Institution: Swansea University

Unit of Assessment: 15 - General Engineering

Title of case study: Improved Aerodynamic Design Process for the Aerospace Industry through Application of Unstructured Mesh Technology

1. Summary of the impact

A computational aerodynamics design system (FLITE) developed by Swansea researchers has been of significant economic benefit to the aerospace industry. When introduced, the unstructured mesh FLITE approach was considered by BAE Systems to be a step change in their design cycle. Using FLITE, highly complex modern aerospace configurations could be analysed in short timescales. The FLITE system has since been utilised by a number of international organisations. Its use in the design of the BLOODHOUND project has also contributed to significant public engagement in science and engineering, including a large-scale education programme with which over 5,000 schools have fully engaged.

2. Underpinning research

A successful unstructured mesh system for aerodynamics contains an efficient compressible flow solver together with a capability for automatically generating meshes for arbitrary geometries. The basic Swansea mesh generator, representing a significant advance in this area, was based upon a Delaunay isotropic triangulation with automatic point creation [R1]. The international significance of this work led to further enhancements, including anisotropic meshing, mesh adaptivity and parallelisation [R2], undertaken in a series of EU funded research projects from 1994 to 2004. Additional robustness and efficiency for real aerodynamic geometries was achieved later with the support of the DTI and Airbus [R3].

Research undertaken with the support of the NASA Ames Research Center led to the development of an unstructured mesh inviscid aerodynamic flow solver using an edge based data structure [R4]. With this data structure, and with colouring techniques employed to ensure optimum performance on vector computers, this solver was internationally leading, as the computational penalties commonly associated with unstructured mesh solution methods were reduced to an acceptable level. The significance of this work was recognised by the invitation to submit a review article to *Reports on Progress in Physics* [Web of Knowledge IF 14.72] in 1998 [R5]. Detailed research provided the basic framework for the extension of this procedure to allow for the analysis of viscous flows and was supported by DRA and BAE Systems. The computational performance has been further improved by the addition of an agglomerated multigrid method and more recently sophisticated turbulent flow models have been incorporated with EPSRC support.

In the mid-1990s, the objective of the UK THRUST Supersonic Car (SSC) project was to be the first to take the World Land Speed Record beyond the speed of sound. As wind tunnel testing could not provide the correct modelling of the interaction between the moving vehicle and the ground, the aerodynamic design of THRUST SSC was undertaken using the FLITE computational aerodynamics system [R6]. The computational model that was developed was validated by comparison with the results obtained experimentally using a limited number of rocket driven scaled model tests. THRUST SSC took the Record to supersonic speed in 1997 and, for his use of FLITE within the THRUST SSC project; Oubay Hassan was awarded the MBE.

Main personnel involved:

- Academic Staff at Swansea University: Prof O. Hassan (1994-present), Prof K. Morgan (1975-1989, 1991-present), Prof N.P. Weatherill (1987- 2008)
- Research Staff at Swansea University: B.J. Evans (2007-11, academic staff, 2011-present), D. Wang (1990-2006), Z.Q. Xie (2004-12)
- Research Students at Swansea University: K.A. Sørenson, U. Tremel

3. References to the research

Publications

Papers R1 to R3 and R6, listed below, were included in submissions to previous RAEs. The unit to which the papers were submitted achieved a 5* rating prior to RAE2008, while the unit in which the papers were included had 100% of submitted papers rated as 2* plus and 95% rated as 3* plus in RAE2008. Papers R1, R2, R3 best indicate the quality of the research.

- ***R1.*** **N.P. Weatherill and O. Hassan**, Efficient three–dimensional Delaunay triangulation with automatic point creation and imposed boundary constraints, *International Journal for Numerical Methods in Engineering*, 37:2005–2039, 1994.
- ***R2.*** **U. Tremel, K. A. Sørensen**, S. Hitzel, H. Rieger, **O. Hassan and N.P. Weatherill**, Parallel remeshing of unstructured volume grids for CFD applications, *International Journal for Numerical Methods in Fluids*, 53:1361–1379, 2003. DOI: 10.1002/fld.1195
- ***R3.*** **D. Wang, O. Hassan, K. Morgan and N.P. Weatherill**, EQSM: an efficient high quality surface grid generation method based on remeshing, *Computer Methods in Applied Mechanics and Engineering*, 194:5621–5633, 2006.
- ***R4.*** **K. Morgan** (principal investigator), Unstructured grid methods for the simulation of 3D transient flows, Final Report on NASA Research Grant NAGW–2962, *NASA–CR–196139,* 1994.
- ***R5.*** **K. Morgan** and J Peraire**,** Unstructured grid finite-element methods for fluid mechanics, *Reports on Progress in Physics*, 61:569-638, 1998.
- ***R6.*** **K. Morgan, O. Hassan and N.P. Weatherill**, Why didn't the supersonic car fly?, *Mathematics Today*, 35:110–114, 1999. [Awarded the Catherine Richards Prize for the best paper published in *Mathematics Today* in 1999].

Major Relevant Research Grants

- ***C1.*** **K. Morgan,** Parallelisation for unstructured grid generation and adaptivity, SERC, 1994–1997, £120K.
- ***C2.*** **N.P. Weatherill**, A parallel simulation user environment for engineering analysis and design, EU, 1994–1996, £230K,
- ***C3.*** **N.P. Weatherill**, Viscous flow modelling using unstructured grids, DRA, 1994–1996, £150K,
- ***C4.*** **K. Morgan,** Viscous flow simulation for arbitrary 3D aerospace configurations, BAE Systems, 1995–1997, £105K.
- ***C5.*** **O. Hassan**, Technology development for aeroelastic simulation on unstructured grids, EU, 2001–2004, £180K.
- ***C6.*** **O. Hassan**, Collaborative aerodynamics simulation toolset 2, DTI, 2005–2007, £130K.
- ***C7.*** **O. Hassan**, Development of hexahedral dominant anisotropic near field and isotropic far field meshes, Airbus, 2007, £80K.
- ***C8.*** **O. Hassan**, Advances in mesh generation, EPSRC Platform Grant, 2006–2011, £1M.
- ***C9.*** **O. Hassan**, The development of unstructured mesh technology for viscous high speed flows, EPSRC, 2007–2010, £910K.

4. Details of the impact

In the early 1990s, the widespread use of computational fluid dynamics, (CFD), for aerodynamic design was restricted by the time required to perform a single simulation using structured multi-block methods. These simulations typically required several months to complete. The introduction into BAE Systems of the unstructured mesh based FLITE system, produced spectacular time savings in large-scale analyses. *"Overnight turnaround times for assessing the aerodynamic properties of complicated geometries, such as the generic large aircraft, are now achievable. Clearly, this has to be a significant factor in shortening the time-to-market lag of future aircraft designs."* [Sowerby Update, The Newsletter of Sowerby Research Centre, Issue 9, Spring 1997].

A complete FLITE unstructured mesh system for computational aerodynamics was supplied to BAE Systems in 1994. Since that time, the FLITE system has also been adopted at Airbus, Cassidian and IHPC Singapore. In addition, FLITE has been used in the BLOODHOUND SSC project. During this reporting period, the following impact has been demonstrated:

Working closely with BAE Systems, this system was modified and industrialised to a point where the FLITE3D suite became the standard solver in BAE Systems, having a major impact on the ability to undertake aerodynamic design over highly complex configurations in short timescales.

"The adoption of this unstructured approach was a step change for BAE Systems and, coming at the same time as more readily available high end computing, ensured that simulation had a major impact on the design cycle. BAE Systems current aerodynamic software, whilst much developed from the original University of Swansea code set, retains the philosophy and a basic algorithm pioneered by Swansea researchers and underpins the design capability for BAE Systems in the areas of UAV design and stores (weapons and other detachable items) release and clearance. In particular, these codes form a key part of the UK IP and workshare in the UK-French collaboration (worth £50m per year per nation collaborative programme) on defence. The codes are also key in the weapons clearance programmes undertaken by BAE Systems (worth many millions of pounds per year for BAE Systems)."

"The unstructured approach to aerodynamic simulation, begun by Swansea University for BAE Systems has resulted in significant further development programmes, collaborating across the UK and Europe. In particular, the recent CFMS programme sponsored by the TSB and involving Airbus, Frazer-Nash, Rolls-Royce, BMT, Eurostep, MBDA, HP, Microsoft, QinetiQ amongst others, (£17.5m completed in 2010) and the subsequent spin out of the CFMS company (an SME) represents well the change of approach to simulation begun by the initial inputs of the software from Swansea University." [University & Collaborative Programmes Relationship Manager, BAE Systems, ATC, Filton]

Airbus has benefited from its long-term research relationship with Swansea University, particularly in the area of unstructured mesh technologies. The FLITE system *"has been heavily used as part of the wing design process for A380 and subsequent aircraft, and as such, has contributed to the continuing success of the Airbus product line and supporting the many jobs involved in aircraft design and manufacture."* In this assessment period 106 A380 Aircraft have been delivered out of the 262 firm orders that have been placed. Unstructured mesh procedures developed at Swansea have also been incorporated into the Solar mesh generation software developed jointly with the Aircraft Research Association (ARA) and Airbus. Solar *"is an important part of the Airbus RANS capability, a capability that has been deployed extensively (order 1000 meshes per year)."* [Technology Product Leader, Airbus, Filton]

At Cassidian, the unstructured meshes used for industrial aerodynamic computations are created using code that is primarily based on software and mesh generation principles developed at Swansea University. In the assessment period, this mesh generator *"has been applied to more than 99% of the CFD-computations conducted in the company, successfully generating hundreds of complex unstructured meshes which have formed the basis for several thousand fluid flow computations for critical projects, such as the Eurofighter and Tornado aircraft, as well as demonstrators and new designs. Based on its quality and run time efficiency the mesh generator has also represented a major building block for the Cassidian activities in several international research projects, conducted on European and Nato level. In several large national aerospace research projects this software was a substantial pillar for the industrial research undertaken by Cassidian. It is believed that the usage of numerical methods, in which the mesh generator plays a crucial role, has incurred savings in the order of several million Euro."* [Manager, Cassidian, Manching, Germany]

IHPC (Institute of High performance Computing) acquired FLITE3D in 2008 as a core capability of its multi-physics simulation framework. Since that time, the system has been actively developed by a team of 10 research scientists at the Department of Fluid Dynamics. To date, this represents an IHPC investment of S$1.0 million. *"The enhanced FLITE system is impacting on the Green Mark certification process in Singapore, an initiative by the government to shape a more environmentally friendly and sustainable built environment. The total secured funding, from governmental agencies and industrial partners, for development and application of the FLITE* *system, is over S$300K since 2010-2011."* [Group Manager and Department Director, IHPC, Singapore]

Following the critical role played by FLITE in the success of the THRUST SSC project, in 2007 the leader of the BLOODHOUND project requested that the FLITE system be used to aid the aerodynamic design process for a new World Land Speed Record vehicle. Initially, the FLITE system was used to demonstrate the practical feasibility of designing an aerodynamic shape that was capable of safely achieving 1000 mph. This initial work enabled the public launch of the BLOODHOUND supersonic car project by Lord Drayson in October 2008. The primary objective was to inspire a new generation of British engineers to tackle the challenges of the 21st century, using science, technology, engineering and mathematics (STEM). Simultaneously, the creation of the BLOODHOUND education programme was announced. This includes school visits, FE roadshows and events, the BLOODHOUND website and resources, the BLOODHOUND Education Centres and the BLOODHOUND Ambassadors programme. As a result of these activities, public engagement with the project has been a phenomenal success with over 5,059 schools signed up as education partners, ensuring the project reached over 1.5 million primary and secondary school students. In addition, 229 UK and overseas colleges and 40 universities have signed up. Over 5,000 people have joined the 1K supporters' club and 11,000 people have contributed to have their names put on the vehicle's tail fin. An army of BLOODHOUND ambassadors continue to travel across the country delivering STEM public engagement activities. The BLOODHOUND project website currently receives an average of 50,000 hits per month. *"The programme has increased young people's understanding of engineering and the importance of STEM subjects."* [S. Straw and A. Dawson, A Follow-Up Audit of Activities for the BLOODHOUND Education Programme, National Foundation for Educational Research Report, Slough, 2012]. Following the public launch, FLITE has been extensively used to guide the shaping of the external geometry of the vehicle to its fully matured final design, completed in late 2012. *"Without the crucial and on-going support of Swansea University, in terms of resource, expertise and the FLITE simulation technology, the BLOODHOUND project simply would not be possible."* [Director, BLOODHOUND Project]. To date, BLOODHOUND Project Ltd has raised in excess of £10M of inward investment funds and created over 40 new jobs.

5. Sources to corroborate the impact

(i) Letter from University & Collaborative Programmes Relationship Manager,
BAE Systems , Advanced Technology Centre, Filton, Bristol BS34 7QW

(ii) Letter from Technology product leader – Integrated Computational Simulation and Design,
Aerodynamic Strategies, Airbus Operation Ltd,
New Filton House, Filton, Bristol BS997AR

(iii) Letter from Manager, Cassidian, Aerodynamics & Methods - COEAI1
Rechliner Strasse, 85077 Manching, Germany

(iv) Letter from Department of Fluid Dynamics Director
Institute of High Performance Computing
#16-16 Fusionopolis, Connexis, Singapore 138632

(v) Letter from BLOODHOUND Project Director
50 Kingston Hill Place, Kingston Upon Thames KT2 7QY