Institution:
Birmingham City University

Unit of Assessment:
11 Computer Science and Informatics (UOA 11)

Title of case study:
Integrating Domain Based Engineering Knowledge in Computational Models to Enhance Design Processes for Engineering Jet Engines at Rolls-Royce.

1. Summary of the impact (indicative maximum 100 words)

Research led by Professor **Chapman** at the Knowledge Based Engineering (KBE) lab has resulted in a thriving partnership with the aerospace division of Rolls-Royce. KBE research captures domain-based knowledge and integrates it into refined computational models with automated tools to enhance design processes for engineering complex systems. This research has contributed to important improvements in the design processes used by Rolls-Royce to achieve substantial benefits in terms of accuracy, efficiency and ease of design and innovation in the development of jet engines. The techniques have also been exploited to enhance decision support processes for sustainable energy.

2. Underpinning research (indicative maximum 500 words)

This case study is underpinned by the research carried out at Birmingham City University during this REF period by **Chapman** who established Knowledge Based Engineering at BCU in 2007. The first goal of this research is to provide a deeper understanding of the processes underlying the development lifecycle of sophisticated technological products, such as components of jet engines, from concepts through design and integration to manufacturing. The second is to engineer better automated tools to support design innovation and enhance product quality, whilst reducing cost and development time. The research exploits the huge potential of virtualisation to create a supporting environment for virtual product development. This relies on careful representation, manipulation and management of reusable engineering knowledge. The representation of product characteristics and engineering knowledge enables the deployment of mature software engineering methods to support the development of complex engineering systems. The potential benefits of adopting this approach are numerous; among which are rapid creation of detailed designs, and ability to examine their properties through extensive low-cost simulations as opposed to slow and expensive testing of real product prototypes. This frees engineers from the burden of routine tasks and allows them to focus on the creative and innovative parts of the design process. The approach also allows the exploration of larger space of design options than would otherwise be possible. However, because these cyber products/components have dual physical representations with complex constraints for compositions and physical assembly, it presents fundamental new research challenges; the solutions of which form the main driver behind this research. Among these are:

(1) Abstraction of product characteristics and their representations in forms that are useful for tools used in the design environment. Object oriented programming classes have been used to implement this abstraction. [R3, R6]
(2) Capturing, storing and accumulating domain based knowledge which is intelligently used in the design, development and production processes with the aim of embodying this knowledge in automated tools to enhance and optimise the whole development lifecycle [R2, R3]
(3) Capturing a repertoire of techniques, constraints and knowledge based on wisdom accumulated through long experience of product development. [R2, R3]
(4) Development of methods for acquiring and structuring enterprise knowledge to support design automation. [R1, R3, R4]
(5) Modelling cyber physical systems that operate in complex and evolving environment [R2,R5,R6].

(6) Developing frameworks in which dual representations of products (cyber and physical) can co-exist and be effectively exploited in the development of better tools. For example, to allow a component to dynamically adapt to changes resulting from interactions with its environment but keeping within physical constraints. [R5]
(7) Developing novel methods based on formal frameworks for the interactions of agents (representing subsystems) with their environment with emphasis on systematically adapting the patterns of interactions to the dynamic evolution of environment. [R5]
(8) Integration of complex systems from components: This is particularly challenging due to high inter-dependencies between subsystems and complex integration constraints in order to form a successful system. [R6]

The formal collaboration with aerospace division of Rolls-Royce has provided immensely valuable opportunities to acquire, structure, and develop sophisticated models for high technology components which can be integrated into complex mission-critical products. The collaboration has resulted in developing a body of specialised knowledge-based engineering focusing on making significant contributions to the design of jet engines that are cheaper, lighter, higher performing and less polluting.

3. References to the research (indicative maximum of six references)

R1. Bochenkov, A., Amini, A., Chapman, C. and Burden, T. (2009) 'A Systematic Approach to Service-Oriented Architecture for Engineering Information Systems', 7th International Conference on Manufacturing Research, ICMR09, University of Warwick, 8-10 September.

R2. Chapman, C. and Amini, A. (2009) 'Virtual Concurrent Engineering Using Knowledge Based Engineering', Conference Proceedings, vol.2, pp. 28-31, edited by D Su, S Zhu and Q Zhang International Conference on Advanced Design and Manufacture, Harbin, China, 24-26 September.

R3. Melville, L. and Chapman, C. (2010) 'Development of decision support tools for integrated bioenergy systems', Symposium for Flexible Automation (ISFA), July 12-14, Tokyo, Japan.

R4. Solanki, M., Skarka, J. and Chapman, C. (2013) 'Linked data for potential algal biomass production'. Semantic Web 4(3): pp. 331-340.

R5. Mordecai, Y., Chapman,C. and Dori, D. (2013) 'Conceptual Modelling of Physical-Informatical Essence Duality of Cyber-Physical Entities'. IEEE International Conference on Systems, Man, and Cybernetics, October 13-16, Manchester.

R6. Thomas, A.M., Vijay, V., Raju, P., Chapman, C., Chima, P., Mathur, A. and Chemaly, A. (2013) 'Parametric virtual laboratory development: A hydropower case study with student perspectives', Advances in Engineering Software, 64, pp. 62-70.

Key Grants:

- 2009-10: Knowledge based partnership, funded by Technology Strategy Board (TSB). PI: **Craig Chapman** and Maria Nicastri (Research Associate). Value: £55K
- 2010-13: Strategic Investment in Low Carbon Engine Technology (SILOET) programme funded by TSB. PI: **Craig Chapman**. Value: 190K
- 2013-15: Strategic Investment in Low Carbon Engine Technology 2 (SILOET2) programme funded by TSB. PI: **Craig Chapman**. Value: 150K
- 2012-12: Hub casting knowledge fusion modelling, funded by Rolls-Royce. PI: Craig Chapman and Pathmeswaran Raju. Value: £26.5K.

PhD Grants:

- 2012-15: "Model & Evaluate Technologies in Virtual Products", funded by Rolls-Royce. PI: **Craig Chapman**. Value: £15K.
- 2012-15: "Computational methods for forging geometry of aero engine discs", funded by

Rolls-Royce. PI: **Craig Chapman**. Value: £15K.

4. Details of the impact (indicative maximum 750 words)

As a leading international company with a high reputation for excellence in engineering, Rolls-Royce has a keen interest in the development of design methods that support creativity and innovation while maintaining high assurance, reducing development time and minimising cost. The collaboration with Rolls-Royce started in 2009 with a TSB funded Knowledge Based Partnership focused on demonstrating the benefits of applying KBE methods to modelling Rolls-Royce's KEY systems, vital control parts of jet engines. The project resulted in several positive outcomes. It contributed to clearer understanding of the complex relationships between components in these systems, allowed larger space for exploring potential designs, enabled efficient integration, and facilitated deployment.

The collaboration with Rolls-Royce was substantially strengthened when the University was selected to enter into a commercial, research activity built around the £90m, Technology Strategy Board funded Strategic Investment in Low Carbon Engine Technology (SILOET) Project. This built on the achievements of the initial project by refining the models of KEY systems and developing service-based architectures to enhance relevant design automation processes. The new architectures integrate various KEY control systems through more efficient workflows of processes that embody specialised KBE concepts.

Economic impact: The project's Research Associate, Maria Nicastri, moved to Rolls-Royce to join a growing group of researchers who have passed through the KBE lab to become permanent members of Rolls-Royce staff.They have joined specialist teams within Rolls-Royce's Design System Engineering division to enable development of KBE solutions to design and engineering problems. By adopting processes based on KBE concepts, Rolls-Royce has gained significant economic benefits through the optimisation of design and manufacturing processes [S1, S2]. As an example, using KBE techniques in the design and development of one aspect of a jet engine has resulted in a reported £0.5M saving through a 40% reduction in overall engineering lead time and a 50% reduction in design staff requirement. Another example focusing on the design of a 3D Aero model from a new specification reduced the time required to accomplish this task from 10 days to one day.

Impact on Professional Practices: Based on the proven benefits demonstrated through the use of KBE at Rolls-Royce, bespoke training in KBE was provided for Rolls-Royce's technical engineering teams.

Educational Impact: Aspects of several case studies resulting from research collaborations with Rolls-Royce have been incorporated into the teaching of specialised postgraduate modules offered by BCU as well as in the delivery of bespoke industrial training courses. This typically exemplifies how research feeds back into teaching and education. It should be noted that, in the spirit of true collaboration, BCU students have been allowed to visit the Rolls-Royce aerospace plant, to see directly how KBE is being used to enhance the design of jet engines. Benefits resulting from KBE partnership with Rolls-Royce were demonstrated [E1] at a number of outreach events, such as Birmingham Made Me 2013, showcasing innovations as results of successful academic-industrial collaborations. Significant interest has arisen from regional businesses in adopting KBE technologies after these events.

Environmental impact: KBE research has directly made substantial contributions to two funded projects addressing environmental issues. These projects aim to make significant contributions to the environment by substantially reducing carbon emission in aviation through the design of greener jet engines. The development of the Rolls-Royce KEY control systems explained in this impact case directly contributed to the deliverables of the £90M TSB funded "Strategic Investment in Low Carbon Engine Technology (SILOET)" project (2010-2013) and to its recently launched follow up programme SILOET2 (2013-2015).

Because of its generic nature, the research underpinning this case study has been adapted to provide innovative solutions in the environmental domain to support the exploitation of sustainable greener energy. In collaboration with Dr Lynsey Melville, head of BCU bioenergy research, a number of sophisticated decision support systems based on the KBE approach have been developed to support two multi-million pound EU funded projects on sustainable energy: EnAlgae [L2] and BioenNW [L3]. The central aim of these projects is to reduce emissions and dependency on unsustainable energy sources in Europe. KBE lab designed intelligent systems that capture domain based knowledge and developed decision-support tools to effectively assist stakeholders in deploying and managing bioenergy projects.

The KBE lab is developing a clear reputation as a leader in the highly specialist field of Knowledge Based Engineering through successful exploitation of its research activities with Rolls-Royce.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Sources:

[S1] Senior Engineer, Design System Engineering division at Rolls-Royce Plc.
[S2] Chief of Design Methods, Design Systems Engineering at Rolls-Royce Plc.

Links:

[L1] Chief of Design Methods, Rolls-Royce, at the outreach event *Birmingham Made Me* in June 2013, highlighting the benefits of exploiting Professor Chapman's Knowledge Based Engineering methods as evaluated in case studies the design of aspects of jet engines at Rolls-Royce. http://birmingham-made-me.org/wp-content/uploads/presentations/20th/Craig%20Chapman%20TEE%20and%20Carl%20Barcock%20Rolls%20Royce%20Copy.pptx; Accessed 23/11/2013.
[L2] http://www.enalgae.eu/ ; Accessed 23/11/2013.
[L3] http://bioenergy-nw.eu/; Accessed 23/11/2013.