Instability in Fluid Dynamics

Ph.D. Program: Mechanics and Advanced Engineering Sciences – 12 hours

Prof. Michele Celli

	Date	Teaching Time	Classroom
1	Monday – 01/09/25	11:00-15:00	AULA 5.2 + DIMSAI virtual aula (TEAMS)
2	Tuesday – 02/09/25	11:00-15:00	AULA 5.2 + DIMSAI virtual aula (TEAMS)
3	Wednesday – 03/09/25	11:00-15:00	AULA 5.2 + DIMSAI virtual aula (TEAMS)

Learning outcomes

The course introduces the concept of instability in fluid dynamics and offers an outline of the procedure employed for the investigation of the threshold condition for emergence of the instability. Modal and absolute instability analysis of thermal convection will be presented by employing the software Wolfram Mathematica. This software is employed both to present the theoretical arguments and to solve the instability problem from a practical viewpoint. At the end of the course, a small project (to be completed by employing the software Mathematica) is assigned which serves as a final assessment.

Course contents

Introduction to stability analysis in fluid dynamics

The instability in fluid dynamics occurs for a number of reasons. The main, most common, triggers for the onset of instability are the inertia forces, which produce hydrodynamic instabilities, and the buoyancy forces, which produce thermal instabilities when combined with the thermal advection term. The onset of instability yields a vortex flow or a convective cellular flow. Such flows are obtained, for the hydrodynamic and thermal instabilities, when, respectively, the inertia forces and the buoyancy forces are sufficiently intense. From the practical viewpoint, the expression “sufficiently intense” identifies the threshold conditions for the onset of this cellular flow: the so–called critical conditions.

The stability analysis answer thus the following question obtains: which are the critical values of the governing parameters (e.g. Reynolds number or Rayleigh number) for the onset of instability? In order to perform a linear stability analysis one can employ the normal modes method and this is why is called modal analysis.

When one considers a fluid flow, then understanding whether or not the fluid experiences modal convection, is not the only possible interesting information. For this configuration, the raising instability is convected downstream by the basic flow rate. Thus, from the laboratory reference frame, this instability can or cannot be observed as a function of the strength of the basic flow: when the flow is strong enough the instability is not visible by the observer. The absolute instability analysis answers this question: will the observer in the laboratory reference frame actually see the unstable behaviour?

Modal and absolute instability analysis of thermal convection in porous media

A brief introduction to heat and mass transfer in fluid saturated porous media is presented. The modal and absolute stability analysis is applied to the case of thermal convection in fluid saturated porous media: the Prats' problem is considered.

Detailed contents

1. Definition of stability/instability: thermodynamical systems - mechanical systems. Description of stability analysis linear/non linear: heat conduction. Introduction to the software Wolfram Mathematica

2. Definition of stability/instability in fluid systems. Comparison between hydrodynamic and convective instabilities: qualitative description of the governing equations and terms triggering instability. Convective thermal instability: modal vs absolute. Mathematical foundations of the stability analysis

3. Modal and absolute instability analysis of the Prats' problem