Degraded Dampers

A Case study in Engine Torsional Vibration

2009 Asia – Pacific Regional Seminar

NZASASI, Rotorua

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NEW ZEALAND
DEFENCE FORCE
TE OPE KAATUA O AOTEAROA

Overview

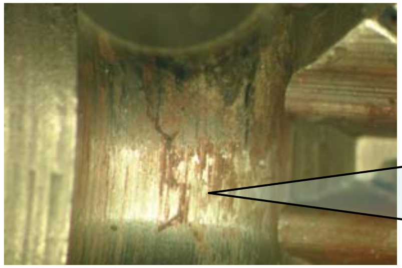
- The problem
- Investigation
  - Fractography
  - Engine instrumentation
- Analysis and discussion
- Conclusions

The problem

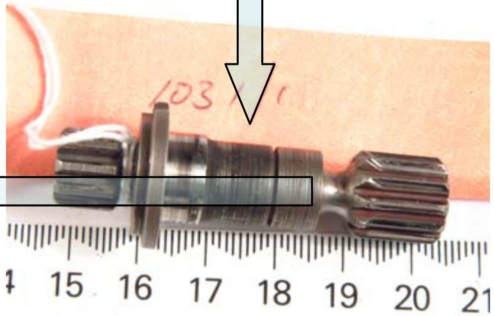
- Accumulated 6 in-flight failures of engine driven fuel pump (EDFP) couplings
- Resulting 2 Mayday and 4 Pan calls
- 1 cracked coupling found during inspection
- Failures at substantially less than normal life

AEIO-540-L1B5

EDFP

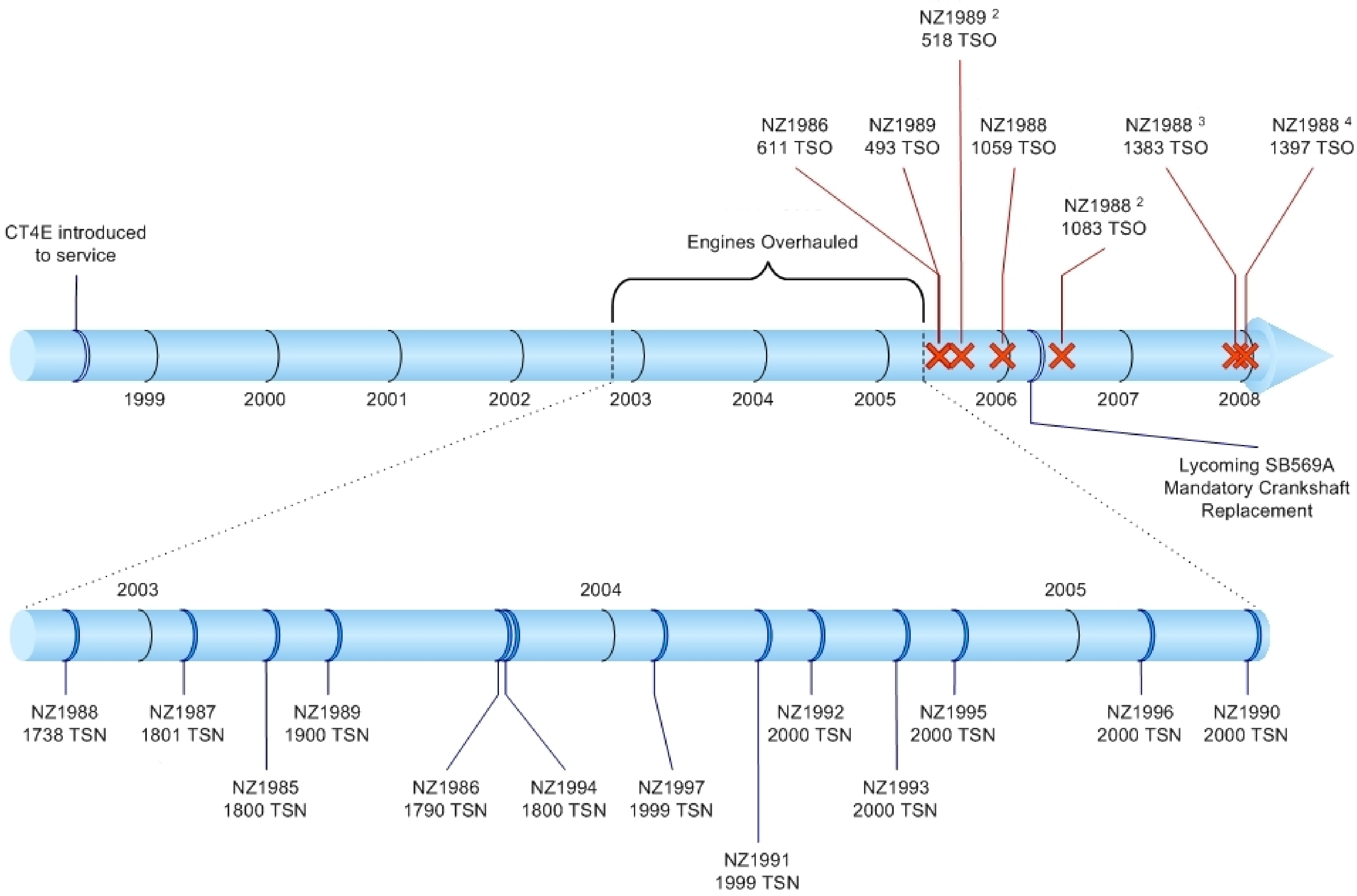


Close-up of cracked coupling

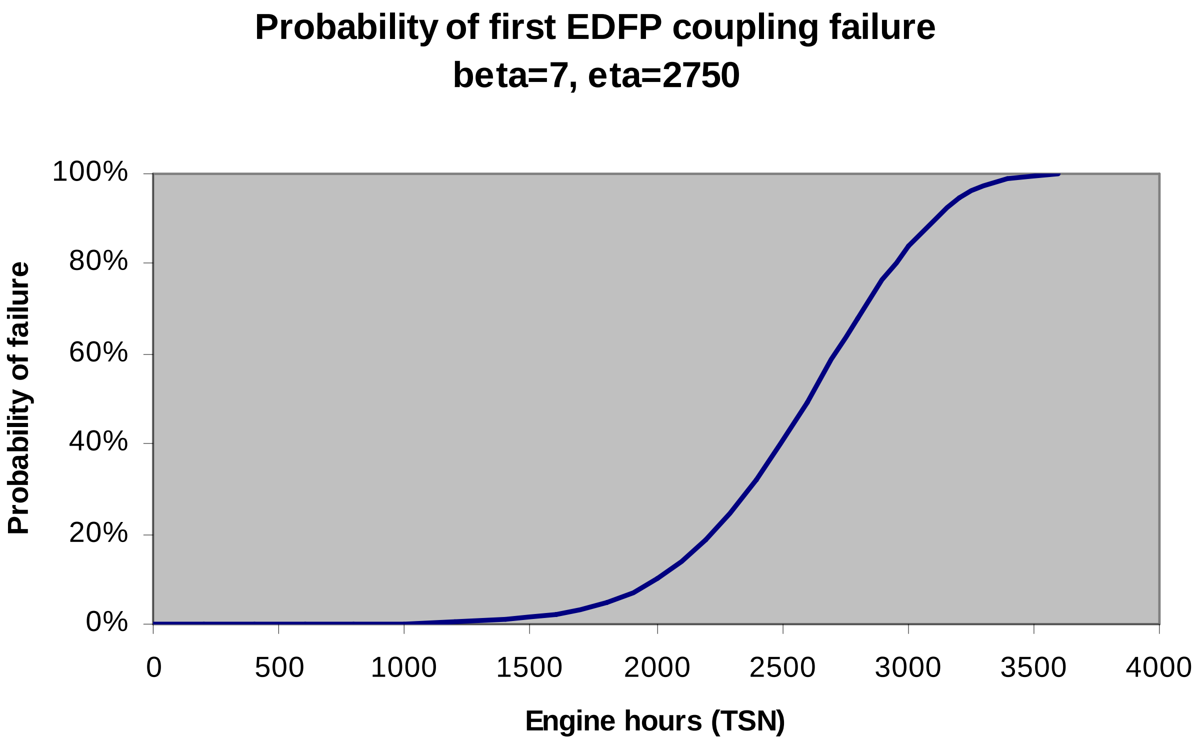


Cracked EDFP drive coupling

History, 1 of 2



History, 2 of 2, Weibull analysis

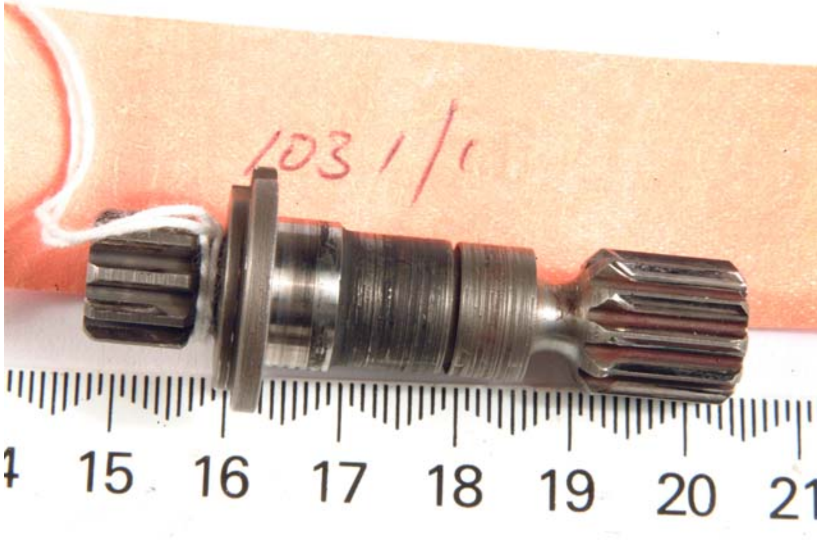


	Probability of failure
• Lycoming recommended TBO, SI1009AS, 1400 hours	1%
• Lycoming approved TBO, 1800 hours	5%
• Extended TBO, 2000 hours	10%

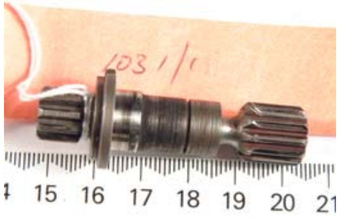
Engine configuration

Component Investigation

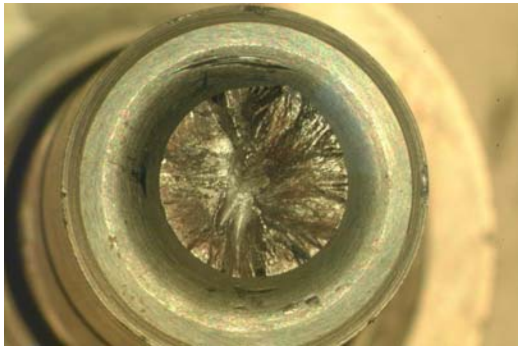
- **Check component suitability**
  - Fractography
  - Materials analysis
  - Finite element analysis



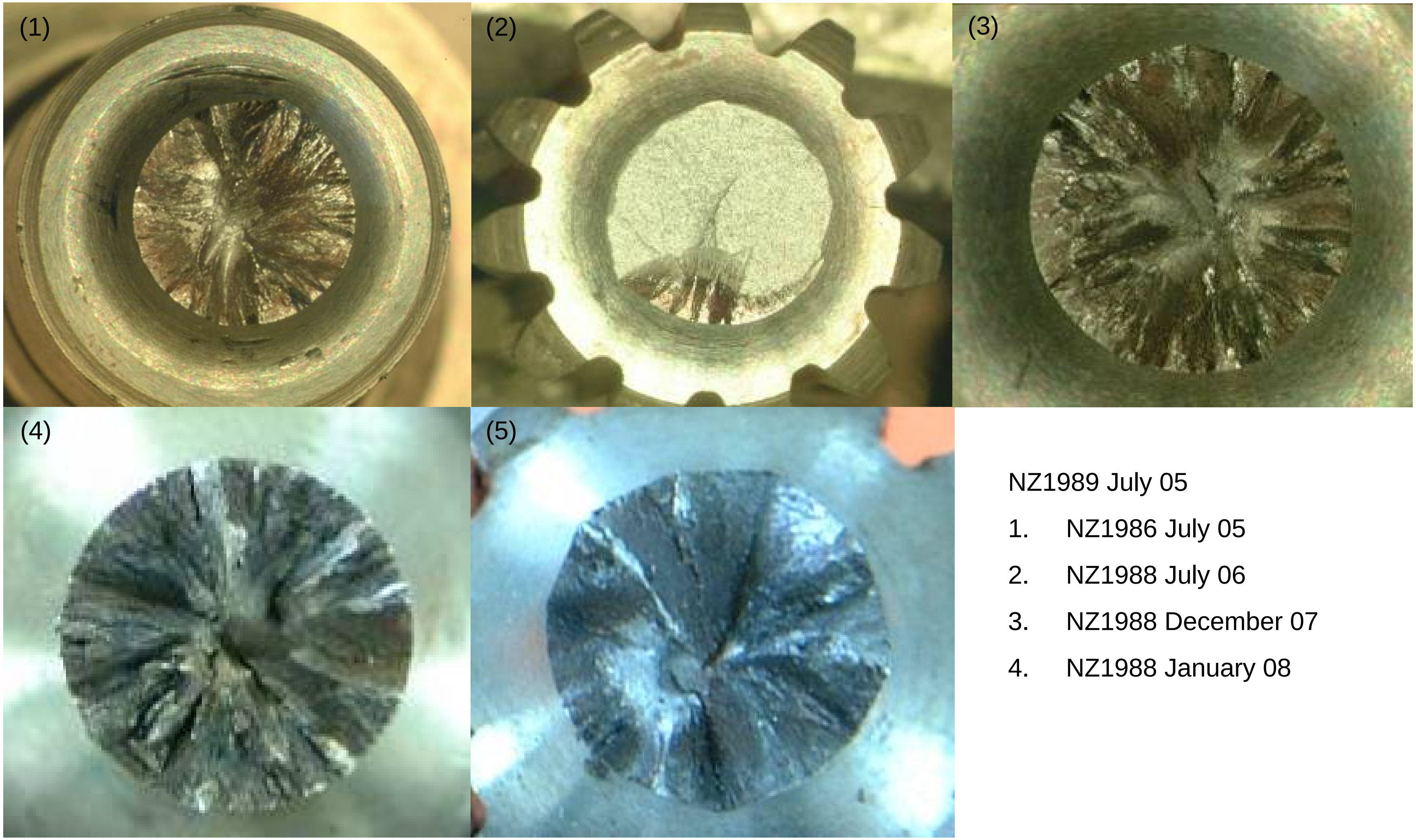
Fractography / material analysis, 1 of 2



- All failures located at waisted portion of shaft
- Exhibited faceting at 90° and ±45°, indicative of **reversed torsional** and bending **fatigue** loads
- Coupling splines and drive gear burnished on both flanks indicative of oscillatory torsional loading
- Analyses by 3 laboratories show no material or component deficiencies



Fractography / material analysis, 2 of 2



NZ1989 July 05

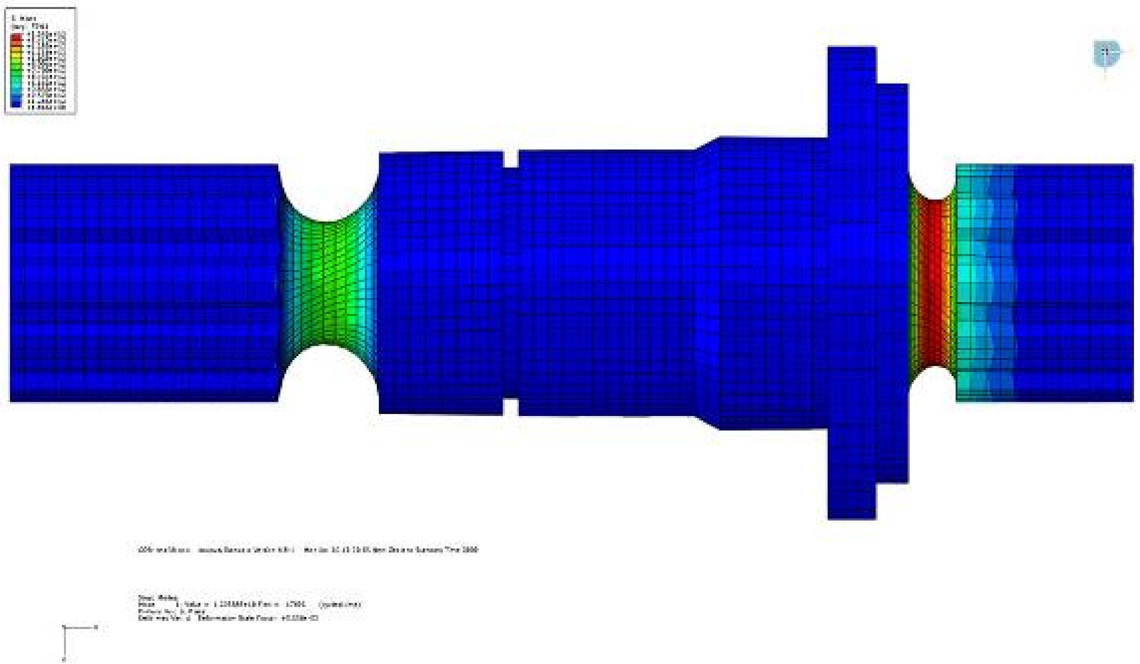
1. NZ1986 July 05
2. NZ1988 July 06
3. NZ1988 December 07
4. NZ1988 January 08

Resonance?

- Resonance is caused by exciting a structure at its natural frequency

Coupling natural frequency

- Engine/pump combination unique to RNZAF fleet
- Finite Element Analysis to determine coupling natural frequency
    - 17,692 Hz or approximately 1,000,000 RPM!
- Highest stress location not at failure location
- Therefore coupling resonance improbable



Comment from the OEMs

- EDFP manufacturer
  - Component failure due to torsional fatigue

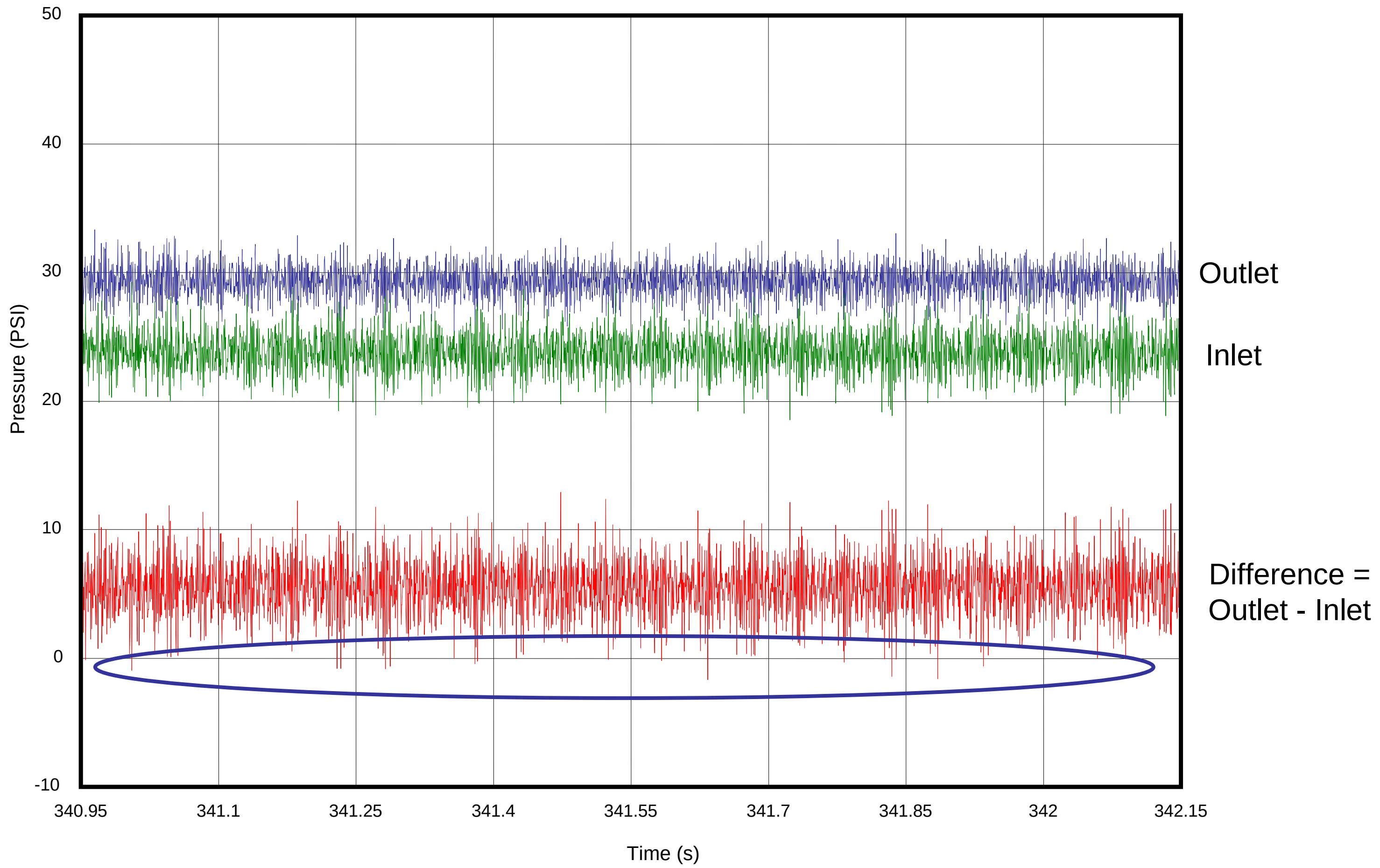
- Engine manufacturer
  - Component failure due to component defect, engine within limits

No faults found… so…

Instrumented engine tests

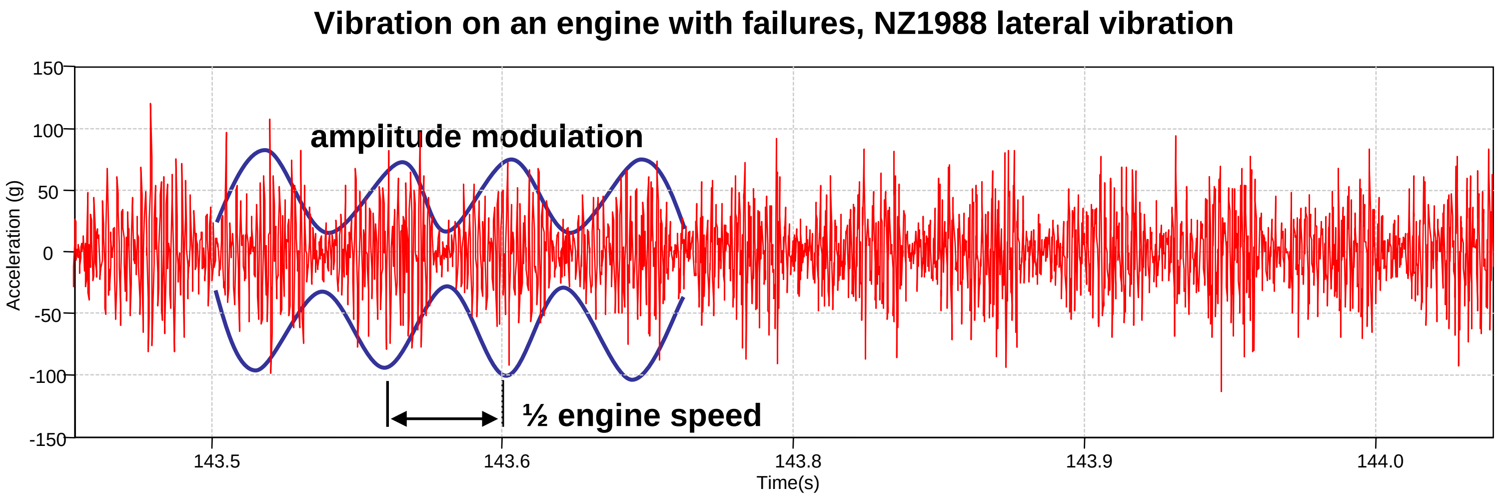
- Assess the 3 failure aircraft for differences from un-failed fleet to identify potential sources of torsional loading
  - Engine run up in increments from idle to full power
  - Parameters recorded
    - EDFP vibration (3-axis linear)
    - Fuel pressure at EDFP inlet, outlet and auxiliary pump outlet
    - Fuel temperature (manually recorded)

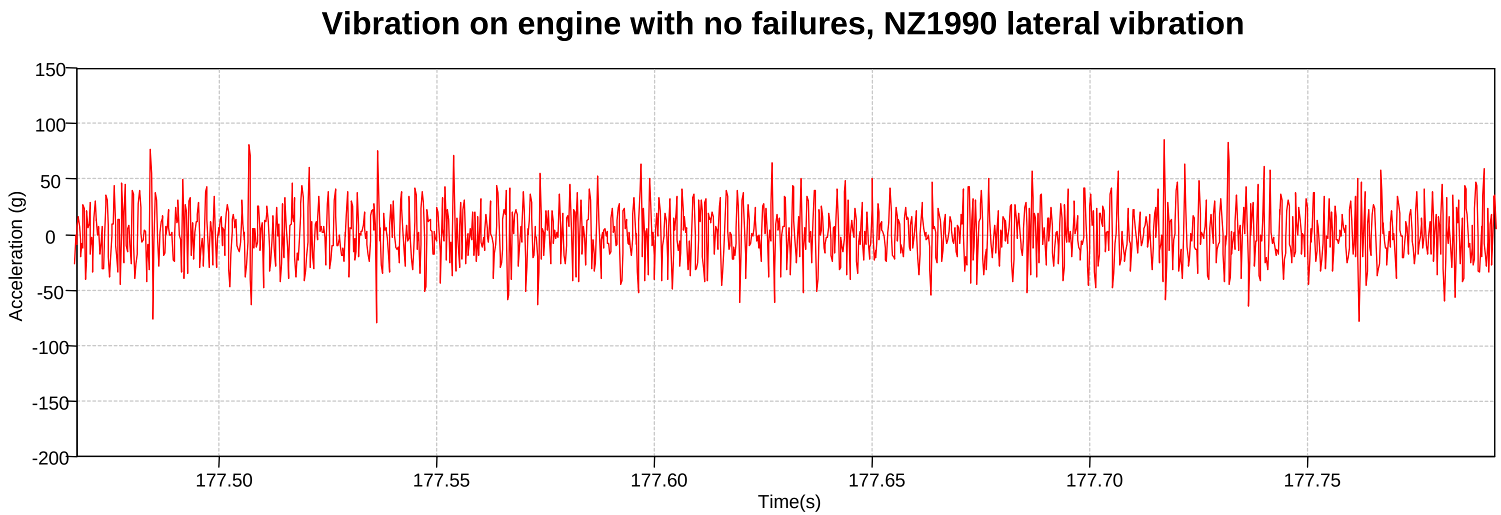
Analysis and discussion – fuel pressure?



- EDFP load reversal indicated
- Solve failures by increasing EDFP relief valve pressure setting? No

Analysis and discussion – vibration?





- Fleet managed by identifying susceptible aircraft, however root cause still unknown

Analysis and discussion

- No detectable EDFP coupling resonance
- No significant temperature fluctuations
- No detectable cavitation or vapour lock
- Amplitude modulation present in EDFP vibration on failed EDFP

- Fuel pipe sizing, fuel pressure setting, propeller balance, propeller type, magneto condition, engine mount stiffness and governor condition were found not to change measured parameters

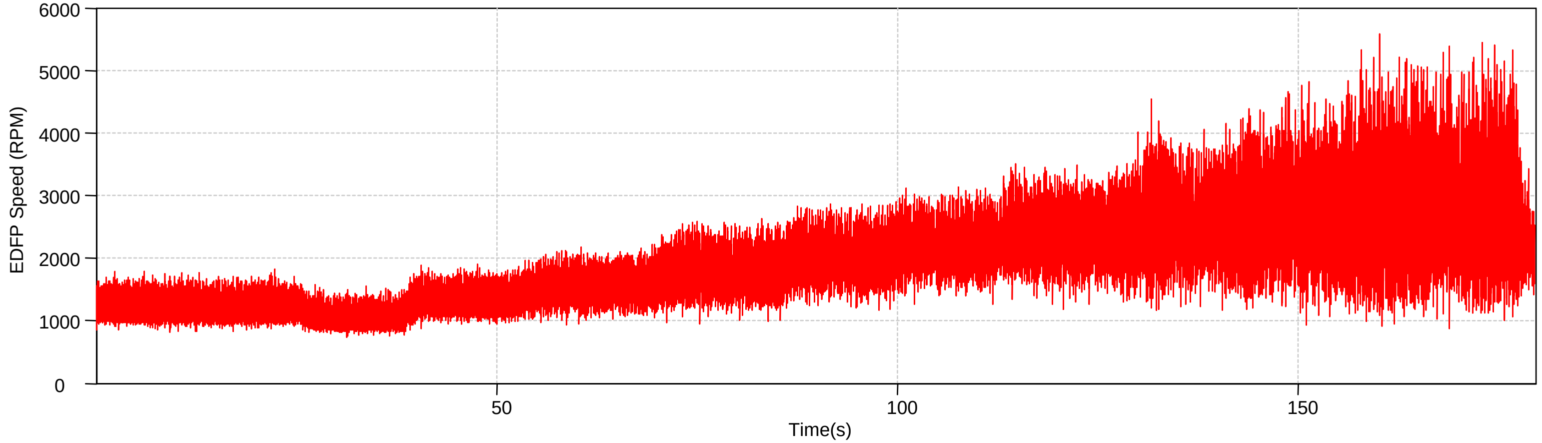
- Root cause undetermined…

Analysis and discussion – torsional vibration

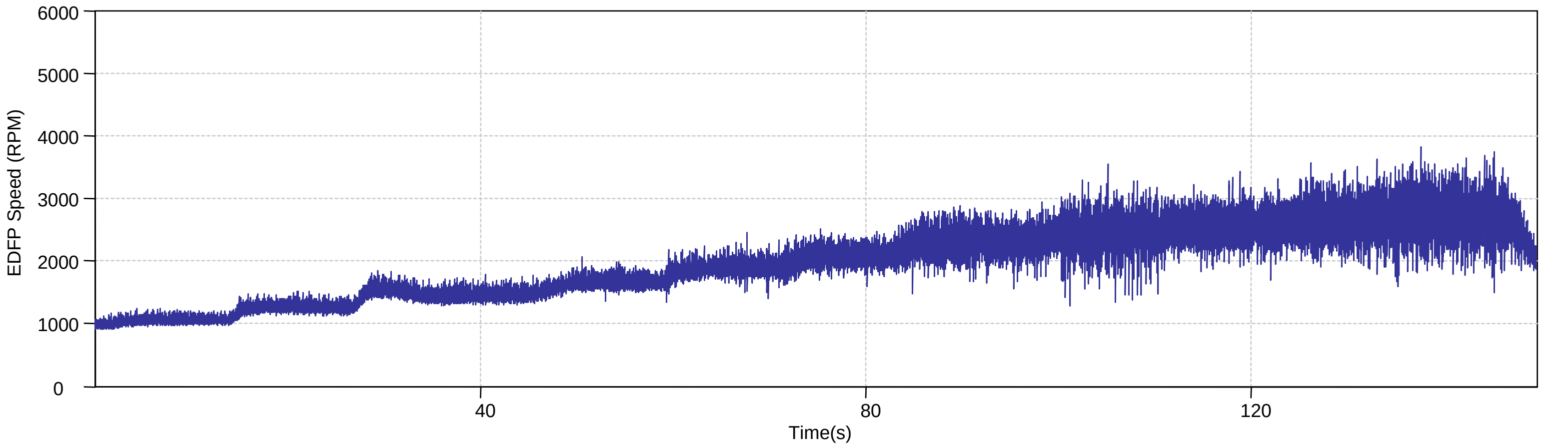
- Addition of torsional vibration measurement to examine EDFP coupling motion
- Installation of a modified EDFP
  - Omron optical rotary encoder, attached to pump rotor and installed in a modified pump
  - EDFP run dry and fuel bypassed. Fuel supplied by backup electrically driven pump
  - Rotary encoder outputs 100 pulses per revolution (1 pulse per 3.6 degrees)

Analysis and discussion – torsional vibration?

Torsional vibration on an engine with failures, NZ1988 EDFP speed

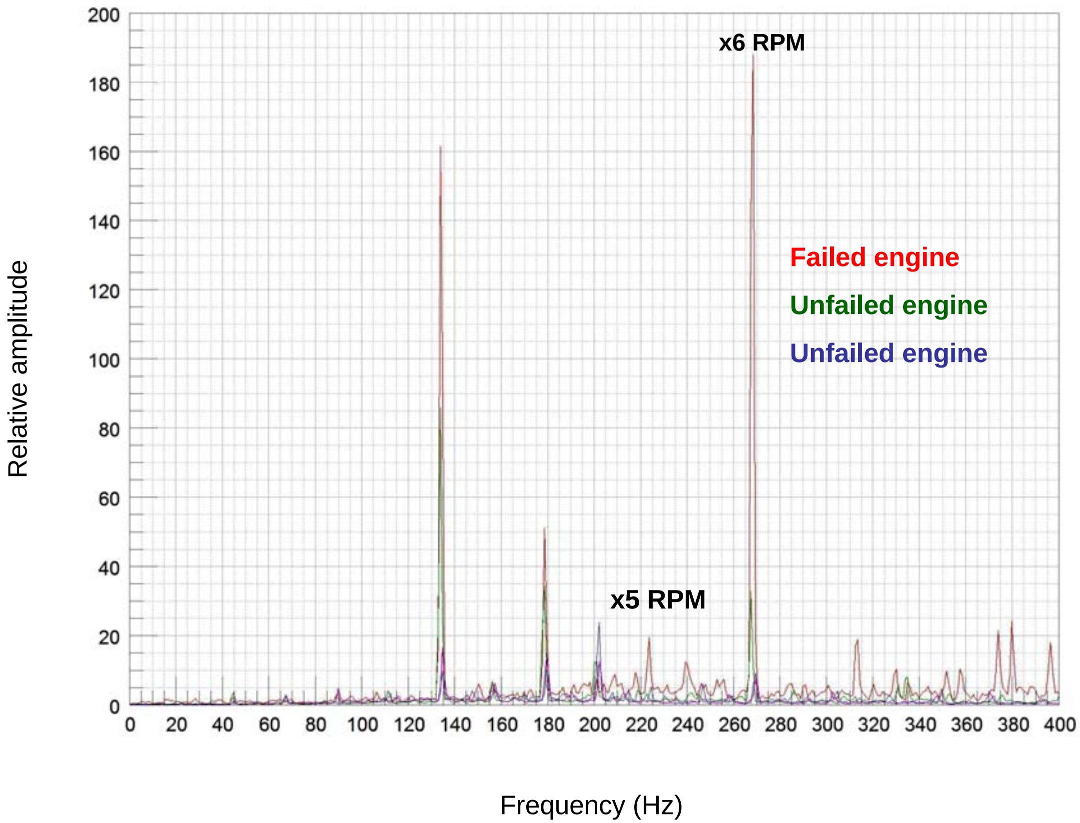


Torsional vibration on an engine with no failures, NZ1996 EDFP speed

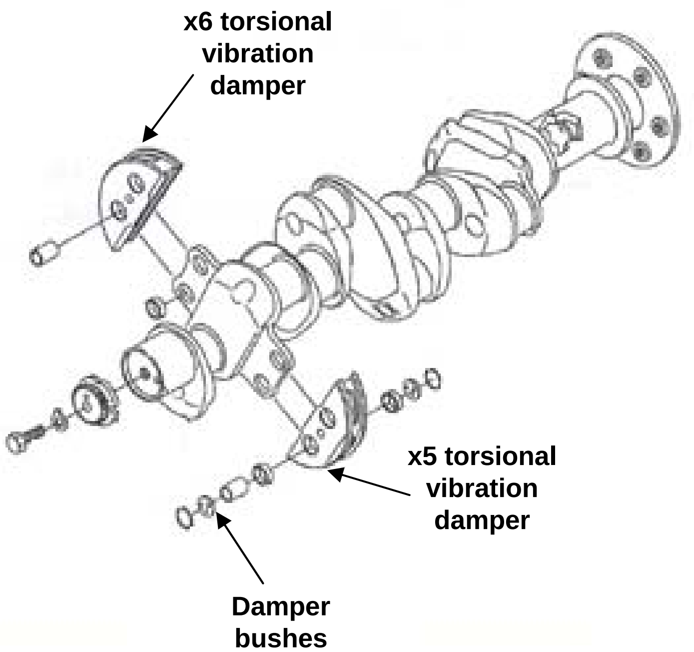


Analysis and discussion – torsional vibration frequencies

Coupling torsional vibration frequency spectrum at take off power

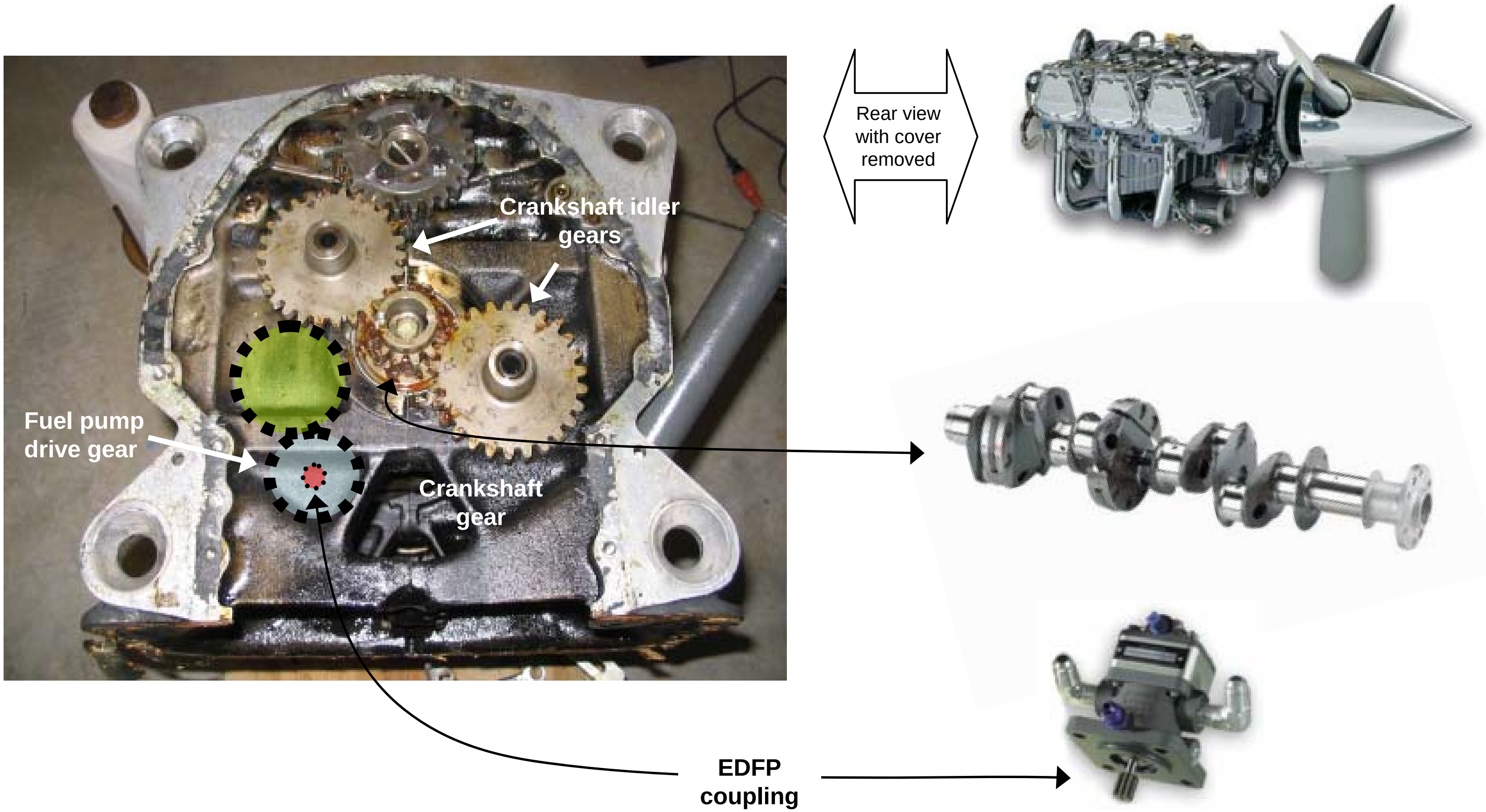


Crankshaft



- Results indicate probable degraded crankshaft torsional dampers

Crankshaft-EDFP coupling interaction



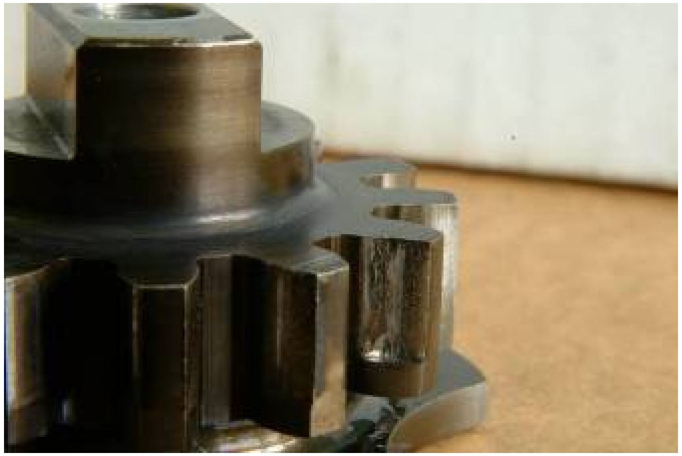
- Torsional vibration from the engine crankshaft is transmitted through the accessory gears to the EDFP

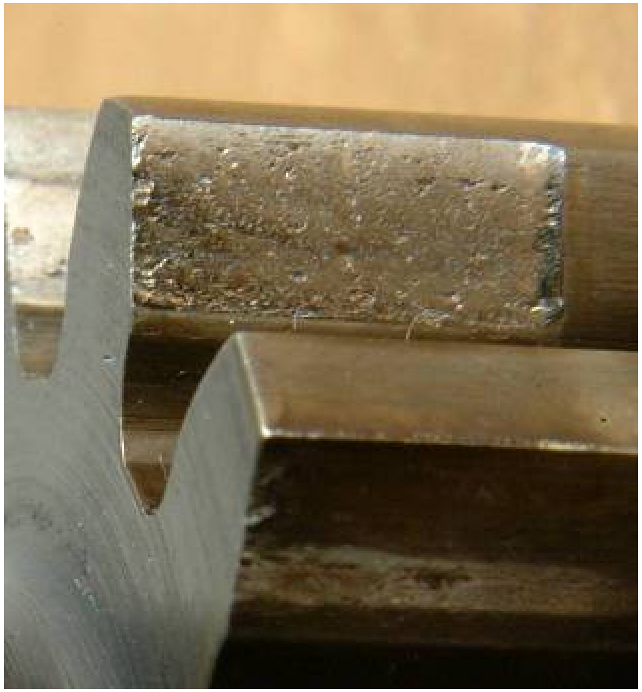
Engine strip investigation – 1 of 3

- Engine selected which had experienced 4 EDFP coupling failures
- Left hand magneto drive (torsional) damper had failed

Engine strip investigation – 2 of 3

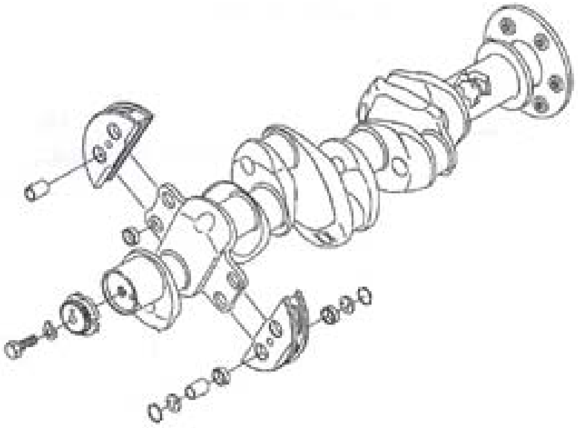
- Excessive wear on accessory drive train
- Gear backlash results are not repeatable



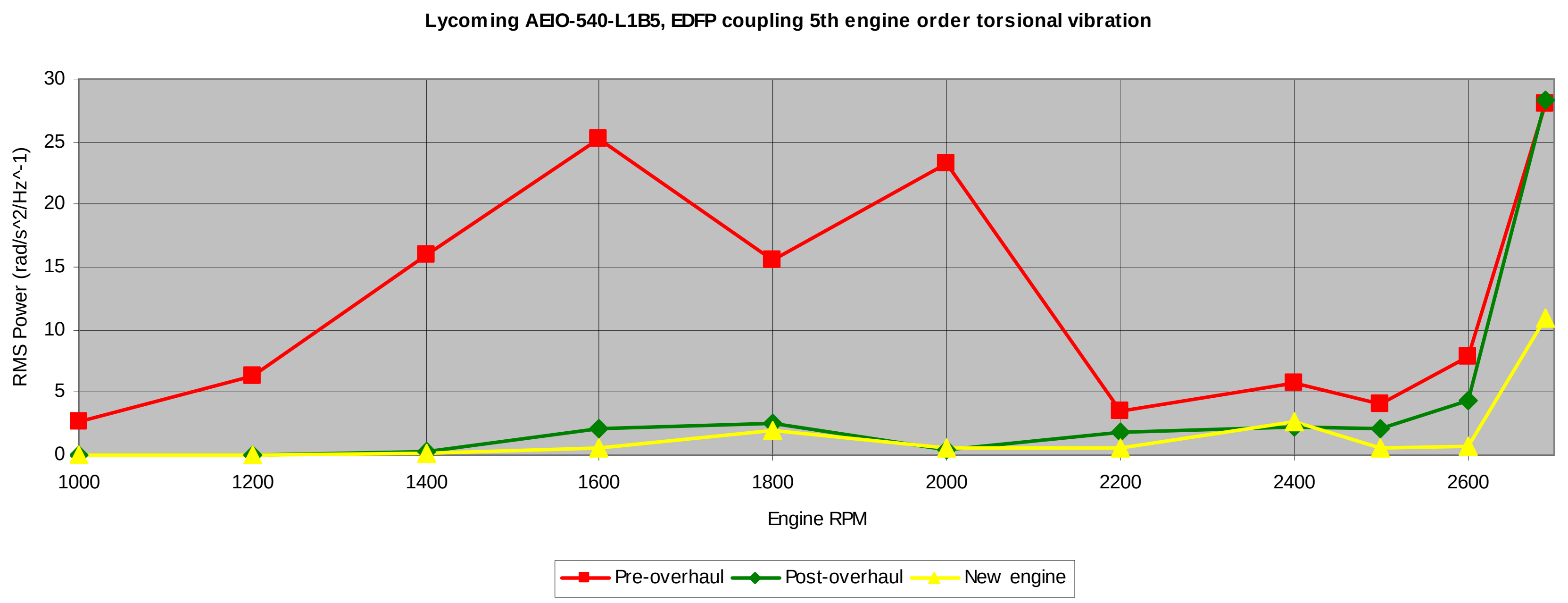


Engine strip investigation – 3 of 3

- Crankshaft and counterweight bushes were worn beyond serviceable limits. One bush, 5 times over the serviceable limits

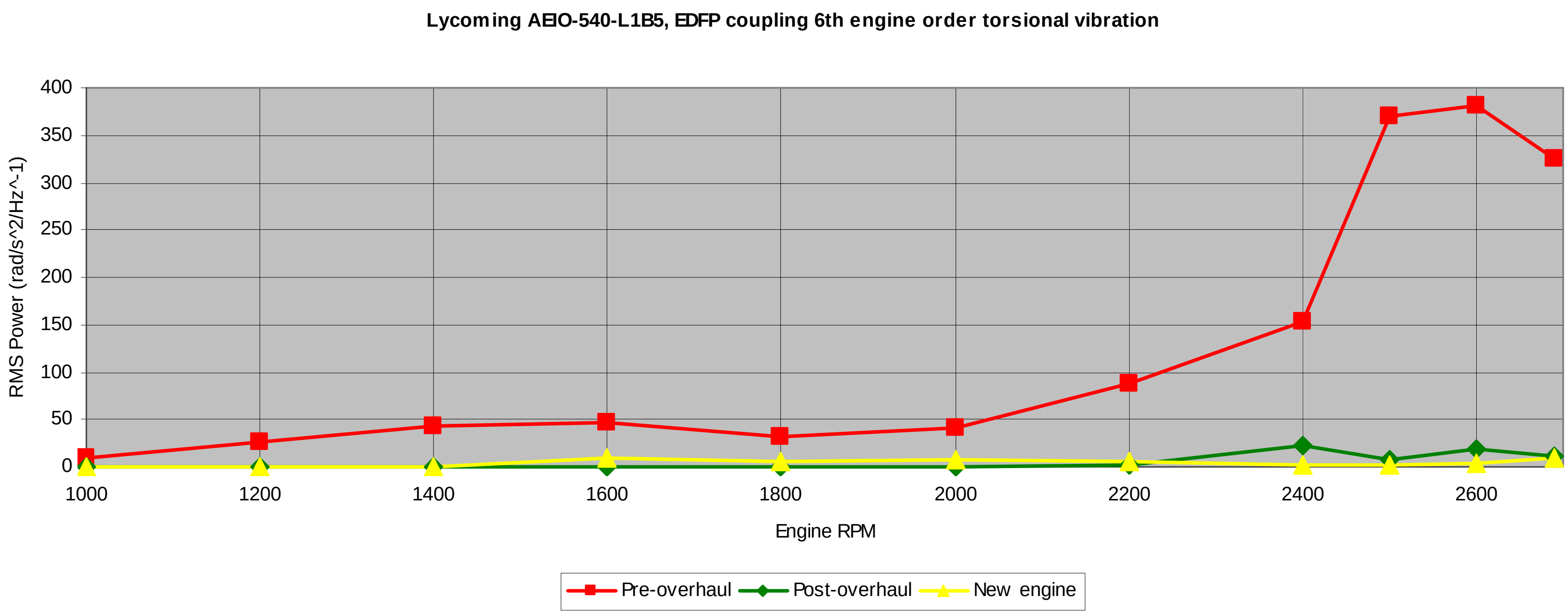


Post-overhaul engine test, 1 of 2



- Significant decrease in 5th engine order torsional vibration, across the entire engine operating range

Post-overhaul engine test, 2 of 2



- Significant decrease in 6th engine order torsional vibration, across the entire engine operating range
- Confirmed the assumption that crankshaft damper condition is the probable cause of EDFP coupling failure

Causal factors

- Textron-Lycoming SB245D (1987), Dynamic Counterweight System Detuning
  - Warns against rapid throttle operation, high engine speed and low manifold pressure
- Aircraft usage profile
  - Training
  - Aerobatics
- No evidence that specific aircraft have been preferentially operated for aerobatics
  - Why do some aircraft have worn counterweight dampers while others do not?
- Overhauls history showed that counterweight bush replacement varied across the fleet of aircraft

OEM guidance

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MANDATORY
SERVICE BULLETIN

DATE: May 25, 2006

Service Bulletin No. 240T
(Supersedes Service Bulletin No. 240S)

SUBJECT: Mandatory Parts Replacement at Normal Overhaul and During Repair or Normal Maintenance

MODELS AFFECTED: All Lycoming reciprocating aircraft engines.

TIME OF COMPLIANCE: As specified below.

<u>AT OVERHAUL:</u>

During overhaul of any Lycoming reciprocating engine, it is mandatory that the following parts be replaced regardless of their apparent condition.

- Counterweight bushings in crankshaft and in counterweights (See latest revision of Service Instructions No. 1142 and 1143 for instructions.)

TEXTRON Lycoming

Williamsport Plant
Textron Lycoming/Subsidiary of Textron Inc.
652 Oliver Street
Williamsport, PA 17701 U.S.A.

SERVICE INSTRUCTION

DATE: April 11, 1988

Service Instruction No. 1143B
(Supersedes Service Instruction No. 1143A)
Engineering Aspects are
FAA Approved

SUBJECT: PART I - Counterweight Bushing Tooling Update.

PART II - Counterweight Bushing Replacement.

MODELS AFFECTED: All Textron Lycoming piston aircraft engines with dynamic counterweights employing 3/4 inch I.D. bushings.

TIME OF COMPLIANCE: During engine overhaul.

Dynamic counterweights are installed on piston engine crankshafts to eliminate vibrations that are caused by torsional frequency changes that occur at different engine speeds and operating conditions. The counterweight is mounted on the crankshaft with two steel rollers that allow the counterweight to move as required to maintain crankshaft balance. Both the counterweight supporting lug of the crankshaft and the counterweight contain hardened steel bushings that are ground to a very smooth and annular finish. If any of these bushings become damaged or worn out of round, the counterweight will become ineffective and cause vibrations that will lead to severe engine damage or failure.

1. Counterweight Bushing Inspection - Wear in the counterweight bushings is usually evident as out-of-round on the inside diameter. Check each bushing with the P/N ST-73 bore gage. The diameter should be between 0.7485 and 0.7505 inch and the out-of-round should not exceed 0.0005 inch. The P/N ST-73 gage can be set with a micrometer. If the diameter of any bushing is oversize or out-of-round all of the bushings in the counterweight must be replaced.

- Mandatory SB reference a condition based SI

Conclusions

- EDFP coupling failure was caused by operation with degraded crankshaft counterweight dampers
- Counterweight degradation can lead to failure of major engine components
- Crankshaft torsional vibration is not easily measured. Gear backlash an ineffective measure
- Accessory gear condition is a measure of accumulated damage
- Flexibility regarding application of mandatory SB240T and SI1143B can lead to default acceptance of airworthiness risk
- SB245D (1987) is pilot centric however pilots may not have visibility of SB. Usage monitoring would be beneficial
- SB245D Dynamic Counterweight System Detuning still appropriate, should be considered when setting TBO.

Questions?

Thanks to the following for their assistance during this investigation

- Aeromotive Limited
- Pacific Aerospace Corporation Limited
- Pilot Training Squadron, RNZAF Base Ohakea
- Central Flying School, RNZAF Base Ohakea