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Predictive low-order modeling of thermo-acoustic response in conical flames

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In boilers, fuel and air are burned and the heat released by the combustion process is transferred to water using a heat exchanger. Perturbations in velocity or mixture composition can lead to a feedback loop – an interaction between the unsteady velocity perturbations and the unsteady heat release rate – known as thermo-acoustic interaction. This interaction leads to pressure oscillations, resulting in noise or sometimes damage due to the magnitude of the fluctuations.
This process is governed by the properties of the flame – mainly the flame shape. Detailed unsteady Computational Fluid Dynamics simulations or flame response measurements using microphone arrays are time-consuming and can be expensive and fast but accurate analytical models will be invaluable tools in the design process.

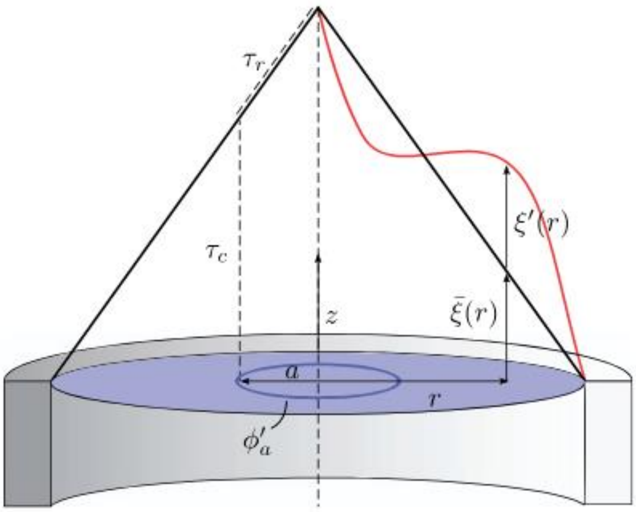

Figure 1: Flame configuration for the G-equation. From Albayrak and Polifke.

The process can be simplified by only considering an equation for the unsteady laminar flame shape using the G-equation. Linearizing leads to uncoupled 1D PDE's with analytical solutions (see e.g. Albayrak and Polifke). These simlpified models are predictive models, i.e. they can predict the change in stability behavior when a parameter changes. Using Fourier Transforms, a Flame Transfer Function can be obtained, which can be used to model the problem as a 0-D feedback control loop. Improved stability can be obtained by increasing the stability margin of the control system (see e.g. Reumschüssel et al.).

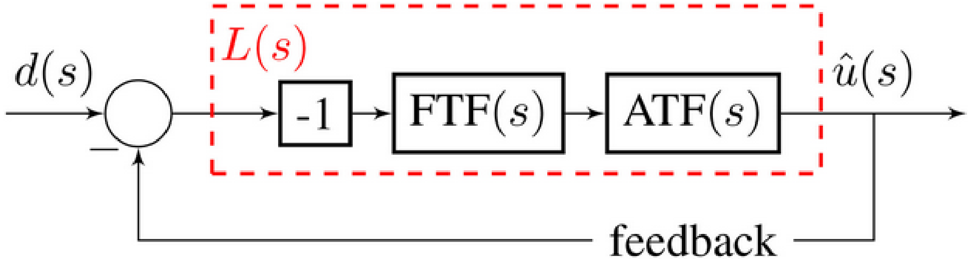

Figure 2: Thermoacoustic system as a feedback loop. From Reumschussel et al.

The final goal in the project is to be able to describe the acoustic properties of methane and hydrogen flames of more practical configurations (single flames but also 'rows of flames'). A second goal is to be able to perform an analysis that gives an optimized performance.

Points that can be considered:

- What is the difference between 2D planar and 2D axisymmetric flames in the formulation of the G-equation?
- Extend this approach from a single flame to a burner with multiple flames. A simple 2-D planar 'slit' burner can be considered for this approach. Is it also possible to extend the single flame approach to a burner with a pattern of round holes?
- What would be the difference between using methane as a fuel and using hydrogen as a fuel?
- Proof of concept can be illustrated with a python code illustrating the solution for the different testcases.
- Assuming a known Flame Transfer Function and Acoustic Transfer Function ('flame in a tube'), stability maps can be created to identify the critical eigenvalue for stability. It would be interesting to know the difference in stability map between hydrogen and methane flames.
- How can a device be optimized? Is it possible to create a simple optimization model that will give better thermo-acoustic properties?

Keywords: thermoacoustic instability, laminar premixed flame, n-tau model, G-equation, Rayleigh Criterion

References:

Albayrak et al (2017)
https://www.sciencedirect.com/science/article/pii/S1540748916300608

Albayrak and Polifke (2018)
https://mediatum.ub.tum.de/doc/1510122/1510122.pdf

Bigongiari A, Heckl MA. A Green's function approach to the rapid prediction of thermoacoustic instabilities in combustors. *Journal of Fluid Mechanics*. 2016;798:970-996. doi:10.1017/jfm.2016.332

Sreenath Malamal Gopinathan, Aswathy Surendran, Maria A. Heckl, Hydrogen-blended fuels: Nonlinear flame dynamics and safe operation limits, International Journal of Hydrogen Energy, Volume 111, 2025, https://doi.org/10.1016/j.ijhydene.2025.02.172.

Reumschüssel et al. (2024)
https://journals.sagepub.com/doi/epub/10.1177/17568277241237068