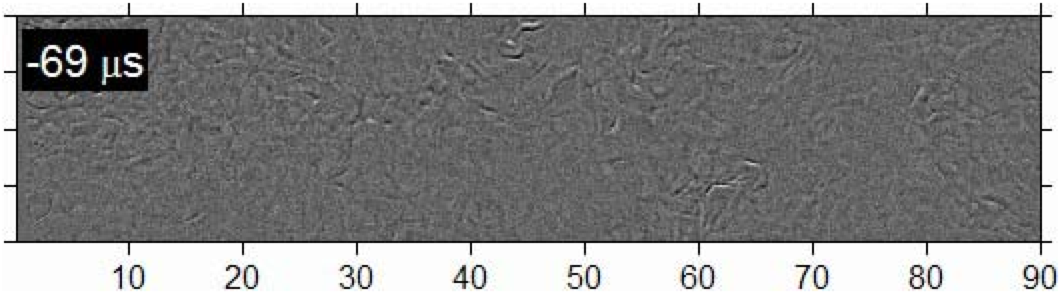
Progress of the Engine Combustion Network



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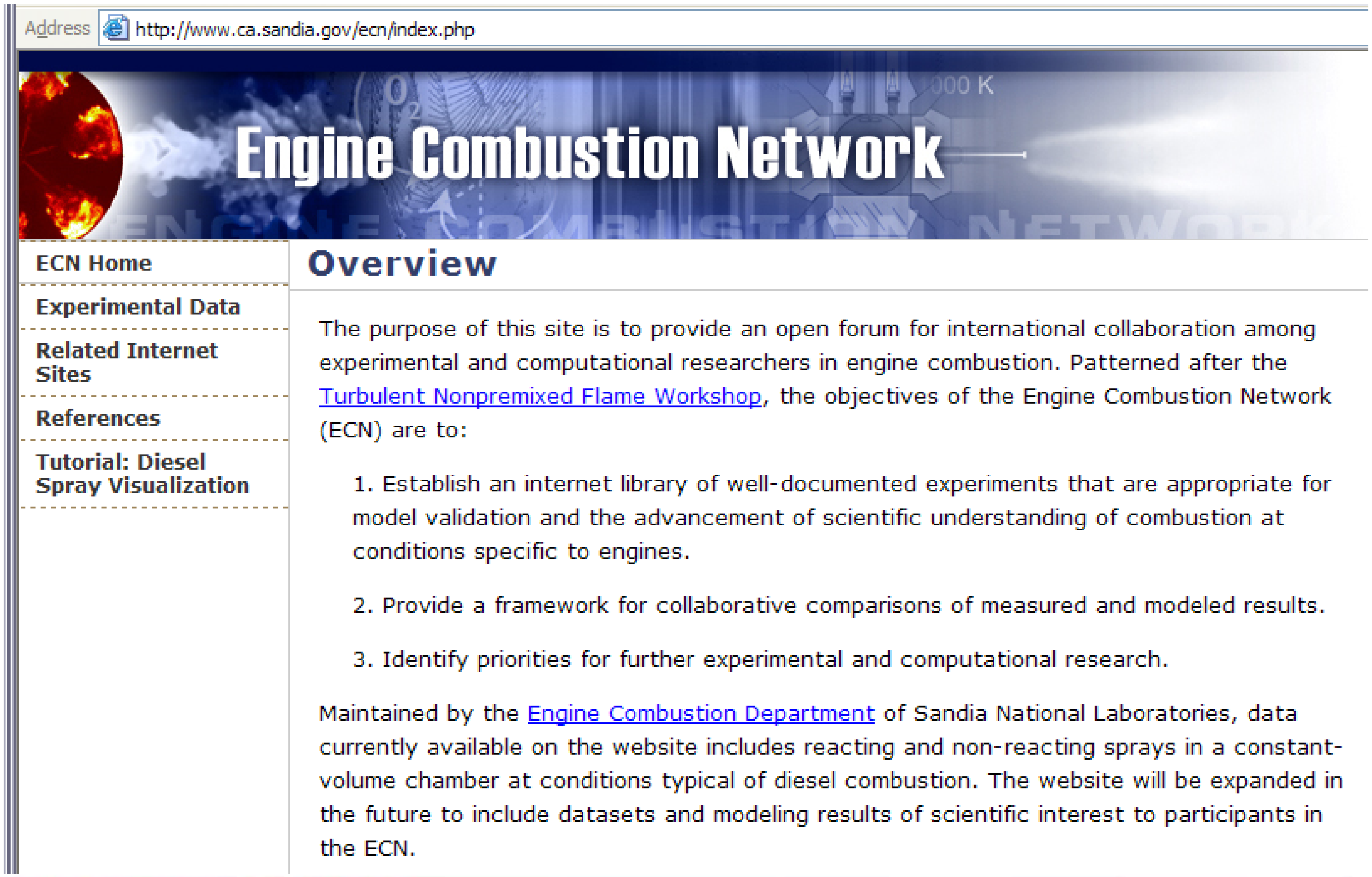
Sandia National Laboratories

Sponsor: DOE Office of Vehicle Technologies

Program Manager: Gurpreet Singh

Introducing the Engine Combustion Network

- Collaborative modeling/experimental website started.
- http://www.ca.sandia.gov/ECN



Address http://www.ca.sandia.gov/ecn/index.php

Engine Combustion Network

- ECN Home
- Experimental Data
- Related Internet Sites
- References
- Tutorial: Diesel Spray Visualization

Overview

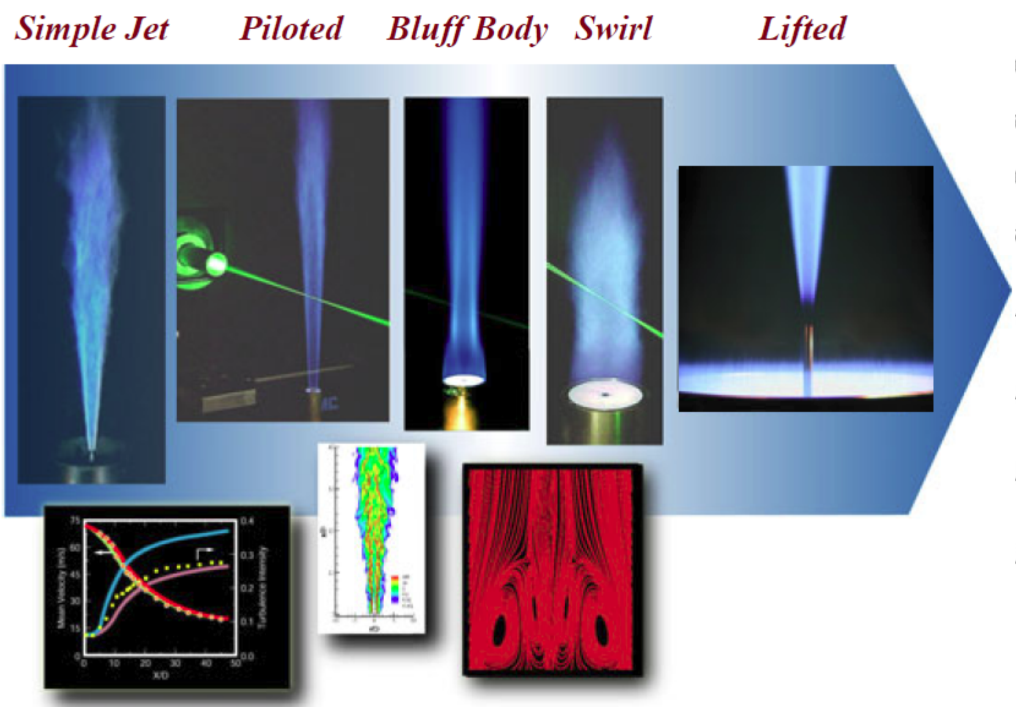
The purpose of this site is to provide an open forum for international collaboration among experimental and computational researchers in engine combustion. Patterned after the Turbulent Nonpremixed Flame Workshop, the objectives of the Engine Combustion Network (ECN) are to:

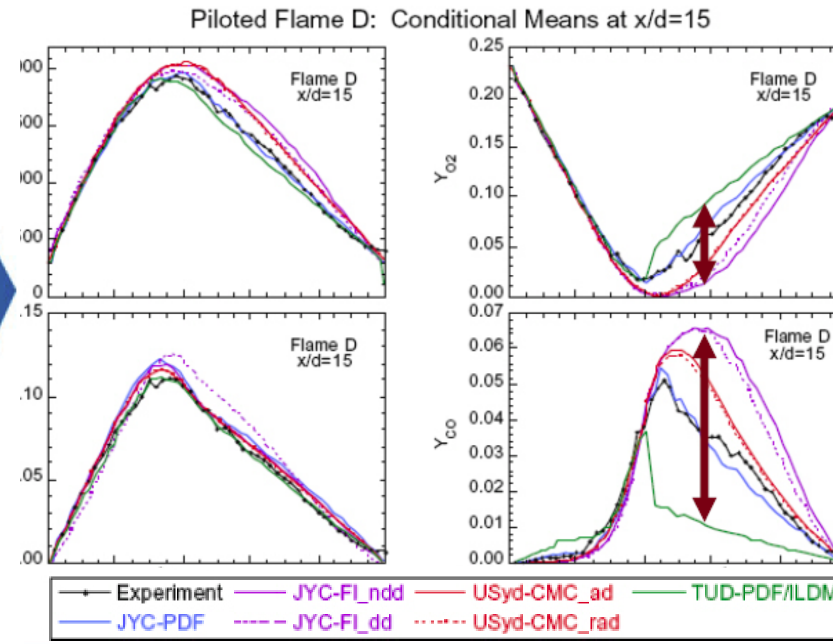
1. Establish an internet library of well-documented experiments that are appropriate for model validation and the advancement of scientific understanding of combustion at conditions specific to engines.
2. Provide a framework for collaborative comparisons of measured and modeled results.
3. Identify priorities for further experimental and computational research.

Maintained by the Engine Combustion Department of Sandia National Laboratories, data currently available on the website includes reacting and non-reacting sprays in a constant-volume chamber at conditions typical of diesel combustion. The website will be expanded in the future to include datasets and modeling results of scientific interest to participants in the ECN.

ECN idea modeled after the Turbulent Non-Premixed Flame (TNF) Workshop.

- Use a series of well-defined, canonical flames to promote model development applicable to turbulent combustion.

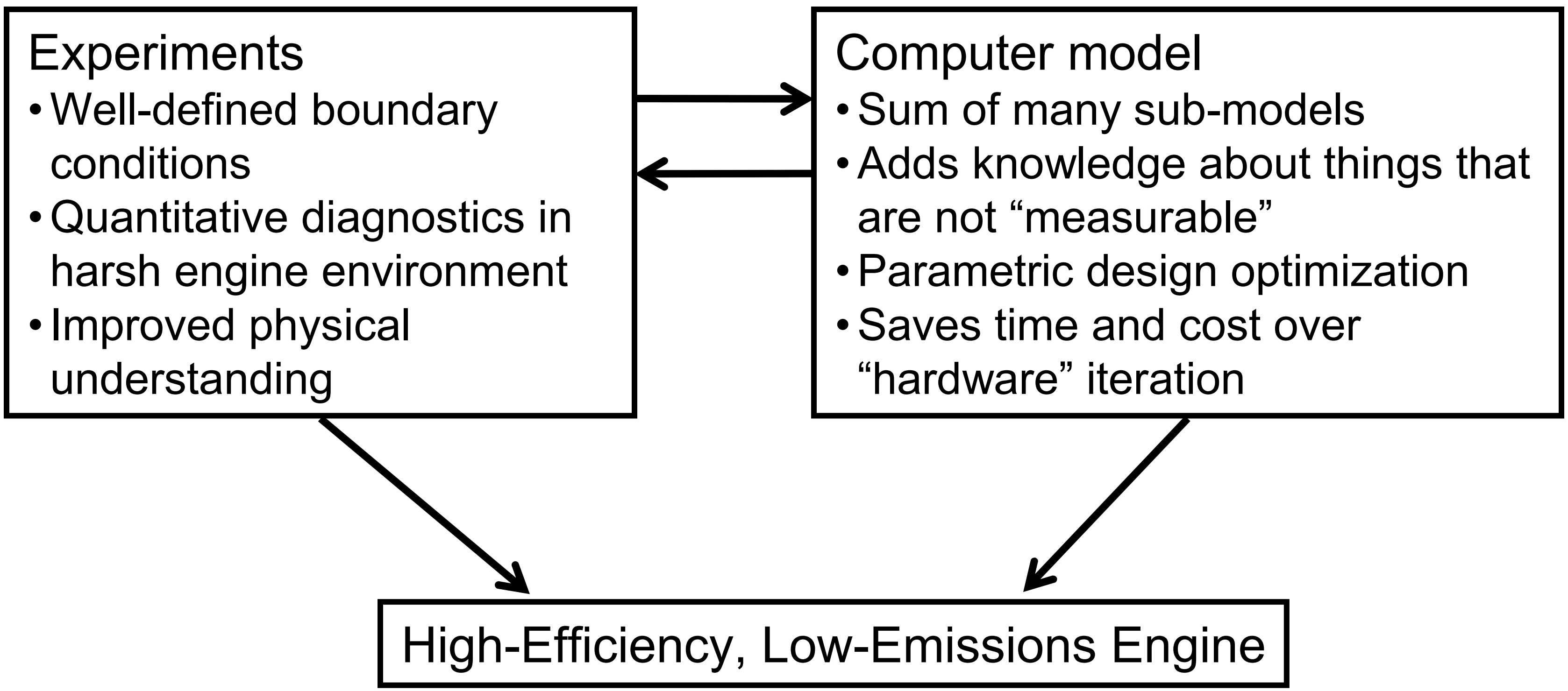




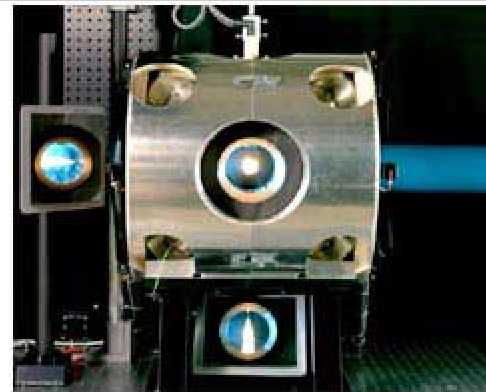
90 participants at last workshop.

- This type of dataset and focused modeling effort does not exist for engine conditions!
- We need to (and can) delve deeper to understand the workings of engine sprays.

Engine development depends upon accurate, predictable models.



Constant-Volume Diesel Combustion



A wide range of ambient (charge-gas) environments can be simulated at the time of fuel injection in this facility, allowing the effect of each variable to be assessed. With full optical access, the following ambient conditions can be generated:

- Ambient gas temperatures from 450 K to 1300 K
- Ambient gas densities from 3 to 60 kg/m^3
- Ambient gas oxygen concentrations from 0% to 21%

These conditions span or exceed those typically experienced in a diesel engine.

Fuel is injected using common-rail fuel injectors with the following parameter range:

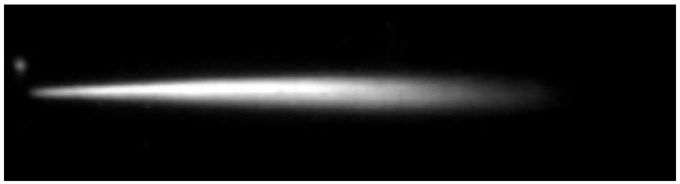
- Injection pressures above ambient from 40 to 200 MPa
- Nozzle sizes from 0.05 to 0.5 mm
- #2 diesel, single-component reference (n-heptane, cetane), and oxygenated fuels

The data obtained in this facility is useful for model development and validation because of the well-defined boundary conditions and the wide range of conditions employed. (Go to experimental data search).

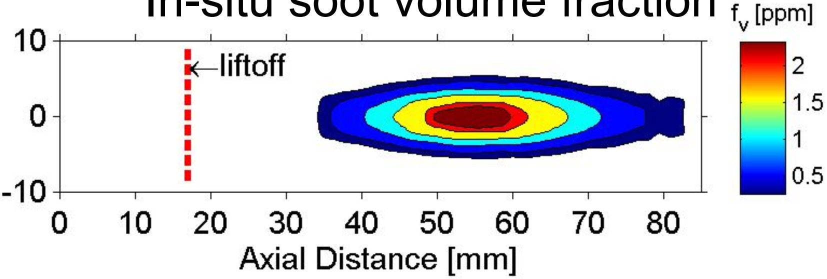
Links at the left describe the methods for generating these conditions, the diagnostics applied, and the archival data acquired in the facility.

Data available on the website

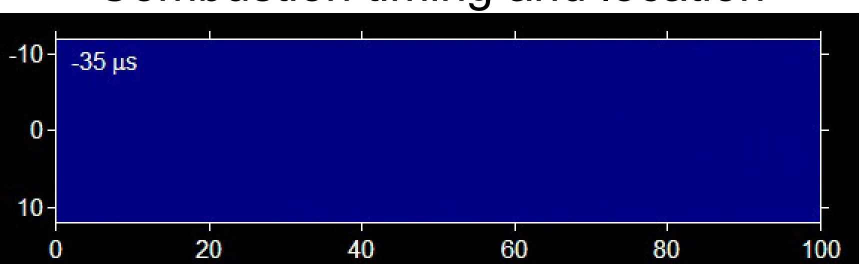
Liquid penetration length



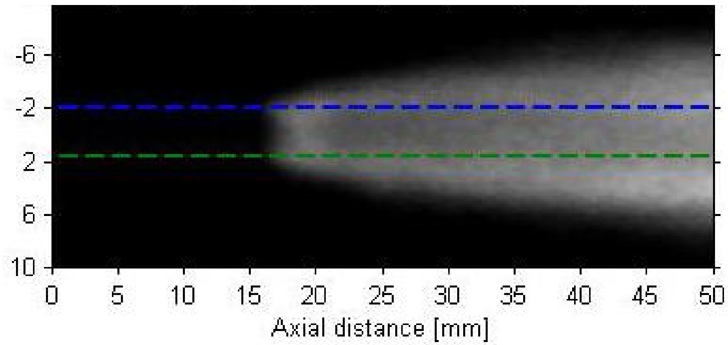
In-situ soot volume fraction



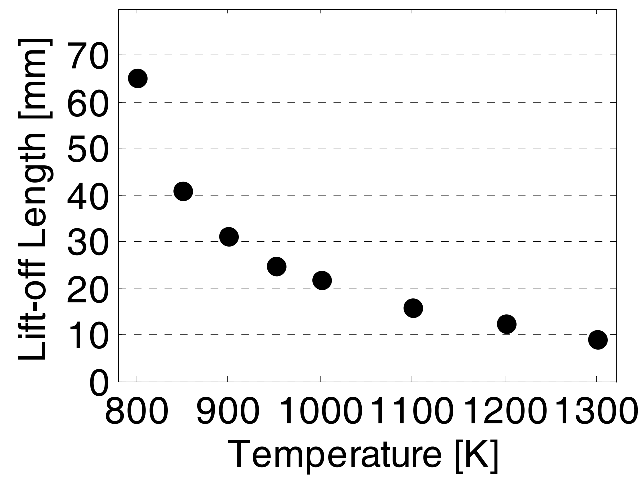
Combustion timing and location



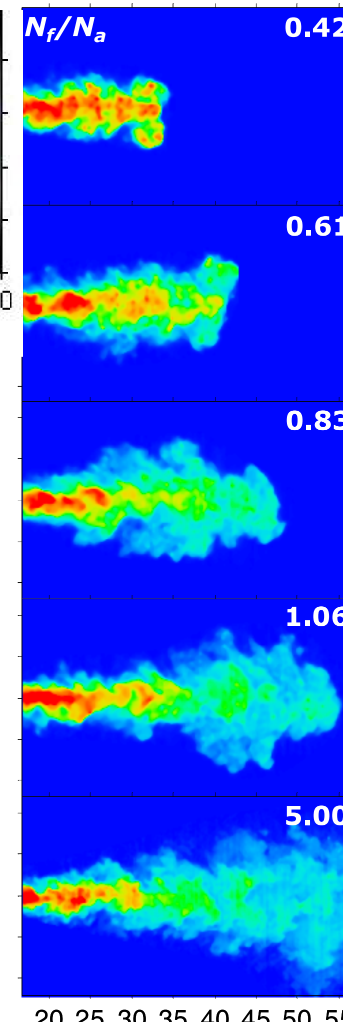
Lift-off length



Parametric Variation



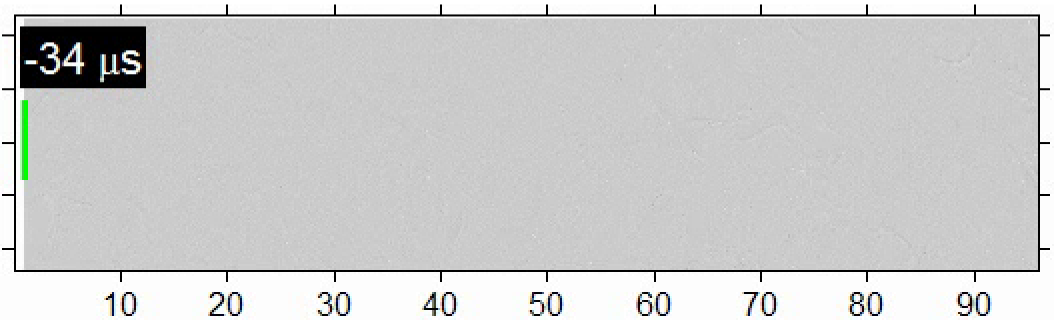
Mixing



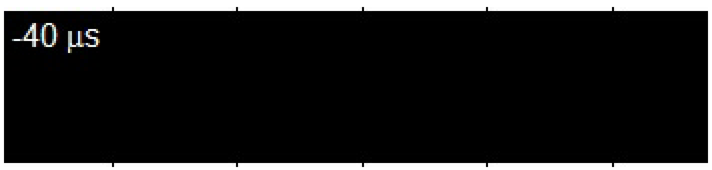
Data obtained over the past 15 years at well-characterized ambient and injector conditions.

High-speed imaging of liquid and vapor boundaries

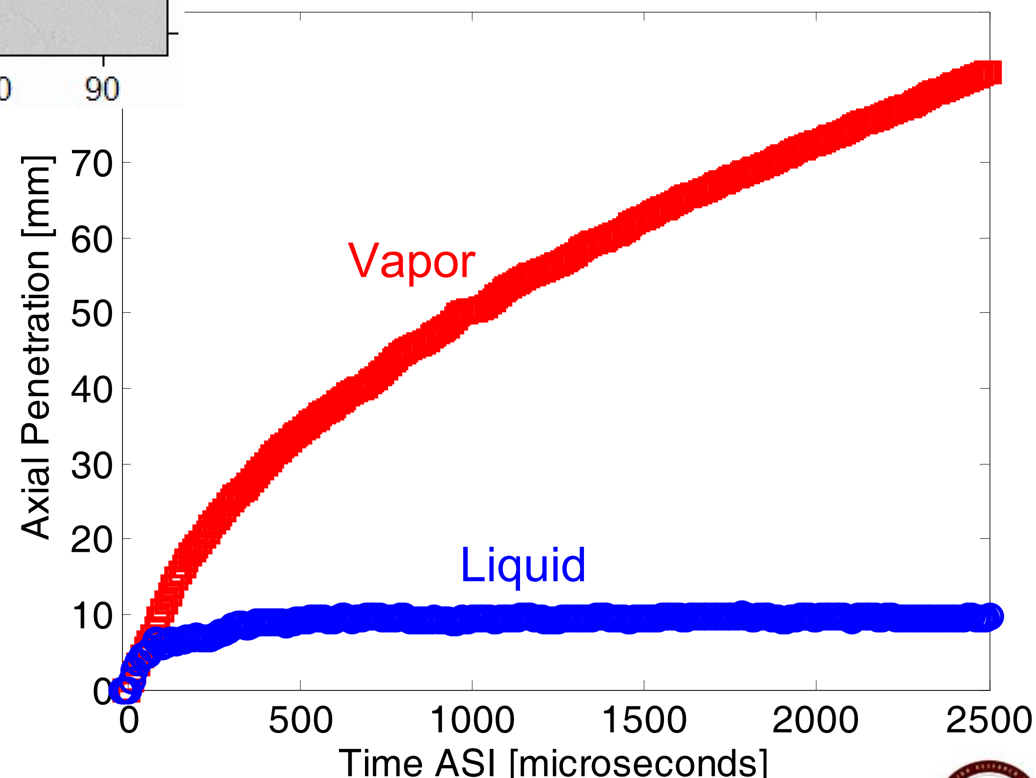
High-speed Schlieren Imaging (Vapor)



High-speed Mie Scatter (Liquid)



Average Axial Penetration



<u>Experimental Conditions</u>

1000 K gas temperature

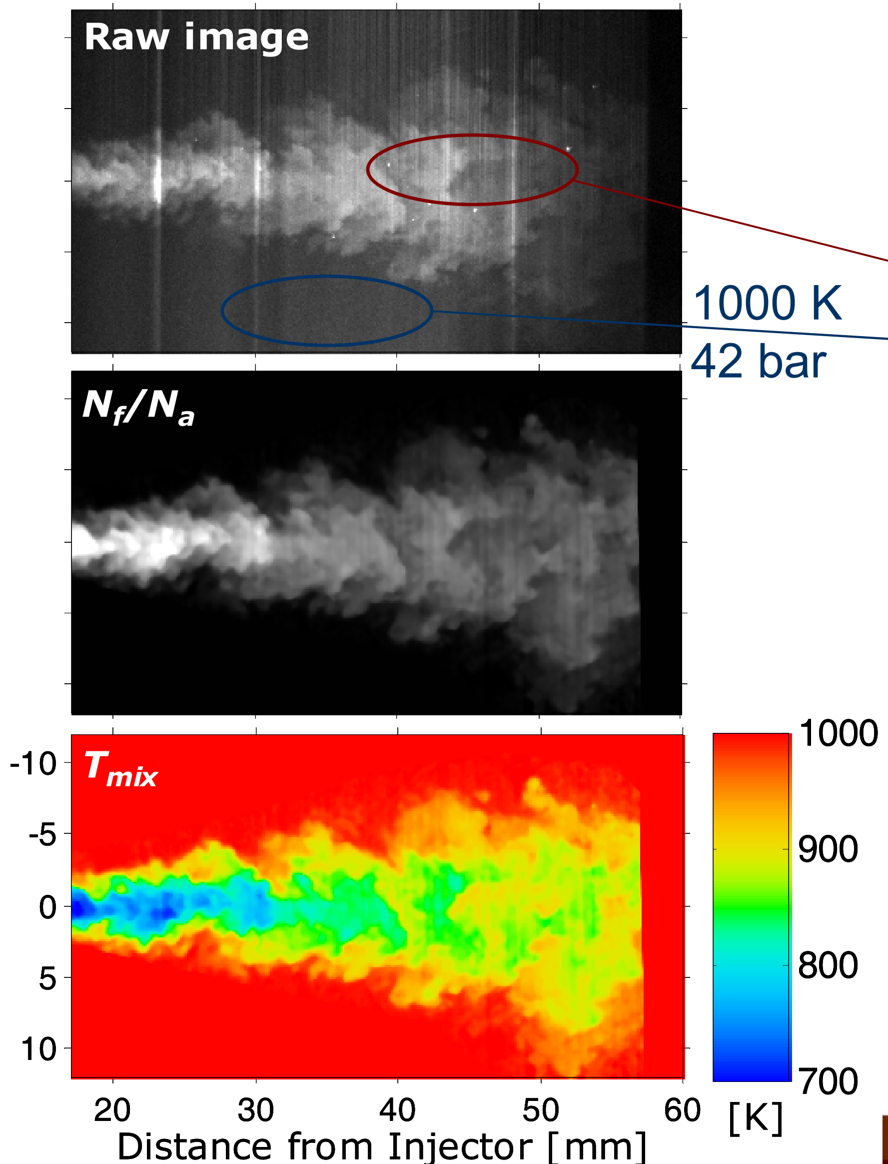
14.8 kg/m^3 gas density

1540 bar injection pressure

0.100 mm nozzle orifice

n-heptane

Quantitative mixing measurements in harsh high-temperature, high-pressure environment.



Rayleigh Molecular Cross-Sections

$\sigma_f/\sigma_a = 55$ n-heptane/DCSF ambient

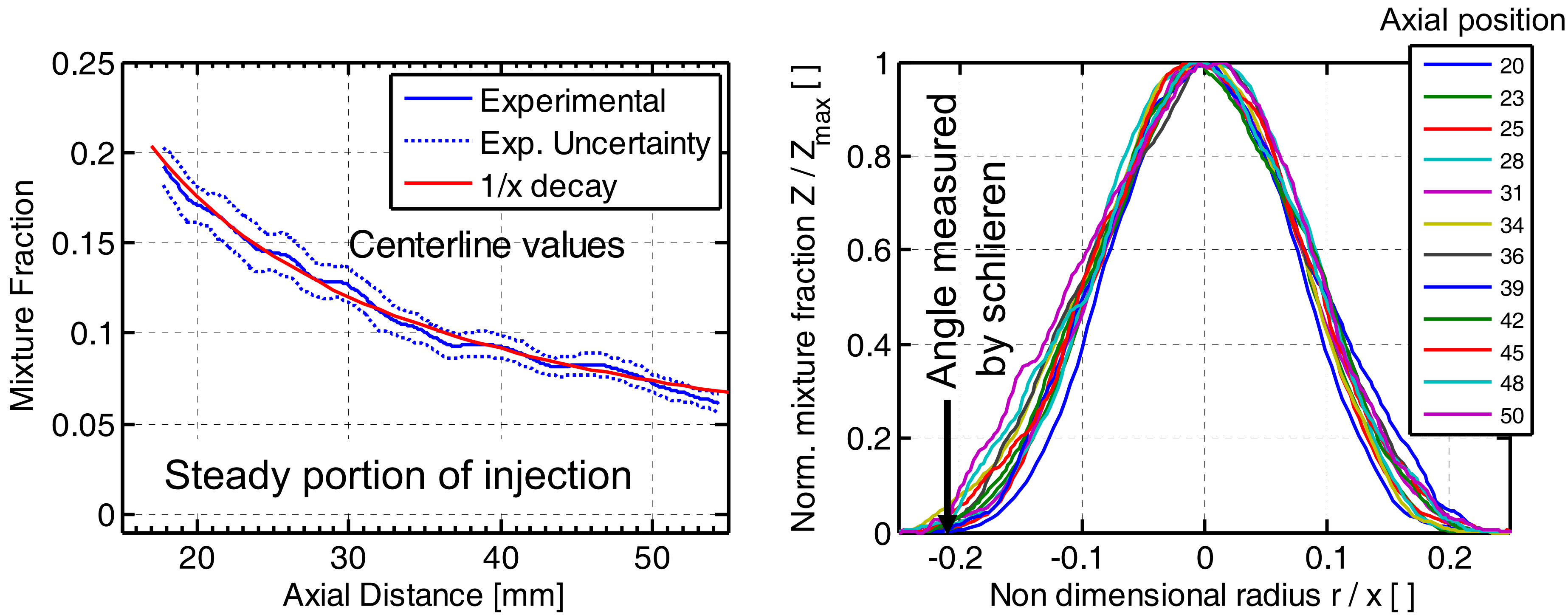
Adiabatic mixing (Espey et al. [1996])

$$\frac{I_{R,j}}{I_{R,a}} = \left(\frac{\sigma_f/\sigma_a + N_a/N_f}{1 + N_a/N_f}\right)\frac{T_a}{T_{mix}}$$

$$T_{mix} = f(N_a/N_f)$$

- Measure both $I_{R,a}$, $I_{R,j}$
  - Allows in-situ calibration for $I_{R,a}$ variation in laser sheet intensity
  - Beam-steering or divergence addressed by using $I_{R,a}$ on bottom and top
- Measurement provides
  - Mixing: N_a / N_f
  - Temperature

Vaporizing sprays show self-similar mixing, similar to gas jets.

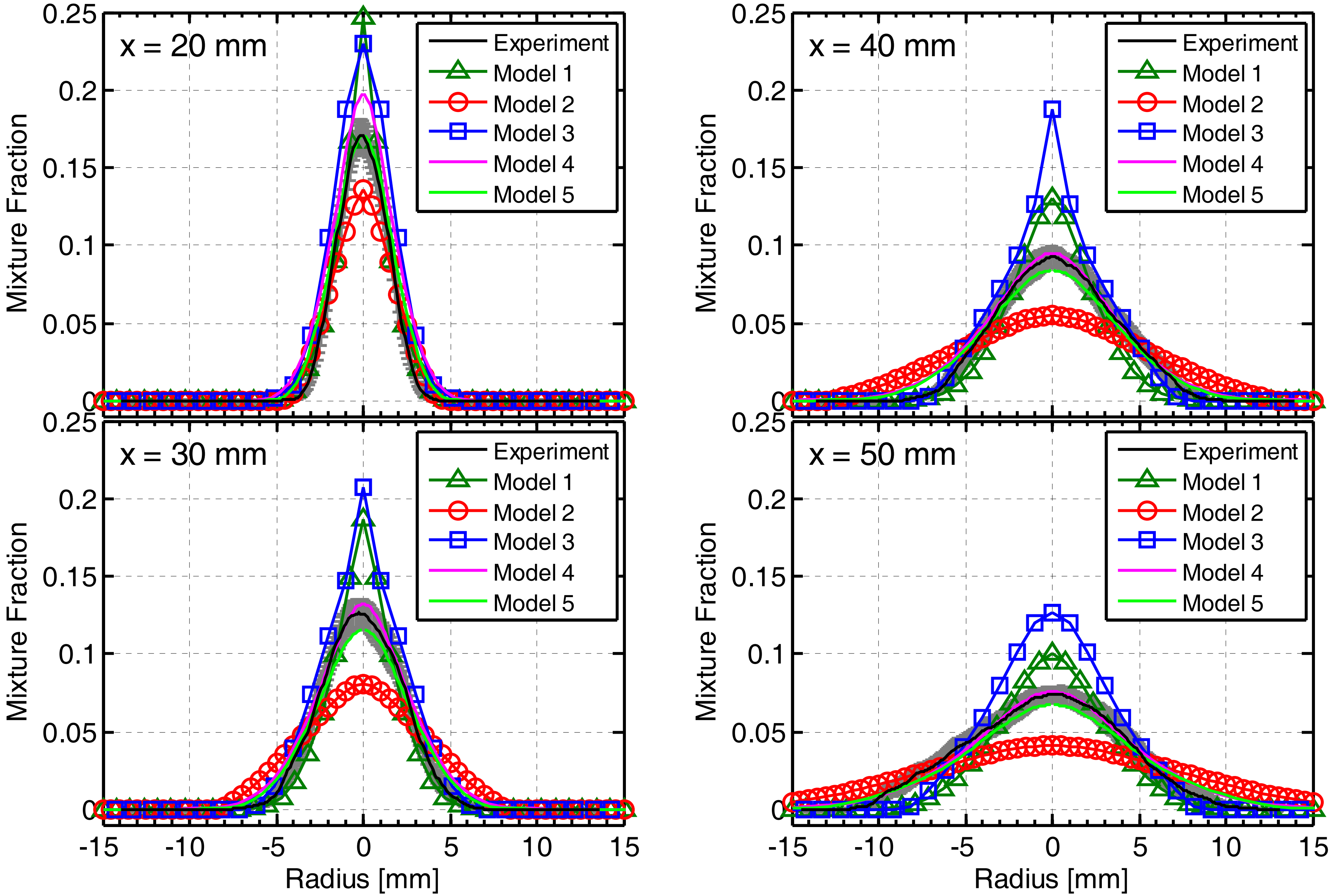


- Mixture fraction decays as 1/x, a well-known result for gas jets.
- Radial profiles shows self-similarity.
- Schlieren detects the very outer edge of the vaporizing spray.

Recent modeling efforts based on ECN spray data:

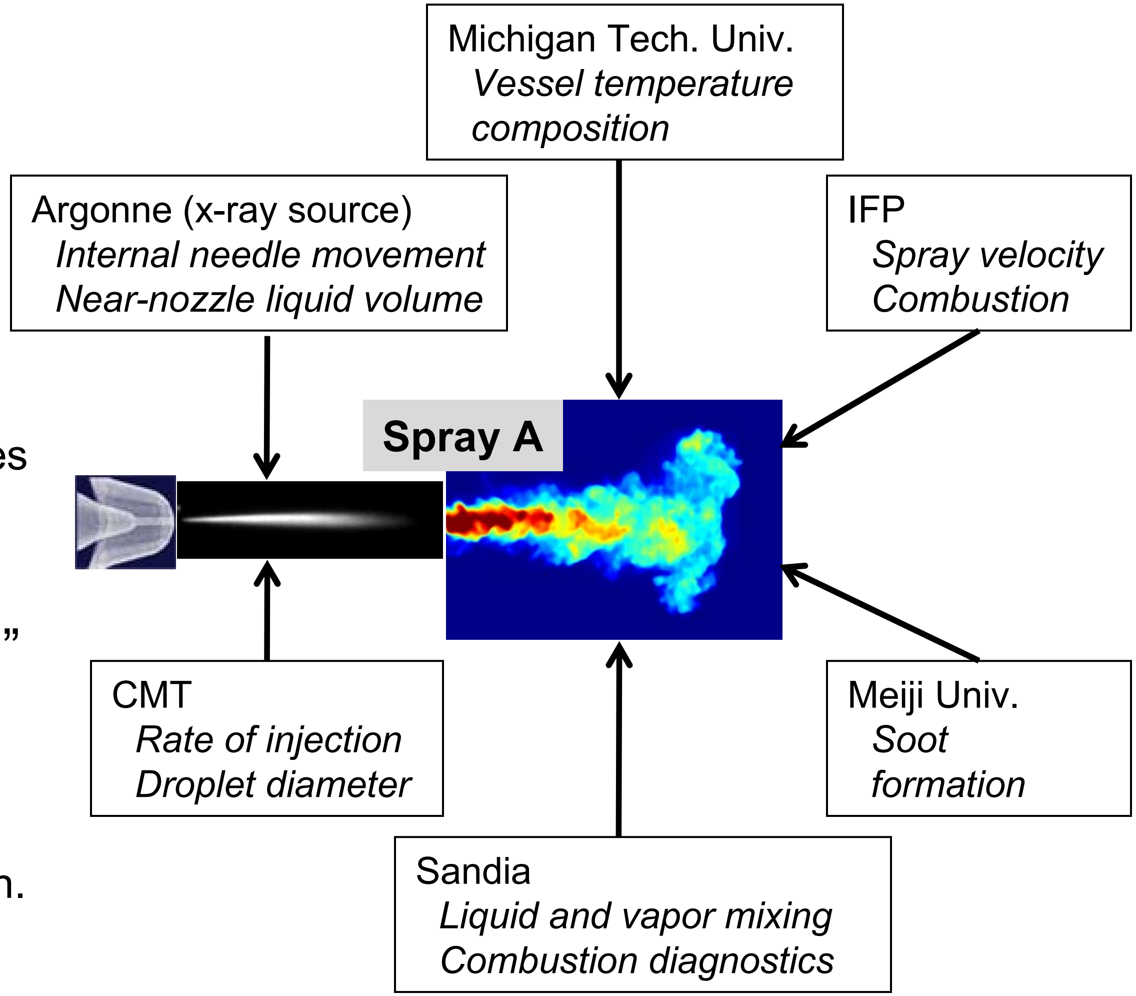
- Quantitative measurements permit direct comparison to results from advanced CFD models.
- Moves beyond “conceptual model” or “global” parameters to more detailed analysis.
- SAE 2008
  - Papers 2008-01-1331, 2008-01-0968, 2008-01-0961, 2008-01-0954
- SAE 2009
  - Papers 2009-01-1971
- ASME
  - Vishwanathan and Reitz
- ICLASS 2009
  - Abraham and Pickett

Non-reacting (0% O_2) Baseline n-heptane conditions
“Steady” conditions, long after start of injection



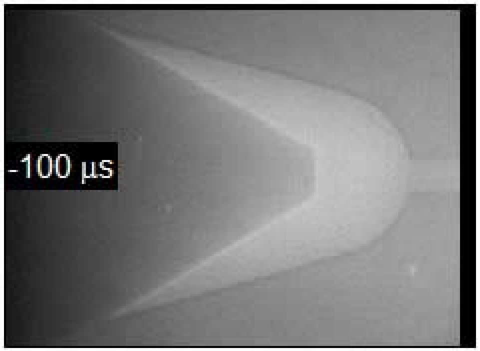
Future Experimental Collaboration in the ECN

- Baseline experimental condition defined "Spray A":
- Ambient:
  - 15% O_2, 900 K, 60 bar
- Injector:
  - common rail, 0.090 mm nozzle, KS1.5/86
  - Multi- (3) and single-hole nozzles
  - 1500 bar, 363 K
  - n-dodecane
- Bosch has donated "identical" injectors/nozzles to Sandia.
  - Sandia will distribute to other groups for voluntary experimentation at this condition.
- Participating facilities must verify boundary conditions.

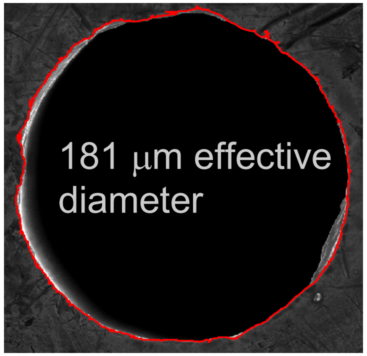


Advanced diagnostics will establish boundary conditions and characterize combustion.

X-ray projection by Argonne National Lab



SEM image of nozzle outlet



<u>Experimental measurements</u>

- Nozzle shape
- Internal needle movement
- Discharge and area contraction coefficients
- Rate of injection
- Near-nozzle liquid volume fraction
- Droplet size and velocity
- Maximum liquid penetration
- Vapor penetration rate
- Velocity and turbulence within spray
- Mixture fraction (non-reacting)
- Ignition delay
- Cool flame position and timing
- Heat-release rate
- Quantitative soot distribution
- Lift-off length

Summary: ECN seeks to accelerate development of clean high-efficiency engines.

Experiments
- Well-defined boundary conditions
- Quantitative diagnostics in harsh engine environment
- Improved physical understanding

Computer model
- Sum of many sub-models
- Adds knowledge about things that are not “measurable”
- Parametric design optimization
- Saves time and cost over “hardware” iteration

High-Efficiency, Low-Emissions Engine

Acknowledgements

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- David Cook and Godehard Nentwig, *Robert Bosch LLC*, *donation of injectors*.

Easy to find data with search utility

- **Temperature Variation**

DATA SEARCHING UTILITY
Simply click on values to narrow selection or choose select conditions below.
Results will be displayed after query yields less than 200 records.
* Baseline Condition Diesel * Baseline Condition n-heptane * Soot vs Inj Press * Soot vs Ambient O
reset search * Soot vs Orifice Diameter * All Soot Measurements

Experimental Type	Ambient O_2 [%]	Ambient T [K]	Amb Dens [kg/m3]	Inj Press [MPa]
ALL	ALL	ALL	ALL	ALL
Soot	21	800	14.8	138
Lift-Off Length		850		
Ignition Delay		900		
Jet Penetration		950		
Liquid Length		1000		
High Speed Movie		1100		
		1200		
		1300		

Expand results table to show more data columns
Click here for the Column header definitions
Tabular data may be copied and pasted into delimited text or Excel file.

O_2 [%]	T_a [K]	ρ_a [kg/m³]	d [mm]	Inj P [MPa]	Fuel Type	Fuel T_{fl} [K]	Liquid Length [mm]	Lift-Off Length [mm]	Ign Dly [ms]	Pres Rise [MPa
21	800	14.8	0.180	138	D2	436	0	65.2	2.12	none
21	850	14.8	0.180	138	D2	436	0	41	1.24	none
21	900	14.8	0.180	138	D2	436	0	31.2	0.88	none
21	950	14.8	0.180	138	D2	436	0	24.7	0.69	none
21	1000	14.8	0.180	138	D2	436	0	21.8	0.56	none
21	1100	14.8	0.180	138	D2	436	0	15.9	0.38	none
21	1200	14.8	0.180	138	D2	436	0	12.5	0.29	none
21	1300	14.8	0.180	138	D2	436	0	9.2	0.23	none

- **EGR Variation (Baseline n-heptane)**

DATA SEARCHING UTILITY
Simply click on values to narrow selection or choose select conditions below.
Results will be displayed after query yields less than 200 records.
* Baseline Condition Diesel * Baseline Condition n-heptane * Soot vs Inj Press * Soot vs Ambient O2
reset search * Soot vs Orifice Diameter * All Soot Measurements

Experimental Type	Ambient O_2 [%]	Ambient T [K]	Amb Dens [kg/m3]	Inj Press [MPa]	Noz Diam [mm]	Fuel Type	T_{Fuel} [K]
ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL
Soot	0	1000	14.8	150	0.100	NHPT	373
Lift-Off Length	21						
Ignition Delay	15						
Jet Penetration	12						
Liquid Length	10						
High Speed Movie	8						

Expand results table to show more data columns
Click here for the Column header definitions
Tabular data may be copied and pasted into delimited text or Excel file.

O_2 [%]	T_a [K]	ρ_a [kg/m³]	d [mm]	Inj P [MPa]	Fuel Type	Fuel T_{fl} [K]	Liquid Length [mm]	Lift-Off Length [mm]	Ign Dly [ms]	Press Rise [MPa]	Soot f_v [ppm] [mm] [mm]	Movies	Jet Penetrate
0	1000	14.8	0.100	150	NHPT	373	9.2	0	0	none	none	Shadow	PenvsTime
21	1000	14.8	0.100	150	NHPT	373	0	17	0.53	PvsT	img f_v x y	Soot; Chemi.	none
15	1000	14.8	0.100	150	NHPT	373	0	23.4	0.73	PvsT	img f_v x y	Soot; Chemi.	none
12	1000	14.8	0.100	150	NHPT	373	0	29.2	0.95	PvsT	img f_v x y	Soot; Chemi.	none
10	1000	14.8	0.100	150	NHPT	373	0	35.1	1.13	PvsT	img f_v x y	Soot; Chemi.	none
8	1000	14.8	0.100	150	NHPT	373	0	42.3	1.52	PvsT	img f_v x y	Chemi.	none