Final Announcement

Int'l Summer School & Workshop on
Non-Normal and Nonlinear Effects in Aero- and Thermoacoustics
Technische Universität München
May 17th - May 20th, 2010

n³l – Int'l Summer School and Workshop on

Non-Normal and Nonlinear Effects in Aero- and Thermoacoustics

In aero-acoustics, nonlinear effects play an important role in generation as well as dissipation of sound. Stability limits and limit cycle amplitudes of self-excited aero- or thermoacoustic instabilities are influenced by nonlinearities. For thermoacoustic interactions, standard linear modal analysis can in general not predict the response of the system to finite amplitude perturbations due to the non-normality of the corresponding evolution operator and nonorthogonality of eigenmodes.

At TU München, a Summer School / Workshop on non-normality and nonlinearity in aero- and thermoacoustics will be held in May 2010.

During the **Summer School** (17th and 18th May), a series of invited lectures will give an introduction to the workshop topics and present the state of the art. Expected audience are doctoral students with some background in fluid mechanics, flow instabilities, aero- or thermoacoustics, or combustion. Of course, more experienced researchers interested in the workshop topics are also welcome.

Confirmed list of speakers:

C. Bailly (École Centrale Lyon)
A. Hirschberg (TU Eindhoven)
M. Juniper (Univ. Cambridge)
P. Schmid (École Polytechnique, Paris)
T. Schuller (École Centrale Paris)
R.I. Sujith (IIT Madras, Chennai)

The purpose of the **Workshop** (19th and 20th May) is to bring together researchers active in aero- and thermoacoustics and to present and discuss original, recent research results on non-normal and nonlinear effects in these disciplines (see following pages for the tentative schedule and the abstracts of the summer school talks).

Registration fees (Deadline: 20th April 2010):

Summer School only:	80	€
Workshop only:	240	€
Summer School & Workshop	280	€

Further information and the registration form are available on the conference website: www.td.mw.tum.de/n3l-conf-2010/.

Sponsored by:

ERCOFTAC
AETHER
Deutsche Forschungsgemeinschaft DFG
IAS TUM Institute for Advanced Study
ALSTOM

Tentative Schedule for Summer School

Int'l Summer School & Workshop on
Non-Normal and Nonlinear Effects in Aero- and Thermoacoustics
Technische Universität München
May 17th - May 20th, 2010

Monday 17th May 2010

12:00 - 13:15	Welcome and Registration including Light Lunch Buffet
13:15 - 13:30	Welcome Speech by W. Polifke (TU München)
13:30 - 15:00	Lecture by A. Hirschberg (TU Eindhoven) Title: Non-Linear Phenomena in Driven and Self-Sustained Acoustical Resonance
15:00 - 15:30	Coffee Break
15:30 - 17:00	Lecture by P. Schmid (Ecole Polytechnique, Paris) Title: Tools for the Analysis of Non-Normal Fluid Systems
19:00 - 23:00	Summer School Dinner at Marktwirt

Tuesday 18th May 2010

08:30 - 10:00	Lecture by C. Bailly (École Centrale Lyon) Title: Non-Linear Aspects in Noise Generation and Propagation
10:00 - 10:30	Coffee Break
10:30 - 12:00	Lecture by T. Schuller (École Centrale Paris) Title: Linear and Nonlinear Combustion Dynamics Analysis
12:00 - 13:30	Lunch Break
13:30 - 15:00	Lecture by R. I. Sujith (IIT Madras) Title: An Overview on Non-Normality and Nonlinearity in Thermoacoustic Instabilities
15:00 -15:30	Coffee Break
15:30 - 17:00	Lecture by M. P. Juniper (Cambridge University) Title: Optimization with Non-Linear Adjoint Looping
17:00 - 18:00	Guided Tour of the LRZ Supercomputer

Tentative Schedule for Workshop

Int'l Summer School & Workshop on
Non-Normal and Nonlinear Effects in Aero- and Thermoacoustics
Technische Universität München
May 17th - May 20th, 2010

Wednesday 19th May 2010

08:00 - 08:30 Registration for Workshop participants

08:30 - 09:45 Session 1: Methods for the limit-cycle prediction of thermoacoustic systems (Part 1)

08:30 - 08:55	P. Palies, D. Durox, T. Schuller, S. Candel	Ecole Centrale Paris	Combustion instabilities analysis based on Flame Describing Function applied to swirling flames
08:55 - 09:20	A. Guaus, A. Di Vita, E. Cosatto, J. Favier, G. Mori, A. Bottaro	Univ. of Genova / Ansaldo	Low order acoustic modeling of industrial premixed combustors: Linear and nonlinear approaches
09:20 - 09:45	A. Di Vita, G. Mori	Ansaldo	On Rayleigh's criterion and the stability of premixed flames

09:45 - 10:15 Coffee Break

10:15 - 11:30 Session 2: Methods for the limit-cycle prediction of thermoacoustic systems (Part 2)

10:15 - 10:40	J. Moeck, O. Paschereit	TU Berlin	The nonlinear interaction of multiple linearly unstable thermoacoustic modes
10:40 - 11:05	F. Selimefendigil, W. Polifke	TU München	A Frequency Domain System Model with Coupled Modes for Limit Cycle Prediction of Thermoacoustic Systems
11:05 - 11:30	R. Kulkarni, P. Palies, D. Durox, T. Schuller, S. Candel, F. Nicoud	Univ. Montpellier / ECP	Predicting the amplitude of limit cycles by using a Helmholtz solver

11:30 - 13:00 Lunch Break

13:00 - 14:15 Session 3: Non-Normal and Non-Linear Effects in Aeroacoustics

13:00 - 13:25	X. Garnaud, L. Lesshafft, P. Schmid, P. Huerre	Ecole Polytechnique	Global modes in compressible hot jets
13:25 - 13:50	J. W. Nichols, S. K. Lele	Stanford Univ.	Non-normal global modes of supersonic jet noise
13:50 - 14:15	P. Martinez, C. Schram, S. Foeller, R. Kaess, W. Polifke	LMS / VKI / TUM	Identification of the aeroacoustic response of ducted low Mach number flows

14:15 -14:45 Coffee Break

14:45 - 16:00 Session 4: Non-Normal and Nonlinear Analysis of the Rijke Tube (Part 1)

14:45 - 15:10	H. Mangesius, W. Polifke	TU München	A simple state-space approach for the investigation of non-normal effects in thermo-acoustic systems
15:10 - 15:35	M. Juniper	Cambridge Univ.	Triggering in the Rijke tube: non-normality, transient growth and bypass transition
15:35 - 16:00	P. Subramanian, S. Mariappan , P. Wahi , M. K. Verma, R. I. Sujith	IIT Madras	Bifurcation analysis of thermoacoustic instability in a Rijke tube

16:00 - 17:00 Lab tour at Lehrstuhl für Thermodynamik

19:00 - 23:00 Workshop Dinner at Weinhaus Neuner

Tentative Schedule for Workshop

Int'l Summer School & Workshop on
Non-Normal and Nonlinear Effects in Aero- and Thermoacoustics
Technische Universität München
May 17th - May 20th, 2010

Thursday 20th May 2010

08:30 - 09:45 Session 5: Non-Normal and Nonlinear Analysis of the Rijke Tube (Part 2)

08:30 - 08:55	S. Mariappan, R. I. Sujith, P. J. Schmid	IIT Madras / Ecole Polytechnique	Non-normal and nonlinear dynamics of thermoacoustic instability in a horizontal Rijke tube
08:55 - 09:20	P. R. Murray, M. A. Heckl	Keele Univ.	Green's function model for a rectangular Rijke tube
09:20 - 09:45	Additional slot		

09:45 - 10:15 Coffee Break

10:15 - 11:30 Session 6: Advanced Analysis of Instability Generation in Thermoacoustic Systems

10:15 - 10:40	K. Wieczorek, C. Sensiau, W. Polifke, F. Nicoud	CERFACS / TUM / Univ. Montpellier	Assessing non-normal effects in thermoacoustic systems with non zero baseline flow
10:40 - 11:05	I. Waugh, M. Geuß, M. Juniper	Cambridge Univ. / TUM	Triggering, bypass transition and the effect of noise on a linearly stable thermoacoustic system
11:05 - 11:30	C. Balaji, S. R. Chakravarthy	IIT Madras	A Simultaneous Multiple Space-/Time-Scale Formulation of Fluid Flow Problems with Application to Combustion Thermoacoustics

11:30 - 13:00 Lunch Break

13:00 - 14:40 Session 7: Nonlinear pulsation effects in practical combustion systems

13:00 - 13:25	N. Noiray, M. Bothien, B. Schuermans	Alstom	Analytical and numerical analysis of staging concepts in annular gas turbines
13:25 - 13:50	F. Boudy, D. Durox, T. Schuller, S. Candel	Ecole Centrale Paris	Nonlinear flame dynamics and nonlinear mode trigerring in a multiple flame combustor
13:50 - 14:15	C. Hassa, J. Heinze, U. Meier, C. Heeger, P. Trunk	DLR Köln/TU Darmstadt	Self-excited Oscillation in a Combustion Chamber Driven by Phase Change in the Liquid Fuel Feed System
14:15 – 14:40	D. Bohn, N. Ohlendorf, J. Willie	RWTH Aachen	Non-linearity and its Effects on the Flame Response and Control of Combustion Instabilities in a Matrix Burner

14:40 -15:30 Farewell

NON-LINEAR PHENOMENA IN DRIVEN AND SELF-SUSTAINED ACOUSTICAL RESONANCE

A. Hirschberg

Fluid Dynamics Laboratory, Faculty of Applied Physics, Technische Universiteit Eindhoven
P.O. Box 513, 5600 MB Eindhoven, Netherlands

Considering driven acoustic resonance of a pipe segment we introduce three elementary non-linear processes: wave steepening, vortex shedding and transition to turbulence. Applications are: the production of brassy sounds by trombones, the generation of spurious noise by bass-reflex ports of loudspeaker boxes and the design of resonators for thermo-acoustic engines. The role of non-linearity in establishing a stable limit cycle for self-sustained oscillation is explained. We illustrate this by a discussion of the thermo-acoustical oscillation of a Rijke tube and of human whistling.

TOOLS FOR THE ANALYSIS OF NON-NORMAL FLUID SYSTEMS

P. J. Schmid

Laboratoire d'Hydrodynamique (LadHyX), CNRS-École Polytechnique
F-91128 Palaiseau, France

Fluid systems that are governed by a non-normal linear evolution operator are ubiquitous in a wide range of applications covering, among others, combustion systems, acoustic devices, turbomachinery, aerodynamic configurations and mixing processes. For an effective, efficient and safe use of these systems, their analysis has to be based on mathematical tools that take account of the non-normal nature of the underlying equations. These tools deviate markedly from conventional eigenvalue analysis and involve matrix exponentials, resolvent norms, numerical abscissa, Lyapunov equations and direct/adjoint systems. They allow the description of stability, transient energy growth, pseudoresonant amplification and bifurcation behavior as well as the analysis of passive control strategies. The presentation will motivate and introduce basic techniques for a non-modal analysis of fluid systems and discuss various extensions that go beyond standard methods and allow the investigation of more complex or large-scale systems.

NON-LINEAR ASPECTS IN NOISE GENERATION AND PROPAGATION

C. Bailly[1], C. Bogey[2]

Laboratoire de Mécanique des Fluides et d'Acoustique
École Centrale de Lyon & UMR CNRS 5509
36 avenue Guy de Collongue, 69134 Écully cedex, France
http://acoustique.ec-lyon.fr

Great progress have been made over the last decade in calculating aerodynamic noise directly from Large-Eddy Simulation (LES). Needs of accurate and efficient numerical solvers in computational aeroacoustics have motivated the developments of low-dispersion and low-dissipation finite-difference schemes as an alternative to more classical methods of applied mathematics over the last two decades. These numerical methods have now reached maturity, even if progress is still necessary to take account of specific physics. The first part of the lecture will focus on the direct computation of subsonic jet noise by using compressible large-eddy simulations, and the use of these simulations to improve our understanding of noise generation by turbulent flows. Thermo-viscous, vibrational relaxation and nonlinear effects will be illustrated in the second part of the talk with the case of low-frequency noise propagation in the Earth atmosphere. Long-range infrasound propagation indeed involves temperature gradients, realistic atmosphere at high altitude and absorption effects.

[1] Professor, École Centrale de Lyon & Institut Universitaire de France.
[2] Research Scientist, CNRS.

LINEAR AND NONLINEAR COMBUSTION DYNAMICS ANALYSIS AND STABILITY PREDICTION

T. Schuller, F. Boudy, P. Palies, D. Durox, S. Candel [1]

Laboratoire EM2C, CNRS and Ecole Centrale Paris
92295 Châtenay-Malabry, France

Prediction of acoustically coupled combustion instabilities is intimately linked to a better description of the flame response to incoming flow perturbations. Progress over the past 15 years on theoretical aspects, reduced order modeling and numerical simulation, as well as on experimental techniques has led to the development of a set of tools for the linear and nonlinear stability analysis of combustors. These are often based on the flame frequency response, the flame transfer function in linear studies, the flame describing function in nonlinear calculations. The main mechanisms impacting the flame response are examined for flow perturbations of different nature and flames featuring different geometries. The case of conical flames, V shaped flames, collection of small conical flames stabilized on a multipoint injector and premixed swirling flames are discussed with emphasis on interactions leading to nonlinearity. A framework is then presented which includes this flame frequency response in a linear and nonlinear stability analysis. The generic case of an unconfined configuration is used as an example to show how one can anticipate an ensemble of nonlinear features often observed in practical combustors like the prediction of limit cycle levels, frequency shifting during transients, mode switching due to nonlinear triggering, hysteresis phenomena and the eventual failure of a damping device. Further validation in the case of confined and swirled flames will be presented in the paper session.

[1] S. Candel is also with Institut Universitaire de France

An Overview of Non-Normality and Nonlinearity in Thermoacoustic Instabilities

R. I. Sujith

Department of Aerospace Engineering, Indian Institute of Technology Madras,
Chennai-600036, India

Thermoacoustic instability, popularly known as combustion instability has traditionally been investigated by linearizing the equations of combustion-acoustic interaction and testing for unstable eigenvalues of the linearized problem. However, the results of such investigations agree poorly in many cases with experiments. Nevertheless, linear effects play a central role in combustion instability. The consequences of non-normality will be illustrated in the context of a horizontal Rijke tube. It will be shown that the coupled thermoacoustic system is non-normal as well as nonlinear. Non-normality can cause algebraic growth of oscillations for a short time even though the eigenvectors of the system could be decaying exponentially with time. This feature of non-normality combined with the effect of nonlinearity causes the occurrence of subcritical transition to instability from initial states that have small energy. A measure to quantify the amount of transient growth will be presented. Further, we will analyze the nature of bifurcations that occur in thermoacoustic systems. Non-normality and nonlinearity that arises in different thermoacoustic systems will be discussed briefly.

OPTIMIZATION WITH NON-LINEAR ADJOINT LOOPING

M. P. Juniper

Department of Engineering, University of Cambridge
Cambridge, CB2 1PZ, U.K.

In many practical situations that evolve in time, it is useful to know the initial condition that is optimal in some user-defined sense. In a thermoacoustic system, for example, this could be the acoustic perturbation whose energy amplifies the most over a given time. In linear systems, this initial condition can often be found with the Singular value Decomposition. In non-linear systems, however, a different technique is required.

Non-linear adjoint looping, which has been adapted from optimal control, is based on constrained optimization. It is an extremely versatile technique, which can handle any reasonable cost functional, any boundary conditions and any governing equations, either linear or non-linear. It also allows accuracy to be traded for speed, by reducing the resolution of the time evolutions or by reducing the tolerance of the optimization.

In this tutorial, non-linear adjoint looping will be demonstrated with Matlab for a simple set of non-linear equations. Further exercises are given that show how to extend the technique to more complicated governing equations.