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FINAL REPORT

RESEARCH GRANT No. AFOSR-74-2659

on

"THEORY AND APPLICATIONS OF UNSTEADY FLOWS"

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July 5, 1979

I. Introduction

In the original proposal jointly submitted by W. R. Sears and S. F. Shen, four categories of problems involving unsteady flows were identified for our research effort. These were the following:

1) Unsteady boundary layers and the separation phenomenon;

2) Aerodynamic responses for bodies encountering time-dependent flows;

3) Noise production and the interaction between sound waves and turbulence;

4) Unsteady flows resulting from thermal and/or physico-chemical mechanisms.

Participating faculty members included Professors D. L. Turcotte, A. R. George, W. R. Sears, and S. F. Shen.

The funding limitation, especially in the face of rising costs, obviously could not permit equal advance over such a wide front. The departure of Professor Sears after 1974 and the loss of Professor Turcotte to the Department of Geological Sciences necessitated a moderate re-orientation of the research emphasis. Later on, investigations of noise problems under Professor George received separate support from a different agency. Thus research under this project in recent years has emphasized mostly the first two categories outlined above, supervised by Professor Shen. Achievements during the last five years are briefly summarized in Section 2. A number of unfinished work and studies still in progress are described in Section 3, followed by a list of publications and conference presentations. The support of AFOSR is gratefully acknowledged. The cooperation and understanding of the program managers, starting with the late Paul Thurston is particularly appreciated.

II. Achievements

Under Professors Sears and George, Pien made an application of the Farassat theory, developed at Cornell under AFOSR sponsorship in an earlier grant, to calculate the far-field helicopter noise for a rigid rotor at constant angular speed, but without shocks. The results are reported in his M.S. thesis (ref. 1)*. An experimental measurement of the acoustic field from two impinging steel spheres, showing satisfactory verification of Farassat's theory, was conducted by Kitaplioglu (ref. 2), again supervised by Professors Sears and George. A thorough theoretical investigation of the interaction between sound waves and turbulence was carried out by Noir, under Professor George, culminating both in a Ph.D. thesis (ref. 3) and a paper (ref. 4). The turbulent mixing of two parallel streams of different densities, specifically He and A, under very low pressure was studied experimentally by Price in his M.S. thesis (ref. 5), for which Professor Turcotte served as the supervisor. Except for these studies, those described below were conducted under Professor Shen.

The investigations of unsteady boundary-layer separation began with Nenni, who developed an asymptotic theory for the outer edge of the unsteady boundary layer and clarified certain important features of the singular behavior of the velocity profile, as well as that of the wall shear, near the separation point and [illegible]rding to the boundary layer theory. The results were reported at a conference (ref. 6), and finally submitted as a Ph.D. thesis (ref. 7). To generate more unsteady boundary-layer solutions with flow reversal, Dr. Wang, a post-doctoral research associate for two years, produced further examples in the class of semi-similar solutions and also discussed the heat transfer problem (refs. 8 and 9). The development of a Lagrangian description of the unsteady boundary layer was then made by van Dommelen, providing a unified

* The reference numbers correspond to the listing of section IV.

basis to analyze separation in both the steady and unsteady cases. His numerical example shows clearly that the separation singularity (of the boundary-layer solution), for an initially unseparated boundary layer, does arise at finite time. This was presented at an international conference (ref. 10). Further analyses of the separation singularity of the boundary-layer equations, in both the semi-similar and the general cases, were summarized in Shen's invited article in Advances in Applied Mechanics (ref. 11). More recent work by van Dommelen in this direction is under review for publication (ref. 12). For three-dimensional boundary layers, the Lagrangian criterion for separation could be generalized and was reported by Shen (ref. 13), although numerical examples would require extensive computations.

Investigations of aerodynamic responses of bodies encountering unsteady flow have taken several directions. A pioneering work to facilitate the application of the sophisticated Wiener-Hermite expansion of non-Gaussian random processes to dynamic problems was carried out by Dr. Wang. The observed statistics on atmospheric turbulence was shown to be describable in a two-term expansion and the non-Gaussian aspects of gust response of an aircraft is treated as an example. The result was reported at the American Physical Society (ref. 14), an AIAA meeting (ref. 15), and will appear in the AIAA Journal (ref. 16). The computational treatment of the transient response of a thick airfoil, in compressible fluid and with particular emphasis of the large distortion of the trailing vortex wake is the Ph.D. thesis (ref. 17) of van Dommelen, now near completion.

In the turbomachinery context, the non-synchronous whirl instability of rotors is an unsolved problem of great practical interest. Our research was in fact motivated by a lecture of Dr. F. Ehrich, Manager of the Aircraft Engine Division of General Electric Company in a colloquium at Cornell. With his encouragement, a careful study of the aeroelastic problem with unsteady aerodynamic effects has been made by Mengle (ref. 18). The work so far exceeds the requirements of an M.S. thesis, but regretfully must be terminated because of the expiration of the current grant. Other studies aiming at the treatment of the choked flutter required the computational attack of unsteady shocks in a channel. The preliminary steady shock problem was the subject of an M.S. thesis by Wadia (refs.19 and 20), and a new approach with the finite-element method was initiated by Shen (ref. 21).

III. Unfinished Studies and Works in Progress

Several topics of research were disrupted after considerable effort and partial success because of personnel changes. Dr. Wang has applied the Wiener-Hermite expansion technique to a system with nonlinear cubic damping (the Duffing equation) forced by a Gaussian white-noise random input. The rigorous results showed agreement with other existing methods, but also raised certain basic questions of the postulate implied in the Fokker-Planck equation approach to stochastic processes. On the cascade flutter problem, Shekher examined the effects of (i) a slow-down of the shed vortices, and (ii) the displacement of the vortex sheet due to steady loading. These were approximately 75% complete when he had to leave for an industrial position. An experimental visualization of unsteady boundary-layer profiles, making use of a stereoplotter for quantitative measurements, was carried out by Tipnis, Lucca and Huq. Considerable development, however, would be needed to make the technique practical. Reddy was assigned to investigate the optimal design for supersonic panel flutter to achieve "mild flutter" under supercritical conditions. Sarihan undertook to develop a hybrid finite-element/finite-difference procedure for the computational treatment of transonic flow with shock. Both of them, for different reasons, had transferred after about a year of orientation. In the transonic shock problem, Dr. Sastri, a research associate during 1976, made a mathematical study using the method of matched asymptotic solutions, but did not come to a logical termination as his appointment could not be extended due to funding cut-off.

For graduate students who remain, their research obviously cannot be diverted abruptly as the funding was unexpectedly stopped. Mengle and van Dommelen have continued their research and are finishing their respective theses, quoted in the last Section. Kim's earlier study of a momentum-integral type procedure suitable for the prediction of separation of boundary layers, incorporating Nenni's suggestion in his thesis (ref. 7), still requires development to overcome the cumbersome algebra. Meanwhile, he has been going onward to generalize the semi-similar concept for unsteady boundary layers to obtain new solutions for the compressible and axi-symmetric cases. Kwon has followed up the idea of up-winding finite-element technique outlined in ref. 21, the ultimate goal including an application to the computation of transonic shocks.

We also hope to retain van Dommelen for the considerable further work needed to clarify the behavior associated with unsteady boundary-layer separation, possibly leading to a practical treatment of this important phenomenon.

It has been most gratifying for us to conduct research under AFOSR sponsorship. We were repeatedly led to believe that our performance had been satisfactory. Perhaps an opportunity to resume the relationship may come up again.

References

1. Pien, W. S., "The Far-Field Sound from a Nonlifting Transonic Rotor," M.S. Thesis, Cornell University, 1975.

2. Kitaplioglu, C., George, A. R., and Sears, W. R., "The Sound due to Acceleration of a Sphere," J. Sound and Vibration, 41, 380-384, 1976.

3. Noir, D. T., "The Absorption of Sound by Turbulence," Ph.D. Thesis, Cornell University, 1975.

4. Noir, D. T. and George, A. R., "Absorption of Sound by Homogeneous Turbulence," J. Fluid Mech., 86, 593-608, 1978.

5. Price. J. D., "Low Pressure Gas Mixing," M.S. Thesis, Cornell University, 1975.

6. Shen, S. F., and Nenni, J.P., "Asymptotic Solution of the Unsteady Two-Dimensional Incompressible Boundary Layer and Its Implications on Separation," in Unsteady Aerodynamics, ed. Kinney, R. B., and Sears, W. R., Univ. of Arizona, vol. I, 245-260, 1975.

7. Nenni, J. P., "An Asymptotic Approach to the Separation of Two-Dimensional Laminar Boundary Layers," Ph.D. Thesis, Cornell University, 1976.

8. Wang, J.C.T. and Shen, S. F., "On the Closed Recirculating Bubble Inside an Unsteady Boundary Layer and Its Effects on the Heat Transfer Calculation," A.I.A.A. paper 77-684, 1977.

9. Wang, J.C.T. and Shen, S.F., "Unsteady Boundary Layers with Flow Reversal and the Associated Heat-Transfer Problem," A.I.A.A. J. 16, 1025-1029, 1978.

10. van Dommelen, L.L. and Shen, S. F., "The Laminar Boundary Layer in Lagrangian Description," 13th Biennial Fluid Dynamics Symposium, Olstzym, Poland, 1977.

11. Shen, S. F., "Unsteady Separation According to the Boundary Layer Equation," Advances Applied Mech., ed. Yih, C.S., 18, 177-220, 1978.

12. van Dommelen, L.L., and Shen, S. F., "Spontaneous Singularity of the Boundary Layer Equation in Lagrangian Description," submitted to Computer and Fluids, 1979.

13. Shen, S.F., "Unsteady Separation of Three-Dimensional Boundary Layers from the Lagrangian Viewpoint," in Nonsteady Fluid Dynamics, Ed. Crow, D.E. and Miller, J.A., ASME, 47-51, 1978.

14. Wang, J.C.T. and Shen, S. F., "A Method for Calculating the Probability Density Function of Turbulent Fluctuations . Am. Phy. Soc. Fluid Dyn. Mtg, Univ. of Maryland, Nov. 24-26, 1975.

15. Wang, J.C.T. and Shen, S. F., "A Rational New Approach to the Response of an Aircraft Encountering Non-Gaussian Atmospheric Turbulence," AIAA 15th Aerospace Sciences Meeting, Los Angeles, Calif., 1977; AIAA paper 77-115.

16. Wang, J.C.T., and Shen, S. F., "A Rational New Approach to the Response of an Aircraft Encountering Non-Gaussian Atmospheric Turbulence," A.I.A.A. J., 1979 (in press).

17. van Dommelen, L. L., "Transient Response of Thick Airfoil with Finite Trailing Edge Angle in a Compressible Fluid," Ph.D. Thesis, Cornell University, 1979.

18. Mengle, V., "Nonsynchronous Whirl Instability of Rotors in Turbomachinery," M.S. Thesis, Cornell University, 1979.

19. Wadia, A.R., "A Least-Square Finite Element Technique for Transonic Flows with Shock," M.S. Thesis, Cornell University, 1977.

20. Wadia, A.R., "A Least-Square Finite Element Technique for Transonic Flow with Shock," AIAA National Student Conference, Washington, D.C., Feb. 1978.

21. Shen, S. F., "Upwind Influence and Shock Discontinuity," Proc. 2nd U.S.-Japan Conference on Interdisciplinary Applications of Finite-Element Method, Aug. 1978, Cornell Univ. (in press).