HCCI – A Technical Review and Progress Report 2006

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August 2007

Scope of Activities in 2006

- Scope of Activities in 2006
  - 2006 SAE Congress
  - 2006 DEER Conference
  - 2006 SAE HCCI Symposium
  - 2006 SAE Power Train and Fluids System Conference
- 72 Written Papers and 99 Presentations
- Topics include Basic Kinetics, Gasoline Engine Development, Diesel Fuel Engine Development, Alternative Fuels, Ignition Assisted HCCI, Fuel Property Effects, Mode Switching, Stratification, etc

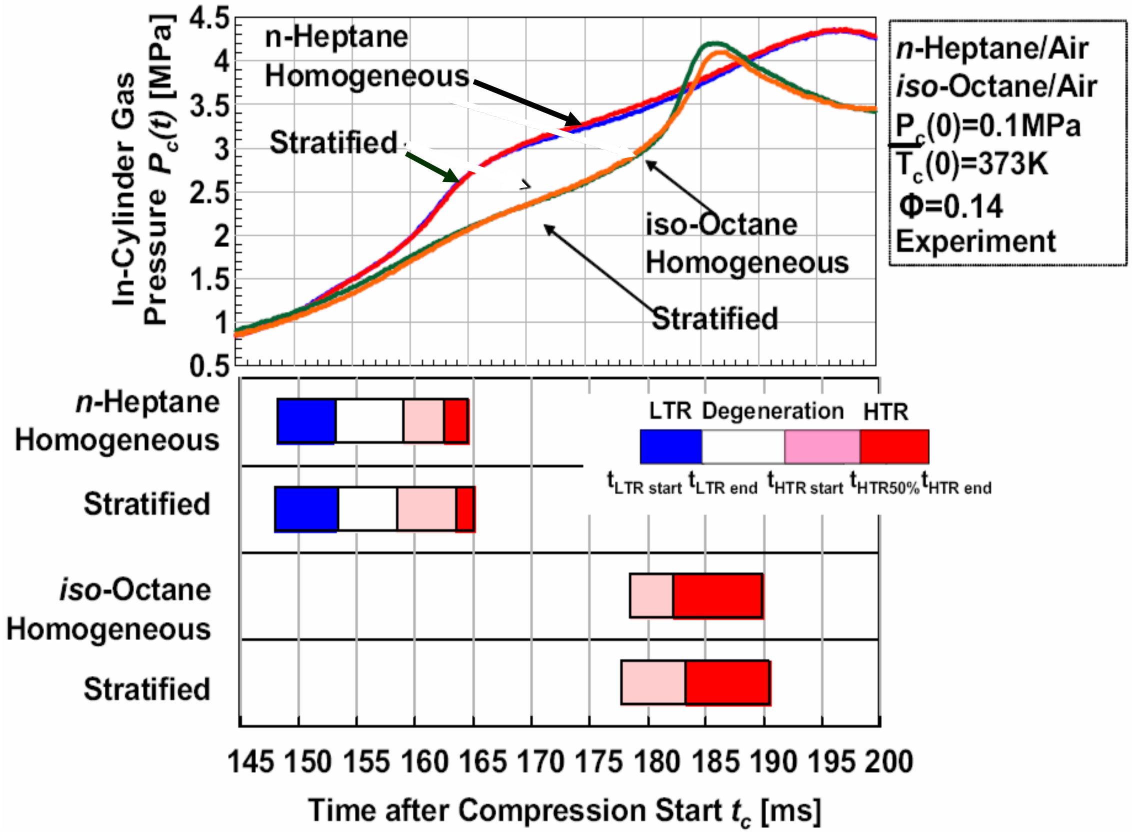
Presentation Focus

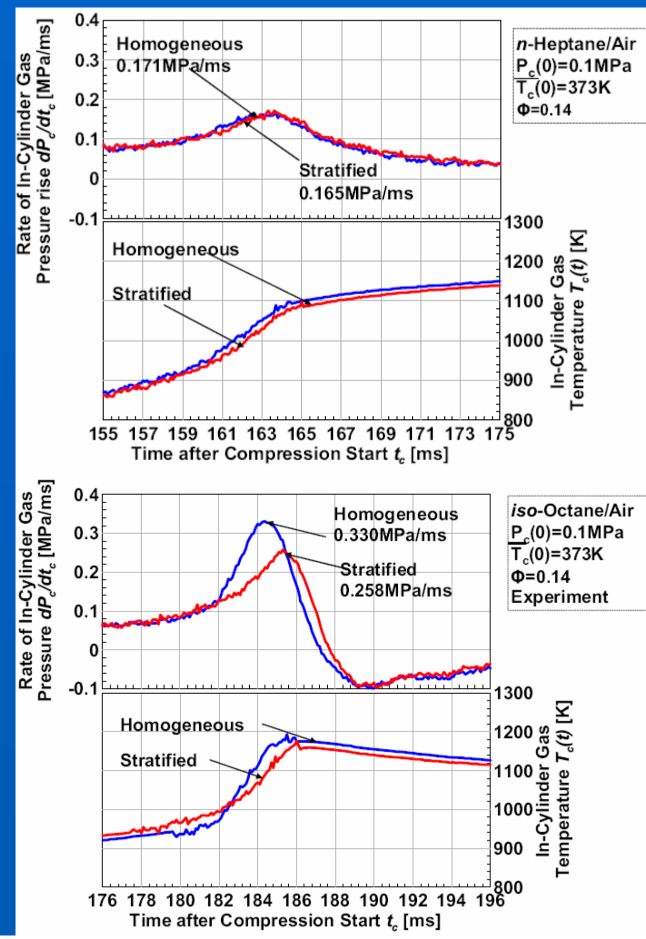
- Summary of Important Recent Findings
- Current Overall Understanding of HCCI

Stratification -

2006-01-3319 Keio University

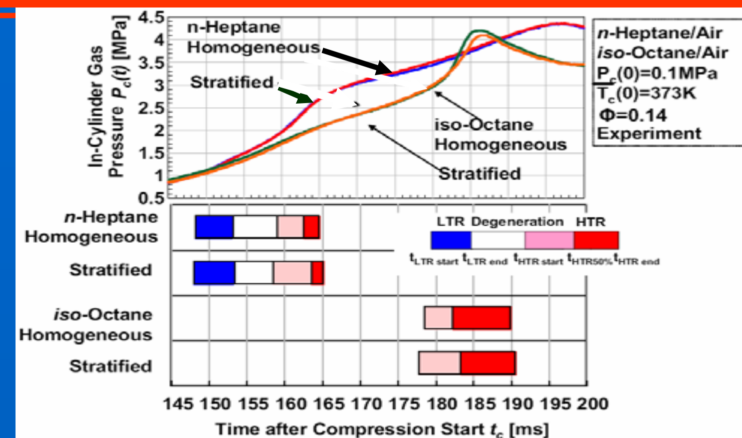
- Rapid Compression Machine Experiments with controlled Stratification show that both Reactive (large LTHR) and non-Reactive Fuels (little LTHR) Display Increased Reaction Duration with Stratification, as shown graphically at the bottom

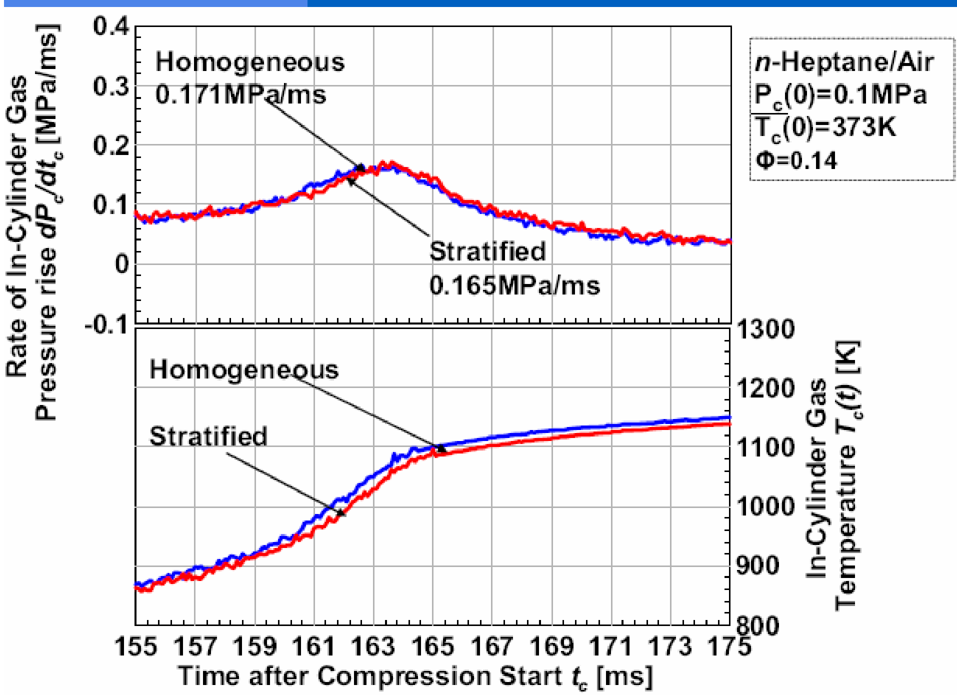


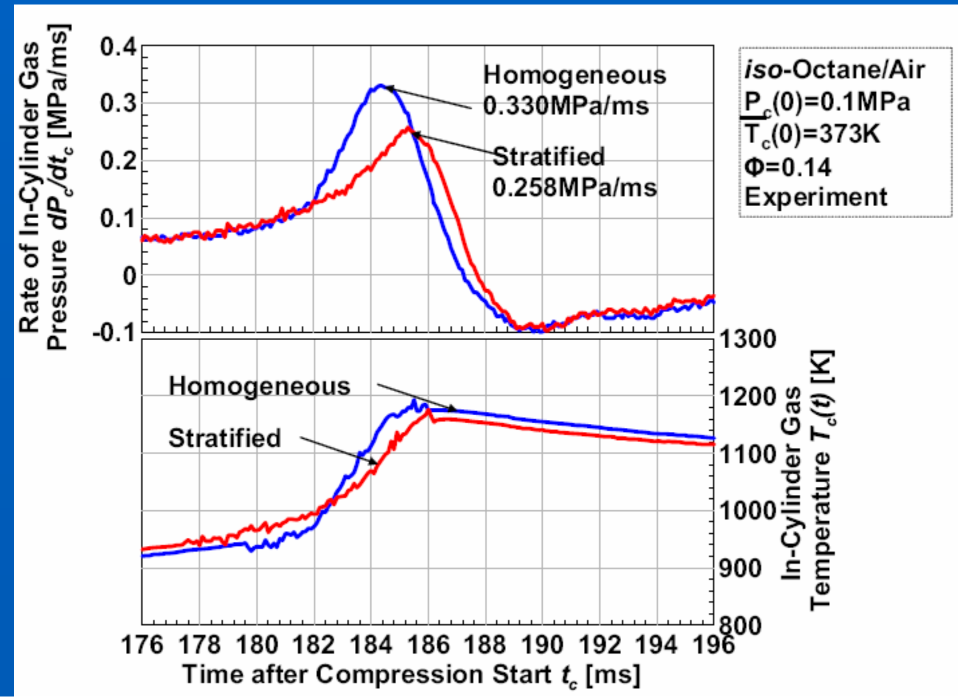


Stratification -
2006-01-3319 Keio University

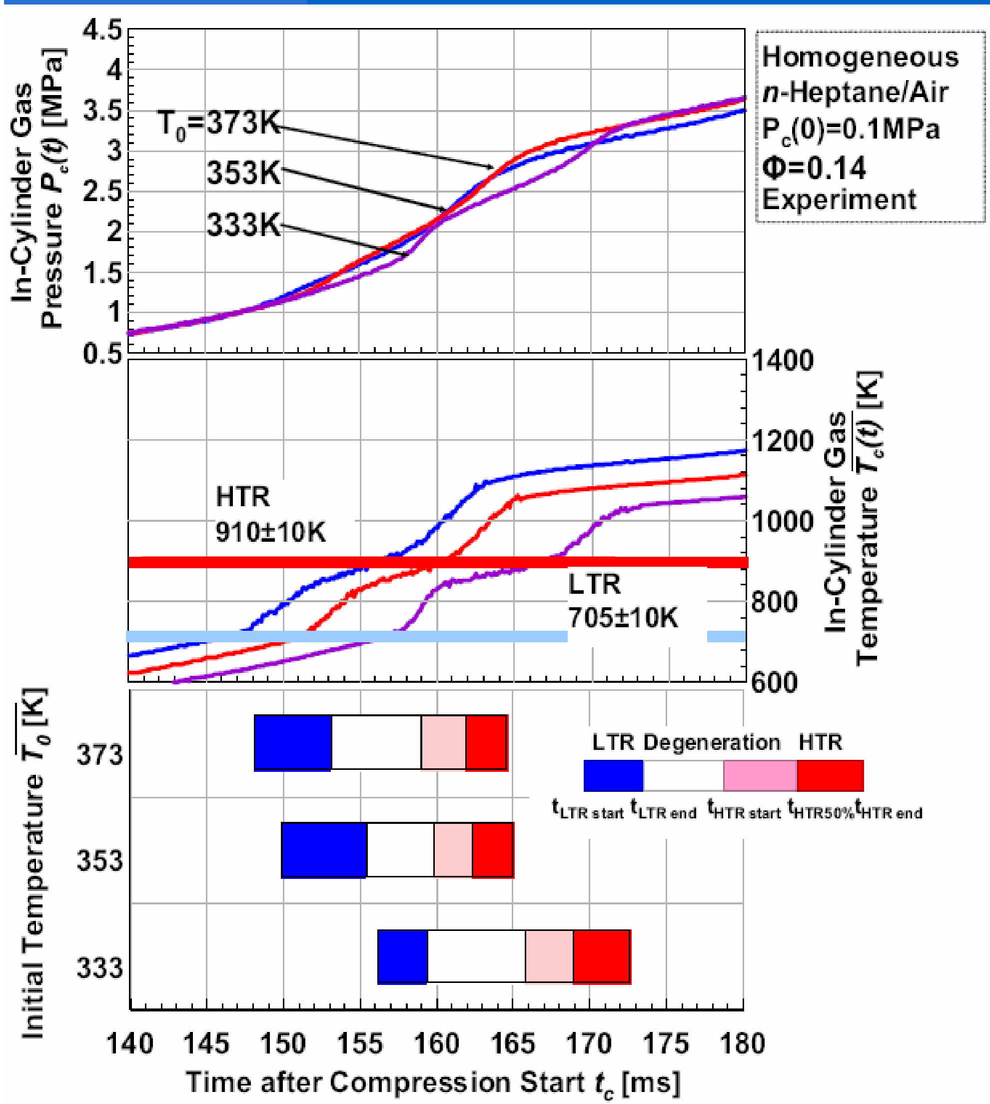
- Stratification has Little Effect on the P Rise Rate for Reactive Fuels and Significant Effect for non-Reactive Fuels





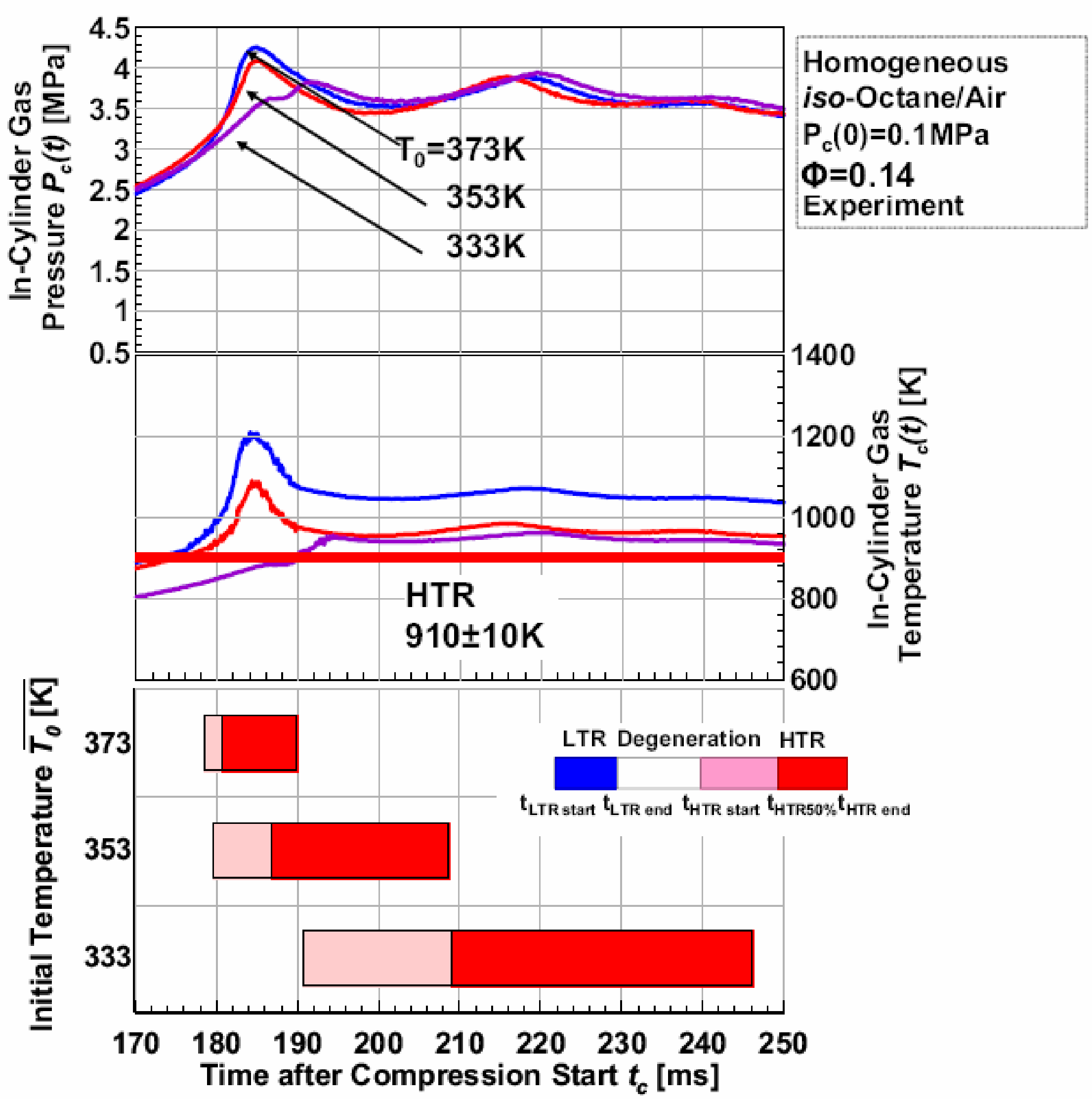


Initiation Processes -
2006-01-3319 Keio University



- Reactive Fuels characterized by a two Stage Initiation Process Involving Low T and High T Reactions
- LTHR and HTHR Initiation are Temperature Dependent
  - Heptane 705 and 910 K
- Parameters that Affect the Compression T History Affect the CA of Occurrence of LTHR and HTHR but not the T of Initiation
- Total Reaction Duration Remains Roughly Constant in this Case because all Reaction is Accomplished before TDC

Initiation Processes -
2006-01-3319 Keio University

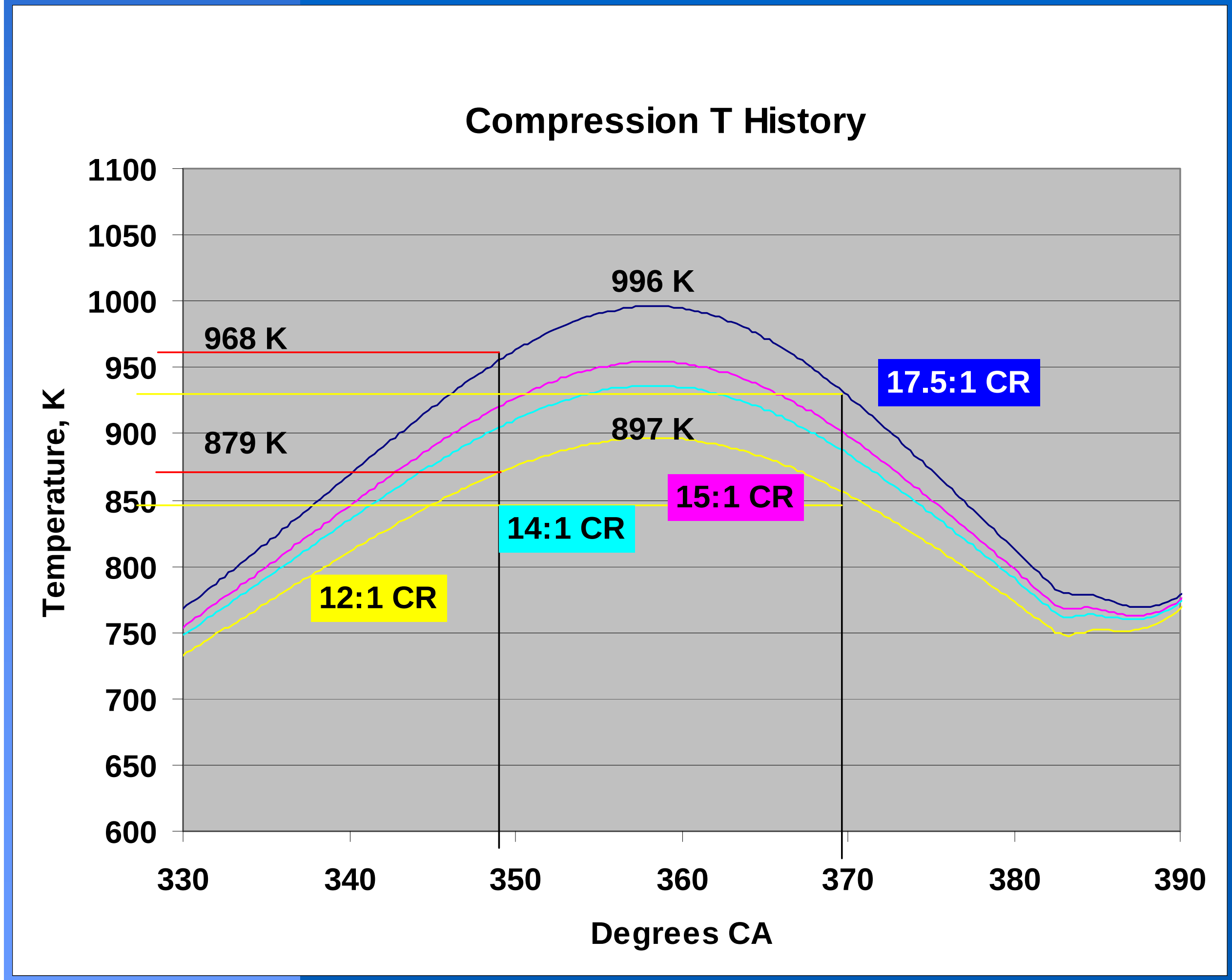


- Non-reactive Fuels Display a Single Stage Initiation Process
- HTHR is T Dependent
- Parameters that Affect the Compression T History Affect the CA of Occurrence of LTHR and HTHR but not the T of Initiation
  - HTHR T for Isooctane is 910 K
- Primary Reference Fuels for ON Rating have the same HTHR Initiation T
- Total Reaction Duration Increases in this case Due to Reaction after TDC

Effects on Temperature History

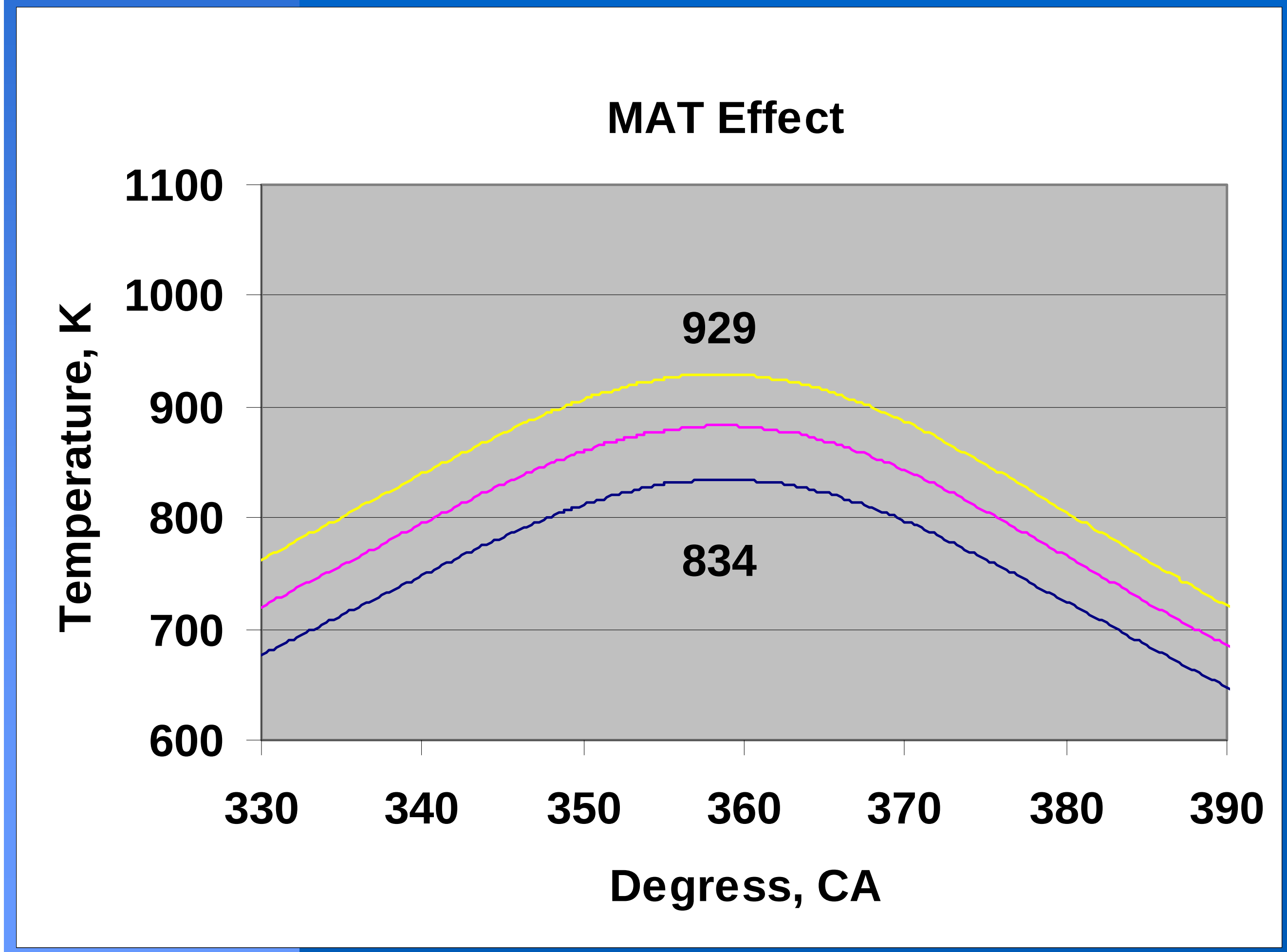
- Temperature History During Compression is Affected by:
  - Compression Ratio
  - Initial T and T Gradients
  - Mixing and Turbulence
  - EGR Level
  - Equivalence Ratio
  - Valve Timing

Compression Ratio Effect – Alamo_Engine Cycle Simulation



- Assumptions: 1liter/cyl Engine, SOR at 25º ATDC, 373 K MAT, 240 kPa MAP, 1800 rpm
- Area of Interest is from 10º BTDC to 10º ATDC
- Increase in CR from 12:1 to 17:1 Increases the T at 10º BTDC by 89 K, and Peak T by 99 K
- At 17.5:1, LTRH for n-Heptane Occurs 37º BTDC, and HTHR for Isooctane Occurs 16º BTDC
- At 12:1, LTHR for n-Heptane Occurs 33º BTDC, and HTHR for Isooctane is Never Achieved

MAT Effect at 14:1 CR – Alamo_Engine Cycle Simulation



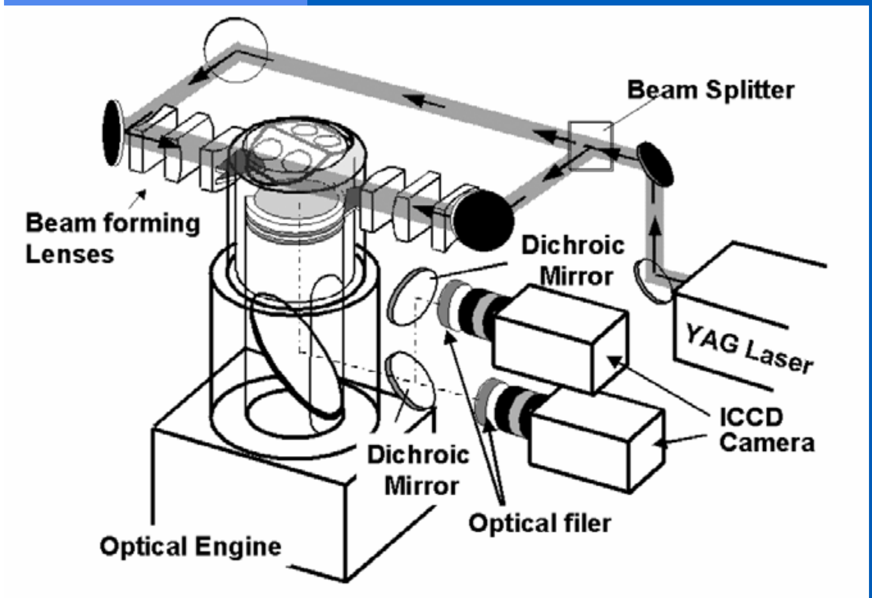
- Assumptions: 1liter/cyl Engine, SOR at 25º ATDC, 240 kPa MAP, 1800 rpm, 50, 100, and 150ºC MAT
- At 50ºC MAT, LTHR for n-Heptane Occurs 25ºBTDC and HTHR for Isooctane is Never Achieved
- At 150ºC MAT, LTHR for n-Heptane Occurs 38º BTDC and HTHR for Isooctane Occurs 9ºBTDC

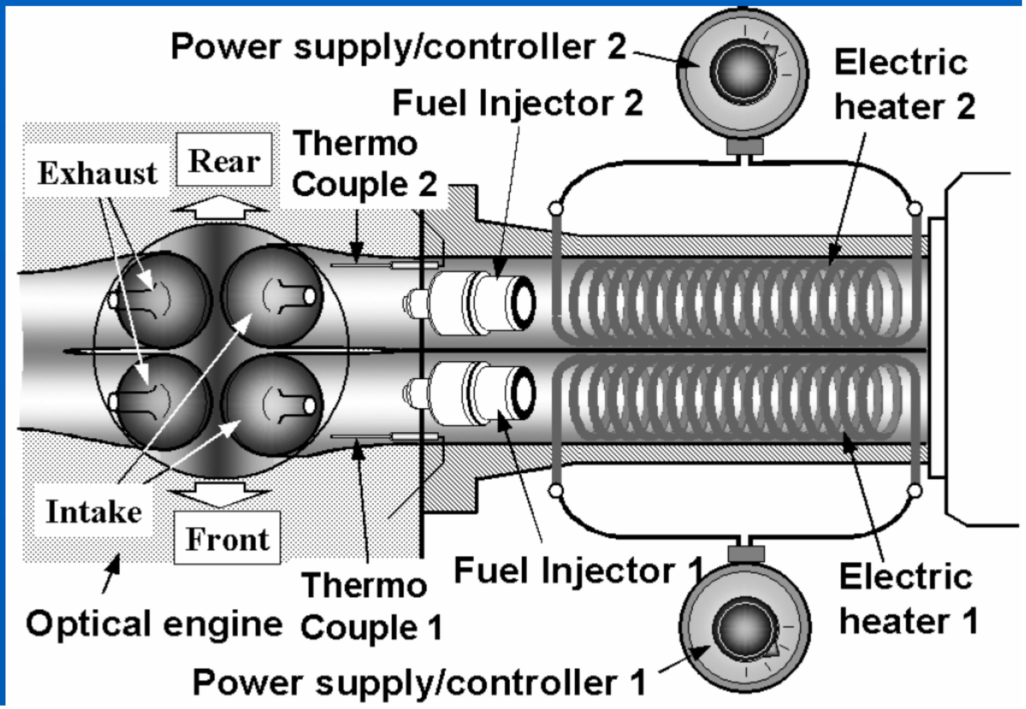
Recall

Temperature Gradient Effects - 2006-01-1202 Nissan Motor Co.

- Temperature and Fuel Stratification were Examined Using Dual Intake Ports with Individual T and Fuel Controls

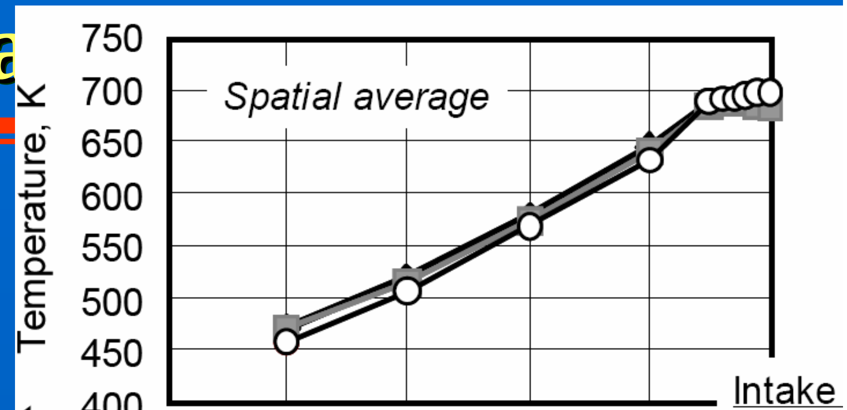
Optical Engine Experiment

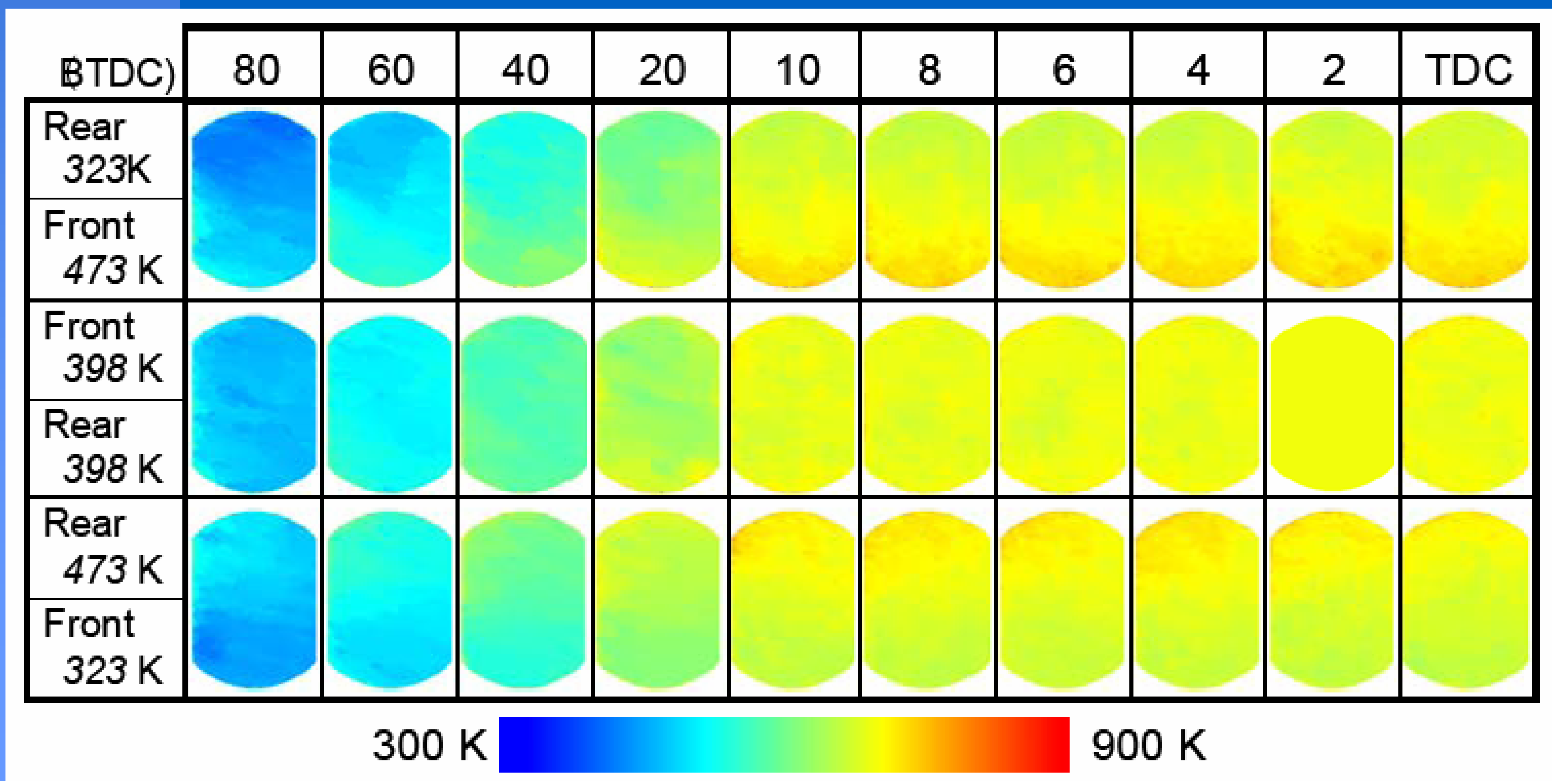




Temperature Gradient Effects - 2006-01-1202 Nissa

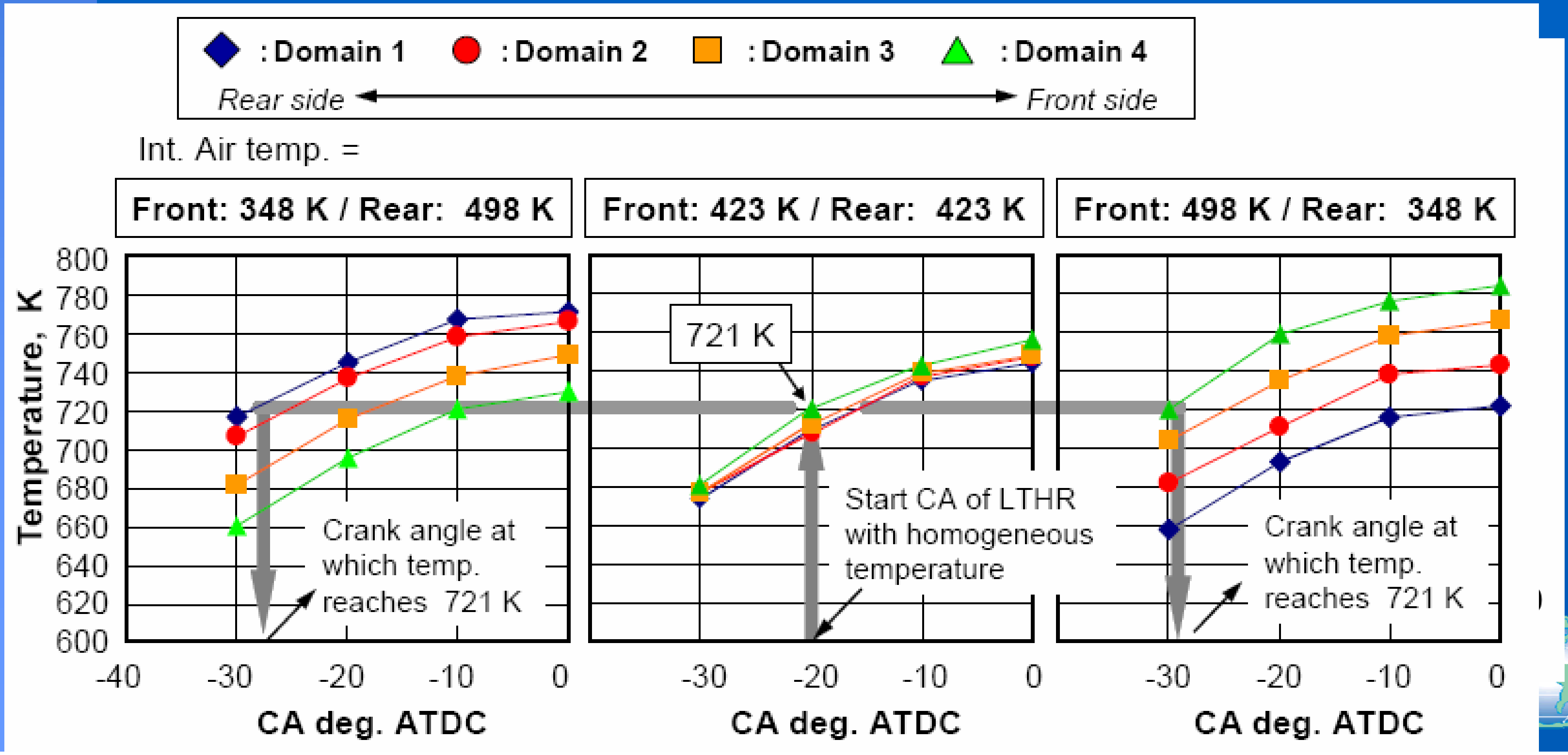
- Using a Fixed Average Temperature they did see T Stratification



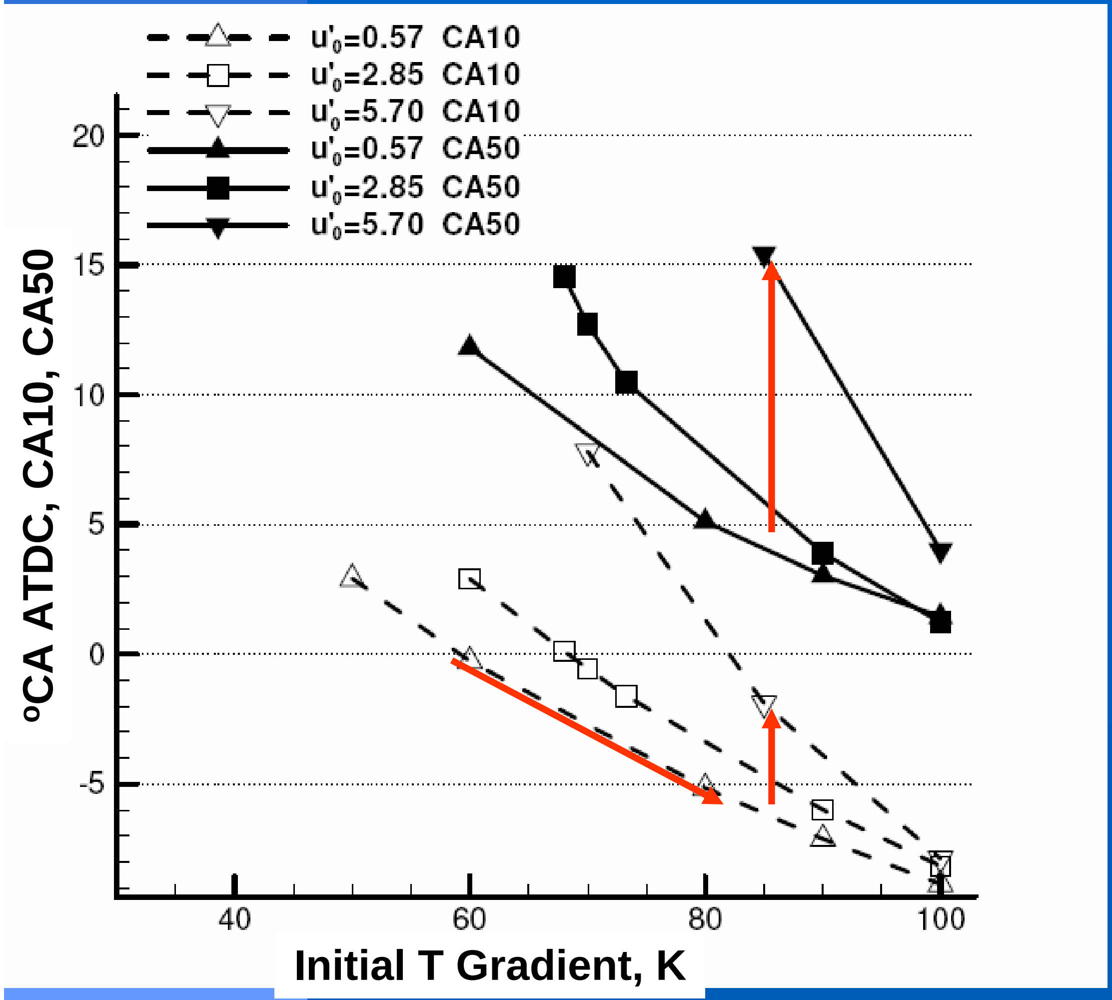


Temperature Gradient Effects - 2006-01-1202 Nissan Motor Co.

- They also Observed Earlier Onset of LTHR, and Calculated Temps in 4 Fixed Zones that Did Predict the Earlier On Set

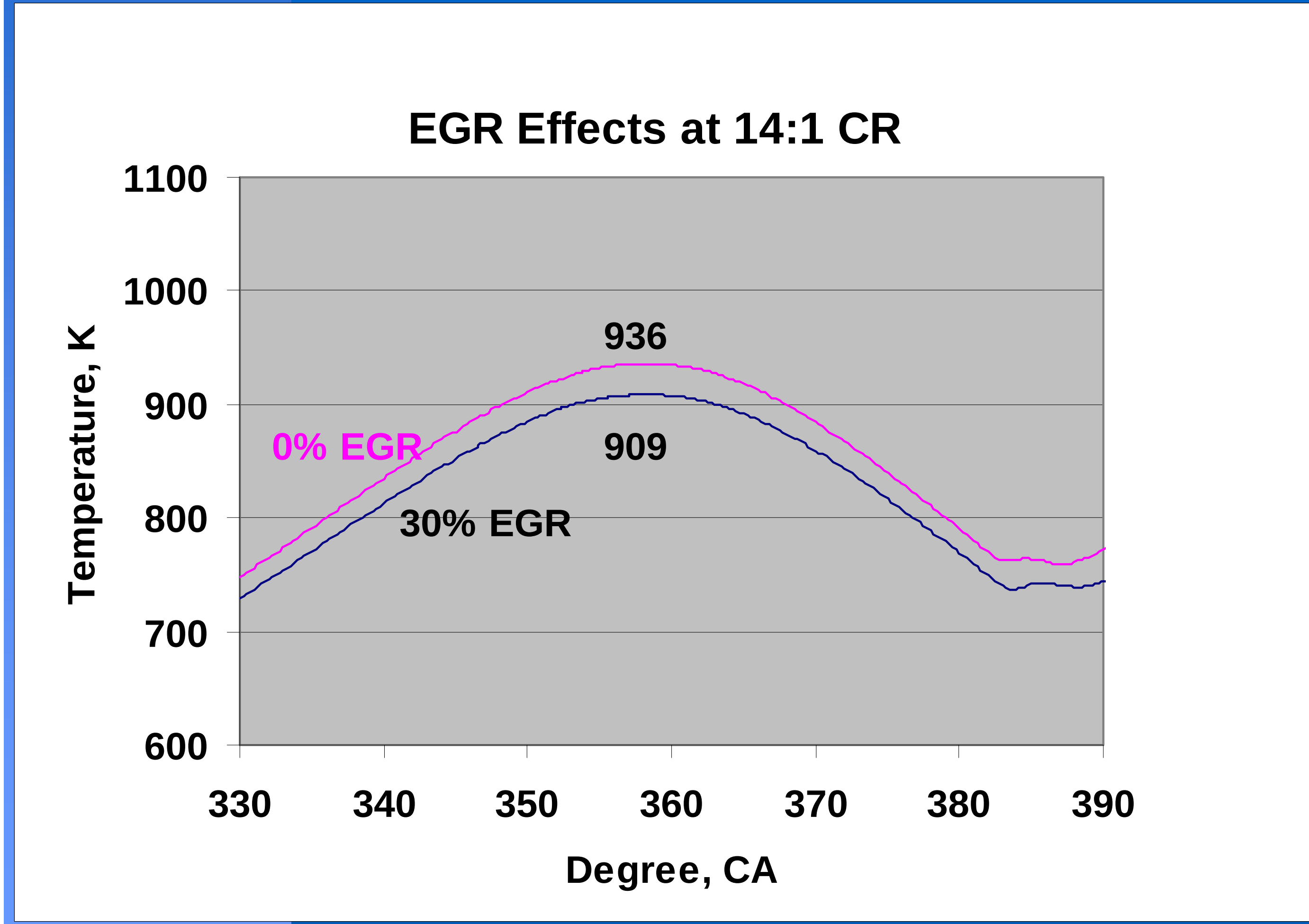


Effects of Turbulence 2006-010-3318



- For Reactive Fuels, Predictions indicate that for Fixed T Gradients, Increases in Turbulence Intensity Retard Ignition and CA50
  - Reduces the T Gradient
- For Fixed Turbulence Intensity, Increases in the T Gradients Result in Advanced Ignition and CA50
  - Hottest Locations get Hotter

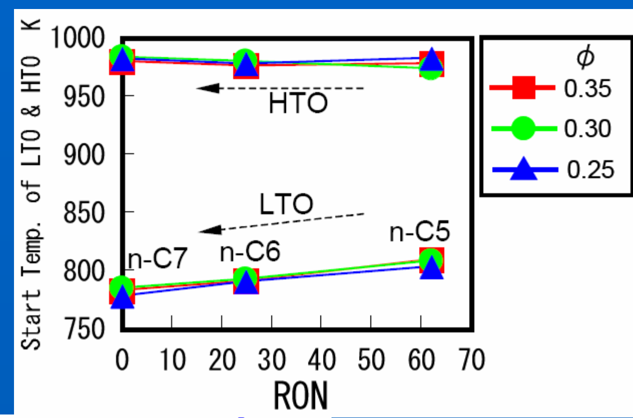
EGR Effect – Alamo_Engine Cycle Simulation

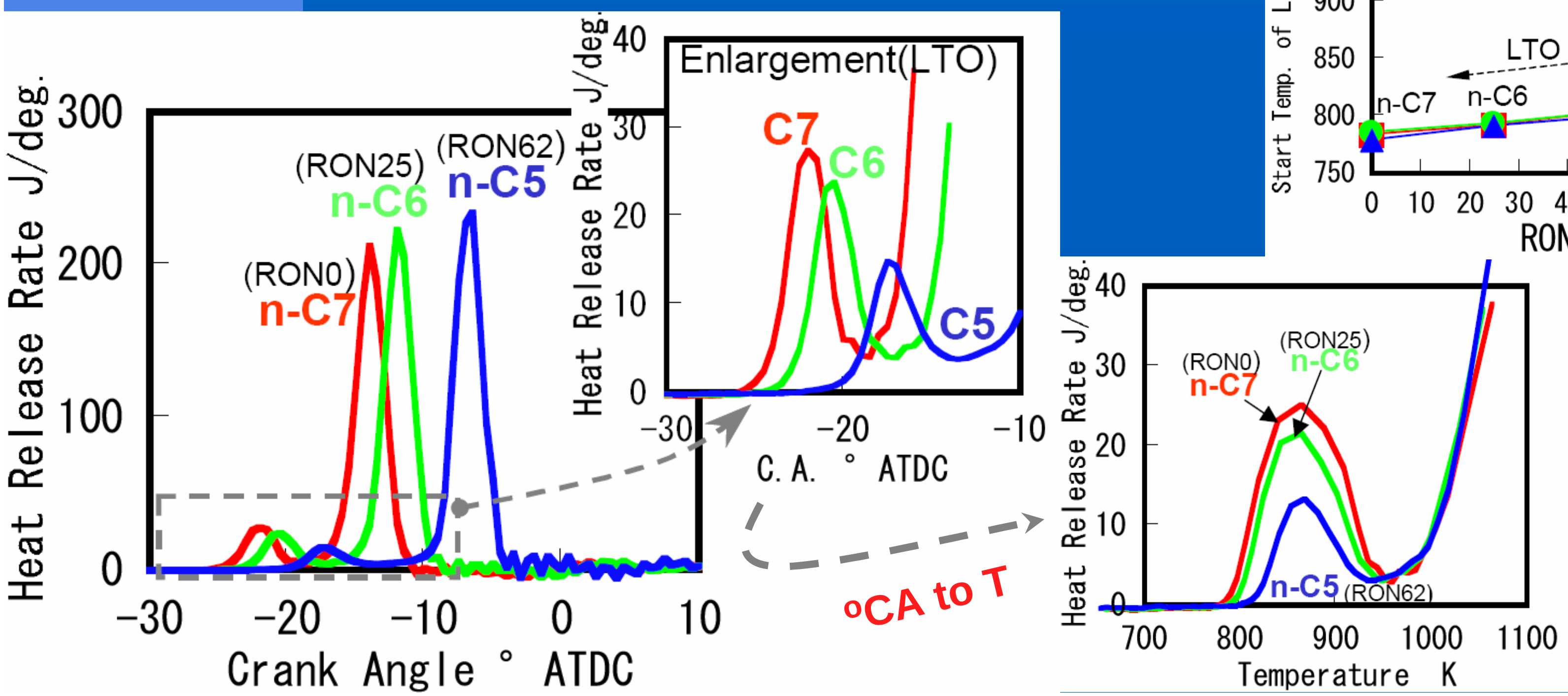


- Assumptions: 1liter/cyl Engine, SOR at 25º ATDC, 373 K MAT, 240 kPa MAP, 1800 rpm
- LTHR for n-Heptane Occurs 35º BTDC with Zero EGR and 32º BTDC with 30% EGR
- HTHR for Isooctane Occurs 10ºBTDC with Zero EGR and is Never Achieved with 30% EGR

Fuel and EGR Effects – SAE 2006-01-0028 Toyota

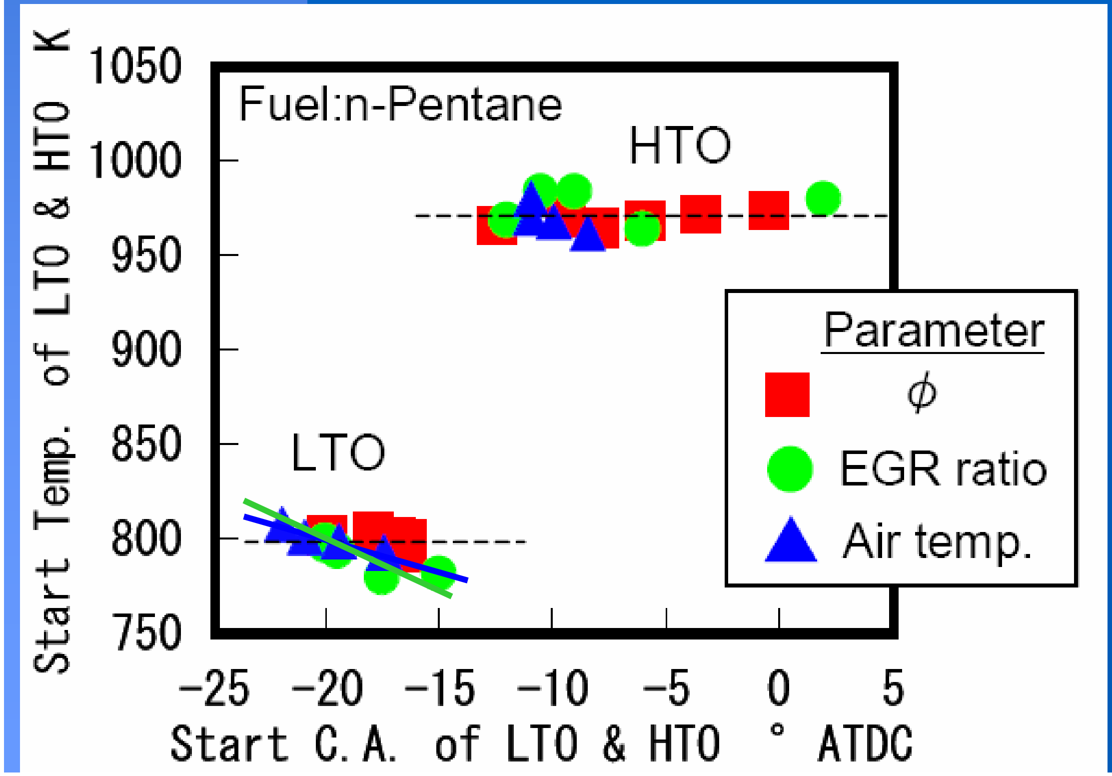
- Reactive Fuels Display LTHR T and LTHR Magnitudes that are Composition Dependent
  - Typically Lower LTHR Magnitudes and Higher LTHR T Correspond
- Specific Relationship is linear with Carbon Chain Length for the n-Paraffins Shown





Fuel and EGR Effects – SAE 2006-01-0028 Toyota

- Authors Claim no Effects of Equivalence Ratio, EGR, or MAT on LTHR and HTHR

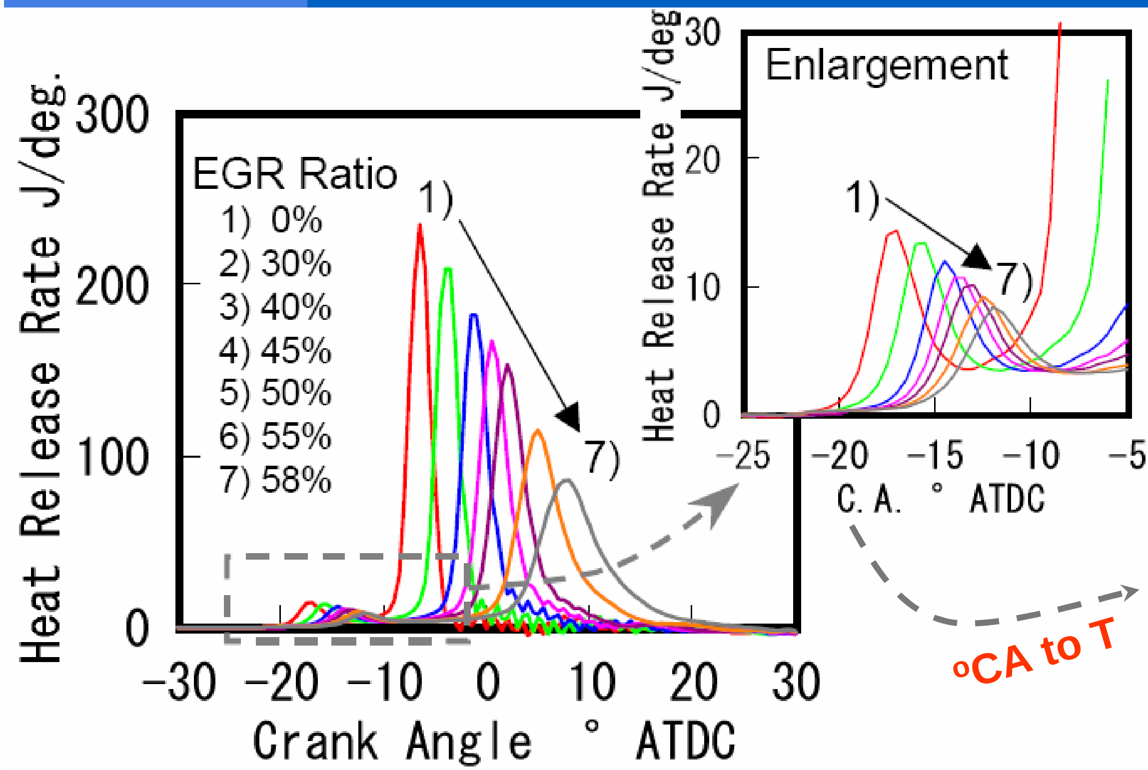


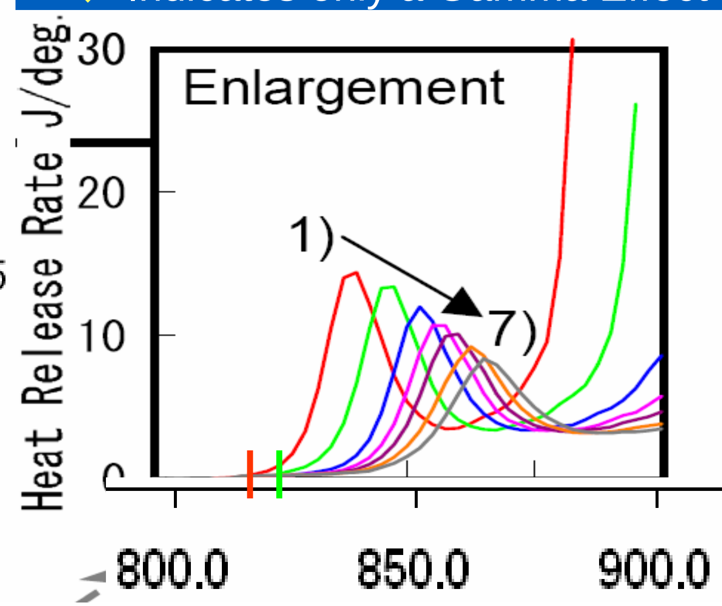
- Agree with the HTHR Conclusion but Disagree with LTHR Conclusion, Figure Shows Significant Slopes for the EGR and MAT Effects
  - LTHR T Varied from 770 to 800 K over the Range of EGR's Tested
  - LTHR T Varied from 790 to 810 K over the Range of MAT's Tested

Fuel and EGR Effects – SAE 2006-01-0028 Toyota

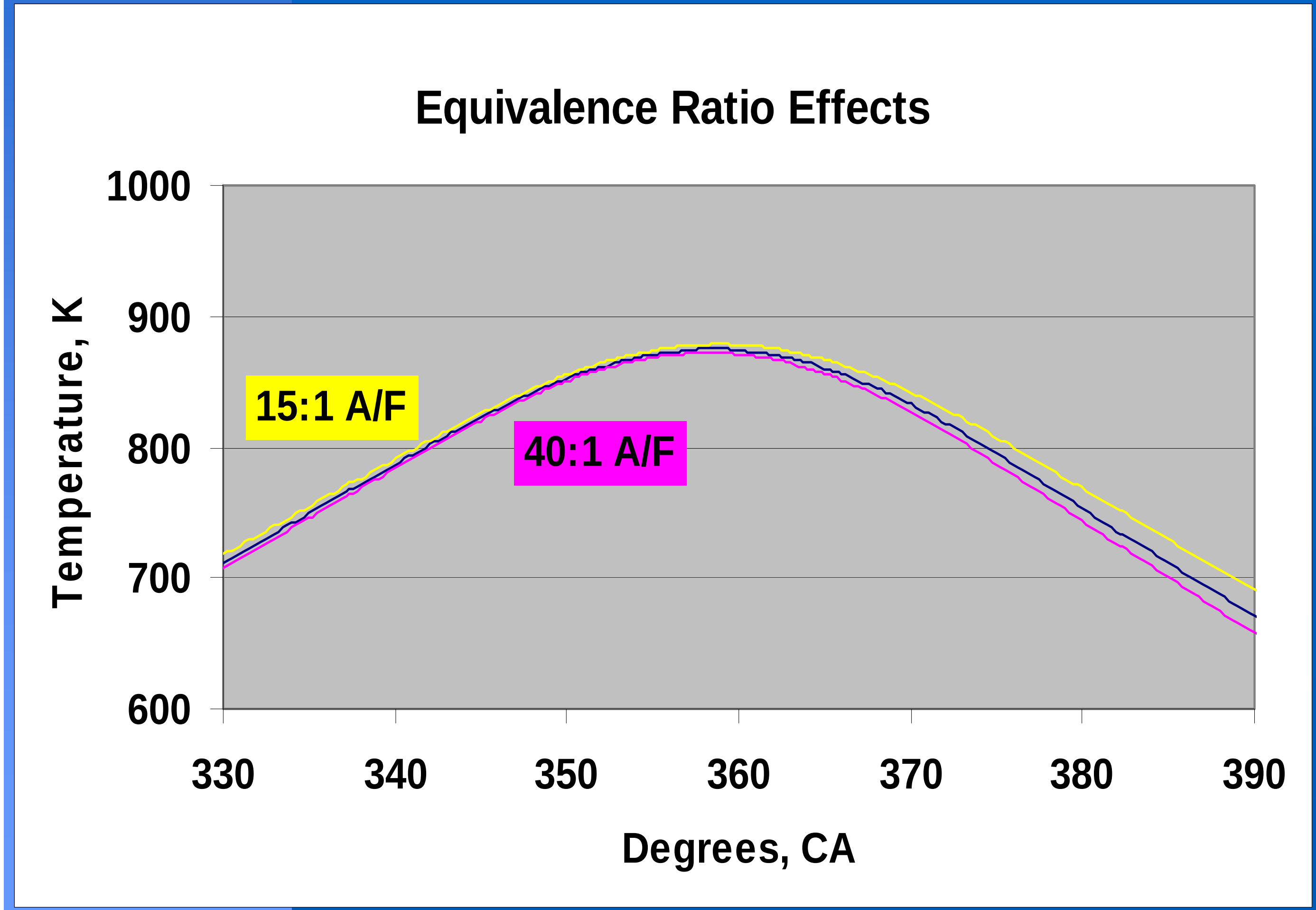
- EGR Effects are Clearly Demonstrated below for n-Pentane

- Assuming the Same Conditions as Shown Previously, Figure Below Shows the EGR Effect on LTHR T
- 0-30% EGR Changes LTHR T by ~6º C Compared to 8ºC Calculated Effect of EGR on the Compression T History
  - Indicates only a Gamma Effect





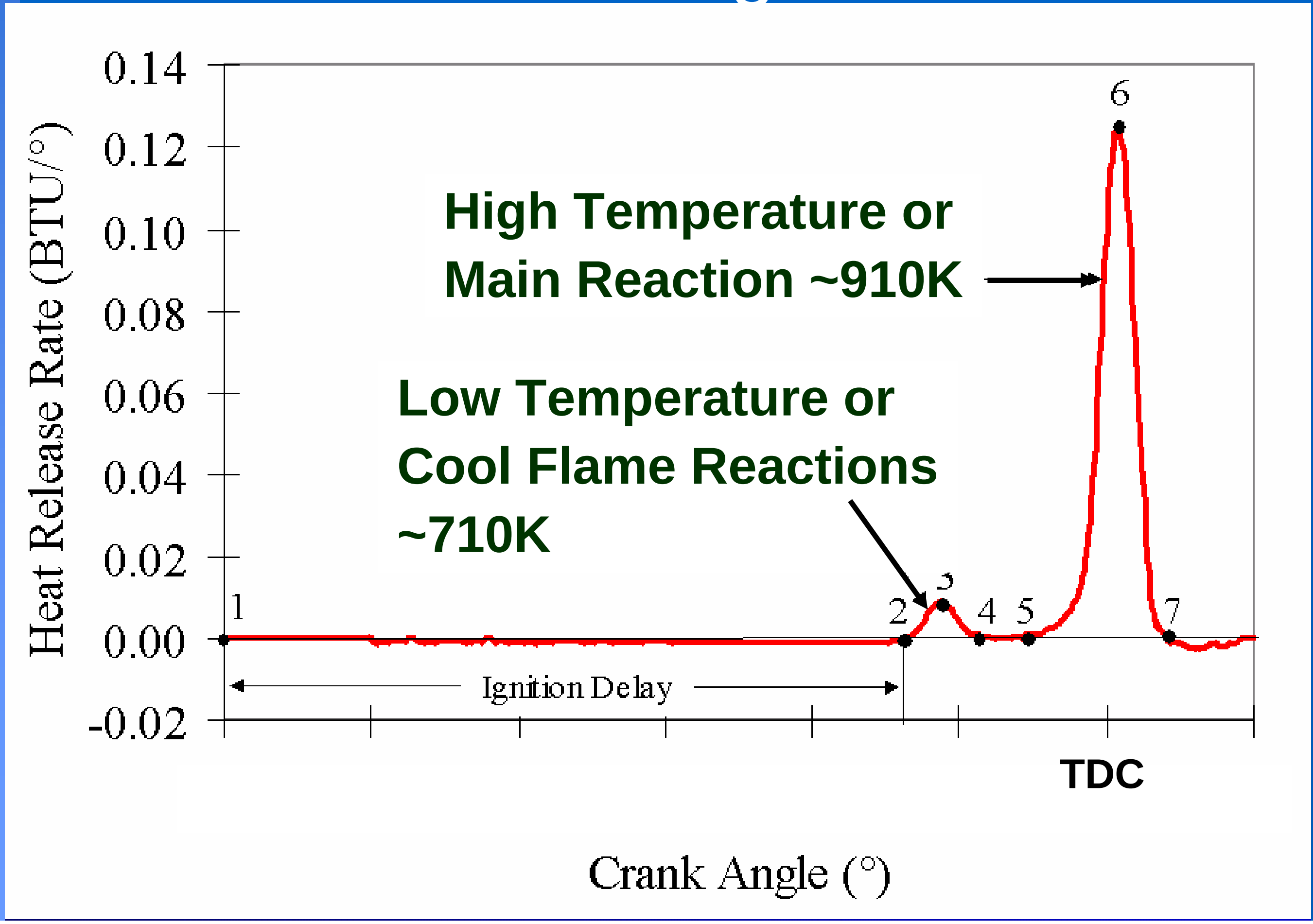
Equivalence Ratio Effect – Alamo_Engine Cycle Simulation



- Assumptions:1 liter/cyl Engine, SOR at 25º ATDC, 373 K MAT, 240 kPa MAP, 1800 rpm, 15, 25 and 40:1 A/F, same BDC T for all cases
- Very Little Difference
- 710 K at 31, 30, and 29o BTDC Respectively for 15, 25 and 40:1 A/F
- 910 K Never Achieved at this CR and Conditions

Reminder

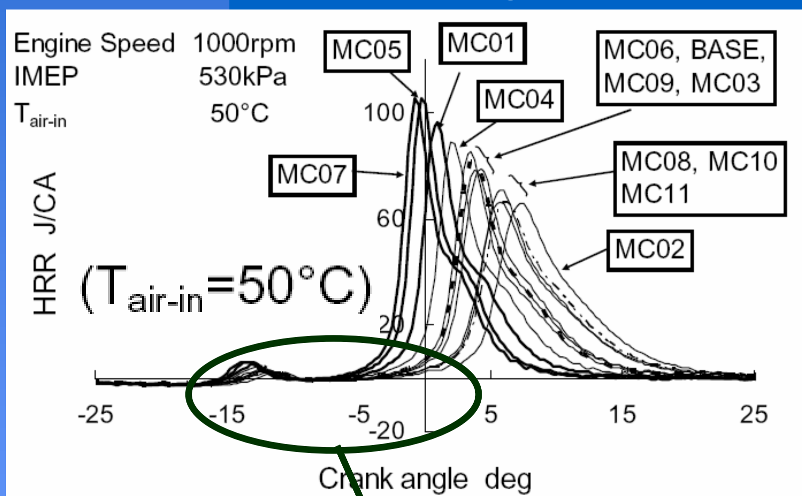
- HCCI Reactions many Times Involve Two Stage Processes

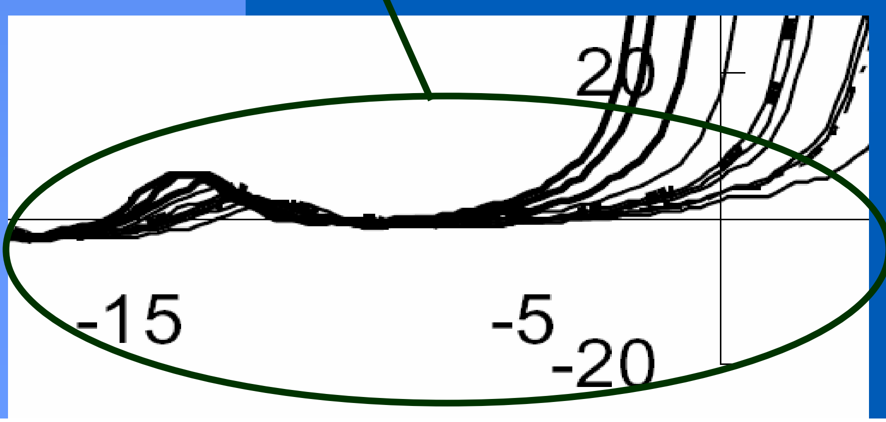


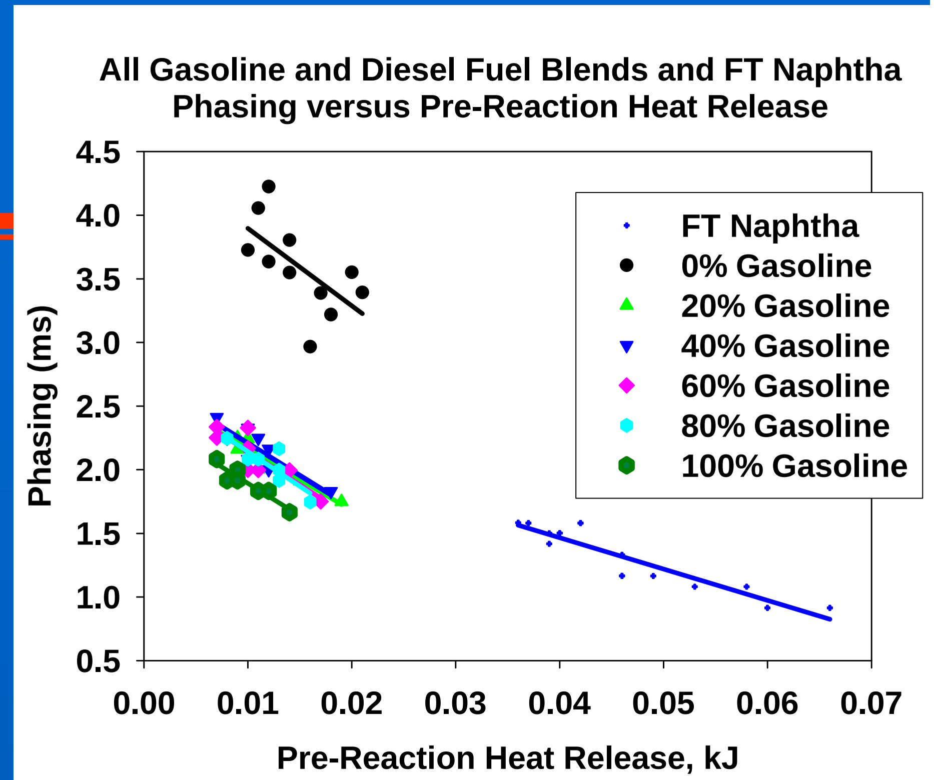
LTHR and HTHR

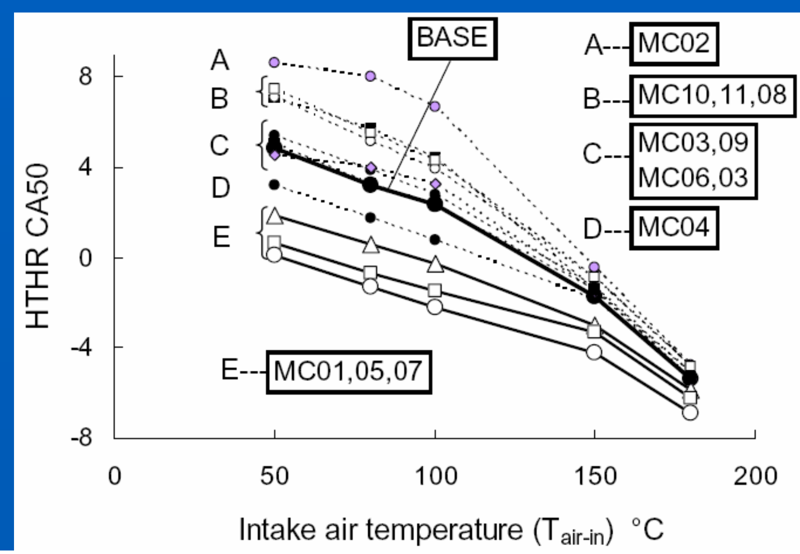
2006-01-0207 Nippon Oil
2004-01-1947 SwRI

- CA of Occurrence of LTHR, and the LTHR Magnitude Define CA50 in HCCI Engine



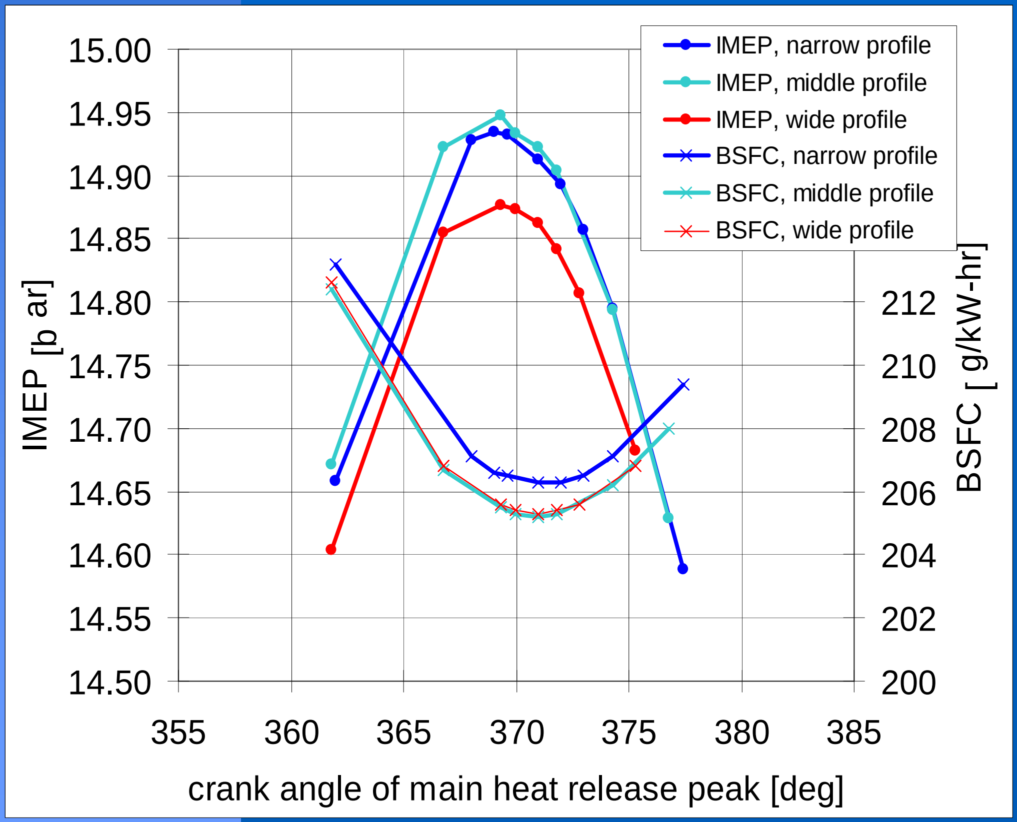


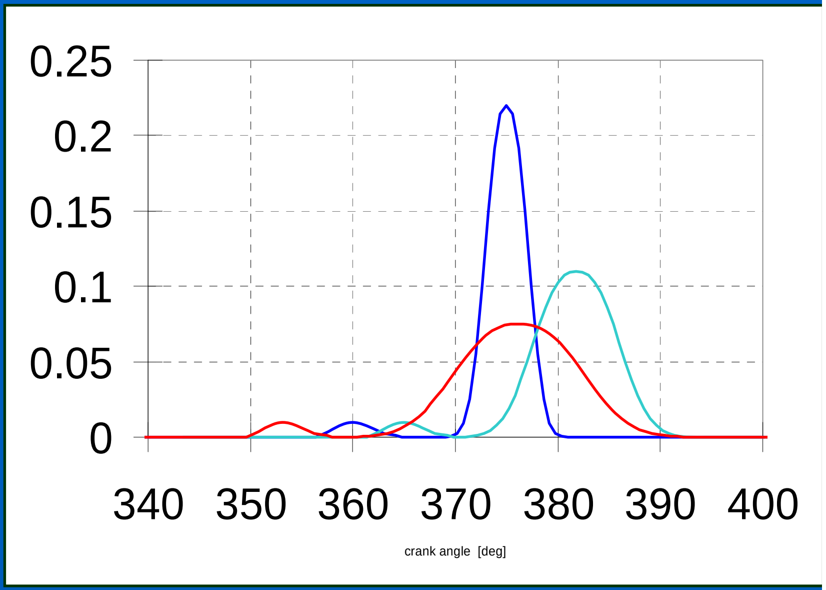




Optimum Reaction Phasing

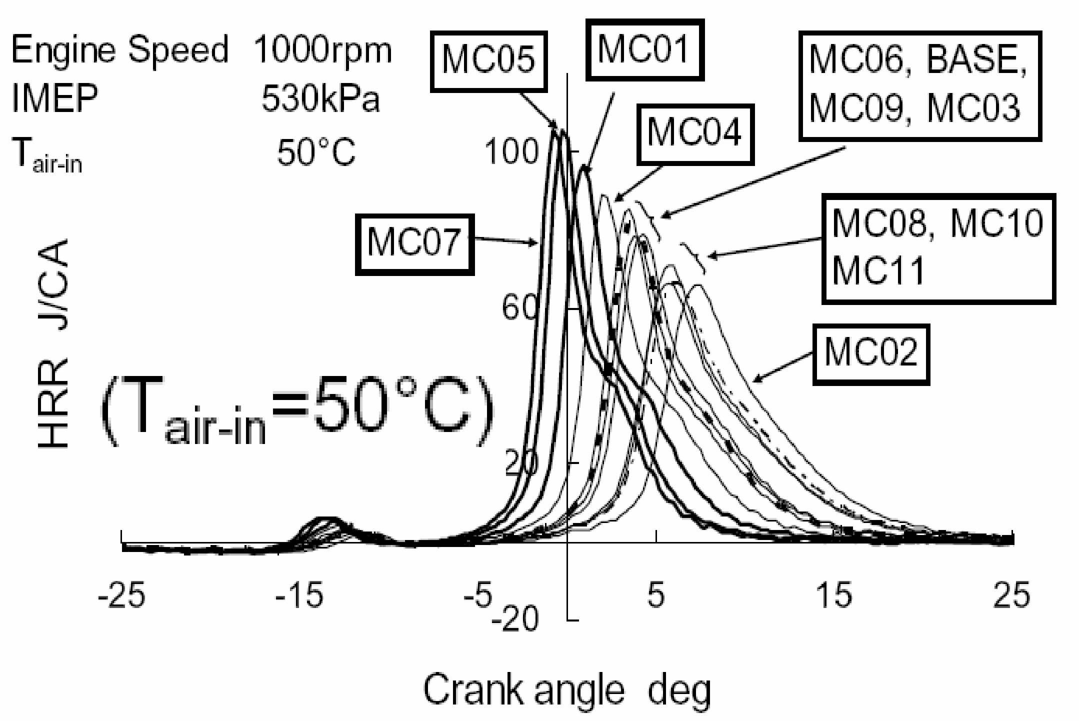
- Lowest BSFC and Highest Load with CA50 at 10º ATDC

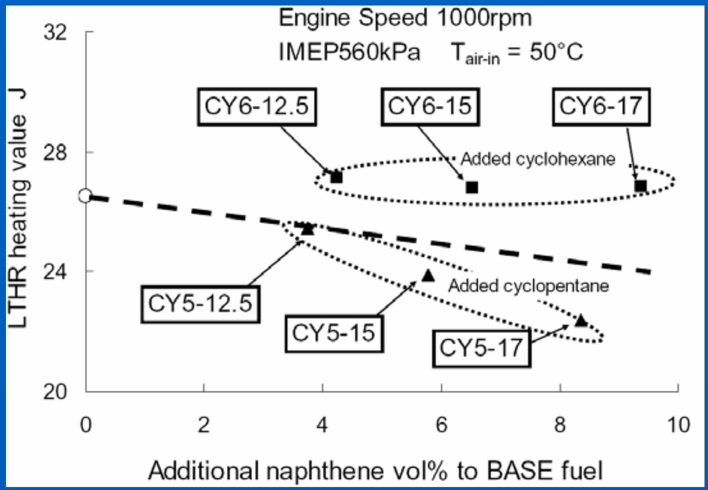




Fuel Effects - 2006-01-0207 Nippon Oil

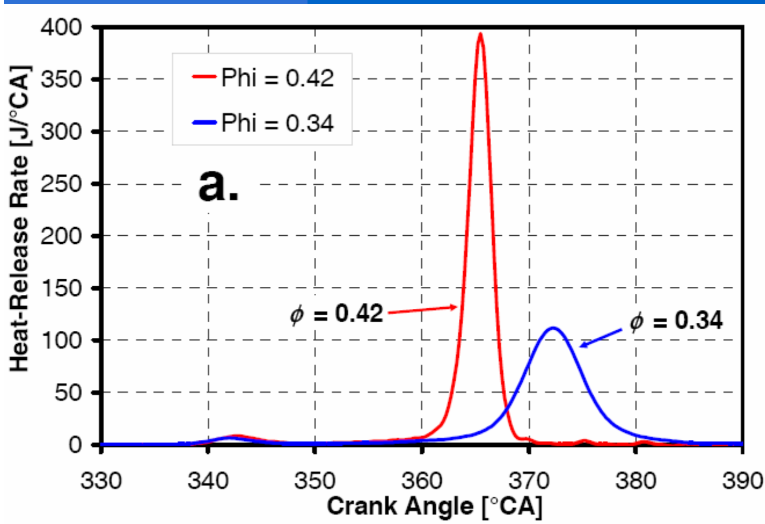
- Low Temperature Reactions (in terms of both EPAIT and Cool Flame Magnitude) are Dependent on Fuel Composition, holding all else constant
  - EPAIT Decreases and Cool Flame Magnitude Increases with n-Paraffin Content
  - Cyclic Compounds Suppress these Effects

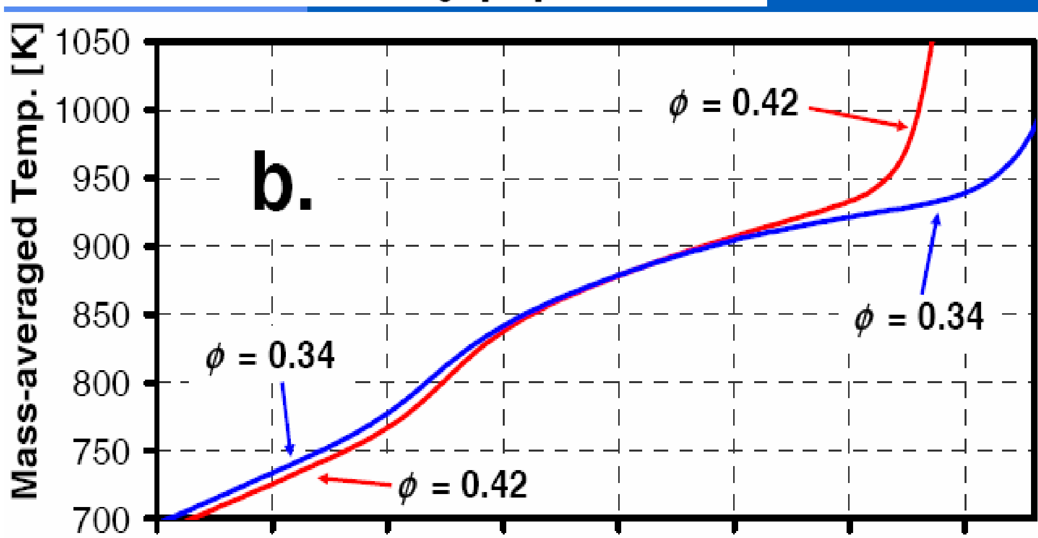


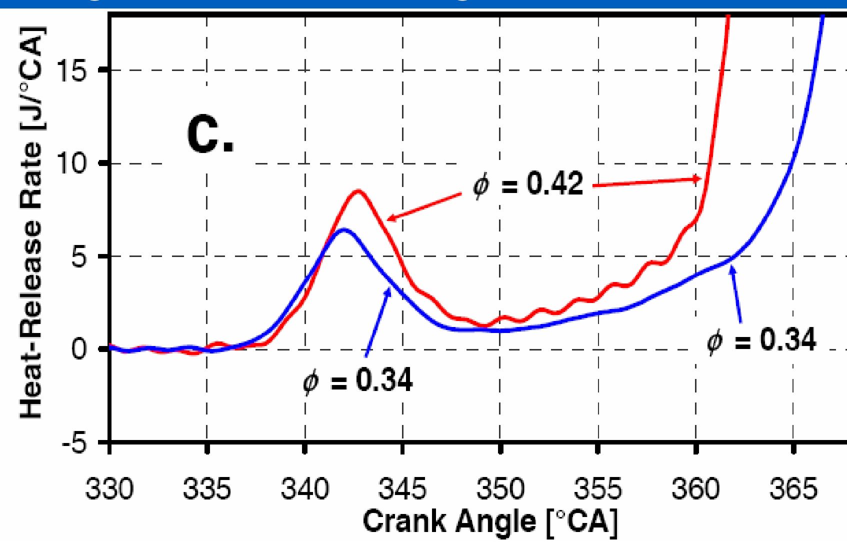


Another Equivalence Ratio Effect –
2006-01-1518 Sandia

- Fuels with Low Temperature Reactions Exhibit more Low Temperature Reaction as Φ Increases due to Higher Concentrations of the Contributing Compounds
  - CA50 Advances with Load
  - Note the Gamma Effect on Compression T History
  - Note Large of Minor Change in LTHR







Summary

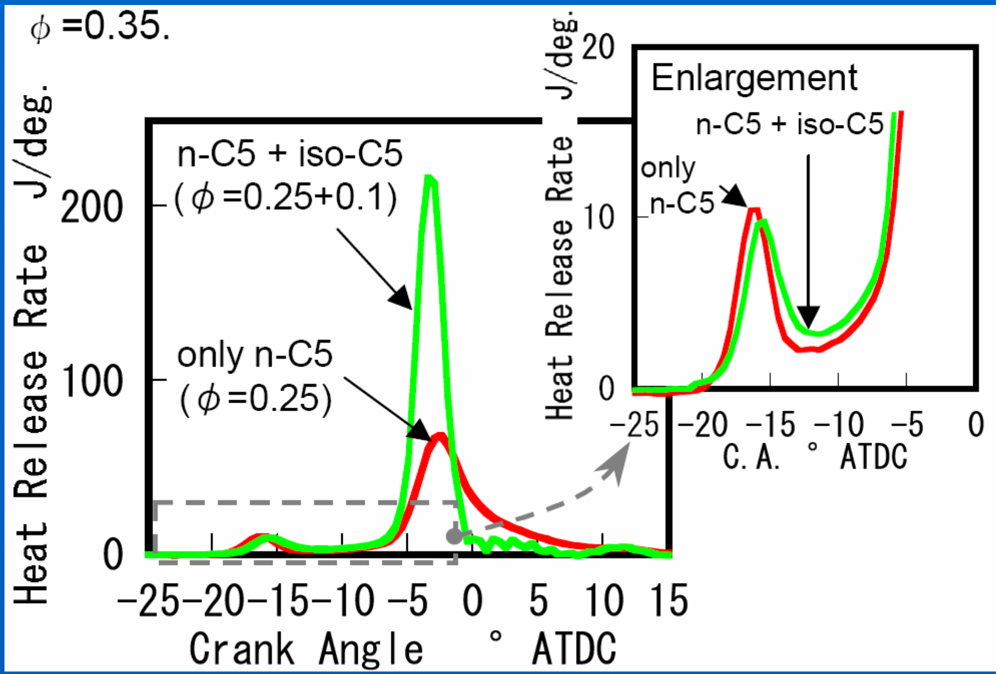
- Start of Reaction T (EPAIT by SwRI IQT Method) and the Magnitude of LTRH (also Possible to Measure in SwRI IQT) are Fuel Properties that can be Measured and are Convenient as Specification Properties
- Non-Reactive Fuels Display Little or No LTHR and the Start of Reaction T (or EPAIT) is the HTHR T
- For Reactive Fuels, LTHR Occurs Early, at Low Compression Temperature, Raising the T for the Following Compression, Thus Advancing HTHR Onset

Summary (continued)

- Given EPAIT and the Cool Flame Magnitude and the Compression Temperature History, it is Possible to Predict CA50 with EGR and Thermodynamic Condition Corrections
  - CR Effect Estimated by Isentropic Compression
  - MAT Effect Estimated by Isentropic Compression
  - EGR Appears to Have Only a Gamma Effect on the Compression T History, Estimated by Isentropic Compression
  - Stratification Effect Estimated by Maximum ΔT
    - Turbulence Effects Estimated by Mixing Rate Calculation

Fine Points – Fuel Effects – SAE 2006-01-0028 Toyota, IFP HCCI Symposium 2004 SwRI

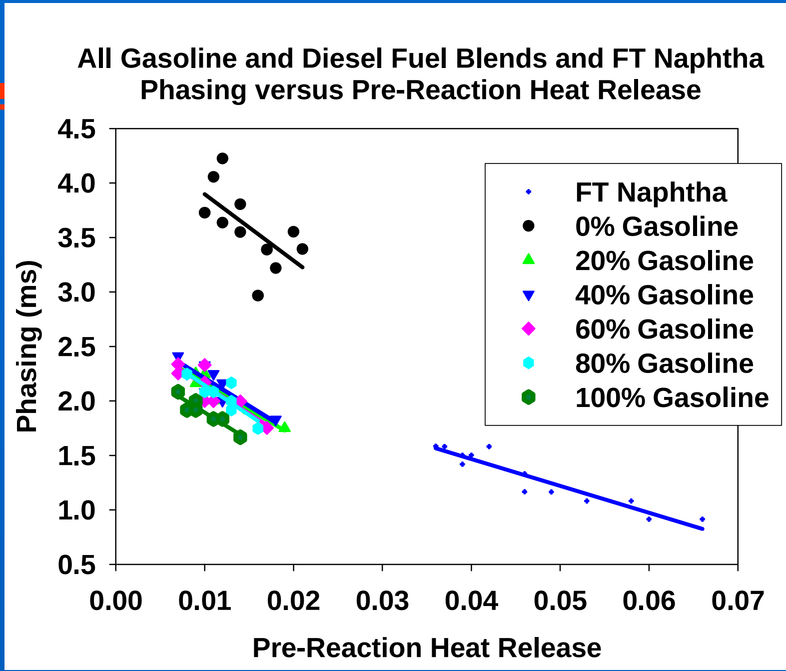
- Fuel Effects Must be Interpreted with Care
  - Addition of a Non-Reactive Component (iso-Pentane) has Little or No Effect on the LTHR T and Magnitude of the Reactive Component (n-Pentane)
    - As Long as the Quantity of Reactive Component is Constant (no Dilution Effect), and
    - As Long as the non-Reactive Component is not a LTHR Suppressor
    - Iso-Pentane had No Effect on the LTHR of the n-Pentane

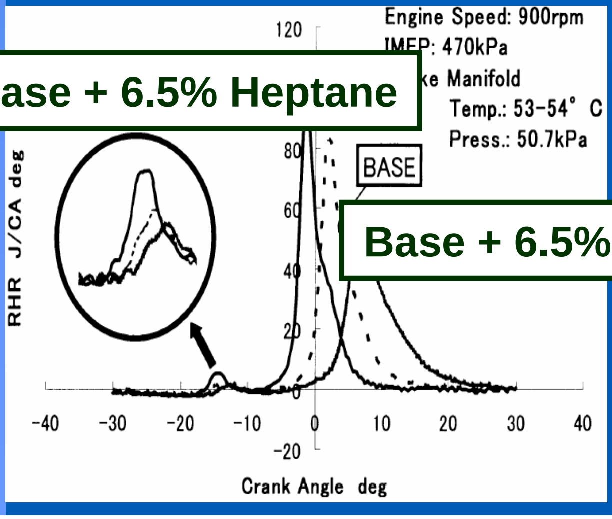


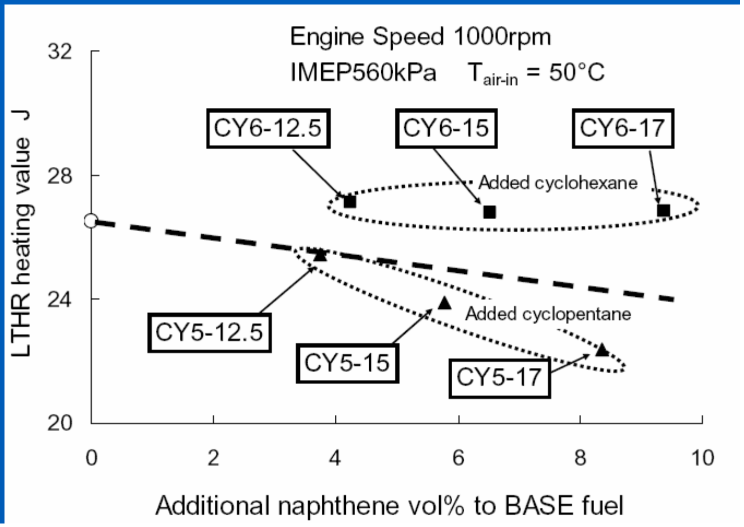
- The Presence of the Reactive Component Has Little or No Effect on the HTHR
  - N-Pentane had No Effect on the HTHR of the iso-Pentane

Fine Points – Fuel Effects – SAE 2006-01-0028 Toyota, IFP HCCI Symposium 2004 SwRI, SAE 2006-01-0207 Nippon Oil

- Fuel Effects Must be Interpreted with Care
  - SwRI Experiments indicate
    - Addition of a Small Quantity of non-Reactive Component (gasoline) has a Major Impact on the LTHR T and Magnitude of the Reactive Component (diesel fuel)
  - Nippon Oil Results Indicate that some non-Reactive Components Actually Suppress the LTHR T and Magnitude of Reactive Components
    - Cyclic Compounds Tend to Act as Suppressors

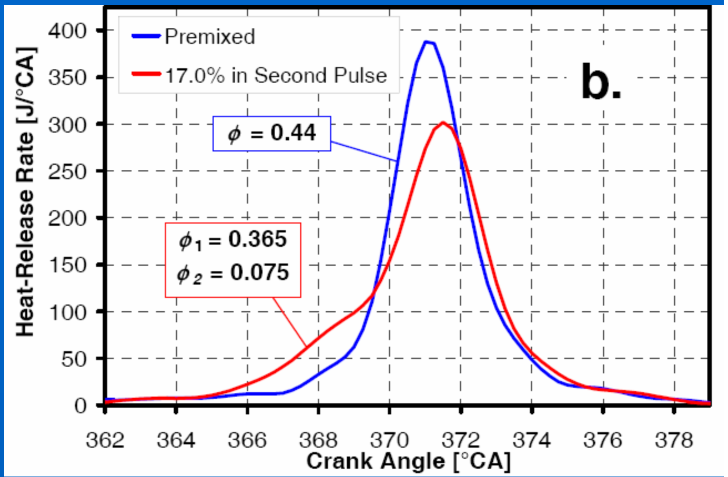


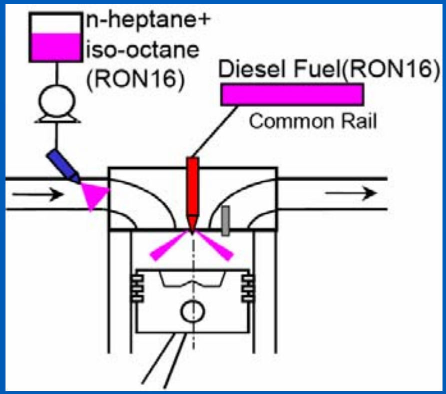


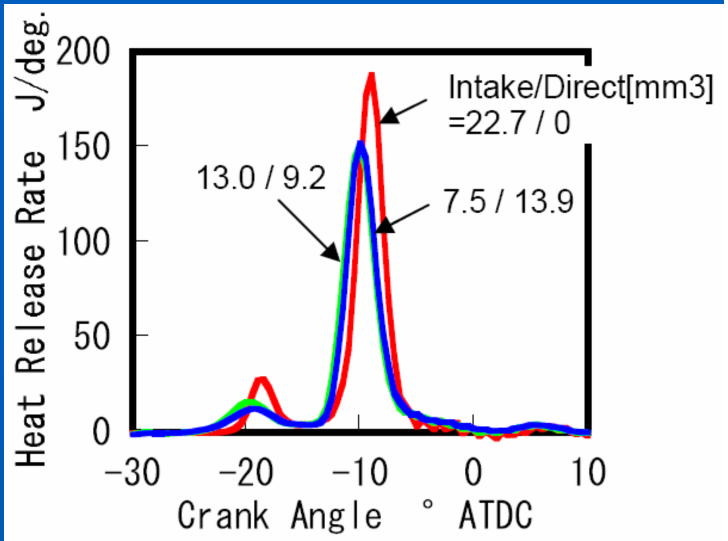


Fine Points-Stratification- SAE 2006-01-0028 Toyota, 2006-01-1518 Sandia

- Stratification can Reduce the Peak Rate of Pressure Rise and Peak Pressure but Caution must be Observed
  - If the Mean T Remains the Same, T Stratification will Lead to Higher Peak T and Earlier Onset of Reaction
  - If the Overall Equivalence Ratio Remains the Same, the Richer Locations will React Earlier
    - Sandia Demonstrated Improvement with Same Fuel in Two DI Injections, one early for Homogeneous and one late for Stratification
    - Toyota Demonstrated using two Injectors with Two Different Fuels with Approximately the Same Reactivity
  - Both Sandia and Toyota Demonstrated the earlier Onset of LTHR and Reduction in the Peak HTHR







Thank you