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AN EXPERIMENTAL STUDY OF THE PROPERTIES OF SURFACE PRESSURE FLUCTUATIONS IN STRONG ADVERSE PRESSURE GRADIENT TURBULENT BOUNDARY LAYERS

1 December 1982 to 31 January 1984

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INTRODUCTION

Noise generated by helicopter and turbomachine rotors is a nuisance that designers would like to predict and to minimize within other design constraints. Brooks and Schlinker (1983) reviewed some recent research on helicopter rotor noise and discussed the categories of noise sources. Their review showed that there is a clear need for experimental information on blade self-noise generation by strong adverse-pressure-gradient attached turbulent boundary layers and by separated turbulent boundary layers that accompany stall. This project has provided such experimental data.

Brooks and Hodgson (1981) showed that starting with given surface pressure fluctuation spectra and convective speeds, then radiated noise due to the turbulent boundary layer can be predicted. Furthermore, if the surface pressure fluctuation spectra and convective speeds can be related to the turbulent flow structure, then turbulent boundary layer flowfield calculation methods could be used when designing rotors to estimate the needed surface pressure fluctuation information.

Thus, a key requirement for this noise calculation procedure is knowledge relating the flowfield structure to the surface pressure fluctuation structure. Unfortunately there are few measurements of both flowfield structure and surface pressure fluctuation structure for a given flow, especially in the presence of adverse pressure gradients. Since only recently have detailed flowfield measurements been made of nominally two-dimensional separated turbulent boundary layers (Simpson et al., 1981 a, b, c; 1983 a, b), this research at SMU (now at VPI&SU) is the first to obtain information on the surface pressure fluctuations for a well-documented velocity flowfield.

SUMMARY OF ACCOMPLISHMENTS DURING THIS GRANT PERIOD

During this grant period there were several significant achievements:

1. Experimental apparatus and techniques were developed. Two Sennheiser Model MKH-110 Instrumentation Microphones were calibrated with a Genrad Model 1956 Sound-level calibrator between 125 Hz and 4 KHz. A piston and cylinder calibrator was built and used for calibration between 0.5 Hz and 30 Hz. The voltage/pressure sensitivities of the two microphones were nearly equal (~ 40 Pa/volt) and were closely equalized by amplifying one output signal.

Plastic housings for the microphones were constructed, each with a 0.029 inches diameter pinhole. The resulting frequency response curves from calibrations indicate that the microphone sensitivity is reduced for frequencies above 2 KHz. Since the pressure fluctuations occur at frequencies below this value, there is no effective reduction in microphone sensitivity.

The microphones and housings are supported directly from the concrete flooring to avoid wind tunnel vibration. Strips of thin cellophane tape are used to make the test surface continuous between the test wall and the plastic housings.

In this wind tunnel, there are streamwise acoustic disturbances that propagate downstream from the blower-muffler-plenum-honeycomb-screen sections into the contraction. The contraction and test section act as wave guides for these disturbances, so that at any streamwise location the streamwise acoustic waves are the same across the test section at any instant in time. The turbulent-flow-produced spectrum is the same across the test section because the mean flow and mean square turbulence structure are two dimensional across the flow (Simpson et al., 1980). The acoustic and turbulent signals are uncorrelated, since the turbulence-produced signal is due to the locally-produced turbulent velocity field. These observations permitted decomposition of the surface pressure fluctuation signals into the propagated acoustic part and the turbulent-flow-generated portion.

The two microphones and housings are located equidistant about the tunnel centerline and far enough apart spanwise across the test section so that the turbulent signals are uncorrelated. The minimum distance between sensors to produce a zero cross-correlation is about 1/2 δ, where δ is the shear layer thickness (Simpson et al., 1977). Physically this means that individual large-scaled motions are no more than about δ in spanwise extent and are uncorrelated to one another. By subtracting or adding the two microphone signals, the symmetric and anti-symmetric acoustic contributions are eliminated, respectively.

To determine the convective wave speed of the turbulent contributions, the two microphones were spaced a small distance apart in the streamwise direction and correlations were obtained.

2. Upstream of detachment, the turbulent surface pressure spectra contained a clear n^{-1} (n is frequency) variation, as observed by Brooks and Hodgson (1981) and others (Willmarth, 1975). The rms pressure fluctuation to time-averaged wall shearing stress ratio ($\sqrt{\overline{p^2}}/\tau_w$) varies from 3 to 6. A slightly better normalizing shearing stress is the maximum shearing stress in the boundary layer $-\rho\overline{uv}_{max}$, resulting in $3 < \sqrt{\overline{p^2}}/(-\rho\overline{uv}_{max}) < 4$.

3. Downstream of the beginning of separation, $\sqrt{\overline{p^2}}/(-\rho\overline{uv}_{max})$ increases. The surface pressure spectra lose the n^{-1} variation. A distinct peak in the nF(n) distribution occurs at progressively lower frequencies for increasing streamwise locations. At higher frequencies a n^{-2} variation of nF(n) was observed.

4. The streamwise wavespeeds for only the low frequency portion of surface pressure fluctuations was measured, since sensor spacings less than 1.4 cm could not be obtained.

5. Measurements of turbulent velocity spectra and wavespeeds were made with two hot wire anemometers separated ΔX apart in regions with no flow reversal. No periodic flow velocities were observed, indicating no periodic flow unsteadiness that would contribute to surface pressure fluctuations. Well-behaved -5/3 power law inertial subranges were observed. These measurements further document the separated flow of Simpson et al. (1981 a, b) and make it a useful test case for computational efforts.

6. An article for submission to the Journal of Fluid Mechanics is being prepared to complement earlier articles of this separated turbulent flow. Detailed data tabulations will be included in a technical report, currently under preparation.

FUTURE RESEARCH

As discussed above, measurements of surface $\sqrt{\overline{p^2}}$, p spectra, and turbulent convective speeds have been made for the one separating flow where detailed turbulent velocity structure measurements have already been obtained. Naturally, the data from this one flow are insufficient to develop correlations with the turbulence structure and to have confidence in these correlations. In a follow-on grant, velocity profile and surface pressure fluctuation will be obtained for several zero pressure gradient, favorable pressure gradient, adverse pressure gradient, and separating turbulent boundary layers to correlate the velocity structure with the pressure fluctuation structure.

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