Institution: Aston University

Unit of Assessment: 15: General Engineering

Title of case study: Advanced fluid flow modelling improves the efficiency of industrial burners

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

Using advanced mathematics and numerical modelling we have demonstrated how fundamental understanding of laminar-turbulent transitions in fluid flows can save energy. From 2008 we helped the cleantech company, Maxsys Fuel Systems Ltd, to understand and improve their technology and demonstrate to customers how it can reduce fuel use by 5–8%. Customers including Ford Motor, Dow Chemical and Findus testify to the impact from financial savings and reduced carbon emissions obtained by installing Maxsys products on industrial burners used widely in many industrial sectors including automotive, bulk chemicals and food. In 2010, Selas Heat Technology Company bought the Maxsys brand to invest in this success.

2. Underpinning research (indicative maximum 500 words)

Nature of research insights

Since the early 2000's, we (Generalis and the team at Aston University) have used a variety of cutting-edge techniques to analyse the effects of turbulence on fluid mixing and energy transfer. In-house deterministic modelling tools can pinpoint the transition between uniform laminar and irregular turbulent flow (key references 3.1-3.2). In our unique approach, we separate the flow into basic uniform laminar flow and the infinitesimal disturbances that promote the descent of the flow into turbulence. We then solve for the disturbances by expanding orthogonal polynomials as harmonic expressions. This allows us to identify rapidly the nature of the different states as the flow bifurcates sequentially from the laminar state (3.1-3.3).

Flows subject to internal forces, which occur in a number of industrial applications, present an especially complex challenge in fluid dynamics. We modelled the interplay between buoyant forces driven by volumetric heating, inertial forces driven by either a constant flux (closed system) or a constant pressure gradient (open system), and the viscous forces which destabilise the flow as it bifurcates (3.1, 3.2). These models have contributed fundamental knowledge regarding the transition to turbulence of volumetrically-heated flows, allowing us to address a variety of industrial problems.

Models for Poiseuille flow were essential to the success of the R&D project for Maxsys Fuel Systems Ltd (3.1, 3.2). We extended the work on volumetric heating to include magnetic forces in Hagen-Poiseuille flow in pipes. This enabled us to specify the optimal orientation of the magnets and the influence they had on the flow, thus allowing significant improvements in the fuel efficiency of industrial burners to be realised.

This breakthrough in energy saving was the direct outcome of an EPSRC Industrial CASE award with Maxsys, in which PhD student Ben Tocher (2007-11) developed numerical models to tackle the influence of the magnetic field on the flow in the pre-combustion treater of the Maxsys burner. The development built on several years of international collaboration focussed on understanding elusive structures at the heart of turbulence. Working with Prof Fujimura of Tottori University, Japan, Generalis had assessed the limits of modelling techniques used to characterise transitions to turbulence (3.1-3.3). Generalis and Itano (Visiting Scholar) later confirmed the existence of a hairpin vortex structure using the models and techniques thus developed (3.4, 3.5). These fundamental insights were essential to the modelling for Maxsys because they contributed to the extent that Generalis' code could be applied and the appropriate techniques used in the search of the transition region of turbulent flow in pipes. Following these pioneering works, Generalis was awarded eight grants including two Marie-Curie Fellowships (Nos. 274367 & 298891, ~550k€), a Leverhulme Trust project grant (RPG-410, ~£175k with PI Dr Yassir Makkawi), a Visiting Professorship (No. 22195, £72k) and a RAEng Distinguished Visiting Fellow. All these initiatives have expanded the scope of turbulence that Dr Generalis' codes can model. Funding won since the publication of 3.1 and 3.2 totals about £750k.

Key Researchers
Dr Generalis (Lecturer/Senior Lecturer/Reader, 1996-date) has worked with Prof K Fujimura (Visiting Scholar, 2007-08 and Royal Academy of Engineering Distinguished Visiting Fellow, 2012), Prof M Nagata (Visiting Scholar, 1999-2005), Dr T Itano (Visiting Scholar, 2006-2011) and Dr B Tocher (EPSRC Case studentship 2007-2011 with Maxsys Fuel Systems Ltd, Aston PhD awarded in 2013) to develop numerical techniques for pinpointing the transition between laminar and turbulent flow and to apply the techniques to everyday engineering problems.

3. References to the research (indicative maximum of six references)
* indicate three papers that best demonstrate research quality

3.1 Nagata, M. and GENERALIS, S. C. (2002). Transition in convective flows heated internally. Journal of heat transfer, 124 (4), pp. 635-642 (DOI: http://dx.doi.org/10.1115/1.1470169).

3.2 *GENERALIS, S. C. and Nagata, M. (2003). Transition in homogeneously heated inclined plane parallel shear flows. Journal of heat transfer, 125 (5), pp. 795-804 (DOI: http://dx.doi.org/10.1115/1.1599370).

3.3 GENERALIS, S. C. and Fujimura, K. (2009). Range of validity of weakly non-linear theory in Rayleigh-Bénard problem. Journal of Physical Society of Japan, 78 (8), 084401 (http://jpsj.ipap.jp/link?JPSJ/78/084401/).

3.4 *Itano, T. and GENERALIS, S.C. (2009). Hairpin Vortex Solution in Planar Couette Flow: A Tapestry of Knotted Vortices, American Physical Society, Phys. Rev. Lett. 102 (11) 114501; Cover of March Issue, 2009 (http://link.aps.org/doi/10.1103/PhysRevLett.102.114501).

3.5 *GENERALIS, S. C. and Itano, T. (2010). Characterization of the hairpin vortex solution in plane Couette flow. Physical review E, 82 (6), 066308 (http://link.aps.org/doi/10.1103/PhysRevE.82.066308).

Key grants awarded to Generalis
- EPSRC Industrial CASE award with Maxsys *"The effect of magnetic field coupling to plane parallel shear flows "* £81k (2007-11).
- Marie-Curie Fellowships (Nos. 274367 & 298891) *"Pre-chaotic bifurcation behaviour of strongly non linear equilibrium solutions for incompressible volumetrically heated shear flows (VHSF) in a long channel - T2T-VHF" (2011-2014) and "Transition to turbulence in ventilated double glazing - T2T-VDG" (2012-2015),* total ~550k€
- Leverhulme Trust project grant (RPG-410) with PI Dr Yassir Makkawi, *"Wet and dry particle flow at the intermediate regime"* (2011) ~£175k
- Leverhulme Trust Visiting Professorship (No. 22195,) "Optical Turbulence" (2012), £72k
- RAEng Distinguished Visiting Fellow. "Transition in Ventilated Double Glazing" (2011) £5,754

Funding won since the publication of 3.1 and 3.2 totals about £750k.

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

Maxsys Fuel Systems Ltd have exploited advanced mathematical techniques developed at Aston for modelling the influence of turbulence on fluid flow in their industrial heating systems. The impacts created are therefore business benefits to Maxsys and Selas, particularly through sales of their processing equipment, plus the consequential impacts of reduced fuel consumption for major international companies using the equipment with the associated benefits to the environment.

Timeline and process
Maxsys developed a product where magnetic fields modify the flow field upstream of a furnace burner to save fuel (5.1-5.3). Following initial success with this technology, they wished to improve the efficiency of their industrial burners for economic and environmental reasons. Maxsys sought

academic expertise to understand and improve the technology and to help communicate its benefits to customers. In May 2007, Advantage West Midlands introduced Maxsys MD / Commercial Director (5.1) to Dr Generalis via Aston's Business Partnership Unit. Dr Generalis was able to describe the flows in the device and explain the underlying physical phenomena. Advantage West Midlands EnviroINNOVATE funded Aston to perform a feasibility study for Maxsys, paving the way for the EPSRC CASE Studentship. The knowledge gained through the collaborations helped Maxsys to expand their customer base such that orders grew to £1M in 2011 (5.4).

Nature and extent of the impact

The impact is from understanding how turbulent flow phenomena can improve the operation and efficiency of commercial products – in this case enabling Maxsys to understand how their pre-combustion treater reduced fuel usage (5.2-5.3). The Aston in-house numerical toolbox (3.2) further enabled the researchers to advise on optimising configurations of the magnets acting on the fluid flowing through the treater upstream of the burner (5.5). This is because the software toolbox used and developed by Generalis and his team can determine the influence of different forces in turbulent flow with far greater accuracy than commercial software packages. The application of a magnetic field to the flow modifies the velocity profile by making it more uniform across the pipe diameter and it also increases the stability of the flow (5.5). By elucidating this mechanism, the studies enabled Maxsys to fine tune the magnetic field to give a cleaner, hotter burn yielding reductions of 5–8% in fuel consumption and in carbon emissions (5.3, 5.6).

Beneficiaries Concerning Environmental Impact

Significant fuel savings of both gas and oil concomitantly reduced carbon emissions and gave quick returns on investments with payback in 24 months (5.3, 5.6). Maxsys audits fuel usage before and after installation to assess the environmental and economic impacts of their customers' fuel use and carbon emissions (5.6). The audited fuel savings also contribute to reductions in the Climate Change Levy and meeting emissions reduction targets for the Emissions Trading Scheme and the National Allocation Plan (5.6). Therefore, besides reporting precise financial benefits, users of Maxsys burners are helping to meet national targets and to provide environmental benefits to society.

Economic Impact

On the back of nearly £1M of orders in 2011, Maxsys was purchased by Selas Heat Technology Company LLC in November 2011 for an initial investment of £500,000. This allowed Maxsys to fulfil orders placed and secure its future with a truly global market reach. Selas Heat Technology Company now markets Maxsys Fuel Systems in America, as one of their branded products (5.4). Maxsys has offices in North America, Benelux, Germany and Japan (5.7).

The improved product has sold in many industrial sectors including automotive, brewing, chemicals, dairy, food and drink, insulation, minerals, health care providers, packaging and paper, pharmaceuticals, plastics, steel and textiles (5.6). Using the technology has allowed individual end users to make significant fuel savings worth up to £240k per year (5.3).

Customer Testimonies Overview (5.6)

- Heavy users of fuel such as Mondi and Union Papertech, who produce packaging and paper, reported savings up to 7430 MWh and 85000 m^3 per year of gas, respectively. Mondi reported that their annual savings were equivalent to CO_2 emissions reductions of nearly 1500 tonnes.
- Goonvean, who extract kaolin as their main product, installed twenty systems on their gas-fired dryers and reduced their CO_2 emission by about 560 tonnes per year (equivalent to 1000 MWh of gas).
- Toray Textiles reported a 5% reduction of gas used per tonne of steam produced, which in the 20 day monitoring period corresponded to a reduction of 12400 m^3 of gas.
- Tensar, which produces ground stabilisation technology, reported savings of up to £10000 per year in fuel costs.
- Ford Motor reported annual savings of 2.4 MWh of gas.

- Findus saved 6.6% of their pre-fitted annual consumption of 2.4 million m^3 of gas per year.
- Dow Chemical Company cited a 5% reduction in fuel use and payback in 10 months – a significant step towards meeting their ambitious emission reduction targets.

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

5.1 Maxsys Fuel Systems Ltd 3 & 4, Conwy House, St Georges Court, Donnington, Telford, Shropshire, TF2 7BF (http://www.maxsysltd.com/company/the-team; http://www.maxsysltd.com/contact).

5.2 Maxsys technology (http://www.maxsysltd.com/technology).

5.3 Reported benefits of using Maxsys Fuel Systems (http://www.maxsysltd.com/).

5.4 Maxsys Fuel Systems Ltd was bought by the Selas Heat Technology Company LLC in 2011 (http://www.maxsysltd.com/news/selas-acquires-maxsys; www.shropshirestar.com/shropshire-business/2011/11/15/telford-heat-treatment-firm-in-american-buyout/).

(http://www.selas.com/the-selas-heritage; http://www.selas.com/selas-brands) Selas retains the Maxsys brand as part of its product range in a global market

5.5 Final Report produced for Maxsys and used in promotional literature: Comparisons of Transitions in Plane Poiseuille Flow and Plane Magnetohydrodynamic Flow, Aston University, July 2010.

5.6 Customers of Maxsys (http://www.maxsysltd.com/customers).

5.7 Locations of Maxsys (http://www.maxsysltd.com/company/locations).