Ferris Research Group

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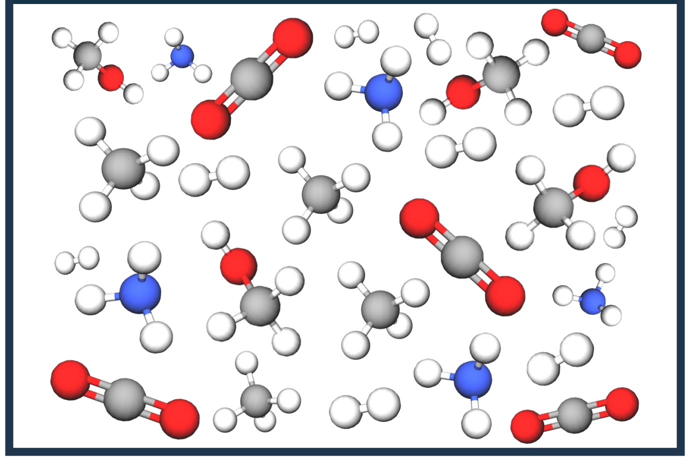
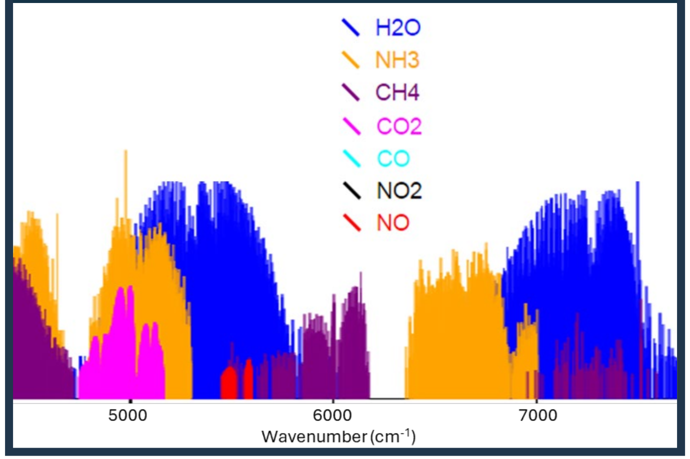
Chemical Kinetics



Optical Diagnostics

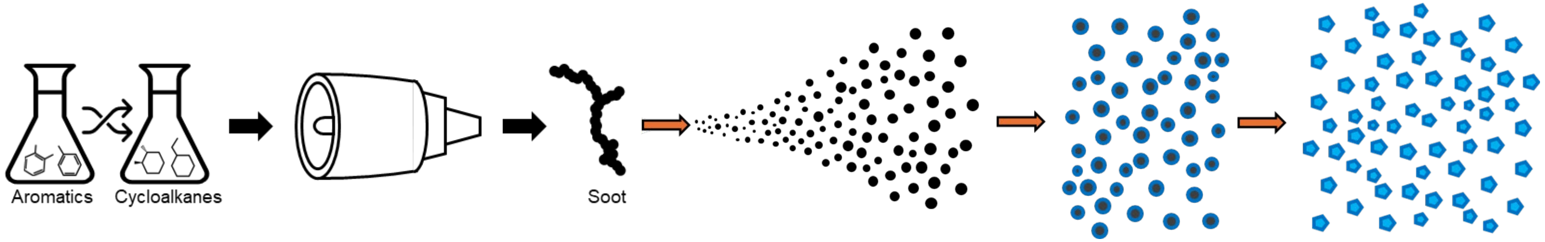


Fuel Design

Research interests: development of **laser-based diagnostics** and **experimental methods** to better understand **gas-phase reaction chemistry**; **design of sustainable fuels**

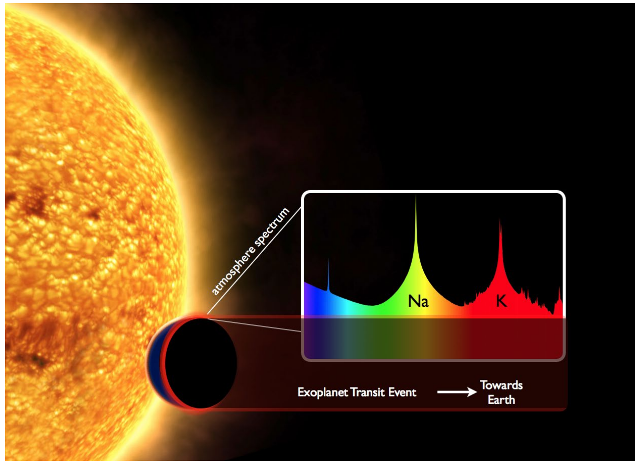
Research Topics

FTIR-based pre-screening tool for sustainable aviation fuel development

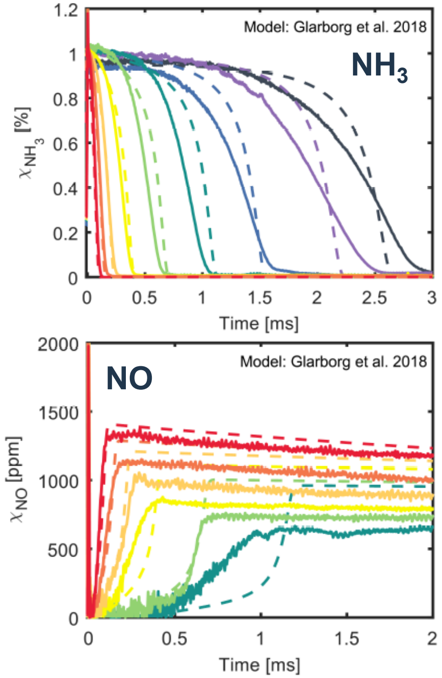


Jet fuel molecular structure effects on soot/contrail formation

Broadband, ultra-fast light sources for simultaneous, multi-species measurements

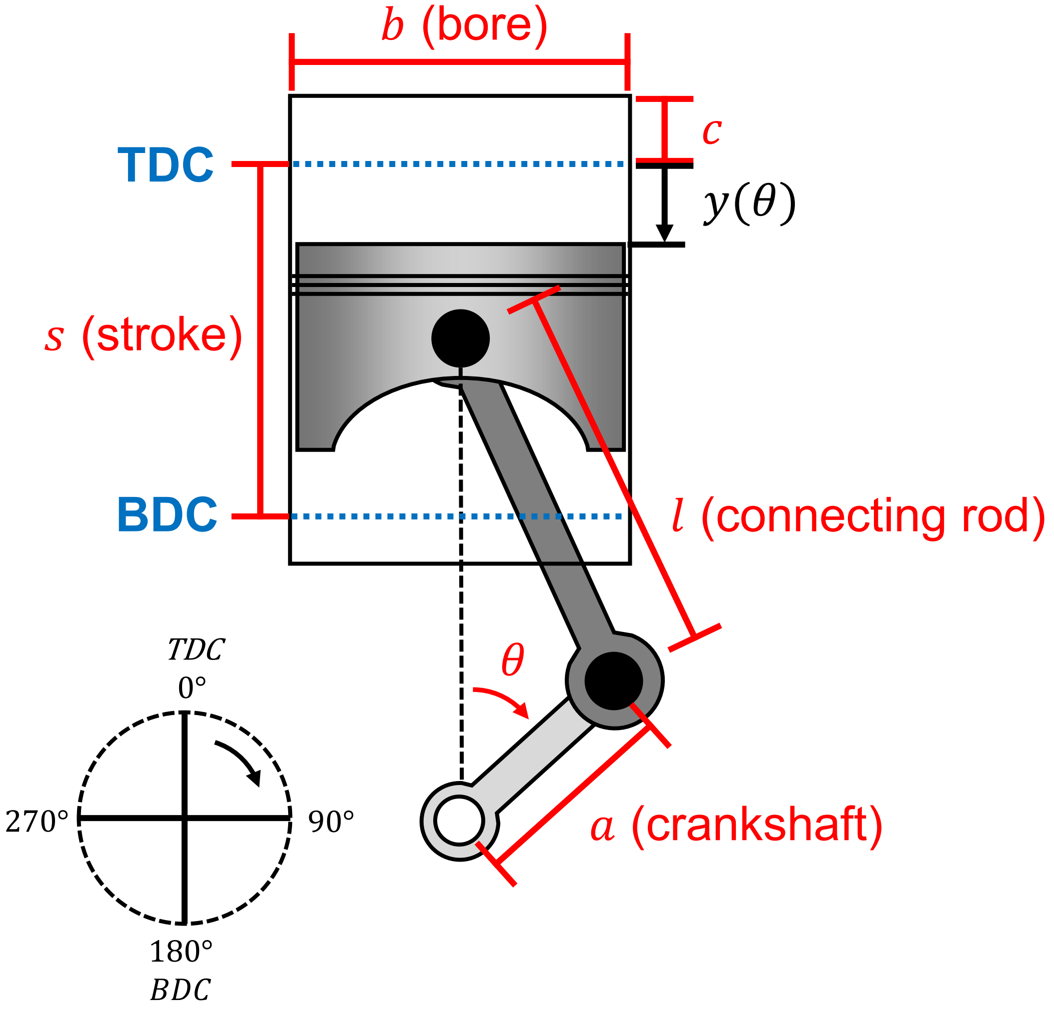


Exoplanet atmospheric chemistry & spectroscopy



Chemistry of low-carbon fuels (e.g., ammonia, etc.)

Volume, Displacement & Compression Ratio



- **Displacement volume**, V_d:

$$V_d = V_{BDC} - V_{TDC} = \frac{\pi}{4} b^2 s$$

  - Total engine displacement volume:
    $V_{d,total} = V_d n_c$ where n_c = number of cylinders

- **Compression ratio**, r:

$$r = \frac{\text{maximum cylinder volume capacity}}{\text{minimum compressed volume}}$$

$$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_{BDC}}{V_c} = \frac{V_d + V_c}{V_c}$$

Engine parameters

	Compression ratio	Bore (cm)	Stroke/Bore
Spark-ignition engines:			
Small (e.g., motorcycles)	6-11	5-8.5	1.2-0.9
Passenger cars	8-10	7-10	1.1-0.9
Trucks	7-9	9-13	1.2-0.7
Large gas engines	8-12	22-45	1.1-1.4
Diesel engines:			
Passenger cars	17-23	7.5-10	1.2-0.9
Trucks	16-22	10-15	1.3-0.8
Locomotive, industrial, marine	12-18	15-40	1.1-1.3
Large engines, marine and stationary	10-12	40-100	1.2-3

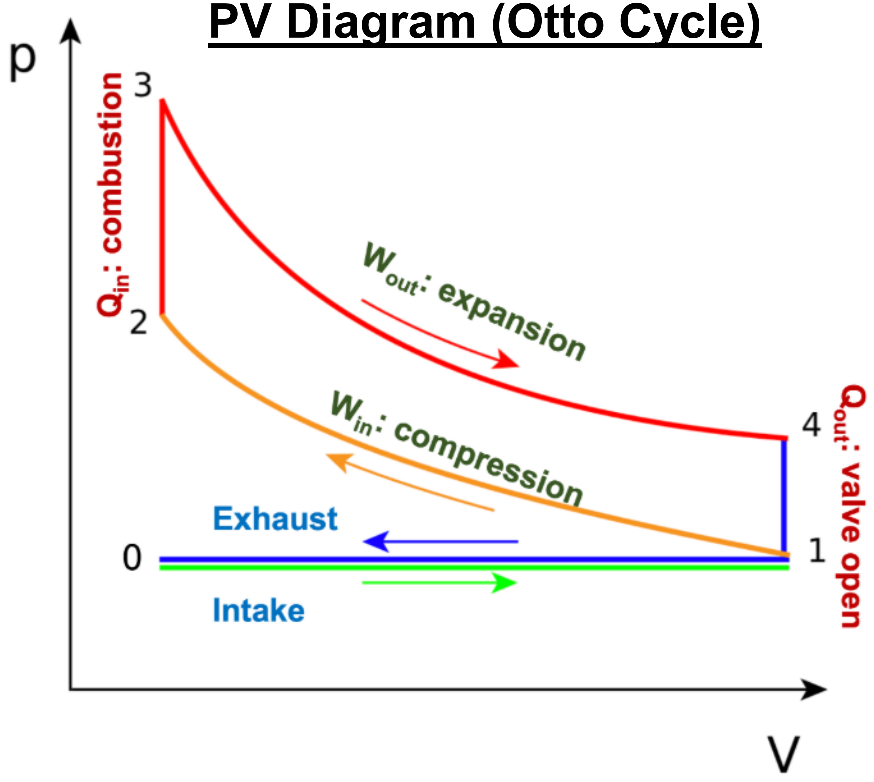
Heywood, *Internal Combustion Engine Fundamentals*, McGraw-Hill, 1988.

Engine efficiency

- Thermal efficiency: actual work per cycle relative to amount of fuel chemical energy released

$$\eta_T = \frac{net\ work\ out}{heat\ in} = \frac{P}{\dot{Q}_{in}} = \frac{P}{\dot{m}_f \cdot LHV}$$ → In terms of **power**

PV Diagram (Otto Cycle)

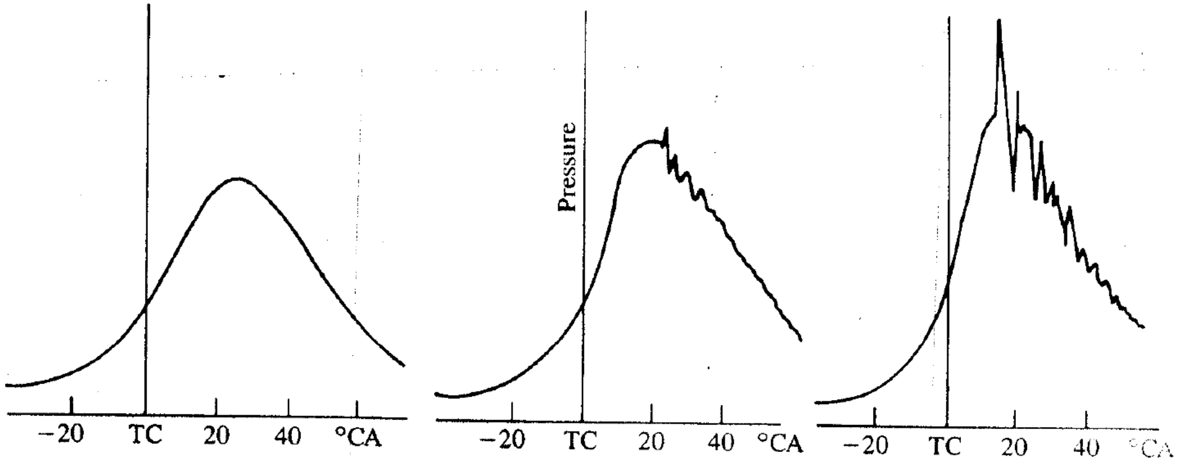


$$\eta_T = \frac{W_{net}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$ → In terms of **work**

$$\boxed{\eta_T = 1 - \frac{1}{r^{\gamma-1}}}$$ → In terms of **compression ratio**

Engine knock

- Increasing the compression ratio of a homogeneous charge spark ignition (HCSI) engine is eventually limited by a phenomenon called “engine knock”
- What is engine knock?
  - Dramatic pressure increase and fluctuation that can occur during the compression process
  - “Light knock” causes a “pinging” noise
  - “Strong knock” can cause large amplitude pressure oscillations, increased heat transfer to the cylinder, and damage to the piston/engine



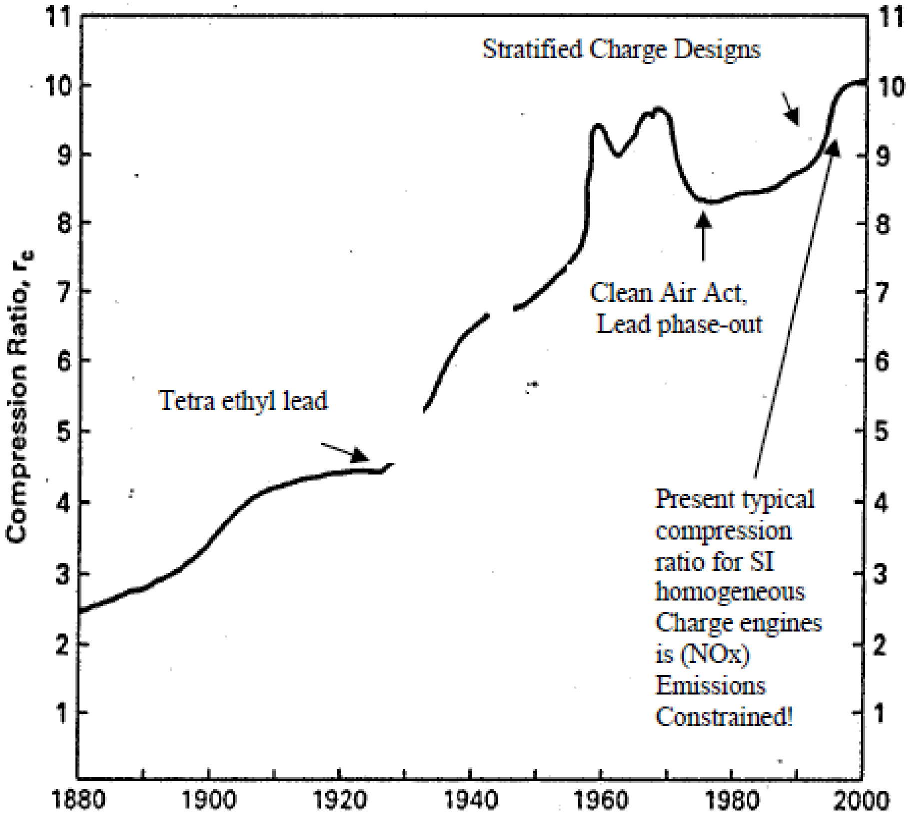
(*a*) Normal combustion, spark 28°BTC

(*b*) Slight knock, spark 28°BTC

(*c*) Intense knock, spark 32°BTC

Techniques for limiting knock

- Use a fuel that is more resistant to autoignition (higher octane number)
- Use an additive
  - Tetraethyllead (TEL) was used as an anti-knock additive from the 1920s-1970s (total phase-out in the US in 1996)
    - TEL decomposes into ethyl radicals, Pb, and PbO (lead oxide); PbO acts as a radical scavenger, thereby inhibiting autoignition
- Stratify the charge
  - Rich, ignitable mixture near the spark plug, lean mixture in the rest of the cylinder
- Optimize spark timing



Octane number

- Indicates a fuel’s “resistance to autoignition”
- Compares fuel to a reference blend of n-heptane (ON = 0) and iso-octane (ON = 100)
  - Octane number is the percent of iso-octane in the reference blend that gives the same resistance to knock as the fuel

- At the pump, you have the choice between “Regular,” “Mid-Range,” and “Premium” gasoline
  - What’s the difference? Resistance to auto-ignition!

Anti-Knock Index (AKI)

- The buttons at the pump actually specify the fuel’s “anti-knock index,” or AKI, which is the average between a fuel’s Research Octane Number (RON) and Motor Octane Number (MON):

$$AKI = \frac{RON + MON}{2}$$

RON and MON

- RON and MON are determined experimentally
  - Tests use a variable compression ratio engine (Cooperative Fuel Research (CFR) engine)
  - Compression ratio of the CFR engine is increased until knock occurs
  - Same test is run with various mixtures of n-heptane/iso-octane until knock occurs at the same compression ratio
- RON and MON tests occur at different operating conditions:

	RON	MON
Engine speed (rpm)	600	900
Intake air temperature (C)	52	149
Spark timing	Fixed	Variable
	Low-speed, low-temperature conditions	High-speed, high-temperature conditions

Source: CFR Engines, Inc. (copyrighted)

An important question…

- What happens if you put diesel in a gasoline engine?
  - Higher viscosity means fuel system (pump) will likely struggle to circulate/inject fuel; if injected, fuel won’t atomize correctly (injection pressure too low) and will coat/foul spark plug and cylinder.
- What happens if you put gasoline in a diesel engine?
  - Gasoline acts like a solvent (light, volatile hydrocarbon!) exacerbating metal-on-metal wear (fuel pumps, injectors); can cause irregular firing cycles/knock

	Gasoline Engine	Diesel Engine
Fuel injection pressure (bar)	2-5 (PFI) 100-150 (DI)	3000
Fuel jet velocity (m/s)	15 (PFI) 50-100 (DI)	>100
Fuel injector hole diameter (mm)	0.15-0.2	0.1-0.5
Kinematic Viscosity (mm/s^2 @ 40 C)	<1	>2.0
Density (kg/m^3)	710-770	820-850