Institution: University of Sheffield

Unit of Assessment: 12A - Aeronautical, Mechanical, Chemical and Manufacturing Engineering: **Mechanical Engineering and Advanced Manufacturing**

Title of case study: New vibration damping technology which extends the life of aircraft engine components.

1. Summary of the impact

Research into vibration damping has had a major economic and operational impact on Rolls-Royce resulting in a new design for [*text removed for publication*] engines used on [*text removed for publication*] wide body airliners. This has saved [*text removed for publication*] engine refit costs. The team has also designed a particle damper to reduce vibrations and significantly increase the life of the fuel system [*text removed for publication*].

2. Underpinning research

The research underpinning this case study aims to increase the inherent damping of aeroengine parts, to increase component life. Aero-engines are exposed to high levels of vibration during service. They are safety critical components, their weight must be minimised, and operating costs due to maintenance and inspection operations are a key factor. These issues mean that damping of individual components can provide significant technical advantages.

The work began in the Department of Mechanical Engineering in 1995. It was originally established by Professor Tomlinson and subsequently led by Dr Rongong, both employed by the Department throughout. Financial support for the research was primarily provided by Rolls-Royce. The case study focuses on two damping technologies for aero-engines:

Syntactic foams

Our syntactic foams comprise lightweight microballoons in a polymer matrix and were designed as fillers for hollow titanium blades in aero-engine fan systems. They dissipate vibration energy when subjected to dynamic strains through viscoelasticity in the polymer matrix. Working with chemists at a materials supplier, Huntsman Advanced Materials, we showed that a suitable matrix needs:

- Constituents that have a range of molecular weights to make the transition zone spread over the expected operating range and hence provide damping,
- Adequate cross-linking to maintain static strength and avoid creep,
- Very low viscosity before cure for pumping into cavities.

An important performance parameter of this blade filler material is the temperature range over which good damping characteristics are achieved. As a result of our research, this temperature range increased [*text removed for publication*].

The main role of the microballoons in the material is to reduce density. We used a combination of rigid glass microballoons that increased modulus at high temperature and flexible polymer balloons that improve pre-cure flow. This approach enabled an increase in temperature performance without detriment to the component assembly process. To help select suitable combinations of polymer and microballoons, we developed a model based on homogenisation theory to predict modulus and loss factors for the foam based on the constituents [*text removed for publication*].

We found that to be an effective damper, a blade filler needs to have particular properties as it must be deformed significantly when the blade vibrates. We developed efficient routines to interface with large finite element models at Rolls-Royce that would predict vibration levels in viscoelastic, damped structures under static and rotating conditions. These employed improvements to the classical Modal Strain Energy routine to minimise errors [R3].

Lightweight material used to fill static or rotating blades must have a high level of durability – particularly if it is used in fan blades. We were the first to carry out research into the slow-to-medium strain rate behaviour of syntactic foams over a range of temperatures spanning the transition zone [R4]. This research showed that high durability required adjustments to the cross-linking in the polymer matrix and the properties of the microballoons used.

Particle dampers

The material that can be used on some aero-engine components is severely limited due to the high operating temperature. Consequently the research at Sheffield has also focused on damping technologies that are compatible with this high operating temperature. One example is the particle damper: a container, filled with many small hard particles, which is attached to the vibrating structure. Their performance is affected by many parameters including frequency, amplitude, geometry and the type of particles. This makes them difficult to design and optimise. In 2000, Tomlinson, in collaboration with engineers at Rolls-Royce, started to develop an understanding of particle dampers using experimental methods [R5], that was subsequently extended and published in 2005 [R6]. An important contribution of this work was an explanation of the role of inter-particle friction under different conditions. This understanding enabled the design of particle dampers to be tailored for particular aero-engine applications.

3. References to the research

*References that best indicate the quality of the research are indicated ****

R1. [*text removed for publication*].

R2. [*text removed for publication*].

R3. ***Scarpa F, Landi FP, Rongong JA and Tomlinson GR, "Improving the modal strain energy method for damped structures using a dyadic matrix perturbation approach". Proc. IMechE Part C: Journal of Mechanical Engineering Science, 216(12), 1207-1216, 2002, doi: 10.1243/095440602321029445

R4. ***Tan CS, Rongong JA and Ghassemieh E, "Temperature and strain rate dependence of syntactic foam under tensile and shear loads", Proc. IMechE Part L: Journal of Materials Design and Applications, 227(1), 26-37, 2013, doi: 10.1177/1464420712451962.

R5. Tomlinson GR, Pritchard D and Waering R, "Damping characteristics of particle dampers - some preliminary results", Proc. IMechE Part C: Journal of Mechanical Engineering Science, 215(3), 253-257, 2001, doi: 10.1243/0954406011520661.

R6. ***Liu W, Tomlinson GR and Rongong JA, "The dynamic characterisation of disc geometry particle dampers", Journal of Sound and Vibration, 280(3-5), 849-861, 2005, doi: 10.1016/j.jsv.2003.12.047

4. Details of the impact

A new vibration damping material for hollow blades (Araldite 1641) is now used as a filler for guide vanes on more than 2000 **aircraft engines** [*text removed for publication*]**.**

Fan outlet guide vanes are non-rotating aerofoils that guide air flow from the fan and support the engine core. To minimise weight, vanes [*text removed for publication*] comprise a titanium skin into which lightweight, polymer-based filler is pumped. [*text removed for publication*].

The pathway to impact of our research was straightforward: work on syntactic foams was directly funded by Rolls-Royce with the specific aim of addressing the above problems. The research was in collaboration with Huntsman Advanced Materials, a commercial company specialising in chemicals. The Sheffield group's distinct contribution was to understand how the chemical and microstructural properties of the prototype materials were related to desirable behaviour during component assembly and in-service use. Meanwhile, the Huntsman group contributed the chemical formulation and production of the prototype materials.

[*text removed for publication*] Our findings motivated an iterative development activity [*text removed for publication*] to create a material that would surpass previous materials in damping and be excellent for component assembly, or blade-filling. For each material iteration, we used in-house finite element modelling techniques to specify the properties of the material required and our numerical homogenisation-based model to specify the constituent parts required. Huntsman then produced the material, and we evaluated its performance. The end result was a new commercial syntactic foam comprising a blend of several different polymers reinforced by glass and thermoplastic microballoons. This was marketed by Huntsman as Araldite 1641.

[*text removed for publication*]

The component life is increased by approximately 10%. This has reduced annual maintenance costs for the engine owners/operators

[*text removed for publication*]

A revolutionary fan filled with syntactic foam has been developed [*text removed for publication*]

Full-scale rotation and impact tests carried out by Rolls-Royce on fan blades filled with syntactic foams [*text removed for publication*] showed that viscoelastic filler materials required significant improvements in creep and impact strength if used in rotating blades. To address this, we conducted further research in collaboration with Huntsman (material supply), University of Oxford (very high strain rate tests), University of Nottingham (blade filling methods) and Rolls-Royce [*text removed for publication*]. In addition to material design, our contribution included the understanding of creep and failure of the material [*text removed for publication*] and included the development of bespoke predictive software 'JM63' for performing Finite Element analysis of components that incorporate syntactic foams.

A particle damper for an aero-engine fuel pipe is in use on 580 engines

[*text removed for publication*] Using the understanding gained from our research (e.g. the required mass, shape, particle type and fill ratios), we guided Rolls-Royce engineers in the design of a suitable particle damper [*text removed for publication*]. The economic impact is that this damping technology has been adopted in [*text removed for publication*] more than 580 engines [*text removed for publication*].

5. Sources to corroborate the impact

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