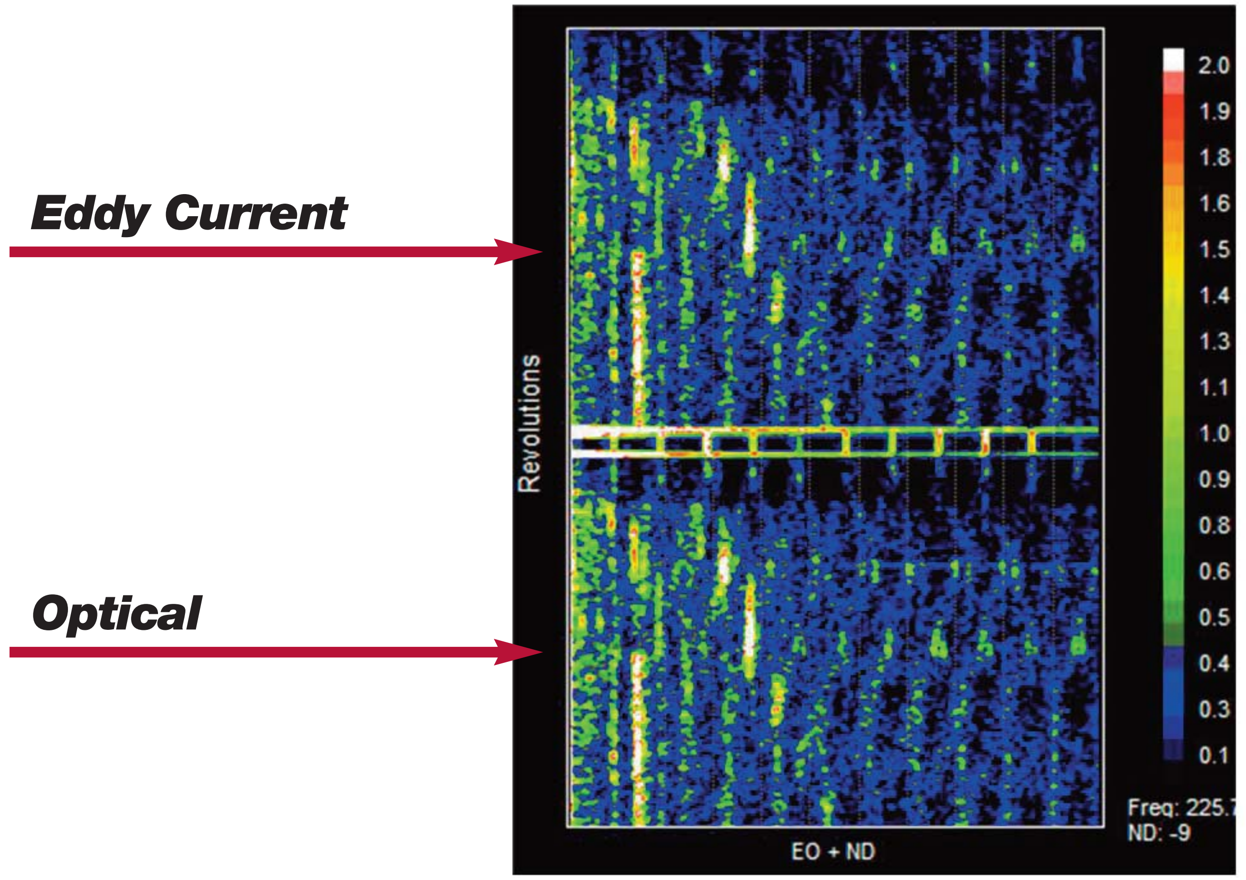

Figure 4: A plot of optical and T^3 blade tip-timing data from the Rolls-Royce tip-timing analysis programme with each plot showing a deceleration. Agreement between the plots is excellent even into the high frequency regions.

Overall, the T^3 demonstrated its effectiveness for in-service tip-timing by:

- Taking measurements equivalent to those derived from optical probes even at high frequencies.
- Taking measurements through casing material of up to 1.5mm thickness.
- Functioning with tip-timing acquisition and analysis systems developed for optical sensors through signal conditioning electronics that allow a triggering connection in real time.

MONITRAN TECHNOLOGY LTD

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About the T^3 Eddy Current Sensor and Driver

Driver unit enclosure:	62.5 x 29.5 x 78.8mm; weight: 0.2kg.
Standard sensor dimensions:	12mm (d) with 25mm diameter mounting flange x 16.5m (h) including 8mm mounting flange.
Driver operating temperature range:	-20 to 85°C.
Sensor operating temperature range:	-20 to 250°C (continuous); -20 to 300°C (intermittent).
Applications:	Monitoring blade health in gas turbines, helicopters, aero engines; gear teeth for cracks and breaks; shafts for twists and eccentricities.

About Monitran Technology

Monitran has been a leading supplier of vibration, displacement and proximity monitoring equipment for over 20 years. During that time the company has established itself as an expert in the field and acquired an unrivalled reputation worldwide for the high quality and reliability of its products.

Now the founders of Monitran have set up Monitran Technology: a new venture that seeks to explore and exploit the growing demand for advanced sensor technology in a wide range of industry sectors – particularly where a substantial element of research and development or joint venture is involved.

Initial projects have made use of recent advances in eddy current technology, while future plans include the enhancement of Monitran's ever-popular range of accelerometers.

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T^3 EDDY CURRENT SENSOR MATCHES OPTICAL BLADE TIP-TIMING SYSTEM PERFORMANCE

Extracted from: THE USE OF EDDY CURRENT SENSORS FOR THE MEASUREMENT OF ROTOR BLADE TIP-TIMING — SENSOR DEVELOPMENT AND ENGINE TESTING by D N Cardwell and KS Chana, QinetiQ Ltd and P Russhard, Rolls-Royce plc Presented at ASME Turbo Expo 2008: Power for Land, Sea and Air

High duality blade tip-timing data for use in engine condition monitoring have been achieved in a series of laboratory and engine tests using the Monitran T^3 eddy current sensor, jointly developed with QinetiQ Ltd.

The T^3 allows measurements of rotor blade arrival times with comparable resolution and bandwidth to industry standard optical blade tip-timing systems – but with significant improvements in terms of durability and immunity to contamination.

The T^3 is immune to flow contamination from dust, dirt, oil and water, and can operate in hotter flow environments. This makes it suitable for in-service monitoring of turbo-machinery blade vibration, a notable step forward from optical systems which, although currently the most widely used in industry, remain susceptible to contamination of the optics and are limited in use to development engine testing.

Background

Monitoring engine components during operation to detect potential failures and predict maintenance requirements is central to the drive to reduce whole life cycle costs of today's modern aircraft, which are required to fly further and faster and having greater aircraft fleet availability front line rejections (red light).

High cycle fatigue, often associated with increases in aerodynamic forcing resulting from blade damage, has a major impact on fleet availability, safety and costs. This makes the detection of changes in blade vibration modes and levels a priority in improving maintenance schedules.

The most advanced and widely used technique to monitor blade vibration levels is blade tip-timing (or non-contact strain measurement). This generally uses optical probes mounted in the blade casing assembly, but only in development testing – the necessity to maintain a clear optical path between the casing and the blade tip makes optical probes unsuitable for in-service use.

The development of robust, easy-to-deploy blade tip-timing probes and associated electronics for use on in-service engines is therefore significant as it will achieve improved probe life, higher temperature capability and better spatial resolution than that currently available.

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Assessing Blade Vibration

The principle on which the optical system operates involves the focusing of a narrow laser light beam on to the passing blade tip, reflecting light back to a photo sensor.

Blade arrival times – the time taken for a particular blade tip to reach the optical probe – are therefore dependent on the blades' rotational speed during normal operation, or the amplitude and frequency of any vibration.

Capture of a particular mode of vibration by a given optical probe depends on the location of the probe with reference to the vibration. Typically measurements are taken towards the leading edge of the blade tip to maintain near maximum sensitivity to the motion of the blade.

About the Tests

Initially trials were carried out at the QinetiQ turbine test facility using three different types of sen sor – eddy current, capacitive and high frequency pressure transducers – against an optical sensor. The eddy current sensor, which is most commonly used for non-contact proximity and displacement measurements in contaminated environments, showed the best promise for further development.

Initial bench tests were carried out on a standard off the shelf eddy current sensor mounted in a pocket to simulate the casing material around the sensor head. Because this had a detrimental effect on performance, the pocket was redesigned with an air cavity around the sensor head. The sensor coil was also remodelled to improve signal output to approximately 10 times that of the original.

This new sensor underwent tip-timing analysis on the first stage 24-blade fan rotor of a Rolls-Royce AE3007 engine running at 8700 rpm (figures 1 and 2).

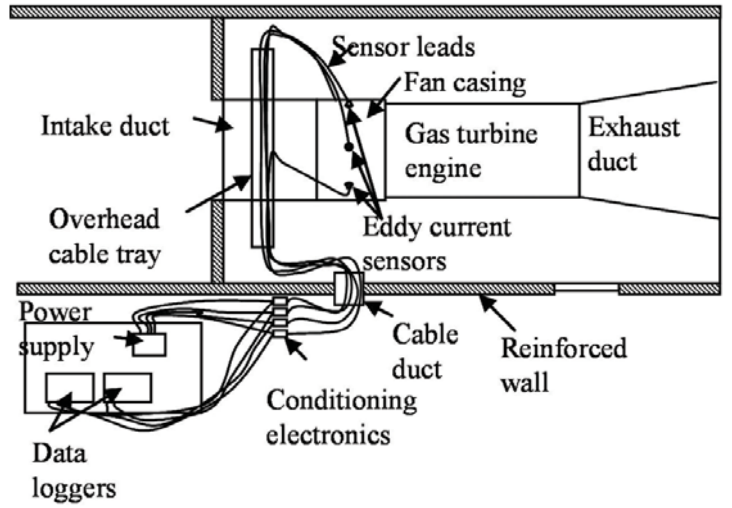

Figure 1: Schematic of the test cell and instrumentation configuration for the tip-timing analysis of the remodelled eddy current sensor on the first stage 24-blade fan rotor of a Rolls-Royce AE3007 engine

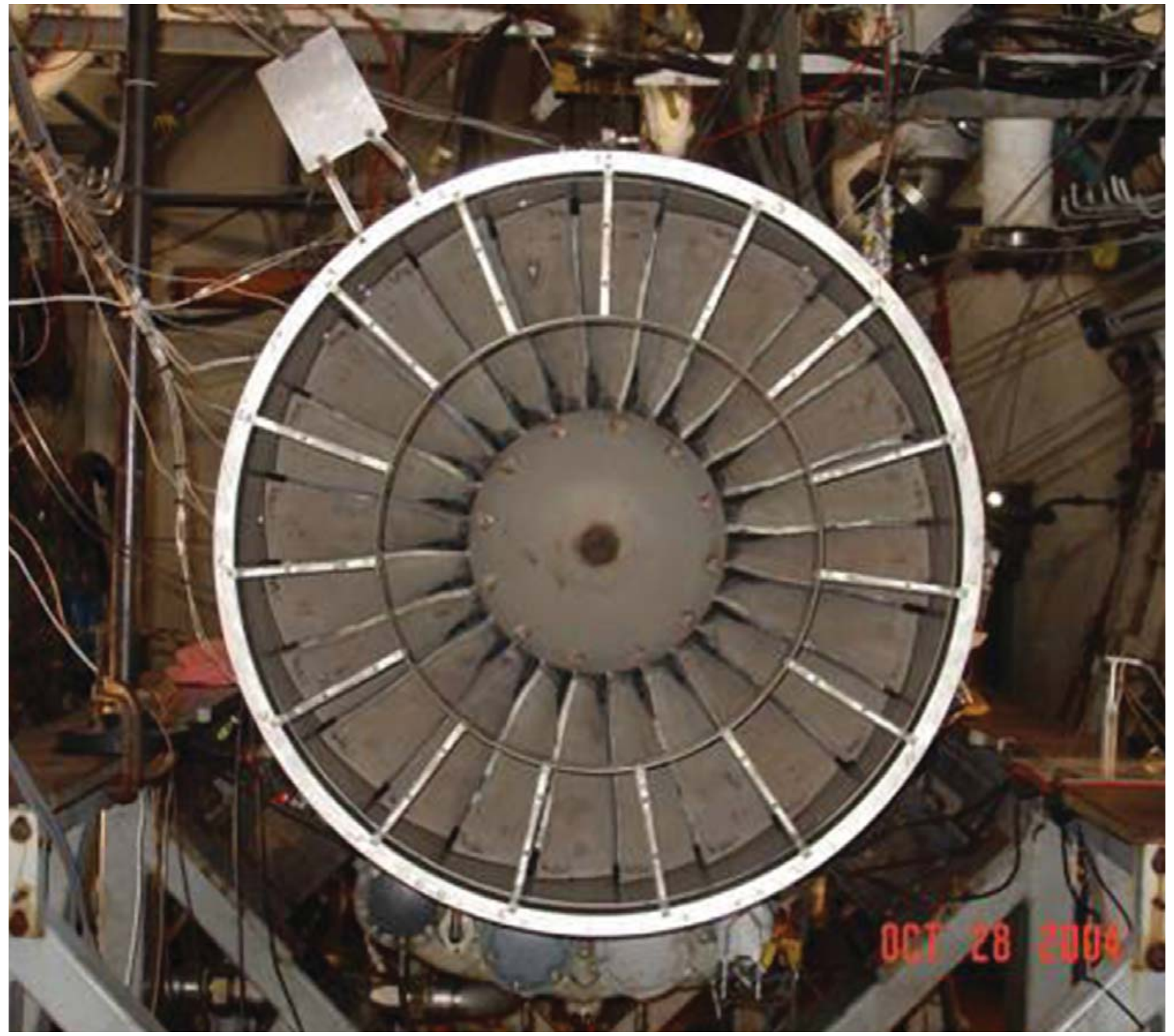

Figure 2: Front view of the Rolls-Royce AE3007 engine in the test cell showing the fan and casing. The sensor pockets are mounted into holes drilled into the fan casing.

The remodelled sensor demonstrated high mechanical integrity and immunity from contamination throughout with no degradation of the signals, and proved itself sufficiently robust to be used without any form of metallic shielding. A final test sensor (the T^3), with a modified coil and driving electronics to improve sensitivity and range, was then tested on a spin facility at Rolls-Royce Derby to simulate tip speed and blade passing frequency against an optical probe (figure 3).

The similarity of the trigger pulse output produced by the analogue electronics of the T^3 and the optical probe confirmed that the T^3 trace could be fed directly into the blade tip-timing system for blade vibration analysis.

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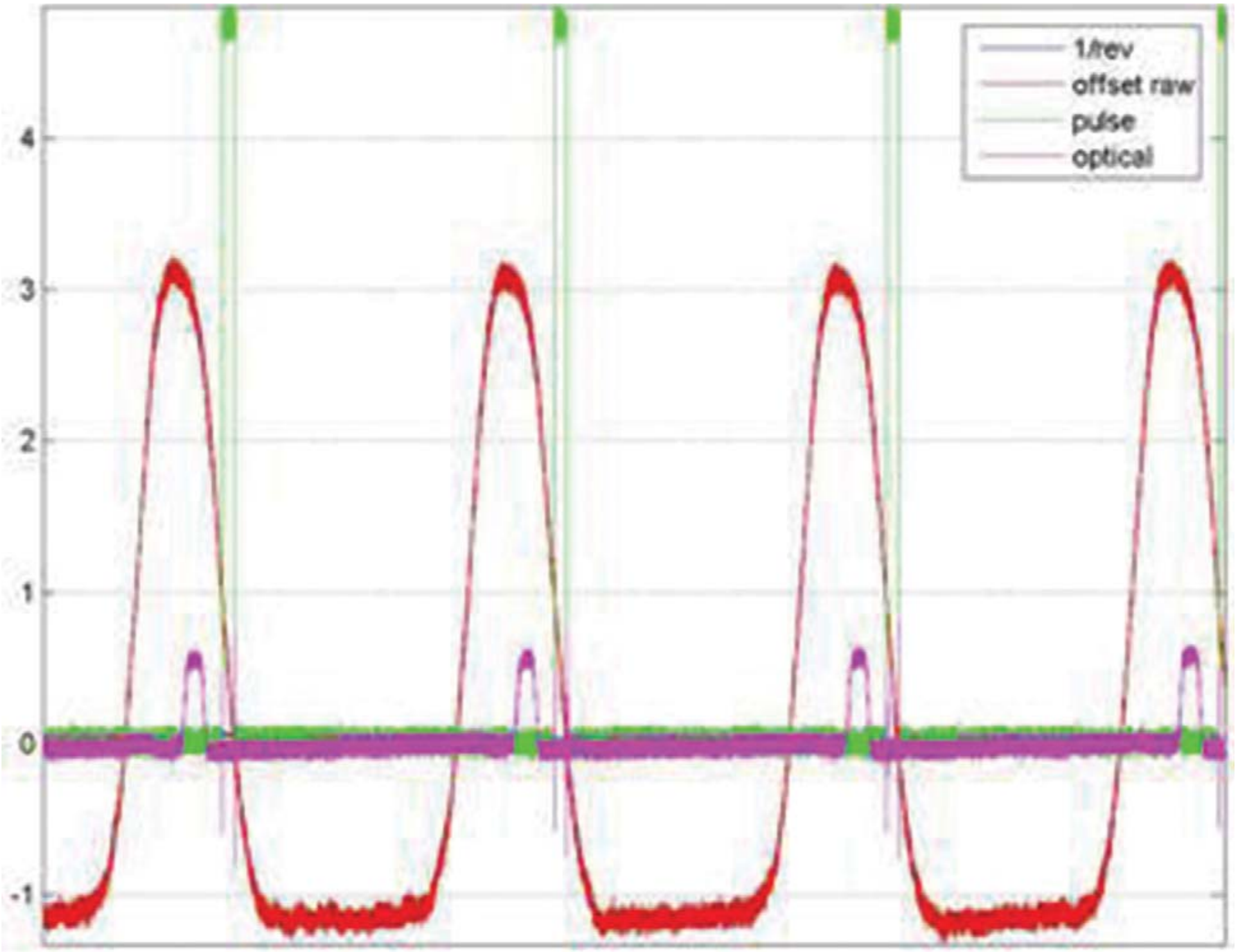

Figure 3: Sensor outputs from spin tests carried out at Rolls-Royce. The red trace shows the raw analogue signal from the T^3, the magenta trace the output from the optical probe and the green trace the trigger pulse produced by the T^3's analogue electronics.

The T^3 underwent more validation tip-timing trials on the open air QinetiQ Spey engine test facility at Shoeburyness.

Here seven eddy current probe locations were machined into the fan casing on both the first and second stage rotor rows of a Spey RB168-101 engine interleaved with five optical probe locations. Six T^3 eddy current sensors and five optical sensors were fitted to measure the blade leading edge on the first two fan rotors.

The eddy current and optical sensor data showed very similar results even into the high frequency regions. Unlike the T^3, however, the optical sensors were affected by rain and suffered severe contamination from the water droplets, dust and dirt.

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