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Turbulent boundary layer separation control and loss evaluation of low profile vortex generators

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ABSTRACT

The present paper analyses the results of a detailed experimental study on low profile vortex generators used to control the turbulent boundary layer separation on a large-scale flat plate with a prescribed adverse pressure gradient, typical of aggressive turbine intermediate ducts. This activity is part of a joint European research program on Aggressive Intermediate Duct Aerodynamics (AIDA). Laser Doppler Velocimetry and a Kiel total pressure probe have been employed to perform measurements in the test section symmetry plane and in cross-stream planes to investigate the turbulent boundary layer, with and without control device application.

Velocity fields, Reynolds stresses, and total pressure distributions are analysed and compared for the controlled and non controlled flow conditions to characterize the mean flow behaviour. The detail and the accuracy of the measurements allow the evaluation of the deformation works of the mean motion in the test section symmetry plane. Normal and shear contributions of viscous and turbulent deformation works have been analysed and employed to explain the distribution of the total pressure loss. For the controlled flow the discussion of the flow field is extended considering the effects of the vortex generated in the cross-stream planes. The experimental data allow the evaluation of the global amount of losses, considering a balance of total pressure fluxes in the different measuring planes.

1. Introduction

In the last 30 years many efforts have been done to apply flow control devices inside a real environment in a reliable and efficient way. Even though the concept of boundary layer control was introduced by Prandtl [1] at the beginning of the 20th century, only recently it has been thought to "control" the flow inside complex machines such as aeroengines. For a modern turbomachine, one of the most interesting applications of boundary layer control is the prevention of flow separation. Boundary layer separation is in fact one of the main causes of total pressure losses and, therefore, the prevention of separation may have a positive impact on turbomachinery efficiency, or the suppression/delay of separation may allow the application of more aerodynamically loaded airfoils and ducts, without decay of aerodynamic performances [2]. For these reasons, the investigation of boundary layer separation control methods applied to internal aeroengine flows becomes of primary importance.

For external aerodynamics, different flow control devices have been proposed and often employed to avoid boundary layer separation. Control devices can be passive, requiring no auxiliary power, or active, requiring energy expenditure [3]. Up to now, one of the most tested passive devices are the vortex generators (VGs), thanks to their relatively easy applicability. They consist of "little wings" embedded in the boundary layer, which generate a tip vortex able to apply momentum transfer from the outer to the inner region of the boundary layer. Until the1980s their height (VGs characteristic dimension) was of the order of the boundary layer thickness [4], but later, in order to reduce parasitic drag, different authors [5–7] introduced sub-boundary layer VGs, also called low profile VGs (height approximately 20% of the boundary layer thickness). Recently, VGs have been applied to internal flows, in particular to diffusing ducts, with two different purposes: secondary flow control and mixing enhancement. Reichert and Wendt [8,9] carried out tests on circular S-ducts with tapered-fin VGs. Sullerey et al. [10] experimentally investigated the effects of various vortex generator configurations in reducing the exit flow distortion and improving pressure recovery in two-dimensional S-duct diffusers.

Flow simulation of vortex generators effects has been carried out using two different numerical approaches: VGs may be included in the computational domain modelling their geometry, or VGs may be replaced by volume forces that create vortices in an analogous way VGs do. This last approach seems computationally more efficient than the first one and it has been implemented in several works (e.g. [11–14]). Most of these works came out from

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