Numerical solutions of plasma flow in the presence of absolute or partial vacuum

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ABSTRACT

This work is concerned with the solution of the MHD equations across the plasma and the equation for the magnetic field across the first wall on a single computational grid. This provides a seamless solution across the various plasma regions and takes into effect the electromagnetic properties of the confinement vessel. An important element of this approach is the representation of the interface between the plasma and the region which separates it from the first vessel wall, i.e. the plasma edge. This can be represented on discrete space as an absolute vacuum or a low-density plasma region (partial vacuum). In the first instance, a multi-material interface fitting approach [1] is employed to model the plasma interaction with absolute vacuum. This is based on the modification of the fluxes of the underlying system of equations, which encodes the effect of the desired boundary condition at the location of the interface. On the other hand, the plasma interaction with partial vacuum is modelled using a single-fluid, interface capturing finite volume scheme. Interactions with various degrees of partial vacuum are investigated by progressively lowering the values for the background density and pressure. Exact solutions for plasma-vacuum Riemann problems, as well as ordinary Riemann problems, are constructed, validating that the aforementioned methods are capable of modelling both cases to a high level of accuracy.

A comparison of the two sets of solutions demonstrates that the two approaches capture different wave configurations. In the former case, a smooth rarefaction wave is observed as the plasma expands into true vacuum, whereas in the latter case, the solution to the Riemann problem consists of a smooth rarefaction, a contact wave and a shock wave which propagates into the low-density background state. This indicates that in the asymptotic limit, where a low-density approximation is used to model vacuum, the continuity assumption used to construct the numerical scheme breaks down, resulting in unphysical flows. In two dimensions, we investigate how the different wave configurations interact with surrounding matter by allowing the plasma expansion to take place within a rigid body of arbitrary geometry. Specifically, the ST40 confinement vessel is used for this purpose and a standard Riemann rigid body ghost fluid method is employed to model this as a perfect conductor.

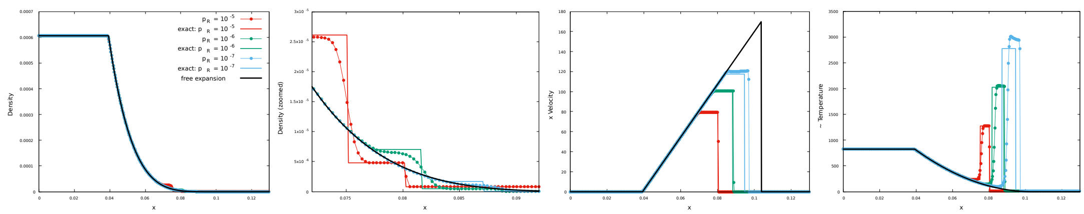

Figure 1: Fluid expansion into varying degrees of low-density background states plotted against a free expansion solution for the same driver state.

References

[1] Wallis, T., Barton, P.T. and Nikiforakis, N., 2021. A Flux-enriched Godunov Method for Multi-material Problems with Interface Slide and Void Opening. Journal of Computational Physics.