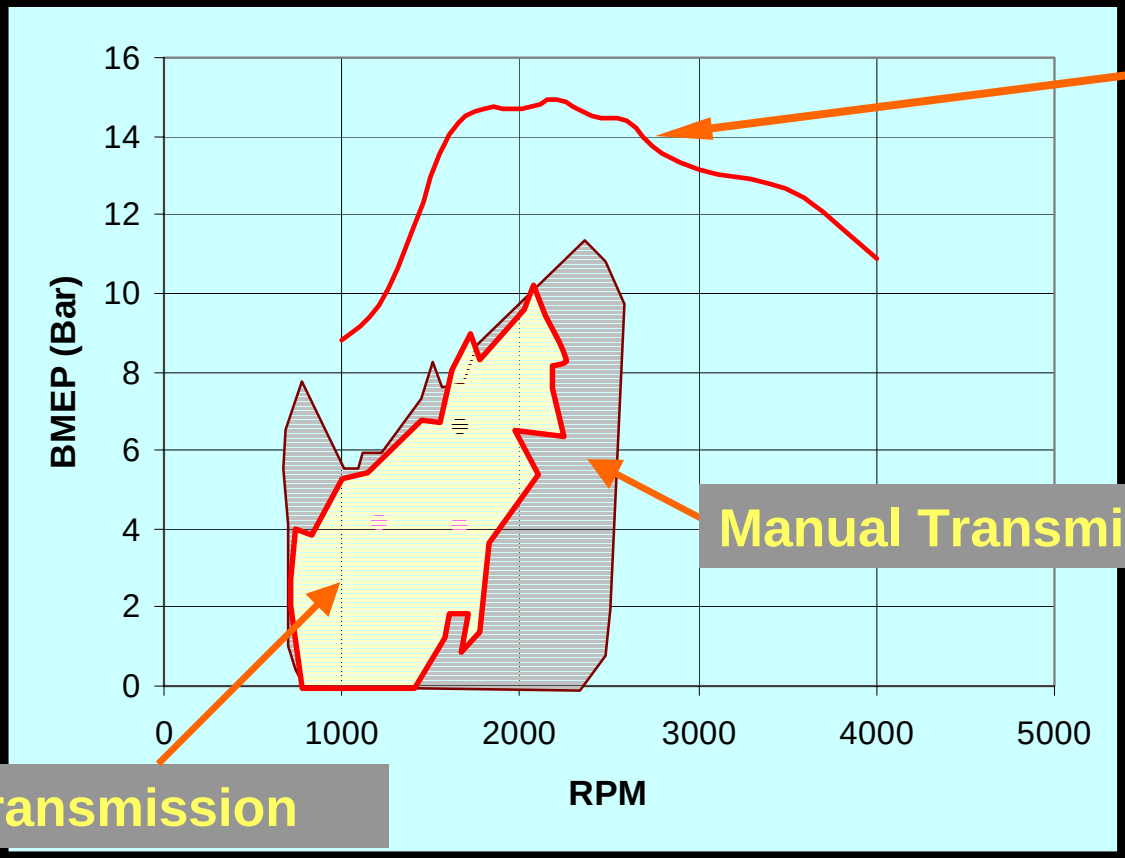
HD Diesel On-highway Transient Cycle



HD Emission Emphasizes Higher Speed (and Load) Region

HSDI Diesel Transient Cycle



Full load curve

Manual Transmission

Automatic Transmission

HSDI Emission Emphasizes Low Speed & Load Operation and Is Vehicle Dependent

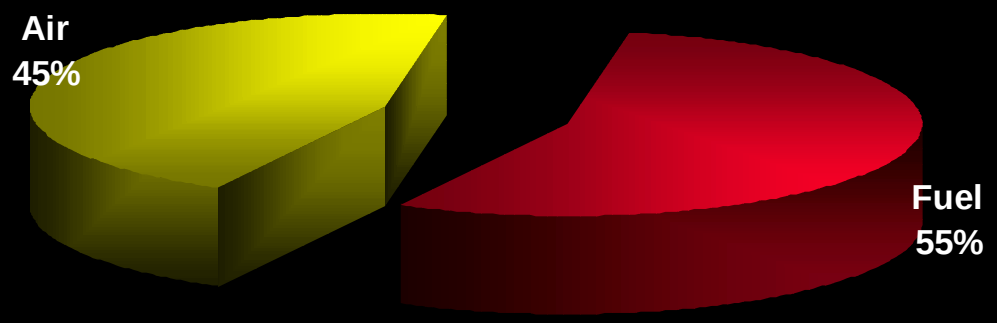
HSDI Vs. HD - Engine Characteristics

at Relevant Emissions Steady-state Conditions

	HSDI	Heavy Duty
BMEP	Low	High
Injection Pressure	Medium	High
Injector Tip	Fewer Holes	More Holes
Compression Ratio	Higher	Lower
Combustion Chamber	Deep Re-entrant	Open
Swirl	Higher	Lower
Prime Mixing	Air Motion & Fuel Injection	Fuel Injection
Charge Density	Low	High
EGR Rate	Higher	Lower

Mixing Kinetic Energy Distribution

At Equivalent Engine Speeds (1900 rpm)



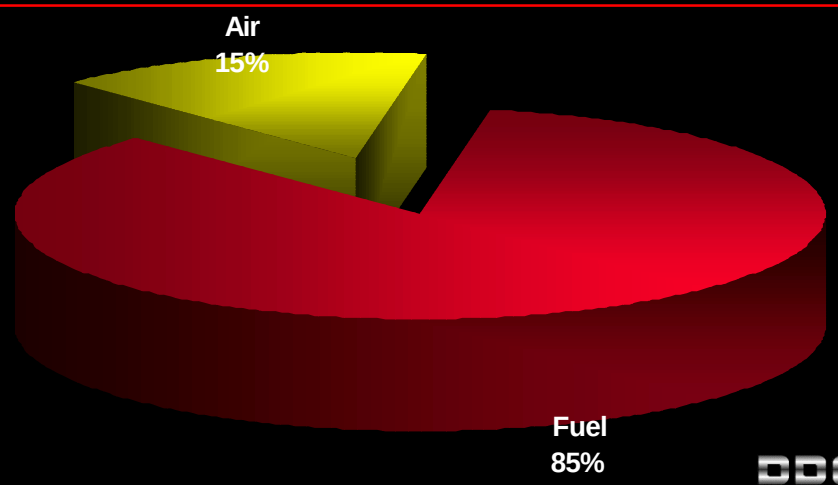
HSDI

- Fuel 55%
- Air 45%

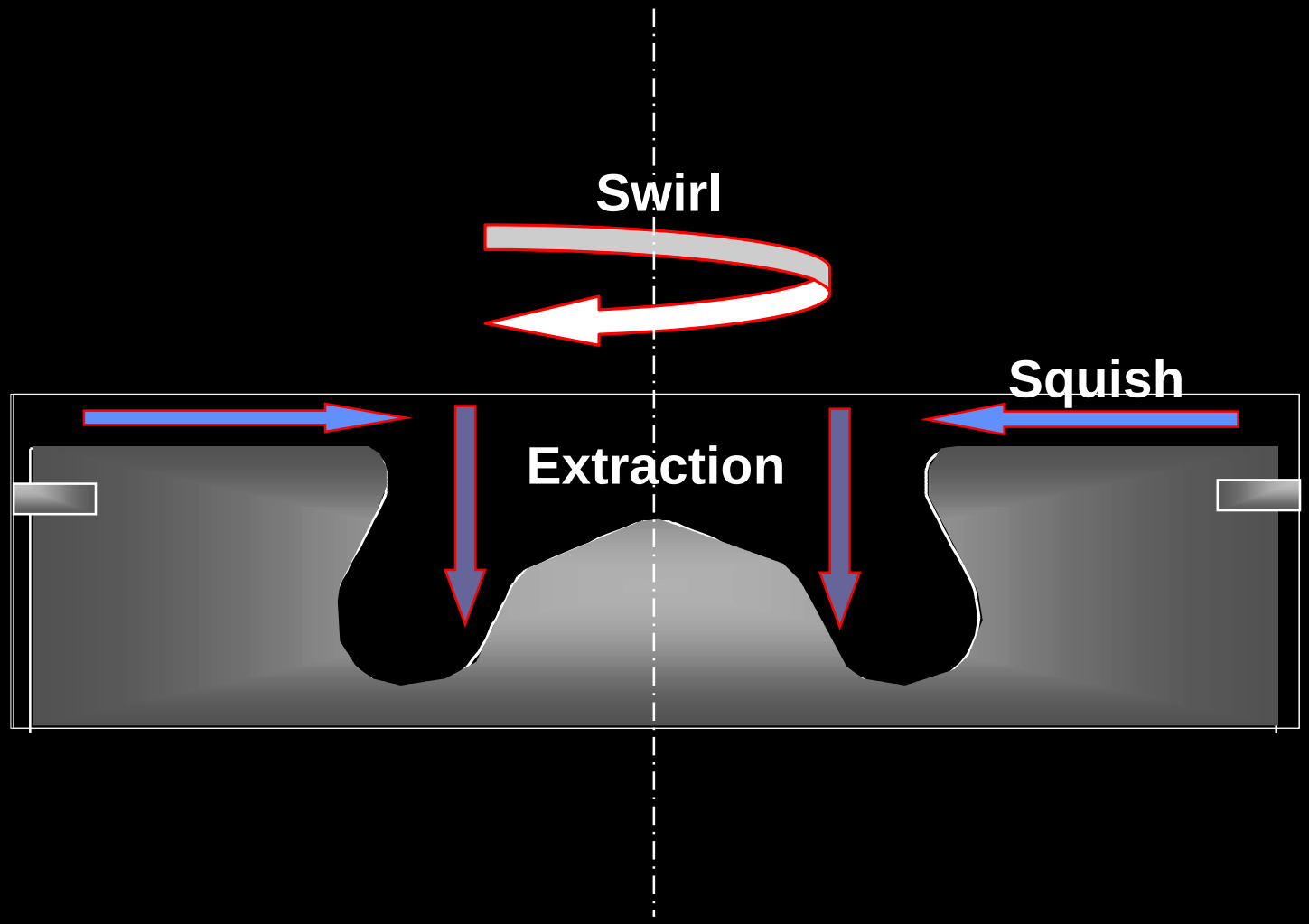
- Integral Mass Averaged KE @ TDC comparable between LD and HD but Different Fuel & Air Contribution Ratios

Heavy Duty

- Fuel 85%
- Air 15%



In-Cylinder Air Motion
(Light Duty Example)



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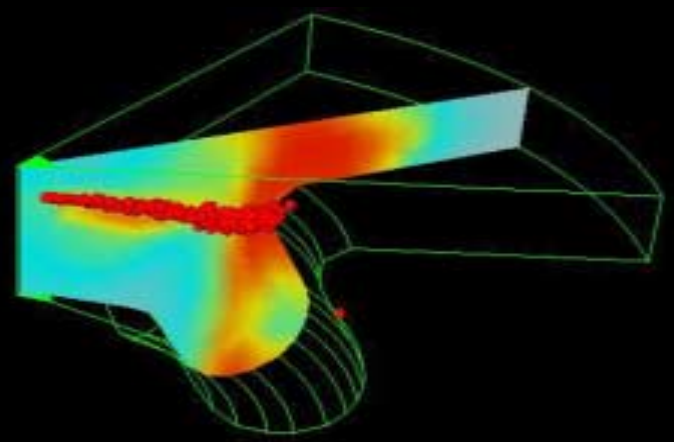
Additional Factors Influencing HSDI Combustion

- Strong Spray to Wall Impingement
  - Near-wall Turbulence Modeling
- Wide Engine Speed Range
  - Large Variation in Time Scales
- High EGR Rate
  - Effect on Ignition Delay and Diffusion Combustion Kinetics

Spray Combustion Dynamics
Predicted by KIVA

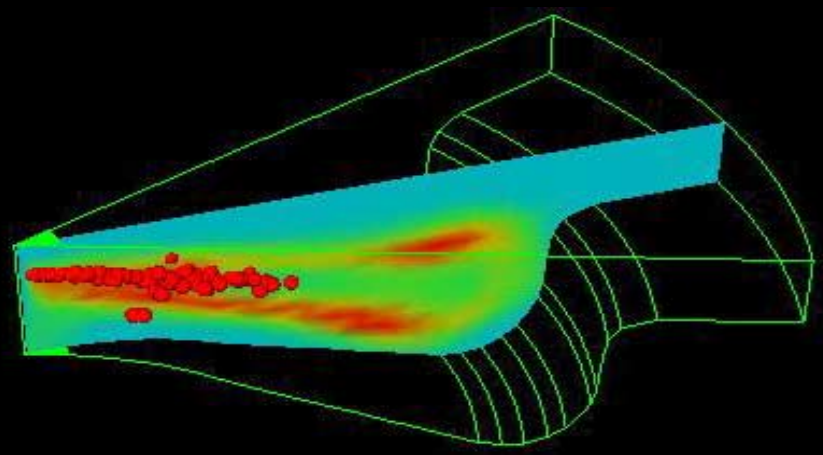


Light Duty

- Droplets Impingement (Piston) Inevitable
- Strong Mixing after Impingement
  - ***Mixing Later in the Cycle***
- Mixing Zone Shaped by Air Motion

Heavy Duty

- No Droplets Impingement
- Mixing Primarily before Wall Interaction
  - ***Mixing Earlier in the Cycle***
- Mixing Zone Controlled by Spray Motion



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Concluding Remarks

- Current KIVA Models Are Predictive and Useful in HD Engine Development IF
  - Carefully Integrated with Other Tools (Boundary and Initial Conditions)
  - Adequately Calibrated/Validated
- Application to Wider Engine Classes and Operating Conditions Requires Further Model Enhancements.

Concluding Remarks (Continued)

- Issues in HSDI Simulation

- Spray modeling in HSDI diesel combustion must consider near wall mixing (impingement)
- Spray break-up and turbulent flow sub-models are of equal significance
- HSDI extends turbulence mixing & reaction time scales (wide engine speed range)
- Critical grid resolution expands beyond HD regimes to include piston rim regions