Indirect Measurements of Flames Based on a Coupling of Laser-Diagnostics and Mathematical Analysis

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Main Topic: (1) Premixed Combustion

During the last decades, laser-diagnostics and mathematical analyses have evolved as two of the main fundaments for the investigation of combustion processes. Mostly, they have been pursued independently from each other, although a closer linkage of these disciplines is likely to deliver significant improvements to laser-based measurements in reactive flows.

In our work, we introduce an indirect measurement method that closely links mathematical analyses and laser-based diagnostics of reacting flows in order to increase precision, accuracy and significance of the measured information.

Specifically, we use a mathematical time-scale analysis of chemically reactive systems, namely the Intrinsic Low Dimensional Manifold (ILDM)-Ansatz [1,2,3,4,5,6], to identify correlations between the physical and chemical quantities of the flow. The amount of unknown quantities in the flow is strongly reduced by these correlations. For instance, in a methane/air flame, 36 variables have to be considered for describing the thermokinetic state of the flame (pressure, temperature, species mole fractions). As a result of the analysis performed in the ILDM-method, the 36 quantities can, to a very good approximation, all be described by a set of only 8 to 10 parameters, depending on the desired accuracy. This fact can be used to decrease the amount of information about the flow that has to be provided by measurements.

A formal framework for this approach is developed (see fig. 1) and formulated in terms of state space variables: a description of measurement processes is added to the existing framework that has been developed for the ILDM method in earlier work.

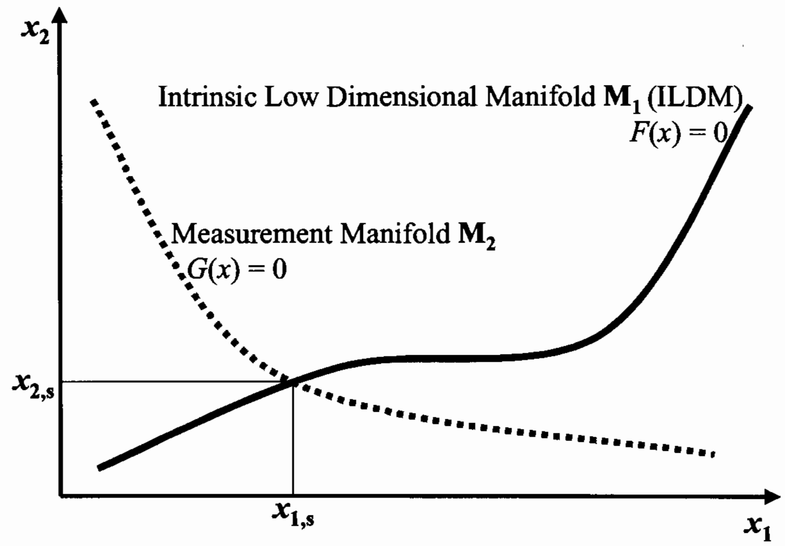

Figure 1 Schematic of the basic idea: Measurements establish relations $G(x) = 0$ between different state variables x_i, thus defining a manifold $\mathbf{M}_2$ in state space. The state of the system ($x_{1,s}$, $x_{2,s}$) lies on the intersection between this manifold and the system's intrinsic low-dimensional manifold $\mathbf{M}_1$ (ILDM): Measurement and mathematical analysis are coupled to yield more information than each approach alone could provide.

The application of our method is demonstrated by a simple example, namely the enhanced evaluation of laser-Raman measurements in premixed flames. By comparing two Raman spectra evaluation schemes, namely one that treats all physical quantities of the flow as independent variables, and one that uses the ILDM-method for evaluation, impacts on accuracy and precision of the ILDM-based evaluation approach can be determined. Furthermore, NO mole fractions that are predicted by the ILDM approach are compared to the values measured directly by probe sampling. It is shown that our approach of using correlations can lead to a considerable enhancement of the quality of the measurement (see figure 2).

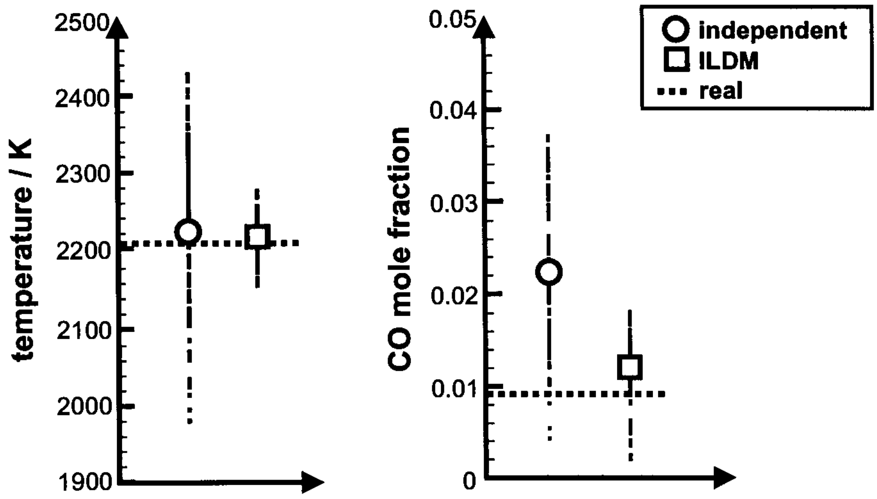

Figure 2 Evaluation results of Raman-spectra recorded in the stoichiometric, near-adiabatic, flat, stationary and laminar CH_4/air flame of a McKenna-burner. 250 evaluation results of temperature and carbon monoxide mole fractions are shown as scatter plots, along with the mean values (large symbols). Each leftmost set of scatter-points denotes results with all variables regarded as independent, each rightmost set denotes results of the ILDM-evaluation approach (2 independent variables). The dotted lines mark "real" values, which were calculated for chemical equilibrium, using a temperature measured in the same flame by CARS.

There are many advantages and prospective further applications of our approach. Possibilities for new measurement strategies occur due to the fact that, with the aid of our approach, quantities that otherwise hardly can be measured may be determined from other, more easily measured quantities. For instance, simple single-shot measurements of temporal derivatives of species concentrations (speed of formation or destruction) may become accessible. Since the validity of the ILDM approach has been proven in many types of reactive flows (premixed/non premixed, laminar/turbulent), and also offers the possibility of *a posteriori* error estimation, the method is not restricted to simple systems, but can be applied e.g. in internal

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