Spark Ignition Engine

Thermal, Fluids, and Energy
Systems Lab

(ME EN 4650)

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Spark Ignition Engine Performance

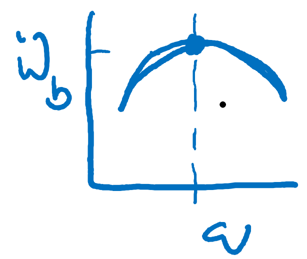
What we want to know:

→ mechanical power ($\dot{W}_b$) vs crankshaft speed (ω)

→ efficiency (η) vs. ω

→ compare with ideal engine (follows otto cycle)

→ mean effective pressure vs. ω



What we can measure:

→ crankshaft speed (optical encoder)

→ engine torque (dynamometer)

→ exhaust, air, fuel temp (thermocouples)

→ inlet air flow rate (orifice meter)

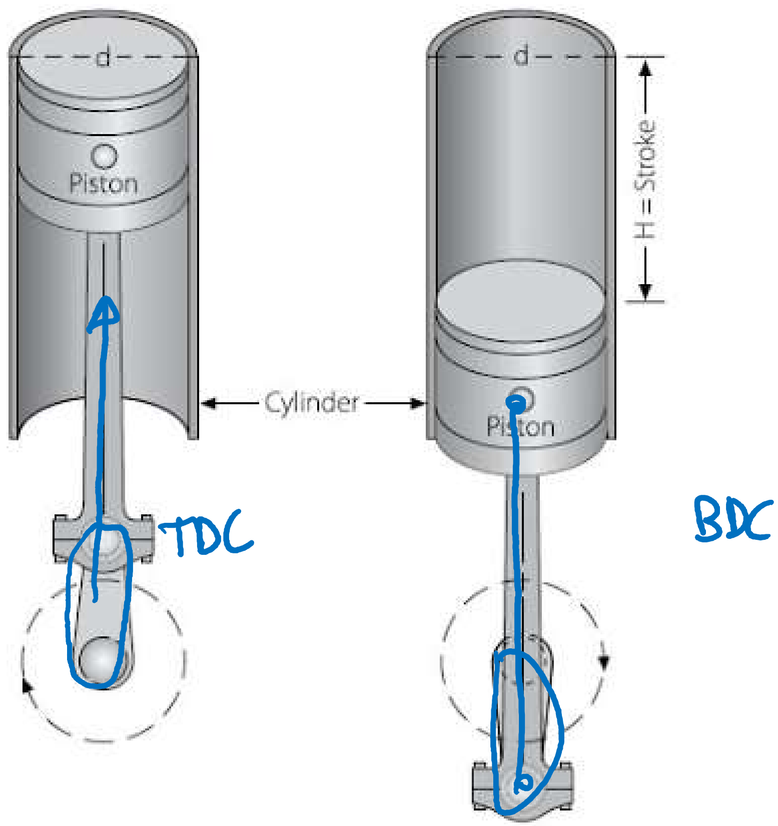
→ fuel flow rate (fill tube)

Bore, B	65.1 mm
Stroke, S	44.4 mm
Displacement Volume, $\mathbb{V}_d$	0.148 L
Compression Ratio, r	7:1
Ignition Timing	20° before TDC
Fuel Type	91 octane gasoline

Lecture Outline

- Background
- Experimental Setup
- Measurements and Instrumentation
- Required Figures
- Data Analysis

Engine Size: Compression Ratio

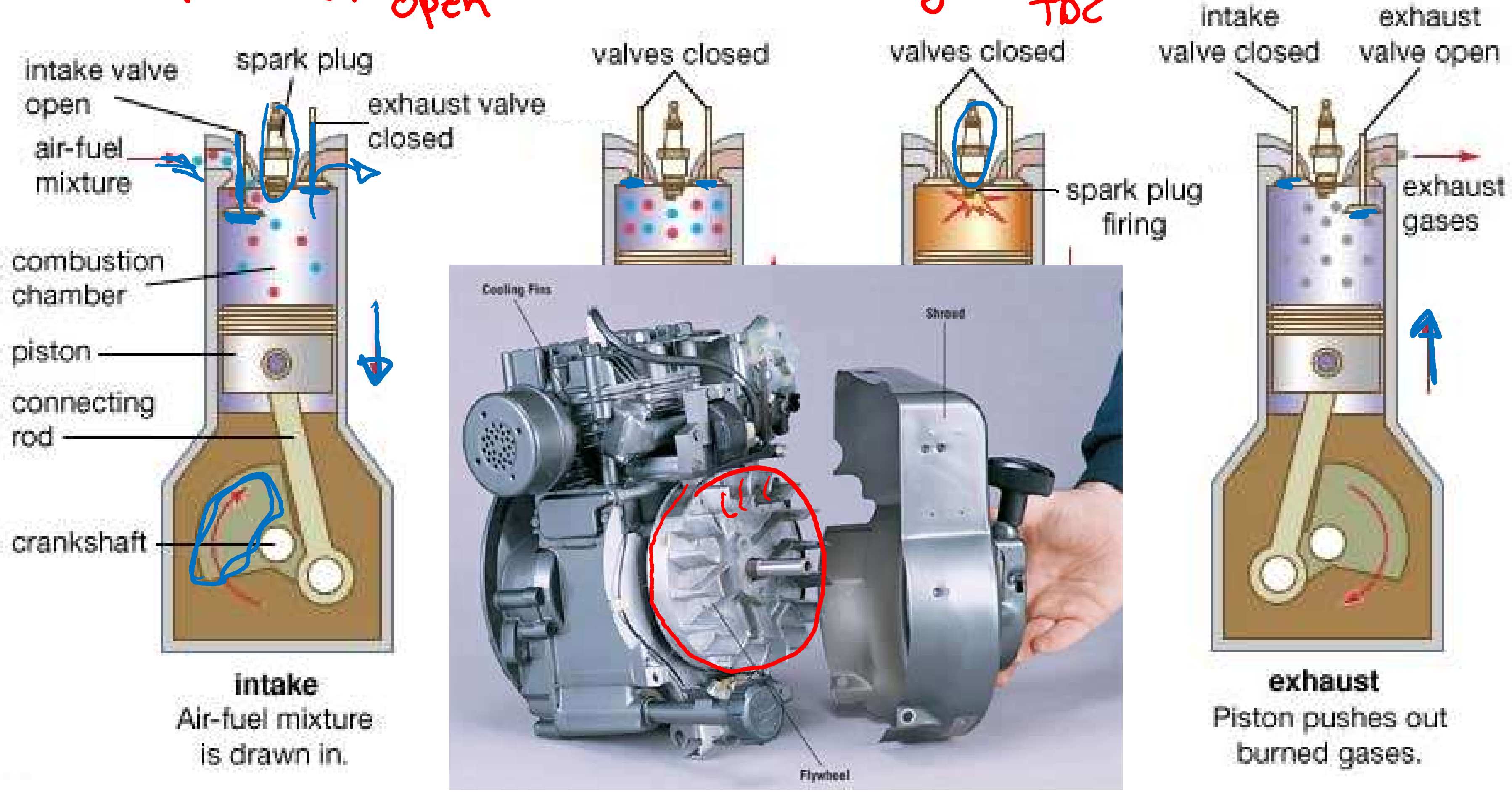


Dead Center

Four-Stroke Engine: Physical Cycle

throttle: fully open

timing: 20° before TDC



Measurements

Quantity	Symbol	Units	Instrument
Sampling interval	Δt	sec	stopwatch
Inlet air temperature	T_{air}	°C	thermocouple
Inlet fuel temperature	T_{fuel}	°C	thermocouple
Exhaust gas temperature	T_{exhaust}	°C	thermocouple
Inlet air volume flow rate	$\dot{\mathbb{V}}_{\text{air}}$	L/min	orifice meter
Volume of fuel consumed	$\mathbb{V}_{\text{fuel}}$	cm^3	fill tube level
Rotational speed of crankshaft	ω	RPM	optical encoder
Torque of crankshaft	τ	N·m	dynamometer

Experiments

Quantity	Symbol	Units	Instrument
Sampling interval	Δt	sec	stopwatch
Inlet air temperature	T_{air}	°C	thermocouple
Inlet fuel temperature	T_{fuel}	°C	thermocouple
Exhaust gas temperature	T_{exhaust}	°C	thermocouple
Inlet air volume flow rate	$\dot{\mathbb{V}}_{\text{air}}$	L/min	orifice meter
Volume of fuel consumed	$\mathbb{V}_{\text{fuel}}$	cm^3	fill tube level
Rotational speed of crankshaft	ω	RPM	optical encoder
Torque of crankshaft	τ	N·m	dynamometer

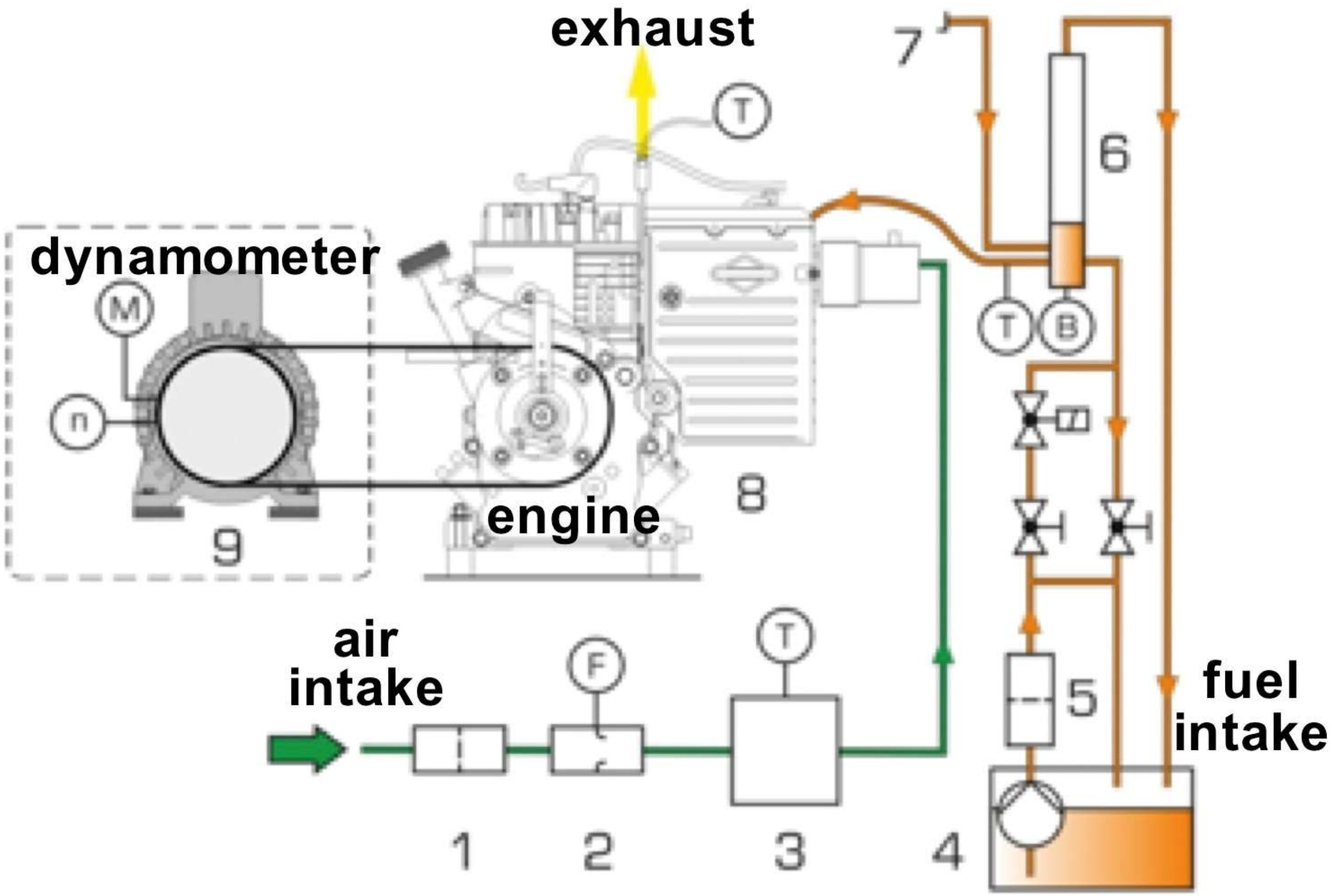
Exp #1 (Performance)

→ Throttle fully open
→ 5 loads
→ 5 crankshaft speed

Exp #2 (Friction)

→ dry run (no combustion)
→ measure τ & ω

Experimental Setup

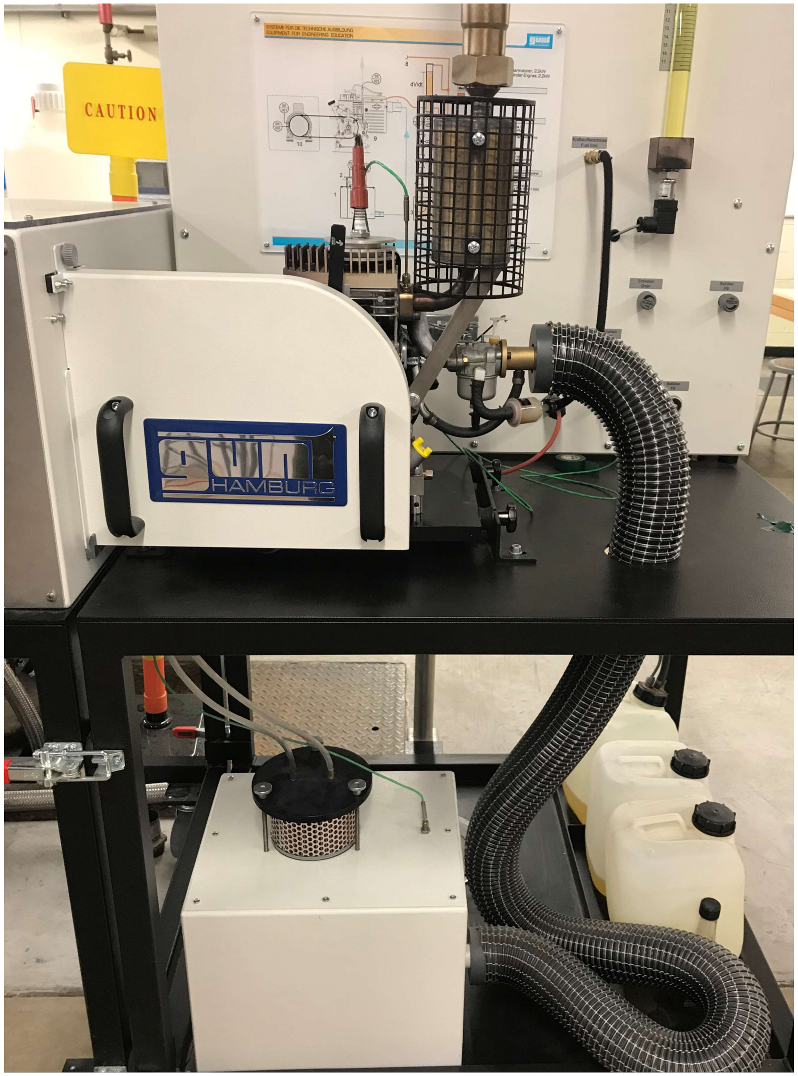


Experimental Apparatus

Dynamometer

Single-cylinder engine

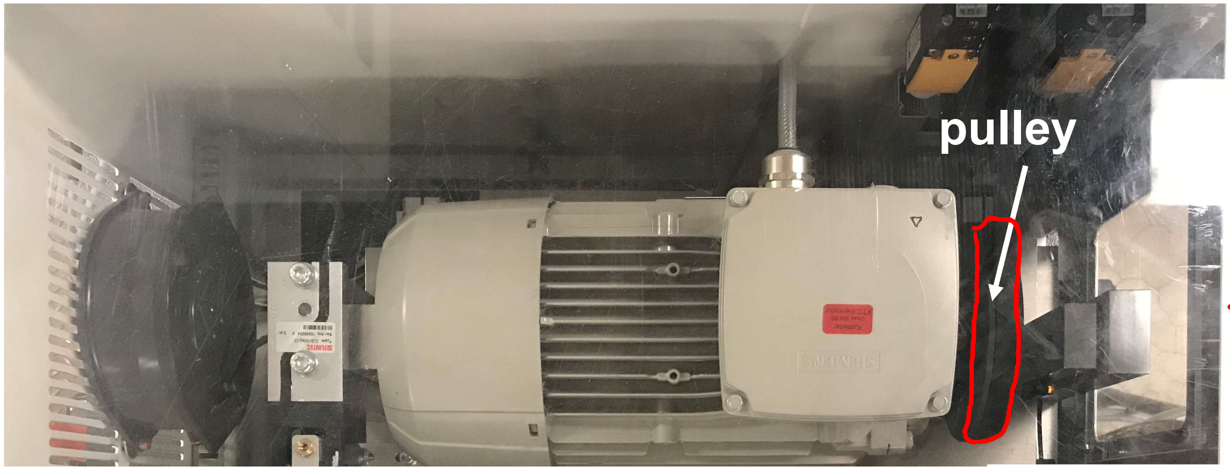
Experimental Apparatus

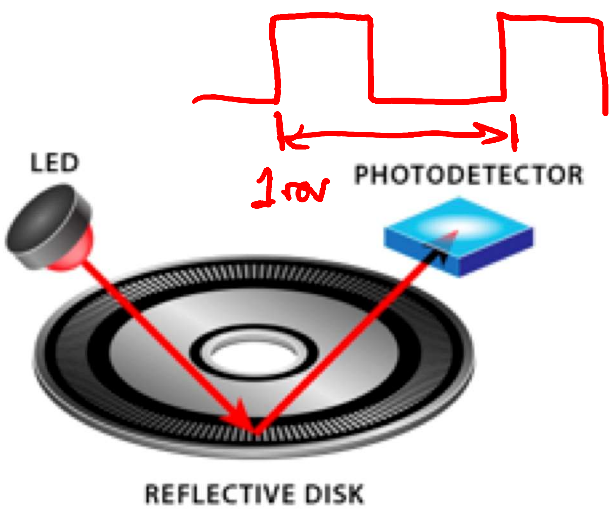


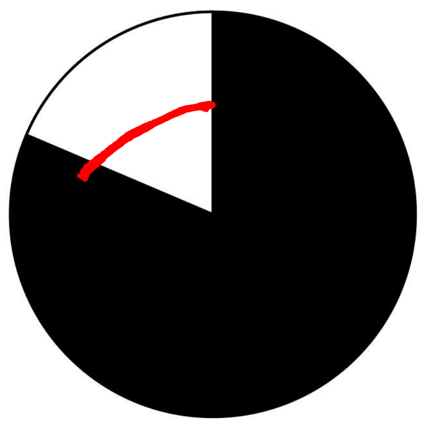
Fuel pump

Dynamometer

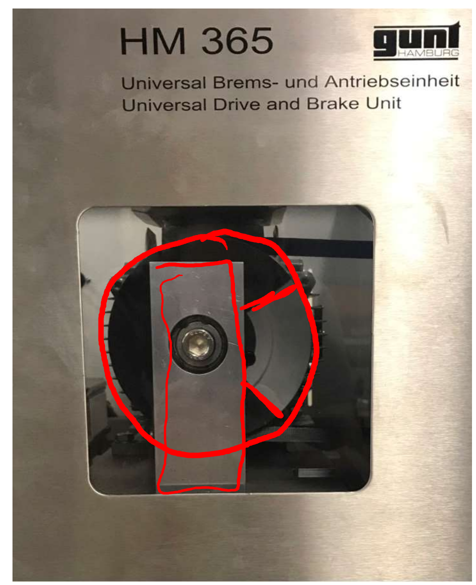
Crankshaft Speed: Optical Encoder





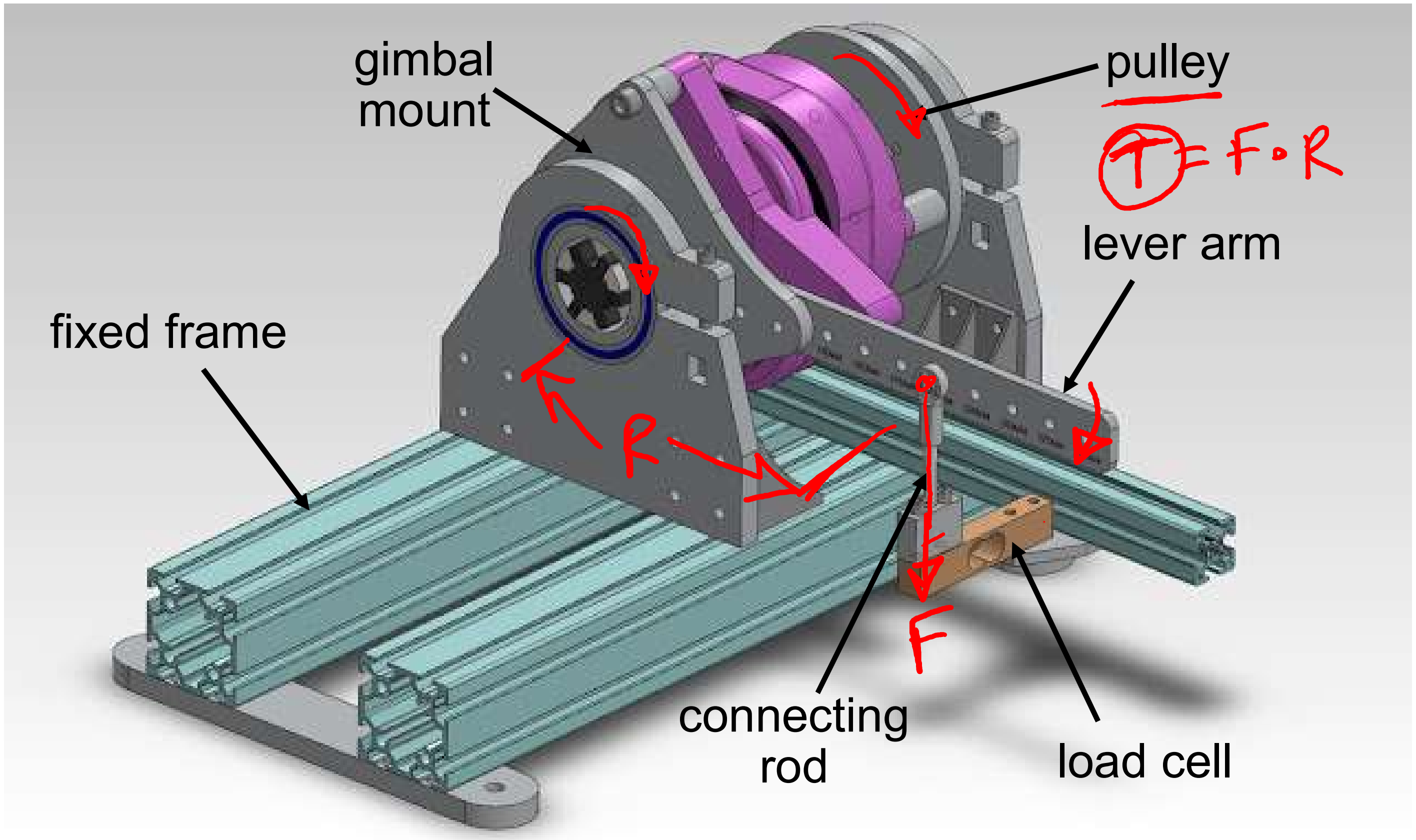


code wheel

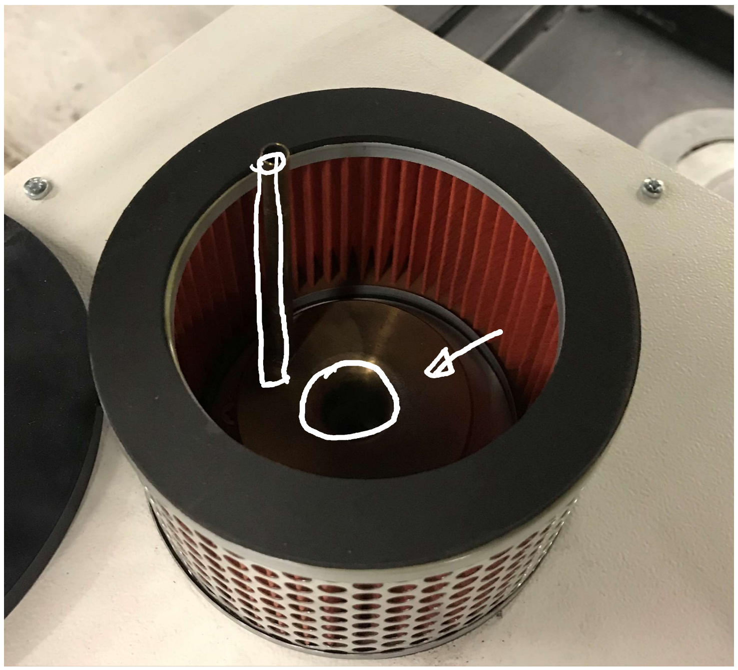


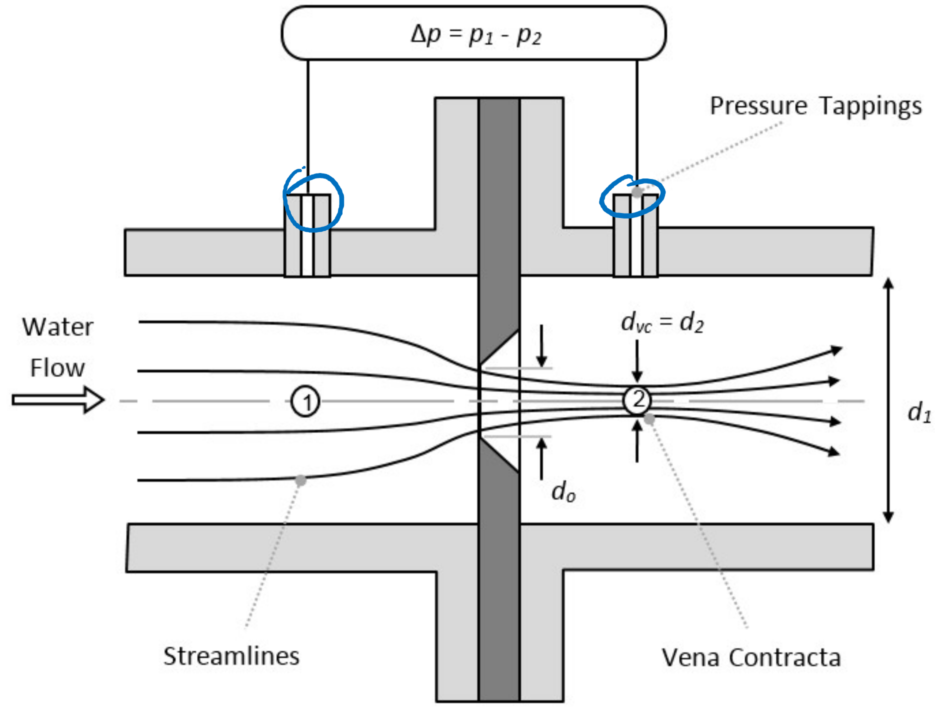
Brake Dynamometer: Measure Torque

Gimbaled Motor Mount with Lever Arm and Load Cell



Air Flow Rate: Orifice Meter





$$\dot{m}_a = \rho_a \dot{V}_a$$

$$\rho_a = \frac{P}{RT} \quad \text{(Ideal gas Law)}$$

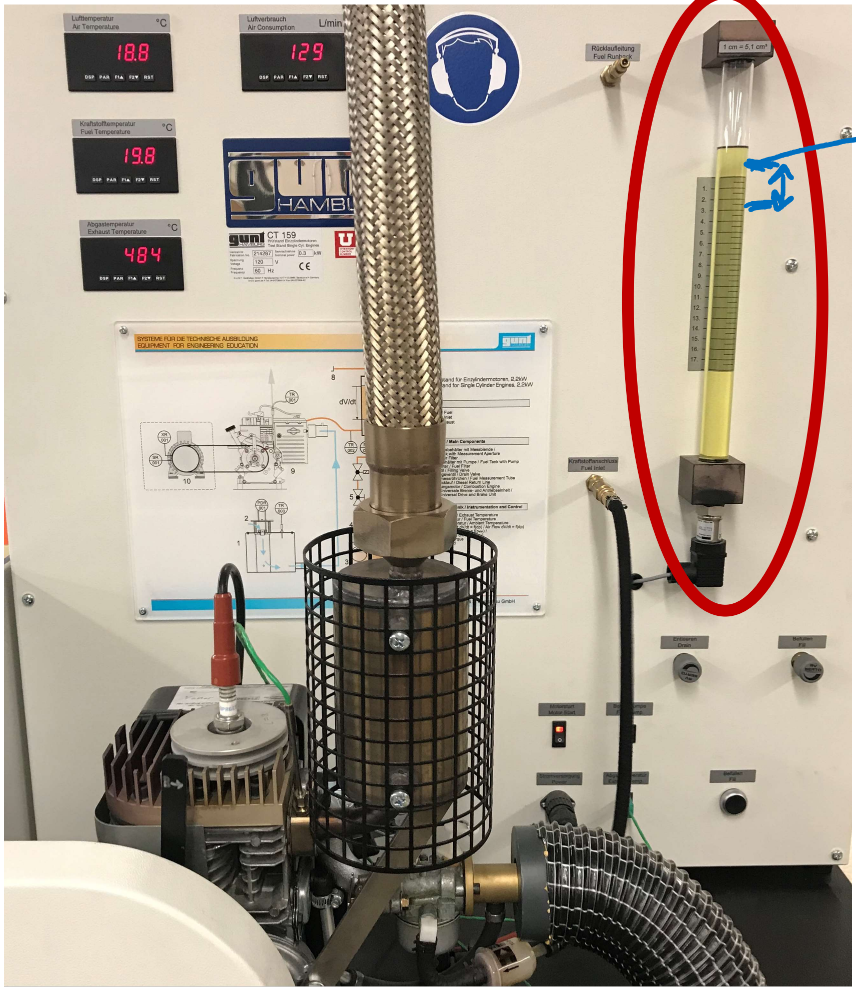
$R = 287.1\ J/kg \cdot K$

$$\dot{V}_a = C\sqrt{\Delta P}$$

discharge coefficient

(L/min)

Fuel Flow Rate: Fill-Tube



$1\,cm = 5.1\,cm^3$

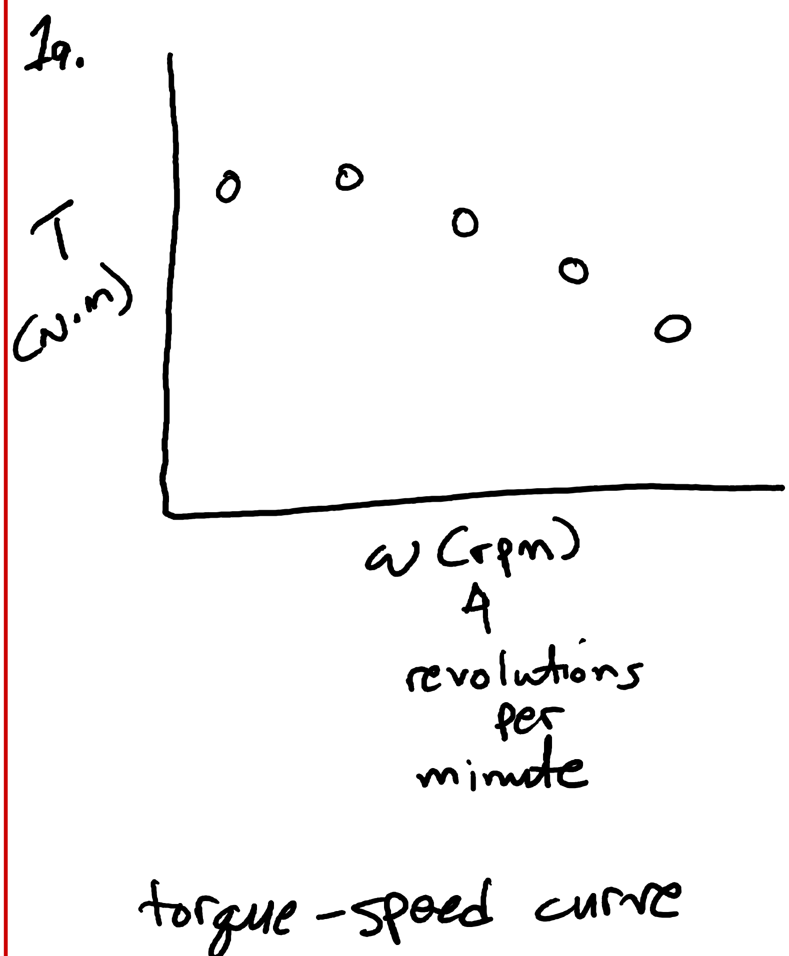
$$\dot{V}_f = \frac{V_f}{t}$$

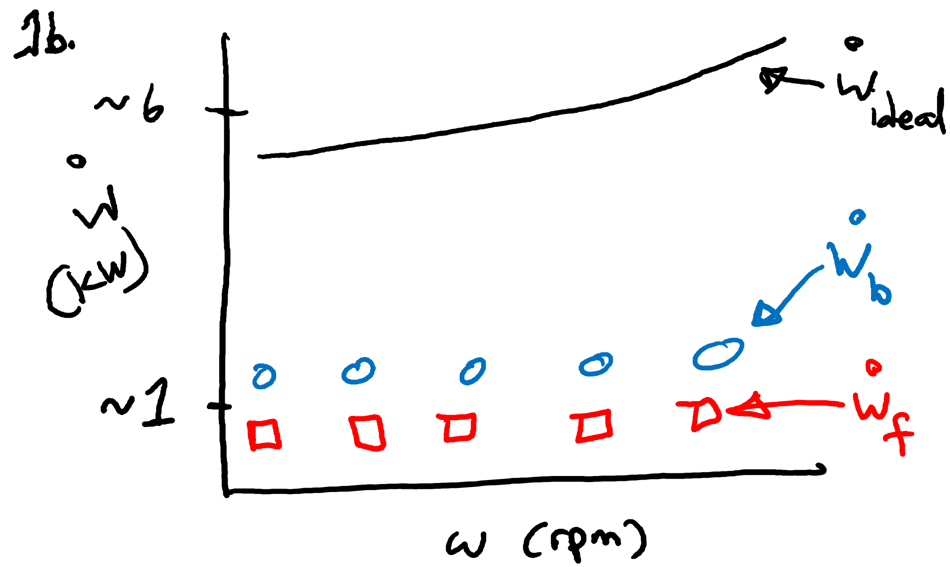
$$\dot{m}_f = \rho_f \dot{V}_f$$

91-octane gas

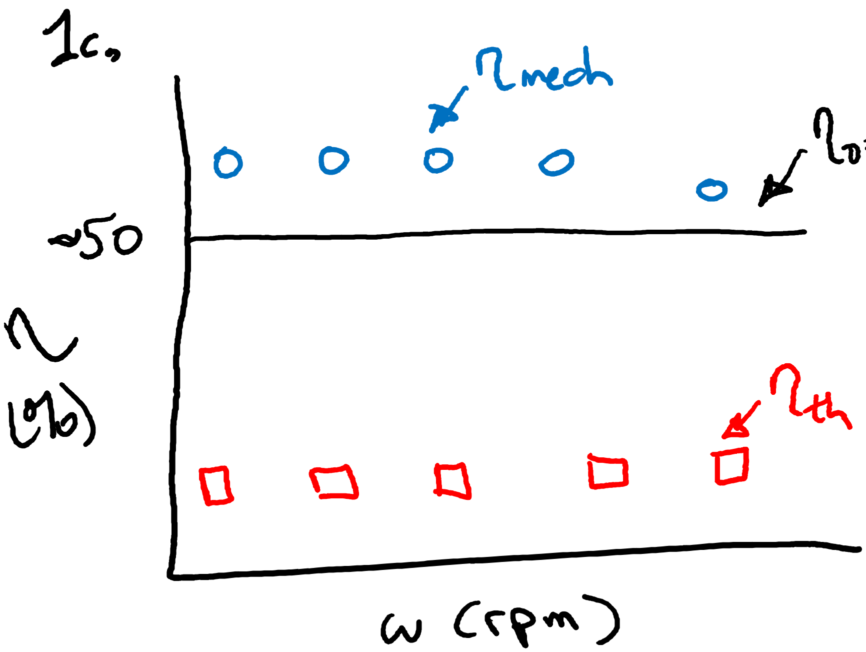
$\sim 726\ kg/m^3$

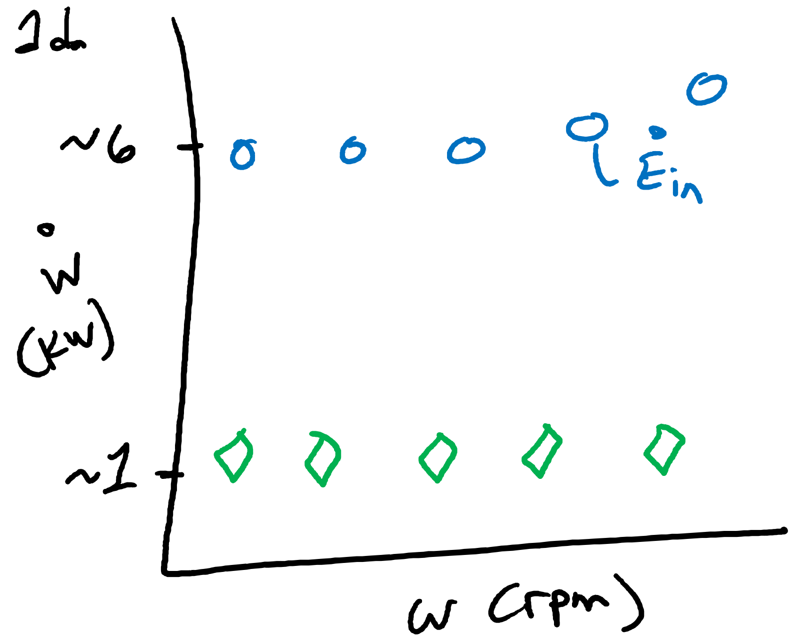
Figures 1a & 1b





Figures 1c & 1d





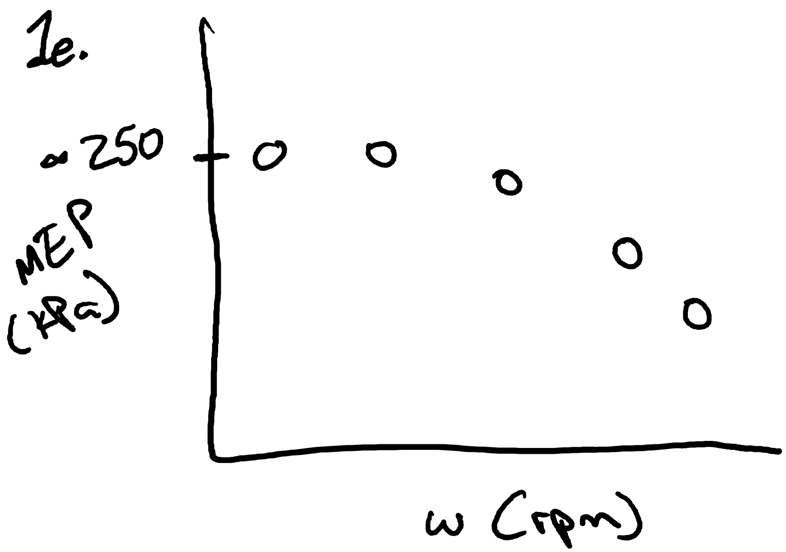
$\dot{E}_{in}$

$\dot{W}_b$

$\dot{W}_f$

$\dot{Q}$

Figures 1e



Spark Ignition Engine: Part II

Thermal, Fluids, and Energy Systems Lab

(ME EN 4650)

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Quantities of Interest (Required Figures)

- τ vs ω (rpm)

  measured ↳ measured (optical encoder)

  $\omega \rightarrow$ rad/s

- $\dot{W}_b$, $\dot{W}_f$, $\dot{W}_{net}$ vs ω

  $\dot{W}_b = \tau\,\omega$ [kW] $\qquad \dot{W}_f = \tau_f\,\omega$

  τ_f: dry run

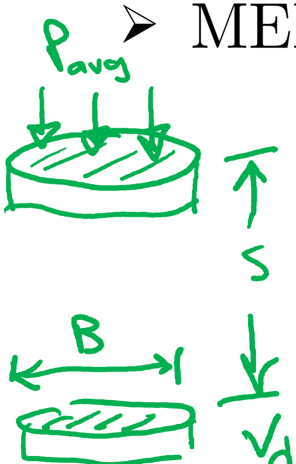
- η_{th}, η_{mech}, η_{Otto} vs ω

  $$\eta_{mech} = \frac{\dot{W}_b}{\dot{W}_b + \dot{W}_f} \cdot 100 \quad [\%]$$

- $\dot{E}_{in}$, $\dot{W}_b$, $\dot{Q}$, $\dot{W}_f$ vs ω

  $$\dot{E}_{in} = \dot{W}_b + \dot{W}_f + \dot{Q}$$
  $$\dot{Q} = \dot{E}_{in} - (\dot{W}_b + \dot{W}_f)$$

- MEP vs ω



$$V_d = \frac{\pi}{4} B^2 S$$

$$W = (MEP)\,V_d \sim 0.148\text{ L (specs)}$$
$$MEP = W/V_d = \dot{W}_b t_c / V_d$$
$$MEP = [\tau \cdot \omega]\left[\frac{1}{\omega}(2\pi)(2)\right] / V_d$$
$$\boxed{MEP = 4\pi\tau / V_d}$$

Thermal Efficiency

$\eta_{th} = \dot{W}_b / \dot{E}_{in}$ ← rate of energy into system via fuel

$\dot{E}_{in} = \underbrace{\dot{m}_f}_{\rho_f \dot{V}_f} (LHV)$

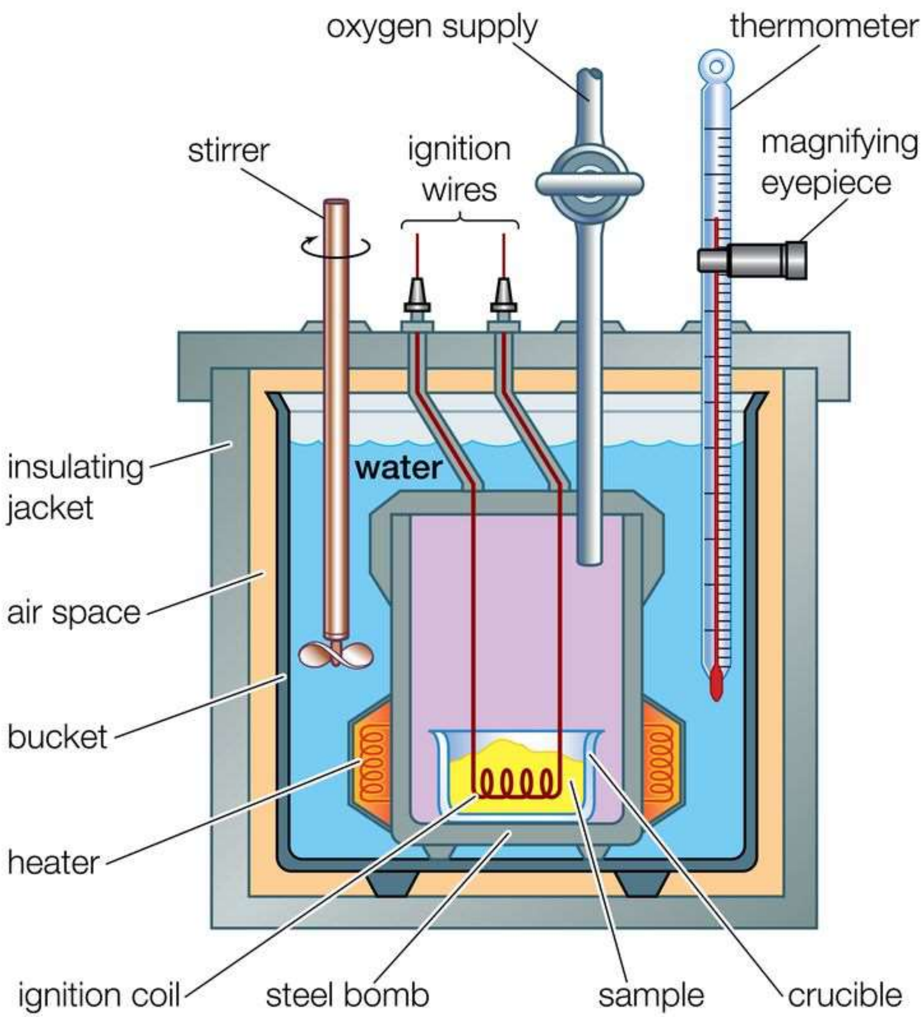
Lower heating value [MJ/kg]

$\underbrace{\rho_f \dot{V}_f}_{\rho_f \, \forall_f / \Delta t}$ → measured

property tables

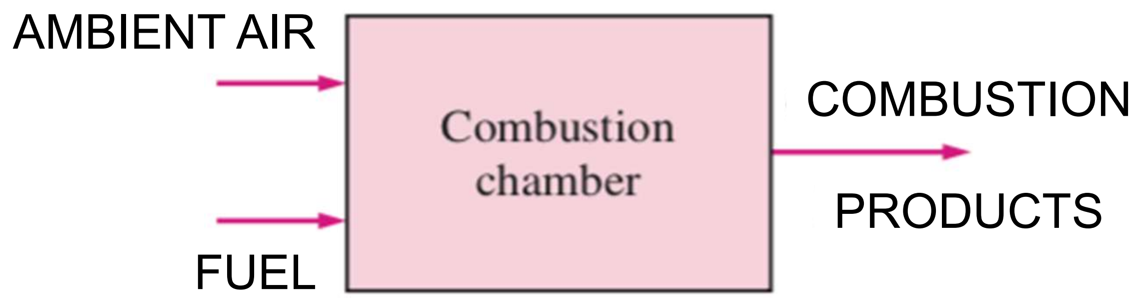
(91 octane gasoline)

Bomb Calorimeter

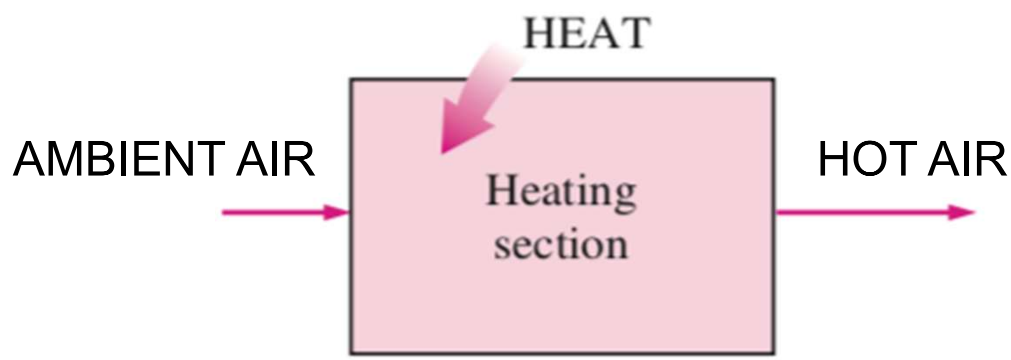


Ideal Thermodynamic Model

Actual:



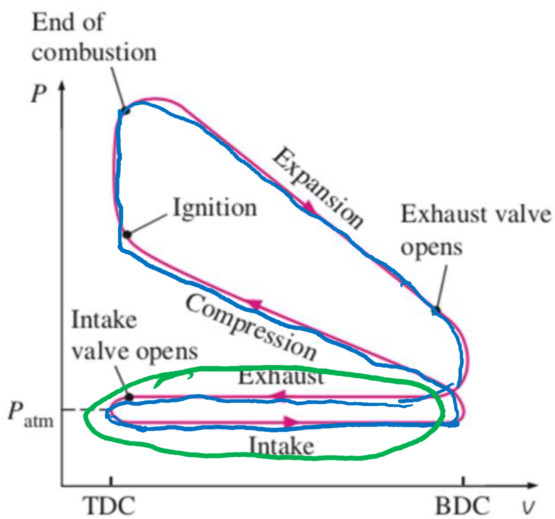
Ideal:

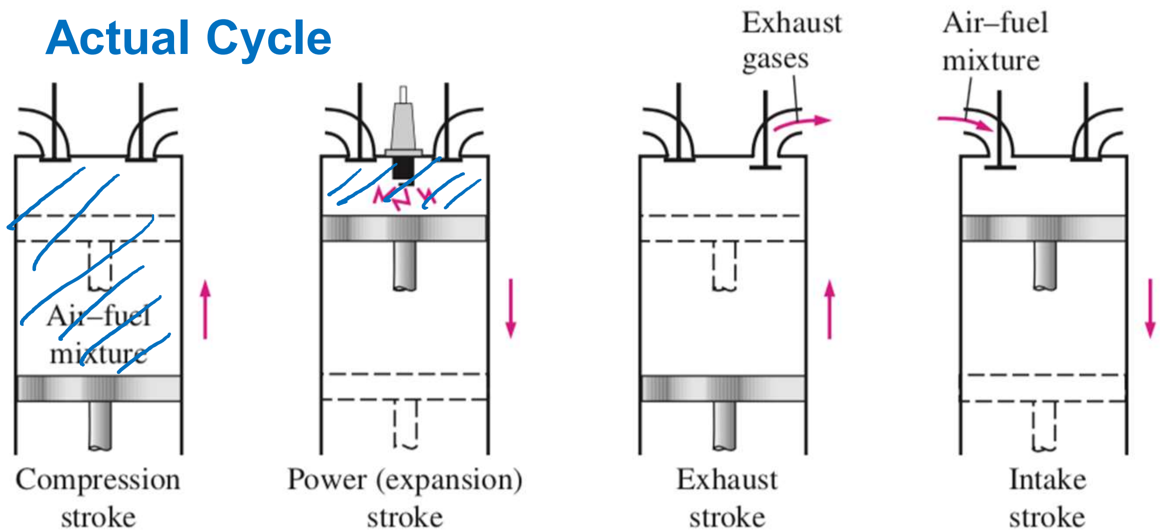


- air (ideal gas)
- processes are reversible
- combustion → heat addition
- exhaust → heat rejection

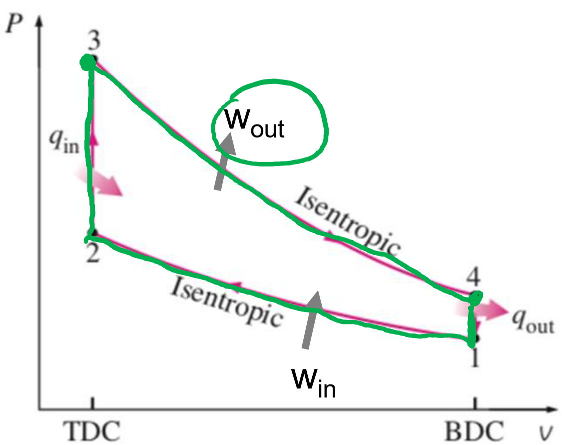
Thermodynamic Model

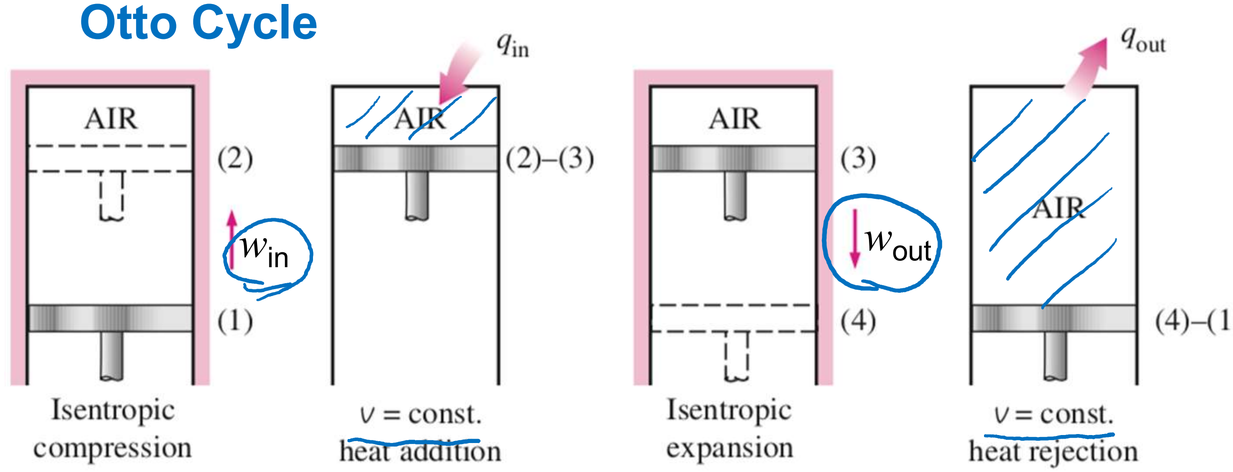
Actual Cycle





Otto Cycle





Ideal Thermal Efficiency and Power

Ideal Thermal Efficiency

$$\eta_{otto} = 1 - \frac{1}{r^{k-1}} \quad \text{where} \quad k = \frac{c_p}{c_v} = 1.4$$

standard-air

r ← compression ratio

Ideal Power

$$\underbrace{\dot{W}_{out} - \dot{W}_{in}}_{\dot{W}_{net}} = \underbrace{\dot{Q}_{in}}_{\dot{E}_{in}} - \underbrace{\dot{Q}_{out}}_{\text{constant-volume}}$$

$$\dot{W}_{net} = \dot{E}_{in} - \dot{m}_a (u_4 - u_1)$$

$$\dot{W}_{net} = \dot{E}_{in} - \dot{m}_a c_v (T_4 - T_1)$$

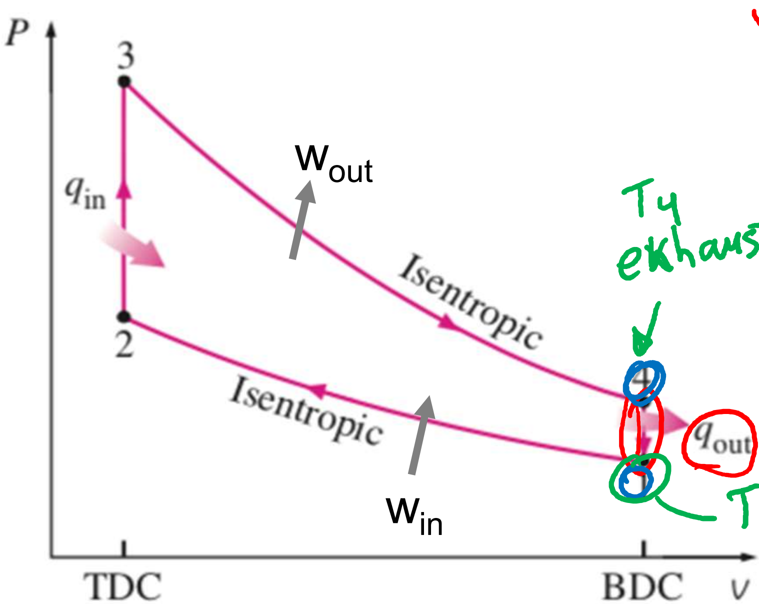
T_4, T_1: measured

c_v: @ standard air

$\dot{m}_a = \rho_a \dot{V}_a$

$\dot{V}_a$: measured

ρ_a: ideal gas law @ 1



T_4 exhaust

T_1 inlet

Questions??

Thank you for your attention!

Let me or the TAs know if you have questions