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DEVELOPMENT OF DIRECT-INVERSE 3-D METHODS
FOR APPLIED TRANSONIC AERODYNAMIC WING DESIGN AND ANALYSIS

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Semiannual Progress Report
January 1, 1988 - June 30, 1988

TEXAS A&M UNIVERSITY

TAMU Report No. 5373-88-02

August 1988

NASA Grant No. NAG-1-619

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TEXAS ENGINEERING EXPERIMENT STATION

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I. Introduction

This report covers the period from January 1, 1988 thru June 30, 1988. The primary task during this period has been the continued development of the TAW5D transonic inverse wing design method with viscous interaction effects included.

II. Personnel

The staff associated with this project during the present reporting period have been Dr. Leland A. Carlson, Principal Investigator, and Robert R. Ratcliff, Graduate Research Assistant. Much of the work associated with this second phase of the project, which concentrates on the inclusion of weak viscous interaction effects in the design process and on design methodology, is forming the basis of the Master's Thesis of Mr. Ratcliff. It is anticipated that Mr. Raticliff will receive his Master's Degree in December 1988.

III. Research Progress

Since the present project is rapidly nearing conclusion, the status of the tasks outlined in the original proposal will be briefly reviewed.

Task 1 -- Viscous Interaction and Wake Curvature Effects

Weak viscous interaction and wake curvature effects have been successfully incorporated into the TAW5D transonic inverse wing design program, and the method has been successfully used to design aft-cambered wings on the fine grid (160x24x32). Tests have indicated that boundary layer displacement effects are very important in the design process and, surprisingly, that wake curvature effects have very little effect on designed airfoil shapes. Details concerning these results and other examples have been presented in Reference (1) and were included in the last progress report.

Task 2 -- Code Optimization and Design Methodology Studies

During the past reporting period, a considerable amount of the total effort has been associated with this task. In particular, several modifications to the design portions of TAW5D have been developed in order to make the code easier to use. For example, the code has been changed so that instead of having to repeat the blocks of invsicid iteration and global iteraction control parameters for each global iteration in the input data file, the user can now specify the number of iterations for each block of control data. This modification removes some of the tedium associated with running long design or viscous analysis cases and considerably reduces the length of a typical control file.

Further, the program has been changed so that it will now create plot files for the grid geometry, for the actual wing, and for the wing displacement surface (designed wing plus boundary layer). Also, in order to assist the user in creating the initial geometry files for the design process, the program has been modified so that it will automatically create wing geometry files containing up to twenty-one spanwise stations using as few as two stations as input. In many cases, this option greatly simplifies the user input necessary to obtain desired initial shapes.

Finally, in the area of code modification, the program has been changed so that now root sections can be designed. In the past, the root section was determined by extrapolation from the first station on the wing because attempts to design the root specifically had failed. Studies have determined that this failure was due to a simple coding error, which when corrected, eliminated the problem.

As mentioned in the last progress report, some problems have been encountered in certain design situations with a spanwise instability. In particular, when doing a fine grid design with user selected relofting and for which the pressure distribution is specified at every span station in the design region, the solution almost converges and then begins to diverge. During this reporting period, considerable effort has been devoted to studying this phenomena and attempting to determine a "fix" or "cure".

Since the instability appeared to be associated with the spanwise direction and with the calculation of the airfoil shapes, it was thought that the problem was in the treatment of the spanwise term in the shape equation

$$\frac{\partial \eta}{\partial \xi} = \frac{V}{U} - \frac{\partial \eta}{\partial \zeta}\frac{W}{U}$$

In the usual approach the spanwise term, $\frac{\partial \eta}{\partial \zeta} W/U$, is included in the integration of the equation. Consequently, the procedure was modified to first calculate the new shape without the spanwise term, reloft the new shape, , calculate the spanwise term, $\partial\eta/\partial\zeta\; W/U$, with the new information, and then reintegrate the equation with the spanwise term included. This process was repeated locally until there was little or no change in the spanwise term or the design shape. Unfortunately, this approach did not cure the divergence problem and had very little effect on the magnitude of the design ordinates since the spanwise term was small compared with the V/U term.

Next it was noted that in computing the new airfoil ordinates in the x-y plane, it had been assumed that the constant i,k grid line leaving the surface of the wing was orthogonal to the surface. Since the grid lines were not exactly orthogonal in all cases, the terms needed to calculate the normal component of the displacement were included. Although this approach did affect the third and sometimes the second significant digits of the changes in the airfoil ordinates, it did not affect the behavior of the spanwise oscillations.

Since the solution always almost converged before the appearance of the spanwise stability problem, it was thought that perhaps smoothing or curve fitting might solve the problem. Thus, the airfoil changes were smoothed up to four times in the spanwise direction before and after relofting. Unfortunately, this procedure slowed the rate of converge appreciably and did not prevent the appearance of the spanwise instability. Similarly, the use of various curve fits in the spanwise direction for the ordinates only slowed convergence and did not subdue the instability.

At this point, it might appear that this spanwise instability is a major problem. Actually, as pointed out in the last progress report and in Ref. 1, the instability is actually only a nagging type of problem and several engineering fixes have been developed which allow the program to yield useful and correct designs. For example, designing at every other spanwise station and interpolating (or lofting) the ordinate changes to the stations in-between permits in most cases convergence without appreciable oscillations. However, it has been discovered that for the inviscid design of low aspect ratio highly swept wings, such as Lockheed Wing B the instability is still present. In fact, as a general rule the instability appears to be worse as sweep increases and aspect ratio decreases. However, results can still be obtained for these cases by specifying the pressures at all design stations but only calculating ordinate changes at every other spanwise station and then, as before, interpolating the changs at the intermediate stations. Consequently, from an engineering standpoint, the spanwise instability problem can be overcome. Nevertheless, it would be desirable to eliminate it entirely.

Since the above tests and studies indicate that the spanwise instability problem is not due to the inverse boundary condition treatment but instead is due to the calculation of ordinate changes at every spanwise station in the design region and since the displacements are a direct function of the residual expression, the behavior of the residual has been investigated. Preliminary results indicate that the "compensation terms" involving spanwise derivatives, particularly the term, are the origin of the odd-even spanwise uncoupling. This behavior is somewhat surprising since the comepnsation terms were designed in the original FLO30 to prevent or at least mitigate odd-even uncoupling. Currently studies are underway to examine these compensation terms at surface grid points in more detail in an attempt to determine specifically why the present algorithm does not prevent this behavior. Hopefully, the results of this study will lead to a solution of the spanwise instability problem.

In other efforts under this task, studies are in progress to determine the best methodology of using the present design code. In general, cases can be classified as being either "easy" or "hard"; and the optimum number of coarse and medium grid iterations before the first relofting and the optimum number of iterations between relofting etc. is different. Consequently, different methodologies are being developed depending upon the parameters of the problem. For example, it has been found that as the wing sweep increases, the size of the direct zone near the leading edge must also be increased in order to "easily" obtain a design solution. It is anticipated that the results of these efforts will be reported at the end of the next reporting period.

Under this task, studies are also in progress concerning grid resolution. Specifically it is desired to determine whether or not preliminary designs can be adequately obtained using medium grids and the effects of viscous interaction on such conclusions. In general the approach being used is to design a wing to an "arbitrary" pressure distribution on the medium grid and then to analyze the wing on the fine grid both at the "design angle of attack" and the "design lift coefficient". By comparing the analysis pressure distributions and aerodynamic coefficients, both locally and overall, with the desired values, the utility of using the medium grid for design purposes will be determined.

Task 3 -- Methods for the Design of Isolated Regions

Studies to investigate the possibility of actually designing a segment of the wing which starts aft of the leading edge and terminates prior to the trailing edge have only recently been initiated. Thus, no definitive results have been obtained so far. In principle, logic similar to that now used at the trailing edge could be used further upstream. However, it is not evident that this approach will actually work easily in practice. Hopefully, some results concerning this possibility will becomne available during the next reporting period.

Task 4 -- Program Improvement Efforts

Many program improvements have been developed and, as described above, incorporated into the program. However, under this task it was originally planned to include in the progam spanwise lofting techniques. As reported in the last progress report and in Ref. (1), such techniques have been included in the method and found to be very useful.

In the original proposal, it was suggested that a correction for the entropy change across the shock wave could be incorporated into the program. However, after consultations with the technical monitor, this effort has been delayed. In addition, in the proposal, the dependence of the final solution on the starting solution was to be investigated since there was some evidence that such a dependence existed. Recent studies do not indicate that this dependence, if it exists at all, is serious or affects the final design solutions.

Task 5 -- Validation, Testing, and Documentation

Presently, this task is in progress and along with Task 2, comprises the major research effort of the project. Originally, it was suggested that the program could be validated by comparing it to experimental data. However, after consultation with the technical monitor and others at NASA Langley, it was decided that uncertainties in experimental data and test conditions (i.e. Mach number, Reynolds number, wall effects, angle of attack, etc.) would make it difficult to verify the code using experimental data. Consequently, it has been decided to verify or validate the code by showing that it is self consistent. In other words, demonstrate that the code can over a range of conditions design wings which when analysed will yield the desired pressure distributions and aerodynamic coefficients.

For this study, it has been decided to use Lockheed Wings A, B, C because these wings cover a range of aspect ratios and sweeps, are aft-cambered, and have readily available ordinates. For a given Mach number and Reynolds number condition, each wing will be analyzed using TAW5D, and the resultant pressure distributions will be considered the "design distributions". These values will then be used as input for design calculations; and the resultant designed wing will subsequently be analyzed. By comparing the analysis results for the designed wing with the analysis results for the original wing, the accuracy and validity of the present design method will be determined. These studies will be conducted over a range of Mach numbers, angles of attack, and Reynolds numbers for each wing in order to determine the range of applicability of the present method.

Efforts are also in progress to develop an appropriate user's manual for the design portion of the TAW5D computer code.

IV. Grant Monitor

The NASA Technical Monitor for this project is Richard L. Campbell, Applied Aerodynamics Group, NTF Aerodynamics Branch, Transonic Aerodynamics Division, NASA Langley.

V. References

1. Carlson, L. A., Ratcliff, R., Gally, T. A., and Campbell, R. L., "Inverse Wing Design in Transonic Flow Including Viscous Interaction," NASA Transonic Symposium -- Theory, Application, and Experiment, April 19-21, 1988, Hampton, Va.