knowledged for allowing the utilization of the VKI-R$_1$ test rig for these measurements.

APPENDIX

1 Definition of Mass-Averaged Quantities:

$$\text{mean axial velocity} \quad \bar{V}_{ax} = \frac{\dot{m}}{\rho \cdot S} \tag{A1}$$

where $\dot{m}$ is the mass flow, ρ specific mass of air and S annulus area.

$$\text{radial velocity} \quad \bar{V}_r = \frac{1}{\bar{V}_{ax}} \int_0^1 V_r \cdot V_{ax} ds/t \tag{A2}$$

$$\text{tangential velocity} \quad \bar{V}_a = \frac{1}{\bar{V}_{ax}} \int_0^1 V_a V_{ax} ds/t \tag{A3}$$

$$\text{tangential velocity relative frame} \quad \bar{W}_a = U_r - \bar{V}_a \tag{A4}$$

$$\text{radial angle} \quad \alpha_r = \text{Arctg}\,(\bar{V}_r/\bar{V}_{ax}) \tag{A5}$$

tangential angle or outlet flow angle absolute frame

$$\alpha_2 = \text{Arctg}\,(\bar{V}_a/\bar{V}_{ax}) \tag{A6}$$

$$\text{relative frame} \quad \beta_2 = \text{Arctg}\,(\bar{W}_a/\bar{V}_{ax}) \tag{A7}$$

2 Correlation terms of pitch-wise velocity distributions V_i and V_j

$$\overline{V_i V_j} = \int_0^1 V_i V_j ds/t - \bar{V}_i \cdot \bar{V}_j \tag{A8}$$

3 Loss coefficient is defined as:

$$\bar{\omega} = 2 \int_0^1 (1 - V/V_{\max}) V/V_{\max} ds/t \tag{A9}$$

References

1 Whitfield, C. E., Kelly, J. C., and Barry, B., "A Three-Dimensional Analysis of Rotor Wakes," *Aero. Quart.*, Nov. 1972.

2 Evans, R. L., "Turbulence and Unsteadiness Measurements Downstream of a Moving Blade Row," ASME Paper No. 74-GT-73.

3 Lackshminarayana, B., "Three-Dimensional Flow Field in Rocket Pump Inducers. Part 1: Measured Flow Field Inside the Rotating Blade Passage and at the Exit," *Journal of Fluids Engineering*, TRANS. ASME, Vol. 95, Dec. 1973, pp. 567–577.

4 Kiock, R., "Turbulence Downstream of Stationary and Rotating Cascades," ASME Paper No. 73-GT-80.

5 Moussa, Z. M., and Eskinazi, S., "Directional Mean Flow Measurements Using a Single Inclined Hot Wire," *The Physics of Fluids*, Vol. 18, No. 3, Mar. 1975.

6 Hirsch, Ch., and Warzee, G., "A Finite Element Method for Flow Calculations in Turbomachines," Report V.U.B.—STR-5, Vrije Universiteit Brussel, Dienst Stromingsmechanica, July 1974.

7 Hirsch, Ch., "Unsteady Contributions to Steady Radial Equilibrium Flow Equations," AGARD Conference on Unsteady Phenomena in Turbomachines, Monterey, Calif., Sept. 1975.

DISCUSSION

D. P. Schmidt[2] and T. H. Okiishi[3]

We appreciate the clarity with which the authors have described their technique for measuring the complicated flow field downstream of an axial-flow turbomachine rotor. It appears as if the kind of detailed information discussed here, made available by advances in instrumentation and data acquisition and reduction procedures and a large amount of hard work, is likely to help all concerned to better understand turbomachine fluid mechanics. We would like to comment briefly on an aspect of rotor exit flow which is not mentioned in this paper but is important in certain instances. As observed by several individuals, Smith [8][4], Walker and Oliver [9], Lockhart and Walker [10], and Okapuu [11], a periodic flow pattern at the inlet of a rotor produced by an upstream stationary row of blades, for example, inlet guide vanes, stators, or nozzles, can influence the rotor exit flow significantly. As discussed by Savell and Wells [12, 13], the attenuation of such periodic variations by a rotor will depend on a number of variables including distortion wave length, rotor design characteristics such as chord length, solidity, loading, flow Mach number levels and angles, and blade angles and flow passage annulus shape. If the rotor exit flow is influenced strongly enough by a periodic inlet pattern, interesting results, such as the noise reduction described by Walker and Oliver [9], can be obtained through appropriate positioning of stationary blade rows.

We have found that the inlet noise level of a three-stage research compressor can be appreciably reduced by optimum circumferential positioning of the stationary blade rows (stationary periodic flow patterns) in the machine. Further, under conditions where rotor inlet periodicity persists at the rotor exit, our ensemble-averaged hot-wire data, while similar in shape to those presented in this paper, indicate that an exit flow pattern of a rotor preceded by a periodic flow can vary considerably with circumferential position, thus making necessary the determination of rotor exit flow patterns for several circumferential locations. Also, we have found that the ensemble-averaged rotor blade section exit flow pattern shape discerned with a hot-wire is dependent on whether a stationary hot-wire is used to periodically sample different portions of the moving rotor exit flow field, or alternatively, a rotor blade section is "frozen" in place each time it comes around via a shaft triggered pulse and the wire is traversed circumferentially as data are collected.

It seems apparent that when a rotor is preceded by a spatially varying flow field, for example, a rotor behind an inlet guide vane row, or a stator row or a turbine nozzle row, the extent of influence of this variation on the rotor exit flow field should be ascertained. If the upstream variations are appreciably transported by the rotor, then information about the precise location of the rotor exit flow measurements becomes important, i.e., the variation of rotor blade section exit flow with circumferential position is likely to be significant.

Additional References

8 Smith, L. H., Jr., "Wake Dispersion in Turbomachines," *Journal of Basic Engineering*, TRANS. ASME, Series D, Vol. 88, Sept. 1966, pp. 688–690.

9 Walker, G. J., and Oliver, A. R., "The Effect of Interaction Between Wakes From Blade Rows in an Axial Flow Compressor on the Noise Generated by Blade Interaction," JOURNAL OF ENGINEERING FOR POWER, TRANS. ASME, Series A, Vol. 94, 1972, pp. 241–248.

10 Lockhart, R. C., and Walker, G. J., "The Influence of Viscous Interactions on the Flow Downstream of an Axial Compressor Stage," *Proceedings of the 2nd International Symposium on Air Breathing Engines*, University of Sheffield, Royal Aeronautical Society, London, 1974.

11 Okapuu, U., "Some Results From Tests on a High Work Axial Gas Generator Turbine," ASME Paper No. 74-GT-81, 1974.

12 Savell, C. T., and Wells, W. R., "Rotor Design to Attenuate Flow Distortion; Part 1, A Semiactuator Disk Analysis," JOURNAL OF ENGINEERING FOR POWER, TRANS. ASME, Series A, Vol. 97, 1975, pp. 11–20.

[2] Graduate Assistant, Mechanical Engineering Department and Engineering Research Institute, Iowa State University, Ames, Iowa.

[3] Assoc. Professor, Mechanical Engineering Department and Engineering Research Institute, Iowa State University, Ames, Iowa.

[4] Numbers in brackets designate Additional References at end of discussion.

13 Savell, C. T., and Wells, W. R., "Rotor Design to Attenuate Flow Distortion; Part 2, An Unsteady Thin Airfoil Cascade Analysis," JOURNAL OF ENGINEERING FOR POWER, TRANS. ASME, Series A, Vol. 97, 1975, pp. 37-46.

Authors' Closure

The authors would like to thank Dr. Schmidt and Professor Okiishi for their interesting comments. We fully recognize the importance of the tangential location of the fixed hot-wire probe for the deduction of the blade-to-blade flow field. This problem has indeed generally not been quoted in early publications on sampled measurements where no reference to the relative position of the probe with respect to the stator blades has been given.

In a series of measurements not reported here we have deduced the relative position of the probe with respect to the rotor blade at the beginning of the sampling procedure with a stroboscope triggered with the sample pulses coming from the periodic averager. A test has also been performed to detect changes in the anemometer signal with tangential position. Small differences were observed but could be neglected in the case of our low-speed compressor since these were not significantly above the reproducibility error of the measurements. Moreover, the influence from upstream wakes on the sampled hot-wire signal is not always systematic when sampling all rotor passages.