DNN Emisley
NAG1-446

IN-34

63686
11P.

FINAL REPORT

to

The National Aeronautics and Space Administration
Langley Research Center

on

Grant NAG-1-446

entitled

AN EXPERIMENTAL STUDY OF THE PROPERTIES OF SURFACE PRESSURE FLUCTUATIONS FOR SEPARATING TURBULENT BOUNDARY LAYERS

15 March 1984 to 15 September 1986

Roger L. Simpson
Roger L. Simpson

Professor of Aerospace Engineering
Principal Investigator

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061
12 November 1986

 The NASA Technical Officer for this grant is Thomas F. Brooks, NASA Langley Research Center.

(NASA-CR-180295) AN EXPERIMENTAL STUDY OF THE PROPERTIES OF SURFACE PRESSURE FLUCTUATIONS FOR SEPARATING TURBULENT BOUNDARY LAYERS Final Report, 15 (Virginia Polytechnic Inst. and State Univ.) 11 p N87-27124

Unclas
G3/34 0063686

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 program is the first to obtain information on the surface pressure fluctuations for well-documented separating velocity flowfields.

SUMMARY OF ACCOMPLISHMENTS DURING THIS GRANT PERIOD

This grant followed NASA Grant NAG-317, which resulted in the publication of Simpson _et al._, (1984, 1986). This grant made use of the experimental approaches and techniques developed during the earlier grant. During this grant period there were several significant achievements:

1. Additional experimental apparatus and techniques were developed. A Data Precision 6000, 4 channel, universal waveform analyzer was purchased. This 14 bit microprocessor unit which contains dual floppy disks, is programmable and capable of performing all required data reduction operations with acquired data. The data stored on disks can be read directly by the new IBM PC.

In order to obtain high quality space-time correlations and spectra, miniature and sensitive pressure fluctuation transducers were required. Knowles Electronic Models BT-1753 and BT-1755 subminiature condenser microphones were selected because of their size (5.6 mm x 7.92 mm x 2.28 mm) and sensitivity (10 mv/Pa). These microphones contain internal amplification and have good shock and vibration resistance.

Two of the Model BT-1755 microphones are used in a plexiglas wall unit, with the position of one microphone being adjustable with respect to the second. This permits space-time correlations of the surface pressure fluctuations with spacings between 0 and 10 mm. The port of each of these microphones has an outside diameter of 1.4 mm. A screen cover used on ENDEVCO Model 8514-10 piezoresistive pressure transducers was mounted on the port opening, subdividing the opening area into a number of smaller areas. While these covers do not improve the spatial resolution of the transducers, they reduce the wavelengths of pressure fluctuations that are resonant with the port opening dimension. The effect of this resonant amplification was observed by Bull and Thomas. By reducing the wavelength at this resonance, the effect is moved into a higher frequency range where there are much lower natural amplitudes and contributions to the mean square pressure fluctuation.

A Model BT-1753 microphone with a port opening diameter of 0.51 mm is also mounted in this plexiglas unit. This microphone has a slightly different frequency response than the Model BT-1755, so different results with improved spatial resolution are being obtained.

For calibration purposes, a 4' x 4' x 4' anechoic chamber was constructed using SONEX sound absorbing sheets on the interior. This chamber permits direct calibrations with instrumentation microphones. Shinpaugh (1986) calibrated these microphones at VPI&SU in the low frequency range of 10-125 Hz, which was not presented by the manufacturer.

2. As originally proposed for the year March 15, 1984 through March 15, 1985, surface pressure fluctuation data for zero-pressure-gradient and accelerating turbulent boundary layers were obtained.

Two zero-pressure-gradient turbulent boundary layers were examined with freestream velocities of 72 fps and 105 fps. The freestream velocity for the accelerating turbulent boundary layer varied from 50 fps to 100 fps. Mean and fluctuation velocity profiles and streamwise velocity spectra and wavespeeds were obtained for momentum thickness Reynolds numbers up to 18000 for the zero-pressure-gradient case and up to 4000 for the favorable-pressure-gradient case (Ahn, 1986). The wall shearing stress was estimated from a Clauser plot of the near wall data.

The Knowles Electronics Models BT-1753 and BT-1755 subminiature condenser microphones that are mounted in each of two plexiglas wall units were used for the surface pressure fluctuation measurements.

Surface pressure spectra for each flow were obtained with the Model BT-1753 microphones, with a 0.51 mm pinhole opening. Cross-spectra, coherence, and phase were obtained in streamwise and spanwise directions using two of the Model BT-1755 microphones, one of which was moveable with respect to the second. Data were obtained at 10 different spacings between 2.5 mm and 10 mm.

The results for the surface pressure fluctuation spectra are presented by McGrath in his M.S. thesis nondimensionalized by different groupings of the outer and inner boundary layer variables. The grouping using the variables, U_e, τ_w and δ_1 collapse the spectra for the low to middle range of frequencies for most test cases. The grouping using the inner variables, U_τ and ν, collapse the spectra for the middle to high range of frequencies for all test cases. The value of p'/τ_w was near 3.8 and 2.8 for the smallest values of d^+

in the zero and favorable pressure gradient flows respectively. The spectral data were corrected using the correction developed by G. M. Corcos. The pinhole effect suggested by Bull and Thomas was not observed.

The coherence exhibits a decay that is not exponential in some cases, but the Corcos similarity parameters $\omega\Delta x/U_c$ and $\omega\Delta z/U_c$ collapse the data for all test cases. The ratio of U_c/U_e shows an increase with increasing $\omega\delta_1/U_e$ up to a certain value of $\omega\delta_1/U_e$, where U_c/U_e becomes constant. This was observed in the present results for both streamwise pressure gradient flows.

The experimental results presented show improved resolution and correlation over previous research.

3. As originally proposed, during the March 15, 1985 to Sept. 15, 1986 period much velocity profile data were obtained for two separate turbulent boundary layers for which surface pressure fluctuation information was obtained. These surface pressure fluctuation and velocity profile data and those obtained by the investigator earlier (Simpson, et al., 1986) revealed much about the velocity-pressure fields relationships. NASA-Langley plans to use a boundary layer calculation method to compute mean velocity profile parameters, such as the maximum shearing stress τ_M, δ, δ^*, and θ for practical cases. Surface pressure fluctuation spectra and convective speeds from cross-spectral measurements are related to these scaling parameters. Consequently, with sufficient data to define these relationships, the radiated noise due to the turbulent boundary layer can be calculated.

Thus, enough velocity profile data are needed for each flow case to define τ_M, δ, δ^*, and θ. The surface pressure fluctuation spectra and cross-spectra can be correlated using outer scaling variables U_∞, δ, δ^*, and θ for low frequencies and inner scaling variables U_M and ν/U_M based on the maximum shearing stress τ_M for higher frequencies. Convective speeds from surface pressure fluctuations at various frequencies can be related to U_M and U_∞. Single-wire and cross-wire hot-wire anemometers and a laser anemometer were used to make the velocity measurements. The wall shearing stress τ_w was estimated from a Clauser plot of the near wall data upstream of detachment.

No valid hot-wire measurements can be obtained in the reversed flow zone of separated flows, so in addition to the laser anemometer the "thermal tuft" developed and used by the principal investigator was used to measure the fraction of time that there is backflow, γ_{pu}. This simple instrument is easy to use and provides important data on the state of a separating flow.

The earlier separating turbulent boundary layer (Simpson, _et al._, 1986) has a momentum thickness Reynolds number of about 13700 at the beginning of detachment. Since the length and velocity scales of the near wall and the outer region turbulent motions affect surface pressure spectra and their correlations for turbulent boundary layers, data need to be obtained for different ratios of near wall and outer region length scales ($\frac{\nu}{U_M \delta}$) and velocity scales (U_M/U_∞). At higher momentum thickness Reynolds numbers, the ratios of length scales and velocity scales are lower and velocity and surface pressure spectra show the effect of Reynolds number. Consequently, measurements were made on two higher Reynolds number strong adverse pressure gradient flows in order to obtain information on the effect of Reynolds number.

In one strong-adverse-pressure gradient flow the freestream velocity was increased to 100 fps with the test section upper wall in the same position as in the earlier research (Simpson, et al., 1986). A momentum thickness Reynolds number flow of about 19,000 was produced near detachment. For the second flow, the same free-stream velocity distribution and test section contour as used in the earlier research was used, but a leading edge single roughness element was placed spanwise across the two-dimensional flow. This produces a momentum thickness Reynolds number flow near 27,000 at the beginning of detachment with the ratio of length scales and the ratio of velocity scales about half those examined in the other above-mentioned test flows.

For these latter two flows, the flow detaches and then reattaches some distance downstream. The surface pressure fluctuations were measured in the detached flow zone for these flows and correlated with the separated shear layer thickness and length of the detached flow zone in the manner suggested by Mabey.

4. Articles for submission to the Journal of Sound and Vibration and the Journal of Fluid Mechanics are being prepared to complement earlier articles on separated turbulent flow. Detailed data tabulations are included in technical reports (McGrath, M. S. Thesis; Ahn, M. S. Thesis; Simpson and Shinpaugh, under preparation).

FUTURE RESEARCH

It is clear that turbulent pressure fluctuations are produced by turbulent velocity fluctuations. Detailed simultaneous measurements of all of these fluctuations are needed to determine in more detail the structural relationships between velocity and pressure fields. Although some measurements have been made for unseparated flows, none have been made for separated flows.

REFERENCES

Ahn, S., (1986), "Sonic Unsteady Features of Turbulent Boundary Layers," M. S. Thesis, Dept. of Aerospace and Ocean Engrg., VPI&SU.

Brooks, T. F. and Hodgson, T. H., (1981), "Trailing Edge Noise Prediction from Measured Surface Pressures," J. Sound and Vibration, 78, pp. 69-117.

Brooks, T. F. and Schlinker, R. H., (1983), "Progress in Rotor Broadband Noise Research," Vertica, 7, pp. 3f.

Shiloh, K., Shivaprasad, B. G., and Simpson, R. L., (1981), "The Structure of a Separating Turbulent Boundary Layer: Part 3, Transverse Velocity Measurements," J. Fluid Mech., 113, pp. 75-90.

Shinpaugh, K., (1986), "Low Frequency Calibration of Knowles BT-Series Microphones," Internal Report, Dept. Aero. and Ocean Engrg., VPI&SU.

Simpson, R. L. and Shivaprasad, B. G., (1983), "The Structure of a Separating Turbulent Boundary Layer: Part 5, Frequency Effects on Periodic Unsteady Freestream Flows," J. Fluid Mech., 131, pp. 319-339.

Simpson, R. L., Chew, Y.-T., and Shivaprasad, B. G., (1980), "Measurements of a Separating Turbulent Boundary Layer," Project SQUID Report SMU-4-PU; NTIS AD-A095 252/3.

Simpson, R. L., Shivaprasad, B. G., and Chew, Y.-T, (1981 a, b), "The Structure of a Separating Turbulent Boundary Layer: Part 1, Mean Flow and Reynolds Stresses; Part 2, Higher Order Turbulence Results," J. Fluid Mech., 113, pp. 23-74.

Simpson, R. L., Shivaprasad, B. G., and Chew, Y.-T., (1983),"The Structure of a Separating Turbulent Boundary: Part 4, Effects of Periodic Freestream Unsteadiness," J. Fluid Mech., 127, pp. 219-261.

Simpson, R. L., Ghodbane, M., and McGrath, B., (1984), "An Experimental Study of Surface Pressure Fluctuations in a Separating Turbulent Boundary Layer," to be published in NASA CR series.

Simpson, R. L., Ghodbane, M., and McGrath, B., (1986), "Surface Pressure Fluctuations in a Separating Turbulent Boundary Layer," in press, J. Fluid Mech.

PUBLICATIONS AND PRESENTATIONS DURING THIS PERIOD

1, 2. Simpson, Ghodbane, and McGrath (1984, 1986) in Reference list.

3. "An Experimental Study of Surface Pressure Fluctuations in a Separating Turbulent Boundary Layer," 5th Symposium on Turbulent Shear Flow, Ithaca, NY, August 7-9, 1985; presented at NASA-Langley, Nov., 1985.

4. "Some Features of Surface Pressure Fluctuations in Turbulent Boundary Layers with Zero and Favorable Pressure Gradients," manuscripts submitted to NASA for consideration as NASA-CR report; also M. S. Thesis of B. E. McGrath, 1985.

5. Ahn, (1986) in Reference list.

PERSONNEL

The following persons contributed to this research:

Dr. R. L. Simpson	Professor of Aerospace Engineering VPI&SU, Blacksburg, VA 24061
Dr. N. Agarwal	Research Associate VPI&SU
Mr. B. McGrath	Graduate Research Assistant VPI&SU; received M.S. Degree, 1985
Mr. S. Ahn	Graduate Research Assistant VPI&SU; received M.S. Degree, 1986.
Mr. K. Nagabushana	Graduate Research Assistant VPI&SU