The Effect of Diesel fuel properties on Emissions-Restrained Fuel Economy at Mid-Load Conditions

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Research and Technology

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High Efficiency Clean Combustion Program (HECC)

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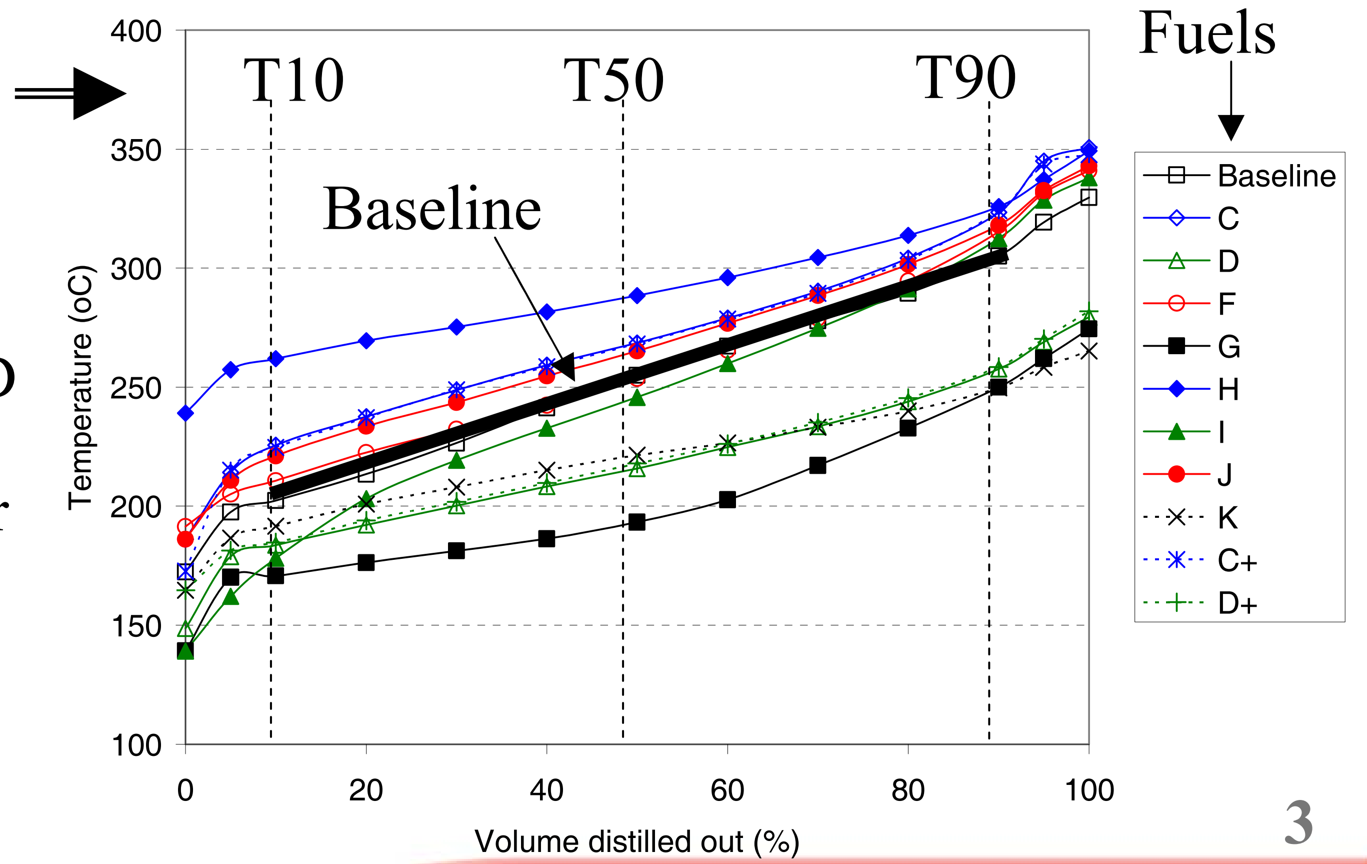
HECC Objectives

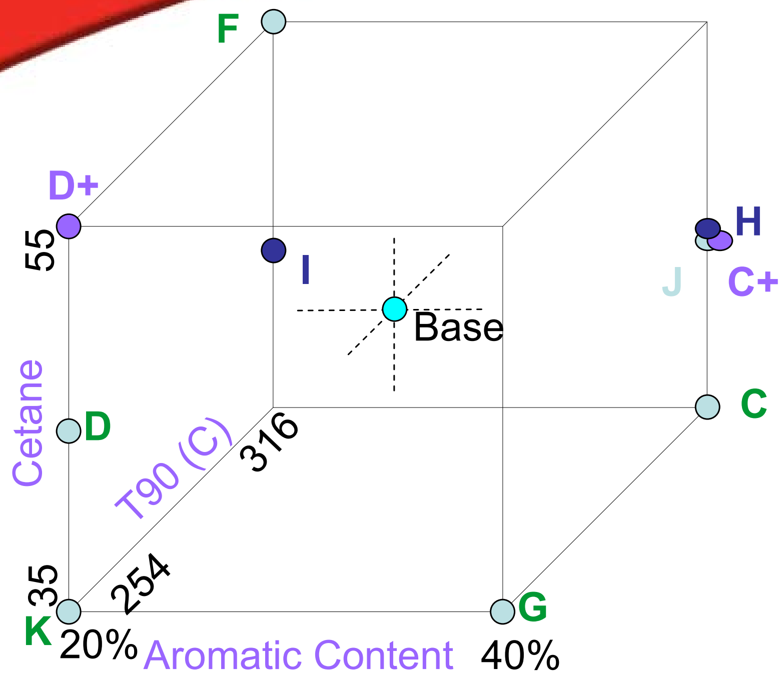
1. Improve brake thermal efficiency by 10% and reduced engine out emissions (2010 compliance)
2. Design and develop enabling components and subsystems (air handling, fuel injection, base engine, controls, etc.)
3. Specify fuel properties conducive to improvements in emissions and fuel efficiency → Focus of this talk
4. System integration for fuel economy optimization (engine and vehicle)

Fuel properties

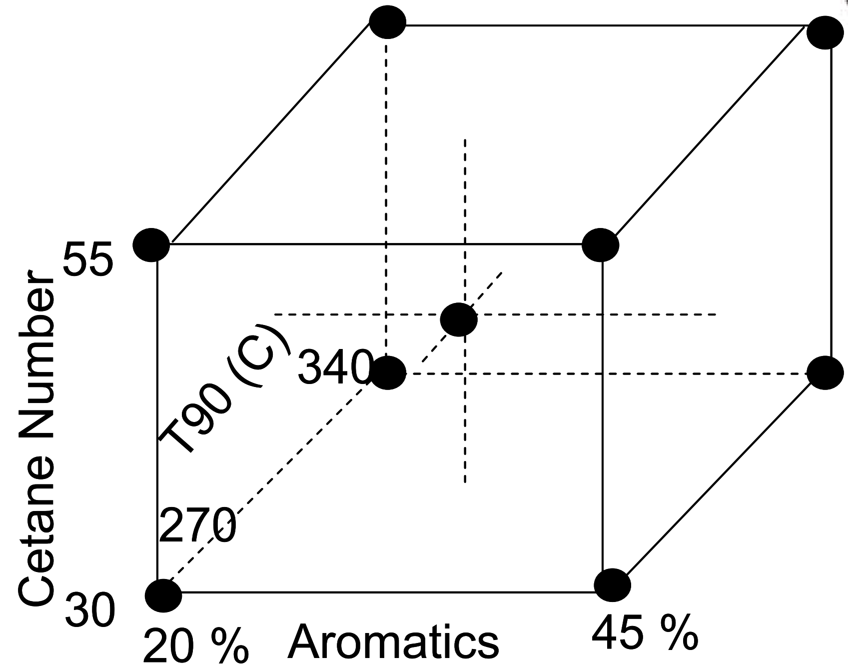
- Eleven diesel fuels were specially blended according to the experimental design with variation in cetane number, distillation characteristics & aromatic content
- Three target Cetane levels (35, 45 and 55)
- Distillation characteristics involved perturbations around the baseline ULSD #2 properties; three levels for T10 and two levels for T90
- Two levels for aromatics



HECC vs. FACE fuels



HECC blends



FACE blends

- High Aromatic and high cetane for the HECC could not be achieved with commercial refinery blends
- Distillation variation is achieved by blending light- or heavy-cut blending streams; cetane number affected by mono- aromatic content
- Heating value, density allowed to float

Modeling Strategy

Engine emissions and performance parameters = f_1 (Engine controls) + f_2 (Fuel properties)

Engine emissions and performance parameters	f_1 (Engine controls)	f_2 (Fuel properties)
NOx Smoke Gross indicated fuel consumption (gisfc) Combustion phasing ….	2nd order with square & interaction terms	1st order with least correlated fuel terms

Fuel property correlations

	T10	T50	T90	Slope	Cetane	Mono-aromatic content	Poly-aromatic content	Total Aromatic content	Density
T50	0.90								
T90	0.74	0.94							
Slope	-0.12	0.30	0.58						
Cetane	0.02	0.14	0.12	0.15					
Mono-aromatic content	-0.32	-0.48	-0.36	-0.15	-0.67				
Poly-aromatic content	0.77	0.78	0.76	0.19	-0.32	-0.17			
Total Aromatic content	0.53	0.45	0.49	0.09	-0.67	0.41	0.83		
Density	0.80	0.74	0.69	0.03	-0.41	0.00	0.97	0.90	
Heating value	-0.67	-0.56	-0.54	0.02	0.59	-0.25	-0.90	-0.97	-0.96

Cells indicate R-value or degree of linear relationship → +1 or -1 (strong correlation)

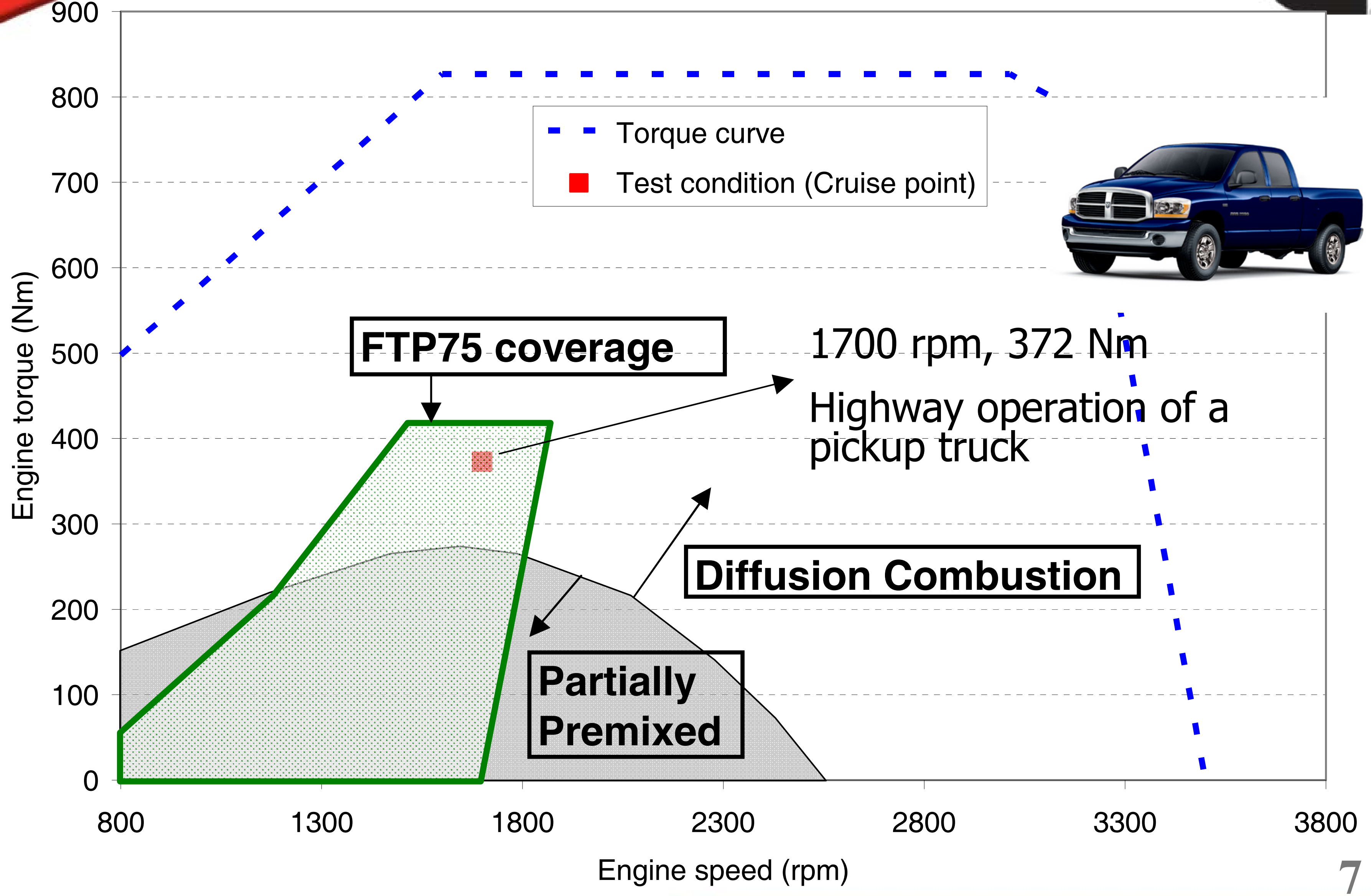
Limiting to physical properties and the least correlated ones,

Cetane → Ignition quality

T50 → Volatility

Slope → Rate of change of volatility (T90 – T10)

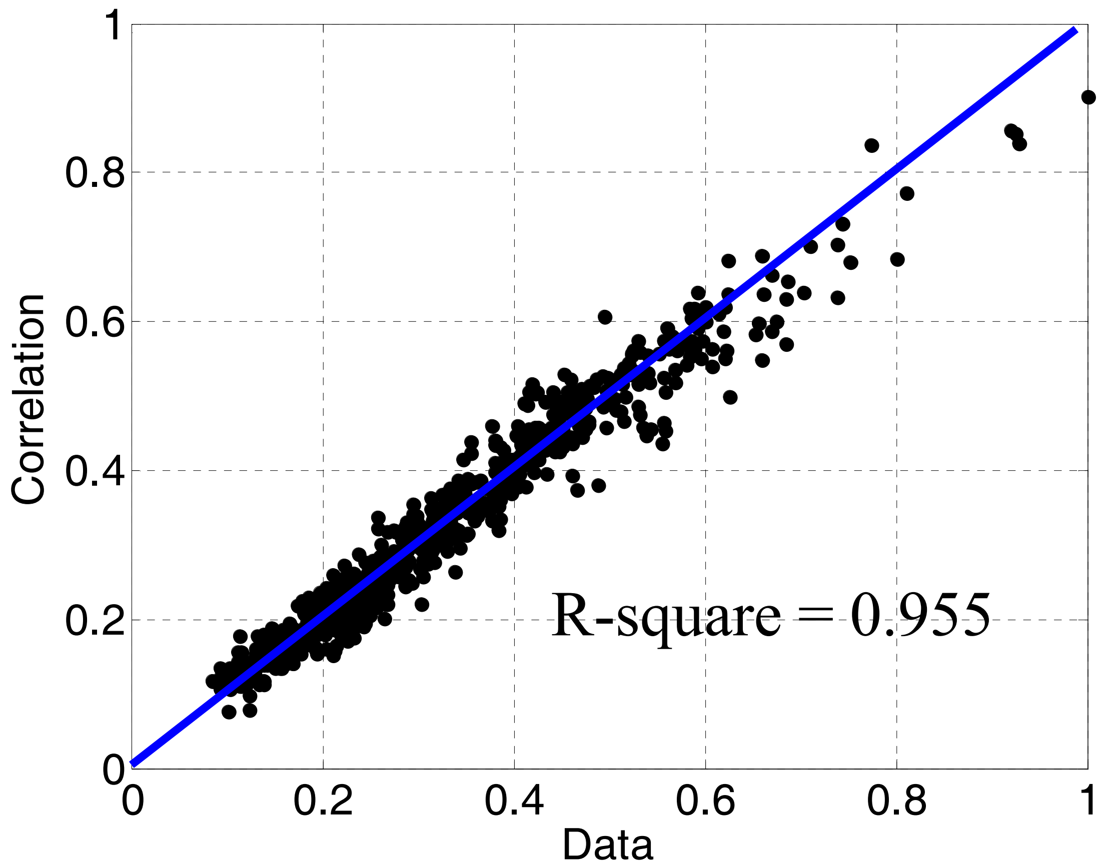
Test condition



Experimental method

- Single cylinder ISB engine (displacement 1.1 L/ cyl) used for the experiments
- Emissions meet 2010 US-EPA targets
- Full-factorial test design involving independent manipulation of
    - o EGR
    - o AF ratio
    - o Rail pressure
    - o Three pulse fuel injection sequence (pilot, main and post)
    - o Main injection (close-to-TDC)

Correlation vs. data for NOx

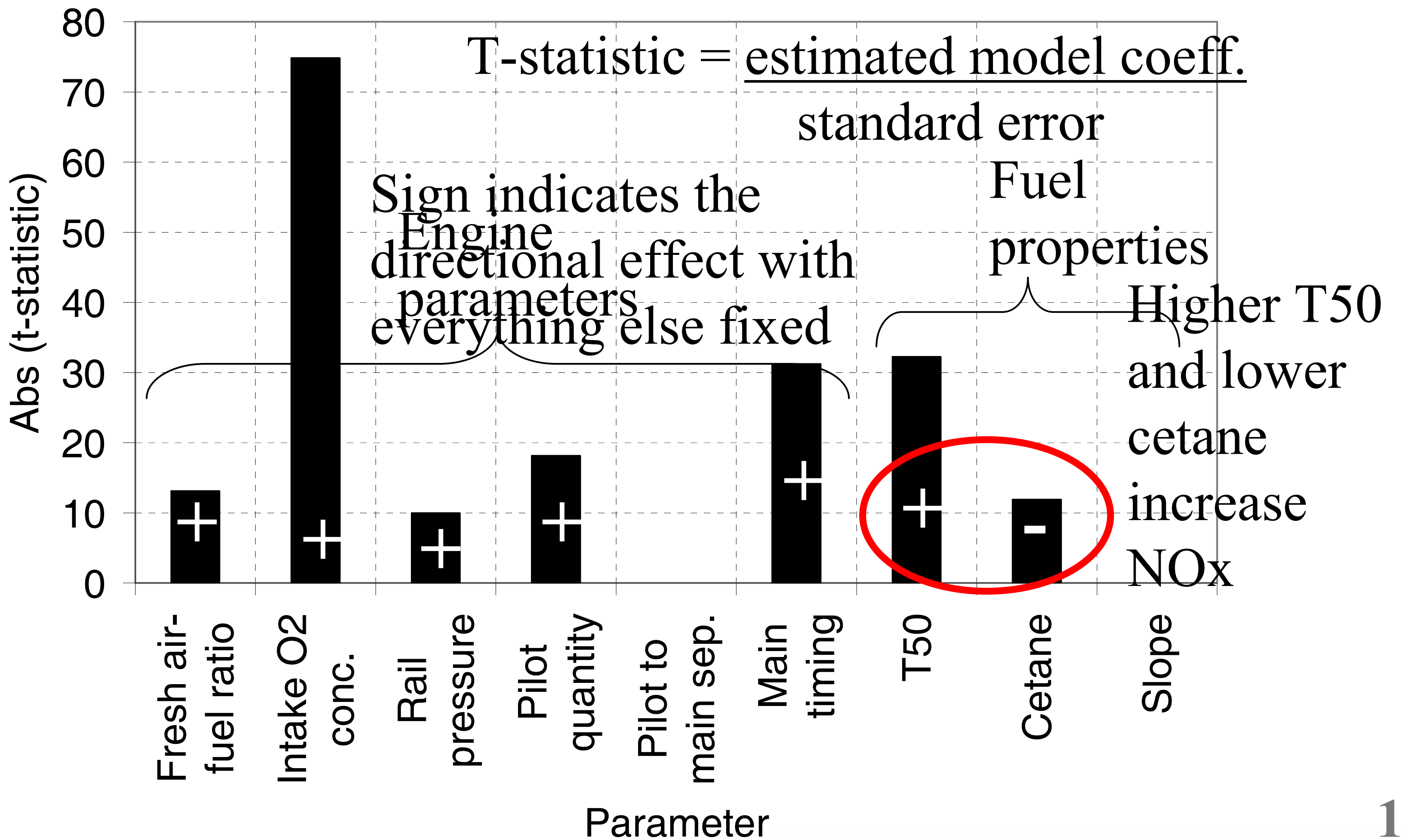


≈ 800 data points

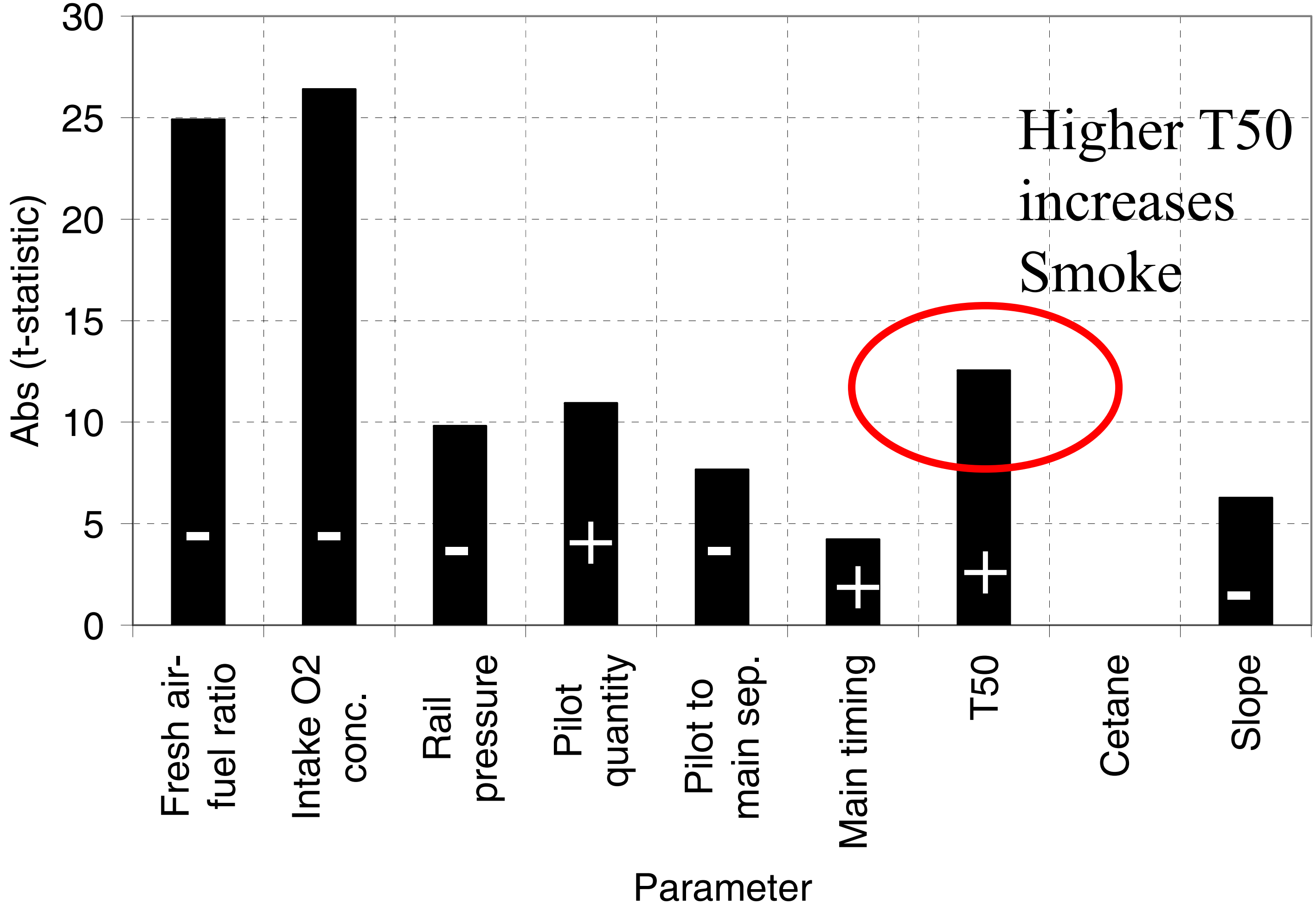
Generally good correlations for other parameters as well:

- Smoke
- Gross indicated fuel consumption (gisfc)
- Combustion phasing, etc.

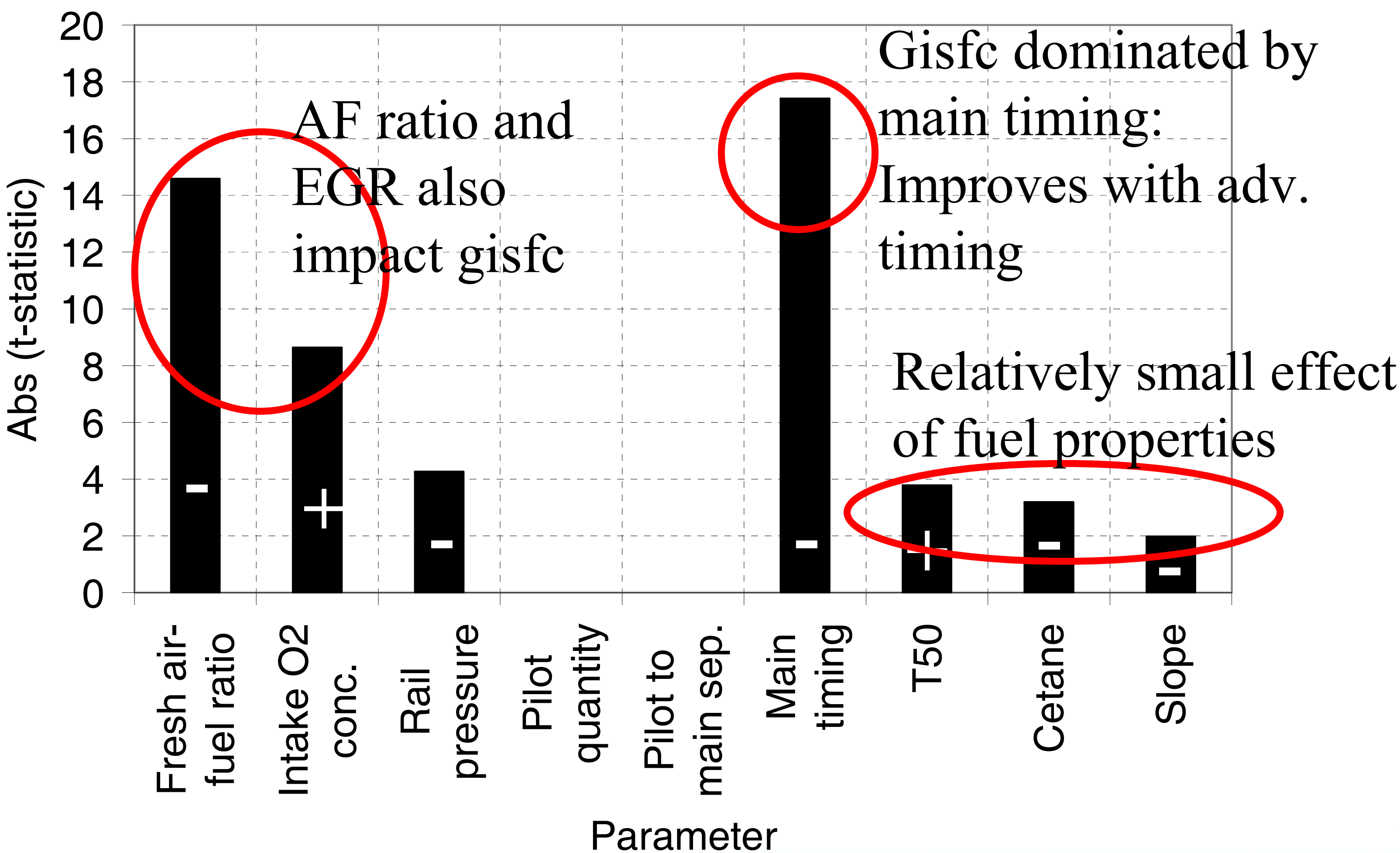
Model Results: First-order terms for NOx



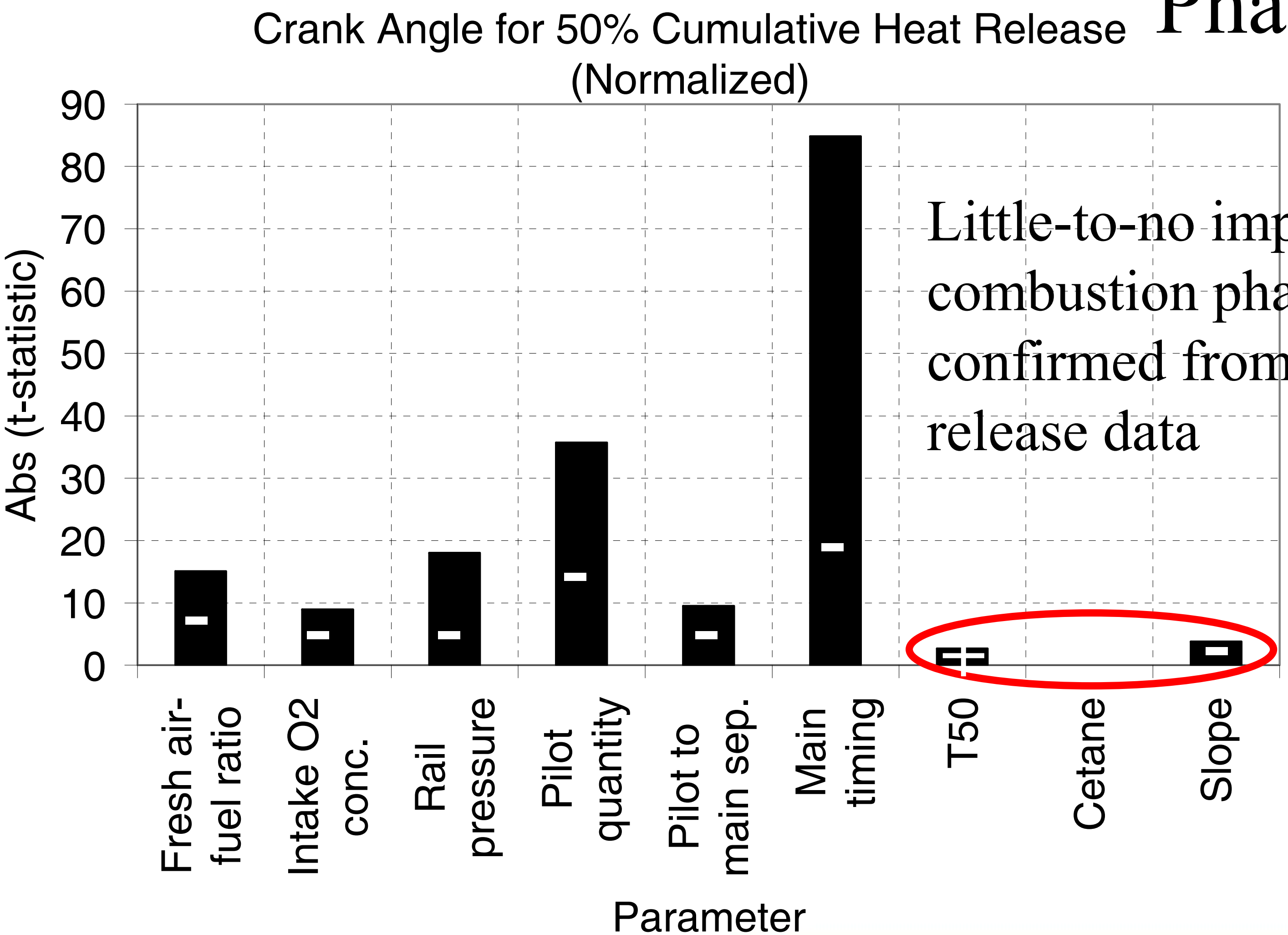
Model Results: First-order terms for Smoke



Model Results: First-order terms for gisfc



Model Results: First-order terms for Combustion Phasing



Little-to-no impact on combustion phasing; confirmed from heat-release data

Summary

- Functional relationships determined between fuel properties and engine emissions (SAE paper will be presented for the 2009 World Congress)
- Direct effect of fuel properties on gisfc is small, but fuel effects on NOx and smoke may result in changes on emissions restrained gisfc
- Lower T50 fuel provides simultaneous NOx and smoke benefit; higher cetane provides a small NOx reduction (cetane and T50 are both correlated with mono- and poly- aromatics respectively).
  - Literature indicates higher Aromatic → higher flame temp.
- Effect of cetane and T50 on heat release characteristics appears too subtle to be detected by in-cylinder pressure based virtual sensing

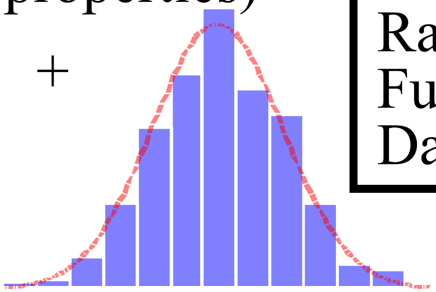
Future work

1. Optimize for lowest gisfc to determine the "ideal" fuel; assess possible improvements over the baseline one

2. Characterize emissions fluctuations due to market fuel property variations

Engine responses = f_1 (Engine controls) + f_2 (Fuel properties)

Frequency distributions for Engine responses = Fix engine controls at optimum settings +



Raw Market Fuel Property Data

3. Combustion-CFD validation of mono- and poly- aromatic hydrocarbon influence

4. Fuels induced effect vs. those of: EGR, Airflow, Swirl, etc.
   - Compensate for the variable with the largest effect first.

5. Bio-diesel combustion and control: Engine experiments & modeling, sensor and compensation algorithms development