Effect of Detailed Surface Geometry on Riblet Drag Reduction Performance

Michael J. Walsh*
NASA Langley Research Center
Hampton, Virginia 23665-5225

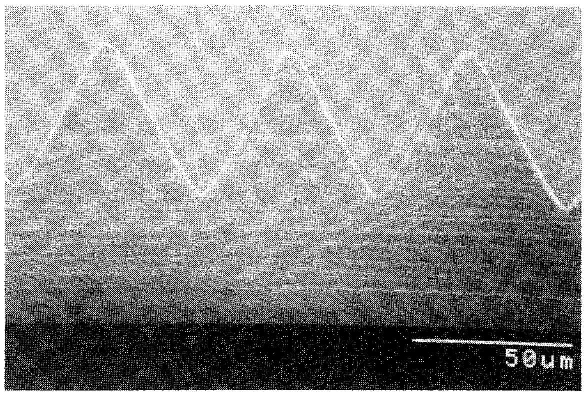
Introduction

SMALL *v* grooves ("riblets") that are aligned with the local flow velocity have been found to reduce the local skin friction of a turbulent boundary layer on the order of 6%.[1-7] Reference 7 is an in-depth review of worldwide riblet research by the present author. The riblet skin-friction reductions have been verified in numerous ground-test facilities as well as in flight tests.[8,9] The 6% skin-friction reduction of riblets can translate into important net drag reductions and fuel savings for aircraft when it is realized that the skin-friction drag represents approximately 50% of the overall drag of a commercial transport aircraft. The research study of riblets, which developed from basic research studies initiated at NASA Langley in the late 1970s, has reached maturity and may soon see application on commercial transport aircraft. The depth of the grooves for the flight conditions encountered by a commercial transport aircraft is expected to be on the order of 0.002–0.004 in. Because of the small physical size of the *v* grooves and manufacturing cost considerations, it is important to establish the allowable tolerances for the *v*-groove geometry that will still maintain maximum drag reduction performance. Manufacturing costs of riblet surfaces will be dependent on the variations in the basic riblet geometry (i.e., peak and valley curvature) that can be allowed while still maintaining maximum drag reduction performance.

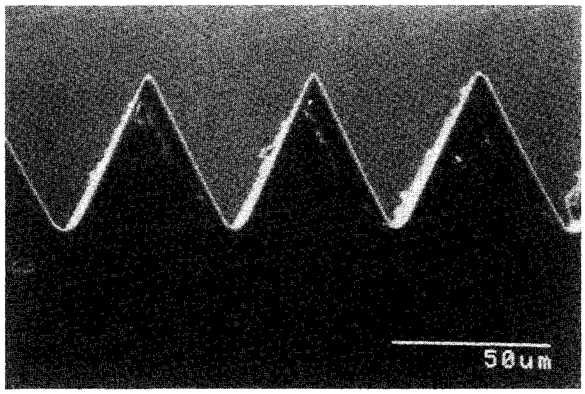
Reference 2 has examined the effect of peak and valley curvature for riblets with *v*-groove depths on the order of 0.020 in. and found that the amount of drag reduction was approximately the same as that for a riblet with sharp peaks and valleys. As stated earlier, the groove sizes for commercial transport aircraft are an order of magnitude smaller than the riblets tested in Ref. 2. The question arises whether or not small changes in the riblet geometry at the peaks and valleys could be important for the smaller riblets associated with flight conditions. The purpose of the present paper is to compare the effect of small changes in *v*-groove geometry for several riblet films that had nominal *v*-groove dimensions on the order of 0.002 in.

Facilities, Instrumentation, and Test Surfaces

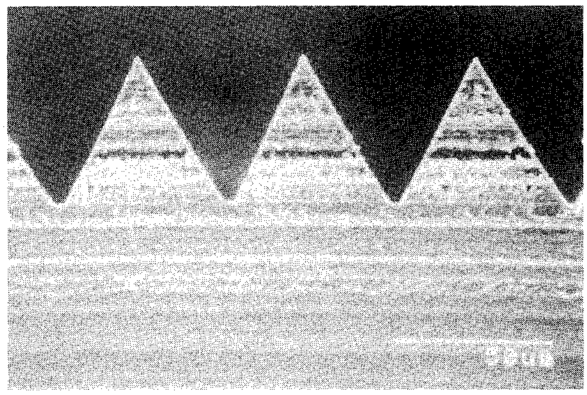
The tests were conducted in a water towing tank facility at NASA Langley Research Center. The towing tank is 20 ft wide, 12 ft deep, and 3000 ft long. Test models, mounted on a free-floating drag balance, were sting-supported from an electrically driven carriage. The test carriage, which can be operated at speeds of 5–50 ft/s, rests on parallel I beams that run the length of the towing tank. The drag balance, used for the present tests, measured the total drag along the axis of the model, consisting of wave drag and skin-friction drag. Large increases in the wave drag component for test speeds less than



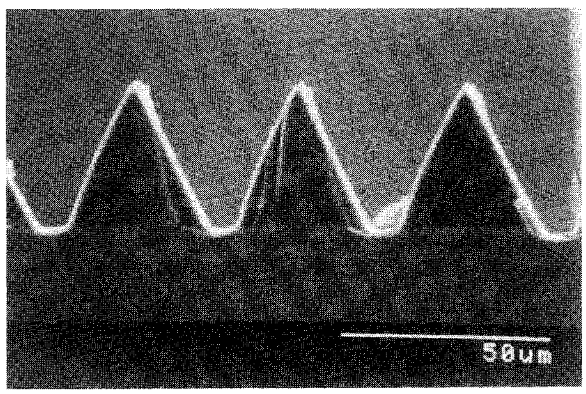
a) Model A (h = 0.00179, s = 0.00224).



b) Model B (h = 0.00190, s = 0.00209).



c) Model C (h = 0.00184, s = 0.00211).



d) Model D (h = 0.00140, s = 0.00161).

Fig. 1 Microphotographs of riblet geometries tested (all dimensions in inches).

Received Dec. 8, 1989.

*Senior Research Scientist.

20 ft/s resulted in poor resolution of the skin-friction component of the drag. The final data analysis was, therefore, restricted to test speeds greater than 22 ft/s. The data indicated that the drag measurements were repeatable within ± 3/4% for test speeds greater than 22 ft/s.

The model used for the present tests was a torpedo-shaped body with a length of 12 ft and a maximum diameter of 21 in. The model was designed for a near zero pressure gradient for the region 1–12 ft downstream of the nose and was closed by a slender tailcone. A trip wire was placed 1 ft from the nose to insure a turbulent boundary layer for the present tests. The corresponding unit Reynolds number for test speeds of 22–50 ft/s were 1.7 to 3.8×10^6 per ft.

The riblet test surfaces were vinyl sheets with adhesive backing. Microphotographs of cross sections of the various films tested are shown in Fig. 1. The individual riblet sheets were overlapped, cut, and butted together as required to completely cover the tapered body from the trip wire back to the tailcone. The width and length of the individual panels was decreased towards the nose of the test body as required for ease of film application as well as to keep the grooves aligned with the estimated local flow direction. After application, the film was allowed to dry overnight under heaters to decrease the curing time of the adhesive. The test body with the film was in the water only during the test period. For extended periods between test runs (for example, overnight) the model was placed in a dry dock.

Results and Discussion

Figures 1a–c show microphotographs of cross sections of three riblet films having nominal dimensions of height (h) and spacing (s) equal to 0.002 in. The cross section shown in Fig. 1d is for a nominal 0.0013 in. riblet film. The height and spacing dimensions measured from the microphotographs are given in Fig. 1. The major difference in the three nominal 0.002 films (models A, B, and C) was the various degrees of curvature at the riblet peaks. The nominal 0.0013 film (model D), shown in Fig. 1, has been tested in several ground facilities (see Refs. 4, 5, 10) and in two flight tests (see Refs. 8–9). Test results have shown that the 0.0013 film can be expected to give approximately 6% drag reduction.

Figure 2 shows drag reduction performance for 0.0013 and 0.003 film. The 0.003 film has also been widely tested in ground facilities and at flight conditions.[4,5,8–10] The ± 3/4% data band shown in Fig. 2 fits the experimental data well. The vertical axis for Fig. 2 is the percent difference in the total body drag (C_D). It is estimated that for the tested body, the skin-friction drag is approximately 60% of the net drag, in which case the drag changes in Fig. 2 would represent a 6% reduction in skin-friction drag. These are the drag reduction levels found previously in other ground and flight tests.

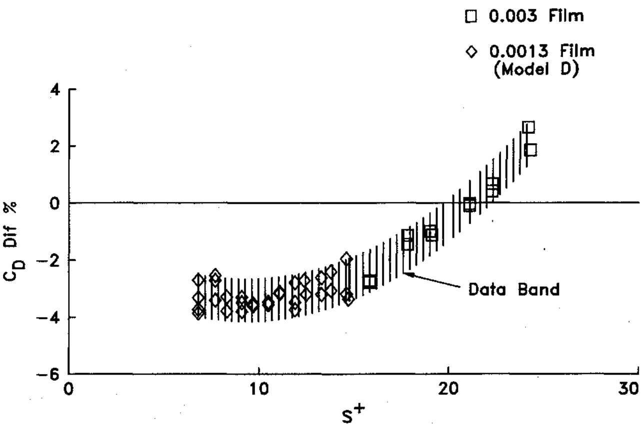


Fig. 2 Drag reduction performance of two riblet films previously tested.

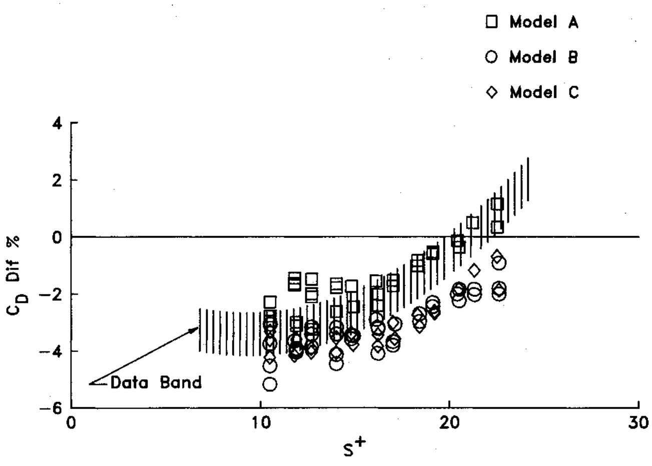


Fig. 3 Effect of geometric detail on riblet drag reduction performance.

Figure 3 shows data for the nominal 0.002 film along with the data band of Fig. 2. The data for model A indicate drag reductions 60% of those for models B and C. Apparently the peak curvature is important for the riblet dimensions tested in the present program. Figure 1 shows the differences in riblet geometry. The radius of curvature of models A and B are approximately 8 and 4% of the riblet height, respectively. Thus, a relatively small change in the peak curvature between model A and model B greatly influenced the drag reduction performance, whereas the data showed that changes in the sharpness of the valleys had an insignificant effect.

Conclusions

Riblet films having height and spacing dimensions on the order of those required for flight applications on commercial transport aircraft have been tested in a water towing tank facility. The results indicate that small deviations in the riblet peak geometry can reduce the riblet drag reduction performance by as much as 40%, whereas valley curvature was not critical to the riblet performance.

References

[1]Walsh, M. J., "Turbulent Boundary Layer Drag Reduction Using Riblets," AIAA Paper 82-0169, Jan. 1982.

[2]Walsh, M. J., and Lindemann, A. M., "Optimization and Application of Riblets for Turbulent Drag Reduction," AIAA Paper 84-0347, Jan. 1984.

[3]Bechert, D. W., Hoppe, G., and Reif, W.-E., "On the Drag Reduction of the Shark Skin," AIAA Paper 85-0546, March 1985.

[4]Reidy, L. W., and Anderson, G. W., "Drag Reduction for External and Internal Boundary Layers Using Riblets and Polymers," AIAA Paper 88-0138, Jan. 1988.

[5]Beauchamp, C. H., and Philips, R. B., "Riblet and Polymer Drag Reduction on an Axisymmetric Body," Symposium on Hydrodynamic Performance Enhancement for Marine Applications, Newport, RI, Oct.–Nov. 1988.

[6]Liu, K., Christodoulou, C., Riccius, O., and Joseph, D., "Drag Reduction in Pipes Lined with Riblets," *AIAA Journal* (to be published).

[7]Walsh, M. J., "Riblets" *AIAA Progress in Aeronautics and Astronautics*: *Viscous Drag Reduction in Boundary Layers,* edited by D. M. Bushnell and J. N. Hefner, Vol. 123, 1990, pp. 203–261.

[8]McLean, J. D., George-Falvy, D. N., and Sullivan, P. P., "Flight-Test of Turbulent Skin-Friction Reduction by Riblets. Presented at the Turbulent Drag Reduction by Passive Means Conference," London, Sept. 1987.

[9]Walsh, M. J., Sellers, W. L., III, and McGinley, C. B., "Riblet Drag Reduction at Flight Conditions," AIAA Paper 88-2554, June 1988.

[10]Coustols, E., "Behavior of Internal Manipulators: 'Riblet' Models in Subsonic and Transonic Flows," AIAA Paper 89-0963, March 1989.