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BODIES HAVING ARBITRARY SHAPES AND MOTIONS
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Seventh Semiannual Report for NASA Grant for Research on "Compressible Unsteady Potential Aerodynamic Flow Around Lifting Bodies Having Arbitrary Shapes and Motions" (NGR-22-004-030)

Covering the Period:
January 1 thru June 30, 1975

Principal Investigator:
Dr. Luigi Morino

prepared for

NASA LANGLEY RESEARCH CENTER

Hampton, Virginia

1. Introduction

This is the Seventh Semiannual Report (covering the period January 1 - June 30, 1975) for the NASA Grant NGR 22-004-030 for "Research on Compressible Unsteady Potential Flow Around Lifting Bodies Having Arbitrary Shapes and Motions". The NASA Technical Officer for this grant is Dr. E. Carson Yates, Jr., of NASA Langley Research Center.

The objectives of the extension covering the period January 1 - December 31, 1975 are:

1. Refinement of the program SOSSA ACTS to include: fully unsteady aerodynamics, wing-body-tail configurations, improved evaluation of the pressure, evaluation of generalized aerodynamic forces, special elements for control surfaces.
2. Assessment (and eventual full computer program) for first-order solution, with various techniques for improving the Kutta condition.
3. Additional items such as gust response and nonlinear effects in supersonic and transonic flow (time permitting).

2. Accomplished Results

The results accomplished during the six-month period covered by this report (January 1 to June 30, 1975) are presented in this Section.

The results relative to SUSSA ACTS are presented first, followed by the ones for ILSA and by the flutter analysis and the nonlinear analysis.

2.1 SUSSA ACTS

The program SUSSA ACTS (Steady and Unsteady Subsonic and Supersonic Aerodynamics for Aerospace Complex Transportation System) is presented here. The new development for fully unsteady (indicial) aerodynamics is discussed first, followed by new developments on normal wash, pressure distribution, generalized forces, supersonic formulation, numerical results, geometry preprocessor, the user manual, control surfaces and first-order formulation.

2.1.1 Indicial Aerodynamics

It is a well known issue in aeronautical engineering that there exists a gap between the aerodynamic and control methodology. Modern linear control theories are based upon operational calculus (Laplace's transform, etc.), while aerodynamic theories around complex aircraft configurations are limited to steady and oscillating flows. This limitation is not a problem for flutter analysis (whereby the problem is circumvented by the introduction of the classical artificial- damping concept). However this limitation becomes a problem, if maneuverability and transient response are to be investigated. On the other hand in this kind of analysis it may be assumed that the motion consists of small perturbations around a steady flow, and starts at time t=0 (this hypothesis is consistent with the ones used for control analysis). Under these conditions it is possible (with the help of the finite-element method for the space discretization) to obtain a very simple and general formulation for unsteady potential compressible aerodynamic flow for arbitrary (small-amplitude) motion. This formulation is presented in Ref. 1 where it is shown that the relationship between the nodal-values of the velocity potential and the ones of its normal derivative on the surface of the aircraft is given by a system of differential-delay equations. Taking the Laplace transform of this system one obtains an algebraic matrix equation from which it is easy to obtain the matrix transfer function. During the past six months the computer program SUSSA ACTS has been improved considerably. The program has been simplified so that the code can be used in the same way for steady oscillatory and unsteady, subsonic and supersonic flows (no diaphragms are now required in supersonic flow).

2.1.2 Normal Wash

A new formulation has been developed for the evaluation of the normal wash from the boundary conditions. This formulation allows for the evaluation of the normal wash from prescribed three-dimensional modes for completely arbitrary configurations.

2.1.3 Evaluation of Aerodynamic Pressure

A new formulation has been developed for the evaluation of the aerodynamic pressure. In SOSSA ACTS (Ref. 1a) a finite-difference evaluation was being used. In SUSSA ACTS a finite-element method is used. From the values of the potential at the centroids, the value of the potential at the nodes is evaluated (by average); from these, a hyperboloidal distribution of the potential within the elements and hence its derivatives along ξ and η are obtained. These yield the perturbation velocity as

$$\vec{v} = \nabla\varphi = \frac{\partial\varphi}{\partial\xi}\vec{a}^1 + \frac{\partial\varphi}{\partial\eta}\vec{a}^2 + \frac{\partial\varphi}{\partial n}\vec{n}$$

where $\vec{a}^\alpha$ are the contravariant base vectors. From the velocity, the pressure can be easily evaluated through the Bernoulli theorem. This formulation has been programmed debugged and exercized. Several alternative methods have been considered for the extrapolation at the trailing edge. A report describing the results is now being written. The additional complexity introduced by other methods does not seem to be justified by the slight increase in accuracy.

2.1.4 Generalized Forces

A general routine for the evaluation of the generalized aerodynamic forces (from prescribed mode shapes) is now available. These forces are given by

$$Q_N = -\oiint_\Sigma p\,\vec{n}\cdot\vec{M}_N\,d\Sigma$$

where $\vec{M}_N$ is the prescribed mode shape (natural mode of vibration). The integral can be evaluated by dividing it into a sum of integrals over each element and evaluating each integral by midpoint quadrature. The generalized forces are evaluated as

$$\left\{Q_N\right\} = \left[Q_{NL}\right]\left\{p_L\right\} = \left[4\, a_1 \times a_2 \cdot M_N \Big|_{p=p_L}\right]\left\{p_L\right\}$$

where p_L are the values of p at the nodes while $\left[Q_{NL}\right]$ is a matrix which depends only upon the geometry and the mode shape (so that it can be evaluated once and for all and used for various values of the Mach number and reduced frequency).

2.1.5 Supersonic Formulation

In SOSSA ACTS, the equations for the upper and lower surfaces were solved independently for supersonic leading edge wings while diaphragms were used for wings with partially or totally subsonic leading edge. In the final version of SUSSA ACTS, supersonic unsteady flow is treated exactly as in the subsonic case, that is, both surfaces are considered simultaneouly and diaphragms can be removed without any loss of accuracy or efficiency. This is a considerable improvement. For, the use of the program is now very simple in the subsonic as well as in the supersonic range. The details of the new formulation are presented in Ref. 3 where it is also shown why in the formulation of Ref. 1 the use of the diaphragm was necessary in order to avoid determinants equal to zero (in the new formulation the time delay is evaluated from the centroid of the portion of the element inside the Mach forecone, instead of the centroid of the element itself).

2.1.6 Numerical Results

The program SUSSA ACTS has been debugged and exercised. The results obtained thus far are divided in two groups. In the first group the results are compared with existing ones in order to assess the accuracy of the new formulation. The second group deals with complex-frequency aerodynamics for which no other (experimental or theoretical) results exist: these are presented in Ref. 4 in order to give an idea of the capabilities of the program SUSSA ACTS.

Typical results of the first group are presented in Ref. 4: lift and moment for a rectangular wing oscillating in pitch with reduced frequency k=1, as functions of the Mach number. The analysis of convergence for the supersonic range is also presented and indicates that the small difference with existing results might be due to convergence. A more thorough convergence analysis is now under way.

In the second group of results, a wing-body configuration oscillating in pitch with complex frequency $s = .2 + i1$ is considered. Pressure distribution and generalized forces are included.

2.1.7 Geometry Preprocessor

A new geometry preprocessor has been written. This includes wing, body, vertical and horizontal tail. Matching of tail and body is now underway.

2.1.8 User Manual

The user manual has been written (Ref. 5) and will be submitted shortly.

2.1.9 Control Surfaces

The control surfaces yield a logarithm singularity for the pressure along the hinge line. This singularity can be easily handled at present time by smoothing the slope discontinuity. However, small elements are then necessary in order to handle the high curvature of the smoothed surface. Therefore the question of special elements is now being explored. The analysis is now limited to simple wings in subsonic flow. If a satisfactory approach is obtained (such as a square root description for the potential) and if time permits the formulation would be included in the program SUSSA ACTS.

2.1.10 First-order Formulation

The finite element formulation has been refined to allow for linear variations in ξ and η directions of the intensity of the source and the doublet integrals within each element. It should be noted that in view of the high priority given to the nonlinear analysis (high subsonic and low supersonic, section 2.3) it was agreeed, with Dr. E. Carson Yates, Jr., technical monitor of the grant, that the first order formulation be given lower priorities. The present preliminary analysis is limited to steady subsonic flow. Parallelipipedal elements are now available. Various ways to implement the Kutta condition are now being explored. Additional work on first order formulation is given in Section 2.2.3.

2.2. ILSAWR

The program ILSAWR (incompressible lifting surface aerodynamics with wake roll-up) is described here. The computer program SUSSA ACTS, analyzes steady and oscillatory subsonic and supersonic flows around complex configurations. For applications to wing-body combinations the hypothesis of straight-vortex wake seems to be acceptable. However, an accurate analysis of the wing-tail interaction might require the correct geometry of the wake. The aim of this portion of the project was to assess a numerical procedure for the evaluation of the effects of the wake geometry to several configurations. Lifting-surface theory has been used for the purpose of performing the feasibility analysis, in order to avoid unnecessary complications in this preliminary analysis. Once the method is proven, it is a straight-forward matter to extend the formulation to SUSSA ACTS.

2.2.1 Formulation

The method considered here makes use of a theoretical formulation developed by Morino and Suciu (Ref. 6). The wake-roll-up implementation is given in Ref. 7. As the thickness of the wing goes to zero, one obtains a lifting surface formulation

$$\frac{\partial \varphi}{\partial n_0} = \iint_\Sigma \frac{\Delta\varphi}{4\pi} \frac{\partial^2}{\partial n \partial n_0}\left(\frac{1}{r}\right) d\Sigma \tag{2.1}$$

For the purpose of solving (2.1), the lifting surface is divided into small qudrilateral elements (hyperboloidal elements) with the geometry given by the four corner points. For the approach considered here, it is assumed that the value of the doublet intensity is constant over the surface of an element, say at the centroid. The wake contributes only to the row of boxes in contact with the trailing edge. A system of linear algebraic equations, in the unknowns, $\Delta\varphi$ is obtained by imposing the boundary condition at the centroids of the elements. The doublet distribution is then easily obtained.

For obtaining a rolled-up geometry for the wake, the following scheme is used: the wake is initially assumed to consist of staight vortex lines. The wake strips are then divided into boxes. By taking the gradient of the velocity potential, one can easily obtain the velocity induced by the wing and the wake at any point in the flow field, in particular at the corner points of the wake elements. Then, the vortex lines of the wake are realigned to be parallel to the velocities at prescribed points. This gives a better approximation to the problem. An improvement is obtained by a process of iteration. The convergence of the iteration scheme has also been considered here.

2.2.2 Results

The lifting surface formulation described above has been implemented in a computer program ILSAWR (acronym for Incompressible

Lifting Surface Aerodynamics with Wake Roll-Up). Typical results are described here.

Converged wake patterns for a rectangular wing of AR = 8, at 5° angle of attack are given in detail in Refs. 7 and 8. Comparisons with existing results as well as the influence of the rolled-up wake on the pressure distribution on the wing are also presented, (the nonlinear Bernoulli Equation has been used in evaluating the pressure coefficient).

The analysis of the convergence of the solution is presented in Appendix A of Ref. 7. The convergence of the iteration scheme is considered in Appendix B. of Ref. 7.

2.2.3 First-Order Analysis

A first-order formulation for incompressible lifting surface aerodynamics has been developed. A computer program for implementing of such formulation has been written and is now being debugged.

2.3 Flutter Analysis

A preliminary work for flutter analysis was completed and is presented in Ref. 1a. Additional work in this direction is not necessary in view of the development of the program FCAP being developed by Aerospace Systems Incorporated (see Ref. 9.)

2.4 Nonlinear Analysis

The nonlinear formulation for low supersonic flow has been improved with respect to the one presented as an appendix in the grant proposal. The new formulation is given in Ref. 10. for high subsonic flow. A preliminary computer program for nonlinear analysis of rectangular wings in subsonic flows is now being written. It is hoped that the numerical results might give a new insight about the supercritical subsonic range.

3. References

1. Morino, L., and Chen, L.T., "Indicial Compressible Potential Aerodynamics Around Complex Aircraft Configurations", Presented at the NASA Conference on Aerodynamic Analysis Requiring Advanced Computers. (Hampton, Va.), March 4-6, 1975.

1a. Chen, L.T., Master Thesis, Boston University, College of Engineering, 1975.

2. Morino, L., Chen, L.T., and Suciu, E.O., "Steady and Oscillatory Subsonic and Supersonic Aerodynamics Around Complex Configurations", AIAA J., Vol. 13, No. 3, March 1975, pp. 368-374.

3. Tseng , K.D. and Morino, L., "Unsteady Supersonic Formulations for SUSSA ACTS", Boston University, College of Engineering, TR-75-01, in preparation.

4. Tseng, K.D., and Morino, L., "SUSSA ACTS: A Computer Program for Steady and Unsteady, Subsonic and Supersonic Aerodynamics for Aerospace Complex Transportation Systems" submitted for presentation at the AIAA XIV Aerospace Sciences Meeting.

5. Tseng, K.D., Chen, L.T., and Morino, L., "SUSSA ACTS: Steady and Unsteady, Subsonic and Supersonic Aerodynamics for Aerospace Complex Transportation Systems", Vol. II: A User's Manual., in preparation.

6. Morino, L. and Suciu, E.O., "A Finite-Element Method for Lifting Surfaces in Steady Incompressible Subsonic Flow", Boston University, College of Engineering, TR-74-05, December, 1974.

7. Suciu, E.O., Master Thesis, Boston University, College of Engineering, 1975.

8. Suciu, E.O., and Morino, L., "A Nonlinear Finite Element Analysis of Lifting Surfaces in Steady Incompressible Flows with Wake Roll-up", submitted for presentation at the AIAA XIV Aerospace Sciences Meeting.

9. Noll, R.B., Morino, L., "Fight Control Analysis Program (FCAP) for Arbitrary Configuration Flexible Aircraft with Active Control", Vol. I, ASI-TR-75-23, May, 1975.

10. Morino, L., "Nonlinear Analysis of Low Suspersonic Aerodynamics for Complex Aircraft Configurations", Boston University, College of Engineering, TN-75-01, 1975.