An Infrastructure for Algorithmic Flexibility in Multi-fidelity and Multi-disciplinary CFD Simulations

S. Morton*, N. Hariharan* and D. McDaniel*,**
Corresponding author: scott.a.morton@usace.army.mil

* US DoD High Performance Computing Modernization Program, USA.
** University of Alabama Birmingham, USA.

Abstract: An infrastructure that is the core of a multi-disciplinary, multi-fidelity, simulation tool in the US Department of Defense High Performance Computing Modernization Program Computational Research and Engineering Acquisition Tools and Environments (HPCMP CREATE^{TM}) program that couples aerodynamics, thermochemistry, stability and control, structures, propulsion, and store separation for a large range of freestream operating conditions, Kestrel, is described. The infrastructure enables a robust and accurate capability targeting fixed-wing aircraft and is being used extensively in government and industry organizations within the US DoD acquisition community. This paper details the new flexible physics coupling strategy in the context of a notional hypersonic trajectory simulation. This strategy provides ultimate flexibility to define exactly when and how different high-fidelity physics solvers are employed during the simulation. Results are presented for the notional trajectory analysis.

Keywords: Numerical Algorithms, Computational Fluid Dynamics, Multi-fidelity Solvers, Multi-physics Simulations.

1 Introduction

In an era when a digital transformation of the US Research, Design, Test, and Evaluation (RDT&E) acquisition process is occurring, it is critical to have an infrastructure that can be flexible enough to include other disciplines such as Propulsion, Stability and Control, Structures, and Thermal Sciences with Computational Fluid Dynamics simulations. In addition to multi-disciplines, it is also key to allow multi-fidelity of the integrated disciplines to allow long trajectory times. Probably the most noteworthy feature addition during the last year to Kestrel[1,2] was the substantial set of changes to the workflow surrounding the coupling of different CFD-related physics capabilities in the simulation software. Two main requirements served as the driving motivation for these changes. First, the introduction of conjugate aero heating capabilities exposed limitations with the existing time-accurate coupled analysis approach for long duration trajectories of flight vehicles. The time scales of these simulations relative to the required solution time made the computations intractable. While still desiring to support high-fidelity, time-accurate simulations of smaller mission segments, it was necessary to support a more flexible coupling strategy between physics modules addressing both the frequency at which different solvers executed as well as the time integration scheme used to converge the solution (e.g. time-accurate versus quasi-steady). Figure 1 shows a notional vehicle trajectory analysis scheme with a computational fluid dynamics (CFD) solution, a computational structural dynamics (CSD) solution, and a thermal solution occurring at non-uniform intervals with different time integration approaches. The second motivating factor was the growing number of users requesting the ability to run simulations with minimal or no aerodynamic modeling included (e.g. a structural heating problem with a prescribed heat flux on the aero-structural boundary). In an effort to support these and other related use cases in a general manner, some key paradigm changes were made to the standard simulation workflow. Targets of opportunity were seized to remove existing awkward interactions and workflows where possible. It is important to emphasize that all existing simulations are automatically converted to the new paradigm. A detailed discussion of the infrastructure will be provided in the full paper.

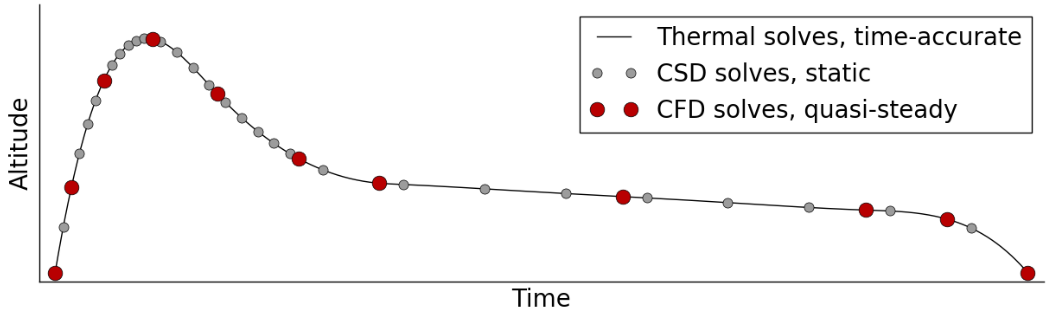

Figure 1. Notional vehicle trajectory with non-uniform physics coupling and time solution schemes.

In the full paper an aero-heating example will be presented that demonstrates the effectiveness of the new simulation strategy for multi-disciplinary, multi-fidelity simulations for a very long trajectory. Key results for this simulation are in Figure 2.

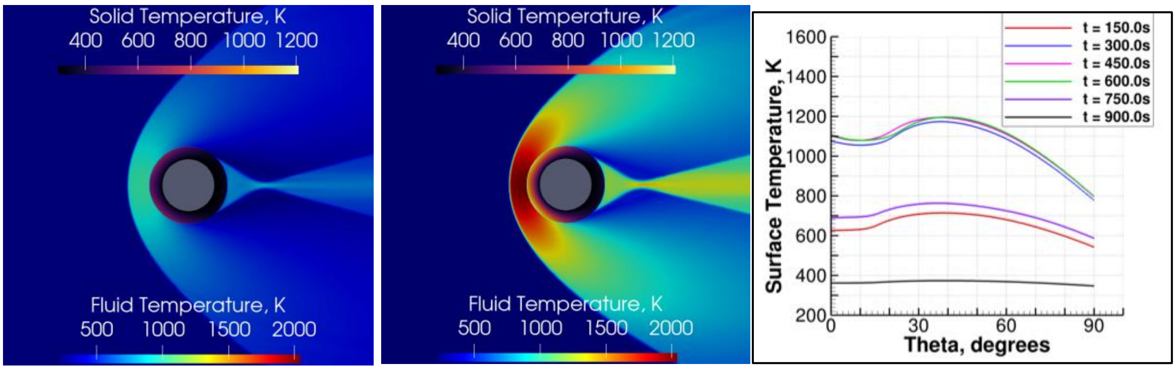

Figure 2. Fluid and structure temperature contours at t=150 sec (left) and t=450 sec(middle) during a fictitious aeroheating trajectory. Evolution of cylinder surface temperature at selected time points during a fictitious aeroheating trajectory (right).

References

[1] McDaniel, D., Tuckey, T., "Multiple Bodies, Motion, and Mash-Ups: Handling Complex Use-Cases with Kestrel," AIAA Paper 2014-0415, 52nd Aerospace Sciences Meeting, National Harbor, Maryland, Jan. 13-17, 2014.

[2] Morton, S.A., McDaniel, D.R., Sears, D.R., Tuckey, T.R., Tillman, B., "Kestrel – A Fixed Wing Virtual Aircraft Product of the CREATE™ Program," 47th AIAA Aerospace Sciences Meeting, 5 - 8 January 2009, Orlando, Florida.