sketch of a "four-way partition" of the flow or equivalently a saddle-point streamline configuration was included in Ref. 5. Trifurcation of the flow is certainly unrealistic, and I know from my discussions with Moore and his co-workers that their sketches simply did not show any details in the wake region. They did not propose a trifurcation configuration.†

References

[1] Sears, W.R. and Telionis, D.P., "Boundary Layers Separation in Unsteady Flow," *SIAM Journal of Applied Mathematics*, Vol. 28, Jan. 1975, pp. 215-235.

[2] Riley, N, "Unsteady Laminar Boundary Layers," *SIAM Review*, Vol. 17, April 1975, pp. 274-297.

[3] Telionis, D.P., "Calculations of Time-Dependent Boundary Layers," *Unsteady Aerodynamics*, ed. R. B. Kinney, July 1975, pp. 155-190.

[4] O'Brien, V., "Unsteady Separation Phenomena in a Two-Dimensional Cavity," *AIAA Journal*, Vol. 13, March 1975, pp. 415-416.

[5] Sears, W.R. and Telionis. D.P., "Unsteady Boundary Layer Separation," *Recent Research of Unsteady Boundary Layers, Proceedings of a Symposium of the International Union of Theoretical and Applied Mechanics*, Vol. 1, edited by E.A. Eichelbrenner, Quebec, Canada, May 1971, pp. 404-447.

†Note added in proof: Communicating privately with Dr. O'Brien I resolved my misunderstanding with regard to "trifurcation of the flow." By this term we understand a point where three streamlines meet which is not possible unless the two of the streamlines coincide with a solid boundary. Dr. O'Brien on the other hand implies a saddle point streamline configuration where two of the streamlines form a closed loop thus partitioning the space into three aeral domains.

Reply by Author to D. P. Telionis

Vivian O'Brien*
The Johns Hopkins University, Laurel, Md.

MY article[1] presents a particular internal flow problem, but I fully intended that it apply as an example for unsteady separation phenomena from two-dimensional solid bodies in a variety of flow situations. Discussion of unsteady flow procssses,[2] as in many flow processes that are not completely understood, suffers from semantic problems. As used in my article, detachment and reattachment apply to all (instantaneous) streamlines that intersect the solid boundary, whatever the characteristic Reynolds number, internal or external flows. A streamline having both a detachment point and a reattachment point is, per force, a closed recirculation region. In aerodynamic parlance, this is a "separation bubble". It may be thick or thin relative to the upstream boundary layer. If it is thick, it appears the boundary layer is breaking away from the body. Yet true boundary-layer "breakaway"[3] is generally reserved for open separated regions that merge with the wake without reattachment to the body; this is called "separation" in Ref. 2 and sometimes "blow-up" in Ref. 4. Common imprecise use of the term "boundary-layer separation" lumps together thin and thick separation bubbles along with true breakaway as if there were no distinction. In each case, the local flow patterns near detachment and/or reattachment points can only be accurately revealed by regular full Navier-Stokes solutions. The common feature is *coincidence of velocity and vorticity zeroes*. This amounts to the usual "vanishing wall-shear" for steady flow, but the criterion applies as well to unsteady shear flow, though not yet properly accepted. We could also speak of mean detachment points and reattachment ones for pulsatile or turbulent flows.

Received August 4, 1975.
Index categories: Hydrodynamics; Boundary Layers and Convective Heat Transfer-Laminar.
*Physicist, Research Center, Applied Physics Laboratory. Member AIAA.

Steady boundary-layer theory has been applied successfully to high Reynolds number external flow problems. Yet the distinction between the apparent singularity of the boundary-layer solution and regular behavior at detachment for the full momentum equation[5] is well-known. (The latter is more accurate, of course.) Likewise the use of unsteady boundary-layer equations,[2,4,6] though used for practical engineering estimates for high Reynolds numbers, cannot be accurate for local flow details near detachment. Such analyses are always incomplete in the sense of Riley (Ref. 7 p. 283). The claim in Ref. 2 that a point of detachment (i.e. "my separation") has no major engineering significance is arguable, because it must always precede the bulk flow reversal region (thick or thin, open or closed, transient or permanent. Such flow regions can seriously affect heat or mass transfer.

Finally, if the body surface is moving forward in the frame of reference, the stagnation-separation point (in the Eulerian description) must occur off the body in the freestream. Zero wall-shear (on the body surface) predicts nothing about the streamline intersection. The "saddle-point streamline configuration" (Ref. 4, Fig. 1a) is my four-way partition (Points C & D, Fig. 2, Ref. 1). However, generally the orthogonal intersection need not be parallel-normal with respect to the solid wall. On the other hand, the unsteady shedding of vortices as revealed by full momentum equation calculations[8,9] does not involve such intersections but an osculating streamline ('trifurcation') where the vorticity is not zero. This is clearly a different thing.

References

[1] O'Brien, V., "Unsteady Separation Phenomena in a Two-Dimensional Cavity," *AIAA Journal*, Vol. 13, March 1975, pp. 415-416.

[2] Telionis, D. P., "Comment on Unsteady Separation Phenomena in a Two-Dimensional Cavity," *AIAA Journal*, Vol. 13, Dec. 1975, pp. 1689-1690.

[3] Stewartson, K., "The Theory of Unsteady Laminar Boundary Layers," *Advances in Applied Mechanics*, Vol. 6, Academic Press, N.Y. 1960, pp. 1-37.

[4] Sears, W. R. and Telionis, D. P., "Boundary-Layer Separation in Unsteady Flow", *SIAM Journal of Applied Mathematics*, Vol. 28, Jan. 1975, pp. 215-235.

[5] Dean, W. R., "Note on the Motion of a Liquid near a Position of Separation," *Proceedings of the Cambridge Philosophical Society*, Vol. 46, 1950, pp. 293-306.

[6] Tsahalis, D. Th. and Telionis, D. P., "Oscillating Laminar Boundary Layers and Unsteady Separation," *AIAA Journal*, Vol. 12, Nov. 1974, pp. 1469-1475.

[7] Riley, N., "Unsteady Laminar Boundary Layers," *SIAM Review*, Vol. 17, April 1975, pp. 274-297.

[8] Lugt, H. J. and Ohring, S., "Rotating Thin Elliptic Cylinder in a Parallel Viscous Fluid Flow," Fourth International Conference on Numerical Methods in Fluid Dynamics, University of Colorado, Springer-Verlag, 1975.

[9] Mehta, U. B. and Z. Lavan, "Starting Vortex, Separation Bubbles and Stall - A Numerical Study of Laminar Unsteady Flow around an Airfoil," *Journal of Fluid Mechanics*, Vol. 67, 1975, pp. 227-256.

Comment on "Theoretical Study of Lift-Generated Vortex Wakes Designed to Avoid Rollup"

Turgut Sarpkaya*
Naval Postgraduate School, Monterey, Calif.

RECENTLY Rossow[1] introduced two hypothetical vortex wakes and explored, through the use of the discrete-

Received June 19, 1975; revision received July 29, 1975.
Index categories: Aircraft Aerodynamics (including Component Aerodynamics); Jets, Wakes, and Viscid-Inviscid Flow Interactions; Aircraft Flight Operations.
*Professor. Member AIAA.