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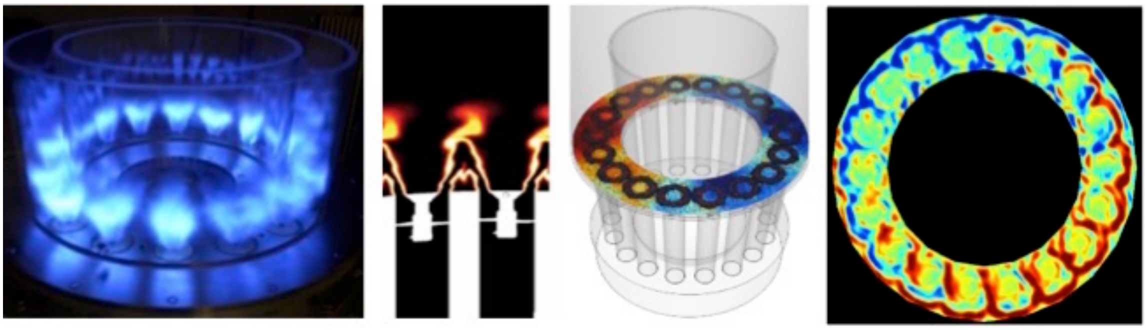

Annular instabilities and transient phenomena in gas turbine combustors

ANNULIGHT Spring School on Adjoints in Thermoacoustics

28th to 3rd April 2020

Montestigliano, Italy

Lecturers:

Prof Matthew Juniper, (UCAM)

Prof Jonas Moeck, (NTNU)

Dr Luca Magri, (UCAM)

Dr Alessandro Orchini (TU Berlin)

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Preliminary Schedule

Description (short paragraph):

The ESRs will be trained on the use of adjoint methods applied to thermoacoustics. The course will start with a brief introduction to adjoint methods in eigenvalue problems and then move on to adjoints of simple thermoacoustic models. Examples of adjoints in other fields will be given. For continuous adjoints, the Lagrangian Optimization framework for continuous adjoints will be used. For discrete adjoints, usually matrix transposes will suffice, but automatic differentiation of code will also be described. Different types of eigenvalues will be introduced, together with the adjoint methods appropriate to each. All subjects will be illustrated with sample code in Matlab (or Octave) and Python3.

Requirements:

You need to have a laptop with Matlab (or Octave) and Python3.

Day 1 – 30.03.20 - Monday (Matthew Juniper)

- The basics of adjoints in thermoacoustics
  - Reminder of the physical mechanisms involved in thermoacoustic instability
  - Different modelling approaches (all in 1D)
  - travelling waves (Riemann invariants)
  - Helmholtz solvers (1D)
  - Basis set comprising acoustic modes (Galerkin method)
- Linear stability analysis
  - general introduction to principles
  - application to each modelling approach (in 1D)
  - calculation of eigenvalues in a model problem (in 1D)
- Introduction to adjoint methods
  - general introduction in matrix form
  - application to each modelling approach (in 1D)
  - obtaining eigenvalue sensitivity in each approach (in 1D)
  - Taylor Tests
- Application to a simple optimization problem

Day 2 – 31.03.20 - Tuesday (Luca Magri)

- Examples from the literature on the use of adjoints in other fields (Fluid Mechanics, Civil engineering, Quantum Mechanics)
  - Derivation in the Lagrangian constrained optimization framework (continuous adjoint)
  - Automatic differentiation
  - Using adjoints in forced problems (adjoint as receptivity to forcing)
- Explanation of why adjoint methods are so efficient in optimization problems
- Exceptional points

Day 3 – 01.04.20 - Wednesday (Jonas Moeck)

- Classification of eigenvalues: simple, semi-simple degenerate, defective; and the associated sensitivity expressions
- Role of the adjoint in spectral perturbation theory; the Fredholm alternative
- Degenerate eigenvalues and the role of spatial symmetries
  - structure of thermoacoustic modes in annular and can annular combustors; symmetries and weak coupling
  - Bloch modes
- Degenerate adjoint perturbation theory
- Splitting of initially degenerate eigenvalues through asymmetries (as an application of the above)

Day 4 – 02.04.20 – Thursday (Jonas Moeck and Alessandro Orchini)

- Degenerate adjoint perturbation theory
  - Splitting of initially degenerate eigenvalues through asymmetries (as an application of the above)
- Theory: Adjoint methods for high-order sensitivities
- Exercise: derive second order sensitivity equation in TA
- Theory: Relation between high-order sensitivities and EPs, and numerical methods for their identification
- Exercise: Identification of EPs in a 1D TA model

Day 5 – 03.04.20 – Friday (Alessandro Orchini and Luca Magri)

- Theory: General intro the the FEM and their advantages w.r.t. adjoints
- Training: PyHoltz, a general framework for the solution of the non-homogeneous 3D Helmholtz equation in TA.
  - Basic functionalities, key classes/functions, output and visualization of results
- Exercises: 2/3 applications with PyHoltz (NTNU Dawson combustor? or MICCA)
  - Calculation of acoustic and TA eigenvalues
  - Linear sensitivity to changes in (i) flame gain, (ii) delay, and (iii) BC
  - Extension to high-order sensitivities: accurate prediction of eigenvalue trajectories
  - Numerical identification of EPs