AIAA JOURNAL
Vol. 30, No. 6, June 1992

Readers' Forum

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the AIAA Journal *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Modification of the van Driest Damping Function to Include the Effects on Surface Roughness"

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Introduction

As proposed by Krogstad,[1] the modification of the van Driest damping function only applies accurately to the fully rough regime and very poorly to the intermediate roughness regime. This is evident in the author's Fig. 1 for the correlation of ΔU^+ with k^+ in the intermediate roughness regime, $k^+ \leq 70$. Yet the intermediate roughness regime concerns, to a large part, most of the irregular roughness problems encountered for aircraft surfaces, ship hulls, ship propellers, underwater body surfaces, etc.

There is an underlying reason for the poor showing of the proposed modification in the intermediate roughness regime. First, even though not mentioned by the author, k^+ refers to the equivalent sand grain roughness that enabled Schlichting to reduce a single relationship the variation of ΔU^+ with k^+ for the fully rough regime. However, there remains in the intermediate roughness regime a large variation in ΔU^+ with k^+ from Nikuradse's sand grain roughness to the correlation of Colebrook and White. This is due to the large variation in the geometry of irregular rough surfaces encountered in practice.

To accommodate the variation of roughness in the intermediate roughness regime, Granville[2] relates the van Driest factor A^+ in effect to ΔU^+ instead of k^+ in the smooth van Driest formula:

$$F = 1 - \exp[-y^+/A^+]$$

This variation of A^+ to ΔU^+ is presented by Granville graphically, which may be now numerically fitted by the following:

$$A^+ = 26 - 5.05\,\Delta U + 0.19(\Delta U^+)^2, \qquad 0 \leq \Delta U^+ \leq 5.2$$

$$A^+ = 20.86 - 3.07\,\Delta U^+, \qquad 5.2 \leq \Delta U^+ \leq 6.2$$

$$A^+ = 280.89 + 94.27\,\Delta U^+ - 7.85\,(\Delta U^+)^2$$

$$6.2 \leq \Delta U^+ \leq 6.525$$

Received Oct. 18, 1991; revision received Dec. 6, 1991; accepted for publication Jan. 14, 1992. This paper is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

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The variation of ΔU^+ with k^+ for a particular roughness configuration[3,4] may be obtained empirically, or given analytically such as that for the Colebrook-White relation.[5]

For the fully rough regime, Granville[2] recommended an earlier formula by Rotta,[6] which in effect related an initial value of mixing length at $y^+ = 0$ to a ΔU^+ variation.

Krogstad[1] uses a mixing length formula of Michel et al.[7] [Eq. (5) in Ref. 1], which has a hyperbolic tangent. As shown by Granville,[8] such hyperbolic tangent functions blend the near wall and the far-field relationships. A more complex formula should include the damping function such that

$$1^+ = 0.085\,\delta^+ \tanh\,[\kappa y^+ F/0.085\delta^+]$$

where $\delta^+ = \delta U_\tau/\nu$.

References

[1]Krogstad, P.-Å., "Modification of the van Driest Damping Function to Include the Effects of Surface Roughness," *AIAA Journal*, Vol. 29, No. 6, 1991, pp. 888–894.

[2]Granville, P. S., "Mixing-Length Formulations for Turbulent Boundary Layers over Arbitrarily Rough Surfaces," *Journal of Ship Research*, Vol. 29, No. 4, 1985, pp. 223–233.

[3]Granville, P. S., "Three Indirect Methods for the Drag Characterization of Arbitrarily Rough Surfaces on Flat Plates," *Journal of Ship Research*, Vol. 31, No. 1, 1987, pp. 70–77.

[4]Granville, P. S., "Drag-Characterization Methods for Arbitrarily Rough Surface by Means of Rotating Disks," *Journal of Fluids Engineering*, Vol. 104, Sept. 1982, pp. 373–377.

[5]Granville, P. S., "The Frictional Resistance and Turbulent Boundary Layer of Rough Surfaces," *Journal of Ship Research*, Vol. 2, No. 3, 1958, pp. 52–74.

[6]Rotta, J., "Das in Wandnähe gulitige Geschwindigkeitsgesetz turbulenter Strömungen," *Ingenieur Archiv*, Vol. 18, 1950, pp. 277–280.

[7]Michel, R., et al., "Hypotheses on the Mixing-Length and Application to the Calculation of the Turbulent Boundary Layers," *Proceedings of Computation of Turbulent Boundary Layers*, AFORS-IFP-Stanford Conference, Stanford Univ., Stanford, CA, 1968.

[8]Granville, P. S., "A Near-Wall Eddy Viscosity Formula for Turbulent Boundary Layers in Pressure Gradients Suitable for Momentum, Heat or Mass Transfer," *Journal of Fluids Engineering*, Vol. 112, June 1990, pp. 240–243.

Reply by the Author to P. S. Granville

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The criticism by Granville[1] is based on what he considers to be a bad agreement in the intermediate roughness range between the computed shift in the law of the wall ΔU^+ and the experimental data presented in Fig. 1 in Krogstad.[2]

Received Dec. 4, 1991; accepted for publication Jan. 14, 1992.
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(Regrettably the abscissa label k^+ has disappeared in the figure.) It was, however, stated in the section "Turbulence Model" of Krogstad[2] that the major problem considered in the paper was the asymptotic behavior of the damping function proposed by van Driest[3] at large roughness numbers k^+. It was shown that for $k^+ > 100$ the original formulation fails completely and the error increases dramatically as k^+ increases. The correction proposed brings the calculations in agreement with the data in this region. Contrary to what Granville writes,[1] it is specifically stated (see, e.g., the abstract) that the shift in the law of the wall produced by the model refers to sand roughness.

It was also stated by Krogstad[2] that "For $k^+ < 100$, the experimental results are no longer unique since they will depend on the fraction of elements that are sufficiently small to be considered aerodynamically smooth." This statement was also supported by Fig. 1 where it is shown that even for sand grain roughness the results depend on the distribution of particles. It therefore seems unreasonable to try to match the results of a prediction method to any of the experimental distributions, and this was stated in the paper. It could, however, be mentioned that, if a particular distribution is to be matched, this may be obtained by changing the exponent in the exponential term of Eq. (7) of Krogstad.[2] The exponent determines the shape of the ΔU^+ curve for $k^+ < R^+$ and R^+ determines where the intermediate roughness range ends.

References

[1]Granville, P. S., "Comment on 'Modification of the van Driest Damping Function to Include the Effects of Surface Roughness'," *AIAA Journal*, Vol. 30, No. 6, 1992, p. 1673.

[2]Krogstad, P.-Å., "Modification of the van Driest Damping Function to Include the Effects of Surface Roughness," *AIAA Journal*, Vol. 29, No. 6, 1991, pp. 888–894.

[3]Van Driest, E. R., "On Turbulent Flow Near a Wall," *Journal of the Aeronautical Sciences*, Vol. 23, Nov. 1956, pp. 1007–1011.

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