Progress Toward Realizing the CFD Vision 2030

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Abstract: With less than a decade remaining until its titular deadline, the goals of NASA's CFD Vision 2030 Study remain generally aspirational. That is not to imply that there have not been advances in the study's focus areas of effective utilization of high performance computing resources, accurate turbulence modeling with transition and separation, implementation of autonomous simulation processes, effective knowledge extraction, and use of multi-disciplinary frameworks. Rather, achievement of these goals is either highly localized within the overall community of CFD practitioners, is the result of heroic versus workmanlike effort, and/or is for only one or two goals rather than all of them simultaneously. Progress since the study's publication in 2014 is used to identify work remaining to realize the vision. Also, ongoing efforts to create grand challenge problems that can help quantify progress toward the Vision are described.

Keywords: CFD, algorithms, high performance computing, turbulence modeling, geometry modeling, mesh generation, knowledge capture, visualization, in-situ processing.

1 Introduction

The CFD Vision 2030 Study [1] (hereinafter, the Study) succinctly stated that by its titular deadline "a single engineer/scientist must be able to conceive, create, analyze, and interpret a large ensemble of related simulations in a time-critical period (e.g., 24 hours), without individually managing each simulation, to a pre-specified level of accuracy."

In order to further emphasize and focus the vision quoted above, the Study identified four grand challenge (GC) problems that NASA, the Study's targeted end user community, must be able to solve by the year 2030. These GC problems are a wall-resolved LES simulation of an aircraft throughout its flight envelope, an off-design turbofan engine transient simulation, a multi-disciplinary simulation of an advanced aircraft, and a probabilistic simulation of a powered space access configuration.

The aerospace CFD community's response to the Study has been strong and sustained. It addition to spawning a large number of technical papers and workshops, a committee was formed within the AIAA's integration and outreach organization (the CFD 2030 Integration Committee, hereinafter the IC) to promote a community of practice dedicated to shaping the future of simulation-based engineering relative to the Study's goals [2]. The author is a member of the IC's steering committee.

2 Progress

The Study developed a roadmap for development of key technologies and capabilities necessary for achieving the vision. In this roadmap (Figure 1), the technology has been divided into five elements: High Performance Computing (HPC), Algorithms, Geometry and Grid Generation, Knowledge Extraction, and MDAO.

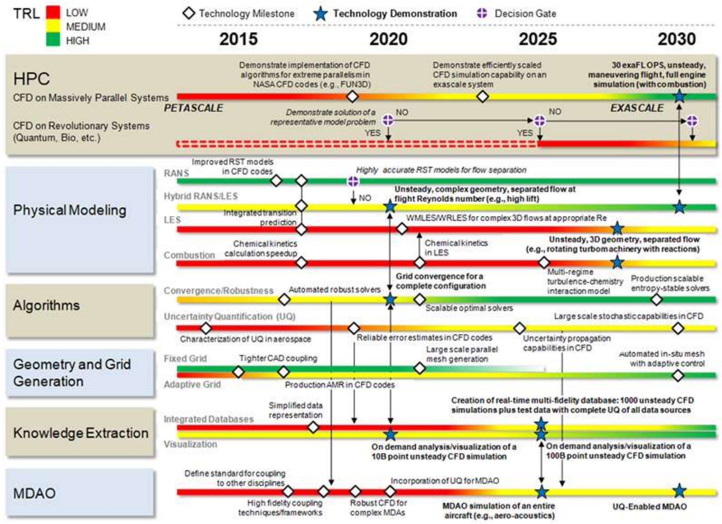

Figure 1: The CFD technology development roadmap from the Study.

An assessment of progress within in each roadmap element at the five-year mark since the Study's publication was the subject of a special session at the AIAA Aviation Forum in 2019 [3, 4, 5, 6, 7, 8, 9]. A special progress report was published by the IC in 2021 [10]. This report provides a comprehensive update of the Vision through 2020 including the status of several technology milestones and demonstrations and through the addition or modification of specific technologies in each of the five elements (Figure 2). The technology readiness level (TRL) of each component technology for each element was also defined.

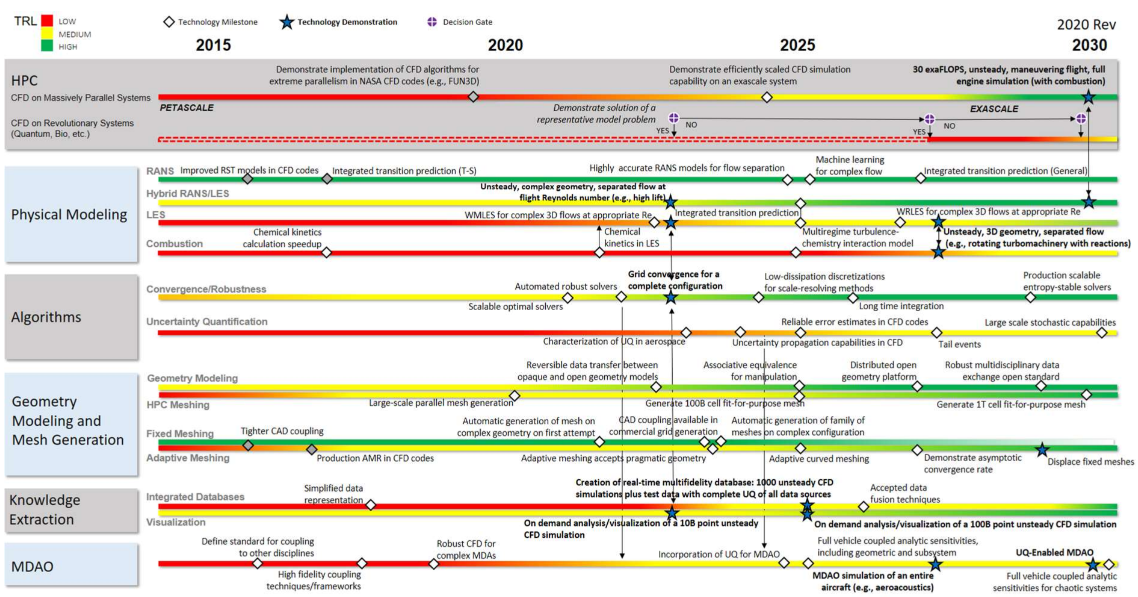

Figure 2: The CFD 2030 Roadmap as updated in 2020.

The following sections will delve into the details of progress in each element of the Roadmap.

2.1 High Performance Computing

2.2 Numerical Algorithms

2.3 Geometry Modeling and Mesh Generation

2.4 Knowledge Extraction

2.5 Multidisciplinary Analysis and Optimization

3 Defining Grand Challenge Problems

In order to better assess the state of CFD relative to the Study's goals, the CFD 2030 IC has reassessed the GC problems included in the Study and commenced the design and implementation of a progression of updated GC problems in the areas of high-lift aerodynamics [11], gas turbine engines [12], and space vehicles [13].

The high-lift aerodynamics GC proposes simulation of a low-speed aircraft maneuver called a wind-up turn that is usually a regulatory requirement for aircraft certification. The propulsion GC proposes simulation of a complete gas turbine engine (compressor, combustor, turbine, and secondary flows) from start to finish within one week's calendar time. The space vehicles GC proposes integrating CFD with Monte Carlo techniques for planetary entry, descent, and landing. While these are all incredibly ambitious GCs, achieving them would represent revolutionary advances in technology with corresponding cost and time-to-market decreases.

The following sections describe the GCs and their associated build-up of sub-GCs in more detail.

3.1 High-Lift Aerodynamics

3.2 Gas Turbine Engines

3.3 Space Vehicles

4 Summary

The CFD Vision 2030 Study has galvanized and focused CFD development toward a shared vision. Whether the year 2030 is a notional target or an achievable milestone remains to be seen. Execution of grand challenge problems and sub-problems offer the ability to quantify progress and more rigorously assess technology readiness levels. While progress in CFD technology will be made regardless, by rallying around the CFD Vision 2030 the industry has an opportunity to achieve something truly transformational.

References

1. Slotnick, Jeffrey et al, "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences," NASA CR-2014-218178, March 2014.
2. www.cfd2030.com
3. Cavolowsky, John, "NASA Aeronautics and CFD 2030," oral presentation, June 2019.
4. Slotnick, Jeffrey, "Progress Towards CFD Vision 2030 – An Industrial perspective for Air and Space Vehicle Applications," June 2019.

5. Medic, Gorazd, “Impact of Vision 2030 on CFD Practices in Propulsion Industry,” AIAA 2019-2943, June 2019.
6. Nielsen, Eric, “High Performance Computing Towards CFD Vision 2030,” oral presentation, June 2019.
7. Mavriplis, Dimitri, “Progress in CFD Discretizations, Algorithms, and Solvers for Aerodynamics Flows,” AIAA 2019-2944, June 2019.
8. Chawner, John, and Taylor, Nigel, “Progress in Geometry Modeling and Mesh Generation Toward the CFD Vision 2030,” AIAA 2019-2945, June 2019.
9. Spalart, Philippe, and Strelets, Michael, “Turbulence Prediction in Aerospace CFD: Reality and the Vision 2030 Roadmap,” oral presentation, June 2019.
10. Cary, A., Chawner, J., Duque, E., Gropp, W., Kleb, W., Kolanay, R., Nielsen, E., and Smith, B., “CFD Vision 2030 - Roadmap Updates,”, URL: http://www.cfd2030.com/report, 2021.
11. Slotnick, J.P., & Mavriplis, D., “A Grand Challenge for the Advancement of Numerical Prediction of High Lift Aerodynamics,” AIAA paper no. 2021-0955, Jan. 2021, https://doi.org/10.2514/6.2021-0955.
12. Anand, M.S., Medic, G., Paliath, U., Suder, K.L., Malik, M.R., & Laskowski, G.M., “Vision 2030 Aircraft Propulsion Grand Challenge Problem: Full-engine CFD Simulations with High Geometric Fidelity and Physics Accuracy,” AIAA paper no. 2021-0956, Jan. 2021, https://doi.org/10.2514/6.2021-0956.
13. Schuster, David M., “CFD 2030 Grand Challenge: CFD-in-the-Loop Monte Carlo Flight Simulation for Space Vehicle Design,” AIAA paper no. 2021-0957, Jan. 2021, https://doi.org/10.2514/6.2021-0957.