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EFFECT OF TUNNEL BLOCKAGE AND SUPPORT ON THE HEAT TRANSFER FROM SPHERES

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IN THEIR paper published in this Journal Raithby and Eckert [1] reported on the effect of support position on the heat transfer from spheres. They showed that Nusselt numbers obtained using a crossflow support were about 10 per cent higher than those obtained using a rear support. A similar study has been carried out at the University of Waterloo to determine the effect of tunnel blockage and support position as well as support size on the overall heat transfer from a single sphere into an air stream. Experiments were performed under the following conditions:

Reynolds number—1500–9000
Turbulence intensity—0·8–1·9 per cent
Blockage ratio—0–17·2 per cent
Support size ratio—0·21–0·55.

Three support positions have been used; which are respectively rear stagnation point 135°-angle from the front stagnation point and equator supports.

The wind tunnel and the sphere used by Lavender and Pei [2] were modified for the present case. A guard heater was also installed on the neck of the supporting stem to eliminate the heat loss by conduction. Schematic diagram on one of the test sections is shown in Fig. 1. Details of the experimental assembly are available elsewhere [3]. The turbulence intensity in the main stream which was measured by a "DISA" hot-wire annemometer is within the range of 0·8–1·9 per cent which can be considered of having negligible effect on the present data [10, 15].

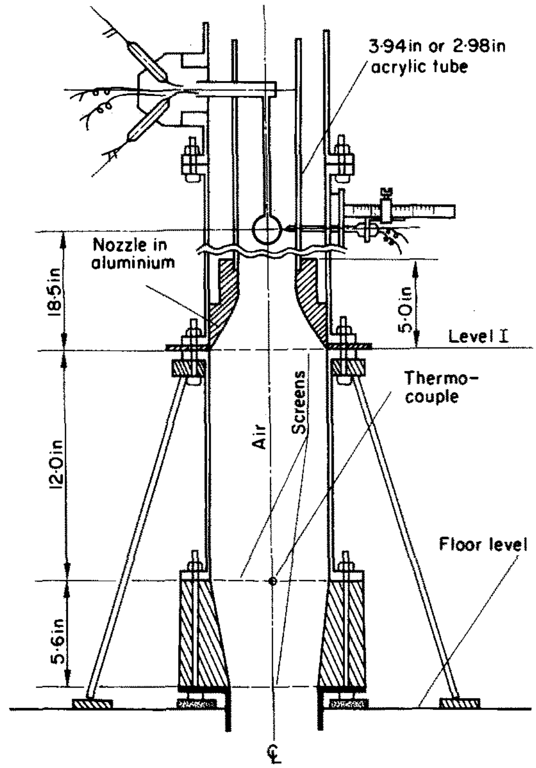

FIG. 1. Schematic diagram of the test section with blockage.

INFLUENCE OF SUPPORT POSITION AND SUPPORT SIZE

As depicted in Fig. 2, the data obtained for the equator and 135°-angle supports are about 12 per cent higher than the rear support, whereas no discernible difference is found between them which implies that 135°-angle support may disturb the wake region of the sphere to the same extent with respect to heat transfer as the equator support. This is in general agreement with the data reported by Raithby and Eckert [1]. Moreover, as shown in Fig. 2, that identical trend prevails for all the support sizes. Hence, it may be concluded that the size of support is of little importance in the heat transfer from spheres compared to the support position. The only apparent influence of the support size was found with the rear support at the Reynolds' number less than 5000 as shown in Fig. 3.

There are several factors involved in the influence of rear support on the heat transfer rates. At relatively low Reynolds' number, its effects on the stream lines may cause a thinner thermal boundary layer which would in turn increase the heat transfer rates. On the other hand, if the support occupies a considerable portion of the sphere surface area which is in the region of high local heat-transfer coefficient at relatively high Reynolds' number, it may result in lowering the overall heat transfer coefficient. Finally, reattachment of the wake to the sphere would cause a decrease in the heat transfer in the aft hemisphere [14].

Therefore, the higher Nusselt numbers for larger support sizes at $Re_f < 5000$ is apparently due to the prevalence of the streamlining effect and as the Reynolds' number increases this is compensated, to a large extent, by the other two factors as suggested above.

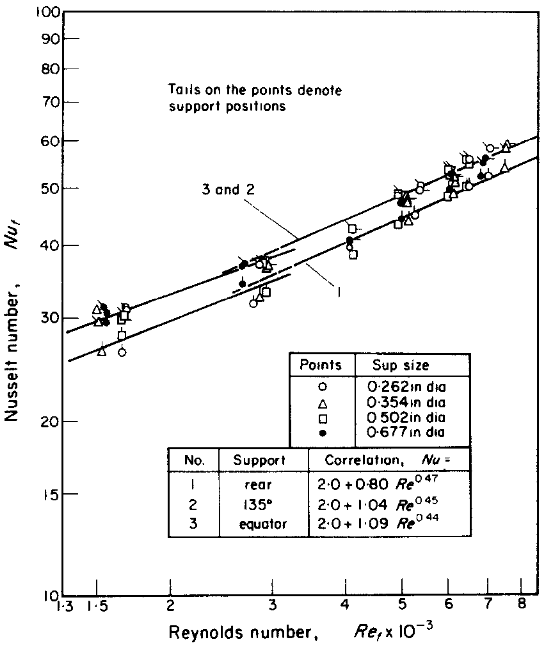

FIG. 2. Effect of support position [zero-blockage].

TUNNEL BLOCKAGE AND VELOCITY CORRECTION

Since most of the measurements on the heat and mass transfer from a single sphere in a fluid stream have been carried out in wind tunnels or liquid troughs of limited size, the flow field around the sphere might be disturbed. The extent of such a disturbance will definitely depend on the fraction of the flow area blocked by the sphere. The ratio of the projected area of the sphere to that of the free stream is generally known as the blockage ratio.

Leppert *et al.* [4, 5] recommended the use of a mean flow area which was defined as the ratio of the flow volume in the channel to the sphere. For a sphere located inside a cylindrical tunnel it gives the velocity correction as:

$$U_c/U_\infty = 1/[1 - 2/3(d/D)^2] \tag{1}$$

where d and D are the diameter of the sphere and that of the tunnel respectively.

On the other hand Robinson *et al.* [6] proposed a velocity correction of the form:

$$U_c/U_\infty = 1 + (d/D) \tag{2}$$

based on potential flow theory. Considerations of the solid blockage as well as the wake blockage on the drag coefficient of a body of revolution were given by Pope [7]. He suggested that

$$U_c/U_\infty = 1 + \frac{K\tau\,(\text{body volume})}{A^{3/2}} + \frac{1}{4}\frac{S}{A}C_D \tag{3}$$

where S and A are cross-sectional area of a sphere and that of tunnel respectively, and C_D is the drag coefficient of the sphere. Numerical values of the constants K and τ are

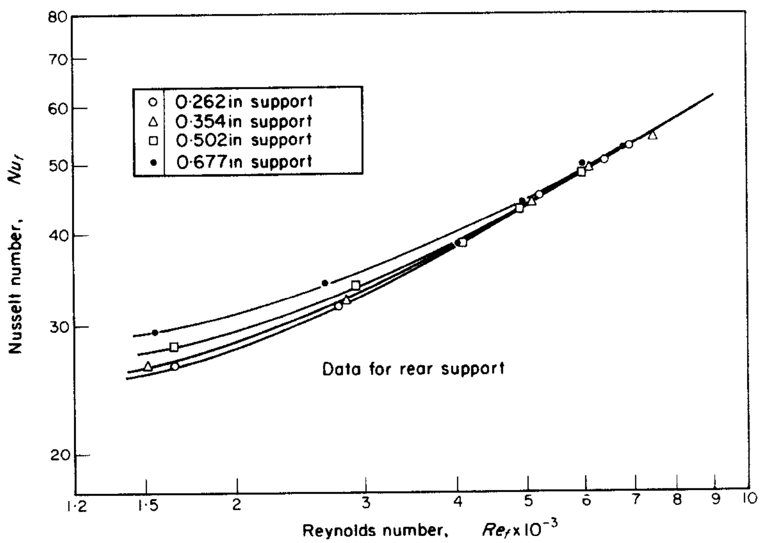

FIG. 3. Effect of support size [zero-blockage].

available for various families of aerofoils and asymmetric slender bodies.

The data at various blockage ratios after being corrected following Leppert *et al.* [4, 5], Robinson *et al.* [6] and Pope [7] are shown in Fig. 4. The dark circles represent the data where open jet was employed, for which zero blockage has been assigned. Both the corrections proposed by Pope [7]

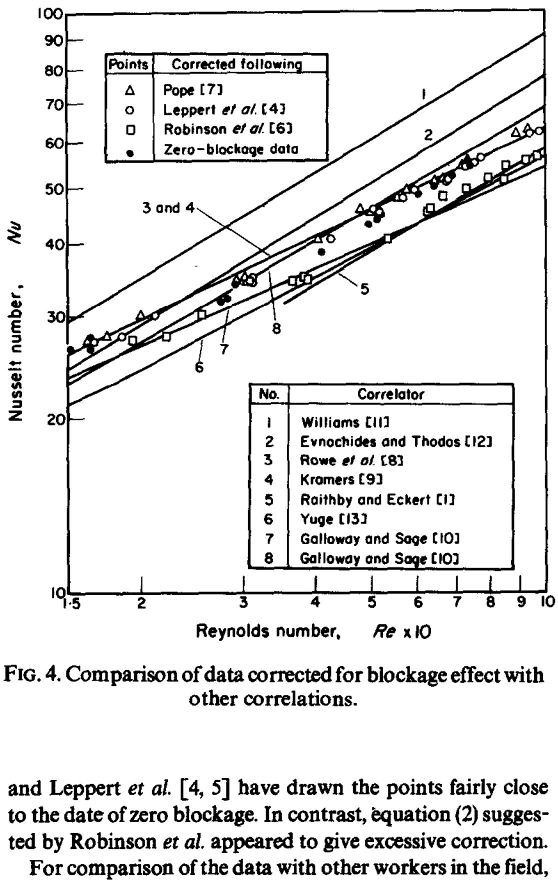

FIG. 4. Comparison of data corrected for blockage effect with other correlations.

and Leppert *et al.* [4, 5] have drawn the points fairly close to the date of zero blockage. In contrast, equation (2) suggested by Robinson *et al.* appeared to give excessive correction.

For comparison of the data with other workers in the field, Fig. 4 also shows that the results from the present investigation agreed fairly well with the correlations suggested by Rowe *et al.* [8], Kramers [9] and Galloway and Sage [10]. However, the data lie under the correlations of Williams [11] and Evnochides and Thodos [12] and above the one proposed by Yuge [13] and Raithby and Eckerts [1].

Using the least square method, the present data after being corrected for tunnel blockage using equation (1) may be represented by the following expression:

$$Nu_f = 2{\cdot}04 + 0{\cdot}54\, Re_f^{\,0{\cdot}515} \qquad (4)$$

with a standard deviation of 2·0 per cent.

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