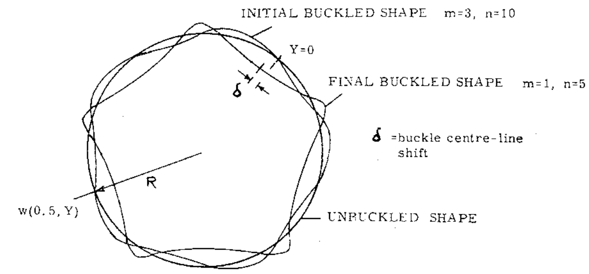

Fig. 4 End view of radial deflection pattern of shell.

can be said to have buckled into two circumferential half-waves and three axial half-waves. This particular shell in its final buckled shape developed into five large diamond-shaped buckles circumferentially, with only one axial half-wave. Since each buckle corresponds to the region photographed, it can be deduced that the shell initially buckled into 10 transverse half-waves. These results are shown in Fig. 4. For the given shell geometry, classical theory[5] predicts that $n = 10$ and $m = 12$. Disagreement occurs only in the axial wave number and can be credited to the effect of end-constraints. Theory assumes that the shell is sufficiently long so that end-conditions have negligible effect on the buckling mode.

Since theory assumes a periodic buckling pattern circumferentially and axially, it cannot be expected to yield a mode shape identical to the observed patterns at the beginning of buckling. However, it appears that the shells tested ($100 \leq R/t \leq 170, 2 \leq L/R \leq 6$) buckled elastically near the classical value with an initial wave shape approximated by the classical waveform, which rapidly degenerates into the large-deflection diamond-shaped buckles observed in the postbuckled configuration.

References

[1] Tennyson, R. C., "A note on the classical buckling load of circular cylindrical shells under axial compression," AIAA J. 1, 475–476 (1963).

[2] Annual Progr. Rept. 63-66, Institute for Aerospace Studies, Univ. of Toronto (October 1963).

[3] Frocht, M. M., *Photoelasticity* (John Wiley and Sons, Inc., New York, 1941), Vol. 1, Chap. 6.

[4] Sechler, E. E., *Elasticity in Engineering* (John Wiley and Sons, Inc., New York, 1952), Chap. 2.

[5] Timoshenko, S. P. and Gere, G. M., *Theory of Elastic Stability* (McGraw-Hill Book Co., Inc., New York, 1961), 2nd ed., Chaps. 10 and 11.

A Simple Device for the Qualitative Measurement of the Vortices

B. Lakshminarayana*
Pennsylvania State University, University Park, Pa.

Introduction

WHERE a vortex field is encountered, a qualitative assessment of the vortices would be most beneficial to the analytical treatment of the aerodynamic problem. Few attempts[1–3] have been made in this direction. Hopkins and Sorensen's[1] device consists of a cylinder, free to rotate about an axis perpendicular to the cylinder, placed in the flow field with its axis of rotation aligned in the freestream direction. The size and shape of the cylinder in combination with the bead thrust bearings used in the instrument are likely to introduce considerable error in the vorticity measurements.

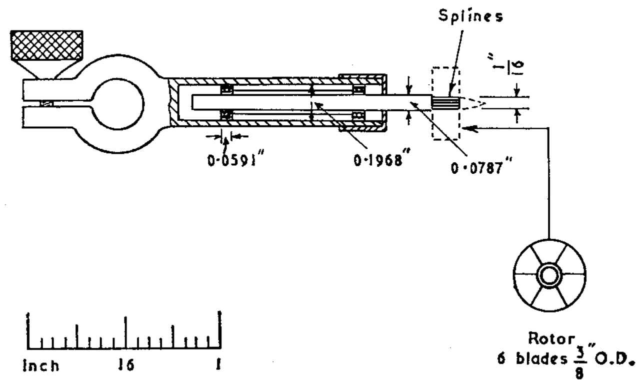

Fig. 1 Vorticity meter with miniature ball bearings.

Bobrik[2] has developed a combined pitot and vorticity meter. The latter consists of a thin plate mounted on pivots. The instrument is likely to encounter appreciable friction because of the pivoting.

Todd's[3] instrument, which has an air-floated spindle, provides very accurate results. The thickness of air cushion is 0.0005 in. This reduces the friction to almost nothing. Furthermore, there is an elaborate arrangement to measure the speed of the rotor. Remote measurements are possible from this instrument, but the manufacture and maintenance need considerable skill and care. The author's[4] experience with such an instrument was not encouraging in view of the care involved and the time consumed in taking measurements. This necessitated the design of a simple instrument (described below) without much sacrifice in sensitivity. The instrument is reliable and simple to operate.

Description of the Instrument

The instrument (Figs. 1 and 2) consists of a $\frac{5}{64}$-in.-diam spindle that runs on two miniature ball bearings. These are completely enclosed in a casing (Fig. 2) to prevent the accumulation of dust and the subsequent failure of the bearings. One end of the spindle has splines cut in it to hold the rotor in position. These rotors (Fig. 2) are filed from solid

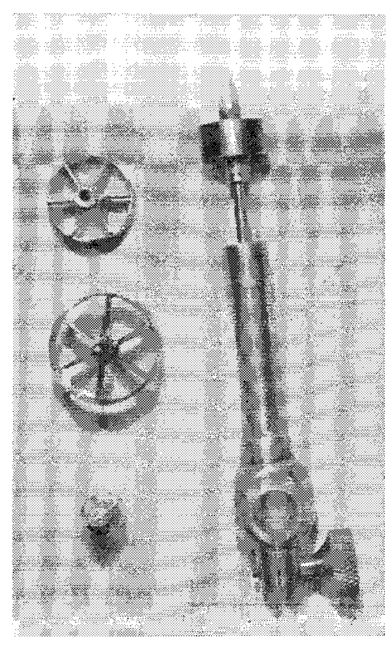

Fig. 2 Photograph of the vorticity meter and rotors.

Received March 16, 1964. The instrument mentioned in this note was developed while the author was a doctoral candidate at the Liverpool University. The author wishes to thank K. W. Todd for the helpful discussions. The ingenuity and skilled craftsmanship of W. Cowie enabled the manufacture of this instrument at Liverpool University workshop.

* Visiting Assistant Professor, Department of Aeronautical Engineering. Member AIAA.

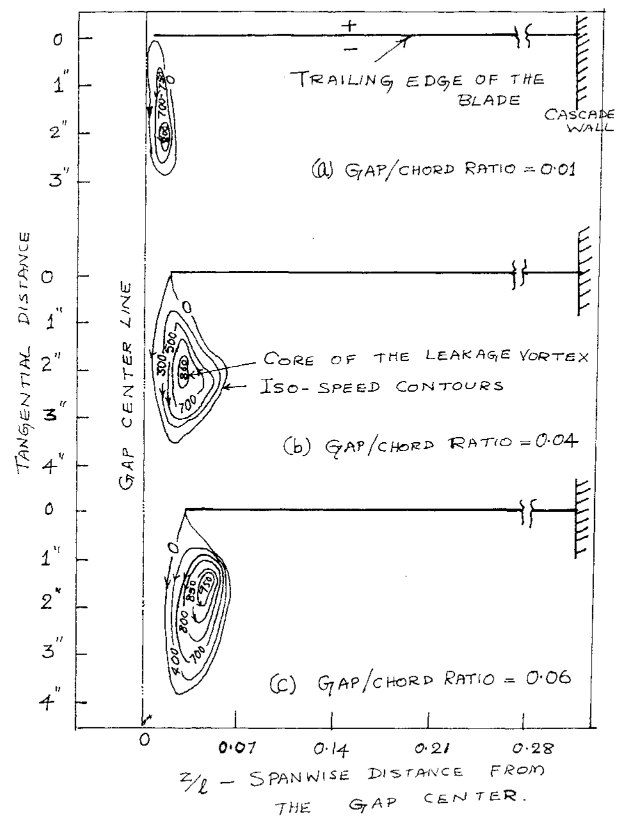

Fig. 3 Comparative strength and location of leakage vortices in a cascade as observed by a vorticity meter for various values of gap/chord ratio. Numbers on the iso-speed contours denote the revolutions per minute of the rotor, and the arrows indicate the sense of rotation.

aluminum and vary from a minimum of three blades to a maximum of six blades, one of $\frac{3}{16}$-, one of $\frac{1}{4}$-, one of $\frac{3}{8}$-, and one of $\frac{1}{2}$-in. diam. All of the rotors have removable shrouds around them. The blades are of aerofoil shape. This, in combination with suitable hub shape, prevents the rotation of the vane in irrotational flow. The constructional details are similar to those used by Todd.[3] The rotors are interchangeable and can be press-fitted to the spindle.

The speed of the rotor was measured by means of a stroboflash. The speed of rotation of a very thin nylon tuft attached to a thin wire was measured in a vortex field and compared with the speeds obtained from the vorticity meter. Nearly identical values confirmed the accuracy of the instrument.

Use of Vorticity Meter for Qualitative Assessment of Leakage Vortices in a Compressor Cascade

The instrument just described was used for measuring, qualitatively, the strengths of the leakage vortices in a compressor cascade at various gap/chord ratios. The instrument was mounted on a traverse gear[4] to enable measurements to be made at various spanwise and passage positions. The iso-speed contours so obtained for various gap/chord ratios are plotted in Fig. 3. The numbers on the contour denote the speed of the rotor in revolutions per minute, and the arrows denote the direction of rotation. The information provided by such contours was found to be very useful. The detailed investigation and conclusions derived therefrom are beyond the scope of this note.

References

[1] Hopkins, E. J. and Sorensen, N. E., "A device for vortex core measurement," J. Aeronaut. Sci. **23**, 396 (1956).

[2] Bobrik, M. J., "A simple method of estimating vortex intensity," J. Aerospace Sci. **27**, 957 (1960).

[3] Todd, K. W., "Some developments in instrumentation in air flow analysis," Proc. Inst. Mech. Engrs. (London) **161**, 213 (1949).

[4] Lakshminarayana, B., "Leakage and secondary flows in axial compressor cascades," Ph.D. Thesis, Liverpool Univ. (September 1963).

Use of Temperature-Sensitive Coatings for Obtaining Quantitative Aerodynamic Heat-Transfer Data

Robert A. Jones* and James L. Hunt*
NASA Langley Research Center, Hampton, Va.

Nomenclature

A = temperature of phase change
$\hat{A}$ = $(A - T_i)/(T_r - T_i)$
h = aerodynamic heat-transfer coefficient
k = thermal conductivity of model material
l = thickness of model surface or allowable depth of heat penetration
M = freestream Mach number
p = parameter used in Eq. (5)
r_d = nose radius
R = Reynolds number based on model diameter and freestream conditions
s = surface distance measured from center of face of model
t = time
t_d = thermal diffusion time
T = temperature
T_i = initial temperature of model
T_r = recovery or adiabatic wall temperature
x = distance normal to model surface
α = thermal diffusivity of model material

SINCE the time that a temperature-sensitive coating was first used at the NASA Langley Research Center for determining qualitative aerodynamic heating rates (early 1959[1]), a development program has been underway to perfect a technique whereby quantitative data could be obtained by this method. It was suggested in Ref. 1 that motion-picture photography could be used to map isotherms at successive times and that this information could be used to estimate the value of the heat-transfer rates. The coating used in Ref. 1 undergoes color changes at certain temperatures. These temperatures are known to be functions of time or heating rate.[1, 2]

Several methods for obtaining quantitative data with this type of coating have been considered. One method would be to measure the time required for the surface to reach the known temperature as indicated by the coating and to calculate the corresponding heat-transfer rate from the transient heat-conduction equation. Another method might be to test a reference body made of the same material as the model (e.g., a sphere for which the heat-transfer rates could be easily calculated) either simultaneously with the model or at the same test conditions, and then to assume that areas on the model and sphere which had color changes at equal times had equal surface temperatures. If the depth of heat penetration is small compared to model dimensions, then these areas would also have equal heat-transfer rates, as indicated by the solution to the heat-conduction equation for a semi-infinite slab. In Ref. 3, the reference sphere method was used with a color-change coating, and heat-transfer rates were determined for a rather complex shape.

Received March 16, 1964.

* Aerospace Engineer.