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Brian Spalding: CFD and reality – A personal recollection

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ABSTRACT

Brian Spalding did not invent CFD. He did not even coin the name. But more than anyone else, he created the practice of CFD – its application to problems of interest to engineers. The author was associated with, and was an integral part of the team led by, Prof. Spalding that developed the basic engineering practice that came to be known as the Imperial College (IC) approach to "CFD". Most of today's commercially available CFD software tools trace their origin to the work done by the IC group in the decade spanning the mid-60s and mid-70s.

This paper is a personal recollection of the key moments of the CFD developments at Imperial College and the role played by Brian Spalding as a leader of, and as an active contributor to, the IC Group. His key insights during this decade often made breakthroughs possible and re-directed the focus at critical moments. The paper also explores the opportunities missed by the IC Group during this decade of breakneck progress in CFD.

1. Introduction

I first met D. Brian Spalding (popularly known as DBS) in 1965. If you search the web for DBS today, other than the Aston Martin DBS V12, one of the items that prominently pops up is Deep Brain Stimulation – an innovative development in Neurology. How appropriate! Of course I did not know that when I first met him. My association with him has certainly been Brain stimulating and has truly changed the course of my life and the point of view with which I view science and engineering.

D. Brian Spalding (Fig. 1) was born on 9th January 1923 in New Malden in the now picturesque suburbia of London. The town finds mention in the Domesday Book as Meldone and seems then to have been a typical rural English village. The fact that Brian grew up close to a pigsty in a semi-rural environment will later lead to a remarkable professional observation. Spalding attended Kings College School from the age of 9–18 and was then admitted to Oxford University where he obtained his B.A. in Engineering Science at the Queens College in 1944. He then worked at Shell for a year. In 1945 he joined the newly established Rocket Propulsion Establishment (RPE) of the Ministry of Aircraft Production. Great Britain did not yet have any rockets at that time; RPE was set up to develop the technology in response to the success of the German V2 Missile. Soon thereafter Brian was dispatched to Germany to learn the secrets and intricacies of rocket engines. During 1945–1946 he was at the Luftfahrtforschungsanstalt Herman Goering (Herman Goering Institute of Aeronautical Research) at Voelkenrode, near Braunschweig and its out-station at Trauen on the Lueneberge Heide. The V2 team, led by Werner von Braun, was already in the American zone; but the British collected 10 members of a different group which had developed the motor for the Messerchmidt 163 rocket-propelled airplane, the propellants of which were hydrazine hydrate and hydrogen peroxide. They brought this team to Trauen and set them to work converting their rocket motor to burn kerosine and liquid oxygen. The work continued until 1946, at which time the Allies agreed that no further such work was to be done in Germany. The Trauen team was then transported to England to continue its work at RPE, which was little more than a collection of huts on a disused airfield. Brian was the mentor of the German team led by Johann Schmidt. Indeed he lived with the German team in one of the huts until his marriage in 1947 to Eda Goericke, who, having formerly worked at a hydrogen-peroxide-making plant in the Harz Mountains, had moved to Voelkenrode when the war ended.

Somewhat later, the reconstruction of the UK Scientific Civil Service resulted in Brian's being transferred, much to his disappointment, to the Metrology Department of the National Physical Laboratory (NPL). An unanswered question remains if this transfer had anything to do with Brian's membership in the communist party during his student days. This was the beginning of the cold war and the Burgess and McLean affair hit the news shortly thereafter in 1951. From the point of view of Brian's career, this proved to be a blessing in disguise because during this time Brian became thoroughly familiar with instrumentation and the art and science of measurements. This stood him in good stead during the next stage of his career. It also resulted in his not standing, as he otherwise would have done, by the side of Johann Schmidt when an explosion of the kerosine-fuelled rocket motor, strong enough to break apart the bolts holding the window through which he was watching, exploded and killed him instantly.

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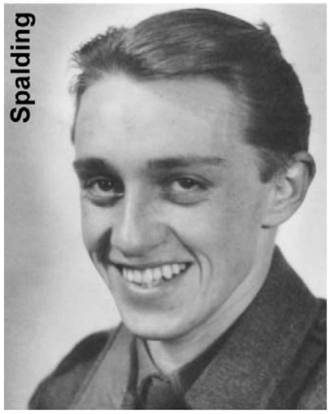

Fig. 1. Brian Spalding.

In 1948 Brian got an ICI (Imperial Chemical Industries, Ltd.) Fellowship to go to Cambridge University (Pembroke College) for a Ph.D. With his RPE background, he knew that he wanted to do research on the combustion of liquid fuels. The Head of Department, John Baker, appointed A.L.L. Bird as his supervisor since he had some interest in diesel engines. Bird and Spalding had very little to do with one another. Brian early on demonstrated his independence and his tendency to go out on a limb. He had a fairly definitive idea of what he wanted to do – and it was not diesel engines. When Bird tried to get Brian to use an existing experimental rig, Brian protested to Baker. Baker advised Bird to "give him enough rope to hang himself". Thereafter Brian was on his own. Bird retired soon thereafter and since the regulations demanded that every Ph.D. must have a supervisor, a new recruit to the staff, Dudley Robinson was appointed his supervisor. Having worked at RPE, Brian already knew more combustion than his supervisor and wound up advising Robinson on his research. Brian's previous experience at RPE and NPL came very handy for his Ph.D. research which was remarkable in that it was entirely self-motivated. Brian obtained his Ph.D. in 1952 with Will Hawthorne and E.S. Sellers as his examiners.

2. Early professional career: 1951–1964

The origin of Spalding's later contribution to CFD goes back to his days at Cambridge University and his Ph.D. Thesis [1]. It is a remarkable thesis in that it "unified" the key hydrodynamic concepts of von Karman [2], the heat transfer concepts of Kruzhilin [3] and the mass transfer concepts of Eckert [4]. He synthesized these to create a general theory of heat and mass transfer with and without combustion. In the process he made a then unforeseen prediction that the chemical-reaction-rate constants had no influence on combustion until a critical rate of mass transfer was reached. This was later borne out by experiments. Spalding deduced these critical rates by adapting the concepts of Zeldovich and Frank-Kamenetsky [5], and Semenov [6], who had been concerned with the quite-different phenomenon of steady laminar flame propagation. This led to a general theoretical framework for the prediction of flame-extinction which was a breakthrough for combustion engineers [7]. His other notable contributions in combustion include the 'centroid rule' [8] which caused the predictions of a range of flame-speed studies to fall on to a single curve, the cooled-liquid-film burner for measuring combustion rates and an innovative method for measuring extinction conditions [1], and a cooled porous burner for measuring flame speeds [9]. He also developed an electrical analogue of combustion [10]. To my knowledge this was a novel and unique concept and I am not aware of other electrical analogues of combustion.

After completing his Ph.D. Spalding stayed at Cambridge for a short time and was then recruited by Prof. Owen Saunders in 1954 to join as Reader in Applied Heat, in the Mechanical Engineering Department at the Imperial College, London. Spalding went on to do seminal work in combustion and made key and innovative contributions in evaporation burning of droplets. This work eventually led to the now universally adopted "B" factor and the Spalding Number. Spalding's efforts at unification led to his remarkable book on Convective Heat and Mass Transfer [11] that has greatly influenced subsequent work in this field.

In late 1950 s Spalding turned his attention to the important issue of the role that wall shear plays in most engineering flows. The turbulent velocity profile for walls was conventionally represented by a three part profile, a "viscous" sub layer, a "transitional" layer and a "fully turbulent" layer. Spalding found an unconventional, elegant, and simple solution: express Y+ in terms of U+ rather than U+ as a function of Y+. This key insight enabled him to develop a continuous 'wall law', covering viscous, transitional and logarithmic regions [12]. He was also not comfortable with the conventional method of treating wall boundary layers, jets and wakes as distinct flows – each with its own physics, mathematics and terminology. Since all these flows are primarily governed by shear, he argued that the underlying physics and mathematics must be represented in a uniform manner. This led to his Unified Theory of Turbulent Boundary Layers, Jets and Wakes [13]. This was his "grand" design built upon the insights of Taylor [14] to have a single theory that covered Boundary Layers, Wakes and Jets. This was based on the remarkable insight that with a "universal" entrainment law and a suitable two-part profile to represent the wall and wake regions, all such flows can be universally represented. A number of his students worked on deriving the entrainment formulae and other input needed for the Unified Theory (e.g. [15–17]). Soon thereafter, Spalding came to the conclusion that instead of searching for an optimum profile, one can "universalize" a profile by simply representing it as a set of piece-wise polynomial – or linear – segments and derive the weighting functions from the governing initial and boundary conditions. This freed one from having to find an "ideal" profile to fit a given flow. However it later became apparent that Spalding's search for a unified theory was not yet over since this approach was found to generate solutions that were occasionally spurious or even singular.

3. Convergence of our paths: 1965–1975

In 1965 Spalding occupied the Chair, Professor of Heat Transfer, at Imperial College. He was appointed to this chair in 1958 when it was created. He also headed the "Thermofluids" Section which was later renamed Computational Fluid Dynamics Unit. Though digital computers had been around for a couple of decades, early 1960's coincided with the "advent" of the computer as a widely available tool and led to the developments that eventually gave rise to what is today known as CFD.

I graduated with a B.Sc in Engineering in 1964 (Fig. 2) and in 1965 won an ICI scholarship in India that gave me the choice to go to any college in the UK for my Ph.D. I wanted to work on drying of sprays – a subject of much interest to ICI and other companies – that involved both heat and mass transfer. Since Spalding was one of the most respected researchers in heat and mass transfer, I wrote to him to accept me as his Ph.D. Student. The essence of his reply was: "I am not interested in working on drying of sprays, but I am happy with last year's ICI scholar – Suhas Patankar (Fig. 3) – so I will accept you as my student and we will figure out what to do once you get here". I suspect another reason may have been his soft corner for an ICI scholarship since he himself had completed his Ph.D. under an ICI Fellowship.