Analyses of transonic flow past wall roughness

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1. Motivation

The key player in increasing the viscous drag on aircraft is the laminar-to-turbulent transition process of the boundary layer. There are a lot of applied techniques that aim to move the laminar-turbulent transition far downstream in order to have a larger laminar region over the wing and, thus, reducing aerodynamic drag.

The understanding of the laminar-to-turbulent transition process is a key feature for drag reduction over an aircraft wing and is important for improving the efficiency of these techniques.

Gaps, rivets or other surface imperfections are typical of an aircraft wing and they have a strong influence on the boundary layer instabilities and transition. Therefore the analysis of the flow physics in the separated regions induced by similar objects is of particular interest for understanding the laminar-to-turbulent transition process at different flow regimes.

2. Research

In this project we analyze the boundary layer separation in transonic flows caused by either a two- or a three-dimensional isolated wall roughness which can be seen as a reduced model of a wing imperfection. The studies are performed using two approaches: the DNS of compressible Navier-Stokes equations at high Reynolds and the numerical solution of the triple-deck equations.

We compare the two approaches for different heights of the hump and for different free-stream Mach number of the DNS computations. The results show a good match and the differences increase as the height increases since the nonlinear effects become more relevant.

3. Application

Since the triple-deck theory relies on the assumption of large Reynolds number (Re) we perform the DNS of Navier-Stokes equations at Re = 4 x 10^5 which is applicable to aeronautical applications. The study demonstrates that the triple-deck theory captures correctly the qualitative mechanism present in the boundary layer and therefore can be used as a reduced model in aircraft design. Specifically it is particular useful in estimates of receptivity where the quantities we have investigated, such as the wall shear stress and the longitudinal pressure gradient, are very relevant. On the other hand the triple-deck quantitative predictions are not entirely reliable especially in the presence of large recirculation regions and for large bump heights.