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## Acoustic Wave Analysis

A study has been made of the mechanism of generation of acoustic waves in a rotor/stator combination with a comparison of the relative strengths of waves generated by different sources in a centrifugal pump.

The velocity leaving a blade row is nonuniform due to both the gradients in the region designated as the potential flow and the viscous boundary layers along the blade surfaces, but is periodic in the mean, the period extending from blade to blade. This nonuniform velocity would appear to a downstream blade row in relative motion to the upstream blade row as a periodic unsteady velocity field which produces unsteady pressures on the downstream blades. Acoustic waves are generated by both the unsteady velocity field at the entrance of the blade row, and the unsteady blade pressure loads on the downstream blades due to the unsteady velocity field.

A primary effort was made to indicate the relative importance of the acoustic waves generated by these two related mechanisms. Before this could be done, the amplitude of the unsteady pressures on the downstream blade row had to be calculated. In the literature, these unsteady pressures have been investigated as a function of four effects which have been designated as the circulation, blade thickness, wake, and wake distortion effects. The analytical development of each is based primarily on the two-dimensional theory of the unsteady flow about a thin airfoil. Only the viscous wake effect was adopted for use in the current program, a computer program being written to calculate the unsteady pressures on a blade due to an approaching arbitrary wake velocity.

The generation of waves into a medium surrounding a plate, by unsteady forces on the plate surface, is a coupled problem requiring solution of the equation of motion for transverse displacement of the plate, as well as solution of the wave equation in the medium. The two solutions are coupled by the boundary conditions which require continuity of both the normal velocity and pressure across the fluid-plate interface. To estimate the order of magnitude of the wave amplitude generated by this coupled motion, a simpler example problem was considered. This example problem consisted of a plate of infinite extent and uniform thickness. The fluid medium above the plate was assumed to be coupled to the plate motion, but the fluid below the plate was not. The coupled equations were solved, yielding for this example problem an expression for the amplitude of the waves generated by an unsteady force on the plate.

To estimate the order of magnitude of the amplitude of the waves generated by an unsteady velocity boundary condition at the inlet of a blade row (or duct), a second simple example was assumed. This example consisted of a straight, infinite, rectangular duct with a simple harmonic velocity at its inlet boundary, which velocity was uniform in the plane of the duct. The wave equation was solved to yield the generated wave amplitude.

Using data for a standard centrifugal pump, the amplitudes of the oscillations generated by these two mechanisms were computed and compared. This comparison indicated that the amplitude of the waves generated by the pressure loading on the blades (which in this case were volute tongues), were less by a factor of $10^4$ to $10^5$ than those generated by the velocity boundary condition. Thus, the primary mechanism for generation of acoustic waves in the centrifugal pump, due to

(continued overleaf)

the rotor/stator interaction, is seen to be that of an unsteady source at the entrance of the blade row as represented by the unsteady velocity field.

**Note:**

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No patent action is contemplated by NASA.

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