Drag and Heat-Transfer Characteristics of Small Longitudinally Ribbed Surfaces

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Abstract

THE drag and heat-transfer characteristics of longitudinally ribbed surfaces have been examined for the case of a turbulent boundary layer. The purpose of the longitudinal fins is to confine the turbulent bursts to regions of small transverse extent, thus altering the local turbulence production. Rectangular, triangular, and razor blade rib geometries were examined. There was some indication that small drag reductions (< 4%) were obtained with two of the triangular grooved models, but further testing, consisting of detailed pitot and hot-wire surveys, is required for validation. The heat-transfer results indicated that several of the triangular grooved surfaces had heat-transfer increases 10% greater than the corresponding drag increases. These surfaces are unique in that heat-transfer augmentation results previously reported in the literature for airflows over external surfaces have always shown greater increases in drag than heat transfer.

Contents

The drag and heat-transfer measurements were made in the Langley 7×11 in. Low-Speed Research Facility which has a 91.4 cm long test section and a cross section 17.8 cm high and 27.4 cm wide. The freestream velocity was varied from 15 to 40 m/s for the present tests. At a freestream velocity of 23.2 m/s, the boundary-layer thickness was 1 cm at $x = 29.7$ cm and 1.63 cm at $x = 76.2$ cm, where $x = 0$ at the test section entrance.

Drag measurements were obtained using a free-floating balance with narrow gaps at the leading and trailing edges (≈ 0.076 cm). In addition, there was a gap (≈ 0.152 cm) along the junction of the test surface and the tunnel side walls. With careful alignment of the leading and trailing edges of the models, the drag measurements were repeatable within ±3%. The direct drag measurements for the reference flat plate were within 5% of the theoretical predictions using the following equation from Ref. 1 for the local skin friction C_f,

$$\tfrac{1}{2} C_f = 0.0296 (Re_x)^{-0.2} \qquad (1)$$

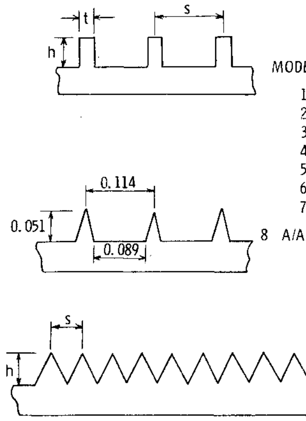
where the Reynolds number Re_x is based on the distance from the virtual origin.

Figure 1 shows the spacings and heights of the rectangular and triangular ribbed configurations investigated. The heights and spacings were selected to confine the turbulent wall bursts to regions of small transverse extent. It is generally believed that the birth region of the turbulent bursts is in the area of $y^+ = 30$ and that separation between bursts in the direction transverse to the mainstream is 100 in terms of law of the wall coordinates. In law of the wall coordinates, the rib height $h = 0.051$ cm corresponds to $y^+ = 25$ at 24 m/s and $y^+ = 50$ at 45 m/s. Therefore, the present rib dimensions are of the right order of magnitude to effect the turbulent bursts.

The drag data for the rectangular ribs indicated that there were no net drag reductions obtained; however, it was found that the drag increase was not as great as the area increase. Thus, local C_f reductions were probably obtained, but due to the wetted surface area increase, the overall drag was increased.

The drag of the triangular ribbed surfaces nondimensionalized by the flat plate drag is presented in Fig. 2 as a function of the freestream velocity u_∞. Figure 2 shows that for the same rib height h and spacing s, the triangular rib model 8 had a smaller drag increase than the rectangular model 2. It is also seen that the drag decreased when the spacing between the triangular ribs was reduced, resulting in a v-groove-type configuration. Figure 2 even indicates that v-groove models 13 and 9 had a 2% and 4% drag reduction, respectively, for $u_\infty = 20$ m/s. As was mentioned earlier, the repeatability of the present drag measurements was within ±3%. Therefore, the indicated drag reductions must be regarded with caution until additional drag measurements as well as pitot and hot-wire surveys are made. However, it is interesting to note that, in terms of the law of the wall coordinates, the height and spacing of the ribs for models 9 and 13 were approximately 25 and 15-20, respectively. It is quite reasonable that this range of height and spacing, which corresponds to the birth region of the turbulent bursts, would be effective in altering the production of turbulence.

Figure 2 shows that many of the triangular or v-groove-type models had relatively small drag increases considering the large wetted surface area increases (e.g., a factor of 6.17 for



RECTANGULAR RIBS

MODEL NO.	h (cm)	s (cm)	t (cm)	A/A_{FP}
1	0.013	0.101	0.025	1.25
2	0.051	0.114	0.025	1.89
3	0.051	0.231	0.025	1.44
4	0.005	0.051	0.013	1.73
5	0.005	0.219	0.013	1.05
6	0.051	0.063	0.025	2.6
7	0.051	0.343	0.025	1.35

8 $A/A_{FP} = 1.7$

TRIANGULAR RIBS

MODEL NO.	h (cm)	s (cm)	A/A_{FP}
9	0.051	0.025	4.2
10	0.025	0.013	4.2
11	0.102	0.051	4.2
12	0.084	0.025	6.17
13	0.051	0.051	2.24

Fig. 1 Rectangular and triangular ribbed surfaces tested.

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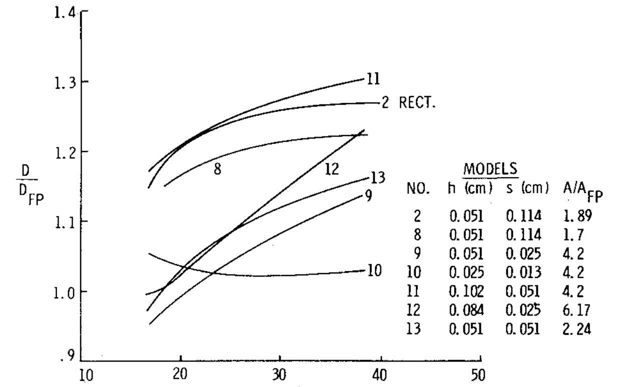

Fig. 2 Drag vs velocity for the triangular ribs.

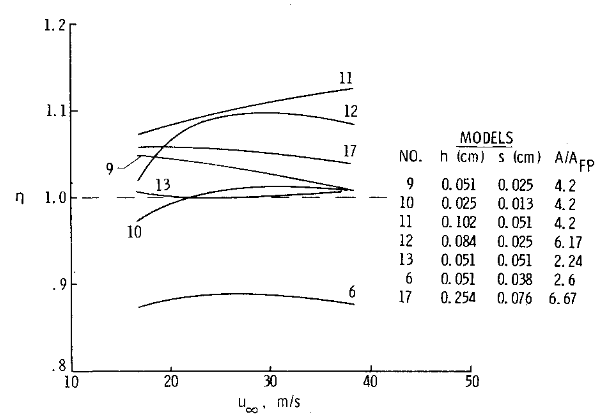

Fig. 3 Heat-transfer efficiency for the heat-transfer surfaces.

model 12). These low-drag, high-surface area configurations would seem to have potential for heat-transfer applications such as compact heat exchangers. Therefore, the heat-transfer characterristics of some of the large wetted surface area models were also examined.

The heat-transfer measurements at various velocities were obtained by mounting the test models on a common heater plate and then monitoring the power input to the heater plate and the temperature difference between the freestream and model at three centerline locations: $x = 10.8$, 45.7 and 80.6 cm. At each test velocity, the model and freestream temperatures were allowed to come to equilibrium, approximately 40-60 min. Using this procedure, the ratio of the heat-transfer coefficient of the ribbed surfaces to the flat plate were repeatable within $\pm 2\%$. Kays[2] and Chapman[3] give detailed equations for the relationship between the skin friction C_f and the Stanton number St_x. These equations, when applied to the present test conditions, give the following relationship:

$$St_x = \beta C_f \tag{2}$$

where $\beta = 0.49$-0.61. The experimental values of β were found to be approximately 0.8, about 30% higher than the theoretical predictions. This discrepancy between theory and experiments may be due to lateral temperature variations which the theoretical predictions do not consider. These lateral temperature variations are due to the experimental method of heating the models. The important result of the present tests is the heat-transfer increase of the ribbed surfaces over that of the reference flat plate. This ratio can be determined if the temperature distribution for the ribbed surfaces is the same as that for the flat plate, which is the case when the same heater plate is used for all models.

Figure 3 presents the heat-transfer efficiency η of the models as a function of freestream velocity, where η is the heat-transfer increase of the ribbed surface divided by the drag increase of the ribbed surface. The dashed line at $\eta = 1$ is the efficiency of a smooth flat plate, meaning an increase in drag gives an equal increase in heat transfer. Figure 3 shows that v-groove models 9, 11, and 12 have efficiences greater than one, indicating that the heat-transfer increases obtained with the ribs are greater than the drag increases. The importance of these configurations is that the literature indicates the roughness geometries previously used for heat-transfer augmentations in air have always had larger drag increases than heat-transfer increases or $\eta < 1$. As shown in Fig. 3, the present tests also indicated heat-transfer efficiences less than one for a longitudinal rectangular ribbed surface. Further testing is required to optimize spacing and heights for the present triangular or v-groove-type configurations.

References

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