THE DIFFERENT FAILURE MODES OF AUTOMOTIVE AND AIRCRAFT PISTON ENGINES

Luca Piancastelli – University of Bologna – luca.piancastelli@unibo.it
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

Luca Piancastelli – University of Bologna – luca.piancastelli@unibo.it
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)

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Typical Common Rail Diesel Engine BSFC

Arthur ARD 24 (2.4 L)
140HP@3500 rpm (marine)
Based on Ford Duratorq 2.4 TDCI

Max Output set by FADEC

Torque ARMOTIVE WORST CONDITION

0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.00
50.00
100.00
150.00
200.00

Power (HP)

BSFC (gal/HPhr)

y = -5.5183 + 4x^6 + 3.56797E-11x + 8.9092E-09x^4 + 9.86707x^3 - 5.3048E-05x^2 + 1.0279E-03x + 5.03788E-02

Overlapp

Typical aircraft

Typical automotive

Luca Piancastelli
luca.piancastelli@unibo.it
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.

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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

- Seizure due to oil starving
- Camshaft bearing seizure
- Valve stem scuffing
- Bearing scuffing

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Generally, the chain gets out of the sprocket due to tensioner failure.
Less common failures

Spring breakage

Valve breakage

Valve scuffing

Teeth breakage

Belt breakage

The hidden enemy: oil seal failure

Gear full failure

Gear tooth failure

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Typical aircraft failures

Overheating due to insufficient cooling (aftercooler, intercooler(s) – radiator)

Overspeed

Luca Piancastelli – University of Bologna – luca.piancastelli@unibo.it
Overheating due to High oil temperature

Luca Piancastelli – University of Bologna – luca.piancastrelli@unibo.it
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

The engine will continue to run

Extremely rare

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CONFRONTATION MAY HELP

FATIGUE
Overload automotive

STARVATION
(Automotive pump failure)

HOT SHORT
(aircraft – overheat)

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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

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Detached pieces in manifold (automotive)

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Severe overheating (aircraft)
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. 6th speed, low rpm, high speed)
# Heat Dissipation (P. Law – Reno Racing)

<table>
<thead>
<tr>
<th>Engines</th>
<th>Shaft Output, BHP</th>
<th>Cooling Load, Horsepower</th>
<th>Cooling Load, BTU/min</th>
<th>Spray Water Req’d, GAL/Min, (8080 BTU/GAL)</th>
<th>Boiler ADI Req’d, GAL/Min, (5900 BTU/GAL)</th>
<th>Used By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merlin</td>
<td>2800</td>
<td>140 (5%)</td>
<td>5,940</td>
<td>0.74</td>
<td>1.00</td>
<td>Stiletto</td>
</tr>
<tr>
<td>Griffon</td>
<td>3200</td>
<td>160 (5%)</td>
<td>6,780</td>
<td>0.84</td>
<td>1.15</td>
<td>Red Barron</td>
</tr>
<tr>
<td>R-2800</td>
<td>3200</td>
<td>320 (10%)</td>
<td>13,570</td>
<td>1.68</td>
<td>2.30</td>
<td>CONQUEST</td>
</tr>
<tr>
<td>R-3350</td>
<td>3700</td>
<td>389 (11%)</td>
<td>16,500</td>
<td>2.04</td>
<td>2.80</td>
<td>SEPTEMBER FURY</td>
</tr>
<tr>
<td>R-4360</td>
<td>3800</td>
<td>383 (10%)</td>
<td>16,250</td>
<td>2.00</td>
<td>2.75</td>
<td>SHOCKWAVE</td>
</tr>
</tbody>
</table>

## Oil Cooling Requirements–Approximate

## Coolant Cooling Requirements–Approximate

## Aftercooler Coolant Cooling Requirements–Approximate

## 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”
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).