

REVIEW

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# Landmarks and new frontiers of computational fluid dynamics

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## Abstract

A narrative of landmarks in computational fluid dynamics (CFD) is presented to highlight the cornerstone achievements, illuminating accomplishments starting from the very beginning of the coherent development until the most recent progress will be elucidated over the span over more than six decades. Meanwhile, the cutting-edge scientific innovations will also be discussed for their lasting impacts to fluid dynamics and the physics-based modeling and simulation discipline. To traverse such a vast domain over time by a single presentation, numerous and excellent contributions to CFD will be unavoidably overlooked. Nevertheless it is my ardent hope that the present discussion will be able to reaffirm excellence in research and to identify new frontiers for scientific research. Especially, the challenges to future innovations will also be delineated to recommend for potential and fertile research areas for the modeling and simulation science.

**Keywords:** Computational fluid dynamics, Numerical algorithms, Turbulence, Interdisciplinary computational fluid dynamics

## 1 Introduction

In order to discuss the physics-based modeling and simulation discipline, the underlying principles must be explicitly stipulated to define its limitations. The traditional computational fluid dynamics (CFD) technique is mostly applying in the continuum gas domain which is limited to the negligible Knudsen number;  $N_{\text{Kn}} = \lambda/l < < 1.0$ . In this physical domain, the mean-free-path of particle collisions is negligible in comparison with the characteristic length of the flowfield considered. In the continuum regime, the compressible Navier-Stokes equations become the governing equation for describing fluid dynamics in the macroscopic scale, and the nonlinear partial differential equations system is the incompletely parabolic type. Even though the incompressible Navier-Stokes was known to us as far back as 1827, only more recently the system of equations was derived in integral form via the control-volume formulation to become the basis for the finite-volume approach. Nevertheless, the necessary initial values, boundary conditions, and their placement and implementation are mandatory to achieve a unique numerical simulation.

Numerical algorithms are inseparable parts of CFD research, also are the most demanding and creative efforts of this discipline, because they dictate the computational accuracy that provides the required physical fidelity to any computational simulations. In the gist, the numerical algorithm and the computational procedure research is a tool

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