

Dynamics of premixed flames within closed vessels

Gautham Krishnan¹, Carlos Pantano², Moshe Matalon^{1*}

* Lead presenter: matalon@illinois.edu

¹ University of Illinois at Urbana-Champaign, United States

² University of Southern California, United States

Premixed flames propagating within closed vessels are numerically investigated using a hybrid Navier-Stokes/embedded-manifold methodology [1], which has been recently developed to simulate the propagation of multi-dimensional flames in the context of a novel hydrodynamic theory [2]. The flame in this model is confined to a surface propagating into a mixture that is continually compressed, leading to substantial increases in pressure and temperature that affect the flow field and consequently the local flame speed defined relative to the unburned gas. The flame speed depends on the surface stretch rate as well as on the progressive reduction in flame thickness due to the pressure rise, and is modulated by a modified Markstein number that progressively decreases in time. The numerical methodology consists of two modules; the first involves solving the fluid dynamic equations with a spatio-temporally varying density field determined from thermodynamic considerations, and the second employs a level-set approach to advance the flame front in time. The two modules are coupled through a mass conservation constraint, and a high-order geometrical closest point method which is used to evaluate quantities defined strictly on the flame surface. An immersed boundary method is utilized to implement boundary conditions at the walls of a vessel of arbitrary shape. The numerical approach has been validated against exact analytical solutions of planar and cylindrical flames and used subsequently to ascertain the effects of flame wrinkling resulting from the Darrieus-Landau instability prevalent in premixed combustion. Salient distinctions are inferred in the onset and subsequent nonlinear evolution of the instability in rectangular and cylindrical vessels when compared to corresponding freely propagating flames.

References

- [1] G. Krishnan, C. Pantano and M. Matalon, A numerical method for the multidimensional hydrodynamic model of flames propagating in closed vessels, 2025, submitted for publication.
- [2] J.K. Bechtold, G. Krishnan and M. Matalon, Hydrodynamic theory of premixed flames propagating in closed vessels: flame speed and Markstein lengths. *Journal of Fluid Mechanics*. 2024; 998:A59.