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FUNDAMENTAL STUDIES OF TURBULENT WALL PRESSURE FLUCTUATIONS WITH APPLICATIONS TO ADVANCED ACOUSTIC SENSOR SYSTEMS

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25 July 1989

Final Report

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Introduction

This is the final technical report of work done under ONR contract N00014-83-K-0227, MIT OSP 93019, 93022, 94341, 95890, 95891. The work was begun on 1 November 1982 and completed on 30 April 1986. Publications, technicals reports, and theses completed under this task are indexed at the end of this report. They are referenced by author and date in the body of the report.

Computation of the Navier-Stokes Equations for Turbulent Channel Flow

The full Navier-Stokes equations were solved for turbulent channel flow using a pseudo spectral method with no closure assumption (direct simulation). Computer solutions obtained by MIT were then analyzed at the Naval Research Laboratory (NRL). Results were reported in Handler *et al.* (1984), Handler *et al.* (1985), Hanson *et al.* (1987), and in the thesis by Bullister (1987). Comparison were made with experiments in turbulent boundary layers for the level of RMS wall pressure and the wall pressure frequency spectrum. Good agreement was obtained for RMS pressure, but limitations on timesteps did not permit resolving high frequencies. Pressure convection speeds compared well with those obtained from cross-spectral measurements. The low wavenumber computations for the channel flow could not be compared with experimental values obtained in boundary layers as the low wavenumber components for channel flow do not vanish as the square of the wavenumber as they do for incompressible turbulent boundary layer flows. Conditional sampling of the computed wall pressure results were carried out using the variable interval time averaging (VITA) technique. Comparison of channel flow experiments was made for the fluctuating streamwise velocity component when the event consisted of a strong positive time slope of this velocity. Good agreement was obtained with experiment even though the Reynolds number, based upon channel half-width in the calculation, was only 5,000 whereas most experimental data were at much higher Reynolds number. Further exploration of conditional sampling of computated results shows considerable promise of enhancing our knowledge of turbulent shear flows. Certain conditional averages can be carried out on computational results which could be difficult, if not impossible, to carry out experimentally.

Conditional Average Measurements

Her (1986) determined experimentally the relation between high amplitude wall pressure fluctuations and flow structures in the near wall region of a zero pressure gradient boundary layer flow using conditional averaging techniques. He found that shear layer structures in the buffer region are to a high degree responsible for the generation of large positive wall pressure peaks. Significantly, he found that the pressure peak amplitude scaled linearly with velocity peak amplitude of the corresponding flow structure, indicating a dominant role is played by the turbulence-mean shear interaction in generating wall pressure.

Analytical Studies of Flow Noise

Akylas and Toplosky (1986) determined the sound radiated from a growing Tollmien-Schlichting wave. Haj Hariri and Akylas (1985a) showed that for low Mach numbers the nature of the singularity in the wavenumber-frequency spectrum of wall pressure is not influenced significantly by variation in the mean velocity profiles. Haj Hariri and Akylas (1985b) showed that the contribution of fluctuating wall shear stress at the wall to boundary layer noise is such as to remove the spectral singularity. It also contributes to the radiation, however, this contribution is small compared to the quadrupole contribution of the boundary layer proper at low Mach numbers and high Reynolds numbers typical of applications.

Low Wavenumber Wall Pressure Measurements

Gedney and Leehey (1984) carried out measurements of the low wavenumber portion of wall pressure during transition on a flat plate. A six element linear array of flush-mounted microphones was used for the measurement. Somewhat surprisingly, the results showed no significant difference between this measurement and that for a fully turbulent boundary layer.

Receptivity of a Laminar Boundary Layer to Sound Excitation

Lee (1985) carried out a finite difference computation of the excitation of a laminar boundary layer by the equivalent of a long wavelength sound wave. He used a rectangularly partitioned domain and imposed the effect of a mean pressure gradient on the outer flow boundary in his computation. His results showed that a Stokes wave developed whose decay was markedly decreased by the imposition of the mean adverse pressure gradient. However, this wave failed to convert significantly to a Tollmien-Schlichting wave. It suggested strongly that a change in body geometry is necessary to achieve the desired wavenumber conversion. Leehey *et al.* (1985) summarized the work at MIT on the receptivity of laminar boundary layers to various forms of external disturbances.

Structural Response to Turbulent Boundary Layer Excitation

Petri (1987) carried out a numerical computation of the response of a line-stiffened fluid-loaded elastic plate to a convecting pressure field. He demonstrated that a outer decoupler was effective in reducing the scattering of the convecting field by a line stiffener. His results also showed that the low wavenumber component of the wall pressure dominated in every case over the convective ridge component of wall pressure in the generation of structural vibration and subsequent reradiation.

Concluding Remarks

Four Ph.D. degrees and one M Sc. degree were granted at MIT directly under this program, and one Ph.D. degree was granted at the University of Michigan in conjunction with the NRL phase of the program.

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Petri, Steven Walter (1987) "The response of line-stiffened fluid-loaded infinite elastic phates to convecting pressure fields," Ph.D. thesis, MIT.

Bullister, E. (1987) "Development and application of high order methods for the solution of the Navier-Stokes equations," Ph.D. Thesis, MIT.

Related Degree Granted:

Leighton, R I. (1986) "Investigation of burst structure in a turbulent channel flow simulation using conditional sampaling techniques," Ph.D. thesis, University of Michigan.