# PAST, PRESENT AND FUTURE OF CFD

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**ABSTRACT** Computational Fluid Dynamics appears to be poised on the threshold of rapid advances powered by the recent developments in Artificial Intelligence, Neural networks and deep machine learning. From the diversity of its use today, it is hard to believe that it originated just about 50 years ago. CFD is where it is today because of the contributions of two brilliant scientists. The science that led to CFD started at Los Alamos under the direction of Frank Harlow who was the first to realize the potential of emerging electronic computers to obtain solutions to the previously "unsolvable" problems governed by the Navier-Stokes equations. But it was the engineer in Brian Spalding at Imperial College who saw the potential of transforming this field engineering. Spalding working with his team to unify the concepts of fluid flow, heat and mass transfer and developed general purpose software tools that have become the mainstay of modern engineering practice. This field of engineering software later became known as CFD. Majority of CFD simulations today employ the Finite Volume Methodology developed at the Imperial College, London, in the mid to late 1960's and early 1970's.

Early applications of CFD were largely in the field of aerospace and defense. However, in the last 5 decades, there is hardly a field of human endeavor that is untouched by CFD. It has become a pervasive and highly useful tool to understand the physics behind a diverse range of applications in engineering and science. This understanding, in turn, has led to innovations and improvements in a variety of fields. The applications of CFD have expanded to include areas such as biomedical, sport, food processing, environmental, fire safety, buildings ventilation and energy efficiency, and a host of other areas of social relevance. The uses of CFD today extend from understanding plate tectonics deep underground, to exploring exo-inhabitation in outer space and exoplanets. It is used to understand the diffusion of drugs deep in the human body and to designing novel systems to ameliorate the environmental and energy crisis facing human existence.

The limitations of the current generation of CFD tools fall in three broad categories. First, for many practical applications, the current CFD methodologies require computational resources that are beyond those available; hence compromises have to be made. Second, the current generation of tools are not robust; they require judgment from trained experts in CFD to ensure that the results are reliable. Finally, the current generation of CFD software lacks intuitive and easy to use human interface backed up by required auxiliary data that is needed to solve a problem. Therefore, extensive training is needed to use CFD tools effectively and accurately. This is expensive.

A number of new technologies have emerged and are entering mainstream that will transform the CFD tools of tomorrow. The foremost amongst these is deep machine learning. Deep machine learning (ML) is an artificial intelligence (AI) technology that is powered by recent advances in deep neural networks. A recent innovation is the physics-informed neural network (PINN) which incorporates the residual of governing equations as part of the cost function to be minimized while "training" the neural network. The PINN in conjunction with reduced order models, digital twins and internet-of-things (IOT) will have a profound impact on how products are designed, manufactured and serviced. It will be possible to embed ML into CAD/PLM software and even spreadsheets. This will enable engineers to rapidly assimilate

these models into the product development process and thereby create optimal designs, without needing the services of a CFD expert. This technology will also be used for optimal control and real time monitoring of the device. All this will have a profound impact on the way that CFD is practiced and utilized. In short, CFD will become ubiquitous but at the same time deeply embedded within systems and devices so a practicing engineer can use it without having to understand the nitty-gritty of CFD. CFD will become like the engine that drives a car but the driver rarely has to deal with it. CFD experts will be more engaged in creating the digital twins and reduced order models using high fidelity computations and of course, in extending the application of CFD into diverse areas of human activity.

Dr. Runchal has seen the CFD emerge in the 1960's as an esoteric and niche research field that evolved into its vibrant and multi-disciplinary state today. He was part of a group of 3 students who worked with Prof. Spalding at Imperial College to develop the FVM methodology. He has been a practicing CFD engineer since then. Dr. Rao has been a developer of CFD algorithms and technology and has been a practicing engineer for over 35 years. This talk is based on their experiences in this field and their thoughts on how it is evolving.