Thermo-Fluid Dynamics Group

Modelling and simulation of thermo-fluid dynamic phenomena in energy and process technology

In 2015 the formulation of state space models for combustion dynamic and acoustic phenomena made significant progress. Focus was also on quantification of noise and uncertainty in thermo- and aero-acoustics.

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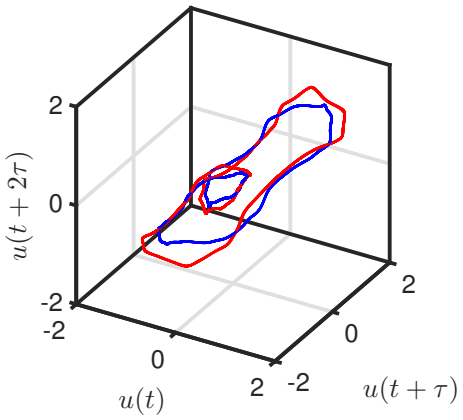
Highlights

- Extended visit by Dr. Luca Magri (U. Cambridge/U. Stanford) in January/ Februrary
- Extended visit by Prof. Arun Tangirla (IIT Madras) in June/July
- Contributed 'Six Lectures on Thermoacoustic Combustion Instability' to the 21st CISM-IUTAM Int'l Summer School on 'Measurement, analysis and passive control of thermoacoustic oscillations' in June
- Participation in the SFB/TRR40 Summer Program 2015 with a project on 'Hybrid CFD/low order modeling of thermoacoustic limit cycles' in collaboration with E. Gopalakrishnan and R. I. Sujith (`zIIT Madras)
- Contributed two lectures on identification of noise and uncertainty in aero-acoustics to a VKI lecture series on 'Progress in simulation, control and reduction of ventilation noise' in November.
- Since December 2015, W. Polifke is Editor in Chief of the 'In'tl J. of Spray and Combustion Dynamics'

State-Space-Models for Combustion Dynamics and Acoustics

Long-term efforts to develop state-space formulations for generation, transmission and scattering of sound in ducted configurations made very significant progress in 2015. A unified framework for integration of a wide range of models in the in-house acoustic toolbox taX was developed. Generation, propagation and dissipation of sound in combustion chambers, ventilation ducts or exhaust systems may now be modelled in a flexible and very efficient manner. Powerful tools are now available for the analysis of thermo- or aero-acoustic instabilities.
State-space models also played a crucial role in the development of robust, flexible time-domain impedance boundary conditions for numerical simulation of compressible flows. The new boundary conditions made possible for the first time the investigation of nonlinear dynamics and bifurcation studies of unstable premixed flames with CFD.



Phase portrait of velocity during period-2 oscillation of unstable premix flame with compressible (blue) and incompressible (red) flow model (from Jaensch et al, 2015)

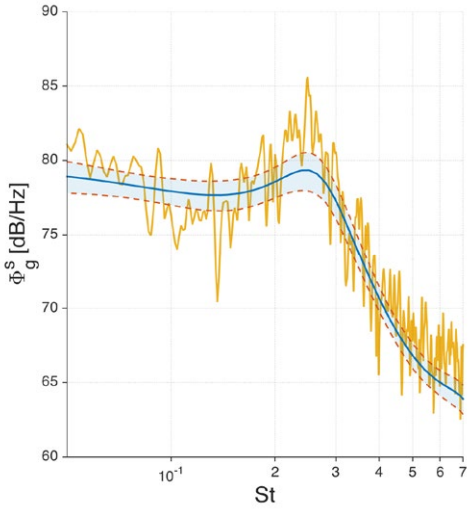
Projects

- FVV, SFB/TRR40

Identification of Noise and Uncertainty

Significant progress was achieved in the concurrent identification of noise sources and acoustic scattering in ducted flows. Advanced tools from system identifcation were combined with high performance computation of compressible, turbulent flow. Both the power spectral distribution of noise generated from turbulent fluctuations as well as the coefficients of the acoustic scattering matrix were determined in a wide range of frequencies from a single large eddy simulation. Moreover, the uncertainty resulting from the limited amount of time series data could be

quantified in terms of confidence intervalls for model parameters, which were deduced by residual analysis. Application of this approach to turbulent flames is the topic of an ongoing joint research project with Ecole Centrale in Paris.
In collaboration with visiting scientist Luca Magri, post-doctoral researcher Camilo Silva quantified the uncertainties of thermoacoustic stability analysis with a high-order adjoint formulation for the non-linear eigenvalue problem that results from the combination of a time-lagged model for the flame dynamics with a Helmholtz solver for combustion chamber acoustics. This approach promises to confidently assess the thermoacoustic stability of configurations of applied interest with high accuracy and efficieny.



Power spectral distribution of noise source downstream of an orifice in ducted flow. Identified model (with confidence band) vs. spectral analysis of LES time series (from Sovardi et al, 2015)

Projects
- Marie Curie FP7 IPN FlowAirs, DFG/ ANR NoiseDyn, SFB/TRR40

Research Focus
- Combustion dynamics
- Thermo- and aero-acoustics
- Stability analysis
- Mixing and reaction in turbulent flows
- Polydisperse multi-phase flows

Competence
- Thermo-fluid dynamics
- Combustion modeling
- Large eddy simulation
- System identification
- Stability analysis
- Low-order acoustic modeling

Infrastructure
- Compute cluster

Courses
- Engineering Thermodynamics
- Wärmetransportphänomene
- Wärme- und Stoffübertragung
- Grundlagen der Mehrphasenströmung
- Grundlagen der numerischen TFD
- Computational Thermo-Fluid Dynamics
- Simulation of Thermofluids with Open-Source Tools

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Carlo Sovardi, M. Sc.
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Publications 2015

- Acher, T., Lenz, S., Gobert, C., Dems, P., Polifke, W., 2015. Numerische Simulation von Hydrodynamik und Stoffübergang in polydispersen Blasensäulenströmungen mit Hilfe einer Momentenmethode, Processnet – Jahrestreffen der Fachgruppen Computational Fluid Dynamics und Mehrphasenströmungen, 6092. VDI, Lüneburg, Germany.
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- Albayrak, A., Polifke, W., 2015. On the propagation velocity of swirl waves in annular flows, 22nd International Congress on Sound and Vibration (ICSV22). IIAV, Florence, Italy.
- Boden, H., Polifke, W., 2015. Uncertainty quantification applied to aeroacoustic predictions, Schram, C. (Ed.), Progress in Simulation, Control and Reduction of Ventilation Noise, VKI Lecture Series 2015. Rhode-St-Genèse, BE.
- Bomberg, S., Emmert, T., Polifke, W., 2015. Thermal Versus Acoustic Response of Velocity Sensitive Premixed Flames. Proc. Combust. Inst. 35, 3185–3192. doi:10.1016/j.proci.2014.07.032.
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- Emmert, T., Bomberg, S., Polifke, W., 2015. Intrinsic Thermoacoustic Instability of Premixed Flames. Combust. Flame 162, 75–85. doi:10.1016/j.combustflame. 2014.06.008
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- Förner, K., Polifke, W., 2015. Aero-Acoustic Characterization of Helmholtz Resonators in the Linear Regime with System Identification, 22nd International Congress on Sound and Vibration (ICSV22). Florence, Italy.
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- Holzinger, T., Baumgartner, A., Polifke, W., 2015. A quasi-one-dimensional model of thermoacoustics in the presence of mean flow. Journal of Sound and Vibration 335, 204–228. doi:10.1016/j.jsv.2014.07.003.
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- Polifke, W., 2015. Six Lectures on Thermoacoustic Combustion Instability, 21st CISM-IUTAM Int'l Summer School on 'Measurement, Analysis and Passive Control of Thermoacoustic Oscillations.' Udine, Italy.
- Silva, C.F., Emmert, T., Jaensch, S., Polifke, W., 2015. Numerical study on intrinsic thermoacoustic instability of a laminar premixed flame. Combust. Flame 162, 3370 – 3378. doi:10.1016/j.combustflame.2015.06.003.
- Silva, C.F., Jaensch, S., Emmert, T., Polifke, W., 2015. On the autoregressive behavior of the intrinsic thermoacoustic feedback loop observed in premixed flames, 22nd International Congress on Sound and Vibration (ICSV22). Florence, Italy.
- Sovardi, C., Polifke, W., 2015. CFD-Based Modeling of Sound Generation in Ducted Discontinuities, Schram, C. (Ed.), Progress in Simulation, Control and Reduction of Ventilation Noise, VKI Lecture Series 2015. VKI, Rhode-St-Genèse, BE.
- Sovardi, C., Polifke, W., 2015. Acoustic characterisation of double-orifice configurations by means of a LES-SI approach, Euronoise 2015 – 10th European Congress and Exposition on Noise Control Engineering.
- Strobio Chen, L., Witte, A., Polifke, W., 2015b. Thermo-acoustic characterization of a heat exchanger in cross flow using compressible and weakly compressible numerical simulation, The 22nd International Congress of Sound and Vibration. Florence, Italy.
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- Tay-Wo-Chong, L., Zellhuber, M., Komarek, T., Im, H.G., Polifke, W., 2015. Combined Influence of Strain and Heat Loss on Premixed Flame Stabilization. Flow Turb. and Comb. doi:10.1007/s10494-015-9679-0.
- Ulhaq, Ahtsham, Silva, C.F., Polifke, W., 2015. Identification of the dynamics of technically premixed flames as multiple-input, single-output systems from LES, Proc. 7th European Combustion Meeting.
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- Witte, A., Polifke, W., 2015. Heat transfer frequency response of a cylinder in pulsating laminar cross flow, 17. STAB-Workshop. Göttingen.
- Zellhuber, M., Polifke, W., 2015. Large Eddy Simulation of High Frequency Flame Dynamics in Perfect Premixed Combustors with Elevated Inlet Temperatures, Fröhlich, J., Kuerten, H., Geurts, B.J.and Armenio, V. (Eds.), Direct and Large-Eddy Simulation IX. Springer.