FINAL REPORT for NAG-1-2246
Control Law — Control Allocation Interaction

F/A-18 PA Simulation Test-Bed

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1 Introduction

This report documents the first stage of research into Control Law — Control Allocation Interactions. A three-year research effort was originally proposed:

1. Create a desktop flight simulation environment under which experiments related to the open questions may be conducted.

2. Conduct research to determine which aspects of control allocation have impact upon control law design that merits further research.

3. Conduct research into those aspects of control allocation identified above, and their impacts upon control law design.

Simulation code was written utilizing the F/A-18 airframe in the power-approach (PA) configuration. A dynamic inversion control law was implemented and used to drive a state-of-the-art control allocation subroutine.

2 Simulation

The airframe used was derived from the F/A-18 model already implemented in CASTLE. The airframe is not realistic, but is intended to be a test-bed for further research. The greatest area in which the test-bed simulation differs from the original airframe is in the treatment of control deflections. There are essentially two sets of control effectors:

1. The original control effectors in the F/A-18 airframe model. These are used only for initial trim and subsequent scheduling.
2. A duplicate set of control effectors that have linear effectiveness. This control set is the input to the control allocator, and the forces and moments they generate are superimposed on those of the bare airframe and original control set. Rate limits of the duplicate set are the no-load rate limits of the original controls. Position limits of the duplicate control effectors are referenced from the trim or scheduled positions of their counterparts in the original controls.

The rationale for incorporating a duplicate control set was to provide a constant, linear control effective matrix with flexibility for future variations and modifications. The control deflections are calculated for the trimmed/scheduled flight condition using the original F/A-18 nonlinear table lookups. The control deflections calculated from the allocator to produce desired moments use the control effectiveness matrix obtained from linearizing the F/A-18 aero database.

2.1 Simulation Code

There are six files that are used in the simulation of the airframe: Aero.f, Aeropa.f, Control.f, Constants.f, Engine.f, and Alloc.f.

2.1.1 Aero.f

The aero code first calls Aeropa.f to calculate the aerodynamics of the scheduled/trimmed flight condition. The code then combines the aerodynamics from the non-linear scheduled/trimmed flight condition and from the control deflections calculated in the allocator to produce the desired moments.
2.1.2 Aeropa.f

This code is taken from the F/A-18 simulation and modified slightly to include the control positions that are used in the table lookups later in the code. This is the only code that gives the airframe F/A-18 like characteristics. All added code is at the top of the RUN section.

2.1.3 Control.f

Stick and rudder pedal commands are taken as inputs and converted into an alpha command $\alpha_{cmd}$, beta command $\beta_{cmd}$, and a roll rate command $p_{cmd}$. These commands are input to a simple dynamic inversion control law that generates desired moments for the control allocation subroutine. First, $\alpha_{cmd}$ and $\beta_{cmd}$ are converted to desired accelerations $\dot{u}_{des}$ and $\dot{v}_{des}$:

\[
\begin{align*}
\dot{u}_{cmd} &= u \tan \alpha_{cmd} \\
\dot{u}_{des} &= \dot{w} (w - u_{cmd}) \\
\dot{v}_{cmd} &= \dot{v} \sin \beta_{cmd} \\
\dot{v}_{des} &= \dot{v} (v - v_{cmd})
\end{align*}
\]

Next, $\dot{u}_{des}$ and $\dot{v}_{des}$ are applied to inversions of the body-axis force equations (treating $q$ and $r$ as controls):

\[
\begin{align*}
q_{cmd} &= \frac{\dot{u}_{des} + pu - g \cos \theta \cos \phi - Z/m}{u} \\
r_{cmd} &= \frac{-\dot{v}_{des} + pu + g \cos \theta \sin \phi + Y/m}{u}
\end{align*}
\]

These two inversions are made as perfect as possible by using actual aircraft states, and the last calculated values of the body-axis forces $Y$ and $Z$ from the
aerodynamic calculations. First-order responses are specified for the desired angular accelerations,

\[ \dot{\phi}_{\text{des}} = \lambda_p (p - p_{\text{cmd}}) \]

\[ \dot{\theta}_{\text{des}} = \lambda_q (q - q_{\text{cmd}}) \]

\[ \dot{\psi}_{\text{des}} = \lambda_r (r - r_{\text{cmd}}) \]

Finally, the desired body-axis moments, required to obtain the desired accelerations, are calculated from inversions of the body-axis moment equations:

\[ C_{\ell,\text{des}} = -C_{\ell} + \frac{I_{xx} \dot{\phi}_{\text{des}} + I_{xy} \dot{\theta}_{\text{des}} + I_{xz} \dot{\psi}_{\text{des}} + (I_{yy} - I_{zz}) qr - I_{xz} pq}{qs} \]

\[ C_{m,\text{des}} = -C_{m} + \frac{I_{yy} \dot{\phi}_{\text{des}} + (I_{xx} - I_{zz}) qr + I_{xz} (p^2 - r^2)}{qs} \]

\[ C_{n,\text{des}} = -C_{n} + \frac{-I_{xz} \dot{\phi}_{\text{des}} + I_{xy} \dot{\theta}_{\text{des}} + (I_{yy} - I_{zz}) pq + I_{xz} qr}{qs} \]

The moment coefficients \( C_{\ell} \), \( C_{m} \), and \( C_{n} \) are the last calculated values of the body-axis moments. Since control-generated moments are superimposed on these values, they are the moments generated by the bare-airframe plus scheduled control deflections. The trimmed flight control deflections are used to calculate moments for the current flight condition to be used in the restoring algorithm. The attained moments are calculated next using the control deflections from the last time step for comparison purposes with the desired moments.

The desired moments, along with the required inputs, are input to the allocator to produce the required control deflections. The last step is to check the control deflections against the limits and reset them accordingly.

### 2.1.4 Constants.f

This section of code sets the model specific constants.
2.1.5 Engine.f

The engine model is taken from the Stevens & Lewis F-16 model [1].

2.1.6 Alloc.f

This code is the control allocator that produces required control deflections for desired moments. This code is explained in detail later.

3 Desktop Simulation

The F/A-18 PA model was first implemented on the UNIX-based CASTLE. The conversion of the simulation to the desktop PC required the CASTLE offline help menu provided with the PC version of CASTLE. Some additional steps were taken to complete the compilation of the airframe. The steps are as follows:

1. The directory structure from UNIX was copied to the CASTLE airframes folder.

2. A project was created in Microsoft Studio 6.0 following the F/A-18 project already included with the PC version of CASTLE. All custom builds were set up in the same way the F/A-18 project had them set up\(^1\). The custom builds were implemented on symbols.sdf and all the FTP data files.

3. In symbols.sdf the realtime CDF section was changed to resemble the

\(^1\)The offline CASTLE help explains a different way of setting up custom builds, but did not work.
F/A-18 realtime CDF section in the corresponding symbols.sdf. The reason is just a difference in structure between the PC CASTLE and UNIX CASTLE.

4 Control Allocation Algorithm

4.1 Introduction

The control allocation algorithm is a FORTRAN implementation of the bisecting, edge-searching algorithm. The theory behind the allocation code is explained in detail in [2]. Following is a step-by-step explanation of the code. Line numbers correspond to those in the attached file "Alloc.f".

4.2 Subroutine DA3

4.2.1 Diagnostics

The sections of code that depend on the DIAGS flag are debugging tools that can be used to dump several relevant variables. Because a great volume of output is generated, the DIAGS flag should be used sparingly.

4.2.2 Code Description

Lines 0126–0146: Array CSPHI is a table of sines and cosines of angles, beginning at 45° and proceeding through 20 bisections.

Lines 0191–0208: The desired moments are checked for zero length, and a vector of zero control deflections returned if they are; otherwise the
vector is normalized.

**Lines 0210–0219:** The initial rotation is performed using the transformation generated by subroutine DCGEN to align the desired moment direction $y_3_d$ with the $y_1$ axis. Subroutine DCGEN is an implementation of the method described in [2, Section 5.1]. Lines 0212–0219 perform the matrix multiplication, $B_3 = TB_{3_{\cdot\cdot\cdot}}$.

**Lines 0221–0231:** The controls that generate the moment with the maximum $y_1$ component are found by examining the sign of the first row of $B$ and setting the control to its maximum or minimum, depending on that sign. The controls are first set to $\pm 1$ (object notation) and then set to their actual limits by subroutine SETU.

**Lines 0233–0243:** This section of code was added to deal with the finite precision of computer math. The variable TOL is a distance in moment space that is related to the smallest bisection angle to be used, at the distance from the origin of the vertex just determined (maximum $y_1$ component). TOL is used in subsequent code to resolve near-zero numbers.

**Lines 0264–0265:** Subroutine R20 solves the 2-D problem for the projection onto the current $y_1$-$y_2$ plane. R20 returns the object-notation vector of controls of the intersecting edge in variable U1, the control that defines that edge in variable IU, and a $\pm 1$ value in variable INFRONT that is $+1$ if the edge is in front of, and $-1$ if it is behind the $y_1$-$y_2$ plane.

The three variables TEMP2, TEMP3, and TEMP4 contain respectively
the sorted list of controls (ITHETA) with an additional zero between the
two controls at the ends of the intersecting edge, the number of vertices
in the list (NANGS), and the index of the position in the list of the addi-
tional zero (INDX). Finally, the logical variable ISVERTEX signals that
the desired moment points directly at a vertex.

**Lines 0274–0293:** This section of code has no counterpart in reference
[2]. It was added during debugging and found to improve the success rate
of the algorithm (decrease the number of estimations required). The most
recently found edges that were in front (Last In Front, LIF) and behind
(Last In Back, LIB) are saved. Theoretically the last two edges found will
be LIF and LIB, but in some cases they were not.

**Lines 0295–0299:** If R20 reports a vertex in ISVERTEX, the controls
that determine that vertex, and the saturation of the desired moment, are
calculated by a call to DOVERT, and the subroutine is exited.

**Lines 0304–0322:** This section of code initializes several variables, in-
cluding the rotation matrix T22.

**Lines 0333–0510:** This is the main loop, in which the 2-D problem is
repeatedly solved for different rotations about the y1 axis.

**Lines 0335–0342:** Used during debugging, retained for possible
future use.

**Lines 0344–0349:** Rotation about y1. B1 is the operative B matrix
throughout. Code performs operation $T \cdot B$. 
Lines 0360–0364: The last returned values of ITHETA, NANGS, and INDX are assigned to those variables to be saved when TEMP2, TEMP3, and TEMP4 are overwritten by R20.

Lines 0366–0367: Call to R20 to solve the 2-D problem for the current orientation of B1 about the $y_1$-axis.

Lines 0376–0395: The edge identified by R20 is assigned to LIF or LIB according to the sign of the variable INFRONT.

Lines 0397–0401: Another vertex check.

Lines 0411–0495: Executed when the most recent and the prior edges differ in sign of their $y_3$ component, as indicated by the variables INFRONT and WASINF. This section of code is the implementation of the description given in [2, Section 5.3]. Through line 0436 the code is doing housekeeping and (possibly) diagnostics.

Lines 0438–0457: This section reflects a subtlety in the implementation of the algorithm not described in [2]. The prior edge was identified using a different $B$ matrix than the most recent edge. All relevant information regarding the prior edge is contained in the saved variables ITHETA, NANGS, and INDX. At lines 0456–0457 a call is made to subroutine GETEDGE, which is also called as the last step of subroutine R20.

**Lines 0486–0493:** Check the last two edges identified to see if they comprise the solution facet. If they do not, the LIF and LIB edges are checked. Both sets of edges are checked using subroutine **ISFACET**, described below. Output from **ISFACET** consists of the logical ISOK, numbers of the two defining controls in IUOUT and JUOUT, and controls (in object notation) at three vertices of the facet as columns of the array U123.

**Lines 0518–0519:** If the variable ISOK is false, the correct facet has not been determined and the maximum number of bisections has been performed. One last check of LIF and LIB is performed.

**Lines 0520–0574:** If ISOK is true, the solution is calculated. Otherwise (lines 0572–0573) the solution is estimated.

**Lines 0521–0565:** A straightforward implementation of [2, Equations (13) and (14)]. $M123$ is the matrix $[\hat{e}_{3,1} (v_1^p - v_2^p) (v_1^p - v_2^p)]$ in [2, Equation (13)]; variables AA, BB, and CC correspond to $\alpha_3$, $C_{1,2}$, and $C_{1,3}$ respectively; and $MTEMP$ is $v_1^p$. The variable $UDA$ is the same as $u^p$ in [2, Equation (14)], except that it has been scaled as necessary.

**Lines 0572–0573:** The estimator is called.
4.3 Subroutine DCGEN

This subroutine is a straightforward implementation of the initial transformation algorithm described in [2, Section 5.1].

**Lines 0789–0798:** The desired moments are normalized using double precision math.

**Lines 0810–0824:** If one or more of the leading components of the normalized moment vector are zero, the size of the problem is reduced.

**Lines 0829–0833:** The first row of the transformation matrix is set to the normalized desired moments.

**Lines 0837–0850:** The remaining terms are calculated in the three nested do-loops in [2, Equation (4)].

**Lines 0858–0868:** The last section of DCGEN ensures that the determinant of the transformation matrix is +1.

4.4 Subroutine R20

To find the edge that the desired moments direction is pointing to, the subroutine R20 is implemented. The theory behind this subroutine is in [2, Section 5.2.2]. All calculations in this subroutine are done in the $y_1$-$y_2$ plane.

**Lines 0928–0961:** The $y_2$ component of the point with the maximum $y_1$ component (UMAX in object notation, XUMAX in control notation) is calculated to determine its sign. The desired moment is checked to see
if its direction points towards a vertex of the attainable moment subset.

If it is a vertex the subroutine is exited and the allocation carries on.

**Lines 0976–0992:** Implementation of [2, Step 1, Page 20]. The array THETA is the needed part of the set $L_{\phi}$, and ITHETA that of $L_{\mu}$. Once the angle is found, $\pi$ is added or subtracted from it if the absolute value is greater than $\pi/2$ and depending on the sign of the angle. In this way, the angles of just the vertices with positive $y_1$ components are generated.

**Lines 0998–1010:** The angles are sorted in a clockwise or counterclockwise manner starting with the vertex that has the largest $y_2$ component. The manner in which they are sorted depends on the sign of the $y_2$ component of the maximum vertex, recorded in SY.

**Lines 1013–1025:** A zero is inserted in THETA and ITHETA to mark the point at which the angle changes sign.

**Lines 1034–1036:** THETA, ITHETA, and NANGS (the number of angles generated) are sent to subroutine GETEDGE to finish the solution to the 2-D problem. Subroutine GETEDGE is provided separately so that it could be called independently from DA3, as described above.

### 4.5 Subroutine GETEDGE

This subroutine is part of the explanation in [2, Section 5.2.2].

**Lines 1090–1127:** The first loop in this subroutine is looking for a sign change in the $y_2$ component between ordered vertices. Since the vertices
were sorted in the manner described, the solution edge will be the first one encountered in traversing the edges starting with the first vertex. The list is stepped through in the proper direction by the index $IX = IX - SY$.

The previous $y_2$ value is stored before the next $y_2$ value is calculated. This new value is compared to the previous one determining whether the edge crosses the $y_1$ axis. If the do loop continues, $U2$ is set to the next vertex by changing the sign of the control that is defining the current edge. The index is updated accordingly with the sign of $y_2$ and the process starts again until the edge is found. The do loop is exited when a new point is found that has a different sign than the point before.

**Lines 1129–1181:** This section deals with possible failure of the previous loop to find an edge, as indicated by (SY.EQ.SSY). The starting values of relevant variables are restored, and the vertex list is traversed in the opposite direction. The first loop should always find the proper edge when `GETEDGE` is called from `R20`, but the first loop may fail when called from within `DA3`. The list is traversed in the opposite direction by the index $IX = IX + SY$. Implementation of this section of code was the reason for inserting a zero in the ordered list of vertices.

**Lines 1190–1200:** One or the other of the previous two loops will have identified $U2$ (a vertex in object notation) and $JU$ (the number of the control that defines the edge). $U2$ is converted to control notation using the subroutine `SETU`. The third row of the $B$ matrix is applied to the two
vertices that define the solution edge to determine the \( y_3 \) component in moment space at the point where the \( y_2 \) component of the edge is zero. If the \( y_3 \) component is positive, the edge is described as "in front", whereas if the \( y_3 \) component is negative, the edge is "behind" the line defined by the direction of the desired moments \( \ell_3 \).

Lines 1202–1217: A final vertex check is made and the subroutine is exited.

4.6 Subroutine DOVERT

Lines 693–728: If it was determined that the desired moments points directly to a vertex the subroutine DOVERT is called. DOVERT uses the maximum or minimum controls that make up the vertex and calculates the total moment from there, scaling it appropriately. The allocator subroutine is then exited and the simulation carries on. This case is rare during simulation, but may occur.

4.7 Subroutine EST

The theory behind the estimator subroutine is explained in [2, Section 5.4.2]. Lines 0604–629 The subroutine starts with the last two edges that the allocator had found and creates a facet by setting the appropriate control to \(-1\) or \(+1\). SETU is used to assign actual control limits to these points which are then put into moment space using the control effectiveness matrix.

Lines 631–669 An interpolation is then made with the estimated facet vertices to determine the solution.
The moments are calculated using the estimated control positions and then scaled with the saturation limits.

### 4.8 Subroutine ISFACET

The subroutine is used to test the facet found by DA3. The subroutine uses the two defining controls from DA3 to find a facet from scratch that these two controls define. This algorithm is the subject of reference [4].

**Lines 1236–1251:** Zeros are set in the appropriate positions of the vertex arrays so that two edges are defined for the facet. The dimension of the union (see [2, Section 4.2]) of the two edges is determined. If the union is not two dimensional, then the edges can not form a facet; ISOK is set to false and the subroutine is exited.

**Lines 1253–1320:** For the two dimensional case the routine begins to calculate from scratch the facet that is determined by the two defining controls. The method used is completely independent of the edge-searching method and is explained in [4].

**Lines 1255–1287:** This section of code was lifted from earlier FORTRAN implementations of the facet-searching allocation method described in reference [4]. The facet defined by the two controls is in the variable TESTFACET.

**Lines 1291–1311:** The facet TESTFACET is compared with the object OBJ that was generated by R20. If they are different, the
facet opposite TESTFACET (also generated by the same two controls) is tested (lines 1300-1311).

**Lines 1322–1336:** If the facet just found is the same facet as the one that was found from the allocator, then \( U_{123} \), which is the matrix whose columns correspond to controls that generate three of the vertices that make up the solution facet, is assembled and returned.

### 4.9 Miscellaneous Subroutines

#### 4.9.1 MINNORM

The purpose of the minimum-norm restoring solution is to keep the controls as close to their trimmed control position as possible. The usual minimum-norm solution keeps the controls as close to zero as possible, however, in this application the zero position is redefined as the trimmed/scheduled control positions.

**Lines 1496–1531:** The subroutine is started by finding the total control position for the current time step and calculating the total attained moment.

**Lines 1533–1554:** If the control limits are zero, the routine is returned and no restoring takes place. Otherwise, the difference between the pseudo-inverse solution redefined at the trim condition, and the controls given by the allocation routine are used to find a delta control position that will drive the controls towards the trimmed position. This delta control position is scaled according to the control limits and a new restored control position is returned.

For more information on control restoring, refer to Bolling. [3, Ch. 4]
4.9.2 SORTC

Lines 1351–1492: A sorting subroutine downloaded from the National Institute of Standards and Technology (NIST) GAMS (Guide to Available Mathematical Software) at http://gams.nist.gov/. This particular algorithm was chosen for its efficiency, and for the fact that it returns a sorted index vector along with the sorted vector.

4.9.3 INVMAT3


5 Verification Data

Sample runs are included to verify the airframe. The four tests cases used are a trimmed flight condition, a step in the longitudinal stick, and step doublets in the lateral stick and rudder pedals. The MANGEN command in CASTLE was implemented to produce the desired stick commands. Complete MATLAB flies of the four cases are attached as trim_dec11.mat, long_dec11.mat, lat_dec11.mat, and dir_dec11.mat.

The plots include selected states of the airframe along with the trimmed/scheduled control positions and the allocated control positions.

Figure 1 shows the time histories of the six global controls in a trimmed flight condition at 8.1 degrees angle of attack, 1200 ft, and 231.52 ft/sec. These settings
are the default when the airframe is loaded. Some settling of the controls to achieve steady state is noted.

Figure 2 shows time histories for a step input in longitudinal stick of 2.5 inches aft from center. The airframe was initialized to the trim conditions described above and the stick step implemented at time \( t = 1 \text{sec} \) for 1 second.

Figure 3 shows the time histories for a step douplet in lateral stick. The lateral stick was driven right 2 inches from center at time \( t = 1 \text{sec} \) for 1 second and then left of center 2 inches for 1 second.

Figure 4 shows the time histories for a step douplet in rudder pedals. The pedals were driven right 2 inches from center at time \( t = 1 \text{sec} \) for 1 second and then left of center 2 inches for 1 second.
Figure 1: Global Control Deflections, Trimmed Flight (Degrees)
Figure 2: Longitudinal Stick Step Input
Figure 3: Lateral Stick Step Doublet
Figure 4: Lateral Rudder Pedal Step Doublet
References


FUNCTION: 3 Moment Control Allocator

Direct Allocation for the 3 objective problem using bisecting edge searching algorithm

DESIGNED BY: Bull Durham
CODED BY: Kevin Scalera
MAINTAINED BY: VPI SIMULATIONS

MODIFICATION HISTORY:

DATE PURPOSE BY

GLOSSARY

ASSIGNMENTS:

NONE

INPUTS:

IMODE Sim. mode: -2=init,-1=reset,0=hold,1=ru

OUTPUTS:

NONE

LOCALS:

NONE

OTHER LOCALS:
SUBROUTINE DA3(UDA, SAT, IERR,
& B, MDES, U_MIN, U_MAX, M, NBI, TIME, DIAGS)

C DECLARATION SECTION

IMPLICIT NONE

** Parameters

** INPUTS:

INTEGER*4 IMODE

** OTHER LOCALS:

BYTE CONPAR, CTLBUF

LOGICAL*4 DIAGS, DIDSWITCH, INITIALIZED, ISOK, ISVERTEX, STUCK

INTEGER*4 I, I_COUNT, IERR, INDEX, I_THETA(21), IU, I_UOUT

INTEGER*4 I_UTEMP(20), I_LIB, I_LIF, J, J_U, J_UOUT, K, M

INTEGER*4 MAXSTEPS, NANGS, NBI, NMAX, STEPS, SY, TEMP2(21)

INTEGER*4 TEMP3, TEMP4, U1(20), U123(20,3), U2(20), U_MAX(20)

INTEGER*4 U_LIB(20), U_LIF(20)

REAL*4 MINV(3,3), M_TEMP(3), MXMAX(3), COS_PHI, CSPHI(2,20)

REAL*4 ABC(3), NORM, PI, SAT, SIN_PHI, DET, AA, INFRONT, T(3,3)

REAL*4 T22(2,2), BB, B_TEMP(2), CC, TIME, TOL, TOLANG, B(3,20)

REAL*4 M123(3,3), MAXNORM, UDA(20), B1(3,20), MD(3), MDES(3)

REAL*4 U_MAX(20), U_MIN(20), WASINF, XU123(20,3), XU_MAX(20)

REAL*4 XU_TEMP(20), Y

** INPUTS:

EQUIVALENCE( CONPAR(1), IMODE)

COMMON SHELL1 / CONPAR( 424)

COMMON/ SHELL1/ CONPAR( 424)
DATA INITIALIZED/.FALSE./
DATA PI/3.141592653589793/

Table of cosines and sines of bisection angle

CSPHI/

\begin{verbatim}
& 7.071067811865475e-01, 7.071067811865476e-01,
& 9.238795325112867e-01, 3.826834323650898e-01,
& 9.807852804032304e-01, 1.950903220161282e-01,
& 9.951847266721969e-01, 9.801740329560606e-02,
& 9.987954562051724e-01, 4.906767432741801e-02,
& 9.996988186962042e-01, 2.454122852291229e-02,
& 9.999247018391445e-01, 1.227153828571993e-02,
& 9.999917528260011e-01, 6.135884649154475e-03,
& 9.999952938095762e-01, 3.067956762965976e-03,
& 9.99998234517019e-01, 1.533980186284766e-03,
& 9.999997058628822e-01, 7.669903187427045e-04,
& 9.999999926465719e-01, 3.834951875713956e-04,
& 9.999999981614293e-01, 1.917475973107033e-04,
& 9.999999995401073e-01, 9.587379909597734e-05,
& 9.9999999998510269e-01, 4.793689960306688e-05,
& 9.999999999997127567e-01, 2.396844980841822e-05,
& 9.99999999999998218992e-01, 1.198422490506971e-05,
& 9.9999999999999820472e-01, 5.992112452642428e-06,
& 9.9999999999999955118e-01, 2.996056226334661e-06,
& 9.9999999999999987808e-01, 1.498028113169011e-06/
\end{verbatim}

ENDIF

IF ( (IMODE.LE.-2) .OR. .NOT.INITIALIZED ) THEN
  ENDIF

IF ( (IMODE.LE.-1).OR.(.NOT.Initialize) ) THEN
  Initialized = .TRUE.
ENDIF

IERR = 0 FACET FOUND, ABC OK
IERR = 1 FACET NOT FOUND, INTERPOLATED SOLUTION

ENDIF

RUN SECTION
IF (DIAGS) THEN
  WRITE(*, '(/ASCI)') ' Entering DA3'
  WRITE(*, '(/ASCI)') ' Calling arguments'
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* B(1, :) = ', B(1, :) 
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* B(2, :) = ', B(2, :) 
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* B(3, :) = ', B(3, :) 
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* MDES = ', MDES 
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* U_MIN = ', U_MIN 
  WRITE(*, '(/ASCI,6E13.6)') ' *DA1* U_MAX = ', U_MAX 
ENDIF

INFRONT = 1.0

NORM = 0.0
DO I = 1, M
   NORM = NORM + MDES(I)*MDES(I)
ENDDO

ENDC

IF (NORM .EQ. 0.0) THEN
  IERR = 0
  SAT = 0.0
  DO I = 1, M
     UDA(I) = 0.0
  ENDDO
  RETURN
ENDIF

NORM = SQRT(NORM)
DO I = 1, M
   MD(I) = MDES(I)/NORM
ENDDO

CALL DCGEN(T, MD)

DO I = 1, M
   DO J = 1, M
      BI(I, J) = 0.0
   DO K = 1, M
      BI(I, J) = BI(I, J) + T(I, K)*B(K, J)
   ENDDO
   ENDDO
ENDDO

DO I = 1, M
   IF (BI(I, I) .EQ. 0.0) THEN
      UMAX(I) = 0
   ELSEIF (BI(I, I) .LT. 0.0) THEN
      UMAX(I) = -1
   ELSE
      UMAX(I) = 1
   ENDF
ENDDO
CALL SETU(XUM/XUM, UMAX, U_MIN, U_MAX, M)
TOLANG = CSPHI(2,MIN(20,2*NBI))
DO I=1, M
   MXMAX(I) = 0.
   DO J=I, M
      MXMAX(I) = MXMAX(I) + B(I,J) * XUMAX(J)
   ENDDO
ENDDO
MAXNORM = SQRT(MXMAX(1)*MXMAX(1))
& + MXMAX(2)*MXMAX(2)
& + MXMAX(3)*MXMAX(3))
TOL = MAXNORM*TOLANG
ENDIF
CALL R20(U1, IU, INFRONT, TEMP2, TEMP3, TEMP4, ISVERTEX,
& B1, UMAX, XUMAX, U_MIN, U_MAX, TOL, M, DIAGS)
ENDIF
IF (IU.NE.0) THEN
   IF (INFRONT.EQ.1.) THEN
      DO I=1, M
         U_LIF(I) = U1(I)
      ENDDO
      I_LIF = IU
   ELSEIF (INFRONT.EQ.-1.) THEN
      DO I=1, M
         U_LIB(I) = U1(I)
      ENDDO
      I_LIB = IU
   ENDIF
IF (DIAGS) THEN
WRITE(*,'(/A30)') ' After 1st LIF/LIB'
WRITE(*,'(/A30)') ' DA1* U_LIF = ', (U_LIF(I), I=1,M)
WRITE(*,'(/A30)') ' DA3* I_LIF = ', I_LIF
WRITE(*,'(/A30)') ' DA3* U_LIB = ', (U_LIB(I), I=1,M)
WRITE(*,'(/A30)') ' DA3* I_LIB = ', I_LIB
ENDIF

ENDIF

IF (ISVERTEX) THEN
WRITE(*,'(A30,ES.6)') ' TIME = ', TIME, ' FIRST CALL TO R29'
CALL DOVERTUDA,SAT,U1,B,U_MIN,U_MAX,M,NORM)
RETURN
ENDIF

IF (M.GE.8) THEN
ICOUNT = 1
ELSE
ICOUNT = 2
ENDIF
ICOUNT = 1
COSPHI = CSPHI(1,ICOUNT)
SINPHI = INFRONT*CSPHI(2,ICOUNT)
T22(I,1) = COSPHI
T22(I,2) = -SINPHI
T22(2,1) = SINPHI
T22(2,2) = COSPHI
MAXSTEPS = 2*INT(ABS(PI/ASIN(SINPHI)))
WASINF = INFRONT
ISOK = .FALSE.
NMAX = NBI + 1
DIDSWITCH = .FALSE.
STEPS = 0
STUCK = .FALSE.
DO WHILE ((ICOUNT.LT.NMAX) .AND. (.NOT.ISOK))
STEPS = STEPS+I
IF (STEPS.GE.MAXSTEPS) THEN
STUCK = .TRUE.
WRITE(*,'(/A30)') ' SKID STOP', STEPS, ' ', TIME
ENDIF
ENDIF

MAIN LOOP ************
DO WHILE ((ICOUNT.LT.NMAX).AND.(.NOT.ISOK))
STEPS = STEPS+1
IF (STEPS.GE.MAXSTEPS) THEN
STUCK = .TRUE.
WRITE(*,'(/A30)') ' SKID STOP', STEPS, ' ', TIME
ENDIF
DO J = 1,M
BTEMP(1) = T22(1,1)*B1(2,J) + T22(1,2)*B1(3,J)
BTEMP(2) = T22(2,1)*B1(2,J) + T22(2,2)*B1(3,J)
B1(2,J) = BTEMP(1)
B1(3,J) = BTEMP(2)
ENDDO

IF (DIAGS) THEN
WRITE (*, */AS0*/) ' In DA3 DO WHILE'
WRITE (*, */AS0*/) ' *DA3* IOCNT = ', IOCNT
WRITE (*, */AS0*/) ' *DA3* STEPS = ', STEPS
WRITE (*, */AS0*/) ' *DA3* MAXSTEPS = ', MAXSTEPS
WRITE (*, */AS0*/) ' *DA3* B1(2,:) = ', (B1(2,I),I=1,M)
WRITE (*, */AS0*/) ' *DA3* B1(3,:) = ', (B1(3,I),I=1,M)
ENDIF

NANGS = TEMP3
INDX = TEMP4
DO I=1,21
ITHETA(I) = TEMP2(I)
ENDDO

CALL R20(UI,IU, INFRONT TEMP2,TEMP3,TEMP4,ISVERTEX, 
& B1,UMAX,XUMAX,U_MIN,U_MAX,TOL,M,DIAGS)

IF (IU.NE.0) THEN
IF (INFRONT.EQ.1.) THEN
DO I=1,M
  ULIF(I) = U1(I)
ENDDO
I_LIF = IU
ELSEIF (INFRONT.EQ.-1.) THEN
DO I=1,M
  ULIB(I) = U1(I)
ENDDO
I_LIB = IU
ENDIF
ENDIF

IF (ISVERTEX) THEN
CALL DOVERT(UDA,SAT,UI,BI,U_MIN,U_MAX,M,NORM)
RETURN
ENDIF

IF (DIAGS) THEN
WRITE(*,'(/AS0:') ' Before testing reversal'
WRITE(*,'(/A30,F14.6)') 'CA3* INFRONT = ', INFRONT
WRITE(*,'(/A30,F14.6)') 'CA3* WASINF = ', WASINF
ENDIF

DIDSWITCH = .FALSE.

IF (INFRONT.NE.WASINF) THEN \ REVERSE DIRECTION
IF (DIAGS) THEN
WRITE(*,'/A_C) ') ' Reversing _
WRITE(*,' A3,3,i3) ') ' *SA_ _ Stems !_aken :
WRITE(*,' A38,13)') '*DA3 _ HAXSTEPS
WRITE(*,' A30,L3 ') '*DA3* S'FUCK
ENDIF
DIDSWITCH = .TRUE.
WASINF = INFRONT
ICOUNT = ICOUNT+1

C Bisection and next transformation
COSPHI = CSPHI(1,ICOUNT)
SINPHI = INFRONT*CSPHI(2,ICOUNT)
T22(1,1) = COSPHI
T22(1,2) = -SINPHI
T22(2,1) = SINPHI
T22(2,2) = COSPHI
MAXSTEPS = 2*INT(ABS(PI/ASIN(SINPHI)))

IF (DIAGS) THEN
WRITE(*,'/_A<_ ' ) ' _isection _nd next _r_nsf_rm_<ion'
WRITE(*, ' :IA20,E16.6 ') ' *DA3* COS_HI = ', COSPHI
WRITE(*, ' A _ E _ 6 2A3")<-YoF" : ' SINPHI
WRITE(*, ' iA30,16) ') ' "3A3" HAXSTEPS = ', MAXSTEPS
ENDIF
STEPS = 0
Y = 0.0
DO I = I,M
Y = Y + BI(2,1)*XUMAX(I)
ENDDO
SY = 1
IF (Y.LT.0.0) SY = -1

CALL GETEDGE(U2, JU, INFRONT, ISVERTEX,
& B1, UMAX, Y, SY, ITHETA, NANGS, U_MIN, U_MAX, INDX, TOL, M, DIAGS)
0459 IF (JU.NE.0) THEN
0460 IF (INFRONT.EQ.1.) THEN
0461 DO I=1,M
0462 U_LIF(I) = U2(I)
0463 ENDDO
0464 I_LIF = JU
0465 ELSEIF (INFRONT.EQ.-1.) THEN
0466 DO I=1,M
0467 U_LIB(I) = U2(I)
0468 ENDDO
0469 I_LIB = JU
0470 ENDIF!
0471 IF (DIAGS) THEN
0472 WRITE(*, '(/A30,13)') ' After GETEDGES LIF/LIB'
0473 WRITE(*, '(/A30,13)') ' *DA3* U_LIF = ', (U_LIF(I), I=1,M)
0474 WRITE(*, '(/A30,13)') ' *DA3* I_LIF = ', I_LIF
0475 WRITE(*, '(/A30,13)') ' *DA3* U_LIB = ', (U_LIB(I), I=1,M)
0476 WRITE(*, '(/A30,13)') ' *DA3* I_LIB = ', I_LIB
0477 ENDIF!
0478 ENDF!
0479 C
0480 IF (ISVERTEX) THEN
0481 C
0482 CALL DOVERT(UDA,SAT,U2,B,U_MIN,U_MAX,M,NORM)
0483 RETURN
0484 ENDF!
0485 IF (JU.NE.0) THEN
0486 CALL ISFACET(ISOK, IUOUT, JUOUT, U123,
0487 & IU, JU, U1, U2, B1, M, TOL)
0488 IF (.NOT.ISOK) CALL ISFACET(ISOK, IUOUT, JUOUT, U123,
0490 & I_LIF, I_LIB, U_LIF, U_LIB, B1, M, TOL)
0491 ELSE
0492 ISOK = .FALSE.
0493 ENDF!
0494 ENDIF!
0495 ENDF ! IF (INFRONT.NE.WASINF) THEN
0496 C
0497 C Must leave on a switch
0498 C
0500 C IF (((ICOUNT.EQ.NMAX).AND.(.NOT.ISOK).AND.(.NOT.DIDSWITCH)) THEN
0501 C NMAX = NMAX+1
0502 C ENDF!
0503 IF (STUCK) THEN
0504 WRITE(*, '(/A50)') ' Stuck in DA3, exiting'
0505 WRITE(*, '(/A50,13)') ' TIME = ', TIME
0506 RETURN
0507 ENDF!
0508 C
0509 C ENDDO ! End of do while statement
0511 C
0512 C END MAIN LOOP ***********************************************
0513 C
IF (DIAGS) THEN
  WRITE(*, '(/AS0)') ' Exited from DA3'
ENDIF

IF (.NOT.ISOK) CALL ISFACET(ISOK, IUOUT, JUOUT, U123,
& I_LIF, I_LIB, U_LIF, U_LIB, B1, M, TOL)
IF (ISOK) THEN
  DO I=1,3
    DO J=1,M
      IUTEMP(J)=U123(J,I)
    ENDDO
    CALL SETU(XUTEMP,IUTEMP,U_MIN,U_MAX,M)
    DO J=1,M
      XU123(J,I)=XUTEMP(J)
    ENDDO
  ENDDO
  DO I=1,3
    DO J=1,3
      MI23(I,J)=0.
      DO K=I,M
        MI23(I,J) =MI23(I,J) +B(I,K)*XUI23(K,J)
      ENDDO
    ENDDO
  ENDDO
  DO I=1,3
    DO J=2,3
      MI23(I,J)=MI23(I,I)-MI23(I,J)
    ENDDO
    MTEMP(I)=MI23(I,I)
    MI23(I,I)=MDES(I)
  ENDDO
  CALL INVMAT3(MI23,MINV,DET)
  DO I=1,3
    ABC(I) = 0.
    DO J=1,3
      ABC(I) = ABC(I)+MINV(I,J)*MTEMP(J)
    ENDDO
  ENDDO
  AA = ABC(1)
  BB = ABC(2)
  CC = ABC(3)
  SAT = 1./AA
  IF (AA.LT.1.) AA = 1.
  DO I=1,M
    UDA(I) = (XU123(I,1)
    & +BB*(XU123(I,2)-XU123(I,1))
    & +CC*(XU123(I,3)-XU123(I,1))/AA
  ENDDO
  IERR = 0
C Call estimate subroutine to estimate solution if facet not found
ELSE
    CALL EST(UDA, SAT, IERR,
    & U_LIF, I_LIF, U_LIB, I_LIB, BI, U_MIN, U_MAX, NORM, M)
ENDIF
RETURN
END

SUBROUTINE EST(UDA, SAT, IERR,
    & U1, IU, U2, JU, B, U_MIN, U_MAX, NORM, M)
IMPLICIT NONE

C INPUTS
REAL*4 B(3,20), U_MAX(20), U_MIN(20), NORM
INTEGER*4 UI(20) , IU, U2(20) , JU, M

C OUTPUTS
REAL*4 SAT, UDA(20)
INTEGER*4 IERR

C LOCALS
REAL*4 XUI(20), XU2(20), XU3(20), XU4(20), XMOM(3)
REAL*4 UPPER1(3), UPPER2(3), LOWER1(3), LOWER2(3), XNORM
REAL*4 XK1, XK2, XK3, XV1(3), XV2(3), XW1(20), XW2(20)
INTEGER*4 U3(20), U4(20)

C OTHER LOCALS
INTEGER*4 I, J, K

IERR = 1
U1(IU) = -I
U2(JU) = -I
DO I=I,M
    U3(I) = U1(I)
    U4(I) = U2(I)
ENDDO
U3(IU) = 1
U4(JU) = 1

CALL SETU(XU1,U1,U_MIN,U_MAX,M)
CALL SETU(XU2,U2,U_MIN,U_MAX,M)
CALL SETU(XU3,U3,U_MIN,U_MAX,M)
CALL SETU(XU4,U4,U_MIN,U_MAX,M)

DO I=1,3
    LOWER1(I) = 0.
    LOWER2(I) = 0.
    UPPER1(I) = 0.
    UPPER2(I) = 0.
    DO J=1,M
        LOWER1(I) = LOWER1(I)*B(I,J)*XU1(J)
        LOWER2(I) = LOWER2(I)*B(I,J)*XU2(J)
        UPPER1(I) = UPPER1(I)*B(I,J)*XU3(J)
        UPPER2(I) = UPPER2(I)*B(I,J)*XU4(J)
    ENDDO
END
ENDDO
ENDDO
IF (LOWER1(2).NE.UPPER1(2)) THEN
  XK1 = LOWER1(2)/(LOWER1(2)-UPPER1(2))
ELSE
  XK1 = 0.
ENDIF
IF (LOWER2(2).NE.UPPER2(2)) THEN
  XK2 = LOWER2(2)/(LOWER2(2)-UPPER2(2))
ELSE
  XK2 = 0.
ENDIF
DO I=i,3
  XV1(I) = XK1*UPPER1(I)+(1-XK1)*LOWER1(I)
  XV2(I) = XK2*UPPER2(I)+(1-XK2)*LOWER2(I)
ENDDO
IF (XV2(3).NE.XV1(3)) THEN
  XK3 = XV2(3)/(XV2(3)-XVI(3))
ELSE
  XK3 = 0.
ENDIF
DO I=I,M
  XMOM(I) = 0.
  DO J=I,M
    XMOM(I) = XMOM(I) + B(I,J)*UDA(J)
  ENDDO
ENDDO
XNORM = SQRT(XMOM(1)*XMOM(1)
& +XMOM(2)*XMOM(2)
& +XMOM(3)*XMOM(3))
IF (XNORM.NE.0.) THEN
  SAT = NORM/XNORM
  XNORM = SAT
ELSE
  SAT = 0.
ENDIF
IF (XNORM.GT.1.) XNORM = 1.
SUBROUTINE DOVERT(UDA, SAT, & U1, B, U_MIN, U_MAX, M, NORM)
IMPLICIT NONE
REAL*4 UDA(20), SAT, U_MIN(20), U_MAX(20), B(3,20), NORM
INTEGER*4 U1(20), M
REAL*4 XMOM(3), XNORM
INTEGER*4 I, J
WRITE(*,*) ' V_ZRI'EX
CALL SETU(UDA, U1, U_MIN, U_MAX, M)
DO 1=1,3
XMOM(I) = 0.
DO J=I,M
XMOM(I) = XMOM(I) + B(I,J) * UDA(J)
ENDDO
ENDDO
XNORM = SQRT(XMOM(1)*XMOM(1) & +XMOM(2)*XMOM(2) & +XMOM(3)*XMOM(3))
SAT = NORM/XNORM
XNORM = SAT
IF (XNORM.GT.1.) XNORM = 1.
DO I = 1,M
UDA(I) = XNORM*UDA(I)
ENDDO
RETURN
END

SUBROUTINE INVMAT3(MATIN, MATOUT, DET)
IMPLICIT NONE
INTEGER*4 I, J
REAL*4 DET, MATIN(3,3), MATOUT(3,3)
C Zero out the output matrix
DO I = 1,3
DO J = 1,3
0742      MATOUT(I,J) = 0.0
0743      ENDDO
0744      ENDDO
0745 C Calculate the determinant of the input matrix
0746 C
0747      DET = MATIN(1,1) * MATIN(2,2) * MATIN(3,3)
0748      & + MATIN(1,2) * MATIN(2,3) * MATIN(3,1)
0749      & + MATIN(1,3) * MATIN(2,1) * MATIN(3,2)
0750      & - MATIN(1,3) * MATIN(2,2) * MATIN(3,1)
0751      & - MATIN(1,2) * MATIN(2,1) * MATIN(3,3)
0752      & - MATIN(1,1) * MATIN(2,3) * MATIN(3,2)
0753 C Find the matrix inverse
0754 C
0755      IF (DET .NE. 0.0) THEN
0756      MATOUT(1,1) = (MATIN(2,2) * MATIN(3,3) - MATIN(2,3) * MATIN(3,2)) / DET
0757      MATOUT(1,2) = - (MATIN(1,2) * MATIN(3,3) - MATIN(1,3) * MATIN(3,2)) / DET
0758      MATOUT(1,3) = (MATIN(1,2) * MATIN(2,3) - MATIN(1,3) * MATIN(2,2)) / DET
0759      MATOUT(2,1) = - (MATIN(2,1) * MATIN(3,3) - MATIN(2,3) * MATIN(3,1)) / DET
0760      MATOUT(2,2) = (MATIN(2,1) * MATIN(3,3) - MATIN(1,3) * MATIN(3,1)) / DET
0761      MATOUT(2,3) = - (MATIN(2,1) * MATIN(2,3) - MATIN(1,3) * MATIN(2,1)) / DET
0762      MATOUT(3,1) = (MATIN(2,1) * MATIN(3,2) - MATIN(1,2) * MATIN(3,1)) / DET
0763      MATOUT(3,2) = - (MATIN(1,1) * MATIN(3,2) - MATIN(1,2) * MATIN(3,1)) / DET
0764      MATOUT(3,3) = (MATIN(1,1) * MATIN(2,2) - MATIN(1,2) * MATIN(2,1)) / DET
0765 C Normalize the desired moments
0766 C
0767      RETURN
0768      END
0769
0770
0771
0772
0773
0774 C-------------------------------------------------------------
0775
0776      SUBROUTINE DCGEN(T, MD)
0777
0778      IMPLICIT NONE
0779      REAL*4 MD(3)
0780      REAL*4 T(3,3)
0781      INTEGER*4 MLOCAL
0782      REAL*8 V(3), VLEN(3), VNORM, XDOT_DC
0783      REAL*4 DETNUM, AMIN DC
0784      INTEGER*4 J, JCOL, KCOL, I, MOM_FLAG, IROW
0785      REAL*8 DTOL
0786 C
0787 C Calculate the norm of the moments
0788 C
0789      DTOL = 1.D-5
0790      VNORM = DSQRT(dble(MD(1)) + dble(MD(1)) + dble(MD(2)) + dble(MD(3)) + dble(MD(3)))
0791 &
0792 &
0793 C Normalize the desired moments
0794 C
0795 C
0796      DO I = 1, 3
0797      V(I) = dble(MD(I)) / VNORM
0798      ENDDO
Zero out the transformation matrix

DO I = 1,3
  DO J = 1,3
    T(I,J) = 0.0
  ENDDO
ENDDO

Check to see if V(I),3 to 1 is approx equal to zero => reduce size of problem

DO I = 3,1,-1
  IF (ABS(V(I)) .LE. DTOL) THEN
    T(I,I) = 1.0
  ELSE
    GOTO 5
  ENDIF
ENDDO

T(1,1) = 1.0 or -1.0 for rotation about x-axis (depends on direction of rot.)

DO JCOL = I,MLOCAL-I
  IROW = MLOCAL + 1 - JCOL
  T(IROW,JCOL) = sngl(DSQRT(I.0D0 * VLEN(JCOL)))
  DO KCOL = JCOL+I,MLOCAL
    XDOT_DC = T(I,JCOL)*T(I,KCOL)
    IF (IROW .NE. MLOCAL) THEN
      DO I = IROW+I,MLOCAL
        XDOT_DC = XDOT_DC + T(I,JCOL)*T(I,KCOL)
      ENDDO
    ENDIF
    T(IROW,KCOL) = -XDOT_DC/T(IROW,JCOL)
    VLEN(KCOL) = VLEN(KCOL) + dble(T(IROW, KCOL))*dble(T(IROW,KCOL))
  ENDDO
ENDDO

Developing orthogonal tranformation with V as 1st row

DO JCOL = 1,MLOCAL-1
  IROW = MLOCAL + 1 - JCOL
  T(IROW,JCOL) = sngl(DSQRT(1.0D0 - VLEN(JCOL)))
  DO KCOL = JCOL+1,MLOCAL
    XDOT_DC = T(I,JCOL)*T(I,KCOL)
    IF (IROW .NE. MLOCAL) THEN
      DO I = IROW+1,MLOCAL
        XDOT_DC = XDOT_DC + T(I,JCOL)*T(I,KCOL)
      ENDDO
    ENDIF
    T(IROW,KCOL) = -XDOT_DC/T(IROW,JCOL)
    VLEN(KCOL) = VLEN(KCOL) + dble(T(IROW, KCOL))*dble(T(IROW,KCOL))
  ENDDO
ENDDO

Tricky stuff here!

DETNUM = int(mod(MLOCAL,4)/2.0)
C Necessary to do, but not easy to explain

IF (DETNUM.EQ.0.0) THEN
  IF (T(1,MLOCAL) .LT. 0.0) THEN
    T(2,MLOCAL-1) = -T(2,MLOCAL-1)
    T(2,MLOCAL) = -T(2,MLOCAL)
  ENDIF
ELSE
  IF (T(1,MLOCAL) .GT. 0.0) THEN
    T(2,MLOCAL-1) = -T(2,MLOCAL-1)
    T(2,MLOCAL) = -T(2,MLOCAL)
  ENDIF
ENDIF
RETURN
END

SUBROUTINE SETU(XU_SETU, IU_SETU, U_MIN, U_MAX, M)

IMPLICIT NONE
REAL*4 U_MAX(20), U_MIN(20)
INTEGER*4 IMODE, M
INTEGER*4 I, IU_SETU(20)
REAL*4 XU_SETU(20)

DO I = 1,M
  IF (IU_SETU(I) .EQ. 1) THEN
    XU_SETU(I) = U_MAX(I)
  ELSEIF (IU_SETU(I) .EQ.-1) THEN
    XU_SETU(I) = U_MIN(I)
  ELSE
    XU_SETU(I) = 0.
  ENDIF
ENDDO
RETURN
END

SUBROUTINE R20(U1, IU, INFRONT, ITHETA, NANGS, INDX, ISVERTEX, & B1, U_MAX, XU_MAX, U_MIN, U_MAX, TOL, M, DIAGS)

IMPLICIT NONE
REAL*4 U_MIN(20), U_MAX(20)
INTEGER*4 IMODE, ITHETA(21), IU, U_MAX(20), M, N, NANGS, SY
INTEGER*4 U1(20)
REAL*4 PIOVR2, B1(3,20), PI, XU(20), Y, XU_MAX(20)
REAL*4 INFRONT, TOL
REAL*4 THETA(21)
LOGICAL*4 ISVERTEX, DIAGS
INTEGER*4 INDX, SSY
INTEGER*4 I, J
REAL*4 ANG, YPREV, XU(20), K, Z, Z1, Z2

0913 DATA PIOVR2/1.570796326794897/
0914 DATA PI/3.141592653589793/
0915 C
0916 IF (DIAGS) THEN
0917 WRITE(*,':ASO') ' Entering R2C'
0918 WRITE(*,':ASO') ' Calling arguments'
0919 WRITE(*,'(A30,ES19.6)') ' R2C* B1(I,:)= ', (B1(I,:), I=1,M)
0920 WRITE(*,'(A30,ES19.6)') ' R2C* B1(2,:) = ', (B1(2,:), I=1,M)
0921 WRITE(*,'(A30,ES19.6)') ' R2C* B1(3,:) = ', (B1(3,:), I=1,M)
0922 WRITE(*,'(A30,13)') ' R2C* UMAX = ', (UMAX(I,:), I=1,M)
0923 WRITE(*,'(A30,ES19.6)') ' R2C* XUMAX = ', (XUMAX(I,:), I=1,M)
0924 WRITE(*,'(A30,ES19.6)') ' R2C* TOL = ', TOL
0925 WRITE(*,'(A30,13)') ' R2C* M = ', M
0926 ENDIF
0927 C
0928 C Calculate Y
0929 C
0930 Y = 0.0
0931 DO I = 1,M
0932 UI(I) = UMAX(I)
0933 Y = Y + B1(2,I)*XUMAX(I)
0934 ENDDO
0935 C VERTEX CHECK
0936
0937 ISVERTEX = .FALSE.
0938 IF (ABS(Y).LT.TOL) THEN
0939 Y = 0.
0940 Z = 0.
0941 DO I=1,M
0942 Z = Z+BI(3,I)*XUMAX(I)
0943 ENDDO
0944 IF (ABS(Z).LT.TOL) THEN
0945 WRITE(*,*) 'Z ',Z,
0946 ISVERTEX = .TRUE.
0947 IU = 0
0948 C
0949 INFRONT = 0.
0950 NANGS = 0
0951 RETURN
0952 ENDIF
0953 C END VERTEX CHECK
0954 C
0955 IF (ABS(Y).LT.TOL) THEN
0956 SY = 0
0957 ELSEIF (Y.LT.0.0) THEN
0958 SY = -1
0959 ELSE
0960 SY = 1
0961 ENDIF
0962 C
0963 IF (DIAGS) THEN
0964 WRITE(*,':ASO') ' First calculations'
0965 WRITE(*,'(A30,ES19.6)') ' R2C* Y = ', Y
0966 WRITE(*,'(A30,13)') ' R2C* SY = ', SY
0967 ENDIF
0968 C
0969 C Get the angle
IF (DIAGS) THEN
    WRITE(*,'(/A33)') ' Getting angles'
ENDIF

NANGS = 0
DO I=1, M
    ANG = ATAN2(-B1(1,I),B1(2,I))
    IF (ABS(ANG) .GT.PIOVR2) THEN
        IF (ANG.LT.0.) THEN
            ANG = ANG+PI
        ELSE
            ANG = ANG-PI
        ENDIF
    ENDIF
    NANGS = NANGS+I
    THETA(NANGS) = ANG
    ITHETA(NANGS) = I
    IF (DIAGS) THEN
        WRITE(*,' A30,_3,AZ0,Ei__.6 , )
    ENDIF
ENDDO

THETA and ITHETA now sorted by control number
Sort THETA by magnitude. ITHETA gets shuffled the same way

IF (DIAGS) THEN
    WRITE(*, ' A30) ') Before sorting'
    WRITE(*, ' :AS0, !3:, ' ' *R20 * .f_nG_ = , NANGS
    WRITE(*,' :A30,613) ') ' *R2C* :THETA
    ENDIF
CALL SORTC(THETA, ITHETA, NANGS,THETA, ITHETA)

IF (DIAGS) THEN
    WRITE(*, ' : A50) ') ' After sorting'
    WRITE(* ' A30,_3. ) ' *R20* NANGS
    WRITE(*,' A30,613) ') ' *R2C* :THETA
    ENDIF

C FIND INDEX OF ZERO
DO I=1,NANGS
    IF (THETA(I).GT.0.) THEN
        INDX = I
        DO J=NANGS,I,-I
            THETA(J+I) = THETA(J)
            ITHETA(J+I) = ITHETA(J)
        ENDDO
        THETA(I) = 0.
        ITHETA(I) = 0
        GOTO 193
    ENDIF
ENDDO
C CONTINUE
IF (DIAGS) THEN
  WRITE(*, '(/A50/)') ' After (nx=nx1)
  WRITE(*, 'A3C,13') ' R0C* INDX = ', INDX
  WRITE(*, 'A3C,13') ' R0C* THETA = ', (ITHETA(I), I=1,NANGS+1)
  WRITE(*, 'A3C,7E18.6') ' R0C* THETA = ', (THETA(I), I=1,NANGS+1)
ENDIF

CALL GETEDGE(U1, IU, INFRONT, ISVERTEX,
  & B1, UMAX, Y, SY, ITHETA, NANGS, U_MIN, U_MAX, INDX, TOL, M, DIAGS)

IF (DIAGS) THEN
  WRITE(*, '(/A50/)') ' Exiting RD0'
  WRITE(*, 'A3C,13') ' RD0* U1 = ', (U1(I), I=1,M)
  WRITE(*, 'A3C,13') ' RD0* IU = ', IU
  WRITE(*, 'A3C,13') ' RD0* INFRONT = ', INFRONT
  WRITE(*, 'A3C,13') ' RD0* ISVERTEX = ', ISVERTEX
ENDIF

RETURN
END

SUBROUTINE GETEDGE(U2, JU, INFRONT, ISVERTEX,
  & B1, UMAX, Y, SY, ITHETA, NANGS, U_MIN, U_MAX, INDX, TOL, M, DIAGS)
IMPLICIT NONE
INTEGER*4 M, SY, UMAX(20), INDX, NANGS, ITHETA(21)
REAL*4 B1(3,20), U_MAX(20), U_MIN(20), XU(20), Y
REAL*4 STUCK
INTEGER*4 I, J, I_COUNT, IX, ICOUNT, IX, I_COUNT
REAL*4 XK, XU2(20), Y_PREV, Z, Z1, Z2, SAVE_Y, MOM(3)

IF (DIAGS) THEN
  WRITE(*, '(/A50/)') ' Entering GETEDGE'
ENDIF

DO I=1,M
  U2(I) = I/MAX(I)
ENDDO
SAVE_Y = Y
IX = INDX-SY
SSY = SY
STUCK = .FALSE.

IF (DIAGS) THEN
  WRITE(*, '(/A50/)') ' Beginning GETEDGE EXECUTE'
  WRITE(*, 'A3C,13') ' GETEDGE* IX = ', (U2(I), I=1,M)
ENDIF
DO WHILE ((SY.EQ.SSY).AND.(IX.GT.0).AND.(IX.LE.NANGS))
   ICOUNT = ICOUNT+1
   YPREV = Y
   JU = ITHETA(IX)
   Y = Y-U2(JU)*B1(2, JU)*(U_MAX(JU)-U_MIN(JU))
   SSY = 1
   IF (Y.LT.0.0) SSY = -1
   IF (ABS(Y).LT.TOL) THEN
      Y = 0.
      SSY = 0
   ENDIF
   U2(JU) = -U2(JU)
   IF (SY.NE.0.) THEN
      IX = IX-SY
   ELSE
      IX = IX-1
   ENDIF
   ICOUNT = ICOUNT+1
   IF (ICOUNT.GT.20) STUCK = .TRUE.
   IF (DIAGS) THEN
      WRITE(*, ':A30,ELg.6 ') ' Bottom of GETEDGE DOWHILE'
      WRITE(*, ':A30,13 ') ' *GETEDGE* ICOUNT = ', ICOUNT
      WRITE(*, ':A30,13 ') ' *GETEDGE* STUCK = ', STUCK
      WRITE(*, ':A30,13 ') ' *GETEDGE* JU = ', JU
      WRITE(*, ':A30,13 ') ' *GETEDGE* Y = ', Y
      WRITE(*, ':A30,13 ') ' *GETEDGE* SSY = ', SSY
      WRITE(*, ':A30,13 ') ' *GETEDGE* SY.EQ.SSY = ', (SY.EQ.SSY)
      WRITE(*, ':A30,13 ') ' *GETEDGE* U2 = ', (U2(I), I=1, M)
      WRITE(*, ':A30,13 ') ' *GETEDGE* IX = ', IX
   ENDIF
   IF (STUCK) THEN
      PAUSE('Stuck in GETEDGE in DOWHILE')
      STUCK = .FALSE.
   ENDIF
ENDDO

IF (SY.EQ.SSY) THEN
   STUCK = .FALSE.
   ICOUNT = 0
   IF (DIAGS) THEN
      WRITE(*, ':A30 ') ' Beginning Alt. GETEDGE DOWHILE'
      WRITE(*, ':A30,613 ') ' *GETEDGE* U2 = ', (U2(I), I=1, M)
      WRITE(*, ':A30,614.6 ') ' *GETEDGE* SAVE_Y = ', SAVE_Y
      WRITE(*, ':A30,13 ') ' *GETEDGE* IX = ', IX
      WRITE(*, ':A30,13 ') ' *GETEDGE* SSY = ', SSY
      WRITE(*, ':A30,13 ') ' *GETEDGE* NANGS = ', NANGS
   ENDIF
ENDIF

Y = SAVE_Y
IX = INDX+SY
DO WHILE ((SY.EQ.SSY).AND.(IX.GT.0).AND.(IX.LE.NANGS+1))

YPREV = Y
JU = ITHETA(IX)
Y = Y-U2(JU)*B1(2,JU)*(U_MAX(JU)-U_MIN(JU))
SSY = 1
IF (Y.LT.0.0) SSY = -1
IF (ABS(Y).LT.TOL) THEN
  Y = 0.
  SSY = 0
ENDIF
U2(JU) = -U2(JU)
IF (SY.NE.0.) THEN
  IX = IX+SY
ELSE
  IX = IX+I
ENDIF
ICOUNT = ICOUNT+I
IF (ICOUNT.GT.20) STUCK = .TRUE.
IF (DIAGS) THEN
  WRITE(*,'(A30,I3)') 'Bottom of Alt. GETEDGE DO WHILE'
  WRITE(*,'(A30,I3)') 'GETEDGE* ICOUNT = ', ICOUNT
  WRITE(*,'(A30,I3)') 'GETEDGE* STUCK = ', STUCK
  WRITE(*,'(A30,E12.6)') 'GETEDGE* YPREV = ', YPREV
  WRITE(*,'(A30,I3)') 'GETEDGE* JU = ', JU
  WRITE(*,'(A30,E12.6)') 'GETEDGE* Y = ', Y
  WRITE(*,'(A30,I3)') 'GETEDGE* SSY = ', SSY
  WRITE(*,'(A30,E12.6)') 'SY.EQ.SSY = ', (SY.EQ.SSY)
  WRITE(*,'(A30,E12.6)') 'U2 = ', (U2(I), I=1,M)
  WRITE(*,'(A30,E12.6)') 'IX = ', IX
ENDIF
IF (STUCK) THEN
  PAUSE('Stuck in GETEDGE in Alt. DO WHILE')
ENDIF

XK = YPREV/(YPREV-Y)
CALL SETU(XU2, U2, U_MIN, U_MAX, M)

Z2 = 0.
DO I=1,M
  Z2 = Z2+B1(3,I)*XU2(I)
ENDDO
Z1 = Z2-U2(JU)*B1(3,JU)*(U_MAX(JU)-U_MIN(JU))
Z = XK*Z2 + (1.-XK)*Z1

IF (Z.LT.0.) INFRONT = -1.

ISVERTEX = ((Y.EQ.0.) .AND. (ABS(Z) .LT.TOL))

IF (DIAGS) THEN
  WRITE(*,'(A9,2)')
  WRITE(*,'(A35,61)')
  WRITE(*,'(A_0,6F14.6)')
  WRITE(*,'(A_C,13)')
  WRITE(*,'A30,E18.6]')
  WRITE(*,'A0,13')
  RETURN
END

SUBROUTINE ISFACET(ISOK, IUOUT, JUOUT, U123, & IU, JU, U1, U2, B, M, TOL)
IMPLICIT NONE
LOGICAL*4 ISOK
INTEGER*4 IU, JU, M, UI(20), U2(20), IUOUT, JUOUT, U123(20,3)
REAL*4 B(3,20), TOL

INTEGER*4 UXI(20), UX2(20), I, J, K, II, JJ, K, KK
REAL*4 THEMAT(2,2), MATINV(2,2), MATDET, T2(2), TI(3), TESTFACET(20)
REAL*4 TEMP
INTEGER*4 DIM, OBJ(20), UDEF(20), ITF(20), THEOBJ(20)

ISOK = .FALSE.
DO I=1,M
  UX1(I) = U1(I)
  UX2(I) = U2(I)
ENDDO
U1(IU) = 0
U2(JU) = 0
DIM = 0
DO I = 1,M
  OBJ(I) = U1(I)
  IF ((I.EQ.IU) .OR. (I.EQ.JU) .OR. (U2(I) .NE.U1(I))) THEN
    OBJ(I) = 0
    DIM = DIM + 1
    UDEF(DIM) = I
  ENDIF
ENDDO
IF (DIM.EQ.2) THEN
  ISOK = .TRUE.
DO II=1,3
   JJ = MOD(II,3) + 1
   KK = MOD(JJ,3) + 1
   THEMAT(1,1) = B(II,UDEF(1))
   THEMAT(1,2) = B(JJ,UDEF(1))
   THEMAT(2,1) = B(II,UDEF(2))
   THEMAT(2,2) = B(JJ,UDEF(2))
   MATDET = THEMAT(1,1)*THEMAT(2,2) - THEMAT(1,2)*THEMAT(2,1)
   IF (MATDET.NE.0.) THEN
      MATINV(1,1) = THEMAT(2,2)/MATDET
      MATINV(1,2) = -THEMAT(1,2)/MATDET
      MATINV(2,1) = THEMAT(1,1)/MATDET
      MATINV(2,2) = THEMAT(1,1)/MATDET
      T2(1) = -MATINV(1,1)*B(KK,UDEF(1)) - MATINV(2,1)*B(KK,UDEF(2))
      T2(2) = -MATINV(2,1)*B(KK,UDEF(1)) - MATINV(2,2)*B(KK,UDEF(2))
      T1(KK) = 1.
      T1(JJ) = T2(1)
      T1(JJ) = T2(2)
   DO I=I,M
      TESTFACET(I) = 0.
      ITF(I) = 0
      UDEF(I) = 0
   DO J=1,3
      TESTFACET(I) = TESTFACET(I) + T1(J)*B(J,I)
   END DO
   IF (ABS(TESTFACET(I)).LT.TOL) THEN
      ITF(I) = 0
   ELSEIF (TESTFACET(I).GT.0.) THEN
      ITF(I) = 1
   ELSEIF (TESTFACET(I).LT.0.) THEN
      ITF(I) = -1
   END IF
   ENDDO
   DIM = 0
   DO I=I,M
      THEOBJ(I) = OBJ(I)
      IF ((OBJ(I).EQ.0) .OR. (ITF(I).EQ.0) .OR. (ITF(I).NE.OBJ(I))) THEN
         THEOBJ(I) = 0
         DIM = DIM + 1
         UDEF(DIM) = I
      ENDIF
   END DO
   IF (DIM.NE.2) THEN
      DIM = 0
      J = 0
      DO I=1,M
         THEOBJ(I) = OBJ(I)
         IF ((OBJ(I).EQ.0) .OR. (ITF(I).EQ.0) .OR. (-ITF(I).NE.OBJ(I))) THEN
            THEOBJ(I) = 0
            DIM = DIM + 1
            UDEF(DIM) = I
         ENDIF
      END DO
   ENDIF
   ENDIF
IF (DIM.NE.2) ISOK = .FALSE.
GOTO 194
ENDIF ! IF (MATDET.NE.0.) THEN
ENDDO ! DO II=1,3
CONTINUE
ENDIF ! IF (DIM.EQ.2)

IF (ISOK) THEN
IUOUT = UDEF(1)
JUOUT = UDEF(2)
DO I=1,M
DO J=1,3
   U123(I,J) = OBJ(I)
ENDDO
ENDDO
U123(IUOUT,1) = 1
U123(JUOUT,1) = 1
U123(IUOUT,2) = -1
U123(JUOUT,2) = 1
U123(IUOUT,3) = 1
U123(JUOUT,3) = -1
ELSE
IUOUT = 0
JUOUT = 0
DO I=1,M
   DO J=1,3
      U123(I,J) = 0
   ENDDO
ENDDO
ENDIF

RETURN
END

SUBROUTINE SORTC(X, IY,N,XS,IYC)
IMPLICIT NONE
INTEGER*4 I, IL SORTC(36), IMED, IPI, IPR, ITY, IU SORTC(36)
INTEGER*4 IY(20), IYC(20), J, JMI, JMK, K, L, LMI, M, MID, N
INTEGER*4 NMI
REAL*4 HOLD, AMED, TX, X(20), XS(20)

CHECK THE INPUT ARGUMENTS FOR ERRORS
IPR=II
IF(N.LT.I)GOTO50
IF(N.EQ.I)GOTO55
HOLD=X(1)
DO60I=2,N
   IF(X(I) .NE.HOLD)GOTO90
60 CONTINUE
WRITE(*, 9) HOLD
DO61I=1,N
XS(I)=X(I)
IYC(I)=IY(I)
61 CONTINUE
RETURN
50 WRITE(*,15)
WRITE(*,47)N
50 RETURN
55 WRITE(*,18)
XS(1)=X(1)
IYC(1)=IY(1)
RETURN
90 CONTINUE
5 FORMAT(IX , '**** NON-FATAL DIAGNOSTIC--THE FIRST INPUT ARGUMENT
INT A VECTOR) TO THE SORTC SUBROUTINE HAS ALL ELEMENTS = '.E15.8,
1 *****')
15 FORMAT(IX , '**** FATAL ERROR--THE SECOND INPUT ARGUMENT TO THE
SORTC SUBROUTINE IS NON-POSITIVE *****')
18 FORMAT(IX , '**** NON-FATAL DIAGNOSTIC--THE SECOND INPUT ARGUMENT
INT TO THE SORTC SUBROUTINE HAS THE VALUE I *****')
47 FORMAT(IX , '**** THE VALUE OF THE ARGUMENT IS ',I8 , ' *****')
C
---START POINT-----------------------------------------------
COPY THE VECTOR X INTO THE VECTOR XS
DO100I=1,N
XS(I)=X(I)
100 CONTINUE
COPY THE VECTOR IY INTO THE VECTOR IYC
DO150I=1,N
IYC(I)=IY(I)
150 CONTINUE
CHECK TO SEE IF THE INPUT VECTOR IS ALREADY SORTED
NM1=N-1
DO200I=1,NM1
IP1=I+1
IF(XS(I).LE.XS(IP1))GOTO200
GOTO250
200 CONTINUE
RETURN
3 FORMAT(IX , '**** THE SECOND INPUT ARGUMENT TO THE
SORTC SUBROUTINE HAS THE VALUE I *****')
47 FORMAT(IX , '**** THE VALUE OF THE ARGUMENT IS ',I8 , ' *****')
C
---START POINT-----------------------------------------------
COPY THE VECTOR X INTO THE VECTOR XS
DO100I=1,N
XS(I)=X(I)
100 CONTINUE
COPY THE VECTOR IY INTO THE VECTOR IYC
DO150I=1,N
IYC(I)=IY(I)
150 CONTINUE
CHECK TO SEE IF THE INPUT VECTOR IS ALREADY SORTED
NM1=N-1
DO200I=1,NM1
IP1=I+1
IF(XS(I).LE.XS(IP1))GOTO200
GOTO250
200 CONTINUE
RETURN
3 FORMAT(IX , '**** THE SECOND INPUT ARGUMENT TO THE
SORTC SUBROUTINE HAS THE VALUE I *****')
47 FORMAT(IX , '**** THE VALUE OF THE ARGUMENT IS ',I8 , ' *****')
IYC(I) = IMED
AMED = XS(MID)
IMED = IYC(MID)

320 L = J
IF (XS(J) .GE. AMED) GOTO 340
XS(MID) = XS(J)
IYC(MID) = IYC(J)
XS(J) = AMED
IYC(J) = IMED

IF (XS(I) .LE. AMED) GOTO 340
XS(MID) = XS(I)
IYC(MID) = IYC(I)
XS(I) = AMED
IYC(I) = IMED
AMED = XS(MID)
IMED = IYC(MID)

GOTO 340

330 XS(L) = XS(K)
IYC(L) = IYC(K)
XS(K) = TX
IYC(K) = ITY

340 L = L - I
IF (XS(L) .GT. AMED) GOTO 340
TX = XS(L)
ITY = IYC(L)

350 K = K + 1
IF (XS(K) .LT. AMED) GOTO 350
IF (K .LE. L) GOTO 330
LMI = L - I
JMK = J - K
IF (LMI . LE. JMK) GOTO 360
IL_SORTC(M) = I
IU_SORTC(M) = L
I = K
M = M + 1
GOTO 380

360 IL_SORTC(M) = K
IU_SORTC(M) = J
M = M - 1
GOTO 380

370 M = M - 1
IF (M .EQ. 0) RETURN
I = IL_SORTC(M)
J = IU_SORTC(M)

380 JMI = J - I
IF (JMI .GE. I) GOTO 310
IF (I .EQ. I) GOTO 305
I = I - I
M = M + 1
GOTO 370

390 I = I + 1
IF (I .EQ. J) GOTO 370
AMED = XS(I + 1)
IMED = IYC(I + 1)
IF (XS(I) .LE. AMED) GOTO 390
K = I
1483 \[ XS(K+1) = XS(K) \]
1484 \[ IYC(K+1) = IYC(K) \]
1485 \[ K = K - 1 \]
1486 \[ \text{IF (AMED.LT.XS(K)) GOTO 395} \]
1487 \[ XS(K+1) = AMED \]
1488 \[ IYC(K+1) = IMED \]
1489 \[ \text{GOTO 390} \]
1490
1491 \[ \text{RETURN} \]
1492 \[ \text{END} \]
1493
1494
1495 
1496 \[ \text{SUBROUTINE MINNORM(UMINNORM, SCALE,} \]
1497 \[ \text{& P, U, UTRIM, MTRIM, UDA, B, U_MIN, U_MAX, M, TIME, XSCALE)} \]
1498
1499 \[ \text{IMPLICIT NONE} \]
1500 \[ \text{** Parameters} \]
1501 \[ \text{** Parameters} \]
1502
1503 \[ \text{** INPUTS:} \]
1504 \[ \text{REAL*4 P(20,3), U(20), UTRIM(20), UDA(20)} \]
1505 \[ \text{REAL*4 B(3,20), MTRIM(3), U_MAX(20), U_MIN(20)} \]
1506 \[ \text{REAL*4 TIME, XSCALE} \]
1507 \[ \text{INTEGER*4 M, IMODE} \]
1508 \[ \text{** OUTPUTS:} \]
1509 \[ \text{REAL*4 UMINNORM(20), SCALE} \]
1510 \[ \text{** LOCALS:} \]
1511 \[ \text{REAL*4 UKDA(20), UP(20), UDELTA(20), M_ATT(3)} \]
1512 \[ \text{INTEGER*4 I, J, K} \]
1513 
1514 \[ \text{SCALE = 1.} \]
1515 \[ \text{DO I=1,M} \]
1516 \[ \text{UKDA(I) = U(I) + UDA(I)} \]
1517 \[ \text{ENDDO} \]
1518 \[ \text{DO I=1,3} \]
1519 \[ \text{M_ATT(I) = 0.} \]
1520 \[ \text{DO J=1,M} \]
1521 \[ \text{M_ATT(I) = M_ATT(I) + B(I,J)*UKDA(J)} \]
1522 \[ \text{ENDDO} \]
1523 \[ \text{ENDDO} \]
1524 \[ \text{DO I=1,M} \]
1525 \[ \text{IF ((U_MIN(I).EQ.0.) .OR. (U_MAX(I).EQ.0.)) SCALE = 0.} \]
1526 \[ \text{UKDA(I) = U(I) + UDA(I)} \]
1527 \[ \text{UP(I) = UTRIM(I)} \]
1528 \[ \text{DO J=1,3} \]
1529 \[ \text{UP(I) = UP(I) + P(I,J) *(M_ATT(J)-MTRIM(J))} \]
1530 \[ \text{ENDDO} \]
1531
UDELTA(I) = SCALE*(UP(I)-UKDA(I))

IF (UDELTA(I).NE.0.) THEN
  IF ((UDELTA(I).GT.U_MAX(I)).AND.(U_MAX(I).GT.0.)) THEN
    SCALE = U_MAX(I)/UDELTA(I)
  ELSEIF ((UDELTA(I).LT.U_MIN(I)).AND.(U_MIN(I).LT.0.)) THEN
    SCALE = U_MIN(I)/UDELTA(I)
  ENDIF
ENDIF
ENDDO

SCALE = XSCALE*SCALE

DO I=1,M
  UMINNORM(I) = UKDA(I) + SCALE*(UP(I)-UKDA(I))
ENDDO

RETURN
END