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COMPUTATION OF THREE-DIMENSIONAL AERODYNAMIC FLOW.(U)
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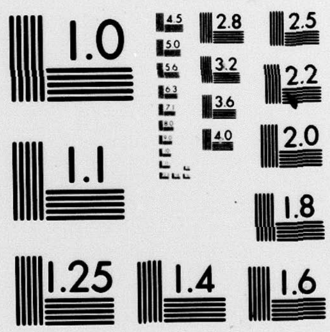
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LEVEL II

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FINAL SCIENTIFIC REPORT

ON

COMPUTATION OF THREE-DIMENSIONAL AERODYNAMIC FLOW

to

Director of Mathematical and Information Services
Air Force Office of Scientific Research (AFSC)
United States Air Force
Under Contract No. F49620-76-C-0004

by

Principal Investigator K.C. Wang

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

The present contract continues ~~a continuation of~~ an earlier one which extended from 1970-1976,

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This contract, F49620-76-C-0004, "Computation of Three-Dimensional Aerodynamics Flow" extended from July 1 1976 to January 31 1980. It was a continuation of an earlier one, F44620-70-C-0085, bearing the same title extending from July 1,1970 to June 30, 1976. The purpose ~~in~~ of this continuing ~~effort~~ coration was to make pioneering calculations of genuine three-dimensional laminar boundary layers. During ~~this~~ the current contracting period, efforts were first focused on investigations of: (1) the general characteristics of three-dimensional flow separation, especially for ~~the~~ aerospace applications and (2) the boundary layer features and the magnus forces.

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20. Abstract cont.

on spinning bodies such as spinning projectiles or missiles. Later emphasis gradually shifted to the boundary layer over an aircraft wing in contrast to that around a body of revolution studied theretofore.

SUMMARY

This contract, F49620-76-C-0004, "Computation of Three-Dimensional Aerodynamics Flow" extended from July 1, 1976 to January 31, 1980. It was a continuation of an earlier one, F44620-70-C-0085, bearing the same title extending from July 1, 1970 to June 30, 1976. The purpose in this continuing effort was to make pioneering calculations of genuine three-dimensional laminar boundary layers. During this contracting period, efforts were first focused on investigations of (1) the general characteristics of three-dimensional flow separation, especially for the aerospace applications and (2) the boundary layer features and the magnus forces on spinning bodies such as spinning projectiles or missiles. Later emphasis gradually shifted to the boundary layer over an aircraft wing in contrast to that around a body of revolution studied theretofore.

I. PROBLEM

Accurate calculation of the viscous flow is essential for determining drag forces, heat transfer and separation patterns. The last, in particular, affects the design and the control and performance of a flying vehicle. Until the past few years, complete solutions of genuine three-dimensional boundary layers were non-existent. Aerospace designers had to apply two-dimensional or axisymmetric concepts to real three-dimensional flows. This practice is not only inaccurate, but also may induce erroneous conclusions.

II. OBJECTIVE

Our objective in this long-term program has continued to be the investigation of genuine three-dimensional laminar boundary layers. Particular attention was given to the aerospace applications such as the flows over missiles, aircraft wings and fuselages, and spinning projectiles.

More specifically, our objectives during this contracting period as well as the prior one comprised: (1) sorting out the basic mathematical structure of the governing equations, (2) developing numerical methods and the accompanying computer programs, (3) performing pioneering calculations of genuine three-dimensional boundary layers and (4) determining the physical flow structure, especially such aspects as reversed flow, separation phenomena and vortices.

III. APPROACH

To study three-dimensional viscous effects, we chose to stick to the boundary layer approach. Although the Navier-Stokes approach provides more complete solutions, it is still not feasible with the existing computers to obtain sensible Navier-Stokes solutions with sufficient resolution. This is true in spite of claims to the contrary which have appeared in the literature. Between the boundary layer theory and the Navier-Stokes approach, there are the thin layer approximation of NASA Ames and the so-called parabolicized Navier-Stokes approach. Efforts required for solving these two problems are still an order of magnitude larger than those for the boundary layer equations, while the scope of physical problems which can be solved and hence the advantage gained is rather limited.

On balance, the boundary layer approach is still the more feasible and profitable method for learning about three-dimensional viscous flows. The relevant numerical methods were largely developed during the early contracting period, though modifications have been continually introduced to suit individual problems. Such modifications are necessary because a computing program of reasonable size cannot cover too many different cases. Otherwise the program will be more complicated and will take too long to develop or it may end up not working at all.

IV. ACCOMPLISHMENTS

The accomplishments of this long-term program have been impressive, and the subject of boundary layer research has, as a result, reached a new stage.

A. The Early Period

During the early contracting period (1970-1976), we classified the basic mathematical equations, established rigorous numerical methods and devised rational computational procedures. We presented complete solutions which revealed basic three-dimensional structures for the first time and discovered new separation concepts. A series of journal publications and technical reports document the details of the investigation results.

Journal Publications

1. "On the Determination of the Zones of Influence and Dependence for Three-Dimensional Boundary-Layer Equations," Journal of Fluid Mechanics, 48, 2,397-404, 1971.

2. "Separation Patterns of Boundary Layer Over an Inclined Body of Revolution," AIAA Journal, 10, 8, 1044-1050, 1972.

3. "Boundary Layer over a Blunt Body at High Incidence with an Open-Type Separation," Proc. of Royal Society, London, A. 340, 33-55, 1974.

4. "Boundary Layer over a Blunt Body at Extremely High Incidence," The Physics of Fluids, 17, 7, 1381-1385, 1974.

5. "Laminar Boundary Layer Near the Symmetry-Plane of a Prolate Spheroid," AIAA Journal, 12, 7, 949-958, 1974.

6. "Boundary Layer over a Blunt Body at Low Incidence with Circumferential Reversed Flow," Journal of Fluid Mechanics, 72, 1, 49-65, 1975.

7. "Concentrated Vortex on the Nose of an Inclined Body of Revolution," with T. Hsieh, AIAA J., 14, 5, 698-700, 1976.

Related publications not supported by this contract:

A-1. "Three-Dimensional Boundary Layer Near the Plane of Symmetry of a Spheroid at Incidence," Journal of Fluid Mechanics, 43, 1, 187-209, 1970.

A-2. "Aspects of Multi-Time Initial-Value Problem Originating from Boundary Layer Equations," The Physics of Fluids, 18,8, 951-955, 1975.

Technical Reports

1. "Three-Dimensional Laminar Boundary Layer over Body of Revolution at Incidence, Part V. Further Investigation near the Plane of Symmetry, RIAS TR 71-14c, September 1971.

2. "Part VI. General Methods and Results of the Case of High Incidence," MML TR 73-02c, Also AFOSR-TR-73-1045, May 1973.

3. "Part VII. The Extremely High Incidence Case," MML TR 73-08c, also AFOSR TR 73-1265, July 1973.

4. "Part VIII. The Case of Low Incidence Involving Circumferential Flow-Reversal," MML TR 74-14c, October 1974.

5. "Part IX. Difference Method and Documentation of Program 'BLIND 3'," With Susan Yamamura, MML TR 75-09c, February 1975.

Related Reports not supported by this contract:

A-1 "Three Dimensional Laminar Boundary Layer Over Body of Revolution at Incidence, Part I. Method of Calculation," RIAS TR 69-14, October 1968.

A-2 "Part II. The Role of Subcharacteristics and Improved Method of Calculation," RIAS TR 6913, September 1969.

A-3 "Part III. Solution near the Plane of Symmetry," RIAS TR 69-14, September 1969.

A-4 "Part IV. Separation Pattern," RIAS TR 70-07, June 1970.

A-5 "Numerical Solution of Three-Dimensional Boundary Layer Equations, Spinning Body at Incidence and Magnus Forces," MML TR 76-14c, February 1976.

B. The Current Period

During this contract period (July 1976 - January 1980), we studied separation characteristics of general three-dimensional flows of aerospace interest including bodies of revolution, wings and intersecting corners.

Supported in part by ARO-D (Army Research Office at Durham), we also calculated the boundary layer over an inclined spinning body with Magnus forces.

Emphasis then shifted to the boundary layer over an airplane wing (in contrast to the body problem considered before). We proposed a physical mechanism to explain the occurrence of spiral vortices over swept wings. This phenomenon had been experimentally observed for some time, but little is understood regarding how and under what circumstances it occurs. We also systematically investigated the symmetry-plane boundary layer over an ellipsoidal wing. Results indicated that the "separation jump" phenomenon occurs also over a wing-like geometry. Such separation jump is likely accompanied by a wing's sudden stall, a phenomenon about which little is known. Sudden stall is usually interpreted to result from the burst of a short separation bubble into a long one, thus representing a mechanism quite different from our findings. Finally, efforts are under way to calculate the boundary layer over the entire ellipsoidal wing at incidence. Detailed formulation of the problem was completed, the computing program was modified for this problem, and initial profiles were generated. Test runs were successful, but the bulk of the computation remains to be carried out.

The following publications and technical reports were written during this period:

Journal Publications

1. "Boundary Layer Over Spinning Blunt-Body of Revolution at Incidence Including Magnus Forces," Proc. Royal Society, London, A. Vol. 363, p. 357-380, 1978.

2. "Separation of Three-Dimensional Flow," Proc. of the Lockheed-Georgia Company Viscous Flow Symposium (by invitation), LG77ER0044, Atlanta, Georgia, June 1977.

Notes and Reports

1. "Separation of Three-Dimensional Flow," MML TR 76-54c, August 1976.
2. "A Note on Spiral Vortex over Swept Wing," August 1979 (to be submitted to AIAA J.).
3. "Separation Jump and Sudden Stall over an Inclined Ellipsoidal Wing," Martin Marietta Labs, TR-79-22c, May 1979 (to be submitted to J. Fluid Mech.).

Related reports not supported by this contract:

A-1 "Unsteady Boundary Layer Separation," MML TR 79-16c, April 1979 (supported by Office of Naval Research).