BOUNDARY LAYER SIMULATOR IMPROVEMENT

December 1984

REMTECH inc.
Huntsville, Alabama
BOUNDARY LAYER SIMULATOR IMPROVEMENT

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Prepared under

Contract NAS8-35976

for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812
FOREWORD

This final report presents work conducted for the Marshall Space Flight Center (MSFC) in response to the requirements of Contract NAS8-35976. The work presented here was performed by REMTECH, Inc., Huntsville, Alabama and is titled, "Boundary Layer Simulator Improvement".

The project manager for this project was Dr. Sarat C. Praharaj. The project was very much aided by the helpful technical support of the NASA contract monitor, Mr. Klaus Gross, and by Mr. A. Krebsbach, both of the Systems Performance Branch of the Mission Analysis Division.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOREWORD</td>
<td></td>
</tr>
<tr>
<td>1.0 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.0 WALL SURFACE ROUGHNESS EFFECTS</td>
<td>6</td>
</tr>
<tr>
<td>2.1 BACKGROUND</td>
<td>6</td>
</tr>
<tr>
<td>2.2 ROUGHNESS OPTIONS</td>
<td>7</td>
</tr>
<tr>
<td>2.3 EXAMPLES</td>
<td>12</td>
</tr>
<tr>
<td>2.4 DISCUSSIONS</td>
<td>28</td>
</tr>
<tr>
<td>2.5 REFERENCES</td>
<td>28</td>
</tr>
<tr>
<td>3.0 RELAMINARIZATION</td>
<td>30</td>
</tr>
<tr>
<td>3.1 BACKGROUND</td>
<td>30</td>
</tr>
<tr>
<td>3.2 RELAMINARIZATION CRITERION</td>
<td>31</td>
</tr>
<tr>
<td>3.3 EXAMPLES</td>
<td>34</td>
</tr>
<tr>
<td>3.4 DISCUSSIONS</td>
<td>41</td>
</tr>
<tr>
<td>3.5 REFERENCES</td>
<td>41</td>
</tr>
<tr>
<td>4.0 PARTICLE EFFECTS</td>
<td>42</td>
</tr>
<tr>
<td>4.1 BACKGROUND</td>
<td>42</td>
</tr>
<tr>
<td>4.2 PARTICLE OPTIONS</td>
<td>44</td>
</tr>
<tr>
<td>4.3 EXAMPLES</td>
<td>49</td>
</tr>
<tr>
<td>4.4 DISCUSSIONS</td>
<td>50</td>
</tr>
<tr>
<td>4.5 REFERENCES</td>
<td>55</td>
</tr>
<tr>
<td>5.0 THRUST LOSS REEVALUATION</td>
<td>56</td>
</tr>
<tr>
<td>5.1 BACKGROUND</td>
<td>56</td>
</tr>
<tr>
<td>5.2 PROCEDURE FOR THICK BOUNDARY LAYERS</td>
<td>58</td>
</tr>
<tr>
<td>5.3 EXAMPLES</td>
<td>64</td>
</tr>
<tr>
<td>5.4 DISCUSSIONS</td>
<td>71</td>
</tr>
<tr>
<td>5.5 REFERENCES</td>
<td>71</td>
</tr>
<tr>
<td>6.0 RECOMMENDATIONS</td>
<td>72</td>
</tr>
<tr>
<td>6.1 ANALYTICAL</td>
<td>72</td>
</tr>
<tr>
<td>6.2 NUMERICAL</td>
<td>73</td>
</tr>
<tr>
<td>6.3 EXPERIMENTAL</td>
<td>74</td>
</tr>
</tbody>
</table>

APPENDIX

LISTING OF THE UPDATED SUBROUTINES IN BLIMPJ
Section 1.0
INTRODUCTION

The primary goal of the work reported here was to improve the existing Boundary Layer Integral Matrix Procedure, Version J (BLIMPJ). BLIMPJ has been used in the industry as a rigorous boundary layer program in connection with the existing JANNAF reference programs such as ODE and TDK. It is capable of treating two-dimensional and axisymmetric nozzles with a variety of wall boundary conditions which include regenerative and transpiration cooling as well as ablation wall materials. The improvements described herein have potential use in the design of the future Orbit Transfer Vehicle (OTV) engines.

The projected engine design for the OTV would utilize an expander cycle operation mode. In this mode, heat energy obtained through a regeneratively cooled wall is used to drive the turbines and pumps. O₂-H₂ propellant system is used to react in the combustion chamber at pressure levels of 1500-2000 psia at a mixture ratio of 6. The reaction products are expanded through a nozzle of large area ratio, ranging from 400 to 3000. Although the above chamber pressures and O/F ratio for a O₂-H₂ system are not uncommon for the currently operating Space Shuttle main engines (SSMEs), the area ratio is only of the order of 80. These high chamber pressure expander cycle engines depend primarily on the heat energy transmitted from the combustion products through the thrust chamber wall. The larger the regenerative heat transfer the higher the chamber pressure which in turn permits larger area ratio motors. These engines


and the associated interior nozzle flowfields are outside the range of current engineering experience. The heat transfer to the nozzle wall is affected by such variables as wall roughness, relaminarization, and the presence of particles in the flow. The motor performance loss for these nozzles with thick boundary layers is inaccurate using the existing procedure coded in BLIMPJ. Flow expansion within large area ratio nozzles and associated low pressures and temperatures may produce two-phase flow conditions (liquid droplets or ice crystals) adjacent to the wall especially in connection with strongly cooled walls. The presence of such particles will have some effect on the friction and heat transfer mechanism within the boundary layer. Moreover, there are discussions in the technical community of replacing the nozzle wall around the throat by an ablative wall. This would reduce high heat-transfer to the nozzle throat because of ablation while introducing the ablation products in the nozzle boundary layer and the inviscid part of the nozzle flowfield. All these modifications and innovations require investigations and implementation in BLIMPJ code of the following simplified analytical formulations:

- Wall surface roughness simulation and its impact on heat transfer and shear effects.
- Prediction of relaminarization regions with approximations on heat transfer and friction along the wall.
- Presence of particles in the boundary layer and their impact on heat transfer and friction.
- Re-evaluation of the existing boundary layer thrust loss calculation method for nozzles with large area ratios, experiencing thick boundary layers at low density and high Mach number flow situations.

Various versions of BLIMPJ were received from Marshall Space Flight Center (MSFC). Apart from the version available at REMTECH, a total of three additional versions including the (1) Aerotherm, (11) MSFC, and (111) mini-versions was
## TABLE 1.1 BLIMPJ SUBROUTINES

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*ENTRY POINT ROUTINE*

---

Routine Modified Or Added By REMTECH
obtained. It was recommended by MSFC to use the mini-version for making modifications to the code. The mini-version is a cleaner and shorter version of the code and has fewer subroutines when compared with the Aerotherm version in Table 1.1. In order to access the code at various subroutines for modifications, a macro flow diagram was prepared and is provided in Fig. 1.1.

The various tasks described earlier are discussed in the following sections. Section 2 discusses the effects of wall roughness on skin friction and heat transfer. Section 3 highlights the mechanism and effects of relaminarization, whereas Section 4 discusses the effects of particles on skin friction and heat transfer rate on the nozzle wall. Section 5, on the other hand, focuses on the re-evaluation of the existing boundary layer thrust loss calculation method for nozzles with large area ratios experiencing thick boundary layers. The last four sections described above are self-contained in that the technical discussion for each item along with the corresponding figures and list of references are contained in that section, independent of any other section. These sections also describe applications of the various modules in a composite fashion if more than one effect needs to be considered. Finally, Section 6 makes recommendations both in the areas of analytical and experimental techniques for future work.
BLKDATA \{ \text{BLOCK DATA} \}

ERP \{ \text{FUNCTIONS} \}

- OUTPUT
- ROUGH
- PARTCL
- POINTS
- FISLEQ

- FUNCTIONAL BLOCKS
  - BLMAIN

- ENTRY POINT ROUTINES
  - FUNKS
  - PRINT

- ROUTINE MODIFIED OR ADDED
  - ENTRY POINT ROUTINES

Fig. 1.1 BLIMPJ Mini-Version Macro Flow Diagram

Routine Modified Or Added By REMTECH
2.1 **Background**

The importance of wall surface roughness which increases the resistance to fluid flows has been recognized for many years. One of the principal parameters influencing the surface heat transfer to a rough wall is the roughness height, \( k \).

The problem of modeling turbulent flow over rough surfaces has been divided into three regimes:

Regime I: **Smooth** - The roughness size is so small that the protrusions are contained within the laminar sublayer. The surface skin friction and heat transfer are not changed from smooth surface values.

Regime II: **Transitional** - Some of the roughness elements protrude outside of the laminar sublayer. The skin friction and heat transfer are increased above the smooth surface values.

Regime III: **Fully Rough** - All surface roughness elements protrude outside of the laminar sublayer. The increase in skin friction is primarily a result of form drag of the roughness elements.

H. Schlichting (Ref. 1) summarizes all the early work on rough wall measurements in turbulent flow and describes the evaluation of the "equivalent sand grain roughness height", \( K_s \), which is based on the early work of Nikuradse (Ref. 2). Many theories and correlations, following Nikuradse, employ the parameter \( K_s \). Defining \( K_s \) for a given surface condition is not a straightforward task. Schlichting (Ref. 1) describes procedures for a given array of roughness elements. Recently, Dirling (Ref. 3) has devised a correlation for \( K_s \) and has applied it to the prediction of nosetip shape change. In modeling the effects of roughness on skin friction, the velocity profile through the boundary layer has
been correlated with surface roughness of sand. Data and empirical correlations have been developed for other types of roughness elements to obtain the equivalent sand roughness. That is, the sand roughness which yields the same velocity profile is the roughness of interest. There is considerable uncertainty in the determination of the equivalent sand roughness for roughness elements which are randomly shaped and spaced. Physical spacing, relating to the type of cavity flow that is established, the inclination of the roughness element surface to the flow direction, and the increased surface area are some of the important elements in the calculation of $K_s$. Figure 2.1 shows the correlation developed by Dirling (Ref. 3). The roughness density parameter $A$ is defined as shown on the figure, where $A_s$ is the windward surface area of the roughness, $A_p$ is the projected area of the roughness in the flow direction and $D$ is the inverse square root of the roughness elements per unit area. The correlation shown is derived from velocity measurements and is applicable for rough wall skin friction calculations. For the analysis given here, the $K_s$ parameter is not investigated, but instead, it is assumed that $K_s$ is given.

2.2 Roughness Options

The purpose of the task in this section is to determine which simplified correlations are appropriate for application in the BLIMPJ computer code. The correlations available in the literature, which perform "point" calculations based on local edge and wall quantities, were reviewed. The significance of "point" calculations lies in the fact that the history effects in the boundary layer at other points do not affect the calculation at the point under consideration. An excellent paper by Seidman (Ref. 4) reviewed some of these correlations and compared them with incompressible and compressible data. The appropriate options performing "point" calculations are given below:
Fig. 2.1 Roughness Density Effect On Equivalent Sand Roughness Depth
The mathematical expressions are given in Ref. 4. There are two options for calculating skin friction and four possible combinations that can be used to calculate heat transfer rate. For reasons described in the next subsection, Hill's correlation was not coded in BLIMPJ. As a result, only two combinations for heat-transfer rate calculation remained. The mathematical expressions for the above options were taken from Ref. 4 and are listed in Table 2.1 along with the input-output variable list that is used in the roughness subroutine. The expression (A.1) in Table 2.1 contain the calculation of a compressibility factor in terms of the enthalpy ratio. Although, in the original paper (Ref. 4) the corresponding temperature ratios are chosen, it is customary to use the enthalpy ratios instead of temperature ratio in order to include real gas effects. This would be appropriate for the \( \text{O}_2-\text{H}_2 \) reactive system to be used in the future OTV motor, where the combustion temperatures are in the order of \( 6000^\circ \text{R} \) and real gas effects exist.

Another option by Cebeci was selected to simulate the effects of a rough wall on the boundary layer and to account for "history" effects in the boundary layer. In Ref. 8, the turbulent mixing length of the eddy viscosity expression is modified for the inner region of a two-layer turbulence model to include the effects of surface roughness. Assuming that the velocity profiles for smooth and rough walls are similar, the expression for the mixing length given by

\[
\lambda = 0.4 \gamma \left( 1 - \exp \left( -y/A \right) \right)
\]

is modified and rewritten as,

\[
\lambda = 0.4 \gamma \left( 1 - \exp \left( -y/A \right) \right)
\]
TABLE 2.1
ROUGH WALL HEAT TRANSFER OPTIONS

Options 1 and 2:

Skin friction compressibility (Young)

\[
\frac{C_f}{C_{f1}} = 0.365 \left( \frac{H_e}{H_{aw}} \right) + 0.635 \left( \frac{H_e}{H_w} \right) \quad (A.1)
\]

Incompressible rough wall skin friction
Option (1) Prandtl-Schlichting

\[
C_{f1} = \left[ 2.87 + 1.58 \log_{10}(X/k) \right]^{-2.5} \quad (A.2)
\]

Option (2) Droblenkov

\[
C_{f1} = 0.0139 (X/k)^{-1/7} \quad (A.3)
\]

Rough surface turbulent Stanton Number (Seidman)

\[
St = \frac{C_f}{2} \left[ 1 + A \left( \frac{C_f}{2} \right)^{0.725} (Re_k)^{0.45} (Pr)^{0.8} \right]^{-1} \quad (A.3)
\]

where \( A = 0.52 \) nominal and range from 0.45 to 0.7 (Owen & Thomson), and \( C_f \) is obtained from Equ. (A.1).

Transition criterion (Fenter)

\[
\eta_k = \frac{\rho_W U_{\tau k}}{\mu_W} \quad \text{where} \quad U_{\tau} = U_e \sqrt{\frac{C_f}{2}} \frac{\rho_e}{\rho_W} \quad (A.4)
\]

\[
\begin{align*}
\eta_k &< 5 \quad \text{Smooth} \\
5 &< \eta_k \leq 100 \quad \text{Transitionally rough} \\
100 < \eta_k \quad \text{Rough}
\end{align*}
\]
TABLE 2.1 (Continued)

INPUT VARIABLES

$X =$ Running length (ft)
$k =$ Sand roughness height (ft)

$H_{aw} =$ Aidabatic wall enthalpy (Btu/lbm)
$H_e =$ B.L. edge enthalpy (Btu/lbm)
$H_w =$ Wall enthalpy (Btu/lbm)
$\rho_e =$ B.L. edge density (lbm/ft$^3$)
$\rho_w =$ Wall density (lbm/ft$^3$)
$\mu_w =$ Wall viscosity (lbm/ft-sec)
$\mu_e =$ Edge viscosity (lbm/ft-sec)
$Pr =$ Prandtl number (Edge)

ICF = Skin friction flag 1 ----> Prandtl-Schlichting
2 ----> Drobenkov

$St_s =$ Smooth wall Stanton number
$U_e =$ B.L. edge velocity (ft/sec)

OUTPUT

$C_f =$ Rough wall skin friction coefficient
$St =$ Rough wall Stanton number

PCT = Percent of transition to fully rough
\[ I = 0.4 \left( y + \Delta y \right) \left[ 1 - \exp \left\{ - \frac{(y + \Delta y)}{A} \right\} \right] \]  \hspace{1cm} (2.2)

where the coordinates are displaced by an amount \( \Delta y \). He expresses \( \Delta y \) as a function of an equivalent sand-grain roughness parameter \( K_s^{+} \) \( ( \equiv K_s \frac{U_{ \tau}}{\nu} ) \), i.e.,

\[ y = 0.9 \frac{(\nu/\tau)}{K_s^{+}} \left( \frac{K_s^{+}}{K_s^{+}} \exp \left\{ - K_s^{+}/6 \right\} \right) \]  \hspace{1cm} (2.3)

This expression is valid for \( 4.535 < K_s^{+} < 2000 \), with the lower limit corresponding to the upper bound for a hydraulically smooth surface.

2.3 Examples

In order to illustrate the validity of the roughness options against measured data, first the skin-friction and heat-transfer data were collected from the original report by Pimenta, Moffat and Kays (Ref. 5). The two sets of data collected were for flat plates at moderate freestream velocities. Since BLIMPJ could not be run for external flow situations, BLIMPK (applicable for external flow) was modified to include the roughness options 1 and 2 and was run for an equivalent sand roughness of \( K_s = 0.002583 \) ft. employing the only-resident, Kendall's turbulence model. Figure 2.2 contains the two cases for which the two skin-friction options were used. It is seen that the two options bracket the data, although Drobenkov's approach is closer to the data. Figure 2.3, on the other hand, shows the heat-transfer computations based on Seidman's Stanton number correlation. Again, the two skin-friction options along with Seidman's heat transfer correlation bracket the heat-transfer data, although one combination seems to predict the data better than the other one. Another Stanton number correlation by Hill was checked out (Fig. 2.4a), by varying the value of \( A \) in Hill's correlation. It is found that Hill's correlation underpredicts the data considerably. Figure 2.4b, on the other hand, gives comparison of
Fig. 2.2 Comparison Of Skin-Friction Correlation With Data
Fig. 2.3 Comparison Of Stanton Number Correlation With Data
Fig. 2.4 Comparison Between Stanton Number Correlation And Data With Variable Parameter A
Seldman's correlation with heat-transfer data for three values of $A$. The nominal value of 0.52 for $A$ seems to predict the data quite well.

The rationale for checking the roughness heat-transfer options against data in external flow is a result of little or no data being available for nozzles having rough walls. Some roughness data obtained in an MSFC test on a 40-K sub-scale regenatvely cooled nozzle (Ref. 6) were communicated to the authors. On closer examination, it was found, however, that the nozzle was rough at the throat region only. In other words, the equivalent sand roughness is not constant throughout the nozzle and none of the roughness options described here applies to such a situation. Moreover, the concept of equivalent sand roughness breaks down, since similarity in the boundary layer can no longer be satisfied. Instead, to exercise the three roughness options in BLIMPJ, the code was modified to integrate all the options. In the meantime, the geometry package of a generic OTV nozzle was received (Ref. 7) along with the wall temperatures and wall pressures (given in Fig. 2.5). The code was first checked out for the OTV smooth wall situation using two different turbulence models including the Kendall and Cebeci-Smith models. The heat transfer distributions on the nozzle wall are given in Fig. 2.6. As noted by other investigators, the Cebeci-Smith model predicted lower heating rates. A fictitious value of the equivalent sand roughness of 0.00125 ft. was used to run BLIMPJ for the OTV nozzle using first the roughness option 3 (which used a modification to Cebeci-Smith turbulence model). An example of the namelist tape for BLIMPJ using a roughness option is given in Table 2.2. The heat-transfer results are plotted in Fig. 2.9 and compared with those for a smooth wall. Heat rates are approximately 3 times higher for the rough wall than for the smooth wall in the peak heating region occurring around the throat. Although the skin friction and heating rate values are quite high for a rough nozzle locally in the throat region, the integrated values of
Fig. 2.5  Input Wall Pressure And Temperature Variation For A Typical OTV Nozzle
Typical OTV Engine

\[ p_c = 2010 \text{ psi}, \text{ Area Ratio} = 1293 \]

--- Kendall Turbulence Model
--- --- Cebeci-Smith Turbulence Model

Wall Heat Transfer Rate, Btu/ft\(^2\)-sec

Normalized Axial Distance \( X/RSTAR \) From BLIMPJ

Fig. 2.6 Comparison Of Two Turbulence Models
### TABLE 2.2 Example Of Namelist Input For Roughness Option

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**Equivalent Sand Roughness, RK = 0.00125 ft.**
Roughness Option, ICF = 2
these quantities over the whole nozzle in relation to the smooth wall values are much lesser in magnitude. Since this roughness option modifies the turbulence model due to the presence of roughness, Fig. 2.7a was prepared to compare the velocity profiles between the rough and smooth wall cases at the nozzle throat. Figure 2.7b, on the other hand, compares the velocity profiles given in normalized y-coordinates. It is clearly seen from both the plots that not only the boundary layer is thicker but is pushed upward as suggested by Cebeci. This phenomenon has also been observed experimentally be Volsinjet (Ref. 9) and is reproduced in Fig. 2.7c as evidence.

The other two roughness options were also exercised for the same OTV nozzle with the above equivalent sand roughness height. Since the enthalpies in the expression (A1) in Table 2.1 are with respect to \( T = 0^\circ R \) as the reference, the concept was modified in BLIMPJ to integrate \( C_p \) with respect to \( T \) from \( T = 0^\circ R \) to either the wall or the edge temperature to calculate \( H_w \) or \( H_e \), respectively. Noting that \( C_p \) is calculated as a function of \( T \) in the boundary layer, an extrapolation was made on \( C_p \) to a value down to \( T = 0^\circ R \) as shown in Fig. 2.8 for the OTV nozzle throat location. A numerical integration was performed within the code to calculate all the required enthalpies, and consequently, to compute skin friction and heat transfer rates. Figures 2.9, 2.10 and 2.11 compare heat flux, Stanton number and skin friction coefficient distribution using all the three available roughness options with \( K_s = 0.00125 \) ft. The comparison among the three options is quite reasonable near the throat and downstream of the throat. However, some disparities remain in Stanton number and skin friction in the subsonic contraction section of the nozzle, particularly for Options 1 and 2.
- Smooth
- Rough
  - Cebeci Roughness Option
  - Sand Roughness Height = 0.00125 ft.

NOTE: Both calculations use Cebeci-Smith turbulence model.

Fig. 2.7a Comparison Of Velocity Distribution Between Rough And Smooth Walls At The OTV Nozzle Throat
Fig. 2.7b Comparison Of Velocity Distribution Between Rough And Smooth Walls At The OTV Nozzle Throat
Fig. 2.7c Typical Velocity Profiles Given By Voisinet (Ref. 9)

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<tr>
<th>RUN</th>
<th>K (INCH)</th>
<th>m (LBS/FT^2/SEC)</th>
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<tr>
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<tr>
<td>4</td>
<td>0.049</td>
<td>0.030</td>
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</table>

K = Equivalent Sand Roughness Height

\( \dot{m} = \) Mass Transfer Rate
Fig. 2.8 Variation Of Specific Heat Of $\text{H}_2/\text{O}_2$ Reaction Products With Static Temperature At OTV Nozzle Throat
Fig. 2.9 Comparison Of Heat Flux Distribution On The Wall Of The OTV Nozzle Wall Using Various Roughness Options
Fig. 2.10 Comparison Of Stanton Number Distribution On The OTV Nozzle Wall Using Various Roughness Options
Fig. 2.11  Comparison Of Skin-Friction Coefficient Distribution On The OTV Nozzle Wall
2.4 Discussions

The correlations and modifications incorporated in BLIMPJ to account for roughness would be very good candidates for evaluating the thermal losses on the OTV nozzles. The results given in Figs. 2.9-2.11 for a fictitious sand roughness show that although the comparison of $q_r$, $St$ and $C_f$ on the OTV wall between the three options is reasonable, there is still about 20 to 30 percent variation in the peak heating areas of the nozzle. It must be noted that certain engineering approximations have been incorporated in the evaluation of $H$ in the calculation of the compressibility factor, $C_f/C_{f_h}$ in Options 1 and 2. The Option 3, on the other hand, is a more systematic modification of the turbulence model to account for wall surface roughness. It not only gives the heat transfer at the wall, but also provides the details of the turbulence scale change effects within the boundary layer. The effects of wall roughness on the law-of-the-wall results have been noted by others (Ref. 8) to cause a downward shift in the profiles with increased roughness. This meant that for the same value of the law-of-the-wall coordinate, $y^+$, the velocity is lower. The same phenomenon was observed in the work presented earlier. One item in the Cebeci roughness model (Ref. 8) is the upper limit of 2000 for the equivalent sand-grain roughness parameter, $K_s$ for which the modification of the length scale is valid. In the code modification, a value of 4000 was used for running the case presented earlier. The validity of this limit must be examined experimentally. Suggestions for future work in this area appear in Sec. 6.

2.5 References


7. Generic OTV Nozzle Geometry - Obtained from Mr. Klaus Gross, EL 24, Marshall Space Flight Center, Al.


Section 3.0
RELAMINARIZATION

3.1 Background

The prediction of relaminarization phenomena is one of the strongest tests of validity of the turbulence models. Relaminarization is basically a reversion from turbulent to laminar boundary layer. Relaminarization is principally caused by severe flow acceleration effects that typically occur internally in the convergent portion of nozzles where subsonic flow exists; in the divergent portion of nozzles where supersonic flow is dominant; and externally in expanding supersonic flows around bodies such as ogive-cylinder and sphere-cylinder configurations. Some of the theoretical and experimental work is reported in Refs. 1-5. Many of these works are experimental in nature. Patel and Head in Ref. 1 have shown experimentally that quite large departures occur from the universal inner-law velocity distribution in the presence of severe favorable pressure gradients in turbulent boundary layers. The work of such investigators as Launder in Ref. 2 has described investigations generally similar to that reported by Patel et al. (Ref. 1), but emphasizes the measurements of turbulence and mean velocity profiles, and covers the complete reversal transition process. In the measurements of Back, Cuffel and Massler (Ref. 3), a reduction in heat-transfer below values typical of a turbulent boundary layer was found when the values of the parameter, $K = \frac{\mu_e}{\rho_e U_e} \frac{dU_e}{dx}$ exceeded about 2 to 3 x $10^6$. One of the best documented experimental investigations of compressible boundary layer relaminarization is that reported by Nash-Webber (Ref. 4). In this work, an instrumented flat plate was tested in the presence of a variety of upper-wall profiles. The profiles were chosen to impose various pressure gradients on the flat-plate turbulent boundary layer. He deduced a comprehensive criterion for
relaminarization, which will be discussed in detail in the following subsection. It was noticed that acceleration effects tend to keep flow laminar beyond the normally-prescribed transition value.

3.2 Relaminarization Criterion

The various turbulence models in BLIMPJ were derived based on zero to moderate pressure gradients existing in the flow direction and thus, would not be able to predict laminarization for severe favorable pressure gradients. However, a treatment done by Adams et al. (Ref. 5) using the IKET (Integral form of the Kinetic Energy of Turbulence) approach was able to predict laminarization on the shoulder of a sphere-cylinder configuration tested at M∞ = 9 in Tunnel F at AEDC. It was also pointed out by Adams that BLIMP could not predict either the onset of relaminarization or the degree of relaminarization.

The acceleration parameter which is a potential candidate for relaminarization and chosen for this study is that due to Nash-Webber (Ref. 4). According to Ref. 4, the acceleration parameter is defined as,

$$K = \frac{\mu_w}{\bar{p}_w U_e} \frac{dU_e}{dx} \quad (3.1)$$

Where the subscript 'w' denotes wall conditions, the subscript 'e' denotes boundary-layer edge conditions, and the barred quantities are time-averaged values. The importance of this parameter is illustrated in Ref. 4 and is reproduced here in Fig. 3.1 for completeness. According to this, the numerical value of K can be used as an indicator for probable occurrence of relaminarization provided that the momentum thickness Reynolds number based on edge conditions is sufficiently low. The recommended boundary value for the onset of relaminarization in Fig. 3.1 seems to be somewhat lower than the threshold recommended by Launder
Fig. 3.1 Turbulent-Laminar Transition Boundary
(Ref. 2) and was curve-fitted by a quadratic polynomial given by

\[ K = aR^2 + bR + C \] (3.2)

where

\[ a = 8.935 \times 10^{-14} \]
\[ b = 2.239 \times 10^{-10} \]
\[ c = 1.0248 \times 10^{-6} \]

The end of relaminarization (complete laminar condition) is the limit (Fig. 3.1) suggested by Kline (given in Ref. 4) where there is complete suppression of turbulence production.

Currently, BLIMPJ contains a criterion for transition where a specified or input value of \( \text{Re}_{e\theta} \) is used to trigger transition. When the prescribed \( \text{Re}_{e\theta} \) exceeds the turbulent transport properties are introduced into the calculations. In order to simulate a transition zone, these transport properties are reduced by a factor varying between 0 and 1 for complete laminar and complete turbulent flow respectively. A linear relationship that is used for varying \( \varepsilon_m \) (eddy viscosity) is given by

\[ \varepsilon_m = I(S) \cdot \varepsilon_m \text{(ref)} \] (3.3)

where \( \varepsilon_m \text{(ref)} \) is the reference value for complete by turbulent flow and

\[ I(S) = \begin{cases} 
-1.0, & S_+ < S < 2S_+ \\
\frac{S}{S_+}, & S 
\end{cases} \]

with

\[ I(S) = 0 \text{ for } S \leq S_+ \]
\[ I(S) = 1 \text{ for } S \geq 2S_+ \]

where \( S \) is the running length and \( S_+ \) is the running length up to the point of transition on the body. It is suggested by Ref. 6 that a flat plate zero pressure gradient value of \( \text{Re}_{e\theta} = 360 \) serves as a nominal estimate. Now, in order to
account for flow acceleration effects, the recommended transition boundaries described in the previous paragraph and given in Fig. 3.1 has been coded in BLIMPJ. For acceleration parameters \( K \) less than \( 1 \times 10^{-6} \), Eq. (3.3) is used to check the state of the boundary layer. However, for acceleration parameter greater than \( 1 \times 10^{-6} \), the new criterion given in Fig. 3.1 and described in the previous paragraph is used. In order to simulate a relaminarization zone, the values of \( K \) are used instead of \( S \) in Eq. (3.3). \( K_1 \) and \( K_2 \) at any \( Re_e, \theta \) corresponding to the beginning and the end of relaminarization have been coded in BLIMPJ according to the following formula:

\[
\varepsilon_m = \frac{K - K_1}{K_2 - K_1} \cdot \varepsilon_m (\text{ref}) \tag{3.4}
\]

It should be observed that \( \varepsilon_m \) linearly varies with \( K \) from a turbulent \( \varepsilon_m (\text{ref}) \) value to a value of zero for completely laminar flow. Incidentally, the percent relaminarization value is

\[
PCT = \frac{K - K_1}{K_2 - K_1} \times 100 \tag{3.5}
\]

This additional logic in BLIMPJ only applies for turbulent flow. Depending on the value \( K \), a value of turbulent eddy viscosity is calculated and fed into the boundary layer calculations.

3.3 Examples

In order to check the limits of relaminarization, an example of flow over the Shuttle clean ET configuration was considered. The aeroheating data were measured on a 0.0175 scale clean ET model tested at \( M_\infty = 7.3 \) in the Ames HWT facility. The measured data had been compared against turbulent and laminar cal-
culations made by other aeroheating codes in Fig. 3.2. Because of tripping of
the boundary layer due to the ET triple-cone nose, the boundary layer becomes
turbulent over the ogive. The flow remains turbulent up to X/L = 0.2, becomes
fully laminar at X/L = 0.25, and finally turbulent again beyond X/L = 0.4. The
acceleration parameter in Eq. (3.2) was examined after calculating the pressure
gradient from the method-of-characteristics procedure and then the acceleration
parameter, and was plotted in Fig. 3.3 as a function of X/L. It is evident that
the parameter peaks at X/L = 0.2 and drops off very rapidly as X/L is increased.
Another way of plotting this information is shown in Fig. 3.4, where K is plot-
ted vs. Re_e,\theta. From both the figures, it is obvious that the peak value is not
higher than the threshold value of K(=1.58 x 10^{-6}) at Re_e,\theta = 1550. This indi-
cates that the acceleration parameter is not high enough to trigger relaminar-
ization, even though the data seem to suggest it. A similar observation was made
by Adams (Ref. 5) for the sphere-cylinder case. Even though his IKET approach
as well as the measured data seemed to show relaminarization, the Nash-Webber
correlation did not strongly suggest that.

In order to examine the validity of this correlation for nozzle boundary
layers, the relevant data taken on a 10^n - 10^n half angle conical nozzle by Back
et al. (Ref. 3) were examined in Fig. 3.5. Wall pressures calculated by TDK
(Ref. 7) were input to the REMTECH version of BLIMPJ, and the heat-transfer
(Fig. 3.5.B) along with the acceleration parameter distributions (Fig. 3.5.C)
were calculated. The acceleration parameter based on edge quantities, K_e, com-
pared quite well with Back's calculations. The K_e peak occurring upstream of the
nozzle throat was not predicted by BLIMPJ because of inadequate wall pressure
definition in this region. The heat-transfer calculations were made by using
the coded relaminarization criterion. The momentum thickness Reynolds number,
Re_e,\theta distribution compared well with Back's calculations. The K_w
vs. \( R_{0} \) correlation for relaminarization [Eq. (3.2)] suggested that the turbulent boundary layer was on the verge of relaminarization at the tangency point located at the juncture of the conical and curved portions of the nozzle contraction section. It is seen from Fig. 3.5.B, however, that the prediction is consistently higher than the measured data and that the boundary layer is predicted to be turbulent throughout the contraction section of the nozzle, but not partially relaminarized as evident from the measured data and as pointed out by Back's analysis. Back et al. point out in their paper that if \( K_{e} \) is higher than 2 to 3 \( \times 10^{-6} \) relaminarization occurs. Since \( K_{e} \) satisfies this criterion in the contraction portion of the nozzle as evident from Fig. 3.5.C, it suggests that relaminarization occurs. The currently coded criterion, which is different from the above criterion and is more definite in structure, is not able to quantify the degree of laminarization as well as suggested by Nash-Webber (Ref. 4).

An example of the name list input to turn on the relaminarization flag is given in Table 3.1.

3.4 Discussions

The Nash-Webber criterion for relaminarization worked only marginally for the external flow situations, whereas for the limited measured data available on nozzles where relaminarization occurs in the boundary layer, this criterion seems to be only approximate. Without going through an extensive analysis such as the IKET-type model (Ref. 5), the current approach needs to be modified somewhat for engineering calculations. In addition, relaminarization can be predicted in the presence of roughness. In order to accomplish this, the roughness option 3 due to Cebeci must be input (RK = ..., ICF = 3) along with the relaminarization option (ILAMIN = 1). The occurrence of relaminarization will tend to reduce the turbulence length scales whereas the presence of wall rough-
$M = 7.3$
$Re_{ft} = 4.8 \times 10^6$
$\alpha = 0^\circ$, $\beta = 0^\circ$
Test IH 68 (Ames HWT)
Runs 210, 213, 214

Peripheral Angles,

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Theory (Turbulent)

- Modified MINIVER Program (MINETT)
- Options:
  - 39.38° Cone Shock
  - MOC Pressure Correlation
  - Spalding-Chi Skin-friction Correlation
  - Reynolds Number Correction Factor Used in Spalding-Chi Correlation
  - von Karman Reynolds Analogy Factor
  - Colburn Reynolds Analogy Factor

---

Fig. 3.2 1.75% Model Space Shuttle External Tank Heat-Transfer Distribution.
Fig. 3.3 Plot of Acceleration Parameters Based On Edge And Wall Conditions And Momentum Thickness Reynolds Number Vs. X/L For The Shuttle ET Model
Fig. 3.4 Acceleration Parameter Vs. $Re_{e,\theta}$ for the Shuttle ET Shoulder Region
Nozzle contraction
area ratio, $c_c = 9.87$

Nozzle expansion
area ratio, $c_e = 6.52$

$r_{throat} = 0.795''$
$r_c/r_{throat} = 2.5$, $r_c = 1.987''$

Fig. 3.5 Relaminarization Analysis Of The Boundary Layer Flow In Back Et Al. $10^6 - 10^6$ Half Cone Angle Nozzle
TABLE 3.1 Example Of Namelist Input For Relaminarization

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Relaminarization Flag, ILAMIN = 1
ness will tend to increase it. Although the code has not been exercised extensively for both being present in a nozzle, it is believed that the code would handle it adequately.

3.5 References


Section 4.0

PARTICLE EFFECTS

4.1 Background

The study of the boundary layer flow containing particles (in the fluid-particle systems) is of special interest because of the influence of the particles on the wall shear and heat transfer, the possible tendency of particles to collect near a wall, and the problem of particle impingement on the wall. Typical data (Ref. 1) in the chemical engineering literature correlated in terms of voidage show that there is negligible effect caused by solid particles until the volume percent of solids reaches 0.05 percent, but a very marked increase occurred in heat transfer for higher solids loading. In fact, Nusselt number increases by factors as high as eight have been reported for the addition of particles to a flowing gas (Ref. 1). Material deposited on the nozzle wall also represents a loss in performance, because the resulting rough surface causes increased skin friction losses.

Correlation of gas-particle heat transfer in terms of solids loading and, sometimes, tube diameter (for pipe flow) is not entirely satisfactory, since such correlations ignore the effect of particle size. The differences in the data reported by Leva (Refs. 2 and 3) suggest that the enhancement in heat transfer is at least partially associated with disturbance of the laminar sub-layer by particles, causing a local increase in heat transfer. On the other hand, reduction in heat transfer and shear stress have been reported in Ref. 4 for large populations of the smallest particles, less than 1μ, by primarily displacing the boundary layer and thereby reducing thermal gradients.

The laminar particle-gas boundary layer has been investigated by Marble (Ref. 5), Soo (Ref. 6), Tabakoff and Hamed (Ref. 7) using momentum integral
techniques. In all these studies, analytical expressions have been found relating wall heat transfer and shear with particles to those without the particles. These investigations have determined that the introduction of particles leads to an increase in the gas boundary layer thickness. In addition, it was found that the gas boundary layer characteristics are more sensitive to particle concentration than any other particulate flow parameter. It has been shown that for gas-particle flow systems, the wall heat transfer and skin friction are related to non-particle flow by a non-dimensional parameter called the "momentum range" which depends on particle size, the fluid viscosity, the fluid velocity and the distance from the leading edge, and another quantity called the "particle momentum interaction parameter", which depends on the ratio of particle mass density to fluid mass density.

Particulate-laden turbulent boundary layer flows in nozzles have not been understood completely and substantial empiricism must be employed to estimate the effects of particle concentration, particle size, density, pressure and entropy gradients on wall shear and heat transfer rate. Tien (Ref. 8) analyzed the increase in heat transfer due to differences in the gas and particle temperatures in boundary layer regions, under the assumptions of incompressible, constant property flow with no radiation or velocity lag effects and no effect of the particles on the gas flowfield. In this case, there is an increase in heat transfer rate while the flow is developing in the pipe. Soo and Tien (Ref. 9) considered particle motion in a turbulent fluid stream with emphasis on the effect of wall interference. The high particle intensity in wall regions increases the heat transfer by increasing the particle to gas heat transfer rates. Disruption of the gas laminar sublayer by particle motion further increases the local heat transfer. Also, if temperatures are high enough for radiation to occur, the radiation from particles to colder walls causes additional
heat transfer. Farbar and Morley (Ref. 10) also concluded from their experimental work on flowing gas-solids mixtures in a circular tube that the use of solids in gaseous heat transfer systems may prove to be advantageous when an increase in the heat transfer rate is desired without any increase in the heat transfer area. It was concluded from this study that the gas-side heat transfer factor increases rapidly for solids loading ratios greater than unity. The solids affect both the gas boundary layer and the heat capacity of the flowing mixture. On the other hand, for solids loading ratios of unity or less, a transitional region exists in which the effect is primarily one of increased heat capacity.

4.2 Particle Options

The various options integrated in BLIMPJ fall into the following two categories:

4.2.1 Laminar Boundary Layer-Particulate Flow

The approach used in the modification of BLIMPJ to account for the presence of particles and their effect on wall shear and heat transfer is taken from the work of Marble (Ref. 10). Marble developed an expression for the shear coefficient from an integral momentum solution of the laminar boundary layer equations, particle continuity and momentum equations for an incompressible flat plate flow. The final expression for the case where $\lambda \sqrt{x} < 1$ is given in Table 4.1. The applicable momentum range, $\lambda \sqrt{x}$, in the OTV-type nozzles would fall basically in this category. We recognize in Eq. (B.1) of Table 4.1 $C_f_0$ as the shear coefficient for the fluid boundary layer without particles. In his original paper, Marble used
Since BLIMPJ provides a shear coefficient for clean flow, that value was used as reference instead to calculate the shear coefficient for the gas-particle system. The quantity, \( \lambda_v \), represents a distance, \( x \), which describes the particle motion relative to the fluid. For \( x < \lambda_v \), there is a high degree of fluid-particle slip, whereas for \( x > \lambda_v \), the particles tend to take on the motions of the gas. The heat transfer characteristics are more complex in the high "particle-slip" regime in that the initial conditions become quite important in such a calculation. Since there are very little work in the literature for this regime, this was not coded in BLIMPJ.

Returning our attention to the expression for shear, the factor \( \sqrt{1 + K} \) multiplying the usual shear coefficient gives the result for no particle slip and represents a minimum value for shearing stress. The first order correction \( 0.49 \left( \frac{\lambda_v}{x} \cdot \frac{K}{1 + K} \right) \) gives shear stress due to particle slip reduction along the flow path.

Heat transfer through the boundary layer was treated in a similar manner as given in Eq. (B.2).

4.2.2 Turbulent Boundary Layer-Particulate Flow

The approach for modification of the heat transfer and skin friction calculations in BLIMPJ for a turbulent boundary layer is based on the analytical results of Tien (Ref. 8) and the empirical expressions of Farbar and Morley (Ref. 10). Tien solved the turbulent gas-particle energy equations for flow in a pipe and found that the qualitative effect of particle concentration is to flatten the temperature profile and consequently to increase the heat transfer. He has theoretically confirmed the test results of Farbar and Morley that

\[
C_f/2 = 0.332/\sqrt{R_x}
\]
TABLE 4.1
GAS-PARTICLE SKIN FRICTION AND HEAT TRANSFER

**Laminar Boundary Layer (Marble)**

\[
C_f = C_{f0} \sqrt{1 + K} \left( 1 + 0.49 \frac{K\lambda_v}{1 + K} \right), \quad \frac{\lambda_v}{X} << 1 \quad (B.1)
\]

and

\[
\dot{q} = \dot{q}_0 \sqrt{1 + K} \left( 1 + 0.49 \frac{K\lambda_v}{1 + K} \right), \quad \frac{\lambda_v}{X} << 1 \quad (B.2)
\]

where

\[
K = \frac{\rho_p}{\rho_e}
\]

\[
\lambda_v = \frac{mU_e}{6\pi \alpha_\mu e}
\]
TABLE 4.1 (Continued)

Turbulent Boundary Layer

For \( \frac{W_p}{W_f} < 1 \) (Tien)

\[
C_f = C_{f_0} (1 + \beta_5)
\]

and

\[
\dot{q} = \dot{q}_0 (1 + \beta_5)
\]

where

\[
\beta_5 = \frac{C_p W_p}{C_f W_f}
\]

For \( \frac{W_p}{W_f} > 1 \) (Farbar and Morley)

\[
Nu = 0.14 \; Re_D^{0.6} \; (W_p/W_f)^{0.45}
\]

\[
\dot{q} = \frac{Nu \cdot Kg}{D} \cdot (T_{aw} - T_w)
\]

Particle Factor = \( \frac{\dot{q}}{\dot{q}_0} \)

\[
C_f = \left( \frac{\dot{q}}{\dot{q}_0} \right) \cdot C_{f_0}
\]
TABLE 4.1  (Continued)

Nomenclature

\[ m \] = average particle mass, lbm
\[ U_e \] = boundary layer edge velocity, ft/sec
\[ \sigma \] = Stokes drag coefficient \( (= 6\pi \mu_e a) \)
\[ a \] = radius of spherical particle, ft.
\[ \mu \] = gas viscosity, lbm/ft.sec
\[ \lambda_v \] = momentum range, ft.
\[ K \] = Particle momentum interaction parameter
\[ \rho_p \] = particle mass density of the gas, lbm/ft\(^3\)
\[ \rho_e \] = gas density, lbm/ft\(^3\)
\[ Re_D \] = edge Reynolds number based on diameter
\[ X \] = running length, ft.
\[ \tau \] = shear stress, lbf/ft\(^2\)
\[ C_{fo} \] = friction coefficient calculated by BLIMPJ
\[ C_f \] = modified friction coefficient
\[ \dot{q}_o \] = heat transfer rate calculated by BLIMPJ, Btu/ft\(^2\)sec.
\[ \dot{q} \] = modified heat transfer rate, Btu/ft\(^2\)sec.
\[ c_p \] = specific heat of the solid particle, Btu/lb.degF
\[ W_p \] = mass flow of particles, lb/sec.ft\(^2\)
\[ c_f \] = specific heat at constant pressure of fluid, Btu/lb.degF
\[ W_f \] = mass flow of fluid, lb/sec.ft\(^2\)
\[ K_g \] = thermal conductivity of the gas, Btu/sec.ft\(^0\)K
\[ D \] = diameter of the tube, ft.
\[ Nu \] = Nusselt's number
suspended solids, having a solids-to-gas loading ratio of less than 1.0, have a negligible effect on heat transfer. As pointed out earlier, Tien's analysis is valid for the entrance region of a pipe. Since the flow is not fully developed in this region of the pipe, the boundary layers do not merge. This flow situation is similar to what happens in a nozzle, where the boundary layers develop near the nozzle wall and do not merge. Consequently, the expressions developed by Tien for the pipe may be applicable to a nozzle. The expressions for particle-to-fluid loading ratio of less than 1 are given in Eq. (B.3) of Table 4.1.

For higher particulate loading where interactions and collisions among particles become important, the above expression is no longer valid. For the case, where the particle-to-fluid loading ratio is more than 1, the experimental results of Farbar and Morley (Ref. 10) have been correlated and are given in Eq. (B.4) of Table 4.1. This expression is valid for a limited Reynolds number range of \(13,500 < Re < 27,000\) which were the limits in the test conditions. It has further been noted by Farbar and Morley that for loading ratios up to unity, the Nusselt number varies as the 0.03 power of the loading ratio, while that above unity varies as the 0.45 power of the loading ratio, except that for the lowest Reynolds number which indicates a variation to the 0.5 power. The expressions for Nu in Eq. (B.4) was used to calculate a particle factor which was then used to calculate skin friction coefficient from Eq. (B.5). The above expressions were coded in BLIMPJ and checked with a few examples.

4.3 EXAMPLES

In order to illustrate the effect of particles in the fluid boundary layer on skin friction and heat transfer rate, the following hypothetical example was chosen. Aluminum particles of 10 µm radius (density of Al = 169 lbm/ft³) and particles-to-fluid loading ratio of 0.5 was chosen. Thus,
\[ r = 10 \mu = 10^{-5} \text{ m} \]
\[ \rho_{al} = 169 \text{ lbm/ft}^3 \]
\[ C_p = 0.208 \text{ Btu/lbm.}^\circ F \]

An example of the namelist input in BLIMPJ for particles-in-flow is given in Table 4.2. The OTV nozzle was used for testing the effects of these particles. The relative magnitudes of the resultant skin friction and heat flux are plotted in Figs. 4.1-4.3. Since the OTV nozzle contains both laminar and turbulent boundary layer flow regimes, both laminar and turbulent expressions for particles-in-flow could be checked out simultaneously.

4.4 Discussions

The particle options chosen in the present work are designed to perform "point" calculations and are not capable of taking into account the "history" effects. The particle option can either be used independently or used along with one or both of the roughness and relaminarization options. The reference value for the particle factor will be obtained either from the smooth wall value or from the relaminarization or rough wall value and then be enhanced by the particle factor. It has been pointed out previously that the particle factor expressions for turbulent flow were derived from tube data and do not represent a rocket nozzle case, and in that sense are only approximate in nature. However, they will provide relative values of wall skin friction and heat flux for various particle sizes and particle loadings. Some relevant suggestions for future work for gas-particle flows in rocket nozzles are given in Sec. 6.
TABLE 4.2 Example Of Namelist Input Particle Option

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA</td>
<td>00</td>
</tr>
<tr>
<td>IDTK</td>
<td>0</td>
</tr>
<tr>
<td>NEL</td>
<td>2</td>
</tr>
<tr>
<td>MG</td>
<td>0.0</td>
</tr>
<tr>
<td>FUEL</td>
<td>2.0, 8.0, 0.0, 2.0, 8.0</td>
</tr>
<tr>
<td>NS</td>
<td>48</td>
</tr>
<tr>
<td>IPLOT</td>
<td>00</td>
</tr>
<tr>
<td>RHOPA</td>
<td>169 lbf/ft²</td>
</tr>
<tr>
<td>CPART</td>
<td>0.208 Btu/lb</td>
</tr>
<tr>
<td>WP</td>
<td>0.5</td>
</tr>
<tr>
<td>PARTICLE Option</td>
<td>IPART = 1</td>
</tr>
<tr>
<td>Radius of the particle, RP</td>
<td>1.0 E-05</td>
</tr>
<tr>
<td>Density of the particle, RHOPA</td>
<td>169 lbf/ft²</td>
</tr>
<tr>
<td>Specific heat of the particle, CPART</td>
<td>0.208 Btu/lb</td>
</tr>
<tr>
<td>Particle loading (W/W)</td>
<td>WP = 0.5</td>
</tr>
<tr>
<td>Particle Option, IPART</td>
<td>1</td>
</tr>
</tbody>
</table>

and so on.
Fig. 4.1 Comparison Of Heat Flux Distribution Over The OTV Nozzle Wall For With And Without Particles In Flow
Fig. 4.2
Comparison of Stanton Number Distribution Over the OTV Nozzle Wall For With and Without Particles in Flow
Fig. 4.3 Comparison Of Skin Friction Coefficient Distribution Over The OTV Nozzle Wall For With And Without Particles In Flow
4.5 References


5.1 Background

A thrust loss calculation method which has been previously implemented in BLIMPJ code is given in Ref. 1. The thrust loss due to the boundary layer effects for a circular cross-section nozzle is given at a specified cross-section by (for vacuum ambient conditions)

$$\Delta F = 2 \pi r e \cos \phi_e (\rho_e U_e^2 \theta - P_B^*)$$  \hspace{1cm} (5.1)

where

- $r_e$ = Body radius at the station of interest
- $\phi_e$ = Wall angle
- $\rho_e$ = Boundary layer edge density
- $U_e$ = Boundary layer edge velocity
- $\theta$ = Momentum thickness
- $P$ = Static pressure in the boundary layer
- $P_B^*$ = Body displacement thickness

The assumptions used in deriving the above expression are the following:

1. The boundary layer is thin, i.e., the thickness of the boundary layer is small compared to the radius of the nozzle at any cross-section.

2. The inviscid values of density and velocity do not change within the thickness of the boundary layer. In other words, if there was no viscosity (i.e. for inviscid flow), there would be no variation of the inviscid values between the edge location and the nozzle wall.

3. The pressure is constant across the boundary layer. This assumption is consistent with the derivation of the usual boundary layer equations.

4. The definitions of body displacement thickness and momentum thickness are given by

$$\delta_B^* = \int_0^e \left( 1 - \frac{\rho U}{\rho_e U_e} \right) dy$$  \hspace{1cm} (5.2)
and

\[
\theta = \int_0^e \frac{\rho U}{\rho_e U_e} \left( 1 - \frac{U}{U_e} \right) \, dy \tag{5.3}
\]

where \( e \) and \( o \) refer to edge and wall conditions respectively.

As the nozzles grow in area ratio, the boundary layers grow in size, and the above assumptions may not hold. The proposed OTV nozzles such as the one given in Fig. 2.5 will utilize an expander cycle operations mode in which the walls will be regeneratively cooled and the heat energy will be used to drive the turbines and pumps. So, while the regeneratively cooled walls will help in reducing the size of the boundary layers to some extent, the large area ratio nozzles will produce thick boundary layers. Consequently, depending on the reservoir and exit conditions, and the geometry of the nozzle, it is possible and very likely that boundary layer thicknesses will vary from small to large values. The displacement and transverse curvature effects become important for thick boundary layers and must be included in the boundary layer calculations. In addition, as the flow expands in the nozzle, it will create low density and high Mach number flows. If the flow passes from the continuum to a non-continuum regime, velocity slip and temperature jump (STJ) may become important.

Similar boundary layer solutions are not applicable for such an investigation, since similarity cannot be satisfied for any specified set of reservoir conditions, nozzle geometry and wall temperature distributions. Fortunately, the boundary layer procedure in BLIMPJ does not assume similarity. Furthermore, it takes into account transverse curvature effects (TVC) in the derivation. It also calculates the displacement effects for thin boundary layers. As far as the STJ effects are concerned, it has been pointed out by previous investiga-
tions (Ref. 2) that they are generally small compared to the other effects discussed above and thus, will be ignored in the present approach.

5.2 Thrust Loss Reevaluation Procedure For Thick Boundary Layers

In accordance with the above discussions, the expression for thrust loss for thick boundary layers has been modified. The assumptions made in deriving Eq. (5.2) and (5.3) are no more strictly valid. The u-component of the velocity in the inviscid flow will vary to some extent between the nozzle wall to the edge location. Consequently, the definitions for \( \delta^*_B \) and \( \theta \) are

\[
\delta^*_B = \int_0^e \left[ 1 - \frac{\rho U}{\rho_1(y) \cdot U_1(y)} \right] dy \quad (5.4)
\]

and

\[
\theta^*_t = \int_0^e \frac{\rho U}{\rho_1(y) \cdot U_1(y)} \left[ 1 - \frac{U}{U_1(y)} \right] dy \quad (5.5)
\]

The expression for the thrust loss calculation given in Eq. (5.1) will also have to be modified in its derivation where the edge quantities, \((\rho_e, U_e)\) and pressure will no more be constants but would be replaced by local inviscid values \(\rho_1(y), U_1(y)\) and \(P(y)\). However, it was decided that the whole procedure of thrust loss calculation will be much more simple and adapted a lot easier in the BLIMPJ algorithm, if the pressure is replaced by an average value of the pressure distribution within the thickness of the boundary layer. As a result, averaged inviscid edge values of velocity and density will automatically be calculated from the BLIMPJ algorithm and could be used in the thrust loss calculation in the existing algorithm in BLIMPJ. In the above calculations, the location of the boundary layer edge is not precisely known and has to be determined by iterating upon the inviscid and viscous flowfields.

There are two different problems to be solved when one attempts to calcu-
late performance for a rocket nozzle having thick boundary layers:

Case 1 - The potential nozzle contour is given and the objective is to define the hardware wall contour and calculate the rocket nozzle performance. For details, see Attachment 5.1.

Case 2 - The hardware wall contour is given and the objective is to define the potential contour and calculate the rocket nozzle performance. For details, see Attachment 5.2.
Attachment 5.1

In the case, where the potential contour is given, the objective is to define the wall contour for thick boundary layer situations. The suggested iteration procedure is given below: (Also see Fig. 5.1).

(I) Run the inviscid code (TDK and RAMP) to define the distribution of pressure on the potential wall and everywhere else in the nozzle, particularly near the potential wall.

(II) Run BLIMPJ with the given pressure distribution on the potential wall. This calculates $\delta$ and $\delta^*$. Then, the body radius is calculated from

$$R_B = R_P + \delta^* \cos \phi$$

This is the first iteration.

(III) Calculate an average inviscid pressure for the height between the potential wall and the boundary layer edge, which was obtained from the previous calculation at each station. Use these pressures to run BLIMPJ again, and calculate $\delta_2$ and $\delta_2^*$. Then, calculate $R_B$. This is the second iteration.

(iv) Iterations stop when convergence on $\delta^*$ is achieved within a specified accuracy.
In the case where the hardware wall contour is given, the objective is to define the inviscid edge for thick boundary layer situations. The suggested iteration procedure is given below: (also see Fig. 5.2)

(I) Run the inviscid code (TDK or RAMP) to calculate the distribution of pressure on the hardware wall in the nozzle.

(II) Run BLIMPJ with the calculated wall pressure distribution on the hardware wall. This calculates $\delta_1$ and $\delta_2$ as a function of the nozzle axial coordinate. Then, the radius of the potential wall is calculated from

$$R_p = R_B - \delta \cos \phi$$

This is the first iteration.

(III) Calculate the pressures again by using the inviscid code (TDK or RAMP) on the new potential wall and everywhere else in the nozzle, particularly near the potential wall.

(iv) Calculate the average pressure for the height between the boundary layer edge, which was obtained previously, and the hardware wall. Use the pressures on the hardware wall to run BLIMPJ again and calculate $\delta_2$ and $\delta_2$. Then calculate $R_p$. This is the second iteration.

(v) Go back to (III) and iterate until a prescribed convergence criterion on $\delta$ is achieved. If it is found that the pressure calculations in (III) in the first two iterations are very close, do not go back to (III), instead go back to the beginning of (iv).

Once the iterations are completed, the thrust loss will automatically have been calculated by BLIMPJ to yield the final answer.
NOTES:

1. The potential contour is given; the objective is to define the wall contour.
2. Subscript refers to iteration number.
3. $\delta^*$ refers to displacement thickness.
4. $\delta$ refers to boundary layer thickness.

Fig. 5.1 Suggested Iteration Procedure For Nozzles With Thick Boundary Layer (Potential Contour Given)
NOTES:

1. The wall contour is given; the objective is to define the inviscid edge.

2. Subscript refers to iteration number.

3. $\delta_*$ refers to displacement thickness.

4. $\delta$ refers to boundary layer thickness.

Fig. 5.2 Suggested Iteration Procedure For Nozzle With Thick Boundary Layer (Wall Contour Given)
5.3 **Example**

For illustrating the procedure given above for calculating thrust loss for thick boundary layer situations, the OTV nozzle given earlier in Sec. 2.3 was used. Furthermore, since the given wall coordinates represent a generic class of OTV nozzles, these coordinates were assumed to represent the potential wall contour of the OTV nozzle. Consequently, the iterations were performed based on the procedure shown in Attachment 5.1.

Since REMTECH did not have the information to run TDK for computing and storing the pressures for the interior points away from the wall, another available code called RAMP (Ref. 3) was run for the OTV nozzle contour to compute the pressure fields both on the wall and near the wall. Figure 5.3 gives a comparison of wall pressure distributions from TDK and RAMP on the nozzle wall. The comparison is quite good. A comparison of $\delta^*$ calculations based on results from both codes is given in Fig. 5.4 showing a close agreement. The pressure distribution near the potential contour obtained from RAMP is given in Fig. 5.5 along with $\delta$ and $\delta^*$ from the first iteration. It is obvious that there is a distribution of pressure through the thickness of the boundary layer and as a result, the shown inviscid edge of the boundary layer is not accurate. Going through the step (III) in Attachment 5.1 yields a new average pressure distribution given in Fig. 5.6, which is distinctly different from the first iteration both in the high pressure region near the throat and in the low pressure region near the exit plane. The BLIMPJ calculation yielded a $\delta^*$ distribution which was compared with the original distribution in Fig. 5.7. Again, the two iterations are somewhat different. A third iteration was done when it was found that the average pressure and $\delta^*$ distributions were very close to the second iteration (Figs. 5.6 and 5.7). The thrust loss in the successive iterations is given in Fig. 5.8.
Fig. 5.3 Comparison of OTV Nozzle Wall Pressure Distribution Using Two Different Codes
Fig. 5.4 Comparison Between TDK And RAMP Output For The Boundary Layer Effective Displacement For First Iteration
Fig. 5.5  Inviscid Pressure Distribution At Various Wall Locations Within The Boundary Layer Thickness
Fig. 5.6  Iterations Of The Wall Pressure Distribution For The OTV Nozzle With Thick Boundary Layer
Fig. 5.7 Iterations Of $\delta^*$ Distribution For The OTV Nozzle With Thick Boundary Layer
Fig. 5.8  Thrust Loss In The OTV Nozzle As A Function Of Iterations
5.4 Discussions

The procedures described before and the example given in Subsection 5.3 are engineering procedures which could be used for thrust loss calculation in nozzles with thick boundary layers. The calculations performed at the time were not all computerized and as a result, could contain some inaccuracies in the various steps of the calculation. Even though the convergence was observed in the pressure distribution in Fig. 5.6 in the third iteration, it was not absolutely so in the convergence of 6° in Fig. 5.7 and thrust loss in Fig. 5.8. However, the difference between the second and third iteration for the thrust loss in the OTV nozzle is around 10 lbs and it might be even less between the third and a fourth iteration. The thrust loss for thick boundary layers has not been programmed, since TDK cannot presently provide the necessary data away from the nozzle wall. However, a number of suggestions are made in Sec. 6 for future work.

5.5 References


Section 6.0

RECOMMENDATIONS

Future work in the OTV research and development areas described in the previous sections may be categorized into three broad areas;

- Analytical
- Numerical
- Experimental

6.1 Analytical

The future analytical work on OTV-class nozzles, with reference to the four modules that have been addressed in the previous sections of this report, consists of the following recommendations:

6.1.1 Wall Roughness Effects

1. Roughness module in BLIMPJ needs to be checked out further with other available data for any size nozzle. This would enhance confidence in the usability of the various roughness options incorporated in BLIMPJ. The modules should also be exercised with the data to be taken on the future OTV model or flight tests.

2. Effects of partially smooth and partially rough nozzle wall on wall skin friction and heat transfer rate need to be examined. This problem does not lend itself to the assumption of an equivalent sand roughness, because the concept of equivalent sand roughness which is based on similarity assumptions breaks down. Some related developments appear in works by T.C. Lin, J.C. Adams, etc.

6.1.2 Relaminarization

1. The relaminarization module needs to be checked out with any other available data for internal flow situations.

2. Questions remain as to whether the relaminarization criterion using wall quantities rather than edge quantities is valid for OTV-type nozzles. What happens to this criterion when wall roughness is present?

3. It is well known that freestream turbulence is present in the inviscid flow inside the nozzle. The question, then, is what role does the freestream turbulence play in the turbulence length scales and thus, in the relaminarization process?
6.1.3 Particle Effects

1. Check the options in BLIMPJ with available data both in laminar and turbulent flows.

2. For the case of replaceable and ablating nozzle inserts, the particles or debris in boundary layer flow will enhance heat transfer at the nozzle wall. If the particle loading could be determined, the effects of ablating nozzle wall could be determined.

3. Modify the turbulent mixing length due to the presence of particles in the flow.

6.1.4 Thrust Loss Reevaluation

1. Check the predicted performance with available nozzle data having large area ratios, and consequently, thick boundary layers.

2. A procedure which consists of a combination of machine and hand calculations has been given in Sec. 5 for computing final performance calculations for large area ratio nozzles. This procedure should be considered approximate. A special software using a flow diagram involving TDK and BLIMPJ needs to be written for smooth calculation of high area ratio nozzles.

3. An optimization procedure needs to be developed to design a nozzle with length and area ratio constraints for minimizing thrust loss in large area ratio nozzles.

6.2 Numerical

Computational fluid dynamics (CFD) procedures should be examined to evaluate the nozzle wall thermal losses due to relaminarization, the presence of wall roughness and particles in flow. Without going into too many details, the following concerns should be borne in mind:

1. The turbulence models in the existing codes need to be examined. The problems of modifying the turbulence models for roughness, particles and relaminarization remain.

2. Acceptable chemistry packages have to be integrated in the CFD codes.

3. On the positive side, the iteration procedure necessary for calculating the thrust loss for thick boundary layers is eliminated in the CFD procedure, since the code defines both the inviscid and viscous flowfields in the nozzle at the same time. However, the thrust loss formula for nozzles needs to be integrated with the CFD code, if the boundary layer effects need to be singled-out.
6.3 Experimental

It is the opinion of the authors that not enough applicable experimental data is available for the OTV-class nozzles. In order to validate the modules described in this report, measurements need to be made to support them. The parameters that need to be measured, the size of the models, the kind of flow to be tested and the accuracies involved in conducting these tests are the items described in modular form in Table 6.1. This table presents a number of choices and possibilities from which any combinations could be selected for future experimental programs to support the OTV nozzle development.
<table>
<thead>
<tr>
<th>STUDY ITEMS</th>
<th>WALL ROUGHNESS EFFECTS</th>
<th>RELAMINARIZATION EFFECTS</th>
<th>PARTICLE EFFECTS</th>
<th>THICK BOUNDARY LAYER ISP LOSSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXISTING DATA BASE FOR NOZZLES</td>
<td>• NO OTV NOZZLE DATA • ROCKETDYNE 40K SUBSCALE CHAMBER TEST • FOR SSME, NO INTERNAL NOZZLE DATA</td>
<td>• BACK AND CUFFEL 10° - 10° HANG ANGLE CONE DATA • NASH-WEBER VARIABLE NOZZLE WHICH STUDIED RELAMINARIZATION EFFECTS</td>
<td>• NO OTV NOZZLE OR ANY OTHER NOZZLE BOUNDARY LAYER DATA AT MSFC • THE AVAILABLE DATA BASE IS FOR TUBES AND PIPES</td>
<td>• NO OTV THICK BOUNDARY LAYER DATA</td>
</tr>
<tr>
<td>MODEL TESTS - SHORT DURATION</td>
<td>• STEADY STATE TEST TIMES 10 MSEC - 100 MSEC • TEST TIME DEPENDENT ON ALTITUDE CHAMBER SIZE AND/OR DIFFUSER CAPACITY • USE DIFFERENT NOZZLES OR NOZZLE INSERTS FOR ROUGHNESS EFFECTS STUDY</td>
<td>• TEST ARRANGEMENT SAME AS WITH WALL ROUGHNESS</td>
<td>• VERY DIFFICULT IF NOT IMPOSSIBLE TO INJECT KNOWN PARTICLES INTO FLOWS ON SHORT DURATION BASIS</td>
<td></td>
</tr>
<tr>
<td>COLD, HOT OR REACTIVE FLOW</td>
<td>• EXACT SIMULATION OF HOT FLOWING H2/O2 @ O/F = 6 AND PCH = 2000 PSI • USE OF COLD/NON-REACTING GASES</td>
<td>• SAME AS WITH WALL ROUGHNESS</td>
<td>• COMBUSTION OF SOLID PROPELLANT - THE PROBLEM IS THE LACK OF CONTROL OR KNOWLEDGE OF PARTICLE SIZE AND CONCENTRATION</td>
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<td>PARAMETERS TO BE MEASURED</td>
<td>• WALL ROUGHNESS • NOZZLE WALL HEAT TRANSFER AS A FUNCTION OF TIME • NOZZLE WALL PRESSURES • NOZZLE WALL TEMPERATURES • EXIT VELOCITY/TEMPERATURE PROFILES</td>
<td>• WALL HEAT TRANSFER • WALL TEMPERATURES • WALL PRESSURES</td>
<td>• WALL HEAT TRANSFER • WALL TEMPERATURES • WALL PRESSURES</td>
<td>• SAME AS WITH WALL ROUGHNESS</td>
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<td>INSTRUMENTS TO BE USED; SPECIAL INNOVATIVE PROBES THAT COULD BE USED</td>
<td>• FAST-RESPONSE PIEZO-ELECTRIC PRESSURE TRANSDUCERS • THIN FILM SHORT DURATION HEAT TRANSFER GAGES • CO-AXIAL SURFACE HEAT TRANSFER GAGES • MINIATURE THIN WIRE/T.C. GAGES • MECHANICAL MEASUREMENTS OF WALL ROUGHNESS</td>
<td>• SAME AS WITH WALL ROUGHNESS</td>
<td>• SAME AS WITH WALL ROUGHNESS</td>
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<td>ACCURACY OF MEASUREMENTS</td>
<td>• ±5% TO ±10% FOR THIN-FILM AND CO-AXIAL GAGES • ±0.5% ON TEMPERATURE • ±2% ON PRESSURE</td>
<td>• ±5% TO ±10% ON HEAT TRANSFER • ±0.5% ON TEMPERATURE • ±2% ON PRESSURE</td>
<td>• ±5% TO 10% ON HEAT TRANSFER • ±0.5% ON TEMPERATURE • ±2% ON PRESSURE</td>
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<td>MODEL SCALE PROBLEMS, IF ANY</td>
<td>• CHEMISTRY, THERMODYNAMICS AND TRANSPORT PROPERTIES ARE REALISTIC IN NOZZLE • SMALL THROAT AREAS AND IMPERFECTIONS MAY OBSCURE EFFECTS BEING SOUGHT</td>
<td>• SAME AS WITH WALL ROUGHNESS</td>
<td>• PARTICLE SIZE AND CONCENTRATIONS VERY DIFFICULT TO SCALE FOR SMALL TEST RIG</td>
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<td>FACILITIES TO BE USED</td>
<td>• IMPULSE BASE FLOW FACILITY (IBFF) AT MSFC • PLUMBROOK SPACE POWER FACILITY AT NASA LEWIS • CHAMBER A AT JOHNSON SPACE CENTER • LUDWIG TUBE AT CALSPAN, BUFFALO</td>
<td>• SAME AS FOR WALL ROUGHNESS EFFECTS</td>
<td>• SAME FACILITIES AS FOR WALL ROUGHNESS STUDIES</td>
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**TABLE 6.1 (Continued)**

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<th>RELAMINARIZATION EFFECTS</th>
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<th>THICK BOUNDARY LAYER ISP LOSSES</th>
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<td><strong>MODEL TESTS - LONG DURATION</strong></td>
<td>DEPENDING ON MODEL SIZE AND TEST DURATION, COSTS CAN BE A FACTOR OF 10 LARGER THAN SHORT DURATION</td>
<td>SAME AS FOR WALL ROUGHNESS EFFECTS</td>
<td>LONG DURATION ALLOWS FOR POSSIBLE UTILIZATION OF PARTICLE INJECTION TECHNIQUES IN COLD/WARM GAS FLOW</td>
<td>LARGE OTV MODELS SHOULD BE USED</td>
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<td>ALLOWS MORE THAN ONE MEASUREMENT PER RUN</td>
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<td>REACTIVE FLOWS STILL HAVE UNKNOWN PARTICLE SIZE/CONCENTRATION</td>
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<td>HIGH ALTITUDE SIMULATION REQUIRES VERY LARGE FACILITY</td>
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<td><strong>COLD, HOT OR REACTIVE FLOW</strong></td>
<td>COLD/WARM FLOWS SIMPLEST AND LEAST COSTLY</td>
<td>SAME AS FOR WALL ROUGHNESS EFFECTS</td>
<td>COLD, HOT OR REACTIVE FLOW SIMULATION IS NOW COMPLICATED BY THE NEED FOR PARTICLES</td>
<td>HOT/REACTIVE FLOWS SIMULATING H₂/O₂ SYSTEM ARE PREFERABLE</td>
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<td>HOT OR REACTIVE FLOWS REQUIRE COMPLEX FACILITY AND MODEL COOLING</td>
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<td>PARTICLE DENSITY AND SIZE</td>
<td>THRUST MEASUREMENT</td>
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<td>WALL PRESSURE AND TEMPERATURE MEASUREMENTS</td>
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<td>WALL HEAT TRANSFER RATE</td>
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<td>LDV VERY ADAPTABLE TO PARTICLE FLOWS</td>
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<td>PROBE THE BOUNDARY LAYER INSIDE NOZZLE</td>
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<td>LDV ±15% DUE TO PARTICLE LAG</td>
<td>LDV ±15% DUE TO PARTICLE LAG</td>
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<td>SCAL PROBLEMS ARE ALLEViated IF MODEL SIZES ARE INCREASEd</td>
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<td>THROAT MUST BE PROTECTED AGAINST HIGH q RESULTING IN WALL TEMPERATURE DISCONTINUITY WHERE MATERIALS CHANGE</td>
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<td>ENGINE TEST FACILITY AT AEDC CAN SIMULATE ALTITUDE</td>
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<td>SAME FACILITIES AS FOR WALL ROUGHNESS STUDIES</td>
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APPENDIX

A LISTING OF THE UPDATED SUBROUTINES IN BLIMPJ
CALL APU (I,J,Y(I) = 1,0,0,10,0,10,YMIN)

IF (NPLOT(J) .EQ. 2) GO TO 26

READ (3) Y(I,3),Y(I,6),Y(I,1),Y(I,19)

IF (NCON .LE. 0) GO TO 42

WRITE (10) N

READ (10) RCIRC,RSQAR,(Z(I),W(I),U(I),V(I), I = 1,N)

WRITE (10) RCIRC,RSQAR,(Z(I),W(I),U(I),V(I), I = 1,N)

WRITE (10) RCIRC,RSQAR,(Z(I),W(I),U(I),V(I), I = 1,N)

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WRITE (10) RCIRC,RSQAR,(Z(I),W(I),U(I),V(I), I = 1,N)
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1.15 - AXISSYMETRIC

00105 25* C OUTPUT VARIABLES
00105 26* C
00105 27* C
00105 28* C
00105 29* C
00105 30* C
00105 31* C
00105 32* C
00105 33* C
00105 34* IF (ICF.EQ.0) GO TO 100
00106 35* C SKIN FRICTION COMPRESSIBILITY (YOUNG)
00110 36* C CFCFI=(0.365*HE/HAH)+(0.635*HE/HW)
00111 37* IF(CFCFI.LE.0.0)CFCFI=0.0
00112 38* C INCOMPRESSIBLE ROUGH WALL SKIN FRICTION
00113 39* IF (ICF.NE.1) GO TO 10
00114 40* C OPTION(1) PRANDTL - SCHLICHTING
00115 41* CFI=(2.87+1.58*LOG10(X/RK))*-2.5
00116 42* GO TO 20
00117 45* 10 CONTINUE
00117 46* 20 CONTINUE
00118 47* C CFI=CFCFI*CFI*FMF
00119 48* C TRANSITION CRITERION (FENTER)
00123 49* C UTAU=UE*SQRT((CFR/2.0)*(RHOE/RHOW))
00124 50* C ETAK=RHOW*UTAU*RK/MWW
00124 51* C ROUGH SURFACE TURBULENT STANTON NUMBER
00125 52* C A=0.52 NOMINAL, RANGE OF 0.45 TO 0.7 (OWEN - THOMSON)
00125 53* C REK=RHOE*UE*RK/MUE
00126 54* STR=CFR/2.*(1.4*((CFR/2.)*HE)**.5*REK**.45*PR**.8)**-1.0 (SEIDMAN)
00126 55* STR=CFR/2.*(1.4*((CFR/2.)*HE)**.5*REK**.45*PR**.8)**-1.0 (HILL)
00126 56* C
00126 57* C 100 USED BY FENTER, 70 USED BY HILL, 65 USED BY PIMENTA
00126 58* C PIMENTA VALUE CURRENTLY USED FOR TRANSITION
00126 59* C ETAK .LE. 5.0 SMOOTH
00126 60* C 5.0 .LE. ETAK .LE. 65.0 TRANSITIONALLY ROUGH
00126 61* C 65.0 .LT. ETAK ROUGH
00126 62* C
00127 63* PCT=(ETAK-5.0)/(65.0-5.0)
00130 64* C IF(PCT.LT.0.0)PCT=0.0
00132 65* IF(PCT.GT.1.0)PCT=1.0
00134 66* CF=(PCT+CFR)**((1.0-PCT)*CFS)
00135 67* ST=(PCT+STR)**((1.0-PCT)*STS)
00136 68* 100 CONTINUE
00137 69* RETURN
00140 70* C END
@SYS$*MSFCFOR$ FOR IS PARTCL.

HSA E3 12/10/84 22:23:46 (.0)

SUBROUTINE PARTCL  ENTRY POINT 000165

STORAGE USED: CODE(1) 000170; DATA(0) 000026; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003 PARTI  000020
0004 RUF  000022

EXTERNAL REFERENCES (BLOCK, NAME)

0005 SQRT
0006 XPRR
0007 NERR3$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001 000000 100L 0001 000005 100L 0001 000010 100L 0001 000015 100L 0001 000020 100L 0001 000025 100L
0000 R 000002 BETAV 00003 R 000005 CF 00004 R 000006 CF 00004 R 000007 CRO 00003 R 000008 CP
0000 R 000009 D 00004 R 000010 DUMM11 00004 R 000011 DUMM17 00004 R 000012 DUMM4 00004 R 000013 DUMMS
0000 R 000014 ILT 00001 ILT 000011 ILT 000012 ILT 000013 ILT 000014 ILT 000015 ILT 000016 ILT 000017 ILT 000018 ILT
0000 R 000019 X 0000 R 000020 Y

00101 1* SUBROUTINE PARTCL
00103 2* REAL K,KG,LAMBV,M,MUE,NU
00104 3* COMMON /PARTI/M,LAMBV,RHOP,RED,CP,WCF,WF,KG,TAW,TW,
00104 4* $ ILL.Q,K,RP,IPART
00105 5* COMMON/RUF/CFRO,STR,X,DUMM4,DUMM5,DUMM6,NDM4,DUMMM,
00105 6* DUMM4,DUMM5,DUMM6,RHOP,DUMMS,
00105 7* C
00105 8* C INPUT VARIABLES
00105 9* C
00105 10* C M - AVERAGE PARTICLE MASS (LBM)
00105 11* C UE - BOUNDARY LAYER EDGE VELOCITY (FT/SEC)
00105 12* C SIGMA - STOKERS DRAG COEFFICIENT (LBM/SEC)
00105 13* C A - RADIUS OF SPHERICAL PARTICLE (FT)
00105 14* C MUE - GAS VISCOSITY (LBM/FT SEC)
00105 15* C LAMBV - MOMENTUM RANGE (FT)
00105 16* C RHOP - PARTICLE MASS DENSITY OF THE GAS (LBM/FT3)
00105 17* C RHOP - GAS DENSITY (LBM/FT3)
00105 18* C RED - EDGE REYNOLDS NUMBER BASED ON D
00105 19* C X - RUNNING LENGTH (FT)
00105 20* C TAU - SHEAR STRESS (LBF/FT2)
00105 21* C CRO - FRICTION COEFFICIENT
00105 22* C STS - SMOOTH STANTON NUMBER

0000000
C CP - SPECIFIC HEAT OF THE SOLID PARTICLE (BTU/LB DEG F)
C WP - MASS FLOW OF PARTICLES (LB/FT2 SEC)
C CF - SPECIFIC HEAT AT CONSTANT PRESSURE OF FLUID (BTU/LB DEG F)
C WF - MASS FLOW OF FLUID (LB/FT2 SEC)
C KD - RATIO OF PARTICLE DENSITY TO FLUID MASS DENSITY AT EDGE
C KG - THERMAL CONDUCTIVITY OF THE GAS (BTU/SEC FT DEG K)
C D - DIAMETER OF THE TUBE (FT)
C NU - NUSSELT'S NUMBER
C TAW - ADIABATIC WALL TEMPERATURE DEG. R
C TW - WALL TEMPERATURE DEG. R
C IIT - FLOW TYPE FLAG 1 - LAMINAR 2 - TURBULENT
C STR - PARTICLE STANTON NUMBER
C CFR - MODIFIED FRICTION COEFFICIENT
C OUTPUT VARIABLES

PI = 3.1415927

IF(IIT.EQ.2) GOTO 100

K = RHOP/RHOE

Y = LAMBW/X

C THE EQUATIONS USED TO COMPUTE QDOT AND CFR ARE DIFFERENT WHEN

C LAMBDA/X IS LESS THAN 1. THAT THE EQUATIONS USED WHEN LAMBDA/X

C IS GREATER THAN 1. HERE ONLY LAMBDA/X LESS THAN 1 CASE IS USED.

C CF = CFRO*SQRT((1.+K)*(1.+((.49*(Y*K)/(1+K)))))

C STR = STS*SQRT((1.+((.49*(Y*K)/(1+K)))))

Q = STR/STS

GOTO 160

GOTO 160

BETA5 = WP*CP/WF

IF(W.WT.1.) OR. ABS(W-1.) LT .001) GO TO 105

IF(W.GT.1.) GOTO 110

C THIS IF STATEMENT SERVES THE SAME PURPOSE AS THE IF STATEMENT FOR

C THE LAMINAR CASE

C CFR = CFRO*(1.+BETA5)

STR = STS *(1.+BETA5)

Q = STR/STS

GOTO 120

N=14*(RED*.6)*(W**.45)

D = RED/(RHOE*UE/MUE)

QDOT = ((NU*KG)/D)*(TAW-TW)

STR=QDOT/((DNUMS-DNUM6)*RHOE*UE)

Q = STR/STS

CFR=0+CFRO

C CONTINUE

GOTO 120

GOTO 160

RETURN

C CONTINUE

RETURN

END
COMMON/RUF/DUMM1, DUMM2, DUMM3, DUMM4, DUMM5, DUMM6, DUMM7, DUMM8, DUMM9,
$ DUMM10, DUMM11, DUMM12, RK, ICF, FMF, DUMM16, DUMM17, DUMM18

COMMON/PARTI/PARTM, DUMM24, RHOPA, DUMM23, CPART, WP, DUMM19, WP,
$ DUMM22, DUMM20, DUMM21, ILT, PF, AK, RP, IPART

COMMON /LAM/ ILAMIN

C DEFAULT VALUES FOR ROUGHNESS OPTION
DATA FMF/1.15/, ICF/0/, RK/0.0/
C DEFAULT VALUES FOR PARTICLE OPTION
DATA IPART/0/, RP/0.0/, WP/0.0/, WF/1.0/, CPART/0.0/, RHOPA/0.0/

C DEFAULT VALUES FOR RELAMINARIZATION OPTION
DATA ILAMIN/O/

BLOCK DATA

STORAGE USED: CODE(1) OOOO0; DATA(0) OOOO0; BLANK COMMON(2) OOOO0

COMMON BLOCKS:

0003 AL OOOO02
0004 CARDS OOOO03
0005 CONSTS OOOO010
0006 CRBCOM OOOO111
0007 EPSCOM OOOO045
0010 EPCOM OOOO035
0011 ETACOM OOOO117
0012 HOLLER O000060
0013 INPUTI O000015
0014 INTCOM O0000115
0015 LOWTH O0000172
0016 NZERO O000001
0017 PLOTS O0000172
0020 PRMALS O0000154
0021 RFTCOM O0000045
0022 RUF O0000022
0023 PARTI O0000020
0024 PARTM O0000041
0025 SAHA O000066
0026 TEMCOM O0000162
0027 UNICOM O0000011
0030 WALT EM O0000715

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0020 O00000 A 0023 O000015 AK 0030 O00000 ALTAB 0012 I O00000 AREA 0006 O00000 ASU
0010 O00000 ATA 0010 R O00000 BASML 0014 O00000 CASE 0014 R O000015 CBAR 0007 R O00000 CNM
0023 R O00000 CPART 0005 R O00000 CFPL 0025 O00000 CH 0015 R O00000 CPL 0012 I O00000 CQ
0012 I O000006 DENS 0012 I O000010 DIST 0007 O000001 DL 0005 R O000001 DPR 0004 O00000 DUBB
0022 O00000 DUMM1 0022 O000011 DUMM10 0022 O000012 DUMM11 0022 O000013 DUMM12 0022 O000017 DUMM16
0022 O00000 DUMM17 0022 O000021 DUMM18 0022 O000022 DUMM19 0022 O000021 DUMM2 0022 O000020 DUMM20
0023 O000012 DUMM21 0023 O000010 DUMM22 0023 O000023 DUMM23 0022 O000001 DUMM24 0022 O000002 DUMM3
0022 O000003 DUMM4 0022 O000004 DUMM5 0022 O000005 DUMM6 0022 O000006 DUMM7 0022 O000007 DUMM8
0022 O000010 DUMM9 0007 R O000020 ELCON 0012 I O000012 ENERGY 0010 R O000031 EPOVRK 0007 O000021 EPSA
0011 R O00000 ETA 0010 O000032 FF 0004 R O000001 FFAR 0004 R O000002 FITMOL 0017 O00000 FDX
0012 I O000014 FLUX 0022 R O000016 FMF 0021 R O000000 F2FIX 0021 O000017 F2FIXT 0005 R O00002 GC
0012 I O000016 HEAT 0015 R O000026 HL 0012 I O000022 HWALL 0014 O000016 I 0015 I O000045 IADD
END OF COMPILATION: NO DIAGNOSTICS.
COMMON/ACCN/ACCPK, ILAM, SPCT

COMMON/RETH/RETHMO

COMMON/RUF/DUMM1, DUMM2, DUMM3, DUMM4, DUMM5, DUMM6, DUMM7, DUMM8, DUMM9,

$ DUMM10, DUMM11, DUMM12, RK, ICF, FMF, DUMM16, DUMM17, DUMM18

COMMON/ PARTIC/PARTM, DUMM24, RHOPA, DUMM23, CPART, WP, DUMM19, WF,

$ DUMM22, DUMM20, DUMM21, IFT, PF, AK, RP, IPART

COMMON / IAM / ILAMIN

COMMON/RUF3/UTAU, DEACY

$ IPART, RP, WP, WF, RHOPA, CPART, ILAMIN.

-97

/ ZP / ZP, FMF, ICF, RK/

MAIN PROGRAM

STORAGE USED: CODE(1) 000576; DATA(0) 002046; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003 AL 000002
0004 BLOCOM 002043
0005 CARDS 000077
0006 COEffs 002354
0007 CRBCOM 000111
0010 EDGCOM 001217
0011 EPSCOM 000045
0012 EOPCOM 002433
0013 EQTOM 000243
0014 ETACOM 002631
0015 INPUT1 000015
0016 INTCOM 000123
0017 INTERI 000007
0020 LOWTH 001372
0021 NDNCOM 035230
0022 PLOTS 001172
0023 PMALS 000243
0024 PRMDRG 000455
0025 RFTCOM 000045
0026 ACCN 000003
0027 RETH 000001
0030 RUF 000022
0031 PAR1 000020
0032 LAM 000001
0033 RUF3 000002
0034 SAHA 000151
0035 SAVE 000010
0036 SAVEQL 000005
0037 SAVHIS 000075
0040 SAVMAT 000056
0041 SAVNCR 000175
0042 SAVOUT 000021
0043 SAVTBL 000067
0044 SAVTRM 000020
0045 STCCOM 000044
0046 TEMCOM 000162
0047 VARCOM 000645
0050 WALL 001212
00441  189*  IF (IS .EQ. NS)  IRITE = 1  ANK 5/83  000502
00443  190*  IF (IS .LE. NS)  GO TO 41  ANK 5/83  000507
00445  191*  IS = NS  ANK 5/83  000513
00446  192*  IF (ICOOL .EQ. 0 .OR. ICON .EQ. 1)  GO TO 15  000515
00450  193*  CALL SATEMP  000527
00451  194*  GO TO 45  000531
00452  195*  15  IF (NP(IS) .LE. NTH)  GO TO 46  ANK 8/83  000533
00454  196*  CALL ROCOUT  ANK 8/83  000537
00455  197*  IF (IPLOT .GT. 0)  CALL PLOT  000541
00457  198*  GO TO 46  000546
00460  199*  50  IF (IPUNCH .NE. 1 .AND. IPUNCH .NE. 2)  CALL EXIT  ANK 8/83  000550
00462  200*  J = O  ANK 8/83  000565
00463  201*  WRITE (15) J  ANK 8/83  000566
00466  202*  END  BLIM 038  000575

END OF COMPILATION:  NO DIAGNOSTICS.
SUBROUTINE NNNCER
ENTRY POINT 002554

COMMON/BLOCOM/002043
COMMON/BUCCOM/000004
COMMON/COECOM/000014
COMMON/COECOM/000047
COMMON/CONS/00003
COMMON/SITES/000110
COMMON/EDGCOM/001216
COMMON/EPSCOM/000042

STORAGE USED: CODE(1) 002562; DATA(0) 000142; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003 BLOCOM 002043
0004 BUCCOM 000004
0005 COECOM 000014
0006 COECOM 000047
0007 CONS/ 00003
0010 SITES/ 000110
0011 EDGCOM 001216
0012 EPSCOM 000042
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**STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)**

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DO LOOP FOR EVAL OF COEFFS AND ERRORS AT EACH ETA

IS UPPER LIMIT (123) MINUS (2*7 + 11 + 4/7 OR 25) (123 - 25)

M = M + MX

INITIALIZE AM MATRIX AND ENL ARRAY; COMPUTE COEFF. FOR NONLINEAR EQUATIONS

IF (I WALL .LE. 2) GO TO 11

EMISC=EMIV(KK)

HP = HPYG(KK)

EMISC = EMIV(KK)

DO 12 J=ISP,NSPEC

DO 32 JK = 1.NEL

DO 15 I = 1,123

AM(I,J) = 0

DO 20 J=ISP,NSPEC

IF (IFLOW .LE. 0) CALL EQUIL (HB(I).PE(IS) ANK 5/83

DO 27 K = 1,NSPM1

IF (NSPM1 .LE. 0) GO TO 58

HB(I) = G(I,1) + C7*F(I,2)**2/2.0

C7 = -UE(IS)**2/ALPH**2/(CPFL*GC)

C5 = 1.0/ALPH

KCC = 2

RETURN

C5 + C7 = BETAV(IS) + C1 - C8

C9 = BETAV(IS) + C1 - C8

KCC = 2

KSL = 0

DO 49 I = 1,NETA

M = MAT1(J) + 1 - NETA

MX = NETA - 1

HP = G(I,2) + C7*F(I,2)**2/2.0

C7 = -UE(IS)**2/ALPH**2/(CPFL*GC)

C5 = 1.0/ALPH

EMISC = EMIV(KK)

DO 11 J=ISP,NSPEC

IF (IWALL .LE. 2) GO TO 11

HPG = HPYG(KK)

DO 10 J=ISP,NSPEC

IF (I WALL .LE. 2) GO TO 11

HCARB=HCAR(KK)

HCARB=HCAR(KK)

DO 12 J=ISP,NSPEC

DO 20 J=ISP,NSPEC

DO 27 K = 1,NSPM1

DO 20 J=ISP,NSPEC

IF (I WALL .LE. 2) GO TO 11

HCARB=HCAR(KK)

HCARB=HCAR(KK)

DO 12 J=ISP,NSPEC

DO 20 J=ISP,NSPEC

IF (I WALL .LE. 2) GO TO 11
00341 130* ENTRY NONCE

00342 131* DUEEDGE=O.

00343 132* SEPD=O.

00344 133* HE = GE

00345 134* CALL LINCER

00346 135* IF (KQ10 .GE. 0) CALL TRMGL(2)

00347 136* TVVC=1.0

00348 137* M=1+1

00351 138* MX=O

00352 139* DO 120 I=1,NETA

00362 140* L=O

00365 141* DO 59 MM=1, 7

00366 142* M=M+MX

00367 143* DO 59 N=98,123

00368 144* L=L+1

00369 145* PREQ(L)=AM(M,N)

00370 146* 59 AM(M,N)=O.

00371 147* C TEST TO BYPASS COMMANDS THAT CANNOT BE PERFORMED AT ETA(1)

00372 148* IF (I .LE. 1) GO TO 60

00373 149* CALL IMONE

00374 150* IF (KQ9 .NE. 0) CALL TVCM1

00375 151* IF (KQ10 .GT. 0) CALL TRMGL(4)

00376 152* C COMPUTE STATIC ENTHALPY AND DETERMINE STATE OF GAS

00377 153* 60 C10 = C7+F(I,2)

00378 154* C13 = C7+F(I,3)

00379 155* HP = C13+F(I,2) + G(I,2)

00380 156* C---- EVAL GROUPINGS WHICH ARE USED AT I-1 AS WELL AS AT I

00381 157* CALL IGEFF

00382 158* IF (KQ9 .NE. 0) CALL TVCCOE

00383 159* IF (KQ10 .GT. 0) CALL TRMGL(3)

00384 160* IF (I .NE. 1) GO TO 100

00385 161* C DLPK,TVCM,VLNK,DLPH, AND Y1 NEEDED ONLY FOR CARBON PROBLEM

00386 162* IF (NSPM1 .LE. 0) GO TO 95

00387 163* DO 90 K = 1,NSPM1

00388 164* WALL(U(K)) = CK6(K)

00389 165* 90 VKJK(W) = CK6(K)/CM3(IS)

00390 166* 95 WALLQ = C32

00391 167* QW = C32/CM3(IS)

00392 168* TFWALL = TP

00393 169* MX = NETA .GT. 1

00394 170* GO TO 120

00395 171* C---- BACK TO CONSERVATION EQUATIONS

00396 172* 100 CALL IONLY

00397 173* IF (KQ10 .GT. 0) CALL TRMGL(5)

00398 174* IF (KQ9 .NE. 0) CALL TVCM1

00399 175* DO 120 M=MAT1+I-MX

00400 176* DD 122 I=2,4

00401 177* DD 122 J=1,NNLQ

00402 178* 122 AM(I,J)=O.

00403 179* ENL(4) = F(NETA,2) - ALPH

00404 180* AM(4,1) = 1.0

00405 181* AM(4,1) = 1.0

00406 182* ENL(3) = - F(I,1,2)

00407 183* AM(3,4) = 1.

00408 184* ENL(2) = CBAR*(F(NETA,2) - (ETA(NETA) - ETA(KAPPA))*F(NETA,3)) - F(KAPPA,2)

00409 185* 1 F(KAPPA,2)

00410 186* IF (NTROPY .LE. 0) ENL(2) = CBAR + F(NETA,2) - F(KAPPA,2)

00411 187* AM(2,KAPPA+3) = 1.

00412 188* AM(2,MAT1) = CBAR

00413 189* IF (NTROPY .EQ. 5) CALL LIAD(-1,2,2*NETA-2,(ETA(NETA) -
DO 140 K = 1, NSP

IF (ITS .GT. 1) GO TO 145

ETA(KAPPA) = CBAR

DO 145 M = 1, NSP

IF (LEFS(K) .LE. 0 .AND. LEF(K) .GT. 0) EASE = 0.050

DO 145 M = 2

MM = MAT1(J-1)

DO 200 I = 1, NRNL

CALL ABRMAX(MM-1, ENL(M), ENL(I), IENL(M))

IENL(I) = IENL(M)+1

M = M+MM

MM = NETA - 1

SOLVE REDUCED SET OF EQUATIONS

IF (IGUES .LT. 0) RETURN

CALL ABRMAX(MM, ENL(M), ENL(I), IENL(M))

ENL(I) = ENL(M+1)

DO 240 J = 1, NNL1Q

DO 240 M = 1, NAM

AM(M,J) = AM(M+1,J)

IF (K010 .LE. 0) GO TO 1001

DO 240 M = 1, NAM

DO 1000 AM(M,3) = AM(M,3) + ENL(M)/NAM

IF (KQ10 .LT. 0) GO TO 1001

IF (IGUESS .LT. 0) RETURN

DO 240 M = 1, NAM

DUB = AMAX1(ABS(G(NETA,1) - G(1,1) - 10E3)

DO 200 I = 1, NAM

IENLM(I) = IENLM(I)+1

CONTINUE

CALL RNLCR

IF (ITRC = 1) PRINT 1001

 Calling RNLCR WITH REDUCED NONLINEAR SET

THE FOLLOWING ROUTINE REARRANGES COLUMNS OF THE NOW RECTANGULAR MATRIX

MULTIPLIES THE INVERSE TIMES THE REMAINING COLUMNS OF AM MATRIX

AND TIMES THE ENL.

CALL REARY (NAM, AM, NISP+1, ENL, 1, NAM, 123, EQT, EQT(106), EQT(219))

EQT(332), EQT(445)

END
00610 250* 627 ENL(K+17)=O.  
00612 251* JJ = NAM + 1  
00613 252* DD 628 I = 2,NNLEQ  
00616 253* DUM = AM(I,1)/AM(I,1)  
00617 254* ENL(I) = ENL(I)-ENL(1)+DUM  
00620 255* DD 628 J = JJ,NNLEQ  
00622 256* 628 AM(I,J) = AM(I,J)-DUM  
00626 257* ENL(I)+O.  
00627 258* DD 631 J = JJ,NNLEQ  
00632 259* 631 AM(1,J)=O.  
00634 260* ITS = ITS+1  
00635 261* EASE = AMINI(EASE,0.2)  
00636 262* IF (ITS - 101) 244,244,244.850  
00636 263* C----EVALUATE LINEAR CORRECTIONS  
00641 264* 629 DD 630 I = 1,MAT1  
00644 265* DD 630 J = 1,MAT1  
00647 266* 630 FLE(I) = FLE(I) - DVNL(J) * BA1(I,J)  
00650 267* JJ = MAT1  
00653 268* DD 635 J = 1,NETA  
00655 269* JJ = JJ + 1  
00656 270* DD 635 I = 1,MAT21  
00658 271* 635 GLE(I) = GLE(I) - DVNL(J) * BA2(I,J)  
00660 272* CORAR(I) = DVNL(I)/ALPH+0.5  
00666 273* 6N1 = NETA  
00667 274* J = MAT1+2  
00670 275* DD 640 I = 2,NETA  
00673 276* 6N2 IF (NSPM1 .LE. 0) GO TO 665  
00674 277* 640 IF (NSPM1 .LE. 0) GO TO 665  
00676 278* DD 655 K = 1,NSPM1  
00677 279* DD 650 J = 1,NETA  
00678 280* JJ = JJ + 1  
00679 281* DD 650 I = 1,MAT21  
00680 282* 628 SLE(I,K) = SLE(I,K) - DVNL(JJ) * BA2(I,J)  
00682 283* J = MAT1 + K*NETA + 2  
00684 284* DD 655 I = 2,NETA  
00685 285* 6N2 IF (EASE LT 0.20) GO TO 673  
00700 289* 665 IF (EASE LT 0.20) GO TO 673  
00700 289* 665 IF (EASE LT 0.20) GO TO 673  
00700 289* 665 IF (EASE LT 0.20) GO TO 673  
00730 290* IF (CORAR(ICORM)/CORMA .LT. 0.330) BUMP = 2.0*BUMP  
00733 291* GO TO 675  
00736 292* 675 CALL ABMAX(L,CORAR,CORMA)  
00735 294* 6N2 IF (ABS(1.0-CORAR(ICORM)/CORMA) .LE. 0.250) BUMP = BUMP/2.0  
00736 295* C CORRECT PRIMARY VARIABLES  
00738 296* DUM = 0.050/BUMP  
00737 297* EASE = AMING(EASE,1.0,DUM/ABS(CORMA))  
00740 297* IFITS.EQ.2) BUMP = AMING(BUMP,.02/ABS(CORMA))  
00742 298* IF (KQ10 .GT. 0) EASE = AMING(ABS(F(I,3))/(DVNL(3)+1.0E-30)/2.),EASE)  
00744 299* IF (EASE .GE. 1.0) GO TO 740  
00746 300* DD 730 I = 1,259  
00751 301* IF (I .LE. 123) DVNL(I) = DVNL(I)+EASE  
00753 302* 730 FLE(I) = FLE(I) + EASE  
00755 303* 740 PLEASE = PLEASE *(1.0 - EASE)  
00756 304* CTE = F(NETA,1) - F(1,1) - XM(5)/F(NETA,2)  
00757 305* DD 785 I = 1,NETA  
00762 306* F(I,2) = F(I,2) + DVNL(I+3)  
00763 307* F(I,4) = F(I,4) + FLE(2,NETA+I-2)  
00764 308* IF (I .GT. 1) GO TO 765  
00766 309* F(I,1) = F(I,1) + DVNL(2)  
00790 310*
00767 310* F(1,3) = F(1,3) + DVNL(3)              002114
00770 311* GO TO 770                            002117
00773 312* 765 F(1,1) = F(1,1) + FLE(I-1)        002121
00776 313* F(1,3) = F(1,3) + FLE(NETA+I-2)      002123
00779 314* 770 LPI=MAT1+I+1                     002127
00782 315* DO 785 K=NUM.NSPM1                   002132
00785 316* IF (1.EQ. NETA) SP(I,1,K) = SP(I,1,K) + SPLE(I,K) 002165
01001 317* IF (1.NE. NETA) SP(I,1,K) = SP(I,1,K) + DVNL(LPI) 002172
01004 318* SP(I,1,2,K) = SP(I,1,2,K) + SPLE(NETA+I,K) 002201
01007 319* IF (1.LE. 1) SP(I,1,2,K) = SP(I,1,2,K) + DVNL(LPI-1) 002210
01010 320* IF (I.GT. 1) SP(I,2,K) = SP(I,2,K) + SPLE(I,K) 002216
01013 321* 785 LPI = LPI + NETA                  ANK 8/83 002223
01016 322* ALPH=ALPH+DVNL(1)                   002242
01019 323* RETHMO=-CMW(IS)+RHOE(IS)*UE(IS)*CTE*VMUE(IS)/VMU(NETA) NEWH02245
01022 324* ACCP=BETAV(IS)+VMUE(IS)**2*ROKAP(IS)**2/2.0/XI(IS) NEWH02255
01025 325* ACCPK=ACCP*RHOE(IS)*VMU(1)/(VMUE(IS)*RHO(1)) 002266
01028 326* IF (ILAMIN.EQ.0) GO TO 79            NEWH02274
01031 327* ILAM=0                                NEWH02276
01034 328* IF (S(IS).GT.2.*STURB.AND.ACCPK.GT.1.1E-06) GO TO 69 NEWH02277
01037 329* GO TO 79                            NEWH02416
01040 330* 69 IF (RETHMO.LT.250.) GO TO 79      NEWH02320
01043 331* ILAM=1                               NEWH02323
01046 332* AA=8.935E-14                         NEWH02325
01049 333* BB=2.239E-10                         NEWH02327
01052 334* CC=1.0247E-06                        NEWH02331
01055 335* ACCPK1=AA+RETHMO**2+BB*RETHMO+CC    NEWH02333
01058 336* IF (RETHMO.LT.4100.) GO TO 98       NEWH02342
01061 337* ILAM=0                               NEWH02346
01064 338* GO TO 99                            NEWH02347
01067 339* ACCPK2=3.5E-06                       NEWH02551
01070 340* IF (ACC PK.LT. ACC PK1) ILAM=0       NEWH02535
01073 341* IF (ACC PK.GT. ACC PK2) ILAM=1       NEWH02537
01076 342* 79 CONTINUE                          NEWH02366
01079 343* IF (ITS .NE. 99 .OR. 1777 .EQ. 777) GO TO 850 NEWH02366
01082 344* 1777 = 777                           002401
01085 345* ITS = 80                              002403
01088 346* 850 IF (KQ10 .GT. -1 .OR. KQ10 .LT. -10) RETURN ANK 4/83 002406
01091 347* RETHMO = -CMW(IS)+RHOE(IS)*UE(IS)*CTE*VMUE(IS)/VMU(NETA) ANK 8/83 002426
01094 348* IF (RETHMO.GT.RETR) STURB = S(IS)    002440
01097 349* IF (RETHMO.GT.RETR) KQ10 = -10       002447
01100 350* IF (RETHMO.GT.RETR) ILT=2           NEWH02455
01103 351* IF (RETHMO.LT.RETR) KQ10 = -10       NEWH02463
01106 352* IF (RETHMO.LT.RETR) ILT=1           NEWH02471
01109 353* RETURN                               NEWH02535
01112 354* END                                  B05A5350 002477

END OF COMPILATION: NO DIAGNOSTICS.
IF(IPART.EQ.1)GO TO 40
IF(ICF.GT.0.AND.ICF.LT.3)GO TO 40
GO TO 41
40 DUMM1=DER(11)+2.
DUMM2=DER(12)
DUMM3=S(IS)
AM=F(NETA,2)/ALPH*UE(IS)/SQRT(GMR(NETA)*VMU(NETA)*TT(NETA)*49732.)
REFF=1.+(GMR(NETA)-1.5)/GMR(NETA)/AM**2
DO 42 I=1,NETA
42 CONTINUE
DZERO=-(DM1(I)-DM2(I))/DM1(I)*DM2(I)
AINT=0.5*(DZERO+DM1(I)+DM2(I))
DUMM4=AINT
DO 43 I=2,NETA
43 CONTINUE
DUMM4=AINT
DUMM5=(G(NETA,1)-HB(NETA)/UCE)*REF
DUMM7=RHO(NETA)
DUMM8=RHO(1)
DUMM9=VNU(1)
DUMM10=VMUE(IS)
DUMM11=PR(NETA)
DUMM12=UE(IS)
IF(IPART.EQ.1.AND.(ICF.EQ.0.OR.ICF.EQ.3))GO TO 41
AFACT=0.52
CALL ROUGH(AFACT)
CF=DUMM18/2
ST=DUMM16
WALLQ=ST*(G(NETA,1)-G(1,1))*RHOE(IS)*UE(IS)
41 CONTINUE
IF(IPART.EQ.1)GO TO 45
GO TO 44
45 IF(ICF.EQ.0.OR.ICF.EQ.3)GO TO 46
DUMM1=DUMM18
DUMM2=DUMM16
46 CONTINUE
DUMM5=G(NETA,1)
DUMM6=G(1,1)
DUMM19=CPBAR(ETA)*UCT/UCE
DUMM20=REFF*ETA/UCT
DUMM21=T(1)/UCT

DUMM22=(DUMM19+VMU(ETA))/UCV/DUMM11
DUMM23=(DUMM7*DUMM12*2.*RDKAP(RS)/RAD5)/DUMM10
PARTM=(4./3.)*(22./7.)*((RP/12.)**3)*RHDA
DUMM24=PARTM+DUMM12/((22./7.)*6.*RP/12.*DUMM10)
CALL PARTCL
CF=DUMM18/2.

ST=DUMM16
WALLQ=ST*(G(ETA,1)-G(1,1))*RHE(IS)*UE(IS)

CONTINUE

IF(IPASS.EQ.0) WRITE(3) CF,CH,WALLQ

ACCPK=ACCP+RHE(IS)/VMU(1)/(VMUE(IS)+RHO(1))

WRITE(6,1009)
1009 FORMAT(1X,56('*'), REMTECH INC. 11-84, '56('*')
1010 FORMAT(1X,132('*'))
WRITE(6,1000) ICF,RK
1000 FORMAT(2X,'ROUGHNESS MODULE USED - OPTION ',12.,
       $ 6X,'EQUIVALENT SAND ROUGHNESS HEIGHT, RK = ',E10.3,'(FEET)'

IF(ICF.EQ.3) GO TO 1112
RFAC=DUMM16/DUMM2
IF(DUMM17.EQ.0.0) WRITE(6,1001)RFAC
IF(DUMM17,ST.0.0 AND.DUMM17,LT.1.0) WRITE(6,1002)RFAC
1001 FORMAT(6X,'SMOOTH',14X,20X,'ROUGHNESS FACTOR = ',F7.3)
1002 FORMAT(6X,'TRANSITIONALLY ROUGH',20X,'ROUGHNESS FACTOR = ',F7.3)
1003 FORMAT(6X,'ROUGH',15X,20X,'ROUGHNESS FACTOR = ',F7.3)
WRITE(6,1008)CF,ST,WALLQ
1008 FORMAT(6X,'PARTICLE MODULE USED',/,6X,'LAMINAR FLOW',5X,
       $ 'HEAT FLUX=',PE10.3)
GO TO 1111

IF(ABS(DUMM17).LE.0.001) WRITE(6,1004)
1004 FORMAT(6X,'SMOOTH')
1005 FORMAT(6X,'ROUGH')
1006 FORMAT(6X,'RKS BEYOND UPPER LIMIT - EQUATION BECOMES INVALID - ',
       $ 'THEREFORE RKS = 0.0 WAS USED.')
WRITE(6,1010)
1111 CONTINUE

IF(IPART.EQ.1) GO TO 1301

GO TO 1302
1301 WRITE(6,1009)
1302 WRITE(6,1003)
1303 FORMAT('PARTICLE MODULE USED',/,6X,'LAMINAR FLOW',5X,
       $ 'PARTICLE SIZE RP=',E10.3,'IN RADIUS',/1X,'PARTICLE LOADING=',
       $ F10.2,10X,'PARTICLE FACTOR =',F10.4)
IF(111.EQ.2) WRITE(6,1305)RP,AK,PF
1305 FORMAT('PARTICLE MODULE USED',/,6X,'TURBULENT FLOW',5X,
       $ 'PARTICLE SIZE RP=',E10.3,'IN RADIUS',/1X,'PARTICLE LOADING=',
       $ F10.2,10X,'PARTICLE FACTOR =',F10.4)
WRITE(6,1008)CF,ST,WALLQ
WRITE(6,1010)
1302 CONTINUE
IF(ILAMIN.EQ.0.OR.ILAM.EQ.0)GO TO 1211
WRITE(6,1009)
WRITE(6,1200)SPECT
1200 FORMAT(/,2X,'RELAMINARIZATION OCCURED'/)
$ ** DEGREE OF RELAMINARIZATION = ',E10.3,' PERCENT' **
WRITE(6,1010)
1211 CONTINUE
WRITE(6,1007)RETHMO,ACCP,ACCPK
1007 FORMAT(/,1X,'RETHMO ACCN PARA ACCN PARA',/1X,
$ ' (EDGE) (WALL)',/ 3X,1P3E10.3)
SUBROUTINE OUTPUT ENTRY POINT 003775

STORAGE USED: CODE(1) 004015; DATA(0) 001251; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003 AL 000002
0004 BLOCOM 002043
0005 COECOM 000317
0006 CONSTS 000010
0007 CRBCOM 000111
0010 EDGCOM 001216
0011 EPSCOM 000040
0012 EQPCOM 002243
0013 ETACOM 000017
0014 FLXCOM 000020
0015 HICSOM 00426
0016 HOLLER 000056
0017 INPUTI 000015
0020 INTCOM 000123
0021 INTERI 000004
0022 PRMALS 000243
0023 PRMORG 000455
0024 PRPCOM 000303
0025 PRPERT 000151
0026 PRPIOP 00016
0027 PRNPNT 000056
0030 RFTCOM 000045
0031 RUF 000022
0032 PARTI 000020
0033 LAM 000001
0034 SAHA 000151
0035 SAVOUT 000021
0036 TEMCOM 000201
0037 TURB 000020
0040 UNICOM 000011
0041 VARCOM 000245
0042 WALL 000454
0043 ACCN 000003
0044 RETH 000001

EXTERNAL REFERENCES (BLOCK, NAME)

0045 ROUGH
0046 PARTCL
0047 REFIT
## STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

<table>
<thead>
<tr>
<th>Block</th>
<th>Type</th>
<th>Relative Location</th>
<th>Name</th>
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<tbody>
<tr>
<td>0000</td>
<td>0011</td>
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</tr>
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</tr>
<tr>
<td>0061</td>
<td></td>
<td>NERR3S</td>
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</tbody>
</table>

*Note: The table represents a list of storage assignments with block numbers, type codes, relative locations, and names.*
| 0033 | 1 | COMMON /IPLOTL,UNIT | 0000 | O000131 | LIT | 0000 | O01211 | INJP$ | 0032 | O00017 | IPART | 0034 | O00063 | IPASS |
| 0030 | 1 | COMMON /IPLOTL,UNIT | 0000 | O00064 | IRITE | 0020 | O00020 | IS | 0020 | O00021 | ISH | 0022 | O00147 | IST |
| 0000 | 1 | COMMON /IPLOTL,UNIT | 0000 | O00026 | IUT | 0017 | O00031 | INIT | 0001 | O00065 | IRNTC | 0000 | O000150 | IU |
| 0003 | 1 | COMMON /IPLOTL,UNIT | 0000 | O00001 | LUNIT | 0017 | O00011 | IWall | 0000 | O00060 | J | 0017 | O00012 | Jw | 0000 | O00046 | K |
| 0021 | 1 | COMMON /KAPPAL,UNIT | 0030 | O00003 | KAPPA | 0030 | O00037 | KAPPAT | 021 | O00000 | KBC | 020 | O00024 | KONRF |
| 0004 | 1 | COMMON /ISH,UNIT | 0000 | O00004 | KG10 | 0021 | O00002 | KG9 | 0020 | O00025 | KR9 | 0007 | O00026 | KS | 0030 | O00040 | KTRUB |
| 0012 | 1 | COMMON /RADS,UNIT | 0020 | O00014 | RADS | 0020 | O00154 | RADS | 0022 | O00154 | RADS | 0036 | O00044 | R4TLM | 0045 | O000077 | R4F |
| 0044 | 1 | COMMON /R4TM,UNIT | 0016 | O00013 | REY | 0000 | O00103 | R4FACT | 023 | O00073 | RHO | 010 | O00147 | RHOE |
| 0032 | 1 | COMMON /RHOV,UNIT | 0042 | O00037 | RHOV | 031 | O00014 | RK | 023 | O00311 | RUKAP | 032 | O00016 | RP |
| 0022 | 1 | COMMON /RVM,UNIT | 0006 | O00004 | PI | 0042 | O00037 | PISEAE | 0000 | R000104 | PIOTD | 025 | O00055 | PR |
| 0000 | 1 | COMMON /RVM,UNIT | 0016 | O00005 | PRES | 0016 | O00005 | PRE5 | 034 | O00067 | OWS | 022 | O00156 | R4F |
| 0023 | 1 | COMMON /TEMM,UNIT | 0022 | O00027 | RADS | 0022 | O00154 | RADS | 0036 | O00044 | R4TLM | 0045 | O000077 | R4F |
| 0010 | 1 | COMMON /TEMM,UNIT | 0016 | O00044 | TEMP | 0036 | O00153 | THELEM | 0000 | O00077 | THOM |
| 0016 | 1 | COMMON /TEMM,UNIT | 0014 | O00017 | TPWALL | 025 | O00013 | TT | 037 | O00001 | TURPR | 010 | O00770 | TVCC |
| 0040 | 1 | COMMON /UCD,UNIT | 0040 | O00000 | UCD | 040 | O00002 | UCL | 040 | O00003 | UCM | 0000 | O00065 | UCMF |
| 0012 | 1 | COMMON /UCP,UNIT | 0040 | O00004 | UCP | 040 | O00006 | UCS | 040 | O00007 | UCT | 040 | O00100 | UCV |
| 0010 | 1 | COMMON /UK7EN,UNIT | 0035 | O00012 | UE | 0035 | O00012 | UKAPPA | 016 | O00052 | VIS | 0040 | O000075 | NS |
| 0014 | 1 | COMMON /VMU,UNIT | 0024 | O00010 | VJkw | 0010 | O00113 | VMUE | 025 | O000132 | MVM | 012 | O001176 | VNU |
| 0004 | 1 | COMMON /WALL,UNIT | 0035 | O00020 | WALLA | 014 | O00001 | WALL | 014 | O00000 | WALL | 012 | O002136 | WAT |
| 0032 | 1 | COMMON /WALL,UNIT | 0032 | O00005 | WP | 012 | O002147 | WM | 0005 | O00247 | XG | 015 | O00344 | XI |
| 0005 | 1 | COMMON /XSP,UNIT | 0005 | O00242 | XM | 0005 | O00254 | XSP | 022 | O00161 | XST | 036 | O00162 | Y |

| SUBROUTINE OUTPUT | B21A 002 | 000000 |

| COMMON /AL/,IPLOTL,UNIT | /AL/ |
| COMMON /BLOC/ | /BLOC/ |
| COMMON /CONEC/ | /CONEC/ |
| COMMON /CONS/ | /CONS/ |
| COMMON /CRBC/ | /CRBC/ |
| COMMON /EDGC/ | /EDGC/ |
| COMMON /EPC/ | /EPC/ |
| COMMON /ETAC/ | /ETAC/ |
| COMMON /FLXCOM/ | /FLXCOM/ |
| COMMON /HISC/ | /HISC/ |
| COMMON /HOLL/ | /HOLL/ |
| COMMON /HOLL/ | /HOLL/ |
| COMMON /INPUT/ | /INPUT/ |
| COMMON /INCOM/ | /INCOM/ |
| COMMON /INTERI/ | /INTERI/ |
| COMMON /MPRLS/ | /MPRLS/ |
| COMMON /MPRLS/ | /MPRLS/ |
| COMMON /PRPER/ | /PRPER/ |
| COMMON /PRPDP/ | /PRPDP/ |
00127 29* COMMON /PRPNT/ HB(31),RHO(15) /PRPNT/ 000000
00130 30* COMMON /RFTCOM/ F2FIX(15),F2FIXT(15),KAPPAL,KAPPAT,KTURB,NETAL, /RFTCOM/ 000000
00133 21* COMMON /RFTCOM/ NETAT,NDPNT,RATLIM /RFTCOM/ 000000
00131 32* COMMON/RUF/DUMM1,DUMM2,DUMM3,DUMM4,DUMM5,DUMM6,DUMM7,DUMM8,DUMM9, 000000
00132 33* $ DUMM10,DUMM11,DUMM12,RK,ICF,FMF,DUMM16,DUMM17,DUMM18 NEW00000
00132 34* COMMON/PART/PARTM,DUMM24,RHOA,DUMM23,CPART,WP,DUMM19,WF, NEW00000
00132 35* $ DUMM22,DUMM20,DUMM11,ILT,PF,AK,RP,IPART NEW00000
00133 36* COMMON /LAM/ ILAMIN NEW00000
00134 37* COMMON /SAHA/ CPH(51),IPASS,IRITE,ITRCNT,NSJ,OWG(50) /SAHA/ 000000
00135 38* COMMON /SAVOUT/ ENTHAL,UKAPPA(15),WALLA /SAVOUT/ 000000
00136 39* COMMON /TEMCOM/ CM(7),DER(50),DUDS(50),THELEM(7),Y(15) /TEMCOM/ 000000
00137 40* COMMON /TURB/ STURB,TPRP(15) /TURB/ 000000
00140 42* COMMON /UNICOM/ UCD,UCE,UCL,UCM,UCP,UCR,UCS,UCT,UCV /UNICOM/ 000000
00141 41* COMMON /VARCOM/ ALPH,F(15,4),G(15,3),SP(15,3,7) /VARCOM/ 000000
00142 43* COMMON /WALL/ FLUXU(250),RHOVW(50) /WALL/ 000000
00143 44* COMMON/ACC/ACCUP,ILAM,SPCT NEW00000
00144 45* COMMON/RETH/RETHMO NEW00000
00145 46* DIMENSION DM(15),DM2(15) NEW00000
00146 47* C NEW00000
00146 48* DIMENSION FLOW(2),PRES(2) ANK 5/83 000000
00147 49* INTEGER AREA,CQ,DENS,DIST,ENERGY,FLOW,HEAT,HWWAL,PRES,PRESS,REY, ANK 8/83 000000
00147 50* 1 SHEAR,TCOM,THER,THRU,VEL,VIS,ATA,ATB ANK 8/83 000000
00150 51* DATA FLOW/12HKG/SECLB/SEC/.NUM/6HNUMBER/.PRES/12H(N/M2)LB/IN2/ 000000
00152 30* COMMON /RFTCOM/ F2FIX(15).F2FIXT(15).KAPPAL,KAPPAT,KTURB,NETAL. ANK 000000
00158 34* COMMON /RFTCOM/ CM(7),F2FIX,HEM(7).THER,TPRP(15) ANK 000000
00163 60* IF (NSPM1.LE.0) GO TO 3051 ANK 4/83 000031
00165 61* DO 305 K = 1,NSPM1 ANK 8/83 000034
00170 62* WALL(K)=VJKW(K) ANK 151 000041
00170 63* $ WALL(K)=0.0 WALL(K) ANK 151 000041
00173 64* 3051 DER(1) = W(2)/C3M(15) ANK 8/83 000047
00174 65* DER(2) = W(3)/C3M(15) ANK 8/83 000052
00175 66* ADR = (W(2) + W(3) - RHOVW(IS))/C3M(15) ANK 8/83 000055
00175 67* IF (ADR*100.0.LT.RHOVW(IS))/C3M(15) ADR = 0.0 ANK 8/83 000063
00179 68* Y(T) = 0.0 ANK 8/83 000074
00201 69* SHFAC = -UE(IS)*(ALPH*2*C3M(15)*GG) ANK 8/83 000075
00202 70* DUDS(1) = F(1,1)+SHFAC*(CAPC(1)+EPSA(1)) ANK 000010
00203 71* DO 182 I=2,NETRA ANK 161 000123
00204 72* DUDS(1) = F(1,1)+SHFAC*(CAPC(1)+EPSA(1)) ANK 161 000123
00207 73* 182 Y(I) = Y(I-1)+C89+CHRM(I-1) ANK 161 000130
00217 74* SHEAD = DUDS(1) ANK 8/83 000135
00212 75* IF (IWALL .LT. 3) EMIS = 0.0 ANK 4/83 000140
00214 76* QDIFU = -CAPC(1)/ALPH+CPBAR(1)/PR(1)+TPWALL/C3M(IS) ANK 8/83 000145
00217 77* CPH(IS) = CPBAR(NETA) ANK 5/83 000155
00216 78* QWQ(GS) = QDIFU ANK 8/83 000160
00217 79* DER(1) = ALPH ANK 8/83 000171
00220 80* DER(12) = ROKAP(IS)/RAD5 ANK 8/83 000183
00221 81* DER(13) = PE(IS)/UCP ANK 8/83 000186
00222 82* DER(14) = UE(IS)/UCL ANK 8/83 000190
00223 83* DX = UE(IS)*#2/RHOE(IS)/GC EV 10/73 000191
00224 84* ACH = DER(12)+RAD6 ANK 8/83 000194
00225 85* DER(15) = BETAP(IS) ANK 7/83 000195
00226 86* DER(16) = BETAV(IS) ANK 000206
00227 87* DER(17) = WALLQ/UCR ANK 000210
00230 88* DER(18) = DER(3)/UCR ANK 000213
00230 89*
11.20 000320
0.0 000551

119* WRITE (6,2) (HEAT(J,UNIT),J=1,2),DIST(UNIT),PRESS(UNIT),
115* ACCP = RHO(NTA)/VMU(NTA)*UE(IS)/ALPH*F(NETA,2)
117* 30 ACCP = RHO(NTA)/VMU(NTA)*UE(IS)/ALPH*F(NETA,2)
118* IF (IRITE .EQ. 0) GO TO 400
119* WRITE (6,2) ((MAB(J,UNIT),J=1,2),K=1,2),ATAK(K),ATB(K),K=1,NSP)
120* 2 FORMAT(//,5X,HEAT,12X,12HMASSF.BARES,2A6,9X,32HELENEAS,M ASS DI
121* 25 FUSIVE FLUXES,2A6,9X,3HSMXOR,3X,17MECHANICAL PYROL.
122* 2 6X,4HCHAR,3X,17MECHANICAL PYROL.
123* WRITE (6,2) (SHEAR(UNIT),J=1,2)
124* 23 FORMAT(4X,6X,3X,7HREMOVAL,5X,3HCHAR)
125* 400 DO 203 I = 1,NTA
126* SP(I,1,NSP) = 1.0
127* SP(I,2,NSP) = 0.0
128* 203 SP(I,3,NSP) = 0.0
129* IF (NSPM1 .LE. 0) GO TO 2021
130* DO 202 K = 1,NSPM1
131* DO 202 I = 1,NTA
132* SP(I,1,NSP) = SP(I,1,NSP) - SP(I,1,K)
133* SP(I,2,NSP) = SP(I,2,NSP) - SP(I,2,K)/ALPH
134* SP(I,2,NSP) = SP(I,2,NSP) - SP(I,2,NSP) - SP(I,2,K)
135* SP(I,3,NSP) = SP(I,3,NSP) - SP(I,3,K)/ALPH**2
136* 202 SP(I,3,NSP) = SP(I,3,NSP) - SP(I,3,K)
137* XSP(S,NSP) = F(NETA,1) - F(1,1)
138* IF (NSPM1 .GE. 1) GO TO 2195
139* VJKW(I) = 0.0
140* CM(1) = 0.0
141* THELEM(1) = 0.0
142* DO 2136 I = 1,NSPM1
143* 2135 DO 2136 I = 1,NSPM1
144* 2136 XSP(S,NSP) = XSP(S,NSP) - XSP(S,1)
145* DO 2131 I = 1,NSP
146* VJKW(I) = 0.0
147* DO 2132 K = 1,NSP
148* 2132 VJKW(I) = VJKW(I) - WALL(K)/WTM(K)*VNU(I,K)
149* ANK 4/83 000067
151 IF (IRITE_EQ.0) GO TO 35
152 DER(11) = SHEAD/UCS
154 DER(12) = ADR*UCMF
158 DER(13) = DER(1) - UC MF
164 DER(15) = RHOV(IS)*UCMF/C3M(IS)
167 DO 2237 I = 1,NSP
168 2237 DER(I+15) = V JKW(I) /UCMF
169 WRITE (6,3) (DER(J), J = 1,NSJ)
170 IF (NSPM.LE.0) GO TO 2074
171 DO 2071 I = 1,NSP
172 THELEM(I) = 0.
173 CM(I) = 0.
175 DO 2072 K = 1,NSP
176 DUZ = DUZ + (DUM3*SP(NETA,1,K)-C89/ALPH*XSP(5,K))/WTM(K)*VNJ(I,K)
177 2072 THELEM(K) = THELEM(K) + (SP(NETA,1,K) - SP(1,1,K))/WTM(K)*VNJ(I,K)
178 IF (ABS(THELEM(I)) .LE. 0.0) GO TO 2071
180 THELEM(I) = DUZ/THELEM(I)
181 2071 CONTINUE
182 IF (K93 .EQ. 0) GO TO 2078
183 TRANSVERSE CURVATURE CALLED FOR BY IBODY INPUT AS B
184 COSOR = TVCC(IS)/VMUE(IS)*0.50/C3M(IS)
185 DO 2076 I = 1, NETA
186 Y(I) = TVCF(Y(I))
187 Y(I) = DUDS(I)*DUDS(I)*(1.0 + COSOR*Y(I))
188 DELST = TVCF(DELST)
189 THMOM = TVCF(THMOM)
190 Y(I) = TVCF(Y(I))
191 THELEM(I) = TVCF(THELEM(I))
192 2072 THELEM(K) = TVCF(THELEM(K))
194 IF (IRITE_EQ.0) GO TO 50
195 CALCULATE THE BOUNDARY LAYER THRUST LOSS
196 DF = 2.0*COSALF(IS)/(UCL*UCS)*(ACH+DX*THMOM - ACH*PE(IS)*DELBD*
197 1 PATM*SPSF + RAD6*SORT(XI(IS)*2.0)*F(1,1)*UE(IS)/GC/UCL*
198 WRITE (6,18) (ATA(K),ATB(K)) K = 1,NEL
199 FORMAT (/3X,20HELEM TRANS HEAT TRANS, 5X, 18BLOWING PARAMETERS, 7X,
200 1 36HELEM ENTERAL MASS TRANSFER COEFFICIENTS/4X,2(6HECOEFF, 4X),25H(NOR)
201 2M. BY RHOE*UE*ST) FOR, 14X,8HCM, FOR/5X,4HCF/2,5X,38HST NO. PYRO
202 3L GAS CHAR TOTAL GAS ,8(1,1,2,4A,1X))
203 DER(10) = RHOE(IS)*UE(IS)
204 DER(11) = CF/DER(10)
205 DER(12) = CH/DER(10)
206 IF (IPART.EQ.1) GO TO 40
207 IF (ICGF_GT.0.AND.ICFLT.9) GO TO 40
00543  209*  40  DUMM=DER(11)*2.  NEW001324
00544  210*  DUMM2=DER(12)  NEW001336
00545  211*  DUMM3=S(IS)  NEW001340
00546  212*  AM=(NETA,2)/ALPH+UE(IS)/SQR((GMR(NETA))/VMW(NETA)*TT(NETA)+49732.)  NEW001343
00547  213*  REFF=(1.+(GMR(NETA)-1.)/2.+PR(NETA)**.333*AM**2)/  NEW001361
00548  214*  $(1.+(GMR(NETA)-1.)/2.+AM**2)  NEW001361
00549  215*  DO 42  I=1,NETA  NEW001415
00550  216*  DM1(I)=CPBAR(I)+RCT/UCE  NEW001415
00551  217*  DM2(I)=TT(I)/UCT  NEW001420
00552  218*  42  CONTINUE  NEW001424
00553  219*  DZERO=DM1(I)-(DM1(2)-DM1(I))/(DM2(2)-DM2(1))*DM2(1)  NEW001424
00554  220*  AINT=0.5*(DZERO+DM1(I)+DM2(I))  NEW001444
00555  221*  DUMM6=AINT  NEW001444
00556  222*  DO 43  I=2,NETA  NEW001444
00557  223*  AINT=AINT+0.5*(DM1(I-1)+DM1(I)))*(DM2(I)-DM2(I-1))  NEW001444
00558  224*  43  CONTINUE  NEW001454
00559  225*  DUMM7=AINT  NEW001455
00560  226*  DUMM5=(DUMM4+(G(NETA,1)-HB(NETA))/UCE)+REFF  NEW001455
00561  227*  DUMM7=RHS(NETA)  NEW001463
00562  228*  DUMM8=RHO(1)  NEW001465
00563  229*  DUMM9=VMU(I)  NEW001467
00564  230*  DUMM10=VMU(I)  NEW001471
00565  231*  DUMM11=PR(NETA)  NEW001473
00566  232*  DUMM12=UE(I)  NEW001475
00567  233*  IF(IPART.EQ.1.AND.(ICF.EQ.0.OR.ICF.EQ.3))GO TO 41  NEW001477
00568  234*  AFACF=0.52  NEW001520
00569  235*  CALL ROUGH(AFACF)  NEW001522
00569  236*  CF=DUMM18/2.  NEW001525
00570  237*  ST=DUMM16  NEW001530
00571  238*  WALLO=ST*(G(NETA,1)-G(1,1))*RHOE(IS)+UE(IS)  NEW001532
00572  239*  41  CONTINUE  NEW001543
00573  240*  IF(IPART.EQ.1)GO TO 45  NEW001543
00574  241*  GO TO 45  NEW001545
00575  242*  45  IF((ICF.EQ.0.OR.ICF.EQ.3))GO TO 46  NEW001547
00576  243*  46  CONTINUE  NEW001547
00577  244*  DUMM1=DUMM18  NEW001560
00578  245*  DUMM2=DUMM16  NEW001562
00579  246*  DUMM5=G(NETA,1)  NEW001565
00580  247*  DUMM6=G(1,1)  NEW001567
00581  248*  DUMM19=CPBAR(NETA)+UCT/UCE  NEW001571
00582  249*  DUMM20=REFF*TE(1)/UCT  NEW001575
00583  250*  DUMM1=TT(I)/UCT  NEW001601
00584  251*  DUMM22=VUMU(NETA)+CX/DUMM11  NEW001604
00585  252*  DUMM23=(DUMM7+DUMM12)/2.*ROAP(IS)/RAD5/DUMM10  NEW001610
00586  253*  PARTM=(4./3.)*(22./7.)*(RP/12.)*RHOPA  NEW001620
00587  254*  DUMM24=PARTM*DUMM12/((22./7.)*6.*RP/12.*DUMM10)  NEW001630
00588  255*  CALL PARTCL  NEW001637
00589  256*  CF=DUMM18/2.  NEW001641
00590  257*  ST=DUMM16  NEW001644
00591  258*  WALL=ST*(G(NETA,1)-G(1,1))*RHOE(IS)+UE(IS)  NEW001646
00592  259*  44  CONTINUE  NEW001657
00593  260*  DER(13) = DER(1)/CH  001657
00594  261*  DER(14) = DER(2)/CH  001661
00595  262*  DER(15) = BLOW  001664
00596  263*  DER(15) = BLOW  EV 10/73
00597  264*  DER(15) = BLOW  EV 10/73 001670
00598  265*  2139 DER(I-15)=CM(I)/DER(10)  001707
00599  266*  STORE ON DRUM FOR PLOTTING: MOMENTUM TRANSFER COEFFICIENT, HEAT  001707
00599  267*  C  TRANSFER COEFFICIENT, TOTAL GAS BLOWING PARAMETER  001707
00600  268*  IF(IPASS.EQ.0) WRITE(3) DER(1), DER(12), BLOW, PLOT  001711
00601  269*  IF(IPASS.EQ.0) WRITE(3) CF, CH, WALLQ  001725
00602  270*  CONTINUE  001725
00662 269* WRITE (6,3) (DER(j), J = 11,NSJ) 001736
00670 270* WRITE (6,4) DIST(IUNIT),REY(IUNIT),(ATA(K),ATB(K), K = 1,NEL) ANK 5/83 001750
00701 271* 4 FORMAT//3X,6HMOMENTUM_DISPLACE, EFFECTIVE ENTHALPY_REYNOLDS, M
00707 272* TASS_THICKNESS IN A6,4H FOR/2X,48THICKNESS THICKNESS BODY TH
00701 272* 2ICKNESS NUMBER/4X,6HTHETA,4X,3HDELSTAR_DISPLACE, LAMBDAP/E PE
00707 274* (6.24) (DIST(IUNIT), K = 1,4) 001767
00710 276* 24 FORMAT (4X,A6) 002000
00711 277* THMOM = THMOM/UCL
00712 278* DELTBD(IS) = DELTBD/UCL 002003
00713 279* DER(13) = DELT/UCL
00714 280* DER(14) = THENGY/UCL
00713 281* DER(15) = ACCP/UCL
00716 282* DO 2140 I=1,NSP EV 10/73
00721 283* 2140 DER(I+15) = THELEM(I)/UCL
00723 284* WRITE (6,3) THMOM,DER(13),DELTBD(IS),(DER(K), K = 14,NSJ)
00723 285* STORE ON DRUM FOR PLOTTING: MOMENTUM THICKNESS, EFFECTIVE DISPLACEMENT
00723 286* IF ((PASS .EQ. 0)) WRITE (3) THMOM,DELTBD(IS)
00723 287* WRITE (6,21) WALL(IUNIT),THRUST(IUNIT),AREA(IUNIT),(FLOW(IUNIT), ANK 8/83
00723 288* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002055
00723 289* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002074
00723 290* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002074
00723 291* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 292* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 293* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 294* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 295* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 296* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 297* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 298* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 299* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 300* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 301* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 302* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 303* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 304* 21 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00723 305* 22 FORMAT (4X,'TOTAL HEAT',7X,6HTHRUST,9X,5HTOTAL,7X,'ACCELERATION') 002110
00727 306* IF((ICF.EQ.0))GO TO 1111
00730 307* WRITE(6,1009)
00730 308* WRITE(6,1009)
00730 309* WRITE(6,1009)
00730 310* WRITE(6,1009)
00730 311* WRITE(6,1009)
00730 312* WRITE(6,1009)
00730 313* WRITE(6,1009)
00730 314* WRITE(6,1009)
00730 315* WRITE(6,1009)
00730 316* WRITE(6,1009)
00730 317* WRITE(6,1009)
00730 318* WRITE(6,1009)
00730 319* WRITE(6,1009)
00730 320* WRITE(6,1009)
00730 321* WRITE(6,1009)
00730 322* WRITE(6,1009)
00730 323* WRITE(6,1009)
00730 324* WRITE(6,1009)
00730 325* WRITE(6,1009)
00730 326* WRITE(6,1009)
00730 327* WRITE(6,1009)
00730 328* WRITE(6,1009)
1004 FORMAT(6X,'SMOOTH')
1005 FORMAT(6X,'ROUGH')
1006 FORMAT(6X,'RKS BEYOND UPPER LIMIT - EQUATION BECOMES INVALID...')$ 'THEREFORE RKS = 0.0 WAS USED.'
1007 WRITE(6,1010)
1008 CONTINUE
1009 IF(IPART.EQ.1)GO TO 1211
1010 WRITE(6,1000) NEW002343
1011 WRITE(6,1200)NEW002353
1012 1200 FORMAT('/2X,RELAMINARIZATION OCCURED'/)
1013 WRITE(6,1010) NEW002343
1014 2X,'DEGREE OF RELAMINARIZATION = ',E10.3,' PERCENT')
1015 WRITE(6,1010) NEW002343
1016 CONTINUE
1017 WRITE(6,1000)NEW002343
1018 1007 FORMAT('/1X,' RETHMO ACCN PARA ACCN PARA'/,1X,
1019 $ ','EDGE')/(WALL')/3X,IP3E110.3)
1020 IF(IPASS .NE. 1) WRITE (4) ETA(I),DER(1),GMR(I),DER(2) PLOT
1021 DER(1) = F(I,2)/ALPH
1022 STORE ON DRUM FOR PLOTTING: TOTAL HEAT TO WALL, WALL AREA, THRUST LOSS,
1023 C ACCELERATION PARAMETER, INVISCID MASS FLOW, AND TOTAL MASS FLOW
1024 WRITE (3) SUMQG,WALLA,DF,ACCP,THENV,THMOM PLOT
1025 55 WRITE (6,6) SHEAR(IUNIT),(ENERGY(IUNIT), K = 1,2) ANK B/83
1026 6 FORMAT (1H1,5X,'NODAL INFORMATION'/1X,2HNO,7X,3HETA,10X,4H4U/UE,
1027 18X,SHGAMA,6X,GSHF,3X,SFDF,8X,FPF,12X,
1028 2 'GP',A6,8X,'GPP',A6)
1029 DD 182 I=1,NET B11A 240 002552
1030 DER(1) = F(I,2)/ALPH
1031 DER(2) = DDSD(I)/UCS
1032 DER(3) = F(I,3)/ALPH**2
1033 DER(4) = G(I,2)/(ALPH*UC)
1034 DER(5) = G(I,3)/(ALPH**2*UC)
1035 C STORE ON DRUM FOR PLOTTING: ETA VALUES, VELOCITY RATIO, GAMMA, AND SHEAR.
1036 183 WRITE (6,12) I,ETA(I),DER(1),GMR(I),DER(2),F(I,1),(DER(J),J=3,5)
1037 12 FORMAT (1X,12,3F13.7,1PE18.7)
1038 WRITE (6,7) DIST(IUNIT),DENS(IUNIT),(ENERGY(IUNIT), K = 1,2).
1039 1 PRES(IUNIT),NUM,NUM
1040 7 FORMAT ('/1X,2HNO,5X,'DISTANCE FROM',8X,'DENSITY',7X,'STATIC ENTHA
1041 1LPY',4X,'TOTAL ENTHALPY',6X,'PITOT TUBE',7X,'MACH',7X,'MOLECULAR',
1042 25X,'WALL',A6,8X,'RHO',A6,8X,'H',A6,9X,'G',
1043 3 A6,5X,'PRESSURE',A6,4X,A6,7X,'WEIGHT',7X,AG
1044 DD 184 I=1,NET B11A 259 002653
1045 GMR(I) = ABS(GMR(I))
1046 ACH = F(I,2)/ALPH*UE(I)/SORT(GMR(I)/VMW(I)**T(I)**GC*VAR)
1047 DER(2) = RHO(I)/UCD
1048 DX = GMR(I) - 1.0
01461 449* 204  \( \text{SP}(I,3,K) = \text{SP}(I,3,K) \times \text{ALPH} \times 2 \)
01464 450* 2041 IF (IFRTE .EQ. 0) GO TO 325
01465 451* WRITE (6,16)
01470 452* 16 FORMAT (/2X14HMOLE FRACTIONS,/) B11A 130
01471 453* DO 196 J = 1,NSPEC B11A 274
01474 454* WRITE (6,14) M0A(J),MOB(J),(F(RJ,I), I = 1,NETA)
01506 455* IF (IFALL .EQ. 4) WRITE (6,17) MAO(ISU),MOB(ISU)
01512 456* 17 FORMAT (/4X,'SURFACE SPECIES IS ',2A6)
01514 458* IF (IS .LT. 1) WALL = WALLQ = CM(IS) ANK 8/83
01514 459* RETURN
01516 460* IF (IS .LT. 1) return
01517 461* J = NETAL - 1
01517 462* M = KAPPA - 1
01517 463* K = KAPPA + 1
01521 462* RETURN
01521 462* RETURN
01522 463* KAPPA=KAPPA
01523 464* IF (KONRFT.EQ.0) RETURN
01524 464* IF (KONRFT.EQ.0) RETURN
01525 465* RETURN
01525 466* IF (IS .EQ. 1) 4002, 4002, 4002
01527 467* C TRANSITION TO TURBULENCE - CHANGE NODE DATA
01532 468* 4019 KTURB=-1
01533 469* Y(I)=Y(I)*UCL EV 10/73
01534 470* NETAL=NETAL
01535 471* KAPPA=KAPPA
01536 472* DO 4020 I=1,NETA
01537 473* 4020 F2FIX(I)=F2FIX(I)
01543 474* DO 4018 I = NETAL,J
01544 475* C SPECIAL ENTROPY OPTION NTROPY
01550 477* C SPECIAL ENTROPY OPTION NTROPY = 5
01552 478* DO 4000 I = 1,M
01555 479* 4000 UKAPPA(I)=F2FIX(I)/F2FIX(KAPPA)
01557 480* UKAPPA(KAPPA)=1.0
01558 481* DO 4001 I = K,J
01563 482* DO 4001 UKAPPA(I)=F2FIX(I)/F2FIX(KAPPA)
01565 483* UKAPPA(NETA)=1.0
01566 484* 4002 IF (KTURB .NE. -1) GO TO 4022
01567 485* KTURB = 0
01570 486* GO TO 327
01571 487* 4022 IF (IS .EQ. NS) RETURN
01574 488* IF (NTROPY .EQ. 0) GO TO 4012
01574 489* C SPECIAL ENTROPY OPTION NTROPY = 5
01576 490* DO 4010 I = 1,M
01576 490* DO 4010 I = 1,M
01580 491* 4010 F2FIX(I) = UKAPPA(I)*F(KAPPA.2)/ALPH
01583 492* F2FIX(KAPPA) = F(KAPPA.2)/ALPH
01584 493* DO 4011 I = K,J
01586 494* 4011 F2FIX(I) = (F(KAPPA.2) + (F(NETA.2) -F(KAPPA.2))*UKAPPA(I))/ALPH ANK 8/83
01586 494* 4011 F2FIX(I) = (F(KAPPA.2) + (F(NETA.2) -F(KAPPA.2))*UKAPPA(I))/ALPH ANK 8/83
01587 495* F2FIX(NETA) = (F(NETA.2)/ALPH...
01588 496* 4012 IF (IS .EQ. 1) GO TO 327
01589 497* 4012 IF (IS .EQ. 1) GO TO 327
01589 497* 4012 IF (IS .EQ. 1) GO TO 327
01590 498* M=I
01591 499* IF (F(I,2) - F2FIX(I)*ALPH .LT. 0.0) M = I + 1 ANK 8/83
01592 500* 326 IF (ABS((F(I,2)-F2FIX(I)*ALPH)/(F(M,2)-F(M-1,2))) GT RATLIM) GOTO 327 ANK 8/83
01593 501* 326 IF (ABS((F(I,2)-F2FIX(I)*ALPH)/(F(M,2)-F(M-1,2))) GT RATLIM) GOTO 327 ANK 8/83
01593 501* 326 IF (ABS((F(I,2)-F2FIX(I)*ALPH)/(F(M,2)-F(M-1,2))) GT RATLIM) GOTO 327 ANK 8/83
01593 501* 326 IF (ABS((F(I,2)-F2FIX(I)*ALPH)/(F(M,2)-F(M-1,2))) GT RATLIM) GOTO 327 ANK 8/83
01594 502* RETURN
01595 503* 327 CALL REFIT
01596 504* KONRFT=2
01597 505* RETURN
01598 506* END

0132 506* END
COMMON/ACPK/ACCPK1,ACCPK2
COMMON/ACCN/ACCPK,ILAM,SPCT
COMMON/RETH/RETHMO
COMMON/RUF/DUMM1,DUMM2,DUMM3,DUMM4,DUMM5,DUMM6,DUMM7,DUMM8,DUMM9.
$ DUMM10,DUMM11,DUMM12,RK,ICF,FMF,DUMM16,DUMM17,DUMM1B
COMMON /LAM/ ILAMIN
-80
IF(ILAMIN.EQ.0)GO TO 39
IF(ILAM.EQ.1)GO TO 29
GO TO 39
29 SALPH=1.-((ACPK-ACPK1)/(ACPK2-ACPK1))
SPCT= (1. - SALPH) * SQRT(I).
39 CONTINUE
-304
C ROUGHNESS OPTION (3)  ICF = 3
C IF(ICF.EQ.3)GO TO 201
GO TO 202
201 CONTINUE
RKS=RK+UTAU+RHO(I)/VMU(I)
IF(RKS.LE.4.535)PCT=0.0
IF(RKS.GT.4.535.AND.RKS.LE.4000.)PCT=1.0
IF(RKS.GT.4000.)PCT=2.0
DUMM17=PCT
IF(ABS(PCT),LE.,0.01)GO TO 203
DEACY=0.9*(VMU(I)/(RHO(I)+UTAU))+(RKS*.5-RKS*EXP(-RKS/6.))
203 CONTINUE
ACY=ALPH+DEL*CAPY+DEACY
202 CONTINUE

SUBROUTINE TRMBL  ENTRY POINT 004622

STORAGE USED: CODE(1) 004637; DATA(0) 000631; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003 COECOM 000017
0004 COECON 000014
0005 EDCGCOM 001216
0006 EPSION 000045
0007 ERRCOM 000051
0010 ETAIOM 000036
0011 HISCOM 00344
0012 INPUT 000006
0013 INTCOM 000123
0014 INTI 000004
0015 NUTER 000043
0016 NZERO 000001
0017 PRMORG 000455
0020 PRCOM 000303
0021 PRPRT 000074
0022 PRNPRT 000076
0023 SAVTBL 000067
0024 TURB 000020
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SUBROUTINE TRMBL(ILK)

COMMON /COECOM/ (A(2), C7, C(2), C10, D, C13, E, C26, C28, C32, O, C53, C56)

COMMON /COECOM/ (C16, C6, C6, C6)

COMMON /EDGCOM/ (CG(100), RHOE(400), TVGC, TVCC(50), UE(50), VMUE(50))

COMMON /EPSCOM/ (CLNUM, DL(15), ELCN, EPSA(15), PR1, RETR, RHODS, SCT, YAP)

COMMON /ERRCOM/ (FLE(254), ENL(123))

COMMON /ETACOM/ (ETA(15), DELTA(15))

COMMON /HISCOM/ (ALPHD, BETA(100), C1, C2, C3M(50), HF(15.5))

COMMON /INPUTI/ (IBUDY(5), IFLOW)

COMMON /INTCOM/ (A(13), CBARI, IQ, IS, ISHM(2), KAPPA, KONFRK, K9(51), TAUW)

COMMON /INTCOM/ (MATI, MAT2(3), NETA, NNLEQ, NON(3), NSF, NSEP)

COMMON /INTERI/ (KBC(3), KQ10)

COMMON /NONCOM/ (AM(123, 123))

COMMON /NZERO/ (NL)

COMMON /PRMORG/ (IDISC(251), S(50))

COMMON /PRPCOM/ (DRHDH, DRHDK(54), DCAPCK(118), DCAPCH, DPRH(6), VMU(15))

COMMON /PRPRT/ (CACP(15), CPBAR(30), PR(15))

COMMON /PRPNT/ (HB(15), HO(15), RHD(15), RHOP(15), TP)

COMMON /SAVTBL/ (CL, DCLNUM, DELCON, DEPC, DPI(15, 2), DVS, EPS1, PIM, PM, SAVTB)

COMMON /STURB/ (ILK, TVC(15), TVCC(50), UE(50), VMUE(50))

COMMON /VARCOM/ (ALPHF(15, 4), G(15, 3), SP(15, 3, 7))

COMMON /VARCOM/ (ACPK(15), ACCPK1, ACCPK2)

COMMON /VAP/ (ILK, TVC(15), TVCC(50), UE(50), VMUE(50))

DIMENSION DCAPOC(7), DELTA(50), DYA(123), FM(4), XP(4)

GO TO (1001, 1002, 1003, 1004, 1005), ILK

ANL 4/83

NEW 000000

NEW 000000

NEW 000000

NEW 000000

NEW 000000

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NEW 000000

NEW 000000
1 WRITE (6, 47) 0000020
2 WRITE (6, 42) ELCON, YAP, CLNUM 0000025
3 WRITE (6, 42) ELCON, YAP, CLNUM 0000025
4 READ (6, 42) ELCON, YAP, CLNUM 0000025
5 READ (6, 42) ELCON, YAP, CLNUM 0000025
6 IF (PRT .GT. 0.0) WRITE (6, 45) PRT 0000035
7 WRITE (6, 45) PRT 0000035
8 WRITE (6, 45) PRT 0000035
9 WRITE (6, 45) PRT 0000035
10 WRITE (6, 45) PRT 0000035
11 IF (PRT .GT. 0.0) GO TO 43 0000035
12 IF (PRT .GT. 0.0) GO TO 43 0000035
13 WRITE (6, 46) TPCON 0000035
14 WRITE (6, 46) TPCON 0000035
15 WRITE (6, 46) TPCON 0000035
16 WRITE (6, 46) TPCON 0000035
17 WRITE (6, 46) TPCON 0000035
18 GO TO 2005 0000035
19 GO TO 2005 0000035
20 GO TO 2005 0000035
21 GO TO 2005 0000035
22 GO TO 2005 0000035
23 CLNUM = DCLNUM*SALPH 0000034
24 CLNUM = DCLNUM*SALPH 0000034
25 CLNUM = DCLNUM*SALPH 0000034
26 CLNUM = DCLNUM*SALPH 0000034
27 CLNUM = DCLNUM*SALPH 0000034
28 ETA(KAPPA) /= ETA(NETA) - ETA(KAPPA) 0000031
29 ETA(KAPPA) /= ETA(NETA) - ETA(KAPPA) 0000031
30 ETA(KAPPA) /= ETA(NETA) - ETA(KAPPA) 0000031
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32 ETA(KAPPA) /= ETA(NETA) - ETA(KAPPA) 0000031
33 TPCON = TPCON*SQRT(SALPH) 0000031
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54 WRITE (6, 47) 0000020
55 GO TO 2005 0000037
56 C BECKWITH-BUSHNELL TURBULENCE MODEL 0000072
57 2003 GO TO 2005 0000072
58 CBECK = 26.0 0000076
59 BBECK = CLNUM 0000100
60 WRITE (6, 48) BBECK, ELCON, PRT 0000102
61 WRITE (6, 48) BBECK, ELCON, PRT 0000102
62 WRITE (6, 48) BBECK, ELCON, PRT 0000102
63 WRITE (6, 48) BBECK, ELCON, PRT 0000102
64 WRITE (6, 48) BBECK, ELCON, PRT 0000102
65 GO TO 2005 0000121
66 C KENDALL TURBULENCE MODEL 0000121
67 2004 WRITE (6, 49) 0000123
68 2004 WRITE (6, 49) 0000123
69 2004 WRITE (6, 49) 0000123
70 2004 WRITE (6, 49) 0000123
71 2004 WRITE (6, 49) 0000123
72 DELCON = ELCON 0000155
73 DCLNUM = CLNUM 0000156
74 IFLOW = IFLOW - 2 0000160
75 KQ10 = 1 0000163
76 IF (RETR .GT. 0.0) KQ10 = -1 0000165
77 IF (RETR .LT. -1.999) KQ10 = RETR - 10.010 0000172
78 RETURN 0000207
79 C**** CALCULATES EPS2/NUE AND ITS DERIVATIVES AS DVS AND AM(1,...) 0000207
80 1002 IWK = 0 0000213
81 C INTERMITTENCY CORRECTIONS 0000213
82 DO 13 I = 1, NETA 0000213
83 VINTR(I) = 1.0 0000227
84 IF (CBECK .LE. 0.0 .AND. 1 .GT. KAPPA) VINTR(I) = 1.0 - (ETA(I) - ETA(KAPPA)) / (ETA(NETA) - ETA(KAPPA)) 0000231
85 1000 ETAF(KAPPA) = 1.0 0000231
86 SALPH = 1.0 0000253
87 IF (ILAMIN.EQ.0.0) GO TO 39 0000255
88 IF (ILAM.EQ.1) GO TO 29 0000257
89 GO TO 39 0000262
90 SALPH = 1.0 - (ACC PK - ACC PK1)/(ACC PK2 - ACC PK1) 0000264
91 SPECT = SALPH**100. * (1 - SALPH) * 1.0 0000272
92 CONTINUE 0000275
93 IF (S(IS) .LT. 2.0*STURB) SALPH = S(IS)/STURB - 1.0 0000275
94 TPCON = DELCON+SORT(SALPH) 0000310
95 TPCON = TPCON+SORT(SALPH) 0000321
96 BBECK = DCLNUM+SORT(SALPH) 0000321
97 CLNUM = DCLNUM+SALPH 0000324
98 C*** DEL/VMUE = RHDOV = DEL/VMUE + RHDOV - RED + RHDOV/(RHOE+UE) 0000324
DEL = -C3M(IS)*VMUE(IS)  
RED = -C3M(IS)*RHOE(IS)*UE(IS)  
RC = RED*CLNUM

PM = 0.0
EPS = 0.0
DEPC = 0.0
RHOESRC = F(I,1) + HF(1,5)

IF (RC.LT.0.0) GO TO 75

IF (I .GT. 1) CALL LIAO(-1.1,NETA-2+1.-RC/OADA*ACY/12.0)

IF (CBECK.GT.0.) GO TO 33

AF = AF + DETA(I)/2.0*(DUM2 - DUM1)
BF = 0.0
AM = AM(1,1) - 0.

DADP = (0.995 - CBAR)/(1.0 - CBAR)

SALPH = SALPH

DUM2 = F(NETA,2)

ACY = - VA

DADVP = RHOE(IS)/RHO(I+1)

PPL = - CAPY

ONK = RHOE(IS)/RHO(I)**2

ACY = - VA

AF = AF + DETA(I)/2.0*(DUM2 - DUM1)

BF = ALPH + DEL*DETA(I)/2.0

IF (I .GT. NETA) GO TO 15

DO 66 I=1,NETA

DO 3 K=1,NSP

L = 117

VA = 0.0

PCY = PPL + CAPY

YA = 0.0

L = 117

DO 66 I=1,NETA

DO 3 K=1,NSP

L = 117

DO 66 I=1,NETA

DO 3 K=1,NSP

L = 117
GO TO 32

C BECKWITH-BUSHNELL MODEL

IF (I.EQ. KAPPA) AM(1,1) = AM(1,1) + DEL*YDI + CRD*CS6+ONK*EPS

IF (I.LT. KAPPA) AM(1,1) = AM(1,1) + DEL*YDI + CRD*CS6+ONK*EPS+DADPP+DEL*YDI

IF (.GE. KAPPA) AM(1,1) = AM(1,1) + EPI+ONK*CRD*CS6

INK = I+3

AM(1,INK) = - CRD*EPS*ONK

AM(1,INK) = - CRD*BF*ONK

INK = INK+1

DO 68 K = 1,NSP

IF (I.EQ. KAPPA + 1) AM(1,INK) = - CRD*BF*ONK

AM(1,INK) = - EPS*ONK*DRHOK(K-1)

IF (I.LT. KAPPA) AM(1,1) = AM(1,1) + DEL*YDI + CRD*C56*EPS

DO 85 I = 1,NNLEQ

IF (I.EQ. KAPPA) AM(1,INK) = AM(1,INK) + DEL*YDI + CRD*EPS + DADPP*DEL*YDI

IF (I.EQ. KAPPA - 1) DELTA(IS) = SALPH

L = MAT1 J + 1

DVS = AMAX1(0.,RC+DVS)

CBECK WITH BUSHNELL MODEL

IF (CBECK .LE. 0.0) DVS = 0.

DO 80 I = 2,NETA

FM(1) = F(I,1)+1

FM(4) = F(I-1,4)

CALL TAYLOR (DETA(I-1),FM(2),FM,XP)

DVS = DVS+F(I,2)*XP(1)+F(I,3)*XP(2)+F(I,4)*XP(3)+F(I-1,4)*XP(4)

AM(1,1+3) = AM(1,1+3) + XP(1)

CALL LIAD (-1.1,NETA+2,XP(2))

CALL LIAD (-1.1,2,2,XP(3))

CALL LIAD (-1.1,2,NETA+3,XP(4))

DO 68 K = 1,NSP

IF (I.EQ. KAPPA) AM(1,INK) = - EPS*ONK*DRHOK(K-1)

IF (I.LT. KAPPA) AM(1,1) = AM(1,1) + DEL*YDI + CRD*C56*EPS

RETURN

DO 80 I = 2,NETA

FM(1) = F(I,1)+1

FM(4) = F(I-1,4)

CALL TAYLOR (DETA(I-1),FM(2),FM,XP)

DVS = DVS+F(I,2)*XP(1)+F(I,3)*XP(2)+F(I,4)*XP(3)+F(I-1,4)*XP(4)

AM(1,1+3) = AM(1,1+3) + XP(1)

CALL LIAD (-1.1,NETA+2,XP(2))

CALL LIAD (-1.1,2,2,XP(3))

CALL LIAD (-1.1,2,NETA+3,XP(4))

DO 68 K = 1,NSP

IF (I.EQ. KAPPA) AM(1,INK) = - EPS*ONK*DRHOK(K-1)

IF (I.LT. KAPPA) AM(1,1) = AM(1,1) + DEL*YDI + CRD*C56*EPS

RETURN

1003 TURPR(1) = PRT

1001 TURPR(1) = 0.

IF (IECONN.LE.0.00001) GO TO 401

IF (IPRT.EQ.1) GO TO 505

IF (IKW.EQ.1) GO TO 401

IF (ICBE.GT.0. OR.CBECK.GT.0.) GO TO 505

C* * * * * Calculates mixing length and its derivatives for kendall model

PIM = PM

PM = SQRT(ABS(RD/C26*(CAPC(1)+F(1,3) - ALPH+ROVS+F(1,2))))/ (CAPC(1)+YAP)

IF (I.LE. 1) GO TO 305

IF (I.EQ. 1) GO TO 305

EPI = EXP((-PM + PIM)/2.0*DETA(I-1))

ONK = PM - PIM

IF (ONK/P.M.GT.1.0E-4) GO TO 103

PM = AMAX1(PM,PIM)

ONK = 1.0

AF = ONK

BF = 1.0/PM

DADA = -2.0/PM*2
CRD = 1.0/PIM

00540 220*  EPS = -2.0/PIM**2

00541 221*  GO TO 104

00542 222*  AF = SQRT(2.0*DETA(I-1)/DNK)

00543 223*  BF = ERP(AF*PM/2.0)

00544 224*  DADA = 1.0 - AF*PM*BF

00545 225*  CRD = ERP(AF*PM/2.0)

00546 226*  EPS = 1.0 - AF*PIM*CRD

00547 227*  BF = BF - EPI*CRD

00550 228*  DUM1 = EPI*AF*CRD - CL*DETA(I-1)/2.0

00551 229*  CL=CL*EPI + AF*BF

00552 230*  DL(I) = ALPH + ELCON*ETA(I) - CL

00553 231*  DUM2 = AF/DNK*(BF/2.0 + DADA*AF*PM/4.0 - EPI*EPS*AF*PIM/4.0)

00554 232*  IF(I-2) 305, 330, 320

00555 233*  305 DL(I) = 0.0

00557 234*  DD 307 J=1,NLLEQ

00558 235*  307 AM(2,J)=0.

00559 236*  CL=0.

00560 237*  DPI(1,2) = CAPC(1)

00567 238*  DPI(3,1) = F(1,3)*DCAPCH

00570 239*  IF (NSPM1.LE.0) GO TO 350

00572 240*  DD 315 K = 1,NSPM1

00575 241*  315 DPI(K+3,1) = F(1,3)*DCAPCK(K)

00577 242*  GO TO 350

00580 243*  320 DD 325 J=1,NNLNEQ

00583 244*  325 AM(2,J) = AM(2,J)*EPI

00586 245*  330 DUM(2,J) = ALPH + ELCNO*(DUM1 + DUM2 - EPI*EPS*AF**2/2.0)*TREF

00587 246*  AM(2,1) = AM(2,1) + (DL(I)) - EPI*DL(I-1))/ALPH

00589 247*  L=I-1

00590 248*  331 AM(2,1) = AM(2,1) + DPI(1,1) * DUM

00591 249*  AM(2,2) = AM(2,2) + DPI(2,1) * DUM

00592 250*  AM(2,3) = AM(2,3) + DPI(1,2) * DUM

00593 251*  AM(2,L-3) = AM(2,L-3) + DPI(2,2) * DUM

00594 252*  J=MATJ+2

00595 253*  DD 340 K=NULL,NSPM1

00596 254*  AM(2,J) = AM(2,J) + DPI(K+3,1) * DUM

00597 255*  AM(2,J+L-1) = AM(2,J+L-1) + DPI(K+3,2) * DUM

00609 256*  J = J + NETA

00622 265*  340 J = J + NETA

00632 264*  IF (L, GE, 1) GO TO 400

00626 265*  350 TREF = RED/C26*(I.+CAPC(I)) * YAP+PM*YAP*CAPC(I)

00627 265*  DPI(3,2) = -PM/TREF*(DCAPCH/CAPC(I)-DRHOH/(2.*RHOL(I)))

00638 265*  DPI(2,2) = C10*DPI(3,2)*RHOLVS+ALPH

00639 265*  DPI(2,1) = -C10*CAPC(2,3)+F(I,2)*RHOLVS

00640 265*  DPI(2,1) = -ALPH+CI*F(I,2)

00643 265*  IF (NSPM1.LE.0) GO TO 362

00635 265*  DD 360 K = 1,NSPM1

00640 265*  360 DPI(K+3,2) = -PM/TREF*(DCAPCK/K)*CAPC(I)-DRHOH/(2.*RHOL(I)))

00642 266*  362 L=I

00643 267*  DUM = -ALPH + ELCNO*(DUM2 - DUM2 + DADA*AF**2/2.0)*TREF

00644 268*  IF (L, LE, 1) RETURN

00646 269*  IF (L, LE, NETA) 331,400,400

00632 270*  IF (L, LE, NETA) 331,400,400

00647 270*  CEBECI-SMITH AND BECKWITH-BUSHNELL MODELS

00651 271*  505 DEL = -C3M(IS)+VME(15)

00652 272*  INK=1-1

00653 273*  DNK = -12.0

00654 274*  IF (1, GT, 1) GO TO 525

00656 275*  INK = 1

00657 276*  DNK = ABS(DNK)

00660 277*  TAUI = AMAX1(C28,1.0E-4)*UE(IS)/ALPH/C3M(IS)

00661 278*  DCAPCK(I) = DCAPCH
00665 280* 515 DCAPCW(K+1) = DCAPCK(K) ANK 8/83 002206
00667 281* DO 520 J = 1, NNLEQ ANK 8/83 002213
00672 282* 520 DYA(J) = 0. ANK 8/83 002213
00674 283* CAPY = 0. ANK 8/83 002214
00675 284* 525 VA = DETA(INK) + C26*(0.50 - C53*DETA(INK)/ONK) ANK 8/83 002216
00676 285* CAPY = CAPY + VA ANK 8/83 002226
00700 286* IF (INK.EQ.NETA) GO TO 532 ANK 8/83 002230
00702 288* DADA = -DETA(INK) / 2.0 + C26/RH0(I) + ALPH + DEL ANK 8/83 002237
00703 289* VA = DADA + DRH0(K) ANK 8/83 002247
00704 290* DYA(I) = DYA(I) - VA ANK 8/83 002252
00705 291* INK = INK + 1 ANK 8/83 002255
00708 292* DYA(INK) = DYA(INK) + VA ANK 8/83 002260
00709 293* INK = INK + 1 ANK 8/83 002264
00710 294* DO 530 K = 1, NSP ANK 8/83 002273
00713 295* INK = INK + NETA ANK 8/83 002273
00714 296* 530 DYA(INK) = DYA(INK) + DADA + DRH0(K) ANK 8/83 002275
00716 297* IF (ERA.I.EQ.1) RETURN ANK 8/83 002303
00717 298* IF (INK.EQ.0) GO TO 406 ANK 8/83 002303
00720 299* ONK = ABS(ONK) ANK 8/83 002311
00722 300* 532 UTAU = SORT(UH0/RH0(I)) ANK 8/83 002317
00724 301* IF (BECK.GT.0.) GO TO 700 ANK 8/83 002326
00724 302* C ********************************************** CEBECI-SMITH MODEL ********************************************** ANK 8/83 002326
00727 303* EP = EXP(YAP/VWP) ANK 8/83 002342
00730 305* PPL = 0. ANK 8/83 002350
00731 306* IF (ABS(BETA(I)) .GE. 1.0E-7) PPL = -BETAP(1)*RH0E(IS)*UE(IS) ANK 8/83 002351
00731 307* 1 /C3M(1)**2*CAPC(I)/(RH0(I)*UTAU)**3 ANK 8/83 002351
00732 308* EPS = EPS + 1.0 ANK 8/83 002330
00734 309* IF (ABS(VWP).LT.1.0E-7) AF = YAP ANK 8/83 002403
00736 310* IF (ABS(VWP).GE.1.0E-7) AF = EPS/VWP ANK 8/83 002411
00740 311* BF = AF*PPL ANK 8/83 002420
00741 312* SALPH = BF + EPS ANK 8/83 002423
00742 313* IF (SALPH.LE.0.0) SALPH = 1.0E-30 ANK 8/83 002425
00743 314* SALPH = SORT(SALPH) ANK 8/83 002432
00745 315* ACEB = CCEB/VMU(I)/RH0(I)/UTAU/SALPH ANK 8/83 002436
00746 316* ACY = ALPH + DEL + CAPY ANK 8/83 002445
00746 317* C ANK 8/83 002445
00746 318* C ROUGHNESS OPTION (3) ICF = 3 ANK 8/83 002445
00746 319* C ANK 8/83 002445
00747 320* IF (ICF.EQ.3) GO TO 201 ANK 8/83 002451
00751 321* GO TO 202 ANK 8/83 002454
00752 322* 201 CONTINUE ANK 8/83 002456
00753 323* RK5 = RK*UTAU + RH0(I)/VMU(I) ANK 8/83 002456
00754 324* IF (RK5.LE.4.535) PCT = 0.0 ANK 8/83 002464
00755 325* IF (RK5.GL.4.535, AND.RK5.LE.4000.) PCT = 1.0 ANK 8/83 002471
00760 326* IF (RK5.GT.4000.) PCT = 2.0 ANK 8/83 002511
00762 327* DUMM17 = PCT ANK 8/83 002517
00763 328* IF (ABS(PCT).LE.0.001) GO TO 203 ANK 8/83 002521
00765 329* DEACY = 9.0*(VMU(I)/(RH0(I)*UTAU))**(RK5**(0.5)-RK5*EXP(-RK5/6.)) ANK 8/83 002525
00767 330* 203 CONTINUE ANK 8/83 002553
00767 331* ACY = ALPH + DEL + CAPY + DEACY ANK 8/83 002553
00767 331* ACY = ALPH + DEL + CAPY + DEACY ANK 8/83 002553
00770 332* 202 CONTINUE ANK 8/83 002560
00771 333* VA = ACY + ACBE ANK 8/83 002560
00772 334* EXP = EXP(-VA) ANK 8/83 002562
00773 335* DL(I) = ELCON + ACY*(1.0 - EXP) ANK 8/83 002727
00774 336* DADA = ELCON*(1.0 - (1.0 - VA)*EXP) ANK 8/83 002575
00775 337* IF (INK.EQ.1) GO TO 555 ANK 8/83 002603
00777 338* DO 545 J = 1, NNLEQ ANK 8/83 002617
AM(2,v) + \frac{1}{2} \cdot AF \cdot AEB(CAP(1))

DADDP = \frac{\text{ACEB} \cdot BF \cdot \text{RHOD}(1) + \text{ACEB} \cdot ALPH + \text{DADVDP} \cdot \text{VWP} \cdot (\text{BF} \cdot \text{RHOD}(1) / 2.0 + 1.0 \cdot \text{ALPH})}{\text{RHO}(1)}

DADA = \sqrt{0.50 - \text{ERF}(EPI) / 2.0}

\text{DVA(J)} = \text{DVA(J)} \cdot \text{DADA}

\text{BBEC} \cdot (\text{DELTA(IS)} / \text{ABECK} \cdot \text{BF} \cdot \text{CRD} / \text{EXPA} + \text{DB} \cdot \text{AF} \cdot \text{CRD} / \cosh(VA)^2)

\text{PRT} = \text{ElCON} / \text{TPCON} \cdot (1.0 - \exp(-\text{AF} / (1.0 - \exp(-\text{BF} / 2.0)))

\text{ACV} = \text{ALPH} \cdot \text{DEL} \cdot \text{CAPV}

\text{GO TO 703}

\text{GO TO 703}

\text{POPI} = 1.772453851

\text{ABEC} = \text{CBECK} / \text{RHOD}(1) \cdot \text{VMU}(1) / \text{UTAU}

\text{ACY} = \text{ALPH} + \text{DEL} \cdot \text{CAPY}

\text{VA} = \text{DB} / \text{ACY} \cdot \text{DELTA(IS)}

\text{EXPA} = \exp(-\text{ACY} / \text{ABEC})

\frac{1}{2} \cdot \text{DLA} \cdot \text{AF} \cdot \text{CRD} / \text{RHOD}(1)

\text{EPS} = \exp(-\text{EPI}^2) 

\text{DADA} = \frac{\text{BBEC} \cdot (\text{DELTA(IS)} / \text{ABEC} \cdot \text{BF} \cdot \text{CRD} + \text{EXPA} + \text{DB} \cdot \text{AF} \cdot \text{CRD} / \text{COSH(VA)}^2}{2} 

\text{DLA} = \frac{\text{BBEC} \cdot (\text{DELTA(IS)} / \text{ABEC} \cdot \text{BF} \cdot \text{CRD} + \text{DB} \cdot \text{AF} \cdot \text{CRD} / \text{COSH(VA)}^2}{2} +
C CEBECI-SMITH AND BECKWITH-BUSHNELL MODELS

DO 701 J=1,NNLEO

AM(2,J) = DYA(J)+DADA + AM(1,J)+DADPP

DADA = ABECK*(C10+C56*(-DCAPCH/CAPC(I) + DRHO(I)) + 1.0/ALPH)

AM(2,1)=AM(2,1)+DLD+A DADA

AM(2,3) = AM(2,3) - DLD+A B ECK/2.0/F(1,3)

INK=INK+1

AM(2,INK) = AM(2,INK) + DLD+A B ECK*C10*(DCAPCH/CAPC(I) - DRHO(I))

INK = INK + NETA + 1

AM(2,INK) = AM(2,INK) + DLD+A B E CK*C10*(DCAPCH/CAPC(I) - DRHO(I))

INK = INK + NETA + 1

AM(2,INK) = AM(2,INK) + DLD+A B E CK*C10*(DCAPCH/CAPC(I) - DRHO(I))

INK = INK + NETA + 1

AM(2,INK) = AM(2,INK) + DLD+A B E CK*C10*(DCAPCH/CAPC(I) - DRHO(I))
C** MODIFIES ENL AND AM AFTER IMONE

1004 L = I - 1

1005 L = I - 1

C** MODIFIES ENL AND AM AFTER IONLY

600 DUM = F(L,3)/SALPH

605 AM(I+3,J) = AM(I+3,J) + DUM + AM(3,J)

650 CALL LIAD (-1,I+3,L+NETA-2,EPS/SALPH)

665 CALL LIAD (-1,I+3,L+NETA-2,EPS/SALPH)

685 MPJ = MATJ(+1,1)

686 IF (I .LT. NETA)

687 DEL = C13 + F(L,2) + EPS/SALPH

688 IF (I .LT. NETA)

689 IF (I .LT. NETA)

690 IF (I .LT. NETA)

691 EPS = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

692 EPS/SALPH = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

693 EPS/SALPH = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

694 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

695 DO 610 J = 1, NNLEQ

696 AM(MPJ,J) = AM(MPJ,J) + DEL + AM(3,J)

697 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

698 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

699 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

700 IF (I .LT. NETA)

701 DO 630 K = 1, NSPM1

702 EPS = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

703 EPS = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

704 EPS = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

705 EPS = EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

706 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

707 DO 630 J = 1, NNLEQ

708 AM(MPJ,J) = AM(MPJ,J) + DEL + AM(3,J)

709 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

710 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

711 AM(MPJ,1) = AM(MPJ,1) - EPS/SALPH*(1.0/SCT - 1.0/PRT)+(HP - CPBAR(L))*IP

END OF COMPILATION: NO DIAGNOSTICS.