Abstract for AIAA SciTech '21 Conference

Evaluation of CFD as a Surrogate for Wind-Tunnel Testing for Mach 2.4 to 4.6 - Project Overview

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I. Introduction

The debate over when wind-tunnel testing (WTT) will be replaced by Computational Fluid Dynamics (CFD) comes and goes. More recently the debate has subsided with a more collaborative spirit between practitioners of these two disciplines resulting in significant improvements in the outcomes of both. There may come a time, however, when CFD has sufficient accuracy to supplant WTT as the dominant or perhaps only tool for aerodynamic simulation. If and/or when that happens, financial pressure result in efforts to close or severely limit the operations of wind tunnels. Presumably additional resources will go toward CFD in order to generate aerodynamic databases, load environments, and new aero/fluid-dynamic knowledge.

It is therefore important to develop appropriate processes by which wind-tunnel closure decisions are made to ensure that facilities critical to industry and government research and development aren't closed prematurely without ensuring that the existing CFD tools have sufficient accuracy and low-enough cost (and enough experts and computational facilities) to take on the traditional role of wind tunnels. This paper will describe a project intended to answer the specific question of whether CFD can replace WTT for the limited Mach-number range 2.4 to 4.6. The wind tunnel being examined in this context is the high-speed leg of the Unitary Plan Wind Tunnel at NASA's Langley Research Center (LaRC UPWT).

II. Objective

The planning phase of this project was executed over several months with a group of experts from government and industry involved in research and development with WTT and CFD experience. The question posed to the group was what represents a sufficient demonstration of CFD capabilities to consider allowing it to replace WTT in the LaRC UPWT. The consensus was that test data covering a sufficiently diverse set of flow physics with CFD predictions in the wind-tunnel environment would be required. Evaluation of the accuracy and resource requirements of the CFD relative to the WTT results would then provide an indication of whether the wind tunnel was required in order to have confidence in the use of CFD only. The review group came up with a list of configurations/flow fields that they felt covered the range of flows that had to be accurately predicted with CFD in this Mach-number range. The cases identified are:

- Control-surface effectiveness for hypersonic and entry/descent vehicles

- Aerodynamic interactions for propulsive descent
- Hypersonic vehicle inlet integration and isolator operational boundaries
- Entry-vehicle reaction control system jet interaction for entry vehicles
- Multi-body aerodynamics for high-speed separation events
- Simple wing/body aerodynamics
- Empty-tunnel flow characterization

The criteria for selecting these cases included lack of understanding of the underlying physics and/or poor track record in prediction of a particular flow/configuration using CFD. In order to demonstrate the ability of CFD to predict these flows, test data is required from tests in the LaRC UPWT along with predictions performed for exactly the same test condition. Examination of the reported flow characteristics in the tunnel showed that without a better understanding of the test-section flow distribution, the comparisons would be flawed from the start. The empty-tunnel flow characterization evaluation case, a simulation of the wind tunnel itself, was added to the list in order to obtain accurate in-flow boundary conditions for the CFD predictions of the other evaluation cases. It also turned out to be an interesting case to compute in its own right.

The project was adopted by the Aerosciences Evaluation and Test Capability (AETC) Program as one of its Technology Challenges in 2018. One of the ground rules affecting the project was that AETC would support the wind-tunnel tests and the CFD would be supplied by partner projects. This accomplished two goals; reducing the cost to AETC, and more importantly, forcing the project to study configurations of sufficient interest to other aeroscience projects to justify their support of CFD in exchange for needed, and unplanned, wind-tunnel test data. This has worked out well with the adopted test cases and configurations serving the necessary dual purpose allowing the necessary collaborations to be quickly established.

Another goal was to have a minimum of two, and preferably more, CFD codes used for each of the evaluation cases. Two reasons for this were to broaden the level of expertise of the CFD practitioners working on the evaluation teams and to get a broader look at how well different codes do with each case.

This paper will present the overall project structure and the common ground rules adopted for the six evaluation teams. The figures below present images of the overall flow fields for the flow characterization and control-surface effectiveness evaluation cases.

III. References

1) Jackson, D. M. Jr., Corlett, W. A., and Monta, W. J., "Description and Calibration of the Langley Unitary Plan Wind Tunnel," NASA TP-1905, 1982.

2) Lee, H. C., Klopfer, G. H., and Onifer, J. T., "Numerical Investigation of the Flow Angularity Effects of the NASA Langley UPWT on the Ares I DAC1 0.01-Scale Model," AIAA paper 2011-1110, 49th AIAA Aerospace Sciences Meeting, January 2011, Orlando FL

3) Cerimele, C. J., et al, "A Rigid Mid-Lift-to-Drag Ratio Approach to Human Mars Entry, Descent, and Landing," AIAA Paper 2018-0615, 2018 SciTech Forum - AIAA Guidance, Navigation, and Control Conference, January 8-12, 2018, Kissimmee, Florida.

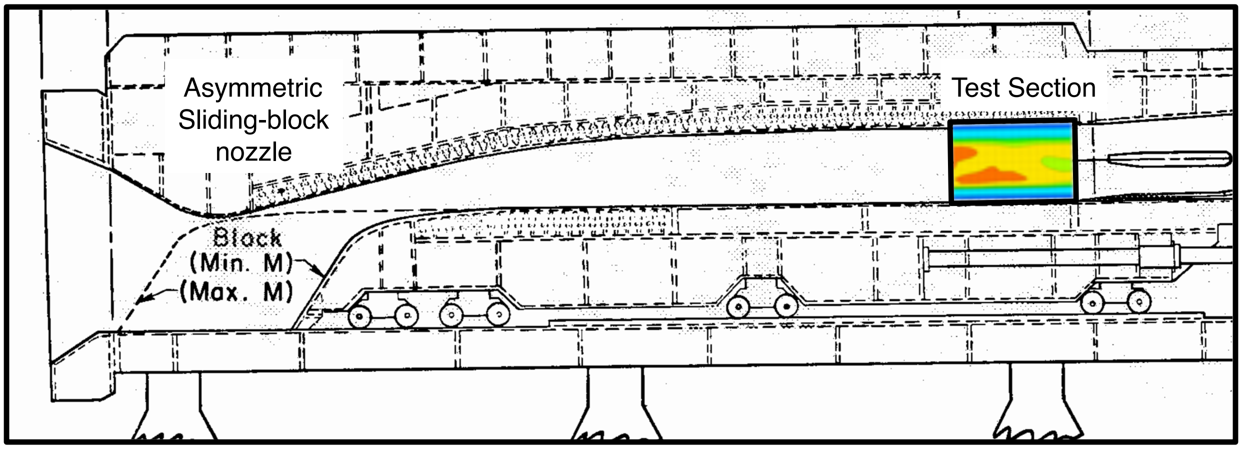

Figure 1. Side view of high-speed leg of LaUPWT showing sliding-block nozzle from Reference 1 and the computed flow distribution in a vertical plane at the center of the test section at Mach 2.4 from Reference 2.

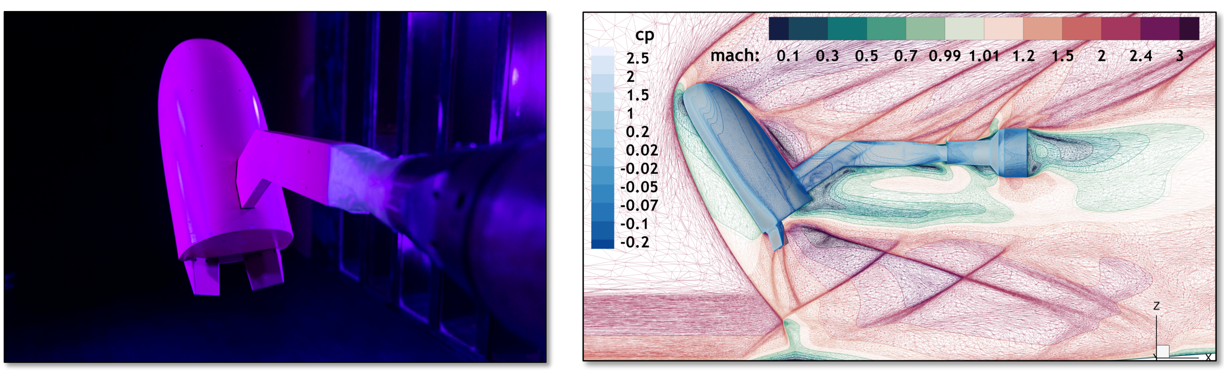

Figure 2. CobraMRV entry vehicle configuration (ref. 3). Wind-tunnel model with Pressure Sensitive Paint in the wind tunnel and sample CFD solution for Mach 2.4, Re 3 M/ft.