Investigating the Effect of the Modified Surface on the Performance of the Wind Turbines

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Abstract:- **In the present work it is intended to investigate the drag on a wind turbine airfoil, whose chord is 0.4 m and is set in the real operating conditions. The airfoil is installed in the real operating conditions and is covered partially with a riblet film at different sections to check the optimal riblet location. Four different symmetrical V-shaped riblets are tested, and their sizes are 40, 58, 96, and 144 μm. Three days during the winter are chosen, and the wind speeds in these days corresponded to three Reynolds numbers whose values are; 653000, 798000 and 976000. Different angles of attack were tested in each case. The results exhibited that the magnitude of drag reduction Varied with the angle of attack, Reynolds number, riblet size, and riblet location. A drag reduction of about to 6% was obtained when using the riblet, whose size is 58 μm, for all values of the range of Reynolds numbers. Also, for each Reynolds number value, there is a riblet size that exhibited the best performance. The optimal Reynolds number value decreased with the increase in riblet size.**

Keywords: **wind turbine, riblet, drag.**

Nomenclature

Alphabetic

C	**airfoil chord**
C_d	**drag coefficient**
C_l	**lift coefficient**
C_m	**quarter-chord pitching moment coefficient**
C_p	**pressure coefficient**
Re	**Reynolds number**

subscripts

tr	**transition**

Greek symbols

α	**angle of attack**

I. INTRODUCTION

During the last thirty years, many researchers were interested in investigating the drag reduction methodologies that are relevant to flight vehicles, marines, and wind turbines [1–6]. In the field of commercial transport aircraft, depending on the size, viscous or skin friction drag accounts for about 40–50% of the total drag under cruise conditions; the saved costs are generally high even with a small level of drag reduction [7].There have been continuous activities around the globe concerning development of new techniques for skin drag reduction [3,6] and many attempts have progressed broadly in the methods for delaying laminar-turbulent boundary layer transition and the methods for modifying the turbulent structure of a turbulent boundary layer. The passive turbulent drag techniques include riblets and large eddy break-up (LEBU) devices. This investigation is concerned with testing the riblets for the airfoil surfaces. Extensive research on riblets has been carried out on riblets, which are micro-grooves on the surface and aligned to the freestream direction [8–10] and the results from these studies have been promising and encouraging.Several international meetings have addressed the subject of riblets, both from the viewpoint of basic fluid mechanics as well as practical applications. Riblets with symmetric v-grooves (height equal to spacing) with adhesive-backed film have been widely investigated in most earlier work and the results have revealed great consistency with regard to the degree of drag reduction as well as certain aspects of flow structure [8]. A variety of two-dimensional flows with zero or mild pressure gradients exhibited viscous drag reductions in the range of 4–8% [8]. A large body of data generated using 3 M riblets reveal [8] that optimum drag reduction occurs in the range of h^+ ($= hu_* /\nu$) of 8–15. Some of the earlier studies, e.g. Refs. [15,16], at low speeds have focused attention on optimizing riblets geometry and drag reduction as high as 10%. In zero-pressure gradient flows, the effects of riblets appear to be confined to the near-wall region ($y^+ < 70$). Detailed mechanisms by which riblets reduce the wall shear stress are not yet understood even in a zero pressure gradient boundary layer flow. Some mechanisms have been suggested such as weakening of the bursting process near the wall [17], significant retardation of the flow in the groove valley dominated by viscous effects [10], some increase in the sublayer thickness, restriction of span-wise motion of longitudinal vortices. Some of the investigators, e.g. [8], have also been reported certain reduction in turbulence intensity and Reynolds shear stress in the wall region. Because of the relatively small groove dimensions, measurements in the close vicinity of the grooves are difficult. In the recent years, measurements of both mean velocity and some turbulence statistics in the grooves have become available by using riblets (of much higher dimensions than 3 M); these results show that wall shear stress is increased near groove peaks and appreciably reduced in the valley and it has been suggested that net drag reduction could result despite increased wetted area. Excellent review papers covering aspects of drag reduction and flow structure due to riblets have been published, e. g.Walsh [8], Coustols and Savill [9], and Coustols [10]. Realistic applications involve pressure gradients, three-dimensionality, and drag reduction under these conditions have been addressed, but not in sufficient detail. The boundary layer on an airfoil is subjected to combined influence of streamwise pressure gradients and surface curvature unlike the flow on a flat plate [18, 20]. The vane sweep introduces three-dimensionality and spanwise gradients in addition. The trials to understand the effectiveness of riblets in the presence of these additional effects are limited. The application of riblets on 2D airfoils at zero or low incidence has revealed viscous drag reduction comparable to zero-pressure gradient flows, e.g. [11, 19]. There have been researches concerning the drag reduction capabilities of riblets in pressure gradients [18]. Very satisfying results were reported from wind tunnel tests on Do-228 aircraft model at low speeds [20] and airbus A-320 wing-body model at transonic Mach numbers [11].The experiments at relatively high Reynolds numbers on a T-33 [12] and [13] have provided considerable support to the riblets' effectiveness. Active researches for riblets on several airfoils and wings covering aspects of drag reduction and flow features due to riblets have been performed and results from many of these studies have been published [19,21].

The objective of the present work is to investigate the drag on a wind turbine airfoil that is partially covered with riblet films. Four riblet sizes are tested on the airfoil which is set in the real operating conditions over a range of angles of attack and wind speeds. The results are proposed to illustrate the performance of the airfoils that are enhanced with riblet films in the real operating conditions. Also it is required to determine the riblet configurations that may be applied to wind turbine blades for maximum energy output.

II. EXPERIMENTAL PREPARATIONS

The investigated airfoil is set in the real operating conditions, and its cord is directed such that, it makes the required angle of attack with the expected wind direction. Figure 1 illustrates the tested airfoil model which is fixed from the bottom and connected to the balance. Figure 2 illustrates the balance installation. The airspeed and dynamic pressure were determined by static pressure measurements. Ambient pressure was measured with an absolute pressure transducer. Ambient temperature was measured with a thermocouple. The performance of the airfoil was measured using a three-component external force and moment balance mounted underneath the model and by a wake rake. the normal force, axial force, and the pitching moment of the airfoil were measured by the three-component balance. Lift and drag were calculated from the normal and axial forces. An additional accurate drag value was calculated using the measurements in the wake rake. The rake contained 56 total pressure probes over a total width of 25 cm. The seven probes on each of the outer sides of the rake were spaced 6.8-mm apart and the rest of the 49 probes were spaced 3.4-mm apart. Eight spanwise wake profiles were measured for each angle of attack starting 10.12-cm after and ending 7.6-cm before the center span, and these profiles are spaced (2.5-cm) apart. Each tested riblet film has a plastic backing with V-shaped riblets on one side and an adhesive on the other. The riblet peak-to-valley and peak-to-peak spacing are the same. Four sizes of riblet films were tested: are 40, 58, 96, and 144 μm.

The tested airfoil was manufactured to be similar to the DU 96-W-180. It is an 18%-thick airfoil that is actively used in wind energy research. This airfoil model had a span of 0.851-m with a 0.457-m chord. For each Reynolds number, four types of riblet surfaces are tested at different angles of attack. Each riblet film was tested in three cases; 1) riblet film covers the upper turbulent surface, 2) riblet film covers the lower turbulent surface, 3) riblet film covers the upper and lower turbulent surface region.

Figure 1 the airfoil model

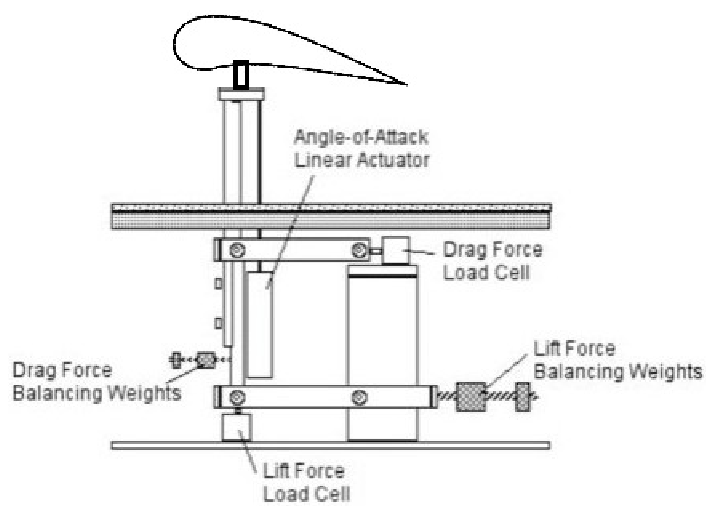


Figure 2 the force balance installation

The stream-wise shading of the film seen in figure 1 was due to adhesive variations beneath the skin of the film, and the riblet film sticks carefully to the model surface. The model was first tested without the riblet film, then, the riblet films with the mentioned sizes and locations on the airfoil surface. The readings are taken ate three times during the day; at 3.00 AM, 5.00 AM, and 8.00 AM. In each one of these experiments, the wind speed in the drag direction and the forces of the airfoil are taken three times, and the averages of these readings are recorded and accordingly, three Reynolds numbers were calculated; 653000, 798000 and 976000. Each riblet configuration was tested over the entire low drag range. The eight spanwise wake surveys were taken for each angle of attack, and the measured drag values are averaged. For each Reynolds number, the clean airfoil is tested alone to obtain the baseline drag. Next, the airfoil was tested with a trip that is mounted ahead of the laminar separation point to determine if there was an optimal location that minimized the drag of the laminar separation bubble. however, no benefit was seen from forcing transition ahead of the separation bubble and in some cases trips even proved to be detrimental to the airfoil performance. Thus, much care has to be taken in placing the riblet film behind the natural laminar separation point. The flow was tripped by using a backward-facing step created by applying a strip of 0.114- μm thick and 7.938- μm wide Chart pack tape at the desired location. The airfoil was tested with riblet film applied to the upper surface turbulent region, lower surface turbulent region and both upper and lower turbulent regions. When any riblet film was placed in the turbulent regions, a narrow piece of tape was used to secure the leading edge of the film to the airfoil and prevent it from debonding.

III. RESULTS AND DISCUSSION

This section discusses the results from the testing of the riblet film on the DU 96-W-180 airfoil. For the purpose of validation, figure 3 illustrates the data from [22] for a Reynolds number of 1000000 with the present data for Reynolds number of 976000. The observed differences between the two sets of data may be interpreted as follows; the data of [22] were taken in a wind tunnel and using honeycomb, but in the present work, the real wind direction is not straight and may vary randomly. Also the effects of the bound layer on the sides and its corresponding shear forces may affect the balance readings.

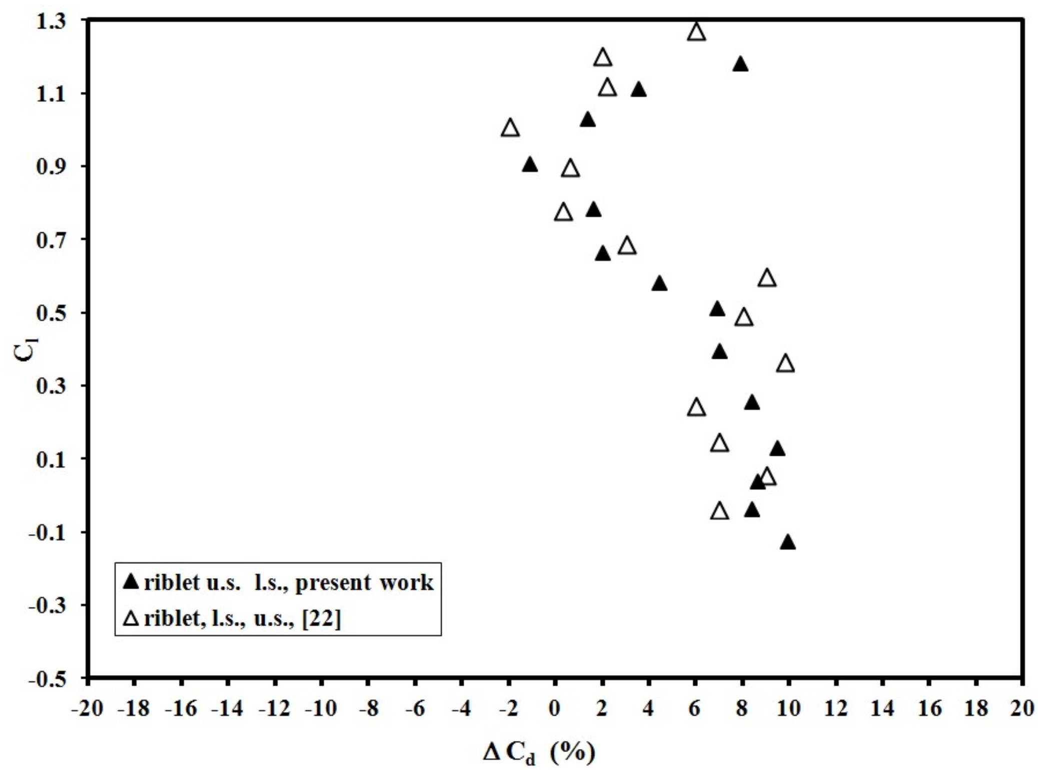
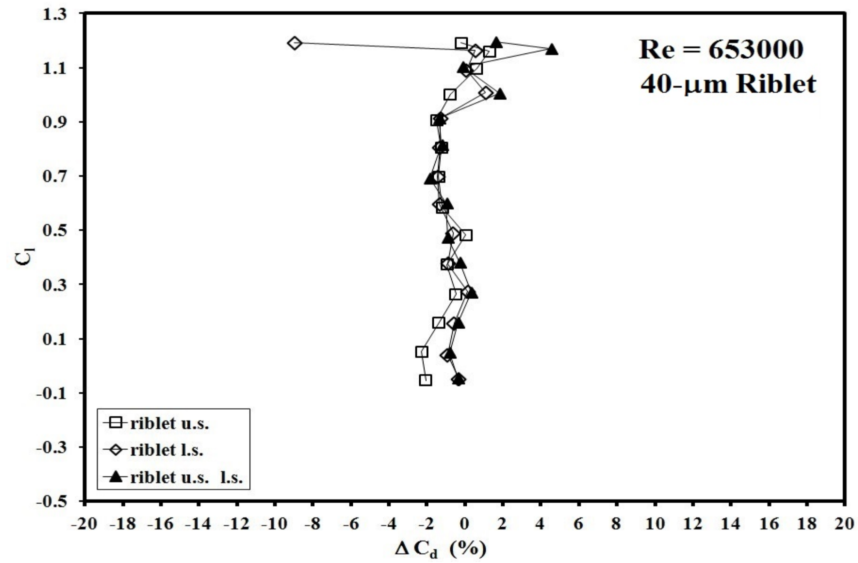


Figure 3 comparison of the data from [22] for Reynolds number of 1000000 and the present data for Reynolds number of 976000.

The following figures illustrate the performance of the DU 96-W-180 airfoil with the trip and the four riblet types that cover the airfoil surface according to three patterns. The figures illustrate the percent change in the drag with respect to that of the clean airfoil (negative indicates drag reduction).

Figure 4 illustrates the percentage of the drag variation on the airfoil with the four types of riblet films for the three coverage patterns at Reynolds number equals 653000.

It is obvious that there is a little decrease in drag due to the 40-μm riblets. The 58-μm riblet produced a maximum reduction in drag of about 6% with the riblets on the upper and lower surface. The 96-μm riblet produced a maximum reduction in drag of about 5.2% with the riblets on the upper and lower surface. The144-μm riblets caused a maximum increase in drag of about 4%. Figure 5 illustrates the percentage of the drag variation on the airfoil with the four types of riblet films for the three coverage patterns at Reynolds number equals 798000. In the figure, a decrease in drag of about 2% was observed for the 40-μm The 58-μm riblets produced a drag reduction which is less than 5%. A little variation is observed in the performance of the three coverage pattern of the 96-μm riblet. The 144-μm riblet exhibited a decrease in drag of about 3%. Figure 6 illustrates the percentage of the drag variation on the airfoil with the four types of riblet films for the three coverage patterns at Reynolds number equals 976. The figure illustrates that the 144-μm riblet exhibited the worst performance and the 58-μm riblet exhibited the best performance for all values of the attack angle. With a maximum decrease in the drag of about 4.5%. the 40-μm riblet almost had no observable effect and its performance deteriorated for the higher values of the attack angle.



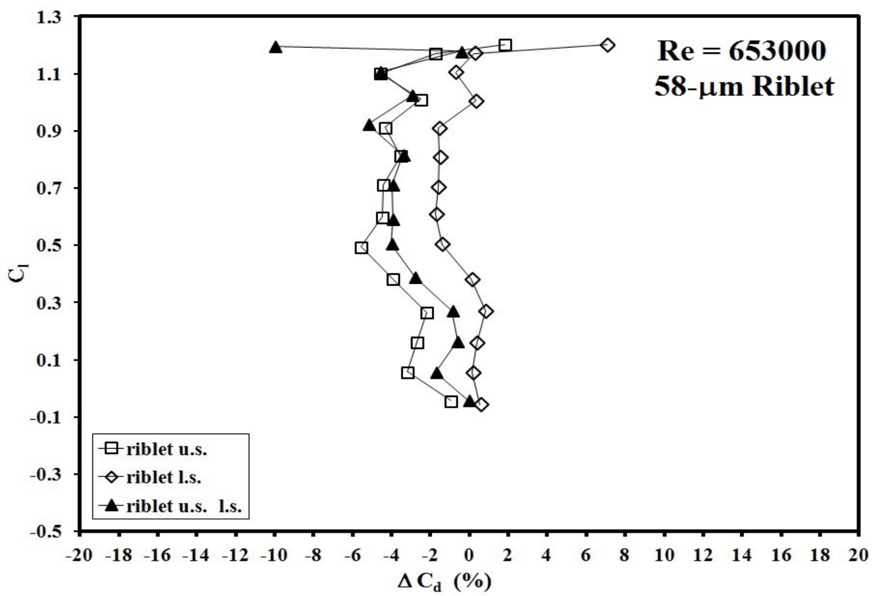
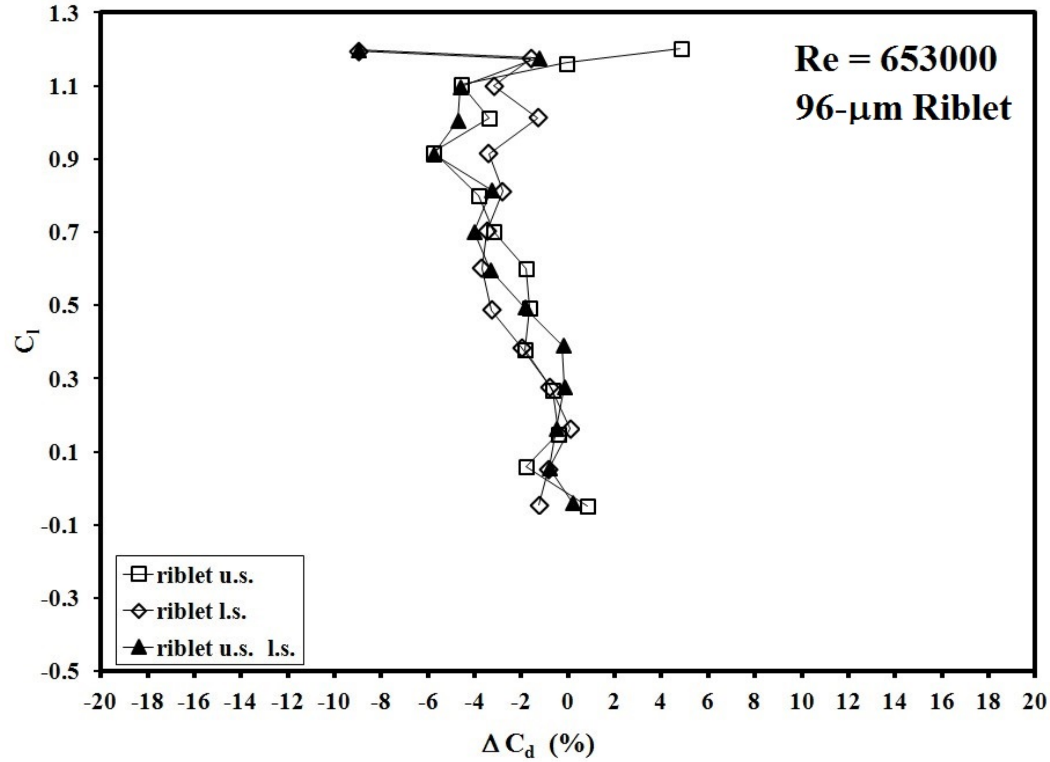
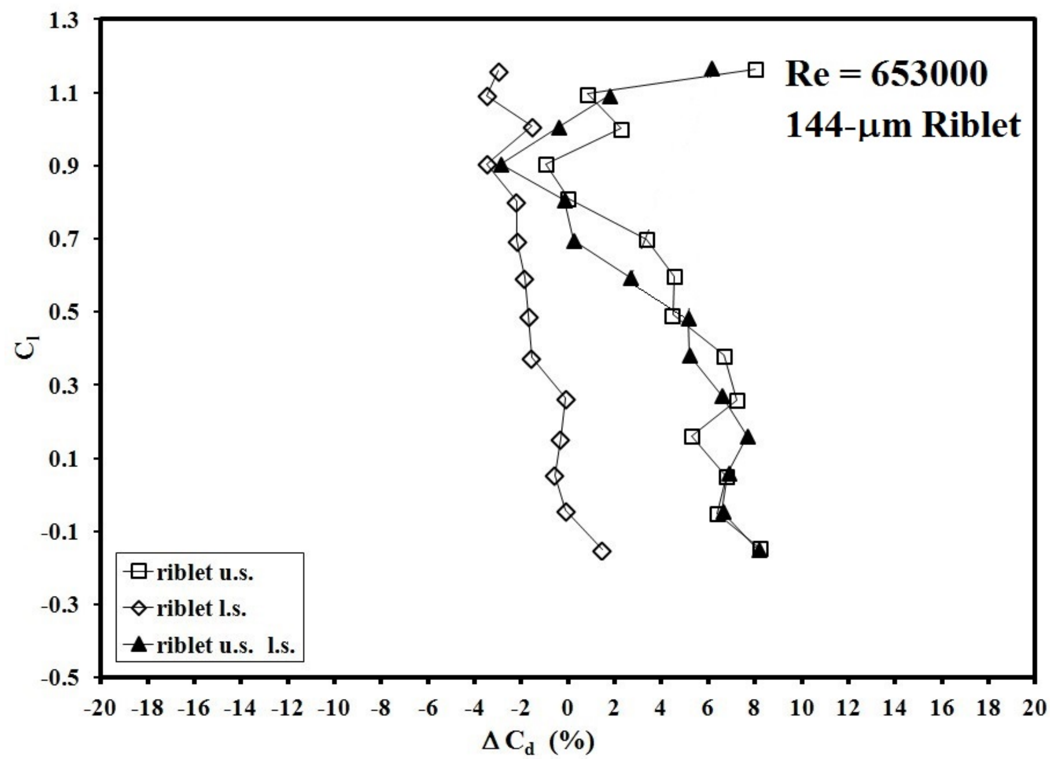


Figure 4 the percentage of the drag variation on the airfoil with the four types of riblet films and with the three coverage patterns at Reynolds number equals 653000.





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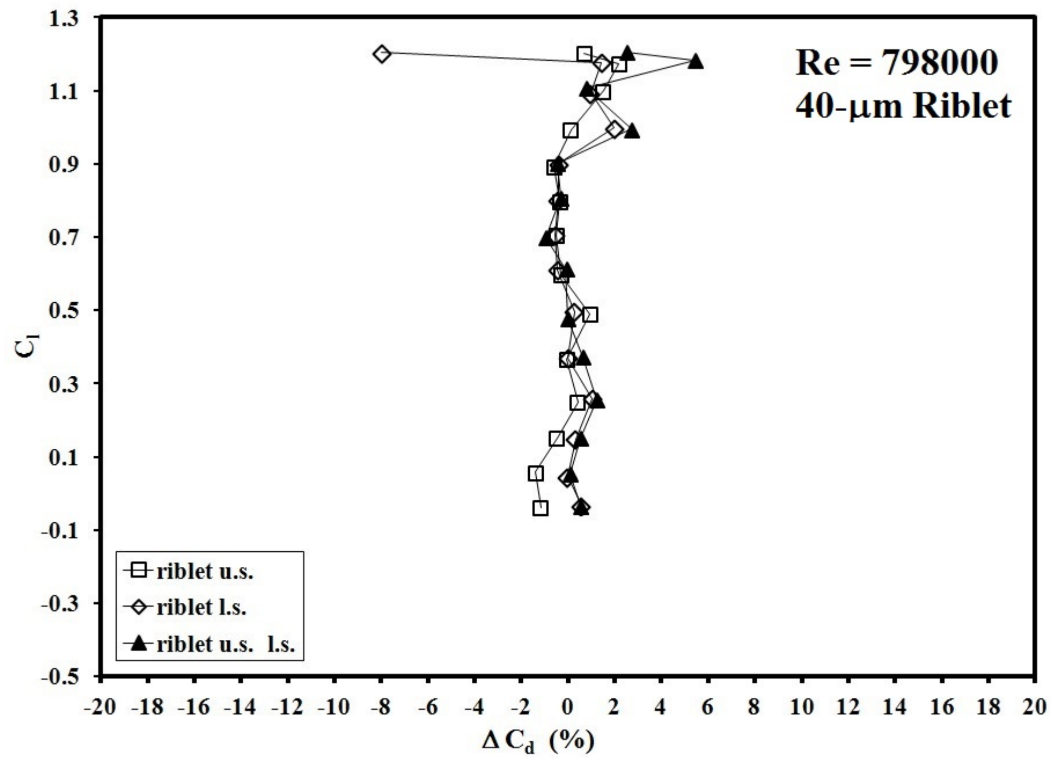


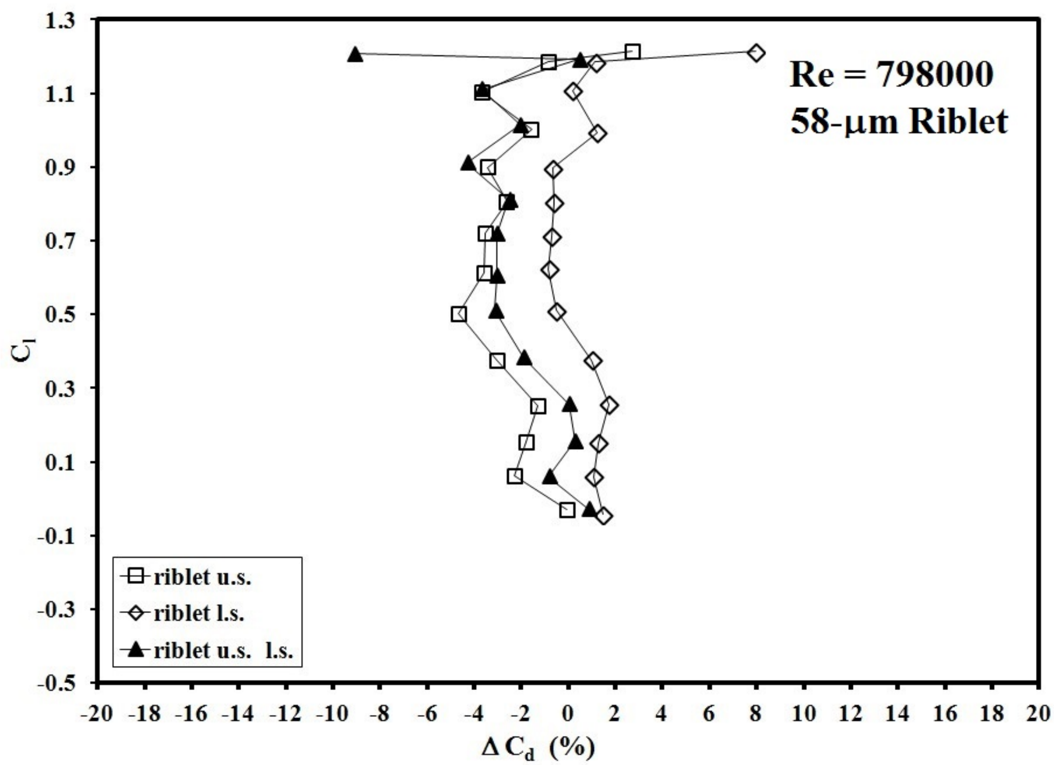
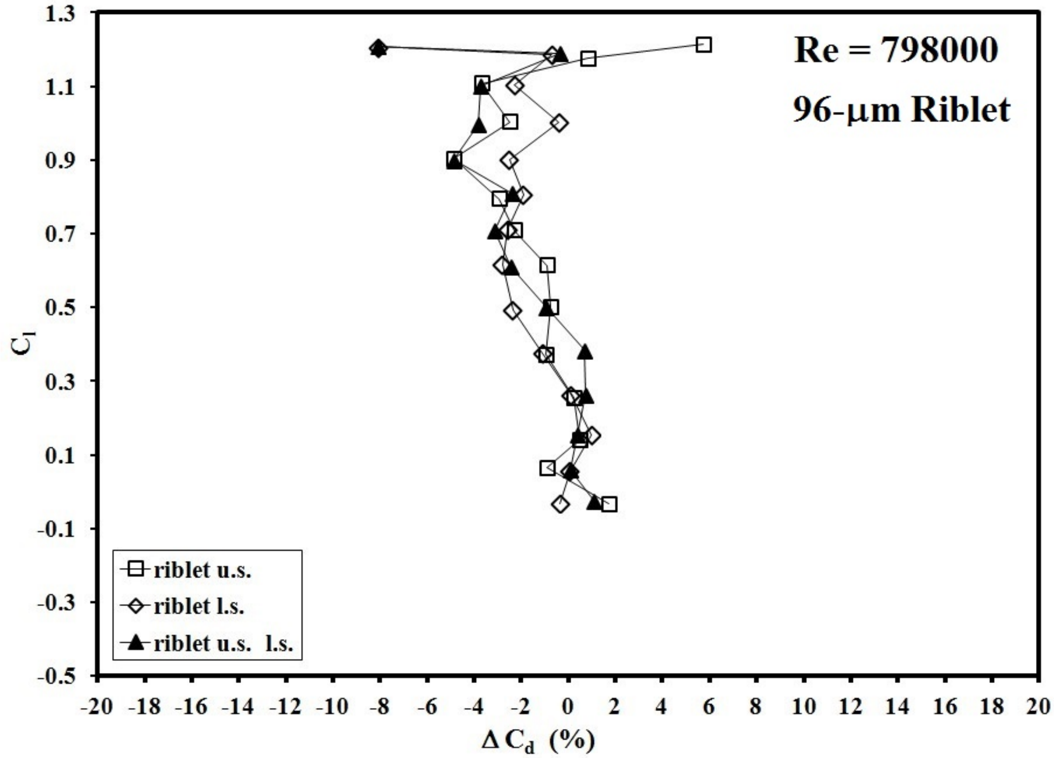
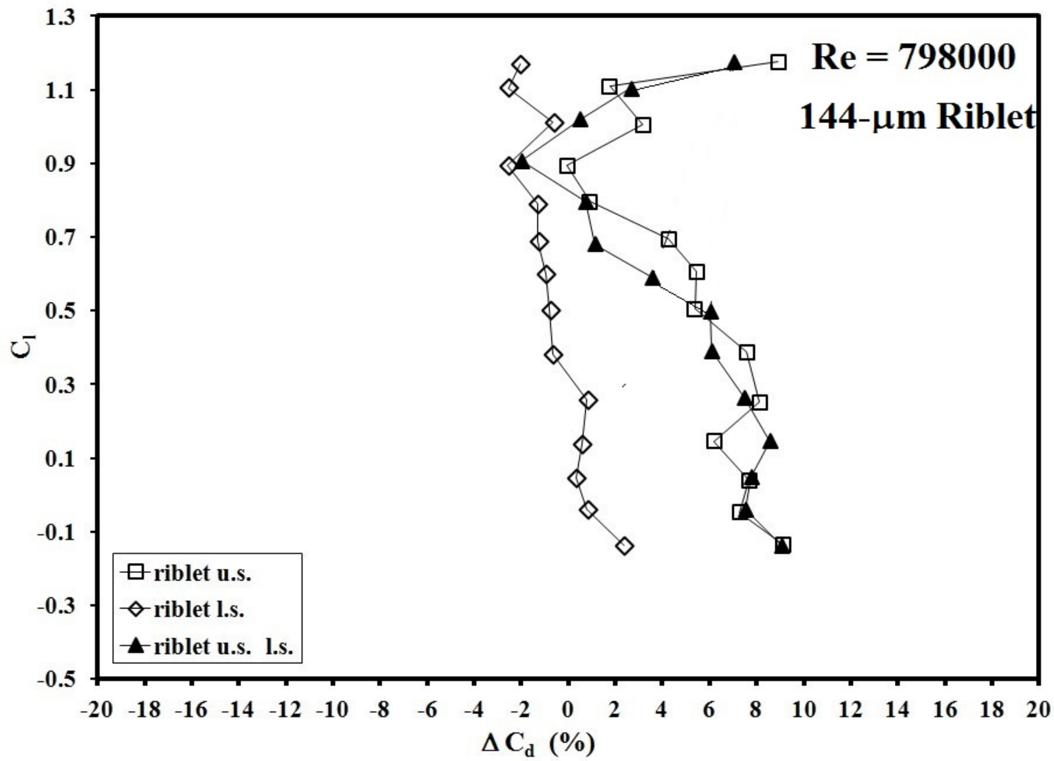


Figure 5 the percentage of the drag variation on the airfoil with the four types of riblet films and with the three coverage patterns at Reynolds number equals 798000.





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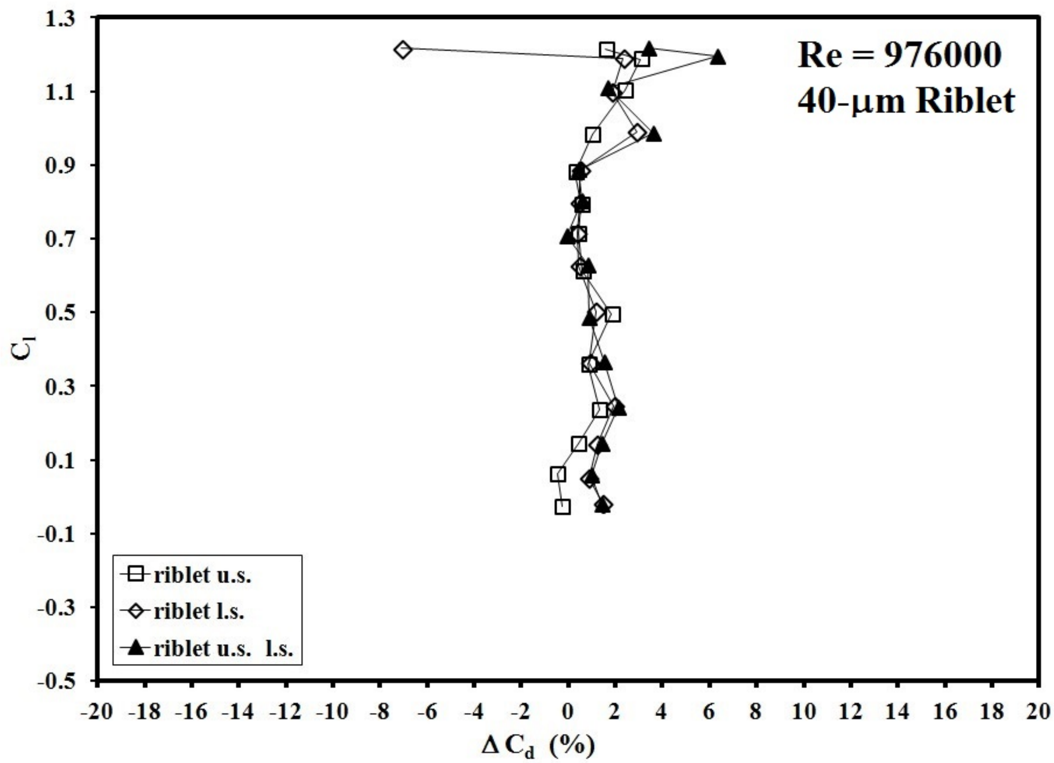


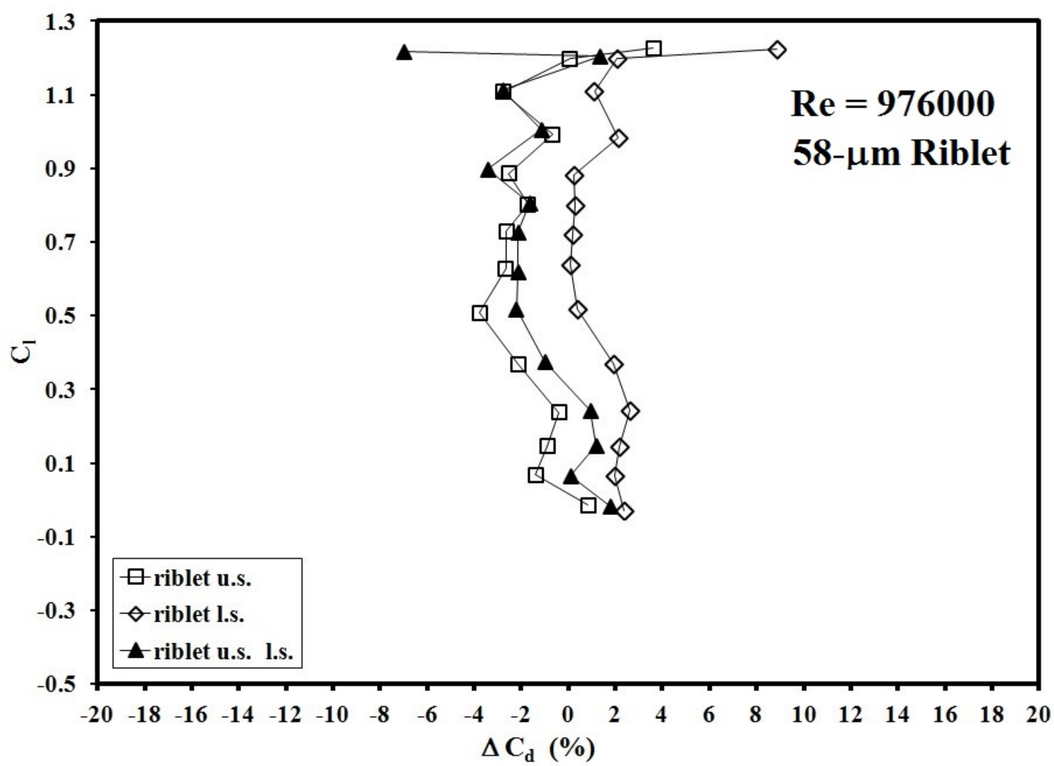
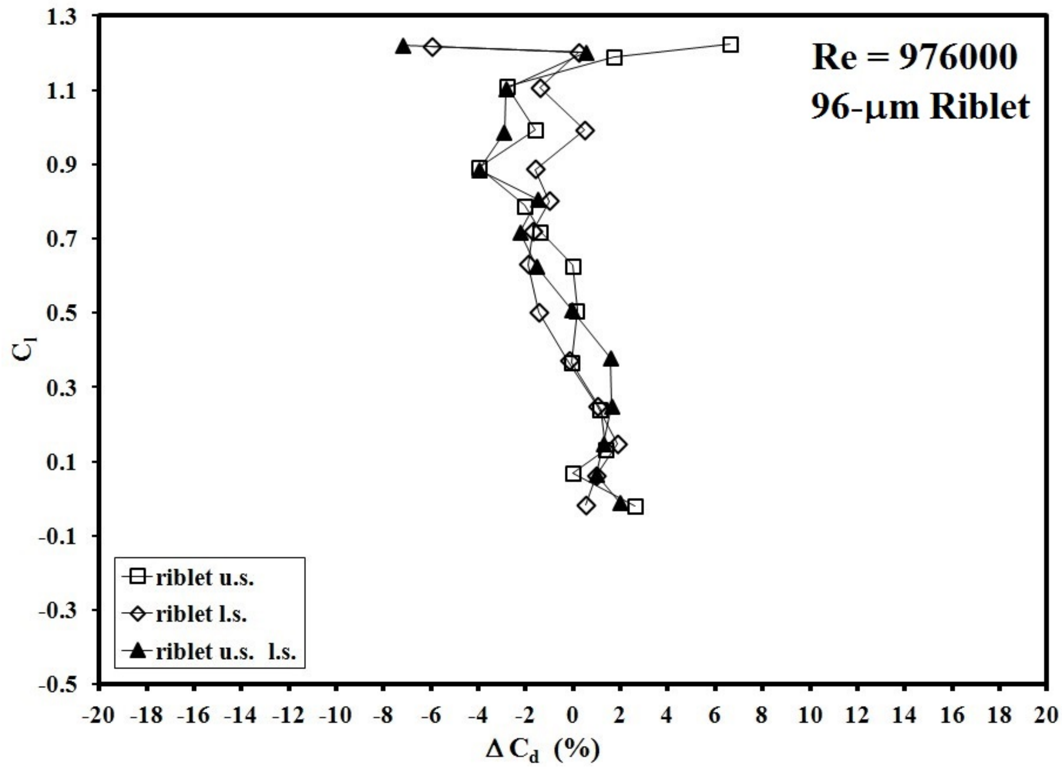


Figure 6 the percentage of the drag variation on the airfoil with the four types of riblet films and with the three coverage patterns at Reynolds number equals 976000.



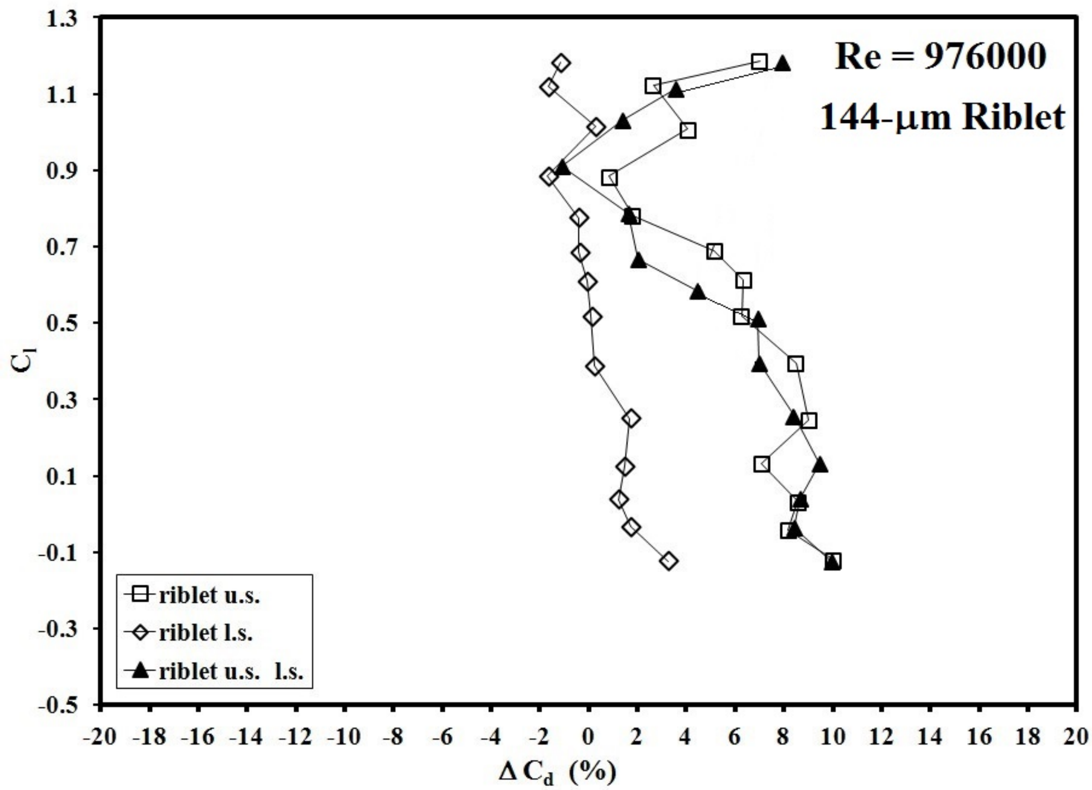


Figure 6 continue.

IV. CONCLUSIONS

An airfoil is installed and tested in the real operating conditions at the shore, where high-speed winds are observed during the whole year. Four sizes of riblet films that covered the airfoil surface according to three patterns were tested at three Reynolds numbers on the DU 96-W-180 airfoil. The results showed that the drag reduction due to riblets depends on the size and location of the riblet film, angle of attack, and Reynolds number. For the airfoil and configurations tested, the optimal riblet size was found to be 58-μm. When applying this optimal riblet in the turbulent

region, it produced a maximum drag reduction of about 6%. For the highest value of attack angle, riblets whose sizes are; 58, 96, and 144, respectively, exhibited sudden decreases that ranged between 7% and10%, but the performances in these conditions were unstable. The drag reduction by using riblets is case-dependent and hence, the optimal riblet size and corresponding drag reduction might differ for other airfoils. It is possible to select a riblet size that performs well over a range of Reynolds numbers and angles of attack.

REFERENCES

[1]. Thomas ASW.Aircraft drag reduction technology—a summary.Aircraft drag prediction and reduction. AGARD-R-723, 1985, Paper No.1.
[2]. Bushnell DB.Turbulent drag reduction for external flows. Aircraft drag prediction and reduction.AGARD-R-723,1985, Paper No.5.
[3]. Hirschel EH, Thiede P, Monnoyer F.Turbulence management—application aspects. Fluid dynamics of three-dimensional turbulent shear flows and transition. AGARD-CP-438, Paper No.23, 1988.
[4]. Bushnell DB.Supersonic aircraft drag reduction.AIAA Paper 90-1596, 1990.
[5]. Bushnell DB.Aircraft drag reduction.Special course on skin friction drag reduction.AGARD-R-786, 1992, Paper No.3.
[6]. Bushnell DB.Viscous drag reduction in aeronautics. Proceedings of the 19th Congress International Council Aeronautical Science.Paper 94-0.1, Anaheim, CA, 1994.
[7]. Robert JP.Drag reduction: an industrial challenge.Special Course on Skin Friction Drag Reduction.AGARD-R786, 1992, Paper No.2.
[8]. Walsh MJ.Riblets.In: Bushnell DB, Hefner JN, editors. Progress in astronautics and aeronautics.Washington, DC: AIAA, 1990, p.203–61.
[9]. Coustols E, Savill AM.Turbulent skin-friction drag reduction by active and passive means.Special course on skin friction drag reduction.AGARD-R-786, 1992.Paper No.8.
[10]. Coustols E.Riblets: main known and unknown features. In: Choi KS, Prasad KK, Truong TV, editors.Emerging techniques in drag reduction.Mechanical Engineering Publications, UK, 1996.p.3–43.
[11]. Coustols E, Schmitt V.Synthesis of experimental riblet studies in transonic conditions.In: Coustols E, editor. Turbulence control by passive means.Netherlands: Kluver Academic, 1990.p.123–40.
[12]. McLean JD, George-Falvy DN, Sullivan PP.Flight-test of turbulent skin friction reduction by riblets.Proceedings of International Conference on Turbulent Drag Reduction by Passive Means, Section 16.London: Royal Aeronautical Society, 1987.p.1–17.
[13]. Walsh MJ, Sellers WL.Riblet drag reduction at flight conditions. AIAA Paper 88-2554, 1988.
[14]. Szodruch J.Viscous drag reduction on transport aircraft. AIAA Paper 91-0685, 1991.
[15]. Walsh MJ, Lindemann AM.Optimization and application of riblets for turbulent drag reduction.AIAA Paper 840347, 1984.
[16]. Bruse M, Bechert DW, Th van der Hoeven JG, Hage W, Hoppe G.Experiments with conventional and with novel adjustable drag-reducing surfaces.In: So RMC, Speziale CG, Launder BE, editors.Near wall turbulent flows. Amsterdam: Elsevier Science Publishers, 1993.p.719–38.
[17]. Schwarz-van Manen AD, Thijssen JHH, Nieuwvett C, Prasad KK, Nieuwstadt FTM.The bursting process over drag-reducing grooved surfaces.In: Gyr A, editor. Proceedings of the IUTAM Symposium on Structure of Turbulence and Drag Reduction.Berlin: Springer, 1990. p.561–8. AIAA Paper 93-3256, 1993.
[18]. Pulvin Ph, Truong TV.Riblets in internal flows with adverse pressure gradients.In: Gyr A, editor.Proceedings of the IUTAM Symposium on Structure of Turbulence and Drag Reduction.Berlin: Springer, 1990.p.569–76.
[19]. Viswanath PR, Mukund R.Turbulent drag reduction using riblets on a supercritical airfoil at transonic speeds. AIAA J 1995;33(5):945–7.
[20]. Van Der Hoven JG, Bechert DW.Experiments with a 1:4.2 model of a commuter aircraft with riblets in a large wind tunnel.In: Choi KS, editor.Recent developments in turbulence management.Dordrecht, Netherlands: Kluwer Academic Publishers, 1991.p.3–24.
[21]. Sundaram S, Viswanath PR, Rudrakumar S.Studies on turbulent drag reduction on a NACA 0012 airfoil using riblets.National Aerospace Laboratories Report PD-EA9401, India, 1994.
[22]. Agrim Sareen, Robert W. Deters, Steven P. Henry, and Michael S. Selig, Drag Reduction Using Riblet Film Applied to Airfoils for Wind Turbines, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition 4 - 7 January 2011, Orlando, Florida