Readers' Forum

Brief discussions 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.*

AIAA 81-4184

Tracer Residence Time in a Nearwake of Bluff Bodies

M. M. Zdravkovich*
University of Salford, Salford, U.K.

COHEN and Director[1] have carried out experiments on transport of fluid from the two-dimensional nearwake behind bluff bodies. They injected a tracer (nitric acid) through holes on the downstream side of circular and triangular cylinders and measured a tracer "residence" time in the nearwake after a closure of bleeding holes. The concentration of the tracer in the nearwake was found to decrease exponentially with time until most of the tracer material had been transported outside the nearwake. The time required to reduce the tracer concentration to $1/e$ of its original concentration was taken as the tracer residence time t_r.

The residence time was measured in the Reynolds number range 8×10^3 to 3×10^5 for turbulence intensities from 3 to 11%. The data showed that the residence time was independent of the intensity of freestream turbulence and strongly depended on vortex shedding frequency, as seen in Fig. 1, Ref. 1. The data was correlated remarkably well by the following relationship:

$$t_r = 2.37\,Stf^{-1/2} \tag{1}$$

where St was the Strouhal number and f the frequency of vortex shedding.

Equation (1) is dimensionally inconsistent and the presence of Strouhal number is artificial because it was introduced to collapse the data obtained for the triangular and circular cylinder into a single curve. It happened that for these two geometries the ratio of the Strouhal number was the same as the ratio of measured residence times.

Cohen and Director[1] attempted to introduce dimensionless grouping, such as t_rU_0/D, but found that it did not result in a good correlation. They also tried to relate the frequency of Gerrard-Bloor's transition eddies in the separated shear layers to the residence time. The Gerrard-Bloor transition eddies depend on the freestream turbulence and they are completely obliterated at such high subcritical Reynolds numbers as used in Ref. 1.

Physically more plausible relationships can be obtained by taking into account that the residence time depends solely on vortex shedding. The vortex shedding process can be described by its frequency f, strength of the fully formed vortices K, and length of the formation region L. The strength (or circulation) of vortices have been measured behind a circular cylinder by Bloor and Gerrard[2] in subcritical regime and found to be independent of Reynolds number. In general, the strength of vortices depends on the shape of the bluff body. For example, a flat plate having a lower Strouhal number than a circular cylinder produces stronger vortices. The wedge-like triangular cylinders, which have been used by Cohen and Director, have higher Strouhal number than the circular cylinder, hence weaker vortices and longer residence time.

The length of formation region was found[2] to be fairly constant in the upper subcritical regime behind the circular cylinder and extended to lower Reynolds numbers as the freestream turbulence was increased. Cohen and Director found the same within their range of Reynolds numbers and freestream turbulence. It should be expected, however, that the length of the formation region depends on bluff body shape and thus affects the residence time.

The application of dimensional analysis leads to the following grouping of relevant parameters:

$$t_r \propto L/\sqrt{Kf} \tag{2}$$

Cohen and Director's empirical relationship [Eq. (1)] is fully confirmed and, in addition, Bloor and Gerrard's[2] tedious measurements and calculations of vortex strength seem to be substantiated. The constant of proportionality in Eq. (2) can be deduced by using $K=0.5\,\pi Ud$ from Ref. 2 and the residence time measured for 1.58 cm circular cylinder at 26.5 m/s from Ref. 1 as given in its Fig. 1. The relationship Eq. (2) becomes

$$t_r = 10(L/\sqrt{fK}) \tag{3}$$

The constant of proportionality depends on the definition of the residence time. Cohen and Director[1] chose t_r to be the time required to reduce the tracer concentration to $1/e$ of its original concentration. All other physical parameters in Eq. (3) are grouped in such a way to form a dimensionally correct equation.

References

[1] Cohen, L. S. and Director, M. N., "Transport Processes in the Two-Dimensional Near Wake," *AIAA Journal*, Vol. 13, Aug. 1975, pp. 969-970.

[2] Bloor, M. S. and Gerrard, J. H., "Measurements on Turbulent Vortices in a Cylinder Wake," *Proceedings of the Royal Society A*, Vol. 294, Oct. 1966, pp. 319-342.

Received Sept. 10, 1980; revision received Dec. 11, 1980.

*Reader, Department of Aeronautical and Mechanical Engineering.