have taken and the care of other investigators have taken, there
is just no shear data involving mass transfer that can be rec-
ognized as a standard set. Consequently, absolute compari-
sion of the accuracies of the shear data cannot be made. The
accuracy can only be inferred by comparing these results to
other similar experiments. I do recognize that the "best set"
of data that can be obtained will come eventually from grad-
ual improvements in the experimental technique. Every ex-
pertiment has something of the Heisenberg uncertainty built
into it. The approach is to minimize the uncertainty caused by
the experimental technique. In the experiment reported, the
authors have introduced a clever technique for maintaining the gap
clearance uniform around the sensing element. In my judgment,
this technique reduces the uncertainty of the experimental meth-

Authors' Closure

We are indeed pleased with the kind comments of Dr. Graham
and his recognition of the care we have tried to exercise in taking
our shear stress measurements. Perhaps his legitimate concern
for the "gap error" will be somewhat relieved if he considers
that the effect if significant would become more pronounced at
high suction rates and for high shear stresses. However, these
are the conditions for which the surest comparisons exist be-

correction, applied to local pressures, is therefore not universally
valid, although it does appear to work reasonably well in the
experiments reported by Farell, et al. It remains to be shown
under what general conditions a correction to local pressure of
the form assumed by Muskell can be used.

A second relevant reference omitted in the discussion of block-
age effects on cylinders, is that by Modi and El-Sherbiny [28] in
which a simple empirical formula for blockage correction is
proposed. It would have been interesting to test this simple
formula against the present data; at least the form appears to be
useful.

It is disturbing to see how different length/diameter ratios give
different results in the present data for apparently two-dimen-
sional tests of circular cylinders. This is presumably an end
effect and it introduces an uncertainty of about 10 percent in
Cp here, which is the same order of magnitude as the blockage
effect. Until two-dimensional results are shown to be independ-
cent of length/diameter ratio, they cannot be accepted as de-

numbers in brackets designate additional references at end of discussion.
4Numbers 31-34 in brackets designate Additional References at end of closure.
and Richter and Naudascher [34]. Primarily because of space limitations the authors restricted the discussion in the present paper specifically to the case of the circular cylinder in the range of Reynolds-number independence. In the critical range of Reynolds numbers the flow past a smooth circular cylinder is characterized by the presence of a laminar separation-turbulent reattachment bubble, followed by turbulent separation, and the bubble location and the location of the final separation from the cylinder are highly sensitive to wind tunnel conditions, in addition to the Reynolds number. When tests are made at Reynolds numbers in this range in different wind tunnels it is expected that blockage will play a dominant role in determining the overall flow characteristics and may lead to dramatically different results. Measurements of lift and drag forces and Strouhal number in the critical Reynolds number range, for rather high blockage ratios, are presented in reference [34], and no attempt was made in the present work to investigate this range of Reynolds numbers. Blockage plays also an important role in the supercritical Reynolds number range, but the physics of the flow is essentially different. In the subcritical Reynolds number range, on the other hand, where the measurements of Modi and El-Sherbiny [26, 32] have been obtained, the characteristics of the flow are rather different from those of the flow in the supercritical range, and the blockage effects may be very different. The large variations of the pressure coefficient $C_p$ in the wake region of the cylinder, already pointed out in the main text, exhibited by the subcritical range data of Modi and El-Sherbiny [26] (the same variations are present in the data in [32], which may overlap with those in [26]), are not present for cylinders with large roughness in the range of Reynolds-number independence, and neither are the "large, seemingly random amplitude modulations of the unsteady pressure" noted by Modi and El-Sherbiny in their experiments [32], which may affect the mean pressure values in a way difficult to predict. For these reasons a comparison with the entirely empirical correction formula in [32] was not presented, since it would add little to the understanding of the physical mechanisms, and only reference [26] was given in the main text, which is more recent than [28].

Regarding the paper by McKeon and Melbourne [31] and their discussion of Maskell's similarity assumption, their data were obtained for flat plates and prisms in boundary layers of various thicknesses. (The authors could not obtain a copy of this paper in time for the writing of this closure, but found some of McKeon and Melbourne's data plotted in [33].) The idea of the authors' work was to analyze the various methods of correction as they apply in the case of circular cylinders in the Re-independent range, precisely because of the seeming arbitrariness of some of the similarity hypothesis on which the theoretical formulae are based, among them the similarity assumption discussed by McKeon and Melbourne [31]. The rather acceptable performances of both Allen and Vincenti's and Maskell's correction formulae was somewhat unexpected from this point of view. It should be noted that the similarity hypothesis is not the only hypothesis open to question in Maskell's analysis: the ad-hoc relationship imposed to take into account the distortion of the wake was justified by Maskell on the basis of empirical data for flat plates only and, for large blockage ratios, neglecting higher-order terms in $S/C$ as done by Maskell may not be accurate enough.

It should also be noted that the similarity hypothesis is embodied in both correction methods for the pressure distribution, and in the variant of Allen and Vincenti's method proposed by the authors (see discussion of equations (6) and (12) in the main text). The present data indicate that it holds well for the blockage ratios examined, up to about 20 percent. It should be noted that an essential feature of the flow analyzed in this paper is the relative insensitivity of the position of separation to blockage, a necessary condition for application of Maskell's correction procedure and the similarity assumption.

The dependence of the flow characteristics on the length-to-diameter ratio had been previously alluded to by various authors and can be considered physically as a consequence of the interaction of the flows around the ends of the cylinder, with the spanwise irregularities very likely resulting (for long enough cylinders) from the instability of the flow downstream of separation from the model (see main text). A detailed investigation of these phenomena is lacking. It should be noted however that the 10 percent uncertainty in the $C_p$ values referred to Gartshore does not carry over into the conclusions of the present study regarding the validity of the correction formulae, which perform well in all cases.

Finally, nowhere in the paper have the authors stated that "wind tunnel tests using smooth uniform flow can represent actual wind conditions" as Gartshore indicates; the generality of this statement alone insures its inaccuracy. The study has been limited to the development of blockage corrections for mean flow parameters for cooling towers in uniform wind. The actual effects of turbulence in the approach stream have not been discussed, nor have the effects of variations with height of the characteristics of the approach wind. However, all experimental wind tunnel values of $C_p$ in Figs. 8, 9, and 10 have been measured in uniform flows, with the exception of Niemann's prototype point. The fact that this point agrees remarkably well with the rest of the data shows that at least certain mean flow parameters can be adequately modeled using tests in smooth uniform flows. A limited discussion of this point can be found in reference [16]; a comprehensive quantitative discussion including measurements of fluctuating pressures does not seem to be possible at present for lack of adequate data.

### Additional References


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**A Survey of Fluid Mechanics Education of Mechanical Engineers**

**P. A. PFUND,²** The authors are to be congratulated for their efforts in providing considerable enlightenment on current practices in fluids education. As an interesting adjunct to their results I wish to present some recent survey data² based on 1700 replies of largely chemists and chemical engineers. Of particular interest is the following question and its answers:

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3. Industrial Research, June 1977, p. 117.