Development of Three-Dimensional Flow Code Package to Predict Performance and Stability of Aircraft With Leading Edge Ice Contamination

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ABSTRACT

In the work reported herein, a simplified, uncoupled, zonal procedure is utilized to assess the capability of numerically simulating icing effects on a Boeing 727-200 aircraft. The computational approach combines potential flow plus boundary layer simulations by VSAERO for the un-iced aircraft forces and moments with Navier-Stokes simulations by NPARC for the incremental forces and moments due to iced components. These are compared with wind tunnel force and moment data, supplied by the Boeing Company, examining longitudinal flight characteristics. Grid refinement improved the local flow features over previously reported work with no appreciable difference in the incremental ice effect. The computed lift curve slope with and without empennage ice matches the experimental value to within 1%, and the zero lift angle agrees to within 0.2 of a degree. The computed slope of the uniced and iced aircraft longitudinal stability curve is within about 2% of the test data. This work demonstrates the feasibility of a zonal method for the icing analysis of complete aircraft or isolated components within the linear angle of attack range. In fact, this zonal technique has allowed for the viscous analysis of a complete aircraft with ice which is currently not otherwise considered tractable.
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1.0 INTRODUCTION

The flow fields associated with complete aircraft configurations are extremely complicated and remain a challenge for applied computational aerodynamics. Linear methods, i.e., pure potential flow solutions that may include nonlinear wake shape effects, have become commonly used techniques for aerodynamic predictions and analysis; however, research scientists are now developing and applying nonlinear methods, thereby incorporating more accurate mathematical models of the actual flow physics, such as compressibility and viscosity. Although much progress has been made in solving full potential, Euler, and various forms of the approximate Navier-Stokes equations (NS), a zonal method of analysis is generally projected for the entire aircraft flow-field calculation because of the wide variation of physical scales of characteristic fluid phenomena. This method is necessary not only to achieve a closed calculation on the next generation of computers, but also to obtain the required numerical accuracy over large regions that must include fine meshes to resolve the viscous layers as well as large flow gradients. Computational requirements for simulating the effects of ice contamination are even more severe since the method must predict aircraft performance and stability degradation caused by the local formation of complex ice shapes. Furthermore, the method should also be practical and fast enough to be utilized in preliminary design studies to ascertain component sensitivity to icing.

In this report, the work described involves a simplified, uncoupled zonal procedure which has been utilized to assess the capability of individual methods for simulating icing effects on a Boeing 727-200 aircraft. The zonal procedure includes the combined potential flow/boundary layer flow method (Program VSAERO\(^1\)) for the un-iced aircraft simulation, while a Navier-Stokes method (Program NPARC\(^2\)) is utilized for the iced components of the aircraft. Wind tunnel data\(^3\) used in this study for the un-iced and iced configurations were provided by the Boeing Company. The calculations described here include comparison with experiment for the longitudinal forces and moments. The grid resolution utilized in this study represents a refinement over previously reported work. Further results including lateral force and moment calculations may be found in an earlier report.\(^4\)

The general method is described in Section 2.0, the geometric considerations are presented in Section 3.0, the results are detailed in Section 4.0, and the conclusions and recommendations are described in Section 5.0. A description of the routines added to NPARC along with a printout is included in Appendix A, listing of the utility program, PRPAMI, developed under this contract is included in Appendix B, a sample NPARC input file may be found in Appendix C, and VSAERO and NPARC manual updates are in Appendix D. The contracted work to enhance the panel model of the DHC-6-200 Twin Otter for future tail-plane ice calculations is included in Appendix E.
2.0 METHODOLOGY

Unlike the previous fully-coupled zonal procedure which provided for an iterative step, the zonal aspect of this method is simplified to include an initial outer boundary flow condition only, which is provided by the potential flow code and utilized by the viscous flow component. At the viscous domain outer boundary (Fig. 1), velocities and pressure are specified and density is calculated from the pressure and free-stream stagnation enthalpy. Since velocities, pressure and density are known, energy at the boundary can be determined. The viscous flow code uses these initial conditions in combination with the characteristic method to treat the outer surface boundary conditions. Further details pertaining to the implementation of flow boundary conditions may be found in the excellent discussion by Raj, et. al.

The initial conditions generally involve effects from other aircraft features that are not included in the viscous domain. These may include, for example, lifting surface wake influence and fuselage blockage or upwash effects as well as the local surface boundary layer profile. In this manner, complications arising from an attempt to include other geometric features in the grid generation process are avoided. The final iced aircraft force and moment characteristics are estimated by superposition. The NPARC predicted incremental force and moment changes due to ice on individual aircraft components are combined with the VSAERO data for the un-iced aircraft. This process yields complete aircraft force and moment quantities under iced conditions. A zonal technique of this nature can allow for the viscous analysis of a complete aircraft with ice which is currently not otherwise considered tractable.

2.1 VSAERO Technical Description

VSAERO solves the Neumann problem of potential flow by converting Laplaces partial differential equation into a boundary integral equation, as described by Morino. The body and wake (i.e., boundary of the fluid) are then broken into finite size elements, or panels, each with an unknown potential value. Whereas, the body shape is known, the wake shape—determined by streamline trajectories from the downstream separation lines on the body—is not. An informed guess for the wake shape normally generates a useful first solution upon which VSAERO can improve iteratively. The displacement of the inviscid fluid boundary from solid surfaces caused by viscosity (namely, the boundary layer) can also be included by an iterative process.

The panel method leads to a matrix equation of the order of the total number of surface panels. The matrix is dense and non-symmetric. The main features of the technique include generating the coefficients of the matrix, solving the matrix, and determining new wake shapes and viscous displacements.
Fig. 1. Boeing 727-200 Wind Tunnel Model with Empennage Zonal Boundary Block Edges and VSAERO Computed Surface Pressure Contours at Zero Alpha.
2.2 NPARC Technical Description

NPARC Version 1.0 (formerly PARC3D), is a multi-block code developed by Sverdrup Technology, Inc., and is based upon ARC3D which was originally developed by Pulliam and Steger at NASA Ames Research Center. The method is based on the implicit approximate factorization algorithm of Beam and Warming for unsteady compressible flow. For turbulent flow, the well-known Baldwin-Lomax model is used for turbulence closure. This turbulence model also has been quite successful in the calculation of transonic flow, unless there is massive separation in the streamwise direction.

NPARC contains several improvements over the original ARC3D code, the most notable being the multi-block capability. Also, the user has the option of specifying flow boundary conditions by means of namelist input. Generally, the modifications are directed toward improvement in user productivity.

Several routines were modified or added to NPARC to accomplish the zonal component of this work. Generally, the changes involved input/output of pertinent flow-field data and proper treatment of the far-field boundary condition. The outer domain zonal boundary condition implemented in this work was patterned after the freestream option available in NPARC (subroutine BCFAR, boundary condition type: 7). As previously mentioned, this boundary condition implementation is based upon the method of characteristics. The BCFAR1 routine (derived from BCFAR), was developed to take advantage of the VSAERO flow information. Also, the contiguous block interface boundary condition (subroutine INTER70, boundary condition type: 70) was modified to remove the restriction that the computational coordinates must be increasing in the same physical direction for two overlapping grid blocks. The topological features of the t-tail grid-block structure did not conform to this requirement. A listing of the specific routines added to NPARC including a brief description are presented in Appendix A.

2.3 Computational Procedure

The step-by-step zonal procedure is outlined in Fig. 2. The user must first provide the basic model geometry in the form required by the particular grid generation package being used. Generally, this process may be accomplished via a CAD database. The simple geometric tools available in VSAERO may be used for basic point redistribution but in some cases the bi-quadratic interpolation has proven inadequate. Step two involves preparation of the volume grid within the flow domain of interest. In this work the grid generation process utilized the GRIDGEN system which results in the generation of a volume-grid data file in binary form.

For projects of this computational magnitude, the hardware utilization generally follows that described in Fig. 3. The user conducts certain elements of the work on a local workstation and via network access, is able to perform the more computationally demanding tasks on a super
<table>
<thead>
<tr>
<th>TASK</th>
<th>SOFTWARE</th>
<th>OUTPUT</th>
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<tr>
<td>(1) PREPARE SURFACE GRID</td>
<td>CAD AND/OR VSAERO</td>
<td>VSAERO AND GRIDGEN SURFACE GEOMETRY DATA FILES</td>
</tr>
<tr>
<td>(2) PREPARE VOLUME GRID</td>
<td>GRIDGEN</td>
<td>BINARY VOLUME GRID FILE</td>
</tr>
<tr>
<td>(3) GENERATE NPARC RESTART DATA FILE</td>
<td>PRPAMI</td>
<td>NPARC RESTART DATA FILE</td>
</tr>
<tr>
<td>(4) PREPARE VSAERO SCAN INPUT DATA</td>
<td>PRPAMI</td>
<td>VELOCITY SCAN INPUT DATA TO BE APPENDED TO VSAERO INPUT FILE</td>
</tr>
<tr>
<td>(5) GENERATE OUTER FLOW B.C.'S AND UN-ICED CL, CM</td>
<td>VSAERO</td>
<td>VELOCITY SCAN OUTPUT DATA FILE</td>
</tr>
<tr>
<td>(6) GENERATE VISCOSOUS FLOW SOLUTION INCLUDING CL, CM</td>
<td>NPARC (AMI VERSION)</td>
<td>NPARC RESTART DATA FILE</td>
</tr>
<tr>
<td>(7) PREPARE GRAPHICS POST-PROCESSING DATA FILE</td>
<td>PRPAMI</td>
<td>OMNI3D GRAPHICS DATA FILE</td>
</tr>
</tbody>
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Fig. 2. Task Summary of Zonal Ice Analysis Method.
HARDWARE UTILIZATION:

SGI WORKSTATION

TCP/IP (INTERNET)

CRAY Y-MP 4E

* GEOMETRY PREP (GRIDGEN)
* VSAERO CALCULATION
* POST-PROCESSING

* NPARC DATA FILE PREP
* NPARC CALCULATION

Fig. 3. Schematic of Hardware Utilization.
computer. For investigations requiring the memory and computational speed of a main frame super computer, the transfer of the volume grid file should proceed in binary form. This will help preserve the numerical accuracy of the model inherent in the binary format. Subsequent use of the binary data on the super computer (usually 64 bit), may require translation from 32 bit to 64 bit format which may be accomplished with the following command:

\[\text{assign } -F -f77 -N \text{ ieee 'filename'}\]

This specific command is for a Cray computer running Unicos and should be used prior to each access of the binary data.

The next task is normally conducted on the main frame computer and is involved with generation of the NPARC restart data file utilizing the utility program PRPAMI, which was developed under this contract. A copy of the code together with a brief description may be found in Appendix B. The GRIDGEN volume grid file is required at this stage. The entire flow domain is initialized with freestream flow conditions which are provided to PRPAMI interactively.

The fourth step is the preparation of the VSAERO velocity scan input data. Again, PRPAMI is used in conjunction with the NPARC input file (INON5), and the restart file (REST.OLD). The user is responsible for specifying the flow boundary conditions in INON5, including the Type 8 zonal boundary condition developed for this work. (An example INON5 data input file may be found in Appendix C). The PRPAMI code will assemble the grid point coordinates associated with all of the Type 8 regions and create a data file called SCAN.DAT in a format suitable for the VSAERO velocity scan input format. The user has the option of appending this data to the end of the VSAERO input files or using a separate data file for the velocity scan Mold 9 input. Modifications to the VSAERO and NPARC user’s manuals pertaining to this task may be found in Appendix D.

The fifth task outlined in Fig. 2 involves the analysis of the complete model with VSAERO. The recommended approach is to conduct an incremental study of the model starting with rigid, specified wake trajectories and potential flow only. After verifying the solution integrity, the wakes may be relaxed and the viscous correction with the streamline-based boundary layer may then be added. This process will eventually provide the force and moment coefficient of the un-iced configuration of interest and yield the off-body velocity-scan flow calculation based upon the SCAN.DAT data file. The local surface boundary layer profile may be included as part of the NPARC flow initialization by setting the variable MEET to -3 in the VSAERO input file, (refer to Appendix D).

The viscous flow solution for the isolated un-iced and iced model component is then determined as outlined under task six. As previously mentioned, the multi-block Reynolds’-averaged NS method NPARC was utilized for this purpose. Depending upon the particular application, the user may have to pay especially close attention to the convergence characteristics.
of the NPARC solution procedure. This topic is treated in more detail in Section 3.0. A procedure to compute the force and moment coefficients has been added to NPARC as a requirement of this work. Based upon the user-specified boundary conditions, this module determines the force and moment quantities associated with each solid surface region in both body and wind axis systems. Total aerodynamic coefficients are included at the end of the region by region force and moment summary written to the NPARC output data file. A listing of the routines that comprise this force and moment module along with a brief description is included in Appendix A.

Task seven should actually be utilized throughout the NPARC flow solution process initiated in task 6 to verify proper specification of flow boundary conditions and solution convergence characteristics. This step involves the generation of an OMNI3D compatible graphics data file with the utility code PRPAMI. The end result is a formatted data file which can be transferred to the OMNI3D platform for graphical processing.
3.0 GEOMETRY MODELING

This section details the work involved in the preparation of the Boeing 727-200 data case which was selected for validation of the proposed zonal concept. The current effort involves the analysis of the model at multiple angles of attack and zero sideslip in an effort to estimate the aerodynamic degradation due to the presence of leading-edge ice on the horizontal and vertical tail.

3.1 Panel Model

A VSAERO model of a complete Boeing 727-200 was prepared for this study. The wing was constructed with a jig twist distribution, which was consistent with the Boeing wind tunnel model (Fig. 1). The horizontal tail setting was -4 degrees with respect to the fuselage reference line. The center engine inlet was modified by removing the ducting inside the highlight and adding an elliptical fairing from the highlight forward. The outboard engine was changed to a flow-through nacelle by extending the inlet duct aft to the trailing edge of the nacelle. Unfortunately, Boeing was not able to provide pictures of the support sting that was attached to the model at the aft end of the fuselage. In lieu of this information, a wake was attached to the trailing edge of the center engine exhaust to simulate the effects of the sting; therefore the accuracy of the modeling of the sting compared with the actual experiment is unknown at this time.

The VSAERO panelization of the starboard side of the aircraft included 4,105 body and 3,899 wake panels in order to simulate the symmetric flight conditions described in this report.

3.2 Grid Generation

Structured multi-block grids were developed individually about the isolated t-tail for both iced and un-iced flight conditions. Because of the zonal approach employed here, the NS domain for both grids was bounded by the region described in Fig. 1. The outer domain boundary shown here is about one semi-span from the horizontal tail. Further, the lower domain boundary includes a section of the vertical tail above the center engine. As previously described, the flow information on the outer faces of these volumes are provided by the VSAERO code including an initial estimation of the boundary layer growth on the vertical tail section.

The minimum grid spacing normal to the body surface is consistent with a $y+$ of order 10 (minimum $\Delta Z/C = 0.0001$). Due to the presence of the vertical tail, an H-O grid topology was used to discretize the flow field (Fig. 4). This representation generally does not resolve the leading-edge region as well as a C-type topology but the t-tail geometric constraints limit the topological choices. The three-block grids about the un-iced and iced t-tail consisted of over 690,000 grid points (194x73x49) and 815,000 (228x73x49) grid points, respectively (See Appendix C). This represents an increase of nearly 90,000 grid points over the grid resolution.
Schematic of T-tail H-O Grid Topology

(b) Front View

(a) Side View

Fig. 4. Schematic of T-tail H-O Grid Topology.
used in previously reported work\textsuperscript{4,13}. The region in the vicinity of the horizontal tail leading-edge has been refined in the work presented here as shown in Fig. 5. Geometry details of the leading-edge ice shape for the horizontal tail are presented in Section 4.0.

Volume grids for both the un-iced and iced t-tail configurations were generated using GRIDGEN3D Version 8.5\textsuperscript{14}. Special modifications were made by MDA Engineering, Inc. to improve the control of orthogonality on selected faces. Specifically, the control functions were averaged across the leading edge of the horizontal tail (\(\xi\) direction), the leading edge of the vertical tail (\(\xi\) direction), and the tip of the vertical tail (\(\zeta\) direction). Also, the foreground control functions were only calculated on the region of the tip block that corresponded to the tip surface of the horizontal tail. It is anticipated that these features will be included in version 9 of GRIDGEN3D\textsuperscript{15}.

The geometry manipulation required in this work was continually plagued with questions regarding accurate representation of the basic surface. The initial surface definition, based upon tabular data supplied by Boeing, as well as the single precision software components of the surface and grid generation processes, contributed to these difficulties. Clearly, grids that achieve \(y^+\) values of \(O(1)\) are desirable for the viscous simulations reported here; however, this level of exactness requires surface definition to a minimum of eight places of accuracy and software tools capable of double precision computations.
Fig. 5. Comparison of Original and Revised Grid in the Vicinity of the Horizontal Tail Tip Section.
4.0 RESULTS

A 0.075-scale model of the Boeing 727-200 was tested in January of 1981 in the Boeing VERTOL Tunnel. Wind tunnel data was obtained at a Mach number of approximately 0.12 and a Reynolds number of 1.24 million, based on wing reference chord. Longitudinal forces and moments were measured for the un-iced cruise configuration and for various combinations of iced leading edges on the horizontal and vertical tail. A summary of the specific flight conditions reported here is included in Table 1 below. This section presents aircraft force and moment comparisons to experiment which have been previously reported\textsuperscript{14,15}, as well as detailed flow features for the iced t-tail at zero degrees angle of attack.

<table>
<thead>
<tr>
<th>CASE DESCRIPTION</th>
<th>CODE</th>
<th>ALPHA (deg)</th>
<th>YAW (deg)</th>
<th>MACH</th>
<th>Re</th>
</tr>
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<tr>
<td>Un-iced Aircraft</td>
<td>VSAERO</td>
<td>-4,0,2,4</td>
<td>0.0</td>
<td>0.12</td>
<td>1.2 x E06</td>
</tr>
<tr>
<td>Un-iced T-Tail</td>
<td>NPARC</td>
<td>0,4</td>
<td>0.0</td>
<td>0.12</td>
<td>1.2 x E06</td>
</tr>
<tr>
<td>Iced T-Tail</td>
<td>NPARC</td>
<td>0,4</td>
<td>0.0</td>
<td>0.12</td>
<td>1.2 x E06</td>
</tr>
</tbody>
</table>

Table 1. Summary of Flow Calculations.

In previous work\textsuperscript{16}, it was not possible to generate an acceptable t-tail grid which would meet the single-block assumption and thin layer approximation of ARC3D. Consequently, longitudinal icing calculations included ice on the horizontal tail only. Icing effects, created by ice on the vertical tail and ice on the outboard Kruegers, were included in the test data, but were neglected in the longitudinal force and moment calculations.

In the current work, the multi-block capability of NPARC removes these earlier restrictions and allows for an improved representation of the empennage. The longitudinal characteristics are examined with leading-edge ice on both horizontal and vertical tail control surfaces as required. Based on practical considerations, the ice on the Krueger flap has been ignored in the present calculations.
4.1 Un-Iced Aircraft Simulation

Since the Mach number in the test was essentially negligible, all VSAERO runs were made without compressibility corrections. Longitudinal calculations included angle-of-attack settings of -4, 0, 2 and 4 degrees. Computed and measured force coefficients were reduced with a reference chord of 180.7 inches, a reference area of 244,800 square inches, and a half span of 648 inches. Moments were referenced to fuselage station 905.3 and waterline 184.2 inches.

The viscous correction for the un-iced VSAERO analysis was accounted for through the coupled, streamline-based integral boundary layer procedure. In the boundary layer calculations, transition was set to occur as soon as the local Reynolds number, based upon momentum thickness, reached a value of 200. Without other test information regarding transition behavior, this method has been found to provide an appropriate boundary layer simulation for such wind tunnel test conditions. Three viscid-inviscid correction iterations were computed for each flight condition. Computed contours of constant pressure coefficient are presented in Fig. 1 for zero degrees angle of attack. Figs. 6 and 7 compare the computed lift and pitching moment characteristics with the experimental data. The VSAERO inviscid computation is included here for qualitative verification of the boundary layer effects. Within the linear range, the VSAERO boundary layer simulation matches the slope of the experimentally measured lift curve to within 1% and the zero lift angle agrees to within about one-tenth of a degree. This comparison is greatly improved over that previously reported in Ref. 16, which exhibited an error of approximately three-fourths of a degree. After further consultation with Boeing, it was determined that the defined wing twist distribution utilized in the previous work did not match the model specification; consequently, the current results represent the correct wing twist distribution. The calculated pitching moment slope of -0.032 compares well to the test value of -0.029 per degree and the computed zero pitching moment angle of attack is within 0.33 degree of the test value. Discussion of the un-iced aircraft longitudinal stability curve is included in the next section.

4.2 Iced Aircraft Simulation

In order to compute the force and moment increments of the aircraft due to ice, the viscous flow characteristics of the Boeing 727-200 empennage with and without leading-edge glaze ice was examined. Table 1 provides a detailed summary of the NPARC computations. Each of the NPARC computations required approximately 2.4x10^5 sec./grid point/iteration and 23 Mw of memory on a CRAY-YMP Model-E.
Boeing 727-200 Lift Comparison

Fig. 6. Comparison of Measured to Calculated Aircraft Lift.
Boeing 727-200 Pitching Moment Comparison

Fig. 7. Comparison of Measured to Calculated Aircraft Pitching Moment.
In all of the NPARC simulations, the flow was assumed to be fully turbulent at a model aircraft Reynolds number of 1.24 million. In these simulations, NPARC required from 10,000 to 15,000 iterations to achieve residual reductions on the order of 2 to 3 for a CFL number of 2 (see for example, Fig. 8). In practice, residual reduction of 3 to 4 orders is the generally accepted convergence criterion. In this study however, various factors have contributed to the poor residual convergence behavior. First, the fine grid resolution tends to restrict the maximum CFL number or time-step size which results in an increased number of iterations. Second, the multi-block nature of the domain decomposition adversely affects solution convergence due to the time lag of the boundary information. Third, the low subsonic Mach number is at or near the operational limit of the compressible flow equation set. Further testing is required to quantify the relative contribution of each factor and to suggest means by which the residual convergence can be accelerated.

In addition to residual history, the integrated lift and pitching moment coefficients were monitored as an aid in determining the convergence level. The history of lift and pitching moment coefficient is shown for the iced and un-iced t-tail configuration in Fig. 9 for an angle of attack of zero degrees. The unsteady behavior previously noted, is not obvious in the current calculations. It is apparent that the grid refinement and/or code differences between PARC3D and NPARC have contributed to this improvement in computed flow characteristics. As shown by the time histories of lift and pitching moment, the iced t-tail required more iterations to insure adequate convergence levels in comparison to the un-iced geometry.

A comparison of the un-iced and iced horizontal tail mid-span sectional pressure distribution at 0° angle of attack is presented in Fig. 10. As indicated, the presence of leading-edge ice generates additional down force resulting in an increased aircraft nose-up pitching moment. A close examination of the iced airfoil indicates that the ice shape produces a negative droop of the leading-edge. Thus the ice shape modifies, locally, the airfoil camber to produce the additional loading. There is also an apparent contribution from the effect of leading-edge ice on the boundary layer which would require further study to identify.

The horizontal tail reversed flow region in the vicinity of the upper and lower ice horn is presented in Fig. 11 for both original and current grid resolution. It is apparent that the flow solution on the refined grid is improved at least in a qualitative sense over the result on the original grid. A close-up view of the lower horn clarifies this point further (Fig. 12). The solid horizontal line in both figures marks the boundary between the upper and lower grid blocks. Note especially the flow vectors in the vicinity of the ice horn leading-edge and block interface. The refined grid result shows marked improvement over the original grid calculation.

The computed increment in lift and moment coefficients due to the presence of ice at zero degrees angle of attack is -0.0025 and 0.0122 respectively; while the corresponding increments based upon the original grid density are -0.0017 and 0.0095. This does not appreciably modify the previously reported force and moment results. Furthermore, this result tends to alleviate the earlier concerns regarding repeatability due to the relatively small force and moment increments.
Fig. 8. History of the Block Average of Solution Residual.
Fig. 9(a). History of Empennage Computed Lift Coefficient.
Fig. 9(b). History of Empennage Computed Pitching Moment Coefficient.
Fig. 11(a). Flow Velocity Vectors in the Vicinity of the Iced Horizontal Tail Leading Edge for the Original Grid. Flow is from Right to Left.
Flow Velocity Vectors in the Vicinity of the Iced Horizontal Tail Leading Edge for the Revised Grid. Flow is from Right to Left.
Fig. 12(a). Close-up View of Flow Velocity Vectors in the Vicinity of the Lower Lobe of Iced Horizontal Tail for the Original Grid. Flow is from Right to Left.
Fig. 12(b). Close-up View of Flow Velocity Vectors in the Vicinity of the Lower Lobe of Iced Horizontal Tail for the Revised Grid. Flow is from Right to Left.
due to ice\textsuperscript{4,13}. In fact, the detailed force and moment comparisons presented in this report are based on calculations utilizing the original grid resolution.

The computed aircraft lift and pitching moment characteristics are compared with experimental data in Figs. 13 and 14 and a quantitative breakdown is presented below in Tables 2 and 3. For comparison purposes, the test data characteristics were estimated by restricting the region of interest to the linear angle-of-attack range. The computed lift curve slope with ice matches the experimental value to within 1\%, and the zero lift angle agrees to within two-tenths of a degree. In addition, the computed pitching moment curve slope of -0.035 correlates with the test value of -0.032 per degree.

<table>
<thead>
<tr>
<th>TEST</th>
<th>CALCULATION</th>
<th>UN-ICED</th>
<th>ICED</th>
<th>(\frac{dC_L}{d\alpha}) (per deg)</th>
<th>(\alpha_e) (deg)</th>
<th>(C_{Lo})</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>0.077</td>
<td>-1.48</td>
<td>0.114</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>0.077</td>
<td>-1.44</td>
<td>0.111</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>0.084</td>
<td>-1.36</td>
<td>0.114</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>0.085</td>
<td>-1.29</td>
<td>0.110</td>
</tr>
</tbody>
</table>

Table 2. Detailed Comparison of the Aircraft Longitudinal Characteristics: \(C_L\) vs, \(\alpha\).
Fig. 13. Comparison of Measured to Calculated Impact of Ice on Aircraft Lift Coefficient.

Boeing 727-200 Lift Comparison

- Test Un-iced
- Calculation Un-iced
- Calculation Iced

Lift Coefficient

Body Angle of Attack [deg]

0.00
5.00
10.00
-5.00
-2.00
Boeing 727-200 Pitching Moment Comparison

![Graph showing pitching moment comparison for different conditions: Test Un-iced, Test Iced, Calculation Un-iced, Calculation Iced.]

Fig. 14. Comparison of Measured to Calculated Impact of Ice on Pitching Moment Coefficient.
Table 3. Detailed Comparison of the Aircraft Longitudinal Characteristics: $C_{m\gamma}$ vs. $\alpha$.

As indicated, the computed absolute slope and intercepts compare well with the test data as well as the increments due to ice. In particular, several incremental quantities may be estimated from the tabulated data. The experimental increment due to ice in lift curve slope, ($\Delta C_L$), zero lift angle of attack, ($\alpha_0$), and lift at zero angle of attack, ($\Delta C_{1\alpha}$), of 0.000, 0.04 and -0.003 compares very well with their respective computed values of 0.001, 0.07 and -0.004 (see Table 2). The experimental increment due to ice in pitching moment curve slope, ($\Delta C_{m\gamma}$), and abscissa intercept, ($\Delta \alpha$), of -0.003 and -0.21 correlates well with their respective computed values of -0.003 and -0.04 (see Table 3). Evidently, for the longitudinal case, the additional effects of the ice on the outboard Kruegers that was included in the experiment are indeed small for the examined angle of attack range.

The aircraft longitudinal stability curve is graphically presented in Fig. 15 and a detailed comparison of the computed and test stability data are presented below in Table 4. As shown, the computed slopes for the un-iced and iced aircraft are within about 2% of the test data. Further, based on estimates derived from Table 4, the experimental increment due to ice in stability curve slope, ($dC_{m\gamma}/dC_L$) and pitching moment at zero lift ($\Delta C_{m\gamma}$), of 0.16 and -0.01 compares favorably with the computed values of 0.18 and -0.003 respectively. In this case, the addition of ice to the vertical and horizontal tail leading-edge is a destabilizing influence.
Fig. 15. Comparison of Measured to Calculated Impact of Ice on Aircraft Stability.
Table 4. Detailed Comparison of the Aircraft Longitudinal Characteristics: $C_{My}$ vs. $C_L$.

Generally, computed increments due to ice are in the proper direction and are of the same magnitude as the test data for the aircraft longitudinal characteristics. The small relative magnitude of these increments, though, makes it difficult to discuss error in terms of percent.
5.0 CONCLUSIONS AND RECOMMENDATIONS

In the work reported here, a simplified, uncoupled, zonal procedure is utilized to assess the capability of numerically simulating icing effects on a Boeing 727-200 aircraft. The computational approach combines potential flow plus boundary layer simulations by VSAERO for the un-iced aircraft forces and moments, with NS simulations by NPARC for the incremental forces and moments due to iced components. The computed lift curve slope with and without empennage ice matches the experimental value to within 1%, and the zero lift angle agrees to within two-tenths of a degree. Furthermore, the computed slope of the un-iced and iced aircraft longitudinal stability curve is within about 2% of the test data. These results demonstrate the feasibility of a zonal method for the icing analysis of complete aircraft or isolated components within the linear angle of attack range. In fact, this zonal technique has allowed for the viscous analysis of a complete aircraft with ice which is currently not otherwise considered tractable.

Future work should include investigation of solution convergence acceleration methods in order to reduce the current CPU requirements, and double precision software in order to improve the geometric accuracy. Additionally, an experimental data base that includes surface definition to a minimum of eight places of accuracy, and an incremental buildup of the iced components as well as surface pressure information should be available in order to thoroughly evaluate the CFD prediction capability.

Acknowledgements

The authors would like to thank NASA Lewis Research Center for its support of this work under Contract NAS3-26310, The Boeing Company for providing the model geometry and wind tunnel data, Jef Dawson of Cray Research, Inc. for providing valuable computer time, and John Chawner of MDA Engineering, Inc. for providing the development version of GRIDGEN as well as expertise in grid generation. In addition the authors would like to thank their colleagues at AMI, David A. Lednicer and Deana Nelson-Wilson for their invaluable help with the surface geometry preparation and the VSAERO calculations.
6.0 REFERENCES


APPENDIX A

The following subroutines have been added to the NS code NPARC version 1.0 and were developed under NAS3-26310. These modifications pertain to the zonal aerodynamic analysis of aircraft or aircraft components with ice.

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFIXED</td>
<td>Opens outer boundary condition data file PARC.SCN as fortran unit 32. Loads uo, vo, wo, cpo arrays. Called from INITIA if type 8 boundary condition specified in input.</td>
</tr>
<tr>
<td>BCFAR1</td>
<td>Patterned after routine BCFAR. Sets zonal boundary condition based upon uo, vo, wo, cpo information. Called from routine BC.</td>
</tr>
<tr>
<td>SETVEL</td>
<td>Sets local flow parameters from uo, vo, wo, cpo arrays. Called from BCFAR1.</td>
</tr>
<tr>
<td>FORMOM</td>
<td>Computes the force and moment coefficients for all type 60 and 61 regions. Called from main routine.</td>
</tr>
<tr>
<td>PATCH</td>
<td>Forms surface panel element information such as, area and normal vector. Called from FORMOM.</td>
</tr>
<tr>
<td>CPCALC</td>
<td>Computes local surface panel element pressure coefficient. Called from FORMOM.</td>
</tr>
<tr>
<td>CORNR</td>
<td>Assembles flow variables at each corner of a surface panel element. Called from CPCALC.</td>
</tr>
<tr>
<td>ANLIZ</td>
<td>Performs loads summation over each surface region and prints out result. Called from FORMOM.</td>
</tr>
</tbody>
</table>
SUBROUTINE RFIXED
C**********************************************************************
cdan New routine added in December 1992 for VSAERO Vscan data.
C**********************************************************************
include 'npami.inc'
PARAMETER (NSCNMX=JMX*KMX*LMX)
COMMON/SCAN/UO(NBX,JMX,KMX,LMX), VO(NBX,JMX,KMX,LMX), WO(NBX,JMX,KMX,LMX),
& CPO(NBX,JMX,KMX,LMX)
OPEN(UNIT=32, FILE='PARC.SCN', FORM='FORMATTED', ERR=802,
& STATUS='OLD')
REWIND 32
NPT=0

C SET DEFAULTS
DO 4 N=I,NBX
DO 4 J=I,JMX
DO 4 K=I,KMX
4 CONTINUE

C READ FIRST TWO DUMMY RECORDS...
READ(32,*)
READ(32,*)
DO 5 J=1,NSCNMX
READ(32,*,END=801,ERR=5) U, V, W, CP, NB, JP, KP, LP
IF(JP.EQ.0)GO TO 5
NPT=NPT+1
UO(NB,JP,KP,LP)=U
VO(NB,JP,KP,LP)=V
WO(NB,JP,KP,LP)=W
CPO(NB,JP,KP,LP)=CP
5 CONTINUE
WRITE(6,*)'ERROR IN RFIXED, ALL BC POINTS HAVE NOT BEEN READ'
WRITE(6,*)'INCREASE NSCNMX PARAMETER'
STOP

801 CONTINUE
WRITE(*,*)'*** TOTAL NUMBER OF FIXED BC POINTS READ...', NPT
RETURN
802 WRITE(*,*)'*** ERROR OPENING UNIT 32 ***'
STOP
END

SUBROUTINE BCFARI (ID, J, KA, KB, LA, LB, ISGN, PINF, TINF,
* XX, XY, XZ, YY, YZ, ZZ, Q )
C**********************************************************************
cdan New routine added in December 1992 for VSAERO Vscan data.
C**********************************************************************
include 'npami.inc'
COMMON/INTEG/ IBF(NM+1), FNMACH(NM), fill(58*N-1+12*NIF)
COMMON/VISFAC/ ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
COMMON/WAYOUT/ A0, R0, U0, V0, W0, E0, P0
COMMON/NBLOC/MBLOCK, MB, MBNEXT
DIMENSION Q(JMAX,KMAX,LMAX,6),
* XX(Jmax,Kmax,Lmax),
* XY(Jmax,Kmax,Lmax),
* XZ(Jmax,Kmax,Lmax),
* YX(Jmax,Kmax,Lmax),
* YY(Jmax,Kmax,Lmax),
* YZ(Jmax, Kmax, Lmax),
* ZX(Jmax, Kmax, Lmax),
* ZY(Jmax, Kmax, Lmax),
* ZZ(Jmax, Kmax, Lmax)

C OUTER BOUNDARY FLOW CONDITIONS
C CAUTION: ONLY SATISFACTORY FOR INCOMPRESSIBLE FLOW CONDITIONS
A0 = SQRT(TINF)
R0 = GAMMA*PINF/TINF

JP=J+ISGN
SGN=ISGN
DO 310 L=LA,LB
DO 301 I=1,NM+1
IBF(I)=0

301 CONTINUE
C IF (ID.EQ.1) THEN
DO 303 K=KA,KB
ZNORM = SGN * SQRT(((XX(J,K,L)**2)+XY(J,K,L)**2+XZ(J,K,L)**2))
DCX = XX(J,K,L)/ZNORM
DCY = XY(J,K,L)/ZNORM
DCZ = XZ(J,K,L)/ZNORM
C EXTRAPOLATE TO BOUNDARY
RI = Q(JP,K,L,1)*Q(JP,K,L,6)
UI = Q(JP,K,L,2)/Q(JP,K,L,1)
VI = Q(JP,K,L,3)/Q(JP,K,L,1)
WI = Q(JP,K,L,4)/Q(JP,K,L,1)
EI = Q(JP,K,L,5)*Q(JP,K,L,6)
PI = GAMMA*( (EI - 0.5*RI*(UI**2 + VI**2 + WI**2) )
UNI = DCX*UI + DCY*VI + DCZ*WI
AI = SQRT( GAMMA*PI/RI )
C OUTER BOUNDARY NORMAL VELOCITY
CALL SETVEL(MB,ID,J,K,L,U0,V0,W0,CPO)
U0=U0*XMAC
V0=V0*XMAC
W0=W0*XMAC
P0=PINF+.5*CPO*XMAC
E0 = PINF*GMIR + .5*R0*(U0**2 + V0**2 + W0**2)
c
write(6,*)'*** bcfarl:',ID,j,jp,k,l,u0,v0,w0,p0
UN0 = DCX*U0 + DCY*V0 + DCZ*W0
C COMPUTE SPEED OF SOUND AND NORMAL VELOCITY COMPONENT
C FROM RIEMANN INVARIANTS
R1 = UN0 + (2.0*GMIR)*A0
R2 = UNI - (2.0*GMIR)*AI
A = 0.25*(R1-R2)*GAMI
UN = 0.50*(R1+R2)
XMN = UN/A

FNMAC(K)=XMN

303 CONTINUE
ELSE IF (ID.EQ.2) THEN
DO 304 K=KA,KB
ZNORM = SGN * SQRT(((YY(K,J,L)**2)+YY(K,J,L)**2+YZ(K,J,L)**2))
DCX = YY(K,J,L)/ZNORM
DCY = YY(K,J,L)/ZNORM
DCZ = YZ(K,J,L)/ZNORM

37
C EXTRAPOLATE TO BOUNDARY
RI = Q(K, JP, L, 1) * Q(K, JP, L, 6)
UI = Q(K, JP, L, 2) / Q(K, JP, L, 1)
VI = Q(K, JP, L, 3) / Q(K, JP, L, 1)
WI = Q(K, JP, L, 4) / Q(K, JP, L, 1)
EI = Q(K, JP, L, 5) * Q(K, JP, L, 6)
PI = GMAM (EI - 0.5 * RI * (UI**2 + VI**2 + WI**2))
UNI = DCX*UI + DCY*VI + DCZ*WI
AI = SQRT( GMAM * PI / RI )
C OUTER BOUNDARY NORMAL VELOCITY
CALL SETVEL(MB, ID, J, K, L, U0, V0, W0, CP0)
U0=U0*XMACH
V0=V0*XMACH
W0=W0*XMACH
PO=PINF+.5*CP0*XMACH
E0 = PINF*GMIR + .5*R0*(U0**2 + V0**2 + W0**2)
ctmp
C write(6,*)'*** bcfarl: ', ID, J, JP, K, L, U0, V0, W0, P0
UN0 = DCX*U0 + DCY*V0 + DCZ*W0
C COMPUTE SPEED OF SOUND AND NORMAL VELOCITY COMPONENT
C FROM RIEMANN INVARIANTS
R1 = UN0 + (2.0*GMIR)*A0
R2 = UNI - (2.0*GMIR)*AI
A = 0.25*(R1-R2)*GMAM
UN = 0.50*(R1+R2)
XMN = UN/A
FNMACH(K)=XMN
C CONTINUE
ELSE IF (ID.EQ.3) THEN
DO 305 K=KA, KB
ZNORM = SGN * SQRT((ZX(K, L, J)**2)+ZY(K, L, J)**2+ZZ(K, L, J)**2))
DCX = ZX(K, L, J)/ZNORM
DCY = ZY(K, L, J)/ZNORM
DCZ = ZZ(K, L, J)/ZNORM
C EXTRAPOLATE TO BOUNDARY
RI = Q(K, JP, L, 1) * Q(K, JP, L, 6)
UI = Q(K, JP, L, 2) / Q(K, JP, L, 1)
VI = Q(K, JP, L, 3) / Q(K, JP, L, 1)
WI = Q(K, JP, L, 4) / Q(K, JP, L, 1)
EI = Q(K, JP, L, 5) * Q(K, JP, L, 6)
PI = GMAM (EI - 0.5 * RI * (UI**2 + VI**2 + WI**2))
UNI = DCX*UI + DCY*VI + DCZ*WI
AI = SQRT( GMAM * PI / RI )
C OUTER BOUNDARY NORMAL VELOCITY
CALL SETVEL(MB, ID, J, K, L, U0, V0, W0, CP0)
U0=U0*XMACH
V0=V0*XMACH
W0=W0*XMACH
PO=PINF+.5*CP0*XMACH
E0 = PINF*GMIR + .5*R0*(U0**2 + V0**2 + W0**2)
ctmp
C write(6,*)'*** bcfarl: ', ID, J, JP, K, L, U0, V0, W0, P0
UN0 = DCX*U0 + DCY*V0 + DCZ*W0
C COMPUTE SPEED OF SOUND AND NORMAL VELOCITY COMPONENT
C FROM RIEMANN INVARIANTS
R1 = UN0 + (2.0*GMIR)*A0
R2 = UNI - (2.0*GMIR)*AI
A = 0.25*(R1-R2)*GMAM
UN = 0.50*(R1+R2)
XMN = UN/A

FNMAC(K) = XMN

CONTINUE
END IF
DO 307 K=KA,KB
IF (FNMAC(K).GT.1.0) THEN
IBF(K)=1  ! SUPERSONIC INFLOW
ELSE IF (FNMAC(K).GT.0.0) THEN
IBF(K)=2  ! SUBSONIC INFLOW
ELSE IF (FNMAC(K).GT.-1.0) THEN
IBF(K)=3  ! SUBSONIC OUTFLOW
ELSE
IBF(K)=4  ! SUPERSONIC OUTFLOW
END IF
CONTINUE
307 CONTINUE
K1=KA
IBFF=IBF(KA)
DO 309 K=KA+1,KB+1
IF (IBF(K).NE.ISFF) THEN
K2=K-1
IF (IBFF.EQ.1) THEN
CALL FARFIX (ID,J,K1,K2,L,BIGA(IPWR) )
ELSE IF (IBFF.EQ.2) THEN
CALL FARIN (ID,J,K1,K2,L,SGN,
     BIGA(IPWXW),BIGA(IPWXY),BIGA(IPWXZ),
     BIGA(IPWYW),BIGA(IPWYX),BIGA(IPBWZ),
     BIGA(IPWZX),BIGA(IPWZY),BIGA(IPWZZ),
     BIGA(IPWR )
) ELSE IF (IBFF.EQ.3) THEN
CALL FAROUT (ID,J,K1,K2,L,SGN,
     BIGA(IPWXW),BIGA(IPWXY),BIGA(IPWXZ),
     BIGA(IPWYW),BIGA(IPWYX),BIGA(IPBWZ),
     BIGA(IPWZX),BIGA(IPWZY),BIGA(IPWZZ),
     BIGA(IPWR )
) ELSE IF (IBFF.EQ.4) THEN
CALL OUTSUP (ID,J,K1,K2,L,BIGA(IPWR) )
END IF
K1=K
IBFF=IBF(K)
END IF
309 CONTINUE
310 CONTINUE
END

SUBROUTINE SETVEL(MB,ID,JPP,K,L,U0,V0,W0,CP0)
************************************************************************
cdan New routine added in December 1992 for VSAERO Vscan data.
************************************************************************
include 'npami.inc'
COMMON/SCAN/U0(NBX,JMX,KMX,LMX),VO(NBX,JMX,KMX,LMX),
     WO(NBX,JMX,KMX,LMX),CPO(NBX,JMX,KMX,LMX)
U0=1001.
IF(ID.EQ.1)THEN
U0=U0(MB,JPP,K,L)
V0=VO(MB,JPP,K,L)
WO=WO(MB,JPP,K,L)
END IF

39
CPO = CPO (MB, JPP, K, L)
ELSEIF (ID. EQ. 2) THEN
U0 = U0 (MB, K, JPP, L)
V0 = V0 (MB, K, JPP, L)
W0 = W0 (MB, K, JPP, L)
CPO = CPO (MB, K, JPP, L)
ELSEIF (ID. EQ. 3) THEN
U0 = U0 (MB, K, L, JPP)
V0 = V0 (MB, K, L, JPP)
W0 = W0 (MB, K, L, JPP)
CPO = CPO (MB, K, L, JPP)
ENDIF
IF (U0. GT. 1000.) THEN
WRITE (6, *) '*** ERROR... VELOCITY NOT SET ***'
WRITE (6, *) ' INDICES DO NOT MATCH SCAN DATA'
WRITE (6, *) ' MB, ID, JPP, K, L, ', MB, ID, JPP, K, L
STOP
ELSEIF (U0. GT. 500.) THEN
WRITE (6, *) '*** ERROR... VELOCITY NOT SET ***'
WRITE (6, *) ' SCAN VELOCITY NOT AVAILABLE'
WRITE (6, *) ' MB, ID, JPP, K, L, ', MB, ID, JPP, K, L
STOP
ELSE
RETURN
ENDIF
END

SUBROUTINE FORMOM
C*****************************************************************************
' Route added for force & moment calc.  7/93
*****************************************************************************
C include 'npami.inc'
PARAMETER (MAXB=4*NIP)
COMMON/MBLOCK/NBLOCK,MB,MBNEXT
COMMON/TIME/DT,IVARDT
COMMON/FORCE/CBAR,SSPAN,SREF,REFMX,REFMY,REFMZ
COMMON/VISFAC/ALPHA,BETA,XMACH,C2B,C2BP,VRAT,RE
COMMON/KEPS / NXLX,NTURB,ORDER,SIGK,SIGEPS,CK1,CK2,CK3,CK4,CK5
COMMON/INTEG/JL(MAXB),KL(MAXB),LL(MAXB)
DIMENSION Q(JMX,KMX,LMX,5),X(JMX,KMX,LMX),Y(JMX,KMX,LMX),Z(JMX,KMX,LMX),XC(NIP),YC(NIP),ZC(NIP),CPP(NIP),AREA(NIP),ANT(NIP,3)
NAMELIST/BOUNDS/ NJSEG,JLINE,JKLOW,JKHIGH,JLOW,JLHIGH,
* NKSEG,KLINE,KLOW,KHIGH,KLOW,KHIGH,
* NLSEG,LLINE,LLLOW,LLHIGH,LLLOW,LLHIGH,
* JTYPE,JSIGN,PRESSJ,TEMPJ,INTERJ,
* KTYPE,KSIGN,PRESSK,TEMPK,INTERK,
* LTYPE,LSIGN,PRESSL,TEMPL,INTERL,
* JEDGE,KEDGE,LEDGE,JDIR,KDIR,LDIR,
* NORMJ,NORMK,NORML
NTI = 5
REWIND NTI
NBPT = 0
NPAT = 0
WRITE (6,800)
WRITE (6,801) CBAR,SREF,SSPAN,REFMX,REFMY,REFMZ,XMACH,ALPHA,BETA
C
C RETRIEVE THE 3D SOLUTION DATA
REWIND 4
READ (4) NC, GAMMA
DO 50 NB=1,NBLOCK
READ (4) JL (NB), KL (NB), LL (NB)
READ (4)
* (((X (J, K, L),
  * J=1, JL (NB)), K=1, KL (NB)), L=1, LL (NB)),
* (((Y (J, K, L),
  * J=1, JL (NB)), K=1, KL (NB)), L=1, LL (NB)),
* (((Z (J, K, L),
  * J=1, JL (NB)), K=1, KL (NB)), L=1, LL (NB))
READ (4) (((Q (J, K, L, N), J=1, JL (NB)), K=1, KL (NB)),
  * L=1, LL (NB)), N=1, 5)
IF (NC.ge.NTURB)
* READ (4) (BIGA (J), J=IPWAK, IPWAK + NXYZ - 1),
* (BIGA (J), J=IPWEPS, IPWEPS+NYYZ-1),
* (BIGA (J), J=IPWTMU, IPWTMU+NYYZ-1)
READ (NTI, BOUNDS) ! Cray version of NAMELIST
READ (NTI, NML=BOUNDS) ! IRIS version of NAMELIST
DO 26 J=1,NJSEG
IF (JTYPE (J).EQ.60. OR. JTYPE (J).EQ.61) THEN
  IORDR=1
  NPAT=NPAT+1
  CALL PATCH (NORMJ (J), IORDR, JLOW (J), JHIGH (J), JLOW (J),
    JLINE (J), X, Y, Z, AREA, ANT, XC, YC, ZC)
  CALL CPCALC (IORDR, JLOW (J), JHIGH (J), JLOW (J), JLINE (J), Q, NBPT, CPP)
  NBPT = NBPT + NBPT
  CALL ANLIZ (NPAT, NBPT, AREA, ANT, CPP, XC, YC, ZC)
ENDIF
26 CONTINUE
DO 27 K=1,NKSEG
IF (KTYPE (K).EQ.60. OR. KTYPE (K).EQ.61) THEN
  IORDR=2
  NPAT=NPAT+1
  CALL PATCH (NORMK (K), IORDR, KLOW (K), KHIGH (K), KLOW (K),
    KLINE (K), X, Y, Z, AREA, ANT, XC, YC, ZC)
  CALL CPCALC (IORDR, KLOW (K), KHIGH (K), KLOW (K), KLINE (K), Q, NBPT, CPP)
  NBPT = NBPT + NBPT
  CALL ANLIZ (NPAT, NBPT, AREA, ANT, CPP, XC, YC, ZC)
ENDIF
27 CONTINUE
DO 28 L=1,NLSEG
IF (LTYPE (L).EQ.60. OR. LTYPE (L).EQ.61) THEN
  IORDR=3
  NPAT=NPAT+1
  CALL PATCH (NORT (L), IORDR, LJLOW (L), LJHIGH (L), LLOW (L),
    LHIGH (L), LLINE (L), X, Y, Z, AREA, ANT, XC, YC, ZC)
  CALL CPCALC (IORDR, LJLOW (L), LJHIGH (L), LLOW (L), LHIGH (L),
    LLINE (L), Q, NBPT, CPP)
  NBPT = NBPT + NBPT
  CALL ANLIZ (NPAT, NBPT, AREA, ANT, CPP, XC, YC, ZC)
ENDIF
28 CONTINUE
50 CONTINUE
CALL ANLIZ(-NPAT,NBP,NBPT,AREA,ANT,CPP,XC,YC,ZC)

"00 FORMAT(1HL,/,5X,'CURRENT SCALING PARAMETERS',
1 ' FOR FORCE AND MOMENT SUMMARY',/,5X,'BY PRESSURE INTEGRATION:')
801 FORMAT(//,5X,'CBAR SREF SSPAN REFMX REFMY',
1 'REFMZ',/5X,6F10.3,/5X,'RMACH ALDEG YAWDEG',//,
2 5X,3F10.3)
RETURN
END

SUBROUTINE PATCH(NRML,IORDR,JF,JL,KF,KL,LVL,X,Y,Z,AREA,*
ANT,XC,YC,ZC)
************************************************************************
cdan Routine added for force & moment calc. 7/93
************************************************************************
cinclude 'npami.inc'
DIMENSION X(JMX,KMX,LMX),Y(JMX,IQ4X,LMX),Z(JMX,KMX,I/LX),
1XC(NIP),YC(NIP),ZC(NIP),CPP(NIP),AREA(NIP),ANT(NIP,3)
EPSS = I.E-15
C
C PATCH GEOMETRY

NP=0
DO 100 K=KF,KL-1
DO 100 J=JF,JL-1
NP=NP+1
IF(IORDR.EQ.1)THEN
  X1 = X(LVL,J,K)
  Y1 = Y(LVL,J,K)
  Z1 = Z(LVL,J,K)
  X2 = X(LVL,J+1,K)
  Y2 = Y(LVL,J+1,K)
  Z2 = Z(LVL,J+1,K)
  X3 = X(LVL,J+1,K+1)
  Y3 = Y(LVL,J+1,K+1)
  Z3 = Z(LVL,J+1,K+1)
  X4 = X(LVL,J,K+1)
  Y4 = Y(LVL,J,K+1)
  Z4 = Z(LVL,J,K+1)
ELSEIF(IORDR.EQ.2)THEN
  X1 = X(J,LVL,K)
  Y1 = Y(J,LVL,K)
  Z1 = Z(J,LVL,K)
  X2 = X(J+1,LVL,K)
  Y2 = Y(J+1,LVL,K)
  Z2 = Z(J+1,LVL,K)
  X3 = X(J+1,LVL,K+1)
  Y3 = Y(J+1,LVL,K+1)
  Z3 = Z(J+1,LVL,K+1)
  X4 = X(J,LVL,K+1)
  Y4 = Y(J,LVL,K+1)
  Z4 = Z(J,LVL,K+1)
ELSEIF(IORDR.EQ.3)THEN
  X1 = X(J,K,LVL)
  Y1 = Y(J,K,LVL)
  Z1 = Z(J,K,LVL)
  X2 = X(J+1,K,LVL)
ELSE
  X1 = X(J,LVL,K)
  Y1 = Y(J,LVL,K)
  Z1 = Z(J,LVL,K)
  X2 = X(J+1,LVL,K)
ENDIF
100 CONTINUE
C
C PATCH GEOMETRY
Y2 = Y(J+1,K,LVL)
Z2 = Z(J+1,K,LVL)
X3 = X(J+1,K+1,LVL)
Y3 = Y(J+1,K+1,LVL)
Z3 = Z(J+1,K+1,LVL)
X4 = X(J,K+1,LVL)
Y4 = Y(J,K+1,LVL)
Z4 = Z(J,K+1,LVL)

ENDIF

XC(NP) = .25* (X1+X2+X3+X4)
YC(NP) = .25* (Y1+Y2+Y3+Y4)
ZC(NP) = .25* (Z1+Z2+Z3+Z4)
XP = .25* (X2+X3-X4-X1)
YP = .25* (Y2+Y3-Y4-Y1)
ZP = .25* (Z2+Z3-Z4-Z1)

SW = SQRT (XP*XP+YP*YP+ZP*ZP)

XP = .25* (X3+X4-X1-X2)
YP = .25* (Y3+Y4-Y1-Y2)
ZP = .25* (Z3+Z4-Z1-Z2)

SWQ = SQRT (XQ*XQ+YQ*YQ+ZQ*ZQ)

PVQX = XP*ZQ-ZP*YQ
PVQY = ZP*XQ-XP*ZQ
PVQZ = XP*YQ-YP*XQ

AR = SQRT (PVQX*PVQX+PVQY*PVQY+PVQZ*PVQZ)

IF (AR .LT. EPSS) AR = EPSS

AREA(NP) = AR*4.0

ANT(NP,1) = PVQX/AR
ANT(NP,2) = PVQY/AR
ANT(NP,3) = PVQZ/AR

IF (NRML .LT. 0) THEN
ANT(NP,1) = -PVQX/AR
ANT(NP,2) = -PVQY/AR
ANT(NP,3) = -PVQZ/AR
ENDIF

100 CONTINUE

RETURN

END

SUBROUTINE CPCALC(IORDR, JF, JL, KF, KL, LVL, Q, NP, CPP)

include 'npami.inc'
COMMON/VISFAC/ ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
DIMENSION Q(JMX,KMX,I_X,5), CPP(NIP)

GD = GAMMA*GAMI
FSMACH = XMACH
CPS = 1./( .5*GAMMA*FSMACH**2)
NP = 0

COMPUTE CP AT 4 'PANEL' CORNERS AND AVERAGE

DO 5 K=KF, KL-1
DO 5 J=JF, JL-1
IF(IORDR.EQ.1) THEN
SUBROUTINE CORNR(J, K, L, CPS, GD, Q, CPP)

include 'npami.inc'

DIMENSION Q(JMX, KMX, LMX, 5)

RR = 1./Q(J, K, L, 1)
Q1 = Q(J, K, L, 1)
Q2 = Q(J, K, L, 2) * RR
Q3 = Q(J, K, L, 3) * RR
Q4 = Q(J, K, L, 4) * RR
Q5 = Q(J, K, L, 5) / GAMMA
PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
CPP = (PP-1.)*CPS

RETURN
END

SUBROUTINE ANLIZ(JP, NBP, NBPT, AREA, ANT, CPP, XC, YC, ZC)

include 'npami.inc'

PARAMETER (MAXB=4*NIP)
COMMON/FORCE/CBAR, SSPAN, SREF, REFMX, REFMY, REFMZ
COMMON/VISFAC/ ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
COMMON/SV/ WIND(3, 3), SUMFX(MBC), SUMFY(MBC), SUMFZ(MBC),
1 SUMMx(MBC), SUMMY(MBC), SUMMZ(MBC)

DIMENSION CPP(NIP), AREA(NIP), ANT(NIP, 3), XC(NIP), YC(NIP), ZC(NIP)

EPS = 1.E-05
CPMIN = -10.
CPMAX = 1.20
JOUT = 6
MODUP = 0
MODWN = 0

IF(JP.GT.0) THEN
  WRITE(JOUT,620)JP, NBPT-NBP+1, NBPT
ENDIF

IF(JP.EQ.1) THEN
  SET UP WIND AXIS SYSTEM
END
YAWR = BETA / 57.29577951
AR = (ALPHA) / 57.29577951
CB = COS (YAWR)
CA = CB * COS (ALR)
SA = CB * SIN (ALR)
UXR = CA
UYR = - SIN (YAWR)
UZR = SA
WIND (1,1) = UXR
WIND (2,1) = UYR
WIND (3,1) = UZR
WIND (1,2) = 0.0
WIND (2,2) = 1.0
WIND (3,2) = 0.0
WIND (1,3) = -1.0
WIND (2,3) = 0.0
WIND (3,3) = 0.0
IF (UZR < 0.0) WIND (1,3) = 0.0
US = SQRT (UXR * UXR + UYR * UYR)
IF (US < EPS) THEN
    WIND (1,2) = - UYR / US
    WIND (2,2) = UXR / US
    WIND (1,3) = - UXR * UZR / US
    WIND (2,3) = - UYR * UZR / US
    WIND (3,3) = US
ENDIF
ELSEIF (JP < 0) THEN
    WRITE (JOUT, 621) 1, NBPT
    JP = JP
    SXF = 0.0
    SFY = 0.0
    SFZ = 0.0
    SMX = 0.0
    SMY = 0.0
    SMZ = 0.0
    DO 100 J = 1, JP
        SXF = SXF + SUMFX (J) / SREF
        SFY = SFY + SUMFY (J) / SREF
        SFZ = SFZ + SUMFZ (J) / SREF
        SMX = SMX + SUMMX (J) / SREF
        SMY = SMY + SUMMY (J) / SREF
        SMZ = SMZ + SUMMZ (J) / SREF
    CONTINUE
    CD = SXF * WIND (1,1) + SFY * WIND (2,1) + SFZ * WIND (3,1)
    CS = SXF * WIND (1,2) + SFY * WIND (2,2) + SFZ * WIND (3,2)
    CL = SXF * WIND (1,3) + SFY * WIND (2,3) + SFZ * WIND (3,3)
    CLMX = (SMX * WIND (1,1) + SMY * WIND (2,1) + SMZ * WIND (3,1)) / SSPAN
    CLMY = (SMX * WIND (1,2) + SMY * WIND (2,2) + SMZ * WIND (3,2)) / CBAR
    CLMZ = (SMX * WIND (1,3) + SMY * WIND (2,3) + SMZ * WIND (3,3)) / SSPAN
    WRITE (JOUT, 629) CD, CS, CL, CLMX, CLMY, CLMZ
    SMX = SMX / SSPAN
    SMY = SMY / CBAR
    SMZ = SMZ / SSPAN
    WRITE (JOUT, 613) SXF, SFX, SFZ, SMX, SMY, SMZ
RETURN
ENDIF
C LOADS SUMMATION
C
SUMFX (JP) = 0.0
SUMFY (JP) = 0.0
SUMFZ (JP) = 0.0
SUMMX (JP) = 0.0
SUMMY (JP) = 0.0
SUMMZ (JP) = 0.0

DO 200 I = 1, NBP
XCM = X(I) - REFMX
YCM = Y(C(I) - REFMY
ZCM = Z(I) - REFMZ
CPA = CPP(I)

IF (CPP(I) .LT. CPMIN) THEN
  MODWN = MODWN + 1
  CPA = CPMIN
ELSE IF (CPP(I) .GT. CPMAX) THEN
  MODUP = MODUP + 1
  CPA = CPMAX
ENDIF

DFX = -CPA * AREA(I) * ANT(I, 1)
DFY = -CPA * AREA(I) * ANT(I, 2)
DFZ = -CPA * AREA(I) * ANT(I, 3)

SUMFX (JP) = SUMFX (JP) + DFX
SUMFY (JP) = SUMFY (JP) + DFY
SUMFZ (JP) = SUMFZ (JP) + DFZ
SUMMX (JP) = SUMMX (JP) + (YCM * DFZ - ZCM * DFY)
SUMMY (JP) = SUMMY (JP) + (ZCM * DFX - XCM * DFZ)
SUMMZ (JP) = SUMMZ (JP) + (XCM * DFY - YCM * DFX)
CONTINUE

WRITE (JOUT, 699) CPMAX, MODUP, CPMIN, MODWN
SFX = SUMFX (JP) / SREF
SFY = SUMFY (JP) / SREF
SFZ = SUMFZ (JP) / SREF
SMX = SUMMX (JP) / SREF
SMY = SUMMY (JP) / SREF
SMZ = SUMMZ (JP) / SREF

CD = SFX * WIND(1, 1) + SFY * WIND(2, 1) + SFZ * WIND(3, 1)
CS = SFX * WIND(1, 2) + SFY * WIND(2, 2) + SFZ * WIND(3, 2)
CL = SFX * WIND(1, 3) + SFY * WIND(2, 3) + SFZ * WIND(3, 3)

CLMX = (SMX * WIND(1, 1) + SMY * WIND(2, 1) + SMZ * WIND(3, 1)) / SSPAN
CLMY = (SMX * WIND(1, 2) + SMY * WIND(2, 2) + SMZ * WIND(3, 2)) / CBAR
CLMZ = (SMX * WIND(1, 3) + SMY * WIND(2, 3) + SMZ * WIND(3, 3)) / SSPAN

WRITE (JOUT, 629) CD, CS, CL, CLMX, CLMY, CLMZ

SMX = SMX / SSPAN
SMY = SMY / CBAR
SMZ = SMZ / SSPAN

WRITE (JOUT, 613) SFX, SFY, SFZ, SMX, SMY, SMZ

RETURN
FORMATT(1H0,50(1H*)/1H0,
123H TOTAL FORCE AND MOMENT,
2 ' ( PANELS ',I5,' - ',I5')',/,
247H(NOTE: THE COEFFICIENTS HERE DO NOT INCLUDE THE,
312H IMAGE SET.))/)
FORMATT(1H0,
118H FORCE AND MOMENT//,
21H ,8X,2HCD,11X,2HCS,11X,2HCL,10X,3HCMX,10X,3HCMY,10X,3HCMZ/ 
31H ,1X,6G13.4/)
FORMATT(8H CPMAX= ,F6.1,18H PANELS MODIFIED= ,I5,/,8H CPMIN= ,F6.1, 
18H PANELS MODIFIED= ,I5)
END
APPENDIX B

Program PRPAMI was developed to aid the user in pre and post-processing of data required by the zonal aerodynamic procedure developed under NAS3-26310. This is an interactive program written in FORTRAN with the specific application in mind. When practical, generality in the code logic was preserved, but future problems with different topological features may require software modification. Following is a brief description of the code features taken from the self-documentation included in the code. The variable IOPT is defined by the user.

<table>
<thead>
<tr>
<th>IOPT</th>
<th>FEATURE</th>
<th>FILES REQUIRED</th>
<th>OUTPUT FILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GENERATE NPARC RESTART DATA FILE</td>
<td>'_____ VOL'</td>
<td>REST. OLD</td>
</tr>
<tr>
<td>2</td>
<td>GENERATE VSAERO SCAN INPUT DATA</td>
<td>INON5, REST. OLD</td>
<td>SCAN. DAT</td>
</tr>
<tr>
<td>3</td>
<td>GENERATE OMNID3D GRAPHICS DATA FILE</td>
<td>INON5, REST. OLD</td>
<td>PARC. FMT</td>
</tr>
<tr>
<td>4</td>
<td>REORDER GRID BLOCKS</td>
<td>'_____ VOL'</td>
<td>'_____ VOL2'</td>
</tr>
</tbody>
</table>

*Note: Filenames in single quotes are provided by user.*
PROGRAM PRPAMI
C*****************************************************************************
C MARCH 1994
C
UTILITY PROGRAM FOR DATA FILE MANIPULATION DEVELOPED BY
C D.J. STRASH AT ANALYTICAL METHODS, INC. UNDER OPTION 2 OF
C NASA LEWIS CONTRACT NUMBER NAS3-26310.
C
????QUESTIONS???? CALL DAN STRASH @ (206)643-9090
C OR E-MAIL dan@amiwest.com
C*****************************************************************************
C
C IOPT FEATURE Files Required Output File
C---------------------------------------------------------------------------------
C 1 GENERATE NPARC RESTART ' .VOL' REST.OLD
C 2 GENERATE VSAERO SCAN INON5, REST.OLD SCAN.DAT
C 3 GENERATE OMNI3D GRAPHICS INON5, REST.OLD PARC.FMT
C 4 REORDER GRID BLOCKS ' .VOL' ' .VOL2'
C
(NOTE: FILENAMES IN SINGLE QUOTES ARE PROVIDED BY USER.)
C*****************************************************************************
C
CHARACTER *2 GRD
5 CONTINUE
WRITE(*,*)' YOU HAVE THE FOLLOWING OPTIONS...
WRITE(*,*)' 1. PREPARE PARC3D RESTART FILE'
WRITE(*,*)' 2. PREPARE VSAERO SCAN INPUT FILE'
WRITE(*,*)' 3. PREPARE OMNI3D PLOT FILE'
WRITE(*,*)' 4. REORDER BLOCKS (.VOL FILE)
WRITE(*,*)' PLEASE TYPE NUMBER OF DESIRED OPTION...
READ(*,*)IOPT

IF(IOPT.EQ.1)THEN
 CALL OPNRES
 CALL RVOL
 CALL PAERO
 WRITE(*,*)' WHAT IS THE GRID TOPOLOGY?'
 WRITE(*,*)' (CO - FOR C-O TYPE, HO - FOR H-O TYPE)
 WRITE(*,*)
 READ(*,80)GRD
 IF(GRD(1:1).EQ.'C')THEN
 CALL COGRD
 ELSE
 CALL HOGRD
 ENDIF
ELSEIF(IOPT.EQ.2)THEN
 CALL OPNSCN
 CALL READRES
 CALL SCNGEN
ELSEIF(IOPT.EQ.3)THEN
 CALL OPNPLT

49
CALL READRES
CALL PLTGEN
ELSEIF (IOPT.EQ.4) THEN
CALL OPNRDR
CALL REORDDR
ELSEIF (IOPT.LT.0) THEN
STOP
ELSE
WRITE (*,*) 'UNSUPPORTED OPTION, TRY AGAIN'
GO TO 5
ENDIF
STOP
80 FORMAT (A2)
END

SUBROUTINE OPNRES
CHARACTER*80 FILUN, FILOT,FILIN
DATA FILOT/'REST.OLD'/
WRITE(*,*) 'INPUT NAME OF GRIDGEN VOLUME GRID FILE.'
READ(*,80)FILIN
OPEN(UNIT=8,FILE=FILIN,FORM='UNFORMATTED',STATUS='OLD',err=9001)
OPEN(UNIT=9,FILE=FILOT,FORM='UNFORMATTED',STATUS='UNKNOWN',err=9002)
REWIND 8
REWIND 9
RETURN
9001 WRITE(*,*) 'UNABLE TO OPEN ',FILIN
STOP
9002 WRITE(*,*) 'UNABLE TO OPEN REST.OLD'
STOP
80 FORMAT(A80)
END

SUBROUTINE OPNSCN
CHARACTER*80 FILUN, FILOT, FILIN
DATA FILIN/'INON5/', FILUN/'REST.OLD'/, FILOT/'SCAN.DAT'/
OPEN(UNIT=7,FILE=FILIN,FORM='FORMATTED',STATUS='OLD',err=9001)
OPEN(UNIT=8,FILE=FILUN,FORM='UNFORMATTED',STATUS='OLD',err=9002)
OPEN(UNIT=9,FILE=FILOT,FORM='FORMATTED',STATUS='UNKNOWN',err=9003)
REWIND 7
REWIND 8
REWIND 9
RETURN
9001 WRITE(*,*) 'UNABLE TO OPEN INON5'
STOP
9002 WRITE(*,*) 'UNABLE TO OPEN REST.OLD'
STOP
9003 WRITE(*,*) 'UNABLE TO OPEN SCAN.DAT'
STOP
END

SUBROUTINE OPNPLT
CHARACTER*80 FILUN, FILOT, FILIN
DATA FILIN/'INON5/', FILUN/'REST.OLD'/, FILOT/'PARC_FMT'/
OPEN(UNIT=7, FILE=FILIN, FORM='FORMATTED', STATUS='OLD', err=9001)
OPEN(UNIT=8, FILE=FILUN, FORM='UNFORMATTED', STATUS='OLD', err=9002)
OPEN(UNIT=9, FILE=FILOT, FORM='FORMATTED', STATUS='UNKNOWN', err=9003)

REWIND 7
REWIND 8
REWIND 9
RETURN

9001 WRITE(*,*)' UNABLE TO OPEN INON5'
STOP

9002 WRITE(*,*)' UNABLE TO OPEN REST.OLD'
STOP

9003 WRITE(*,*)' UNABLE TO OPEN PARC.FMT'
STOP
END

SUBROUTINE OPNRDR
CHARACTER*80 FILUN, FILOT, FILIN
DATA FILOT/'REST. OLD'/
WRITE(*,*)' INPUT NAME OF GRIDGEN VOLUME GRID FILE.'
READ( 80) FILIN
OPEN(UNIT=8, FILE=FILIN, FORM='UNFORMATTED', STATUS='OLD', err=9001)
WRITE(*,*)' INPUT NAME OF MODIFIED GRIDGEN VOLUME GRID FILE.'
READ( 80) FILOT
OPEN(UNIT=9, FILE=FILOT, FORM='UNFORMATTED', STATUS='UNKNOWN', err=9002)
REWIND 8
REWIND 9
RETURN

9001 WRITE(*,*)' UNABLE TO OPEN INON5'
STOP

9002 WRITE(*,*)' UNABLE TO OPEN REST.OLD'
STOP

80 FORMAT(A80)
END

SUBROUTINE rvol

PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
COMMON /GRID/ X(JMX,KMX,LMX,NTB), Y(JMX,KMX,LMX,NTB), Z(JMX,KMX,LMX,NTB), JM(NTB), KM(NTB), LM(NTB), NBLOCKS, NBB, SYM

io3di = 8

DO 100 MB = 1, NBLOCKS
   READ(io3di, END=9010, ERR=9020) NBLOCKS
   IF(NBLOCKS.GT.NTB) THEN
      WRITE(*,1031) NBLOCKS
   ELSE
      WRITE(*,1030) NBLOCKS
   ENDIF
   DO 100 MB = 1, NBLOCKS
      READ(io3di) JM(MB), KM(MB), LM(MB)
   100 CONTINUE

write(*,1040) mb,jm(mb),km(mb),lm(mb)
read(io3di,end=9010,err=9020)
   ( ( ( x(i,j,k,mb),
      i = 1, jm(mb) ),
      j = 1, km(mb) ),
      k = 1, lm(mb) ),
   ( ( y(i,j,k,mb),
      i = 1, jm(mb) ),
      j = 1, km(mb) ),
      k = 1, lm(mb) ),
   ( ( z(i,j,k,mb),
      i = 1, jm(mb) ),
      j = 1, km(mb) ),
      k = 1, lm(mb) )
100 continue

close(unit=io3di)
return
9010 write(*,1010)
stop
9020 write(*,1020)
stop
1010 format(/,5X,'ERROR: END OF FILE READING VOLGRID FILE',
   & '20 format(/,5X,'ERROR: ERROR READING VOLGRID FILE',
   & '/)
1030 format(/,5X,' NUMBER OF BLOCKS IN VOLGRID FILE... ',i3,
   & '/)
1031 format(/,5X,' ERROR READING VOLGRID FILE... ',/,
   & 5X,' INCREASE BLOCK DIMENSIONS (NTB) TO ',i3,
   & '/)
1040 format(/,5X,' NO. OF PTS IN BLOCK ',i3,' OF VOLGRID FILE',
   & '/5X,' VOLGRID - ',i3,' X ',i3,' X ',i3,
   & '/
end

subroutine reordr

PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
common /grid/ x(jmx,kmx,lmx,NTB),y(jmx,kmx,lmx,NTB),
   & z(jmx,kmx,lmx,NTB),jm(NTB),km(NTB),lm(NTB),NBLOCKS,NBB,SYM
DIMENSION IB(NTB)
io3di = 8
io3do = 9

read(io3di,end=9010,err=9020) nblocks
write(io3do) nblocks
write(*,1030) nblocks
            
do 100 mb = 1, nblocks
read(io3di) jm(mb), km(mb), lm(mb)
write(*,1040) mb,jm(mb),km(mb),lm(mb)

read(io3di, end=9010, err=9020)
( ( ( x(i,j,k,mb),
    i = l, jm(mb) ),
    j = l, km(mb) ),
    k = l, lm(mb) ),
( ( ( y(i,j,k,mb),
    i = l, jm(mb) ),
    j = l, km(mb) ),
    k = l, lm(mb) ),
( ( ( z(i,j,k,mb),
    i = l, jm(mb) ),
    j = l, km(mb) ),
    k = l, lm(mb) )
100 continue

write(*,*), 'WOULD YOU LIKE TO SCALE AND TRANSLATE GRID?'
write(*,*), '(I = YES, 0 = NO)'
read(*,*) iopt
if(iopt.ne.0)then
5 write(*,*), 'INPUT REFERENCE LENGTH, XT, YT, ZT'
write(*,*)
read(*,*) refl,xt,yt,zt
if(abs(refl).lt.1.e-07)then
write(*,*), 'TRY AGAIN...'
go to 5
endif
do 150 mm = l,nblocks
  do 155 j = l,jm(mm)
    do 155 k = l,km(mm)
      do 155 l = l,lm(mm)
        x(j,k,l,mm) = x(j,k,l,mm)/refl + xt
        y(j,k,l,mm) = y(j,k,l,mm)/refl + yt
        z(j,k,l,mm) = z(j,k,l,mm)/refl + zt
      155 continue
    155 continue
  150 continue
endif
write(*,*), 'PLEASE TYPE IN NEW BLOCK ORDER,'
write(*,*), '(e.g. 1,3,2).'
write(*,*)
read(*,*) (ib(n), n = l, nblocks)
do 200 mm = l,nblocks
  mb = ib(mm)
write(io3do) jm(mb), km(mb), lm(mb)
write(*,1040) mb,jm(mb),km(mb),lm(mb)
write(io3do)
53
& i = 1, jm(mb) ),
& j = 1, km(mb) ),
& k = 1, lm(mb) ),
( ( z(i,j,k,mb),
  i = 1, jm(mb) ),
  j = 1, km(mb) ),
  k = 1, lm(mb) )

200 continue

close(unit=io3di)
close(unit=io3do)
return

9010 write(*,1010)
  stop
9020 write(*,1020)
  stop

1010 format(/,5X,'ERROR: END OF FILE READING VOLGRID FILE', &
  /)
1020 format(/,5X,'ERROR: ERROR READING VOLGRID FILE', &
  /)
1030 format(/,5X,'NUMBER OF BLOCKS IN VOLGRID FILE...',i3, &
  /)
1040 format(/,5X,'NO_ OF PTS IN BLOCK ',i3,' OF VOLGRID FILE', &
  /,5X,' VOLGRID - ',i3,' X ',i3,' X ',i3,&-
  end

SUBROUTINE PAERO
PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
common /grid/ x(jmx,kmx,lmx,NTB),y(jmx,kmx,lmx,NTB), &
  z(jmx,kmx,lmx,NTB),jm(NTB),km(NTB),lm(NTB),NBLOCKS,NBB,SYM
COMMON/AERO/ R(jmx,kmx,lmx),RU(jmx,kmx,lmx),RV(jmx,kmx,lmx), &
  RW(jmx,kmx,lmx),E(jmx,kmx,lmx),ALPHA,BETA,FMACH,CBAR
CHARACTER *1 GOM
LOGICAL SYM
DATA G/I.4/, GMI/0.4/, SYM/.FALSE./

WRITE(*,*)
WRITE(*, *) ' INPUT ALPHA, BETA, MACH NUMBER AND CBAR...
WRITE(*,*)' (CBAR USED TO SCALE GEOMETRY')
WRITE(*,*)
READ(*,*)ALDEG,YAWDEG,FMACH,CBAR
IF(ABS(YAWDEG).GE.0.1)THEN
  WRITE(*,*)
  WRITE(*,*)' SHOULD THE GEOMETRY BE MIRRORED ACROSS X-Z PLANE?'
  WRITE(*,*)' (T-TRUE, F-FALSE')
  WRITE(*,*)
  READ(*,80)GOM
  IF(GOM(1:1).EQ.'T')SYM=.TRUE.
ENDIF
IF(FMACH.LT.0.1)FMACH=0.1
NBB=NBLOCKS
IF(SYM)NBB=2*NBLOCKS
IF(NBLOCKS.GT.NTB)THEN
C Form the Arrays of Non-Dimensional Conservation Variables
C Consistent with the Free-Stream Mach Number

YAWR = YAWDEG / 57.29577951
ALR = ALDEG / 57.29577951
CB = COS(YAWR)
CA = CB * COS(ALR)
SA = CB * SIN(ALR)

FACT = (1. + 2 * FMACH**2)
PBAR = FACT**(-3.5) / G
RHOB = FACT**(-2.5)
RHOU = RHOB * FMACH * SQRT(1./FACT)
EBAR = PBAR / GM1 + 0.5 * (RHOU**2) / RHOB

RHOU = RHOU * CA
RHOV = -RHOU * SIN(YAWR)
RHOW = RHOU * SA

DO 4 L = 1, LMX
DO 4 K = 1, KMX
DO 4 J = 1, JMX
R(J, K, L) = RHOB
RU(J, K, L) = RHOU
RV(J, K, L) = RHOV
RW(J, K, L) = RHOW
E(J, K, L) = EBAR
CONTINUE

SUBROUTINE HOGRD

C Assumes the following:
C 1. 3-Block H-O Topology
C 2. Blocks and Indices are in Proper Order (upper-tip-lower)

PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
COMMON/grid/x(jmx, kmx, lmx, NTB), y(jmx, kmx, lmx, NTB),
& z(jmx, kmx, lmx, NTB), jm(NTB), km(NTB), lm(NTB), NBLOCKS, NBB, SYM
COMMON/AERO/R(jmx, kmx, lmx), RU(jmx, kmx, lmx), RV(jmx, kmx, lmx), RW(jmx, kmx, lmx),
& E(jmx, kmx, lmx), ALPHA, BETA, FMACH, CBAR
DIMENSION XX(JMX, KMX, LMX), YY(JMX, KMX, LMX), ZZ(JMX, KMX, LMX)
LOGICAL SYM
DATA G/I4/, GM1/0.4/

jto = 9
WRITE RESTART TAPE
NC1=0
WRITE(jto) NC1, G
WRITE(*,*) 'JMAX KMAX LMAX'
DO 2 MB=1,NBLOCKS
C BLOCK #1: STARBOARD UPPER
IF (MB.EQ.1) THEN
  JMAX=JM(MB)
  KMAX=KM(MB)
  LMAX=LM(MB)+1
  WRITE (*,*) JMAX, KMAX, LMAX
  DO 5 J=1,JMAX
  DO 5 K=1,KMAX
  DO 5 L=1,LMAX
    IF (L.NE.1) THEN
      XX(J,K,L)=X(J,K,L,MB)/CBAR
      YY(J,K,L)=Y(J,K,L,MB)/CBAR
      ZZ(J,K,L)=Z(J,K,L,MB)/CBAR
    ELSEIF (K.EQ.1) THEN
      XX(J,K,L)=X(J,KM(NBLOCKS)-K+1,L,MB)/CBAR
      YY(J,K,L)=Y(J,KM(NBLOCKS)-K+1,L,MB)/CBAR
      ZZ(J,K,L)=Z(J,KM(NBLOCKS)-K+1,L,MB)/CBAR
    ELSEIF (K.EQ.NBLOCKS) THEN
      XX(J,K,L)=X(J,KM(NBLOCKS)-L+1,L,MB)/CBAR
      YY(J,K,L)=Y(J,KM(NBLOCKS)-L+1,L,MB)/CBAR
      ZZ(J,K,L)=Z(J,KM(NBLOCKS)-L+1,L,MB)/CBAR
    ENDIF
  5 CONTINUE
  CALL WRDAT(JTO,JMAX,KMAX,LMAX,XX,YY,ZZ,R,RU,RV,RW,E)
ELSEIF (MB.EQ.NBLOCKS) THEN
C BLOCK 3: STARBOARD LOWER
  JMAX=JM(MB)
  KMAX=KM(MB)
  LMAX=LM(MB)
  WRITE (*,*) JMAX, KMAX, LMAX
  DO 15 J=1,JMAX
  DO 15 K=1,KMAX
  DO 15 L=1,LMAX
    XX(J,K,L)=X(J,K,L,MB)/CBAR
    YY(J,K,L)=Y(J,K,L,MB)/CBAR
    ZZ(J,K,L)=Z(J,K,L,MB)/CBAR
  15 CONTINUE
  CALL WRDAT(JTO,JMAX,KMAX,LMAX,XX,YY,ZZ,R,RU,RV,RW,E)
ELSE
C BLOCK #2: STARBOARD TIP
  JMAX=JM(MB)
  KMAX=KM(MB)+2
  LMAX=LM(MB)
  WRITE (*,*) JMAX, KMAX, LMAX
  DO 10 J=1,JMAX
  DO 10 K=1,KMAX
  DO 10 L=1,LMAX
    IF (K.EQ.1) THEN
      XX(J,K,L)=X(J,KM(MB)-1,L,MB-1)/CBAR
      YY(J,K,L)=Y(J,KM(MB)-1,L,MB-1)/CBAR
      ZZ(J,K,L)=Z(J,KM(MB)-1,L,MB-1)/CBAR
    ELSEIF (K.EQ.KMAX) THEN
      XX(J,K,L)=X(J,2,L,MB+1)/CBAR
      YY(J,K,L)=Y(J,2,L,MB+1)/CBAR
      ZZ(J,K,L)=Z(J,2,L,MB+1)/CBAR
    ELSE

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\[ \begin{align*}
XX(J, K, L) &= X(J, K-1, L, MB)/C\text{BAR} \\
YY(J, K, L) &= Y(J, K-1, L, MB)/C\text{BAR} \\
ZZ(J, K, L) &= Z(J, K-1, L, MB)/C\text{BAR}
\end{align*} \]

ENDIF

10 CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ENDIF

2 CONTINUE

IF (.NOT. SYM) GO TO 99

DO 3 MB=NBLOCKS, 1, -1

IF (MB.EQ.NBLOCKS) THEN

C BLOCK 4: PORT LOWER

JMAX=JM(MB)
KMAX=KM(MB)+1
LMAX=LM(MB)
WRITE(*,*) JMAX, KMAX, LMAX
DO 20 J=1, JMAX
DO 20 K=1, KMAX
DO 20 L=1, LMAX
IF (K.GT.1) THEN

XX(J, K, L) = X(J, KM(MB)-K+2, L, MB)/C\text{BAR}
YY(J, K, L) = Y(J, KM(MB)-K+2, L, MB)/C\text{BAR}
ZZ(J, K, L) = Z(J, KM(MB)-K+2, L, MB)/C\text{BAR}
ELSE

XX(J, K, L) = X(J, KM(MB)-1, L, MB)/C\text{BAR}
YY(J, K, L) = Y(J, KM(MB)-1, L, MB)/C\text{BAR}
ZZ(J, K, L) = Z(J, KM(MB)-1, L, MB)/C\text{BAR}
ENDIF

20 CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ELSEIF (MB.EQ.1) THEN

C BLOCK #6: PORT UPPER

JMAX=JM(MB)
KMAX=KM(MB)+1
LMAX=LM(MB)+1
WRITE(*,*) JMAX, KMAX, LMAX
DO 30 J=1, JMAX
DO 30 K=1, KMAX
DO 30 L=1, LMAX
IF (K.NE. KMAX) THEN

IF (L.NE.1) THEN

XX(J, K, L) = X(J, KM(MB)-K+1, L-1, MB)/C\text{BAR}
YY(J, K, L) = Y(J, KM(MB)-K+1, L-1, MB)/C\text{BAR}
ZZ(J, K, L) = Z(J, KM(MB)-K+1, L-1, MB)/C\text{BAR}
ELSE

XX(J, K, L) = X(J, K, L+1, NBLOCKS)/C\text{BAR}
YY(J, K, L) = Y(J, K, L+1, NBLOCKS)/C\text{BAR}
ZZ(J, K, L) = Z(J, K, L+1, NBLOCKS)/C\text{BAR}
ENDIF
ELSE

IF (L.NE.1) THEN

XX(J, K, L) = X(J, 2, L-1, MB)/C\text{BAR}

ENDIF

ENDIF

ENDIF
YY(J,K,L) = Y(J, 2, L-1, MB)/CBAR
ZZ(J,K,L) = Z(J, 2, L-1, MB)/CBAR

ELSE
XX(J,K,L) = X(J, KM(NBLOCKS)-1, L+1, NBLOCKS)/CBAR
YY(J,K,L) = Y(J, KM(NBLOCKS)-1, L+1, NBLOCKS)/CBAR
ZZ(J,K,L) = Z(J, KM(NBLOCKS)-1, L+1, NBLOCKS)/CBAR
ENDIF

ENDIF

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ELSE

C BLOCK $5$: PORT TIP
JMAX=JM(MB)
KMAX=KM(MB)+2
LMAX=LM(MB)
WRITE(*,*) JMAX, KMAX, LMAX
DO 25 J=I, JMAX
DO 25 K=I, KMAX
DO 25 L=I, LMAX
IF (K.EQ.KMAX) THEN
XX(J,K,L) = X(J, KM(1)-1, L, 1)/CBAR
YY(J,K,L) = Y(J, KM(1)-1, L, 1)/CBAR
ZZ(J,K,L) = Z(J, KM(1)-1, L, 1)/CBAR
ELSEIF (K.EQ.1) THEN
XX(J,K,L) = X(J, 2, L, NBLOCKS)/CBAR
YY(J,K,L) = Y(J, 2, L, NBLOCKS)/CBAR
ZZ(J,K,L) = Z(J, 2, L, NBLOCKS)/CBAR
ELSE
XX(J,K,L) = X(J, KM(MB)-K+2, L, MB)/CBAR
YY(J,K,L) = Y(J, KM(MB)-K+2, L, MB)/CBAR
ZZ(J,K,L) = Z(J, KM(MB)-K+2, L, MB)/CBAR
ENDIF
25 CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ENDIF

3 CONTINUE

99 RETURN

9001 WRITE(*,1050)
 STOP
1050 FORMAT(/,5X,'ERROR OPENING OUTPUT FILE ',&
     /)

END

SUBROUTINE COGRD

********************************************************************
C %SSUM_S THE FOLLOWING:
C 1. 3-BLOCK C-O TOPOLOGY
C 2. BLOCKS AND INDICES ARE IN PROPER ORDER
********************************************************************
C PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)

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COMMON //grid//x(jmx,kmx,lmx,NTB),y(jmx,kmx,lmx,NTB),
& z(jmx,kmx,lmx,NTB),jm(NTB),km(NTB),lm(NTB),NTB,NBLOCKS,NBB,SYM
COMMON/AERO/ R(jmx,kmx,lmx),RU(jmx,kmx,lmx),RV(jmx,kmx,lmx),
1 Rw(jmx,kmx,lmx),E(jmx,kmx,lmx),ALPHA,BETA,FMACH,CBAR
DIMENSION XX(JMX,KMX,LMX),YY(JMX,KMX,LMX),ZZ(JMX,KMX,LMX)
LOGICAL SYM
DATA G/1.4/, GMI/0.4/

jto = 9
C WRITE RESTART TAPE
NCI=0
WRITE(jto) NCI,G
WRITE(*,*)'JMAX KMAX LMAX'
DO 2 MB=1,NBLOCKS
C BLOCK #1: STARBOARD UPPER
IF(MB.EQ.1) THEN
JMAX=JM(MB)+1
KMAX=KM(MB)
LMAX=LM(MB)+1
WRITE(*,*)JMAX,KMAX,LMAX
DO 5 J=2,JMAX
DO 5 K=I,KMAX
DO 5 L=I,LMAX
IF (L.NE. I) THEN
XX(J,K,L)=X(J-1,K,L-1,MB)/CBAR
YY(J,K,L)=Y(J-1,K,L-1,MB)/CBAR
ZZ(J,K,L)=Z(J-1,K,L-1,MB)/CBAR
ELSE
XX(J,K,L)=X(J-1,KM(NBLOCKS)-K+I,L+I,NBLOCKS)/CBAR
YY(J,K,L)=Y(J-1,KM(NBLOCKS)-K+I,L+I,NBLOCKS)/CBAR
ZZ(J,K,L)=Z(J-1,KM(NBLOCKS)-K+I,L+I,NBLOCKS)/CBAR
ENDIF
5 CONTINUE
DO 8 K=1,KMAX
DO 8 L=1,LMAX
IF(L.LT.1) THEN
XX(1,K,L)=X(2,KM(NBLOCKS)-K+I,L-1,NBLOCKS)/CBAR
YY(1,K,L)=Y(2,KM(NBLOCKS)-K+I,L-1,NBLOCKS)/CBAR
ZZ(1,K,L)=Z(2,KM(NBLOCKS)-K+I,L-1,NBLOCKS)/CBAR
ELSE
XX(1,K,L)=X(1,KM(NBLOCKS)-K+I,L,NBLOCKS)/CBAR
YY(1,K,L)=Y(1,KM(NBLOCKS)-K+I,L,NBLOCKS)/CBAR
ZZ(1,K,L)=Z(1,KM(NBLOCKS)-K+I,L,NBLOCKS)/CBAR
ENDIF
8 CONTINUE
CALL WRDAT(JTO,JMAX,KMAX,LMAX,XX,YY,ZZ,R,RU,RV,RW,E)
ELSEIF(MB.EQ.NBLOCKS) THEN
C BLOCK 3: STARBOARD LOWER
JMAX=JM(MB)
KMAX=KM(MB)
LMAX=LM(MB)
WRITE(*,*)JMAX,KMAX,LMAX
DO 15 J=1,JMAX
DO 15 K=1,KMAX

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DO 15 L=1,LMAX
XX(J,K,L)=X(J,K,L,MB)/CBAR
YY(J,K,L)=Y(J,K,L,MB)/CBAR
ZZ(J,K,L)=Z(J,K,L,MB)/CBAR
15 CONTINUE

CALL WRDAT(JTO,JMAX,KMAX,LMAX,XX,YY,ZZ,R,RU,RV,RW,E)

ELSE

C BLOCK #2: STARBOARD TIP
JMAX=JM(MB)
KMAX=KM(MB)+2
LMAX=LM(MB)
WRITE(*,*)JMAX,KMAX,LMAX
DO 10 J=1,JMAX
DO 10 K=1,KMAX
DO 10 L=1,LMAX
IF(K.EQ.1) THEN
   XX(J,K,L)=X(J,KM(MB)-1,L,MB-1)/CBAR
   YY(J,K,L)=Y(J,KM(MB)-1,L,MB-1)/CBAR
   ZZ(J,K,L)=Z(J,KM(MB)-1,L,MB-1)/CBAR
ELSE IF(K.EQ.KMAX) THEN
   XX(J,K,L)=X(J,2,L,MB+1)/CBAR
   YY(J,K,L)=Y(J,2,L,MB+1)/CBAR
   ZZ(J,K,L)=Z(J,2,L,MB+1)/CBAR
ELSE
   XX(J,K,L)=X(J,K-1,L,MB)/CBAR
   YY(J,K,L)=Y(J,K-1,L,MB)/CBAR
   ZZ(J,K,L)=Z(J,K-1,L,MB)/CBAR
ENDIF
10 CONTINUE

CALL WRDAT(JTO,JMAX,KMAX,LMAX,XX,YY,ZZ,R,RU,RV,RW,E)

ENDIF
2 CONTINUE
IF(.NOT.SYM)GO TO 99
DO 3 MB=NBLOCKS,1,-1
IF(MB.EQ.NBLOCKS) THEN
   C BLOCK 4: PORT LOWER
JMAX=JM(MB)
KMAX=KM(MB)+1
LMAX=LM(MB)
WRITE(*,*)JMAX,KMAX,LMAX
DO 20 J=1,JMAX
DO 20 K=1,KMAX
DO 20 L=1,LMAX
IF(K.GT.1) THEN
   XX(J,K,L)=X(J,KM(MB)-K+2,L,MB)/CBAR
   YY(J,K,L)=Y(J,KM(MB)-K+2,L,MB)/CBAR
   ZZ(J,K,L)=Z(J,KM(MB)-K+2,L,MB)/CBAR
ELSE
   XX(J,K,L)=X(J,KM(MB)-1,L,MB)/CBAR
   YY(J,K,L)=Y(J,KM(MB)-1,L,MB)/CBAR
   ZZ(J,K,L)=Z(J,KM(MB)-1,L,MB)/CBAR
ENDIF
20 CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ELSEIF (MB.EQ.1) THEN

C BLOCK #6: PORT UPPER
JMAX=JM(MB)+1
KMAX=KM(MB)+1
LMAX=LM(MB)+1
WRITE(*,*) JMAX, KMAX, LMAX
DO 30 J=2, JMAX
DO 30 K=1, KMAX
DO 30 L=1, LMAX
IF (K.LT. KMAX) THEN
  IF (L.NE.1) THEN
    XX(J, K, L) = X(J-1, KM(MB) - K+1, L-1, MB) / CBAR
    YY(J, K, L) = Y(J-1, KM(MB) - K+1, L-1, MB) / CBAR
    ZZ(J, K, L) = Z(J-1, KM(MB) - K+1, L-1, MB) / CBAR
  ELSE
    XX(J, K, L) = X(J-1, K, L+1, MB) / CBAR
    YY(J, K, L) = Y(J-1, K, L+1, MB) / CBAR
    ZZ(J, K, L) = Z(J-1, K, L+1, MB) / CBAR
  ENDIF
ELSEIF (L.EQ.1) THEN
  XX(J, K, L) = X(J-1, 2, L-1, MB) / CBAR
  YY(J, K, L) = Y(J-1, 2, L-1, MB) / CBAR
  ZZ(J, K, L) = Z(J-1, 2, L-1, MB) / CBAR
ELSE
  XX(J, K, L) = X(J-1, KM(NBLOCKS) - K+1, L-1, MB) / CBAR
  YY(J, K, L) = Y(J-1, KM(NBLOCKS) - K+1, L-1, MB) / CBAR
  ZZ(J, K, L) = Z(J-1, KM(NBLOCKS) - K+1, L-1, MB) / CBAR
ENDIF
ENDIF
ENDIF
30 CONTINUE

DO 32 K=1, KMAX
DO 32 L=1, LMAX
IF (K.LT. KMAX) THEN
  IF (L.NE.1) THEN
    XX(1, K, L) = X(2, K, L-1, NBLOCKS) / CBAR
    YY(1, K, L) = Y(2, K, L-1, NBLOCKS) / CBAR
    ZZ(1, K, L) = Z(2, K, L-1, NBLOCKS) / CBAR
  ELSE
    XX(1, K, L) = X(3, K, L, NBLOCKS) / CBAR
    YY(1, K, L) = Y(3, K, L, NBLOCKS) / CBAR
    ZZ(1, K, L) = Z(3, K, L, NBLOCKS) / CBAR
  ENDIF
ELSEIF (L.EQ.1) THEN
  XX(1, K, L) = X(2, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
  YY(1, K, L) = Y(2, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
  ZZ(1, K, L) = Z(2, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
ELSE
  XX(1, K, L) = X(3, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
  YY(1, K, L) = Y(3, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
  ZZ(1, K, L) = Z(3, KM(NBLOCKS) - K+1, L-1, NBLOCKS) / CBAR
ENDIF
ENDIF
CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)

ELSE

C BLOCK 5: PORT TIP
JMAX=JM(MB)
KMAX=KM(MB)+2
LMAX=LM(MB)
WRITE(*,*)JMAX, KMAX, LMAX
DO 25 J=1, JMAX
   DO 25 K=1, KMAX
      DO 25 L=1, LMAX
         IF (K.EQ. EMAX) THEN
            XX(J,K,L) = X(J, KM(1) -1, L, 1)/CBAR
            YY(J,K,L) = Y(J, KM(1) -1, L, 1)/CBAR
            ZZ(J,K,L) = Z(J, KM(1) -1, L, 1)/CBAR
         ELSEIF (K.EQ. 1) THEN
            XX(J,K,L) = X(J, 2, L, NBLOCKS)/CBAR
            YY(J,K,L) = Y(J, 2, L, NBLOCKS)/CBAR
            ZZ(J,K,L) = Z(J, 2, L, NBLOCKS)/CBAR
         ELSE
            XX(J,K,L) = X(J, KM(MB) -K+2, L, MB)/CBAR
            YY(J,K,L) = Y(J, KM(MB) -K+2, L, MB)/CBAR
            ZZ(J,K,L) = Z(J, KM(MB) -K+2, L, MB)/CBAR
         ENDIF
      25 CONTINUE
      CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)
   ENDIF
25 CONTINUE

CALL WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)
ENDIF

3 CONTINUE

99 RETURN

9001 WRITE(*,1050)
   STOP
1050 FORMAT(/,'ERROR OPENING OUTPUT FILE ', &
   /)
END

SUBROUTINE WRDAT(JTO, JMAX, KMAX, LMAX, XX, YY, ZZ, R, RU, RV, RW, E)
PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
DIMENSION XX(JMX, KMX, LMX), YY(JMX, KMX, LMX), ZZ(JMX, KMX, LMX),
     R(JMX, KMX, LMX), RU(JMX, KMX, LMX), RV(JMX, KMX, LMX),
     RW(JMX, KMX, LMX), E(JMX, KMX, LMX)

WRITE(JTO) JMAX, KMAX, LMAX
WRITE(JTO) ((( XX(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( YY(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( ZZ(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX)
WRITE(JTO) ((( R(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( RU(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( RV(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( RW(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX),
            ((( E(J,K,L), J=1, JMAX), K=1, KMAX), L=1, LMAX)

62
SUBROUTINE READRES
PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
DIMENSION R(JMX,KMX,LMX), RU(JMX,KMX,LMX), RV(JMX,KMX,LMX), 
  RW(JMX,KMX,LMX), E(JMX,KMX,LMX), X(JMX,KMX,LMX), Y(JMX,KMX,LMX),
COMMON DATA /
  NBLK, JMAX(NTB), KMAX(NTB), LMAX(NTB)
   READ RESTART TAPE
   NBLK=0
   NTP=8
   50 READ (NTP)NC1,G
   50 READ (NTP, END=99) JMAX(NBLK+1), KMAX(NBLK+1), LMAX(NBLK+1)
   NBLK=NBLK+1
   WRITE (*) ' READING BLOCK ', NBLK
   READ (NTP) ((( X(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( Y(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( Z(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK))
   C TRANSLATE AND SCALE...
   DO 10 J=1,JMAX(NBLK)
   DO 10 K=1,KMAX(NBLK)
   DO 10 L=1,LMAX(NBLK)
   X(J,K,L)=X(J,K,L)*184.
   Z(J,K,L)=Z(J,K,L)+1595.3
   10 CONTINUE
   WRITE (9+NBLK) ((( X(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( Y(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( Z(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK))
   READ (NTP) ((( R(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RU(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RV(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RW(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( E(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK))
   WRITE (29+NBLK) ((( R(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RU(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RV(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( RW(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   * ((( E(J,K,L), J= 1,JMAX(NBLK)), K=I, KMAX(NBLK)), 
   * L=1, LMAX(NBLK)),
   RETURN
END
SUBROUTINE SCNGEN
PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
* adjustable : max print, max B.C.'s, max patches per block
PARAMETER (MPS=10, MBC=25, MP=50)
* block specific info
COMMON /CPOZN/ MAX(NTB),SKR(NTB),SGM(NTB),RPR(NTB),COFMIX,DTBLK,DIS2,DIS4,
* RTPTS,
* PRES(JBC),TEMP(JBC),
* PRESSK(JBC),TEMPP(JBC),
* IPWZ,IPW2,IPW,IPWBU,IPWBU,IPWBU,IPW,IPW,
* IPWS1,IPWVDT,IPWXX,IPWYY,IPWXY,IPWXX,
* IPWYY,IPWZ,IPWZ,IPWZ,IPWZ,IPWZ,IPWZ,IPWZ,
* IPWZ,IPW2,IPW2,IPW2,IPW2,IPW2,IPW2,IPW2,
* NXYZ,LMODE,LTURB,
* JMAX,MAXX,MAXN,MJ,LM,INVISC,3,ALAMIN,3),
* NSSEG,JKLPI(3,3,MPS),IPORD(2,MPS),
* JTYPE(JBC),JSIGN(JBC),INTERJ(JBC),
* NSSEG,KLINE(JBC),KLOW(JBC),KHIGH(JBC),KLOW(JBC),KHIGH(JBC),
* KTYPE(JBC),KSIGN(JBC),INTERK(JBC),
* NLSEG,LLINE(JBC),LLOW(JBC),LHIGH(JBC),LLOW(JBC),LHIGH(JBC),
* LTYPE(JBC),LSIGN(JBC),INTERL(JBC),
* JEDGE(JBC),KEDGE(JBC),LEDGE(JBC),JDIR(JBC),KDIR(JBC),LDIR(JBC),
* NORMJ(JBC),NORMK(JBC),NORML(JBC),
* NJSEG,JLINE(3),KSEG(3),JSEG(3),KSEG(3),LSEG(3),JSEG(3),KSEG(3),LSEG(3),
* NJPAT,JPJ(MP),JPJM(MP),JPK2(MP),JPK2(MP),JPK2(MP),JPK2(MP),
* JSEG,JP2(MP),LPJ2(MP),LPJ2(MP),LPJ2(MP),LPJ2(MP),LPJ2(MP),LPJ2(MP),
* NAMELIST/BOUNDS/ NSSEG,JLINE,KSEG,JKLINE,KJHIGH,KJLOW,KJHIGH,KJLOW,
* NLSEG,KLINE,KLOW,KHIGH,KLOW,KHIGH,
* JTYPE,JSIGN,PRESSJ,TEMPP,INTERJ,
* KTYPE,KSIGN,PRESSK,TEMPP,INTERK,
* LTYPE,LSIGN,PRESSL,TEMPL,INTERL,
* JEDGE,KEDGE,LEDGE,JDIR,KDIR,LDIR,
* NORMJ,NORMK,NORML

COMMON/VISFAC/ ALPHA,BETA,XMACH,C2B,C2BP,VRAT,RE
NAMELIST/INPUTS/PREF,TREFR,VRAT,TSUTH,RE,PR,PRT,DDUMP,
* DTCAP,FCQMAX,SPLNDS,SMO,STOP2,STOPFR,ALPHA,BETA,XMACH,
* NBLOCK,NMAX,NSPRRT,NI,IPFRRT,IFXPL,T2PLOT,
* IPLT,NUMDT,IVARRT,ISOLVE,IRHS,IFILT,ITMUTUR,
* MBORD,IBORD,NSECTR,LPR,IR,DIS2,DIS4,
* NBOBT,IFMAX,IMASS,P0sd,T0sd,Lrec45,
* ORDER,NTURB,IFILT,NSMK,STOPTM,CBAR,SSPAN,SRF,
* REPXY,REPMY,REPMZ
NAMELIST/BOUNDS/ NSSEG,JLINE,KSEG,JKLINE,KJHIGH,KJLOW,KJHIGH,KJLOW,
* NLSEG,KLINE,KLOW,KHIGH,KLOW,KHIGH,
* JTYPE,JSIGN,PRESSJ,TEMPP,INTERJ,
* KTYPE,KSIGN,PRESSK,TEMPP,INTERK,
* LTYPE,LSIGN,PRESSL,TEMPL,INTERL,
* JEDGE,KEDGE,LEDGE,JDIR,KDIR,LDIR,
* NORMJ,NORMK,NORML

DIMENSION R(JMX,KMX,LMX),RU(JMX,KMX,LMX),RV(JMX,KMX,LMX),
1 RW(JMX,KMX,LMX),E(JMX,KMX,LMX),X(JMX,KMX,LMX),Y(JMX,KMX,LMX),
2 Z(JMX,KNX,LNX)
COMMON/DATA/ NBLK, JMM(NTB), KMM(NTB), LMM(NTB)
LOGICAL FORM
DATA FORM/.TRUE./
DATA MINUS1/-1/,IZERO/0/,IONE/1/
BODSYM=0
INCENT=0
NC=0
NDUM=0
NTI = 7
NTP = 9
REWIND NTP
NPNI=0
ITTR=1

C************************************************************************************************************
C BASIC DATA
C************************************************************************************************************
!
C READ(NTI,INPUTS) ! Cray version of NAMELIST
!
C READ(NTI,NML=INPUTS) ! IRIS version of NAMELIST

C************************************************************************************************************
C PATCH GEOMETRY
C************************************************************************************************************
!
C BODY SURFACE: L=1; J=1,JMX; K=1,KMX
C SIDE WALL UPPER: K=2; J=1,JMX; L=1,LNX
C SIDE WALL LOWER: K=KMX-1; J=1,JMX; L=1,LNX
C END WALL: J=JMX; K=2,KMX-1; L=1,LNX
C CALL BGOM(NP,NPNL, IORDR,N1,N2,N3,N4,N5)
C WHERE:
C NP= PATCH NO.
C NPNL= RUNNING PANEL COUNT
C IORDR= J,K OR L CONSTANT (1,2 OR 3)
C N1 THRU N5= LOOP COUNTERS
C N1,N2 RUN FIRST
C N3,N4 RUN SECOND
C N5 IS CONSTANT COUNTER
C

C ASSUMES C-C GRID...

WRITE(*,*)' BODY GEOMETRY...'
NPCH=0
DO 25 NN=1,NBLK
READ(NTI,BOUNDS) ! Cray version of NAMELIST
!
READ(NTI,NML=BOUNDS) ! IRIS version of NAMELIST
DO 26 J=1,NJSEG
IF (JTYPE(J).EQ.7.OR.JTYPE(J).EQ.8) THEN
  NPCH=NPCH+1
  IORDR=1
  CALL SGOM(NN,NPCH,IORDR,JLOW(J),JLHIG(J),JHIG(J),JLOW(J),JHIG(J),JLINE(J),NPNL)
ENDIF
26 CONTINUE
!
DO 27 K=1,NKSEG
IF (KTYPE(K).EQ.7.OR.KTYPE(K).EQ.8) THEN
NPCH=NPCH+1
IORDR=2
CALL SGOM(NN,NPCH,IORDR,KLOW(K),KLHIGH(K),KJLOW(K),KJHIGH(K),
1       KLINE(K),NPNL)
ENDIF
27 CONTINUE
DO 28 L=1,NLSEG
IF(LTYPE(L).EQ.7.OR.LTYPE(L).EQ.8) THEN
NPCH=NPCH+1
IORDR=3
CALL SGOM(NN,NPCH,IORDR,LJLOW(L),LTHIGH(L),LKLOW(L),LKHIGH(L),
1       LLINE(L),NPNL)
ENDIF
28 CONTINUE
25 CONTINUE
WRITE(*,*)' SCAN DATA INPUT IN FILE SCAN.DAT'
RETURN
701 FORMAT(2A4)
702 FORMAT(S15)
703 FORMAT(6E12.5)
704 FORMAT(S15/(6E12.5))
705 FORMAT(6E12.5/2E12.5,I5)
706 FORMAT(6E12.5)
707 FORMAT(20A4)
END
SUBROUTINE SGOM(NB,NPTCH,IORDR,N1,N2,N3,N4,N5,NPNL)
PARAMETER(NTB=3, JMX=230, KMX=32, LMX=50)
DIMENSION R(JMX,KMX,LMX) ,RU(JMX,KMX,LMX) ,RV(JMX,KMX,LMX),
1       RWCJMX,
KMX.,I_MX) ,E (JMX,
KMX,
LMX), X (JMX,
IKMX,
LMX), Y (JMX,
EMX,
LMX),
2       Z (JMX,
KMX,
LMX)
COMMON/DATA/ NBLK, JMAX(NTB), KMAX(NTB), LMAX(NTB)
LOGICAL FORM
DATA FORM/. TRUE./
NTP = 9
IZERO=0
ID=2
NR=N2-N1
NC=N4-N3
NTOT = (NR+1)*(NC+1)
READ(9+NB) (((( X(J,K,L),J= 1,JMAX(NB)),K=1,KMAX(NB)),
*     L=1,LMAX(NB)));
* (((( Y(J,K,L),J= 1,JMAX(NB)),K=1,KMAX(NB)),
*     L=1,LMAX(NB)));
* ((( Z(J,K,L),J= 1,JMAX(NB)),K=1,KMAX(NB)),
*     L=1,LMAX(NB)));
REWIND 9+NB
IF(FORM) THEN
WRITE(NTP,702) ~3, 4,0,0...
WRITE(NTP,702) NTOT,1,1,0
ELSEIF(IORDR.EQ.1) THEN
WRITE(NTP,703) (X(N5,K,L),Y(N5,K,L),Z(N5,K,L),NB,N5,K,L,
1     L=N1,N2), K=N3,N4)
ELSEIF(IORDR.EQ.2) THEN
WRITE(NTP,703) (X(J,N5,L),Y(J,N5,L),Z(J,N5,L),NB,J,N5,L,
1     L=N1,N2), J=N3,N4)}
ELSEIF (IORDR. EQ. 3) THEN
  WRITE (NTP, 703) ((X(J,K,N5), Y(J,K,N5), Z(J,K,N5), NB,J,K,N5,
                      J=NI,N2), K=N3,N4)
ENDIF
ELSE
  WRITE (NTP) -3, -4, 0, 0
  WRITE (NTP) NTOT, 1, 1, 0
DO 100 I=N3,N4
  IF (IORDR. EQ. 1) THEN
    WRITE (NTP) ((X(N5,K,L), Y(N5,K,L), Z(N5,K,L), NB,N5,K,L,
                   L=NI,N2), K=N3,N4)
  ELSEIF (IORDR. EQ. 2) THEN
    WRITE (NTP) ((X(J,N5,L), Y(J,N5,L), Z(J,N5,L), NB,J,N5,L,
                   L=NI,N2), J=N3,N4)
  ELSEIF (IORDR. EQ. 3) THEN
    WRITE (NTP) ((X(J,K,N5), Y(J,K,N5), Z(J,K,N5), NB,J,K,N5,
                   J=NI,N2), K=N3,N4)
  ENDIF
CONTINUE
ENDIF
NPNL=NPNL+NR*NC
FORMAT (2A4)
FORMAT (515)
FORMAT (6E12.5)
RETURN
END

SUBROUTINE PLTGEN
PARAMETER (NTB=3, JMAX=230, KMAX=32, LMX=50)
  adjustable : max print, max B.C.'s, max patches per block
PARAMETER (MPS=10, MBC=25, MP=50)
block specific info
COMMON /CPOIN/
  * GAMMA, GAM1, GAMR, GGM1, GSGM, RPR, RPRT, COFMIX, DTABLE, DDIS2, DDIS4,
  * RTPTS,
  * PRESSJ (MBC), TEMPJ (MBC),
  * PRESSK (MBC), TEMPK (MBC),
  * PRESSL (MBC), TEMPL (MBC),
  * IPWX, IPWY, IPWZ, IPWR, IPWLR, IPWRL, IPWR, IPWE, IPWQ,
  * IPWS1, IPWS2, IPWS3, IPWS4, IPWS5, IPWS6, IPWCOF,
  * IPW28, IPW29, IPW30, IPW31, IPW32, IPW33, IPW34,
  * NXYZ, IMODE, ILTURB,
  * JMAX, KMAX, LMAX, KM, LM, INVISC(3), LAMIN(3),
  * NPSEG, JKLPJ (3, 3, MPS), IPORD (2, MPS),
  * NJSEG, JLINE (MBC), JKLOW (MBC), JKHIGH (MBC), JLLOW (MBC), JLHIGH (MBC),
  * JTYPES (MBC), JSIGN (MBC), INTERJ (MBC),
  * NKSEG, KLINE (MBC), KLOW (MBC), KHIGH (MBC), KLLOW (MBC), KLHIGH (MBC),
  * KTYPES (MBC), KSIGN (MBC), INTERK (MBC),
  * NLSEG, llINE (MBC), LLOW (MBC), LHIGH (MBC), LLOW (MBC), LHIGH (MBC),
  * LTYPE (MBC), LSIGN (MBC), INTERL (MBC),
  * JEDGZ (MBC), JEDGE (MBC), LEDGE (MBC), JDIR (MBC), KDIR (MBC), LDIR (MBC),
  * NORMJ (MBC), NORMK (MBC), NORML (MBC),
  * NJPAT, JKP2 (MBC), JKP3 (MBC), JKP4 (MBC), JKP5 (MBC), JKP6 (MBC), JKP7 (MBC),
  * NKPAT, KKP2 (MBC), KKP3 (MBC), KKP4 (MBC), KKP5 (MBC), KKP6 (MBC), KKP7 (MBC),
  * NLPAT, LKP2 (MBC), LKP3 (MBC), LKP4 (MBC), LKP5 (MBC), LKP6 (MBC), LKP7 (MBC),

COMMON /VISFAC/
  ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
NAMELIST INPUTS/
  PREF, TREFR, VRAT, TSUTH, RE, PR, PRT, DDUMP,
* DTCAP, PCQMAX, SPLOOD, SMOO, STOPL2, STOPTR, ALPHA, BETA, XMACH,
* NBLOCK, NMAX, NC, NSFR, NT, IFXPR, IFXSLT, L2PLOT,
* IPILOT, NUMDT, IVARDT, ISOLVE, IRHS, IFILTR, NUMTHUR,
* MBORD, IBORD, NSECTR, LRES, LREST, GAMMA, DIS2, DIS4,
* NOBORT, IFMAX, TIME, POSd, T0sd, Lrec45,
* ORDER, NTURB, IFIL, NSKIP, STOPLM, CBAR, SSPAN, SREF,
* RFMX, RFMY, RFMZ

NAMELIST/BOUNDS/ NJSEG, JLINE, JKLLOW, JKHIGH, JLMLOW, JLMHIGH,
* NKSEG, KLINE, KKLLOW, KKHIGH, KLMLOW, KLMHIGH,
* NLSEG, LLINE, LLLOW, LLMHIGH, LLMLOW, LLMHIGH,
* JTYPE, JSIGN, PRESSJ, TEMPJ, INTERJ,
* KTYPE, KSIGN, PRESSK, TEMPK, INTERR,
* LTYPE, LSIGN, PRESSL, TEMPL, INTERL,
* JEDGE, KEDGE, LEDGE, JDIR, KDIR, LDIR,
* NORMJ, NORMK, NORML

C

DIMENSION R(JMX,KMX,LMX), RG(JMX,KMX,LMX), RV(JMX,KMX,LMX),
1 RW(JMX,KMX,LMX), E(JMX,KMX,LMX), X(JMX,KMX,LMX), Y(JMX,KMX,LMX),
2 Z(JMX,KMX,LMX)

COMMON/DATA/ NBLK, JMM(NTB), KMM(NTB), LMM(NTB)

LOGICAL FORM

DATA FORM/. TRUE./

DATA MINUS1/-1/, IZERO/0/, IONE/I/

BODSYM=0

INCENT=0

NC=0

NDUM=0

NTI = 7

NTP = 9

REWIND NTP

NPNL=0

ITTR=1

C******************************************************************************

C BASIC DATA

******************************************************************************

C READ(NTI,INPUTS) ! Cray version of NAMELIST

C READ(NTI,NML=INPUTS) ! IRIS version of NAMELIST

C CALL BSIC

******************************************************************************

C PATCH GEOMETRY

******************************************************************************

C BODY SURFACE: L=1; J=1,JMX; K=1,KMX

C SIDE WALL UPPER: K=2; J=1,JMX; L=1,LMX

C SIDE WALL LOWER: K=KMX-1; J=1,JMX; L=1,LMX

C END WALL: J=JMX; K=2,KMX-1; L=1,LMX

C CALL BSGM(NP,NPNL,IORDR,N1,N2,N3,N4,N5)

WHERE:

NP= PATCH NO.

NPNL= RUNNING PANEL COUNT

IORDR= J,K OR L CONSTANT (1,2 OR 3)

N1 THRU N5= LOOP COUNTERS

N1, N2 RUN FIRST

N3, N4 RUN SECOND

N5 IS CONSTANT COUNTER

*********
IF (FORM) THEN
WRITE (NTP, 701)  'BGIN', 'BODG'
ELSE
WRITE (NTP)  'BGIN', 'BODG'
ENDIF

C ASSUMES C-C GRID...

WRITE (*,*)  'BODY GEOMETRY...
NPCH = 0
DO 25 NN = I, NBLK
READ (NTI, BOUNDS)  ! Cray version of NAMELIST
READ (NTI, NML=BOUNDS)  ! IRIS version of NAMELIST
DO 26 J = 1, NJSEG
IF (JTYPE (J) .EQ. 60. OR. JTYPE (J) .EQ. 61) THEN
NPCH = NPCH + 1
IORDR = 1
CALL BGOM (NN, NPCH, IORDR, JLOW (J), JHIGH (J), JKLOW (J), JKHIGH (J), JLINE (J), NPNL)
ENDIF
26 CONTINUE
DO 27 K = 1, NKSEG
IF (KTYPE (K) .EQ. 60. OR. KTYPE (K) .EQ. 61) THEN
NPCH = NPCH + 1
IORDR = 2
CALL BGOM (NN, NPCH, IORDR, KLOW (K), KHIGH (K), KJLOW (K), KJHIGH (K), KLINE (K), NPNL)
ENDIF
27 CONTINUE
DO 28 L = 1, NLSEG
IF (LTYPE (L) .EQ. 60. OR. LTYPE (L) .EQ. 61) THEN
NPCH = NPCH + 1
IORDR = 3
CALL BGOM (NN, NPCH, IORDR, LLOW (L), LHIGH (L), LKLOW (L), LKHIGH (L), LLINE (L), NPNL)
ENDIF
28 CONTINUE
25 CONTINUE

IF (FORM) THEN
WRITE (NTP, 701)  'END ', 'GRUP'
ELSE
WRITE (NTP)  'END ', 'GRUP'
ENDIF

C IF ITTR .GT. 0 THEN WRITE AERO AWAY TO TAPE...

C**********************************************************************
C AERODYNAMICS
C**********************************************************************

IF (FORM) THEN
WRITE (NTP, 701)  'BGIN', 'AERO'
WRITE (NTP, 701)  'STRT', 'ITER'
WRITE (NTP, 702)  NPNL, ITTR, IZERO, IZERO, IZERO
ELSE
WRITE (NTP)  'BGIN', 'AERO'
WRITE (NTP)  'STRT', 'ITER'
ENDIF
WRITE(NTP)  NPNL, ITTR, IZERO, IZERO, IZERO
ENDIF

CALL AERO(IORDR,N1,N2,N3,N4,N5)
WHERE:
  IORDR= J,K OR L CONSTANT (1,2 OR 3)
  N1 THRU N5= LOOP COUNTERS

REWIND NTI
WRITE(*,*) ' AERODYNAMICS...
DO 35 NN=I,NBLK
READ(NTI,BOUNDS) ! Cray version of NAMELIST
READ(NTI,NML=BOUNDS) ! IRIS version of NAMELIST
DO 36 J=I,NJSEG
   IF(JTYPE(J).EQ.60.OR.JTYPE(J).EQ.61) THEN
      IORDR=1
      CALL AERO(NN, IORDR, JLLOW(J), JHIGH(J), JKLOW(J), JKHIGH(J),
                    JLINE(J))
   ENDIF
36 CONTINUE
DO 37 K=I,NKSEG
   IF(KTYPE(K).EQ.60.OR.KTYPE(K).EQ.61) THEN
      IORDR=2
      CALL AERO(NN, IORDR, KLLOW(K), KLHIGH(K), KJLOW(K), KJHIGH(K),
                    KLINE(K))
   ENDIF
37 CONTINUE
DO 38 L=I,NLSEG
   IF(LTYPE(L).EQ.60.OR.LTYPE(L).EQ.61) THEN
      IORDR=3
      CALL AERO(NN, IORDR, LW(L), LATHIGH(L), LKLOW(L), LKHIGH(L),
                    LLINE(L))
   ENDIF
38 CONTINUE
35 CONTINUE

IF(FORM) THEN
   WRITE(NTP,701) 'END ', 'GRUP'
ELSE
   WRITE(NTP) 'END ', 'GRUP'
ENDIF

C******************************************************************
C OFF-BODY DATA SCAN
C******************************************************************
CALL OFFB(IORDR,N1,N2,N3,N4,N5)
WHERE:
  IORDR= J,K OR L CONSTANT (1,2 OR 3)
  N1 THRU N5= LOOP COUNTERS

IF(FORM) THEN
   WRITE(NTP,701) 'BGIN', 'OFFB'
ELSE
   WRITE(NTP) 'BGIN', 'OFFB'
ENDIF
REWIND NTI
WRITE(*,*) ' OFF BODY DATA...
DO 45 NN=1,NBLK
READ(NTI,BOUNDS) ! Cray version of NAMELIST
READ(NTI,NML=BOUNDS) ! IRIS version of NAMELIST
DO 46 J=1,NJSEG
  IF(JTYPE(J).EQ.50) THEN
    IORDR=1
    CALL OFFB(NN, IORDR, JLLOW(J), JHIGH(J), JKLOW(J), JKHIGH(J), JLINE(J))
  ENDIF
  46 CONTINUE
DO 47 K=1,NKSEG
  IF(KTYPE(K).EQ.50) THEN
    IORDR=2
    CALL OFFB(NN, IORDR, KLLOW(K), KLINE(K), KLHIGH(K), KJLOW(K), KJHIGH(K))
  ENDIF
  47 CONTINUE
DO 48 L=1,NLSEG
  IF(LTYPE(L).EQ.50) THEN
    IORDR=3
    CALL OFFB(NN, IORDR, LJLOW(L), LLINE(L), LJHIGH(L), LKLOW(L), LKJHIGH(L))
  ENDIF
  48 CONTINUE
45 CONTINUE

'ID-SPAN PLANE...
KMID=KMM(1)/2
IF(2*KMID.NE.KMM(1)) KMID=KMID+1
CALL OFFB(1,2,1,JMM(1),KLINE(1),KMID)
KMID=KMM(NBLK)/2
IF(2*KMID.NE.KMM(NBLK)) KMID=KMID+1
CALL OFFB(NBLK, 2, 1, LMM(NBLK), LLINE(L), KMID)

IF(FORM) THEN
  WRITE(NTP,701) 'END ','GROUP'
  WRITE(NTP,701) 'END ','FILE'
ELSE
  WRITE(NTP) 'END ','GROUP'
  WRITE(NTP) 'END ','FILE'
ENDIF

DO 95 J=1,NBLK
  CLOSE 9+J
  95 CONTINUE

WRITE(*,*)' PLOT FILE DATA IN FILE PARC.FMT'
RETURN
701 FORMAT(2A4)
702 FORMAT(S15)
  03 FORMAT(6E12.5)
 704 FORMAT(S15/(6E12.5))
705 FORMAT(6E12.5/2E12.5,I5)
706 FORMAT(6E12.5)
707 FORMAT(20A4)
SUBROUTINE BSIC
COMMON/VISFAC/ ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
LOGICAL FORM
CHARACTER *80 TITL
DATA FORM/. TRUE./
NTP = 9
WRITE(*,*)' PLEASE INPUT TITLE FOR PLOT FILE.'
READ (*,80) TITL
RSYM = 0.0
RGPR = 0.0
ALDEG = ALPHA
YAWDEG = BETA
RMACH = 0.0
RMINF = XMACH
CBAR = 1.0
SREF = 1.0
SSPAN = 1.0
REFL = 1.0
SCALX = 1.0
REFMX = 0.0
REFMY = 0.0
REFMZ = 0.0
IF (FORM) THEN
WRITE(NTP,701) 'BGIN', 'BSIC'
WRITE(NTP,707) TITL
WRITE(NTP,703) RSYM, RGPR, ALDEG, YAWDEG, RMACH, RMINF
WRITE(NTP,703) CBAR*REFL, SREF*REFL*REFL, SSPAN*REFL, REFMX*SCALX,
REFMY*REFL, REFMZ*REFL
WRITE(NTP,703) CBAR, CBAR, CBAR, CBAR, CBAR, CBAR
WRITE(NTP,701) 'END', 'GRUP'
ELSE
WRITE(NTP) 'BGIN', 'BSIC'
WRITE(NTP) TITL
WRITE(NTP) RSYM, RGPR, ALDEG, YAWDEG, RMACH, RMINF
WRITE(NTP) CBAR*REFL, SREF*REFL*REFL, SSPAN*REFL, REFMX*SCALX,
REFMY*REFL, REFMZ*REFL
WRITE(NTP) CBAR, CBAR, CBAR, CBAR, CBAR, CBAR
WRITE(NTP) 'END', 'GRUP'
ENDIF
RETURN
80 FORMAT(A80)
701 FORMAT(2A4)
703 FORMAT(6E12.5)
707 FORMAT(A80)
SUBROUTINE BGOM(NB, NPTCH, IORDR, N1, N2, N3, N4, N5, NPNL)
PARAMETER (NTB=3, JMX=230, KMX=32, LMX=50)
DIMENSION R(JMX,KMX,LMX) , RU(JMX, KMX, LMX), RW(JMX, KMX, LMX), X(JMX, KMX, LMX), Y(JMX, KMX, LMX), Z(JMX, KMX, LMX)
COMMON/DATA/ NBLK, JMAX(NTB), KMAX(NTB), LMAX(NTB)
LOGICAL FORM
DATA FORM/. TRUE./
NTP = 9
IZERO=0
END
ID=2
NR=N2-N1
NC=N4-N3

READ(9+NB) ((((X(J,K,L), J=1, JMAX(NB)), K=1, KMAX(NB)),
  *  I=1, LMAX(NB)),
  * (((Y(J,K,L), J=1, JMAX(NB)), K=1, KMAX(NB)),
  * L=1, LMAX(NB)),
  * (((Z(J,K,L), J=1, JMAX(NB)), K=1, KMAX(NB)),
  * I=1, LMAX(NB))
REWIND 9+NB

IF (FORM) THEN
  WRITE(NTP, 701) 'STRT', 'PTCH'
  WRITE(NTP, 702) NPTCH, ID, NR, NC, ZER0
  IF (IORDR.EQ.1) THEN
    WRITE (NTP, 703) (X(N5,K,L), Y(N5,K,L), Z(N5,K,L), L=NI,N2)
  ELSEIF (IORDR.EQ.2) THEN
    WRITE (NTP, 703) (X(J,N5,L), Y(J,N5,L), Z(J,N5,L), L=NI,N2)
  ELSEIF (IORDR.EQ.3) THEN
    WRITE (NTP, 703) (X(J,K,N5), Y(J,K,N5), Z(J,K,N5), J=NI,N2)
  ELSE
    WRITE (NTP) 'STRT', 'PTCH'
    WRITE (NTP) NPTCH, ID, NR, NC, ZER0
    DO 100 I=N3,N4
    IF (IORDR.EQ.1) THEN
      WRITE (NTP) (X(N5,K,L), Y(N5,K,L), Z(N5,K,L), L=NI,N2),
      1 K=N3,N4
    ELSEIF (IORDR.EQ.2) THEN
      WRITE (NTP) (X(J,N5,L), Y(J,N5,L), Z(J,N5,L), L=NI,N2),
      1 J=N3,N4
    ELSEIF (IORDR.EQ.3) THEN
      WRITE (NTP) (X(J,K,N5), Y(J,K,N5), Z(J,K,N5), J=NI,N2),
      1 K=N3,N4
    ENDIF
  100 CONTINUE
ENDIF

NPNL=NPNL+NR*NC
701 FORMAT (2A4)
702 FORMAT (5I5)
703 FORMAT (6E12.5)
703 FORMAT (6E20.9)
RETURN
END

SUBROUTINE AERO(NB, IORDR, N1, N2, N3, N4, N5)
PAREMETER (NTB=3, JMX=230, KMX=32, LMX=50)
COMMON/ VISFAC/ ALPHA, BETA, XMACH, C2B, C2BP, VRAT, RE
DIMENSION R(JMX, KMX, LMX), RO(JMX, KMX, LMX), RV(JMX, KMX, LMX),
  1 RW(JMX, KMX, LMX), E(JMX, KMX, LMX), X(JMX, KMX, LMX), Y(JMX, KMX, LMX),
  2 Z(JMX, KMX, LMX)
COMMON / DATA/ NBLK, JMAX(NTB), KMAX(NTB), LMAX(NTB)
LOGICAL FORM
DATA FORM/.TRUE./, GAMMA/1.4/, GAMI/.4/
NTP = 9

73
GD = GAMMA*GAMI
FSMACH = XMACH

CPS = 1./(.5*GAMMA*FSMACH**2)

READ(29+NB) ((( R(J,K,L), J= 1, JMAX(NB)), K=1, KMAX(NB)),
* I=1, LMAX(NB)),
* (((RU(J,K,L), J= 1, JMAX(NB)), K=1, KMAX(NB)),
* L=1, LMAX(NB)),
* (((RV(J,K,L), J= 1, JMAX(NB)), K=1, KMAX(NB)),
* L=1, LMAX(NB)),
* (((RW(J,K,L), J= 1, JMAX(NB)), K=1, KMAX(NB)),
* L=1, LMAX(NB)),
* ((( E(J,K,L), J= 1, JMAX(NB)), K=1, KMAX(NB)),
* I=1, LMAX(NB))
REWIND 29+NB

ZER=0.
IF (IORDR.EQ.1) THEN
DO 5 K=N3, N4-1
DO 10 L=N1, N2-1
RR = 1./R(N5,K,L)
Q1 = R(N5,K,L)
Q2 = RU(N5,K,L)*RR
Q3 = RV(N5,K,L)*RR
Q4 = RW(N5,K,L)*RR
Q5 = E(N5,K,L)/GAMMA
PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
CPTMP = (PP-1.)*CPS
QQ=SQRT(Q2*Q2+Q3*Q3+Q4*Q4)

Q2=Q2/FSMACH

CC Q3=Q3/FSMACH
CC Q4=Q4/FSMACH

IF (FORM) THEN
WRITE (NTP, 703) Q2, Q3, Q4, ZER, CPTMP, QQ, R(N5, K, L), Q5
ELSE
WRITE (NTP) Q2, Q3, Q4, ZER, CPTMP, QQ, R(N5, K, L), Q5
ENDIF
10 CONTINUE
5 CONTINUE

ELSEIF (IORDR.EQ.2) THEN
DO 15 J=N3, N4-1
DO 20 L=N1, N2-1
RR = 1./R(J,N5,L)
Q1 = R(J,N5,L)
Q2 = RU(J,N5,L)*RR
Q3 = RV(J,N5,L)*RR
Q4 = RW(J,N5,L)*RR
Q5 = E(J,N5,L)/GAMMA
PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
CPTMP = (PP-1.)*CPS
QQ=SQRT(Q2*Q2+Q3*Q3+Q4*Q4)

Q2=Q2/FSMACH

CC Q3=Q3/FSMACH
CC Q4=Q4/FSMACH

IF (FORM) THEN
WRITE(NTP,703)Q2,Q3,Q4,ZER,CPTMP,QQ,R(J,N5,L),Q5
ELSE
WRITE(NTP)Q2,Q3,Q4,ZER,CPTMP,QQ,R(J,N5,L),Q5
ENDIF

20 CONTINUE
15 CONTINUE

ELSEIF (IORDR.EQ.3) THEN
DO 25 K=N3,N4-1
DO 30 J=N1,N2-1
RR = 1./R(J,K,N5)
Q1 = R(J,K,N5)
Q2 = RU(J,K,N5)*RR
Q3 = RV(J,K,N5)*RR
Q4 = RW(J,K,N5)*RR
Q5 = E(J,K,N5)/GAMMA
PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
CPTMP = (PP-I.)*CPS
QQ=SQRT(Q2*Q2+Q3*Q3+Q4*Q4)
ELSEIF (IORDR.EQ.3) THEN
WRITE(NTP,703)Q2,Q3,Q4,ZER,CPTMP,QQ,R(J,K,N5),Q5
ELSE
WRITE(NTP)Q2,Q3,Q4,ZER,CPTMP,QQ,R(J,K,N5),Q5
ENDIF

30 CONTINUE
25 CONTINUE
ENDIF

703 FORMAT(6E12.5)
RETURN
END

SUBROUTINE OFFB(NB, IORDR, N1, N2, N3, N4, N5)
PARAMETER (NTB=3, JMX=230, KMX=32, LMX=50)
COMMON/VISFAC/_,BETA, XMACH, C2B, C2BP, VRAT, RE
DIMENSION R(JMX,KMX,LMX) ,RU(JMX,KMX,LMX) ,RV(JMX,KMX,LMX),
RW(JMX,KMX,LMX),E(JMX,KMX,LMX),X(JMX,KMX,LMX),Y(JMX,KMX,LMX),
Z(JMX,KMX,LMX)
COMMON/DATA/ NBLK, JMAX(NTB), KMAX(NTB), LMAX(NTB)
LOGICAL FORM
DATA FORM/.TRUE./, GAMMA/1.4/, GAMI/0.4/

FSMACH = XMACH
GD=GAMMA*GAMI
CPS = 1./(0.5*GAMMA*FSMACH*FSMACH)
NTP = 9
ZER=0.
IONE=1
IZERO=0.
JH=N2-N1+1
KN=N4-N3+1
READ(9+NB) (((X(J,K,L) ,J= 1,JMAX(NB)) ,K=1,KMAX(NB)),
* L=1,LMAX(NB)),

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* ((( Y(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB)),
* ((( Z(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB))
REWIND 9+NB

READ(29+NB) ((( R(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
* L= 1, LMAX(NB)),
* ((( RU(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB)),
* ((( RV(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB)),
* ((( RW(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB)),
* ((( E(J,K,L), J= 1, JMAX(NB)), K= 1, KMAX(NB)),
  L= 1, LMAX(NB))
REWIND 29+NB

IF (FORM) THEN
  WRITE (NTP, 701) 'STRT', 'BLCK'
  WRITE (NTP, 702) IONE, IZERO, IZERO, IZERO, IZERO
  WRITE (NTP, 702) KN, JN, IZERO, IZERO, IZERO
ELSE
  WRITE (NTP) 'STRT', 'BLCK'
  WRITE (NTP) IONE, IZERO, IZERO, IZERO, IZERO
  WRITE (NTP) KN, JN, IZERO, IZERO, IZERO
ENDIF

IF (IORDR.EQ.1) THEN
  DO 5 K=N3, N4
     I0 CONTINUE
  DO 10 L=N1, N2
     IF (ABS(R(N5,K,L)).GT.1.E-10) THEN
       RR = 1./R(N5,K,L)
     ELSE
       RR = 1.
     ENDIF
     Q1 = R(N5,K,L)
     Q2 = RU(N5,K,L)*RR
     Q3 = RV(N5,K,L)*RR
     Q4 = RW(N5,K,L)*RR
     Q5 = E(N5,K,L)/GAMMA
     PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
     CPTMP = (PP-1.)*CPS
     QQ = SQRT(Q2*Q2+Q3*Q3+Q4*Q4)
     IF (FORM) THEN
       WRITE (NTP, 703) X(N5,K,L), Y(N5,K,L), Z(N5,K,L), Q2, Q3, Q4,
       1 CPTMP, Q5
     ELSE
       WRITE (NTP) X(N5,K,L), Y(N5,K,L), Z(N5,K,L), Q2, Q3, Q4,
       1 CPTMP, Q5
     ENDF

10 CONTINUE
5 CONTINUE

ELSEIF (IORDR.EQ.2) THEN
  DO 15 J=N3, N4
     I0 CONTINUE
  DO 20 L=N1, N2
     IF (ABS(R(J,N5,L)).GT.1.E-10) THEN
RR = 1./R(J,N5,L)
ELSE
RR = 1.
ENDIF
Q1 = R(J,N5,L)
Q2 = RU(J,N5,L)*RR
Q3 = RV(J,N5,L)*RR
Q4 = RW(J,N5,L)*RR
Q5 = E(J,N5,L)/GAMMA
PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
CPTMP = (PP-1.)*CPS
QQ=SQRT(Q2*Q2+Q3*Q3+Q4*Q4)

IF (FORM) THEN
  WRITE(NTP,703) X(J,N5,L), Y(J,N5,L), Z(J,N5,L), Q2, Q3, Q4,
  1 CPTMP, Q5
ELSE
  WRITE(NTP) X(J,N5,L), Y(J,N5,L), Z(J,N5,L), Q2, Q3, Q4,
  1 CPTMP, Q5
ENDIF

ELSEIF (IORDR.EQ.3) THEN
DO 25 K=N3,N4
  DO 30 J=N1,N2
    IF (ABS(R(J,K,N5)).GT.1.E-10) THEN
      RR = 1./R(J,K,N5)
    ELSE
      RR = 1.
    ENDIF
    Q1 = R(J,K,N5)
    Q2 = RU(J,K,N5)*RR
    Q3 = RV(J,K,N5)*RR
    Q4 = RW(J,K,N5)*RR
    Q5 = E(J,K,N5)/GAMMA
    PP = GD*(Q5-.5*(Q2**2+Q3**2+Q4**2)*Q1)
    CPTMP = (PP-1.)*CPS
    QQ=SQRT(Q2*Q2+Q3*Q3+Q4*Q4)
    IF (FORM) THEN
      WRITE(NTP,703) X(J,K,N5), Y(J,K,N5), Z(J,K,N5), Q2, Q3, Q4,
      1 CPTMP, Q5
    ELSE
      WRITE(NTP) X(J,K,N5), Y(J,K,N5), Z(J,K,N5), Q2, Q3, Q4,
      1 CPTMP, Q5
   ENDIF
  30 CONTINUE
25 CONTINUE
ENDIF
707 FORMAT (20A4)
RETURN
END
APPENDIX C

Included here is an example NPARC input file utilized in the zonal aerodynamic analysis of the Boeing 727-200 with horizontal and vertical tail leading-edge ice. This example is for the un-iced t-tail at zero degrees angle of attack and sideslip, Mach 0.12 and a Reynolds number 1.2 million. Note the use of the type 8 boundary condition and the LDIR variable in conjunction with the type 70 boundary conditions. The grid structure for this particular problem is summarized below:

Block 1
- JMAX = 194 (Freestream direction)
- KMAX = 25 (Spanwise direction)
- LMAX = 50 (Normal direction)

Block 2
- JMAX = 194 (Freestream direction)
- KMAX = 25 (Spanwise direction)
- LMAX = 49 (Normal direction)

Block 3
- JMAX = 194 (Freestream direction)
- KMAX = 25 (Spanwise direction)
- LMAX = 49 (Normal direction)

For Block 1, L=1 coincides with L=2 of Block 3 for so-called wake-cut treatment. For Block 2, K=1 and K=KMAX coincides K=KMAX-1 of Block 1 and K=2 of Block 3 respectively. These overlap regions were added automatically with the H-O topology option in PRPAMI. The horizontal and vertical tail surfaces are defined by the following indicial ranges:

<table>
<thead>
<tr>
<th>SURFACE</th>
<th>BLOCK</th>
<th>J Range</th>
<th>K Range</th>
<th>L Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper vertical</td>
<td>1</td>
<td>20 - 170</td>
<td>1 - 1</td>
<td>2 - 35</td>
</tr>
<tr>
<td>Upper horizontal</td>
<td>1</td>
<td>64 - 163</td>
<td>1 - 25</td>
<td>2 - 2</td>
</tr>
<tr>
<td>Horizontal tip</td>
<td>2</td>
<td>64 - 163</td>
<td>2 - 24</td>
<td>1 - 1</td>
</tr>
<tr>
<td>Lower horizontal</td>
<td>3</td>
<td>64 - 163</td>
<td>3 - 25</td>
<td>1 - 1</td>
</tr>
<tr>
<td>Lower vertical</td>
<td>3</td>
<td>20 - 170</td>
<td>25 - 25</td>
<td>1 - 49</td>
</tr>
</tbody>
</table>

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$INPUTS
NMAX=5000, NP=3000,
PRE=15.0, TRBF=500.0,
IFPRT=1, NBLOCK=3,
DIS2=0.16, DIS4=0.32, IMUTUR = 3, IFILTR = 2,
DTCAP=2.0, PCON=10.0, IVARDT=2,
NSPR=50, STOL=1.E-20, STOPT=50, STOPTM = '00002500',
RE = 1.2E+06, XMACH = 0.12, NOBORT = 1,
ALPHA = 0.0, BETA = 0.0,
SEND
SBOUND : #1
NPSEG=0,
INVISC(1)=1, INVISC(2)=1, INVISC(3)=1,
LAMIN(1)=0, LAMIN(2)=0, LAMIN(3)=1,
SEND
SBOUND :
NJSEG=2,
JLINE(1)=1, JTYPE(1)=8, JSIGN(1)=1,
JLOW(1)=2, JHIGH(1)=25,
JLINE(2)=2, JTYPE(2)=60, JSIGN(2)=1,
JLOW(2)=1, JHIGH(2)=50,
NKSEG=5,
KLINE(1)=1, KTYPE(1)=60, KSIGN(1)=1,
KLOW(1)=20, KHIGH(1)=170,
KLINE(2)=25, KTYPE(2)=70, KSIGN(2)=1,
KLOW(2)=1, KHIGH(2)=193,
KLINE(3)=1, KTYPE(3)=50, KSIGN(3)=1,
KLOW(3)=171, KHIGH(3)=194,
KLINE(4)=1, KTYPE(4)=50, KSIGN(4)=1,
KLOW(4)=1, KHIGH(4)=193,
KLINE(5)=1, KTYPE(5)=50, KSIGN(5)=1,
KLOW(5)=20, KHIGH(5)=170,
NKSEG=4,
LLINE(1)=2, LTYPE(1)=60, LSIGN(1)=1,
LLINE(1)=64, LHIGH(1)=163,
LLINE(2)=1, LTYPE(2)=50, LEDGE(1)=45,
LLINE(2)=164, LHIGH(2)=193,
LLINE(3)=50, LTYPE(3)=8, LSIGN(3)=1,
LLINE(3)=1, LHIGH(3)=194,
LLINE(4)=1, LTYPE(4)=70, LSIGN(4)=1,
LLINE(4)=2, LHIGH(4)=64,
LLINE(4)=2, LHIGH(4)=25,
SEND
SBOUND
$BLOCK : #2
NPSEG=0,
INVISC(1)=1, INVISC(2)=1, INVISC(3)=1,
LAMIN(1)=0, LAMIN(2)=0, LAMIN(3)=1,
SEND
$BLOCK
HJSEG=2,  
JLINE(1)=1,  JTYPE(1)=8,  JSIGN(1)=1,  
JKLOW(1)=2,  JKHIGH(1)=24,  
JLLOW(1)=2,  JLHIGH(1)=48,  
PRESSJ(1)-1.0,  TEMPJ(1)=1.0,  
JLINE(2)=194,  JTYPE(2)=8,  JSIGN(2)=-1,  
JKLOW(2)=1,  JKHIGH(2)=25,  
JLLOW(2)=1,  JLHIGH(2)=49,  
PRESSJ(2)-1.0,  TEMPJ(2)=1.0,  
NKSEG=2,  
KLINE(1)=1,  KTYPE(1)=70,  KSIGN(1)=1,  
KJLOW(1)=1,  KJHIGH(1)=193,  
KLINE(2)=25,  KTYPE(2)=70,  KSIGN(2)=-1,  
KJLOW(2)=1,  KJHIGH(2)=193,  
KLLOW(2)=1,  KLHIGH(2)=48,  
INTERK(2)=4,  
NLSEG=4,  
LINE(1)=1,  LTYPE(1)=60,  LSIGN(1)=1,  
LJLOW(1)=64,  LJHIGH(1)=163,  
LJLOW(1)=64,  LJHIGH(1)=25,  
LINE(2)=2,  LTYPE(2)=82,  LSIGN(2)=1,  
LJLOW(2)=164,  LJHIGH(2)=194,  
LJLOW(2)=164,  LJHIGH(2)=24,  
LINE(3)=49,  LTYPE(3)=8,  LSIGN(3)=-1,  
LJLOW(3)=1,  LJHIGH(3)=194,  
LJLOW(3)=1,  LJHIGH(3)=25,  
PRESSL(3)-1.0,  TEMPL(3)=1.0,  
LINE(4)=2,  LTYPE(4)=82,  LSIGN(4)=1,  
LJLOW(4)=1,  LJHIGH(4)=464,  
LJLOW(4)=2,  LJHIGH(4)=24,  
$  
$BLOCK :3  
NPSEG=0,  
INVISC(1)=1,  INVISC(2)=1,  INVISC(3)=1,  
LAMIN(1) =0,  LAMIN(2) =0,  LAMIN(3) =1,  
$END  
$END  
$END  
$END  
$END  
$END  
$END
LLINE(2)=1, LTYPE(2)=70,  LSIGN(2)=1,
LJLOW(2)=164, LJHIGH(2)=193,  INTERL(2)=2,  LDIR(2)=2,
LKLOW(2)=1,  LKHIGH(2)=24,
LLINE(3)=49, LTYPE(3)=8,  LSIGN(3)=1,
LJLOW(3)=1,  LJHIGH(3)=194,
LKLOW(3)=1,  LKHIGH(3)=25,
PRESL(3)=1.0, TEMPL(3)=1.0,
LLINE(4)=1, LTYPE(4)=70,  LSIGN(4)=1,
LJLOW(4)=2,  LJHIGH(4)=64,
LKLOW(4)=1,  LKHIGH(4)=24,
INTERL(4)=3,  LDIR(4)=2,
SEND
APPENDIX D

Included here is a discussion of the specific additions made to the NPARC input stream. The user should consult the NPARC users manual as a reference for this discussion. Additional pages to be inserted into the VSAERO Revision E.5 User’s Manual are also included.
SUMMARY OF NPARC INPUT MODIFICATIONS

The parameter STOPTM was added to the namelist INPUTS section, (manual, page 69). This variable acts much like STOPTR (manual, page 83), but it represents the specific time the job execution should terminate normally. The format is in month, day, hour and minute format (MMDDHHMM). This option is useful for dedicated time execution on a CRAY computer.

The boundary condition type 8 was added to the namelist BOUNDS section which allows the specification of external boundary flow-conditions via the data file PARC.SCN (manual, page 53). This option acts much the same as the freestream type 7 boundary condition except the flow takes on local characteristics provided by the PARC.SCN data file. Further information may be found in section 2.3 of this report.

The input variables JDIR, KDIR and LDIR were added to the namelist BOUNDS section to remove a built-in directionality in the type 70 boundary conditions (manual, page 42). These parameters represent arrays similar to the other input within the BOUNDS group (manual, page 57). The user is given control of the directionality of a boundary condition region. The values for JDIR, KDIR and LDIR are summarized below:

<table>
<thead>
<tr>
<th>Segment type</th>
<th>JDIR</th>
<th>KDIR</th>
<th>LDIR</th>
<th>Value</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>JLINE</td>
<td>x</td>
<td>x</td>
<td></td>
<td>2</td>
<td>Reverses K index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Reverses L index</td>
</tr>
<tr>
<td>KLINE</td>
<td>x</td>
<td></td>
<td></td>
<td>1</td>
<td>Reverses J index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Reverses L index</td>
</tr>
<tr>
<td>LLINE</td>
<td>x</td>
<td></td>
<td></td>
<td>1</td>
<td>Reverses J index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Reverses K index</td>
</tr>
</tbody>
</table>

Any other value for these variables will not modify the directionality of the boundary condition region.
### 4.3.5 OFF-BODY VELOCITY SCAN INPUT

**CARD 27: SCAN BOX.**

<table>
<thead>
<tr>
<th>Cols</th>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
<th>FrmT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>MOLD</td>
<td></td>
<td>Shape of velocity scan volume, see Sections 3.9.1—3.9.7</td>
<td>6I5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>Stops the scan</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Skewed box option: allows a single point, points along a straight line or straight lines within a parallelogram or within a parallelepiped. Requires CARD 28, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Allows points along radial lines in a cylindrical volume. Requires CARD 29, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>x,y,z array. Requires CARD 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Single panel-to-panel (center-to-center) scan. Requires CARD 31</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Multiple panel-to-panel scan. Requires CARD 32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Single panel-to-point scan. Requires CARD 33</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>Multiple panel-to-point scan. Requires CARD 32 and CARD 34</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>X,Y,Z array for zonal NS applications. Requires CARD 34.1.</td>
<td></td>
</tr>
</tbody>
</table>
CARD 27: SCAN BOX. (Cont'd)

<table>
<thead>
<tr>
<th>Cols</th>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-10</td>
<td>MEET</td>
<td></td>
<td>Controls the intersection line routine (see 3.9.1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interpolat'n</th>
<th>Moved</th>
<th>Flagged</th>
<th>B.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>-1</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>-2</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>-3</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: Interpolation is used along the scan line to set velocity vectors on points inside panel near-field regions using velocities from outside the region and surface intersection point velocities.

Note: Inside points just adjacent to a surface intersection are moved to the intersection point and take the surface velocity value.

Note: Points inside bodies are flagged as such.

Note: Include boundary layer profile if NVPI > 1.

11-15 | NEAR     | Controls the near-field routine in the velocity calculation (see 3.9.1) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Active</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Active only for surface panels (wake near field off)</td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td>Inactive</td>
<td></td>
</tr>
</tbody>
</table>

Note: Meet of -3 recommended for MOLD 9 option.
CARD 34.1: GLOBAL COORDINATE ARRAY. (Include if MOLD=9 on CARD 27)

<table>
<thead>
<tr>
<th>Cols</th>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
<th>Frmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>NP1</td>
<td></td>
<td>Dimensions of array of points entered on CARD 34.2. If NP1 &lt; 0 array of points read from separate Unit 31 data file, NAME.SCI.</td>
<td>4I5</td>
</tr>
<tr>
<td>6-10</td>
<td>NP2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-15</td>
<td>NP3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-20</td>
<td>IPVPRT</td>
<td>0</td>
<td>Suppress print of results</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Print results</td>
<td></td>
</tr>
<tr>
<td>75A</td>
<td>NAME</td>
<td></td>
<td>Prefix of scan output data file path name and optional scan input data file path name left adjusted, (e.g., NAME.SCO, NAME.SCI).</td>
<td></td>
</tr>
</tbody>
</table>

CARD 34.2: (Include NP1 * NP2 * NP3 points)

<table>
<thead>
<tr>
<th>Cols</th>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
<th>Frmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>X(J,K,L)</td>
<td></td>
<td>Global coordinates of scan point.</td>
<td>3F10.</td>
</tr>
<tr>
<td>11-20</td>
<td>Y(J,K,L)</td>
<td></td>
<td>Order of input is (((J=1,NP1),K=1,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NP2),L=1,NP3))</td>
<td></td>
</tr>
<tr>
<td>21-30</td>
<td>Z(J,K,L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31-35</td>
<td>NB</td>
<td></td>
<td>Block index number transferred to NAME.SCO data file.</td>
<td></td>
</tr>
<tr>
<td>36-40</td>
<td>JP</td>
<td></td>
<td>Grid point indicial location (J,K,L), transferred to NAME.SCO data file.</td>
<td></td>
</tr>
<tr>
<td>41-45</td>
<td>KP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46-50</td>
<td>LP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Format of optional NAME.SCI input data file is a repeat of CARD 34.1 and the CARD 34.2 set. This option is useful for very large data input arrays.
APPENDIX E

ENHANCEMENT OF THE DHC-6-200 TWIN OTTER PANEL MODEL

The existing VSAERO panel model of the DHC-6-200 Twin Otter was refined and enhanced under Task 5.3 of the contract. Initially, the existing VSAERO model was reviewed and compared to a geometry description of the aircraft supplied by DeHavilland Canada. Several areas of the existing panel model were reworked to comply with the available aircraft documentation. These areas included the nose of the fuselage, the wing and the vertical and horizontal tail definition.

The fuselage was first rebuilt, with a continuous maximum width line established through the nose. Based upon the DeHavilland documentation, the wing was revised and the intersection with the fuselage and the engine nacelle was determined. Similarly, the vertical and horizontal tail was rebuilt and a new intersection was defined. The basic refined model is presented in Fig. E.1.

Further, the wing lift struts, main landing gear strut and wheel and main gear/strut attach-fitting-faring were defined. Also, the nose landing gear strut and wheel were added to the model. All struts were modeled in their in-flight, extended positions. This enhanced model is shown in Fig. E.2.

Finally, an actuator disk propeller model was included for simulation of power effects. The wake system attached to this disk provides a model of the propeller swirl. As the swirl must have a specified rotation, it was decided to represent the propeller on the starboard side of the aircraft. Since a symmetric panel model was previously assumed, the port propeller is represented as the mirror image of the starboard propeller, which results in a reverse rotation to that on the actual aircraft. This simplification may be removed by explicitly defining both port and starboard sides. The resulting model of the DHC-6-200 Twin Otter is presented in Fig. E.3.

At each stage described here, fine-tuning of the panel model was accomplished by examination of the VSAERO flow solution and subsequent repair as necessary.
Fig. E.1. Baseline Panel Model of the DHC-6-200 Twin Otter.
Fig. E.2. Front View of the Enhanced Panel Model of the DHC-6-200 Twin Otter.
Fig. E.3. Rear View of the Enhanced Panel Model of the DHC-6-200 Twin Otter With Propeller Simulation.
# Title and Subtitle

Development of Three-Dimensional Flow Code Package to Predict Performance and Stability of Aircraft With Leading Edge Ice Contamination

## Abstract

In the work reported herein, a simplified, uncoupled, zonal procedure is utilized to assess the capability of numerically simulating icing effects on a Boeing 727-200 aircraft. The computational approach combines potential flow plus boundary layer simulations by VSAERO for the un-iced aircraft forces and moments with Navier-Stokes simulations by NPARC for the incremental forces and moments due to iced components. These are compared with wind tunnel force and moment data, supplied by the Boeing Company, examining longitudinal flight characteristics. Grid refinement improved the local flow features over previously reported work with no appreciable difference in the incremental ice effect. The computed lift curve slope with and without empennage ice matches the experimental value to within 1%, and the zero lift angle agrees to within 0.2 of a degree. The computed slope of the un-iced and iced aircraft longitudinal stability curve is within about 2% of the test data. This work demonstrates the feasibility of a zonal method for the icing analysis of complete aircraft or isolated components within the linear angle of attack range. In fact, this zonal technique has allowed for the viscous analysis of a complete aircraft with ice which is currently not otherwise considered tractable.

## Subject Terms

Aircraft icing; Computational fluid dynamics; Grid generation; Navier-Stokes equation; Panel method; Multigrid methods

## Distribution/Availability Statement

Unclassified - Unlimited
Subject Category 02
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