Icons of CFD

Prof. Antony Jameson

The next time you fly on a commercial aircraft, take a moment to reflect on its aerodynamic design; for this will almost certainly owe a huge debt to the CFD technology and computer codes developed by Prof. Antony Jameson.

The Boeing 767, 757, 747-400, 777, 737-700 and the 787 Dreamliner have all have been designed using aerodynamic codes based on CFD methods devised by Prof. Jameson. His methods have also been used by the European aerospace industry. And we haven't space to list all of the numerous McDonnell-Douglas aircraft, as well as many regional and business jets, whose aerodynamic design also benefited from his CFD expertise.

Amongst Prof. Jameson's many awards is the 2006 Elmer A. Sperry Award, sponsored by the ASME, IEEE, SAE, SNAME, AIAA and ASCE, and given in recognition of distinguished engineering contributions which, "through application, proved in actual service, have advanced the art of transportation, whether by land, sea or air". It was Elmer A. Sperry (1860 – 1930) who coined the phrase 'automotive'. Previous recipients include Igor Sikorsky and Sir Geoffrey de Havilland. It is important to note that this award is only given for engineering contributions that have been proven through application; nor is it awarded every year. Prof. Jameson's citation reads as follows:

"To Antony Jameson in recognition of his seminal contributions to the modern design of aircraft through his numerous algorithmic innovations and through the development of the FLO, SYN and AIRPLANE series of CFD codes".

What attributes made these algorithms and CFD codes so successful? To find the answers we should examine some of the engineering challenges that Jameson has tackled, but let us turn first to his background.

Antony Jameson began using computational methods in aerodynamic design in 1970, at the age of 36, as an employee of the Grumman Aerospace Corporation in New York – which he joined in 1966. Previously he had been working at Grumman, but on control theory for stability augmentation systems; his experience in this field proved of considerable utility some two decades on, when he redirected his research into aerodynamic shape optimisation (about which more is said later). Prior to Grumman he had been chief mathematician at Hawker Siddeley Dynamics in Coventry.

Jameson is a graduate of Cambridge University, Trinity Hall, 1958, with 1st class honours in engineering, where he stayed to gain his PhD in magnetohydrodynamics, followed by a period as a Research Fellow at Trinity Hall.

His first job on leaving Cambridge in 1964 was actually as an economist with the UK Trades Union Congress. Jameson lists Len Murray, former Head of the TUC Economics Department and later General Secretary, as being one of several significant people in his life. Earlier, he had served as a lieutenant in the British Army, Malaya.

Clearly, Jameson had wide-ranging experience before he focused on CFD in his mid-thirties. It was then that he wrote his first two CFD codes: FLO 1 and SYN 1 . These programs solved for idealised fluid flow (non-viscous and irrotational) over 2-D airfoils, with FLO 1 calculating the pressure distribution for a given airfoil, and SYN 1 calculating the inverse problem, i.e. the shape of an airfoil given a target pressure distribution. As computer memory was very limited, Jameson ensured that the memory requirements were small. These codes also ran fast, taking between 5 and 10 minutes. The efficiency of Jameson's codes is characteristic of his work.

The computation of transonic flow over airfoils soon became his main focus, and in 1972 Jameson moved to the Courant Institute of Mathematical Sciences, New York University, to further pursue this topic.

In transonic flow the Mach number is a little below unity in most parts of the flow field, i.e. the flow is mostly subsonic. However, locally it becomes supersonic. This is a crucial flow regime for commercial aircraft, as cruising speed needs to be high to give good range, but when locally supersonic flow occurs on a wing it can potentially lead to strong shock waves that give large increases in drag. Large commercial aircraft typically operate at a Mach number of about 0.8, which is in the transonic regime, so their wing shape needs to be designed to minimise the strength of any shocks and ideally to avoid them altogether. Jameson1 provides an overview of the wider challenges and constraints in airfoil design.

At the Courant Institute, Jameson wrote a CFD code for the prediction of idealised transonic flow past swept wings, known as FLO 22, in collaboration with David Caughey. FLO 22 was very robust, with convergence all but guaranteed. The code was immediately put to use by McDonnell-Douglas and others. FLO 22 is a remarkable code, as it has been run continuously since it was written, and is still in use today.

The methodology in FLO 22 was extended in FLO 27 and FLO 28 to be applicable to arbitrary meshes, so that geometries such as complete wing-bodies could readily be computed. Boeing evaluated the extended code in 1978 and subsequently incorporated it in their own 'A488' software - which was the main computational tool used in wing analysis for the Boeing 757, 767 and 777 aircraft.

In 1980, Jameson joined Princeton University and from 1982 was the James S. McDonnell Distinguished University Professor of Aerospace Engineering. He moved to Stanford University in 1997, where he continues to research, teach and publish, as the Thomas V. Jones Professor of Engineering in the Department of Aeronautics and Astronautics.

Advances in computer hardware during the 1980s meant that it became possible to solve the Euler equations for flow over airfoils. This removes the restriction of irrotationality imposed by idealised fluid flow. It heralded a major step forward in aerodynamic design, especially for transonic flows, as shock strength and in particular shock location can be in error with idealised flow models. Jameson2 worked with collaborators at Dornier and the University of Tel Aviv to devise a groundbreaking 3-D Euler code, known as FLO 57, which allowed shocks to be predicted accurately for complex aerodynamic shapes. Prof Charles Hirsch, author of Numerical Computation of Internal and External Flows3, writes:

"The method developed by Jameson and co-workers is a remarkable combination of components such as efficient dissipation terms, convergence acceleration ingredients and multi-grid techniques, leading to (the) most efficient and accurate prediction codes"

The methods embodied in FLO 57, colloquially known as the 'JST' model, were quickly adopted by the aerospace community, including British Aerospace (now BAE Systems), Lockheed, Dornier and NASA.

Jameson made numerous other advances in numerical methods and algorithms throughout the 1980s, including the use of unstructured meshes to allow the very first computation of flow over a complete aircraft. This breakthrough was achieved using a new code developed jointly by Jameson, Timothy Baker and Nigel Weatherill, in 1985, called 'Airplane', which was adopted as the basis of aerodynamic codes used by McDonnell Douglas, NASA, Mitsubishi and EADS.

Together with his development of software for unstructured meshes, Jameson continued to work on improving the speed of solution algorithms, as well as the accuracy and robustness of discretisation schemes. In essence, he worked across all of the areas that were important in furthering CFD as a tool for aerodynamic design.

As he brought these methods to maturity, he redirected his research towards the challenge of finding the optimal shape of aerodynamic designs to meet performance targets, subject to a range of constraints, such as wing thickness - which determines structural weights. His work in this field is based on a merging of control theory and CFD.

This led to a new series of 'SYN' codes, such as SYN 87 and 88 for optimal wing design solving the Euler equations and, in 1997, SYN 107* solving the full Navier-Stokes equations that govern viscous fluid flows. In 2003 he wrote the code 'Synplane', allowing the optimisation of aerodynamic design for a complete aircraft. As an example, SYN 107 can handle several thousand design variables, and was used for the aerodynamic design of the Gulfstream G650 business jet which entered service this year and has a range of 6000 nautical miles at its high cruise speed of Mach 0.9.

Jameson's work on aerodynamic shape optimisation is as important as that of his earlier research on CFD methods and algorithms.

The most fitting end to this latest in the Icons of CFD series is provided by the summary of Prof. Jameson's overall achievements taken from his Elmer A. Sperry Award citation, 2006:

"The core elements of Antony Jameson's achievement are the following: First, based on his background in engineering, economics and mathematics, and his industrial experience in the jet engine and aircraft industries, he was able to identify key barriers which must be overcome to advance the practice of aerodynamic design. Second: he devised new and innovative mathematical and algorithmic solutions to previously intractable or infeasible problems that enabled the necessary advances. Third: he implemented these new algorithms in structured, modular and essentially error free software that was robust enough for sustained industrial use (30 years in the case of FLO 22), and actually enabled significant improvements in the aerodynamic performance of many aircraft now flying."

Some of the most significant algorithmic contributions introduced by Jameson:

1973 Rotated difference scheme for transonic potential flow
1981 Jameson - Schmidt - Turkel scheme2 for the Euler equations
1983 Full approximation multigrid scheme for the Euler equations
1986 Unstructured mesh scheme for complete aircraft calculations
1988 Lower-Upper Symmetric Gauss-Seidel (LUSGS) scheme for the Euler and Navier Stokes equations
1988 Aerodynamic shape design via control theory
1991 Dual time-stepping scheme for unsteady flows
2007 Kinetic energy preserving conservative scheme
2010 - 2012 Stability proofs for high-order-schemes and formulation of energy stable flux reconstruction (ESFR) schemes

Much more information on Prof. Jameson and his work can be found on his home-page at Stanford University, **http://aero-comlab.stanford.edu/jameson/** , including copies of many of his publications – of which there are over 400.

References

[1] A. Jameson, "Re-engineering the Design Process Through Computation", AIAA 97-0641, AIAA 35th Aerospace Sciences Meeting and Exhibit, Reno, January 1997, Journal of Aircraft, Vol. 36, 1999, pp 36-50.
[2] A. Jameson, W. Schmidt, and E. Turkel, "Numerical Solutions of the Euler Equations by Finite Volume Methods Using Runge-Kutta Time-Stepping Schemes", AIAA Paper 81-1259, AIAA 14th Fluid and Plasma Dynamic Conference, Palo Alto, June 1981.
[3] C. Hirsch, "Numerical Computation of Internal and External flows", Volume 2, "Computational methods for inviscid and viscous flows", 1990, John Wiley and Sons.

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*SYN107 is now commercialized under the name J-FLO, by Newmerical Technologies Int.