Bayesian parameter inference of a vortically perturbed flame model for the prediction of thermoacoustic instability

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Abstract

Thermoacoustic instabilities can be highly detrimental to the operation of aircraft gas turbine combustors within design conditions, and hence their prediction and suppression are crucial. This work uses a Bayesian machine learning method to infer the parameters of a bluff-body stabilised, physics-informed flame model. The flame front is modelled using the G-equation, a level-set method which segments the flow into regions of reactants and products. The flow past the bluff-body is modelled with a discrete vortex method to account for vortical perturbations on the flame front. Using the physics-informed model with the learned parameters, a flame transfer function is obtained, from which the growth rates of instability in the system can be calculated. A heteroscedastic Bayesian neural network ensemble (BayNNE) is trained on a library of flame front simulations with known target parameters in both models. The trained BayNNE is a surrogate model for a Bayesian posterior of the target parameters given the input flame front coordinates. The ensemble predicts some parameters with more certainty than others, showing which are more influential in affecting the flame shape. Using the learned posterior, the flame fronts are re-simulated to extrapolate the flame both in physical space and parameter space. These extrapolated flame shapes are then used to calculate the thermoacoustic frequencies and growth rates. We observe that the growth rates and frequencies do not show a strong dependency on the amplitude of forcing, which is one of the inferred parameters of the physics-informed model. This important result suggests that a flame transfer function derived at high amplitude, when it is observable, is also valid at low amplitude, when it is not observable.

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