1. ENGINE FUNDAMENTALS
   1.1 Basic Definitions
2. - *Bore (D)*: Cylinder diameter (mm)
3. - *Stroke (L)*: Piston travel TDC→BDC (mm)
4. - *Swept volume*: Vs = (π/4)·D²·L (cm³)
5. - *Compression ratio*: CR = (Vs + Vc) / Vc
6. - Petrol passenger cars: 8.5–11:1
7. - Turbo-petrol: 9–10.5:1
8. - Diesel: 15–22:1
9. - *Firing order*: 1-3-4-2 (most 4-cyl), 1-5-3-6-2-4 (most 6-cyl inline)

1.2 Four-Stroke Otto Cycle (SI)

Table
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Stroke	**Crank °**	**Piston**	**Valves**	**What Happens**
Intake	0–180	Down	IN open	Draw 14.7:1 A/F mix
Compression	180–360	Up	Both closed	T ≈ 350 °C, P ≈ 12 bar
Power	360–540	Down	Both closed	Spark @ 20–35 °BTDC, peak P ≈ 50 bar
Exhaust	540–720	Up	EX open	Blow-down, P drops to atm

One complete cycle = **720 ° crankshaft = 4 piston strokes**

1.3 Two-Stroke Basics (for bikes / outboards)

- Ports (no valves) – piston skirt controls timing

- Power every revolution → *2× power density, but **higher fuel / oil consumption* & *emissions*.

- Crankcase is pressurised → requires oil premix or injection.

2. AIR-FUEL MIXTURE & COMBUSTION

2.1 Stoichiometry

- *Petrol (C_8H_{18})* ideal ratio = *14.7:1* (mass)
- *Lambda (λ)* = actual AFR / 14.7
  - λ = 1 → stoich
  - λ > 1.05 → lean burn (NOx ↑, knock risk)
  - λ < 0.9 → rich (CO ↑, soot, cool combustion)

2.2 Flame Front & Knock

- *Flame speed*: 15–30 m/s in SI engines
- *Knock* = auto-ignition of end-gas → metallic hammer, broken ring lands, holed piston.
- *Octane number* = knock resistance; RON 95 vs 97 vs 100.

2.3 Diesel Combustion (CI)

- *No throttle* – quantity control via injected fuel
- *Injection pressure*: 300–2500 bar (common-rail)
- *Ignition delay*: 0.5–1.5 ms → controls noise (Diesel knock).
- *AFR*: 18–70:1 globally, always lean overall.

3. FORCED INDUCTION

3.1 Turbocharger

- *Turbine side*: hot exhaust drives cast Inconel wheel
- *Compressor side*: aluminium wheel, boosts intake 0.4–2.0 bar (rel)
- *Waste-gate*: bypass exhaust to limit shaft speed (80 000–220 000 rpm)
- *Inter-cooler*: drops T by 40–60 °C → density ↑ 8–12 %

3.2 Supercharger

- *Mechanically driven* (belt) – instant boost, but consumes 5–10 % power.
- *Types*: Roots (positive displacement), Twin-screw, Centrifugal.

3.3 Service Points

- *Turbo cool-down*: 30–60 s idle after hard run → prevents oil coking.

- *Oil feed pipe*: 0.8–1.2 mm orifice – never kink.

- *Boost leak test*: pressurise to 0.5 bar, spray soapy water → no bubbles.

4. ENGINE LUBRICATION

4.1 Oil Functions

- Lubricate (hydrodynamic film 2–10 µm)

- Cool piston undersides (30 % of total heat)

- Seal combustion chamber (ring pack)

- Suspend soot / wear particles (detergents/dispersants)

Table

Grade	Low-Temp °C	100 °C cSt	Use
0W-20	–35	5.6–9.3	New petrol, fuel-econ
5W-30	–30	9.3–12.5	Turbo-petrol
10W-40	–25	12.5–16.3	Hot climate, high mileage
15W-40	–20	12.5–16.3	Diesel, mixed fleet

"W" = winter crank viscosity – lower = faster cold-flow.

4.3 Oil Change Interval Strategy

- *Time*: 6–12 months (moisture & additive depletion)

- *Distance*: 5 000 km (mineral) – 15 000 km (full synth + mid-SAPS)

- *Severe service*: taxi, towing, dust → halve mileage.

4.4 Quick Oil-Pressure Diagnosis

- *Spec*: 1.5–5.0 bar @ 3 000 rpm, 90 °C

- *Low hot* → bearing wear, relief valve stuck, pickup partial block

- *High cold* (< 60 °C) → normal; persistent high → wrong grade, blocked gallery.

5. COOLING SYSTEM

5.1 Coolant Type

Table

Tech	Colour	Life	Notes
IAT (Inorg. Add.)	Green	2 yr / 50 k	High silicate, good for copper/brass
OAT (Org. Add.)	Orange	5 yr / 250 k	No silicates, aluminium safe
HOAT	Yellow / pink	5 yr	Hybrid, Euro spec (G30, G48)

Never mix IAT + OAT → gel, blocked heater matrix.

5.2 Pressure Cap

- *Raised boiling point*: +1 °C per 5 kPa → 100 kPa cap = 120 °C boil

- *Two valves*: 1) pressure 2) vacuum (prevents hose collapse on cool-down)

5.3 Rapid Coolant Leak Locator

1. *Pressure tester* pump to 1.2 bar → watch 2 min drop ≤ 0.1 bar

2. *UV dye* + black-light → fluorescent trace

3. *Block-test liquid* (blue→yellow) checks combustion gas in header tank → failed head gasket.

6.1 Air Filter

- *Paper element*: 99.9 % @ 5 µm; service when ΔP ≥ 2.5 kPa (manometer)

- *Oil-foam / cotton gauze*: clean & re-oil every 10 000 km; over-oil ruins MAF.

6.2 Manifold Absolute Pressure (MAP)

- *Linear output*: 0.5 V = 20 kPa, 4.5 V = 250 kPa (absolute)

- *Fail*: clogged port → reads low → rich mixture, smoke.

6.3 Mass Air-Flow (MAF) – Hot-Wire

- *Burn-off* self-clean 1 s after every hot-soak (1 000 °C flash)

- *Cleaner spray*: non-residue, plastic-safe; let dry 10 min.

Table

Gas	Normal Petrol	High Reading Implies
CO	< 0.3 %	Rich mixture, clogged air filter
HC	< 100 ppm	Misfire, weak spark, low compression
NOx	< 500 ppm	Lean, EGR fault, overheating
O_2	0.5–1.0 %	Exhaust leak, catalyst not lit