Manufacture of a small demonstrator aero-engine entirely through additive manufacturing (Aero-engine)

Additive manufacturing (AM) of metals covers a rapidly growing series of technologies aimed at fabricating components layer-by-layer directly from CAD files. This allows extraordinary design freedoms, reduced material waste and less energy consumption relative to traditional manufacturing. The technologies explored in this project are grouped by their energy sources into three complementary categories: laser additive manufacturing (LAM), electron beam melting (EBM) and high-speed cold spray (CS). Each technology has its own advantages and disadvantages with respect to factors such as alloys of choice, productivity, surface finish, microstructure, mechanical properties and geometrical complexity.

This SIEF research project was awarded to Prof Xinhua Wu of Monash University and included research partners at Deakin University, CSIRO, Safran Power Units and Amaero Engineering. The rationale was to look at all 13 conventionally manufactured components of an old Saphir 42 / Dassault Falcon 20 auxiliary power unit aero-engine from Safran Power Units and decide whether it was possible to manufacture each of these by LAM, EBM and/or CS. At the start of the project, CAD files of all the components were generated from old engineering drawings and/or by scanning parts that were originally fabricated from cast or wrought products. Meanwhile, decisions were made about the most suitable AM technology for each component, based on factors such as alloys of choice, property requirements and geometrical complexity. For some components, two or more materials and/or AM technologies were trialled. Alloys of choice were primarily aluminium alloy A357 (Al-7Si-Mg) for cold sections, Ni-based superalloy Hastelloy X for hot sections and Ti-6Al-4V for other parts of the aero-engine.

Apart from aiming to build the world's first complete aero-engine entirely by AM, the project also focused on developing a user-friendly interface to enable engineers to conveniently re-design components specifically for AM in the future. This included large modelling / simulation efforts at Deakin and Monash to enable superfluous material to be removed from lightly stressed regions of components via advanced topology optimisation and stress modelling methodologies to achieve weight savings without impairing the performance of the components in any way.
Furthermore, the project provided a unique opportunity to integrate fundamental science with education, advanced manufacturing, complex engineering and the aerospace supply chain. The whole value chain from Australia's Ti mineral resource to Ti powder production and Ti aero-engine component fabrication by AM was examined and streamlined from a waste reduction perspective primarily by CSIRO, though LAM was carried out at Monash. The whole project therefore spanned the full spectrum from fundamental research by PhD students and scientists to various engineering solutions and the commercial manufacturing of components by Amaero Engineering.

The project has thereby contributed significantly towards positioning Australia as one of the leading contenders in a rapidly growing global AM market. This has been reinforced by the considerable amount of publicity that has been generated around the world ever since the additively manufactured aero engine was first displayed at the Avalon and Paris air shows in 2015. More recently, this led to the launch of the Monash-Amaero-Safran Power Units commercial partnership at the Australian Embassy in Paris on 8th November 2016 (with significant associated publicity). This demonstrates the uptake and adoption of AM by the end user Safran Power Units to achieve improved outcomes such as light weighted components made with fewer processing steps and reduced material waste, and for an Australian SME becomes a qualified supplier to a global aerospace company and sector. A broader impact has also been generated as this aero engine project has stimulated business opportunities for Safran Power Units, Amaero Engineering and a wide range of suppliers/customers, not to mention new spin-off research and commercialisation opportunities for Monash, Deakin and CSIRO.

Further outcomes and impact from the project include the following:

1. The SIEF aero engine itself has made a great impact in that it has generated a lot of publicity and new business opportunities for the partners as the advantages of AM have been demonstrated so tangibly.
2. The 'EzyOpt' software developed within the project is being adopted for AM design purposes.
3. Tangible weight savings have been demonstrated on a number of aero engine components. The re-designed air intake, for example, has now been approved by Safran Power Units and has been manufactured by SLM with a weight saving of >20% relative to the original part. This has resulted in great interest and new projects/funding to re-design other components.
4. The tremendous amount of work done on optimising the processing parameters and thermal treatments for various alloys now enables the partners to produce high integrity components with good and repeatable mechanical properties.
5. The large amount of microstructural and mechanical characterisation of countless samples has led to a more thorough understanding of alloy-processing-microstructure-property relationships in AM, including significant progress in understanding the fatigue performance. Apart from advancing and disseminating scientific knowledge in the field via publications and presentations, this has also provided tools and confidence for end users e.g. to design new AM parts for new engines, including a willingness to explore rotating parts since the fatigue behaviour is now better understood.

Overall, the project outcomes and impact have exceeded the original expectations.