Table 3

AR	K	γ	C_m*
0	0.12	0.21	0.0067
0.122	0.15	0.20	0.0088
0.192	0.13	0.19	0.0094
0.453	0.13	0.18	0.0113
0.700	0.10	0.15	0.0124

Coefficients and exponents in the equation $C_m = K(\text{Re})^{-\gamma}$ at different aspect ratios, all at a radial clearance ratio (σ/R) of 0.0085, an axial clearance ratio (S/R) of 0.025, and a disk thickness-radius ratio (t/R) of 0.140; C_m* is value of moment coefficient at Reynolds number equal to 10^6.

Figs. 6 and 7 show the small influence of typical radial and axial clearances on moment coefficient for several aspect ratios all at a Reynolds number of 10^6. These results are representative of all data taken and indicate that choice of housing clearances is dictated by other than frictional loss considerations provided such clearances are reasonably small. When clearances become large, increasing blade aspect ratio can cause substantial losses as seen in Fig. 8. The contribution of momentum exchange in the blades to the total loss is indicated by the small influence of housing clearance for the bladeless disk. Fig. 8 also cross-plots the data of Fig. 4 to show the influence of aspect ratio on moment coefficient at Reynolds number equal to 10^6.

To evaluate the influence of blading solidity on losses, every other blade in the 0.453 aspect ratio wheel was removed. Tests at an axial clearance ratio of 0.0085 and a radial clearance ratio of 0.025 indicated a six per cent increase in moment coefficient at Reynolds number equal to 10^6. Thus typical changes in solidity have only small effects on losses.

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DISCUSSION

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This paper is a useful addition to our knowledge of losses in small turbines. In many cases, extrapolation of the Stodola equation leads to extremely pessimistic values for pumping and windage losses and it will be helpful to the small turbine designer to have information for the geometries of interest to him. In view of the strong dependence of moment coefficient on axial clearance for large S/R, it would be desirable to have results for several values of S/R on one side, with small clearance on the other (approximating conditions in a single-stage turbine with open exhaust). What happens when S/R is even greater than 0.31?

Authors' Closure

We thank Dr. Stenning and those who participated in the discussion following the paper's presentation for their pertinent comments.

For the case of different clearances on each side of the disk, moment coefficient would be the arithmetic mean of the values corresponding to the large and small clearances, assuming little or no axial flow across the plane of disk symmetry perpendicular to the axis of rotation. Of course, here, as in any case where working-fluid flow through the turbine occurs, the direct and the indirect effects of working fluid flow on the disk friction flow must be considered in determining the "over-all effective" friction drag on the wheel.

The maximum clearance ratios were determined by the physical limitations of the apparatus. Measurements at larger clearances would have involved extensive modifications.

The following comments are in response to questions posed at the presentation of the paper.

In order to measure axial clearance, two holes were drilled in each disk on a circle of radius equal to approximately three tenths that of the disk (see Fig. 1). Since C_m varies as the fifth power of the radius, one would expect these holes to have little effect on the measurements of C_m. This assumption was verified by filling the holes in two of the disks with epoxy resin finished flush with the disk surface. Upon retesting no significant difference in C_m was observed.

In arriving at the disk thickness correction, no account was taken of the influence of variations in radial clearance. For the unbladed disk, based on the existence of an inviscid core flow between the boundary layers on the disk edge and on the housing, one can assume that the thickness of such a core would have little effect on the total drag. Experimentally with bladed disks, Fig. 7 shows little or no change in over-all moment coefficient for more than a fourfold increase in radial clearance.

Figs. 6, 7, and 8 raised some questions of interpretation. They are intended to show the individual effects of the parameters axial clearance, radial clearance, and aspect ratio. Fig. 6 represents a constant radial clearance ratio $\sigma/R = 0.0085$ where each of the three curves shows the effect of the turbine disk when S/R is varied. Similarly, Fig. 7 shows the effect of varying σ/R when S/R is held constant at 0.025. On each curve of Fig. 8 the data points represent different turbine disks of successively increasing aspect ratio all operated at the same axial and radial clearances.

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