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Final Report Covering the Period

8/15/72 to 10/31/74 on Grant Number NGR-34-002-179 for

Research Entitled

"Development of Computer Programs to Determine The Aerodynamic Characteristics of Complete Light Aircraft"

by

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October 1974

The work conducted under this grant may be viewed as a logical continuation of the activities carried out under previous grants in this series. The principal objective of the series is to package aspects of modern aircraft technology as developed for the air transportation industry and the military in a form suitable for use by the general aviation industry. A secondary objective has been to rekindle faculty and student interest in aeronautics after years of almost total concentration on space.

The series began with the preparation of a three-volume review (NASA CR-1484, 1485, 1486, March 1970) of the NACA/NASA literature published from 1940 to 1968 for its pertinence to light aircraft problems. This effort indicated to the authors that the area of stability and control offered the most promise for the immediate introduction of modern estimation and analysis techniques. Accordingly, they prepared a 409-page Contractor's Report (CR-1975, March 1972) detailing the application of these techniques to typical light aircraft designs. Computer programs for performing part of the analysis tasks were also prepared and listings and user instructions were included in the report. In a follow-on report, CR-2016, (May 1972) they discussed methods for verifying these estimates through flight tests and provided computer programs by which one could calculate stability derivative values if given the aircraft geometry. These programs, along with those given in CR-1975, make it possible to determine the response of an airplane to a small disturbance given the geometric and inertial characteristics of the airplane.

In CR-2272 (June 1973) computerized methods for treating point and path performance of light aircraft were given. These methods permit one to fit any arbitrary drag-speed curve and power-speed curve and obtain very accurate performance data.

A review of the work to this point was given at the SAE Business Aircraft Conference in April 1973 (Paper #730305).

Unfortunately, construction of a rigorous drag-speed curve is very difficult. In the past, for preliminary design purposes such curves were usually constructed from quasi-analytical correlations of rather badly scattered flight test data taken on similar aircraft. However, in the mid 1960's the major airframe contractors and others began to develop large computer programs to treat portions of this problem in an analytical fashion. Reports on these activities began to appear in the literature in 1970 and 1971. Some of this work was done at NASA or was supported by NASA. As a result, it was reported in considerable detail. Examination of the reports indicated that the programs often contained many options not needed for light aircraft work and could therefore be shortened substantially for light aircraft work. While no single program was available to do an adequate job on an entire airplane, sufficient programs were available which, when modified, could be patched together to enable one to treat an entire airplane. The modifications needed, however, were not insignificant nor was the patching process simple. This situation was responsible for the genesis of the work on the present grant.

Begun in August of 1972, the work first undertook a review, specialization, and simplification of the computer program described in NASA CR-1843. As originally received from Langley, the program deck was dimensioned to compute the lift, drag, and moment characteristics of a four-element, two-dimensional airfoil by the method of distributed vortices on the airfoil surface (for the inviscid solution), coupled with a momentum integral type of boundary layer solution (to determine the viscous contribution to the flow). The flap portions of the program, however, had been removed. The modifications to this program consisted of

(1) reducing arrays to a size consistent with a single airfoil element.

(2) cleaning up other aspects of the programming to reduce storage requirements and speed execution time by a factor 20.

(3) fixing the segments used to represent the airfoil at 65.

(4) changing the method used to represent the airfoil wake within the inviscid flow formulation.

(5) doubling the Reynolds number used in the boundary layer calculations.

(6) removing one of the two turbulent boundary layer calculation routines.

(7) modifying the computed lift coefficient to account for the loss of lift which occurs physically because of the effect of the wake on the net circulation.

(8) modifying the computed drag coefficient to account for the fact that the computations do not always give a zero drag value in inviscid flow as they should. (This is primarily a precision problem in the formation and inversion of a 65 by 65 matrix; rather than sort out and correct problems associated with taking differences between two large, almost alike, numbers, the residual drag in the inviscid case was treated as a tare to be subtracted from the results of subsequent calculations.)

These modifications resulted in improved predictions of airfoil characteristics. As received from Langley, drag estimates at low angles of attack were 60% to 100% high. The modified program gave results within 15% of those obtained by experiment for the same cases. Agreement with experimental lift values was within 6% and frequently much better for $C_L < 0.8$ and airfoil thicknesses between 9% and 18% of chord. Modern low drag airfoils up to 21% thick are also handled well but older airfoils such as the 2424 produce regions of flow separation. The latter cannot be treated adequately within the framework of the viscous flow theory used. As a result, the characteristics of airfoils with concave surfaces cannot be estimated properly. Very thin airfoils and airfoils with flat surfaces also cannot be treated satisfactorily because they lead to ill-conditioned matrices. This problem is inherent in the method used to represent the flow about such bodies. The lift predicted by the Langley version of the program was slightly greater than that given by the NCSU version (a lift curve slope about 6% greater). Both versions, of course, overpredicted the lift at higher C_L's.

The Langley version of the program contained a provision for correcting the results to higher Mach number flight. This provision was retained in the NCSU version. A limited check indicated that it gave useful results, using the NCSU lift and drag coefficients, to about 80% of critical Mach number.

Ordinarily, complete wings are treated by representing them with a vortex lattice. While quite rigorous, this approach has two principal disadvantages:

1. For equal accuracy, the inviscid representation is many times (≈ 20) more complex than the representation of a two-dimensional airfoil.

2. None of the available vortex lattice programs are as yet combined with three-dimensional boundary layer programs. Further, the latter are not generally available for non-axisymmetric bodies.

Fortunately, NASA CR-1646 contained a computerized method called STALL for converting <u>experimental</u> two-dimensional data to three dimensions following the lifting-line representation of moderate-to-high aspect ratio, unswept wings. This method was originally intended to enable one to predict the stall characteristics of finite wings of this type; but because most light aircraft have such wings, it also seemed ideally suited to converting 2-D theoretical results to 3-D in a far simpler fashion than the vortex lattice scheme. Since the 2-D airfoil program now treats a single component only, the portion of STALL dealing with flaps was removed. Also, since the boundary layer portion of the airfoil program does not permit one to treat separated flows, that portion of STALL dealing with aerodynamic characteristics near stall was removed. The experimental input data in tabular form was replaced by a curve fit of the output of the airfoil program. Comparison of the results indicate that for input data of equal accuracy there is less than a 3% variation between the results given by original version of STALL and the modified version. Thus any failure to given suitable three-dimensional lift and drag predictions for low-to-moderate angles of attack are a result of failures to compute the two-dimensional characteristics correctly, provided of course that the wing planform conforms to requirements (moderate-to-high aspect ratio and unswept). Four comparisons with experimental data for complete wings gave excellent results for the entire procedure.

The foregoing was accomplished during the first year of the grant. During the second year, attention was turned to predicting the fuselage characteristics. The writer became aware of the availability of three programs which could be used as a starting point in this work:

(1) A combined wing-body program at the Ames Research Center which represented the fuselage by line-sources

(2) A combined wing-body program described in NASA CR-2228 which represented the body by source distributions on the body surface

(3) A body only program from the Naval Ship Research and Development Center which represented the body by a source distribution on the surface and, in addition, calculated the flow streamlines on the body surface.

All three programs were acquired, mounted on the local computer, and checked out for the test cases supplied. Further study indicated that the program from the Navy would be easiest to use for the intended purpose besides offering the advantage of giving the flow streamlines on the body surface.

None of the programs provided for drag computations (Except wing induced drag). Also, no general three-dimensional boundary layer programs were found to be available. Thus in order to get a fuselage drag prediction of any kind the following approach was adopted:

(1) Since quasi-axisymmetrical bodies at zero angle of attack cause the flow about them to exhibit very small components in the cross flow direction and

(2) Since it can be shown that for such bodies the boundary layer flow along streamlines is like two-dimensional flow except near the nose and tail of the bodies,

(3) Assume that the angle of attack is restricted to the neighborhood of zero and that

(4) The wall shear and displacement thickness along streamlines can be computed by the same boundary layer routines as are used for the airfoil.

(5) The complete drag is obtained by integrating the skin friction over the surface and by appending a wake body whose size is determined by the boundary layer displacement thickness near the downstream end to the physical body, recomputing the inviscid pressure distribution over the entire physical body plus wake body combination, and integrating this new pressure distribution over the <u>physical</u> body to obtain the form drag as well as the body lift.

The procedure was found to require a great many quadrilaterals in order to represent the surface of the fuselage adequately (~ 500 or more). As a result, about 12 minutes are needed to compute the lift and drag of a single isolated fuselage at $\alpha = 0$. In order to insure that the input data for such a lengthy calculation is correct, it is first submitted to the plot routine described in NASA TMX-2374. It is then converted by another routine to the required input form for the body program.

Computed results for streamlined bodies of revolution were within about 20% of published experimental data and computed results for a Cessna 182 fuselage appeared reasonable although no experimental data are available against which to compare.

Listings of these modified programs along with user instructions are given in a 500-page Contractor's Report which has been submitted to NASA for publication. Also included in this report are:

(1) An extensive literature review discussing the chronology leading to the development of the theoretical bases of the programs.

(2) A detailed exposition of these theoretical methods.

(3) A discussion of wing-fuselage interactions and wing-tail interactions.

(4) A discussion of ways to integrate the foregoing to obtain lift, drag, and moment predictions for complete configurations.

(5) Several simpler programs for computing the lift of symmetrical airfoils from M = 0 to M = 1.0 and for a closed-form solution of the inviscid pressures over prolate spherioids. These may be used to indicate approximately the results to be obtained by the more complex programs.

(6) A supplementary bibliography listing nearly 200 very recent references thought to contribute to an understanding of the problem of predicting lift, drag, and moment of complete configurations by analytical methods.

It is hoped that this Contractor's Report will be useful to university students and aeronautical engineers generally as well as to those charged with the task of implementing the computer programs for their companies. Release of this report by NASA is expected in late spring 1975.

The wing program and the earlier stability and performance programs have been supplied to the major firms in the general aviation industry on a no-cost basis. These firms indicate that they have made frequent use of the programs with quite satisfactory results. The university can now provide the body program as well upon request.

The reader will recognize that during the current grant period it has not been possible to determine adequately the validity of the complete lift and drag predictions. The time required to complete the program modifications was somewhat longer than expected. The cost of running the program is sufficiently high that one does not run a case without considerable forethough. An most importantly, there is a paucity of reliable experimental data against which to compare the predictions. The latter condition, hopefully, will be corrected during the follow-on work now beginning under grant number NSG-1077. In this work, an advanced technology light twin aircraft will be given extensive flight tests designed specifically to provide reliable data for comparison with the predictions of the whole series of computer programs developed to date. As part of this effort it is expected that the analytical work done to date on wing-tail interference will be programmed for computer solution so as to be included in preparing the lift, drag, and moment estimates of the complete airframe. Also being prepared is a computer program for a new method to extract lift, drag, and power information separately from flight test data. The latter will provide the comparisons with the lift and drag predictions. Performance predictions will be made first with the estimated lift, drag, and power data and then with the values extracted from the initial flight results.

CR-1975, as noted above, contains methods for predicting the values of the various airplane stability derivatives. These methods are computerized in CR-2016. Estimates made by these procedures will then be compared with the stability derivative values extracted from flight test data by other techniques described in CR-2016. Thus, the Contractor's Report to be issued on the next phase of the work will provide extensive comparisons (for one airplane only) between the predictive theory developed to data and experimental values as well as new computer programs for flight test data reduction and wing-tail interference prediction.

In addition to providing the general aviation industry with some more modern analytical tools, the effort of the last six years has had its impact as well in aeronautical engineering education. The original review work involved 10 undergraduate students, three of whom stayed around for graduate work to participate in succeeding phases of the work. Three other graduate students have also become involved in the activity for varying periods of time. CR-1975 has been used as a supplementary text in the senior flight vehicle design course and CR-2272 has been used as a supplementary text in the flight vehicle performance course, neither of which were taught by the present writer. Faculty at the University of Illinois (Champaign-Urbana) requested and were sent copies of the stability and performance programs for use in their classes. It is to be expected that as the power of these programs and their ease of use becomes more widely known, faculties in the 57 departments offering Aerospace Engineering degrees will begin to reexamine their curricula with a view toward optimizing available instructional time by concentrating on those aspects of fluid mechanics and dynamics undergirding the computer design methods and by giving the student the opportunity to run some of these or equivalent programs in the course of his own design experience.

One cannot conclude this review without noting that the work over the last six years has benefitted very greatly from the thoughtful comments and suggestions of many people in the industry and at the Langley Research Center, in particular the project technical officers: first, Mr. Joe Stickle, and now, Mr. Harold Crane. Their contributions are hereby greatfully acknowledged.