Thermo-Fluid Dynamics

High performance simulation with added value

■ In 2017 we have made significant progress in the development of modelling concepts and simulation software for combustion dynamics and combustion noise. Furthermore, consequences of intrinsic thermoacoustic feedback for the convective scaling of eigenfrequencies were elucidated.

Thomas Emmert was awarded the Dissertation Prize of the Faculty of Mechanical Engineering for his doctoral thesis ‘State Space Modeling of Thermoacoustic Systems with Application to Intrinsic Feedback’.

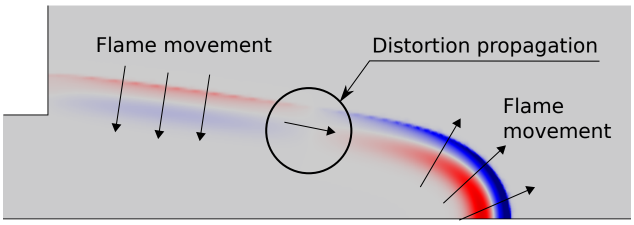
Wolfgang Polifke and Camilo Silva contributed a course with the title ‘Systemidentifikation bei Unsicherheiten – Nix g’naus woas ma ned’ to the Ferienakademie Sarntal.

Research Focus

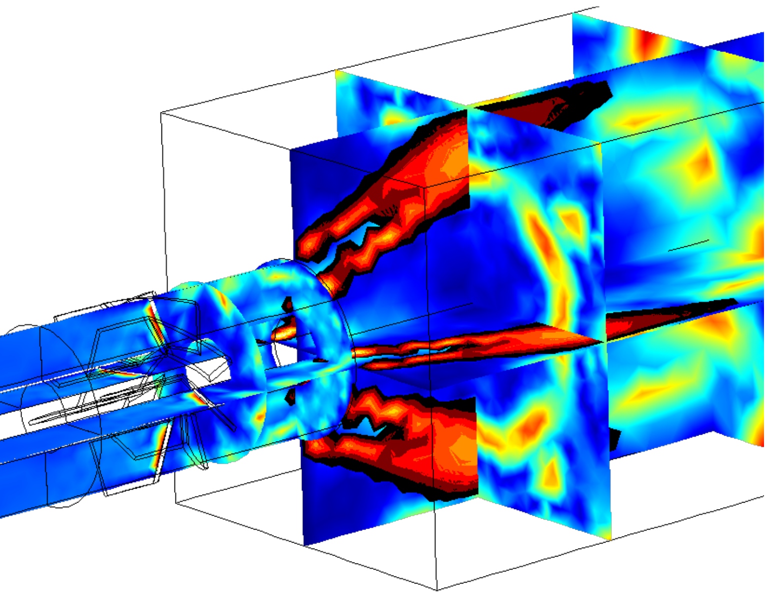
In recent years, the research efforts of the TFD group have focused almost exclusively on thermoacoustic combustion instabilities. This type of self-excited instability results from feedback between fluctuations of heat release rate and acoustic perturbations of velocity and pressure, and may occur in combustion applications as diverse as domestic heaters, gas turbines or rocket engines. Possible consequences are increased emissions of noise or pollutants, limited range of operability or severe mechanical damage to a combustor. Thermoacoustic instabilities have hindered the development of low-emission, reliable and flexible combustion systems for power generation and propulsion. Due to their multi-scale and multi-physics nature, the prediction and control of such instabilities is a very challenging problem with manifold exciting research opportunities.

Linearized (Reactive) Flow Solvers

Analysis of thermoacoustic combustion instabilities is typically based on linearized perturbation equations for compressible reactive flow, with important effects of convection by mean flow. A discontinuous Galerkin finite element method with superior accuracy and stability for this type of equation has been developed in the TFD group. Combined with the state-space framework of the in-house taX software, this method makes possible the computation of transfer functions and thermoacoustic eigenmodes with unprecedented speed and flexibility. Inclusion of a linearized source term for species production and heat release allows the explicit inclusion of flow-flame-acoustic coupling in the computation of thermoacoustic eigenmodes, which has hitherto not been possible. Inertial waves as well as entropy waves can also be described in this framework. First results on the propagation speed of inertial waves, the effect of inertial waves on flame dynamics, and the source term of entropy waves have been achieved and published. Such fundamental investigations of flow-flame-acoustic interactions provide important guidance for the proper formulation of analysis and design tools for thermoacoustic stability.



Distribution of heat release rate fluctuations of the intrinsic thermoacoustic eigenmode of a laminar flame (from Avdonin et al., submitted to Proc. Combust. Inst., 2018).



Axial velocity of the unstable, intrinsic thermoacoustic eigenmode of a swirl burner (from Meindl et al., submitted to J. Comp. Phys).

Project

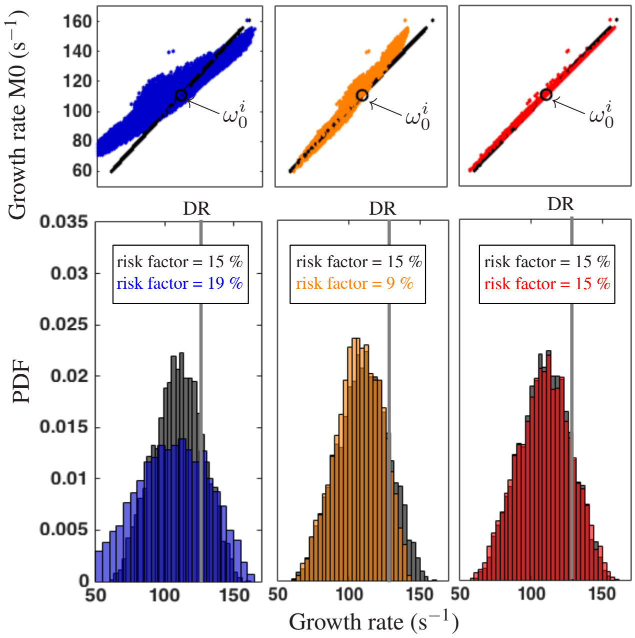
- AG Turbo COOREFLEX, FVV ‘Vorhersage von Flammentransferfunktionen’

Uncertainty quantification

Thermoacoustic instabilities are highly unpredictable, because they respond in a very sensitive manner to slight changes in operating or boundary conditions. As a result instabilities are detected often only at the later stages of development in full combustor tests, resulting in significant overruns of development cost or time. It is essential to deploy robust and reliable simulation methodologies that include strategies to quantify the uncertainty of model predictions and their sensitivity to parameter changes. The TFD group has developed and applied successfully a variety of strategies for uncertainty quantification in thermoacoustics, such as non-intrusive polynomial chaos expansion, or active subspace. The development of surrogate models by analytical means, or by exploiting adjoint numerical solutions, has played an important role in these efforts.

Project

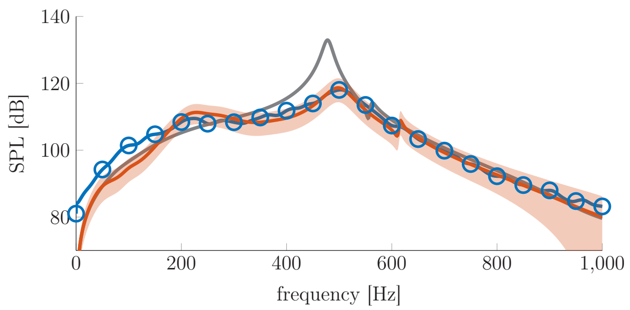
- CSC Scholarship, AG Turbo COOREFLEX



Uncertainty of growth rates and risk factor of thermoacoustic instability, predicted with adjoint-based surrogate models of increasing order (from Silva et al, JGTP, 2017).

Combustion noise

In the past year, the TFD group has developed characteristic-based, state-space boundary conditions, which allow to impose non-trivial acoustic impedances at the computational domain boundaries in a robust and flexible manner. Furthermore, advanced techniques for system identification were introduced, which estimate noise models as well as confidence intervals from time series data generated by high-fidelity simulations. Combining these techniques with large eddy simulation of turbulent combustion makes possible the accurate and efficient prediction of combustion noise. Furthermore, eigenmode analysis of the spectral distribution of pressure fluctuations elucidates the interplay between combustion noise generation, flame dynamics and thermoacoustic resonances. The results emphasize the necessity of including full two-way coupling in simulations of flow-flame-acoustic interactions.



Power spectral distribution of pressure fluctuations generated by an enclosed turbulent swirl burner. Measurements (O) vs. modelling with one-way (—) and two-way coupling (—). Shading indicates the 95% confidence interval of results.
(Merk et al, submitted to Proc. Combust. Inst.)

Project

- DFG/ANR NoiseDyn

Thermo-Fluid Dynamics

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Research Focus
- Thermo- and aeroacoustics
- Turbulent reacting flow
- Heat and mass transfer

Research Competence
- Modelling and simulation
- Stability analysis
- System identification
- Model reduction
- Uncertainty quantification
- AVBP, OpenFOAM
- taX

Courses
- Engineering Thermodynamics (MSE)
- Wärmetransportphänomene
- Wärme- und Stoffübertragung
- Grundlagen der Mehrphasenströmung
- Grundlagen der numerischen TFD
- Computational Thermo-Fluid Dynamics
- Simulation of Thermofluids with OpenSource Tools

Selected Publications 2017

- Albayrak, A., Steinbacher, T., Komarek, T., and Polifke, W., 'Convective Scaling of Intrinsic Thermo-Acoustic Eigenfrequencies of a Premixed Swirl Combustor,' J. Eng. Gas Turbines and Power, vol. 140, 2017, DOI 10.1115/1.4038083, pp. 041510-041510-9
- Avdonin, A., Jaensch, S., Silva, C. F., Češnovar, M., and Polifke, W., 'Uncertainty quantification and sensitivity analysis of thermoacoustic stability with non-intrusive polynomial chaos expansion', Combustion and Flame, vol. 189, Mar. 2018, DOI 10.1016/j.combustflame.2017.11.001, pp. 300–310
- Emmert, T., Bomberg, S., Jaensch, S., and Polifke, W., 'Acoustic and Intrinsic Thermoacoustic Modes of a Premixed Combustor', Proceedings of the Combustion Institute, vol. 36, 2017, DOI 10.1016/j.proci.2016.08.002, pp. 3835-3842
- Silva, C. F., Magri, L., Runte, T., and Polifke, W., 'Uncertainty quantification of growth rates of thermoacoustic instability by an adjoint Helmholtz solver', J. Eng. Gas Turbines and Power, vol. 139, 2017, DOI 10.1115/1.4034203, p. 011901
- Silva, C. F., Merk, M., Komarek, T., and Polifke, W., 'The Contribution of Intrinsic Thermoacoustic Feedback to Combustion Noise and Resonances of a Confined Turbulent Premixed Flame', Combustion and Flame, vol. 182, 2017, DOI 10.1016/j.combustflame.2017.04.015, pp. 269-278