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EXPERIMENTAL ANALYSIS OF TURBULENT SMOOTH AND ROUGH CHANNEL FLOWS

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Abstract. Researches about turbulent flows based on the drag reduction is one of the most important topics in Fluid Mechanics. Turbulent flows in circular and rectangular geometries are very different from each other, mainly, due to the presence of secondary flows in the last one. This work pretends to confirm the occurrence of the drag reduction phenomenon in rectangular geometry with a wall of different roughness. The variation of the friction factor of a Newtonian fluid for several Reynolds numbers is calculated using the experimental pressure drop in the channel. Non-intrusive laser optical measurement techniques, such as Particle Image Velocimetry (PIV) was used to study the influence of protuberances in the velocity fields and the turbulent flow statistics for different configurations.

Keywords: Turbulent flow, rectangular channel, roughness, drag reduction.

1. INTRODUCTION

Many works about drag reduction were developed in the last years, showing that this topic has a big importance at improving the land, sea and air transportation, and the flow of any kind of fluid, particularly, in the petroleum industry. The typical drag reduction techniques are classified in Active and Passive techniques. In the first one, energy is supplied in the system to reduce pressure losses; some examples are the injection of fluids or polymers. In the other hand, the Passive techniques use the geometry and shape of the surface to modify the turbulent structures near the wall; some examples are the longitudinal ribs (riblets).

Many authors studied wall roughness effects and one the very first equation is the presented by Colebrook (1938), this equation can be used to calculate the friction coefficient for many kinds of fluid flows. Other authors like Nikuradse (1950), worked with a random distribution of rough elements into a pipe. These elements were the responsible for a higher friction coefficient value. Other works like Walsh (1982 and 1990) and Walsh and Lindemann (1984) analyzed the turbulent flow for different kind of longitudinal ribs, identifying the best geometry for the riblets (rectangular one). Some authors (Bechert, *et al.*, 1985 and Luchini, *et al.*, 1993) studied the boundary layer structure and observed that, under certain conditions, wall roughness reduce the losses (showing an atypical behavior).

Numerical works (Krogstad, *et al.*, 1992, Leonardi, *et al.*, 2003, Bhaganagar, *et al.*, 2004, Krogstad, *et al,* 2005 and Leonardi and Castro, 2010) focused in the study of different riblets geometry in a rectangular channel. These studies found that the flow follows the law of the wall for smooth and rough surfaces.

Santos, *et al.*, 2016, worked with organized rough elements and different Reynolds numbers for a turbulent pipe flow. For low Reynolds numbers, pressure losses were equivalent to the sand roughness data (Nikuradse, 1950); for higher Reynolds numbers, the friction factor was reduced compared with the presented by Nikuradse (1950). This phenomenon was not explained before in literature, but it is clear that drag reduction happens due to changes the turbulent structures into the boundary layer.

In this work, several experiments are developed to identify the presence of this phenomenon for organized rough elements into a fully developed turbulent rectangular channel flow and the turbulent kinetic energy is calculated using optical measurement techniques (Particle Image Velocimetry).

2. THE EXPERIMENT

A 2.2 m transparent rectangular transparent acrylic channel from the Interdisciplinary Center of Fluid Dynamics NIDF, was used for these experiments. The channel is feed by a 0.5 m^3 water reservoir located 3 m above the diffuser entry. This is a closed system, and at the end of the channel, there is a storage tank. The fluid is pumped by a *Dancor W16* centrifuge pump. A *Promag 10D50* electromagnetic flow meter is used to measure the flow in the channel. A *Endress+HauserDeltabar M* transmitter was used to measure the differential pressure between eight points along the

channel with a distance between two consecutive points equal to 120 mm. The test section and the internal dimensions of the channel are shown in Figs. 1 and 2 respectively.
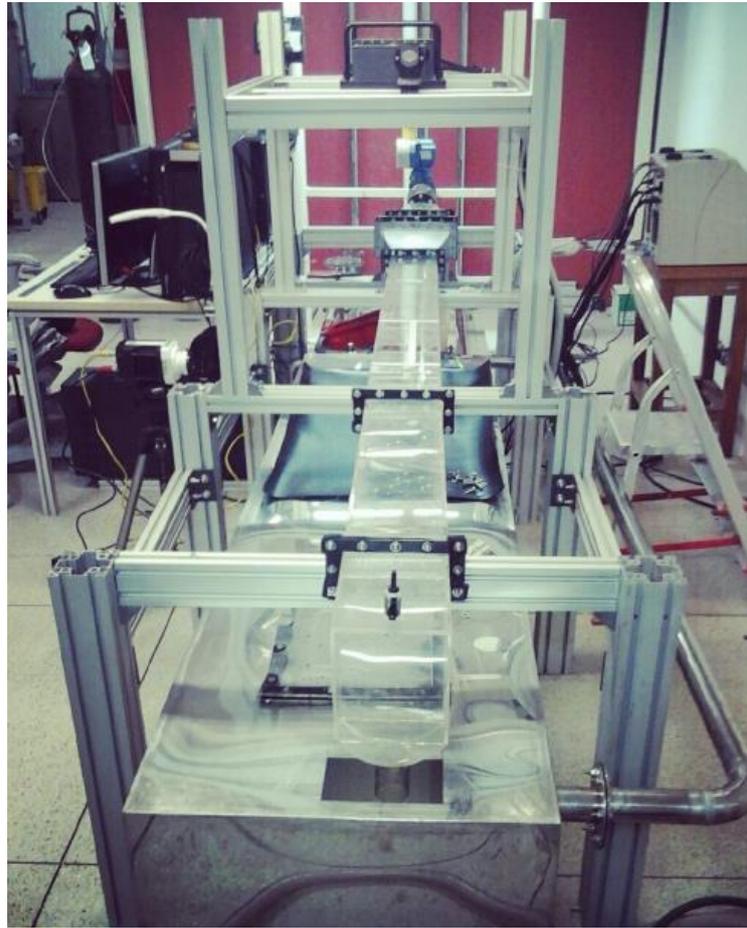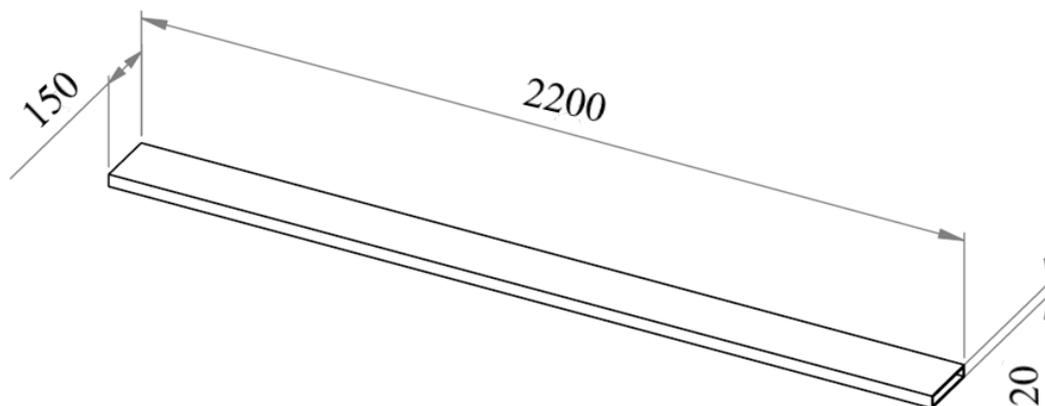

Figure 1. Test section rectangular cannel

Figure 2. Internal dimensions of the rectangular channel in mm

Four different roughness distributions were used for the experiments. Two of them made out from granular silicon carbide with grain size of 100 and 180 (Fig. 3a-b).

Other two configurations were made using the vacuum forming technique. This technique creates plastic shapes using a heat-suction balance. In this case, 1 mm PETG (Polyethylene Terephthalate Glycol) sheets are heated and deposited over a vacuum chamber with a circular holes distribution, Fig. 4.

A suction pump is connected in a lateral face of the chamber making the hot material enter the holes. The final results are PETG sheets with little organized rough elements that are placed in the bottom of the channel. The

temperature and suction time are controlled to get elements with height k_s about 0.67 mm. These configurations are shown in Fig. 3c-d.
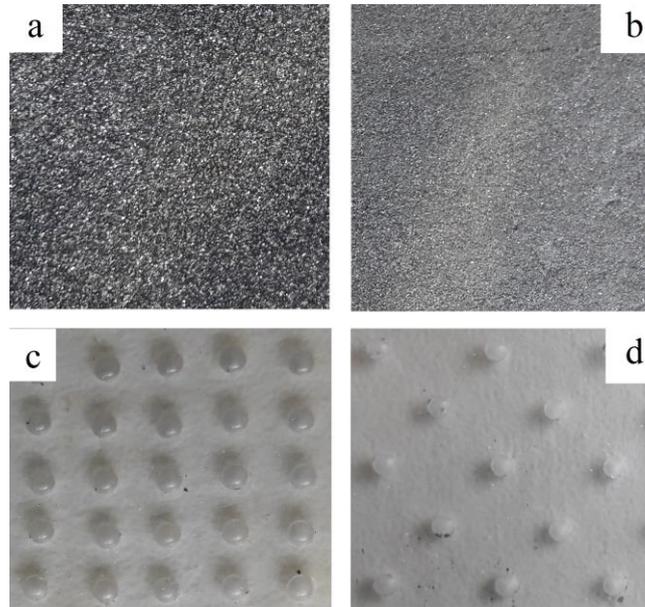

Figure 3. Roughness used in the experiments: a) grain size 100 (h/k_s=27.4), b) grain size 180 (h/k_s=73.7), c) PETG – four points configuration (h/k_s=33.2), d) PETG – five points configuration (h/k_s=31.7)
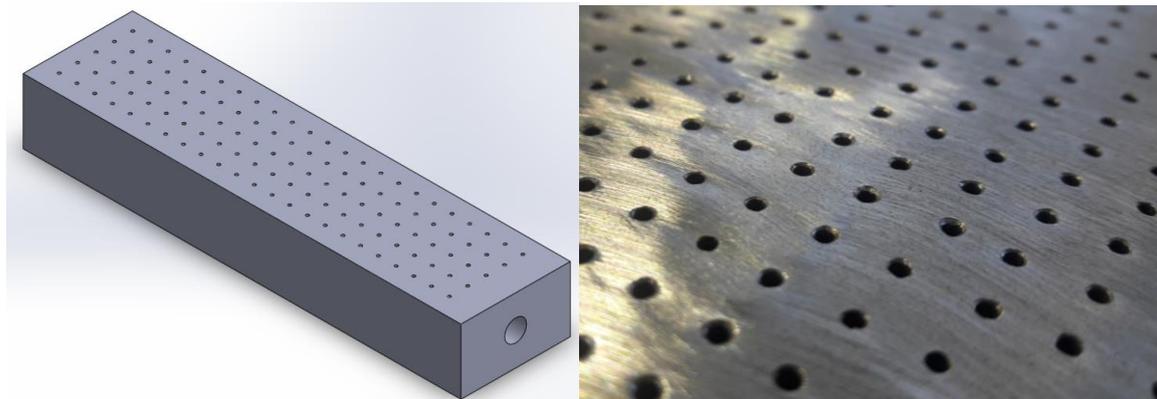

Figure 4. Vaccum chamber

3. PRESSURE DROP AND FRICTION FACTOR RESULTS

The differential pressure was measure for a smooth and four rough channels. Fig. 5 show the experimental pressure drop along the smooth and 5 points configuration channels. As expected, a higher pressure drop is shown due to the spaced elements compared with the smooth surface. The friction factor was calculated using the classic Darcy-Weisbach equation, Eq. 1.

$$\lambda = \frac{2\Delta P D}{\rho L \overline{U}^2}$$
(1)

where λ is the friction factor, ΔP is the differential pressure between two points in the channel, D is the characteristic length of the channel (for this case twice the height channel), ρ the fluid density, L the distance between two points for the corresponding ΔP and $\overline{U}$ is the mean velocity of the flow. The friction factor for different Reynolds numbers in smooth and rough channels is presented in Fig. 6.

The friction factor experimental dots for the smaller sand particles (granulometry 180) are closer from the smooth channel results. In the other hand, bigger sand particles result in higher losses. The 5 points configuration and the sand

with granulometry 100 have a good matching, showing that they produce similar losses along the channel for that Reynolds number range. In the case of the 4 points configuration, the friction factor is slightly higher. This difference could be the result of the smaller spacing between the dots compared with the 5 points spacing. To analyze this difference, turbulent kinetic energy profiles are compared in the next section.
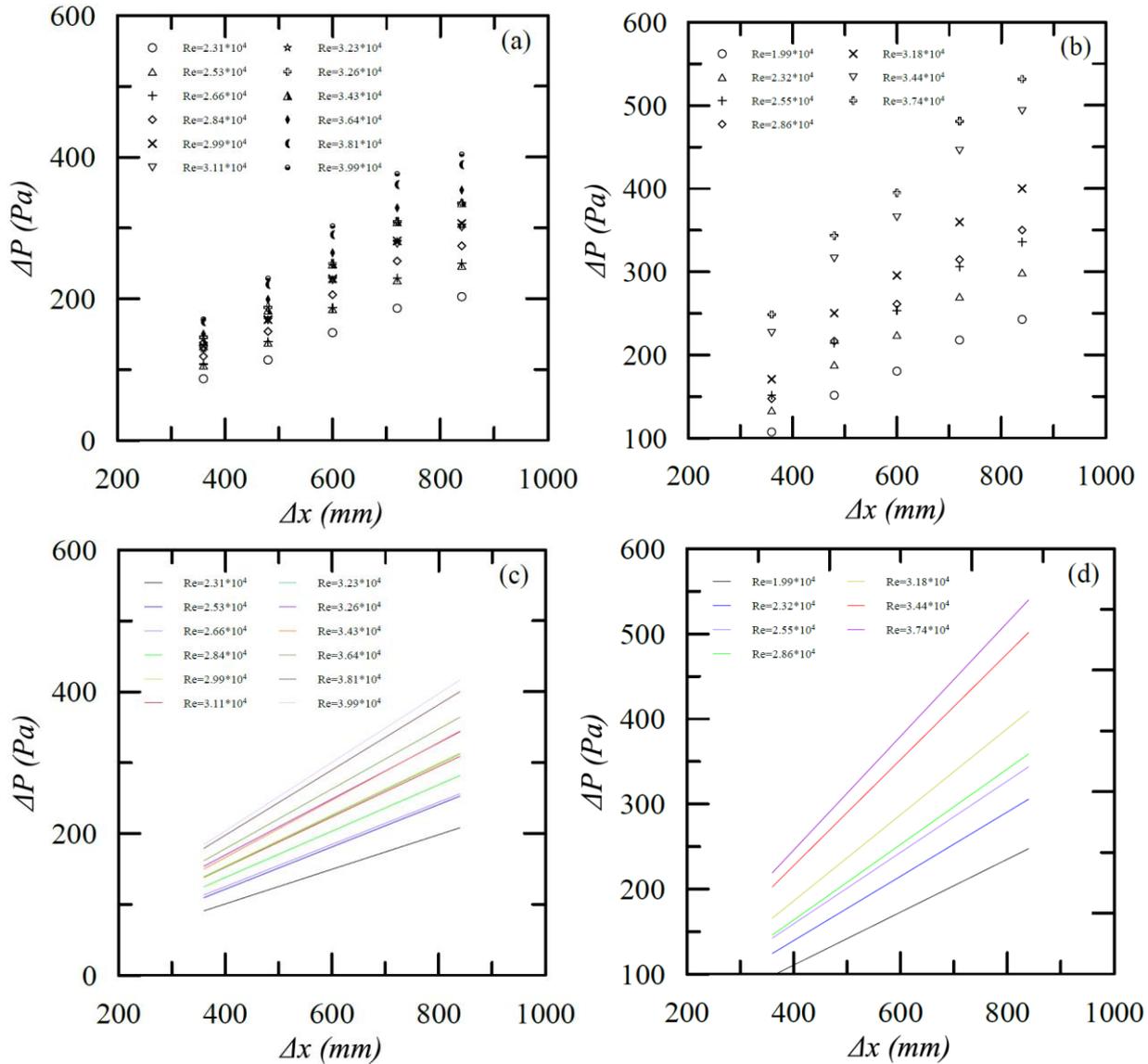

Figure 5. Pressure drop along the channel. a) Smooth, b) 5 points pattern, c) experimental points tendency for the smooth channel, d) experimental points tendency for the 5 points pattern.

4. VELOCITY AND TURBULENT KINETIC ENERGY RESULTS

In order to analyze the effect of the discrete elements distribution in the flow, the Particle Image Velocimetry PIV was used to get the velocity fields for the smooth, four and five points configuration channels. For the rough channels there is a reduction on the velocity values near the wall (Fig. 7a) and the position of the maximum velocity changed for these configurations, being located at a height around $0.8h$. These changes can be explained for the increase of the turbulent kinetic energy k near the rough wall. Fig. 7b shows the k peaks for the spaced elements distributions. The 4 points configuration presents a higher k value increase when getting closer to the wall. Then, the losses for this configuration can be due to this energy production near the wall.
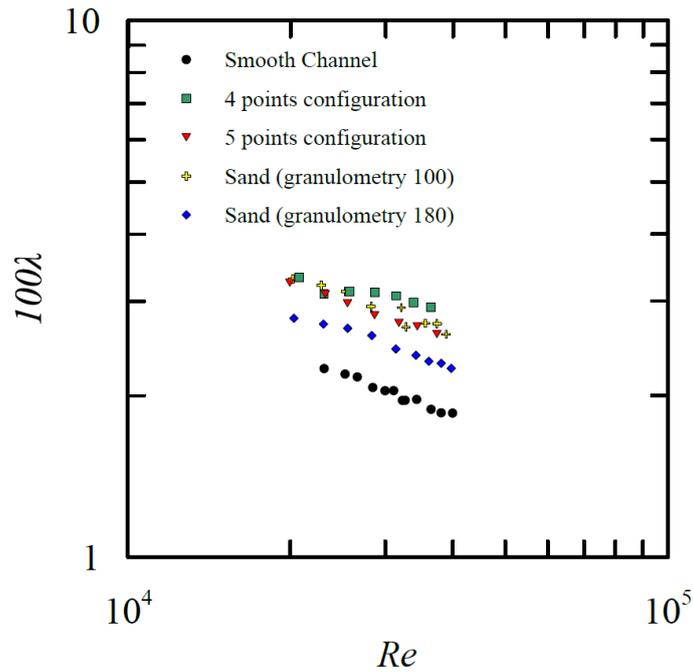
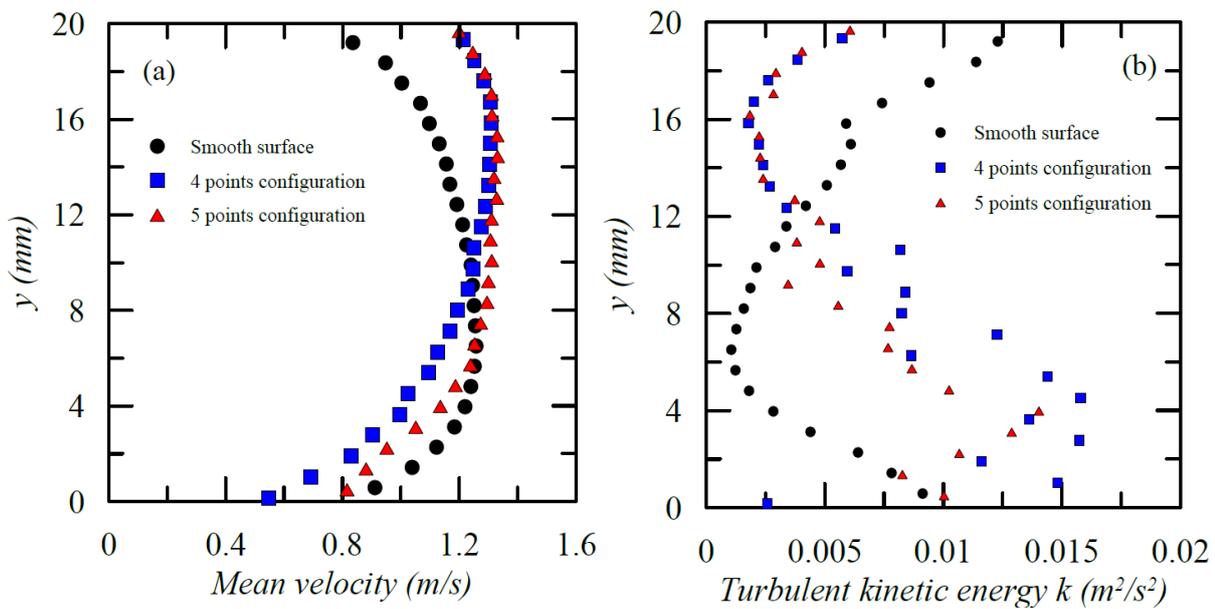Figure 6. Friction factor for all the channels

Figure 7. a) Mean velocity profiles, b) Turbulent kinetic energy profiles. Smooth channel for Re=29387, 4 points configuration for Re=29591, 5 points configuration for Re=29760.

5. CONCLUSIONS

This work studies the effect of different roughness distributions in a turbulent channel flow. Pressure drop information is used to calculate the friction factor for smooth and sand rough channels. The friction factor results showed how the 5 points configuration has the same general effect in the flow compared with the sand surface with grain size of 100. For smaller sand particles, the friction factor tends to be closer to the smooth channel results. The friction factor for the 4 points configuration was higher than the other roughness. Turbulent kinetic energy profiles, calculated from the PIV measurements showed that the losses due to this rough surface are related to the energy production near the wall.

6. ACKNOWLEDGEMENTS

7. REFERENCES

Bechert, D. W., Hoppe, G. e Reif, W. E., 1985. ''On drag reduction of the shark skin''. In *AIAA Journal*, ,No. 10.2514/6.1985-546.

Bhaganagar, K., Kim, J. e Colem, G., 2004. ''Effect of roughness on wall-bounded turbulence''. In *Flow, Turbulence and Combustion*, ,No. 72, pp. 463-492.

Colebrook, C.F., 1938. ''Turbulent flow in pipes, with particular reference to the transition between the smooth and rough pipe laws''. J. Inst. Civ. Eng.London. , No. 11, pp. 133-156.

Krogstad, P. A., Andersson, H. I., Bakken, O. M. e Ashrafian, A., 2005. ''An experimental and numerical study of channel flow with rough walls''. In *J. Fluid Mech.*, ,No. 530, pp. 327-352.

Krogstad, P. A., Antonia, R. A. e Browne, L. W. B., 1992. ''Comparison between rough- and smooth- wall turbulent boundary layers''. In *J. Fluid Mech.*, ,No. 245, pp. 599-617.

Leonardi, S. e Castro, L. P., 2010. ''Channel flow over large cube roughness: a direct numerical simulation study''. In *J. Fluid Mechan.*, ,No. 651, pp. 519-539.

Leonardi. S., Orlandi, P., Smalley, R. J.,Djenidi, L. e Antonia, R., A., 2003. ''Direct numerical simulations of turbulent channel flow with transverse square bars on one wall''. In *J. Fluid Mech.*, ,No. 491, pp. 229-238.

Luchini P; Manzo F; Pozzi A, 1991.Resistance of a groovedsurface to parallel flow and cross-flow. In *J. Fluid Mech* No. 228, pp. 87-109.

Nikuradse, J., 1950. Laws of flow in rough pipes. National Advisory Committee for Aeronautics Washington.

Santos, C.M.M., Anbarlooei, H., Cruz, D., Silva Freire, A.P. e Loureiro J.B.R., 2016. ''On the organized rough elements distributions and the drag reduction effects of turbulent flows in pipes''. In *16th Brazilian Congress of Thermal Sciences and Engineering*. ABCM, Vitória, ES, Brazil.

Walsh, M. J. e Lindemann, A. M., 1984 ''Turbulent drag reduction''. In *AIAA 22nd Aerospace Sciences Meeting*.

Walsh, M. J., 1982. ''Turbulent boundary layer drag reduction using riblets''. In *AIAA 20th Aerospace Sciences Meeting*, ,pp. 1-8.

Walsh, M. J., 1990. ''Effect of detailed surface geometry on riblet drag reduction performance''. In *Journal of Aircraf*, , v.27, No. 6, pp. 572-573.

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