GMRC Engine Analyzer Workshop

San Antonio, Texas
July 2022

Balancing Slow Speed Reciprocating Engines

The Old and The New
July 2022

RCT
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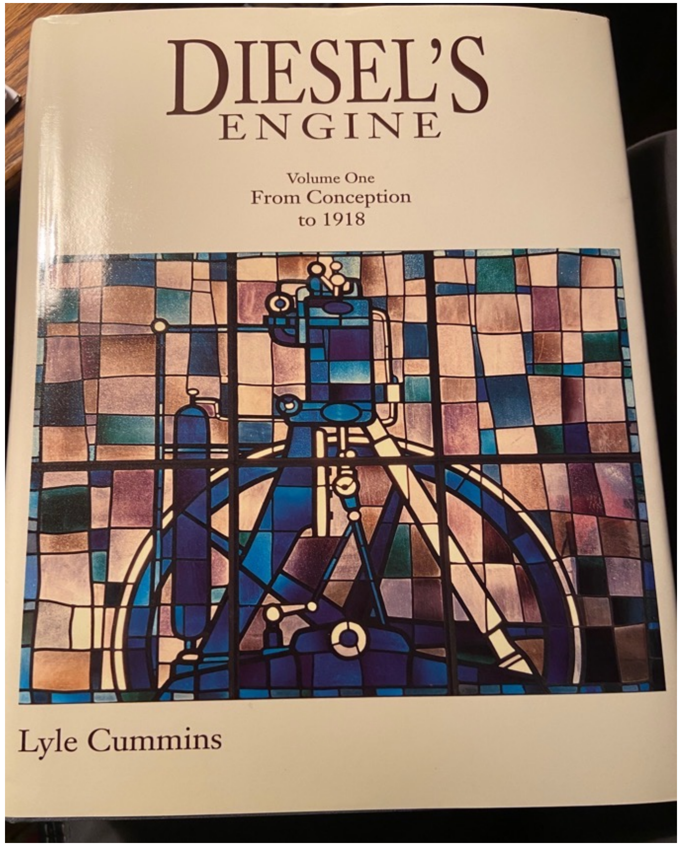
To begin my presentation,
I would like to review how we got where we are!!



Historical Balancing Methods

Great Book!!

Historical Balancing Method

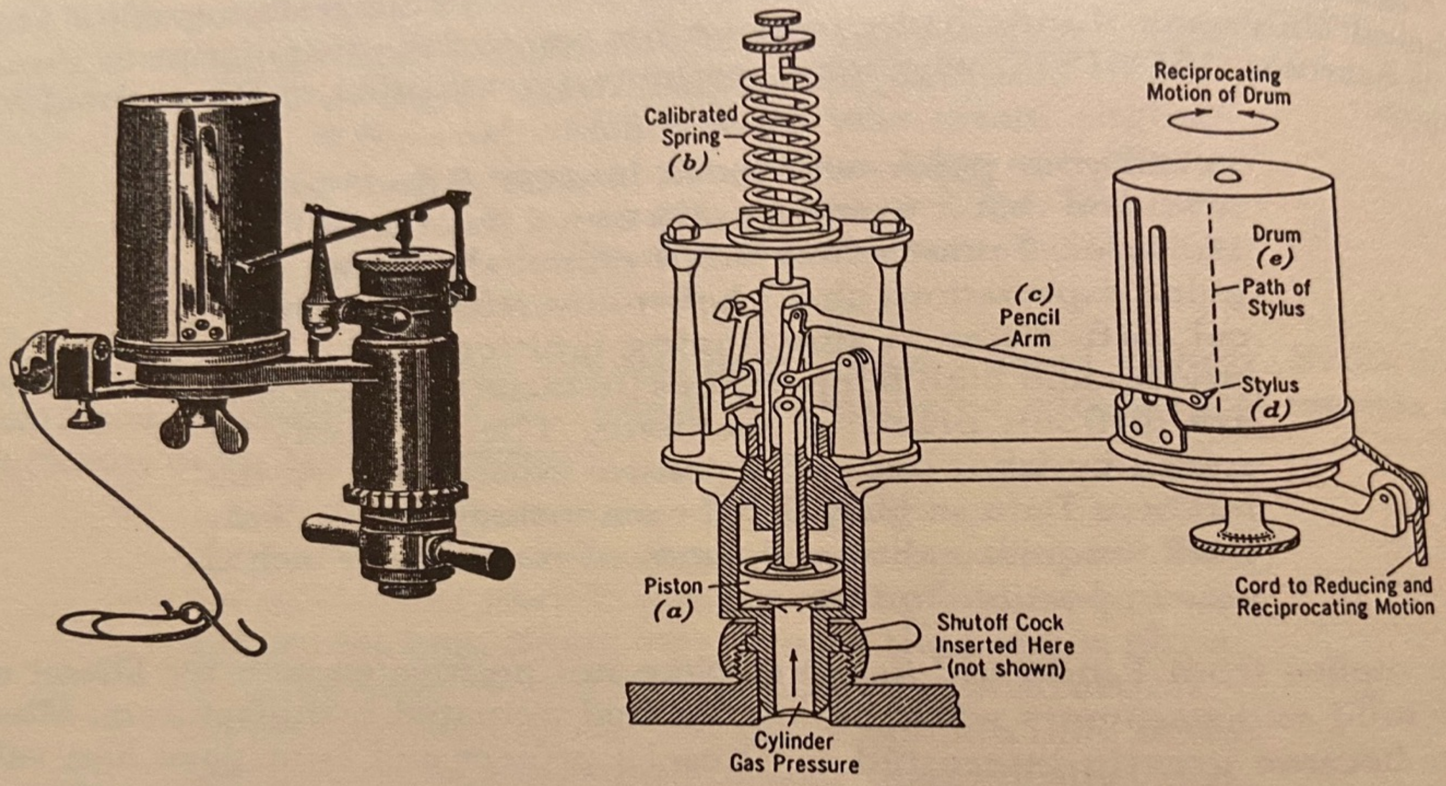
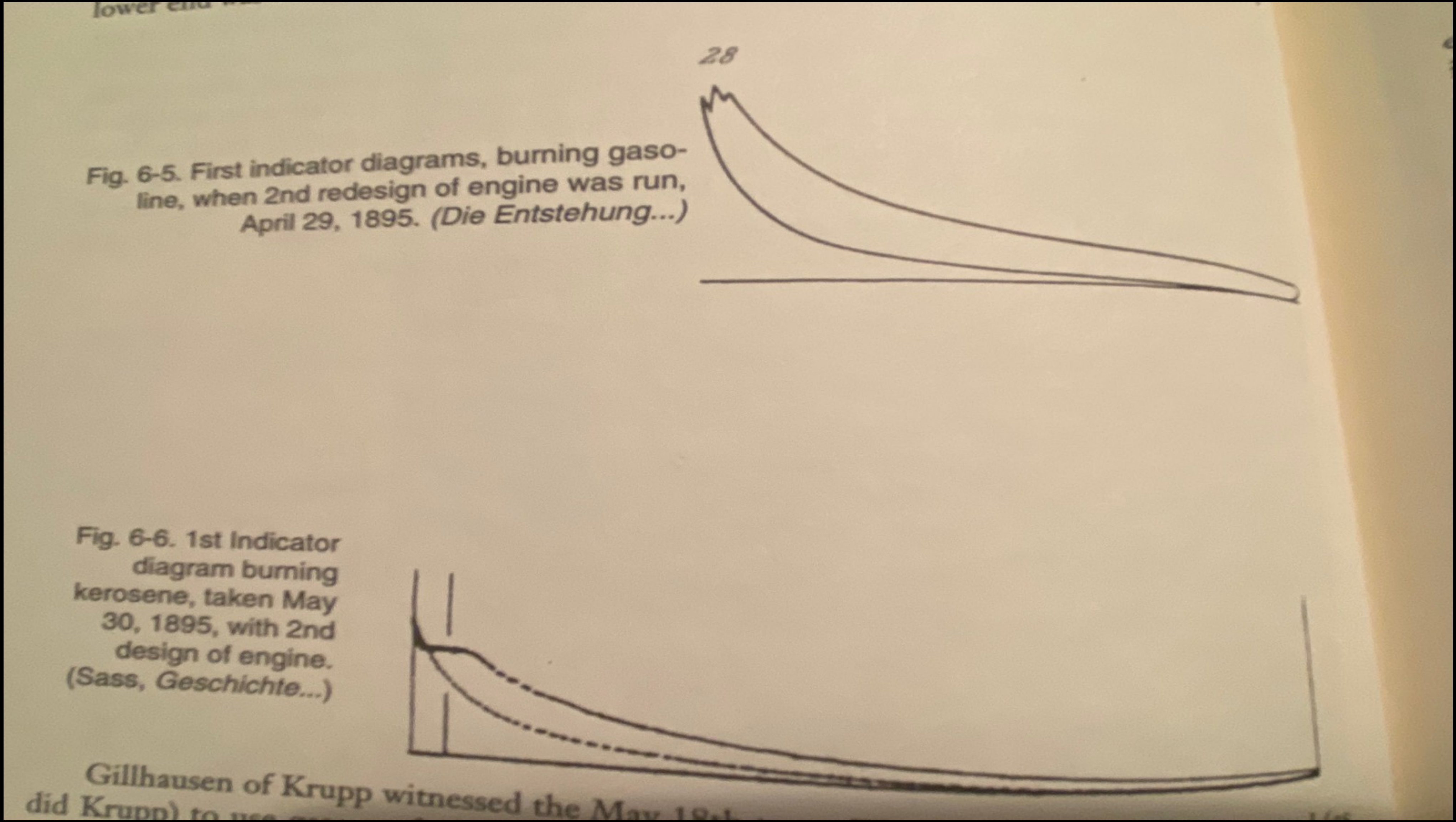


Fig. 3–4. Indicator for making a P–V diagram (indicator card). A pressure trace is made on paper wound on the drum as piston movement turns the drum. This provided a record of the cylinder pressure at each point in the piston stroke. (*Hawkins' Indicator Catechism*, 1903)

worry about how to “fatten” his diagram.

The first traces from the device when Rudolf Diesel first ran his engine in 1895!!

First traces from Rudolf Diesel, 1895



lower end

Fig. 6-5. First indicator diagrams, burning gasoline, when 2nd redesign of engine was run, April 29, 1895. *(Die Entstehung...)*

Fig. 6-6. 1st Indicator diagram burning kerosene, taken May 30, 1895, with 2nd design of engine. (Sass, *Geschichte...*)

Gillhausen of Krupp witnessed the May

did Krupp) to use

Leutert MSI-3 EPPI

(Circa 1940)

Electronics Evolve

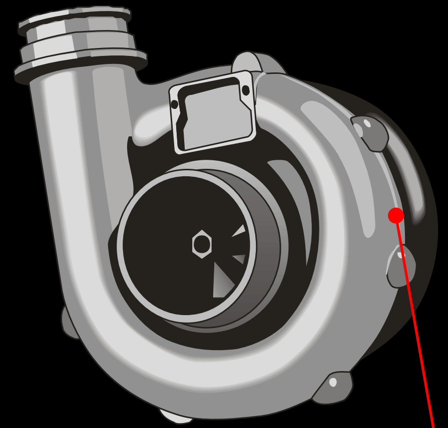
Beta-Trap
Windrock 6310 CA
Windrock Autobalance™
MMS Snapshot®
Hoerbiger/Cooper Hyperbalance III™
MMS ProBalance® / ProBalance® Plus

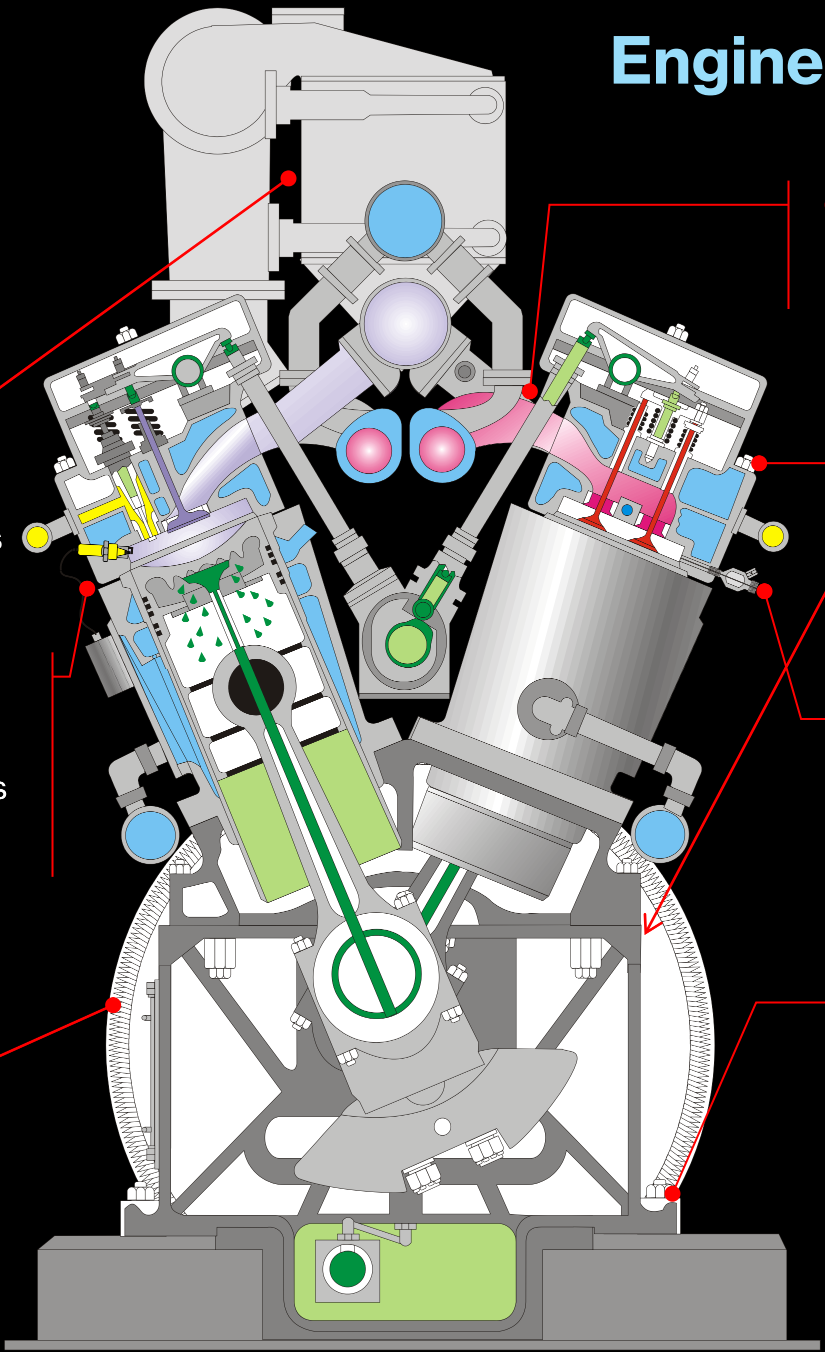
Safety

Always complete a Job Safety Analysis (JSA) before entering the work area. It should include but not be limited to:

- Hazardous atmosphere
- Toxic chemicals
- Flammable gases and liquids
- Low headroom
- Slips, trips, or fall hazards
- Extreme surface temperatures
- High pressures
- Pinch points, rotating parts
- Overexertion
- Poor visibility, weather, noise
- Required PPE condition

Engine Data Collection





Turbocharger/blower
- Standard accelerometer mounted on bearings and near turbine and compressor wheels
- Frequency domain vibration

Ignition secondary
- Capacitive connection to unshielded spark plug cable
- Multi-cycle sampling statistics
- Ignition secondary patterns

Ignition primary (not shown)
- Connection to primary box
- Ignition primary firing patterns

TDC Reference
- Shaft encoder
- Magnetic pickup
- Phased data
- RPM

Cylinder exhaust temperatures
- Infrared temperature wand
- pyrometer

Cylinder, valve, wrist pin and bearing vibration
- Ultrasonic microphone
- Standard accelerometer
- Time domain data phased to crankshaft position

Cylinder pressure
- Pressure transducer
- Time domain data phased to crankshaft position
- Peak pressure statistics

Frame vibration (displacement)
- H, V, A taken at various locations on engine frame
- Both Time & Frequency domain data

Engine Concerns

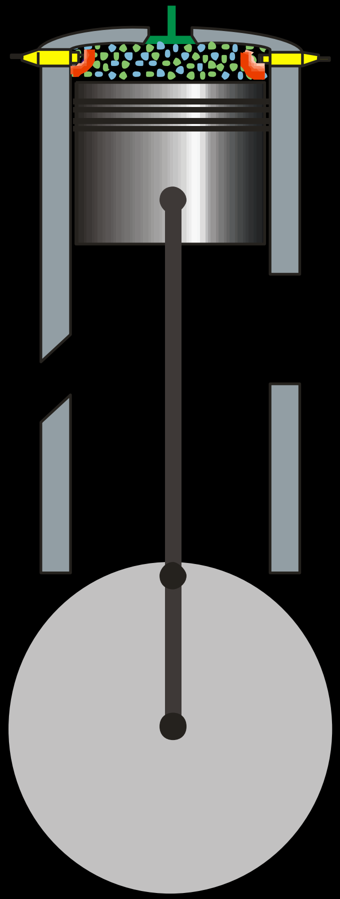
- Ignition
- Fuel
- Combustion
- Mechanical condition
- Lubrication
- Cooling

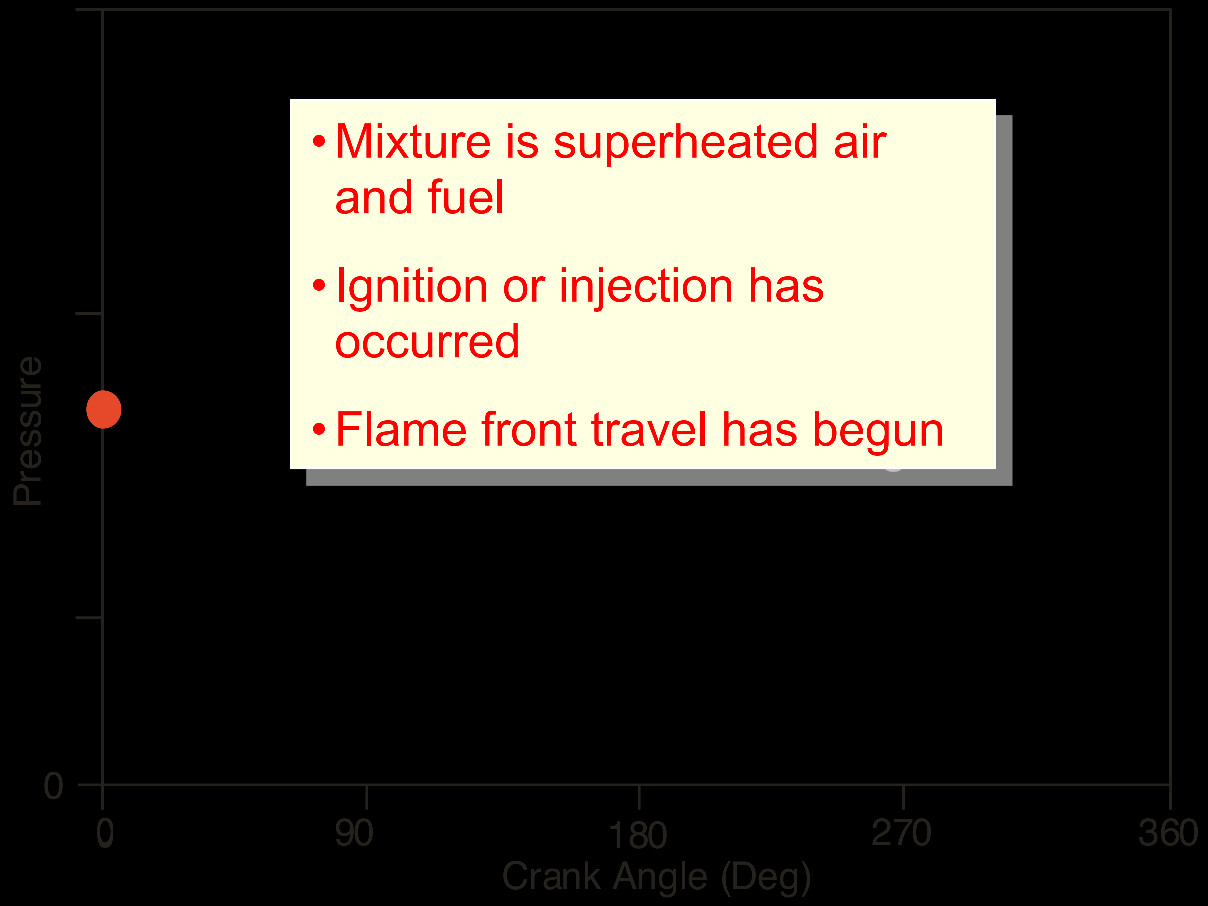
The Two-Stroke Engine

- The complete combustion cycle (compression, power, exhaust and intake) is accomplished in one revolution of the crankshaft
- Portions of both the intake and exhaust processes (scavenging) are accomplished at the end of the power stroke and the beginning of the compression stroke
- The fuel valve cam is driven at engine speed
- Can not be naturally aspirated

Sequence of events for a 2-stroke engine

PT: start of cycle

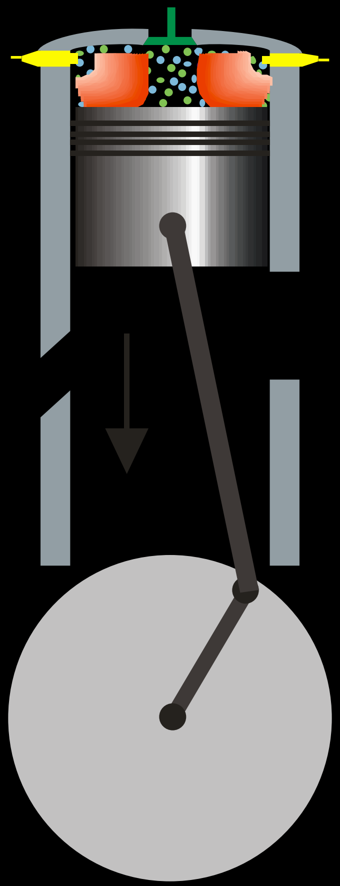


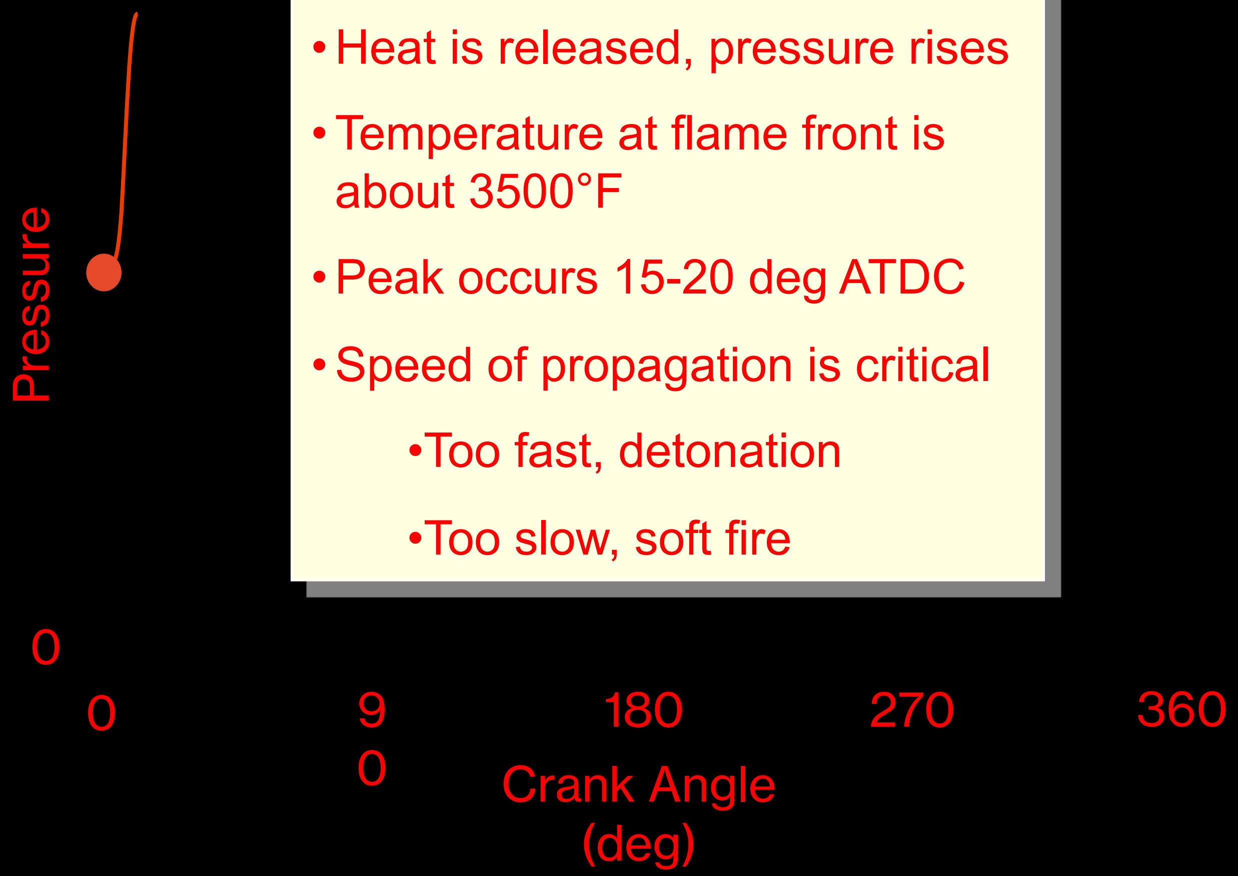


- Mixture is superheated air and fuel
- Ignition or injection has occurred
- Flame front travel has begun

Sequence of events for a 2-stroke engine

PT: combustion

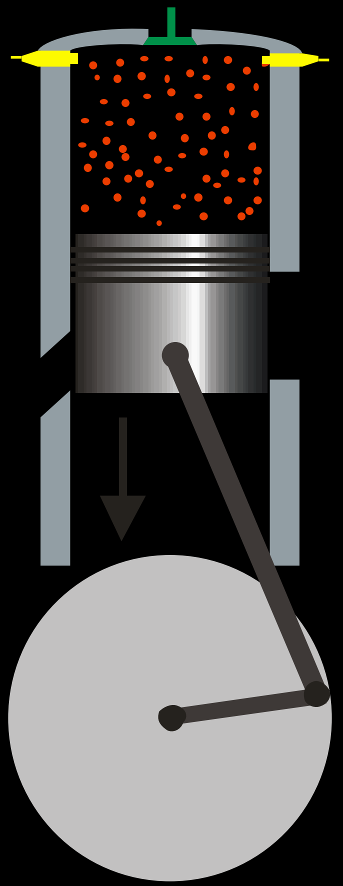


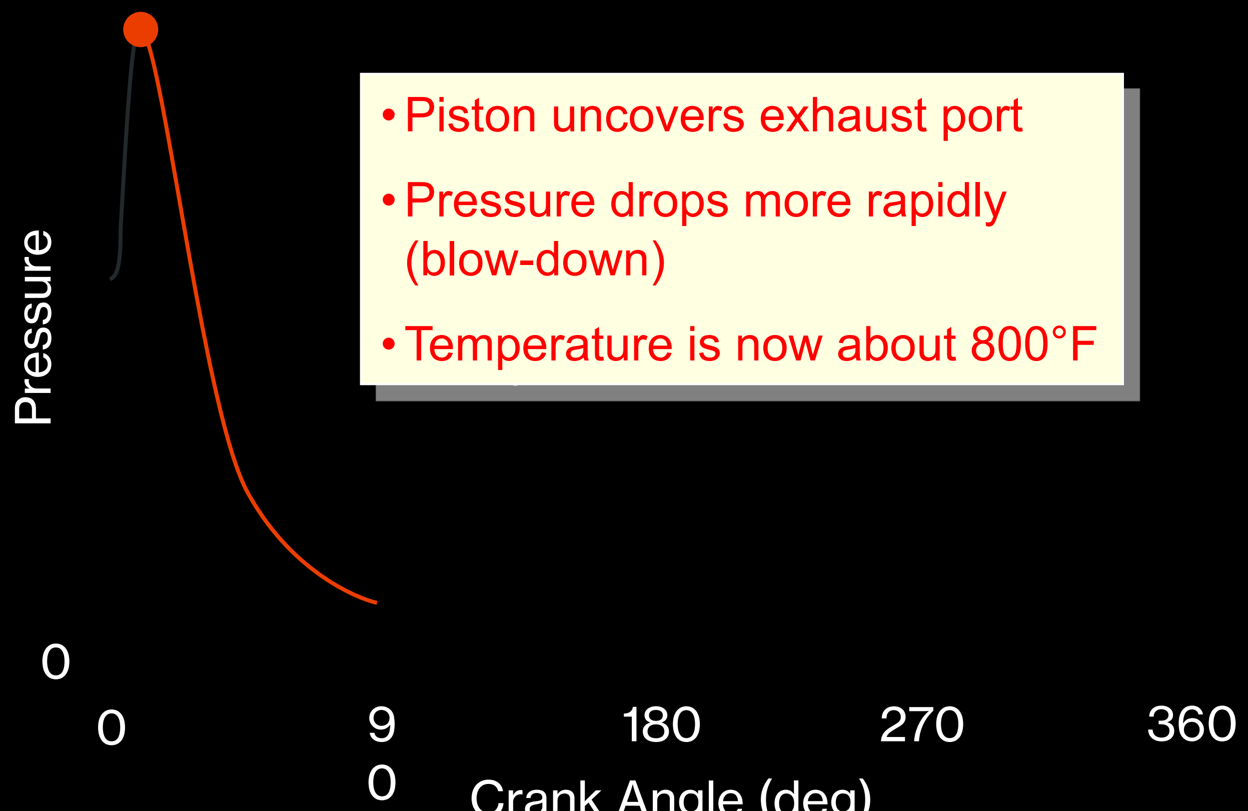


- Flame travels through chamber
- Heat is released, pressure rises
- Temperature at flame front is about 3500°F
- Peak occurs 15-20 deg ATDC
- Speed of propagation is critical
    - Too fast, detonation
    - Too slow, soft fire

Sequence of events for a 2-stroke engine

PT: power

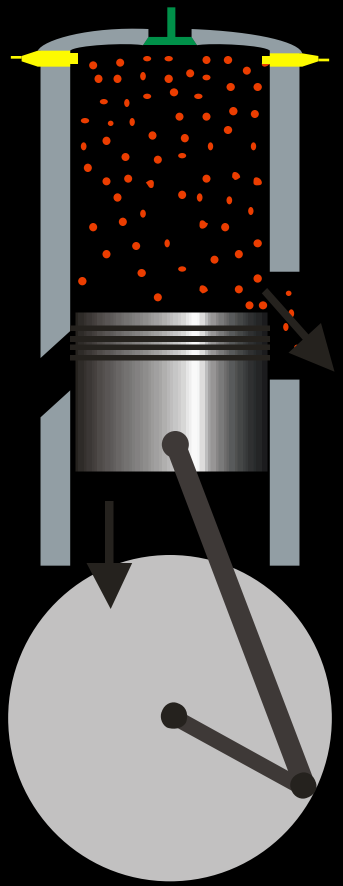


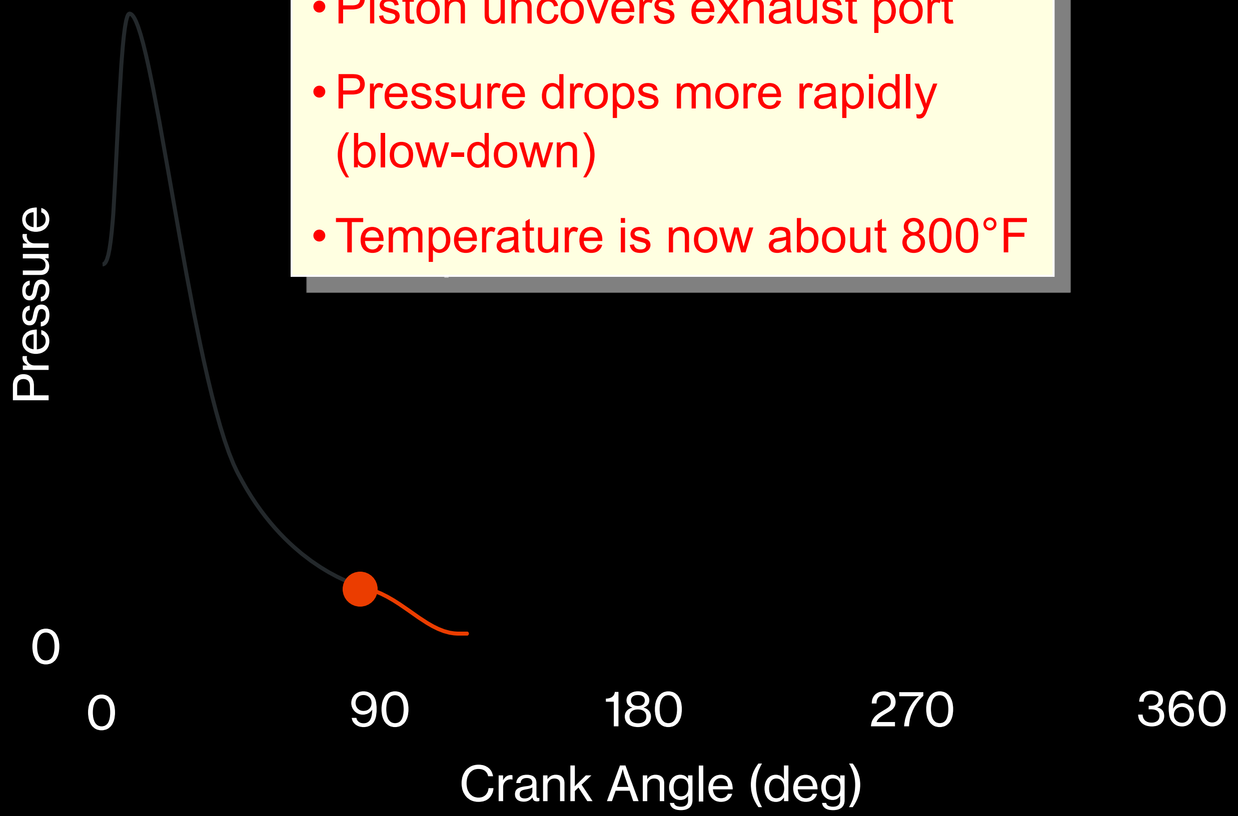


- Piston uncovers exhaust port
- Pressure drops more rapidly (blow-down)
- Temperature is now about 800°F

Sequence of events for a 2-stroke engine

PT: exhaust blowdown

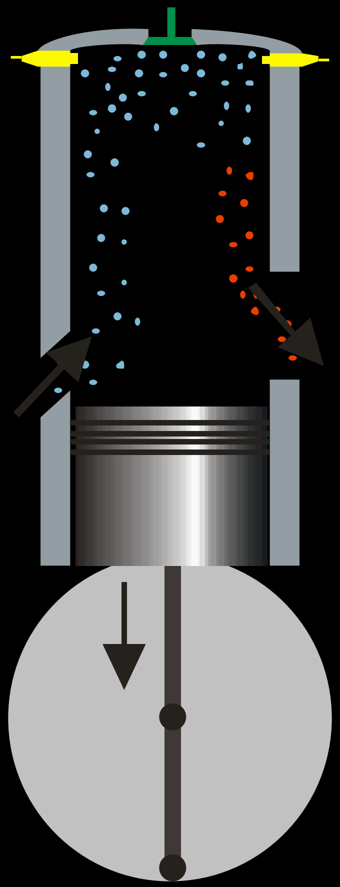


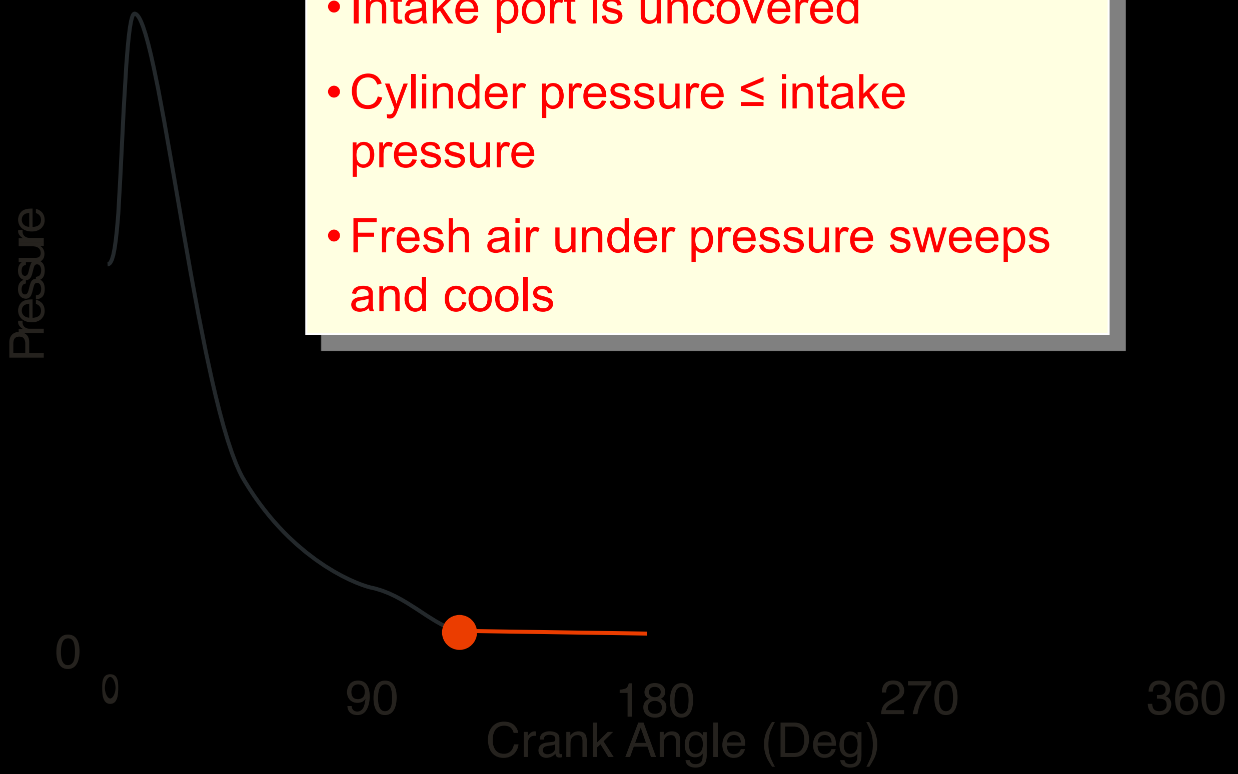


- Piston uncovers exhaust port
- Pressure drops more rapidly (blow-down)
- Temperature is now about 800°F

Sequence of events for a 2-stroke engine

PT: air intake

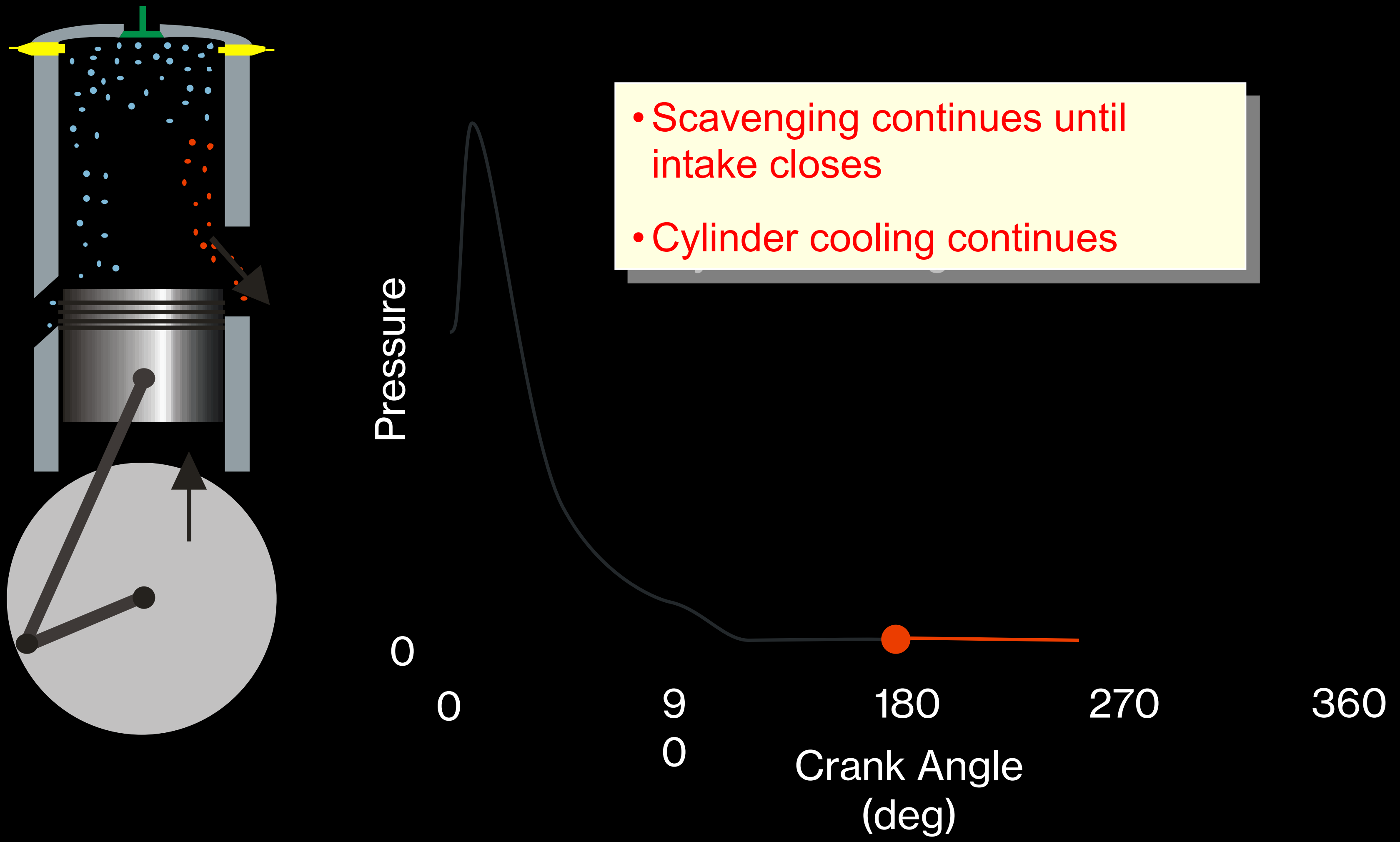




- Intake port is uncovered
- Cylinder pressure ≤ intake pressure
- Fresh air under pressure sweeps and cools

Sequence of events for a 2-stroke engine

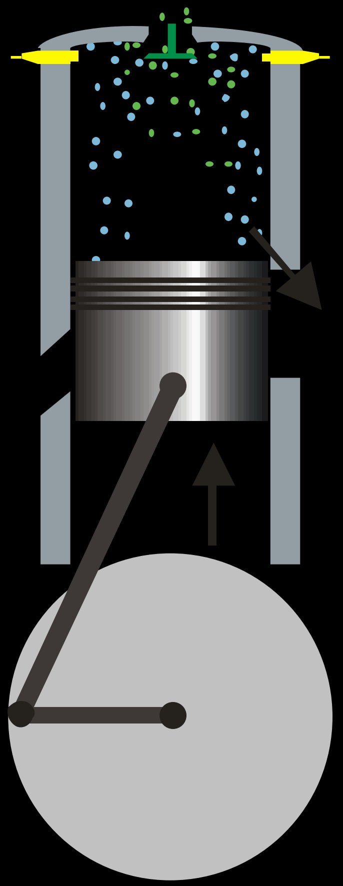
PT: scavenging

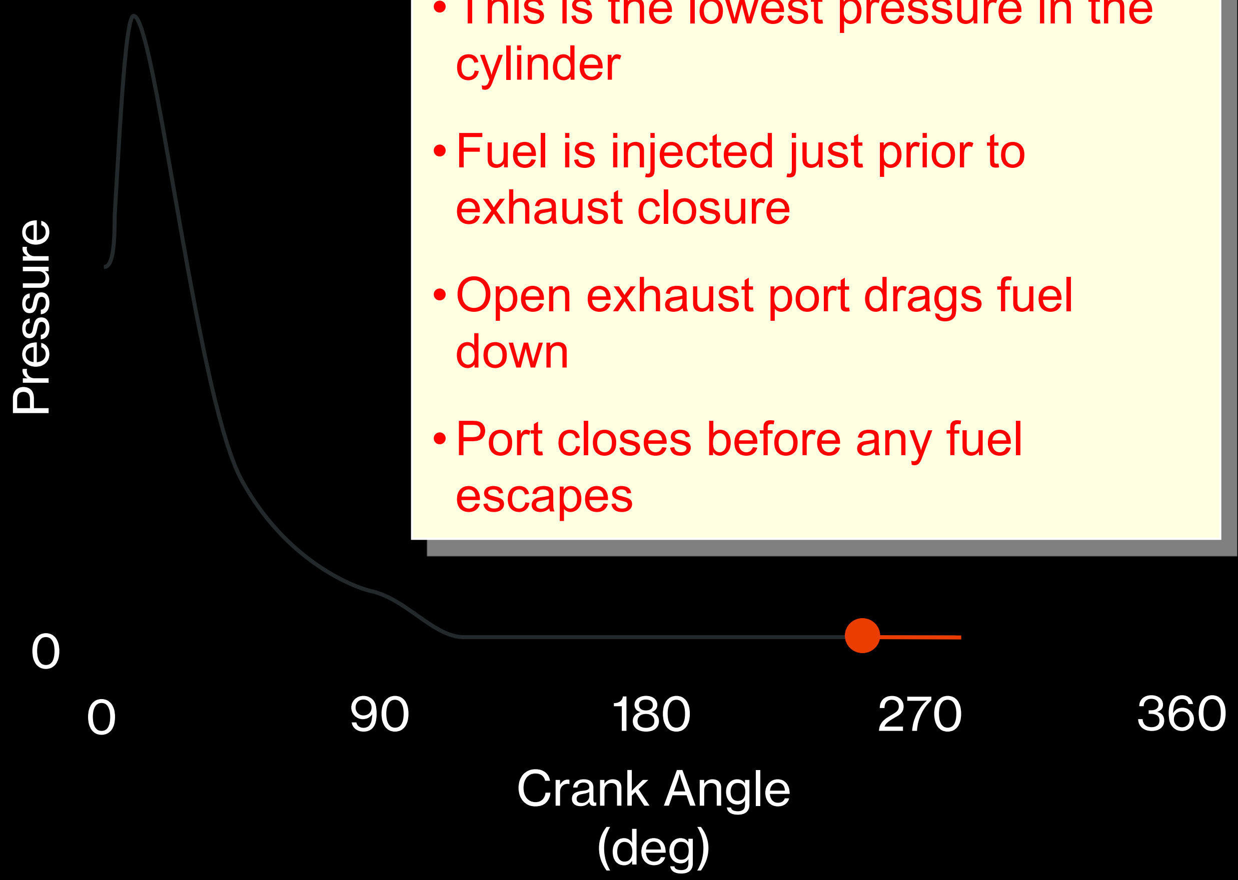


- Scavenging continues until intake closes
- Cylinder cooling continues

Sequence of events for a 2-stroke engine

PT: fuel intake

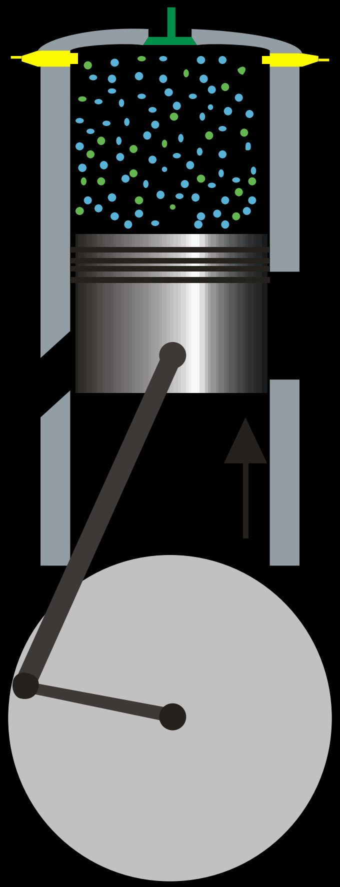


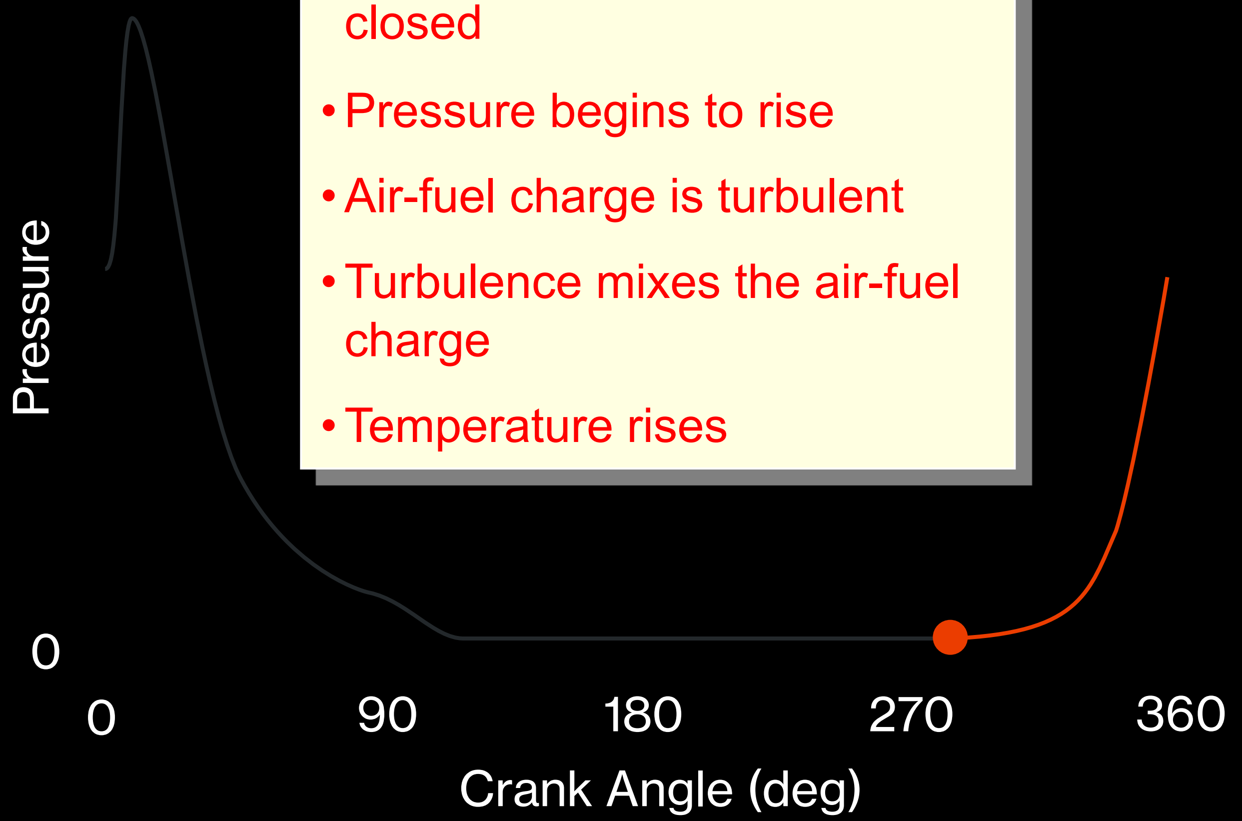


- Scavenging continues until intake closes
- This is the lowest pressure in the cylinder
- Fuel is injected just prior to exhaust closure
- Open exhaust port drags fuel down
- Port closes before any fuel escapes

Sequence of events for a 2-stroke engine

PT: compression

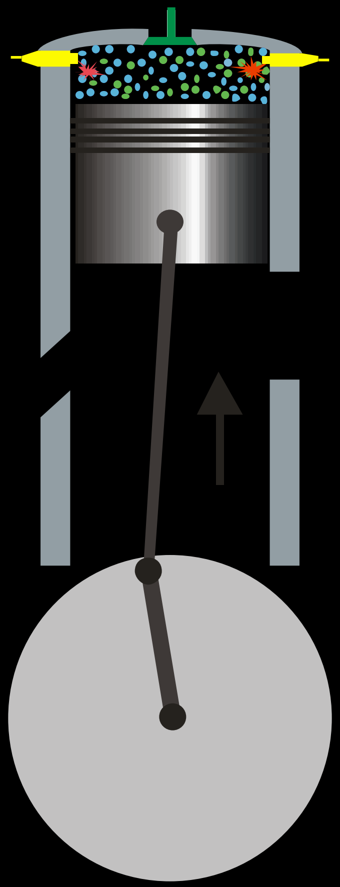




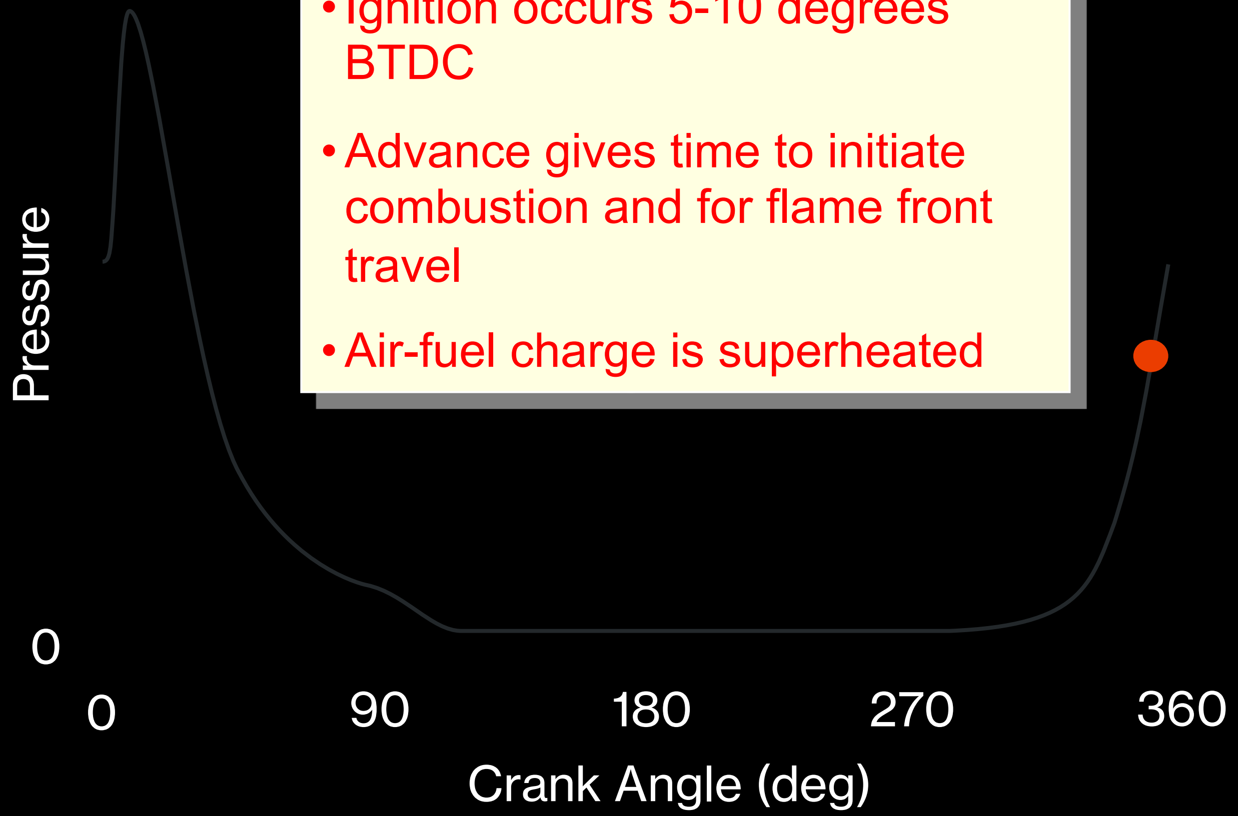
- Fuel valve closes, ports are closed
- Pressure begins to rise
- Air-fuel charge is turbulent
- Turbulence mixes the air-fuel charge
- Temperature rises

Sequence of events for a 2-stroke engine

PT: ignition

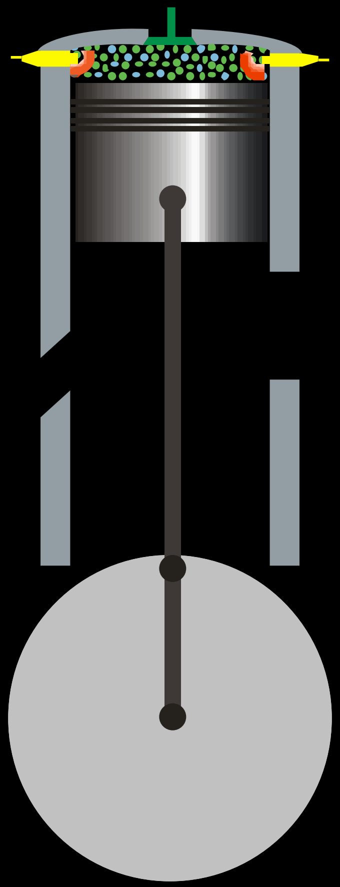


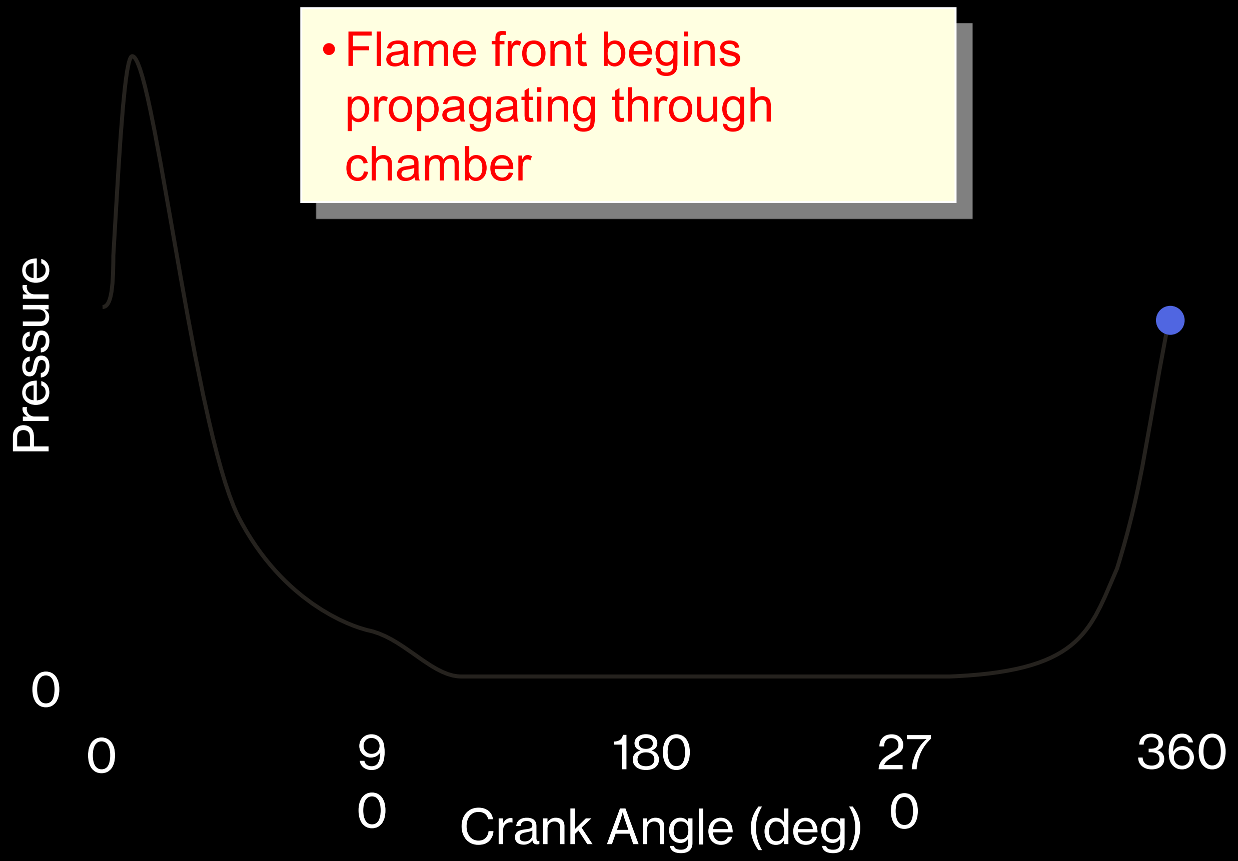
- Ignition occurs 5-10 degrees BTDC
- Advance gives time to initiate combustion and for flame front travel
- Air-fuel charge is superheated



Sequence of events for a 2-stroke engine

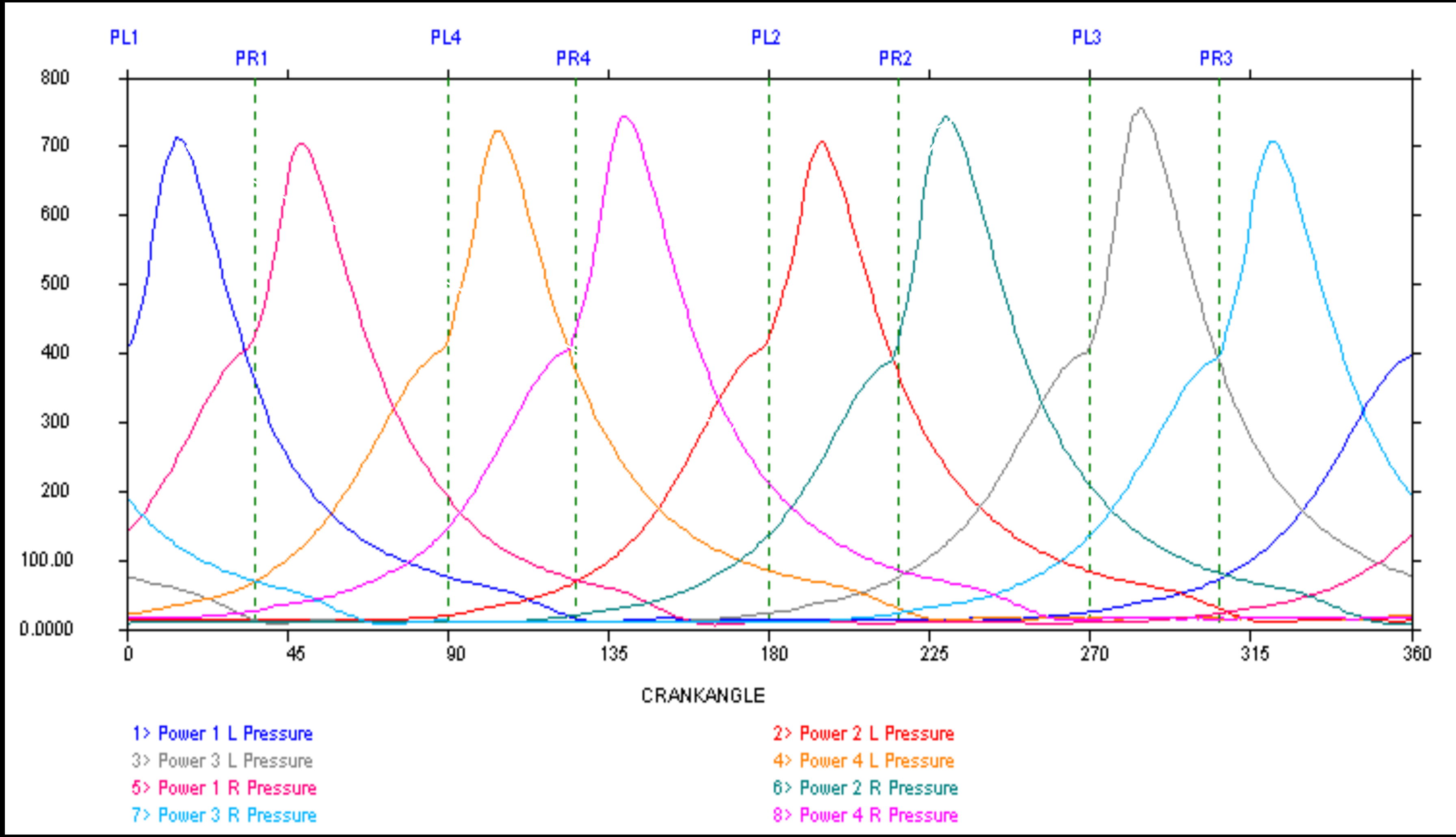
PT: end of cycle



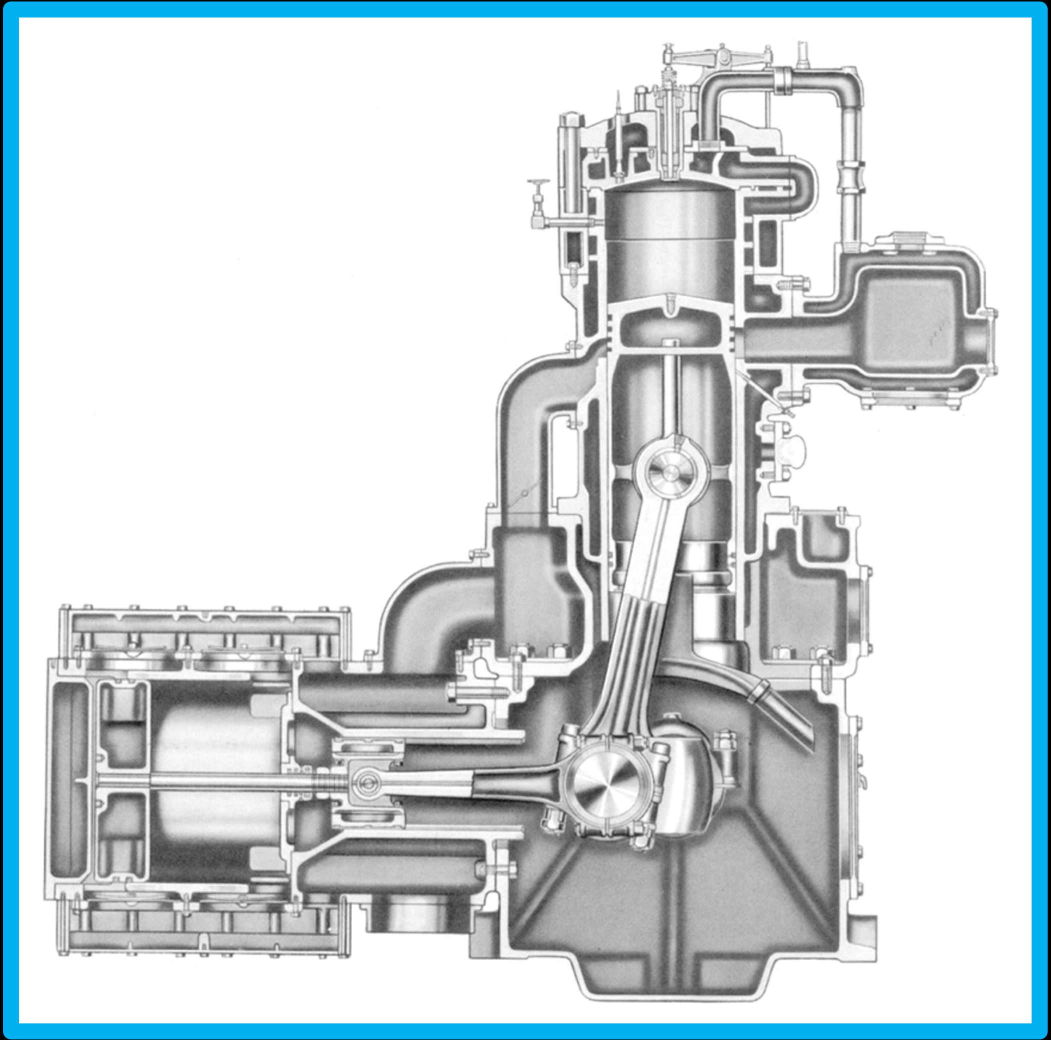


2-Stroke Pressure Parade

Averaged Pressure Trace



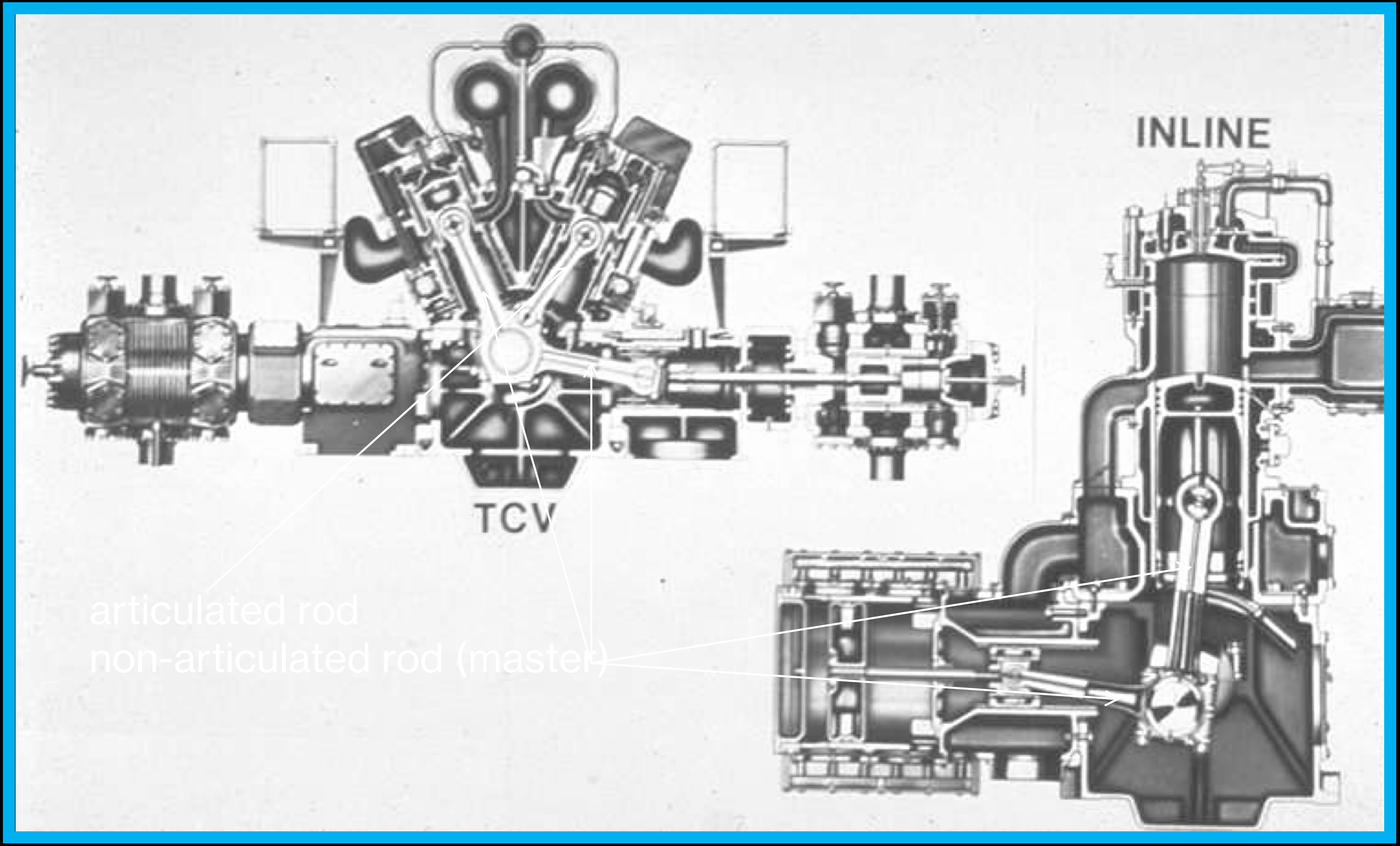
2 Stroke Scavenged Engine



Dresser-Rand (Clark) RA, 2stroke integral gas engine & compressor with non-articulated power connecting rods

Integral types have a common crankshaft shared between the power cylinders and compressor cylinders.

2 Stroke Integral (Vee & Inline)



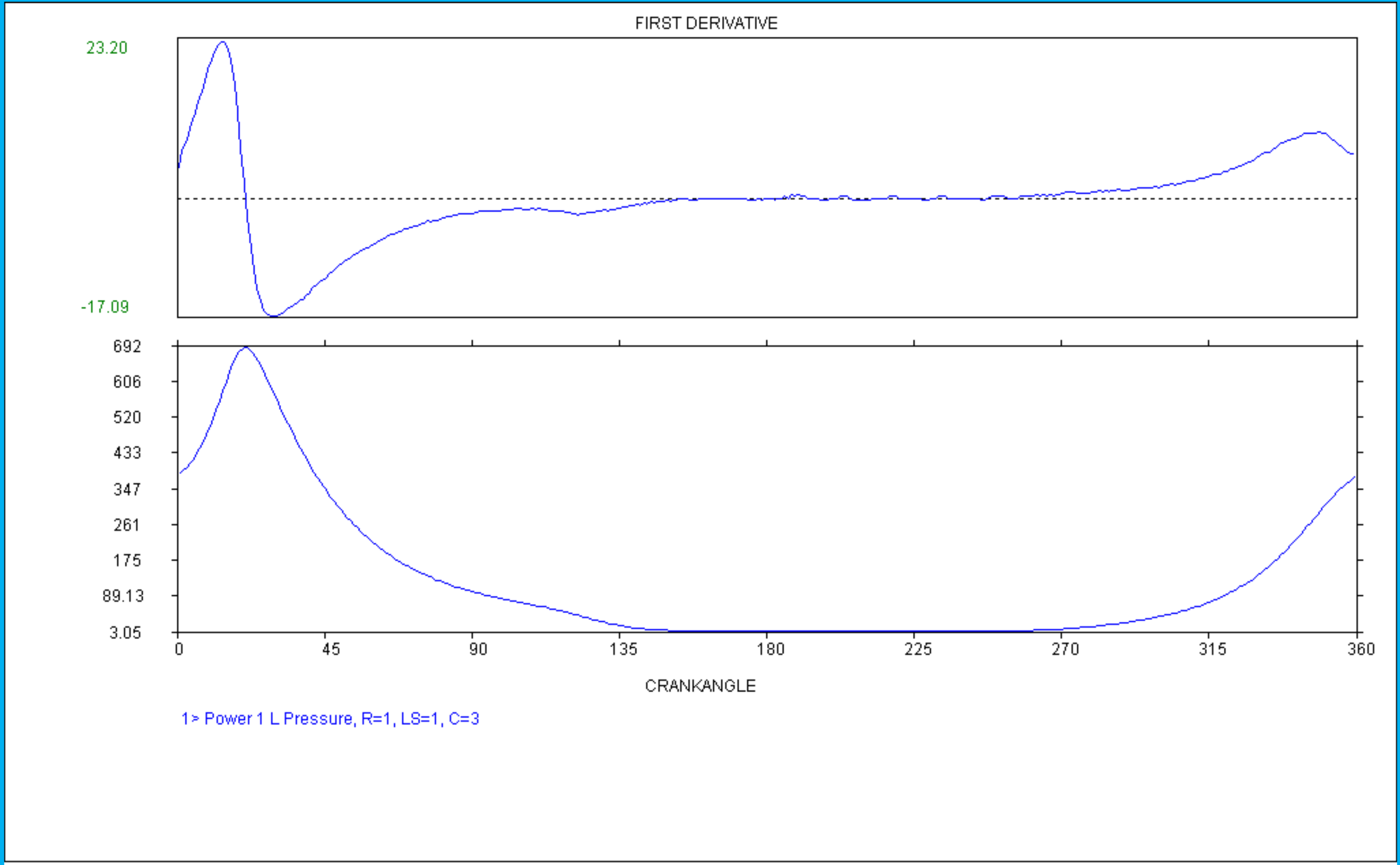
Combustion Types (2 & 4 Stroke)

- Normal
- No Ignition
- Early Ignition
- Late Ignition
- Detonation
- Pre-ignition
- Intermittent Firing

Normal Combustion Requirements

- Correct amount of fuel with the proper BTU
- The right amount of air at the right pressure and temperature to control the combustion rate
- Proper amount of ignition energy at the right degree of crankshaft rotation

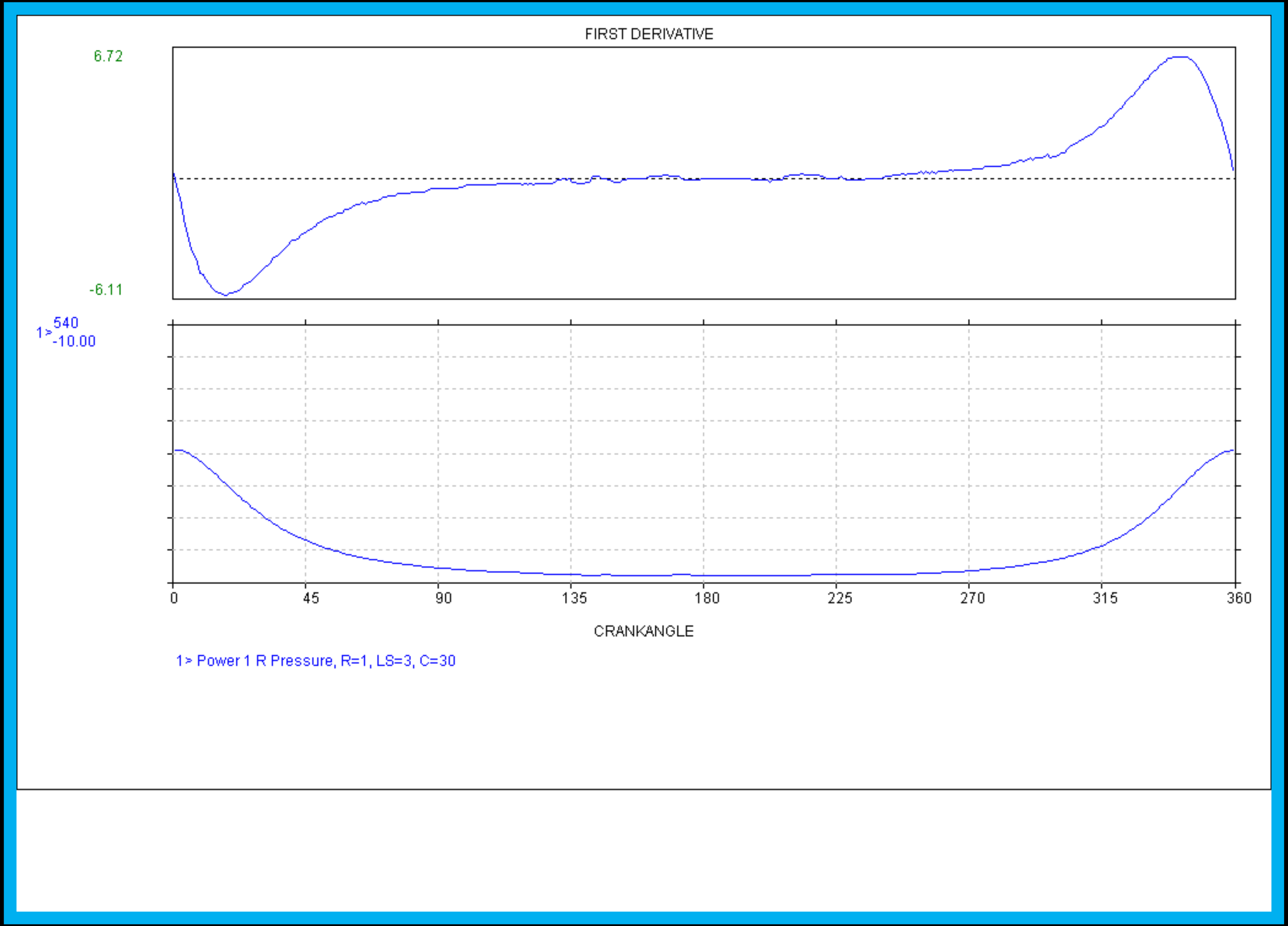
Normal Combustion



No Combustion

- The air/fuel charge does not ignite and there is no pressure rise except from the compression process
- Negative horsepower results due to pumping losses
- Caused by problems with air, fuel, foreign material or defective ignition

No Combustion



Electronics Evolve

- Beta-Trap
- Windrock 6310 CA
- Windrock Autobalance™
- MMS Snapshot®
- Hoerbiger/Cooper Hyperbalance III™
- MMS ProBalance® / ProBalance® Plus

Balancing Methods

Peak Firing Pressure Balancing

- **Peak Firing Pressure (PFP)** is the most common balancing method – probably due to the history of balancing – it was easy to measure.

- It is accomplished by measuring the firing pressures of all the cylinders, calculating the mean of those pressures, and adjusting the firing pressures as close to that mean pressure as possible.

Peak Pressure Ratio Balancing

- **Peak Pressure Ratio (PPR)** is a method suggested in EPPL / SWRI / DOE study in 2008. In this method, the PFP and the unfired Compression Pressure (Cp) of each cylinder is measured.

- The compression pressure is an indication of how much air is trapped in the cylinder. Since we cannot change that, by inputting the proper amount of fuel into each cylinder, we can control the equivalence ratio, which influences the combustion process.

Peak Pressure Ratio Balancing

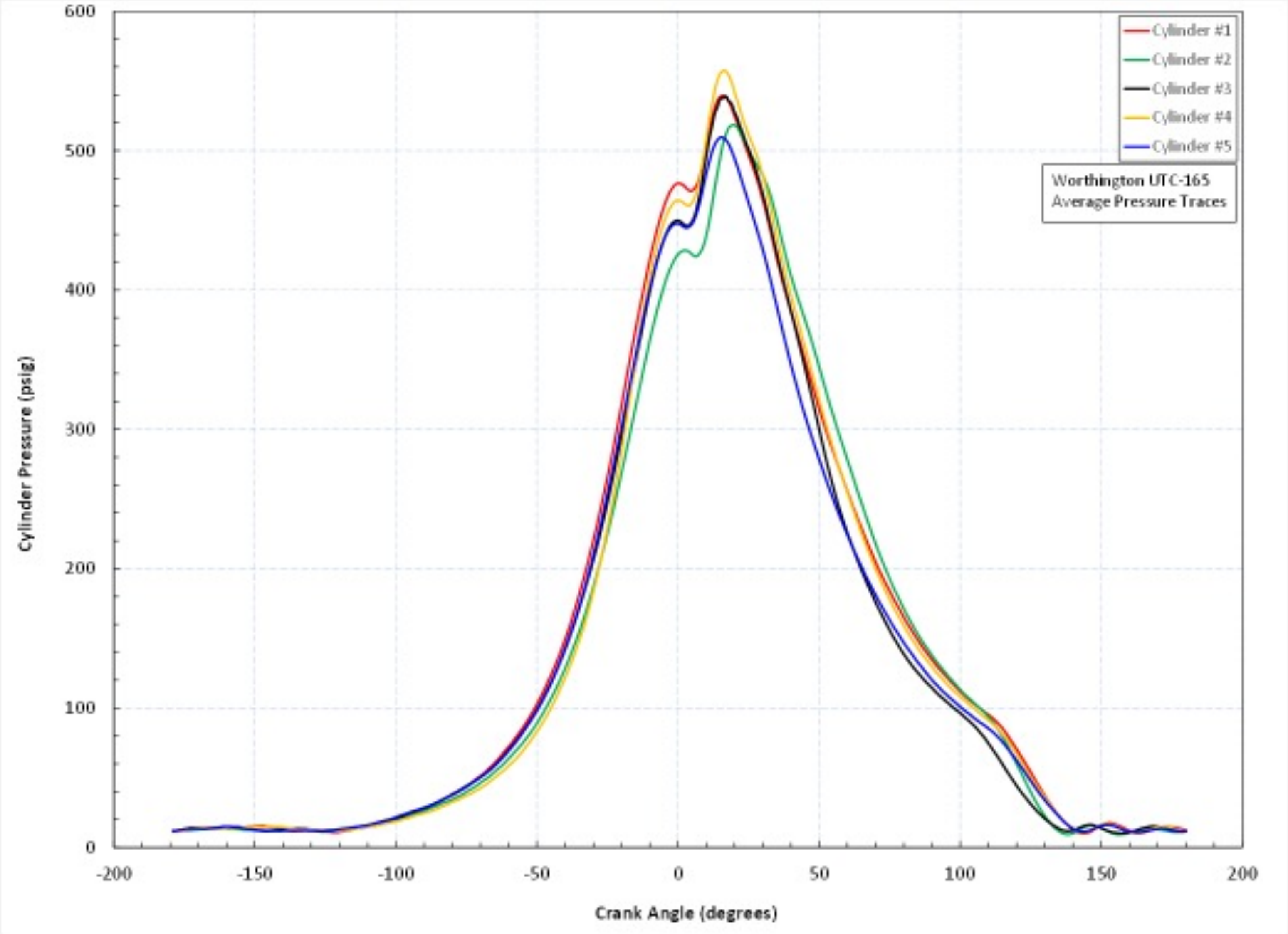
- The PFP is divided by the Cp establishing the PPR.

$$PPR = PFP \div Cp$$

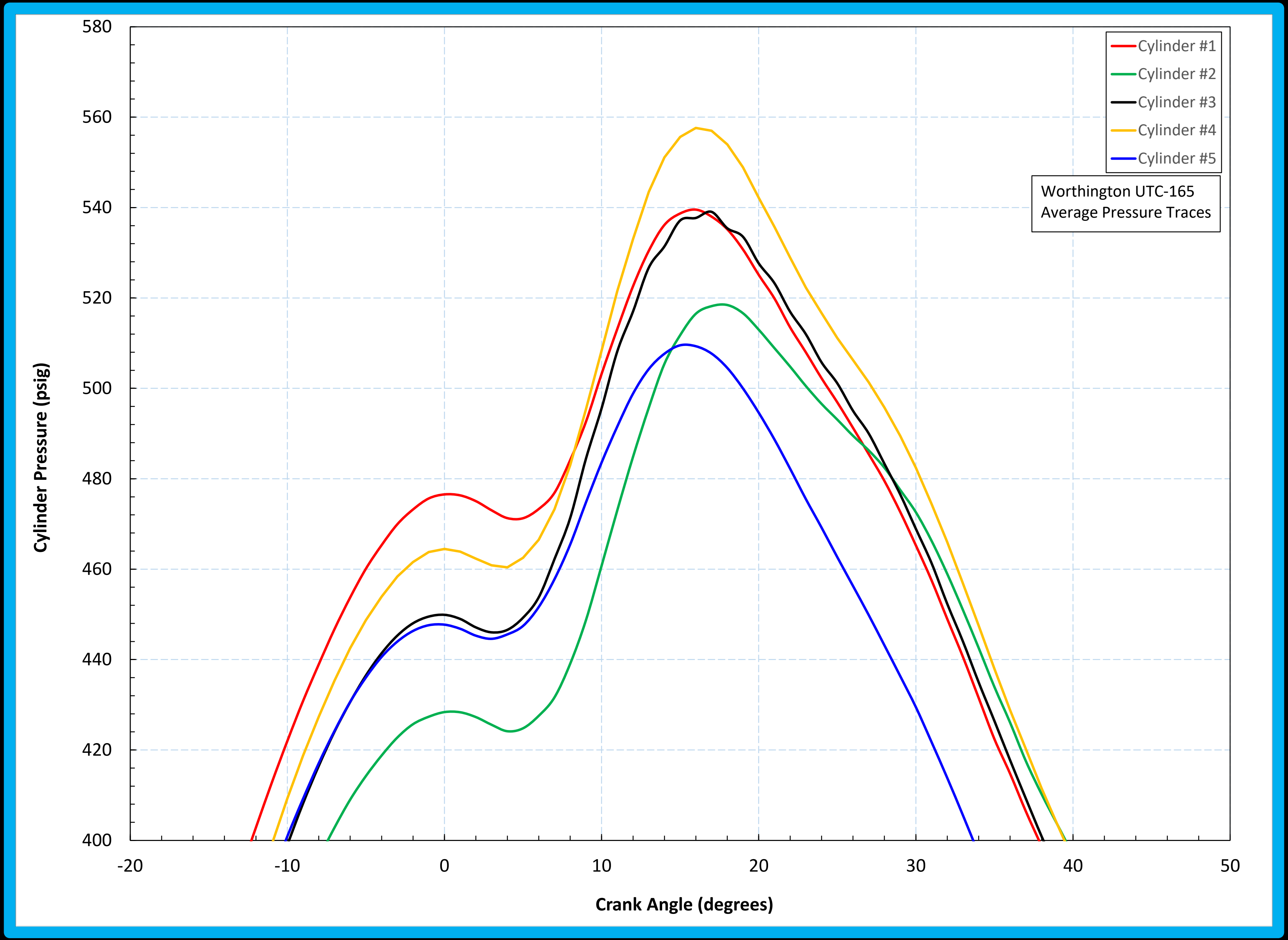
- Multiplying the Average PPR by the individual cylinder Cp's generates the target PFP for that cylinder.

- Research has proven that utilization of the PPR method reduces NOx, COV's and associated crankshaft stresses induced by rapid variations in angular velocities imparted by unbalance and misfires*.

*FINAL REPORT
SwRI® Project No. 18.06223
DOE Award No. DE-FC26-02NT41646

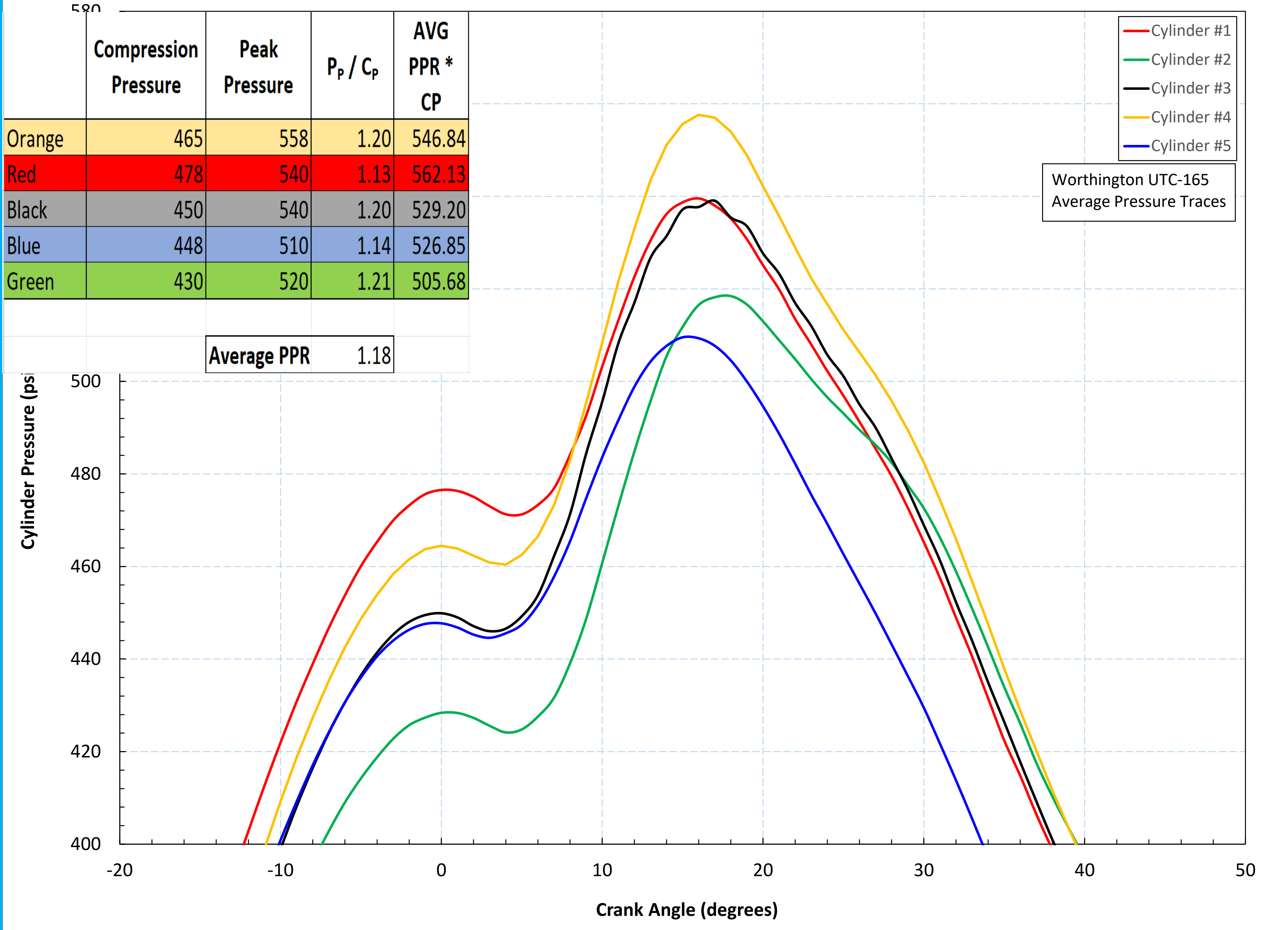


Cylinder #1
Cylinder #2
Cylinder #3
Cylinder #4
Cylinder #5
Worthington UTC-165
Average Pressure Traces
Cylinder Pressure (psig)
600
500
400
300
200
100
0
-200
-150
-100
-50
0
50
100
150
200
Crank Angle (degrees)

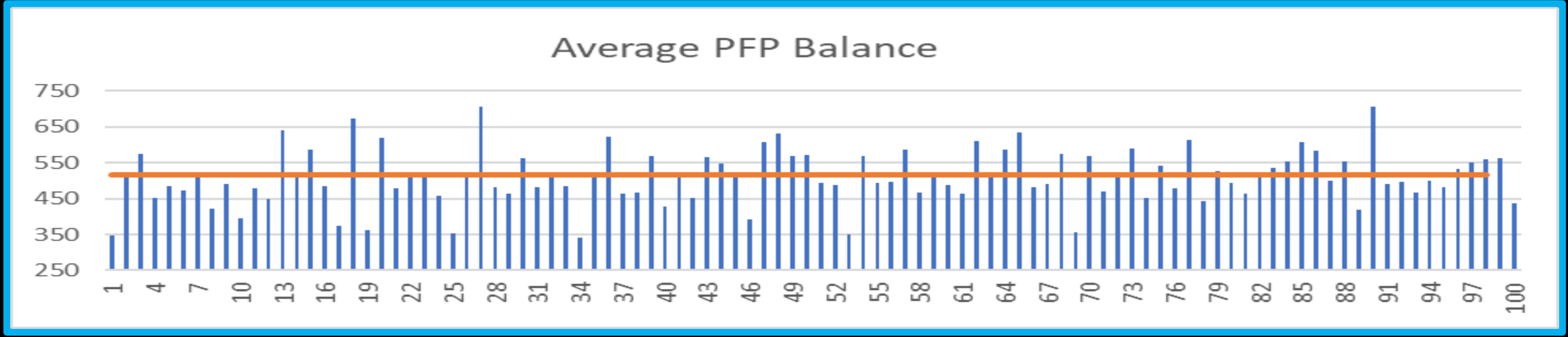

Cylinder #1
Cylinder #2
Cylinder #3
Cylinder #4
Cylinder #5
Worthington UTC-165
Average Pressure Traces
Cylinder Pressure (psig)
580
560
540
520
500
480
460
440
420
400
-20
-10
0
10
20
30
40
50
Crank Angle (degrees)

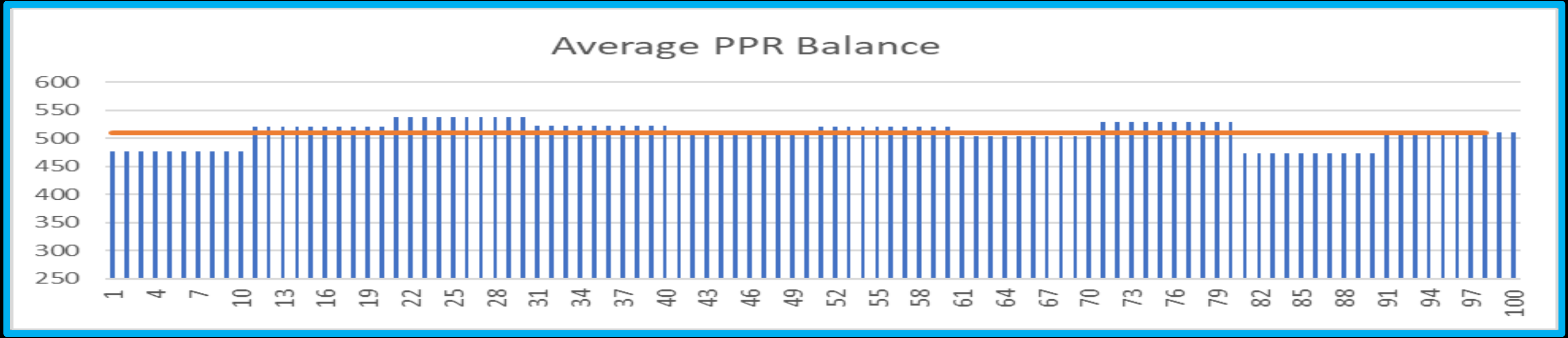
	Compression Pressure	Peak Pressure	P_P / C_P	AVG PPR * CP
Orange	465	558	1.20	546.84
Red	478	540	1.13	562.13
Black	450	540	1.20	529.20
Blue	448	510	1.14	526.85
Green	430	520	1.21	505.68

Average PPR	1.18



PFP to PPR Comparison





Next Steps

- Education – End users need to understand the benefits of PPR.
- Implementation – Some systems have the ability to utilize PPR in their balancing methodology.

Thank you

Questions?