Technical Comments

A Remark Concerning Engine-Inlet Distortion

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Introduction

THE effect of inlet d'stortion on axial compressor performance is both a current and complex problem. During the past 15 years the problem has been tackled by many investigators at both a practical engineering level and, for certain simplified geometries, at a sophisticated mathematical level. The essential stumbling block to predicting and controlling nonuniform and nonsteady flows into the compressor is lack of a suitable analytical framework upon which to base understanding of full-scale multistage compressor aerodynamics.

In view of this handicap, NACA undertook an extensive experimental investigation of the problem in the early 1950's. Reference 1 is one of the last reports of these tests, and contains a bibliography of much of the earlier NACA efforts. Beginning to appear at about this time were several analytical examinations of nonaxisymmetric inflow, based primarily on the actuator disk model of a compressor blade row. The work of Katz[2] is merely one example of this approach. Reference 3 is a more recent analysis containing an extensive bibliography of similar efforts. It is unfortunate that the comprehensive experimental efforts of Ref. 1 and the theoretical analysis of Ref. 2 were published about the same time. The references of each imply that neither was aware of the other's work. Although both Katz and Dunham included their own experimental data, which compared adequately with theory, these were obtained on low-tip-speed research compressor rigs. Perhaps partly for this reason, the adaptation by the engineering community of these theories (for improved mastery of engine-inlet distortion problems) has been slow in developing.

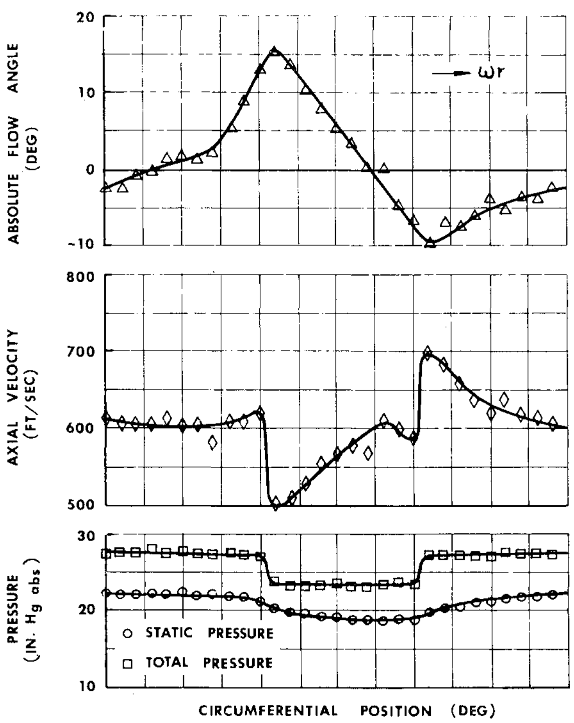

Fig. 1 Variation of flow properties with circumferential position just upstream of the rotor. Mean radius, design speed. (Adapted from Ref. 1.)

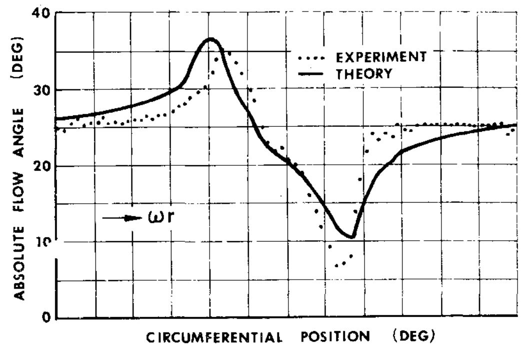

Fig. 2 Variation of absolute flow angle just upstream of rotor. (Adapted from Ref. 2.)

An Observation of Previous Results

The purpose of this comment is to emphasize the usefulness of the actuator disk results (as presented by Katz, for example) in interpreting some of the "full-scale" test data of Robbins and Glazer, obtained in a five-stage transonic compressor operated as a component of an existing jet engine. Attention is drawn here to only one facet of the distortion problem, namely, the upstream readjustment of the flow ahead of the rotor.

Figure 1, adapted from Ref. 1, is a plot of the measured flow parameters prior to the first rotor [no inlet guide vane (IGV)]. The solid lines have been faired in by the writer for emphasis. These data are for a 120°, pure, circumferential, total pressure well created by screens. They further pertain to a mean radius survey at design speed (1100-fps tip speed). Notice that a "square-wave" input in total pressure is reflected in some rather complicated variations for the other aerodynamic properties.

The interesting feature of Katz's work is the analytical prediction of precisely these shapes as shown in Figs. 2 and 3 which have been adapted from Ref. 2. It should be emphasized that the writer has not recalculated Katz's theory for the test conditions of Ref. 1. Thus Figs. 1 and 2 should not be mistaken as applying to precisely the same conditions. Nevertheless, both results apply to the common problem of a pure, circumferential, square-wave total pressure depression upstream of a rotor. The intention here is to stress the utility of the analysis in qualitatively depicting the essential features

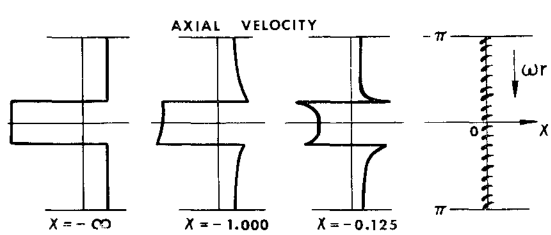

Fig. 3 Development of axial velocity circumferential profile at three stations upstream of the rotor. (Adapted from Ref. 2.)

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of the flow. The solid line of Fig. 2 is the analytical prediction of the absolute flow angle variation circumferentially. The points are Katz's own data for the same conditions, and are included to provide an indication of the quantitative agreement obtained. The similarity of the predicted flow angle variation and the test data shown in Fig. 1 should be noted. The analytic prediction of the buildup of the circumferential axial velocity variation is shown in Fig. 3. The quantity X is the axial distance from the rotor plane referenced to the rotor radius. The curve at $X = -0.125$ should be compared with the corresponding plot in Fig. 1.

Katz carried out the actuator analysis to the point of reducing the governing differential equations to algebraic equations. At this point the remainder of the solution was handled numerically. Thus a physica' explanation as to how the rotor tends to speed up the upstream low-velocity fluid (thus creating a static pressure well) is obscured. Nevertheless, this static pressure well thereupon tends to promote the cross flow that is responsible for the variation of absolute flow angle. It is interesting to note that speculation in Ref. 1 of streamlines bowing out around the distortion producing screen (Fig. 6a of Ref. 1) is not necessarily completely correct. This is attested to by Katz's analysis, which depicts a similar flow angle distribution, yet the analysis is not dependent on any "screen blockage" at some finite distance upstream of the rotor. The flow picture appears to be more nearly that deduced by Pearson and McKenzie[4] by two independent arguments.

Concluding Remarks

Although the physical cause of the flow behavior is somewhat unclear, its implications are less so. As noted by Dunham, quantifying inlet distortion solely on the basis of total pressure data (or velocity data) as recorded behind an isolated inlet can lead to significant misrepresentations of the flowfield which the first stages of a compressor will encounter. Rather, if only isolated inlet total pressure data are available, some estimate of the static pressure disturbance due to the rotor must be made before rotor velocity fields can be inferred. The actuator disk technique seems to form a good starting point from which such estimates may be made.

References

[1] Robbins, W. and Glaser, F., "Experimental investigation of the effect of circumferential inlet flow distortion on the performance of a five-stage axial flow research compressor with transonic rotors in all stages," NACA RM E57J17 (March 5, 1958).

[2] Katz, R., "Performance of axial compressors with asymmetric inlet flows," Air Force Office of Scientific Research TR-58-8 (June 1958).

[3] Dunham, J., "Nonaxisymmetric flows in axial compressors," Institution of Mechanical Engineers, Mechanical Engineering Science Monograph 3 (October 1965).

[4] Pearson, H. and McKenzie, A., "Wakes in axial compressors," J. Roy. Aeronaut. Soc. **63,** 415–416 (July 1959).