Summary

The development of aerospace propulsion systems has always strived to increase the efficiency and reliability of aircraft and spacecraft engines. This aspect has led to the introduction of advanced thrust vectoring techniques, in order to enhance maneuverability, design efficiency, and operational flexibility. In fact, these techniques enable better control in flight regimes that are otherwise difficult to manage using conventional aerodynamic control surfaces, for example when flying at low airspeed, high angles of attack, or even in post-stall conditions.

Traditionally, thrust vectoring capabilities have been achieved through mechanical means, where the geometry of the nozzle itself is manipulated through physical actuators to change the direction of the exhaust flow.

In this context, Fluidic thrust vectoring (FTV) techniques represent an interesting alternative, leveraging other methods of fluid manipulation within a fixed geometry nozzle, in order to create an asymmetry in the flow field. This diverts the primary exhaust flow and modifies the direction of thrust, introducing a lateral force component.

Among the various FTV methods described in the literature, the scientific investigation and the related analyses within this thesis will concern the methods of Shock Vector Control (SVC) and Differential Throttling (DT). SVC is a thrust vectoring technique that involves the injection of a secondary flow from the walls of a supersonic nozzle, introducing a controlled disruption of the shock wave structure.

DT is a technique used primarily in configurations where multiple engines or thrust chambers can be throttled independently. As such, an interesting application of this method can be found for aerospike nozzles, especially in clustered configurations. Numerical simulations have been carried out to investigate various aspects of these FTV techniques. Two-dimensional and three-dimensional RANS simulations in cold flow conditions have been performed to obtain information on the characteristic flowfield and the disruptive effect of the application of SVC to a traditional convergent-divergent nozzle, and of DT to both a linear and an axisymmetric aerospike nozzle. The performance of these FTV methods have been evaluated for multiple nozzle working conditions, and for various degrees of FTV control intensity. The presence of an external flowfield has been taken into account through a parametric study of the performance of the SVC method in relation to external Mach number.

The influence of high temperature and real gas effects in nozzles on the effectiveness of the SVC method has also been investigated and taken into account. In fact, the properties and chemical composition of the working gas can change at higher temperatures. As a result, an investigation has been carried out regarding the influence of the numerical modeling approach of the gas on the nozzle flowfield structure and performance. Moreover, the presence of a combustion chamber ahead of the nozzle produces non-homogenous chemical composition, temperature and velocity distribution, and can generate regions of high vorticity. These aspects have an effect on the flowfield and performance of both the nozzle and the FTV technique that is applied to it.

In addition to numerical simulations, an experimental campaign has been devised and carried out in order to validate the numerical framework used to study these FTV methodologies. An experimental test-rig has been assembled for the purpose of testing scale models of advanced nozzles and of FTV techniques. In this regard, two linear aerospike models of different truncation length have been tested, both in nominal conditions and at various differential throttling levels. The experimental results are in good agreement with those obtained from the numerical simulations.