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BIOFUEL (AND SYNTHETIC FUEL) RESEARCH AT NPS

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Presentation Outline

- Introduction to Bio and Synthetic Liquid Fuels - Hydrocarbons
- Navy Energy Use and Goals
- Navy Bulk Fuels and Potential Issues with Biofuels and Blends
  1. JP-5 (Aircraft: Gas Turbines)
  2. F-76 (Ships: Gas Turbines, Diesels, Conventional Steam)
- Office of Naval Research Biofuels Programs
- Overview of NPS Biofuels Work
  1. Thermal–Physical Properties
  2. Physical Properties – Sprays
  3. Chemical-Combustion Properties
- Other Energy Related Research Topics
  1. Advanced Cycles – PDE/RDE
  2. Better Ship Integration and Use.
- Future Work with Thesis Students

Bio and Synthetic Liquid Fuels

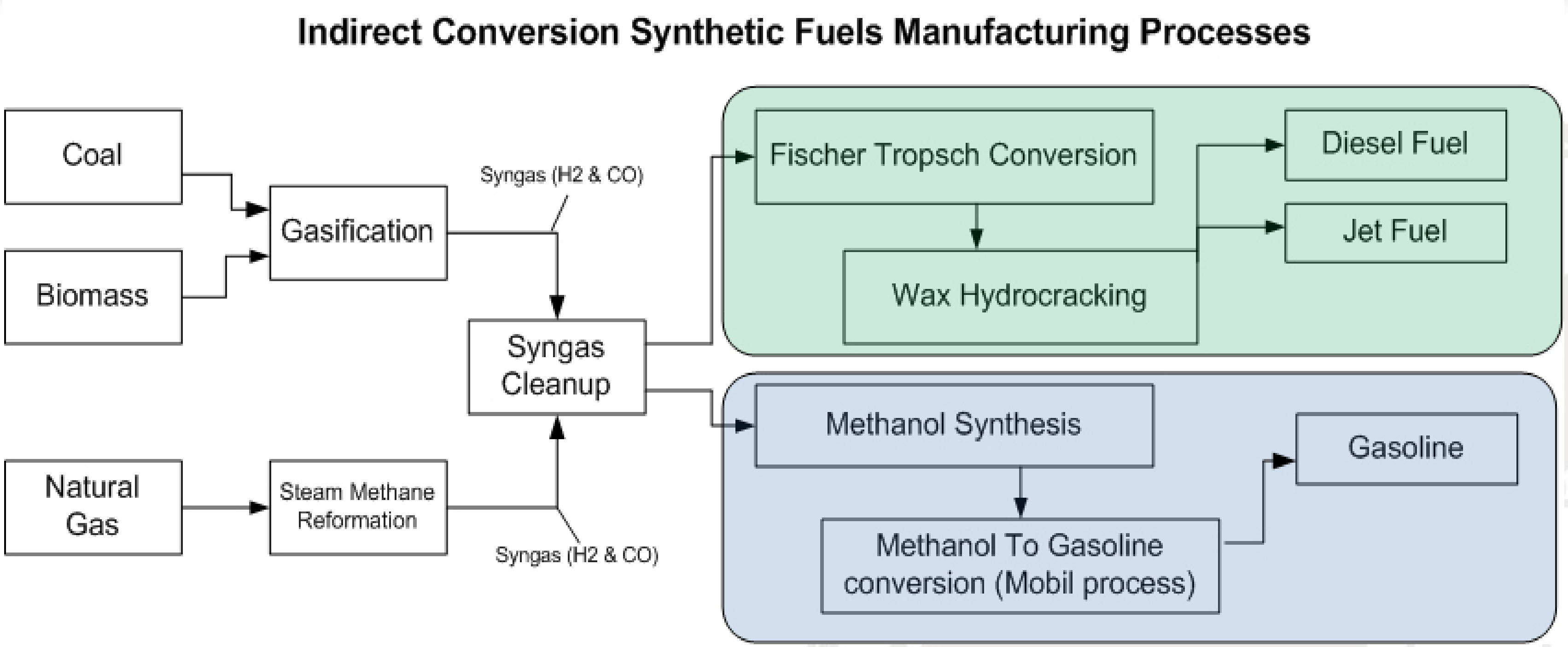
- Long History – Not New
  - * Original Diesel fuels were vegetable oils (1890s).
  - * Synthetic fuels: Fischer–Tropsch (FT-1920s). CO+H …
    - - solid (coal) to liquid and gas (NG) to liquid.
  - * 30% of German WWII liquid fuel was synthetic (coal to liquid).
  - * Most of South African liquid fuel was synthetic (Sasol)

- Liquid (Hydrocarbon) fuels have great properties. Storability, energy density, etc. If we did not have them, we would create them! Bio-Diesel (FAME) not good for military use.

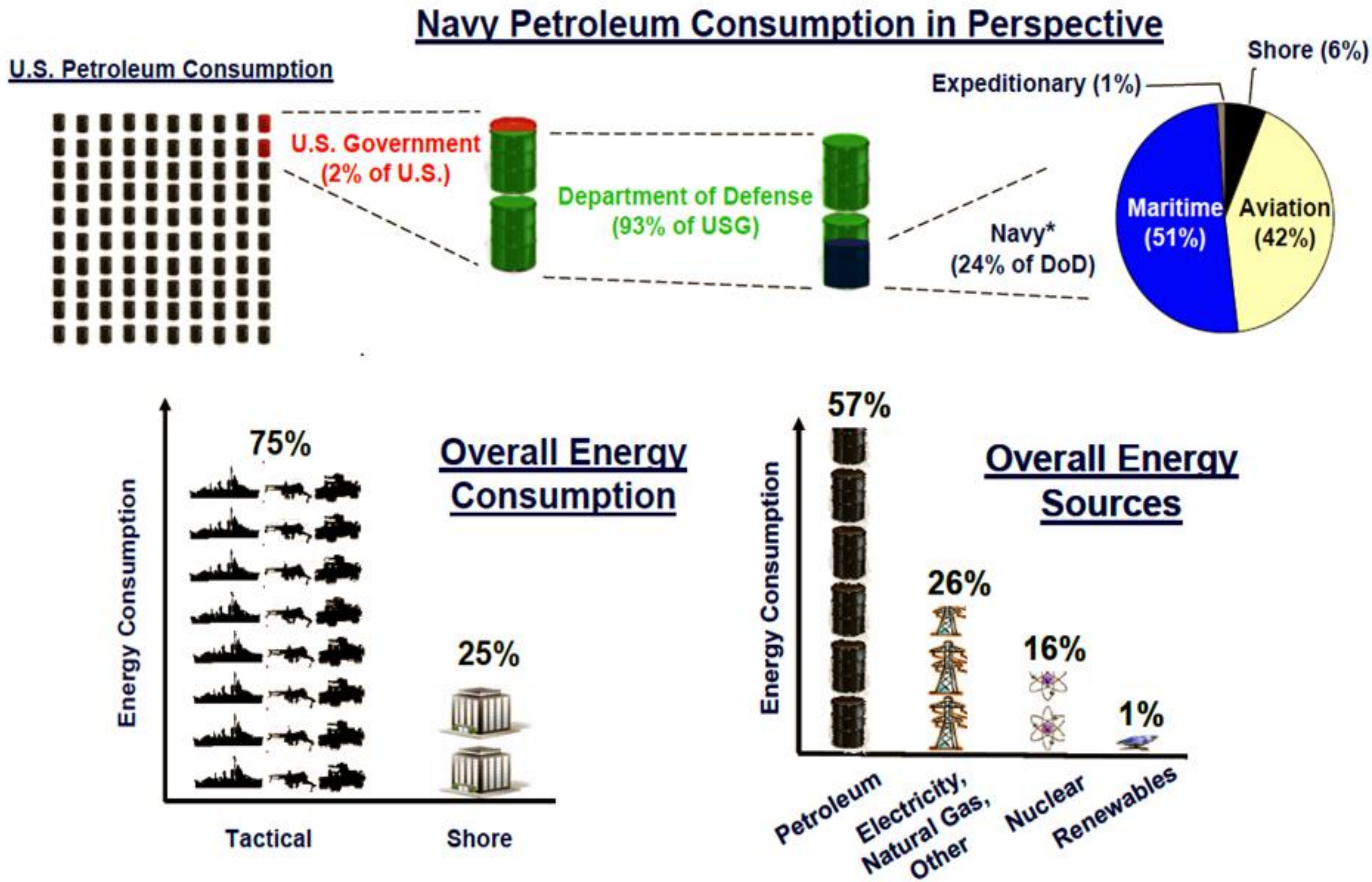
- Cost? $120+/bbl. Huge coal and natural gas reserves.

- Biomass: Algae, Camelina, Jatropha, etc.

Creation of liquid fuel from (solid/gas)



DoD Navy Energy/Petroleum Use



Navy Energy Goals from 2009

Increase Alternative Energy Department-wide	By 2020, 50% of total Department energy consumption will come from alternative sources
Increase Alternative Energy Sources Ashore	By 2020, at least 50% of shore-based energy requirements will be met by alternative sources; 50% of Department installations will be net-zero
Reduce Non-tactical Petroleum Use	By 2015, Department will reduce petroleum use in vehicles by 50%
Sail the "Great Green Fleet"	Department will demonstrate a Green Strike Group in local operations by 2012 and sail it by 2016
Energy Efficient Acquisition	Evaluation of energy factors will be mandatory when awarding contracts for systems and buildings

CNO Navy Energy Strategy

CNO Guidance: Provide a Navy Energy Strategy that treats energy as a strategic resource

Ends

Vision

- A Navy that values energy as a strategic resource
- A Navy that understands energy security as fundamental to executing the Navy mission afloat and ashore
- A Navy resilient to any potential energy future

Ways

Strategic Imperatives

- Assure Mobility
- Protect Critical Infrastructure
- Lighten the Load
- Expand Tactical Reach
- Green Our Footprint

Targets

- Increase Efficiency Afloat
- Increase Efficiency Ashore
- Increase Alternatives Afloat
- Sail the Great Green Fleet
- Increase Alternative Energy Ashore
- Reliable Power for Critical Infrastructure
- Reduce Non-Tactical Petroleum Use
- Energy Efficient Acquisition

Means

Enablers

- Leadership
- Technology
- Policy
- Strategic Partnerships
- Culture Change

Energy Security is having assured access to reliable and sustainable supplies of energy and the ability to protect and deliver sufficient energy to meet operational

SECNAV Reviews NPS Biofuels Research

Mechanical Engineering Student, LT Omari Buckley, USN, demonstrates the capabilities of NPS' Biofuels Testing Facility to Secretary of the Navy Ray Mabus, left, during a visit to campus

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SECNAV Reviews NPS Biofuels Research

Navy Biofuel Research/Cert. Program

1. Certify drop-in replacements for JP5 and F76.
2. Problems with pure biofuels. Seals, etc.
3. Use 50/50 Blends JP-5/HRJ and F-76/HRD.
4. Many potential problems
   * Storage (long term, seawater, etc.)
   * Material Compatibility (fuel system, engines)
   * Injectors, Combustion, Hot-Corrosion, etc.
5. Office of Naval Research (ONR) Program.
6. NPS focus on fundamental and Diesel sprays/combustion. Work with USNA/U.Wisc.

Fuel Characteristics

Fuel/ Properties	F-76 Diesel	Biodiesel	Fischer-Tropsch	Hydrotreated Renewable Diesel	Synthetic Paraffinic Kerosene	Direct Sugar to Hydrocarbon
ρ [kg/m^3]	844.2 [a]	885.1	753.9 [a]	778.1 [a]	740	766 [a]
σ [mN/m]	25.8 [b]	24.0	25.3	24.9 [b]	26.8	26
μ (cSt)	2.955 [c]	6.489	4.503	2.748 [c]	1.088 [c]	4.1 [a]
T_{10} -T_{90} [°C]	-	-	173-244	-	-	244-245
T_{50} [°C]	-	-	207.5	-	-	245
LHV [MJ/kg]	42.75	37.6	43.94	43.96	44.05	43.9
Cetane No.	52	56	75	~75	24.7	60
Composition						
Wt% C	86.4	-	96.78	85	84.8	85.1
Wt% H	13.32	-	3.22	15	15.2	14.9
Wt% O	0	10.9	0	0	0	0
% paraffin	70.7	-	95.3	98.5	94.3	99.9
% olefin	2.3	-	1.1	0.9	4.7	0
% aromatic	27	-	3.6	0.6	1.0	0

Finding Fuels of Interest

Desired Attributes

"Green" fuel that does not interfere with commodity pricing.

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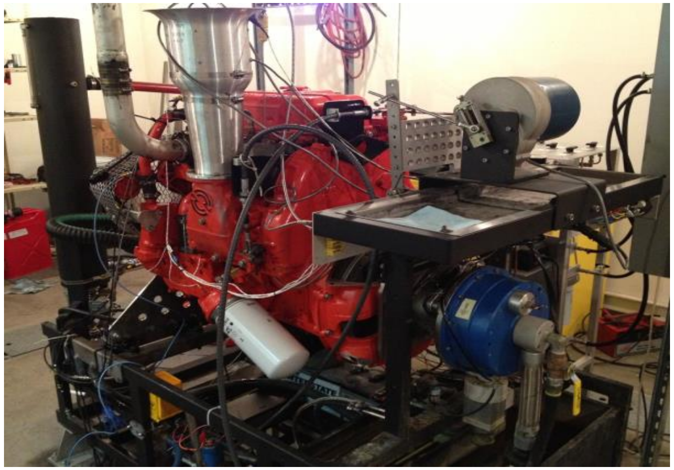
HRD: Higher Cetane Number than F76

- Diesel OEM’s have concerns with HRD use
- In last years Green Strike Group within RIMPAC Exercise HRD wasn’t used as planned
- High Cetane Number
  - Main concern with regards to fuel combustion performance
  - Cetane number is a measure of how easily a fuel auto ignites
  - Higher cetane number lead to shorter ignition delay
- F-76 Spec: 42 (min) to 67 (max) Cetane. HRD 78. Research Question: How will higher Cetane number impact engine. Shock and Stress?

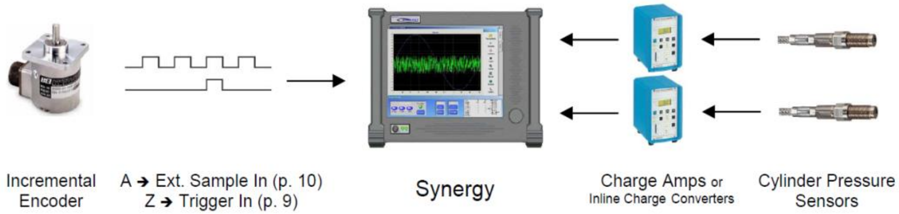
Approach

- Engine Testing
  - Operate Detroit Diesel on F-76 and Alternative Blends.
  - Measure Heat Release Rate (HRR), Specific Fuel Consumption(SFC), and Torque as a function of RPM.
- Atomization and Ignition Tests
  - Select 4 Navy-relevant fuel injectors
  - Particle Sizing (F-76 vs. HRD, SPK, others)
  - Ignition Delay Tests

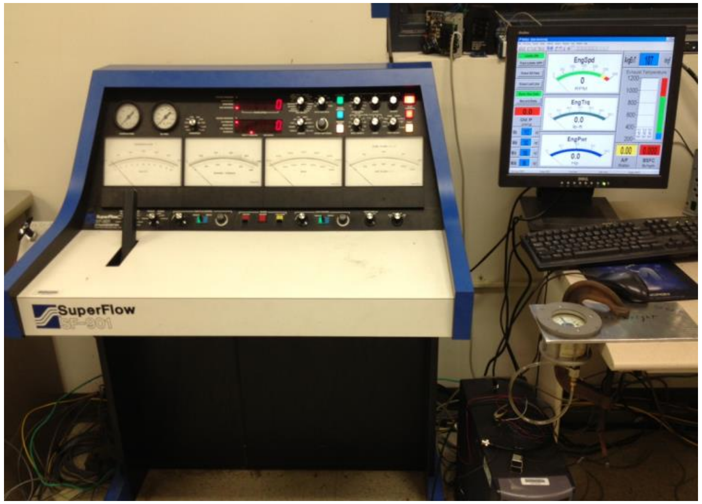
Blends of HRD/F-76 – Impact on Diesels

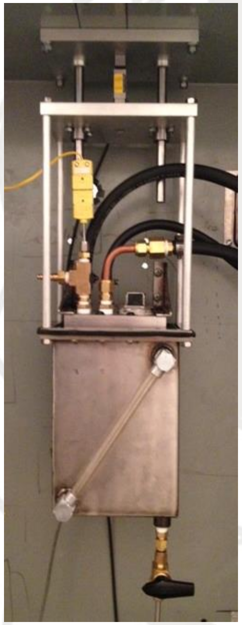


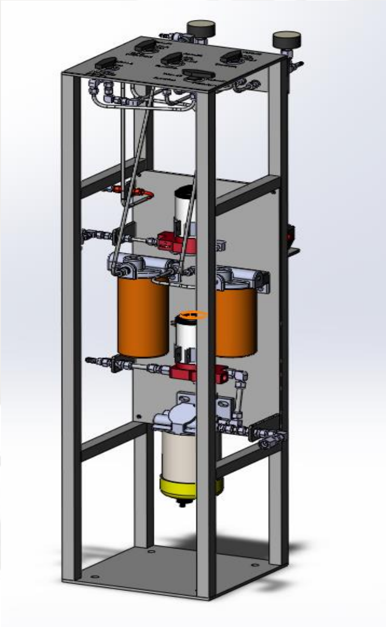
Detroit Diesel 3-53



Data Acquisition System



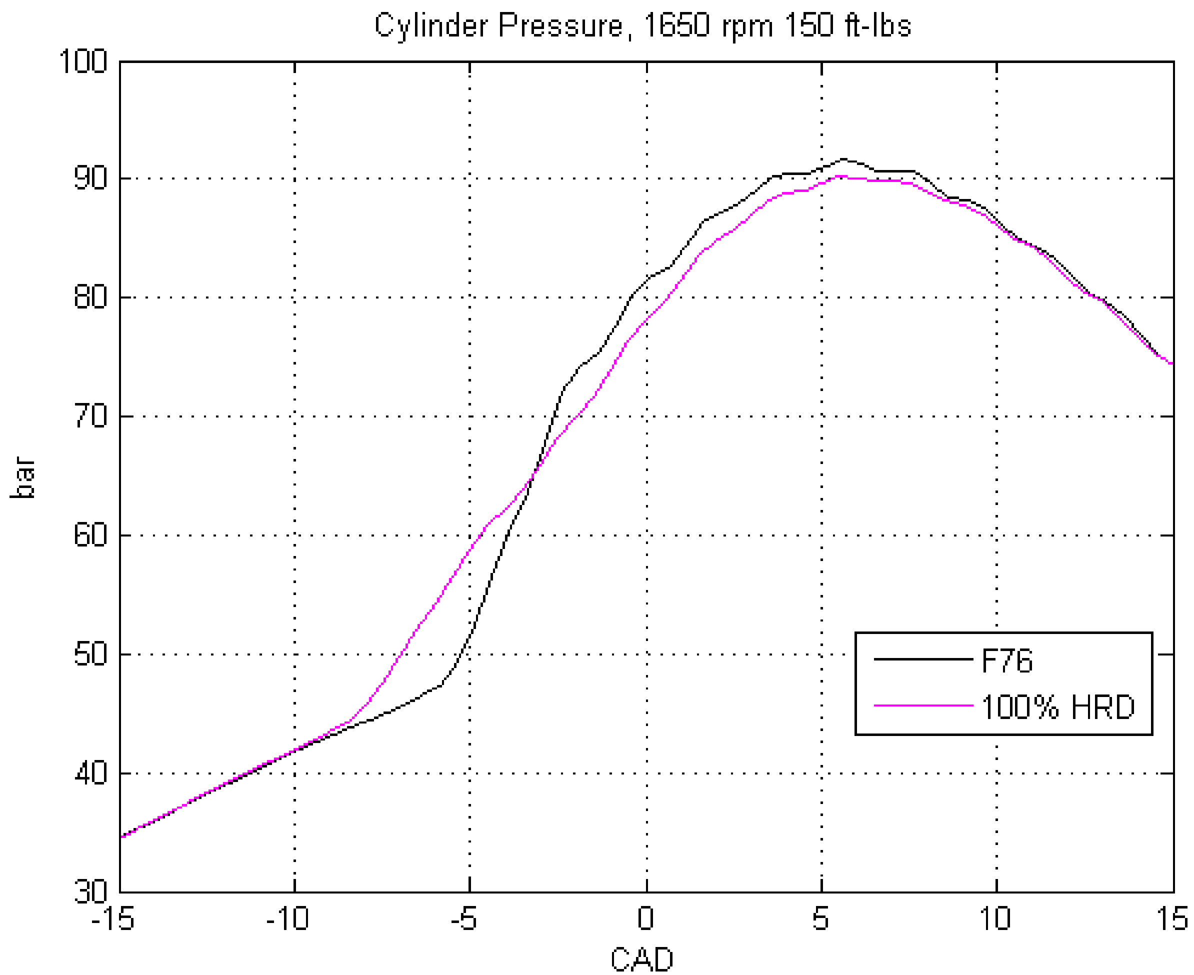




Gravimetric Fuel system

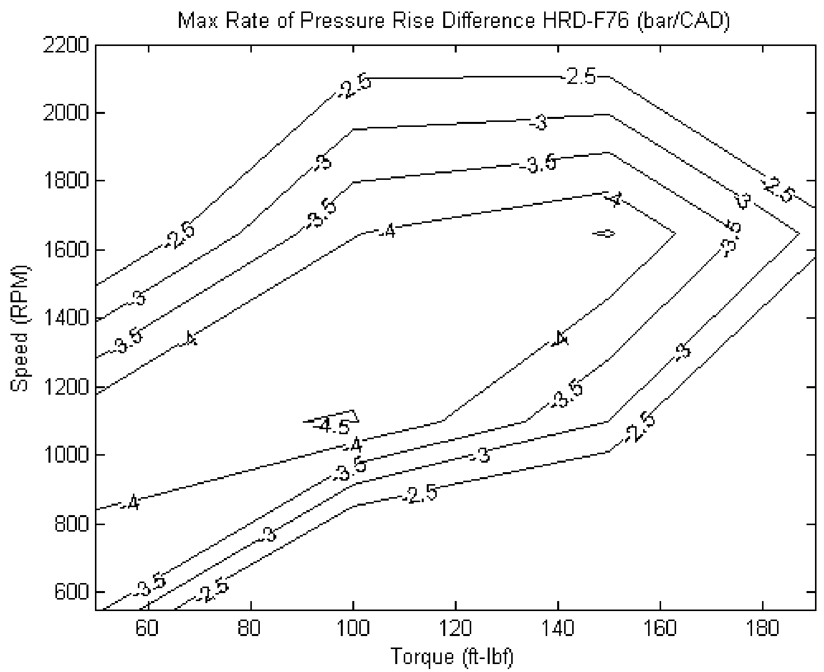
Typical Engine Data: Pressure vs. CAD

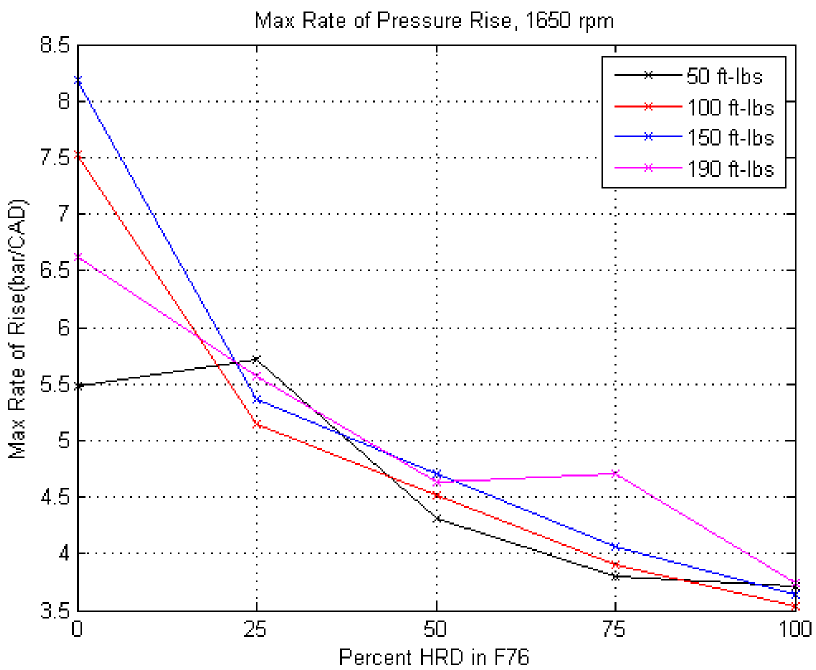
In Cylinder Pressure (Indicator Diagrams)



Engine "Shock" for 0-100% HRD

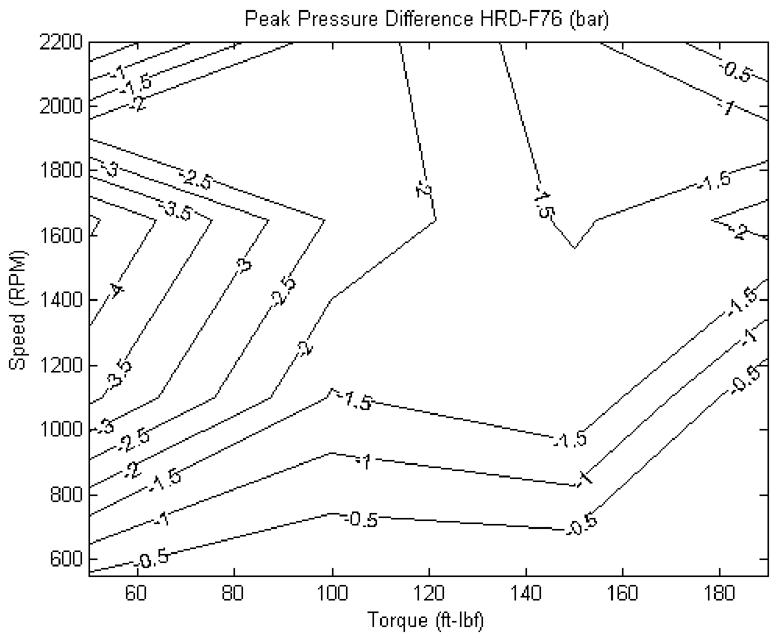
Maximum Rate of Pressure Rise ("shock to engine")

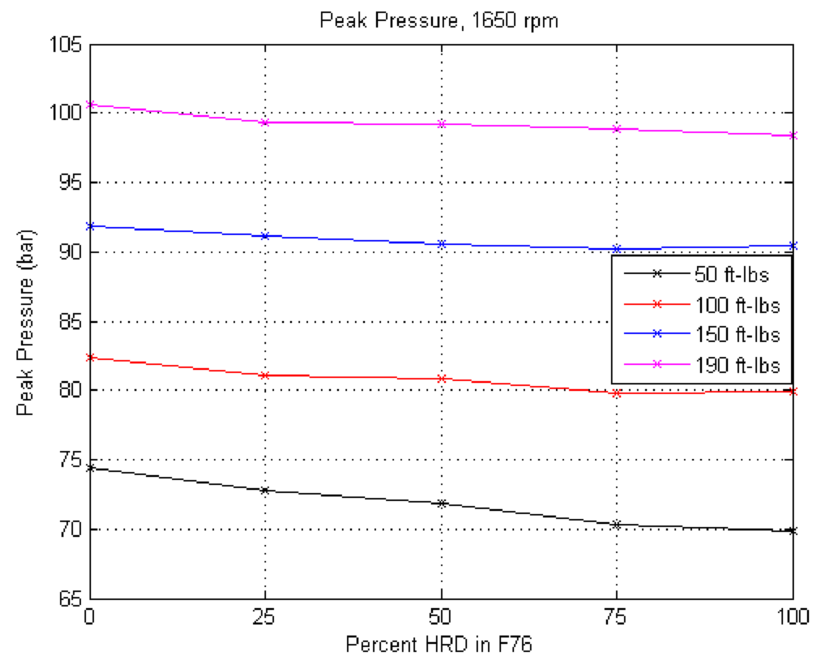




Engine Stress for 0-100% HRD

Peak Pressure ("Stress")

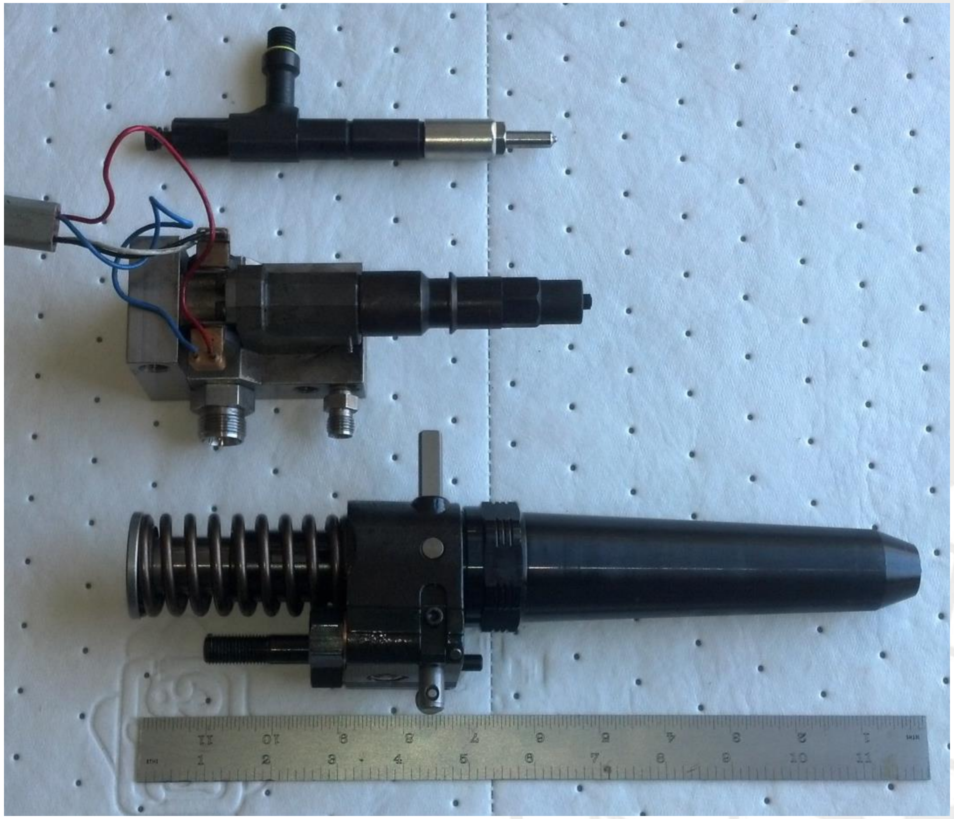




Atomization Testing

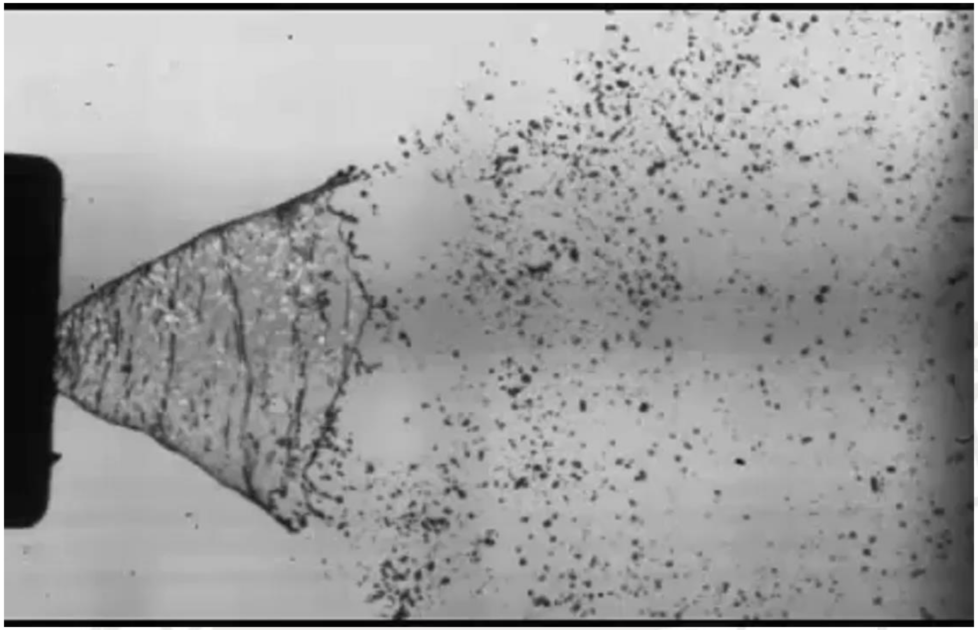
Fuel Injector Selection

Type	Application
Yanmar	Spec Op Boats
Sturman	Academic Research
Electro Motive Diesel (EMD)	Nimitz-Class Carrier Emergency Generator

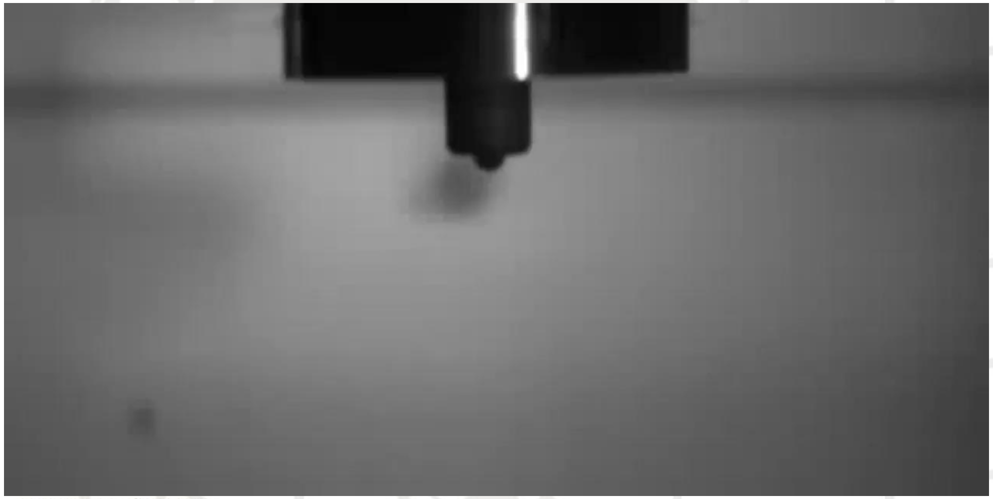


Particle Sizing

Atomization



Surface tension effects are clearly visible at low pressure and temperature conditions.

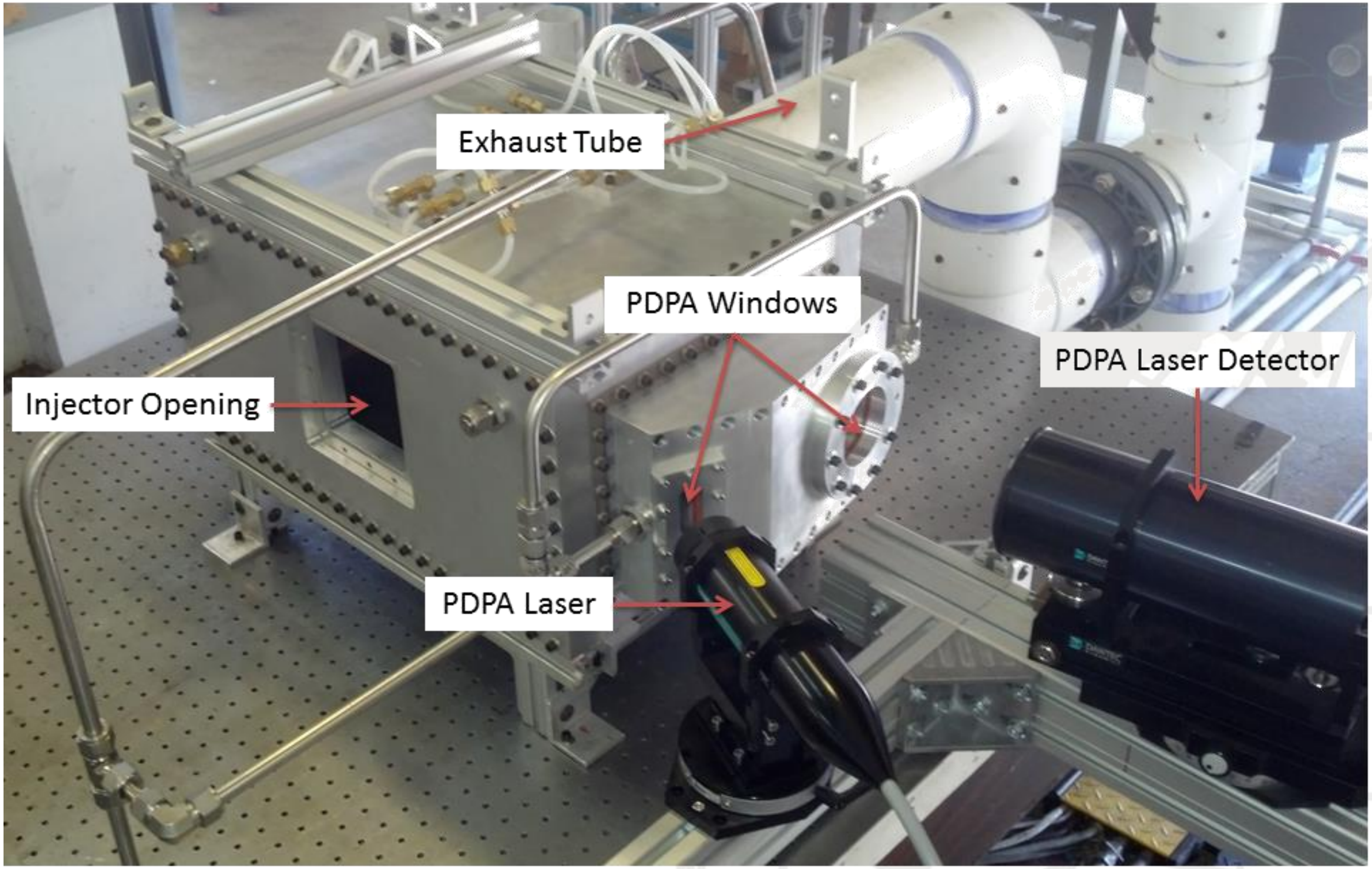


Fuel injection into combustion chamber conditions improve the atomization substantially.

*Taken with Shimadzu camera

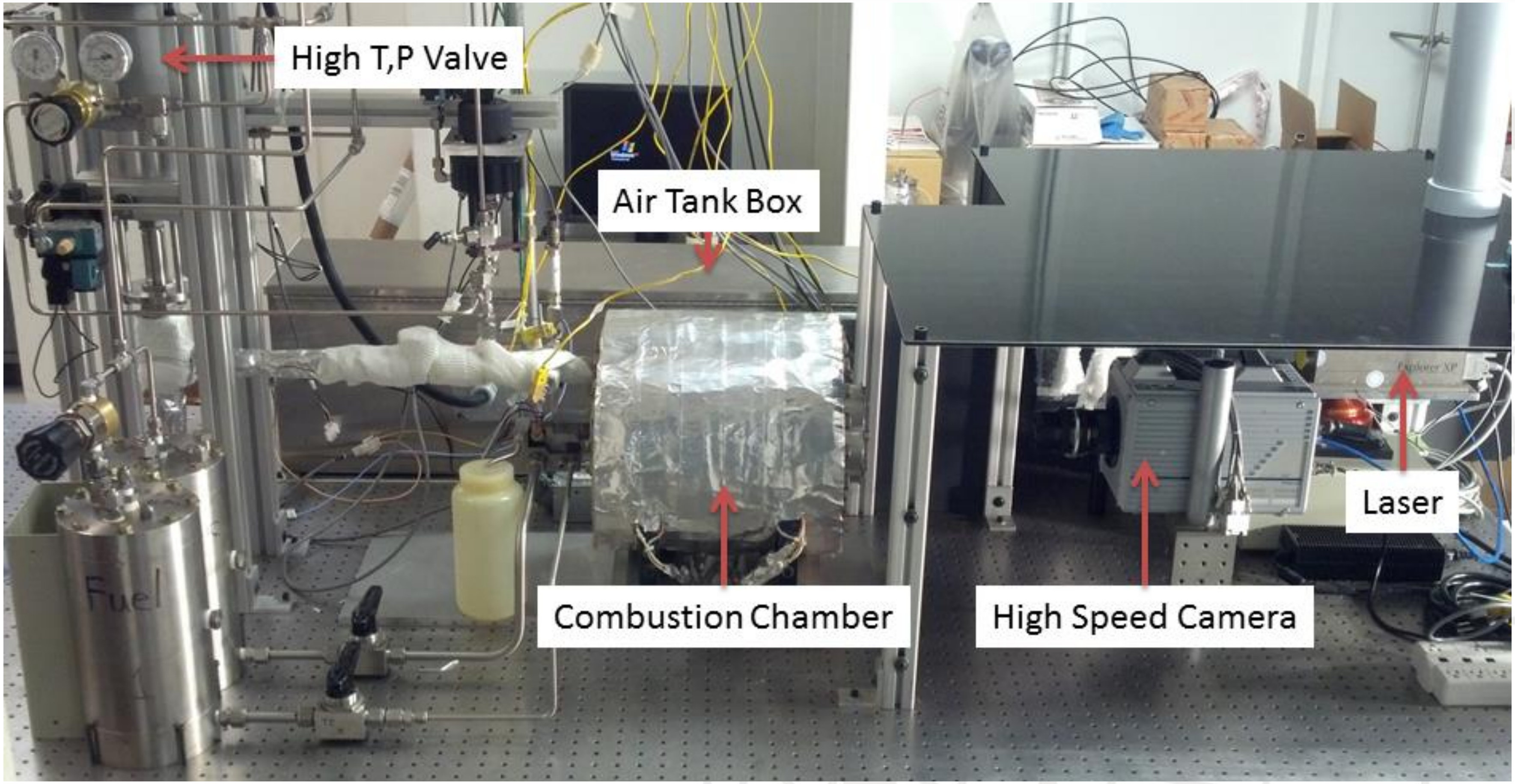
Experimental Setup

Particle Sizing



Allows for diesel injector sprays to be characterized
(Particle size vs. Fuel source and operating pressure/temperature)

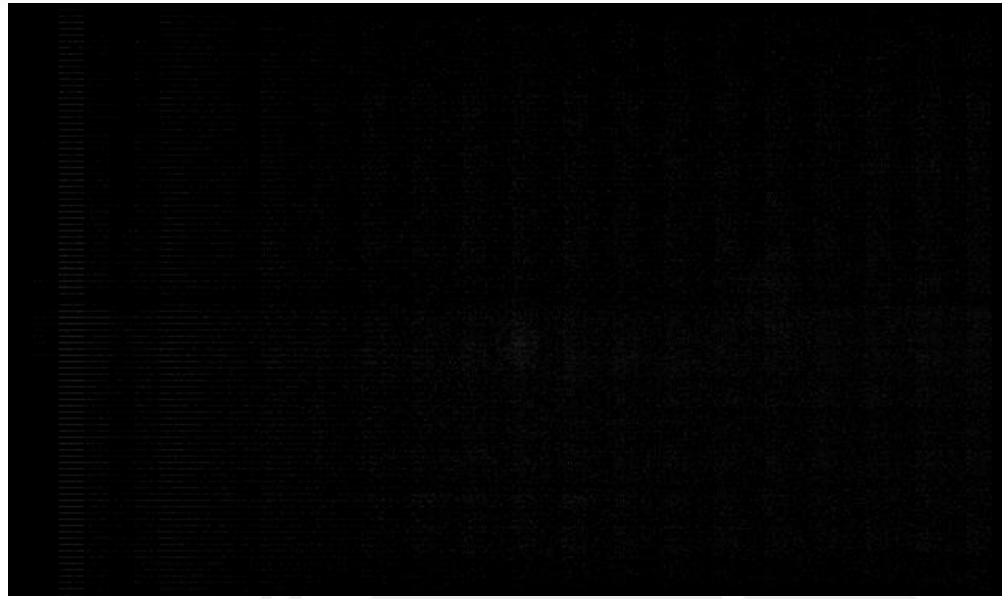
Experimental Setup



Combustion Chamber for Ignition Delay Testing
- Rated for up to 3000 psi conditions

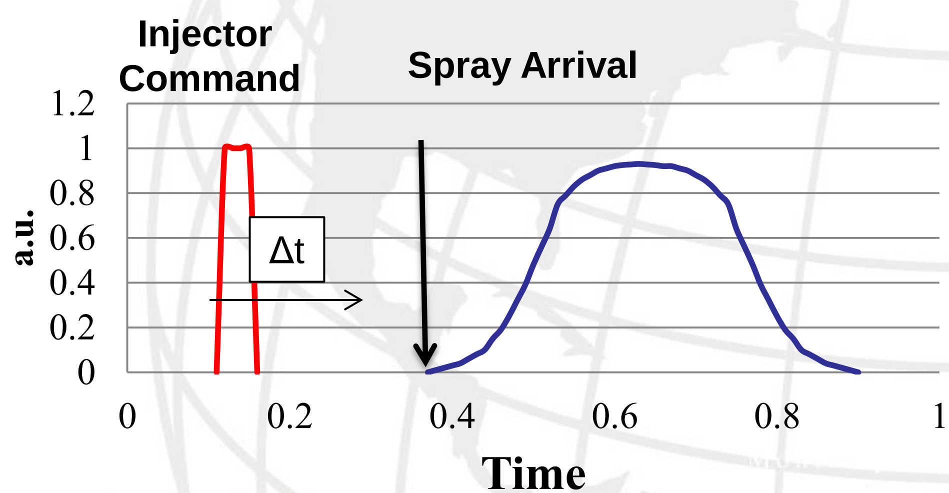
Fuel Injection Delay Imaging

Sturman Injector

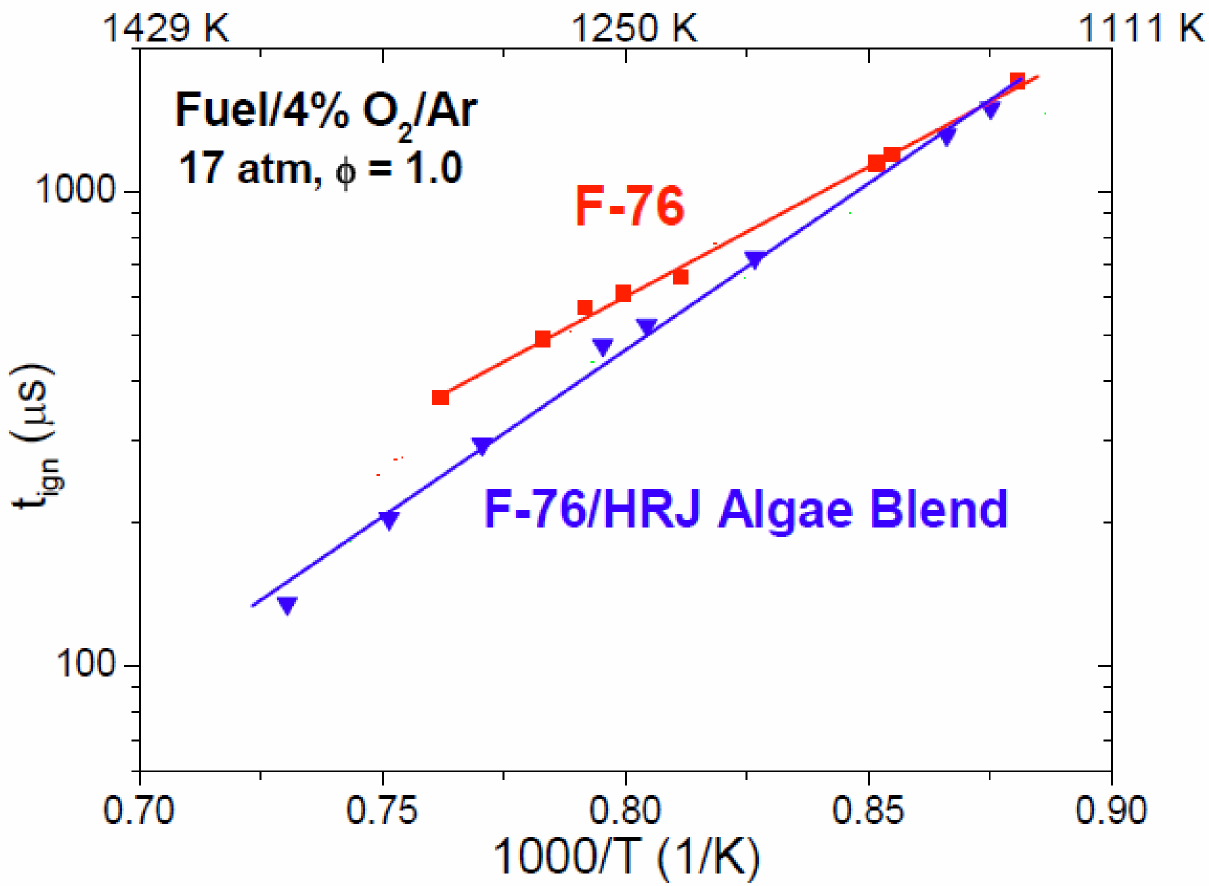


- Fluorescent Dye
- 532 nm laser excitation
- 570 nm fluorescence
- 30 kHz frame rate

No noticeable injection delay differences between fuels to-date.



Results
Ignition Delay



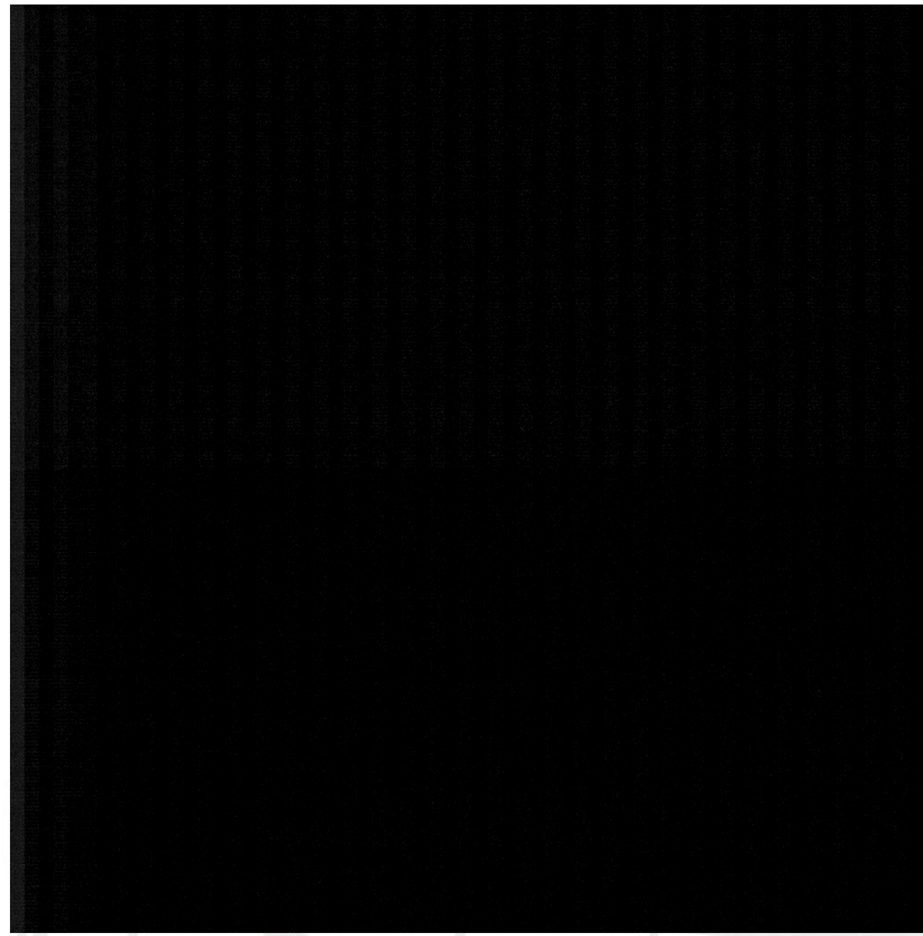
- Stanford University is contracted for shock-tube studies.
- Homogeneous / well-conditioned mixtures
- Ignition delay and species consumption-production data.

Results

Ignition Delay

Injector-Specific

- CH* chemiluminescence at 431.5 nm
- 10 kHz Imaging
- Flame Front Marker
- Compare with chamber pressure rise.



Ignition delay variations are being observed and agree qualitatively with engine tests

Conclusions and Synthetic (SPK) Tests

- 50/50 HRD/F-76 blends have lower shock and stress in typical Diesel engines.
- Higher blend ratios are even better from a combustion standpoint.
- Also tested low Cetane number (26) Synthetic Paraffinic Kerosene (SPK).
- Obtained from USAF (Sasol). Used in Gas Turbines.
- Significantly worse. High rate of pressure rise and peak pressure.

Sponsors

The alternative fuel studies were sponsored by Sharon Beermann-Curtin at the Office of Naval Research.