Non-invasive Sensing for Aerospace Fuel Systems

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ABSTRACT

An aerospace fuel system contains valves required to operate in inhospitable environments where conventional position sensing cannot achieve the required reliability. This work demonstrates the use of non-invasive, high temperature sensors to monitor valve position.

Novel fuel systems, as required for lean burn combustion, can carry a high risk failure mode. The rapid detection of these failure modes, such as valve sticking or impending sticking would reduce this risk. However, sensing valve state is challenging due to hot environmental temperatures, which result in a low reliability for conventional position sensing. Conventional sensing also requires moving parts that can be prone to induce leaks and other failure modes to the valve.

Acoustic emission (AE) sensing technology is evaluated to provide a non-invasive, remote and high temperature tolerant solution. The fluidic turbulence created by flow through a narrow valve opening can be sensed to determine the valve state. A pilot scale aviation fuel thermal stability rig has been utilised to place passive AE sensors to verify the detection capability of valve state. Data collected from experiments exhibited an acoustic response allowed open and closed states to be distinguished. The sensitivity to different sensor locations and an analysis of the ability to characterise opening time response as well as open / closed state is performed - this is expected to provide diagnostics of incipient fault conditions.

1. INTRODUCTION

Lean premixing of fuel and air is needed for a step change in NOx and smoke performance for high power combustion applications, such as large aerospace gas turbines (Lazik et al. 2008). It is necessary to apply fuel staging for combustor operability: a rich pilot for low power stability; and a lean main zone for minimised NOx and smoke. To realise this advanced combustion process, the fuel system must independently meter fuel into the pilot and main injectors, including several flight cycle operational points where mains fuel is switched on and off. When in off-state, the mains lines need to remain primed with fuel, to allow satisfactory thrust response times, and allow the fuel to circulate to prevent thermal degradation. One potential solution is to include injector check valves, marked as nodes ‘V’ in the example lean burn architecture shown in Figure 1, that prevent flow into the combustor at low pressures needed for the fuel recycling, but open at higher pressures to allow mains flow. A sticking fault in any one valve has implications of combustor temperature profile on engine performance and life. In particular, should any one of these valves fail open, the recycling fuel could enter the combustor raising the local temperature to an unacceptable level causing significantly increased degradation rates. Detection of this event is beneficial to realising this architecture, providing that system constraints on weight, volume, and reliability can be respected.

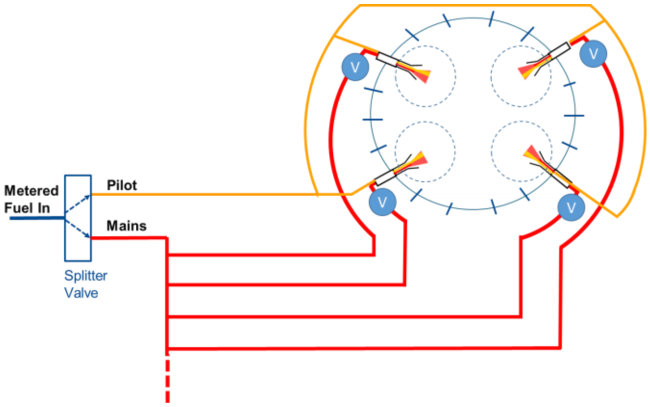

Figure 1: Example staged fuel system architecture shown with four combustion cans and independently controlled pilot and mains fuel manifolds.

The local operating environment imposes challenges to sensing the state of valves or flow in the injector lines. The local temperature, in excess of 700°C, is significantly greater than conventional sensor solutions, which imposes reliability challenges as well as sensor drift and noise inaccuracies, which are explored in the literature review of available solutions. Found to be imperfect, the prior art of passive and non-invasive sensing techniques are reviewed. Following

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Section 2, a novel architecture for passive acoustic sensing is proposed that allows a single transducer to identify flows into the combustor by exploiting the acoustics of the fuel system's flow mechanics. In Section 4, the experimental set-up and results from the valve sensing system is validated on an aerospace fuel thermal stability (AFTS) test rig (Daggett et al. 1995).

2. LITERATURE

This literature evaluates the principle means to sense valve state and liquid flow rate in the context of an aviation fuel system. Prior work to employ sensing in a non-invasive manner is reviewed and suggests that the prior reported successes in acoustic monitoring of flow may be exploited to solve the challenge of check valve fault detection.

2.1. Conventional fuel system sensing

In gas turbines, LVDTs are typically used to measure actuator and valve position by physical connection to the moving component, i.e. the valve spool. Operation within temperature environments in excess of 500°C, and beyond with integrated fuel cooling, are possible with bespoke design, but come with sealing challenges due to need for physical interfacing with the valve spool. Non-contact devices position sensing, such as magneto-resistive or hall effect, ultrasonic and eddy current methods avoid the complications of mechanical linkage to the valve but must still be installed in the extreme temperature environment local to the combustor.

An alternative is to measure the downstream flow rate in the individual injector feed pipes, since a relative change in flow rate in one part of the fuel manifold indicates a stuck position of a valve. Mechanical meters (piston, gear, turbine, etc.) or force-based variable area meters placed in the flow path are a proven but high weight method. Measuring the pressure disruption to flow by a mechanical feature is used in orifice plate meters or those exploiting Venturi effect of restrictions. Turbulent flow disruptions are exploited by vortex shedding meters, which use physical correlation between shedding frequency and flow rate. Potentially less invasive are reflectometry methods that detect flow suspended particles with laser or ultrasonic Doppler measurement. Ultrasonic transducers are also used to measure the effect the movement of the liquid has on time of flight, once temperature sensitivities have been rejected. Thermal mass flow meters, measuring heat transfer rate from source to thermal sensor, these are also called hot wire sensors due to the constant heat flux heating element used to transfer heat into the transport path of the flow. All flow measures suffer from the need to install individual sensors on each line thus presenting recurring cost, increased weight and maintenance burdened on the system.

2.2. Non-invasive and passive concepts

One route to reducing the system impacts is to exploit these concepts but to implement them in a passive fashion, with minimal alteration to the system architecture. Concepts for non-invasive sensing have been explored in many applications (King et al. 2018; Cheng et al. 2010). In our application, the fuel system geometry is designed to transport the commanded metered fuel to each combustor can. The distribution fuel manifold must navigate engine geometry through high temperature environment. It is thus subject to conduction heat into the fuel for the transportation time duration, slower flow is thus expected to heat more for the same temperature differential across the pipe. However, non-invasive measurement of fluid temperature inside of a pipe is challenging and high thermal conduction of the pipe temperature will be hold the pipe wall at the environment temperature (Gorman et al. 2013). The fluid mechanics effects of the piping geometry might also be exploited to identify mains fuel flow into the combustor, this is particularly attractive as the acoustics associated with flow into the combustor might propagate to a single point potentially requiring only one sensor. Depending on the frequency of the acoustics a number of sensing principles and transducer types may be applied: condenser or dynamic microphones, fibre-optics, and various MEMS approaches. At higher frequencies solid pieces of piezo-electric materials maybe used and these provide very high temperature ranges, commercially in excess of 650 °C (Turner et al. 1994; Jiang et al. 2013). The application of acoustic sensing is explored in the next section.

2.3. Acoustic Emissions Sensing in Control Systems

Acoustic emissions health monitoring has been proposed to complement vibrational methods for rotating machinery, such as machine tooling, other rotating machinery and structural integrity (Shiroishi et al. 1997; Inasaki 1998; Harris & Dunegan 1974).

The success of the technique as a health monitoring tool has motivated researchers to explore application to fluidic systems. The detection of leaks has become a standard method (ASTM 1998; Miller et al. 1999) for industry using sensors to detect high frequency material surface waves created by leaking fluid's interaction with pipes and other conduit structures. Health monitoring capability has been demonstrated for large process valves in a nuclear cooling loop (Lazik et al. 2008), where valve leaks were detectable. In Lazik's work, the amplitude of frequency spectrum components, in the frequency range of 100 kHz-225 kHz, were shown to be dependent on pressure and flow rate. Similar results are found in valve leaks simulated in Mostafapour & Davoudi (2013) and Yan et al. (2015). The issues of noise generated by control valve operation is presented in Miller (2017), with the measured acoustic amplitude of flow through a restriction valve found to correlate with flow rate (El-Shorbagy 1983). In Mc Caffrey et al. (2017) the potential to apply acoustic emissions in explosive environments with wireless technologies is shown.

Acoustic emission is an attractive flow detection solution potentially avoiding structural changes or flow disruption and using low-cost high temperature sensors.

3. PASSIVE ACOUSTIC FLOW SENSING DESIGN AND MODELLING

3.1. Concept for passive flow sensing

The overarching process for the passive acoustic measurement of flows is shown in Figure 2. The kinetic energy contained in flow is converted into acoustic energy by its interaction with the geometry of its physical environment (through processes described in the next Section). The acoustic signature is propagated around various lossy transmission paths to a location where the signature may be measured with a sensor with an appropriate frequency response.

Figure 2: Principles for the measurement of fluidic flow by passive means.

For the fuel system of interest, pipe restrictions and valve orifices offer geometric features of interest that may cause the generation of acoustic signature indicating flow through specific pathways of the fuel system.

3.2. Acoustic Energy Generation

There exist three potential mechanisms for fluid flow to generate acoustic signatures in the fuel manifold: flow forces exciting pipe vibration modes; turbulent effects and flow separation; and two-phase flow phenomena such as cavitation.

The pressures imposed on a pipe which is not infinitely stiff can set up excitation at frequency related to the resonance of the structure (Kaneko & Mureithi 2008). This phenomena generates low frequency vibrations, as demonstrated in Evans et al. (2004) to occur with a centre frequency of 6Hz. These low frequency vibrations are likely to be 'lost' in the high vibration environment of a gas turbine system.

It is well known that one of the principle sources of vibration and pressure irregularities are structures in the flow that shed vortices (Blevins 1990), the nature of which are similar regardless of geometry shape but highly dependent on Reynolds number. At high Reynolds numbers, where flow is dominated by fluid inertial forces, but below the supercritical range, periodic shedding frequencies become less regular broadening the frequency content of the shedding phenomena. The vortex shedding behaviour is described by the Strouhal number (S) as a ratio of frequency of vortex shedding (normalised by the characteristic length (L) of the structure in the flow) and fluid velocity (U), Equation 1. The acoustic power (W) generated by these effects is proportional to a power (n>5) of the flow velocity for a given characteristic length (Equation 2), but which has been shown to fluctuate at in the higher Reynolds numbers.

$$f_s = \frac{SU}{L} \qquad \text{Equation 1}$$

$$W \sim U^n L \qquad \text{Equation 2}$$

Typical values of Strouhal number are 0.2 – 0.5 for cylinders in flow. Valve induced vortex shedding experiments (Kaewwaewnoi et al. 2010) have been shown to correlate flow rate to measured acoustic energy (in the range 100–300 kHz) when the flow velocity is raised to n=8 as suggested by the theory of Lighthill (1952) for a freely expanding jet. The phenomena has been shown to occur in control valves (El-Shorbagy 1983), and can also induce resonant whistling for certain geometries (Testud et al. 2009).

The pressure fluctuations associated with the vortices can result in the formation of cavitation bubbles/clouds if the pressure fluctuations are large enough to cause the local pressure to fall below the fluid's vapour pressure. Cavitation is known to generate a broadband range of frequencies up to approximately 15kHz (IEC 2015). For example, two–phase cavitation effects were shown for water passing through an orifice, when the downstream pressure was close to atmospheric pressure (Numachi et al. 1960).

Cavitation is not expected to be present in our system since vapour pressure of kerosene at 180°C is lower than ambient water and the fuel has a bulk downstream pressure of greater than 10 bar. As such, vortex shedding is considered to be the dominant source of higher frequency noise.

3.3. Transmission path

Acoustic energy is dissipated in free space by both a square law 'spreading' of the energy and transfer of its kinetic energy (e.g. conversion to heat). In a fuel system, the acoustic energy transferred into the pipe walls from the turbulent pressure fluctuations is only attenuated in amplitude (A) over distance, d, according to an energy loss described by Equation 3 (Kinsler 2000).

$$A(d) = A_0 e^{-\frac{\alpha}{f}d} \qquad \text{Equation 3}$$

The α/f is a material specific coefficient measured at some frequency, and linearly proportional to frequency. For the rig's stainless steel pipes, α/f is 4.94×10^{-8}, measured at 10 MHz. When expressed in decibels per unit length, convenient for practical application, the value is 8.686α. Thus a 200 kHz frequency will decay by 0.85 dB per meter in steel. For our experiment transmission distances is a maximum of 0.15m thus transmission loss is expected to be insignificant.

3.4. Sensor and Acquisition System

The AFTS rig was originally developed by Rolls-Royce to evaluate fuel thermal decomposition and deposition rates. This rig has been further developed at the University of Sheffield, in conjunction with industry, to include a variety of an aero-engine valves, filters and other fuel system components. Typical operation involves fuel circulation at 20 litres per hour over 300 hours at 180 °C, during which time the various system valves are periodically actuated. Figure 3 shows a subsection of the fuel system containing the flow scheduling valve (FSV), and close to this check valve, the mounting of a housing for a piezo-electric acoustic emission sensor (Mistral WD-HT) that mechanically couples the transducer to the pipework. The sensor is connected to a pre-amplifier and a National Instruments 7855R data acquisition unit recording the data at up to 1M samples per second.

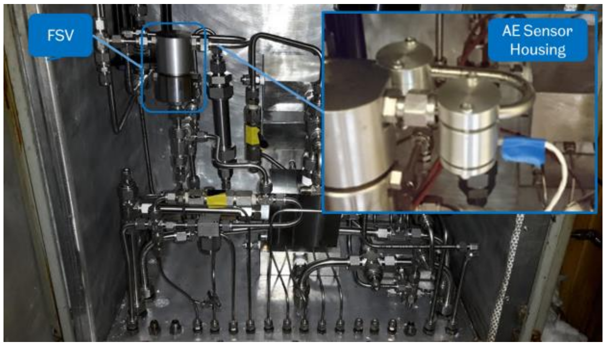

Figure 3: The heated section of AFTS rig containing the flow scheduling valve (FSV) and the acoustic sensor.

4. DATA ANALYSIS

4.1. Experiment Set up

The AFTS rig heats aviation kerosene (JetA-1) fuel (CRC 1983) to 180°C by passing it at a flow rate (q) 20-30 litre per hour through pipework of 0.005m internal diameter (D). At these conditions the fuel has a kinematic viscosity (ν) ~0.2 cSt ($0.2 \times 10^{-6}\, m^2 s^{-1}$) and speed of sound of 1100 ms^{-1}. From this data we can calculate the developed flow velocity (U) and Reynolds number (Re):

$$U = \frac{4}{\pi} * \frac{q}{D^2} = \frac{4}{\pi} * \left(\frac{30}{3600}\right) * \frac{1}{0.005^2} = 340\, ms^{-1}$$

$$Re = \frac{UD}{\nu} = \frac{340 * 0.005}{0.2 * 10^{-6}} = 8.5 * 10^6$$

The rig includes an actuated flow control valve of the same geometry as the production check valve along with an orifice plate used to measure flow rate. The valve and orifice plate in the pipe may be modelled as circular restrictions acting as the vortex shedding features, with a characteristic length of L. Assuming a typical Strouhal number of 0.3, a feature with L equal to the pipe diameter (5mm) in the full flow conditions would estimate the shedding frequencies to be 20.4 kHz (using Equation 1). For an orifice, a reduced area increases the local fluid velocity, i.e. the square of the characteristic length, resulting in an increase in shedding frequency as the cube of orifice size reduction. Thus an orifice of D=2.5mm is expected to produce approximately 200kHz shedding frequencies, though the high Reynold's number is likely to spread acoustic signatures over a broader range. The actuation of the valve has several effects which interact to change shedding frequency: characteristic length, volumetric flow rate, and local velocity over the restriction. It is expected that all frequencies will vary with flow rate as the valve actuates.

4.1. Experimental Analysis

A recording of the acoustic signature for a check valve opening event is shown in the time and frequency domain plots in Figure 4. The valve starts in the closed state, where some low amplitude signatures above 150 kHz can be seen along with some lower frequency artefacts of signal processing. The valve rapidly opens at 1.5 seconds, with an estimated transient time of 0.2 seconds. In the established open condition, a novel frequency at approximately 180 kHz can be seen to emerge along with an increase in the energy at multiple frequencies in the 200kHz-400kHz range. There is only evidence of amplitude, and not frequency, change during valve transients. The measured frequencies are both in line with those found in other literature and consistent with theoretical expectations related to the flow shedding effects from fuel system geometry. There is also a low frequency (c. 1Hz) amplitude oscillation in the open state as described for systems with these Reynolds numbers in Blevins (1990).

It has not been possible to fully validate the correlation acoustic energy to flow rate (Equation 2) due to the poor signal-to-noise ratio of the measured data, though some a monotonic relationship is apparent in Figure 4 and Figure 6.

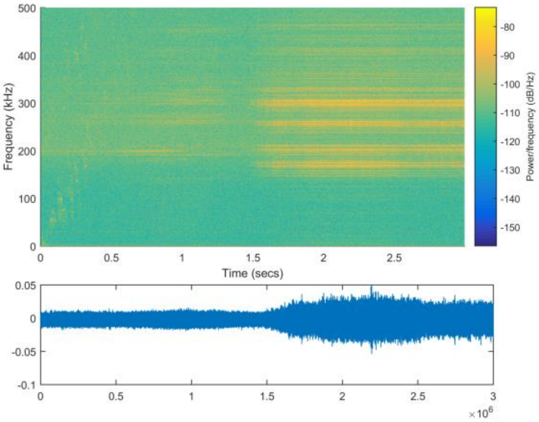

Figure 4: Opening flow scheduling valve response

4.2. Sensor Location Sensitivity Analysis

It is desirable to place the sensor as far as possible from the frequency generating structure in order to establish the most benign operating environment. To evaluate the sensitivity to distance from the valve a set of valve cycling events were triggered with the sensor in different locations, and comparing measured acoustic energy with orifice plate pressure drop (proportional to flow). The locations are labelled P1-P4 in Figure 5 and the broadband energy response are shown in Figure 6. The movement from position P1 to P2 makes no discernible change, and increasing distance from valve with location P3 makes little difference to open behaviour but shows a signature from another (unknown) source when the valve is closed. Positioning the sensor on a different pipeline (P4) erases any detectable signature, as does installing the senor incorrectly in position P2 with a slackened coupling (shown in the figure at time 16.05 in the greyed-out area).

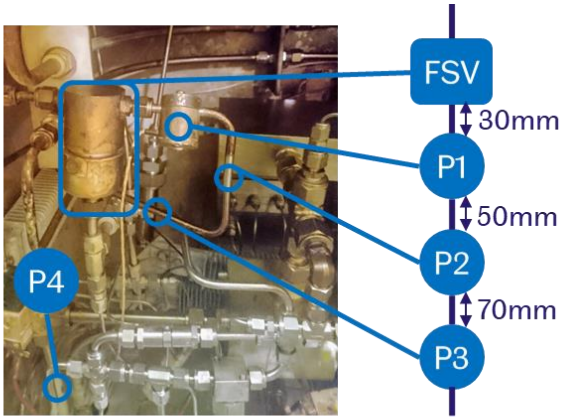

Figure 5: Sensor locations in proximity to Flow Scheduling Valve, where P1, P2 and P3 are increasing distances from valve and P4 is on a different pipe line.

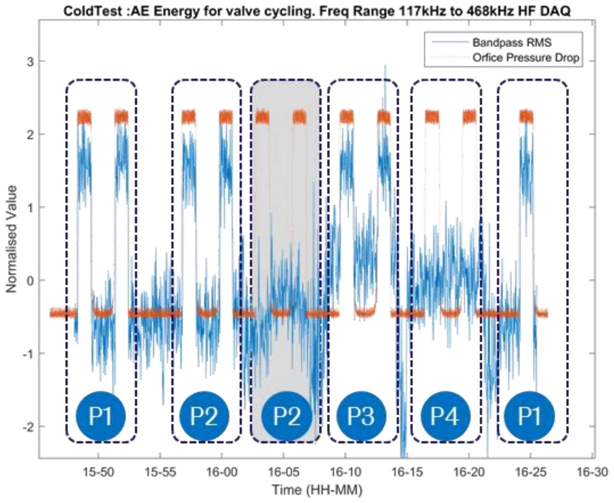

Figure 6: Broadband energy measured for 11 valve cycles for different installations

4.3. Experiment Set up

The sensor was placed in the AFTS rig over a period of 2 years during which time over 2000 hours of operation at temperature have been recorded, with no sensor faults being seen. To enable logging of data over these log periods only nine 3-second snapshots of data during each valve cycling were recorded. The nine snapshots were triggered at consistent time intervals during valve a commanded close-open-close profile, with snapshots 6 & 7 occurring in the valve open state. The snapshots were processed using a bandpass filtered RMS energy measurement and also a frequency domain difference calculation between the snapshot 1 and every other snapshot. Two months of this post processed data is shown in Figure 7, showing a reliable difference between open (snapshots 6 & 7) and closed state.

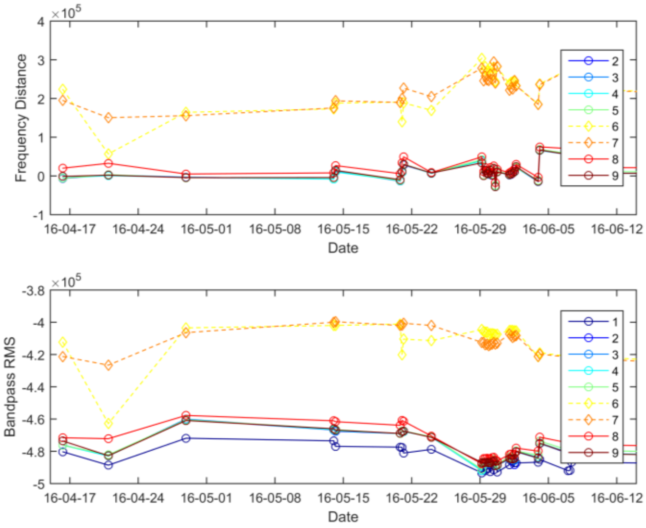

Figure 7: Acoustic spectrum features generated from data snapshots collected between April and June 2016, showing difference between open state (snapshots 6 & 7) and the closed state.

4.4. Capability for Health Management

It is clear that inference of valve positon using the techniques outlined in this paper provide capability for the detection of valve failure, by sensing uncommanded or non-responsive flow rate change. However, for effective health management the detection of incipient faults, which provide sufficient warning of failure, and the trending of such indicators, are needed to enable preventative maintenance policies.

In Eleffendi et al. (2012) we discussed health management strategies for valve diagnosis. The work assumed that a measure of flow / valve position and actuation force were available to observe the static friction growth increasing the required force, F_M, to initiate movement in the valve, which is shown in the valve response a nominal and degraded conditions in Figure 8 generated from the AFTS rig. In the architecture presented in Figure 1, the actuation force is a function of engine pump speed and splitter valve position. Given an indication of when the valve opens (from a detected flow change), a correlation to estimated actuation valve initiation force (F_M) may be calculated and thus trending of frictional force growth. The need for a position or flow sensors, to provide the indication of valve opening, can be eliminated using the method provided in this paper along with the benefits described in Section 1 and 2.

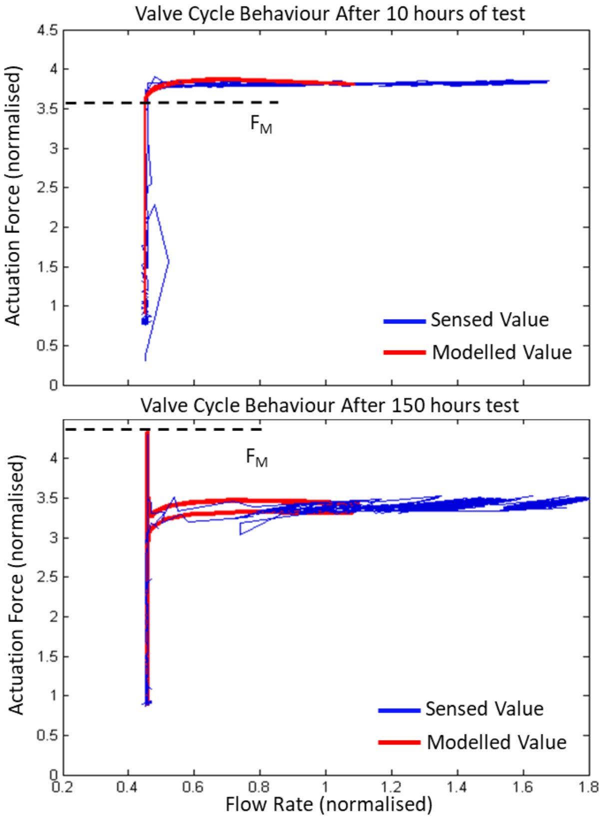

Figure 8: Valve actuation response to before and after fuel endurance testing on the AFTS rig.

5. CONCLUSIONS

5.1. Summary

Detection of fuel system faults can be performed by identifying changes to the flow rate within a fuel manifold using acoustic measurement. Acoustic emission measurements, acquired from an aviation fuel rig, are found to be consistent with theoretical expectations related to the flow shedding effects from fuel system geometry. Algorithms processing these acoustic signatures changes are shown to reliably detect when there is flow through a checking valve by using piezo-electric sensors downstream of the valve. The prototype system has completed 2 years of reliable operation.

5.2. Recommendations

The prototype system has demonstrated that there is potential to locate the sensor at a distance along the pipe from the valve of interest but that the signature requires a fluid geometry feature that generates acoustic energy. The important next step is to deploy the concept to a geometrically representative gas turbine fuel system.

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REFERENCES

ASTM, 1998. *ASTM E1211 / E1211M - 17 Standard Practice for Leak Detection and Location Using Surface-Mounted Acoustic Emission Sensors*, 10.1520/E1211_E1211M-17

Blevins, R.D., 1990. *Flow-induced vibration*, Van Nostrand Reinhold.

Blevins & R.D., 1990. *Flow-induced vibration*, New York, NY (USA); Van Nostrand Reinhold Co., Inc.

Cheng, S., Azarian, M. & Pecht, M., 2010. Sensor systems for prognostics and health management. *Sensors*.

CRC, 1983. *Handbook of aviation fuel properties*, Coordinating Research Council.

Daggett, D. et al., 1995. The Development of an Aviation Fuel Thermal Stability Test Unit. *Journal of Engineering for Gas Turbines and Power*, 117(3), pp.468–474.

El-Shorbagy, K.A., 1983. An investigation into noise radiation from flow control valves with particular reference to flow rate measurement. *Applied Acoustics*, 16(3), pp.169–181.

Eleffendi, M.A., Purshouse, R. & Mills, A.R., 2012. Gas Turbine Fuel Valve Diagnostics. In *IEEE Aerospace Conference*.

Evans, R.P., Blotter, J.D. & Stephens, A.G., 2004. Flow Rate Measurements Using Flow-Induced Pipe Vibration. *Journal of Fluids Engineering*, 126(2), p.280.

Gorman, J.M., Sparrow, E.M. & Abraham, J.P., 2013. Differences between measured pipe wall surface temperatures and internal fluid temperatures. *Case Studies in Thermal Engineering*, 1(1), pp.13–16.

Harris, D.O. & Dunegan, H.L., 1974. Continuous monitoring of fatigue-crack growth by acoustic-emission techniques. *Experimental Mechanics*, 14(2), pp.71–81.

IEC, 2015. *60534-8-4:2015 Prediction of Noise Generated by Hydrodynamic Flow*,

Inasaki, I., 1998. Application of acoustic emission sensor for monitoring machining processes. *Ultrasonics*, 36(1–5), pp.273–281.

Jiang, X. et al., 2013. High-Temperature Piezoelectric Sensing. *Sensors*, 14(1), pp.144–169.

Kaewwaewnoi, W., Prateepasen, A. & Kaewtrakulpong, P., 2010. Investigation of the relationship between internal fluid leakage through a valve and the acoustic emission generated from the leakage. *Measurement*, 43(2), pp.274–282.

Kaneko, S. & Mureithi, N.W., 2008. *Flow-induced vibrations : classifications and lessons from practical experiences*, Elsevier.

King, S.P. et al., 2018. *Equipment health monitoring in compex systems*, Artech House.

Kinsler, L.E., 2000. *Fundamentals of acoustics*, Wiley.

Lazik, W. et al., 2008. Development of Lean-Burn Low-NO. In *Volume 3: Combustion, Fuels and Emissions, Parts A and B*. ASME, pp. 797–807.

Lighthill, M.J., 1952. On Sound Generated Aerodynamically. I. General Theory. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 211(1107), pp.564–587.

Mc Caffrey, C. et al., 2017. Energy Autonomous Wireless Valve Leakage Monitoring System With Acoustic Emission Sensor. *IEEE Transactions on Circuits and Systems I: Regular Papers*, 64(11), pp.2884–2893.

Miller, H.L., 2017. A Brief History of Control Valve Noise Prediction. *Sound and Vibration*.

Miller, R.. et al., 1999. A reference standard for the development of acoustic emission pipeline leak detection techniques. *NDT & E International*, 32(1), pp.1–8.

Mostafapour, A. & Davoudi, S., 2013. Analysis of leakage in high pressure pipe using acoustic emission method. *Applied Acoustics*, 74(3), pp.335–342.

Numachi, F., Yamabe, M. & Ōba, R., 1960. Cavitation Effect on the Discharge Coefficient of the Sharp-Edged Orifice Plate. *Journal of Basic Engineering*, 82(1), p.1.

Shiroishi, J. et al., 1997. Bearing Condition Diagnostics Via Vibration and Acoustic Emission Measurements. *Mechanical Systems and Signal Processing*, 11(5), pp.693–705.

Testud, P. et al., 2009. The whistling potentiality of an orifice in a confined flow using an energetic criterion. *Journal of Sound and Vibration*, 325(4–5), pp.769–780.

Turner, R.C. et al., 1994. Materials for high temperature acoustic and vibration sensors: A review. *Applied Acoustics*, 41(4), pp.299–324.

Yan, J. et al., 2015. Nondestructive Detection of Valves Using Acoustic Emission Technique. *Advances in Materials Science and Engineering*, 2015, pp.1–9.

BIOGRAPHIES

Andrew R Mills (CEng, PhD) is a Senior Research Fellow and Programme Manager for the Rolls-Royce University Technology Centre, which hosts a portfolio of funded research, PhD projects and MSc projects aimed at delivering high quality academic and industrially exploitable research output. Dr Mills is the technical lead on the health management work stream. He is active in the development and application of diagnostic and prognostic techniques and heads the academic effort in developing health management technologies in various Industrial focused projects. After graduating the University of Sheffield with an MEng in Control Systems Engineering, he has worked in the defence industry on aerospace and automotive applications before returning to the University as a researcher and completing his PhD. Current research interests are in the application of control systems engineering principles to a broad range of applied control and health management research challenges.

Dr Simon Blakey is a Senior Lecturer in the Department of Mechanical Engineering at the University of Sheffield and Director of the LCCC. Much of his research activity has focused on the technical suability of alternative fuels for aviation sector and the development of methods for the “fit for purpose” assessment of potential fuels and fuel compositions including combustion performance, with a particular focus on fuel system and fuel compatibility. He has been involved in the following European fuels research programmes: AERONET II, ECATS, ALFABIRD, SWAFEA, and JETSCREEN as well as engine development programmes such as TECC-AE, International fuels research programmes on the development of synthetic fuels in particular the QSTP international consortium and the US Federal Aviation Authority led CLEEN and PARTNER programmes, and the UK national alternative fuels programme: OMEGA. He is the on Alternative Fuels Working Group Leader within ECATS, a European Network of Excellence on Aviation and the Environment. To date he has been involved in research grants from a number of different sources (Industrial funded, EU and Innovate UK), the value of these grants to the research group is £4.8M (£3.8M as principle investigator).

Spiridon Siouris (MRAeS, MAIAA, PhD) is a Research Fellow at the Low Carbon Combustion Centre at Mechanical Engineering of The University of Sheffield. Dr. Siouris graduated with an MEng. in Mechanical Engineering in 2004 and then pursued PhD research in thermal degradation of aviation lubricants. Since then, he has been involved in several research projects in fuel and lubricant thermal degradation from an experimental and modelling perspective, aerodynamics and active flow control in numerical simulation frameworks, and stochastic optimisation for chemical kinetics. His work can be found published in several high impact journals. Currently he is involved in the development of numerical models for prediction of deposition growth due to fouling within fuel systems in aviation gas turbines. He is a member of the Royal Aeronautical Society and the American Institute of Aeronautics and Astronautics.

Visakan Kadirkamanathan received the B.A. degree in electrical and information sciences and the Ph.D. degree in information engineering from the Department of Engineering, Cambridge University, Cambridge, U.K. Following brief postdoctoral research positions at the Universities of Surrey and Cambridge, he was appointed as a Lecturer in the Department of Automatic Control and Systems Engineering at the University of Sheffield, Sheffield, U.K. He is currently a Professor in Signal and Information Processing and is also the Director of the RollsRoyce University Technology Centre for Control and Monitoring Systems Engineering at Sheffield. His research interests are in the areas of modeling, signal processing, and control with applications in aerospace, biomedical, and other dynamic systems. He has published more than 180 papers in peer-reviewed journals and conferences. His professional activities include being the Editor-in-Chief of the International Journal of Systems Science among other conference and journal activities.