Institution: University of Sheffield

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

Title of case study: Transforming the manufacturing of aero-engine casing components for Rolls-Royce and its supply chain.

1. Summary of the impact

Aeroengine casings are some of the highest value components within the modern gas turbine, since their complex geometries and exotic materials lead to significant manufacturing challenges. The Advanced Manufacturing Research Centre (AMRC) has helped Rolls-Royce to overcome these challenges by developing a novel optimised manufacturing approach for aeroengine casings. This has led to substantial economic impact on Rolls-Royce as the manufacturing time for these components has reduced by up to [*text removed for publication*] saving more than [*text removed for publication*] since 2008. [*text removed for publication*]

2. Underpinning research

Superalloys have been developed for use in aero-engines as they provide high strength and heat resistance, allowing engines to operate in hotter (and hence more efficient) combustion regimes. Unfortunately due to their strength these materials are difficult to machine from both a tool vibration and wear perspective. This problem is exacerbated when the material is used for large thin walled cylindrical sections such as engine casings, due to the high local flexibility of the component. As a result these components are traditionally very costly to manufacture.

Four research activities all performed by AMRC staff, have resulted in a step change in the productivity of casing manufacture:

- In 2008, a novel pneumatic fixture was designed by Geng [R1]. This consists of a moulded polyurethane layer pressed onto the inner wall of the component via pneumatic pressure. [*text removed for publication*].
- The process-damping phenomenon in difficult-to-machine metals (such as titanium and superalloys) was extensively researched [R2-R3], partly funded through EPSRC project EP/D052696/1 (2006-2010). This research showed how machining could be performed at low surface speeds without suffering from high vibrations. The influence of feed rate, tool geometry, and tool dynamics was understood so that optimal machining parameters could be chosen.
- Tool wear mechanisms, and the use of coatings along with ultra-high pressurised coolant systems to enhance tool life were investigated [R4], partly funded by Sandvik Coromant [R5]. This demonstrated the importance of tool geometry, coating and coolant selection on surface integrity and tool life.
- The determination of residual forging stresses and those induced by machining [R6] was used to determine an optimised sequence of manufacturing operations for a given part, ensuring minimum manufacturing cycle times along with a conforming product. This work was undertaken on Rolls-Royce components (part of the SAMULET programme) under the supervision of Turner (2005 – 2012), and in the AMRC Laboratory on funded project work for Sandvik supervised by Sharman (2004-2007).

In developing a manufacturing strategy for a part, these four research areas were brought together by research staff at the AMRC.

3. References to the research

References that best indicate the quality of the research are indicated with asterisks (***).

R1. Geng, Z, Adaptive design of fixture for thin-walled shell/cylindrical components, UK patent P112668GB international publication on 06/03/2007, EU patent P112668EP publication on 23/02/2011, China patent 200880007363.0-07 publication on 13/01/2012 and India patent PCT/GB2008/000745 publication on 20/01/2012.

R2. Yusoff, AR; Turner, S; Taylor, CM; Sims, ND. The role of tool geometry in process damped milling. *International Journal of Advanced Manufacturing Technology,* 2010, 50: 883-895.

R3. *** Sims, N; Turner, S. The influence of feed rate on process damping in milling: Modelling and experiments. *Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture*, 2011, **255**: 799-810. (Winner of the Joseph Whitworth Award 2011).

R4. *** Sharman, ARC; Hughes, JI; Ridgway, K. Surface integrity and tool life when turning Inconel 718 using ultra-high pressure and flood coolant systems. *Proceedings of The Institution Of Mechanical Engineers Part B-Journal Of Engineering Manufacture.* 2008, 222: 653-664.

R5. *** Krain, HR; Sharman, ARC; Ridgway, K. Optimisation of tool life and productivity when end milling Inconel 718TM. *Journal of Materials Processing Technology,* 2007, 189: 153-161.

R6. Sharman, ARC; Hughes, JI; Ridgway, K. An analysis of the residual stresses generated in Inconel 718 (TM) when turning. *Journal of Materials Processing Technology,* 2006, 173: 359-367.

4. Details of the impact

Rolls-Royce identified a need to develop a world class manufacturing solution for its aero-engine casing components and consequently, initiated a project at the AMRC within the remit of the Environmentally Friendly Engine (EFE) programme [S1]. This £95M initiative included research into ‘Novel high temperature materials and associated manufacturing processes’ [S2], which provided a suitable platform to develop the Technology Readiness Level of the underpinning research.

The AMRC’s role was to deliver [*text removed for publication*] prototype engine casings to Rolls-Royce, and to quantify the cost savings that could be achieved by developing and integrating the underpinning research topics [S1]:

- [*text removed for publication*]
- [*text removed for publication*]
- [*text removed for publication*]

[*text removed for publication*]

Based upon this result, Rolls-Royce worked with the AMRC to implement the novel machining approaches across a wide range of their commercial product range. This has led to economic impact:

£[*text removed for publication*] **saved by adopting new processes (economic impact)**

> *“[text removed for publication]. The AMRC staff demonstrated how their novel machining approaches could be applied to this component. Subsequently, [text removed for publication] has implemented the AMRC’s manufacturing methodology and has achieved an estimated cost saving of [text removed for publication] across all the components manufactured between 2008 and July 2013.” [S1].*

[*text removed for publication*].

Adoption of new processes (economic impact)

> *“In June 2010, the AMRC worked with our casings manufacturing facility at [text removed for publication], to implement their novel approach on the [text removed for publication] casing. A [text removed for publication] reduction in the component cycle time was achieved.” [S1].*

[*text removed for publication*].

Adoption of new processes (economic impact)

*"From November 2010, the AMRC worked with our casings manufacturing team to design the machining process for an engine casing for the [*text removed for publication*]. This has demonstrated a cycle time reduction of [*text removed for publication*] and cost savings of [*text removed for publication*] per component. [*text removed for publication*]." [S1].*

[*text removed for publication*].

In addition to this direct impact on Rolls-Royce business, the underpinning research has had the following broader impact:

Impact on best practice: Sandvik published new technical guidelines for their customers

The underpinning research work undertaken into machining of heat resistant superalloys was extended to conventional carbide tooling undertaken in conjunction with Sandvik Coromant. The results of this activity have been translated into Sandvik Best Practice Guide for machining of casings made from heat resistant superalloys [S3]. This guide is downloadable from the Sandvik website, and also provides the foundation of the training provided to their global application engineering team in this area.

Impact on society: MANTRA

The AMRC was awarded the EPSRC's 2007 Knowledge Transfer Challenge [S4] (£500k), which funded the MANufacturing Technology Transporter (MANTRA). During the period 2008 to July 2013, MANTRA has hosted nearly 18,000 visitors from the general public, and has visited over 100 schools and colleges. MANTRA visited the palace of Westminster on two occasions to promote the impact of industrial research on the UK High Value Manufacturing sector [S5]. The underpinning research from this case study has been used in the MANTRA project, as reported by the EPSRC:

"… highlights of advanced research which are in clear demand from industry are among its [MANTRA's] features. A way of machining more efficiently resulting from university work with Rolls-Royce allows material to be removed from the casings nearly 20 times faster than usual…" [S6].

Impact on the environment: Environmentally Friendly Engines

The operational practice of Rolls-Royce has been changed to help achieve environmental objectives. This is evidenced by the AMRC's role in the environmentally friendly engine (EFE) programme: a technology demonstrator project to help Rolls-Royce to meet stricter environmental standards set by the Advisory Council for Aeronautics Research in Europe (ACARE 2020) [S2]. These standards include a 50% reduction in CO_2 emissions, and an 80% cut in NOx emissions. Four prototype engine casings were delivered to Rolls-Royce as part of the EFE programme [S1].

5. Sources to corroborate the impact

S1. Letter from Rolls-Royce (held on file). This can corroborate the testimonials and facts directly cited in Section 4.

S2. Pages 1-2, Letter to Member State, EU State aid case number N 193/2006: Large R&D aid to Rolls-Royce et al., Environmentally Friendly Engine (EFE), http://ec.europa.eu/eu_law/state_aids/comp-2006/n193-06.pdf (held on file). This provides evidence of the EFE programme, its value, and its emissions targets. Page 3: Total eligible costs will be £ 94 946 489. Page 2: A 50% cut in carbon dioxide (CO_2) emissions.

S3. Heat Resistant Superalloys Machining Guide http://www.sandvik.coromant.com/sitecollectiondocuments/downloads/global/technical guides/en-gb/c-2920-034.pdf (held on file). This provides evidence of the new technical guidelines. Acknowledgment of the AMRC's input appears on the penultimate page.

S4. http://www.epsrc.ac.uk/newsevents/news/2007/Pages/knowledgetransferchallenge.aspx (held on file). This provides evidence of the EPSRC funding for MANTRA, and the link with the casings research.

S5. Internal data (held on file), collected by MANTRA coordinators.

S6. EPSRC Annual Report and Accounts 2009-10, p43 (Economic and Societal Impact Case Studies). http://www.epsrc.ac.uk/newsevents/pubs/corporate/annualreport/annualreport0910/economicimpact/casestudies/Pages/mantra.aspx (held on file). This provides evidence of MANTRA's relationship with the underpinning research, as quoted in Section 4.