Comment on "Hypersonic Wakes and Trails"

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LEES concludes "that at hypersonic speeds, transition in the wake of a blunt body cannot occur aft of $(x/d) \cong 40$."[1] To arrive at this conclusion, Lees combines an $(Re_{f,\ d})_{\min,\ cr}$ from cylinder experiments at Jet Propulsion Laboratory (JPL) (Ref. 35)† with an $(Re_{x,\ f})_{TR} = 56{,}000$ derived from both cylinder experiments at Graduate Aeronautical Laboratory, California Institute of Technology (GALCIT) (Refs. 1 and 8) and from sphere experiments at Lincoln Laboratory (Refs. 7 and 9): $(x/d)_{\min,\ cr} = (Re_{x,\ f})_{TR}/(Re_{f,\ d})_{\min,\ cr} \cong 40$.

The farthest point downstream at which wake transition can occur is taken to be $(x/d)_{\min,\ cr}$. Beyond this point, according to Lees' reasoning,[1] wake turbulence cannot maintain itself against the action of viscous dissipation; roughly speaking, at this point, $\bar{\epsilon}_T \approx \nu_f$. This reasoning seems superficially appealing; but further thought reveals that the criterion is conceptionally more applicable to the location of the *quenching* of the turbulent motion and not to the location of inception. Inception involves linear and then nonlinear amplifications of small disturbances and does not involve $\bar{\epsilon}_T$.

Figure 11a of the original paper is reproduced here as Fig. 1. This shows the data points and the correlation $(Re_{x,\ f})_{TR} = 56{,}000$. Added to the original figure are data points from Ref. 7 for $(x/d) \geq 35$. The numerical values for each of these new data points is taken from Demetriades and Gold,[3] as is the case for all of the original data points in Fig. 1. Two things are to be noted. First, $(x/d)_{TR}$ can be >40 as was presented in Ref. 7, Fig. 3. Furthermore, in their paper in this issue of the AIAA Journal, Clay, Labitt, and Slattery[2] show that $(x/d)_{TR}$ can be $\gg 40$ (see Fig. 6). Second, the correlation $(Re_{x,\ f})_{TR} = 56{,}000$ is for data points $(x/d)_{TR} \leq 35$, as noted in the original legend of Fig. 1. It is obvious that the $(Re_{x,\ f})_{TR}$ correlation is not valid for the transition point moving off to distances far downstream. Hence, it is inappropriate to use $(Re_{x,\ f})_{TR}$ to obtain an $(x/d)_{\min,\ cr}$, since this correlation is invalid in the regions of $(x/d)_{\min,\ cr}$. It is likely that the $(Re_{x,\ f})_{TR}$ correlation is valid only in the region of strong favorable pressure gradients and compressibility effects which, for blunt bodies and $M_\infty \lesssim 10$, is in the region $(x/d) \leq 35$. Goldburg[4] has suggested that a second correlation must be obtained in the downstream region where pressure decay and compressibility effects are small:

$$(Re_{f,\ d})_{TR} \cdot (d/x)_{TR} = [(d/x)_{TR}]_{\substack{\text{upstream} \\ \text{limit of second} \\ \text{correlation}}} \times \{(Re_{f,\ d})_{TR} - (R_{f,\ d})_{\min,\ cr}\}$$

From the sphere data of Fig. 1 (Refs. 7 and 9), the second correlation leads, in the asymptotic limit of $(x/d)_{TR} \to \infty$, to an $(Re_{f,\ d})_{\min,\ cr} = 6000$, $M_\infty = 3$ to 10, based on average local properties along the wake front in the downstream regions. This value agrees with the $(Re_{f,\ d})_{TR}$ of the Lincoln Laboratory data at $(x/d)_{TR} \approx 100$, and with the $(Re_{f,\ d})_{TR}$ derived from the Avco-Everett Research Laboratory experiments.[5]

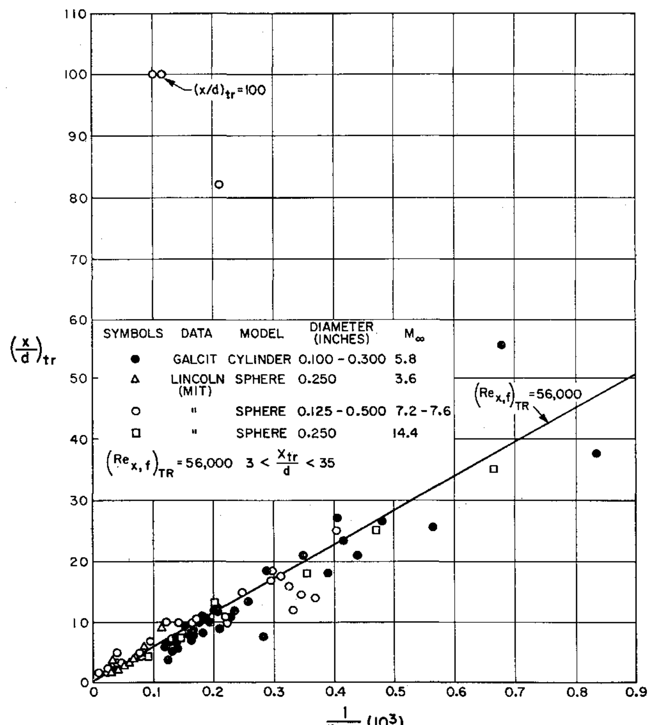

Fig. 1 Correlation of transition in hypersonic wake behind blunt bodies; Fig. 11a of the original paper[1] with additional data points for $(x/d)_{TR} \geq 35$.

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† The notation and the references are the same as in the original paper.

References

[1] Lees, L., "Hypersonic wakes and trails," AIAA J. **2**, 417–428 (1964); see Sec. 3.

[2] Clay, W. G., Labitt, M., and Slattery, R. E., "Measured transition from laminar to turbulent flow and subsequent growth of turbulent wakes," AIAA J. **3**, 837–841 (1965).

[3] Demetriades, A. and Gold, H., "Correlation of blunt-bluff body wake transition data," Graduate Aeronautical Laboratory, California Institute of Technology, Hypersonic Research Project, Internal Memo 12 (September 20, 1962).

[4] Goldburg, A., "Analysis of hypersonic wake transition experiments," Avco-Everett Research Laboratory Research Note 391 (to be published).

[5] Fay, J. A. and Goldburg, A., "Unsteady hypersonic wake behind blunt bodies," AIAA J. **1**, 2264–2272 (1963).

Reply by Authors to A. Goldburg

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GOLDBURG has apparently misunderstood the significance of the local minimum critical Reynolds number $(Re_{f,\ d})_{\min,\ cr}$. When the effective turbulent diffusivity $\bar{\epsilon}_T$ is smaller than the kinematic viscosity ν_f, the work done by the Reynolds stresses is more than counterbalanced by the rate of viscous dissipation. Thus, turbulence in the wake cannot exist when $(\bar{\epsilon}_T/u_f d) < (\nu_f/u_f d)$, or when $Re_{f,\ d} < (Re_{f,\ d})_{\min,\ cr}$, any more than turbulent flow in a pipe can exist below a critical Reynolds number of 2000. If one chooses to call this "quenching," that is a problem in semantics and not in fluid mechanics. In Ref. 1, the value of $(Re_{f,\ d})_{\min,\ cr}$ was estimated roughly at about 500 for blunt bodies. Not unexpectedly, experiments on cylinder wakes by Kendall[2] and by one of us (Behrens, unpublished) showed that the actual value lies in the range 1200–1500, at least for two-dimensional wakes. None of the data on wake transition, whether new or old, shows any evidence of turbu-

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