Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: PROPHY
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Type: Oral
Status of corresponding author: Student
For student corresponding author: student member of one of the following:

Reduced Order Modeling for the prediction of combustion instabilities in liquid rocket engines: coaxial injection response and acoustic damping modeling

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The prediction of combustion instabilities is a significant challenge for the development of liquid rocket engines [1]. Because experiments on full-size engines and high-fidelity simulations remain long and costly, low-order tools have received an increasing attention providing a rapid and adaptive exploratory set of solutions for the pre-design stage. In this context, the EM2C laboratory, in partnership with CNES and ArianeGroup, has undertaken the development of StaHF (Stability High-Frequency) [2], a reduced-order code based on a Galerkin decomposition where the pressure oscillations are projected onto the modal base formed by the acoustic eigenmodes of the engine. Flame responses to various types of perturbations are modeled and integrated in the solver in the form of Flame Transfer (respectively Describing) Functions FTF (respectively FDF), which depend on the perturbation frequency (respectively frequency and amplitude). Selected damping phenomena have been modeled. First, compact and non-compact nozzle losses are modeled with a frequency-dependent impedance formulation. A model for viscous and thermal damping at walls is integrated, based on the approach of [3]. These losses are probably not of primary importance in liquid-rocket engines, but do not have to be set aside on smaller laboratory scale test benches. A model is also developed to evaluate the interaction between the acoustics and the turbulence. However, this mechanism may not lead to high values of damping. Finally, the role of the injection plan on the overall damping is modeled assuming the behavior of a perforated plate [4]. Applications are first made on the NPCC cold-flow test bench and compared to the numerical results from LES of [5]. The damping estimation allows to retrieve the correct order of magnitude of the limit cycle in a linear regime. Then, the BKD test bench [6], representative of a real rocket engine, is computed with StaHF.

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