Riblets as a Viscous Drag Reduction Technique

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Abstract

THE viscous drag of turbulent boundary layers is a significant factor contributing to the fuel costs of the airlines. Several studies have indicated that microsurface geometry variations which change the near-wall structure of the flow have been effective in reducing drag. Summarized here is an investigation into the verification and extension of the most promising of these riblet variations.

Contents

Shortages and rising costs of energy have re-emphasized research directed toward the viscous drag reduction of turbulent boundary layers. Even viscous drag reductions as small as 10% on the fuselage alone are significant when it is realized that these small reductions translate into a $350 million per year fuel savings for the airlines. Walsh and Weinstein[1] and Walsh[2] have examined a viscous drag reduction technique that uses microsurface geometry variations to change the near-wall structure of the turbulent boundary layer. The microsurface geometries were aligned with the flow and included rectangular, V-groove, razor blade, semicircular groove, and alternating transverse curvature. References 1 and 2 indicate that V-groove surface geometries gave net drag reductions when the riblet dimensions were on the order of the typical turbulent wall streaks.

The purpose of the present investigations was to 1) improve the accuracy and verify earlier drag reduction measurements, 2) extend the available data base for V-groove geometries to smaller heights and spacings, 3) determine effect of freestream sweep angle upon riblet drag reduction performance, 4) examine the effect of riblet cross-sectional geometry to optimize net drag reductions, and 5) document turbulence characteristics of a riblet surface which gave a net drag reduction. Details of the investigation are given in Ref. 3.

The drag reduction performance of V-groove riblets is a function of the groove height h^+ and spacing, s^+ in law of the wall coordinates where h^+ and s^+ are defined as

$$h^+ = \sqrt{C_f/2}\,(hu_\infty/\nu) \tag{1}$$

$$s^+ = \sqrt{C_f/2}\,(su_\infty/\nu) \tag{2}$$

where ν, u_∞, and C_f are the kinematic viscosity, freestream velocity, and skin friction, respectively. The variation of drag reduction performance with h^+ and s^+ is shown in Fig. 1. Each line represents the h^+ and s^+ variation for a particular V-groove model, where the variation was obtained by changing the freestream velocity. The tic marks on each line are the ratio of the riblet drag to that of a flat-plate reference. Several of the models (9 and 38, 33 and 13R, and 34 and 29) have overlapping h^+ and s^+ regions, although the models have physically different dimensions. The data show that the drag reduction performance of a riblet is determined by h^+ and s^+. Figure 1 shows that drag reduction occurred whenever $s^+ < 30$ and $h^+ < 25$. A maximum drag reduction of 8% occurred at approximately $h^+ = 10$ and $s^+ = 15$. As h^+ and s^+ were further reduced, the drag reduction approached zero.

In attempts to improve the riblet drag reduction performance, three rib geometries were tested: peak curvature, valley curvature, and a notched peak V-groove. The notched peak riblet had a smaller V-groove superimposed on the peak of a larger V-groove. Figures 2-4 present data for the effect of peak curvature, valley curvature, and the notched-peak riblets, respectively. Each figure also contains data for a V-groove model having the same height and spacing, model 29. The data indicate that peak curvature decreased and valley curvature increased the riblet drag reduction performance. The data in Fig. 4 show that notching the peak of a V-groove riblet did not increase the magnitude of the drag reduction, but that it did extend the drag reduction to higher h^+ and s^+. In terms of operational capability, increasing the h^+ and s^+ range is equivalent to increasing the velocity range over which drag reduction is obtained.

In summary, the data presented in Figs. 1-4 indicate a maximum drag reduction of 8% for a V-groove geometry with valley curvature (model 51) and a sharp peak and sharp valley geometry (model 13). This maximum drag reduction occurred for $h^+ = 8\text{-}12$ and $s^+ = 15\text{-}20$. In addition all models that gave drag reduction had spacings $s^+ < 30$. These experimental data are consistent with the bursting process observed by Kim, Kline, and Reynolds.[4] Kim et al.[4] found that the near-wall flow consisted of low- and high-speed regions or streaks. The low-speed streaks had transverse extents, $z^+ \approx 30$, and spacing between the streaks, $\lambda^+ \approx 100$. Kim et al. further observed that the bursting process consisted of three stages: 1) low-speed streak lift-off in the range $0 < y^+ < 10$; 2) streak oscillation and growth in the range $8 < y^+ < 12$; and 3) streak eruption in the range $10 < y^+ < 30$. A comparison of the heights and spacings of the present riblets with these burst dimensions leads to the speculation that the riblet geometries are sized to constrain the oscillations and growth of the low-speed streaks. The probable result of these mechanisms is a dampening of the streak eruption. This is also indicated in the turbulence data presented in Ref. 3 which showed that there are just as many eruptions over a drag reduction riblet surface but that the intensities are

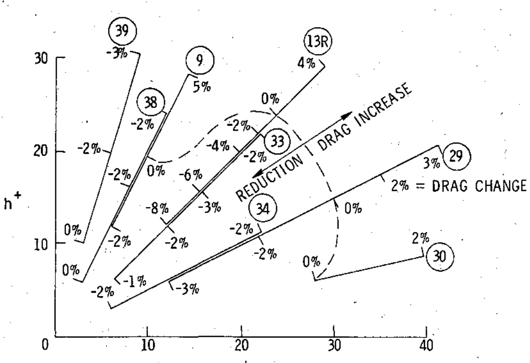

Fig. 1 Drag reduction region of h^+-s^+ for symmetric V-groove riblets.

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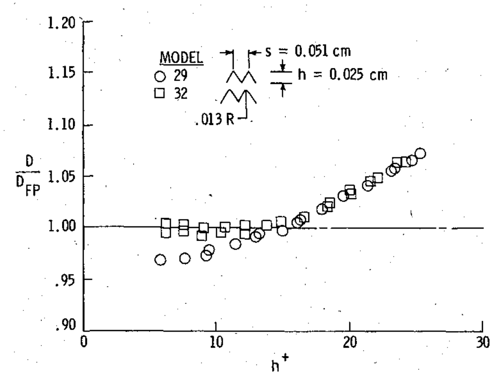

Fig. 2 Effect of peak curvature.

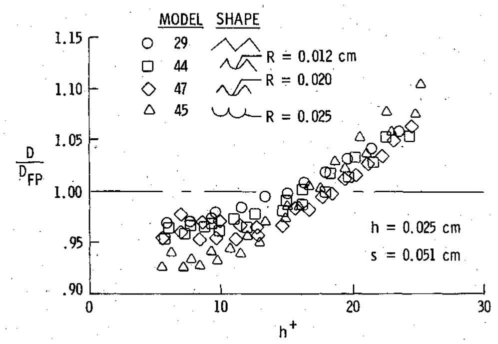

Fig. 3 Effect of valley curvature.

decreased. The significant improvement of riblets having valley curvature also supports the idea of the riblets constraining the low-speed streaks. Reference 4 found that the streaks are vortical having diameters $10 < z^+ < 30$. The shape of the valley curvature riblet would be expected to better capture and constrain a vortex.

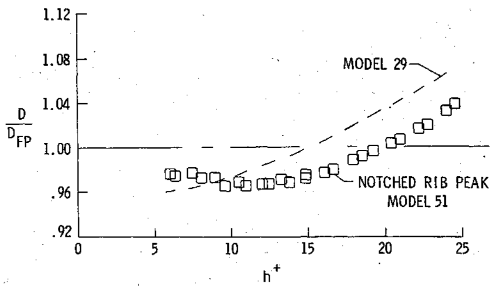

Fig. 4 Modified symmetric grooved geometries.

The h^+ and s^+ scaling applied to CTOL aircraft indicates physical riblet dimensions somewhat smaller than the present models. Although riblets on a near-transonic aircraft would operate at a higher velocity than the present tests, the reduction in density due to cruise altitude mitigates somewhat the physical size reduction required by velocity scaling in Eqs. (1) and (2). At a cruise altitude of 12.2 km, a Mach number of 0.8, and a Reynolds number $R_x = 10^6$, $h^+ = 12$ corresponds to a riblet height of 0.076 mm.

References

[1] Walsh, M.J. and Weinstein, L.M., "Drag and Heat Transfer on Surfaces With Small Longitudinal Fins," AIAA Paper 78-1161, July 1978.

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[4] Kim, H.T., Kline, S.J., and Reynolds, W.C., "The Production of Turbulence Near a Smooth Wall in a Turbulent Boundary Layer," *Journal of Fluid Mechanics,* Vol. 50, Pt. 1, 1971, pp. 133-160.