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EFFECT OF RIBLETS ON A COMPLEX CONFIGURATION IN TRANSONIC CONDITIONS

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INTRODUCTION

This paper faces the issue of simulating the effect of riblets installed over complex configurations. Riblets consist of streamlined grooved micro-surfaces and are one of the most interesting passive devices for turbulent drag reduction. Their simulation in complex geometries in presence of pressure gradient flows has been limited until now by the required huge computational resources since a DNS would be required. Therefore, the adoption of a RANS method is proposed here, modelling the effect of riblets as a singular roughness problem.

The model has been validated for 2D and 3D flows and then applied to the analysis of a wing-body configuration in transonic conditions. Reasonable results have been achieved, and an interesting effect on position and strength of the shock waves has been noted.

MODEL REDUCTION

The effect of the riblets can be reduced to a shift of the constant in the logarithmic law of the velocity[3]:

$$U^+ = \frac{1}{\kappa_a} log(y^+) + B - \Delta U^+ \tag{1}$$

where the superscript + stands for wall viscous units and κ_a is the von Kármán constant. Equation 1 is the same formula describing the effect of wall roughness on turbulent flows. In case of roughness ΔU^+ is positive with an increase of drag, while riblets return negative values of ΔU^+ with a decrease of drag. Tani [12] re-analyzed the data of Nikurades [8] for turbulent flows over rough walls and realized that transitional roughness, defined as a roughness with a non dimensional grain in wall units $\kappa_s^+ < 50$, produces a reduction of the skin friction. Jiménez [3] renewed the idea that riblets can be seen as a transitional roughness effect, and Mele and Tognaccini [5] have proposed to use the $k-\omega$ tubulence models with the well-known wall boundary condition for ω

$$\omega = \frac{\rho u_\tau^2}{\mu} S_R \tag{2}$$

properly modified to take into account for the effect of the riblets. S_R is connected to the cross sectional area of the riblets A_g^+ as

$$S_R = \frac{C_1}{(l_g^+ - C_2)^{2n} + C_3} \tag{3}$$

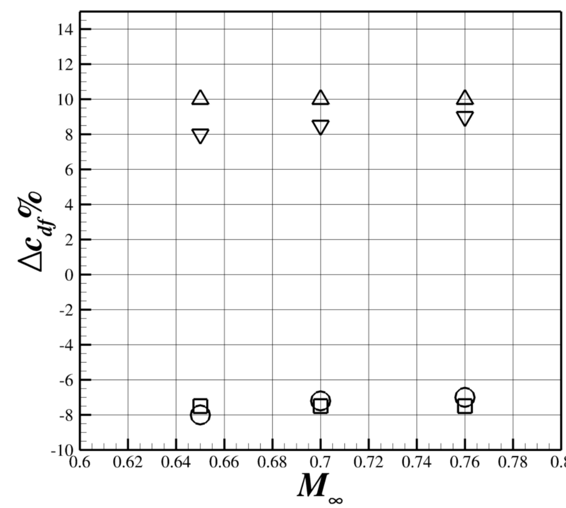

Figure 1: CAST 7 airfoil, $Re_\infty = 3 \times 10^6$, $\alpha = 0°$. Computed and measured friction drag reduction due to riblets at different free-stream Mach numbers and riblet height. △: experiment [2] for $h = 0.051$ mm; ▽: computed for $h = 0.051$ mm; □: experiment [2] for $h = 0.023$ mm; ○: computed for $h = 0.023$ mm.

with n, C_1, C_2, and C_3 constants and $l_g^+ = \sqrt{A_g^+}$. The height of the riblets can be linked to l_g^+. As an example, for *V-grooved* section the relation $h^+ = \sqrt{2} l_g^+$ stands.

VALIDATION OF THE MODEL

RANS simulations have been performed by the $k-\omega$ SST model [7] with the boundary conditions summarized by equations 2 and 3 to reproduce the effect of riblets for 2D cases. The incompressible flows over a flat plate and the NACA 0012 airfoils and the transonic flow around the CAST 7 airfoil have been considered.

As an example, the variation of friction drag obtained for the CAST 7 airfoil at different Mach numbers for two riblet heights is reported in figure 1. A very satisfactory comparison with the experiments [2] has been achieved. It is worth noting that the proposed model has been able to predict the decrease but also the increase of drag obtained in case of riblets with

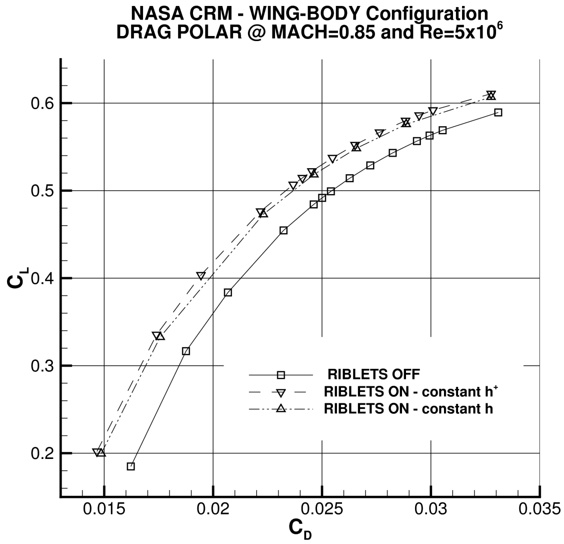

Figure 2: NASA CRM, Drag Polar at Mach=0.85 and $Re_\infty = 5\times10^6$ (FLOWer). —□—: Clean configuration; —▽—:Riblets on - constant $h^+ = 14.85$; —△—: Riblets on - constant $h = 0.05$ mm

height $h = 0.051$ mm.

The subsonic flow around a 25° swept-angle wing with riblets films of *V-grooved* section has been employed as 3D test-case for further validate the model. A reduction of drag of about 5.9% has been computed in good agreement with the experimental value [11] of 6%.

TRANSONIC WING-BODY CONFIGURATION

The NASA Common Research Model (CRM), subject of the 5^{th} Drag Prediction Workshop [4, 10], has been used to test the proposed model for a complex configuration at transonic conditions.

The specification of the flow is Mach =0.85 and Reynolds number (based on the reference chord) 5×10^6. Two different flow solvers, FLOWer [9] by DLR and UZEN [1] by CIRA, have been applied. The codes have provided very similar results thus confirming the robustness and the ease of implementation of the proposed model.

RANS simulations [6] have been performed considering the clean configuration, the configuration with riblets of constant viscous height h^+ and with riblets of constant physical height h.

In case of riblets of constant h^+, a decrease of the drag of about 10% has been obtained at constant C_L. At constant angle of attack α, the riblets have produced an increase of lift and, as a consequence of the induced drag, and the gain in drag is reduced to about 5%.

Different physical heights of the riblets have been considered at the same α. An optimum height of 0.5 mm, with an increase in lift of about 4% and a decrease in drag of about 3% has been found

The drag polar of the NASA CRM in shown in figure 2. The results for the clean configuration, the configuration with riblets of constant h^+ and the constant optimum h are reported. The gain in drag coefficient is always slightly higher for the constant-h^+ riblets with the difference between the two kind of devices decreasing as C_L increases.

The proposed model has been able to reasonably predict the effect of the riblets on a complex configuration at transonic conditions. An inluence of the drag-reduction device on the location and strength of the shocks has also been evidenced in the results. This effect has never been highlighted in literature and is worth a further deeper investigation.

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