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A NUMERICAL STUDY OF BOUNDARY LAYER INJECTION AS A SCALE CONTROL METHOD

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Abstract

A boundary layer injection method of controlling scale-buildup in geothermal two-phase flow nozzles is studied. The object of this study is to set an upper limit on the ratio of the injected mass flow rate to the free stream mass flow rate that is necessary to isolate the scale carrying free stream flow from the nozzle wall. In order to develop a numerical model of the boundary layer flow, assumptions are made which reduce the results to order of magnitude approximations.

Two configurations of nozzles with various injection flow rates are tried. It is found by numerical experiment that a nozzle with injection through a 1 mm. thick ring near the inlet, is more efficient at isolating the free stream than a porous nozzle. A mass flow rate ratio of 0.173% was necessary to achieve this effect. It may be concluded that an upper limit on the mass flow rate ratio is about 2.0% with injection through a ring near the inlet, and that boundary layer injection is a reasonable method of controlling scale-buildup.

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I. Introduction

It is well known that the "Brine", used as the working fluid in the "Total Flow" concept of geothermal power production, is not ideal material to work with. In addition to undissolved solids, it carries dissolved chemicals which have a tendency to precipitate out of solution.

Scaling, caused by the deposition of these precipitates, occurs very quickly, and changes the inside dimensions of the fluid handling machinery. From previously performed experiments the greatest scale buildup occurs on the diverging side of the turbine nozzles. Less buildup occurs in the piping that feeds the nozzle. A turbine was not used in these experiments.

Scaling buildup in the nozzle occurs at the highest measured rate in the diverging section and, if untreated, changes the nozzle's dimensions sufficiently to destroy much of its efficiency in several hours.

Various means of controlling scale-buildup have been proposed. The subject of this paper is a boundary layer control method involving injection of "clean" material through the nozzle walls to "insulate" the "dirty" free stream brine from wall-contact.

The problem is first described and the difficulties inherent in its solution are discussed. Assumptions were made in order to produce estimates of the injection mass flow rate and these are discussed along with the results of the numerical experiments. Documentation, flowcharts and listing will be found in the appendices.

II. Object

This paper looks at the possibility of preventing the precipitates in the brine from depositing themselves on the nozzle walls by injecting clean material into the nozzle. The object is to set an upper limit on the ratio of injected mass to free stream mass (Brine), necessary to achieve this effect.

III. The Problem

Solution of the problem involves both chemical and fluid mechanics principles that are presently the subject of research. A paper has recently been published (Ref. 6) describing the chemical processes involved in scale formation. The reader is referred to this paper because the brine chemistry is beyond the scope of this report. In the solution of the problem, assumptions were made about the brine chemistry that are, hopefully, quite conservative. The presently available knowledge was not incorporated into this study for two reasons:

1. The more detailed knowledge was not available at the start of the study.
2. Lack of time available.

These assumptions will be described below under: Section IV Assumptions, Simplifications and Deviations from Reality.

The fluid flow characteristics are not well understood. The brine enters the turbine nozzle with a quality of about 12%. It is thought that the liquid droplets carry most of the precipitate and that the steam is relatively clean.

As the mixture proceeds through the nozzle the quality increases to about 37% at the nozzle exit, and the temperature and pressure fall as internal energy is converted to kinetic energy. These factors greatly influence the scale formation. As the quality rises, the liquid mass decreases, with a corresponding increase in concentration of the scale forming material. At the same time the solubility is falling because of the decrease in temperature. It is thought that the precipitate remains in the liquid however, so it becomes necessary to discover where the liquid is located and to trace the trajectories of droplets.

Two-phase nozzle flow can be divided into two regions:

1. The free stream, where vapor viscosity may be considered equal to zero.
2. The boundary layer

Since the scale deposition must occur in and through the boundary layer, this report is focused on the determination of boundary layer characteristics.

The nature of this boundary layer is uncertain. A liquid film may exist on the wall in which the longitudinal velocity increases from zero to some fraction of the free stream velocity. The additional change to a uniform velocity profile could take place in the vapor with viscous coupling at the interface. Another possibility is that the entire boundary layer is composed of vapor and that precipitate reaches the wall carried by droplets which traverse it. In any case it is assumed in this study that scaling occurs whenever liquid touches the wall.

Table 1
Inlet Flow Conditions to Nozzle Model
Vapor Conditions Only at Saturation

	English Units	SI Units
Pressure	435 psia	3.0×10^6 Pa
Temperature	453° F	506° K
Density	$.809 \frac{\text{lbm}}{\text{ft}^3}$	$13.0 \frac{\text{kgm}}{\text{m}^3}$
Quality	12%	12%

At the velocities encountered in the nozzle, the boundary layer becomes turbulent very quickly after passing the inlet. The critical Reynolds number for this transition is:

$$R_e = \frac{U_{\infty} X}{\nu} = 3.5 \times 10^5 \text{ to } 1.0 \times 10^6$$

(Ref. 1)
p435
Schlichting

At a velocity midway between that of the inlet and that of the throat, 250 m/s, pressure of 3.0×10^6 Pa, and a density of 13.0 kg/m^3 this corresponds to a longitudinal distance of 1.5mm. Therefore the approximation is made that the entire boundary layer is turbulent. Inlet conditions will be seen in Table 1.

At the present time there are no analytical or numerical methods of accurately describing such a boundary layer. It is necessary to revert to a description of average properties at any given point. The boundary layer characteristics were calculated by a modification of the Patankar-Spalding Program (Ref. 2) which approximates turbulent behavior with average values. The modifications are described below in: Appendix B Program Documentation.

It is assumed that the presence of liquid droplets does not affect the vapor velocity calculations. It is then simply necessary then to trace the droplet trajectories through the vapor by treating them as small spheres.

Several forces are at work on the droplets that enable them to move relative to a given fluid element, they are:

1. Centrifugal force - The droplet possesses an inertia. It must follow a curved path if it is to remain in the boundary layer through the nozzle throat.
2. Pressure gradient.

3. Magnus force - this is the classical lift force on a spinning sphere with a translational velocity.

$$F_m = -d^3 \rho_f U_r \left[\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right] \quad (\text{Ref. 3})$$

4. Saffman Force - this force is due to the fluid shear acting on an arbitrarily spinning sphere.

$$F_s = \frac{1.615 \mu U_r d^2 \left[\left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right) \right]^{\frac{1}{2}}}{\left(\frac{\mu}{\rho_f} \right)^{\frac{1}{2}}} \quad (\text{Ref. 3})$$

5. Drag

$$F_D = \frac{1}{8} \rho_f U^2 r C_d \pi d^2 \quad (\text{Ref. 3})$$

6. Bassett force - non steady droplet boundary layer effects due to droplet acceleration.
7. Virtual mass effect - due to mass exchange from front to rear of droplet.

Only three of these forces are considered in the program, the Magnus, Saffman, and Drag forces. The centrifugal force and the pressure gradient were not evaluated because of the structure of the program. The Basset force and the Virtual mass effect were neglected for simplicity.

It can be seen that the problem is quite complex and presently beyond exact solution, however, many assumptions have been made in order to obtain an estimate of the feasibility of this boundary layer control method.

IV. Assumptions Simplifications and Deviations from Reality.

The major assumptions made in the computer programs and in the solution of the problem follow. They will be discussed afterward:

1. The liquid wall film if it exists has no effect on the flow calculations.
2. Deposition of scale occurs when a droplet strikes the wall.
3. Additional precipitation does not take place in the liquid deposited by the droplets after collision with wall.
4. The droplets have no effect on the vapor velocity calculations in the boundary layer.
5. The turbulence is replaced by average fluid properties.
6. The vapor behaves as an ideal gas.
7. There is no mass exchange between the liquid and the vapor.
8. The free stream brine follows an isentropic expansion.
9. The boundary layer is calculated as if it were on a flat plate.
10. Forces on the droplets that are neglected are:
 - a. Centrifugal force
 - b. Pressure gradient
 - c. Virtual mass effect
 - d. Bassett force
11. Droplet size is constant.
12. The brine behaves as the steam-water system.
13. The Saffman equation is considered to be valid even though the droplet Reynolds number sometimes exceeds the range of the equation.

Reasons for these assumptions follow in order:

1. Flow of a liquid film with a vapor viscosity coupled to it is not well understood. A program was available that, with modification would calculate the compressible boundary layer, but would not handle a liquid film.
2. All deposition must take place from droplets which cross the boundary layer and strike the wall. The liquid film, if it exists, arises from two sources:
 - a. Droplets striking the wall
 - b. Condensation directly on the wall.

Since condensation occurs from the relatively clean vapor, the major source of scale comes from droplets which enter the nozzle as liquid.

3. All deposition is considered to have occurred when the droplet strikes the wall. The trajectory program terminates when the test droplet reaches the wall. This begs the question by assuming that an intolerable situation exists with the first droplet collision. Amounts of scale deposition are not calculated.
4. In reality there is a great interaction between the two phases. Both energy transfer and mass transfer occur. The interaction between phases and its effect on the boundary layer is not well understood.
5. There is no general analytical or numerical way of representing turbulence on a fundamental level.
6. The boundary layer program is set up for an ideal gas and would have required more time than was available to modify.

7. Mass and energy exchange along with their effect on free stream and boundary layer characteristics would also have required more time than was available. These two regions are the subject of other studies at the present time.
8. The compressible isentropic flow equations provided a convenient way of calculating free stream characteristics to be used as constraints in the boundary layer program.
9. The flat plate boundary layer is the easiest to approximate.
10.
 - a. Since the boundary layer is represented on a flat plate there is no trajectory curvature due to wall curvature.
 - b. The boundary layer program assumes a constant pressure profile from the wall out to the free stream. The longitudinal pressure gradient acts only in the longitudinal direction which was not of interest.
 - c. The Basset force was too difficult to model quickly.
 - d. The assumption of a rigid sphere to represent the droplets precludes any mass transfer around the drop.
11. The assumption of constant droplet diameter was made for simplicity. Spin breakup and Weber number criteria would be more accurate.
12. It is unknown how the dissolved scale forming materials affect the equation of state.
13. Little is known about the Saffman force outside of the Reynolds number range for which it was intended. The only other relation proved inapplicable.

Figure 1a.
Possible boundary layer configuration
in the real two-phase nozzle.

Figure 1b.
Representation of the boundary layer
in a one-phase compressible fluid.

Comparison of these two figures will show that a one-phase boundary layer representation can lead to an overestimate of the boundary layer thickness. Near the wall the fluid shear is overestimated leading to droplet forces that are larger than reality.

Deviations from reality expected from these assumptions. In order:

1. The wall film, if it exists undoubtedly supports part of the velocity gradient from the wall to the free stream. In solving for the compressible vapor boundary layer the assumption of zero velocity at the inside edge will obviously be incorrect and will lead to larger velocity gradients near the wall. It is expected that the forces acting on the droplets will be less than calculated because of the high estimates of velocity gradient. This would lead to larger estimates of injection mass flow. See Figure 1.
2. & 3. The scale deposition mechanism is beyond the scope of this paper. The reader is again referred to (Ref. 6). In reality deposition may not occur when a given droplet strikes the wall or the liquid film. It may rebound back into the free stream or it may become part of the liquid film without depositing scaling-material. It is expected that the liquid film can be enriched in dissolved solids by this method. As the film is carried downstream into lower pressure and temperature regions it is possible that further deposition occurs directly from the liquid film.

In any case scale is assumed to have been formed when the first drop reaches the wall and the analysis terminates. This would lead to larger estimates of the injection mass flow.

4. Since the void fraction, defined as:

$$\theta = \frac{V_{\text{vapor}}}{V_{\text{mixture}}}$$

ranges from about 88% at the inlet to 99.9 + % at the exit it is expected that the presence of the droplets can accurately be neglected.

5. By replacing turbulence with average values, the trajectories, that are calculated will be average trajectories from a given starting position. It can be expected that some trajectories will be more unfavorable than those calculated. If it is assumed that any droplet reaching the wall is intolerable then this assumption may unfortunately predict low mass flow rates.

- 6., 7. & 8. The ideal gas assumption and no mass transfer combined with the isentropic compressible flow assumption produce free stream vapor velocities that are higher than reality by roughly a factor of two. Estimates of the boundary layer thickness based on a flat plate at the exit conditions show that these assumptions probably underestimate the boundary layer thickness. The fluid rotation due to shear can be estimated by

$$2\omega = \left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right) \sim \frac{U}{y} \quad \frac{U_{\infty}}{\delta}$$

Rotation is expected to be less than that which was calculated. The Magnus and Saffman forces both depend on fluid rotation, so the high estimate of rotation is expected to overestimate the relative velocities between the droplet and the vapor this will lead to larger predictions of injected mass flow.

9. The dimensions of the boundary layer are small in comparison to the radial dimension of the nozzle, but the trajectories followed by droplets take them considerably farther from the nozzle wall. It is expected that the vapor boundary layer is approximated

reasonably well by the flat plate assumption. However the droplet trajectories are liable to vary considerably from the which was calculated when they move a distance out from the wall comparable to the nozzle radial distance. It is unclear what effect this will have but fortunately the effects in the immediate neighborhood of the boundary layer are small.

10. a. Centrifugal force in the throat region is expected to act in our favor.
- b. Any transverse pressure gradient that may exist can be expected to be small and to act in a favorable direction.
- c. & d. Virtual mass effect forces and Bassett forces act along the trajectory of the particle which is very close to parallel with the wall and therefore unimportant. They are negligible in any case.

This treatment of forces will also tend to over estimate injection mass flow.

11. Droplet size and relative velocity are related to mass and energy exchange between droplet and liquid. The effects of neglecting this exchange are discussed above in C-6, 7 & 8.
12. The effect of an approximate equation of state is felt to be small in comparison to the ideal gas, isentropic flow, and no mass transfer assumptions.
13. As described below in: VI. A further discussion of droplet forces it is felt that the Saffman force is less than that which was calculated. This will lead to overestimates of the injection mass flow.

The combined effects of the above assumptions except for the turbulence approximation tend to overestimate the necessary injected mass flow rate. It is felt that the predictions made below in VII. Results of the study can be viewed as maximum values for a given nozzle configuration.

V. Plan of Attack

Use of the above assumptions allows independent calculation of the vapor boundary layer characteristics and the droplet trajectories. The nozzle geometry, including the amount and disposition of injection, is described to the boundary layer program. This program takes initial conditions at the inlet and calculates the free stream flow characteristics. The free stream values along with the wall characteristics are then used as boundary conditions when solving the boundary layer equations. The program is "stepped" through the nozzle from inlet to exit, first calculating boundary conditions, then calculating boundary layer characteristics. Output consists of two matrices of velocities describing motion in the longitudinal and cross-stream dimensions, a matrix of densities, a matrix of temperatures, and several variables corresponding to surface area, injected mass flow, pressure, and longitudinal pressure gradient.

This data is used as input to the droplet trajectory program. It describes the vapor flow field that the droplet must traverse. Given an initial position in this flow field, the various forces which act on the droplet are calculated. These forces are summed. An acceleration is calculated, and integrated to produce a new velocity and a new position, after which the process is begun again.

Figure 2. Flow of information in the process of determining a suitable nozzle configuration.

If the droplet strikes the wall, the program terminates. In this case the nozzle, that was described to the boundary layer program, is considered unsuitable and a new configuration is tried. A flow chart depicting this sequence of events is shown in Figure (2).

VI. A further Discussion of Droplet Forces

As mentioned above, the droplet Reynolds number is outside the range of applicability of the Saffman equation. The only equation available for the Reynolds number range of interest is the Eichorn and Small equation. (Ref. 3)

$$F_{ES} = 7.0 \times 10^4 \pi \rho_f U_r^2 d^2 \left(\frac{d^2}{U_r D Re_p} \frac{\partial u}{\partial y} \right)^2$$

This equation, unfortunately, was designed for pipe flow and explicitly incorporates the diameter of a pipe. Our problem, by assuming flat plate geometry, cannot use a pipe diameter. Therefore the Saffman equation was retained for lack of a more suitable relation. A calculation of the Eichorn-Small equation using a diameter of the same order of magnitude as the nozzle showed it to be much smaller than the calculated Saffman force. Retaining the Saffman equation, therefore, predicts high transverse droplet velocities with a corresponding over estimation of the injection mass flow rate.

VII. Results of the Study

The bulk of work in this study involved the development of the computer programs used to model the nozzle. The interested reader will find documentation and listings in the appendices. As stated earlier the prime goal was to produce

a single number, ratio of the injected mass flow rate to the free stream mass flow rate, for each nozzle configuration, and then to determine if this nozzle was satisfactory. Several configurations were tried with no serious effort made at optimization.

Several difficulties have come to light in the use of these programs. The major problem has been a numerical instability in the boundary layer program. The velocities produced follow the general trends expected, but because of variations from a smooth profile derivatives near the free stream edge change sign. This produces reversals in the direction of forces acting on the droplet. Unfortunately time has not permitted correction of these instabilities, so an earlier version of the droplet trajectory program has been reverted to.

Two nozzle configurations were tried with a variety of injection rates. As stated above numerical difficulties prevented use of the latest version of the trajectory program and forced the use of an earlier version with the transverse droplet velocity as a parameter. Estimation of this velocity was done by summing the Saffman and Magnus forces, equating them to the drag force and solving for the terminal velocity. This calculation was performed at several places in the nozzle and produced the largest transverse velocity near the exit. This velocity was approximately 20.0 meters/second and is probably an upper limit. Therefore the velocity parameter was set at three values for input to the programs: 5.0, 10.0 and 20.0 meters/second. The nozzle configurations are:

1. A porous - walled nozzle

2. A nozzle with injection through a ring one millimeter wide located one millimeter from the inlet.

A half cross-section of the two nozzles is shown in Figure 3.

It was first thought that injection through a porous-walled nozzle would be the most efficient boundary-layer-control method. As shown in Table 2 the nozzles with the injection ring appear to be more efficient at isolating the free stream flow. The droplet trajectories corresponding to the two nozzle configurations and the various injection rates will be found in Figures 4 through 7. The most efficient nozzle in the test was number 3 which isolated the free stream for all the test values of droplet transverse velocity and had a ratio of injected mass flow to free stream mass flow of 0.173%.

VIII. Discussion of Results

It is the authors belief that the assumptions made in order to reduce this problem to a manageable level render all the numbers very inaccurate. These results should be taken as an order of magnitude analysis. It is felt that experiments should be made to verify the validity of the boundary layer model, which is in serious doubt, and to verify the order of magnitude of the injection rate. It is the authors belief that the results of this study show that boundary layer injection is a reasonable method of controlling scale buildup, but the effect on nozzle efficiency is unknown.

CROSS-SECTION OF NOZZLE

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13:35:26

Figure 3.

TABLE 2

Comparison of Various Nozzle Configurations

Free Stream Mass Flow = $.2205 \frac{\text{Kgm}}{\text{s}}$

NOZZLE	TYPE*	INJECTION RATE $\left(\frac{\text{Kgm}}{\text{m}^2}\right)$	TOTAL INJECTION	$\frac{\text{TOTAL INJECTION}}{\text{FREE STREAM}}$	PERFORMANCE †
1	1	0.2	1.913×10^{-4}	0.086%	Unsatisfactory
2	1	0.3	2.870×10^{-4}	0.130%	Marginal
3	1	0.4	3.826×10^{-4}	0.173%	Satisfactory
4	2	.005	1.996×10^{-3}	0.905%	Unsatisfactory
5	2	.010	4.010×10^{-3}	1.820%	Unsatisfactory
6	2	.020	6.027×10^{-3}	2.730%	Unsatisfactory
7	2	.030	1.167×10^{-2}	5.290%	Unsatisfactory

* 1 - Nozzle with solid walls. Injection through a ring 1mm. wide, located 1mm from the inlet.

2 - Porous Walled Nozzle. Uniform injection

† satisfactory is defined as stopping a droplet with a 20 m/s transverse velocity

TRAJECTORY OF DROPLETS. DROPLET VELOCITY=5.0 M/S
INJECTION 1 TO 2 MM. RATES: 0.2, 0.3, 0.4 KGM/M**2

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15:01:14

Figure 4.

TRAJECTORIES OF DROPLETS. DROPLET VELOCITY=10.0 M/S.
INJECTION 1 TO 2 MM. RATES: 0.2, 0.3, 0.4 KGM/M**2

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13:49:37

Figure 5.

TRAJECTORIES OF DROPLETS. DROPLET VELOCITY=20.0 M/S
INJECTION 1 TO 2 MM. RATES. 0.2, 0.3, 0.4 KG/M**2

16 SEP 75
14:39:54

• Figure 6.

TRAJECTORIES OF DROPLETS WITH UNIFORM INJECTION.
INJECTION RATE=.83G KG/M**2. DROPLET VELOCITIES=5.0 & 10.0 M/S.

24 SEP 75
08:45:17

• Figure 7.

IX. Extension of this Work

Should it be decided to continue the analytic and numerical aspects of this study, there are several areas that need immediate attention:

1. The ideal gas equations must be replaced with real properties the boundary layer program.
2. The numerical instability in the boundary layer program must be fixed.
3. The compressible flow boundary conditions must be replaced by a real two-phase nozzle flow code.
4. Mass and energy transfer between droplets and vapor must be introduced.
5. Turbulence must be looked at and some approximation (perhaps statistical) to its character must be introduced to the trajectory program.
6. These modifications will probably necessitate combining the boundary layer and trajectory programs.
7. The effects of a liquid film with liquid injection must be looked at.
8. The circular geometry of the nozzle must be introduced to the boundary layer program and to the trajectory program.

These areas will lead to many other questions but it is felt that they represent a reasonable outline of future analytic work.

Acknowledgements

It should be known that the main body of the boundary layer program is the program written by S. V. Patankar and D. B. Spalding to whom credit is given. The entire listing is being published to show the modifications that I have made to it to solve our problem.

I would like to thank Professor Clayton T. Crowe for the help he gave me in making the boundary layer program work. Thanks also go to Professor Warren Giedt, William Comfort, and Terry Alger for putting up with my questions both in and out of class. I appreciate the free hand given me by George Bokanich and George Tardiff who let me work under my own direction and special thanks must go to the R & S machines (CDC 7600's) as they must be smoking hot by now.

NOMENCLATURE

- A - area
- C_d - coefficient of drag
- D - pipe diameter
- d - droplet diameter
- R_e - droplet reynolds number
- U_r - relative velocity between droplet and vapor
- U_∞ - free stream velocity in x-direction
- u - x-velocity of vapor
- V - volume
- v - y-velocity of vapor
- x - x-dimension
- y - y-dimension
- θ - void fraction
- δ - boundary layer thickness
- ω - fluid rotation
- ν - kinematic vapor viscosity
- μ - absolute vapor viscosity

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Appendix A

GLOSSARY OF VARIABLES FOR PROGRAM
GMD15SR8

ALPHA - Temporary storage
AMINAR - Difference in area ratio between two adjacent iterations in the
mach number calculation
ARATIO - A/A^* , area/(throat area), compressible flow
ARTEMP - Temporary area ratio used while iterating toward ARATIO
ATHROT - Throat area
BETA - Temporary storage
DMACH - Incremental change in mach number
DMASS - Incremental injected mass flow over DX
DPDDX - Derivative of pressure with respect to $x \frac{\partial p}{\partial x}$
DRUDX - Derivative of the product of density and x-velocity with respect
to $x \frac{\partial}{\partial x} (\rho u)$
DRV - Incremental change in the product of density and y-velocity in the
y-direction
DX - Incremental change in x
DXTOT - Sum of two adjacent DX's
DXVEL(2) - Temporary storage for two adjacent DX's
FACTOR - Interpolation factor
FLAREA - Nozzle flow area
FLMASS - Total mass flow
GAMMA - Temporary storage
GASCON - Universal gas constant
ICOUNT - Iteration Counter
INFO - Controls reading of data
ISTEP - Number of the iteration step
ISTM1 - ISTEP minus 1
NUMX - Number of x-positions describing nozzle contours
PRESS - Pressure
PRESSZ - Reservoir pressure
PRMIN - Pressure at the previous x-position
RADIUS - Nozzle radius at x-position
RADMIN - Nozzle radius at the previous x-position
RHO(43) - Cross-stream densities

RHOVEL(3, 43) - Density grid used to calculate derivatives
RK - Ratio of specific heats
RMACH - Mach number
RMI - Injected mass flow at position XU
SFAREA - Incremental nozzle interior surface area
SFATOT - Total nozzle interior surface area
SMASS - Total injected mass flow
TA - Initial free stream temperature
U(43) - Cross stream x-velocities
UA - Initial A-stream x-velocity
UB - Initial B-stream x-velocity
UC - Initial C-stream x-velocity
UD - Initial D-stream x-velocity
UVEL(3, 43) - x-velocity grid used to calculate derivatives
VVEL(43) - Cross stream y-velocities
WMIX - Molecular weight of vapor
XPOS(20) - x-positions at which nozzle contours are described
XRAD(20) - Nozzle radii at XPOS(20)
XRMI(20) - Injected mass flow at XPOS(20)
XTHROT - x-position of throat
XU - x-position
XUMIN - Previous x-position
Y(43) - Cross stream y-distances
YVEL(3, 43) - y-velocity grid used to calculate derivatives
ZMASS - Original free stream mass flow at inlet

GLOSSARY OF VARIABLES FOR PROGRAMS
TRACK11 AND TRACK12

ACCELX - Droplet acceleration in the x-direction
ACCELY - Droplet acceleration in the y-direction
CD - Coefficient of drag
DIAM - Droplet diameter
DMACH - Incremental change in mach number
DMASS - Incremental injected mass flow
DPDDX - Derivative of pressure with respect to $x \frac{\partial p}{\partial x}$
DPMASS - Droplet mass
DRAG - Total drag force
DS - Total distance moved during one time step DT
DSMAX - Maximum allowable motion during one time step DT
DT - Time step
DUDROP - Incremental change in droplet x-velocity
DUDY - Derivative of vapor x-velocity with respect to $y \frac{\partial u}{\partial y}$
DVDROP - Incremental change in droplet y-velocity
DVMAX - Not used
DX - Incremental change in X
DY - Incremental change in Y
FLMASS - Total mass flow
IFIN - Terminates program if droplet strikes the wall
INT - Integration counter
INT1 - Integration counter
INTMAX - Maximum number of iterations
ISTMAX - Number of x positions at which boundary layer data is available
NP3 - Number of cross stream points at which boundary layer data is available
PRESS - Pressure
PRESSZ - Reservoir pressure

RADIUS - Nozzle radius at position XP
REP - Droplet Reynolds number
RHO(200, 22) - Vapor density grid
RHON(22) - Temporary storage for vapor density
RHOXP(22) - Interpolated vapor densities at XP
RMACH - Vapor mach number
RMAG - Total Magnus force
RMI - Wall injection
RMULT - Controls sense of Saffman force
SAFMAN - Saffman force
SFATOT - Total nozzle interior surface area
SMASS - Total injected mass flow
SMULT - Controls sense of Saffman force
T - Time
U(200, 22) - Vapor x-velocity grid
UDROP - Droplet x-velocity
UN(22) - Temporary storage for vapor x-velocity
UREL - Total relative velocity between droplet and vapor
URELX - Relative velocity in x-direction
URELY - Relative velocity in y-direction
UX - Vapor x-velocity
UXP(22) - Interpolated vapor x-velocities at XP
V(200, 22) - Vapor y-velocity grid
VDROP - Droplet y-velocity
VEL - Transverse droplet velocity resulting from Magnus and Saffman forces
VISC - Vapor viscosity
VN(22) - Temporary storage for vapor y-velocity
VY - Vapor y-velocity
VXP(22) - Interpolated vapor y-velocities at XP
X(200) - X-positions at which boundary layer data is available
XDRAG - X component of drag force
XEND - Total x-dimension of nozzle

XFCTR - Interpolation factor
XFORCE - Sum of y-components of forces
XMAG - X-component of Magnus force
XN - Temporary storage for x positions
XP - X-position
Y(200, 22) - Grid of y distances from nozzle wall
YDRAG - Y-component of drag force
YFCTR - Interpolation factor
YFORCE - Sum of y-components of forces
YMAG - Y-component of Magnus force
YN(22) - Temporary storage of y distances
YP - Y- position
YXP(22) - Interpolated y-positions at XP

Appendix B

PROGRAM GMD15SR8 .

This program is a modification of the Patankar-Spalding program Ref. (2). Modifications have been confined as much as possible to the addition of subroutines. There have been some modifications to the MAIN program though these chiefly concern the representation of free stream boundary conditions; temperature pressure and x-velocity. Modifications to these variables allowed them to take on the different values as calculated in the subroutine INTERP.

INTERP has the function of calculating the free stream characteristics by use of the compressible flow relationships (1).

- (1) The free stream mass flow is calculated and the injected mass flow is calculated and integrated.

The subroutine VELOCITY calculates the y-components of velocity from the continuity relation

$$\left(\frac{\partial}{\partial x}\right) \rho u + \frac{\partial}{\partial y} (\rho v) = 0$$

Differences in the MAIN program from the original to the current version can be understood from the accompanying listings. The additional subroutines are also listed and their flow charts accompany this appendix.

Input to this program consist of two files:

1. File name: BLYERIN

This file contains a single line of alphanumeric information that is used as the title of one of the output files.

2. File name: PROFILE

This file contains information about the geometry and disposition of injection in the nozzle. It contains information as shown in Table 3. A sample listing of this file is shown in Appendix C.

Output consists of two files they are:

1. File name: BLYEROUT

This is the original output of the Patankar-Spalding program and is self-explanatory.

2. File name: BLYROUT2

This file contains the boundary layer characteristics in a more condensed form for use as input to the trajectory program. It also contains a series of lines of data used as a check on operating characteristics. Information is written into the file as shown in Table 4. A sample listing of one data set is shown in Appendix C.

The sample files are set up for 22 cross stream grid points as shown but may range up to 43 points.

Subroutines for Program GMPHRES

Figure 3. Flowchart for Subroutine VELOCITY

Figure 2. Flowchart for Subroutine INTERP

TABLE 3

Layout of information in File: PROFILE

NUMX may have a maximum value of 20

LINE	FORMAT	
1	(1X, 110)	NUMX
2	(1X, 5F10.8)	ATHROT, XTHROT, RK, RMACH, PRESS
3 THROUGH NUMX + 2	(1X, 3F10)	XPOS(I), XRAD(I), XRMI(I)

1	17		
2	.00005242	.03416900	1.33 .03515404 3000000.0
3	0.0	.02000000	.000
4	.00100001	.01949997	.000
5	.00100000	.01949997	.100
6	.00200001	.01899995	.100
7	.00200001	.01899994	.000
8	.02971720	.00514060	.000
9	.03000000	.00500470	.000
10	.03100000	.00460710	.000
11	.03200000	.00432750	.000
12	.03300000	.00415590	.000
13	.03400000	.00400600	.000
14	.03416900	.00400600	.000
15	.03500000	.00411790	.000
16	.03600000	.00425040	.000
17	.03603200	.00425610	.000
18	.12000000	.02000000	.000
19	9.99999999	.02000000	.000

Figure 8 Listing of File: PROFILE

TABLE 4

Layout of information in File: BLYROUT2. This table shows the layout of one data set. This pattern is repeated for each X-position in the nozzle.

LINE	FORMAT	VARIABLES WRITTEN
1	(1X, 21E10.3)	XU, DX
2	(1X, 11E10.3)	Y(I), I = 1,11
3	(1X, 11E10.3)	Y(I), I = 12,22
4	(1X, 11E10.3)	U(I), I = 1,11
5	(1X, 11E10.3)	U(I), I = 12,22
6	(1X, 11E10.3)	VVEL(I), I = 1,11
7	(1X, 11E10.3)	VVEL(I), I = 12,22
8	(1X, 11E10.3)	RHO(I), I = 1,11
9	(1X, 11E10.3)	RHO(I), I = 12,22
10	(1X, 11E10.3)	FLMASS, SFATOT, RADIUS, RMACH, DPDDX, PRESS, RMI, SMASS, DMASS, PRESSZ, DMACH

Programs TRACK11 and TRACK12

Each of these programs calculates the trajectory of a single droplet placed initially at an arbitrary position. The primary difference between the two is in the way they determine a relative velocity between the droplet and the vapor.

TRACK12 sets this velocity as a parameter. This is the program that was used to generate the data in the body of this report. The relative velocity VEL is directed toward the nozzle wall.

TRACK11 uses a dynamic representation as described in the Section: V "plan of Attack" but because of discrepancies in the input data to this program it does not function properly.

Listings of both programs and a flow chart of TRACK11 are included. The logic of TRACK12 is identical to TRACK11 except for the velocity calculation.

Input to either program consists of two files

1. File name: BLYROUT2

This file is one of the output files of program GMD15SP8 and is used unchanged. See Appendix C and Table 4.

2. File name: PARAI

This file describes the initial position of the droplet, number of permissible integrations, size of BLYROUT2 and maximum change in position during one integration. It takes slightly different forms for each of the two programs these are shown in Tables 5 & 6.

Output is a single file

1. File name: PATH

This file contains the independent variable, time, the trajectory, and the velocity for each integration as shown in Table 7. The last two (or three) lines written show the method of program

Figure 9 Interpolation scheme used in the trajectory programs TRACK11 and TRACK12 to find vapor properties from the property matrices.

Figure 11. Flowchart for Subroutine INTERP

Figure 10. Flowchart for MAIN. Programs TRACK11 and TRACK12

TABLE 5

Layout of Information in File: PARAM
for input to Program: TRACK11

LINE	FORMAT	VARIABLES READ
1	(1X, 3I10)	Istmax, NP3, INTMAX
2	(1X, 5E10.3)	DVMAX, DSHAX, XP, UP, DLAM
3	(1X, E10.3)	XEND

TABLE 6

Layout of Information in File: PARAM
for input to Program: TRACK12

LINE	FORMAT	VARIABLES READ
1	(1X, 3I10)	ISTMAX, NP3, INTMAX
2	(1X, 5E10.3)	DVMAX, DSMAX, XP, YP, VEL

Table 7
Layout of Information in File: Path

Line	Format	Variables Written
1 to Last - 4	(1X, 5E10.3)	T, XP, YP, UX, VY
Last - 2 Last - 1 Last	Alphanumeric	Describes method of program termination

Appendix C

```

1 PROGRAM BLYER (BLYERIN,TAPE5=BLYERIN,BLYEROUT,TAPE6=BLYEROUT
2 1,BLYROUT2,TAPE7=BLYROUT2,PROFILE,TAPE8=PROFILE)
3 C *****
4 C GM4A KASE 7, LAMINAR BOUNDARY LAYER ON A FLAT PLATE.
5 C THE MOMENTUM THICKNESS REYNOLDS NUMBER OF A FLAT PLATE BOUNDARY
6 C LAYER IS  $.864 \times \text{SQRT}(\text{LENGTH REYNOLDS NUMBER})$ . AND LOCAL  $CF/2$ 
7 C EQUALS  $.332/\text{SQRT}(\text{LENGTH REYNOLDS NUMBER})$ . THE PRODUCT OF THESE
8 C IS THE QUANTITY CALCULATED AS  $\text{TAUID}$ . DOES THE PROGRAM GIVE A GOOD
9 C PREDICTION...?
10 C THE DISPLACEMENT THICKNESS REYNOLDS NUMBER IS EQUAL TO
11 C  $1.7208 \times \text{SQRT}(\text{LENGTH REYNOLDS NUMBER})$ . IS THIS IN ACCORDANCE
12 C WITH THE PREDICTION OF  $M12$ ? ...
13 C  $\text{TAUID}/\text{AJID}(1)$  SHOULD BE  $(\text{PR})^{**2./3}$ . IS IT ? ...
14 C
15 C *****
16 C ***** G E N M I X 4A *****
17 C ----- D.B.SPALDING, IMPERIAL COLLEGE, 1972 -----
18 C -----VERSION OF THE APPENDIX B PROGRAM OF S.V.PATANKAR AND D.B.SPALDING
19 C 'HEAT AND MASS TRANSFER IN BOUNDARY LAYERS',INTERTEXT,LONDON,
20 C 2ND. EDITION,1970.
21 C ----- THIS VERSION COMPRISES ONE STANDARD CASE (KASE=1, COMBUSTION OF
22 C METHANE AND AIR IN A DIVERGENT DUCT EXHAUSTING INTO THE
23 C ATMOSPHERE) TOGETHER WITH A NUMBER OF LESSONS AND OTHER KASES.
24 C THE FORMER ARE INTENDED TO AID SELF-INSTRUCTION IN THE USE OF
25 C THE PROGRAM, THE LATTER ARE SPECIAL VERSIONS LIKELY TO BE OF
26 C INTEREST TO POTENTIAL USERS.
27 C CARDS FOR LESSONS AND KASES ARE SUPPLIED SEPARATELY.
28 C
29 C -----
30 C CHAPTER00000000000000000000 PRELIMINARIES 00000000000000000000000000000000
31 C ----- DIMENSIONS AND COMMON BLOCKS.
32 C COMMON/COMA/ A(43),AJE(5),AJI(5),B(43),C(43),CSALFA,D(43),DPDX(43),
33 C 1 DX,EUU(43),F(5,43),FS(5,43),IAX,IEND,IFIN,INDE(5),INDI(5),ICUT,
34 C 2 ISTEP,ITEST,IUTRAP,JS,JSW,JV,JY,KEX,KIN,KRAD,N,ND2,NF,NOVEL,NPI,
35 C 3 NP2,NP3,OM(43),CMD(43),P(43),PEI,PR(5),PREF(5,43),PSIE,PSII,R(43)
36 C 4,RHO(43),RME,RMI,RU(43),SD(5,43),SU(5,43),TAUE,TAUI,U(43),XD,XU,
37 C 5 Y(43),YE,YI
38 C COMMON/COMB/ AK,ALMG,ARRCON,EWALL,FR,H,HFU,INERT,MASSTR,MODEL,
39 C 1 OXDFU,PREEXP,PRESS,UBAR,UFA
40 C COMMON/COMC/YVEL(3,43),UVEL(3,43),RHOVEL(3,43)
41 C 1 DXVEL(2),VVEL(43)
42 C COMMON/COMD/NUXX,ATHROT,XTHROT,RK,XPOS(20),XRAD(20),XRMI(20)
43 C 1,FLAREA,FLMASS,ZMASS,RADMIN,XUMIN,SFAREA,SMASS,PRESSZ,PRMIN
44 C 2,SFATOT,RADIUS,ALPHA,BETA,GAMMA,RMACH,DPDDX,DMASS
45 C COMMON/COME/INFO,AMINAR,ARTEMP,ARATIO,ICOUNT,DMACH,UA
46 C 1,UB,UC,UD,TA,TB,TC,TD,GASCON,WMI
47 C DIMENSION TITLE(18),OUT(43)
48 C DIMENSION XPLT(43),YPLT(10,43),YAXES(10,2),SYMBOL(10)
49 C DIMENSION FLUX(5),DFI(5),DFE(5),AJID(5),AJED(5)
50 C
51 C CALL CHANGE (7H+CBLYER)
52 C READ(5,1) TITLE
53 C 1 FORMAT(18A4)
54 C
55 C -----
56 C CHAPTER11111111111111111111 PARAMETERS AND CONTROL INDICES 1111111111111111
57 C LESSON=0
58 C KASE=7
59 C ----- NSTAT= NO. OF STEPS BETWEEN OUTPUT OF SINGLE VARIABLES.
60 C ----- NPROF= NO. OF STEPS BETWEEN OUTPUT OF ARRAY VARIABLES.

```

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```

181 C      SEQUENCE TO PUT CELL BOUNDARY AT OMDIV.
182 IF(OMDIV.EQ.0..OR.OMDIV.EQ.1.) GO TO 53
183 DO 52 I=3,NP2
184 IF(CM(I).LE.OMDIV) GO TO 52
185 DIF=OMDIV-.5*(CM(I)+CM(I-1))
186 OM(I-1)=AMAX1(OM(I-1)+DIF,OM(I-2)+1.E-7)
187 CM(I)=AMIN1(CM(I)+DIF,OM(I+1)-1.E-7)
188 GO TO 53
189 52 CONTINUE
190 53 CONTINUE
191 C
192 C ----- INITIAL PROFILES ARE UNIFORM.
193 DO 50 I=1,NP3
194 IF(CM(I).GT.OMDIV) GO TO 51
195 U(I)=UB
196 F(1,I)=F1B
197 F(2,I)=F2B
198 F(3,I)=F3B
199 GO TO 50
200 51 U(I)=UC
201 F(1,I)=F1C
202 F(2,I)=F2C
203 F(3,I)=F3C
204 50 CONTINUE
205 PSII=FLQA
206 PEI=FLOB+FLOC
207 PSIE=PSII+PEI
208 FLQTOT=PEI
209 C
210 C -----
211 CHAPTER6SGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG THERMODYNAMIC PROPERTIES GGGGGGGG
212 C ***** START OF MAIN LOOP *****
213 60 CONTINUE
214 C
215 C CALL INTERPOLATION SUBROUTINE FOR DP/DX AND WALL INJECTION
216 C CALL INTERP
217 C
218 C ----- TEST 1
219 C
220 IF(ITEST) 602,601,602
221 602 WRITE(6,200)
222 200 FORMAT(1H,6X,"TEST 1")
223 WRITE(6,100) R(1),PRESS,DZ,PSII,PSIE,PEI,FRA,ULIM,PEILIM,AFAC,
224 1 AECDLM
225 WRITE(6,205)
226 205 FORMAT(1H,6X,"U")
227 WRITE(6,100) (U(I),I=1,NP3)
228 WRITE(6,210)
229 210 FORMAT(1H,6X,"F(1,I)")
230 WRITE(6,100) (F(1,I),I=1,NP3)
231 WRITE(6,215)
232 215 FORMAT(1H,6X,"F(2,I)")
233 WRITE(6,100) (F(2,I),I=1,NP3)
234 WRITE(6,220)
235 220 FORMAT(1H,6X,"F(3,I)")
236 WRITE(6,100) (F(3,I),I=1,NP3)
237 601 CONTINUE
238 C
239 PDGSCN=PRESS/GASCON
240 DO 65 I=1,NP3

```

[illegible]

[illegible]


```

421 WRITE(6,1030) ISTEP, IAX, IEND, IOUT, KIN, KEX, DX, PSII, PSIE, RMI, RME, PEI
422 1030 FORMAT(7H ISTEP=,15,5H IAX=,15,6H IEND=,15,6H IOUT=,15,5H KIN=,12,
423 1 5H KEX=,12,4H DX=,1PE11.3,6H PSII=,E11.3,6H PSIE=,E11.3/
424 2 5H RMI=,E11.3,5H RME=,E11.3,5H PEI=,E11.3)
425 C
426 C
427 UBAR=0.
428 DO 1020 J=1,NF
429 1020 FLUX(J)=0.
430 DO 1021 I=2,NP1
431 UBAR=UBAR+CMD(I)*(U(I)+U(I+1))
432 DO 1021 J=1,NF
433 1021 FLUX(J)=FLUX(J)+CMD(I)*(F(J,I)+F(J,I+1))
434 UBAR=.5*UBAR
435 UFLUX=PEI*UBAR
436 DO 1022 J=1,NF
437 1022 FLUX(J)=.5*PEI*FLUX(J)
438 C
439 UREF=U(NP3)+1.E-30
440 RUREF=UREF*RHO(NP3)
441 AEXD=0.
442 DO 1023 J=1,NF
443 DF1(J)=(F(J,1)-F(J,NP3))+1.E-30
444 1023 DFE(J)=DF1(J)+F(J,1)-F(J,NP3)
445 UFLUX=UFLUX-PSIE*U(NP3)+U(1)*PSII
446 GO TO (1041,1042,1043), NF
447 1043 FLUX(3)=FLUX(3)-PSIE*F3D+F3A*PSII
448 1042 FLUX(2)=FLUX(2)-PSIE*F2D+F2A*PSII
449 1041 FLUX(1)=FLUX(1)-PSIE*F1D+F1A*PSII
450 PRESSD=PRESS/PRESS1-1.
451 C
452 WRITE(6,1031) XU, UFLUX, PRESS, AEXD, (FLUX(J), J=1,NF)
453 1031 FORMAT(4H XU=,1PE11.3,7H UFLUX=,E11.3,8H PRESS=,E11.3,
454 1 6H AEXD=,E11.3,9H FLUX(J)=,5E12.3)
455 C
456 IF(KIN.NE.1) GO TO 1024
457 TAU1D=TAU1/UREF/RUREF
458 DO 1025 J=1,NF
459 1025 AJID(J)=AJI(J)/RUREF/DF1(J)
460 DEL2=PEI*(1.-UBAR/(U(NP3)+1.E-30))/RHO(NP3)/(U(NP3)+1.E-30)
461 DEL1=Y(NP3)-PEI/RHO(NP3)/(U(NP3)+1.E-30)
462 RDEL2=DEL2*RHO(NP3)*U(NP3)/EMU(NP3)
463 H12=DEL1/DEL2
464 TAU1D=TAU1D*RDEL2** .25
465 AJID(1)=AJID(1)*RDEL2** .25
466 WRITE(6,1029) KIN, TAU1D, H12, RDEL2, (AJID(J), J=1,NF)
467 1029 FORMAT(5H KIN=,12,7H TAU1D=,1PE11.3,5H H12=,E11.3,7H RDEL2=,E11.3,
468 1 9H AJID(J)=,6E11.3)
469 C
470 1024 IF(KEX.NE.1) GO TO 1026
471 TAUED=TAUE/UREF/RUREF
472 DO 1027 J=1,NF
473 1027 AJED(J)=AJE(J)/RUREF/DFE(J)
474 WRITE(6,1028) KEX, TAUED, (AJED(J), J=1,NF)
475 1028 FORMAT(5H KEX=,12,7H TAUED=,1PE11.3,9H AJED(J)=,6E11.3)
476 1026 CONTINUE
477 C
478 CHAPTER 10D -----PROFILES AND OTHER ARRAYS.
479 IF(IPRINT.EQ.1) GO TO 110
480 C

```

```

481 WRITE(6,290)
482 290 FORMAT(1H,6X'R1,Y'S')
483 DIV=1.
484 DO 1095 I=1,NP3
485 1095 OUT(I)=Y(I)/DIV
486 WRITE(6,100) R('),(OUT(I),I=2,NP2),Y(NP3)
487 DO 1085 I=1,NP3
488 1085 XPLOT(I)=OUT(I)
489 C -
490 WRITE(6,295)
491 295 FORMAT(1H,6X'U ')
492 SUB=0.
493 DIV=U(NP3)+1.E-30
494 IF(KIN.EQ.3) SUB=U(NP3)
495 IF(KIN.EQ.3) DIV=U(1)+1.E-30
496 DO 1094 I=1,NP3
497 1094 OUT(I)=(U(I)-SUB)/DIV
498 IF(NOVEL.NE.1) WRITE(6,100) U(1),(OUT(I),I=2,NP2),U(NP3)
499 NY=1
500 DO 1084 I=1,NP3
501 1084 YPLOT(I,I)=OUT(I)
502 C
503 WRITE(6,555G)
504 555G FORMAT(1X,6X,1HV)
505 WRITE(6,100) (VVEL(I),I=1,NP3)
506 C
507 WRITE(6,300)
508 300 FORMAT(1H,6X'TEMP ')
509 SUB=FS(2,1)
510 DIV=(FS(2,NP3)-FS(2,1))+1.E-30
511 DO 1093 I=1,NP3
512 1093 OUT(I)=(FS(2,I)-SUB)/DIV
513 OUT(2)=OUT(1)
514 OUT(NP2)=OUT(NP3)
515 WRITE(6,100) FS(2,1),(OUT(I),I=2,NP2),FS(2,NP3)
516 NY=2
517 DO 1083 I=1,NP3
518 1083 YPLOT(2,I)=OUT(I)
519 C
520 IF(IPRINT.EQ.2) GO TO 110
521 WRITE(6,1070) XU,ISTEP
522 1070 FORMAT(1H,11HPLOT AT XU=,1PE11.3,6H, 1STEP=,15)
523 DO 1071 J=1,NY
524 1071 YPLOT(J,2)=YPLOT(J,1)
525 YPLOT(J,NP2)=YPLOT(J,NP3)
526 CALL PLOTS(XPLOT,43,NP3,YPLOT,10,NY)
527 C -----
528 CHAPTER 11 11 11 11 11 11 11 11 11 11 END OF MAIN LOOP
529 110 IF(ISTEP.GE.LASTEP.OR.XU.GE.XULAST.OR.IFIN.NE.O) GO TO 111
530 C
531 C -----STRIDE3-----STRIDE3-----STRIDE3-----STRIDE3
532 CALL STRIDE(3)
533 CALL VELOCITY
534 WRITE(7,6000) XU,DX
535 WRITE(7,6000) (Y(JK),JK=1,NP3)
536 WRITE(7,6000) (U(JK),JK=1,NP3)
537 WRITE(7,6000) (VVEL(JK),JK=1,NP3)
538 WRITE(7,6000) (RHG(JK),JK=1,NP3)
539 WRITE(7,6000) FLMASS,SFATOT,RADIUS,RMACH,DPODY,PRESS,
540 1RM1,SMASS,DMASS,PRESSZ,DMACH

```

```
541 6000 FORMAT(1X,11E10.3)
542 IF(IFIN) 1011,60,111
543 C
544 C ----- TERMINATION
545 111 WRITE(6,112) ISTEP,LASTEP,XU,XULAST,IFIN
546 112 FORMAT(23H TERMINATED WITH ISTEP=,15,8H LASTEP=,15,
547 1 4H XU=,1PE11.3,8H XULAST=,E11.3,6H IFIN=,13)
548 C -----
549 120 CONTINUE
550 CALL EXIT (1)
551 100 FORMAT(9X,1P11E11.3/(9X,11E11.3))
552 101 FORMAT(9X,11111)
553 END
```

[illegible]

```

61      14 EL12=(YEDGE(2)-YEDGE(1))*ALMG
62      EL34=(YEDGE(4)-YEDGE(3))*ALMG
63      EL56=(YEDGE(6)-YEDGE(5))*ALMG
64      EL23=.5*(EL12+EL34)
65      EL45=.5*(EL34+EL56)
66 C ----- TEST 8
67      IF(ITEST) 19,18,19
68      19 WRITE(6,225)
69      225 FORMAT(1H,6X,"TEST 8")
70      WRITE(6,230)
71      230 FORMAT(1H,6X,"EL'S ")
72      WRITE(6,100)          EL12,EL23,EL34,EL45,EL56
73      WRITE(6,235)
74      235 FORMAT(1H,6X,"YEDGE'S")
75      WRITE(6,100)          (YEDGE(I),I=1,6)
76      18 CONTINUE
77 C -----
78      DO 12 I=2,NP1
79      IF(Y(I)-YEDGE(1)) 120,121,121
80      121 IF(Y(I)-YEDGE(2)) 122,123,123
81      123 IF(Y(I)-YEDGE(3)) 124,125,125
82      125 IF(Y(I)-YEDGE(4)) 126,127,127
83      127 IF(Y(I)-YEDGE(5)) 128,129,129
84      120 SU(3,I)=0.
85      GO TO 130
86      122 SU(3,I)=EL12
87      GO TO 130
88      124 SU(3,I)=EL23
89      GO TO 130
90      126 SU(3,I)=EL34
91      GO TO 130
92      128 SU(3,I)=EL45
93      GO TO 130
94      129 SU(3,I)=EL56
95 C ----- UPPER LIMITS TO MIXING LENGTH
96      130 SU(3,I)=AMIN1(SU(3,I),.5*UDMAX/(ABS(SU(1,I))+1.E-30))
97      IF(KIN-1) 131,132,131
98      132 SU(3,I)=AMIN1(SU(3,I),AK*.5*(Y(I)+Y(I+1)))
99      131 IF(KEX-1) 12,133,12
100     133 SU(3,I)=AMIN1(SU(3,I),AK*(Y(NP3)-.5*(Y(I)+Y(I+1))))
101     12 CONTINUE
102 C ----- TEST 9
103     IF(ITEST) 109,108,109
104     109 WRITE(6,240)
105     240 FORMAT(1H,6X,"TEST 9")
106     WRITE(6,245)
107     245 FORMAT(1H,6X,"SU(3,I)")
108     WRITE(6,100)          (SU(3,I),I=1,NP3)
109     108 CONTINUE
110 C -----
111 C 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 VISCOSITIES
112 C ----- LAMINAR VISCOSITIES FOR CELL BOUNDARIES
113     200 DO 23 I=2,NP1
114     23 EMU(I)=.5*(EMU(I)+EMU(I+1))
115     IF(MODEL.EQ.1) GO TO 29
116 C ----- TURBULENT CONTRIBUTION
117     DO 20 I=2,NP1
118     DUDYL=ABS(SU(1,I)*SU(3,I))
119     UDMIN=UFAC*.5*(U(I)+U(I+1))
120     DUDYL=AMAX1(DUDYL,UDMIN)

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121 RHM=.5*(RHO(1)+RHO(1+1))
122 EMUT=RHM*SU(3,1)*DUDYL
123 C ----- IN THIS VERSION, THE TURBULENT AND LAMINAR CONTRIBUTIONS
124 C ARE SIMPLY ADDED. AN ALTERNATIVE WOULD BE TO INTRODUCE
125 C THE VAN DRIEST DAMPING FUNCTION.
126 EMU(1)=EMU(1)+EMUT
127 20 CONTINUE
128 C ----- TEST 10
129 IF(1TEST) 202,201,202
130 202 WRITE(6,250)
131 250 FORMAT(1H,6X,"TEST 10")
132 WRITE(6,255)
133 255 FORMAT(1H,6X,"EMU(1)")
134 WRITE(6,100) (EMU(1),I=1,NP3)
135 WRITE(6,260)
136 260 FORMAT(1H,6X,"SD(1,1)")
137 WRITE(6,100) (SD(1,1),I=1,NP3)
138 201 CONTINUE
139 C ----- MODIFICATION OF EMU ARRAY
140 29 DO 24 I=2,NP1
141 EMU(1)=EMU(1)/(Y(I+1)-Y(I))
142 IF(KRAD.EQ.0) GO TO 25
143 DO 26 I=2,NP1
144 EMU(1)=EMU(1)*.5*(R(1)+R(1+1))
145 25 IF(ISTEP) 28,28,300
146 C ----- INITIAL PREF S.
147 28 DO 27 J=1,NF
148 DO 27 I=1,NP3
149 27 PREF(J,1)=PREF(J,1)
150 C 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 SOURCES
151 C ----- VELOCITY U
152 300 DO 307 I=2,NP2
153 307 SD(3,1)=PE1*(OM(1+1)-OM(1-1))/RHO(1)/U(1)
154 GO TO (310,312,312), KIN
155 310 SD(3,2)=(R(1)+.5*(R(2)+R(3)))*YI
156 GO TO 313
157 312 SD(3,2)=PE1*OM(3)/RHO(3)/U(3)
158 313 GO TO (314,315,315), KEX
159 314 SD(3,NP2)=(R(NP3)+.5*(R(NP1)+R(NP2)))*YE
160 GO TO 316
161 315 SD(3,NP2)=PE1*(1.-OM(NP1))/RHO(NP1)/U(NP1)
162 316 CONTINUE
163 DO 308 I=2,NP2
164 308 US(1)=DPDX(1)*SD(3,1)
165 IF(NF.EQ.0) RETURN
166 C ----- KINETIC HEATING.
167 C ----- TEMPORARY USE OF SD ARRAY.
168 GO TO (303,304), NOVEL
169 303 DO 305 I=1,NP3
170 SU(1,1)=0.
171 305 SD(1,1)=0.
172 GO TO 306
173 304 DO 30 I=2,NP2
174 30 SD(1,1)=U(1)*U(1)
175 DO 31 I=2,NP1
176 31 SD(1,1)=EMU(1)*(SD(1,I+1)-SD(1,I))
177 SD(1,1)=0.
178 SD(1,NP2)=0.
179 DO 32 I=2,NP2
180 T=(1.-1./PREF(1,1))*5

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181 32 SU(1,1)=(SD(1,1)-SD(1,1-1))*T
182 DO 33 I=2,NP1
183 33 SD(1,1)=0.
184 C ----- TEST 11
185 306 IF(1TEST) 302,301,302
186 302 WRITE(6,265)
187 265 FORMAT(1H, 6X,"TEST 11")
188 WRITE(6,270)
189 270 FORMAT(1H, 6X,"SD(1,1)")
190 WRITE(6,100) (SD(1,1),I=1,NP3)
191 WRITE(6,275)
192 275 FORMAT(1H, 6X,"SU(1,1)")
193 WRITE(6,100) (SU(1,1),I=1,NP3)
194 301 CONTINUE
195 IF(NF.EQ.1) RETURN
196 C ----- FUEL -----
197 T1=.5*PREEXP*PRESS**2
198 DO 40 I=2,NP2
199 IF(INERT-1) 45,41,45
200 45 F2=F(2,1)
201 F3=F(3,1)
202 FS1=FS(1,1)
203 FS2=FS(2,1)
204 IF(I-2) 42,46,42
205 46 F2=F2+.25*(F(2,3)-F2)
206 F3=F3+.25*(F(3,3)-F3)
207 FS1=FS1+.25*(FS(1,3)-FS1)
208 FS2=FS2+.25*(FS(2,3)-FS2)
209 42 IF(I-NP2) 43,47,43
210 47 F2=F2+.25*(F(2,NP1)-F2)
211 F3=F3+.25*(F(3,NP1)-F3)
212 FS1=FS1+.25*(FS(1,NP1)-FS1)
213 FS2=FS2+.25*(FS(2,NP1)-FS2)
214 43 IF(F2) 41,41,43D
215 43D IF(FS1) 41,41,43D
216 431 FUBRNT=.5*(ABS(F3)-F3)/OXDFU
217 EXPO=EXP(-ARRCON/FS2)
218 TERM1=-T1*FS1*EXPO
219 TERM2=TERM1*SD(3,1)
220 IF(-DX*TERM1-.5) 48,48,49
221 48 SU(2,1)=TERM2*F(2,1)
222 SD(2,1)=0.
223 GO TO 40
224 49 IF(F2-FUBRNT) 41,41,44
225 44 SD(2,1)=TERM2*F2/(F2-FUBRNT)
226 SU(2,1)=-FUBRNT*SD(2,1)
227 GO TO 40
228 41 SU(2,1)=0.
229 SD(2,1)=0.
230 40 CONTINUE
231 C ----- TEST 12 -----
232 IF(1TEST) 402,401,402
233 402 WRITE(6,280)
234 280 FORMAT(1H, 6X,"TEST 12")
235 WRITE(6,285)
236 285 FORMAT(1H, 6X,"SD(2,1)")
237 WRITE(6,290)
238 290 FORMAT(1H, 6X,"SU(2,1)")
239 WRITE(6,100) (SU(2,1),I=1,NP3)
240 401 CONTINUE

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```
241 IF(NF.EQ.2) RETURN
242 C ----- OX-FU*OXDFU -----
243 DO 50 I=2,NP2
244 SU(3,I)=0.
245 50 SD(3,I)=0.
246 C ----- TEST 13 -----
247 IF(1TEST) 502,501,502
248 502 WRITE(6,292)
249 292 FORMAT(1H,6X,"TEST 13")
250 WRITE(6,294)
251 294 FORMAT(1H,6X,"SD(3,I)")
252 WRITE(6,100) (SD(3,I),I=1,NP3)
253 WRITE(6,296)
254 296 FORMAT(1H,6X,"SU(3,I)")
255 WRITE(6,100) (SU(3,I),I=1,NP3)
256 501 CONTINUE
257 RETURN
258 100 FORMAT(9X,1P11E11.3/(9X,11E11.3))
259 END
```

09

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1 SUBROUTINE STRIDE(ISW)
2 COMMON/COMA/A(43),AJE(5),AJI(5),B(43),C(43),CSALFA,D(43),DPDX(43),
3 DX,EMU(43),F(5,43),FS(5,43),IAX,IEND,IFIN,INDE(5),INDI(5),IOUT,
4 ISTEP,ITEST,IUTRAP,JS,JSW,JV,JY,KEX,KIN,KRAD,N,ND2,NF,NOVEL,NP1,
5 NP2,NP3,OM(43),OMD(43),P(43),PEI,PR(5),PREF(5,43),PSIE,PSII,R(43),
6 RHO(43),RME,RMI,RU(43),SD(5,43),SU(5,43),TAUE,TAUI,U(43),XD,XU,
7 Y(43),YE,YI
8 C/----- SUBROUTINE FOR PROGRAM GENMIX 4A
9 C/----- D.B.SPALDING, IMPERIAL COLLEGE, 1972 -----
10 C/ THIS SUBROUTINE PERFORMS THE SAME OPERATIONS AS THE ONE IN GENMIX4A
11 C BUT MORE ECONOMICALLY. THE A,B,C ARRAYS ARE ONE-DIMENSIONAL. SOME
12 C OFTEN USED FUNCTIONS OF OM ARE STORED, AND A D ARRAY SAVES
13 C UNNECESSARY ARITHMETIC IN THE TDMA OPERATION.
14 C-----
15 DIMENSION A2(5),ANP2(5),B2(5),BNP2(5),C2(5),CNP2(5),D2(5),DNP2(5),
16 1 AHLPT(43),BOMT3(43),FDIFE(5),
17 2 FDIFI(5),GE(5),GI(5),PBCOM(43),PGCOM(43),THLPT(43),TTPF(5),
18 DIMENSION BOM(43),OMPOM(43),US(43)
19 EQUIVALENCE (DPDX(1),US(1))
20 C
21 GO TO (1000,2000,3000,4000), ISW
22 C
23 C***** STRIDE 1 *****
24 1000 IF(ISTEP) 1003,1003,1100
25 1003 OM1= 5*OM(3)
26 CME= 5*(1.-OM(NP1))
27 DO 1002 I=2,NP2
28 BOM(I)=OM(I+1)-OM(I-1)
29 BOMT3(I)=3.*BOM(I)
30 OMPOM(I)=OM(I)+OM(I+1)
31 1002 OMD(I)=OM(I+1)-OM(I)
32 OMD(I)=BOM(2)
33 BPE=1.
34 BPI=1.
35 Y(1)=0.
36 IF(KRAD.EQ.1) GO TO 1100
37 DO 1001 I=1,NP3
38 R(I)=1.
39 R25=1.
40 RN15=1.
41 IF(ITEST.NE.0) WRITE(6,9010) (R(I),I=1,NP3),R25,RN15
42 C----- CALCULATION OF RHO*U'S -----
43 1100 DO 1101 I=1,NP3
44 IF(RHO(I).GT.0.) GO TO 1101
45 WRITE(6,1108) RHO(I),I,RHO(I)
46 1108 FORMAT(36H ***** NEGATIVE OR ZERO RHO(I)=,1PE11.3,6H AT I=,
47 1 13,6X,21HSET TO ABS OF RHO(I)=,E11.3,17H ***** STRIDE1)
48 RHO(I)=ABS(RHO(I))
49 1101 RU(I)=RHO(I)*U(I)
50 RU3=RU(3)
51 RUN1=RU(NP1)
52 DO 1102 I=2,NP1
53 1102 RU(I)= 5*(RU(I)+RU(I+1))
54 IF(ITEST.NE.0) WRITE(6,9010) (RU(I),I=1,NP3),RUN1,RU3,PEI
55 C----- CALCULATION OF Y'S AND R'S -----
56 C----- Y'S FOR PLANE GEOMETRY -----
57 YI=PEI*OM1/(BPI*RU(2))
58 Y(3)=YI+PEI*OM(3)/(RU(2)+RU3)
59 Y(2)=2.*YI-Y(3)
60 DO 1103 I=4,NP1

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61 1103 Y(I)=Y(I-1)+PEI*OMD(I-1)/RU(I-1)
62 YN15=Y(NP1)+PEI*OMD(NP1)/(RU(NP1)+RUN1)
63 YE=PEI*C1E/(BPE*RU(NP1))
64 Y(NP3)=YN15+YE
65 Y(NP2)=2.*YN15-Y(NP1)
66 IF(KRAD.EQ.0) RETURN
67 C ----- Y'S AND R'S FOR AXISYMMETRICAL GEOMETRY
68 IF(CSALFA.EQ.0.) GO TO 1110
69 C ----- CSALFA NE ZERO
70 COSD2=.5*CSALFA
71 IF(R(1).NE.0.) GO TO 1105
72 C ----- R(1)=0.
73 DO 1106 I=2,NP3
74 Y(I)=SQRT(ABS(Y(I)/COSD2))
75 1106 R(I)=Y(I)*CSALFA
76 YI=SQRT(ABS(YI/COSD2))
77 YN15=SQRT(ABS(YN15/COSD2))
78 GO TO 1107
79 C ----- R(1) NE 0.
80 1105 R1D2=.5*R(1)
81 R1D2SQ=R1D2*R1D2
82 DO 1104 I=2,NP3
83 Y(I)=Y(I)/(R1D2+SQRT(ABS(R1D2SQ+COSD2*Y(I))))
84 1104 R(I)=R(1)+Y(I)*CSALFA
85 YI=YI/(R1D2+SQRT(ABS(R1D2SQ+COSD2*YI)))
86 YN15=YN15/(R1D2+SQRT(ABS(R1D2SQ+COSD2*YN15)))
87 1107 R25=R(1)+YI*CSALFA
88 RN15=R(1)+YN15*CSALFA
89 YE=Y(NP3)-YN15
90 RETURN
91 C ----- CSALFA EQ ZERO
92 1110 DO 1111 I=2,NP3
93 Y(I)=Y(I)/R(1)
94 1111 R(I)=R(1)
95 YI=YI/R(1)
96 YN15=YN15/R(1)
97 R25=R(1)
98 RN15=R(1)
99 YE=Y(NP3)-YN15
100 RETURN
101 C***** S T R I D E 2 *****
102 C ----- PRELIMINARIES FOR COEFFICIENTS
103 2000 PX=PEI/DX
104 PD8=.125*PX
105 PD4=PD8+PD8
106 G=RM1-RME
107 ARM1=ABS(RM1)
108 ARM1E=ABS(RME)
109 GD4=.25*G
110 PG=PX+G
111 PGD8=.125*PG
112 PGD4=PGD8+PGD8
113 RM1D2=.5*RM1
114 DO 2004 I=2,NP2
115 PBC1(I)=PX*BCM(I)
116 2004 PGCM(I)=PGD4*CMD(I)
117 PAC1P=PD4*BOM(2)
118 C ----- GRID POINT 2
119 C ----- TAU1, BPI, T1
120 IF(KIN.NE.1) GO TO 2001

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121 CALL WF(0,1,BP1,T1,TAU1)
122 GO TO 2002
123 2001 T1=0.
124 IF(KRAD.EQ.0) BP1=.33333+.66667*RU(1)/RU(2)
125 IF(KRAD.EQ.1) BP1=(R(1)*(5.*RU(1)+RU(2))+3.*R25*
126 (RU(1)+RU(2)))/6./(R(1)+R25)/RU(2)
127 C ----- BOUNDARY COEFFICIENTS FOR VELOCITY
128 2002 HLP=RMID2-GD4*OMPOM(2)
129 AHLP=ABS(HLP)
130 THLP=HLP+HLP
131 THLPT(2)=THLP
132 TP=EMU(2)
133 TTP=TP+AHLP+ABS(TP-AHLP)
134 A(2)=TTP-THLP-T1-PGOM(2)
135 B(2)=2.*T1+RMI+ARMI
136 C(2)=P4OM1P=(3.*U(2)+U(3))-US(2)
137 D(2)=A(2)+B(2)+PBO(2)
138 C ----- BOUNDARY COEFFICIENTS FOR F'S
139 IF(NF.EQ.0) GO TO 2304
140 DO 2300 J=1,NF
141 TPF2=TP/PREF(J,2)
142 TTPF(J)=TPF2+AHLP+ABS(TPF2-AHLP)
143 IF(KIN.NE.1) CO TO 2301
144 CALL WF(J,1,FDIFI(J),T1F,G1(J))
145 IF(INDI(J).EQ.2) GO TO 2303
146 AJI(J)=G1(J)*(F(J,1)-.5*(F(J,2)+F(J,3))-FDIFI(J))
147 GO TO 2302
148 2301 T1F=0.
149 FDIFI(J)=0.
150 2302 A2(J)=TTPF(J)-THLP-T1F-PGOM(2)+.5*SD(J,2)
151 B2(J)=2.*T1F+RMI+ARMI
152 D2(J)=A2(J)+B2(J)+PBO(2)-2.*SD(J,2)
153 T=-T1F*FDIFI(J)
154 GO TO 2305
155 2303 A2(J)=TTPF(J)-THLP-PGOM(2)+.5*SD(J,2)
156 B2(J)=0.
157 D2(J)=A2(J)+PBO(2)-2.*SD(J,2)+RMI*2.
158 T=RMI*F(J,1)+AJI(J)*R(1)
159 2305 TT=3.*F(J,2)+F(J,3)
160 2300 C2(J)=P4OMP*TT+2.*(T+SU(J,2))
161 C ----- GRID POINT NP2
162 C ----- TAUE, BPE, TNP3
163 2304 IF(KEX.NE.1) GO TO 2003
164 CALL WF(0,NP3,BPE,TNP3,TAUE)
165 GO TO 2310
166 2003 TNP3=0.
167 IF(KRAD.EQ.0) BPE=.33333+.66667*RU(NP3)/RU(NP1)
168 IF(KRAD.EQ.1) BPE=(R(NP3)*(5.*RU(NP3)+RU(NP1))+3.*RN15*
169 (RU(NP3)+RU(NP1)))/6./(R(NP3)+RN15)/RU(NP1)
170 C ----- BOUNDARY COEFFICIENTS FOR VELOCITY
171 2310 HLM=RMID2-GD4*OMPOM(NP1)
172 AHLM=ABS(HLM)
173 THLM=HLM+HLM
174 TM=EMU(NP1)
175 TTM=TM+AHLM+ABS(TM-AHLM)
176 P4OM1=PD4*BOM(NP2)
177 A(NP2)=2.*TNP3-RME+ARME
178 B(NP2)=TTM+THLM-TNP3-PGOM(NP1)
179 C(NP2)=P4OMM*(3.*U(NP2)+U(NP1))-US(NP2)
180 D(NP2)=A(NP2)+B(NP2)+PBO(NP2)

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181 IF(NF.EQ.0) RETURN
182 C ----- BOUNDARY COEFFICIENTS FOR F'S
183 DO 2320 J=1,NF
184 TMF=TM/PREF(J,NP1)
185 TTMF=TMF+AHLM+ABS(TM-AHLM)
186 IF(KEX.NE.1) GO TO 2311
187 CALL WF(J,NP3,FDIFE(J),TNP3F,GE(J))
188 IF(INDE(J).EQ.2) GO TO 2313
189 AJE(J)=GE(J)*(.5*(F(J,NP2)+F(J,NP1))+FDIFE(J)-F(J,NP3))
190 GO TO 2312
191 2311 TNP3F=0.
192 FDIFE(J)=0.
193 2312 ANP2(J)=2.*TNP3F-RME+ARME
194 BNP2(J)=TTMF+THLM-TNP3F-PGOM(NP1)+.5*SD(J,NP2)
195 DNP2(J)=ANP2(J)+BNP2(J)+PBOM(NP2)-2.*SD(J,NP2)
196 T=-TNP3F*FDIFE(J)
197 GO TO 2315
198 2313 ANP2(J)=0.
199 BNP2(J)=TTMF+THLM-PGOM(NP1)+.5*SD(J,NP2)
200 DNP2(J)=BNP2(J)+PBOM(NP2)-2.*SD(J,NP2)-RME*2.
201 T=-RME*F(J,NP3)-AJE(J)*R(NP3)
202 2315 TT=3.*F(J,NP2)+F(J,NP1)
203 2320 CNP2(J)=P4GIM*TT+2.*(T+SU(J,NP2))
204 RETURN
205 C***** STRIDE 3 *****
206 3000 DO 3003 I=3,NP1
207 THLM=THLP
208 HLP=RMID2-GD4*OMPOM(I)
209 THLP=HLP+HLP
210 THLPT(I)=THLP
211 AHLPT(I)=AHLPT(I)+HLP
212 TTM=TTT
213 TP=EMU(I)
214 TTP=TP+AHLP+ABS(TP-AHLP)
215 A(I)=TTP-THLP-PGOM(I)
216 B(I)=TTM+THLM-PGOM(I-1)
217 C(I)=PD4*(BOHT3(I)*U(I)+CMD(I)*U(I+1)+CMD(I-1)*U(I-1))-US(I)
218 D(I)=A(I)+B(I)+PBOM(I)
219 3005 CONTINUE
220 GO TO (3021,302D), NOVEL
221 3020 IF(ITEST) 3900,3905,3900
222 3900 WRITE(6,3901) (A(I),I=2,NP2)
223 WRITE(6,3902) (B(I),I=2,NP2)
224 WRITE(6,3903) (C(I),I=2,NP2)
225 WRITE(6,3904) (D(I),I=2,NP2)
226 3901 FORMAT(7H A(I) ,1P11E11.3/(7X,11E11.3))
227 3902 FORMAT(7H B(I) ,1P11E11.3/(7X,11E11.3))
228 3903 FORMAT(7H C(I) ,1P11E11.3/(7X,11E11.3))
229 3904 FORMAT(7H D(I) ,1P11E11.3/(7X,11E11.3))
230 3905 CONTINUE
231 C-----
232 IF(KIN.EQ.2.AND.RU(1).NE.0.) U(1)=U(1)-DPDX(1)*DX/RU(1)
233 IF(KEX.EQ.2.AND.RU(NP3).NE.0.) U(NP3)=U(NP3)-DPDX(NP3)*DX/RU(NP3)
234 C----- SOLVE FOR DOWNSTREAM U'S -----
235 B(2)=(B(2)*U(1)+C(2))/D(2)
236 A(2)=A(2)/D(2)
237 DO 3048 I=3,NP2
238 T=D(I)-B(I)*A(I-1)
239 A(I)=A(I)/T
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241 3048 B(I)=(B(I)*B(I-1)+C(I))/T
242 DO 3050 IDASH=2,NP2
243 / I=N+4-IDASH
244 U(I)=A(I)*U(I+1)+B(I)
245 C ----- TEST FOR NEGATIVE U'S
246 C/IUTRAP=0, NO ACTION/ .GT.0, SET TO 1.E-30/ .GT.1, IFIN=-1/ .GT.2, ITEST=1/
247 IF(IUTRAP.EQ.0.OR.1.EQ.2.OR.1.EQ.NP2) GO TO 3050
248 IF(U(I)) 3046,3046,3050
249 3046 J=ISTEP+1
250 WRITE(6,3047) U(I),I,J
251 3047 FORMAT(25H ***** U (LE ZERO) =,1PE10.3,6H AT I=,I3,
252 1 8H, ISTEP=,I6,84H, SET U TO 1.E-30 ***** STRIDE3)
253 U(I)=1.E-30
254 IFIN=-IUTRAP/2
255 ITEST=IUTRAP/3
256 3050 CONTINUE
257 C -----
258 IF(KIN.EQ.3) U(I)=.5*(U(2)+U(3))
259 IF(KEX.EQ.3) U(NP3)=.5*(U(NP1)+U(NP2))
260 3021 IF(ITEST) 3011,3013,3011
261 3011 WRITE(6,3012) (U(I),I=1,NP3)
262 3012 FORMAT(3H U ,6X,1PE11.3/(9X,11E11.3))
263 C -----
264 3013 IF(NF) 3060,3060,3014
265 3014 DO 3321 J=1,NF
266 C ----- SOLVE FOR DOWNSTREAM F 'S -----
267 A(2)=A2(J)
268 B(2)=B2(J)
269 C(2)=C2(J)
270 D(2)=D2(J)
271 A(NP2)=ANP2(J)
272 B(NP2)=BNP2(J)
273 C(NP2)=CNP2(J)
274 D(NP2)=DNP2(J)
275 DO 3002 I=3,NP1
276 TTMF=TPPF(J)
277 TPF=EMU(I)/PREF(J,I)
278 TTPF(J)=TPF+APLPT(I)+ABS(TPF-APLPT(I))
279 A(I)=TTPF(J)-THLPT(I)-PGOM(I)
280 B(I)=TTMF+THLPT(I-1)-PGOM(I-1)
281 C(I)=PD4*(BOMT3(I)*F(J,I)+OMD(I)*F(J,I+1)+OMD(I-1)*F(J,I-1))+
282 2.*SU(J,I)
283 3002 D(I)=A(I)+B(I)+PGOM(I)-2.*SD(J,I)
284 IF(ITEST) 3906,3907,3906
285 3906 WRITE(6,3901) (A(I),I=2,NP2)
286 WRITE(6,3902) (B(I),I=2,NP2)
287 WRITE(6,3903) (C(I),I=2,NP2)
288 WRITE(6,3904) (D(I),I=2,NP2)
289 3907 CONTINUE
290 C -----
291 B(2)=(B(2)*F(J,1)+C(2))/D(2)
292 A(2)=A(2)/D(2)
293 DO 3148 I=3,NP2
294 T=D(I)-B(I)*A(I-1)
295 A(I)=A(I)/T
296 3148 B(I)=(B(I)-B(I-1)+C(I))/T
297 DO 3150 IDASH=2,NP2
298 I=N+4-IDASH
299 3150 F(J,I)=A(I)*F(J,I+1)+B(I)
300 C ----- ADJUST F(J,1) AND F(J,NP3) -----

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301 GO TO (3210,3220,3230),KIN
302 IF(INDI(J).EQ.2) F(J,1)=FDIFI(J)+.5*(F(J,2)+F(J,3))+AJI(J)/GI(J)
303 GO TO 3220
304 3230 F(J,1)=.5*(F(J,2)+F(J,3))
305 3220 GO TO (3310,3320,3330),KEX
306 3310 IF(INDE(J).EQ.2) F(J,NP3)=FDIFE(J)+.5*(F(J,NP2)+
307 1 F(J,NP1))-AJE(J)/GE(J)
308 GO TO 3320
309 3330 F(J,NP3)=.5*(F(J,NP1)+F(J,NP2))
310 3320 IF(1TEST) 3322,3321,3322
311 3322 WRITE(6,3323) J,(F(J,I),I=1,NP3)
312 3323 FORMAT(6H F, J=,13,1P11E11.3/(9X,11E11.3))
313 3321 CONTINUE
314 C -----
315 3060 XU=XD
316 PS11=PS11-RM1*DX
317 PS1E=PS1E-RME*DX
318 PE1=PS1E-PS11
319 ISTEP=ISTEP+1
320 RETURN
321 C***** STRIDE 4 *****
322 4000 CONTINUE
323 ND2=N/2
324 NP1=N+1
325 NP2=N+2
326 NP3=N+3
327 OM(1)=0.
328 OM(NP3)=1.
329 ISTEP=0
330 IEND=10000
331 IAX=10000
332 IOUT=10000
333 XU=1.E-30
334 DX=1.E-30
335 IFIN=0
336 KIN=1.
337 KEX=1
338 RETURN
339 9010 FORMAT(1H ,1P11E11.3)
340 END
```

```

1 SUBROUTINE WF(J, I1, OUT1, OUT2, OUT3)
2 COMMON/COMA/A(43), A1E(5), A1I(5), B(43), C(43), CSALFA, D(43), DPDX(43),
3 1 DX, EMU(43), F(5, 43), FS(5, 43), IAX, IEND, IFIN, INDE(5), INDI(5), IOUT,
4 2 ISTEP, ITEST, IUTRAF, JS, JSW, JV, JY, KEX, KIN, KRAD, N, ND2, NF, NOVEL, NP1,
5 3 NP2, NP3, OM(43), OMD(43), P(43), PEI, PR(5), PREF(5, 43), PSIE, PSII, R(43),
6 4 RH0(43), RME, RMI, RU(43), SD(5, 43), SU(5, 43), TAU, TAU1, U(43), XD, XU,
7 5 Y(43), YE, YI
8 COMMON/COMB/AK, ALMG, AFRCON, EWALL, FR, H, HFU, INERT, MASSTR, MODEL,
9 1 OXDFU, PREEX, PRESS, UBAR, UFAC
10 C/----- SUBROUTINE FOR PROGRAM GENMIX 4A
11 C/----- D.B.SPALDING, IMPERIAL COLLEGE, 1972 -----
12 C
13 C EFFECTS OF PRESSURE GRADIENT AND MASS TRANSFER ARE INCLUDED
14 C EFFECTS OF RADIUS VARIATION ARE NEGLECTED
15 C FOR VELOCITY, OUT1=BP, OUT2=T, OUT3=TAU
16 C FOR F'S, OUT1=FIDIF, OUT2=T, OUT3=0
17 C
18 DATA SHALF/.04/, BPLAST/.9/
19 INT=1/I1
20 I2=I1-1+2*INT
21 I3=I1-2+4*INT
22 I25=I3-INT
23 IF(J) 100, 100, 200
24 C ----- VELOCITY
25 100 UREF=.5*(U(I2)+U(I3))
26 RHOREF=.5*RHO(I1)+.25*(RHO(I2)+RHO(I3))
27 RUREF=RHOREF*UREF
28 RREF=.5*(R(I2)+R(I3))
29 VREF=EMU(I1)
30 YREF=Y1+(YE-Y1)*OM(I1)
31 RE=UREF*RHOREF*YREF/VREF
32 RRUREF=RREF*RUREF
33 AM=(RMI-(RME+RMI)*OM(I1))/RRUREF
34 EF=YREF*DPDX(I1)/RUREF/UREF
35 IF(MODEL.EQ.1) GO TO 110
36 IF(RE.LT.132.25) GO TO 110
37 C ----- EXTENDED LOG LAW
38 ER=RE*EWALL
39 NIT=0
40 101 SHALF1=SHALF
41 S=SHALF**2
42 SLOC=S+AM+EF
43 IF(SLOC.GT.0.) GO TO 104
44 SLOC=1.E-30
45 SHALF=SQRT(ABS(AM+EF))
46 104 BEE=SQRT(SLOC)/AK
47 ARG=ER*(SHALF+(AM/(1.+BEE)+.5*EF)/SHALF)
48 IF(ARG.GT.11.5*EWALL) GO TO 106
49 GO TO 110
50 106 SHALF=AK/ALOG(ARG)
51 IF(ABS(SHALF-SHALF1).LT..0001.OR.NIT.GT.10) GO TO 102
52 NIT=NIT+1
53 GO TO 101
54 102 S=SHALF**2
55 SAV=.5*(SHALF**2+SLOC)
56 OUT1=1./(1.+BEE)
57 EMU(I25)=.25*RHOREF*RREF*ABS(U(I3)-U(I2))*(AK/OUT1)**2
58 GO TO 103
59 C ----- LAMINAR FLOW
60 110 AMRE=AM*RE

```



```
61 FRE=EF*RE
62 IF(ABS(AMRE).LT..01) GO TO 111
63 AMRE=AMAX1(-50.,AMIN1(60.,AMRE))
64 EXPMRE=EXP(AMRE)
65 STORE=EXPMRE-1.-AMRE
66 AMRESQ=AMRE*AMRE
67 SRE=AMRE*(1.-STORE*FRE/AMRESQ)/((EXPMRE-1.))
68 OUT1=SRE*STORE/AMRESQ+FRE*(STORE-.5*AMRESQ)/(AMRESQ*AMRE)
69 GO TO 112
70 111 SRE=(2.-FRE*(1.+AMRE/3.))/(2.+AMRE)
71 OUT1=SRE*(.5+AMRE/6.)+FRE*(.16667+AMRE/24.)
72 112 IF(SRE.GT.1.E-30) GO TO 113
73 SRE=1.E-30
74 OUT1=.33333
75 113 S=SRE/RE
76 EIU(125)=VREF=RREF/ABS(Y(13)-Y(12))
77 103 OUT2=S*RRUREF
78 OUT3=OUT2*UREF/R(11)
79 C ----- UNDER-RELAX OUT1.
80 OUT1=.1*OUT1+.9*BPLAST
81 BPLAST=OUT1
82 RETURN
83 C----- STAGNATION ENTHALPY, FUEL, GX-FU/CXDFU
84 200 IF(RE.LT.132.25) GO TO 210
85 IF(MODEL.EQ.1) GO TO 210
86 IF (ARG.LE.11.5*EWALL) GO TO 210
87 PRRAT=PR(J)/PREF(J,125)
88 PJAY=9.*(PRRAT-1.)/PRRAT*.25
89 S=SAV/PREF(J,125)/(1.+AMAX1(-.99999,PJAY*SQR(ABS(SAV))))
90 OUT1=0.
91 IF(J.EQ.1) OUT1=(H-1.)*.5*UREF**2
92 OUT2=S*RRUREF
93 OUT3=OUT2/R(11)
94 RETURN
95 210 IF(ABS(AMRE).LT..01) GO TO 211
96 S=AM/(EXP(PR(J)*AMRE)-1.)
97 GO TO 212
98 211 S=1./PR(J)/RE/(1.+5*PR(J)*AMRE)
99 OUT1=0.
100 212 IF(J.EQ.1) OUT1=(PR(J)-1.)*.5*UREF**2
101 OUT2=S*RRUREF
102 OUT3=OUT2/R(11)
103 RETURN
104 END
```

```

1      SUBROUTINE PLOTS (X, IDIM, IMAX, Y, JDIM, JMAX)
2 C*****14.8.72*****
3 C
4 C      SUBROUTINE FOR PLOTTING J CURVES OF Y(J,I) AGAINST X(I).
5 C
6 C      X AND Y ARE ASSUMED TO BE IN ANY RANGE EXCEPT THAT NEGATIVE VALUES
7 C      ARE PLOTTED AS ZERO.
8 C      X AND Y ARE SCALED TO THE RANGE 0. TO 1. BY DIVISION BY THE MAXIMA,
9 C      WHICH ARE ALSO PRINTED.
10 C      IDIM IS THE VARIABLE DIMENSION FOR X.
11 C      IMAX IS THE NUMBER OF X VALUES.
12 C      XAXIS STORES THE NAME OF THE X-AXIS.
13 C      JDIM IS THE VARIABLE DIMENSION FOR Y.
14 C      JMAX IS THE NUMBER OF CURVES TO BE PLOTTED, (UP TO 10).
15 C      THE ARRAY YAXES(J) STORES THE NAMES OF THE CURVES.
16 C      THE ARRAY SYMBOL(J) STORES THE SINGLE CHARACTERS USED FOR PLOTTING.
17 C
18 C*****
19 C      DIMENSION X(IDIM),Y(JDIM,IDIM),YAXES(4,2),SYMBOL(4),
20 C      1 A(101),YMAX(10)
21 C      DATA DOT,CROSS,BLANK/1H.,1H+,1H /
22 C      DATA XAXIS/4HY(1)/
23 C      DATA YAXES/4VELC,4HTEMP,4HFUEL,4HOXYG,4HITY.,
24 C      14H 4H 4HEN /
25 C      DATA SYMBOL/1HU,1HT,1HF,1HO/
26 C***** SCALING X ARRAY TO THE RANGE 0 TO 50
27 C      XMAX=1.E-30
28 C      DO 1 I=1,IMAX
29 C      1 IF(X(I).GT.XMAX) XMAX=X(I)
30 C      DO 2 I=1,IMAX
31 C      X(I)=X(I)/XMAX*50.
32 C      2 IF(X(I).LT.0.) X(I)=0.
33 C***** SCALING Y ARRAY TO THE RANGE 0 TO 100
34 C      DO 3 J=1,JMAX
35 C      YMAX(J)=1.E-30
36 C      DO 4 I=1,IMAX
37 C      4 IF(Y(J,I).GT.YMAX(J)) YMAX(J)=Y(J,I)
38 C      DO 3 I=1,IMAX
39 C      Y(J,I)=Y(J,I)/YMAX(J)*100.
40 C      3 IF(Y(J,I).LT.0.) Y(J,I)=0.
41 C***** IDENTIFYING THE VARIOUS CURVES TO BE PLOTTED
42 C      WRITE(3,103) XAXIS,XMAX
43 C      WRITE(3,100)((YAXES(I,J),J=1,2),I=1,JMAX)
44 C      WRITE(6,106) (SYMBOL(I),I=1,JMAX)
45 C      WRITE(6,102) (YMAX(I),I=1,JMAX)
46 C      DO 5 I=1,11
47 C      5 A(I)=0.1*FLOAT(I-1)
48 C      WRITE(6,101) (A(I),I=1,11)
49 C***** MAIN LOOP. EACH PASS PRODUCES AN X-CONSTANT LINE.
50 C      DO 40 I=1,51
51 C      IF(I.EQ.1.OR.I.EQ.51) GO TO 32
52 C      GO TO 33
53 C***** ALLOCATE . CR + AS MARKER ON THE Y-AXIS
54 C      32 DO 30 K=1,101
55 C      30 A(K)=DOT
56 C      DO 31 K=11,101,10
57 C      31 A(K)=CROSS
58 C***** ALLOCATE . OR + MARK ON THE X-AXIS, ALSO THE APPROPRIATE X VALUE
59 C      33 A(1)=DOT
60 C      A(101)=DOT

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```
61 K=I-1
62 46 K=K-5
63 IF(K)48,47,46
64 47 A(I)=CROSS
65 A(101)=CROSS
66 48 XL=0.02*FLOAT(I-1)
67 C***** CHECK IF ANY Y( X(I) ) VALUE LIES ON THIS X-CONSTANT LINE
68 C***** IF YES GO TO 41, OTHERWISE GO TO 42
69 DO 43 K=1,IMAX
70 IF(IFIX(X(K)+1.5)-1) 43,41,43
71 C***** LOCATE Y( X(I) )
72 41 DO 44 J=1,JMAX
73 NY=Y(J,K)+1.5
74 A(NY)=SYMBOL(J)
75 44 CONTINUE
76 GO TO 42
77 43 CONTINUE
78 C***** PRINT X-CONSTANT LINE
79 42 WRITE(6,105) XL,(A(K),K=1,101),XL
80 C***** PUTTING BLANKS INTO X-CONSTANT LINE
81 DO 49 K=1,101
82 49 A(K)=BLANK
83 40 CONTINUE
84 DO 50 I=1,11
85 50 A(I)=.1*FLOAT(I-1)
86 WRITE(6,104) (A(I),I=1,11)
87 RETURN
88 100 FORMAT(11H Y-AXES ARE 5X,10(1X,A6,A4))
89 101 FORMAT(1H0,2X,11F10.1)
90 102 FORMAT(15H MAXIMUM VALUES,1P10E11.3)
91 103 FORMAT(11H0X-AXIS IS ,A6,17H ,MAXIMUM VALUE =,1PE10.3)
92 104 FORMAT(3X,11F10.1/1H1)
93 105 FORMAT(2H X,F6.2,3X,101A1,F6.2)
94 106 FORMAT(7H SYMBOL,9X,10(1X,A10))
95 END
```

SUBROUTINE VELOCITY

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COMMON/COMA/A(43),AJE(5),AJI(5),B(43),C(43),CSALFA,D(43),DPDX(43),
1 DX,EMU(43),F(5,43),FS(5,43),IAX,IEND,IFIN,INDE(5),INDI(5),IOUT
2 ISTEP,ITEST,IUTRAP,JS,JSW,JV,JY,KEX,KIN,KRAD,N,ND2,NF,NOVEL,NP1
3 NP2,NP3,OM(43),OMD(43),P(43),PEI,PR(5),PREF(5,43),PSIE,PSII,R(43)
4,RHO(43),RME,RMI,RU(43),SD(5,43),SU(5,43),TAUE,TAUI,U(43),XD,XU,
5 Y(43),YE,YI
COMMON/COMB/AK,ALMG,ARRCON,EWALL,FR,H,HFU,INERT,MASSTR,MODEL,
1 OXDFU,PREEXP,PRESS,UBAR,UFAC
COMMON/COMC/YVEL(3,43),UVEL(3,43),RHOVEL(3,43)
1 DXVEL(2),VVEL(43)
1 STM1=ISTEP-1
IF(ISTEP.NE.1) GO TO 104
DO 105 I=1,NP3
DO 105 J=1,3
YVEL(J,I)=Y(I)
UVEL(J,I)=U(I)
105 RHOVEL(J,I)=RHO(I)
DXVEL(1)=DX
DXVEL(2)=DX
RETURN
104 CONTINUE
DO 100 I=1,NP3
DO 101 J=1,2
YVEL(J,I)=YVEL(J+1,I)
UVEL(J,I)=UVEL(J+1,I)
RHOVEL(J,I)=RHOVEL(J+1,I)
101 CONTINUE
100 CONTINUE
DO 115 I=1,NP3
YVEL(3,I)=Y(I)
UVEL(3,I)=U(I)
RHOVEL(3,I)=RHO(I)
115 CONTINUE
DXVEL(1)=DXVEL(2)
DXVEL(2)=DX
DXTOT=DXVEL(1)+DXVEL(2)
IF(ISTEP.LT.3) RETURN
VVEL(2)=RMI/(DX*RHOVEL(2,1))
VVEL(1)=VVEL(2)
DO 103 J=2,NP2
DRUDX=(RHOVEL(3,J)*UVEL(3,J)-RHOVEL(1,J)*UVEL(1,J))/DXTOT
DRV=-DRUDX*(YVEL(J+1)-YVEL(J))
VVEL(J+1)=VVEL(J)+DRV/RHOVEL(2,J)
103 CONTINUE
RETURN
END

```

```

1  SUBROUTINE INTERP
2  COMMON/CCMA/A(43),AJE(5),AJI(5),B(43),C(43),CSALFA,D(43),DPDX(43),
3  1 DX,EMU(43),F(5,43),FS(5,43),IAX,IEND,IFIN,INDE(5),INDI(5),IOUT,
4  2 ISTEP,ITEST,IUTRAP,JS,JSW,JV,JY,KEX,KIN,KRAD,N,ND2,NF,NOVEL,NP1,
5  3 NP2,NP3,OH(43),CMD(43),P(43),PEI,PR(5),PREF(5,43),PSIE,PSII,R(43)
6  4,RHO(43),RME,RMI,KU(43),SD(5,43),SU(5,43),TAUE,TAUI,U(43),XD,XU,
7  5 Y(43),YE,YI
8  COMMON/COMB/AK,ALMG,ARRCON,EVAL,FR,H,HFU,INERT,MASSTR,MODEL,
9  1 OXDFU,PREEXP,PRESS,UBAR,UFAC
10 COMMON/COND/NUMX,ATHROT,XTHROT,RK,XPOS(20),XRAD(20),XRMI(20)
11 1,FLAPEA,FLMASS,ZMASS,RADMIN,XUMIN,SFAREA,SMASS,PRESSZ,PRMIN
12 2,SFATOT,RADIUS,ALPHA,BETA,GAMMA,RMACH,DPDX,DMASS
13 COMMON/COIE/INFO,AMINAR,ARTEMP,ARATIO,ICOUNT,DMACH,UA
14 1,UB,UC,UD,TA,TB,TC,TD,GASCON,WMIK
15 IF(INFO.NE.0) GO TO 310
16 READ(8,8000) NUMX
17 READ(8,8001) ATHROT,XTHROT,RK,RMACH,PRESS
18 DO 101 I=1,NUMX
19 READ(8,8001) XPOS(I),XRAD(I),XRMI(I)
20 101 CONTINUE
21 8000 FORMAT(1X,11I10)
22 8001 FORMAT(1X,11F10.8)
23 FLAREA=3.14159*XRAD(1)**2
24 AMINAR=0.0
25 ALPHA=(RK-1.0)/2.0
26 BETA=((RK+1.0)/(2.0*(RK-1.0)))
27 GAMMA=2.0/(RK+1.0)
28 GO TO 300
29 301 CONTINUE
30 UA=RMACH*(RK*GASCON*TA/WMIK)**0.5
31 UB=UA
32 UC=UA
33 UD=UA
34 PRESSZ=PRESS*((1.0+ALPHA*RMACH**2)**(RK/(RK-1.0)))
35 RADMIN=XRAD(1)
36 XUMIN=XU
37 SMASS=0.0
38 PRMIN=PRESS
39 SFATOT=0.0
40 INFO=1
41 RETURN
42 310 IF(ISTEP.GT.1) GO TO 100
43 FLMASS=RHO(NP3)*FLAREA*U(NP3)
44 ZMASS=FLMASS
45 100 DO 102 K=1,NUMX
46 I=K
47 IF(XPOS(I).GT.XU)GO TO 103
48 102 CONTINUE
49 103 FACTOR=(XU-XPOS(I-1))/(XPOS(I)-XPOS(I-1))
50 RADIUS=XRAD(I-1)+FACTOR*(XRAD(I)-XRAD(I-1))
51 FLAREA=3.14159*RADIUS**2
52 300 CONTINUE
53 DMACH=-.075
54 ICOUNT=1
55 ARATIO=FLAREA/ATHROT
56 210 CONTINUE
57 IF(XU.LT.XTHROT) GO TO 800
58 IF(ABS(RMACH-1.0).GT.0.15) GO TO 800
59 IF(ICOUNT.GE.2) GO TO 800
60 RMACH=1.15

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61 800 CONTINUE
62 ARTEMP=(1.0/RMACH)*(GAMMA*(1.0+ALPHA*RMACH**2))**(BETA)
63 IF(ABS(ARTEMP-ARATIO).LT.0.0005) GO TO 200
64 IF(ABS(ARTEMP-ARATIO)-ABS(AMINAR)) 201,202,203
65 202 RETURN
66 203 DMACH=-0.95*DMACH
67 GO TO 205
68 201 DMACH=0.95*DMACH
69 RMACH=RMACH+DMACH
70 ICOUNT=ICOUNT+1
71 IF(ICOUNT.GT.200) GO TO 200
72 IF(XU.LT.XTHROT) GO TO 900
73 IF(RMACH.GT.1.0) GO TO 900
74 RMACH=1.05
75 GO TO 800
76 900 CONTINUE
77 AMINAR=ARTEMP-ARATIO
78 GO TO 210
79 200 CONTINUE
80 IF(INFO.EQ.0) GO TO 301
81 PRESS=PRESSZ/((1.0+ALPHA*RMACH**2))**(RK/(RK-1.0))
82 105 DPDDX=(PRESS-PRMIN)/DX
83 IF (ISTEP.LT.2) DPDDX=0.0
84 RMI=XRMI(1-1)+FACTOR*(XRMI(1)-XRMI(1-1))
85 DMASS=SFAREA*RMI
86 FLMASS=FLMASS+DMASS
87 SFAREA=SFAREA+(RADIUS+RADMIN)*3.14159*DX
88 RADMIN=RADIUS
89 XUMIN=XU
90 SMASS=SMASS+DMASS
91 PRMIN=PRESS
92 SFATOT=SFATOT+SFAREA
93 RETURN
94 END
```

73

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1  PROGRAM TRJKTRY(PARAM,TAPE4=PARAM,BLYROUT2,TAPE5=BLYROUT2,
2  1PATH,TAPE6=PATH,CHECKDATA,TAPE7=CHECKDATA)
3  CALL CHANGE(8H+TRJKTRY)
4  COMMON/COMA/ISTMAX,NP3,DVMAX,DSMAX,XP,YP,XN,DX,X(200),INTMAX
5  1,YN(22),UN(22),VN(22),RHON(22),Y(200,22),U(200,22),V(200,22)
6  2,RHO(200,22),DT,IFIN,T,INT,UX,DY,VY,K,L,XFCTR,YXP(22),UXP(22)
7  3,VXP(22),YFCTR,RHOXP(22),RHOX,DUDY
8  READ(4,600) ISTMAX,NP3,INTMAX
9  READ(4,601) DVMAX,DSMAX,XP,YP,DIAM
10 READ(4,601) XEND
11 DO 100 I=1,ISTMAX
12 READ(5,601) XN,DX
13 X(I)=XN
14 READ(5,601)(YN(J),J=1,NP3)
15 READ(5,601)(UN(J),J=1,NP3)
16 READ(5,601)(VN(J),J=1,NP3)
17 READ(5,601)(RHON(J),J=1,NP3)
18 READ(5,601) FLMASS,SFATOT,RADIUS,RMACH,DPDDX,PRESS,RMI,SMASS
19 1,DMASS,PRESSZ,DMACH
20 DO 101 J=1,NP3
21 Y(I,J)=YN(J)
22 U(I,J)=UN(J)
23 V(I,J)=VN(J)
24 RHO(I,J)=RHON(J)
25 101 CONTINUE
26 100 CONTINUE
27 601 FCRMAT(1X,11E10.3)
28 600 FORMAT(1X,10I10)
29 DT=.001
30 T=0.0
31 INT=1
32 INT1=1
33 IFIN=0
34 VISC=1.43E-5
35 DPMASS=1000.0*4.0/3.0*3.14159*(DIAM/2.0)**3
36 UDROP=UX
37 VDROP=VY
38 103 IF(INT.GE.INTMAX) GO TO 106
39 IF(INT1.GE.INTMAX) GO TO 104
40 CALL INTERP
41 DT=.001
42 INT1=INT1+1
43 IF(IFIN.NE.0) GO TO 106
44 URELX=UX-UDROP
45 URELY=VY-VDROP
46 SMULT=1.0
47 IF(URELX.LT.0.0) SMULT=-1.0
48 UREL=((URELX**2)+(URELY**2))**.5
49 REP=UREL*DIAM*RHOX/VISC
50 CD=(24.0/REP)+(4.0/(REP**.33333))
51 DRAG=0.5*RHOX*UREL**2*CD*3.14159/4.0*DIAM**2
52 XDRAG=(URELX/UREL)*DRAG
53 YDRAG=(URELY/UREL)*DRAG
54 MAGNUS=3.14159/6.0*DIAM**3*RHOX*UREL*DUDY
55 XMAG=(-URELY/UREL)*MAGNUS
56 YMAG=(-URELX/UREL)*MAGNUS
57 RMULT=1.0
58 IF(DUDY.LT.0.0) RMULT=-1.0
59 DUDY=RMULT*DUDY
60 SAFMAN=6.46*VISC*UREL*DIAM**2*DUDY**0.5/(4.0*(VISC/RHOX)**0.5)*RMULT*SMULT

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```
61 XFORCE=XDRAG+XMAG
62 YFORCE=YDRAG+YMAG+SAFFMAN
63 ACCELX=XFORCE/DPMASS
64 ACCELY=YFORCE/DPMASS
65 105 DUDROP=DT*ACCELX
66 DVDROP=DT*ACCELY
67 DX=0.5*ACCELX*DT**2+UDROP*DT
68 DY=0.5*ACCELY*DT**2+VDROP*DT
69 DS=(DX**2+DY**2)**0.5
70 IF(DS.LT.DSNAX) GO TO 104
71 DT=0.5*DT
72 GO TO 105
73 104 XP=XP+DX
74 YP=YP+DY
75 UDROP=UDROP+DUDROP
76 VDROP=VDROP+DVDROP
77 T=T+DT
78 T=T+DT
79 INT1=1
80 IF(YP.LT.0.0) GO TO 106
81 IF(XP.GT.XEND) GO TO 106
82 WRITE(6,601) T,XP,YP,UX,VY,REP,DUDY,UREL,DRAG,MAGNUS,SAFMAN
83 WRITE(7,601) T,UDROP,VDROP,URELX,URELY,XDRAG,YDRAG,XFORCE,YFORCE,
84 1ACCELX,ACCELY
85 INT=INT+1
86 GO TO 103
87 106 WRITE(6,602)
88 WRITE(6,600) INT,IFIN
89 602 FORMAT(1X,20HINTEGRATIONS AND TERMINATION)
90 CALL EXIT(1)
91 END
```

75


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1  SUBROUTINE INTERP
2  COMCON/COMA/ISTMAX, NP3, DVMAX, DSMAX, XP, YP, XN, DX, X(200), INTMAX
3  1, YN(22), UN(22), VN(22), RHO(22), Y(200, 22), U(200, 22), V(200, 22)
4  2, RHO(200, 22), DT, IFIN, I, INT, UX, DY, VY, K, L, XFCTR, YXP(22), UXP(22)
5  3, VXP(22), YFCTR, RHOXP(22), RHOX, DUDY
6  IF(XP.GT.X(1)) GO TO 100
7  UX=U(1, NP3)
8  VY=0.0
9  DUDY=0.0
10 RHOX=RHO(1, NP3)
11 RETURN
12 100 IF(XP.LT.X(ISTMAX)) GO TO 101
13 WRITE(6, 500)
14 500 FORMAT(1X, 20H)TABLE LIMITS EXCEEDED)
15 IFIN=1
16 RETURN
17 C FIND X POSITION IN TABLE
18 101 DO 102 I=1, ISTMAX
19 K=I
20 IF(X(I).GT.XP) GO TO 103
21 102 CONTINUE
22 103 XFCTR=(XP-X(K-1))/(X(K)-X(K-1))
23 C CONSTRUCT WEIGHTED VALUES AT X POSITION
24 DO 104 J=1, NP3
25 YXP(J)=(1.0-XFCTR)*Y(K-1, J)+XFCTR*Y(K, J)
26 RHOXP(J)=(1.0-XFCTR)*RHO(K-1, J)+XFCTR*RHO(K, J)
27 UXP(J)=(1.0-XFCTR)*U(K-1, J)+XFCTR*U(K, J)
28 104 VXP(J)=(1.0-XFCTR)*V(K-1, J)+XFCTR*V(K, J)
29 IF(YP.LT.YXP(NP3)) GO TO 107
30 UX=UXP(NP3)
31 VY=VXP(NP3)
32 DUDY=0.0
33 RHOX=RHOXP(NP3)
34 RETURN
35 107 CONTINUE
36 C INTERPOLATE Y VALUES AT POSITION XP
37 DO 105 J=1, NP3
38 L=J
39 IF(YXP(J).GT.YP) GO TO 106
40 105 CONTINUE
41 106 YFCTR=(YP-YXP(L-1))/(YXP(L)-YXP(L-1))
42 UX=UXP(L-1)+YFCTR*(UXP(L)-UXP(L-1))
43 VY=VXP(L-1)+YFCTR*(VXP(L)-VXP(L-1))
44 RHOX=RHOXP(L-1)+YFCTR*(RHOXP(L)-RHOXP(L-1))
45 DUDY=(UXP(L)-UXP(L-1))/(YXP(L)-YXP(L-1))
46 RETURN
47 END

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```

1  PROGRAM TRJKTRY(PARAM,TAPE4=PARAM,BLYROUT2,TAPE5=BLYROUT2,
2  1PATH,TAPE6=PATH)
3  CALL CHANGE(8H+TRJKTRY)
4  COMMON/COM1A/ISTMAX,NP3,DVMAX,DSMAX,XP,YP,XN,DX,X(200),INTMAX
5  1,YN(22),UN(22),VN(22),RHON(22),Y(200,22),U(200,22),V(200,22)
6  2,RHO(200,22),DT,IFIN,T,INT,UX,DY,VY,K,L,XFCTR,YXP(22),UXP(22)
7  3,VXP(22),YFCTR
8  READ(4,600) ISTMAX,NP3,INTMAX
9  READ(4,601) DVMAX,DSMAX,XP,YP,VEL
10 DO 100 I=1,ISTMAX
11 READ(5,601) XN,DX
12 X(I)=XN
13 READ(5,601)(YN(J),J=1,NP3)
14 READ(5,601)(UN(J),J=1,NP3)
15 READ(5,601)(VN(J),J=1,NP3)
16 READ(5,601)(RHON(J),J=1,NP3)
17 READ(5,601) FLMASS,SFATOT,RADIUS,RMACH,DPDDX,PRESS,RMI,SMASS
18 1,DMASS,PRESSZ,DMACH
19 DO 101 J=1,NP3
20 Y(I,J)=YN(J)
21 U(I,J)=UN(J)
22 V(I,J)=VN(J)
23 RHO(I,J)=RHON(J)
24 101 CONTINUE
25 100 CONTINUE
26 601 FORMAT(1X,11E10,3)
27 600 FORMAT(1X,10I10)
28 DT=.001
29 T=0.0
30 INT=1
31 INT1=1
32 IFIN=0
33 103 IF(INT.GE.INTMAX) GO TO 106
34 IF(INT1.GE.INTMAX) GO TO 104
35 IF(XP.GT.0.125) GO TO 106
36 CALL INTERP
37 DT=.001
38 INT1=INT1+1
39 IF(IFIN.NE.0) GO TO 106
40 105 DX=UX*DT
41 DY=VY*DT
42 IF(ABS(DX).LT.DSMAX.AND.ABS(DY).LT.DSMAX) GO TO 104
43 DT=0.5*DT
44 GO TO 105
45 104 XP=XP+DX
46 YP=YP+DY
47 YP=YP-VEL*DT
48 T=T+DT
49 INT1=1
50 IF(YP.LT.0.0) GO TO 106
51 WRITE(6,601) T,XP,YP,UX,VY
52 GO TO 103
53 106 WRITE(6,602)
54 WRITE(6,600) INT,IFIN
55 602 FORMAT(1X,28HINTEGRATIONS AND TERMINATION)
56 CALL EXIT(1)
57 END

```

```
1 SUBROUTINE INTERP
2 COMMON/CCIIA/ISTMAX, NP3, DVMAX, DSMAX, XP, YP, XN, DX, X(200), INTMAX
3 1, YN(22), UN(22), VN(22), RHON(22), Y(200, 22), U(200, 22), V(200, 22)
4 2, RHO(200, 22), DT, IFIN, I, INT, UX, DY, VY, K, L, XFCTR, YXP(22), UXP(22)
5 3, VXP(22), YFCTR
6 IF(XP.GT.X(1)) GO TO 100
7 UX=U(1, NP3)
8 VY=0.0
9 RETURN
10 100 IF(XP.LT.X(ISTMAX)) GO TO 101
11 WRITE(6, 500)
12 500 FORMAT(IX, 20HTABLE LIMITS EXCEEDED)
13 IFIN=1
14 RETURN
15 C FIND X POSITION IN TABLE
16 101 DO 102 I=1, ISTMAX
17 K=I
18 IF(X(I).GT.XP) GO TO 103
19 102 CONTINUE
20 103 XFCTR=(XP-X(K-1))/(X(K)-X(K-1))
21 C CONSTRUCT WEIGHTED VALUES AT X POSITION
22 DO 104 J=1, NP3
23 YXP(J)=(1.0-XFCTR)*Y(K-1, J)+XFCTR*Y(K, J)
24 UXP(J)=(1.0-XFCTR)*U(K-1, J)+XFCTR*U(K, J)
25 104 VXP(J)=(1.0-XFCTR)*V(K-1, J)+XFCTR*V(K, J)
26 IF(YP.LT.YXP(NP3)) GO TO 107
27 UX=UXP(NP3)
28 VY=VXP(NP3)
29 RETURN
30 107 CONTINUE
31 C INTERPOLATE Y VALUES AT POSITION XP
32 DO 105 J=1, NP3
33 L=J
34 IF(YXP(J).GT.YP) GO TO 106
35 105 CONTINUE
36 106 YFCTR=(YP-YXP(L-1))/(YXP(L)-YXP(L-1))
37 UX=UXP(L-1)+YFCTR*(UXP(L)-UXP(L-1))
38 VY=VXP(L-1)+YFCTR*(VXP(L)-VXP(L-1))
39 RETURN
40 END
```

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