Global Flow Instability and its potential applications

Despite of many years of theoretical, experimental and numerical investigations turbulent flows are not fully understood till now and remain as an active research field in many academic and industrial research centers. The most characteristic feature of all turbulent flows is a presence of flow structures of very wide range of length and time scales. Due to the multiscale character of turbulence mathematical modelling of turbulent flows is very difficult. Numerical solution of the set of non-linear differential equations describing the dynamics of all scales of turbulent flows requires prohibitive computational time and very large storage capacity exceeding abilities of even the most powerful computers nowadays. However, theoretical investigations showed that only large flow scale structures are dependent on the flow type and flow domain geometry, while small scale eddies responsible for turbulence energy dissipation into heat are much more isotropic and universal. This feature of turbulent flows led to an idea of Large Eddy Simulation (LES), according which only large scale flow structures are described by the equations of motion and numerically solved using meshes of a limited size. An influence of small scales, so called subgrid scales, on the flow dynamics is mathematically modelled introducing additional terms into the set of equations that does not require excessive mesh refinement. Since the small scale motion is isotropic and universal such subgrid models could be considered as flow independent. Especially complex flow structure is encountered in transitional flows in which an initially laminar flow becomes unstable and is gradually transformed into turbulent one. During the transition process first large scale coherent vortices are formed and further they break up into smaller and smaller scale structures. An interesting situation appears when newly formed eddies can impose some oscillations on the region where consecutive structures are created leading to a resonant or self-sustained mechanism. In such a situation the flow oscillations are very strong and periodic affecting a large flow region. Oscillations of this type are called as a global mode or global instability. The global modes lead to the maximum possible amplification of vortices without external energy. Hence they could potentially be applied in all the technical devices in which mixing intensity of various species or heat transfer are important to make industrial processes more efficient without additional costs for energy input. In the figure on the left a globally unstable round jet is visualized. It can be seen that such a jet in a short distance breaks up into smaller flow structures. However, global instability can be released in other flow types commonly applied in technical applications like combustion chambers in aeroengines and gas turbines or chemical reactors. Theoretical works show that global instability could be triggered in single and double annular jets, swirling jets and counter-current jets. In the figure below a burner is shown in which all these flow types are applied. The global flow oscillations in such a burner could lead to a perfect mixing of fuel, oxidizer and flowing back flue gases leading to a uniform temperature distributions and significant decrease of nitric oxides. The project is focused on the numerical calculations using an advanced stability theory and Large Eddy Simulations to solve the equations governing motion of the large scale flow structures. The results will contribute to better understanding of the instability mechanisms in a variety of flow types. This knowledge will allow one to an improved design of combustion chambers or chemical reactors with enhanced efficiency and lower emission of toxic components in the flue gases.