AIAA JOURNAL
Vol. 35, No. 8, August 1997

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 "Supersonic Separation with Obstructions"

Oktay Özcan* and K. Bülent Yüceil†
Istanbul Technical University, Istanbul 80626, Turkey

VERMA and Gupta[1] recently presented experimental data for the supersonic turbulent flow past a circular cylinder mounted on a flat plate at a freestream Mach number of $M = 1.6$. Using their oil flow visualization data, Verma and Gupta[1] made an attempt to correlate the primary separation distance S with the cylinder diameter D and the thickness of the undisturbed boundary-layer δ. Reference 1 concluded that the appropriate length scale for the separation distance is $S/\sqrt{(D\delta)}$ (for $H > \delta$) and proposed the following correlation:

$$S/\sqrt{D\delta} = 0.736(H/\delta) - 0.036(H/\delta)^2 \qquad (1)$$

Reference 1 stated that "the length scale chosen for nondimensionalizing S cannot be the cylinder diameter D." This claim is not supported by the vast amount of experimental data reported in the literature.[2–4] Westkaemper[3] was among the first investigators who noted that S/D correlated with H/D. Settles and Dolling[4] and Dolling and Rodi[5] noted the similarities between the flowfields of cylinders and hemicylindrically blunted fins mounted on a flat plate. For blunt fins, not only the separation distance but also the spanwise development of the flowfield, as well as its vertical extent, depend primarily on diameter D (Ref. 5). The freestream Mach number M and Reynolds number Re have only secondary effects on the scaling in the turbulent flow regime.[5] These observations are supported by computational studies as well.[6]

We used our own experimental results[7–9] and the data of other experiments reported in the literature[1,2] to verify universal applicability of Eq. (1). All of the data utilized in our analysis were obtained for cylinders by oil flow visualization. Figure 1 gives the variation of $S/\sqrt{(D\delta)}$ with H/δ for seven different M and Re_δ values. Re_δ is the Reynolds number based on the undisturbed boundary-layer thickness δ, which was measured in Ref. 2 and calculated for the other data sets by using the van Driest transformation. Equation (1) (which is shown by a dashed line in Fig. 1) has a maximum at $H/\delta = 10.2$ and does not produce an asymptotic S value for infinite H. The solid line in Fig. 1 is a plot of the correlation given by

$$S/\sqrt{D\delta} = 2.8\{1 - \exp[-0.6(H/\delta)]\} \qquad (2)$$

which fits the data more accurately than Eq. (1). However, there is considerable scatter in the data due, mainly, to the effect of D/δ on the correlation. D/δ values for large H/δ are indicated in Fig. 1. $S/\sqrt{(D\delta)}$ increases with increasing D/δ for $H/\delta > 6$. A definite trend does not exist for $H/\delta < 6$. The ranges of D/δ values for the data used in Fig. 1 are $4.2 < D/\delta < 16$ (Ref. 1), $0.7 < D/\delta < 3.3$ (Ref. 2), $0.1 < D/\delta < 3.6$ (Ref. 8), and $0.3 < D/\delta < 1.6$ (Ref. 9).

Received Dec. 2, 1996; accepted for publication April 22, 1997.

*Professor, Faculty of Aeronautics and Astronautics.
†Assistant Professor, Faculty of Aeronautics and Astronautics.

Sedney and Kitchens[2] note that, when S/D is plotted as a function of H/δ, a strong dependence on D/δ is observed. (Figure 4 in Ref. 2 shows that S/D decreases with increasing D/δ.) Figure 1 shows that plotting $S/\sqrt{(D\delta)}$, instead of S/D, as a function of H/δ does not remove the dependence on D/δ. Realizing that H/δ is not a suitable correlation parameter, Sedney and Kitchens[2] proposed the following correlation:

$$S/D = \alpha\{1 - \exp[-\beta(H/D)]\} \qquad (3)$$

where α and β are weak functions of Reynolds number and depend mainly on M (Refs. 2, 4, and 7). The results of Refs. 2 and 7 indicate that α values are scattered around 2.3 and β increases monotonically from 1 to 1.5 as M goes from 1.7 to 3.5. Note that Eq. (2) can be derived directly from the correlation of Sedney and Kitchens[2] by inserting $D/\delta = 1.8$ (a midrange value) in Eq. (3) (with $\alpha = 2.1$ and $\beta = 1.1$).

Figure 2 gives the variation of S/D with H/D for the same data set plotted in Fig. 1. The solid line denotes Eq. (3) (with $\alpha = 2.3$ and $\beta = 1.2$). The dashed line is a plot of the correlation suggested by Westkaemper,[3] who used separation distance data obtained by employing four different techniques. For reasons discussed in Ref. 2, the accuracy of Westkaemper's correlation is not sufficiently good. Compared to Fig. 1, Fig. 2 displays much less scatter of the data. D/δ values for large H/δ are indicated in Fig. 2. For fixed M, S/D appears to be independent of D/δ.

To compare the accuracies of the correlations discussed here, we computed the rms of the deviations between the measured and predicted $S/\sqrt{(D\delta)}$ (and S/D) values. The coefficients in Eqs. (2) and (3) were chosen so as to minimize the rms values. The rms values of the deviations for Eqs. (1), (2), and (3) (with $\alpha = 2.3$ and $\beta = 1.2$) are $\sigma_1 = 0.73$, $\sigma_2 = 0.39$, and $\sigma_3 = 0.20$, respectively.

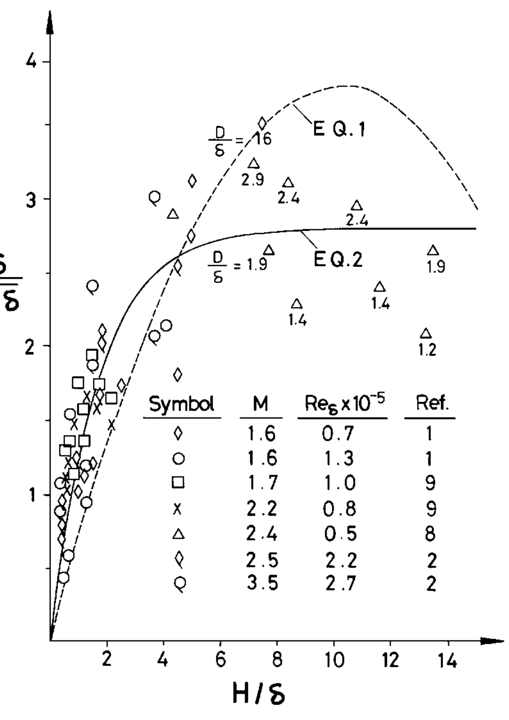

Fig. 1 Variation of $S/\sqrt{(D\delta)}$ with H/δ.

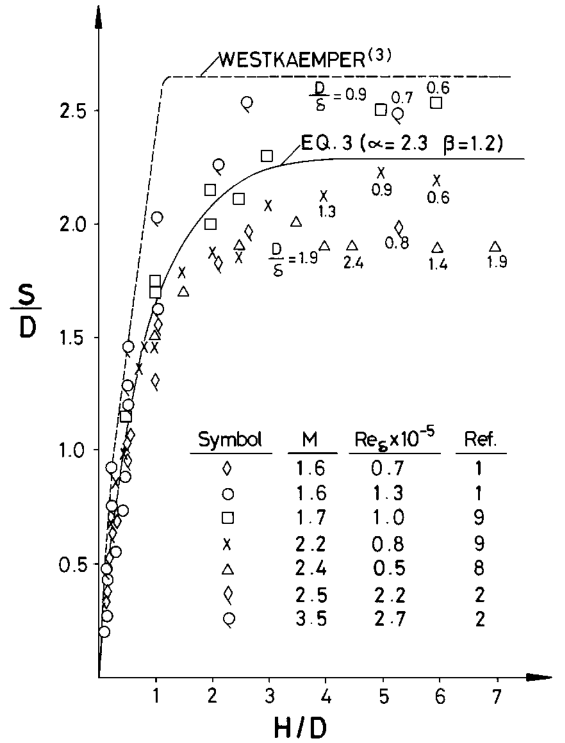

Fig. 2 Variation of *S/D* with *H/D*.

Thus, Eq. (3) is approximately four times more accurate than Eq. (1), which is twice less accurate than Eq. (2). The superiority of the correlation given by Eq. (3) over the other correlations is more apparent for small values of H/δ and H/D: $\sigma_1 = 0.70$ and $\sigma_2 = 0.34$ for $H/\delta < 2$, whereas $\sigma_3 = 0.13$ for $H/D < 1$.

Two important conclusions must be restated: 1) the cylinder diameter D is the appropriate scaling parameter for this flow and 2) the correlations given by Eqs. (1) and (2) are not as accurate as the correlation of Sedney and Kitchens.[2]

References

[1] Verma, S. B., and Gupta, V., "Supersonic Separation with Obstructions," *AIAA Journal*, Vol. 34, No. 4, 1996, pp. 849–851.

[2] Sedney, R., and Kitchens, C. W., "Separation Ahead of Protuberances in Supersonic Turbulent Boundary Layers," *AIAA Journal*, Vol. 15, No. 4, 1977, pp. 546–552.

[3] Westkaemper, J. C., "Turbulent Boundary-Layer Separation Ahead of Cylinders," *AIAA Journal*, Vol. 6, No. 7, 1968, pp. 1352–1355.

[4] Settles, G. S., and Dolling, D. S., "Swept Shock-Wave/Boundary-Layer Interactions," *Tactical Missile Aerodynamics*, edited by M. J. Hemsch and J. N. Nielsen, Vol. 104, Progress in Astronautics and Aeronautics, AIAA, New York, 1986, pp. 297–379.

[5] Dolling, D. S., and Rodi, P. E., "Upstream Influence and Separation Scales in Fin-Induced Shock Turbulent Boundary-Layer Interaction," *Journal of Spacecraft and Rockets*, Vol. 25, No. 2, 1988, pp. 102–108.

[6] Hung, C., and Buning, P. G., "Simulation of Blunt-Fin Induced Shock-Wave and Turbulent Boundary-Layer Interaction," *Journal of Fluid Mechanics*, Vol. 154, May 1985, pp. 163–185.

[7] Özcan, O., and Yüceil, B. K., "Cylinder-Induced Shock-Wave Boundary-Layer Interaction," *AIAA Journal*, Vol. 30, No. 4, 1992, pp. 1130–1132.

[8] Özcan, O., "An Experimental Investigation of Three-Dimensional Boundary-Layer Separation in Supersonic Flow Past a Circular Cylinder on a Flat Plate," Ph.D. Dissertation, Dept. of Mechanical Engineering, Univ. of California, Berkeley, CA, March 1982.

[9] Yüceil, K. B., "An Experimental Investigation of Shock-Wave/Boundary-Layer Interaction Induced by Cylindrical Obstacles," M.S. Thesis, Dept. of Aeronautics and Astronautics, Istanbul Technical Univ., Istanbul, Turkey, June 1989.

P. R. Bandyopadhyay
Associate Editor

Reply by the Authors to O. Özcan and K. B. Yüceil

S. B. Verma* and Vijay Gupta†
Indian Institute of Technology, Kanpur 208 016, India

THE authors would like to thank Özcan and Yüceil for their comments.[1] The exponential curve fit of Eq. (2) in their comments is quite clearly a better equation. The authors proposed Eq. (1) because it was quite adequate for the data available to them. However, the contention of Ref. 1 that the cylinder diameter D is the appropriate scaling parameter for this flow is not borne out by the evidence presented by them. The true measure of the relative scatter is not the standard deviation σ in cases where different variables are being considered, as in the present case, but σ normalized with a characteristic value of the relevant variables. The values of δ/D are fairly small so that the values of the variables in Fig. 1 of Ref. 1 are much larger than the corresponding values in their Fig. 2. Then again, most of the new points[2,3] (from their[1] Refs. 8 and 9), which appear as quite scattered on Fig. 1, are lying mostly below the curve for Eq. (3) in Fig. 2 (see Ref. 1).

The discussor's evidence is, therefore, not conclusive. Further, from a physical point of view alone, the characteristic length for separation distance should be derivable from blockage area rather than D.

References

[1] Özcan, O., and Yüceil, K. B., "Comment on 'Supersonic Separation with Obstructions,'" *AIAA Journal*, Vol. 35, No. 8, 1997, pp. 1423, 1424.

[2] Özcan, O., "An Experimental Investigation of Three-Dimensional Boundary-Layer Separation in Supersonic Flow Past a Circular Cylinder on a Flat Plate," Ph.D. Dissertation, Dept. of Mechanical Engineering, Univ. of California, Berkeley, CA, March 1982.

[3] Yüceil, K. B., "An Experimental Investigation of Shock-Wave/Boundary-Layer Interaction Induced by Cylindrical Obstacles," M.S. Thesis, Dept. of Aeronautics and Astronautics, Istanbul Technical Univ., Istanbul, Turkey, June 1989.

P. R. Bandyopadhyay
Associate Editor

Received March 10, 1997; accepted for publication March 10, 1997.

*Research Scholar, Department of Aerospace Engineering.

†Professor, Department of Aerospace Engineering.