IconsofCFD

Prof. David Gosman

Computational Fluid Dynamics is about solving difficult engineering problems, using expensive software, enormous computing resources and highly trained engineers. If the problems weren't difficult, or very important, then it is doubtful that anyone would devote so much effort, time, and money at solving them. From the perspective of a modern engineer, it would be easy to assume that this desire to apply simulation technology complex problems is a recent concern; that only today are we able to contemplate solving tough industrial problems, armed with a complex array of multi-physics simulation tools.

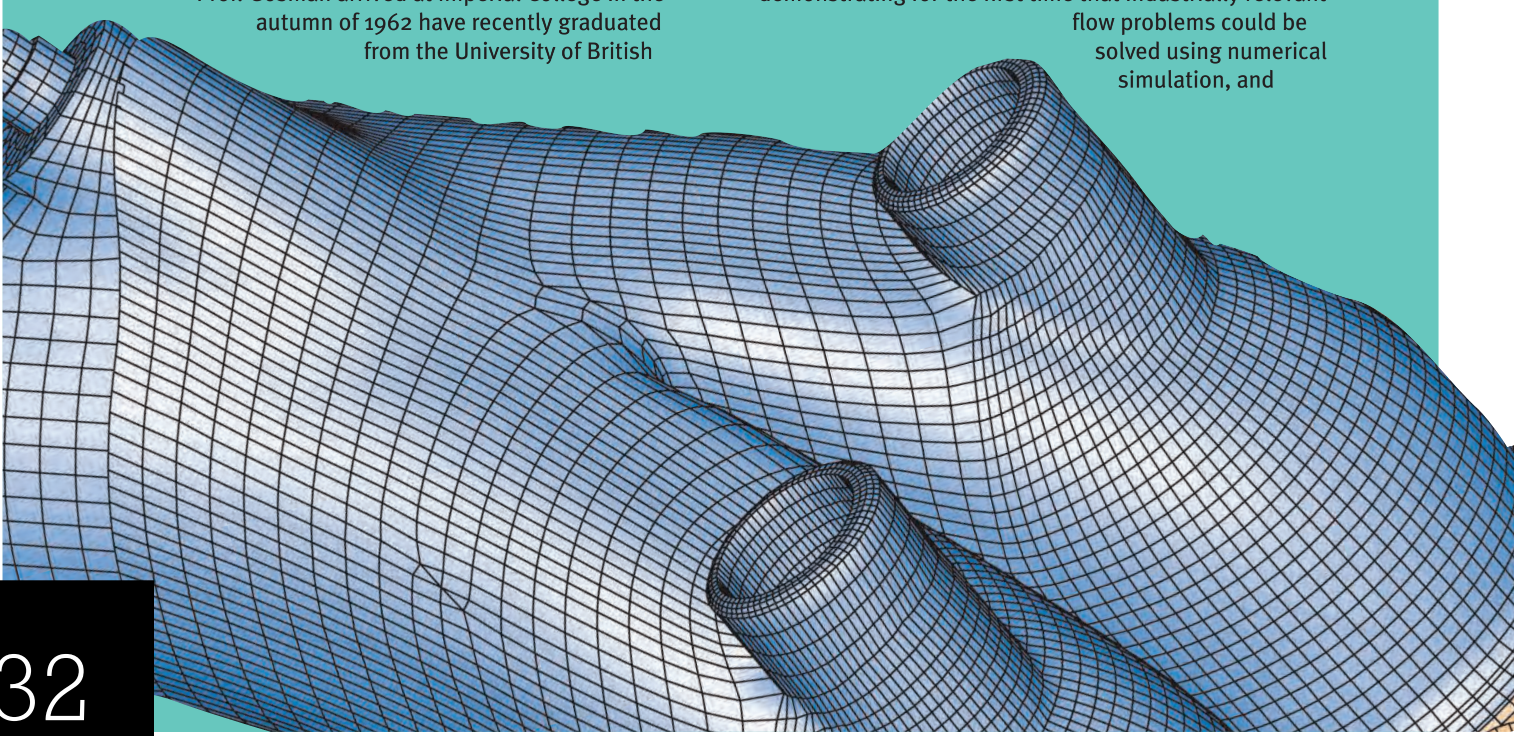
This is a misconception. Forty years ago, CFD was born from a desire to solve difficult problems involving turbulence, heat-transfer, and combustion, based on the vision of a small group of pioneering researchers who were able to see beyond the meager computing resources available at the time, and to develop the techniques and methods that would ultimately revolutionize engineering.

Prof. David Gosman is one of those pioneers. As a member of Prof. Spalding's Imperial College CFD research group from the beginning, he played a pivotal role in developing simulation methodologies that could cope with the complex geometries of real industrial problems, many of which are employed in all commercial CFD codes today. He also pioneered the use of CFD for combustion in reciprocating engines and methodologies and software that he developed have been applied to investigate the design of almost every automotive engine designed since the early 1990s.

Prof. Gosman arrived at Imperial College in the autumn of 1962 have recently graduated from the University of British Columbia, to study for his PhD under Prof. Brian Spalding. In the early 1960s the focus of the Spalding's research was the development of a 'universal method' for computing turbulent flows, using momentum integral methods for two-dimensional shear flows, and designed to account for free flows and wall jets. Although these techniques proved moderately successful for the prediction of "parabolic" boundary layer type flows, they were not applicable to more general "elliptic" type problems (with strong pressure gradients, separation, recirculation and impingement).

Since the solution of "industrial" type problems, especially those including combustion, required the solution of elliptic type problems, Prof. Spalding and his team eventually abandoned the 2D-parabolic approach in favor of a discretized "stream-function-vorticity" approach, that solved the two-dimensional Navier-Stokes equations (cast in terms of stream function and vorticity) using a finite-volume approach and upwind differencing. Although Prof. Gosman's mainly experimental PhD did not directly involve the development of these methods, he soon became entangled in their development, to such an extent that the publication of his thesis was delayed by a number of years. It was this diversion that was to ultimately define his whole career.

The culmination of the stream-function-vorticity approach was the publication of the 1969 book "Heat and Mass Transfer in Recirculating Flow"[1], for which Prof. Gosman was the editor, and which included the source code for the CFD tool called ANSWER, developed by Runchal and Wolfshtein. This book marked a turning point for CFD, demonstrating for the first time that industrially relevant flow problems could be solved using numerical simulation, and



providing a tool with which to do it. The techniques advocated by this publication were subsequently used to provide the first examples of CFD applied to a recirculating flow exhibiting combustion.

Having demonstrated that the stream-function-vorticity approach could be used to simulate low-speed two-dimensional flow problems, Prof. Spalding and his team began to investigate the extension of the methods to three-dimensions. However, they quickly realized that the solution of Navier-Stokes Equations in three dimensions requires the solution of six equations when cast in terms of stream-function and vorticity, but only four equations if cast in terms of the primitive variables of velocity and pressure.

This realization development was followed quickly by two important developments: the 1976 introduction of Patankar and Spalding's SIMPLE algorithm variants of which were to form the backbone of almost every CFD code that followed; a year later, Launder and Spalding published the standard k-epsilon model, which provided the first practical method of modeling turbulence without invoking an arbitrary length scale. With these essential ingredients in place, Prof. Spalding's group were now free to start developing problem specific CFD codes that were capable of addressing real engineering problems. Although simple by contemporary standards, these codes could easily be considered an early prototype for all that followed, performing important role in establishing the credibility of the new discipline of Computational Fluid Dynamics and directly inspiring all of the commercial CFD codes that would eventually follow.

Prof. Gosman's own contribution during this period was a two-dimensional code called TEACH, which he originally developed (together with Dr W.P. Pun) as an educational tool for the post-experience courses in CFD that Spalding's team were beginning to offer. With TEACH, Prof. Gosman pioneered the use of CFD in the classroom, introducing numerical simulation into the curriculum for undergraduate mechanical engineering students, authoring the first course to make practical use of CFD as a learning tool for fluid mechanics and heat transfer, and publishing the first text book [2]. This showed tremendous foresight; although CFD techniques were beginning to be tentatively examined in some "high technology" sectors of industry, the release of the first general purpose commercial CFD codes was still half a decade away, and practical fluid mechanics was almost entirely dominated by experimental methods.

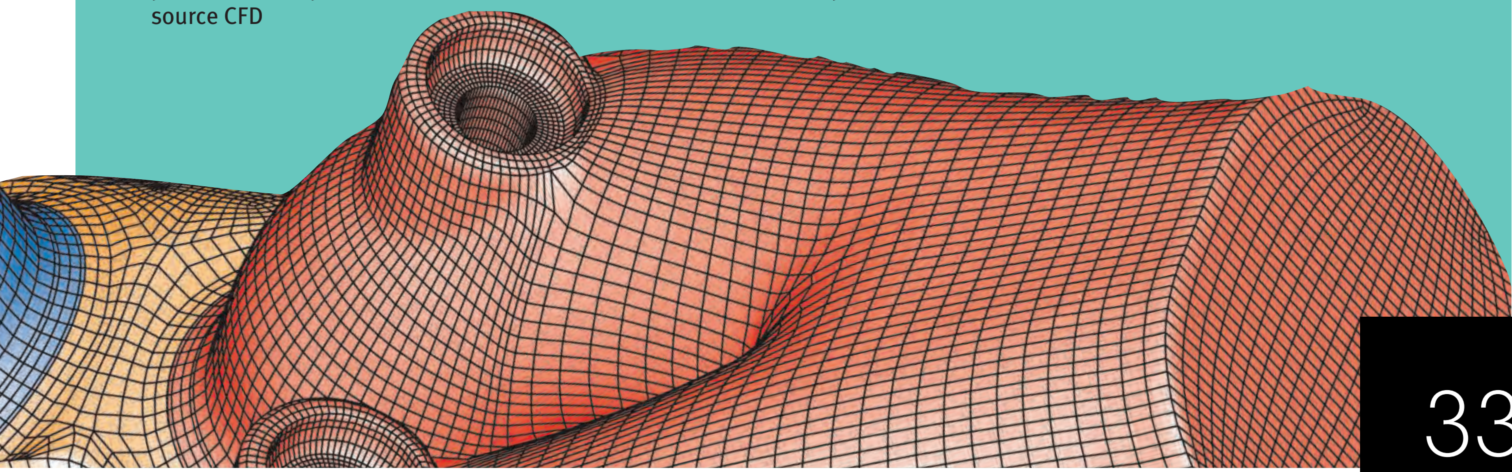
Although TEACH was originally conceived as a teaching tool, by publishing the source code (as a 1000 line FORTRAN program at the back of a text book), Prof. Gosman may have inadvertently pioneered the open source CFD movement. TEACH was subjected to much modification and extension, and was probably the most widely used CFD code in the pre-commercial world [3,4].

The original motivation for Spalding had to been to develop simulation methods for problems involving heat-transfer and combustion, which unlike pure fluid mechanics problems involved recirculation zones that were not easily addressed by either existing theoretical methods or experimental investigation. It was now, in the late 1970s, that some of these ambitions started to be realized, with the first practical simulations of combustion in gas turbines and stationary combustors.

Despite this success, the most significant combustion problem of all, that of the automobile engine, remained unaddressed. Unlike other combustion problems, engine flow combustion processes are non-stationary; taking place in a solution domain that has a complex geometry and moving boundaries. The accurate simulation of engine combustion would also require the development of multi-phase models to account for fuel-sprays and films, as well as ignition, combustion and turbulence models. Of course, considering the unsteady nature of the problem, the complex physics and the large mesh sizes required, the solution of engine combustion problems also necessated the development of a robust and efficient solution algorithm to perform the large number of time-steps necessary to achieve a credible solution using the limited computing resources available.

Prof. Gosman published the first axisymmetric CFD simulation of cold flow in a reciprocating engine in 1978[5], before dedicating much of the next decade to developing the techniques that would allow the simulation of a fully-detailed engine combustion process in three-dimensions. To account for the movement of pistons and valves, he developed a novel Eulerian-Lagrangian moving mesh methodology, which eventually included cell-layer addition and removal to prevent numerical problems that can occur in high aspect ratio cells. In the field of fuel spray modeling, he also co-developed the Huh-Gosman model for spray atomization and the Gosman-Bai model for wall impingement. To address time-step and stability concerns, Prof. Gosman implemented the non-iterative PISO algorithm developed by Imperial colleague Dr Raad Issa, which allowed the computationally efficient solution of unsteady compressible flows using relatively large time-steps.

The combination of this work, with many other developments, resulted in the CFD code SPEED, which was developed as a semi-commercial collaboration between Prof. Gosman's Imperial team and a number of industrial partners.



Prof. Gosman's other significant research interest was in developing simulation methodologies that could cope with the complex geometries of real engineering problems. The commercial CFD codes of the time relied almost entirely on fully structured cartesian computational grids, which dealt with complexity using a crude "stair-step" approach, which in effect led to large inaccuracies in any geometry that could not be represented as a combination of cylinders and boxes. A decade spent trying to model the geometries of complex engine combustion chambers and induction systems had convinced Gosman of the need to develop a more robust methodology for simulation using body-fitted meshes, not just for engines, but also for all types of industrial CFD problems. He therefore set out to systematically find a way of producing flexible mesh methodology that would fit all geometries, however complex. After significant investigation of many alternatives, he finally settled on an approach based on co-located Cartesian velocities inspired by work of Rhie and Chow and then generalized this to partially and then fully unstructured CFD meshes, including those with sliding interfaces.

By the middle of 1980s Prof. Gosman's team had assembled a formidable set of simulation tools, many of which were far in advance of the commercial CFD codes that had begun to emerge, particularly in the field of complex geometry handling. The experience of testing and supporting SPEED had convinced Prof. Gosman that academia was not an ideal environment from which to develop a CFD code and so, together with Dr Raad Issa, he formed Computational Dynamics Ltd as a commercial venture, with the aim of developing an unstructured body-fitted industrial CFD code.

Incorporated on Monday December 19th 1987, the day known to the rest of the world as "Black Monday", Computational Dynamics faced an uneasy birth. Unsurprisingly, as the world's stock markets crashed around them, Gosman and Issa initially struggled to find investors willing to fund their start-up company, in what was still a relatively obscure corner of the technology market. That funding would eventually come from adapco; a New York based structural engineering consultancy company, which had been performing structural analysis of engine cylinder heads. adapco had recently turned to CFD simulation as a mechanism for providing more accurate heat-transfer coefficients boundary conditions for their FEA simulations, but had been frustrated by the fact that none of the commercial codes offered the body-fitted methodologies required to provide results with enough accuracy. adapco's President Steve MacDonald was introduced to Prof. Gosman by a mutual contact at the Ford Motor Company, and quickly determined that Gosman's CFD code would not-only solve his heat transfer coefficient problems, it would also provide a useful tool for the water-jacket flow-balancing simulations that some of his customers were demanding.

With adapco's backing, Computational Dynamics set about producing a commercial version of their body-fitted CFD code named STAR-CD (which stands for Simulating Transport in Arbitrary Regions). The first version was block-structured but, by its second release in 1991, STAR-CD had become the first truly unstructured commercial code, offering engineers the ability to construct meshes from any combination of hexahedral, tetrahedral and prismatic cells and thereby providing unparalleled geometrical flexibility. Technology that had been developed for SPEED also made its way into STAR-CD, and it quickly became the default CFD code for the simulation of engine combustion problems.

More than 25 years after its first release, STAR-CD is still going strong, and continues to occupy a leading position in the engine simulation market. The vast majority of engines developed since the early 1990s have been designed and numerically tested with the aid of STAR-CD, providing insight that has allowed engine manufacturers to significantly reduce both fuel consumption and emissions. Computational Dynamics and adapco now jointly trade under the name CD-adapco, and collectively employ more than 800 people in developing and supporting STAR-CD and their next-generation CFD tool STAR-CCM+.

Despite the success of this commercial venture, Gosman remained dedicated to his academic work, and was appointed Professor of CFD at Imperial College in 1988, eventually publishing over 200 papers on CFD. In the same way that Spalding's group eventually spawned multiple CFD codes including TEACH, the current leading Open Source CFD code FOAM (now OpenFOAM) was developed by Dr Henry Weller during his time in Prof. Gosman's research team.

Until recently Prof. Gosman could proudly confess that, despite a whole career spent pioneering, developing and educating with CFD tools, he had never actually performed a CFD calculation using a commercial CFD code. However, he was recently observed participating in "STAR-CCM+ for beginners" training class. Maybe this is his greatest legacy: after more than 40 years of development CFD tools are now so accessible that even a CFD Icon can learn how to use them.

References

[1] Gosman A D (Editor), 1969 "Heat and Mass Transfer in Recirculating Flows", ISBN 0122919505

[2] Gosman A D, Launder B E, Reece GJ, 1985, "Computer-aided Engineering, Heat Transfer and Fluid Flow", ISBN 0853128669

[3] Runchal A K, 2008, "Brian Spalding: CFD and reality", Proc. CHT-08, ICHMT - International Centre for Heat and Mass Transfer, International Symposium on Advances in Computational Heat Transfer, May 11 ss Transfer, International

[4] Hirschell E H (Editor), 2009, "Notes on Numerical Fluid Mechanics': 40 Years of Numerical Fluid Mechanics and Aerodynamics in Retrospect", ISBN 3540708049

[5] Gosman A D and Johns R J R, 1978, "Development of a predictive tool for in-cylinder gas motion in engines" SAE International Congress, Detroit, paper 780315

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