Engine Health Diagnostics Using Radar

David Shephard, Barbara Wright, Gordon Richards
BAE Systems Advanced Technology Centre
West Hanningfield Road
Chelmsford
Essex
UNITED KINGDOM

david.shephard@baesystems.com

ABSTRACT

This paper reviews the work undertaken by the Advanced Technology Centre to demonstrate that low power microwave radar can be utilised for condition monitoring of a jet engine.

The impact of a damaging item of FOD on a highly stressed compressor blade or HCF may often not produce visible damage, but the impact will have altered the stress within the blade. This can drastically alter the life of the blade and possibly instigate early fatigue failure, often with catastrophic effect. This paper postulates that the EHDUR system could be used to monitor both the engine intakes for FOD ingestions and the compressor stages for changes in there vibration characteristics.

The system can be easily fitted to engine test rigs by utilising existing inspection ports. To date the sensors have in excess of 300 hours of rig time.

1.0 ENGINE HEALTH DIAGNOSTICS USING RADAR

BAE SYSTEMS Advanced Technology Centre (ATC) has developed a unique and novel solution to the problem of Jet engine diagnostics and health monitoring. The Engine Health Diagnostics Using Radar (EHDUR) product uses low power, spread spectrum radar technology to provide continuous monitoring of engine performance.

EHDUR is engine type independent allowing standardisation of measurement equipment across multiple platforms. The system provides contactless monitoring of air intake and compressor stages. The modular design utilising COTS technology with data processing performed on a standard PC, enables cost effective upgrade paths to accommodate advances in sensor technology, processing capability and algorithm development.

Developed in partnership with the UK Ministry of Defence, EHDUR provides a measurement capability to accurately determine the health and operating characteristics of an installed jet engine.

Foreign Object Debris (FOD) has a major impact on engine health, performance and lifespan. It has the potential to cause catastrophic engine failure resulting in aircraft and human loss. The EHDUR system includes an Ingestion Debris Monitoring System (IDMS) with the ability to detect and classify ingested FOD events. This enables preventative measures to be taken to reduce the risk of engine failure. With a proven capability to detect, analyse and classify foreign objects entering the air intake, EHDUR can discriminate between damaging and non-damaging objects to inform the maintenance process. This ability reduces the uncertainty inherent in visual engine inspections with direct implications for safe engine

Shephard, D.; Wright, B.; Richards, G. (2005) Engine Health Diagnostics Using Radar. In *Evaluation, Control and Prevention of High Cycle Fatigue in Gas Turbine Engines for Land, Sea and Air Vehicles* (pp. 4-1 – 4-6). Meeting Proceedings RTO-MP-AVT-121, Paper 4. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

operation and maintenance scheduling. The use of conformal radar antennas within the air intake ensures minimal disruption to engine airflow. For military applications the use of ultra low power transmission coupled with spread spectrum techniques ensures no increase in airframe RCS enabling stealth characteristics to be retained.

An engine's operating characteristics will change over time as a result of FOD, vibration and general wear. The effects of High Cycle Fatigue (HCF) leads to a reduction in engine performance and effective operating life. Current techniques used to determine and measure HCF may only be performed on specialised engine test equipment. EHDUR provides the ability to measure and analyse HCF with the engine installed on the aircraft. The sensing antennas enable contactless monitoring of compressor blades and are designed to fit existing inspection ports, thereby minimising disruption to the engine. The system will detect changes in the vibration characteristics of the engine and changes in engine speed with an ability to provide temporal profiles of engine performance. The information obtained from the EHDUR system allows changes in engine characteristics to be taken into account when setting operating profiles for engine usage, thereby increasing engine life, reducing the risk of blade failure and improving maintenance efficiency.

2.0 EXPERIMENTAL PROGRAMME

The current EHDUR system is designed as an instrumentation radar and can be easily installed onto an engine test rig. The electronics are contained in a standard 1 ATR crate and connected to the engine sensors via standard RF cables.

2.1 Foreign Object Detection

For FOD detection the sensors are ideally placed in the intake to obtain clear view of the object as it enters the duct as shown in Figure 1. This enables sufficient characteristics to be measured by the radar to enable detection and classification of the object as damaging or non-damaging. The current waveform is designed to enable the flight dynamics of the FOD to be determined. The classification is achieved by determining if the trajectory is ballistic or aerodynamic. A trials programme was undertaken at a MoD engine test facility in Essex, UK. The test facility is shown in Figure 2. During this work a SPEY 101 jet engine was subjected to seeded ingestions of a wide variety of FOD. Examples of typical FOD are shown in Figure 3 through Figure 6. These trials were successful and showed that a radar based IDMS systems could detect all damaging FOD and correctly classify 82% of the items. The radar based IDMS system is currently assessed as being at TRL 5/6. This work is more fully explained in Reference [1].

2.2 High Cycle Fatigue

The current system is designed to operate as a bi-static radar. The optimal position for blade monitoring is to place the sensors either side of a row of blades as shown in Figure 7. These engine sensors are microwave antennas designed to replace an existing blanking plug used in a standard inspection port. The example shown in Figure 8 was designed for the low pressure stage inspection ports of a Pegasus engine. This antenna design is compact and uses a ceramic material as a dielectric. The current design is specified to 200°C and is suitable for the temperature range experienced in the low pressure compressor stages of an engine. The sensor design is robust and currently has in excess of 300 hours fitted to a Pegasus engine at Rolls Royce. The use of higher temperature dielectric would enable these sensors to be easily fitted into the high pressure compressors or turbine stages of an engine.

The system monitors the engine by analysing the radar reflections from the blades of a specific stage. The motion of the blades past the sensors induces the primary modulation on the radar signal. In addition to this non rotational vibration of the fan blades will induce secondary modulation on the radar signal. An example of the measured signal from a jet engine is shown in Figure 9. In the image the stronger lines are the primary modulation lines due to the blades passing the sensor. The weaker underlying lines we believe are due to blade vibration. The work is currently at the stage of developing a mathematical model of the blade motion and vibration to enable the secondary spectral lines to be associated with specific vibrational modes. This is on going work and will hopefully be published at a future conference. More examples of this work are shown in Reference [2].

3.0 FUTURE DEVELOPMENTS

The work to date has shown that EHDUR has the capability of providing an integrated IDMS and HCF engine monitoring and measurement capability. The system currently has in excess of 300 hours fitted to engine rigs. It is hoped that future trials opportunities will enable the capabilities of this technology to be fully demonstrated.

EHDUR may be easily combined with additional engine monitoring systems to provide comprehensive engine Prognostics and Health Management (PHM). The system may be integrated into new aircraft build or retrofitted to existing engine installations. The EHDUR system could be installed as a permanent engine sensor on operational aircraft, used as an on ground maintenance tool to provide rapid engine characterisation between flights, or used on test rigs to support engine development programmes.

In addition to civil and military aircraft, EHDUR could also be used within alternative environments including marine turbine power plants, vehicle turbines and electrical power generation plants providing the operator with the benefits of increased engine life and reduced maintenance requirements as outlined.

REFERENCES

[1] Foreign Object Detection Using Radar, IEEE Aerospace Conference 2005

[2] Jet Engine Condition Monitoring Using Radar, IEE Aircraft Condition Monitoring 2003

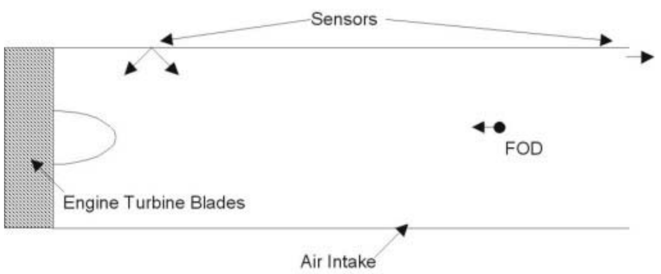

Figure 1: A Typical Air Intake Installation.

Figure 2: Engine Test Facility.

Figure 3: Plastic Bag.

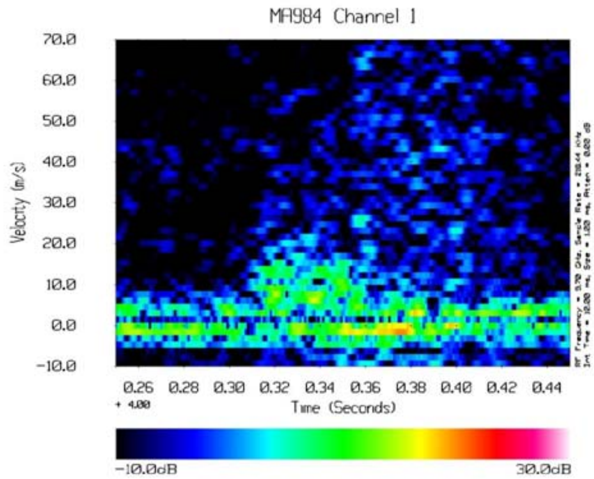

Figure 4: Radar Signature of Plastic Bag.

Figure 5: Tab Washer.

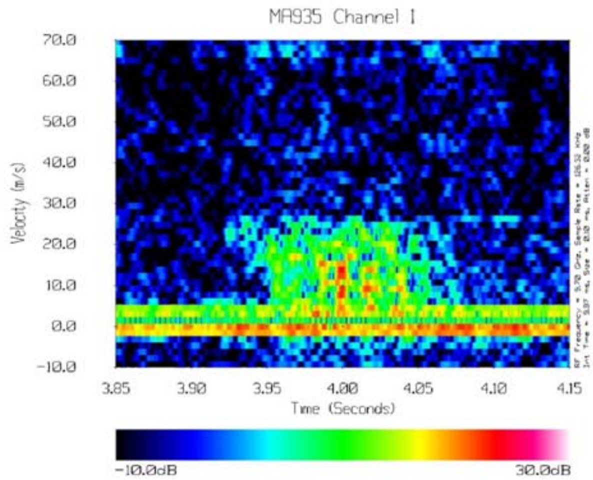

Figure 6: Radar Signature of Tab Washer.

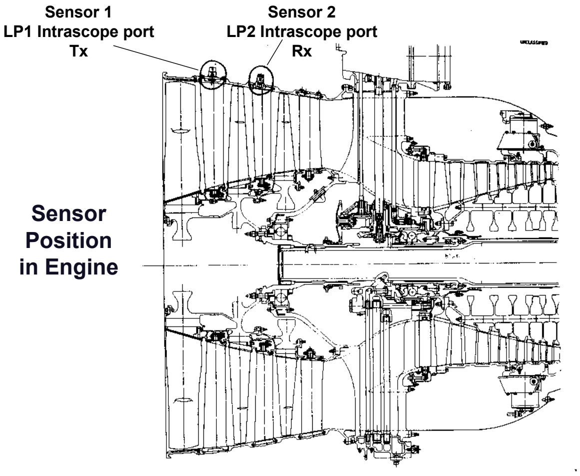

Figure 7: Cross Section of Pegasus Engine.

Figure 8: Intrascope Port Sensor.

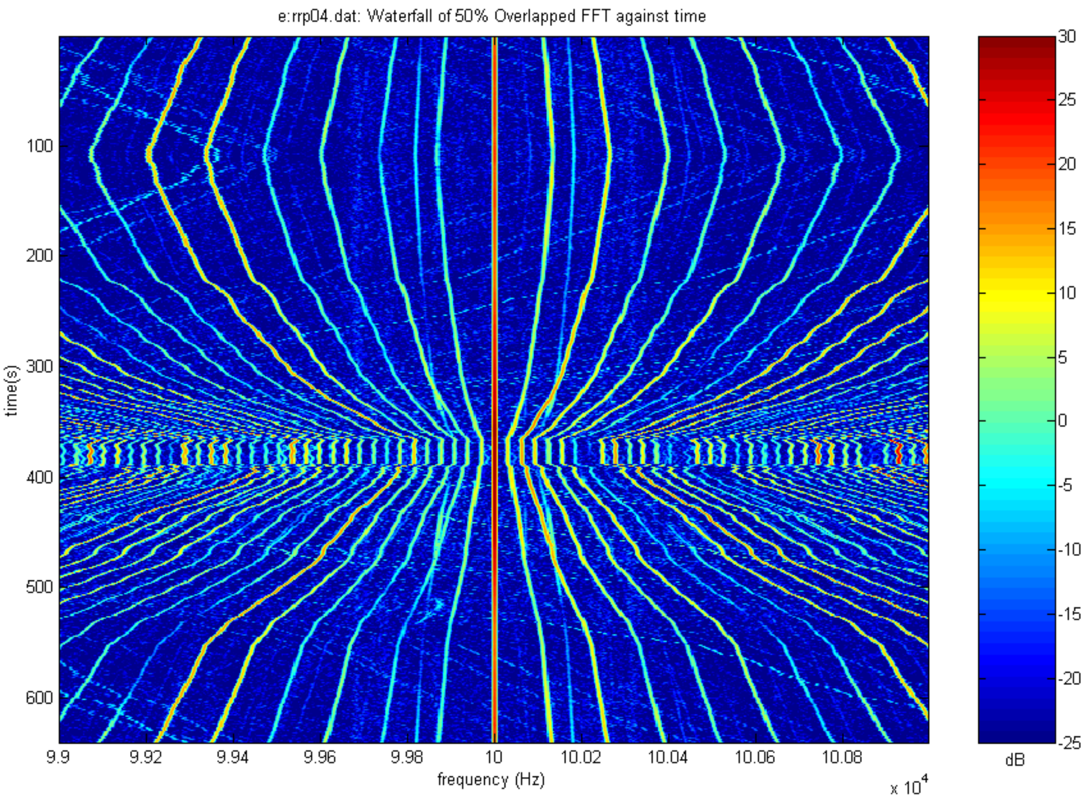

Figure 9: Radar Data Over an Engine Acceleration and Deceleration.

SYMPOSIA DISCUSSION – PAPER NO: 4

Author's name: D. Shephard

Discussor's name: R. Szczepanik

Question: What is the FOD sensitivity of the system?

Answer: We were not able to measure the FOD size on blades. During the trials we used small stones less than 3mm diameter.

Discussor's name: J. Schofield

Question: You stated that you could distinguish between damaging and non-damaging FOD. Clearly one can distinguish between a washer and a plastic bag, but how does one distinguish between damaging and non-damaging FOD for real FOD events?

Answer: WE achieved an 80% success rate in a 'blind' trial.

Discussor's name: H. Pfoertner

Question: Is one sensor sufficient to cover the whole intake area?

Answer: We would put a transmitter in the inlet and a receiver behind the first stage.

Discussor's name: A. von Flotow

Question: Is the time domain signal from the radar sensor clean enough to be used for tip-timing (NSMS) purposes?

Answer: Yes, we think so. But, we have no tip-timing data analysis capability.