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PROPOSITION DE SUJET DE THESE

Intitulé : Analysis of thermoacoustic phase-change driven engine: stability and control

Référence : MFE-DMPE-2026-**23**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2026	**Date limite de candidature : 31/07/2026**

Mots clés

Thermoacoustic engines

Profil et compétences recherchées

Master 2 in Fluid Mechanics or Applied Mathematics, Engineering schools, etc.

Good knowledge in numerical analysis.

Présentation du projet doctoral, contexte et objectif

State of the art

*Thermoacoustic engines (*TAEs*),* see Fig. 1 (a), are thermodynamic systems that make use of a temperature gradient along a porous medium, to generate self-sustained acoustic oscillations, which in turn can be converted to usable electric power. From a physical standpoint, it is established that a gas in a tube with a stack inserted becomes unstable starting a self-sustained cycle if the temperature gradient along the stack is appropriately steep (Yazaki et al. (1998)).

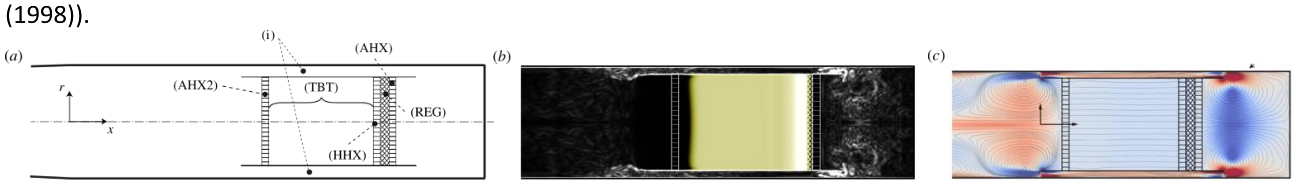

Figure 1 (a) Sketch of a Travelling Wave TAE (TW-TAE). (b) Visualization of streaming in terms of temperature (color) and vorticity (white lines) (c) Visualization of the axial velocity and streamlines. Extracted from Scalo (2015).

The design of TAEs has historically relied on asymptotic linear theories, such as the long-wave approximation (Sugimoto, 2010), and their weakly nonlinear extensions (Karpov et al. 2002). Only recently have high-fidelity simulations (Scalo et al., 2015; Lin et al., 2016) been employed to resolve the full physics. These simulations reveal that at large limit-cycle amplitudes, efficiency is significantly degraded by acoustic streaming—a quasi-steady mean flow driven by the acoustic field, see Fig. 1(b-c).
In addition, despite their advantage of having no moving parts, making them attractive for aerospace and maritime applications, TAEs have seen limited industrial adoption. Most systems are conduction-driven, using an inert gas. A paradigm shift involves introducing a condensable vapour to create a phase-change-driven system, where heat transfer occurs at constant temperature, enabling operation at lower temperature gradients. The theory for such systems was pioneered by Raspet et al. (2002) and Slaton et al. (2002), and later refined by Offner et al. (2019) to include sorption effects. Experimentally, the reduced onset temperature was first demonstrated by Noda & Ueda (2013) and rigorously quantified by Tsuda & Ueda (2015, 2017) across various engine geometries.

Objectives

This thesis project aims to analyse the effect of phase change on the thermoacoustic instability and to develop a numerical strategy in order to improve the performance of TW-TAEs.

Numerical methodology for the compressible Navier—Stokes equations with pahse change

In the studies of Scalo et al. (2015) and Lin et al. (2016) it has been shown the importance of the usage of high-fidelity simulations whenever the acoustic amplitude is large. In this thesis we would like to develop a high-fidelity computational model by solving the compressible Navier-Stokes equations. This involves implementing and comparing advanced phase-change methods: (i) a phase-field (Zimmerman et al. (2021)) with a diffusive interface between the gas and the liquid, (ii) a level-set method, and (iii) a multi-species (inert gas, liquid and vapour) multi-scale solver where the phase-change is accounted by a homogenized boundary condition. The homogenized condition shall account for the exchange of mass and energy, and shall depend on the thermodynamic properties of the gas and the liquid, i.e., temperature, humidity etc. Since the objective is to determine the effect on the phase-change on the acoustic field, we will favour robust numerical methods that do not produce any spurious acoustic radiation; the method (iii) is expected to satisfy these constraints. In the solver we will include the modelling of the porous stack using a homogenized tensor and wall-resolved approaches, with comparisons between both methods at low and high acoustic amplitude. Finally, the solver will be based on a Discontinuous Galerkin method.

Linear stability and sensitivity analysis of the thermoacoustic instability

A comprehensive parametric study of the thermoacoustic instability onset—involving a large number of parameters such as the temperature gradient, Prandtl number, and Jakob number—is not feasible via DNS due to its excessive computational cost. Concurrently, the applicability limits of linear long-wave approximations are poorly defined when their foundational hypotheses are not met. To bridge this methodological gap, this project will employ Global Linear Stability Analysis (GLSA) (Fabre et al., 2018), leveraging the solver developed in the first step, to accurately identify the instability neutral curves. In addition, in order to determine the role of the condensable thin liquid film in the amplification of the acoustic wave, we propose to employ sensitivity analysis based on the direct and adjoint global modes to quantify for the change of the growth rate and frequency due to the phase-change. At this stage, we can propose a new engine design by means of shape optimisation.

Continuation of the limit cycle, secondary stability and optimization

The nonlinear saturation to a limit cycle will be investigated using a multi-fidelity approach: WNL for moderate amplitudes and the TSM/HBM for larger amplitudes (Sierra-Ausin, 2022). Floquet-Hill theory based on TSM/HBM will be then used for the identification of secondary instabilities (Sierra-Ausin (2021)). Such an approach will allow us to efficiently identify secondary instabilities. In a second step, the WNL and TSM/HBM frameworks will be integrated within a direct-adjoint optimization loop, with the primary objective being to maximize the nonlinear acoustic amplitude while minimizing the required stack temperature difference.

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Collaborations envisagées

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