A FLAMELET GENERATED MANIFOLD MODEL FOR PARTIALLY PREMIXED LAMINAR FLAMES

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Motivation

The purpose of the present piece of research is to develop a combustion model suitable for the representation of laminar combustion in household, gas-fired stove burners.

Several approaches have been developed over the years to reduce the computational effort needed to simulate a combustion system. One of them is the Flamelet-Generated Manifold (FGM) [1, 2, 3, 4, 5, 6, 7].

The FGM method has been hitherto used to model premixed, non-adiabatic flames, *eg* [6] and non-premixed, adiabatic flames, *eg* [7], both laminar and turbulent. In such cases, two-dimensional manifolds are often enough to represent the composition space accessed in the physical configurations, and the models described and implemented in those works reproduce with fair accuracy the results obtained with full chemistry models.

Partially-premixed, strongly non-adiabatic flames, however, present new challenges. Such flames require at least three-dimensional manifolds if one is to capture the composition space accessed by these flames. Some works have extended the FGM methodology to include the third dimension in the manifold, but this extension has been applied only to very simple configurations, where the amount of heat extracted is very small or no secondary air is introduced.

However, in a real, complex system, several fuel inlets with different compositions may enter the system; also, a secondary air flow is often present. Besides, significant amounts of heat may be transferred to other parts of the system (for instance to heat water, in the case of a boiler; or to heat a cooking pan, in gas-fired cooking ranges). Heat extraction cools the combusting mixture, even down to temperatures close to the ambient ones.

The extent of the composition space accessed in a flame of such characteristics is substantially larger than in simpler premixed flames. In these situations, the methodologies employed in previous works are not capable of accessing all the thermochemical space that the actual flame accesses; critically, they do not access the very-low-enthalpy range or mixture fractions outside the flammability limits.

In addition to the previous limitations, other important effects have not been accounted for: neither radiation nor conjugate heat transfer have been considered in any of the works reviewed; and only recently differential diffusion effects begun to be included, *eg* [2].

Development

To improve on existing FGM models, we have developed a comprehensive means of using flamelets to traverse the compositional space that will be accessed in the actual flame calculation. This space critically includes regions of low enthalpy, that are difficult to access using only one-dimensional premixed free flames. To provide stably burning flamelets with low enthalpy regions, we use several flamelet families which include counterflow premixed flames, and feature heat extraction in varying degrees.

The storage of these several flamelet families in the manifold is not as straightforward as in previous applications using a single family. To store the resulting unstructured cloud of data points, we first use a Delauney triangulation; then, to speed up the retrieval of the information at runtime, we remap this triangulation onto a structured mesh. This strategy allows also for the easy extension of the manifold to further dimensions. For the type of flames targeted in this research, at least three manifold dimensions are required: mixture fraction, reaction progress and enthalpy; but further dimensions, such as additional reaction-progress variables, can be easily accommodated.

The model includes conjugate heat transfer (heat conduction and convection in the fluid and heat conduction in solids), as well as heat exchange by radiation.

The FGM add-on has been implemented in OpenFOAM as a new solver, fgmFOAM.

Results

We have used the new FGM model to simulate both laboratory flames and commercial-type stove-top burners. The Yale burner configuration is used for validation in laboratory-type configurations, by comparison with experimental data and with calculations carried out with full integration of the thermochemistry. Figure 1, left, is a representation of the thermochemical space actually accessed during the calculation with direct integration of the thermochemistry (dots in dark blue) and with the several flamelet families during the generation of the FGM (all other colours). The figure shows that the flamelet generation strategy successfully spans the required composition space.

The results are very good for the main combustion species, and for the overall heat transfer efficiency. Figure 1, right, shows a rendering of the stove burner and the temperature field calculated by the FGM.

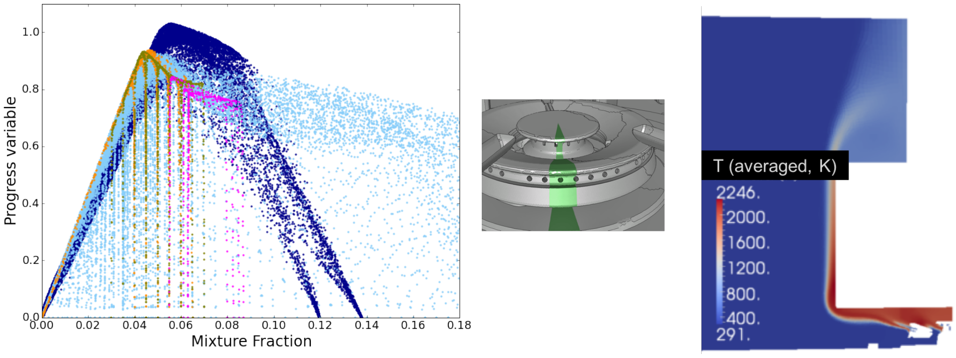

Figure 1: Left: Representation of the composition space accessed in the simulation with direct chemistry integration (light blue) and during the generation of the 3D manifold (all other colours) for the household burner configuration: progress variable vs. mixture fraction. Right: Burner configuration and computed temperature field

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