THE DIFFERENT FAILURE MODES OF AUTOMOTIVE AND AIRCRAFT PISTON ENGINES

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Objectives

Provide background information useful to conversion of automotive background into aircraft/helicopter applications

Describe differences in failure modes and seizures

Typical Automotive Common Rail Diesel Engine Design

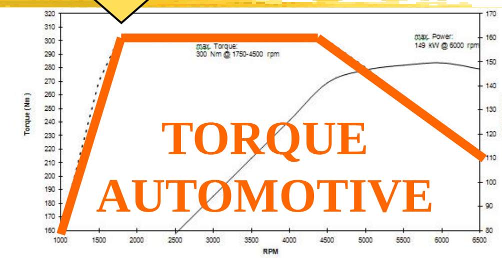
- 0.8 to 6 lt displacement
- 3 to 6 in line, V6 – V8 – V12
- Turbocharged
- Aftercooling
- 40-100 HP at 4000-6600 rpm
- 60-1000 Nm Max Torque at 1750-2000 rpm
- Dry weight 75-380 kg
- Reliability/Durability
  - 100,000 km/2 year base warranty
  - 250,000 km/5 year design life

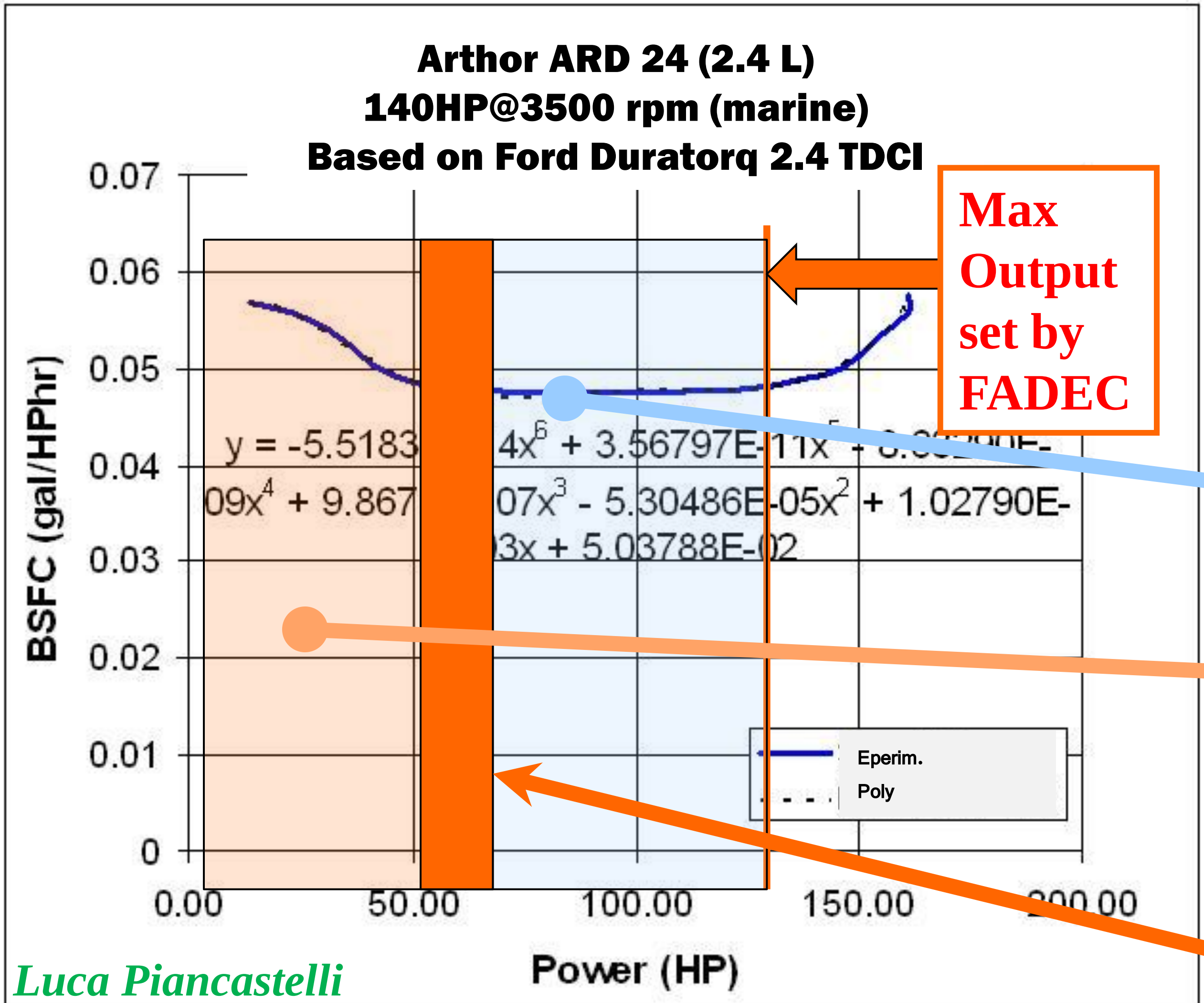
Typical AVIO Diesel Engine Design

- 0.8 to 6 lt displacement
- 3 to 6 in line, V6 – V8 – V12
- Turbocharged
- Intercooling/Aftercooling
- 100-800 HP at 4000-6600 rpm
- 130-1000 Nm Max Torque at 2000-4000 rpm
- Dry weight 90-450 kg
- Reliability/Durability
  - 1200 Hrs (warrant)
  - 3000 Hrs (foreseen)

Typical Common Rail Diesel Engine BSFC

AUTOMOTIVE WORST CONDITION





Typical aircraft

Typical automotive

Overlap

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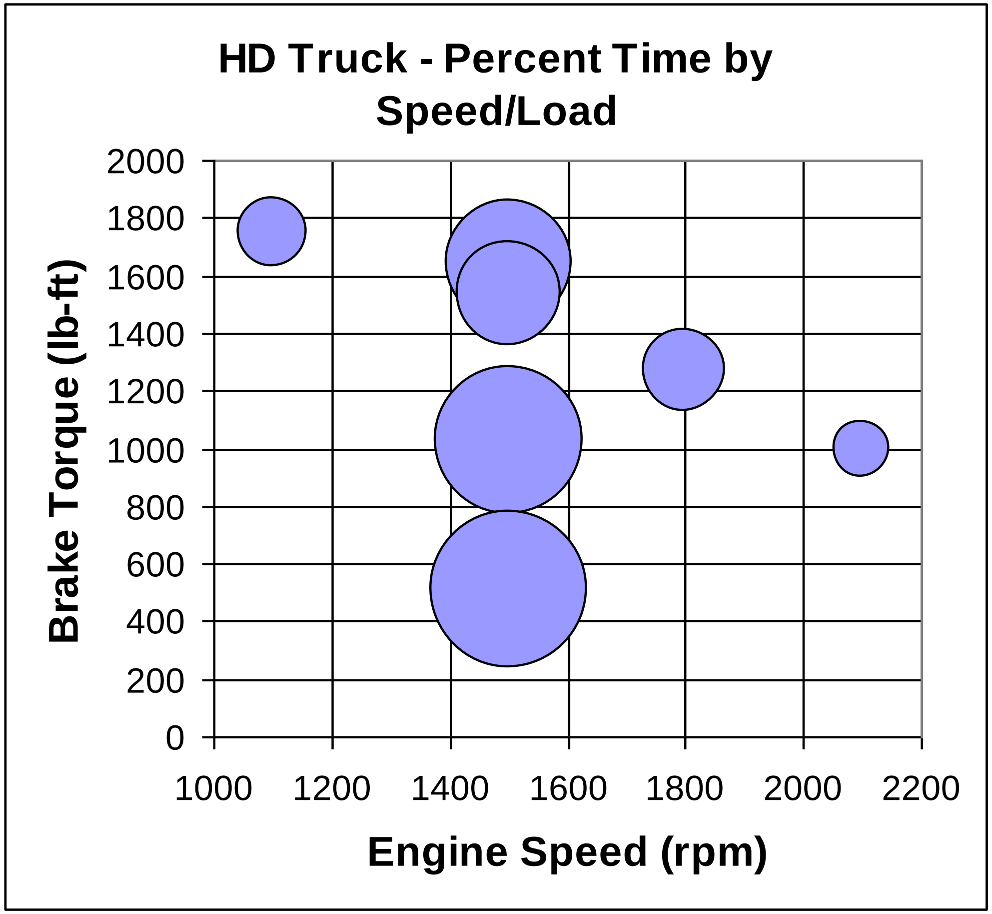
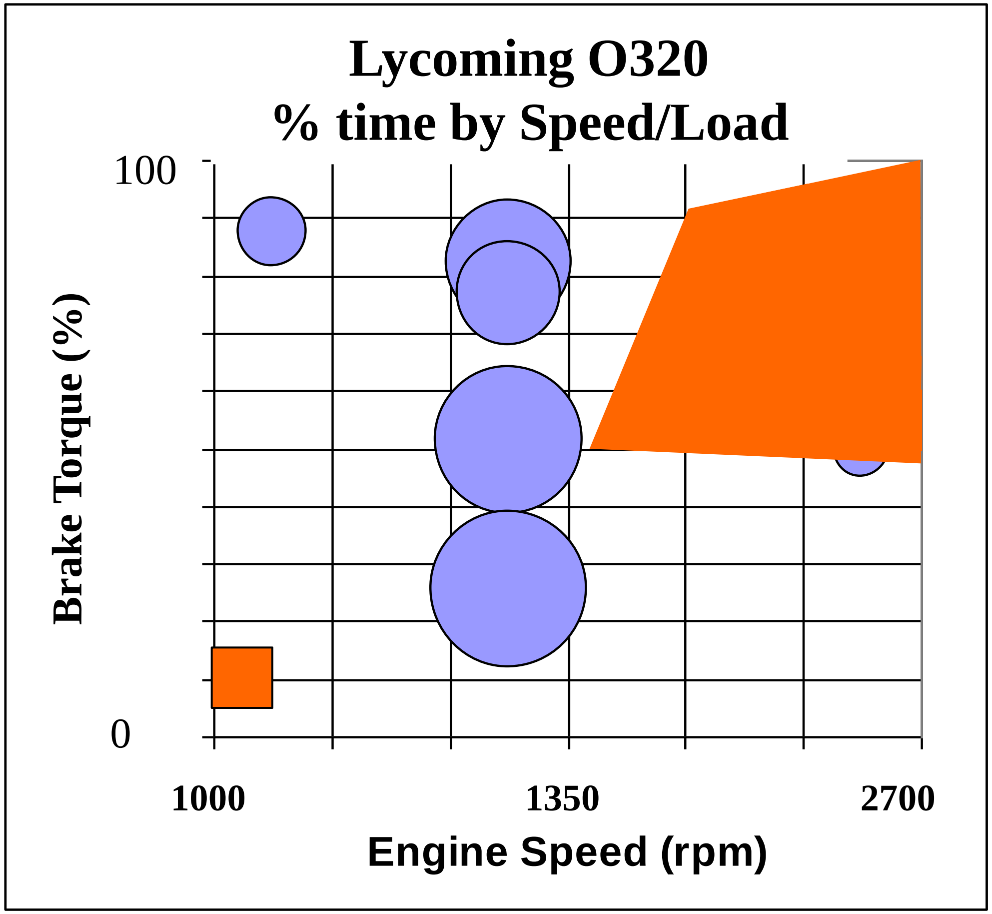
Typical HD Diesel Engine Duty Cycle (data from Cummins)

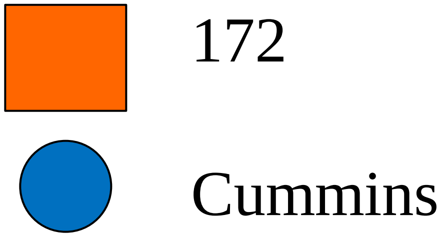


- Average load of 180-200 HP (30% Maximum power)
- Most of fuel used at “cruise” rpm of 1400-1700 rpm (about half maximum speed)
- Varying load at cruise due to operation of cruise control
- Varying engine speed due to road speed changes in traffic or urban operation

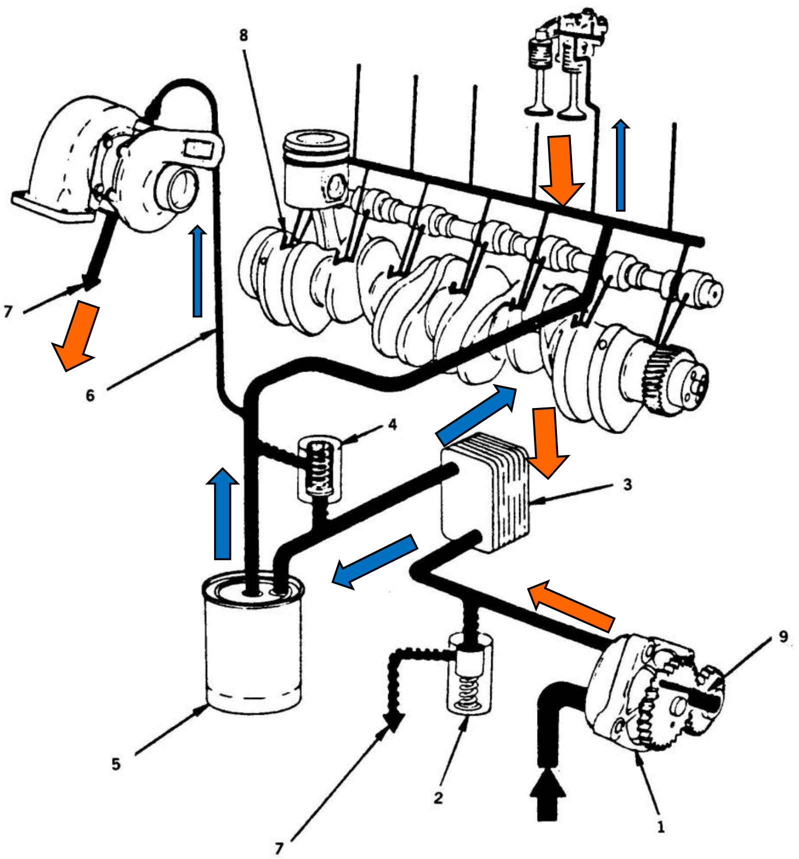
Lycoming O320 typical duty Cycle (data Cessna 172 Flight Manual)



- Average load of 80 HP (50% Maximum power)
- Most of fuel used at "cruise" rpm of 2200 rpm (about 80% the maximum speed)
- Approximately steady load at cruise
- Varying engine speed only at take off, climb and glide/approach.

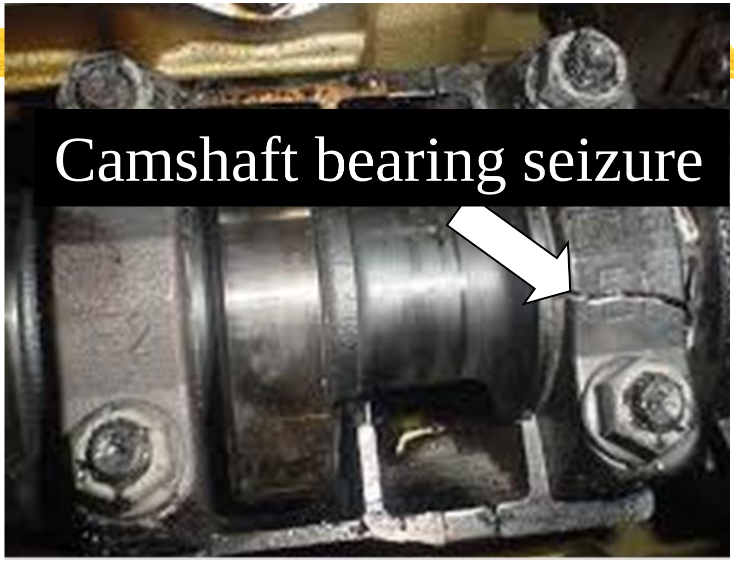


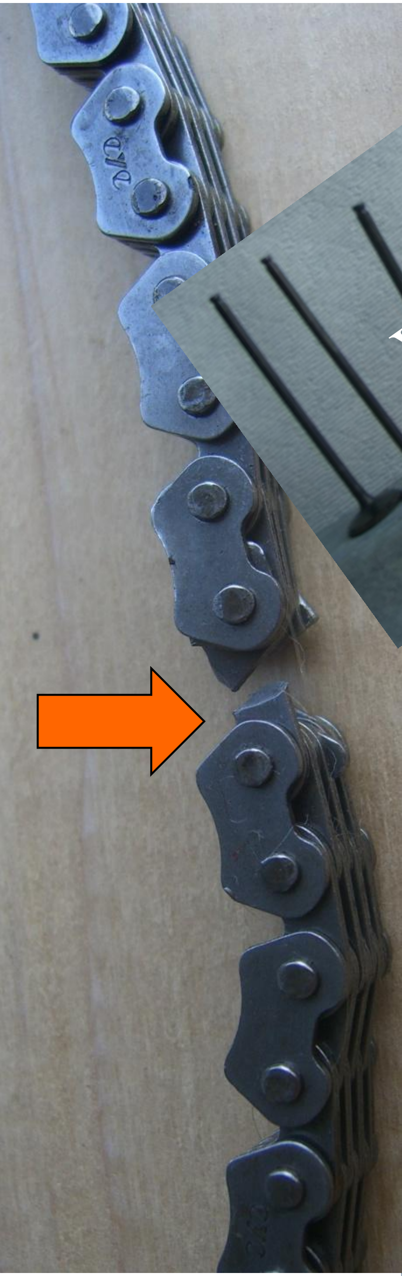
Lubrification system

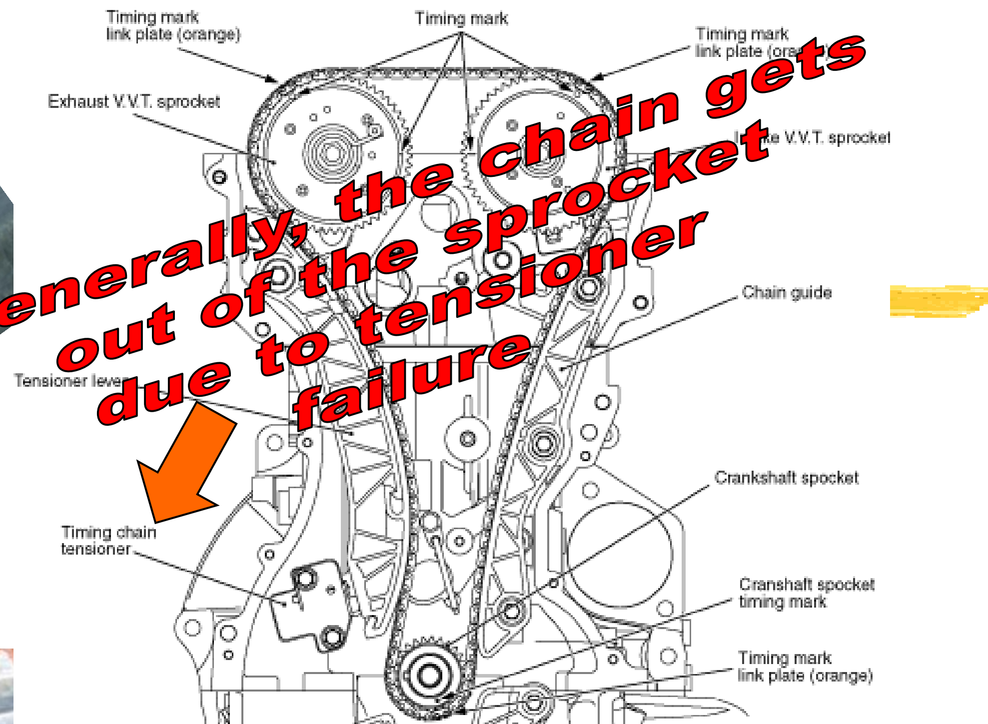


1) Pump
2) Limit pressure valve
3) Oil cooler
4) Filter bypass (emergency)
5) Oil filter
6) Turbocharger oil line
7) Turbocharger exhaust
8) Crankshaft journal bearing supply line

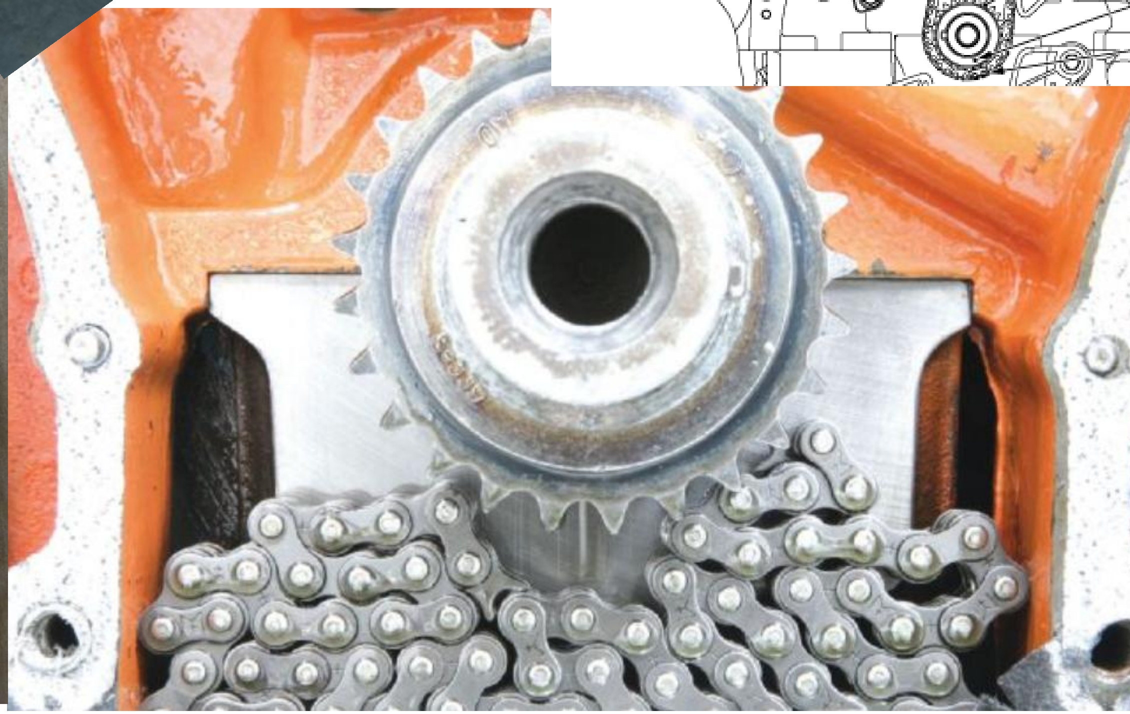
The camshaft: the last of the line







Generally, the chain gets out of the sprocket due to tensioner failure



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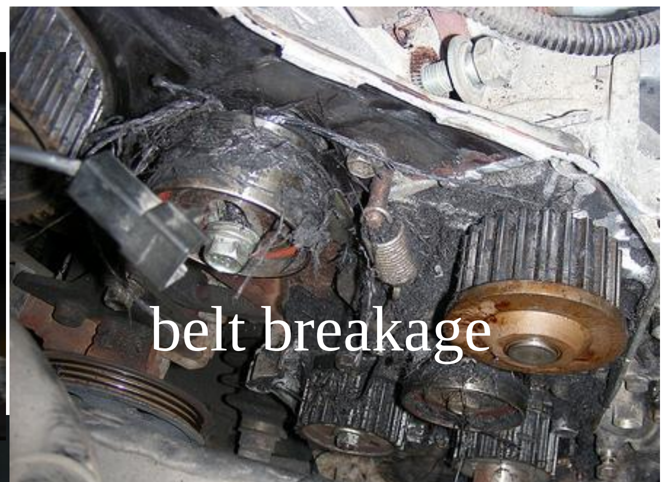
Less common failures



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Typical aircraft failures

Overheating due to insufficient cooling

(aftercooler, intercooler(s) – radiator)

Overspeed

Overheating due to High oil temperature

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Rod failure (both)

Insufficient screw strength (both)

Poor lubrication (automotive)

Excessive loads (both)

Crankshaft failure (both)

Bearing seizure (automotive)
Flaws (automotive)
Overload at low rpm (automotive)
Overload at cranking (automotive)
Overload at full stop (aircraft)
Overload at high rpm (aircraft)
Overspeed (aircraft – racing)

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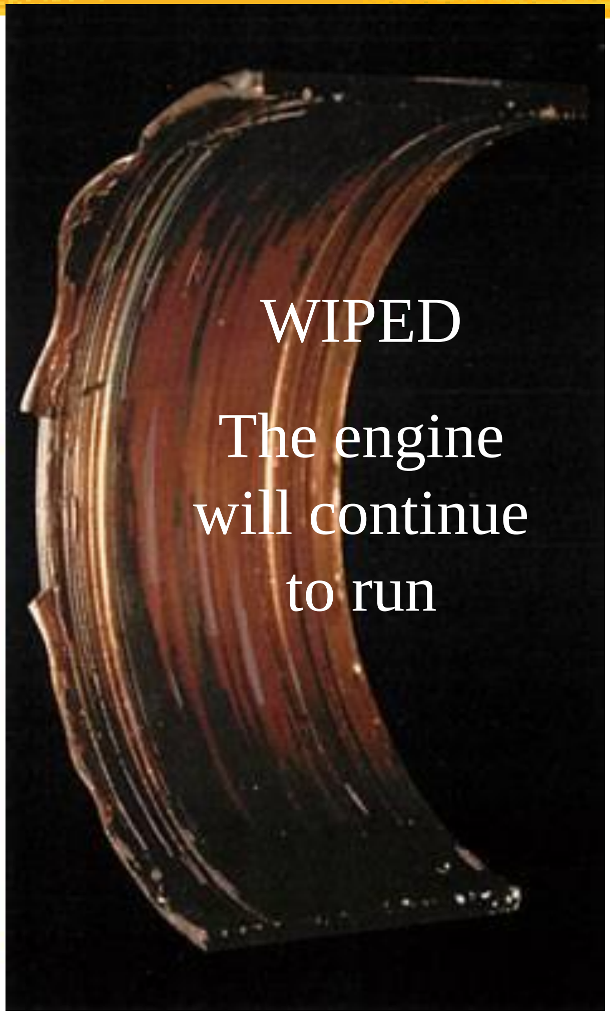
Journal bearings: when it is wiped, diagnosis is difficult

NORMAL WEAR

Appearance: Wear pattern covering approximately 2/3 of the bearing surface. Wear should diminish near the parting line ends of the bearing surface. Pattern may be intermittent in both axial and circumferential directions on bimetal aluminum depending on geometry of mating surfaces.

Extremely rare



WIPED

The engine will continue to run

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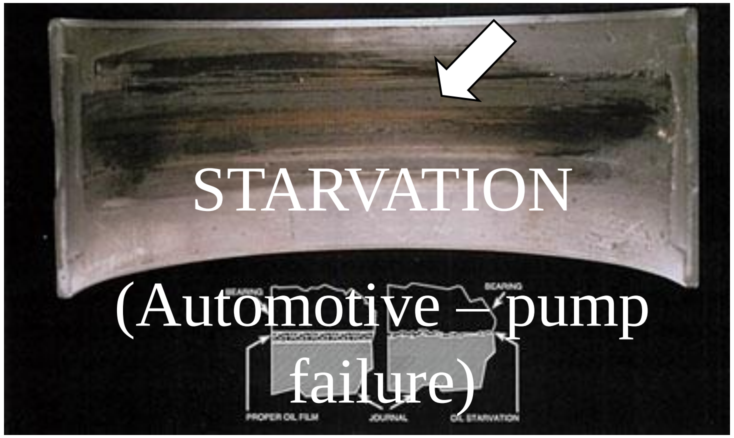
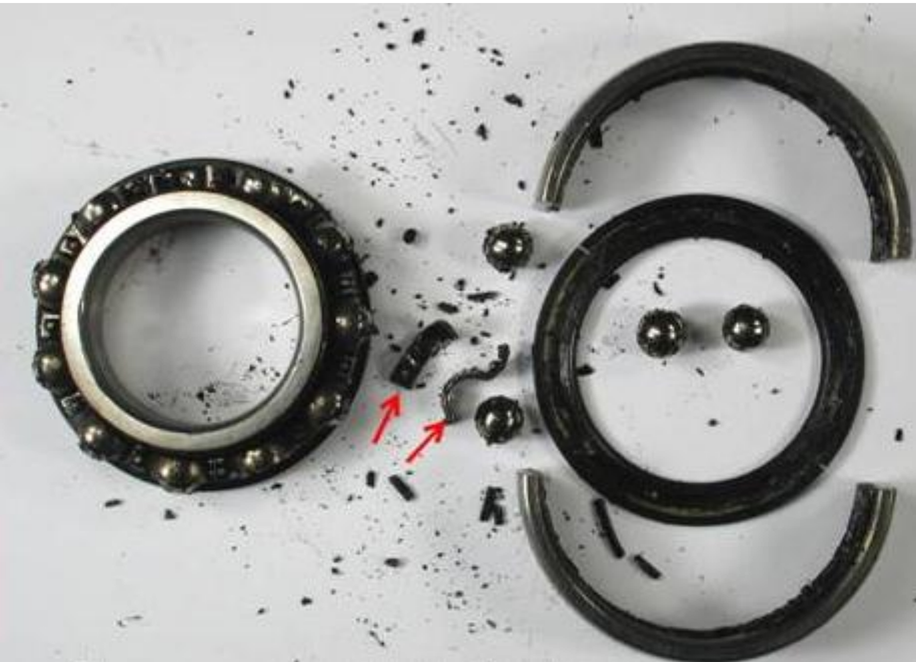
CONFRONTATION
MAY HELP


FATIGUE
Overload automotive


STARVATION
(Automotive – pump failure)

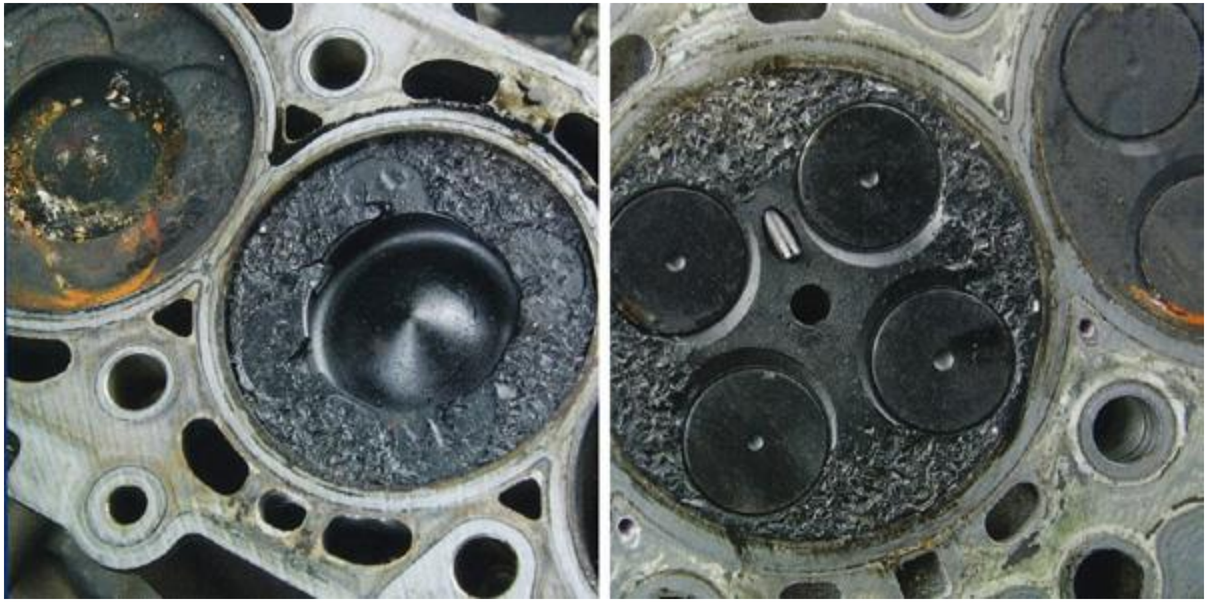

HOT SHORT
(aircraft – overheat)

Roller bearings: when they fail the engine stops



Piston destroyed due to overspeed compressor blown up, detached pieces in intake manifold

Detached pieces in manifold



Detached pieces in manifold (automotive)

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Severe overheat (aircraft)

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Summary

Automotive engine conversions lead to completely different engines

Load history / rpm are completely different

Failure modes are completely different

Aircraft: overheat and overspeed (High rpm)

Automotive: overload or oil starvation (low rpm high load: for ex. 6^{th} speed, low rpm, high speed)

Heat Dissipation (P. Law –Reno Racing)

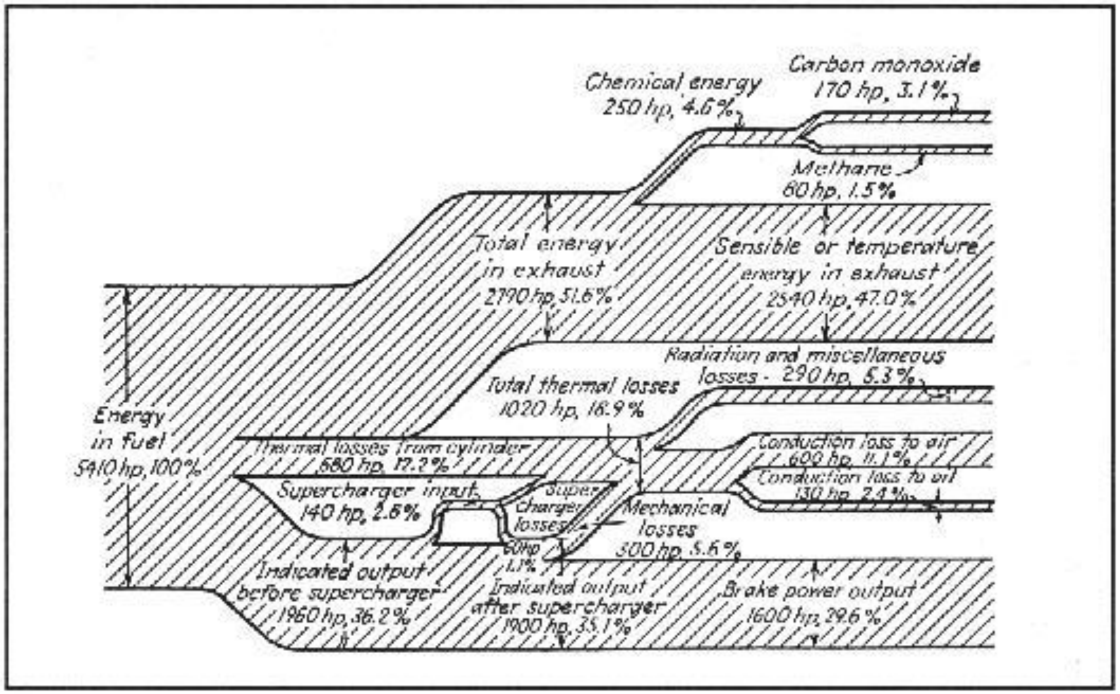
Engines	Shaft Output, BHP	Cooling Load, Horsepower	Cooling Load, BTU/min	Spray Water Req'd, GAL/Min, (8080 BTU/GAL)	Boiler ADI Req'd, GAL/Min, (5900 BTU/GAL)	Used By
Oil Cooling Requirements-Approximate						
Merlin	2800	140 (5%)	5,940	0.74	1.00	*Stiletto*
Griffon	3200	160 (5%)	6,780	0.84	1.15	*Red Barron*
R-2800	3200	320 (10%)	13,570	1.68	2.30	*CONQUEST*
R-3350	3700	389 (11%)	16,500	2.04	2.80	*SEPTEMBER FURY*
R-4360	3800	383 (10%)	16,250	2.00	2.75	*SHOCKWAVE*
Coolant Cooling Requirements-Approximate						
Merlin	2800	840 (30%)	35,620	4.41	5.40	*Stiletto*
Griffon	3200	1120 (35%)	47,490	5.88	8.05	*Red Barron*
Aftercooler Coolant Cooling Requirements-Approximate						
Merlin	2800	140 (5%)	5,940	0.74	1.00	*Stiletto*
Griffon	3200	160 (5%)	6,780	0.84	1.15	*Red Barron*

Cylinder Head and Barrel Cooling-Radials

At high power some radials use 2.0 GPM of water spray on cylinders

Examples are: R-4360-63A Powered Racers "*Dreadnought*", "*Super Corsair*", "*Furias*"

Summary



A typical heat balance, or efficiency diagram, for a supercharged aero engine (such as a Rolls-Royce Merlin) of the 1940s. Much more energy is wasted in the exhaust than is used to drive the propeller (SAE paper by Pierce and Welsh).