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NUMERICAL SOLUTION FOR THE TEMPERATURE DISTRIBUTION IN
A COOLED GUIDE VANE BLADE OF A RADIAL GAS TURBINE

BY

W. Hosny and W. Tabakoff

Supported by:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Contract No. NAS2-7850
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A two-dimensional finite-difference numerical technique is presented to determine the temperature distribution of an internal cooled blade of radial turbine guide vanes.

A simple convection cooling is assumed inside the guide vane blade. Such cooling has relatively small cooling effectiveness at the leading edge and at the trailing edge. Heat transfer augmentation in these critical areas may be achieved by using impingement jets and film cooling.

A computer program is written in Fortran IV for IBM 370/165 computer.
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SUMMARY

A two-dimensional finite-difference numerical technique is presented to determine the temperature distribution of an internal cooled blade of radial turbine guide vanes.

A simple convection cooling is assumed inside the guide vane blade. Such cooling has relatively small cooling effectiveness at the leading edge and at the trailing edge. Heat transfer augmentation in these critical areas may be achieved by using impingement jets and film cooling.

A computer program is written in Fortran IV for IBM 370/165 computer.
INTRODUCTION

In a turbomachine, performance benefits could be achieved with high turbine inlet temperature and high pressure ratio. Efficient expansion from a high pressure requires more than one axial turbine, of which the first one may become exceedingly small. Large tip clearance, thick trailing edge and secondary losses in such small turbines tend to offset the advantages of high inlet temperatures. On the other hand, the small radial turbine has demonstrated an excellent performance at high stage loadings. The power output of a gas turbine is directly proportional to the inlet temperature of the combustion gases. Certainly, higher inlet temperatures are desired in order to achieve higher output. In recognition of this, researchers have devoted considerable efforts to the development of higher temperature blade materials and efficient methods of cooling.

Radial turbine rotor cooling is accomplished by using cooling air passages through each rotor blade. The cooling air is then exhausted at the blade suction surface. The guide vane blades are internally cooled by streams of cooling air which after having cooled the vanes is ejected into the primary gas stream. In general, the different cooling techniques used for axial flow turbines, could be applied as well for radial turbines. For modest increases in turbine inlet temperature, simple convection cooled blades may be used. As further increases in the temperatures are required, the engine designer must use impingement cooling and film cooling techniques. Very high cycle temperature requires consideration of transpiration cooled blades.

Oxidation and thermal creep are forms of failure in turbines with high inlet temperatures. The guide vanes are more exposed to failure by local oxidation than creep and hence are highly influenced by local hot spots. Such areas are usually localized at the leading and trailing edges. A theoretical method for estimating the temperature distribution inside the cooled guide vane blade, using simple convection cooling effectiveness will be presented.
GUIDE VANE COOLING

A radial guide vane does not usually experience a high spanwise temperature gradient at its inlet. In addition, the heat conducted to the two guide vane back plates is also negligible. Therefore, a two dimensional solution for the temperature distribution is acceptable.

The isotherm lines in an uncooled radial guide vane blade are shown in Figure 1 (taken from Ref. 1). In the vicinity of the leading edge, the material temperature is very close to the gas temperature. The blade temperature drops toward the trailing edge. The high temperature at the leading edge region is the result of the high heat transfer coefficient near the stagnation point.

The convection cooling requirements can be determined by considering the blades as heat exchangers and evaluating the heat capacity of the cooling air flow through the vanes. Such analysis will require the solution of the heat conduction equation within the material combined with the heat balance equation for the cooling air.

Obtaining solutions for the heat conduction equation pose some difficulties due to the irregular shape of the vane blade boundary, and the variations in the temperature and the heat transfer coefficient around the surface. Due to the above circumstances, it is necessary to resort to a numerical solution. A finite difference technique similar to Reference 1 will be used. Modification to account for the cooling passage has been introduced.

Convective heat transfer coefficient on both the inner and the outer sides of the blade surface can be estimated theoretically as follows:

Hot gas side heat transfer coefficient (outside the blade):

The heat transfer coefficient could be obtained from the boundary layer characteristics around the guide vane blade. The boundary layer solution is obtained by using the computer program written by Herring and Mellor (Ref. 2). The velocity distribution needed for the boundary layer calculations is determined using the computer program given by Katsanis (Ref. 3), assuming
that the amount of heat transferred to the coolant from the hot gases will not affect the flow behavior around the blade. The heat transfer coefficient is then determined using the Reynolds analogy. Figures 2, 3 and 4 show respectively the gas velocity, temperature and heat transfer coefficient distribution on the outside surface of the guide vane blade.

Cooling side heat transfer coefficient (inside the vane):

The cooling air passes usually through axial hole passages of constant area, large enough to ensure turbulent flow. Thus the heat transfer coefficient for simple convection cooling could be estimated from the conventional formula given in Reference 4,

\[ \text{Nu} = 0.02 \text{Re}^{0.8} \frac{T_S}{T_C}^{0.45} \]

where

\[ \text{Nu} = \frac{hD}{k}, \quad \text{Re} = \frac{pVD}{\mu} \]

\( T_S \) is the material temperature on the cooling side surface

\( D \) is the hydraulic diameter of the cooling passage.

For other patterns of cooling the heat transfer correlation for flow between plates could be used, which is given as:

\[ \text{Nu} = 0.014 \text{Re}^{0.81} \]

If impingement cooling is used, the semi empirical correlation, given in Reference 5 could be used to determine the convective heat transfer coefficient.

**GOVERNING EQUATIONS AND FINITE DIFFERENCES**

In the rectangular coordinate system, the differential equation governing the steady state two dimensional temperature distribution is given by

\[ \frac{3}{3x} (k \frac{3T}{3x}) + \frac{3}{3y} (k \frac{3T}{3y}) = 0 \]  \( (1) \)

In the above equation it is assumed that there is no heat generation in the blade body. Further simplifications could
result by assuming constant thermal conductivity, corresponding to the vane blade average temperature. Consequently, the heat equation could be reduced to:

\[
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0
\]  

(2)

The heat balance equation written at a point on the outside surface is:

\[k \frac{\partial T}{\partial n} = h_g (T_g - T_s)\]  

(3)

where \(n\) is the normal to the blade surface at the point under consideration.

The heat balance equation at the blade inner surface is given by

\[k \frac{\partial T}{\partial n} = h_c (T_c - T_s)\]  

(4)

Equation (2) is an elliptic equation, the boundary conditions are given by Equations (3) and (4). Each boundary condition relates the temperature gradient normal to the surface to the local surface temperature. Such boundary conditions are of the Fourier type, relating the local heat transfer to the temperature on the boundary.

To solve equation (2), one has to use either finite difference or finite element technique. In this study the first approach is used to obtain the solution. For any grid point \(P\), as shown in Figure 5, the partial differential equation (2) can be written in the finite difference form in terms of the temperatures at the points A, B, C, D and \(P\). The points A and C are located at \(\varepsilon_1, \varepsilon_2\) fractions of \(DX\), while the points B and D are located at \(\delta_1, \delta_2\) fractions of \(DY\) from the mesh point \(P\). For equally spaced grid points, the factors \(\varepsilon_1, \varepsilon_2, \delta_1\) and \(\delta_2\) will be equal to 1.0. The finite difference equation is given by:
\[
\frac{2}{\Delta X^2 (\varepsilon_1 + \varepsilon_2)} \left[ \frac{T_{i-1,j}}{\varepsilon_1} - T_{i,j} \left( \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} \right) + \frac{T_{i+1,j}}{\varepsilon_2} \right] \\
+ \frac{2}{\Delta Y^2 (\delta_1 + \delta_2)} \left[ \frac{T_{i,j-1}}{\delta_1} - T_{i,j} \left( \frac{1}{\delta_1} + \frac{1}{\delta_2} \right) + \frac{T_{i,j+1}}{\delta_2} \right] = 0
\]

which could be written in a more convenient form as:

\[
T_{i,j} = \frac{1}{E} \left\{ \frac{T_{i-1,j}}{\varepsilon_1 (\varepsilon_1 + \varepsilon_2)} + \frac{T_{i,j+1}}{\varepsilon_2 (\varepsilon_1 + \varepsilon_2)} \right\} + \left( \frac{\Delta X}{\Delta Y} \right)^2 \left[ \frac{T_{i,j-1}}{\delta_1 (\delta_1 + \delta_2)} + \frac{T_{i,j+1}}{\delta_2 (\delta_1 + \delta_2)} \right] 
\]

where

\[
E = \left[ \frac{1}{\varepsilon_1 \varepsilon_2} + \left( \frac{\Delta X}{\Delta Y} \right)^2 \frac{1}{\delta_1 \delta_2} \right] 
\]

The above equations are second order accurate when \( \delta_1 = \delta_2 \) and \( \varepsilon_1 = \varepsilon_2 \).

At the blade boundary points, such as the point D shown in Figure 6, the convective boundary condition given by Equation (3) or (4) could be written in the following finite difference form:

\[
\frac{\partial T}{\partial n} = \frac{T_D - T_N}{\Delta N} = \frac{h_{g,c}}{k} (T_{g,c} - T_D)
\]

i.e.

\[
T_D = \frac{T_N + \frac{h_{g,c}}{k} \frac{\Delta N}{\Delta N} T_{g,c}}{1 + \frac{h_{g,c}}{k} \Delta N}
\]

where

- \( T_D \) is the material temperature at the inner or outer surface point D;
- \( T_N \) is the material temperature at the interior point N;
- and \( g,c \) are subscripts for gas or cooling flow.

Solution of Equation (6) along with Equation (9) using suitable iteration technique would give the temperature distribution in the internally cooled blade.
COMPUTER PROGRAM

The details of the input to the computer program are given in Appendix A. Initially, the temperature matrix \( T \) is set to any conveniently chosen temperature. The iteration then proceeds using the Gauss-Seidel method. Temperatures at the interior points are calculated by subroutine "MESH", while boundary point temperatures are calculated in the main program. Referring to Figure 7, the calculation of the boundary temperatures proceed for each of the I lines and then in a similar manner for each of the J lines. The iteration process is repeated until the sum of the squares difference between two successive iterations is less than a prescribed value,

\[
\sum_{\text{all points}} (T_N - T_{N-1})^2 \leq \varepsilon
\]

i.e.

\[
\sum_{\text{all points}} (T_N - T_{N-1})^2 \leq \varepsilon
\]  

Where \( T_N \) is the temperature after the \( N \) iteration; 
\( T_{N-1} \) is the temperature after the \( (N-1) \) iteration; 
and \( \varepsilon \) is the prescribed error limit.

The process of convergence could be accelerated by using an over-relaxation factor, \( \omega \), in the following formula:

\[
T_N = \omega T_N' + (1 - \omega)T_{N-1}
\]  

(11)

Where \( T_{N-1} \) is the temperature after \( (N-1) \) iterations; 
\( T_N' \) is the temperature computed after \( N \) iterations; 
\( \omega \) is the over-relaxation factor; 
\( T_N \) is the temperature used for the \( (N+1) \) iteration.

The optimum over-relaxation factor is determined from different trials. Figure 8 gives the variation in the number of iterations, needed for certain convergence limit, with the relaxation factor. The number of iterations is significantly reduced from 440 at \( \omega = 1.0 \) to about 140 for \( \omega = 1.6 \).

After the final iteration, all the temperatures at the grid points are printed and the isothermals are found by linear interpolation.
The computer program could be used for simple internal cooling. It can also be used for internal cooling with jet impingement. For film cooling, the program can be used after some modifications to include the dimensions and configuration of the injection slots.

RESULTS AND DISCUSSION

The turbine blade and the grid network used in these calculations are shown in Figure 7. The blade inner and outer boundary surface coordinates and its material properties are given in Table I.

The velocity, temperature and heat transfer coefficient distribution on the outer surface are shown in Figures 2, 3 and 4 respectively. The heat transfer coefficient on the inner surface was determined for cooling air to hot gas mass flow ratio of two percent. These different data are used as input to the computer program to calculate the blade material temperature distribution. The program is listed in Appendix C and is written in FORTRAN IV for an IBM 370/165 computer.

A sample output of the program is given in Appendix B. The coordinates of the boundary points through which a least square parabolic curve is fitted are printed in the output. This serves as a check on the program input parameters. The mean square average error is also printed for every iteration, making it possible to monitor the convergence process. After the final iteration, the internal grid temperatures and the surface temperatures are printed as well as the isothermal lines coordinates.

The isothermal lines for the guide vane blade with single central cooling passages are shown in Figure 9. The difference between the maximum and minimum blade temperature was around 400°C. The thermal performance of the cooled guide vane blades can be described by evaluating the surface local cooling effectiveness. The cooling effectiveness on a surface point is defined as:

\[ \eta = \frac{T_g - T_s}{T_g - T_c} \]
Figure 10 shows the cooling effectiveness distribution along the blade surface length, for the convex and concave surfaces of the guid vane blade. It is clear that simple convection cooling has relatively small cooling effectiveness at the leading and trailing edges. In these areas other cooling methods have to be used if high local metal temperatures are to be avoided. At the leading edge, the cooling can be enhanced by application of jet impingement to provide high local cooling heat transfer coefficient. A cooling improvement may be achieved at the trailing edge by using film cooling. It can thus be concluded that simple convection cooling is only a primary means of cooling radial guide vanes, it must be enhanced by film cooling slots and impingement jets in critical areas.
REFERENCES


NOMENCLATURE

D  Hydraulic diameter
A,B,C,D  Points indicated in Figure 5
DN  Distance along normal to surface of blade (Figure 3) (inches)
DX  Grid spacing in x direction (inches)
DY  Grid spacing in y direction (inches)
E  Constant defined by Equation (7)
h  Heat transfer coefficient ($\frac{\text{Btu}}{\text{hr \ in}^2 \ ^\circ\text{F}}$)
I  Grid line numbers in x direction
J  Grid line numbers in y direction
k  Thermal conductivity of material of the blade ($\frac{\text{Btu}}{\text{hr \ in}^2 \ ^\circ\text{F}}$)
n  Normal direction to the blade surface
Nu  Nusselt Number
P  A point of grid structure as in Figure 5
Re  Reynolds number of the flow inside cooling passage.
T  Temperature
V  Velocity inside the cooling passage
X  X-coordinate
Y  Y-coordinate
$\rho$  Density of cooling air
$\delta_1$  Fraction of grid spacing for point B in Figure 5
$\delta_2$  Fraction of grid spacing for point D in Figure 5
$\zeta_1$  Fraction of grid spacing for point A in Figure 5
$\zeta_2$  Fraction of grid spacing for point C in Figure 5
$\epsilon$  Error term as defined in Equation (10)
**Subscripts:**

<table>
<thead>
<tr>
<th>Subscript</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Cooling air</td>
</tr>
<tr>
<td>D</td>
<td>Corresponds to boundary point in Figure 6</td>
</tr>
<tr>
<td>g</td>
<td>Corresponds to gas</td>
</tr>
<tr>
<td>i,j</td>
<td>Mesh line numbers in x and y directions</td>
</tr>
<tr>
<td>N</td>
<td>Corresponds to the point where normal to the boundary at D cuts the mesh line AP (Figure 6)</td>
</tr>
<tr>
<td>S</td>
<td>Surface</td>
</tr>
</tbody>
</table>
TABLE I

PARTICULARS OF RADIAL TURBINE NOZZLE BLADE:

Leading edge Radius = 0.0815 in
Trailing edge Radius = 0.0157 in
c = 1.94 in

Thermal conductivity = 12 \( \text{Btu} \)
\( \text{hr ft} \ ^\circ \text{F} \)

Boundary points:

<table>
<thead>
<tr>
<th>X in</th>
<th>Y (Lower) in</th>
<th>Y (Upper) in</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.1</td>
<td>0.028</td>
<td>0.180</td>
</tr>
<tr>
<td>0.2</td>
<td>0.025</td>
<td>0.203</td>
</tr>
<tr>
<td>0.4</td>
<td>0.068</td>
<td>0.233</td>
</tr>
<tr>
<td>0.6</td>
<td>0.105</td>
<td>0.249</td>
</tr>
<tr>
<td>0.8</td>
<td>0.133</td>
<td>0.255</td>
</tr>
<tr>
<td>1.0</td>
<td>0.148</td>
<td>0.250</td>
</tr>
<tr>
<td>1.2</td>
<td>0.155</td>
<td>0.238</td>
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<tr>
<td>1.4</td>
<td>0.147</td>
<td>0.215</td>
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<tr>
<td>1.6</td>
<td>0.127</td>
<td>0.183</td>
</tr>
<tr>
<td>1.8</td>
<td>0.100</td>
<td>0.143</td>
</tr>
<tr>
<td>1.94</td>
<td>0.100</td>
<td>0.100</td>
</tr>
</tbody>
</table>

DX = 0.050 in ; DY = 0.025 in
FIGURE 1. ISOTHERMAL LINES IN THE UNCOOLED BLADE.
FIGURE 2 VELOCITY DIST. AROUND THE BLADE
FIGURE 3. STATIC GAS TEMPERATURE DISTRIBUTION AROUND THE BLADE.
FIGURE 4  HEAT TRANSFER COEFF. AROUND THE BLADE
FIGURE 5 GENERAL GRID POINT WITH UNEQUAL SPACINGS

FIGURE 6 POINTS ON A BOUNDARY
FIGURE 7 BLADE GRID NETWORK
FIGURE 8 VARIATION OF NUMBER OF ITERATIONS WITH $\omega$
Temperatures in Degrees Rankine

\[ T_{ci} = \text{Initial Temperature of the Coolant} = 1400 \]

\[ T_{cs} = \text{Temperature of the Coolant at the Vane Cross-section} = 1400 \]

**FIGURE 9** NOZZLE VANE TEMPERATURE DISTRIBUTION WITH 3% COOLANT
FIGURE 10. EFFECTIVENESS OF COOLING ON BLADE SURFACES WITH 3% COOLANT
APPENDIX A

PROGRAM INPUT
This computer program is an extension of the solid blade program of Reference 1. The blade is drawn in the grid network such that there are no multiple intersection points, i.e. each grid line has no more than two intersections with the outer boundary. The blade also has to be drawn, such that I = 1 line is tangential to the blade.

In order to read the coordinates of the boundary points at the grid line intersections, they are numbered in a counterclockwise direction starting from any arbitrary point of intersection on the boundary as shown in Figure 7. In this figure the numbering is shown only for the outer boundary; a similar procedure can be followed for the inner boundary points. In case a vertical and a horizontal grid line intersect with the boundary at the same point, that point is given only one number.

Input for the computer program:

The input to the program consists of four main parts:
1. Physical parameters for the grid system and the blade.
2. Blade outer and inner boundary points.
4. Heat transfer coefficients on the outer and the inner boundary surfaces.

The first part of the input consists of the following items:

DX, DY, XK, OME, SUMM, NX, NY, N1, N2, N3, N4, IMAX, NTE, NXO, NXI. These items are specified according to the format 5F5.3, 6I2, 4I3, and are explained below:

DX:  The grid spacing in the x-direction (inches).
DY:  The grid spacing in the y-direction (inches).
XK:  Thermal conductivity of the blade material (Btu/hr.in.°F).
OME: Relaxation factor (If not known, use the value 1.0).
NX:  The total number of mesh lines in x-direction (≤ 40).
NY:  The total number of mesh lines in y-direction (≤ 25).
N1, N2 I mesh lines enclosing the blade inner hole without intersecting it; see Figure 7. In case of solid blade put N1 = N2 = NX.
N3, N4: J mesh lines enclosing the blade inner hole without intersecting it. In case of solid blade put N3 = N4 = NY.

IMAX: Maximum number of iterations allowed.

NTE: Number of iterations after which a print out of the results is required.

NXO: Total number of mesh lines intersections with the outer boundary. (< 120).

NXI: Total number of mesh lines intersections with the inner boundary. (< 120).

The second part of the input read in the blade inner and outer boundary coordinates. The Y1(I) array, corresponding to Y coordinates of the intersections of the I mesh lines with the lower surface of outer boundary are read according to 12F6.3 FORMAT. The next set is IP(I) point numbers (which are the sequence numbers for Y1(I) points), these are read according to 20I4 FORMAT. Similar values are read for upper surface of outer boundary, namely Y2(I) and IP(I). Then the X1(J) arrays, corresponding to the X coordinates of the points of intersection of the outer J mesh lines with the outer boundary (12F6.3). The next set is IP(J) numbers corresponding to these points. The arrays X2(J), IP(J) correspond to the second intersections of J lines with the outer boundary. All the previous coordinate sets are for the outer boundary. The inner boundary coordinates are defined in a similar manner as follows:

Y3(I), IP(I) Lower surface of inner boundary
Y4(I), IP(I) Upper surface of inner boundary
X3(J), IP(J) Near surface of inner boundary (first intersection)
X4(J), IP(J) Farther surface of inner boundary (second intersection)

In case of a solid blade N1 = N2 and N3 = N4, this last input part should be omitted.
The third part of the input specifies the surface gas temperatures (°R) in the following order:

**TG(I,1):** Gas temperature at the intersection points of the I mesh line with the lower surface of the outer blade boundary.

**TG(I,2):** Gas temperature at the intersection points of the I mesh lines with the upper surface of the outer blade boundary.

**TGX(1,J):** Gas temperature at the first intersection points of the J mesh lines with the surface of the blade outer boundary.

**TGX(2,J):** Gas temperature at the second intersection points of the J mesh lines with the surface of the blade outer boundary.

The gas temperature distribution on the inner boundary are defined in a similar way:

**TG(I,3)** Lower surface of inner boundary.

**TG(I,4)** Upper surface of inner boundary.

**TGX(3,J)** Near surface of inner boundary.

**TGX(4,J)** Far surface of inner boundary.

The fourth part of the input specifies the heat transfer coefficients (Btu/hr.in²°F) in a similar order as the temperature input:

**H(I,1)** Lower surface of outer boundary.

**H(I,2)** Upper surface of outer boundary.

**HX(1,J)** Near surface of outer boundary.

**HX(2,J)** Far surface of outer boundary.

**H(I,3)** Lower surface of inner boundary.

**H(I,4)** Upper surface of inner boundary.

**HX(3,J)** Near surface of inner boundary.

**HX(4,J)** Far surface of inner boundary.
$DX = 0.05000 \quad DY = 0.02500 \quad OMEGA = 1.60004 \quad THRM\_COND = 1.00000$

$NX = 39 \quad NY = 25 \quad MAX\_ERROR = 0.02000$

$N1 = 2 \quad N2 = 21 \quad N3 = 15 \quad N4 = 23$

$NX0 = 112 \quad NX1 = 50$
GAS TEMPERATURE DISTRIBUTION ON THE BLADE INNER AND OUTER SURFACE

**INPUT DATA**

BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF OUTER BOUNDARY
(START FROM i = 2 TO i = 36)


BOUNDARY POINTS ON I-LINES FOR UPPER SURFACE OF OUTER BOUNDARY
(START FROM i = 2 TO i = 38)


BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF INNER BOUNDARY
(START FROM i = 3 TO i = 20)

1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
1400.00 1400.00 1400.00

BOUNDARY POINTS ON I-LINES FOR UPPER SURFACE OF INNER BOUNDARY
(START FROM i = 3 TO i = 20)

1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
1400.00 1400.00 1400.00

BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF OUTER BOUNDARY
(START FROM j = 2 TO j = 24)

1978.30 1977.00 1972.00 1965.60 2000.00 1999.00 1999.00 1998.50

BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF OUTER BOUNDARY
(START FROM j = 2 TO j = 24)


BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF INNER BOUNDARY
(START FROM j = 16 TO j = 22)

1400.00 1400.00 1400.00 1400.00 1400.00 1400.00

BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF INNER BOUNDARY
(START FROM j = 16 TO j = 22)

1400.00 1400.00 1400.00 1400.00 1400.00 1400.00
**INPUT DATA**

**HEAT COEFFICIENT DISTRIBUTION ON THE BLADE INNER AND OUTER SURFACE**

**BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF OUTER BOUNDARY**
(START FROM I= 2 TO I= 38 )

<table>
<thead>
<tr>
<th>J</th>
<th>1.34</th>
<th>0.86</th>
<th>0.96</th>
<th>0.99</th>
<th>1.00</th>
<th>1.01</th>
<th>1.00</th>
<th>1.02</th>
<th>1.05</th>
<th>1.08</th>
<th>1.12</th>
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**BOUNDARY POINTS ON I-LINES FOR UPPER SURFACE OF OUTER BOUNDARY**
(START FROM I= 2 TO I= 38 )

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**BOUNDARY POINTS ON J-LINES FOR LOWER SURFACE OF INNER BOUNDARY**
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**BOUNDARY POINTS ON J-LINES FOR UPPER SURFACE OF INNER BOUNDARY**
(START FROM J= 3 TO J= 20 )

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**BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF OUTER BOUNDARY**
(START FROM J= 2 TO J= 24 )

| I   | 1.79 | 1.76 | 1.75 | 1.75 | 1.74 | 1.70 | 1.64 | 1.61 | 1.62 | 1.67 | 1.71 | 1.66 | 1.50 | 1.20 |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| I   | 1.40 | 1.19 | 1.10 | 1.70 | 2.29 | 2.55 | 2.50 | 2.29 |

**BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF OUTER BOUNDARY**
(START FROM J= 2 TO J= 24 )

| I   | 1.10 | 1.22 | 1.28 | 1.34 | 1.40 | 1.44 | 1.49 | 1.54 | 1.58 | 1.60 | 1.61 | 1.60 | 1.54 | 1.38 |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| I   | 1.21 | 1.07 | 1.01 | 0.98 | 0.85 | 0.74 | 0.69 | 1.13 |

**BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF INNER BOUNDARY**
(START FROM J= 16 TO J= 22 )

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<th>0.36</th>
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**BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF INNER BOUNDARY**
(START FROM J= 16 TO J= 22 )

| I   | 0.45 | 0.44 | 0.42 | 0.40 | 0.37 | 0.37 | 0.36 |
The first part of the output serves as a check for the input data and the calculation procedures. The coordinates of the boundary points, through which a parabolic curve is fitted in the subroutine CURVE, are printed out together with the coefficients of the parabola. To distinguish between the boundary points on the interior and exterior blade surfaces, an integer I is assigned the value 0 in the first case and 1 in the second case. To monitor the convergence process the sum of the difference square between two successive iterations values at all the grid points is also printed. The second part of the output deals with the temperature distribution after the final iteration. The temperature at all the grid points, including the fictitious points which lie outside the region of calculations, are printed out. Next, the temperature at the interior points of the blade are listed after eliminating the fictitious points at which the temperatures are constant and equal to the initialized temperature value. Temperature distribution on the boundary points are also given in the output as well as the coordinates of the isothermal lines.
TEMPERATURE DISTRIBUTION INSIDE THE BLADE AND ON ITS SURFACE

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TEMPERATURE DISTRIBUTION ON THE BOUNDARY

BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF OUTER BOUNDARY
(START FROM I = 2 TO I = 38)

** 1904.30 1903.20 1893.31 1871.49 1861.14 1852.41 1847.35 1845.26 1844.44 1844.77 1846.06 1847.97 1850.90 1854.34 1859.09

BOUNDARY POINTS ON I-LINES FOR UPPER SURFACE OF OUTER BOUNDARY
(START FROM I = 2 TO I = 38)

** 1914.05 1902.76 1886.78 1876.01 1867.42 1861.58 1855.51 1849.76 1843.55 1837.56 1833.21 1830.46 1820.87 1833.51 1838.16

BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF INNER BOUNDARY
(START FROM I = 3 TO I = 20)

1893.73 1882.77 1867.07 1855.68 1846.41 1841.28 1838.77 1837.69 1837.65 1836.66 1840.59 1842.59 1846.04 1850.22 1855.23
1864.34 1875.22 1892.04

BOUNDARY POINTS ON I-LINES FOR UPPER SURFACE OF INNER BOUNDARY
(START FROM I = 3 TO I = 20)

1899.42 1880.96 1866.74 1859.77 1853.05 1846.88 1841.19 1.75.57 1830.07 1826.07 1824.05 1824.73 1827.20 1832.00 1837.90
1847.41 1860.01 1873.27

BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF OUTER BOUNDARY
(START FROM J = 2 TO J = 24)

1846.90 1868.38 1901.02 1910.70 1917.24 1918.97 1918.14 1916.14

BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF OUTER BOUNDARY
(START FROM J = 2 TO J = 24)

1922.04 1989.19 1861.31 1843.93 1834.94 1830.46 1940.51 1859.50

BOUNDARY POINTS ON J-LINES FOR NEARER SURFACE OF INNER BOUNDARY
(START FROM J = 16 TO J = 22)

1882.08 1856.28 1841.03 1849.94 1882.58 1888.71 1900.16

BOUNDARY POINTS ON J-LINES FOR FARTHER SURFACE OF INNER BOUNDARY
(START FROM J = 16 TO J = 22)

1901.56 1863.45 1843.87 1830.01 1824.05 1831.01 1849.23
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APPENDIX C

PROGRAM LISTING
COMMON T(40,25),TBX(4,25),TG(4,25),H(40,4),HX(4,25),Y1(40),Y2(40),Y3(40),Y4(40),X1(25),X2(25),X3(25),X4(25),BX(12,20),BY(120),BXR(120),BYI(120),IP(120)

COMMON DX, DY, NX, NY, NXO, NXI, ITER, N1, N2, N3, N4

READ(5,5) DX, DY, X, CME, SUMM, NX, NY, N1, N2, N3, N4, IMAX, NTE, NXO, NXI

5 FORMAT(5F5.3,6I2,4I3)

NXI=NX-1
NY1=NY-1
NLN1=N1+1
N21=N2-1
N31=N3+1
N41=N4-1

DO 46 I=1,NX
DO 46 J=1,NY

46 T(I,J)=1600.

DO 44 I=1,NX

DO 44 J=1,4

44 TBX(I,J)=1600.

DO 49 J=1,NY

DO 49 I=1,4

49 TBX(I,J)=1600.

READS IN BOUNDARY POINTS SET AND THE CORRESPONDING SEQUENCE NUMBERS FOR THE BOUNDARY POINTS

READ(5,10) (Y1(I),I=1,NX1)

10 FORMAT(12F6.3))

READ(5,11) (IP(I),I=1,NX1)

11 FORMAT(20I4)

DO 12 I=1,NX

X=FLOAT(I-1)*DX

BX(IP(I))=X

12 BY(IP(I))=Y1(I)

READ(5,10) (Y2(I),I=1,NX1)

READ(5,11) (IP(I),I=1,NX1)

DO 16 I=1,NX1

X=FLOAT(I-1)*DX

BX(IP(I))=X

16 BY(IP(I))=Y2(I)

READ(5,10) (X1(J),J=1,NY1)

READ(5,11) (IP(J),J=1,NY1)

DO 20 J=1,NY1

Y=FLOAT(J-1)*DY

BX(IP(J))=X1(J)

20 BY(IP(J))=Y

READ(5,10) (X2(J),J=1,NY1)

READ(5,11) (IP(J),J=1,NY1)

DO 24 J=1,NY1

Y=FLOAT(J-1)*DY

BX(IP(J))=X2(J)

24 BY(IP(J))=Y

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.
IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 80
READ(5,10) (Y3(I),I=N11,N21)
READ(5,11) (IP(I),I=N11,N21)
DO 28 I=N11,N21
X=FLOAT(I-1)*DX
BXI(IP(I))=-X
28 BYI(IP(I))=Y3(I)
READ(5,10) (Y4(I),I=N11,N21)
READ(5,11) (IP(I),I=N11,N21)
DO 32 I=N11,N21
X=FLOAT(I-1)*DX
BXI(IP(I))=X
32 BYI(IP(I))=Y4(I)
READ(5,10) (X3(J),J=N31,N41)
READ(5,11) (IP(J),J=N31,N41)
DO 36 J=N31,N41
Y=FLOAT(J-1)*DY
BXI(IP(J))=X3(J)
36 BYI(IP(J))=Y
READ(5,10) (X4(J),J=N31,N41)
READ(5,11) (IP(J),J=N31,N41)
DO 40 J=N31,N41
Y=FLOAT(J-1)*DY
BXI(IP(J))=X4(J)
40 BYI(IP(J))=Y
80 CONTINUE
C
READS IN GAS TEMPS AND THEN HEAT TRANSFER COEFFICIENTS
C
READ(5,50) (TG(I,1),I=1,NX1)
READ(5,50) (TG(I,2),I=1,NX1)
IF(N1.EQ.N2) GO TO 82
READ(5,50) (TG(I,3),I=N11,N21)
READ(5,50) (TG(I,4),I=N11,N21)
82 CONTINUE
50 FORMAT(10F8.2)
READ(5,50) (TGX(1,J),J=2,NY1)
READ(5,50) (TGX(2,J),J=2,NY1)
IF(N3.EQ.N4) GO TO 83
READ(5,50) (TGX(3,J),J=N31,N41)
READ(5,50) (TGX(4,J),J=N31,N41)
83 CONTINUE
READ(5,45) (H(I,1),I=1,NX1)
READ(5,45) (H(I,2),I=1,NX1)
IF(N1.EQ.N2) GO TO 84
READ(5,45) (H(I,3),I=N11,N21)
READ(5,45) (H(I,4),I=N11,N21)
84 CONTINUE
45 FORMAT(10F8.4)
READ(5,45) (HX(1,J),J=2,NY1)
READ(5,45) (HX(2,J),J=2,NY1)
IF(N3.EQ.N4) GO TO 85
READ(5,45) (HX(3,J),J=N31,N41)
IVG LEVEL 21

READ(5,45)(HX(4,J),J=N31,N41)

85 CONTINUE
ITER=1
WRITE(6,86)

86 FORMAT(///,25X,'INPUT DATA')
WRITE(6,88)

88 FORMAT(///,15X,'BLADE BOUNDARY POINTS COORDINATES'////17X,'OUTER 1 BOUNDARY',9X,'INNER BOUNDARY',//10X,'PT.NO.',5X,'X',9X,'Y',6X, 2*PT.NO.',6X,'X',9X,'Y'//)
NXII=NXI+1
WRITE(6,851)((I,BX(I),BY(I),I,8XI(I),BY(I)),I=1,NXI)
WRITE(6,853)((I,BX(I),BY(I)),I=NXI1,NX0)

851 FORMAT(i,2,F10.6)
853 FORMAT(i,2,F10.6)

NXI=NXI+1
WRITE(6,530) (TG(I,1),I=1,NXI)
WRITE(6,525) (TG(I,1),I=1,NXI)
WRITE(6,531) (TG(I,2),I=1,NXI)
IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 98
WRITE (6,532) N11,N21
WRITE(6,526) (TG(I,3),I=N11,N21)
WRITE(6,533) N11,N21
WRITE(6,526) (TG(I,4),I=N11,N21)

98 CONTINUE
WRITE(6,534) NY1
WRITE(6,526) (TGX(1,J),J=2,NY1)
WRITE(6,535) NY1
WRITE(6,526) (TGX(2,J),J=2,NY1)
IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 96
WRITE(6,536) N31,N41
WRITE(6,537) N31,N41
WRITE(6,537) N31,N41
WRITE(6,533) N11,N21
WRITE(6,526) (TGX(4,J),J=N31,N41)
WRITE(6,534) NY1
WRITE (6,526) (HX(1,J),J=2,NY1)

96 CONTINUE
WRITE(6,562)

562 FORMAT(///,15X,'INPUT DATA'/15X,'HEAT COEFFICIENT DISTRIBUTION 1ON THE BLADE INNER AND OUTER SURFACE',//)
WRITE(6,530) NX1
WRITE(6,525) (HI(I,1),I=1,NXI)
WRITE(6,531) NX1
WRITE(6,525) (HI(I,2),I=1,NXI)
IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 97
WRITE(6,532) N11,N21
WRITE(6,526) (HI(I,3),I=N11,N21)
WRITE(6,533) N11,N21
WRITE(6,526) (HI(I,4),I=N11,N21)

97 CONTINUE
WRITE (6,534) NY1
WRITE(6,526) (HX(1,J),J=2,NY1)
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WRITE(6,535) NY1
WRITE(6,526) ( HX(2,J),J=2,NY1)
IF(NL.EQ.N2.AND.N3.EQ.N4) GO TO 95
WRITE(6,536) N31,N41
WRITE(6,526) ( HX(3,J),J=N31,N41)
WRITE(6,537) N31,N41
WRITE(6,526) ( HX(4,J),J=N31,N41)
WRITE(6,401)

95 CONTINUE

C
PRINT TITLE FOR SUBROUTINE CURVE OUTPUT

C
WRITE(6,43)
43 FORMAT('H1,/5X, 'SUBROUTINE CURVE -OUTPUT- '//5X,'I=0, OUTER BOUNDARY. I=1, INNER BOUNDARY'/5X,'I=IP BOUNDARY POINT NUMBER')
WRITE(6,41)
41 FORMAT('5X, '(B2,C2) IS THE POINT ON THE BOUNDARY. (B3,C3) AN
1D (B3,C3) ARE THE SURROUNDING POINTS ON BLADE. A,B,C, ARE THE COEF
25'/5X, 'OF THE PARABOLIC CURVE Y=A+B*X+C*X*X','/5X,'A',3X,'B',5X,
3'B1',8X,'C1',8X,'B2',8X,'C2',8X,'B3',8X,'C3',9X,'A',9X,'B',9X,'C',
4'/')
1 CONTINUE

C
STARTING OF GAUSS-SEIDELL METHOD OF ITERATION ON I LINES

C
SUM=0.

DN 250 I=2,NX1
IL=IFIX(Y1(I)/DY+0.0001)+2
IH=IFIX(Y2(I)/DY+0.0001)+1
IF(ABS(Y2(I)-FLOAT(IH-1)*DY).LT.0.00001) IH=I-1

C
OUTER LOWER BOUNDARY

B2=FLOAT(I-1)*DX
C2=Y1(I)
CALL CUR(B2,C2,B,C,0)
XMN=B+2.*C*B2
IF(I.EQ.NX1) XMN=0.01
YT=FLOAT(IL-1)*DY
IF(ABS(XMN).LE.0.015) GO TO TC325
X=(C2-YT)*XMN+B2
IF(X.LE.B2) GO TO T0315
XR=B2+DX
IF((X2(IL)-XR).GT.0.0001) GO TO 324
TTT=T(I,IL)+(TBX(2,IL)-T(I,IL))*{(X-B2)/(X2(IL)-B2)}
GO TO 320

324 CONTINUE
TTT=T(I,IL)+(T(I+1,IL)-T(I,IL))*(X-B2)/DX
GO TO 320

315 TTT=T(I,IL)-(T(I,IL)-T(I-1,IL))*(B2-X)/DX
320 XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
XNL=SQR(XNL)
GO TO 330

43
IV G LEVEL 21 MAIN

325 TTT=T(I,IL)
    XNL=YT-C2
330    AL=H(I,1)/XK
    TNEW=(XNL*AL*TG(I,1)+TTT)/(1.+XNL*AL)
    TNEW=(1.-OME)*TB(I,1)+OME*TNEW
    SUM=SUM+(TB(I,1)-TNEW)*(TB(I,1)-TNEW)
    TB(I,1)=TNEW
    IF(I.GT.NL.AND.I.LT.N2) GO TO 230

INTERIOR POINTS STARTING FROM LOWER END FOR I LINES WHICH DO NOT CUT
THE INNER BOUNDARY

DO 210 J=IL,IH
    CALL MESH(I,J,TNEW)
    TNEW=(1.-OME)*TB(I,J)+OME*TNEW
    SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
210    T(I,J)=TNEW
    GO TO 249

FOR I LINES INTERSECTING INNER BOUNDARY—ALL INTERIOR POINTS FROM
LOWER SURFACE OF OUTER BOUNDARY TO LOWER SURFACE OF INNER BOUNDARY

230 CONTINUE
    ILI=IFIX(Y3(I)/DY+0.0001)+1
    IF(ABS(Y3(I)-FLOAT(ILI-1)*DY).LT.0.00001) ILI=ILI-1
    IHI=IFIY(Y4(I)/DY+0.0001)+2
    DO 235 J=IL,ILI
        CALL MESH(I,J,TNEW)
        TNEW=(1.-OME)*TB(I,J)+OME*TNEW
        SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
235    T(I,J)=TNEW

INNER BOUNDARY—LOWER SURFACE

B2=FLOAT(I-1)*DX
    C2=Y3(I)
    CALL CUR(B2,C2,B,C,I)
    XMN=B+2.*C+B2
    IF(I.EQ.N21) XMN=0.01
    YT=FLOAT(ILI-1)*DY
    IF(ABS(XMN).LE.0.015) GO TO 355
    X=(C2-YT)*XMN+B2
    IF(X.LE.B2) GO TO 350
    TTT=T(I,ILI)+(T(I+1,ILI)-T(I,ILI))*(X-B2)/DX
    GO TO 352
350    TTT=T(I,ILI)-(T(I+1,ILI)-T(I,ILI))*(B2-X)/DX
352    XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
    XNL=SQRT(XNL)
    GO TO 358
355    TTT=T(I,ILI)
    XNL=C2-YT
AL=H(I,3)/XK
TNEW=(XNL*AL*TG(I,3)+TTT)/(1.*XNL*AL)
TNEw=(1.-OME)*TB(I,3)+OME*TNEW
SUM=SUM+(TB(I,3)-TNEW)*(TB(I,3)-TNEW)
TB(I,3)=TNEW

C

UPPER SURFACE OF INNER BOUNDARY

C2=Y4(I)
CALL CUR(B2,C2,B,C,1)
XMN=B+2.*C*B2
IF(I.EQ.N21) XMN=0.01
YT=FLOAT(IHI-1)*DY
IF(ABS(XMN)*LE.0.015) GO TO 370
X=(C2-YT)*XMN+B2
IF(X.LE.B2) GO TO 360
TTT=T(I,IHI)+(T(I+1,IHI)-T(I,IHI))*(X-B2)/DX
GO TO 365

360 TTT=T(I,IHI)+(T(I,IHI)-T(I-1,IHI))*(B2-X)/DX
XNL=SQRT(XNL)
GO TO 375

370 TTT=T(I,IHI)
XNL=YT-C2

AL=H(I,4)/XK
TNEW=(XNL*AL*TG(I,4)+TTT)/(1.*XNL*AL)
TNEw=(1.-OME)*TB(I,4)+OME*TNEW
SUM=SUM+(TB(I,4)-TNEW)*(TB(I,4)-TNEW)
TB(I,4)=TNEW

C

INTERIOR POINTS FROM UPPER SURFACE OF INNER BOUNDARY TO THE UPPER SURFACE OF OUTER BOUNDARY

DO 240 J=IHI,IH
CALL MESH(I,J,TNEW)
TNEW=(1.-OME)*T(I,J)+OME*TNEW
SUM=SUM+(TNEW-T(I,J))*(TNEW-T(I,J))
240 T(I,J)=TNEW
249 CONTINUE

C

UPPER BOUNDARY OF CUTER SURFACE

C2=Y2(I)
CALL CUR(B2,C2,B,C,0)
XMN=B+2.*C*B2
IF(I.EQ.NX1) XMN=0.01
YT=FLOAT(IH-1)*DY
IF(ABS(XMN)*LE.0.005) GO TO 340
X=(C2-YT)*XMN+B2
XL=B2-DX
IF((XL-X(IH))*.GT.0.00001) GO TO 336
TTT=T(I,IH)-(T(I,IH)-TBX(I,IH))*(B2-X)/(B2-X(IH))
GO TO 337
336 CONTINUE
IF(X*LE.B2) GO TO 335
TTT=T(I,IN)+T(I+1,IN)-T(I,IN)*((X-B2)/DX
GO TO 337
335 TTT=T(I,IN)-T(I+1,IN)-T(I-1,IN)*((B2-X)/DX
337 XNL=(X-B2)*(X-B2)+(C2-YT)*(C2-YT)
XNL=SQRT(XNL)
GO TO 340
340 TTT=T(I,IN)
XNL=C2-YT
345 AL=H(I,2)/XK
TNEW=(XNL*AL*TG(I,2)+TTT)/(1.*XNL*AL)
TNEW=(1.-OME)*TB(I,2)+OME*TNEW
SUM=SUM+(TB(I,2)-TNEW)*(TB(I,2)-TNEW)
TB(I,2)=TNEW
GO TO 345
250 CONTINUE
C
C ITER. FOR J LINES ONLY BOUNDARY POINTS INTERSECTED BY J LINES
C
DO 490 J=2,NYL
IN =IFIX(X1(J)/DX+0.0001)+2
IA =IFIX(X2(J)/DX+0.0001)+1
IF(ABS(X2(J)-FLOAT(IA-1)*CX).LT.0.0001) IA=IA-1
C
C NEAR SURFACE OF OUTER BOUNDARY
C
B2=X1(J)
C2=FLOAT(J-1)*DY
CALL CUR(B2,C2,B,C,0)
XMN=B+2.*C*B2
XT=FLOAT(IN-1)*DX
IF(ABS(XMN).GE.5.)GO TO 410
XL=XT-DX
X=-DY*XMN+B2
IF(X*LE.B2) GO TO 406
IF((X2(J+1)-XT).GT.0.0001) GC TO 405
TTT=T(IN-1,J)+T(BX(2,J+1)-T(IN-1,J+1))*((XT-X)/X2(J+1)-X)
GO TO 407
405 CONTINUE
TTT=T(IN,J)+T(IN-1,J)+T(IN,J+1)*((XT-X)/DX
GO TO 407
406 CONTINUE
X=DY*XMN+B2
TTT=T(IN,J-1)+(TBX(1,J-1)-T(IN,J-1))*(XT-X)/(XT-X1(J-1))
407 XNL=(B2-X)*(B2-X)+DY*DY
XNL=SQRT(XNL)
GO TO 415
410 TTT=T(IN,J)
XNL=XT-B2
415 AL=HX(1,J)/XK
TNEW=(TTT+AL*XNL*TGX(1,J))/(1.+XNL*AL)
TNEW=(1.-OME)*TBX(1,J)+OME*TNEW

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SUM=SUM+(TNEW-TBX(1,J))*(TNEW-TBX(1,J))
TBX(1,J)=TNEW
IF(J>GT.N3.AND.J<LT.N4) GO TO 418
GO TO 445

C C FOR J LINES INTERSECTING INNER BOUNDARY-BOUNDARY POINTS ON THE C NEARER SURFACE OF INNER BOUNDARY

C 418 CONTINUE
INI=IFIX(X3(J)/DX+0.0001)+1
IF(ABS(X3(J)-FLOAT(INI-1)*DX)>LT.0.00001) INI=INI+1
IAI=IFIX(X4(J)/DX+0.0001)+2
B2=X3(J)
CALL CUR(B2,C2,B,C,1)
XMN=B2+C*E2
XT=FLOAT(INI-1)*DX
IF(ABS(XMN)>GE.5.) GO TO 425
X=DX*XMN+B2
IF(X*GT.R2) GO TO 421
TTT=T(INI,J-1)+(T(INI+1,J-1)-T(INI,J-1))*(X-XT)/DX
GO TO 422

421 X=-DY*XMN+B2
TTT=T(INI,J+1)+(T(INI,J+1)-T(INI+1,J+1))*(X-XT)/DX

422 XNL=(B2-X)*(B2-X)+DY*DY
XNL=SQR(T(XNL))
GO TO 426

425 XNL=T(INI,J)
XNL=B2-XT

426 AL=HX(3,J)/XK
TNEW=(TTT+AL*XNL*TGX(3,J))/((1.*XNL*AL)
TNEW=(1.-CME)*TBX(3,J)+OME*TNEW
SUM=SUM+(TNEW-TBX(3,J))*(TNEW-TBX(3,J))
TAX(3,J)=TNEW

C C FARTHER SURFACE OF INNER BOUNDARY

C B2=X4(J)
CALL CUR(B2,C2,B,C,1)
XMN=B2+C*E2
IF(J.EQ.N31) XMN=6.0
XT=FLOAT(IAI-1)*DX
IF(ABS(XMN)>GE.5.) GO TO 435
X=DY*XMN+B2
TTT=T(IAI,J-1)+(T(IAI-1,J-1)-T(IAI,J-1))*(XT-X)/DX

430 XNL=(B2-X)*(B2-X)+DY*DY
XNL=SQR(T(XNL))
GO TO 440

435 XNL=XT-B2

440 AL=HX(4,J)/XK
TNEW=(TTT+AL*XNL*TGX(4,J))/((1.*XNL*AL)
IV G LEVEL 21	 MAIN 	 DATE = 74346 	 16/55/51

TNEW=(1.-OME)*TBX(4,J)+OME*TNEW
SUM=SUM+(TNEW-TBX(4,J))*TNEW-TBX(4,J))
TBX(4,J)=TNEW

C FARTHER BOUNDARY POINTS ON OUTER SURFACE

445 B2=X2(J)
CALL CUR(B2,C2,B,C,O)
XMN=B2*C*B2
IF(J.EQ.2 ) XMN=6.0
XT=FLOAT(IA-1)*DX
IF(ABS(XMN).GE.5.) GO TO 455
XR=XT+DX
X=DY*XMN+B2
IF((XT-X1(J-1)).GT.0.00001) GO TO 450
TTT=TBX(1,J-1)-(TBX(1,J-1)-T(IA+1,J-1))*(X-X1(J-1))/(XR-X1(J-1))
GO TO 452

450 CONTINUE
TTT=T(IA,J-1)+(T(IA+1,J-1)-T(IA,J-1))*(X-XT)/DX

452 XNL=(B2-X)*(B2-X)+CY*CY
XNL=SQRT(XNL)
GO TO 460

455 TTT=T(IA,J)
XNL=B2-XT

460 AL=HX(2,J)/XK
TNEW=(TTT+AL*XNL*GX(2,J))/(1.+XNL*AL)
TNEW=(1.-OME)*TBX(2,J)+OME*TNEW
SUM=SUM+(TBX(2,J)-TNEW)*(TBX(2,J)-TNEW)
TBX(2,J)=TNEW

490 CONTINUE
DO 495 I=1,NX1
DO 495 J=1,NY1
X=FLOAT(I-1)*DX
TB(I,J)=TBX(I,J)
Y=FLOAT(J-1)*DY
IF(ABS(X-X1(J)).LT.0.00001.AND.ABS(Y-Y1(I)).LT.0.00001) T(I,J)=TB( I1,I)
IF(ABS(X-X1(J)).LT.0.00001.AND.ABS(Y-Y2(I)).LT.0.00001) T(I,J)=TB( I1,1)
IF(ABS(X-X2(J)).LT.0.00001.AND.ABS(Y-Y2(I)).LT.0.00001) T(I,J)=TB( I1,2)
495 CONTINUE

COMPLETION OF AN ITERATION-CHECKS FOR REQUIRED CONVERGENCE

IF(ITER.EQ.1) WRITE(6,509)
509 FORMAT(1H1)
WRITE(6,510) ITER,SUM
510 FORMAT(5X,'ITERATION=',I3,3X,'ERRCR=',E12.5)
IF(ITER/NTE*4) GO TO 520
IF(SUM.LE.SUMM) GO TO 520
IF(ITER.GE.IMAX) GO TO 600
ITER=ITER+1
GO TO 1
520 CONTINUE
WRITE(6,540)
540 FORMAT(11H1/////////9X,'TEMPERATURE DISTRIBUTION IN A HOLLOW BLADE'
1'/////////)
WRITE(6,541) DX,dy,ome,XK,NX,NY,SUMM,N1,N2,N3,N4,NX0,NXI
541 FORMAT(3X,'DX =',F8.5,5X,'DY =',F8.5,5X,'OMEGA =',F8.5,5X,'THRM CON
1D =',F8.5,5X,'NX =',I8,5X,'NY =',I8,5X,'MAX.ERR.CR =',F8.5,5X,'N1 ='
2,I8,5X,'N2 =',I8,5X,'N3 =',I8,5X,'N4 =',I8,5X,'NXO =',I8,5X,'NXI =
3*I6/I1)
WRITE(6,522)
522 FORMAT('/',10X,'T-MATRIX,GIVES ALL INTERIOR POINTS.INITIAL SETTING
1 OF T IS 1600.0,'/10X,'ONLY THOSE INSIDE BLADE ARE CHANGED AND WILL
2 BE DIFFERENT FROM 1600.00')
WRITE(6,523)
523 FORMAT(/,2X,'I =',4X,'J =',4X,'K =',4X,'L =',4X,'M =',4X,'N =',4X,'O =',4X,'P =',4X,'Q =',4X,'R =',4X,'S =',4X,'T =',4X,'U =',4X,'V =',4X,'W =',4X,'X =',4X,'Y =',4X,'Z ='/
22X,'I =')
IF(NY.GT.15) WRITE(6,521)
521 FORMAT(8X,'16','6X','17','6X','18','6X','19','6X','20','6X','21','6X','22','6X
1','23','6X','24','6X','25')
DO 603 I=1,NX
603 WRITE(6,525) I,(T(I,J),J=1,NY)
525 FORMAT(/,2X,'I =',15F8.2) WRITE(6,524)
524 FORMAT(11H1/////////9X,'TEMPERATURE DISTRIBUTION ON THE BOUNDARY',/////////)
WRITE(6,530) NX1
530 FORMAT('/',10X,'BOUNDARY POINTS ON I-LINES FOR LOWER SURFACE OF
1 OUTER BOUNDARY',/12X,'(START FROM I = 2 TO I = ',I3,)')
WRITE(6,525) (TB(I,1),I=1,NXI)
WRITE(6,531) NX1
531 FORMAT('/',10X,'BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF
1 OUTER BOUNDARY',/12X,'(START FROM I = 2 TO I = ',I3,)')
WRITE(6,525) (TB(I,2),I=1,NXI)
IF(N1.EQ.N2.AND.N3.EQ.N4) GO TO 87
WRITE(6,532) N11,N21
532 FORMAT('/',10X,'BOUNDARY POINTS ON I LINES FOR LOWER SURFACE OF
1 INNER BOUNDARY',/12X,'(START FROM I = ',I3,' TO I = ',I3,)')
WRITE(6,526) (TB(I,3),I=N11,N21)
WRITE(6,533) N11,N21
533 FORMAT('/',10X,'BOUNDARY POINTS ON I LINES FOR UPPER SURFACE OF
1 INNER BOUNDARY',/12X,'(START FROM I = ',I3,' TO I = ',I3,)')
WRITE(6,526) (TB(I,4),I=N11,N21)
87 CONTINUE
WRITE(6,534) NY1
534 FORMAT('/',10X,'BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF
1 OUTER BOUNDARY',/12X,'(START FROM J = 2 TO J = ',I3,)')
WRITE(6,526) (TA(I,J),J=2,ANY1)
WRITE(6,535) NY1
535 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF OUTER BOUNDARY',/12X,'(START FROM J=2 TO J='I3',')')
WRITE(6,526)(TBX(I,J),J=2,NY1)
IF(N1.LE.N2.AND.N3.LE.N4) GO TO 89
WRITE(6,536) N31,N41
536 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR NEARER SURFACE OF INNER BOUNDARY',/12X,'(START FROM J='I3', TO J='I3',')')
WRITE(6,526)(TBX(3,J),J=N31,N41)
WRITE(6,537) N31,N41
537 FORMAT(//,10X,'BOUNDARY POINTS ON J LINES FOR FARTHER SURFACE OF INNER BOUNDARY',/12X,'(START FROM J='I3', TO J='I3',')')
WRITE(6,526)(TBX(4,J),J=N31,N41)
WRITE(6,5401)
401 FORMAT(1H1)
526 FORMAT(3(/,5X,F8.2))
89 CONTINUE
WRITE (6,801)
DO 701 J=2,NY1
DO 702 I=1,NX
J=NY+1—J
XR=FLOAT(I-1)*DX
IF( (XR—X(I,J)) .GE. 0.0001) I1=I
IF(ABS(XR—X(I,J)) .GE. 0.0001) I1=I+1
IF( (XR—X(I,J)) .GE. 0.0001) GO TO 704
702 CONTINUE
704 DO 703 I=I1,NX
XR=FLOAT(I-1)*DX
IF( (XR—X2(J)) .GE. 0.0001) I2=I-1
IF(ABS(XR—X2(J)) .GE. (0.0001*DX)) I2=I2-1
IF( (XR—X2(J)) .GE. 0.0001) GO TO 705
703 CONTINUE
705 CONTINUE
J=NY+1—J
IF(J.EQ.2) WRITE(6,824)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.3) WRITE(6,823)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.4) WRITE(6,822)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.5) WRITE(6,821)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.6) WRITE(6,820)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.7) WRITE(6,819)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.8) WRITE(6,818)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.9) WRITE(6,817)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.10) WRITE(6,816)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.11) WRITE(6,815)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.12) WRITE(6,814)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.13) WRITE(6,813)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.14) WRITE(6,812)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.15) WRITE(6,811)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.16) WRITE(6,810)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.17) WRITE(6,809)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.18) WRITE(6,808)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.19) WRITE(6,807)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.20) WRITE(6,806)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.21) WRITE(6,805)(TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)

50
IF(J.EQ.22) WRITE(6,804) J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.23) WRITE(6,803) J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)
IF(J.EQ.24) WRITE(6,802) J,TBX(1,J),(T(I,J),I=I1,I2),TBX(2,J)

801 FORMAT(1H1,15X, BlTEMPERATURE DISTRIBUTION INSIDE THE BLADE AND ON XN ITS SURFACE//2X,*J=*')
802 FORMAT(/2X,I2, 4X,20F8.2)
803 FORMAT(/2X,I2, 6X,20F8.2)
804 FORMAT(/2X,I2, 8X,20F8.2)
805 FORMAT(/2X,I2,10X,13F8.2/24X,7F8.2)
806 FORMAT(/2X,I2,12X,13F8.2/24X,7F8.2)
807 FORMAT(/2X,I2,14X,13F8.2/24X,7F8.2)
808 FORMAT(/2X,I2,16X,13F8.2/24X,7F8.2)
809 FORMAT(/2X,I2,18X,13F8.2/24X,7F8.2)
810 FORMAT(/2X,I2,20X,20F8.2)
811 FORMAT(/2X,I2,22X,20F8.2)
812 FORMAT(/2X,I2,24X,20F8.2)
813 FORMAT(/2X,I2,26X,20F8.2)
814 FORMAT(/2X,I2,28X,20F8.2)
815 FORMAT(/2X,I2,30X,20F8.2)
816 FORMAT(/2X,I2,32X,20F8.2)
817 FORMAT(/2X,I2,34X,20F8.2)
818 FORMAT(/2X,I2,36X,20F8.2)
819 FORMAT(/2X,I2,38X,20F8.2)
820 FORMAT(/2X,I2,40X,20F8.2)
821 FORMAT(/2X,I2,42X,20F8.2)
822 FORMAT(/2X,I2,44X,20F8.2)
823 FORMAT(/2X,I2,46X,20F8.2)
824 FORMAT(/2X,I2,48X,20F8.2)
701 CONTINUE
IF(SUM.LE.SUMM) GO TO 600
ITER=ITER+1
GO TO 1
600 CONTINUE
633 WRITE(6,665)
665 FORMAT(1H1,38X,*ISOTHERMAL LINE LOCATIONS */,9X,*I*,4X,*J*,3X,*T*,
14X,*T - 1*,6X,*T - 2 *,8X,*FRAC,\))/
DO 623 I=2,NX1
IA=IFIX(Y1(I)/DY+0.0001)+1
IB=IFIX(Y3(I)/DY+0.0001)+2
IC=IFIX(Y4(I)/DY+0.0001)+1
ID=IFIX(Y2(I)/DY+0.0001)+2
IB=IB-1
ID=ID-1
IF(I.GT.N1.AND.I.LT.N2) GO TO 629
IT1=TB(I,1)
IT2=TB(I,2)
IL=IT1
IH=IT2
IF(IT1.GE.IT2) IL=IT2
IF(IT1.GE.IT2) IH=IT1
IAA=IA
DO 623 J=IAA,ID
IF(T(I,J).LT.FLOAT(IL)) IL=IFIX(T(I,J))

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
IF(T(I,J) .GT. FLOAT(IH)) IH = IFIX(T(I,J))
620 CONTINUE
623 CONTINUE
DO 624 II = IL, IH
DO 625 J = IA, ID
IF((FLOAT(J) * DY) .GT. Y2(I)) T(I, J+1) = TB(I, 2)
IF(Y1(I) .GT. (FLOAT(J-1) * DY)) T(I, J) = TB(I, 1)
TV = FLOAT(IH)
IF(T(I, J) .GT. TV .AND. T(I, J+1) .GE. TV) GO TO 627
IF(T(I, J) .GE. TV .AND. T(I, J+1) .LT. TV) GO TO 627
GO TO 625
627 CONTINUE
RX = (T(I, J) - TV) / (T(I, J) - T(I, J+1))
WRITE(6, 666) I, J, II, T(I, J), T(I, J+1), RX
625 CONTINUE
624 CONTINUE
GO TO 601
629 CONTINUE
IT1 = TB(I, 1)
IT2 = TB(I, 3)
IT3 = TB(I, 4)
IT4 = TB(I, 2)
IL = IT1
IH = IT2
II = IT3
IH1 = IT4
IF(IT1 .GE. IT2) IL = IT2
IF(IT1 .GE. IT2) IH = IT1
IF(IT3 .GE. IT4) II = IT4
IF(IT3 .GE. IT4) IH1 = IT3
DO 604 II = IL, IH
DO 605 J = IA, ID
TV = FLOAT(IH)
IF(Y1(I) .GT. (FLOAT(J-1) * DY)) T(I, J) = TB(I, 1)
IF((FLOAT(J) * DY) .GT. Y3(I)) T(I, J+1) = TB(I, 3)
IF(T(I, J) .GT. TV .AND. T(I, J+1) .GE. TV) GO TO 607
IF(T(I, J) .GE. TV .AND. T(I, J+1) .LT. TV) GO TO 607
GO TO 605
607 RX = (T(I, J) - TV) / (T(I, J) - T(I, J+1))
WRITE(6, 666) I, J, II, T(I, J), T(I, J+1), RX
666 FORMAT(5X, 3I5, 3F11.4)
604 CONTINUE
DO 605 II = IH1, IH
DO 607 J = IC, ID
TV = FLOAT(IH)
IF(Y1(I) .GT. (FLOAT(J-1) * DY)) T(I, J) = TB(I, 4)
IF((FLOAT(J-1) * DY) .GT. Y2(I)) T(I, J+1) = TB(I, 2)
IF(T(I, J) .GT. TV .AND. T(I, J+1) .GE. TV) GO TO 617
IF(T(I, J) .GE. TV .AND. T(I, J+1) .LT. TV) GO TO 617
GO TO 615
617 RX = (T(I, J) - TV) / (T(I, J) - T(I, J+1))
WRITE(6, 666) I, J, II, T(I, J), T(I, J+1), RX
605 CONTINUE
604 CONTINUE
DO 614 II = IH, IH1
DO 615 J = IC, ID
TV = FLOAT(IH)
IF(Y1(I) .GT. (FLOAT(J-1) * DY)) T(I, J) = TB(I, 4)
IF((FLOAT(J-1) * DY) .GT. Y2(I)) T(I, J+1) = TB(I, 2)
IF(T(I, J) .GT. TV .AND. T(I, J+1) .GE. TV) GO TO 617
IF(T(I, J) .GE. TV .AND. T(I, J+1) .LT. TV) GO TO 617
GO TO 615
617 RX = (T(I, J) - TV) / (T(I, J) - T(I, J+1))
WRITE(6, 666) I, J, II, T(I, J), T(I, J+1), RX
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615 CONTINUE
614 CONTINUE
601 CONTINUE
649 CONTINUE
STOP
END
SUBROUTINE MESH(I,J,TNEW)
COMMON T(40,25),TB(40,4),TX(4,25),TG(40,4),TXG(4,25),H(40,4),HX(4,25),YI(40),Y2(40),Y3(40),Y4(40),XI(25),X2(25),X3(25),X4(25),BX(12),BY(120),BXI(120),BYI(120),IP(120)

COMMON DX,dy,NX,NY,NXO,NXI,ITER,NI,N2,N3,N4

SUBROUTINE FINDS SI-1,SI-2,DEL-U,DEL-2. FOR EACH INTERIOR POINT AND GETS NEW TEMPS FOR EVERY INTERIOR POINT

PAR=FLOAT(I-1)*DX
IF((PAR-X1(J)).LE.DX)S1=(PAR-X1(J))/DX
IF((PAR-X1(J)).LE.CX)T1=TBX(1,J)
IF((PAR-X1(J)).LE.CX)GO TO 20
IF(J.GT.N3.AND.J.LT.N4)GO TO 10
GO TO 15
10 IF((PAR-GE,X4(J)).GT.40)GO TO 12
GO TO 15
12 IF((PAR-X4(J)).LE.DX)S1=(PAR-X4(J))/DX
IF((PAR-X4(J)).LE.CX)T1=TBX(4,J)
IF((PAR-X4(J)).LE.DX)GO TO 20
15 S1=1.0
T1=TI-I,J)
IF(Abs(X1(J)-PAR+DX).GE.0.00001) T1=TBX(1,J)
IF(Abs(X4(J)-PAR+DX).GE.0.00001) T1=TBX(4,J)
20 CONTINUE
IF((X2(J)-PAR).LE.DX)S2=(X2(J)-PAR)/DX
IF((X2(J)-PAR).LE.CX)T3=TBX(2,J)
IF((X2(J)-PAR).LE.DX)GO TO 35
IF(J.GT.N3.AND.J.LT.N4)GO TO 25
GO TO 30
25 IF(X3(J).GT.PAR)GO TO 27
GO TO 30
27 IF((X3(J)-PAR).LE.DX)S2=(X3(J)-PAR)/DX
IF((X3(J)-PAR).LE.CX)T3=TBX(3,J)
IF((X3(J)-PAR).LE.DX)GO TO 35
30 S2=1.
T3=TI-I+1,J)
IF(Abs(X2(J)-PAR-DX).GE.0.00001) T3=TBX(2,J)
IF(Abs(X3(J)-PAR-DX).GE.0.00001) T3=TBX(3,J)
35 PAR=FLOAT(J-1)*DY
IF((PAR-Y1(I)).LE.DY)D1=(PAR-Y1(I))/DY
IF((PAR-Y1(I)).LE.DY)T2=TB(I,1)
IF((PAR-Y1(I)).LE.DY)GO TO 50
IF(I.GT.N1.AND.I.LT.N2)GO TO 40
GO TO 45
40 IF((PAR-GE,Y4(I)).GT.40)GO TO 42
GO TO 45
42 IF((PAR-Y4(I)).LE.DY)D1=(PAR-Y4(I))/DY
IF((PAR-Y4(I)).LE.DY)T2=TB(1,4)
IF((PAR-Y4(I)).LE.DY)GO TO 50
45 D1=1.0
T2=T(I,J-1)
IF(ABS(Y1(I)-PAR+DY)*LT.0.00001) T2=TB(I,1)
IF(ABS(Y4(I)-PAR+DY)*LT.0.00001) T2=TB(I,4)

50 CONTINUE
IF((Y2(I)-PAR).LT.0.00001) T2=TB(I,2)
IF((Y2(I)-PAR).LE.DY) GO TO 65
IF((Y2(I)-PAR).LT.N2) GO TO 55
GO TO 60

55 IF(Y3(I).GT.PAR) GO TO 57
GO TO 60

57 IF((Y3(I)-PAR).LE.DY) D2=(Y3(I)-PAR)/DY
IF((Y3(I)-PAR).LE.DY) T4=TB(I,3)
IF((Y3(I)-PAR).LE.DY) GO TO 65

60 D2=1.0
T4=T(I,J+1)
IF(ABS(Y2(I)-PAR-DY)*LT.0.00001) T4=TB(I,2)
IF(ABS(Y3(I)-PAR-DY)*LT.0.00001) T4=TB(I,3)

65 CONTINUE
A1=T1/S1/(S1+S2)
A2=T2/D1/(D1+D2)
A3=T3/S2/(S1+S2)
A4=T4/D2/(D1+D2)
E=1/S1/S2*(D1/D2)*(D1/D2)
TNEW=(A1+A3+D4/D2)*(D1/D2)*E/A4)
RETURN
END
SUBROUTINE SLO(X1,Y1,X2,Y2,X3,Y3,A,B,C)

FINDS EQUATION THRU THREE POINTS AS Y = A + B*X + C*X*X

CALL UNDFLW
IF(ABS(X1-X2) .LE. 0.001 .AND. ABS(X2-X3) .LE. 0.001) GO TO 10
X3=X3*X3
X3=X2*X2
X3=X1*X1
D1=X2*X3-X3*X3
D2=X1*X3-X3*X3
D3=X1*X2-X2*X2
D=D1-D2+D3
IF(ABS(D) .LE. 0.000001) GO TO 10
A1=Y1*(X2*X3-X3*X3)
A2=Y2*(X1*X3-X3*X3)
A3=Y3*(X1*X3-X2*X3)
A=(A1-A2+A3)/D
B1=Y2*X3-Y3*X3
B2=Y1*X3-Y3*X3
B3=Y1*X2-Y2*X3
B=(B1-B2+B3)/D
C1=X2*Y3-X3*Y2
C2=X1*Y3-X3*Y1
C3=X1*Y2-X2*Y3
C=(C1+C2+C3)/D
RETURN
10 A=100.
B=100.
C=100.
RETURN
END
SUBROUTINE CUR(B2, C2, B, C, I)
COMMON T(40, 25), TB(40, 4), TBX(4, 25), TG(40, 4), TGX(4, 25), H(40, 4), HX(4, 25), Y1(40), Y2(40), Y3(40), Y4(40), X1(25), X2(25), X3(25), X4(25), BX(12), BY(120), BXI(120), BYI(120), IP(120)
COMMON DX, DY, NX, NY, NXO, NXI, ITER, N1, N2, N3, N4

SUBROUTINE TO FIND ADJACENT TWO POINTS FOR THE POINT (B2, C2) AND THEN PASSES A CURVE Y = A + BX + CX^2 AND DETERMINES A, B, C. B, C COEFFICIENTS ARE RETURNED TO MAIN PROGRAM TO GET SLOPE OF CURVED BOUNDARY AT THE POINT

IF(I.EQ.1) GO TO 25
DO 10 M=1, NXO
IF(ABS(B2-BX(M)).LE.0.0001.AND.ABS(C2-BY(M)).LE.0.0001) GO TO 12
10 CONTINUE
12 IF(M.EQ.1) GO TO 15
B1=BX(M-1)
C1=BY(M-1)
GO TO 13
15 B1=BX(NXO)
C1=BY(NXO)
13 CONTINUE
B3 = BX(M+1)
C3 = BY(M+1)
IF(M.EQ.NXO) B3=BX(1)
IF(M.EQ.NXO) C3=BY(1)
IF(B3.EQ.B2 .AND. C3.EQ.C2) GO TO 14
GO TO 37
14 B3 = BX(M+2)
C3 = BY(M+2)
GO TO 37
25 DO 30 M = 1, NXI
IF(R2.EQ.BXI(M).AND.C2.EQ.BYI(M)) GO TO 32
30 CONTINUE
32 IF(M.EQ.1) GO TO 34
B1=BXI(M-1)
C1=BYI(M-1)
IF(M.EQ.17) R1=5.8
IF(M.EQ.17) C1=1.74
GO TO 33
34 B1=BXI(NXI)
C1=BYI(NXI)
33 CONTINUE
B3 = BXI(M+1)
C3 = BYI(M+1)
IF(M.EQ.NXI) B3=BXI(1)
IF(M.EQ.NXI) C3=BYI(1)
IF(R3.EQ.B2 .AND. C3.EQ.C2) GO TO 35
GO TO 37

57
35 B3 = B3I(M+2)
   C3 = BYI(M+2)
37 CALL SLO(B1, C1, B2, C2, B3, C3, A, B, C)
   IF (ITER, EQ, 1) WRITE(6,40) I, M, B1, C1, B2, C2, B3, C3, A, B, C
40 FORMAT(3X, I2, I5, 9F10.5)
   RETURN
   END