Proceedings of the 9th World Congress on Mechanical, Chemical, and Material Engineering (MCM'23)
Brunel University, London, United Kingdom –August 06-08, 2023
DOI: 10.11159/htff23.002

Machine Learning and Automatic Mesh Optimization: Watershed Methodologies for Heat Transfer and Fluid Flow Optimal Numerical (and Experimental) Simulations

Dr. Wagdi G. Habashi
Professor, Department of Mechanical Engineering, and
Director, Computational Fluid Dynamics Laboratory
McGill University
Montreal, Quebec, Canada
Email: wagdi.habashi@mcgill.ca
Websites: www.cfdlab.mcgill.ca, www.certifice.com

Abstract

Many areas of CFD and CHT require, or ought to be using, large samplings to perform parametric explorations and, ultimately, optimization of flow-based components or processes. This is demanding in 3D and even more so for multidisciplinary problems combining CFD, CHT, and, often, CSD.

Nowhere is this problem more apparent than in the certification of aircraft, rotorcraft, and jet engines for flying into known icing. The required analyses involve the simultaneous simulation of high-Mach external aerodynamics over the aircraft, small and large droplets and ice crystals impingement, low-Mach internal aerodynamics inside ice protection systems or in engines, conjugate heat transfer across multiple fluid-structure interfaces, liquid-to-ice-to-liquid-crystals phase changes, changing geometries due to ice accretion or ablation on external and internal components, fluid-structure interaction induced deformations, and ice cracking and tracking.

These complexities have made component optimization, the ultimate aim of any simulation capability a rarity in this field. While keeping the approach applicable to a wide variety of problems, the Lecture will thus use in-flight icing as a relevant application example.

The Lecture will review aspects of modern CFD-Aero and CFD-Icing that straddle the analysis, design, testing, and certification processes, via a Reduced Order Modeling (ROM) calculation for a complete aircraft flow + supercooled droplets or ice crystals impingement + ice accretion + performance degradation, in seconds or minutes and not days!

The methodology is based on Proper Orthogonal Decomposition, multi-dimensional interpolation, and machine learning algorithms, along with an error-driven iterative sampling method to adaptively select an optimal set of snapshots. Hundreds of such snapshots (full 3D solutions) can be obtained within a day on a supercomputer at a fraction of the cost of a day in a tunnel. The methodology can provide engineers and certification consultants with a CFD simulator and no need for a CAD system, a CFD code, a mesh generator, running codes, adjusting parameters, and monitoring solution and mesh convergence. This gamechanger ought to allow OEMs and their second-tier suppliers to use the same toolset without divulging proprietary geometries which is currently a serious obstacle.

The lecture will also demonstrate an alternative to the recommendations of using systematic mesh refinement to demonstrate grid convergence, a quasi-impossibility in industry where the motivation for carrying out CFD is not publishing papers but improving products

The combined ROM + Mesh Optimization methodologies will be demonstrated on “a complete aircraft” going through its combined aerodynamic and icing certification envelopes, providing rich complementary data to dry/icing tunnels or natural ice flights and a path to the optimization of hot air and electrical ice protection systems.

Finally, “Gappy-ROM” will be demonstrated for using ROM in enriching fluid and heat transfer experimental data and reducing test models’ complexity.

Machine Learning paves the way for any organization to analyze/optimize components with data as rich as, and compatible with, the associate OEM.