

Effect Of Intake Pressure And Temperature On Auto-Ignition Of Fuels With Different Cetane Number And Volatility

C. Jayakumar, U. Joshi, Z. Zheng, N. A. Henein,
W. Bryzik

Wayne State University, Detroit, MI

&

E. Sattler

US Army RDECOM-TARDEC, Warren, MI

Disclaimer: Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoA, and shall not be used for advertising or product endorsement purposes.

SAE *International*™

2012-01-1317

UNCLASSIFIED

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 12 APR 2012		2. REPORT TYPE Briefing Charts		3. DATES COVERED 12-04-2012 to 12-04-2012	
4. TITLE AND SUBTITLE EFFECT OF INTAKE PRESSURE AND TEMPERATURE ON AUTO-IGNITION OF FUELS WITH DIFFERENT CETANE NUMBER AND VOLATILITY				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Eric Sattler; C. Jayakumar; U. Joshi; Z. Zheng; W. Bryzik				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army TARDEC ,6501 E.11 Mile Rd,Warren,MI,48397-5000				8. PERFORMING ORGANIZATION REPORT NUMBER #22764	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000				10. SPONSOR/MONITOR'S ACRONYM(S) TARDEC	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) #22764	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Briefing charts presented to SAE World Congress 2012					
14. ABSTRACT Briefing Charts					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 27	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Outline

- ▶ Motivation and goals
- ▶ Diesel cycle simulation
- ▶ Analysis of auto-ignition processes
- ▶ Experimental investigations:
ULSD, S-8, JP-8 (44), JP-8 (31)
- ▶ Experimental results and discussions
- ▶ Conclusions
- ▶ Acknowledgements

Motivation and goals

▶ Motivation:

- Depletion of petroleum reserves
- Rising fuel costs & Security of supply
- Alternate fuels possess a wide range of properties

▶ Goals:

- To investigate the chemical and physical processes during auto-ignition of different fuels

▶ Approach:

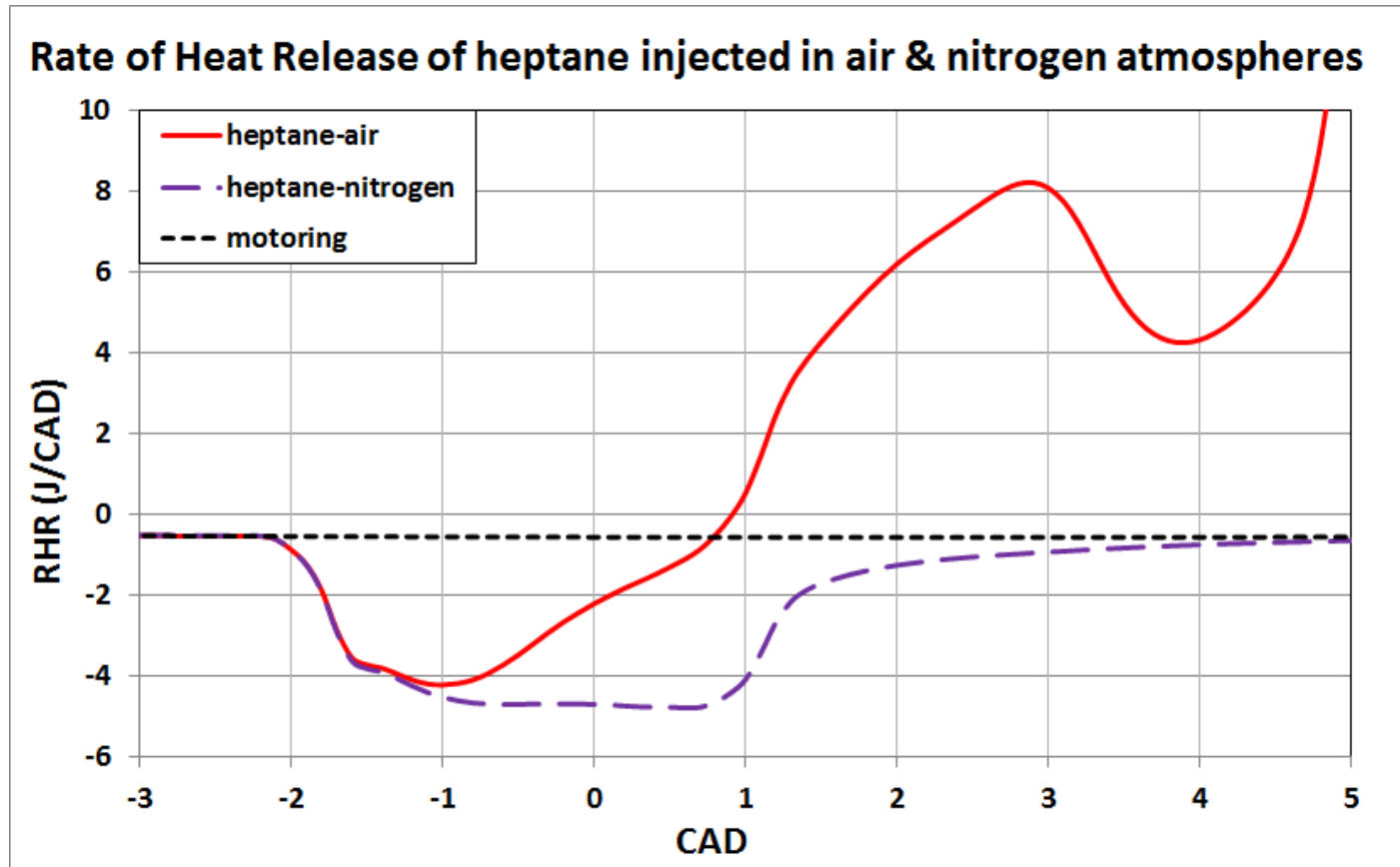
- Computer simulations validated by experimental results at different intake pressures and temperatures using fuels with different cetane number and volatility

Simulation Results/Findings

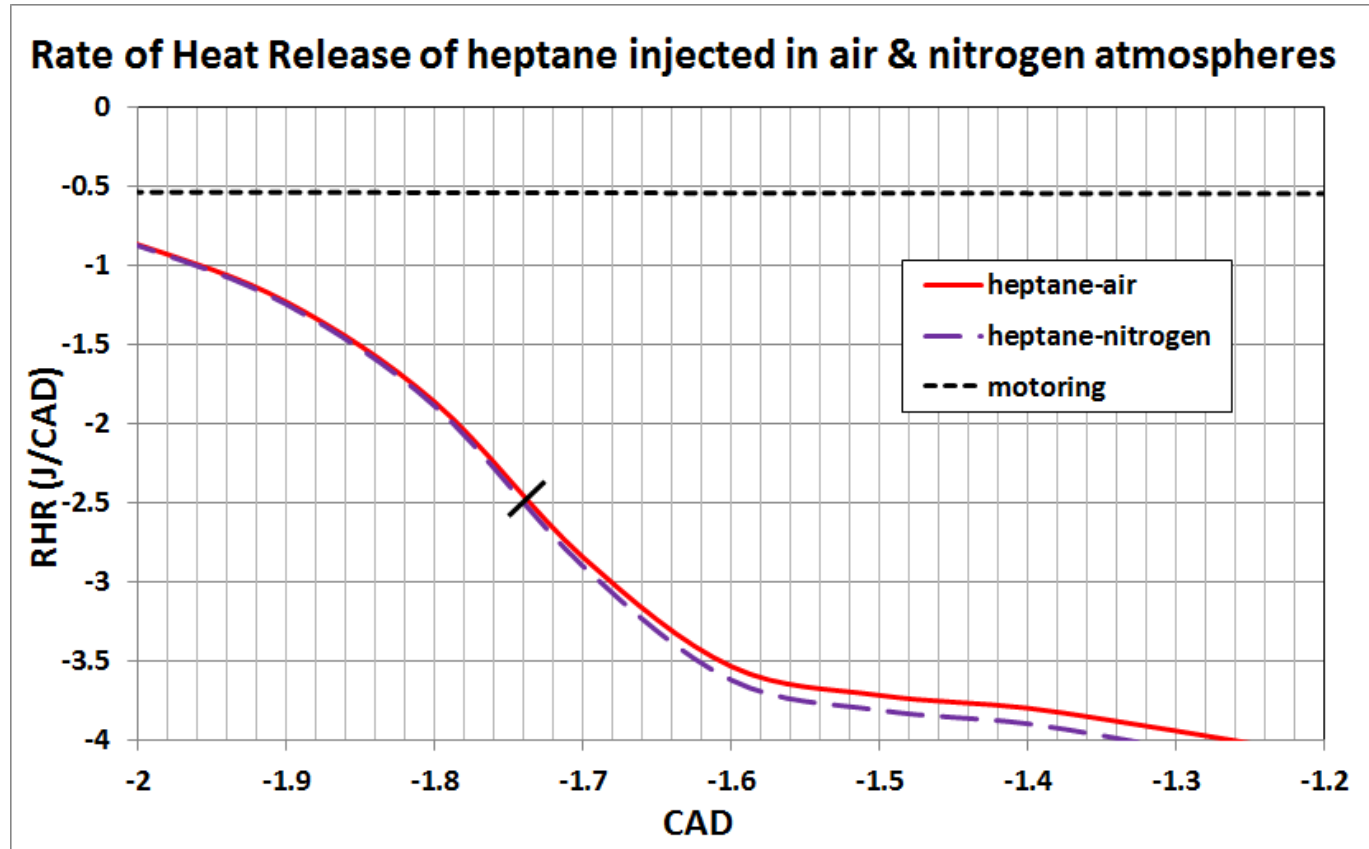
Diesel cycle simulation

- ▶ Model: 3D-CFD simulation software coupled with the chemistry of auto-ignition and combustion
- ▶ Mechanism: Reduced n-Heptane Mechanism with 33 species & 122 reactions
- ▶ Engine: PNGV single cylinder, direct injection diesel engine equipped with a common rail injection system
- ▶ Conditions:
 - 1500 rpm, Swirl: 3.77, P_{inj} : 800 bar, SOI: 2.2 CAD bTDC, Intake pressure 1.1bar-1.5bar, Intake temperatures: 80°C-190°C

Simulation Results

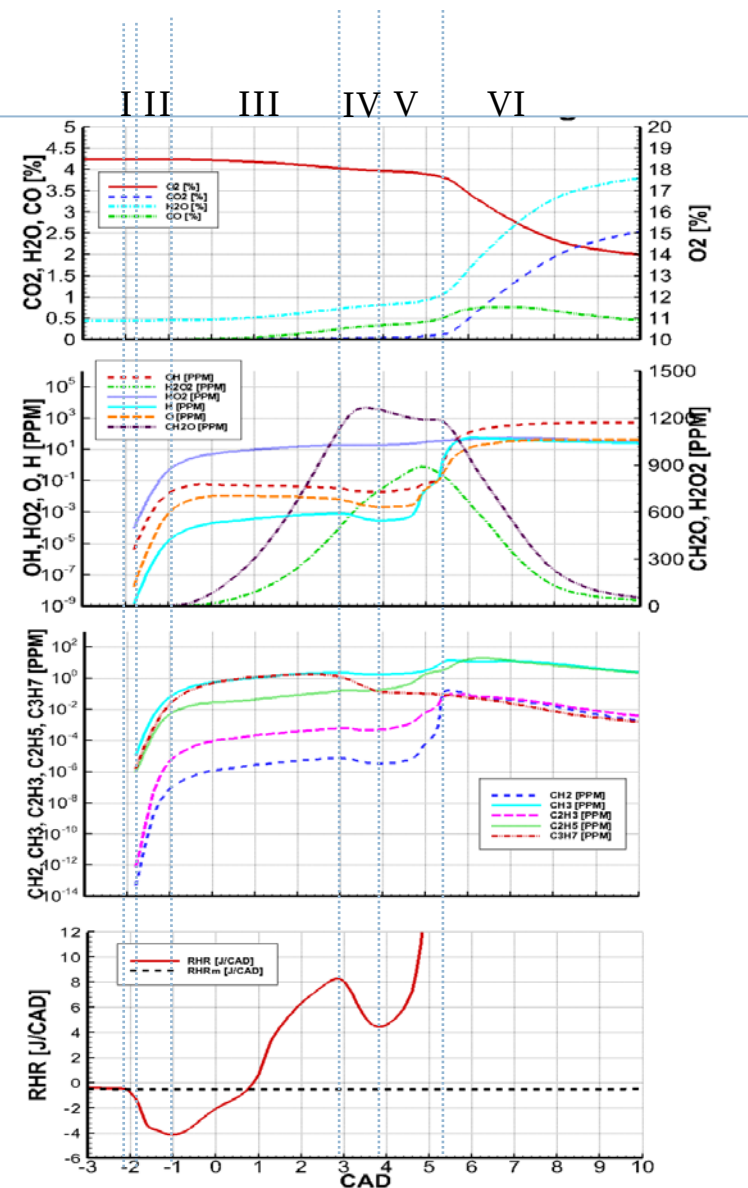


Point of Inflection – Beginning of Exothermic Reactions

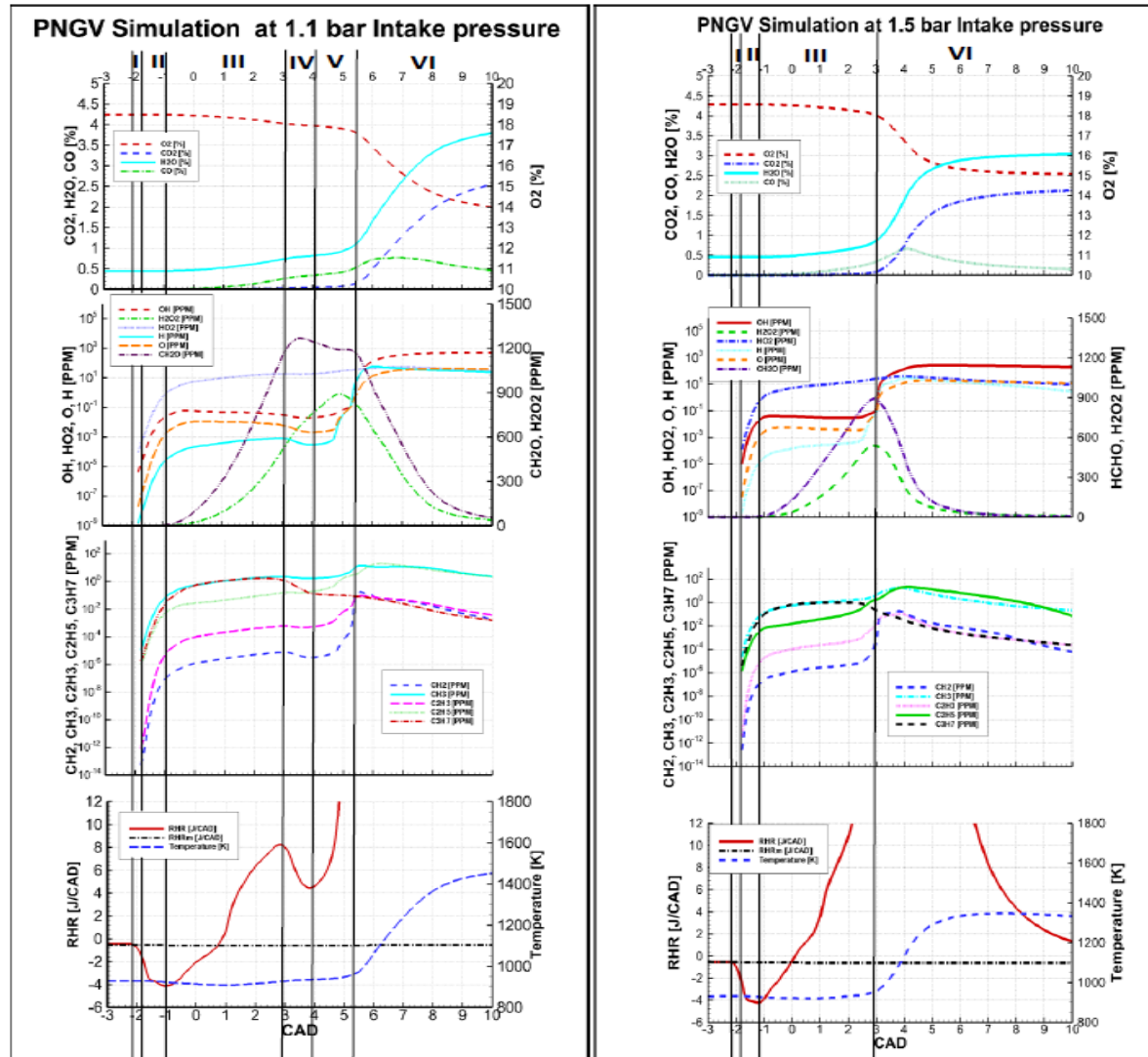


Analysis of Auto-ignition processes

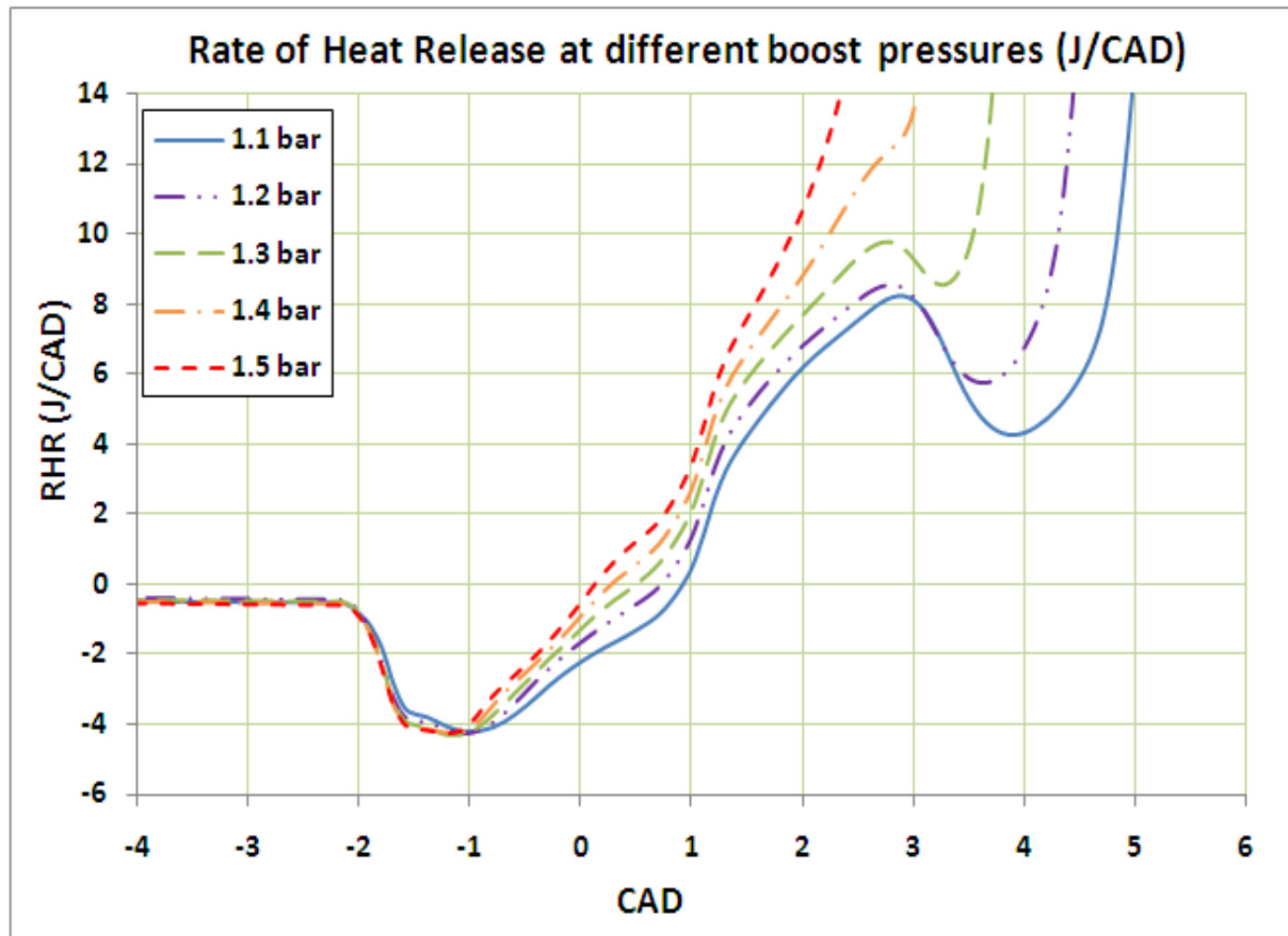
- ▶ **Zone I:** Fuel evaporation
- ▶ **Zone II:** Endothermic reactions, fuel break-down, beginning of exothermic reactions
- ▶ **Zone III:** LT regime, formation of HCHO, H₂O₂, species formation slowing down (plateau)
- ▶ **Zone IV:** NTC regime, HCHO reaches peak, species conc dropping (valley)
- ▶ **Zone V:** Increase in other species, H₂O₂ reaches peak, HCHO reaches a second peak
- ▶ **Zone VI:** Main combustion, HCHO, O₂ starts to drop, H₂O₂ drops faster, CO₂ and H₂O starts increasing a faster rate



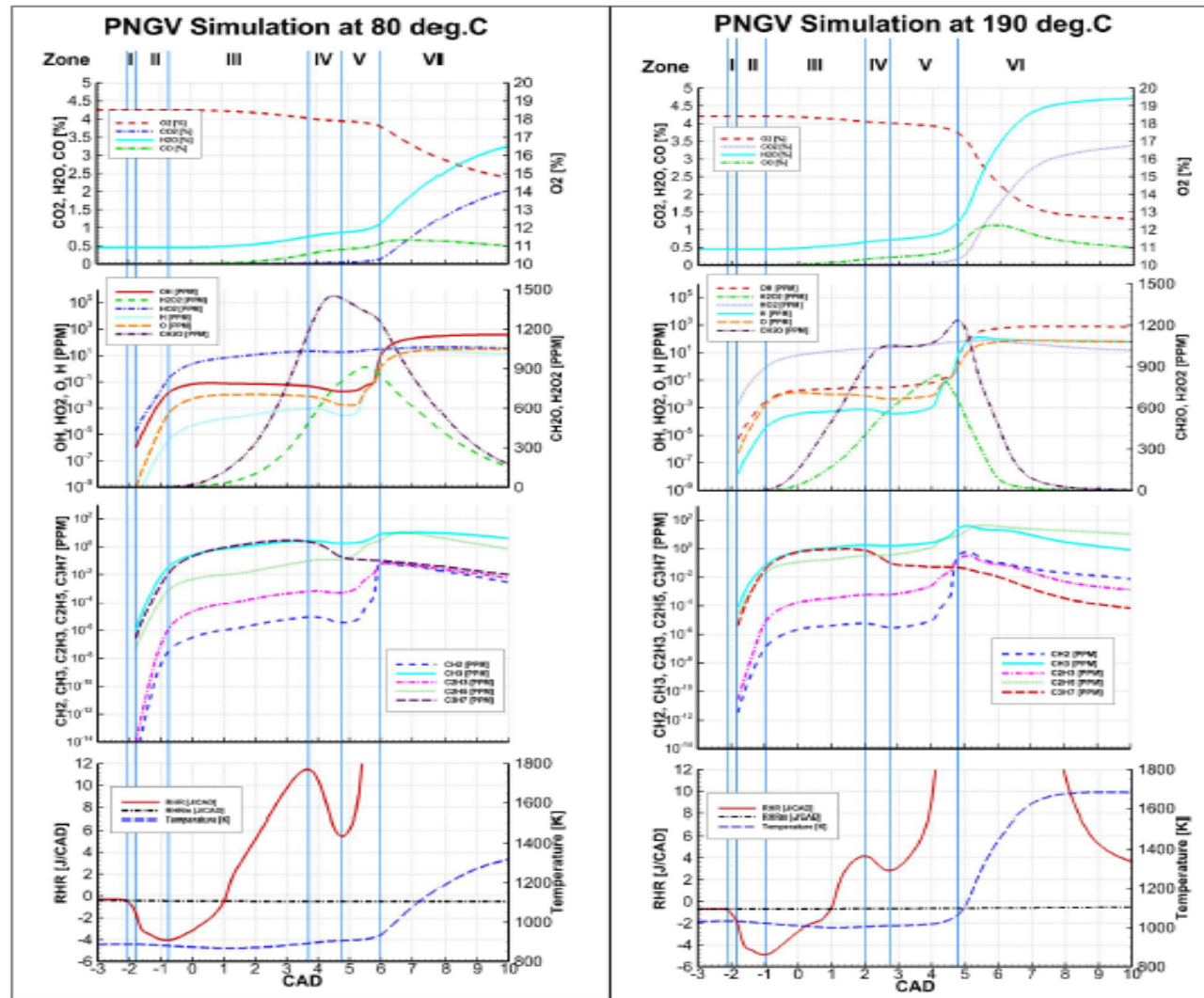
Comparison between 1.1 bar & 1.5 bar



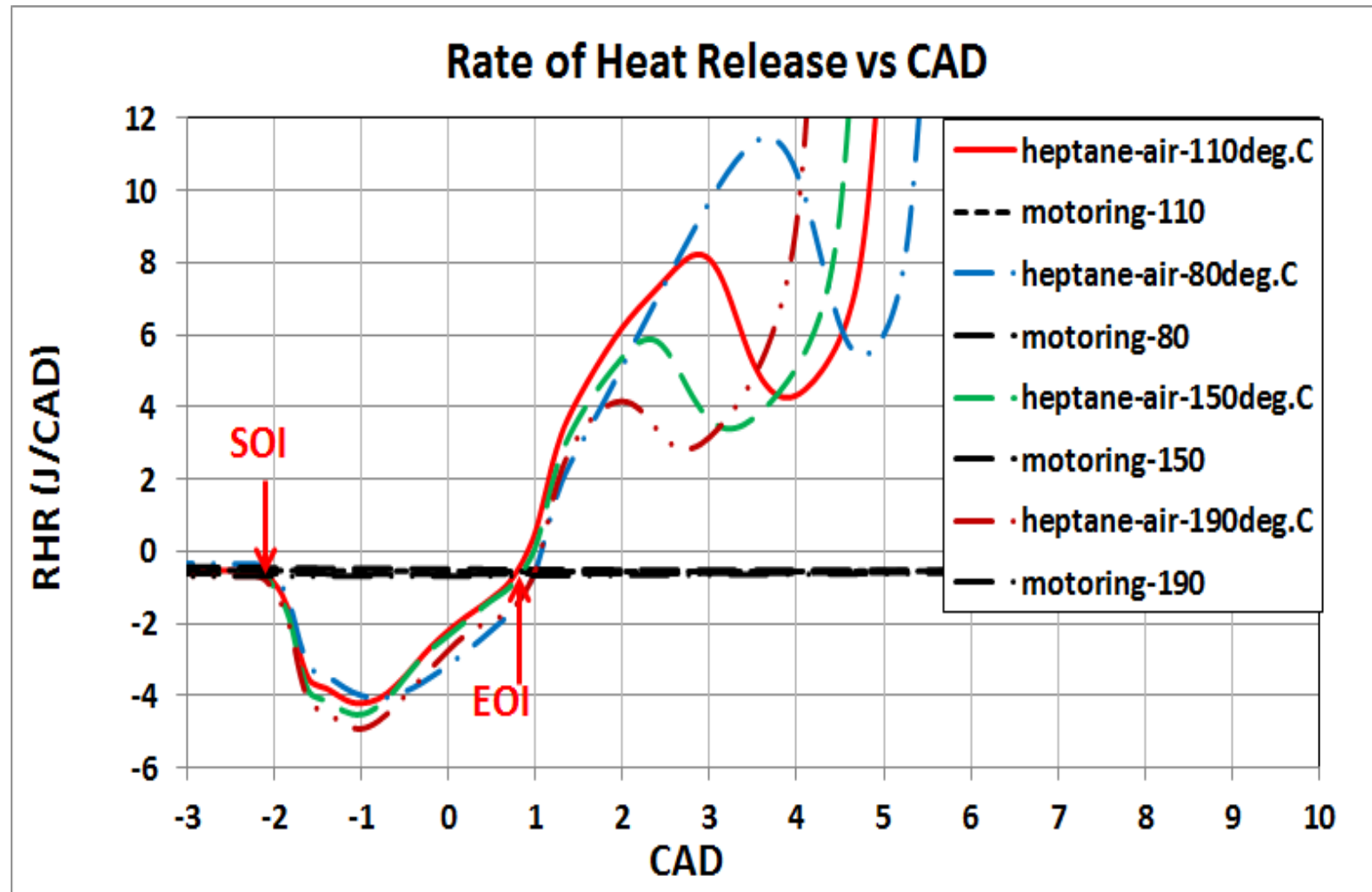
NTC at Different Intake Pressures



Comparison between 80°C & 190°C



NTC at Different Intake Temperatures



Experimental Results

Experimental Set-Up

▶ Engine Specifications:

- Engine Type : 0.42 liter direct injection
- Bore x Stroke : 79.5 mm x 85 mm
- Compression Ratio :20:1
- Number of valves: 4
- Combustion Chamber : Re-entrant
- Fuel Injection system : Common Rail
- Injection Pressure: up to 1200 bar



Photograph of the Engine Setup

SAE *International*™

2012-01-1317
UNCLASSIFIED

Test Matrix

EFFECT OF INTAKE PRESSURE	
FUELS	ULSD, JP-8 (HCN), F-T SPK, JP-8(LCN)
INJECTION PRESSURE (in Bars)	800
ENGINE SPEED (rpm)	1500
LOAD	3 bar IMEP
SWIRL	3.77
EGR	0%
START OF INJECTION	-2.0 CAD* bTDC
INJECTION DURATION	0.358 ms
INTAKE AIR PRESSURE	1.1 bar – 1.5 bar
INTAKE AIR TEMPERATURE	60°C
COOLANT OUTLET TEMPERATURE	82.2°C

Test Matrix

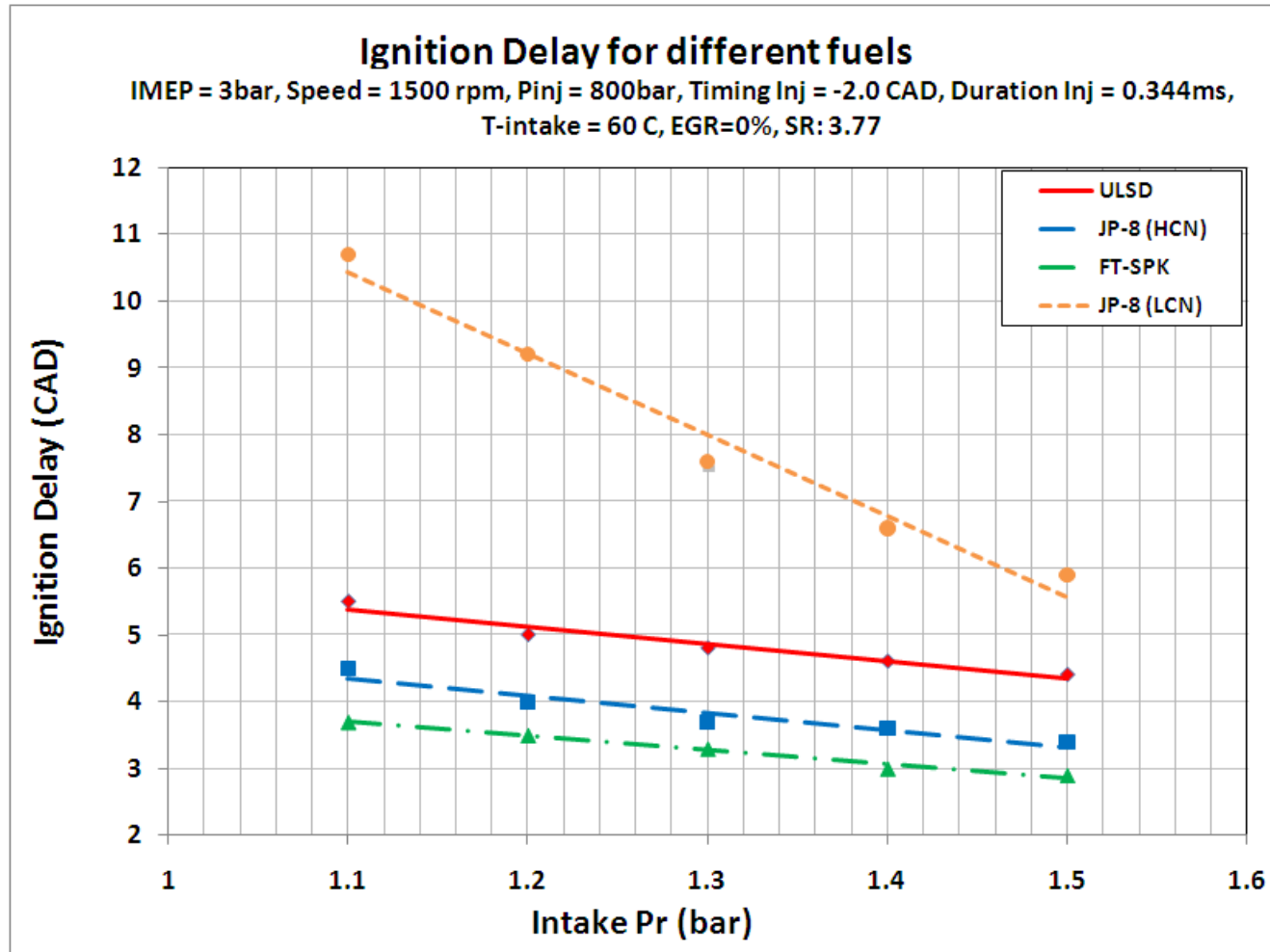
EFFECT OF INTAKE TEMPERATURE		
FUELS	ULSD, JP-8 (CN#44), S-8, JP-8(CN#31)	ULSD, JP-8 (CN#44), S-8, JP-8(CN#31)
INJECTION PRESSURE (in Bars)	800	800
ENGINE SPEED (rpm)	1500	1500
LOAD	3 bar IMEP	5 bar IMEP
SWIRL	3.77	3.77
EGR	0%	0%
START OF INJECTION	-2.0 CAD* bTDC	-2.5 CAD bTDC
INJECTION DURATION	0.358 ms	0.402 ms
INTAKE AIR PRESSURE	1.1 bar	1.1 bar
INTAKE AIR TEMPERATURE	30°C-110°C	30°C-110°C
EXHAUST GAS PRESURE	1.1 bar	1.1 bar
COOLANT OUTLET TEMPERATURE	82.2°C	82.2°C

*JP-8 (31) was injected at 6.0 CAD bTDC for 3 bar IMEP tests as the engine misfired at 2.0 CAD bTDC

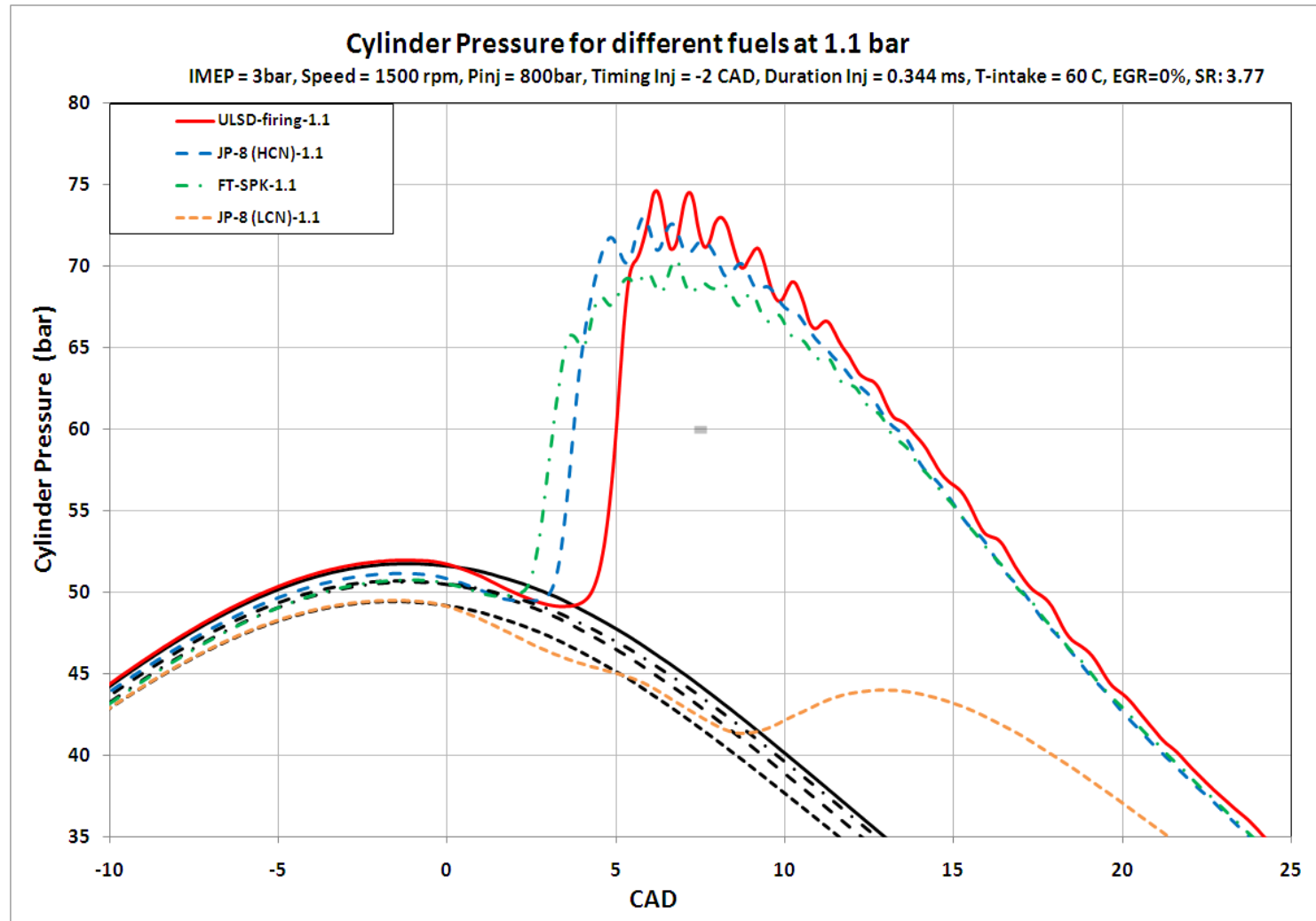
Fuel Properties

Property	ULSD	JP-8 (HCN)	F-T SPK	JP-8 (LCN)	Heptane
Flash point (°C)	74	56.8	37.8	53	-4
Density (Kg/m3)	836.5	770	736.2	768.8	669
Derived Cetane Number (ASTM D6890)	46	50	58	31	56
Lower Heating Value (MJ/Kg)	41.2	42.1	44.1	44.0	44.6

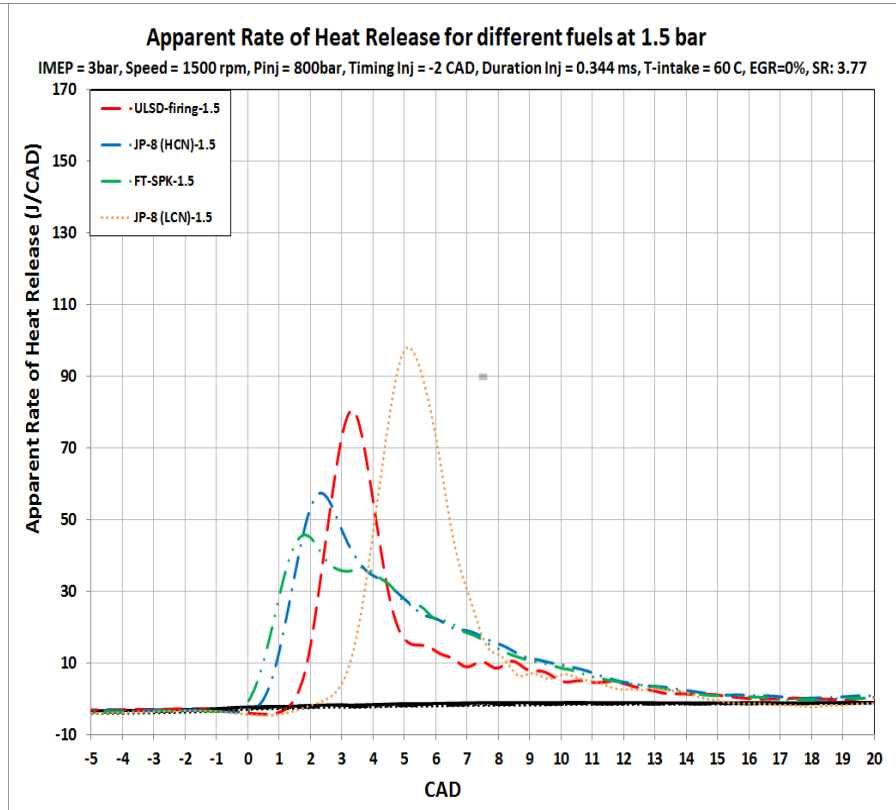
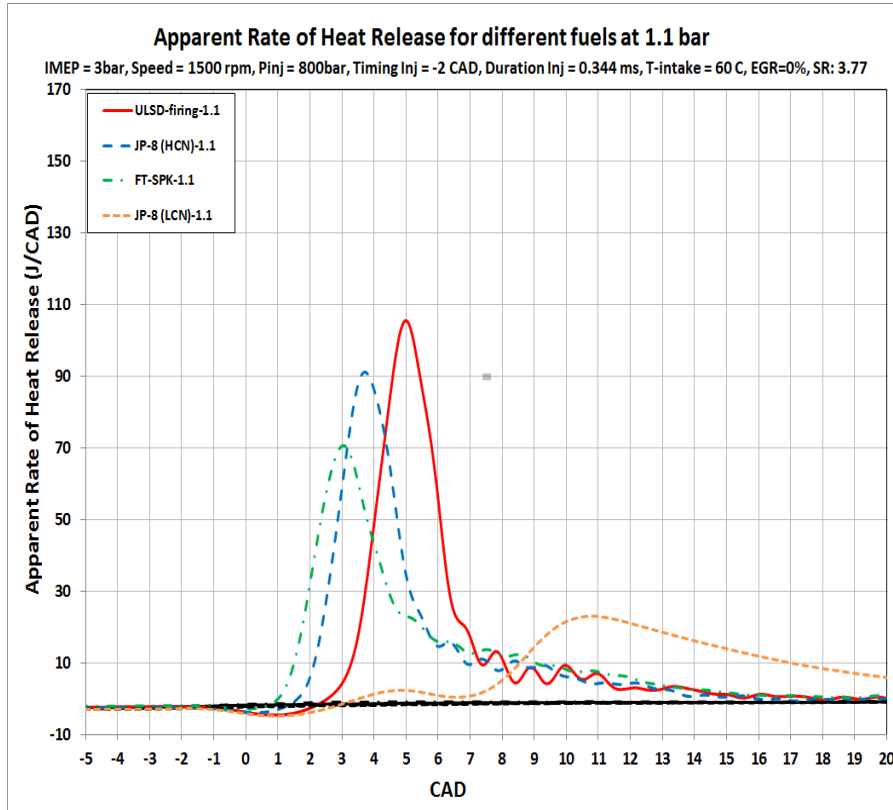
Ignition delay for different fuels



Cylinder pressure traces for different fuels



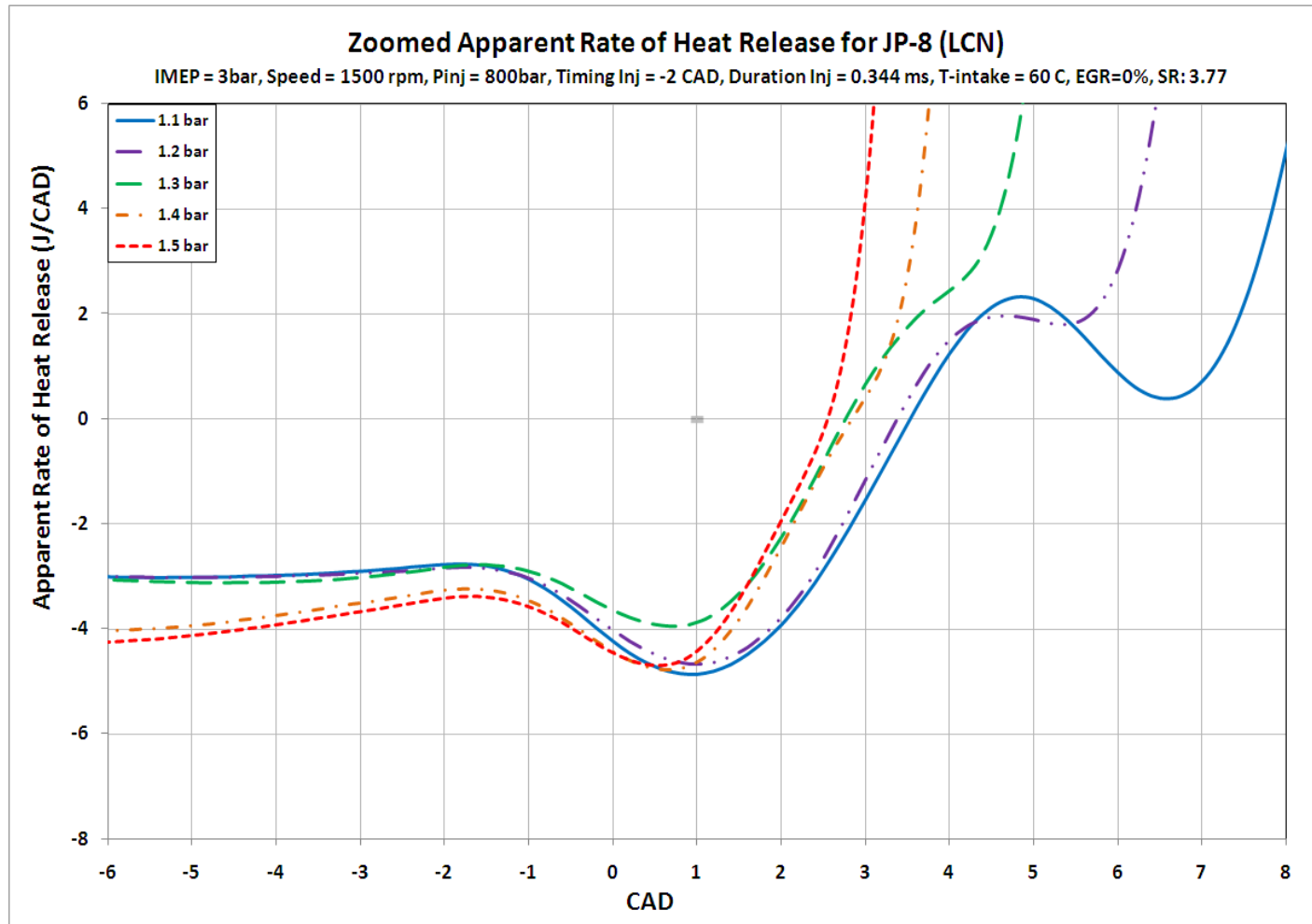
Apparent rate of heat release traces at 1.1 & 1.5 bar boost pressures



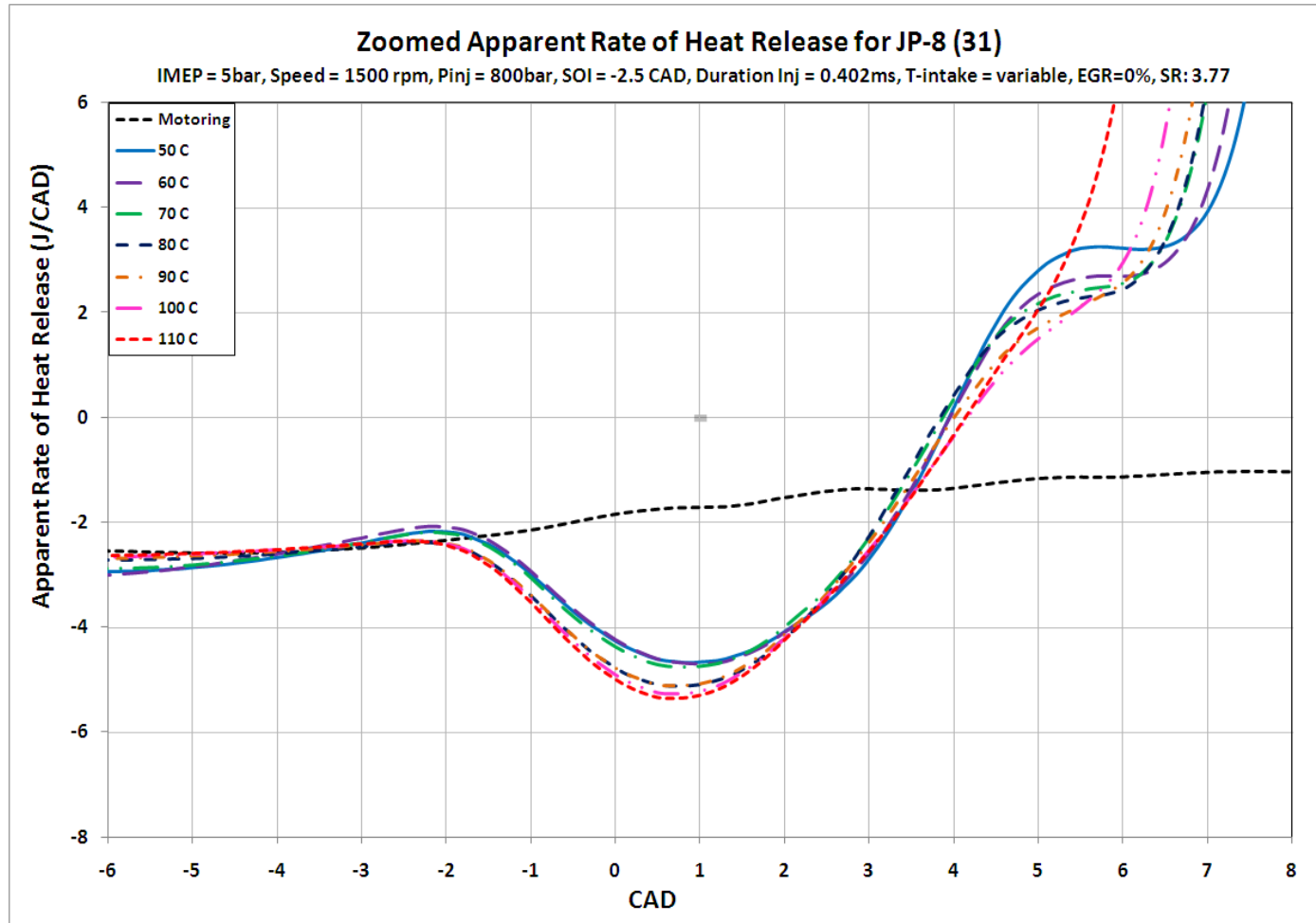
Physical and chemical Ignition Delays

	Duration from SOI to POI (CAD)		Duration from POI to SOC (CAD)	
Fuel	1.1 bar boost	1.5 bar boost	1.1 bar boost	1.5 bar boost
ULSD	2.1	1.9	3.4	2.5
JP-8 (HCN)	1.6	1.4	2.9	2
FT-SPK	1.5	1.1	2.2	1.8
JP-8 (LCN)	1.9	1.9	8.8	4

Auto-ignition regimes at different pressures



Auto-ignition regimes at different temperatures



Conclusions

- ▶ The 3D simulations showed the following:
 1. The low temperature (LT: cool flames) and the NTC regimes occur during the auto-ignition of n-heptane under the engine operating conditions.
 2. The LT and NTC regimes are reduced by the increase in charge pressure and temperature.
 3. The Model demonstrated the major role the aldehydes and hydrogen peroxide play in the auto-ignition reactions.
 4. The model predictions have been validated by the experimental results on the single cylinder engine at different intake pressures and temperatures.

Acknowledgements

- ▶ The authors gratefully acknowledge the sponsorship of this program by ARC: Center of Excellence sponsored by US Army RDECOM-TARDEC and led by University of Michigan.
- ▶ Special thanks are due to Laura Hoogterp of US Army RDECOM-TARDEC for her support of this program.
- ▶ The help of Dr. Paul Miles of Sandia National Lab and Dr. Inderpal Singh of Daimler are greatly appreciated .

Thank you for your attention

Questions?