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A Thermodynamically Consistent Manifold Model for Premixed Detonations and Deflagrations

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There is a critical need for better understanding of the coupling between the small- and large-scale processes in detonative combustion processes. This is a difficult challenge for computational studies due to the need to resolve the finest scales of the flow. As a result, many studies sacrifice fidelity elsewhere to decrease computational cost [1], for example, by simplifying the geometry (e.g., "unrolling" a Rotating Detonation Engine (RDE)) or by simplifying the chemistry, typically using (quasi-) global chemistry. The latter approach generally grossly oversimplifies the chemistry and does not allow for the complex coupling between the chemical reactions and flow processes in the detonation to be properly captured. In the context of low-speed reacting flows, models exist that can greatly decrease computational cost with minimal loss in accuracy, but these models are not suitable for high-speed, compressible reacting flows, notably those featuring detonations.

Manifold-based combustion models [2] have demonstrated considerable success in reducing computational cost for low-speed reacting flows with minimal loss in accuracy. Various attempts over the years have tried to extend manifold-based models to compressible flows; however, a fundamental difficulty is ensuring consistency between the thermodynamic state of the model and the flow solver [3,4]. Recent work has overcome this difficulty for high-speed, nonpremixed reacting flows by using an iterative approach to ensure thermodynamic consistency between the manifold model and the flow solver [5]. This work extends this iterative approach to premixed detonations and deflagrations and demonstrates the feasibility and accuracy of the model using an *a priori* analysis of results from a model RDE. Analysis of the results indicates the critical need to ensure thermodynamic consistency to maintain the accuracy of the manifold-based model for detonations. The resulting method demonstrates an important leap in model fidelity with the potential to dramatically lower computational cost of simulating detonative combustion processes without sacrifices in fidelity of the chemistry model.

References

[1] Raman, V., Prakash, S., & Gamba, M. (2023). Nonidealities in Rotating Detonation Engines. Annual Review of Fluid Mechanics, 55(Volume 55, 2023), 639–674.
[2] M. E. Mueller, Physically-derived Reduced-order Manifold-Based Modeling for Multi-modal Turbulent Combustion, Combustion and Flame 214 (2020) 287–305.
[3] A. Saghafian, V. E. Terrapon, and H. Pitsch, An Efficient Flamelet-Based Combustion Model for Compressible Flows, Combustion and Flame 162 (2015) 652–667.
[4] Baumgart, A., Yao, M. X., & Blanquart, G. (2025). Tabulated Chemistry Approach for Detonation Simulations. Combustion and Flame, *272*, 113878.
[5] E. Cisneros-Garibay and M. E. Mueller, Consistent Coupling of Compressibility Effects in Manifold-Based Models for Supersonic Combustion, AIAA Journal 62 (2024) 590-601