ME – PhD Thesis Defence

Stability of wall-bounded compressible shear flows.

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July 12, 2023, at 03:00PM
Venue: Conference Room, ME @ IISc

ABSTRACT

Fluids flows are unstable to infinitesimal perturbations under certain flow conditions. Compared to incompressible flows, the stability characteristics of a flow become significantly different in nature when the mean flow velocity is comparable to the speed of sound. In this work, we study the linear stability of compressible shear flows in wall bounded flows. A steady fully-developed laminar flow of an ideal gas, driven in a channel/pipe by a constant body acceleration, is considered as the base state. Small amplitude normal mode perturbations are added to this flow and the temporally growing solutions are studied.

For both the channel and pipe flows, the numerical solutions of the stability equations show the presence of compressible higher modes that do not have a counterpart in the incompressible limit. These modes become unstable at finite wave-numbers above a critical Mach number. We have extended the classical stability theorems to compressible flows in bounded domains and a new criterion for the existence of neutral modes is derived which is used to obtain the values of the critical Mach numbers for the stability of the higher modes. In addition to higher compressible modes, a channel flow is unstable to the extension of the Tollmien-Schlichting mode, which gets stabilized with increasing compressibility. However, pipe flow is unstable only to the compressible modes. The critical Reynolds numbers for the unstable modes are obtained at different Mach numbers for both channel and pipe flows and a universal scaling is observed at high Mach numbers.

Numerical calculation of the stability equations in the inviscid limit reveal that the dominant instabilities in both channel and pipe flows are viscous in nature. The instability arises due to the emergence of a critical point singularity very close to the walls. An asymptotic analysis at high Reynolds numbers is performed to obtain the scaling exponents for the wave-number and wave-speed, as well as the thickness of the localized regions of viscous regularization. An adjoint-based procedure is employed to obtain the leading order eigenvalues at high Reynolds numbers.

In this work, we also study the stability of a compressible flow in a channel with compliant walls. The compliant walls are modelled as spring-backed plates that move in a direction normal to the flow due to the fluid stresses acting at the walls. Wall compliance introduces additional instabilities, referred to as FSI modes, in addition to the Tollmien-Schlichting and compressible higher modes. The numerical studies indicate flow compressibility to have a stabilising effect on the FSI modes, and wall compliance to have a stabilising role on the compressible higher modes. Both flow compressibility and wall compliance are observed to have a stabilising effect on the Tollmien-Schlichting mode. We also calculate the perturbation energy budgets for the different instabilities which allow us to differentiate the different mechanisms of destabilisation of these modes.

ABOUT THE SPEAKER

Mandeep Deka is a PhD student from the Dept. of Mechanical Engineering, IISc Bangalore. He completed his B.Tech. in Mechanical Engineering from National Institute of Technology (NIT), Silchar in 2015. Following that, he completed his Master's (M.Tech.) in 2017 from Indian Institute of Technology, Guwahati (IITG) from Mechanical Engineering Department with specialization in Fluid and Thermal Engineering. His research interests are broadly in fluid mechanics with emphasis on hydrodynamic stability, and in developing numerical algorithms for fluid flows. His dissertation is on the stability of compressible shear flows in channels and pipes.