Institution: University of Leeds

Unit of Assessment: 12

Title of case study 4: Flow modelling research leads to innovative and profitable products

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

Our flow modelling and process optimisation research has improved significantly the scientific understanding of key industrial coating, printing and droplet flow systems. We have implemented our research findings in software tools for staff training and process optimisation which have enabled: (i) the worldwide coating industry to improve the productivity and sustainability of their manufacturing processes; (ii) [text removed for publication]; (iii) a major automotive supply company to develop an award-winning droplet filtration system for diesel engines. [text removed for publication].

2. Underpinning research (indicative maximum 500 words)

Since 1995 **Gaskell**, **Kapur**, **Summers**, **Thompson** and **Wilson** have developed accurate flow modelling and process optimisation methodologies for a number of industrial coating, printing and droplet flow systems. The research challenge has been to develop accurate and computationally inexpensive models for gas-liquid flow systems which can account adequately for key influences, such as geometry or gas-liquid boundary conditions, and which agree well with experiment. The high computational efficiency of these models has enabled them to be used practically by industry end-users on desktop computers for process and product optimisation and staff training through which the impact is demonstrated.

Between 1995 and 1998, **Gaskell**, worked with **Summers** and **Thompson**, to develop models for different industrial coating processes (DTI LINK IL 12/5/54, PI **Gaskell**, £564K, 1994-98). A key research challenge was to develop new, computationally efficient geometry parameterisation techniques which could model accurately the boundary conditions in gas-liquid coating systems. **Gaskell**, **Summers** and **Thompson** created new computer models for roll coating systems [1,2], which predicted when recirculating flow and wetting line locations in the coating fluids lead to coating defects, enabling end-users to prevent defects and improve product quality. This research was published in the Journal of Fluid Mechanics and Chemical Engineering Science [1,2].

Since 2000 the Leeds flow models have been extended to and validated experimentally for other coating, printing and droplet flow systems with complex boundary conditions: (i) gravure coating and screen printing (**Kapur, Gaskell**) - reference [3] develops the first model to predict film thicknesses in screen printing processes; droplet flows over real surfaces (**Wilson, Kapur**) [4], used to develop innovative printing techniques for pharmaceutical tablets (TSB TP/14/HVM/6/I/BD352J, PI **Kapur**, £1.1M, 2009-2011). From 2009 **Kapur** and **Thompson** extended their research on gas-liquid flow systems with droplets to create an accurate flow optimisation methodology for droplet flows in the jet pumps of filtration systems used on diesel engines [5]. The research challenge was to develop, and validate, an accurate flow model with a computationally-inexpensive geometry parameterisation that could predict when shock waves form in the jet pump. **Kapur** and **Thompson** developed an accurate computer-based flow modelling methodology whose predictions agreed well with experiment and used it to investigate how the shape and geometry of the pump affected local pressure changes and shock formation [6; Yorkshire Forward: Euro 6 Crankcase Ventilation Emissions Control System, PI **Kapur** , £375K, 2009-11]. They worked with Toropov in Civil Engineering to represent the results of their work by analytical functions using genetic programming techniques to create a practical software optimisation design tool for use within Parker Hannifin.

Whilst complex, these models have been developed to run on desktop computers and have been widely exploited within the industries to bring about process and product optimisation.

Research team within this UoA

Professor Philip **Gaskell,** Professor of Fluid Mechanics,1996-2013.
Professor Harvey **Thompson**: Research Fellow, 1995-2000; Lecturer, 2000-04; Senior Lecturer

2004-11; Professor of Computational Fluid Dynamics, 2011-present.
Professor Nikil **Kapur**: Strategic Research Fellow, 2000-2005; Lecturer, 2005-2009; Senior Lecturer, 2009-2013; Professor of Applied Fluid Mechanics, 2013-present.
Dr Mark **Wilson**: Postdoctoral Research Fellow, 1997-2005; RCUK Academic Fellowship, 2005-2010; Lecturer, 2010-present.
Dr Jon **Summers**: Research Fellow, 1994-98; Lecturer, 1998-2005; Senior Lecturer 2005-present.

Contributions from researchers outside UoA
Professor Mike Savage**,** School of Physics, University of Leeds, 1996-present: worked with team to develop one-dimensional roll coating models.
Dr S.J. Abbott, R&D Director MacDermid Autotype, 1998-2011: provided access to pilot plant facilities.
Professor V.V. Toropov; School of Civil Engineering, University of Leeds, 2005-2013: contributed to design parametrisation of jet pump and metamodelling/genetic programming of optimisation results.
D. Copley, A. Mincher, Design Engineers, Parker Hannifin, 2009-present: experimental validation of jet pump model.

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

1. **Gaskell**, P.H., Savage. M.D., **Thompson**, H.M. (1998). Stagnation-saddle points and flow patterns in Stokes' flow between contra-rotating cylinders', *Journal of Fluid Mechanics*, **370**, 221-247. DOI: http://dx.doi.org/10.1017/S0022112098002031
2. **Thompson**, H.M., **Kapur** N, **Gaskell**, P.H., **Summers**, J.L, Abbott, S.J. (2001). A theoretical and experimental investigation of reservoir-fed, rigid roll coating, *Chemical Engineering Science*, **56**, 4627-4641. http://dx.doi.org/10.1016/S0009-2509(01)00006-9
3. **Kapur**, N., Abbott, S.J., Dolden, E.D., **Gaskell**, P.H. (2013). Predicting the behaviour of screen printing, *IEEE Transactions on Components, Packaging and Manufacturing Technology,* 3(3), 508-515. DOI: 10.1109/TCPMT.2012.2228743
4. Fan, J., **Wilson**, M.C.T., **Kapur**, N. (2011). Displacement of liquid droplets on a surface by shearing air flow. *Journal of Colloid and Interface Science*, **356**, 286-292. http://dx.doi.org/10.1016/j.jcis.2010.12.087.
5. Eves J, Toropov, V.V., **Thompson HM**, **Kapur**, N, Fan J, Copley D, Mincher A (2012) Design optimization of supersonic jet pumps using high fidelity flow analysis Structural and Multidisciplinary Optimization 45(5) 739-745 DOI: 10.1007/s00158-011-0726-8
6. Fan, J., Eves, J., **Thompson**, H.M., Toropov, V.V. **Kapur**, N., Copley, D., Mincher, A. (2011). Computational fluid dynamic analysis and design optimization of jet pumps, *Computers Fluids*, **46**, 212-217. DOI: 10.1016/j.compfluid.2010.10.024.

[This was an invited paper to the journal].

Note: Key Leeds researchers in **bold**. All of the above journals are internationally recognised with rigorous review processes and international editorial boards. The quality of the underpinning research is demonstrated by references 2, 3 and 6.

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

Innovative and Profitable Coated Products
MacDermid Autotype Ltd is a global industrial manufacturer of high quality precision coated films and blended liquids for use in the printing, automotive and electronics industries. Statement [A] corroborates that MacDermid Autotype have exploited the Leeds flow models of coating manufacturing processes, including roll [2] and in screen printing [3], to develop several new highly profitable products. [text removed for publication].

Statement [A] describes how the company applies the findings from the Leeds models to upstream operations (designing and manufacturing products) and in downstream activities such as explaining the technical benefits of new products. Statement [A] also confirms that MacDermid Autotype collaborated with Leeds to publish an eBook *How to be a great screen printer* in 2011 [B] and that this resource has been used extensively by other practitioners of screen printing to develop a range of high-tech screen-printed products, including solar cells, printed electronics and touch panel displays.

An award-winning crankcase droplet filter – the Super Impactor

Statement [C] confirms that the Leeds flow optimisation research funded by Yorkshire Forward [6] provided Parker Hannifin with a new product optimisation software design tool, which the company used successfully to design jet pump components of their droplet filters which were 20% more energy-efficient. The new Super Impactor crankcase ventilator, the engineering solution developed as a result of the Leeds modelling, reduces engine emissions in line with Euro 6 requirements, and boosts fuel efficiency. Statement [C] confirms that the new component, found in droplet filtration systems in diesel engines, was awarded the prestigious Grand Prix prize (in addition to the Green Product of the Year) at the 2012 British Engineering Excellence Awards: *"An inventive engineering solution that solves a significant environmental problem and which has strong commercial drivers to a large potential market."* [D]

[text removed for publication].

Knowledge transfer to industry

This UoA's coating research has had a major impact of the academic and industrial coating and printing communities. In 1995 **Gaskell** and **Summers** organised the first biennial European Coating Symposium (ECS). The ECS event is still thriving (see e.g. http://www.european-coating-symposium.eu/ecs2013.html; in 2009 the 8th ECS had 146 participants from across the world [E]). It is now supported through the worldwide International Society of Coating Science and Technology (www.iscst.org). Staff at Leeds have used their coating research in several industrial training courses. **Summers**, **Kapur** and **Thompson** have taught the subject of Web Coating and Drying on the AIMCAL (Association of Industrial Mettalizers, Coaters and Laminators) European Converting Schools in 2004, 2006, 2008, 2010 and 2012 [F]. On these courses industrialists have used the Leeds models to explore process operating limits and optimise changes in production and quality control. Statement [G] corroborates the effectiveness of our AIMCAL courses and that the knowledge transfer to the worldwide coating industry from this UoA's research has: (i) significantly improved the education and training of coating engineers and (ii) enabled staff to improve the productivity and sustainability of their coating processes.

[text removed for publication].

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

A. Individual written corroboration from Screen Products Marketing Manager, MacDermid Autotype Ltd, regarding the involvements of the Leeds research team in modelling its coatings processes and the influence of the research in the development and sales of new products.
B. 'How to be a great screen printer' ISBN 978-0-9551220-1-9, http://issuu.com/fespa/docs/macdermid_autotype_how_to_be_a_great_screen_printe/1?e=1328857/5279646 (accessed 18/10/13).
C. Individual written corroboration from Research and Development Manager, Parker Hannifin, regarding the Yorkshire Forward project, the design of new jet pump components and the influence of the research on the company's growth strategy and its ability to win new manufacturing contracts.
D. http://www.beeas.co.uk/winners/beeas-2012-winners.pdf (accessed 18/10/13, see page 3).
E. http://www.ecs2009.eu/downloads/Pressemeldung_2009_10%20ECS2009%20in%20Karlsruhe_englisch.pdf (accessed 18/10/13)
F. http://www.packagingessentials.com/2010/03/17/aimcal-converting-school-holds-six-courses-in-brussels/ (accessed 3/11/13)
G. Individual written corroboration from an Independent Coating Consultant in US and Asia, regarding the impact of the thin films and coatings research carried out at the University of Leeds.
H. Individual written corroboration from a former Principal Scientist, The Procter and Gamble Company, regarding the impact for the company of the Leeds research.
I. Individual written corroboration from Senior Technical Director at Glaxo Smith Kline, Barnard Castle, regarding the impact of the Leeds research on droplets.