the two papers by Henderson and Fleeter contain the fruits of much hard work and careful experimentation. The approach adopted, in which simple disturbances are allowed to interact with a downstream blade row, may be termed traditional. The analytical method with which the measurements are compared was written by Smith (1972) more than twenty years ago. The authors were therefore most unfortunate to publish these papers when the work by Manwaring and Wisler (1993) was about to appear, since they were unable to adapt their papers to either the new measurements and computation methods used by Manwaring and Wisler or to the conclusions drawn. Manwaring and Wisler, in a very extensive and impressive paper, showed unsteady measurements made in a low-speed compressor and turbine, each of which had geometry and loading representative of current aeroengine practice. These measurements were compared with a total of five different unsteady prediction methods, several very recent and one of which is nonlinear. Most significantly it appears that a linear approximation for the unsteady flow is good in a wide range of flows and the discrepancies found in the past are not associated with linearization, even for the interaction of closely spaced blade rows. It seems to me that the entire topic has been altered by Manwaring and Wisler's paper.

I therefore wonder whether Dr. Henderson and Professor Fleeter would like to modify the abstracts and conclusions of their papers in the light of Manwaring and Wisler. Would they, for example, like to modify their conclusion in Part 1 concerning the ability of linear unsteady aerodynamic theory to predict the unsteady behavior. Similarly the conclusion regarding the linear theory in Part 2 could with advantage be altered. I would also like to suggest that the term "linear-gust" be dropped. As Manwaring and Wisler show, the cases that allow reasonable prediction with the very simple theory are those having a primarily vortical inlet perturbation and the amplitude of the perturbation does not seem to be the limiting quantity. When potential interactions are present, as they generally are with loaded blade rows closely spaced, a more complete specification of the inlet conditions is necessary, but linear theory can still predict reasonably well what is measured.

The presence of a significant potential velocity perturbation is revealed by the phase angle between the streamwise and normal components of the combined velocity perturbation (the sum of the potential and vortical perturbations). A purely vortical disturbance corresponds to a perturbation in velocity parallel to the undisturbed flow; such a disturbance requires that the streamwise and normal components to be either in phase or in antiphase, i.e., 0 or 180 deg apart. The streamwise and normal components for a potential perturbation are 90 deg apart. If the amplitude of the potential disturbance is very small the phase angle between the streamwise and normal components of the combined velocity perturbation will approximate 0 or 180 deg.

Authors' Closure

The authors concur with the intent of the statements of Wisler and Cumpsty. The confusion is a matter of semantics. At the time of our paper, Giles decomposition of the forcing function into a vortical and potential part had not been published and classical linear unsteady aerodynamic theories did not include provisions for decomposing measured forcing functions into vortical and potential components. The authors were certainly aware of linear theories that modeled vortical disturbances and potential disturbances.

However, the method of decomposing a measured forcing function into these components was not widely known. At the time, the authors and much of the unsteady aerodynamics community considered theories that modeled only wakes or vortical disturbances as the state-of-the-art since this was considered to be the dominant forcing function for a downstream blade row. Giles provided a much needed contribution: a method of decomposing a measured forcing function, thereby enabling the unsteady force acting on a downstream blade row to be calculated from the individual vortical and potential parts.

The objective of our research was to point out the shortcomings of the vortical-only analyses. Henderson and Fleeter (1991) introduced the importance of the gust or disturbance component phase, and showed experimentally that when this phase angle was 0 or 180 deg, the velocity vectors were parallel to the time-averaged flow field and that no static pressure gradient, i.e., potential field, was present, the requirement for a vortical-only disturbance. When the disturbance component phase angle is neither 0 or 180 deg, the disturbance velocity vectors were not parallel to the time-averaged flow field and a static pressure gradient, i.e., potential field, was measured. Our results show that linear theories that model vortical disturbances are valid when a pure vortical disturbance is present, but the vortical-only linear theory is lacking when the disturbance contains a potential component. In fact, we suggested that the analysis could be improved by modeling the potential component of the gust and incorporating it into the analysis. Had we been privy to the Giles decomposition method, a better correlation of the resulting unsteady pressure and lift on the downstream vane row would have been obtained by superpositioning of the vortical and potential solutions, obtained for example from Smith (1972) or other unsteady aerodynamic analyses.

It should be noted that Giles splitting of the measured gust into vortical and potential components was implemented by Manwaring and Wisler utilizing unsteady velocity data only. However, although vortical gusts only involve velocity fluctuations, potential gusts are characterized by static pressure fluctuations as well. Thus the data analysis technique of Manwaring and Wislers attributed any violation of the vortical gust constraints to the presence of an unsteady potential perturbation. However, these constraints can be violated by effects not modeled by linear theory, such as momentum diffusion in the wake. In addition, any experimental error that affects the measured unsteady velocity field directly affects the calculated unsteady potential field. Thus, linear theory gusts reconstructed from the components calculated using only velocity fluctuations may yield erroneous static pressure perturbations.

References

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