

Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Drag Reduction Due to Riblets on a GAW(2) Airfoil

N. Subaschandar,* Rajeev Kumar,* and S. Sundaram*
National Aerospace Laboratories,
Bangalore 560 017, India

Nomenclature

C_{DT}	= total drag coefficient = drag force/ $q_\infty * c$
C_p	= pressure coefficient
c	= airfoil chord
h	= riblet height
h^+	= $(hu_\tau)/\nu$
p	= static pressure
p_∞	= freestream static pressure
q_∞	= freestream dynamic pressure
u_τ	= friction velocity
x	= distance along the airfoil chord
y	= distance normal to tunnel axis
α	= angle of attack
β	= Clauser pressure-gradient parameter = $(\delta^*/\tau_w)(dp/dx)$
$\Delta C_{DT}/C_{DT}$	= $(C_{DTrib} - C_{DTsmooth})/C_{DTsmooth}$
δ^*	= boundary-layer displacement thickness
ν	= kinematic viscosity
τ_w	= wall shear stress

Introduction

THE study of turbulent drag reduction by use of riblets has been an area of significant research during the past decade.^{1,2} Riblets with symmetric V grooves with adhesive-backed film manufactured by the 3M Company (U.S.) have been widely used in earlier studies. The effectiveness of riblets in reducing the drag of a simple two-dimensional configuration is fairly well established now.² Although there has been some effort³⁻⁵ to assess the effectiveness of riblets on airfoils, the results reported by Sundaram et al.³ on a NACA 0012 airfoil at low speeds have been particularly noteworthy. Their studies³ showed that both total and viscous drag reduction increased monotonically with an angle of attack up to 6 deg; it was also shown³ that the higher drag reduction resulted primarily from the airfoil upper (or suction) surface, suggesting increased effectiveness of riblets in adverse pressure gradients. In a subsequent study by Subaschandar et al.,⁶ who extending the work of Sundaram et al.³ to higher angles of attack (by using the same NACA 0012 model and the same wind tunnel), it was observed that the drag reduction decreased rapidly beyond $\alpha = 6$ deg with virtually no drag reduction at $\alpha = 12$ deg.

The present study is an attempt to assess the total drag reduction that is due to riblets on a cambered airfoil up to high angles of attack at low speeds. The 13% thickness General Aviation Wing [GAW(2)]

airfoil section was chosen because of its strong relevance in many applications. Furthermore, it was expected that the results would provide a basis for comparing riblet effectiveness on an infinite swept wing with the GAW(2) profile currently in progress at our laboratory.

Experiments

Facility and Model

The experiments were conducted in the 300×1500 mm boundary-layer wind tunnel as in the previous study.³ The airfoil model, having a chord of 600 mm and a span of 300 mm, was mounted vertically in the test section. Since the major interest in this study was to assess the total drag reduction with α , the model was not instrumented with static pressure ports.

Measurements

The tests were carried out at a freestream velocity of 30 m/s, providing a chord Reynolds number of 1×10^6 . The boundary layer developing on the top and the bottom surfaces were tripped at 10% chord from the leading edge by a sandpaper strip (24 grade and 30 mm wide). The riblet film manufactured by 3M was applied between $0.12c$ and $0.96c$ on both the surfaces, providing a riblet length of 510 mm. Total drag was determined from pitot-static measurements in the wake by use of the method of Jones as described by Schlichting.⁷ The reference configuration for determining drag reduction was the smooth airfoil with the same transition trip, but without the smooth vinyl sheet (0.1 mm thick), which is often used to account for the riblet backing sheet.

Selection of Riblets

In the present study, the measurements have been made with riblet sheets with $h = 0.076$ mm. Figure 1 shows the streamwise variation

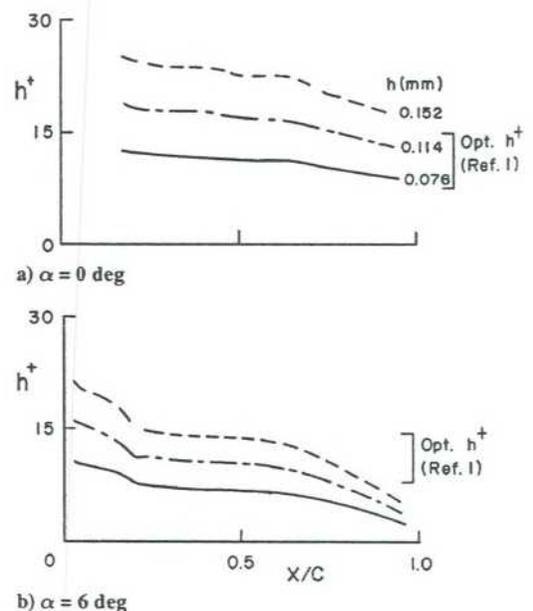


Fig. 1 Variations of h^+ on airfoil upper surface.

Received 2 July 1997; revision received 2 March 1999; accepted for publication 4 March 1999. Copyright © 1999 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

*Scientist, Experimental Aerodynamics Division.

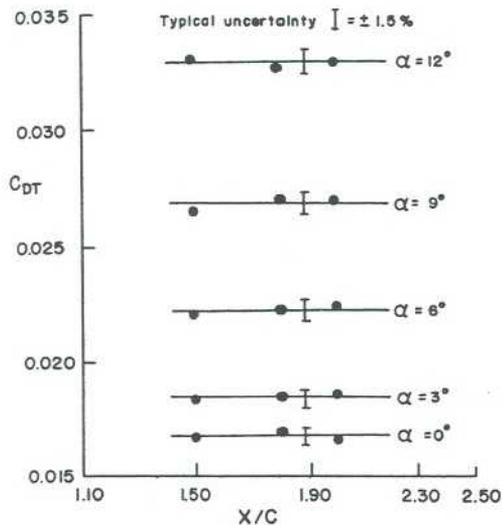


Fig. 2 Streamwise variation of total drag coefficient.

of h^+ for the airfoil upper surface for three values of h : 0.152, 0.114, and 0.076 mm. Information of wall skin friction required for estimating h^+ was obtained by use of a lag-entrainment integral boundary-layer code³ with C_x distributions obtained with an airfoil potential flow code.¹⁰ As may be seen in Fig. 1a, a riblet with $h = 0.076$ mm is a very good choice for the airfoil upper surface at $\alpha = 0$ deg; optimizing h^* for the upper surface is important as it contributes more to the viscous drag reduction than the airfoil lower (or windward) surface.³ At $\alpha = 6$ deg, the h^+ variation is still in the drag reduction regime (Fig. 1b). The lower surface h^+ varied between 9 and 5 (not shown in Fig. 1), which is also in the drag reduction regime.¹ Furthermore, the same riblet geometry with $h = 0.076$ mm is being currently used in the swept wing experiment with GAW(2) section at the National Aerospace Laboratories, India.

Accuracy of the Measured Data

Uncertainty in the measured drag, estimated with the methodology of Kline and McClintock¹¹ and with repeatability taken into account, is as follows:

$$\Delta C_{DT} = \pm 0.015 C_{DT} (20-1)$$

Two-Dimensionality

Two dimensionality of the mean flow in the experiments was assessed with the well-known two-dimensional momentum integral technique in the wake. Pitot profiles in the wake were measured at three streamwise locations ($x/c = 1.5, 1.8, 2.0$). Figure 2 shows the variations of the measured total drag coefficient (C_{DT}) plotted against the streamwise distance in the wake. It may be observed that, in the entire range of α tested, the variations of the measured total drag are within $\pm 1.5\%$, which is also the estimated uncertainty in C_{DT} . These results suggest good mean-flow two dimensionality over the entire range of α investigated.

Results and Discussion

Results of percentage total drag reduction $\Delta C_{DT}/C_{DT}$ with airfoil incidence are shown in Fig. 3; also shown in the figure is the variation of the Clauser pressure-gradient parameter (β) with α . At each α , β is estimated midway in the adverse pressure-gradient zone on the upper surface of the airfoil ($0.5 < x/c < 1.0$); surface pressure distributions obtained from the potential flow code^{9,10} are utilized for the calculation of the average pressure gradient and for the estimation of δ^* and τ_w by use of the turbulent boundary-layer code.⁸ The results show increased total drag reduction with α up to 6 deg, beyond which there is a rapid decrease in drag reduction with virtually no drag reduction at $\alpha = 12$ deg. These results bear a strong similarity to those obtained by Sundaram et al.³ on a NACA 0012 airfoil model under very similar test conditions, which are also

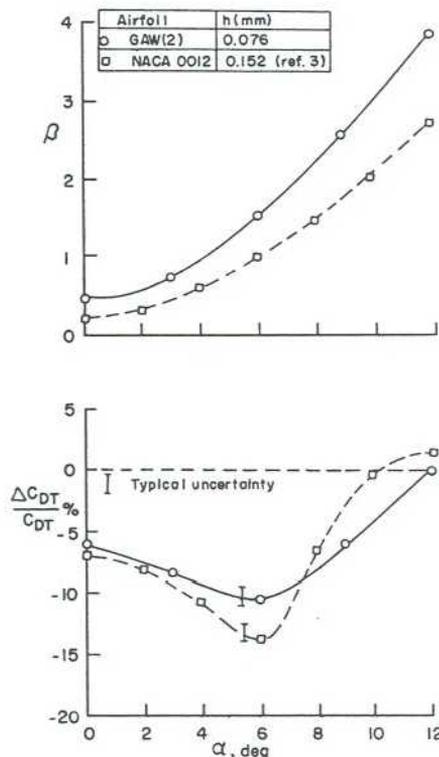


Fig. 3 Drag reduction by use of riblets on a GANV(2) airfoil.

shown in Fig. 3. It is interesting to note that the drag reduction is maximum at $\alpha = 6$ deg, although the riblet height ($h = 0.076$ mm) chosen is not the optimum at $\alpha = 6$ deg (Fig. 1); these results, once again, indicate increased effectiveness of riblets in adverse pressure gradients as long as the riblet chosen is in the drag reduction regime.

Conclusions

The results show conclusively, once again, that drag reduction due to riblets increases initially with incidence even on a cambered airfoil; the total drag reduction is as high as 10% at $\alpha = 6$ deg, implying an even larger viscous drag reduction. This trend is qualitatively similar to the results obtained on a NACA 0012 airfoil model under very similar test conditions.³ These results, once again, demonstrate the increased effectiveness of riblets in adverse pressure gradients up to a certain value of α , beyond which the effectiveness is reduced, presumably because of the strong deceleration of the boundary layer, which leads to separation on the airfoil upper surface. It would be very useful to examine the validity of the above conclusions at much higher Reynolds numbers in future studies.

Acknowledgments

The authors acknowledge many useful discussions with P. R. Viswanath. The authors thank Rajeshwari Ramamurthy for providing results by using potential flow code. The authors thank Khem Singh and C. Jayapal for their help during experiments.

References

- Walsh, M. J., "Riblets," *Viscous Drag Reduction in Boundary Layers*, edited by D. M. Bushnell and G. Hefner. Vol. 123, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1990, pp. 203-261.
- Coustols, E., and Savill, A. M., "Turbulent Skin Friction Drag Reduction by Active and Passive Means," *Special Course on Skin Friction Drag Reduction*, edited by E. Cousteix, AGARD-786 FDP/VKI, 1992.
- Sundaram, S., Viswanath, P. R., and Rudra Kumar, S., "Studies of Turbulent Drag Reduction Using Riblets on a NACA 0012 Airfoil," *AIAA Journal*, Vol. 34, No. 4, 1994, pp. 676-682.
- Viswanath, P. R., and Mukund, R., "Turbulent Drag Reduction Using Riblets on a Supercritical Airfoil at Transonic Speeds," *AIAA Journal*, Vol. 33, No. 5, 1995, pp. 945-947.

⁵Coustols, E., "Control of Turbulence by Internal and External Manipulators," *Proceedings of the 4th International Conference on Drag Reduction*, edited by A. M. Savil, Vol. 46, No. 3, Applied Scientific Research, Kluwer Academic, Norwell, MA, 1989, pp. 183-196.

⁶Subaschandar, N., Rajeev Kumar, and Sundaram, S., "Drag Reduction Due to Riblets on NACA 0012 Airfoil at Higher Angles of Attack," National Aerospace Laboratories, Rept. PD EA-9504, Bangalore, India, 1995.

⁷Schlichting, H., *Boundary Layer Theory*, 7th ed., McGraw-Hill, New York, 1979, p. 711.

⁸Desai, S. S., and Kiske, S., "A Computer Program to Calculate Turbulent Boundary Layer and Wake in Compressible Flow with Arbitrary Pressure Gradient Based on Green's Lag-Entrainment Method," Rhur Univ., Bericht No. 89/1982, Bochum, Germany, 1982.

⁹Dutt, H. N. V., "Analysis of 2-D Multicomponent Airfoils in Viscous Flows," National Aerospace Laboratories, Rept. TM AE-8701, Bangalore, India, 1987.

¹⁰Dutt, H. N. V., "Analysis of Multielement Airfoils by a Vortex-Panel Method," *AIAA Journal*, Vol. 7, No. 5, 1989, pp. 658-660.

¹¹Kline, S. J., and McClintock, F. A., "Describing Uncertainties in Single Sample Experiments," *Mechanical Engineering*, Vol. 75, No. 1, 1953, pp. 3-8.
