A Multi-Physics Modeling Framework for Plasma Wind Tunnels

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Abstract: This work discusses the development of a multi-physicsmodeling framework for Inductively Coupled Plasma (ICP) wind tunnels. As opposed to a monolithic approach, separate in-house solvers are considered to deal with the different parts of the complete model. The flowfield is modeled using hegel, a finite volume solver for non-equilibrium plasmas. The simulation of the electric field and the thermal Protection System (TPS) material sample is accomplished via a finite element solver and a finite volume solver (flux and pato, respectively). The three tools are coupled using the preCICE library. Results for a two-dimensional axi symmetric ICP configuration are presented and discussed to illustrate the effectiveness of the proposed coupled approach for modeling ICP discharges along with material response and electromagnetic phenomena.
Keywords: Multi-physics, Numerical Algorithms, Computational Fluid Dynamics.

Introduction

The purpose of this paper is the development of a multi-physics modeling framework for ICP wind tunnels. Instead of adopting a monolithic approach the hydrodynamics, electric field and material response are handled by separate stand-alone solvers developed either within the *Center for Hypersonic and Entry Systems Studies* (CHESS) at University of Illinois, or by external collaborators. Hydrodynamics is modeled using HEGEL [1], a finite volume solver for nonequilibrium plasmas. The simulation of the electric field and the thermal Protection System (TPS) material sample is accomplished via a finite element and a finite volume solver (FLUX [2] and PATO [3], respectively). Coupling is realized by means of the preCICE open-source library [4]. Here details are only provided for the fluid solver. Information on the material response and electric field solvers may be found in the companion papers.

Problem Statement

The multi-physics model for ICP wind tunnels is build based on the coupling of three stand-alone solvers responsible for: (i) the flowfield, (ii) the thermophysical properties of the TPS sample being tested and (iii) the electric field.

The fluid solver is hegel (High-fidElity tool for maGnEto-gasdynamics simuLations), a parallel structured grid finite volume code written in modern Fortran 2008 for ideal gases, and LTE and NLTE plasmas discussed [1]. This code is MPI parallel and uses the functionalities provided by the petsc library to distribute data among processors. The calculation of thermodynamic and transport properties, and kinetics source terms for LTE/NLTE plasmas is accomplished via the plato (PLAsmas in Thermodynamic nOn-equilibrium) library [1].

The flow governing equations are solved in hegel using a cell-centered finite volume method based on method-of-lines approach to separate temporal and spatial discretization. Inviscid fluxes are evaluated using flux functions such as Roe's approximate Riemann solver or the AUSM-family schemes along with reconstruction procedures (e.g., MUSCL, WENO) to achieve high-order accuracy. Diffusive fluxes are computed using Green-Gauss' theorem to evaluate face-averaged gradients. The integration of the space discretized equations may be accomplished via explicit, implicit or implicit-explicit

(IMEX) methods. More details can be found in Ref. [1]. Hegel has been successfully employed to model laser discharges and hypersonic flows. In this work its capabilities have been extended to i) deal with two- and three-dimensional block-structured grids, ii) enable coupling with other solvers (e.g., material response , electric field), iii) minimize spurious numerical reflections at boundaries via characteristic-based LODI boundary conditions.

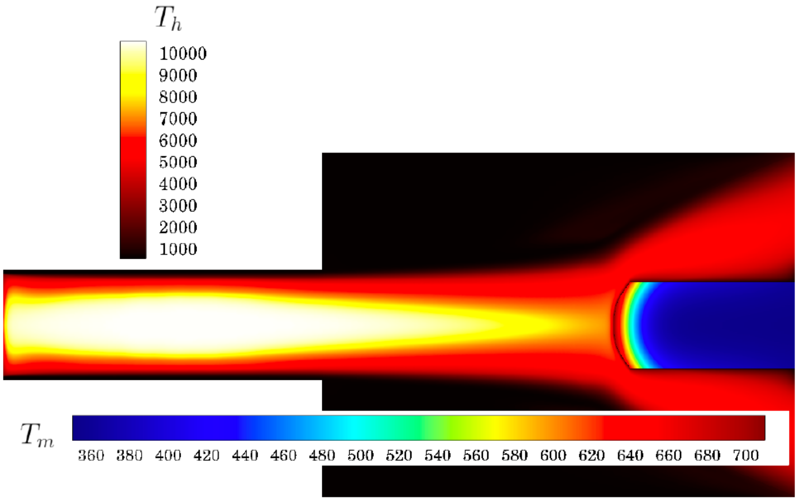

Figure 1. Simulation of ICP facility: temperature distribution of the plasma and within the sample.

Conclusion and Future Work

This paper will present and discuss the development of a multi-physics framework for the modeling ICP wind tunnels. As opposed to a monolitic approach, three stand-alone solvers responsible for the evolution of: (i) the flowfield, (ii) the electromagnetic field, and (iii) the thermo-physical properties of the material sample, have been coupled using the preCICE open-source library. After assessing the correct implementation via verification tests, the feasibility of the proposed approach has been demonstrated for an axi-symmetric ICP facility configuration.
Future work will focus on extending the developed framework to three-dimensional configurations, and to account for ablation and material recession by means of the CHyPS high-performance material response solver developed
within CHESS.

References

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