In the last twenty years the fuel cost has experienced a remarkable growth with a significant impact on the costs of the aircraft transport. In addition, a policy of safeguarding of the environment in which we live has been launched by the European Community by introducing very stringent constraints concerning the emissions of polluting gases, such as carbon dioxide and oxides of nitrogen, and the noise emission of the next future commercial aircrafts. According to the 2020 ACARE (Advisory Council for Aerospace Research in Europe) directives, the aircraft of new generation will have features such as to reduce the emissions of nitrogen oxide of the eighty percent and the emissions of carbon dioxide of the fifty percent, while the noise shall be reduced of 10 EPNdB (equivalent to halving the noise of an aircraft built with 2000s technology). Hence the strong demand of the aviation industry for the development of technologies targeted to the reduction of any form of aerodynamic drag, so as to ensure a consequent reduction of the fuel consumption and of the emission of polluting gases. It is expected that any obtained aerodynamic improvement through improved efficiency of the aircraft has, as an indirect consequence, an improvement on noise emissions.

In fact, the elimination of any flow separation on aircraft components achieved by improving the integration of pylon-wing-nacelle, as well as an improvement of the integration of wing-fuselage or of the tail-plane-fuselage, etc., definitely has beneficial effects on the noise issues. Obviously, the most important contribution to the achievement of this goal will come from the development of new engines with low fuel consumption and, hence, low emission of pollutants, such as the Geared Turbo Fan and the Counter Rotating Open Rotor, but this will be not sufficient. In this context, every technology, able to potentially improve the efficiency of the aircraft, has received a renewed attention. Flow control techniques such as macro and micro vortex generators, riblets, synthetic jets, plasma actuators, unsteady blowing, steady and unsteady suction, micro-roughness elements, morphed structures, gurney flaps, winglets, trapped vortex, only to mention few of the most popular, have received an new boost to the development and research. Some of these techniques are now normally used on aircraft, such as the micro and macro generators vortices or winglets, while others still have a low level of Technological Readiness Level (TRL) for which they are still in a phase of study and testing. Given the strong interest of CIRA (*Centro Italiano di Ricerca Aerospaziale*) for these flow control techniques some of them have been studied both through numerical simulations and experiments, as the technique of the unsteady blowing [1], the application of synthetic jets for the control of flow separation [2], [3], the trapping of vortices to increase the lift and to reduce the drag ([4], [5], [6], [7]), or the use of plasma actuators for the control of the buffeting and for the reduction of the intensity of the shock wave [8], [9]. Among these techniques, the most interesting is certainly those of the trapped vortex. This technique has inspired the study performed in this thesis, and i.e. the study of the instabilities that develop in a cavity. The presence of vortices in the flows around aerodynamic bodies or in internal flows, such as in the combustion chambers, has surely an effect sometimes negative and undesirable (for example, vortices that detach from the flap of an aircraft by causing either a turbulent separation either noise, or a flow separation with a vortical wake accompanied by a consequent loss of lift and increase of drag as in the case of a wing stall) and sometimes positive as it happens in the combustion chambers where, in general, vortices help to stabilize the flame. Anyway, both the mechanisms that generate the vortices and either the theoretical models for their simulation are still under investigation. The idea to trap a vortex in a cavity embedded in an airfoil is interesting because it has two possible positive effects, namely produce increased lift due to the net increase of circulation introduced by the presence of the vortex and, at the same time, a drag reduction due to the suppression or delay of the flow separation (pressure drag reduction). This concept becomes especially true as the greater the thickness of the airfoil. Obviously, the cavity has to have a particular shape to trap the vortex and it has to be correctly positioned on the upper surface of the airfoil in the region of the trailing edge. Several numerical and experimental studies have been performed in CIRA (*Centro Italiano di Ricerca Aerospaziale*) to investigate the potentiality of this technique to increase the lift and reduce the drag. The main conclusion has been that this technique works when the vortex rotates and it is positioned in the center of the cavity. This result can be achieved only by using suction to stabilize the vortex presence, but most of the benefits are lost. The main reason for which the vortex without suction is ejected it has to be attributed to some instability mechanisms that develop in open cavities.

Since any means of transport, from cars to trains, from ships to airplanes has on its external surface some cavities, sometimes due to needs related to the motion of the same vehicle, as in the case of the wheels of a car or the landing gear of a plane, sometimes linked to the need of installation of instrumentation or at the throwing of objects (launch of parcels, parachutists, etc.) as happens the case for aircrafts for transportation or for rescue. In all these cases, the presence of the cavity triggers acoustic disturbances with strong self-sustaining oscillations that can cause structural damages due to fatigue or large increases of aerodynamic drag. A simple experiment showing this acoustic phenomenon is the opening of a window of a speeding car. You immediately notice an acoustic noise with resulting strong flow fluctuations which increase in intensity with increasing speed (and therefore of Reynolds number) because the passenger cabin works such as a Helmholtz resonator. This phenomenon becomes even more dramatic in the case of aircrafts where are present the landing gear cavities, or the ventral openings of aircrafts having the need of throwing some objects during the flight (Canadair for the launch of water, rescue vehicles for throwing food, military aircrafts for the launch of material supply, etc.), but also in all those cases in which the cavities are used as flow control techniques such as occurred in the capture of the vortices. In all these cases it is necessary to suppress these oscillations and, for this purpose, active or passive control flow techniques can be used. But in order to identify the most efficient technique is necessary to know and understand the mechanisms that trigger the phenomenon and this was the main motivation of the study of this thesis, i.e. identify what types of instabilities develop in the open flow cavity, since only in this way you can identify a flow control technique, that with a minimum energy expenditure, eliminates these undesirable phenomena. There is no doubt that if we are also able to calculate the most sensitive region to possible structural perturbations, the so-called structural sensitivity, this also helps us in finding the best location where to place and implement the systems for the flow control.

Studies have focused on the instability that trigger in 2.5D cavities (so named by analogy to the concept of the infinite wing), that is, the cavity having infinite dimension in spanwise direction and on full 3D cavities. To this end, analysis of global stability and structural sensitivity both were conducted for a 2.5D square cavity invested by a Couette flow and by a Blasius boundary layer. Furthermore, these analyzes were also conducted for the closed cavity. An open source code to finite elements (called freefem) was used to perform the numerical simulations for the three cases mentioned. The simulations have allowed calculating the global stability and the structural sensitivity and visualizing in all three cases, the region of wavemaker, i.e. the region of the flow field more sensitive to any structural change in the system that governs the motion. The analysis of the results has showed that in both cases of open and closed cavities, the region of the wavemaker is always all contained within the cavity. Since the wave number for which occurs the first instability, as well as the Reynolds number based on the average speed along the streamline that connects the two outside corners of the cavity, were, on average, the same for the three cases investigated, a conjecture on the existence of a single mechanism that triggers the instability in the 2.5D cavities (open or closed which they are) has been proposed. This type of instability occurs to a Reynolds number lower than that of the pure 2D cavity and it is caused by a stationary bifurcation of Pitch Fork type.

The cubic cavity has been investigated by performing a series of expensive (from the computational point of view) numerical simulations using a spectral element method that combines the great accuracy of the spectral methods and the flexibility of finite elements in approaching complex geometries. Also in this case the code used is open source and the calculations were performed on the cluster Fermi available at CINECA by using 4000 and 8000 processors in parallel. Both global stability analysis and structural sensitivity were performed by varying the Reynolds number. From this preliminary analysis it was possible to make some conjectures and in particular

- The instability in the case of 3D cavities occurs because of an unsteady Hopf bifurcation,
- The instabilities that trigger in the 3D cavity are external to cavity itself,
- The instability of 3D cavities have a similarity with those studied by Sipp and Lebedev [10], i.e. they are of *Wake Mode* type, and hence they are more similar to those that occur in a purely 2D cavity

It is mandatory to stress that these conclusions are valid only in the case of cubic cavity, because it is to be expected that a variation of the spanwise dimension of the cavity, may trigger a different type of instability. It is presumable that an increase of the width of the cavity compared to the length, i.e. an increasing of the Aspect Ratio, triggers a different instability mechanism. Moreover, in order to complete this study and assess these preliminary conclusions, further 3D simulations will be performed. For an exhaustive completion of the work, it would be desirable to also design an experiment aimed to confirm and test the numerical results obtained.

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