Institution: University of Manchester

Unit of Assessment: UoA13a Metallurgy and Materials

Title of case study: So You Think You Can Design A Jet Engine?! - A Toolkit For Communicating Materials Research

1. Summary of the impact

This prize-winning outreach project exploits our capability in 3D X-ray imaging to showcase our world-leading research activities in aeroengine materials and manufacturing processes, stimulating young people's interest in science and technology by challenging them to design an engine of their own. Involving an extensive schedule of public events, workshops and activity days, as well as a permanent exhibit at Manchester's Museum of Science & Industry, the project has engaged and enthused hundreds of thousands of members of the public. These outreach activities were recognised by the Royal Academy of Engineering through the award of its Nexia Solutions Education Innovation prize.

2. Underpinning research

The key academics leading this activity and the periods over which they have contributed to the work are:

- Professor P.J. Withers: 1998 – present (residual stress),
  Professor M. Preuss: Post Doc 1999 - 04; Lecturer 2004 - 2011; Chair 2011 - present (Ti alloys and friction welding)
- Dr J. Quinta da Fonseca: PDRA 2004-2008; Lecturer 2008 – present (deformation)
- Professor P. Xiao: Lecturer: 2004 - 2008, Chair 2008 – present (thermal barrier coatings)
- Dr Kevin Tan: PDRA 2002-2011

The impact is based on research in the School of Materials into aeroengine materials and 3D X-ray tomography. The aeroengine research was initiated in 1999 when JIF/EPSRC funding enabled the establishment of the Stress and Damage Characterisation Unit, now an internationally recognised centre of excellence for residual stress characterisation. In 2007, the Henry Moseley X-ray Imaging Facility was set up through an EPSRC grant; the Facility contains 7 X-ray scanners, the widest range of laboratory CT systems in the UK. Research into materials for use in jet engines includes:

- Working with samples joined using industrial-scale inertia welding equipment at Manufacturing Technology Inc (MTI) in the USA and at Rolls-Royce, we were able to characterise the steep microstructural gradients and residual stresses introduced by a new process, namely inertia rotational welding, developed specifically to join the next generation of high γ' containing RR1000 Ni superalloy discs for jet engines. Using the ISIS neutron source we were able to carry across optimised treatments from small prototype tests to a full scale disc assembly [1, 6]. A key finding was that the new high γ' containing alloys generate larger residual stresses and require higher post-weld heat treatments than conventional alloys.
- Linear friction welding has been proposed as a method for joining single crystal blades to discs for jet engines. We were the first to measure the residual stresses and effects of crystal orientation on weldability and microstructural evolution [2].
- We were able to develop novel high resolution sub-surface mapping of residual stress by synchrotron diffraction to determine the residual stresses introduced by laser peening in both plates and jet engine fan blade roots [3]. We were able to show how, unlike conventional shot peening, laser peening produces stresses deep into the blade roots that are resistant to fretting in-service.
- Our X-ray facility is specially designed for in situ imaging of engineering materials and components across a wide range of environments, timescales and length scales [5]. We were the first to develop techniques able to monitor in 3D how the development of a thermally-grown oxide sub-surface at the ceramic top-coat/metal-bond coat interface of a

jet engine turbine blade leads to flaws that ultimately cause spalling of the coating [4].

3. References to the research

The research has been published in leading international Journals such as *Metallurgical and Materials Transactions A* and *Reports on Progress in Physics*, and has received a significant number of citations listed on the Web of Science. Recognition of the quality of this research coupled with the associated outreach activities led in part to the award of the Armourers & Brasiers' Company Prize, Royal Society, London 2010 to Professor Philip Withers.

Key References Indicating the Quality of the Research

1. Preuss, M., J. Pang, P.J. Withers, and G.J. Baxter, Inertia Welding Nickel-based Superalloy. Part I: Metallurgical Development, *Metallurgical and Materials Transactions*, 2002. 33A: p. 3215-25 (32 citations) DOI:10.1007/s11661-002-0307-y
2. Karadge, M., M. Preuss, P.J. Withers, and S. Bray, Importance of Crystal Orientation in Linear Friction Joining of Single Crystal to Polycrystalline Nickel-Based Superalloys. *Materials Science and Engineering* A, 2008. 491: p. 446-453. (20 citations) DOI:10.1016/j.msea.2008.04.064
3. King, A., A. Steuwer, C. Woodward, and P.J. Withers, Effects of Fatigue and Fretting on Residual Stresses Introduced by Laser Shock Peening. *Materials Science and Engineering*, 2006. 435-6: p. 12-18. (29 citations) DOI:10.1016/j.msea.2006.07.020

Other References

4. Zhao, Y., A. Shinmi, X. Zhao, P.J. Withers, N. Markocsan, P. Nylen and P. Xiao, Investigation of Interfacial Properties of Atmospheric Plasma Sprayed Thermal Barrier Coatings with Four-Point Bending and Computed Tomography Techniques. *Surface & Coatings Technology*. 2012. 206(23): p. 4922-4929 (4 citations) DOI:10.1016/j.surfcoat.2012.05.099
5. Withers, P.J., Residual Stress and its Role in Failure, *Reports on Progress in Physics*, 2007. 70: p. 2211-2264 (83 citations). DOI:10.1088/0034-4885/70/12/R04
6. Karadge, M., B. Grant, P.J. Withers, G. Baxter, and M. Preuss, Thermal Relaxation of Residual Stresses in Nickel-Based Superalloy Inertia Friction Welds. *Metallurgical and Materials Transactions*, 2011. 42A(8): p. 2301-2311. (5 citations) DOI:10.1007/s11661-011-0613-3

4. Details of the impact

Context

Engineering is crucial to the Government's strategy to rebalance the UK economy. The sector accounted for a fifth of UK GDP in 2009 and employs over 4.5 million people across nearly half a million businesses representing 24% of UK turnover. In spite of this, there is still a shortage of young people studying STEM subjects, leading to a shortfall in the number of high-quality engineering graduates. Public engagement with our research has led to impacts in public awareness of the impact of science on society and in schoolchildren's interest in STEM subjects.

Pathways to Impact

We have used the state-of-the-art imaging capability developed through our research activities to demonstrate the behaviour of advanced materials and components in a new and exciting way. Our 3D journey through a jet engine entitled '***So You Think You Can Design A Jet Engine***' is an excellent toolkit for enthusing school children and the general public about the wonders of engineering and materials. The University of Manchester, partnering with Rolls-Royce, the Museum of Science & Industry (MOSI), Institute of Materials, Minerals and Mining, Royal Academy of Engineering, Manufacturing Institute, NW Aerospace Alliance and NW Development Agency

have engaged with thousands of schoolchildren, teachers and parents. The toolkit consists of:

- **Interactive 3D stereoscopic journey through a jet engine** – developed in collaboration with Rolls-Royce and based on our research into X-ray imaging, this 3D display allows visitors to explore the interior of a Trent 900 engine from an Airbus A380. Short linked videos explain how the engine design relates to materials research.
- **Jet engine designer software** – reinforces concepts learned about materials selection in engines by allowing young people to design their own engines and see if they can fly.
- **Materials Top Trump Cards** support the jet engine design game by allowing users to compare materials, and can also be used as a separate game of guessing material properties.
- **Augmented reality tools** show materials superimposed with their microstructure.
- **Aviation and Environment** debate pack to debate the global impacts of our science.

Reach and Significance

These public outreach activities have taken place in the 2008-2013 period with thousands of young people and hundreds of teachers, stimulating their interest in science and technology through the variety of different mechanisms listed below These outreach activities were recognised by the Royal Academy of Engineering through the award of its Nexia Solutions Education Innovation prize. The project was also showcased as an exemplar of good practice at two EPSRC PPE regional workshops (Manchester and Birmingham, 2008), and was selected for the Royal Academy of Engineering Exhibition (2009).

Make It in Manufacturing Campaign [A]

The Manufacturing Institute launched the *Make It in Manufacturing* campaign to promote the breadth of exciting and interesting career opportunities the sector can offer to the brightest and best young people. It is the banner for a whole raft of high profile education and awareness raising activities aimed at introducing teenagers to manufacturing and dispelling the many myths that contribute to a negative public image of the sector. In 2009 we participated in Skills North West Make it in Manufacturing Campaign at the Reebok Stadium, Bolton. Of the 15,000 12/13 pupils attending 2,250 participated in the Design a Jet Engine activity over 3 days. After visiting the Make It stand, 70% wanted to know more about careers in Manufacturing and Engineering, 82% would recommend a career in manufacturing and Engineering to a friend and 70% had positively changed their minds about engineering.

Permanent Interactive Display at MOSI [B,C]

To maximise our accessible target audience we partnered with MOSI to enable sustainability of the impact. How to Design a Jet Engine is now on permanent display at the Air & Space Gallery of the Museum of Science & Industry (Manchester). Exposure of the display over the period has been extensive targeting both our primary audience of schools at KS4, as well as secondary audience of family visitors. In the 2010 MOSI report the exhibit was highlighted has been very popular. In 2009 MOSI attracted 600,000 visitors of which 50,000 were educational in nature. The display has also acted as a focal point for 3 Meet the Engineer Family days at MOSI (2009) with 500 visitors spending over an hour each doing interactive challenges and an Environment debate day at Museum of Science & Industry (MOSI), October 2009 for 40 Year 9-11 pupils

Broader Outreach [D]

We have made extensive use of a wide range of different public, school and teaching engagement mechanisms. Examples of these have included large scale public events including: 6 Air shows (Farnborough (2008 - 2012), Southport (2009 - 2011)) ~12,000 total visitors to stand; Big Bang fair (2009, 2010) in partnership with Rolls-Royce – ~9,000 school visitors; and 2 science shows (2009 and 2010) at 'Scientrific', Wrexham Science Festival – ~5,000 visitors. Manchester Science Festival Schools Events along with Science days at Schools and Educator Conferences directly

reached ca. 1,500 students and 200 teachers.

Inspiring the Future [E]

The RAE Ingenious Award funded the training of 30 young engineers in public engagement. The trainees gained practical experience by participating in the public and schools events above. Some 97% of the participants indicated that their presentation skills had improved and that they had increased their interest in public engagement. The success of these outreach activities has led to the development of a follow-on activity based upon School of Materials research on materials for the nuclear power industry: "So you think you know about nuclear energy!" (2010-2014).

5. Sources to corroborate the impact

A. 'Skills NW' 2009 at Reebok Stadium, Bolton (Interactive activity report) comparative and quantitative feedback regarding our exhibit and interactives.
B. Manchester Museum of Science & Industry Assessment report on the 'Journey through a Jet Engine' Project, 2010.
C. Corroborating letter Manchester Science Festival Director, MOSI (dated 16th September 2013) confirming visitor numbers
D. Final Report on EPSRC PPE project:' So you think you can design a jet engine' 2010 that funded much of our outreach development.
E. Final Report on the quantitative and qualitative outcomes of the Ingenious Royal Academy of Engineering Project 2009 – feedback on the training of 30 young engineers in public engagement.