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Title

Assessment of RANS methods for low-Reynolds number compressible flows

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Abstract

This paper presents an assessment of the CIRA in-house developed solver UZEN (Unsteady Zonal Euler Navier-Stokes) for flows at low Reynolds and high Mach numbers. The compressible aerodynamics of low Reynolds number flow (Reynolds number of order of magnitude 10^4 - 10^5 and Mach number of 0.2 - 0.7) characterizes the low altitude Martian atmosphere. The need in the exploration of the Martian surface has increased the interest in this particular aerodynamic regime. These flow specifications have been scarcely investigated because do not occur in the Earth atmosphere and an assessment of the numerical methods is necessary.

Three suitable airfoils for compressible low-Reynolds aerodynamics in Martian atmosphere have been selected: Triangular, NACA 0012-34 and Ishii airfoils. All respect three suggested shape characteristics delivering high aerodynamic performance in a low-Reynolds-number region: sharp leading edge to fix the separation point at the leading edge; flat upper surface to reduce the separation region; cambered airfoil to gain a lift higher than a symmetric airfoil.

The experiment in the low density CO_2 tank of the Mars Wind Tunnel of Tohoku University over a Triangular, NACA0012-34 and Ishii airfoils with global forces and local PSP measurements, has been considered. The UZEN code has been applied by employing several turbulence models. The flow over the Triangular airfoil has been simulated inside the wind tunnel at Reynolds number of 3×10^3 and 1×10^4 , at Mach numbers of 0.15, 0.50, and 0.70 with three settings corresponding to the incidence of 5°, 10°, and 15°. The flow field at the aerodynamic coefficients have been reasonably well reproduced at the low-medium incidences. A disagreement with the experimental data has been, instead, noted at the highest α where the flow is completely separated over the airfoil. The analysis carried out over the NACA 0012-34 airfoil, has partially returned the non-linear behavior of the lift curves at all the Mach numbers considered. The complex flow field around the airfoil has been reproduced. This is characterized by vortex shedding from $\alpha = 0°$. The laminar separation bubble that occurs at $\alpha = 7°$ near the leading becomes longer as the incidence increases up to covering the entire upper surface of the airfoil. The results of the numerical simulations performed on the Ishii airfoil, are globally in good agreement with experimental data in terms of aerodynamic coefficients. The complex flow field has been discretely reproduced. The laminar separation bubble at $\alpha = 6°$ starts from the leading edge and then extends over the entire upper surface of the airfoil enlarging the separated region as the incidence increases. Numerical simulations performed on the three considered airfoils have provided results in good agreement with the experimental data, in terms of aerodynamic performances, especially at the low and medium incidences. The influence of the Mach number has been also investigated. The numerical results have shown that the increase in Mach numbers does not critically influence the flow field. It seems, on the contrary, that Mach number energizes the flow that is able to withstand with the adverse pressure gradients and becomes less prone to the separation.

References

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