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Origins and Development of the Finite Volume CFD Method at Imperial College

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The majority of CFD simulations today employ the Finite Volume Methodology. The ground work for this methodology was laid at the Imperial College, London, in the mid to late 1960's. Those developments led to the first general purpose two-dimensional finite volume CFD code that was published in 1969. The basic technology was then further refined and extended to 3D Flows in a series of developments in the early 1970's. In 1964 Brian Spalding and his group at IC had been working on a "Unified Theory" for Boundary Layer, Jet and Wake flows (Spalding, 1964) that relied on generalization of the profile methods first developed by Polhausen and others in 1920's. In 1965 Brian Spalding asked two of his new students, Runchal and Wolfshtein, to extend the Unified Theory to Separated Flows and Wall Jets, respectively. However, it soon became apparent that the Unified Theory, and consequently the profile method, could not deal with such flows that had no self-similar profiles and were dominated by strong diffusion and pressure gradient terms in multiple directions. Runchal and Wolfshtein abandoned the profile method in favor of finite difference methodology. Soon thereafter it became apparent that the finite difference methodology had its limitations when applied to non-linear convection terms. This had been recognized by a number of research workers including Burggraff (1966). The IC team came up with the idea of "up-winding" that allowed them to obtain solutions for arbitrarily high Reynolds number flows (Runchal & Wolfshtein, 1966). It turned out that one-sided differences had been previously explored and commented upon by a number of research workers including Courant et al. (1952). In early 1967 Spalding realized that fluid flow is better represented in terms of exchange of fluxes than just solely as an interaction of state variables represented by discrete basis functions and Taylor Series. To properly account for this exchange of fluxes he formulated the first version of the Finite Volume method based upon a "Tank & Tube" analogy. Runchal and Wolfshtein (1968), who till then had been working independently on their projects, used this analogy to write a general purpose 2D CFD Code to solve the stream-function vorticity version of the Navier-Stokes equations. Wolfshtein

(1968) used this method to solve the problem of a Wall Jet. Runchal (1969) then derived the discrete finite volume equations by explicitly integrating the governing equations over a control volume without the use of Taylor Series and finite difference approximations. He used this integral approach to solve the problems of a square cavity with moving lid and flow behind a backward facing step in a pipe.

As often happens in science, what is done by one has often been done by someone else – albeit in a different context. Ironically Finite Volume method is the oldest method of dealing with fluids and solids. After all, all differential equations are derived by finite control volumes which are then assumed to go to the limit of zero. This approach of course fails to properly account for discontinuities and non-linearities that cannot be expressed as continuous functions such as Taylor Series. Had Leibnitz prevailed over Newton, we would have only had integrals and finite control volumes. So, what was rediscovered at Imperial College is the very essence of how best to deal with fluids that move. That is, in terms of flux exchanges across interfaces that impact the state variables that represent the state of a fluid. This approach naturally and automatically satisfies the conservation laws at the local - and hence the global - scale. What was abandoned was the “mathematical” artifact of representing state variables by a presumed Taylor Series in a discrete space with approximate “basis” functions.