Modeling Natural Gas Combustion in Laminar and Turbulent Chemically Reactive Flows

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ABSTRACT

The combustion of CH_4 in air is examined through the use of computational fluid dynamics modeling. The standard laminar and turbulent case conservation equations are revised or in some instances replaced with non-differential algebraic equations. A conserved scalar approach utilizing an assumed probability function, in the turbulent case, based on the mixture fraction is used to determine the enthalpy, species mass fraction, and temperature fields as a function of the mixture fraction and initial boundary conditions. These alterations have been successfully implemented into the FORTRAN code of Phoenics 1.6, a computational fluid dynamics program, for the laminar case of a jet issuing into co-flowing air.

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INTRODUCTION

The question of how combustion proceeds has been a topic of interest to thermodynamics researchers for several years. As a result, researchers have been studying this phenomenon in detail to determine the most accurate and precise data measurement and analysis techniques. One technique is the use of turbulent and laminar combustion models to simulate the flow field and provide a simple and cost effective method for observing the effects that different boundary conditions may impose on a combustion situation. The term *combustion model* describes any computational method applicable to the general case of statistically three-dimensional time-dependent flows, and which calculates, at a minimum, the mean velocity and composition fields (Pope 1990). The purpose of this University Undergraduate Fellows research project has been to investigate the methods involved in computational fluid dynamics modeling and integrate theoretical approaches into the set of computational equations currently used for fluid flow analysis in order to build upon the range and type of computational methods available.

Considering the ease of access to the FORTRAN coding and the adaptability of the program to different configurations, Phoenics 1.6 is the computational fluid dynamics program chosen for this research. The natural gas combustion case studied involves flames formed from a jet of fuel issuing into co-flowing air. While this system is much simpler than the flames from sprays and multiple jets in swirling and recirculating flows in practical burners, it incorporates the basic ingredients of a chemical reaction under turbulent non-uniform density mixing conditions (Kent & Bilger, 1976). As such, a simple case is the ideal starting point for the introduction of additional equations into the computational fluid dynamics coding of Phoenics 1.6. Whether the test is case is of simple or complex geometry, the fundamental equations involved and the boundary conditions of the system are the same with an improved speed to convergence in the more geometrically simple case. Phoenics 1.6 has the capability to model a highly complex geometry once the exact equation formulations are baselined.

The format of this thesis includes three primary sections. The conservation equations involved in combustion along with the assumptions involved in the use of these equations in computational fluid dynamics are included in the first section. Also, a discourse on the theories behind probability density functions and their application to turbulent flow is described. Following this section, the laminar flame analysis begins with a description of the conserved scalar approach and its implementation into Phoenics 1.6 FORTRAN coding. The results of the research on laminar flame modeling with Phoenics 1.6 are presented and discussed in the second section as well. The turbulent flame analysis, described in the third section, includes the use of probability density functions, (pdf's), in turbulent chemically reacting flow models. Proposed implementation of pdf's into Phoenics 1.6 and future research opportunities are also examined in this final section.

THEORY

For gas phase combustion, in the absence of radiation, the local values of velocity, concentration of chemical species, and enthalpy can be represented by the following conservation equations (Jones & Whitelaw, 1982):

Momentum

$$\rho\frac{\partial U_i}{\partial t}+\rho U_j\frac{\partial U_i}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left\{\mu\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}-\tfrac{2}{3}\delta_{ij}\frac{\partial U_k}{\partial x_k}\right)\right\}+\rho g_i$$

Continuity

$$\frac{\partial \rho}{\partial t}+\frac{\partial U_i}{\partial x_i}=0$$

Chemical Species

$$\rho\frac{\partial Y_\alpha}{\partial t}+\rho U_j\frac{\partial Y_\alpha}{\partial x_j}=\frac{\partial}{\partial x_j}\left\{\frac{\mu}{Sc}\frac{\partial Y_\alpha}{\partial x_j}\right\}+\rho\dot{r}_\alpha,\quad \alpha=1,N$$

Enthalpy

$$\rho\frac{\partial h}{\partial t}+\rho U_j\frac{\partial h}{\partial x_j}=\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_j}\left\{\frac{\mu}{\mathrm{Pr}}\frac{\partial h}{\partial x_j}+\frac{\mu}{\mathrm{Pr}}\left(\frac{\mathrm{Pr}}{\mathrm{Sc}}-1\right)\times\sum_{\alpha=1}^{N}h_\alpha\frac{\partial Y_\alpha}{\partial x_j}\right\}$$

where,

- Pr is the Prandtl Number
- Sc is the Schmidt Number
- g_i is the gravitational acceleration vector
- U_i is the velocity vector
- Y_α is the mass fraction of species α
- h is the enthalpy
- p is the pressure
- $\rho\dot{r}_\alpha$ is the net mass formation rate per unit volume through reaction of species α

Also included in the set of equations is the equation of state for an ideal gas and auxiliary thermodynamic data relating the enthalpy of each species to temperature.

$$\rho = \frac{p}{RT\sum_{\alpha=1}^{N}(Y_\alpha / M_\alpha)}$$

$$h = h_\alpha(T)$$

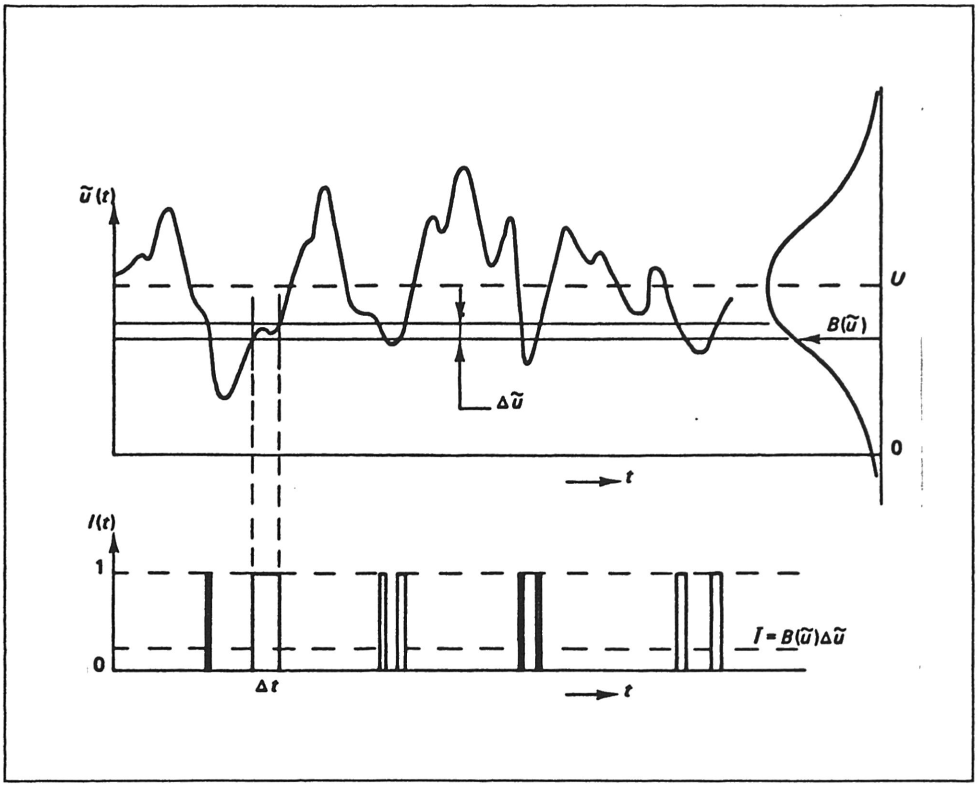
$$h = \sum_{\alpha=1}^{N}(Y_\alpha h_\alpha)$$

The above equations represent the needed variables to obtain closure for standard laminar flow combustion cases. Additions and revisions to these equations are made to achieve either more accurate results, avoid unnecessary computation time, or obtain closure in an iterative solution. The general assumptions and simplifications made in this research to simplify the above equations include: setting Prandtl and Lewis Numbers equal to one, neglecting radiation and gravitation effects, setting the source term for the fuel and air mass fractions to zero, and assuming 29 grams/mole for every point in the fluid flow.

One such instance that requires adaptation of the conservation equations is when solving for turbulent chemically reactive flows. The section on turbulent flame analysis presents the revised equations for that particular case. Also involved in turbulent chemically reactive flow modeling is the use of an assumed probability density function as one method to obtain closure of the equation set. It is convenient at this point to discuss the theory and application behind probability density functions as a review to the reader for the upcoming section.

It is important to the understanding of turbulence to examine how fluctuations are distributed around an average value and how adjacent fluctuations (next to each other in time and space) are related. The study of distributions around a mean value requires the introduction of the probability density function (Tennekes & Lumley, 1990). The top graph in Figure 1.1 provides an example of a stationary or statistically steady function such as axial velocity measurement at a particular location in a combustion chamber. The value in question is the relative amount of time that u(t) spends at various levels. A possible means of measuring this value is by use of a gating circuit that turns on when the signal is between two adjacent levels. The output of such a device is shown as the lower graph in Figure 1.1. If the time spent in a particular range, Δu, is summed and divided by the total measurement time, the percentage of time spent within that range is determined.

Figure 1.1 - Measurement of the probability density
of a stationary function (Tennekes & Lumley, 1990)



Adjusting this range or window to successively different heights yields a function similar to the one on the right of the upper graph of Figure 1.1. The probability density function B(u) can then be defined as the probability of finding u(t) in the range of u(t) to {u(t)+Δt}.

$$B(u)\Delta u \equiv \lim_{T\to\infty}\frac{1}{T}\sum(\Delta t) \quad \text{where}$$

$$B(u)\geq 0, \qquad \int_{-\infty}^{\infty} B(u)du = 1$$

Now, the average of any function, f(u), can be expressed in terms of B(u). The time average of function f(u) can be formed by summing all of the time intervals between

t_o and $t_o + \Delta T$ during which u(t) is between u and u + Δu, multiplying by f(u), and summing over all levels. Since the proportion of time spent between u and u+Δu is equal to B(u)Δu, the following expression, (also known as the Ergodic Assumption) results (Tennekes & Lumley, 1990):

$$\bar{\mathrm{f}} = \lim_{T\to\infty} \frac{1}{T} \int_{t}^{t_o+T} \mathrm{f}(u)dt = \int_{-\infty}^{+\infty} \mathrm{f}(u)B(u)du,$$

By squaring the difference between the time averaged function and the instantaneous function and integrating over the range of u(t), the root mean squared fluctuation of the function f(u) is computed.

$$\overline{\mathrm{f}''^2} = \int_{-\infty}^{+\infty} \left[\mathrm{f}(u) - \bar{\mathrm{f}}(u)\right]^2 B(u)du$$

The usefulness of these expressions lie in their ability to calculate the mean and the root mean squared fluctuation of a function given the probability density of the function and the instantaneous value of that function at a given position and time.

LAMINAR FLAME ANALYSIS

The conserved scalar approach is a useful method for decreasing and simplifying the set of computational fluid dynamics equations for non-premixed flames or laminar diffusion flames. In gas phase diffusion flames, the fuel and oxidizer are initially separated in different streams and enter the reactor in separate eddies which must be contacted on a molecular level before reaction can occur. The assumption of "fast chemistry" is then made wherein once the stoichiometric ratio of fuel to oxidizer is achieved, combustion proceeds instantaneously. The micromixing process is rate-limiting, not the kinetic process. This allows the chemistry to be computed from equilibrium considerations (BYU Code).

The scalar set of all of the molecular species concentrations and enthalpy can be reduced to a single conserved variable ξ called the "mixture fraction." Separate equations for the enthalpy and molecular species do not appear since under the usual assumptions of equal diffusivities for species, unit Lewis number, and fast chemistry these are instantaneously functions only of the mixture fraction: $Y_i(\xi)$, $h(\xi)$, and hence $T(\xi)$ and $\rho(\xi)$ (Kent & Bilger, 1976). Hence, by describing the degree of "mixedness" or "unmixedness" in the form of the mixture fraction, ξ, a great simplification is achieved compared to the larger set of equations described in the theory section for the kinetic scheme (BYU Code).

Using Phoenics 1.6, calculation of the mixture fraction for the laminar diffusion flame case is accomplished by equating the mass fractions of fuel and air to the mixture fraction through a Beta function. (Appendix II contains the FORTRAN coding used in this case.) The Beta functions are Shvab-Zel'dovich coupling parameters and conserved scalars. Using the definition of the mixture fraction, a Beta function is a function of the mixture fraction as shown (Kuo, 1986).

$$\xi \equiv \frac{Z_i - Z_{i2}}{Z_{i1} - Z_{i2}} = \frac{\beta - \beta_A}{\beta_F - \beta_A}$$

In the above equation, Z_i is any conserved scalar of species I and β is one of several Shvab-Zel'dovich coupling parameters which can then be shown to be a conserved scalar. The subscripts 1,2 or F,A represent the inlet streams, 1 and 2, or Fuel and Air, respectively. Application of the particular Beta function,

$$\beta = Y_F - \frac{Y_O}{r}, \quad \text{where} \quad \frac{1}{r} = \left(\frac{\mathrm{F}}{\mathrm{O}}\right)_{ST},$$

into the equation for mixture fraction yields the following correlation between mixture fraction and the mass fractions of fuel, CH_4, and oxidizer, O_2.

$$\xi = \frac{\left(\mathrm{Y_F} - \left(\frac{\mathrm{F}}{\mathrm{O}}\right)_{ST} \mathrm{Y_O}\right) - \left(\mathrm{Y_F} - \left(\frac{\mathrm{F}}{\mathrm{O}}\right)_{ST} \mathrm{Y_O}\right)_{\mathrm{A}}}{\left(\mathrm{Y_F} - \left(\frac{\mathrm{F}}{\mathrm{O}}\right)_{ST} \mathrm{Y_O}\right)_{\mathrm{F}} - \left(\mathrm{Y_F} - \left(\frac{\mathrm{F}}{\mathrm{O}}\right)_{ST} \mathrm{Y_O}\right)_{\mathrm{A}}}$$

Based on the equation for mixture fraction, the maximum value attainable for ξ is 1 where only fuel is present and the minimum value attainable is zero when only oxygen is present. For the specific case of methane, CH_4, combustion in air,

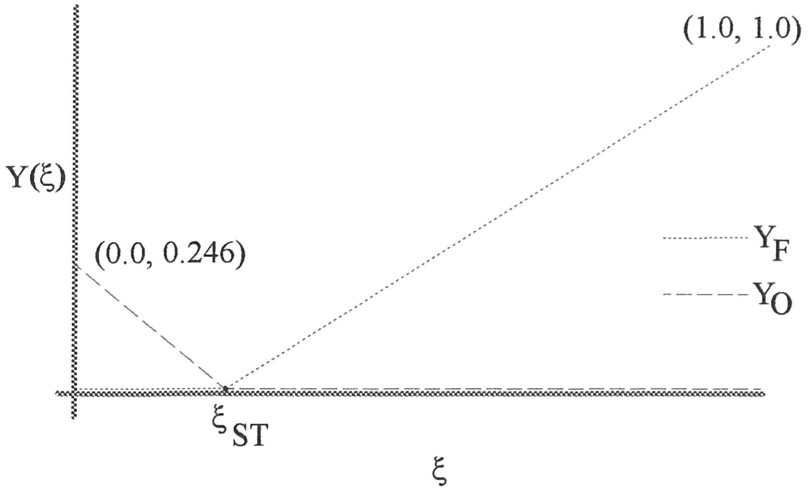
$$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2$$

we have:

- $(F/O)_{ST} = 0.25$ (Calculated on a mass basis)
- $(Y_F)_F = 1.0$
- $(Y_F)_A = 0.0$
- $(Y_O)_F = 0.0$
- $(Y_O)_A = 0.246$, (Air is 24.6% Oxygen by weight)

The resulting expression is graphically represented in Figure 2.1, Mass fraction vs. Mixture fraction. Note that the mass fractions of fuel and oxygen are never both positive quantities at any given value of the mixture fraction. When this occurs, the assumption of "fast chemistry" dictates that the combustion reaction instantaneously occur as well until either excess fuel or oxygen remains or until both reactants are expelled as is the case at the stoichiometric mixture fraction, $\xi_{ST} = 0.05482$.

Figure 2.1
Mass Fraction vs. Mixture Fraction



The equations governing this relationship are listed below.

For,	$\xi = \xi_{ST}$	$Y_F = 0$	$Y_O = 0$
	$\xi > \xi_{ST}$	$Y_F = 1.0615\xi - .0615$	$Y_O = 0$
	$\xi < \xi_{ST}$	$Y_F = 0$	$Y_O = -4.246\xi + 0.246$

With a mixture fraction determined for every point in the fluid flow, (Figure 4.2 in Appendix I), the next step is to use this value as the independent variable in an equation for temperature. Equations developed in <u>Introduction to Combustion Phenomena</u> by A. Murty Kanury relate the temperature of the flow field to the mixture fraction with two linear relationships illustrated on the following page.

For $\xi > \xi_{ST}$,

$$T = \xi\left((T_{FUEL_i} - T_{AIR_i}) - \frac{\xi_{ST}(Y_O)_O \Delta H}{C_p} \right) + \left(\frac{\xi_{ST}(Y_O)_O \Delta H}{C_p} + T_{AIR_i} \right)$$

For $\xi < \xi_{ST}$,

$$T = \xi\left(\left(T_{FUEL_i} - T_{AIR_i}\right) + \frac{\Delta H}{C_p} \right) + \left(T_{AIR_i}\right)$$

where

- $T_{FUELi} = T_{AIRi} = 298$ K
- H = 50100 KJ/(kg K)
- $C_p = 1.007$ KJ/(kg K)

Thus, for the laminar case, the equations solved include:

- Momentum
- Continuity
- Species Concentration for CH_4 and O_2

The following equations are then calculated from the solved values:

- Mixture Fraction
- Temperature as a function of mixture fraction
- Density via Ideal gas Law as a function of pressure and mixture fraction

Integration of this set of equations into the laminar diffusion case results in the temperature profile shown in Figure 4.4 of Appendix I. Theoretically, the maximum temperature in the flow field is along that portion of the flame where $\xi=\xi_{ST}$. Figure 4.5 of Appendix I illustrates the location of the stoichiometric mixture fraction on the bottom half of a cylindrical combustion chamber with inlets on the right side of the illustration vs the temperature profile as shown in the upper half of the cylindrical combustion chamber. Higher temperatures do appear to follow the streamline of stoichiometric mixture fraction although an increase in grid size will improve the resolution of the temperature profile.

To close the equation set for the laminar diffusion flame case, density is calculated from temperature as a function of mixture fraction, $T=T(\xi)$, to obtain the resulting contour shown in Figure 4.3 of Appendix I. If desired, enthalpy, since it is a conserved scalar, can be calculated from the mixture fraction as well.

Additional figures included in Appendix I that may be of interest to the reader include Figure 4.1 - Combustion Chamber Grid Scheme, Figure 4.2 - Mixture Fraction, Figure 4.3 - Density, Figure 4.4 - Temperature, Figure 4.5 - Temperature & ξ_{ST} Relationship, and Figure 4.6 - Axial Velocity. The input file to Phoenics 1.6 is included in Appendix II under LDF_46, and the list of numerical results is included in Appendix II under RSLT_46.

TURBULENT FLAME ANALYSIS

Where in the laminar diffusion flame case the mixture fraction, ξ, is determined from the mass fraction, in the turbulent case the mean and average fluctuation of the mixture fraction is determined by integration of partial differential equations similar to those for coninuity and momentum. Then, through application of an assumed probability density function, the mass fraction, temperature, enthalpy and other conserved scalars are computed as functions of the mixture fraction.

The flow in practical combustion systems is invariably turbulent, and the temporal and spatial variations in the dependent variables encompass such a wide range of time and length scales as to preclude the direct numerical simulation of the governing simulations (Jones & Whitelaw, 1982). It is impracticable - now or in the future - to use direct numerical simulation to calculate the flow within practical combustion devices. PDF, probability density function, methods appear to be the best approach available since they completely overcome the closure problem associated with nonlinear reaction rates (Pope, 1990). Previous studies (Jones and Whitelaw, 1984) have established that the "mixed-is-burned" model (equilibrium chemistry) along with the $\kappa-\varepsilon$ eddy viscosity turbulence model and an assumed shape pdf/moment equations for scalar fluctuations, are computationally tractable in complex flows (Correa & Shyy, 1987).

With minor modifications, the conservation equations presented in the section on theory are still applicable to the case of turbulent chemically reactive flows. Dependent variables are decomposed into mean and fluctuating components, and the resulting equations averaged to convert them into statistical equations describing the evolution of mean quantities (Jones & Whitelaw, 1982). Additionally, since the Reynolds number is high for turbulent flows, turbulent transport via inertial effects is dominant over molecular diffusion effects. For this reason, molecular transport terms are dropped from the conservation equations. With density-weighted averaging, the equations of continuity and conservation of momentum for a high Reynold's number are expressed as follows:

Continuity

$$\frac{\partial}{\partial x_i}\left(\overline{\rho}\tilde{U}_i\right) = 0$$

Momentum

$$\frac{\partial}{\partial x_i}\left(\overline{\rho}\tilde{U}_i\tilde{U}_j\right) = \overline{\rho}g_i - \frac{\partial \overline{P}}{\partial x_i} - \frac{\partial}{\partial x_j}\left(\overline{\rho}\widetilde{u_i''u_j''}\right)$$

A difficulty arises in turbulent flow calculations on how to solve for the Reynolds stress tensor, the last term in the momentum equation, due to the need to take the average of two fluctuations multiplied together. The common approach to this problem is a form of the two-equation model introduced by Jones and Launder (1972) that involves an assumed linear relation between the Reynolds stress tensor and the rate of strain (Jones & Whitelaw, 1982):

$$\overline{\rho}\widetilde{u_i''u_j''} = \tfrac{2}{3}\delta_{ij}\left\{\overline{\rho}\kappa + \mu_t\frac{\partial \tilde{U}_k}{\partial x_k}\right\} - \mu_t\left(\frac{\partial \tilde{U}_i}{\partial x_j} + \frac{\partial \tilde{U}_j}{\partial x_i}\right)$$

The turbulent or eddy viscosity, μ_t, is given by

$$\mu_t = C_\mu \bar{\rho} \kappa^2 / \varepsilon$$

The terms κ and ε are the turbulence kinetic energy and the turbulence dissipation rate respectively, and can be obtained by solving the transport equations listed below.

$$\bar{\rho}\tilde{U}_j \frac{\partial \kappa}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left(\frac{\mu_t}{\sigma_\kappa} + \mu\right)\frac{\partial \kappa}{\partial x_j}\right\} - \bar{\rho}\widetilde{u_i'' u_j''}\frac{\partial \tilde{U}_i}{\partial x_j} - \frac{\mu_t}{\bar{\rho}^2}\frac{\partial \bar{\rho}}{\partial x_i}\frac{\partial \bar{\rho}}{\partial x_i} - \bar{\rho}\varepsilon$$

$$\bar{\rho}\tilde{U}_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left(\frac{\mu_t}{\sigma_\varepsilon} + \mu\right)\frac{\partial \varepsilon}{\partial x_j}\right\} - C_1 \frac{\varepsilon}{\kappa}\left[\bar{\rho}\widetilde{u_i'' u_j''}\frac{\partial \tilde{U}_i}{\partial x_j} + \frac{\mu_t}{\bar{\rho}^2}\frac{\partial \bar{\rho}}{\partial x_i}\frac{\partial \bar{\rho}}{\partial x_i}\right] - C_2 \bar{\rho}\frac{\varepsilon^2}{\kappa}$$

The above equations are known as the κ-ε Model for Reynolds stress. The assumptions involved in this model are discussed in Jones & Launder (1972) and Jones & McGuirk (1980). The constants in these equations are taken as (Launder and Spalding, 1974):

$C_\mu = 0.09$ $C_1 = 1.44$ $C_2 = 1.92$

$\sigma_\kappa = 1.0$ $\sigma_\varepsilon = 1.30$

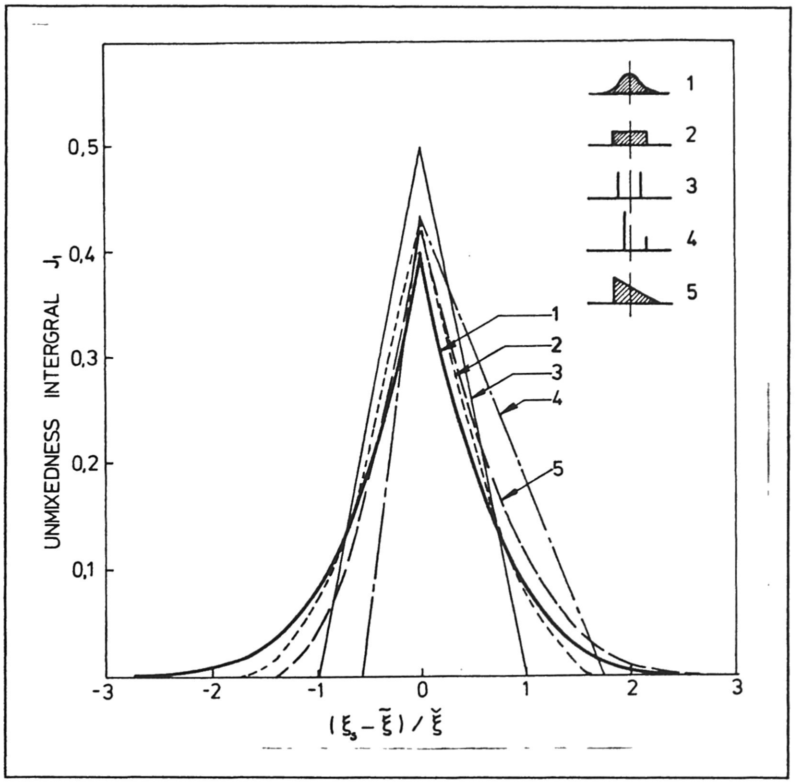
With the κ-ε Model equations and the revised continuity and momentum equations presented, the next equations in the overall set of relations necessary to model the turbulent chemically reactive flow are for the mean and fluctuating values of the mixture fraction. From these, an assumed probability density function relates the mixture fraction to any conserved scalar, i.e. enthalpy and mass fraction, and closes the set of equations. Because of the strong linearity of these relations it is necessary to take account of the fluctuations in mixture fraction which arise in all turbulent diffusion flames (Jones & Whitelaw, 1982). The most convenient way of achieving this is via the introduction of the probability density function, $\mathcal{P}(\xi; x_i)$, in terms of the mean and variance of the mixture fraction. With Favre averaging, these values are obtained by solving the equations listed below.

$$\bar{\rho}\tilde{U}_j \frac{\partial \tilde{\xi}}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\frac{\mu_t}{\sigma_t}\frac{\partial \tilde{\xi}}{\partial x_j}\right\}$$

$$\bar{\rho}\tilde{U}_j \frac{\partial \tilde{\xi''^2}}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\frac{\mu_t}{\sigma_t}\frac{\partial \tilde{\xi''^2}}{\partial x_j}\right\} + 2\frac{\mu_t}{\sigma_t}\left(\frac{\partial \tilde{\xi}}{\partial x_j}\right)^2 - C_D \frac{\bar{\rho}\varepsilon}{\kappa}\tilde{\xi''^2} \quad \text{where } C_D = 2$$

Several different forms of the probability density function shape are now possible to relate the mean and variance terms of the mixture fraction to a conserved scalar. Figure 3.1 presents examples of the unmixedness integral for assumed different probability density function forms of the mixture fraction such as (1) Gaussian, (2) conditionally uniform, (3) symmetrical bivariate, (4) unsymmetrical bivariate, and (5) conditionally triangular. In actuality, the probability density function for a conserved scalar is

Figure 3.1 (Bilger, 1980)

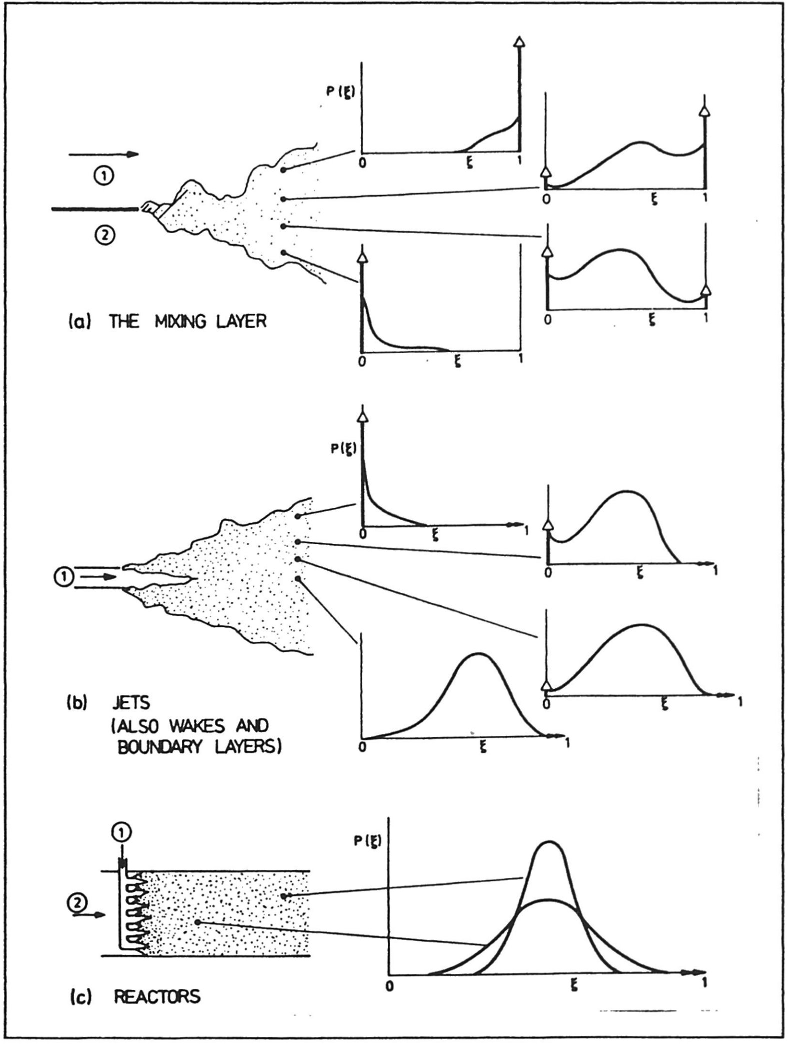


different for individual points in a particular fluid flow as shown in Figure 3.2. For the purpose of this research, the Gaussian probability function is chosen based on the equation:

$$\mathcal{P}(\xi;x_i)=\frac{1}{2\pi\xi'}\exp\left[\frac{-(\xi-\tilde{\xi})}{2\xi'^2}\right]$$

Interestingly, the form of the probability density function is found to have little effect on the velocity and conserved scalar mean fields but is more significant in determining mean temperatures and molecular species compositions (Kent & Bilger, 1982). Regardless of

Figure 3.2
Probability Density Function Forms for a
Conserved Scalar in Various Type of Flow (Bilger, 1980)



the form, the probability density function now constructed is a density weighted function that allows for the evaluation of both density-weighted and time average mean values of a conserved scalar.

Density weighted:

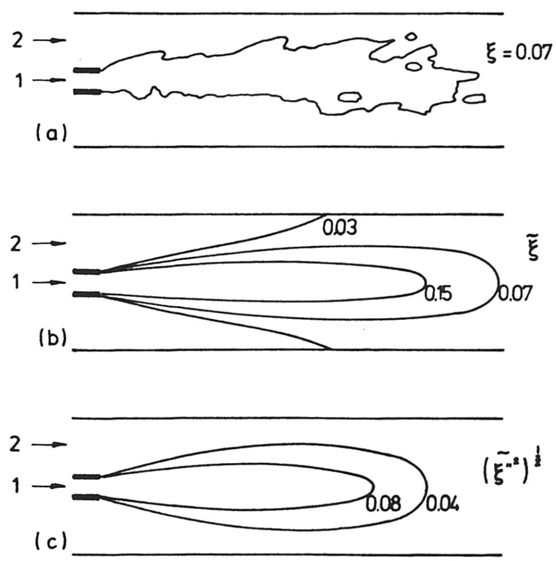
$$\tilde{\phi} = \int_0^1 \phi(\xi)\mathcal{P}(\xi; x_i)d\xi$$

Time Averaged:

$$\bar{\phi} = \bar{\rho}\int_0^1 \frac{\phi(\xi)}{\rho(\xi)} \mathcal{P}(\xi ; x_i) d\xi$$

Solutions for enthalpy and mass fraction of CH_4 and O_2 using the above equations and hence calculation of the temperature and density fields obtains closure for the equation set of the turbulent chemically reactive flow case. Research is underway to complete the implementation of this approach into Phoenics 1.6. Predicted results for the contours of the conserved scalars of the system are shown in Figure 3.3.

Figure 3.3 (Bilger, 1980)



Mixing patterns in a typical turbulent reacting flow with nonpremixed reactants entering with feeds 1 and 2. **(a)** Instantaneous isopleth for a conserved scalar ξ; **(b)** isopleths for the Favre average of ξ; **(c)** contours of root mean square fluctuation of ξ

An abundance of research opportunities exist in the further study of turbulent chemically reactive flows. The use of joint probability density functions, a probability density function of two or more variables, for turbulent modeling is another method which may further simplify flow calculations. A velocity-composition joint probability density function approach), has been successfully applied to premixed flames that exhibit counter-gradient diffusion (Anand & Pope, 1987) and to the early stages of development of a turbulent flame from a spark kernel (Pope & Cheng, 1988). In addition, the use of the velocity-composition joint probability density function almost removes the need for a turbulence model (Pope, 1990). Additional research possibilities lie in the method of obtaining the joint probability density function from its transport equation rather than assuming a certain shape or form (Jones & Whitelaw, 1982). However, because of the complex nature of probability density function transport equation models, solutions have been obtained only for a few simple flows.

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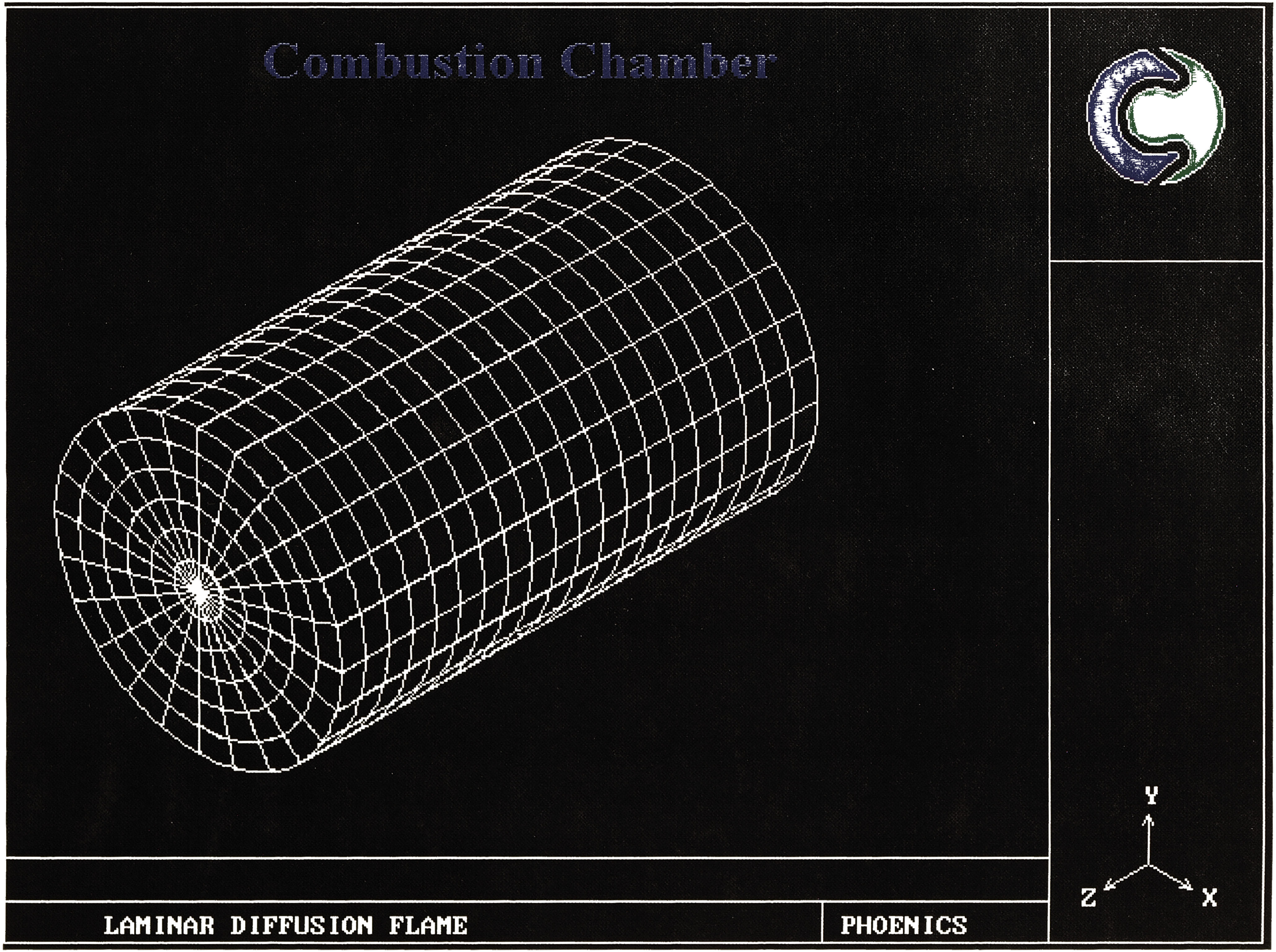
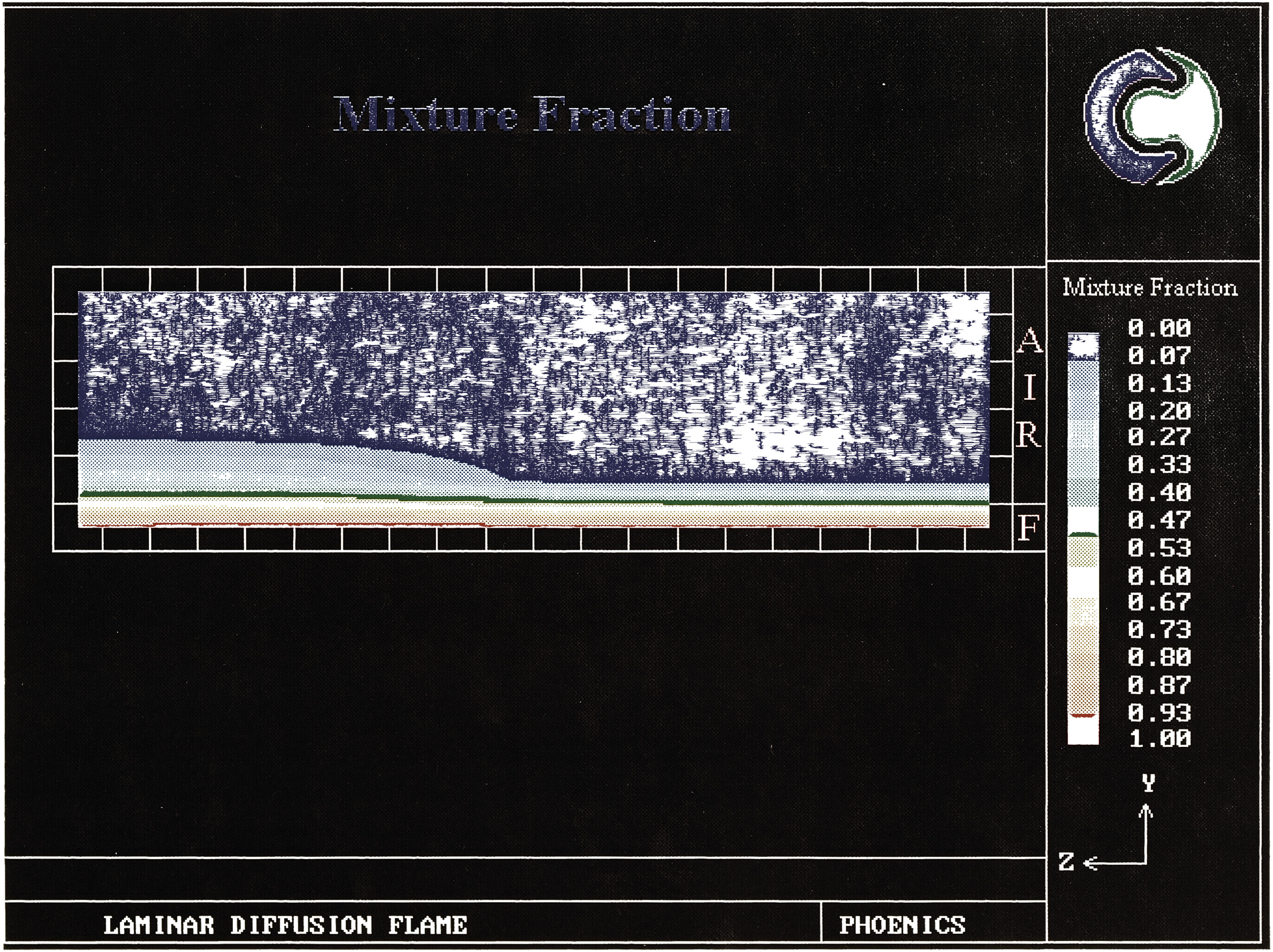
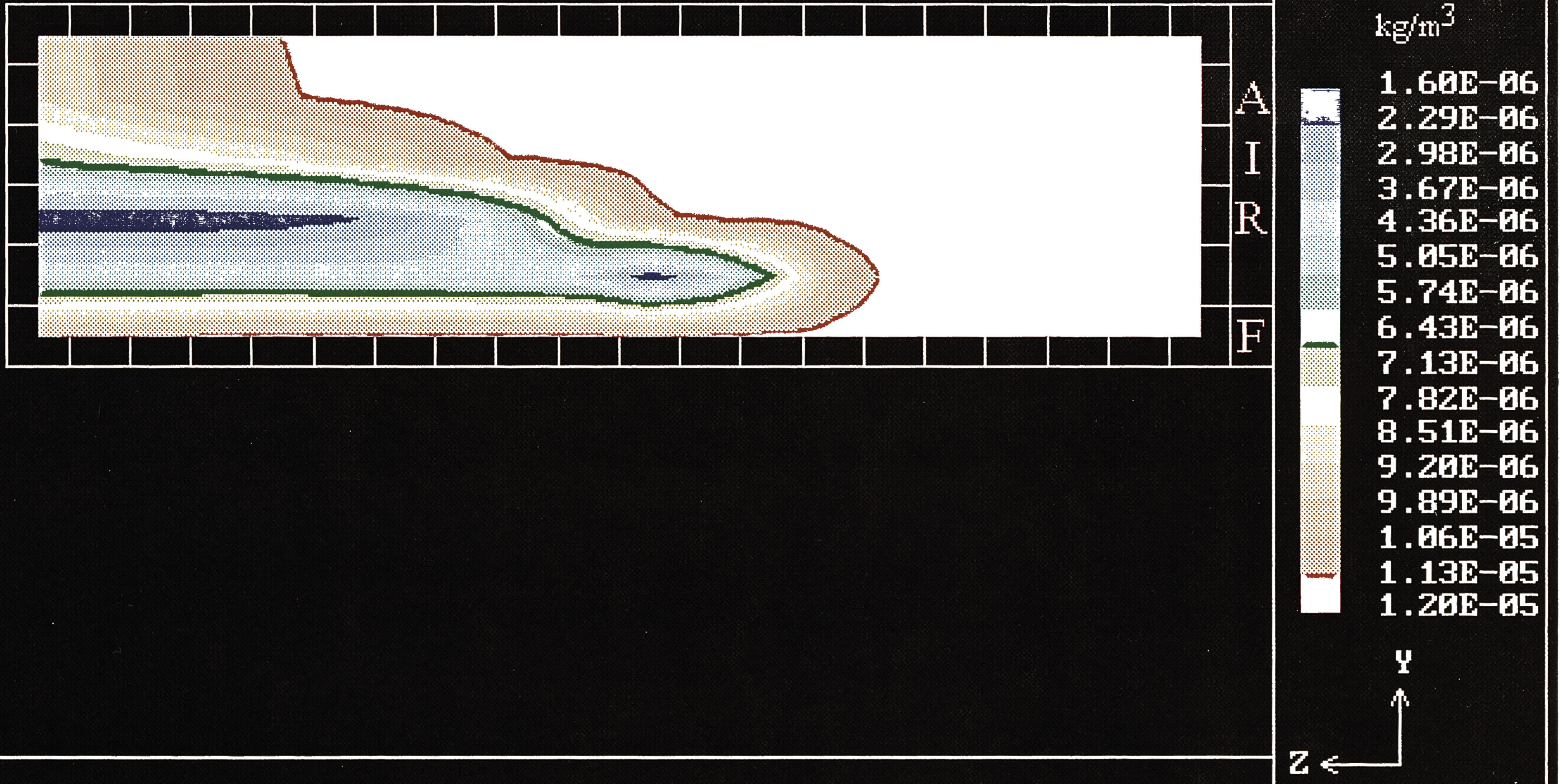
APPENDIX I - FIGURES

Combustion Chamber



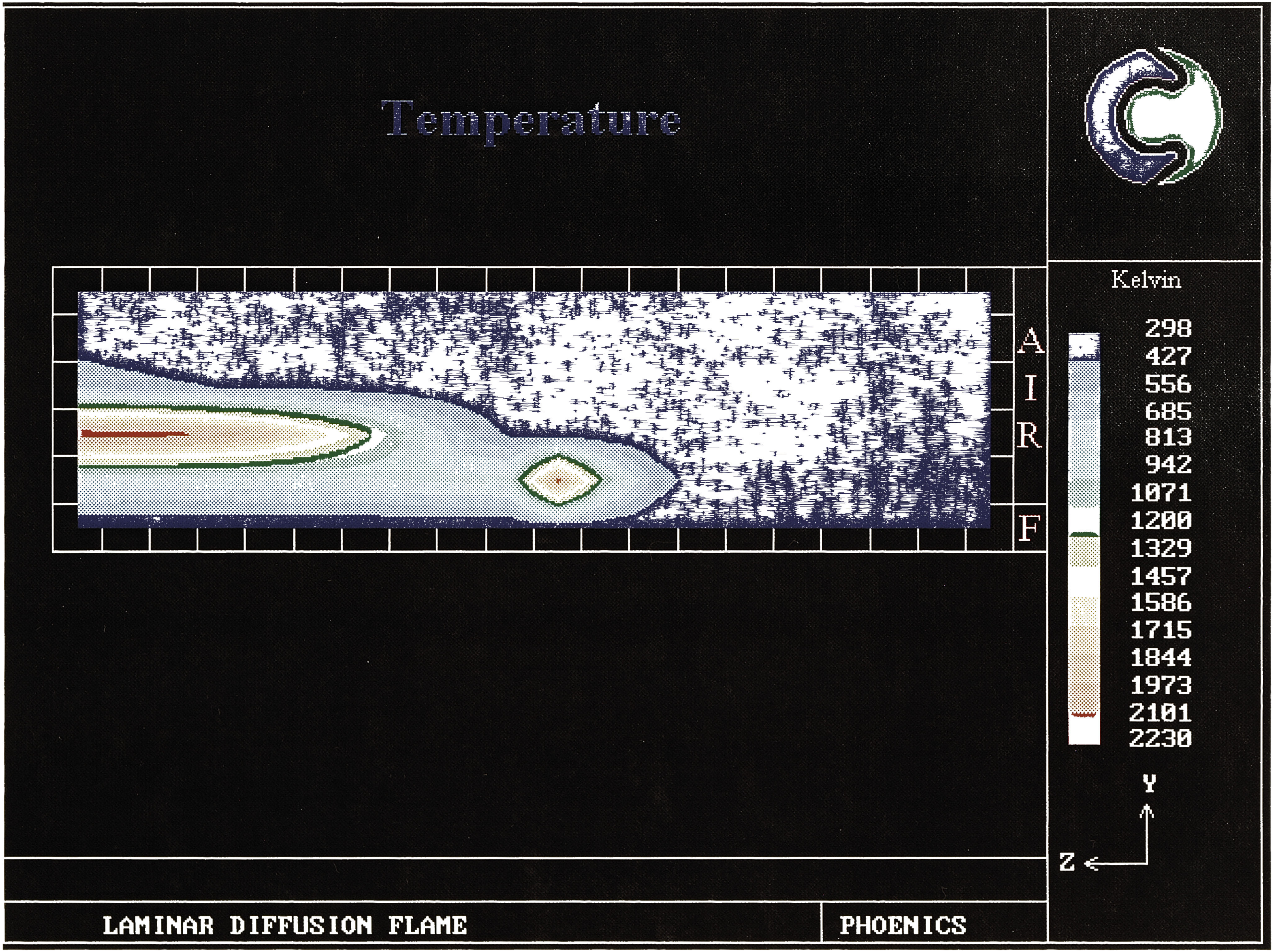

Mixture Fraction
A
I
R
F
Mixture Fraction
0.00
0.07
0.13
0.20
0.27
0.33
0.40
0.47
0.53
0.60
0.67
0.73
0.80
0.87
0.93
1.00
Y
Z
LAMINAR DIFFUSION FLAME
PHOENICS

Density



LAMINAR DIFFUSION FLAME

PHOENICS

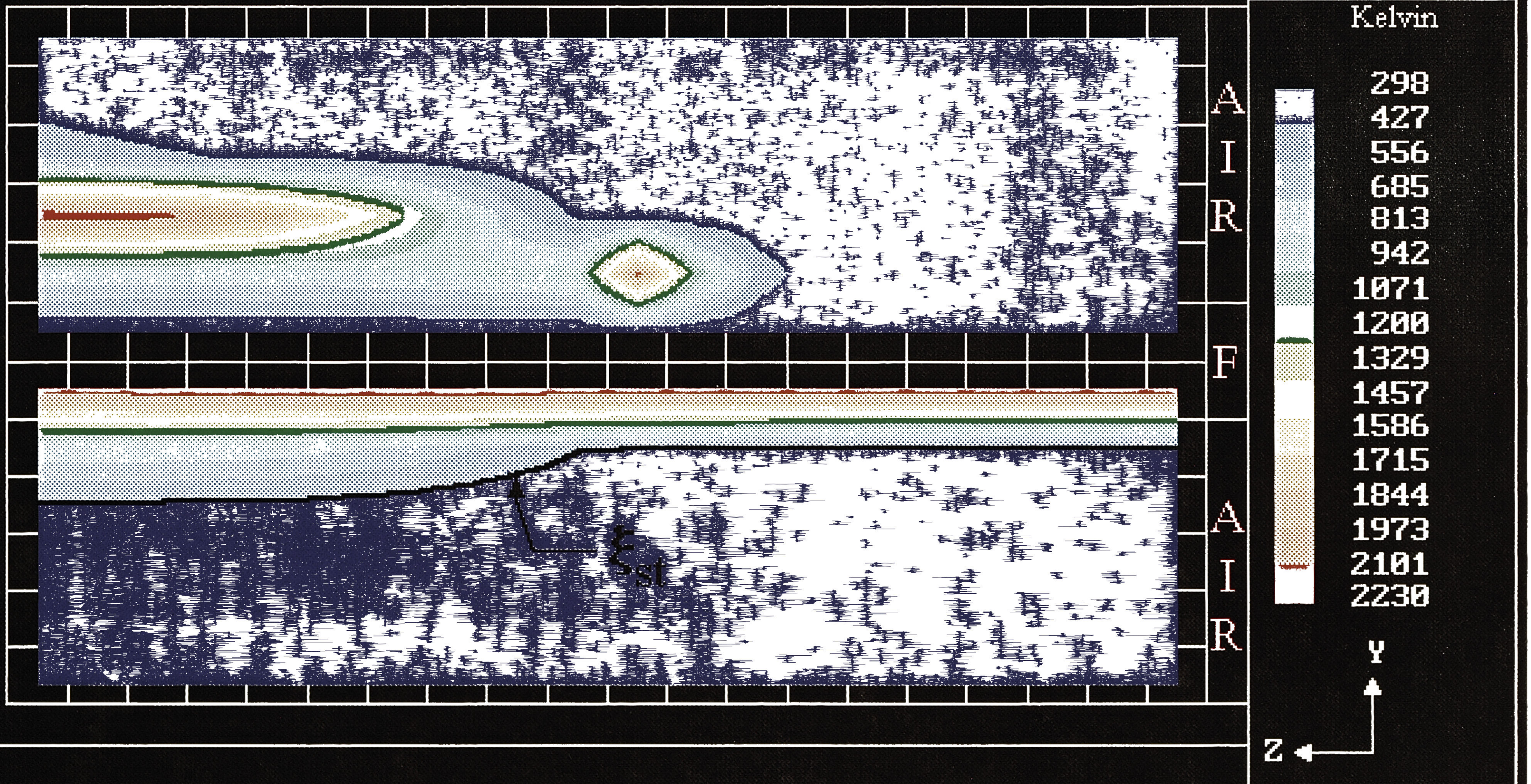


Temperature

LAMINAR DIFFUSION FLAME

PHOENICS

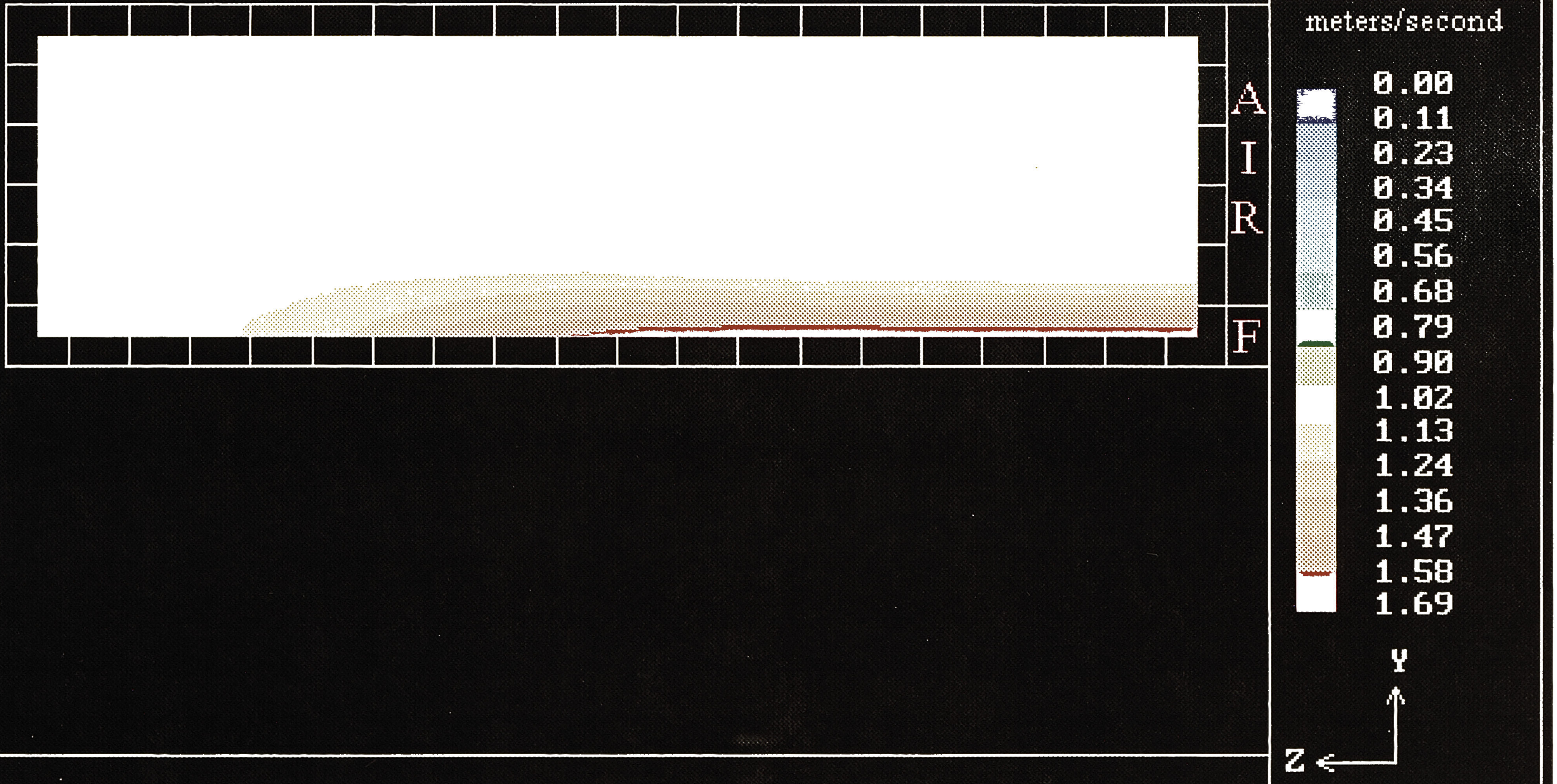
Temperature & ξ_{st} Relationship



LAMINAR DIFFUSION FLAME

PHOENICS

Axial Inlet Velocities



LAMINAR DIFFUSION FLAME

PHOENICS

APPENDIX II - FORTRAN CODING

LDF_46

```
TALK=F;RUN( 1, 1);VDU=VGACURSR
NOCOPY=T;NOCOMM=T
  *
  ************************************************************
  *
  * GROUP 1.  Run identifiers and other preliminaries.
  *
TEXT(LAMINAR DIFFUSION FLAME)

  ** Declarations
REAL(FST,YFF,YFO,YOF,YOO,HR,CP,TFUEL,TAIR,MIXFST)
REAL(A,B1,B2,COEF1,COEF2,COEF3,COEF4)

  ** MIXTURE FRACTION COEFFICIENTS
  * Yf = CH4   Yo = AIR (Oxygen in Air Stream 24.6%)
FST=0.25;YFF=1.0;YFO=0.0;YOF=0.0;YOO=0.246
A=(-1.0*(YFO-FST*YOO))/((YFF-FST*YOF)-(YFO-FST*YOO))
B1=(1.0)/((YFF-FST*YOF)-(YFO-FST*YOO))
B2=(-1.0*FST)/((YFF-FST*YOF)-(YFO-FST*YOO))
  ** MIXF=B1*CH4 + B2*AIR + A ---- FUNCTION 10


  ** TEMPERATURE FROM MIXTURE FRACTION
  ** EQS 7.63 & 7.64 OF KANURY "INTRO. TO COMBUSTION PHENOM."
HR=50100000;CP=1007;TFUEL=298;TAIR=298;MIXFST=.05482
COEF1=TFUEL-TAIR-YOO*MIXFST*HR/CP
COEF2=TAIR+YOO*MIXFST*HR/CP
COEF3=TFUEL-TAIR+HR/CP
COEF4=TAIR

  ** RICH CASE
  ** 7.63 MIXF>MIXFST  --> TMP1 = COEF1 * MIXF + COEF2

  ** LEAN CASE
  ** 7.64 MIXF<MIXFST  --> TMP1 = COEF3 * MIXF + COEF4


  ** Density from Ideal Gas Law
  ** GCON1 = Gas Constant (J/kg K)
REAL(GCON1);GCON1=2.8710E+02
  ** RHO1 = P1 / (GCON1 * TMP1) ---- FUNCTION 15


  * Elliptic Simulation
PARAB=F
  *
  ************************************************************
  *
  * GROUP 2.  Time-dependence and related parameters.
  *
  * Steady-state simulation
```

```
STEADY=T
  *
  *********************************************************
  *
  * GROUP 3.  x-direction grid specification.
  *
  * Polar grid selected
CARTES=F
  * Write objects
RSET(D,CHAM,6.2830E+00,6,20,1,0)
RSET(B,INLTA,0,0,0,6.2800E+00,1,0,1,0)
RSET(B,INLTB,0,1,0,6.2830E+00,5,0,1,0)
RSET(B,WALL,0,6,0,6.2830E+00,0,20,1,0)
RSET(B,OUTLT,0,0,20,6.2830E+00,6,0,1,0)
  *
  * Total number of REGIONS in X direction 1
  * Total number of cells in X direction 24
  * Total length in X direction   6.2800E+00 RAD
  *
NREGX=1;REGEXT(X,1)
IREGX=1;GRDPWR(X,24,6.2800E+00,1)
  *
  *********************************************************
  *
  * GROUP 4.  y-direction grid specification.
  *
  *
  * Total number of REGIONS in Y direction 2
  * Total number of cells in Y direction 6
  * Total length in Y direction   6 m
  *
NREGY=2;REGEXT(Y,1)
IREGY=1;GRDPWR(Y,1,1,1)
IREGY=2;GRDPWR(Y,5,5,1)
  *
  *********************************************************
  *
  * GROUP 5.  z-direction grid specification.
  *
  *
  * Total number of REGIONS in Z direction 1
  * Total number of cells in Z direction 20
  * Total length in Z direction   20 m
  *
NREGZ=1;REGEXT(Z,1)
IREGZ=1;GRDPWR(Z,20,20,1)
  *
  *********************************************************
  *
  * GROUP 6.  Body-fitting and other grid distortions.
  *
  *
  *********************************************************
  *
```

```
  * GROUP 7.  Variables (including porosities) named,
  *           stored & solved.
  *
NAME(C1)=CH4
NAME(C2)=AIR
NAME(C3)=MIXF
NAME(C4)=TMP1
NAME(C5)=RHO1
  * Solve for U1 (the VELOCITY_IN_THE_X_DIRECTION)
SOLVE(U1)
  * Solve for V1 (the VELOCITY_IN_THE_Y_DIRECTION)
SOLVE(V1)
  * Solve for W1 (the VELOCITY_IN_THE_Z_DIRECTION)
SOLVE(W1)
  * Solve for P1 by whole-field method
  * The PRESSURE
SOLVE(P1)
SOLUTN(P1,Y,Y,Y,N,N,N)
  * Solve for CH4 (the CONCENTRATION/U-N_CH4)
SOLVE(CH4)
  * Solve for AIR (the CONCENTRATION/U-N_AIR)
SOLVE(AIR)
  * Mixture Fraction from CH4 & AIR concentrations
STORE(MIXF)
  * Temperature as derived from mixture fraction, MIXF
STORE(TMP1)
  * Density from Ideal Gas Law
STORE(RHO1)
  ************************************************************
  *
  * GROUP 8.  Terms (in differential equations) and devices.
  *
  *
  ************************************************************
  *
  * GROUP 9.  Properties of the medium (or media).
  *
  * Reference pressure (N/m^2)
PRESS0=1.0000E+05
  * CONSTANT density formulation
  * Density (kg/m^3)
REAL(RREF1)
  * RHO1=1.1610E+00;RREF1=RHO1
RREF1=RHO1
  * Initial Values
FIINIT(RHO1)=1.1610E+00
PRNDTL(CH4)=1
PRNDTL(AIR)=1
  * Laminar kinematic viscosity (m^2/s)
ENUL=1.5890E-05
  * Turbulence treatment LAMINAR
  * Turbulent kinematic viscosity (m^2/s)
ENUT=0
  *
```

```
 *********************************************************
 *
 * GROUP 10. Interphase-transfer processes and properties.
 *
 *
 *********************************************************
 *
 * GROUP 11. Initialization of fields of variables,
 *           porosities, etc.
 *
 *
 *********************************************************
 *
 * GROUP 12. Convection and diffusion adjustments
 *
 *
 *********************************************************
 *
 * GROUP 13. Boundary conditions and special sources
 *
  * INLET boundary condition, name INLTA (CH4 INLET)
INLET(INLTA,LOW,#1,#1,#1,#1,#1,#1,#1,#NREGT)
VALUE(INLTA,U1,0)
VALUE(INLTA,V1,0)
VALUE(INLTA,W1,1.6900E+00)
VALUE(INLTA,P1,1.6900E+00*RREF1)
VALUE(INLTA,CH4,YFF)
VALUE(INLTA,AIR,YOF)
  * INLET boundary condition, name INLTB (AIR INLET)
INLET(INLTB,LOW,#1,#1,#2,#2,#1,#1,#1,#NREGT)
VALUE(INLTB,U1,0)
VALUE(INLTB,V1,0)
VALUE(INLTB,W1,1)
VALUE(INLTB,P1,1*RREF1)
VALUE(INLTB,CH4,YFO)
VALUE(INLTB,AIR,YOO)
  * OUTLET boundary condition, name OUTLT
OUTLET(OUTLT,HIGH,#1,#1,#1,#2,#1,#1,#1,#NREGT)
VALUE(OUTLT,U1,SAME)
VALUE(OUTLT,V1,SAME)
VALUE(OUTLT,W1,SAME)
VALUE(OUTLT,P1,0)
VALUE(OUTLT,CH4,SAME)
VALUE(OUTLT,AIR,SAME)
COVAL(OUTLT,P1,FIXP,0)
  * WALL boundary condition, name WALL
PATCH(WALL,NWALL,#1,#1,#2,#2,#1,#1,#1,#NREGT)
COVAL(WALL,U1,GRND2,0.0)
COVAL(WALL,W1,GRND2,0.0)
  *
  *********************************************************
  *
  * GROUP 14. Downstream pressure (for free parabolic flow).
  *
```

```
  *
  ************************************************************
  *
  * GROUP 15. Termination criteria for sweeps and
  *           outer iterations.
  *
  * Number of sweeps
LSWEEP=35
  *
  ************************************************************
  *
  * GROUP 16. Termination criteria for inner iterations.
  *
SELREF=T; RESFAC=1.0000E-03
  *
  ************************************************************
  *
  * GROUP 17. Under-relaxation and related devices.
  *
  * Variable declarations
REAL(MAXV,MINL,RELX)
  * Estimate of the maximum velocity within domain
MAXV=1.7500E+00
  * Estimate of the minimum cell dimension
MINL=7.8500E-01
  * Level of relaxation (100 - weak, 0.1 - strong)
RELX=1
  * AUTO Linear relaxation applied to P1
RELAX(P1,LINRLX,0.8)
  * AUTO False time-step relaxation applied to U1
RELAX(U1,FALSDT,MINL/MAXV*RELX)
  * AUTO False time-step relaxation applied to V1
RELAX(V1,FALSDT,MINL/MAXV*RELX)
  * AUTO False time-step relaxation applied to W1
RELAX(W1,FALSDT,MINL/MAXV*RELX)
  * AUTO Linear relaxation applied to CH4
RELAX(CH4,LINRLX,0.5)
  * AUTO Linear relaxation applied to AIR
RELAX(AIR,LINRLX,0.5)
  *
  ************************************************************
  *
  * GROUP 18. Limits on variables values or increments
  *           to them.
  *
  *
  ************************************************************
  *
  * GROUP 19. Data communicated by SATELLITE to GROUND
  *
  ** IG(1)=3 ACTIVATES THE ADDITIONAL CODING IN GROUND.FOR
  ** IN GROUP 19 SECTION 6 UNDER (HEREWEGO)
 IG(1)=3
  *
```

```
  ** REAL NUMBER COEFFICIENTS MUST BE ASSIGNED TO TRANSFER
  ** THESE VALUES FROM SATELLITE TO GROUND
  *  MIXF CODING USES RSG1-3
  *  TMP1 CODING USES RSG4-8
  *  RHO1 CODING USES RSG9-10
RSG1=A;RSG2=B1;RSG3=B2
RSG4=COEF1;RSG5=COEF2;RSG6=COEF3;RSG7=COEF4;RSG8=MIXFST
RSG9=1/GCON1;RSG10=0.0
  *
  *
  *******************************************************
  *
  * GROUP 20. Control of preliminary printout
  *
  *
  *******************************************************
  *
  * GROUP 21. Frequency and extent of field printout.
  *
  *
  *******************************************************
  *
  * GROUP 22. Location of spot-value & frequency of
  *          residual printout.
  *
  * Set frequency of spot-values/residuals print-outs
TSTSWP=12345
  *
  *******************************************************
  *
  * GROUP 23. Variable-by-variable field printout and plot
  *          and/or tabulation of spot-values and residuals.
  *
  * Control tabulation & plotting of spot-values/residuals
  * Tables and plots
ITABL=3
  * Set the frequency of tabulation and plotting
NPLT=1
  *
  *******************************************************
  *
  * GROUP 24. Preparation for continuation runs.
  *
  *
  *******************************************************
STOP
```

Additional GROUND.FOR Coding required for implementation:

```
196 CONTINUE
```

```
C  * ------------------- SECTION 6 ---- Finish of iz slab.
C  * Herewego

   if(ig(1).EQ.3) then

C  * C3=MIXF, C1=CH4, C2=AIR, RSG1=A, RSG2=B1, RSG3=B2
   CALL FN10(C3,C1,C2,RSG1,RSG2,RSG3)

C  * C4=TMP1, C3=MIXF, RSG5=COEF2, RSG4=COEF1
C  * RSG7=COEF4, RSG6=COEF3, RSG8=MIXF=.05482
   DO 1960 IX=1,NX
    DO 1960 IY=1,NY
     IF(VARYX(C3).LE.RSG8) THEN
      F(INDYX(C4))=RSG6*VARYX(C3)+RSG7
     ELSE
      F(INDYX(C4))=RSG4*VARYX(C3)+RSG5
     ENDIF
1960 CONTINUE


C  * C5=RHO1, P1=PRESSURE, C4=TMP1, RSG10=0.0, RSG9=1/GCON1
   CALL FN15(C5,P1,C4,RSG10,RSG9)

   endif
   RETURN
```

RSLT_46

```
*********************************************************


 --------------------------------------------------------
     CCCC HHH       PHOENICS - EARTH    Version 1.6.6
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 CCCCCCC HHHHHHHHHHHHH  Wimbledon, London, SW19 5AU
  CCCCCCC HHHHHHHHHH  Tel: 081-947-7651
   CCCCCCCC HHHHH      Facsimile: 081-879-3497
     CCCC HHH       The option level is   -18
 --------------------------------------------------------
This program forms part of the PHOENICS installation for:
         PC 386/486 Installation
 --------------------------------------------------------
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 --------------------------------------------------------
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specifically authorised in writing by
Concentration, Heat, and Momentum Ltd.
 --------------------------------------------------------

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

Number of F-array location available is          300000
Number used before BFC allowance (if any) is       92692
*********************************************************
 Group 1. Run Title and Number
*********************************************************
*********************************************************

TEXT(LAMINAR DIFFUSION FLAME                )

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

IRUNN   =        1 ;LIBREF =        0
*********************************************************
 Group 2. Transience
STEADY  =    T
*********************************************************
 Group 3. X-Direction Grid Spacing
CARTES  =    F
NX      =      24
XULAST  = 6.280E+00
XFRAC (  1) =  4.167E-02 ;XFRAC (  2) =  8.333E-02
XFRAC (  3) =  1.250E-01 ;XFRAC (  4) =  1.667E-01
```

```
XFRAC (  5) =  2.083E-01 ;XFRAC (  6) =  2.500E-01
XFRAC (  7) =  2.917E-01 ;XFRAC (  8) =  3.333E-01
XFRAC (  9) =  3.750E-01 ;XFRAC ( 10) =  4.167E-01
XFRAC ( 11) =  4.583E-01 ;XFRAC ( 12) =  5.000E-01
XFRAC ( 13) =  5.417E-01 ;XFRAC ( 14) =  5.833E-01
XFRAC ( 15) =  6.250E-01 ;XFRAC ( 16) =  6.667E-01
XFRAC ( 17) =  7.083E-01 ;XFRAC ( 18) =  7.500E-01
XFRAC ( 19) =  7.917E-01 ;XFRAC ( 20) =  8.333E-01
XFRAC ( 21) =  8.750E-01 ;XFRAC ( 22) =  9.167E-01
XFRAC ( 23) =  9.583E-01 ;XFRAC ( 24) =  1.000E+00
*********************************************************
 Group 4. Y-Direction Grid Spacing
NY     =      6
YVLAST  = 6.000E+00
YFRAC (  1) =  1.667E-01 ;YFRAC (  2) =  3.333E-01
YFRAC (  3) =  5.000E-01 ;YFRAC (  4) =  6.667E-01
YFRAC (  5) =  8.333E-01 ;YFRAC (  6) =  1.000E+00
*********************************************************
 Group 5. Z-Direction Grid Spacing
PARAB   =    F
NZ     =     20
ZWLAST  = 2.000E+01
ZFRAC (  1) =  5.000E-02 ;ZFRAC (  2) =  1.000E-01
ZFRAC (  3) =  1.500E-01 ;ZFRAC (  4) =  2.000E-01
ZFRAC (  5) =  2.500E-01 ;ZFRAC (  6) =  3.000E-01
ZFRAC (  7) =  3.500E-01 ;ZFRAC (  8) =  4.000E-01
ZFRAC (  9) =  4.500E-01 ;ZFRAC ( 10) =  5.000E-01
ZFRAC ( 11) =  5.500E-01 ;ZFRAC ( 12) =  6.000E-01
ZFRAC ( 13) =  6.500E-01 ;ZFRAC ( 14) =  7.000E-01
ZFRAC ( 15) =  7.500E-01 ;ZFRAC ( 16) =  8.000E-01
ZFRAC ( 17) =  8.500E-01 ;ZFRAC ( 18) =  9.000E-01
ZFRAC ( 19) =  9.500E-01 ;ZFRAC ( 20) =  1.000E+00
*********************************************************
 Group 6. Body-Fitted Coordinates
*********************************************************
 Group 7. Variables: STOREd,SOLVEd,NAMEd
ONEPHS  =    T
NAME( 1) =P1   ;NAME( 3) =U1
NAME( 5) =V1   ;NAME( 7) =W1
NAME(16) =CH4  ;NAME(17) =AIR
NAME(18) =MIXF ;NAME(19) =TMP1
NAME(20) =RHO1
SOLUTN(P1  ,Y,Y,Y,N,N,N)
SOLUTN(U1  ,Y,Y,N,Y,N,N)
SOLUTN(V1  ,Y,Y,N,Y,N,N)
SOLUTN(W1  ,Y,Y,N,Y,N,N)
SOLUTN(CH4 ,Y,Y,N,N,N,N)
SOLUTN(AIR ,Y,Y,N,N,N,N)
SOLUTN(MIXF,Y,N,N,N,N,N)
SOLUTN(TMP1,Y,N,N,N,N,N)
SOLUTN(RHO1,Y,N,N,N,N,N)
DEN1    =     20
TEMP1   =     19
*********************************************************
```

```
 Group 8. Terms & Devices
TERMS (P1  ,Y,Y,Y,N,Y,N)
TERMS (U1  ,Y,Y,Y,N,Y,N)
TERMS (V1  ,Y,Y,Y,N,Y,N)
TERMS (W1  ,Y,Y,Y,N,Y,N)
TERMS (CH4 ,N,Y,Y,N,Y,N)
TERMS (AIR ,N,Y,Y,N,Y,N)
DIFCUT  = 5.000E-01 ;ZDIFAC = 1.000E+00
GALA    =    F ;ADDDIF =    F ;BLOCKZ =    T
ISOLX   =    -1 ;ISOLY =    -1 ;ISOLZ =    -1
************************************************************
 Group 9. Properties
RHO1    = 1.000E+00 ;TMP1   = 0.000E+00 ;EL1    = 0.000E+00
TABS0   = 0.000E+00
ENUL    = 1.589E-05 ;ENUT   = 0.000E+00
PRNDTL(U1  ) =  1.000E+00 ;PRNDTL(V1  ) =  1.000E+00
PRNDTL(W1  ) =  1.000E+00 ;PRNDTL(CH4 ) =  1.000E+00
PRNDTL(AIR ) =  1.000E+00
PRT   (U1  ) =  1.000E+00 ;PRT   (V1  ) =  1.000E+00
PRT   (W1  ) =  1.000E+00 ;PRT   (CH4 ) =  1.000E+00
PRT   (AIR ) =  1.000E+00
************************************************************
 Group 10.Inter-Phase Transfer Processes
************************************************************
 Group 11.Initialise Var/Porosity Fields
FIINIT(P1  ) =  1.000E-10 ;FIINIT(U1  ) =  1.000E-10
FIINIT(V1  ) =  1.000E-10 ;FIINIT(W1  ) =  1.000E-10
FIINIT(CH4 ) =  1.000E-10 ;FIINIT(AIR ) =  1.000E-10
FIINIT(MIXF) =  1.000E-10 ;FIINIT(TMP1) =  1.000E-10
FIINIT(RHO1) =  1.161E+00
  No PATCHes yet used for this Group
INIADD  =    T
FSWEEP  =      1
NAMFI   =CHAM
************************************************************
 Group 13. Boundary & Special Sources

 PATCH(INLTA   ,LOW    ,   1,  24,   1,   1,   1,   1,   1,   1)
 COVAL(INLTA   ,P1   , FIXFLU     , 1.690E+00)
 COVAL(INLTA   ,U1   , 0.000E+00, 0.000E+00)
 COVAL(INLTA   ,V1   , 0.000E+00, 0.000E+00)
 COVAL(INLTA   ,W1   , 0.000E+00, 1.690E+00)
 COVAL(INLTA   ,CH4 , 0.000E+00, 1.000E+00)
 COVAL(INLTA   ,AIR , 0.000E+00, 0.000E+00)

 PATCH(INLTB   ,LOW    ,   1,  24,   2,   6,   1,   1,   1,   1)
 COVAL(INLTB   ,P1   , FIXFLU     , 1.000E+00)
 COVAL(INLTB   ,U1   , 0.000E+00, 0.000E+00)
 COVAL(INLTB   ,V1   , 0.000E+00, 0.000E+00)
 COVAL(INLTB   ,W1   , 0.000E+00, 1.000E+00)
 COVAL(INLTB   ,CH4 , 0.000E+00, 0.000E+00)
 COVAL(INLTB   ,AIR , 0.000E+00, 2.460E-01)

 PATCH(OUTLT   ,HIGH  ,   1,  24,   1,   6,  20,  20,   1,   1)
```

```
COVAL(OUTLT   ,P1  , 1.000E+00, 0.000E+00)
COVAL(OUTLT   ,U1  , 0.000E+00, SAME     )
COVAL(OUTLT   ,V1  , 0.000E+00, SAME     )
COVAL(OUTLT   ,W1  , 0.000E+00, SAME     )
COVAL(OUTLT   ,CH4 , 0.000E+00, SAME     )
COVAL(OUTLT   ,AIR , 0.000E+00, SAME     )

PATCH(WALL    ,NWALL ,   1,  24,   6,   6,   1,  20,   1,   1)
COVAL(WALL    ,U1  , GRND2    , 0.000E+00)
COVAL(WALL    ,W1  , GRND2    , 0.000E+00)
XCYCLE =   F
************************************************************
 Group 14. Downstream Pressure For PARAB
************************************************************
 Group 15. Terminate Sweeps
LSWEEP =      35 ;ISWC1  =       1
LITHYD =       1 ;LITFLX =       1 ;LITC   =       1 ;ITHC1  =       1
RESREF(P1  ) =  1.000E-08 ;RESREF(U1  ) =  1.000E-08
RESREF(V1  ) =  1.000E-08 ;RESREF(W1  ) =  1.000E-08
RESREF(CH4 ) =  1.000E-08 ;RESREF(AIR ) =  1.000E-08
************************************************************
 Group 16. Terminate Iterations
LITER (P1  ) =   20 ;LITER (U1  ) =    1
LITER (V1  ) =    1 ;LITER (W1  ) =    1
LITER (CH4 ) =   20 ;LITER (AIR ) =   20
ENDIT (P1  ) =  1.000E-08 ;ENDIT (U1  ) =  1.000E-08
ENDIT (V1  ) =  1.000E-08 ;ENDIT (W1  ) =  1.000E-08
ENDIT (CH4 ) =  1.000E-08 ;ENDIT (AIR ) =  1.000E-08
************************************************************
 Group 17. Relaxation
RELAX(P1  ,LINRLX, 8.000E-01)
RELAX(U1  ,FALSDT, 4.486E-01)
RELAX(V1  ,FALSDT, 4.486E-01)
RELAX(W1  ,FALSDT, 4.486E-01)
RELAX(CH4 ,LINRLX, 5.000E-01)
RELAX(AIR ,LINRLX, 5.000E-01)
RELAX(MIXF,LINRLX, 1.000E+00)
RELAX(TMP1,LINRLX, 1.000E+00)
RELAX(RHO1,LINRLX, 1.000E+00)
OVRRLX  = 0.000E+00
EXPERT  =    F  ;SELREF =    T  ;NNORSL =    F
RESFAC  = 1.000E-03
************************************************************
 Group 18. Limits
VARMAX(P1  ) = 1.000E+10 ;VARMIN(P1  ) =-1.000E+10
VARMAX(U1  ) = 1.000E+10 ;VARMIN(U1  ) =-1.000E+10
VARMAX(V1  ) = 1.000E+10 ;VARMIN(V1  ) =-1.000E+10
VARMAX(W1  ) = 1.000E+10 ;VARMIN(W1  ) =-1.000E+10
VARMAX(CH4 ) = 1.000E+10 ;VARMIN(CH4 ) =-1.000E+10
VARMAX(AIR ) = 1.000E+10 ;VARMIN(AIR ) =-1.000E+10
VARMAX(MIXF) = 1.000E+10 ;VARMIN(MIXF) =-1.000E+10
VARMAX(TMP1) = 1.000E+10 ;VARMIN(TMP1) =-1.000E+10
VARMAX(RHO1) = 1.000E+10 ;VARMIN(RHO1) =-1.000E+10
************************************************************
```

```
 Group 19. EARTH Calls To GROUND Station
USEGRD =   T ;USEGRX =   T
NAMGRD =NONE
RSG1   = 5.794E-02
RSG2   = 9.421E-01
RSG3   =-2.355E-01
RSG4   =-6.709E+02
RSG5   = 9.689E+02
RSG6   = 4.975E+04
RSG7   = 2.980E+02
RSG8   = 5.482E-02
RSG9   = 3.483E-03
IG( 1) =   3
************************************************************
 Group 20. Preliminary Printout
ECHO   =   T
************************************************************
 Group 21. Print-out of Variables
INIFLD =   F ;SUBWGR =   F
OUTPUT(P1  ,Y,N,N,Y,Y,Y)
OUTPUT(U1  ,Y,N,N,Y,Y,Y)
OUTPUT(V1  ,Y,N,N,Y,Y,Y)
OUTPUT(W1  ,Y,N,N,Y,Y,Y)
OUTPUT(CH4 ,Y,N,N,Y,Y,Y)
OUTPUT(AIR ,Y,N,N,Y,Y,Y)
OUTPUT(MIXF,Y,N,N,N,N,N)
OUTPUT(TMP1,Y,N,N,N,N,N)
OUTPUT(RHO1,Y,N,N,N,N,N)
************************************************************
 Group 22. Monitor Print-Out
IXMON  =      1 ;IYMON  =      1 ;IZMON  =      1
NPRMON =  10000 ;NPRMNT =  10000 ;TSTSWP =  12345
UWATCH =   F ;USTEER =   F
HIGHLO =   F
************************************************************
 Group 23.Field Print-Out & Plot Control
NPRINT =  10000 ;NUMCLS =      5
NXPRIN =      4 ;IXPRF  =      1 ;IXPRL  =     24
NYPRIN =      1 ;IYPRF  =      1 ;IYPRL  =      6
NZPRIN =      4 ;IZPRF  =      1 ;IZPRL  =  10000
XZPR   =   F ;YZPR   =   F
IPLTF  =      1 ;IPLTL  =     35 ;NPLT   =      1
ISWPRF =      1 ;ISWPRL =  10000
ITABL  =      3 ;IPROF  =      1
ABSIZ  = 5.000E-01 ;ORSIZ  = 4.000E-01
NTZPRF =      1 ;NCOLPF =     50
ICHR   =      2 ;NCOLCO =     45 ;NROWCO =     20
  No PATCHes yet used for this Group
************************************************************
 Group 24. Dumps For Restarts
SAVE   =   T ;AUTOPS =   F ;NOWIPE =   F
NSAVE  =CHAM

 *** grid-geometry information ***
```

```
X-coordinates of the cell centres
  1.308E-01  3.925E-01  6.542E-01  9.158E-01  1.177E+00
  1.439E+00  1.701E+00  1.962E+00  2.224E+00  2.486E+00
  2.748E+00  3.009E+00  3.271E+00  3.533E+00  3.794E+00
  4.056E+00  4.317E+00  4.579E+00  4.841E+00  5.103E+00
  5.364E+00  5.626E+00  5.888E+00  6.149E+00
Y-coordinates of the cell centres
  5.000E-01  1.500E+00  2.500E+00  3.500E+00  4.500E+00
  5.500E+00
Z-coordinates of the cell centres
  5.000E-01  1.500E+00  2.500E+00  3.500E+00  4.500E+00
  5.500E+00  6.500E+00  7.500E+00  8.500E+00  9.500E+00
  1.050E+01  1.150E+01  1.250E+01  1.350E+01  1.450E+01
  1.550E+01  1.650E+01  1.750E+01  1.850E+01  1.950E+01

--- INTEGRATION OF EQUATIONS BEGINS ---


***********************************************************
TIME STP=    1 SWEEP NO=   35 ZSLAB NO=    1 ITERN NO=    1


***********************************************************
TIME STP=    1 SWEEP NO=   35 ZSLAB NO=    4 ITERN NO=    1


FLOW FIELD AT ITHYD=  1, IZ=  4, ISWEEP= 35, ISTEP=    1
FIELD VALUES OF P1
IY=  6  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  5  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  4  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  3  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  2  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  1  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IX=       1          5          9         13         17
IY=  6  1.020E+00
IY=  5  1.020E+00
IY=  4  1.020E+00
IY=  3  1.020E+00
IY=  2  1.020E+00
IY=  1  1.020E+00
 IX=     21
FIELD VALUES OF U1
IY=  6 -1.428E-07  1.727E-07  1.604E-07 -4.551E-07 -1.440E-06
IY=  5 -2.066E-08  9.384E-08  6.685E-08 -6.769E-07 -1.870E-06
IY=  4 -2.363E-07 -1.491E-07 -3.826E-07 -1.165E-06 -2.287E-06
IY=  3 -4.132E-07 -8.663E-07 -1.662E-06 -2.290E-06 -2.440E-06
IY=  2 -5.631E-07 -3.607E-06 -5.286E-06 -4.427E-06  9.774E-07
IY=  1  1.870E-06  8.500E-06  1.695E-05  2.464E-05  2.475E-05
 IX=      1          5          9         13         17
IY=  6 -1.458E-06
IY=  5 -1.984E-06
IY=  4 -2.106E-06
IY=  3 -1.420E-06
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```
IY=  2  4.565E-06
IY=  1  1.295E-05
 IX=     21
FIELD VALUES OF V1
IY=  5 -1.956E-03  -1.956E-03  -1.956E-03  -1.956E-03  -1.956E-03
IY=  4 -1.905E-03  -1.905E-03  -1.905E-03  -1.905E-03  -1.905E-03
IY=  3 -1.843E-03  -1.843E-03  -1.844E-03  -1.844E-03  -1.844E-03
IY=  2 -1.698E-03  -1.698E-03  -1.698E-03  -1.699E-03  -1.699E-03
IY=  1 -1.078E-04  -1.073E-04  -1.076E-04  -1.052E-04  -9.951E-05
 IX=      1           5           9          13          17
IY=  5 -1.956E-03
IY=  4 -1.905E-03
IY=  3 -1.843E-03
IY=  2 -1.696E-03
IY=  1 -9.472E-05
 IX=     21
FIELD VALUES OF W1
IY=  6  9.945E-01   9.945E-01   9.945E-01   9.945E-01   9.945E-01
IY=  5  1.002E+00   1.002E+00   1.002E+00   1.002E+00   1.002E+00
IY=  4  1.002E+00   1.002E+00   1.002E+00   1.002E+00   1.002E+00
IY=  3  1.002E+00   1.002E+00   1.002E+00   1.002E+00   1.002E+00
IY=  2  1.004E+00   1.004E+00   1.004E+00   1.004E+00   1.004E+00
IY=  1  1.691E+00   1.691E+00   1.691E+00   1.691E+00   1.691E+00
 IX=      1           5           9          13          17
IY=  6  9.945E-01
IY=  5  1.002E+00
IY=  4  1.002E+00
IY=  3  1.002E+00
IY=  2  1.004E+00
IY=  1  1.691E+00
 IX=     21
FIELD VALUES OF CH4
IY=  6  3.380E-13   2.235E-14  -6.815E-15  -3.271E-14  -4.374E-14
IY=  5  9.985E-13   6.828E-13   6.539E-13   6.286E-13   6.182E-13
IY=  4  7.176E-11   7.145E-11   7.144E-11   7.146E-11   7.155E-11
IY=  3  4.602E-09   4.602E-09   4.603E-09   4.605E-09   4.612E-09
IY=  2  1.417E-06   1.415E-06   1.410E-06   1.410E-06   1.418E-06
IY=  1  9.994E-01   9.994E-01   9.994E-01   9.994E-01   9.995E-01
 IX=      1           5           9          13          17
IY=  6 -1.313E-14
IY=  5  6.494E-13
IY=  4  7.169E-11
IY=  3  4.621E-09
IY=  2  1.434E-06
IY=  1  9.995E-01
 IX=     21
FIELD VALUES OF AIR
IY=  6  2.460E-01   2.460E-01   2.460E-01   2.460E-01   2.460E-01
IY=  5  2.460E-01   2.460E-01   2.460E-01   2.460E-01   2.460E-01
IY=  4  2.460E-01   2.460E-01   2.460E-01   2.460E-01   2.460E-01
IY=  3  2.460E-01   2.460E-01   2.460E-01   2.460E-01   2.460E-01
IY=  2  2.460E-01   2.460E-01   2.460E-01   2.460E-01   2.460E-01
IY=  1  1.401E-04   1.393E-04   1.385E-04   1.358E-04   1.316E-04
 IX=      1           5           9          13          17
```

```
IY=  6  2.460E-01
IY=  5  2.460E-01
IY=  4  2.460E-01
IY=  3  2.460E-01
IY=  2  2.460E-01
IY=  1  1.288E-04
 IX=     21
FIELD VALUES OF MIXF
IY=  6 -2.620E-09 -2.620E-09 -2.620E-09 -2.620E-09 -2.620E-09
IY=  5 -2.619E-09 -2.620E-09 -2.620E-09 -2.620E-09 -2.620E-09
IY=  4 -2.548E-09 -2.549E-09 -2.549E-09 -2.549E-09 -2.549E-09
IY=  3  1.990E-09  1.990E-09  1.991E-09  1.993E-09  2.000E-09
IY=  2  1.417E-06  1.414E-06  1.410E-06  1.409E-06  1.417E-06
IY=  1  9.994E-01  9.994E-01  9.994E-01  9.994E-01  9.995E-01
 IX=      1          5          9         13         17
IY=  6 -2.620E-09
IY=  5 -2.620E-09
IY=  4 -2.549E-09
IY=  3  2.009E-09
IY=  2  1.434E-06
IY=  1  9.995E-01
 IX=     21
FIELD VALUES OF TMP1
IY=  6  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  5  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  4  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  3  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  2  2.981E+02  2.981E+02  2.981E+02  2.981E+02  2.981E+02
IY=  1  2.984E+02  2.984E+02  2.984E+02  2.984E+02  2.984E+02
 IX=      1          5          9         13         17
IY=  6  2.980E+02
IY=  5  2.980E+02
IY=  4  2.980E+02
IY=  3  2.980E+02
IY=  2  2.981E+02
IY=  1  2.984E+02
 IX=     21
FIELD VALUES OF RHO1
IY=  6  1.192E-05  1.192E-05  1.192E-05  1.192E-05  1.192E-05
IY=  5  1.192E-05  1.192E-05  1.192E-05  1.192E-05  1.192E-05
IY=  4  1.192E-05  1.192E-05  1.192E-05  1.192E-05  1.192E-05
IY=  3  1.192E-05  1.192E-05  1.192E-05  1.192E-05  1.192E-05
IY=  2  1.192E-05  1.192E-05  1.192E-05  1.192E-05  1.192E-05
IY=  1  1.190E-05  1.190E-05  1.190E-05  1.190E-05  1.190E-05
 IX=      1          5          9         13         17
IY=  6  1.192E-05
IY=  5  1.192E-05
IY=  4  1.192E-05
IY=  3  1.192E-05
IY=  2  1.192E-05
IY=  1  1.191E-05
 IX=     21

************************************************************
```

```
TIME STP=    1 SWEEP NO=   35 ZSLAB NO=    8 ITERN NO=    1


FLOW FIELD AT ITHYD=   1, IZ=   8, ISWEEP=  35, ISTEP=    1
FIELD VALUES OF P1
IY=  6   1.018E+00   1.018E+00   1.018E+00   1.018E+00   1.018E+00
IY=  5   1.018E+00   1.018E+00   1.018E+00   1.018E+00   1.018E+00
IY=  4   1.017E+00   1.017E+00   1.017E+00   1.017E+00   1.017E+00
IY=  3   1.016E+00   1.016E+00   1.016E+00   1.016E+00   1.016E+00
IY=  2   1.014E+00   1.014E+00   1.014E+00   1.014E+00   1.014E+00
IY=  1   1.014E+00   1.014E+00   1.014E+00   1.014E+00   1.014E+00
 IX=       1           5           9          13          17
IY=  6   1.018E+00
IY=  5   1.018E+00
IY=  4   1.017E+00
IY=  3   1.016E+00
IY=  2   1.014E+00
IY=  1   1.014E+00
 IX=      21
FIELD VALUES OF U1
IY=  6   1.443E-08   7.374E-07   2.032E-06   3.083E-06   3.539E-06
IY=  5  -4.303E-07   1.022E-06   2.674E-06   4.011E-06   4.603E-06
IY=  4  -6.490E-07   1.453E-06   3.554E-06   5.068E-06   5.572E-06
IY=  3  -1.082E-06   2.300E-06   4.823E-06   6.233E-06   6.077E-06
IY=  2  -1.762E-06   3.126E-06   4.972E-06   5.127E-06   2.424E-06
IY=  1  -3.495E-06  -1.201E-05  -1.154E-05  -2.597E-06   8.971E-06
 IX=       1           5           9          13          17
IY=  6   2.493E-06
IY=  5   3.197E-06
IY=  4   3.713E-06
IY=  3   3.696E-06
IY=  2   1.079E-06
IY=  1   1.072E-05
 IX=      21
FIELD VALUES OF V1
IY=  5  -3.007E-03  -3.007E-03  -3.007E-03  -3.008E-03  -3.008E-03
IY=  4  -4.752E-03  -4.752E-03  -4.753E-03  -4.753E-03  -4.753E-03
IY=  3  -7.842E-03  -7.843E-03  -7.844E-03  -7.845E-03  -7.844E-03
IY=  2  -1.334E-02  -1.335E-02  -1.335E-02  -1.335E-02  -1.335E-02
IY=  1   9.773E-04   9.754E-04   9.660E-04   9.590E-04   9.633E-04
 IX=       1           5           9          13          17
IY=  5  -3.007E-03
IY=  4  -4.752E-03
IY=  3  -7.843E-03
IY=  2  -1.335E-02
IY=  1   9.829E-04
 IX=      21
FIELD VALUES OF W1
IY=  6   9.846E-01   9.846E-01   9.846E-01   9.846E-01   9.846E-01
IY=  5   1.001E+00   1.001E+00   1.001E+00   1.001E+00   1.001E+00
IY=  4   1.001E+00   1.001E+00   1.001E+00   1.001E+00   1.001E+00
IY=  3   1.002E+00   1.002E+00   1.002E+00   1.002E+00   1.002E+00
IY=  2   1.048E+00   1.048E+00   1.048E+00   1.048E+00   1.048E+00
IY=  1   1.693E+00   1.693E+00   1.693E+00   1.693E+00   1.693E+00
```

```
 IX=    1         5         9        13        17
IY=  6  9.846E-01
IY=  5  1.001E+00
IY=  4  1.001E+00
IY=  3  1.002E+00
IY=  2  1.048E+00
IY=  1  1.693E+00
 IX=    21
FIELD VALUES OF CH4
IY=  6  5.068E-11  9.720E-12  6.932E-12  4.826E-12  4.397E-12
IY=  5  2.443E-09  2.402E-09  2.400E-09  2.399E-09  2.401E-09
IY=  4  2.174E-07  2.174E-07  2.175E-07  2.175E-07  2.177E-07
IY=  3  1.252E-05  1.252E-05  1.252E-05  1.252E-05  1.253E-05
IY=  2  4.803E-03  4.801E-03  4.790E-03  4.782E-03  4.788E-03
IY=  1  9.970E-01  9.970E-01  9.970E-01  9.970E-01  9.971E-01
 IX=    1         5         9        13        17
IY=  6  7.470E-12
IY=  5  2.408E-09
IY=  4  2.180E-07
IY=  3  1.255E-05
IY=  2  4.815E-03
IY=  1  9.971E-01
 IX=    21
FIELD VALUES OF AIR
IY=  6  2.460E-01  2.460E-01  2.460E-01  2.460E-01  2.460E-01
IY=  5  2.460E-01  2.460E-01  2.460E-01  2.460E-01  2.460E-01
IY=  4  2.460E-01  2.460E-01  2.460E-01  2.460E-01  2.460E-01
IY=  3  2.460E-01  2.460E-01  2.460E-01  2.460E-01  2.460E-01
IY=  2  2.448E-01  2.448E-01  2.448E-01  2.448E-01  2.448E-01
IY=  1  7.231E-04  7.242E-04  7.293E-04  7.294E-04  7.201E-04
 IX=    1         5         9        13        17
IY=  6  2.460E-01
IY=  5  2.460E-01
IY=  4  2.460E-01
IY=  3  2.460E-01
IY=  2  2.448E-01
IY=  1  7.042E-04
 IX=    21
FIELD VALUES OF MIXF
IY=  6  8.128E-07  8.128E-07  8.128E-07  8.128E-07  8.128E-07
IY=  5  8.152E-07  8.152E-07  8.152E-07  8.152E-07  8.152E-07
IY=  4  1.030E-06  1.030E-06  1.030E-06  1.030E-06  1.030E-06
IY=  3  1.333E-05  1.333E-05  1.333E-05  1.333E-05  1.334E-05
IY=  2  4.804E-03  4.802E-03  4.791E-03  4.783E-03  4.789E-03
IY=  1  9.970E-01  9.970E-01  9.970E-01  9.970E-01  9.971E-01
 IX=    1         5         9        13        17
IY=  6  8.128E-07
IY=  5  8.152E-07
IY=  4  1.031E-06
IY=  3  1.336E-05
IY=  2  4.815E-03
IY=  1  9.971E-01
 IX=    21
FIELD VALUES OF TMP1
```

```
IY=  6  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  5  2.980E+02  2.980E+02  2.980E+02  2.980E+02  2.980E+02
IY=  4  2.981E+02  2.981E+02  2.981E+02  2.981E+02  2.981E+02
IY=  3  2.987E+02  2.987E+02  2.987E+02  2.987E+02  2.987E+02
IY=  2  5.370E+02  5.369E+02  5.364E+02  5.360E+02  5.363E+02
IY=  1  3.000E+02  3.000E+02  3.000E+02  3.000E+02  3.000E+02
 IX=      1          5          9         13         17
IY=  6  2.980E+02
IY=  5  2.980E+02
IY=  4  2.981E+02
IY=  3  2.987E+02
IY=  2  5.376E+02
IY=  1  2.999E+02
 IX=     21
FIELD VALUES OF RHO1
IY=  6  1.190E-05  1.190E-05  1.190E-05  1.190E-05  1.190E-05
IY=  5  1.189E-05  1.189E-05  1.189E-05  1.189E-05  1.189E-05
IY=  4  1.189E-05  1.189E-05  1.189E-05  1.189E-05  1.189E-05
IY=  3  1.185E-05  1.185E-05  1.185E-05  1.185E-05  1.185E-05
IY=  2  6.577E-06  6.578E-06  6.585E-06  6.590E-06  6.586E-06
IY=  1  1.176E-05  1.176E-05  1.176E-05  1.176E-05  1.176E-05
 IX=      1          5          9         13         17
IY=  6  1.190E-05
IY=  5  1.189E-05
IY=  4  1.189E-05
IY=  3  1.185E-05
IY=  2  6.570E-06
IY=  1  1.176E-05
 IX=     21

************************************************************
TIME STP=     1 SWEEP NO=   35 ZSLAB NO=    12 ITERN NO=     1


FLOW FIELD AT ITHYD=   1, IZ=  12, ISWEEP=  35, ISTEP=     1
FIELD VALUES OF P1
IY=  6  1.019E+00  1.019E+00  1.019E+00  1.019E+00  1.019E+00
IY=  5  1.019E+00  1.019E+00  1.019E+00  1.019E+00  1.019E+00
IY=  4  1.018E+00  1.018E+00  1.018E+00  1.018E+00  1.018E+00
IY=  3  1.017E+00  1.017E+00  1.017E+00  1.017E+00  1.017E+00
IY=  2  1.016E+00  1.016E+00  1.016E+00  1.016E+00  1.016E+00
IY=  1  1.016E+00  1.016E+00  1.016E+00  1.016E+00  1.016E+00
 IX=      1          5          9         13         17
IY=  6  1.019E+00
IY=  5  1.019E+00
IY=  4  1.018E+00
IY=  3  1.017E+00
IY=  2  1.016E+00
IY=  1  1.016E+00
 IX=     21
FIELD VALUES OF U1
IY=  6  3.074E-07  4.581E-07  1.001E-06  1.711E-06  2.250E-06
IY=  5 -3.255E-08  6.199E-07  1.301E-06  2.187E-06  2.856E-06
IY=  4 -3.358E-07  8.122E-07  1.687E-06  2.663E-06  3.351E-06
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IY=  3  -9.473E-07   1.098E-06   2.299E-06   3.180E-06   3.665E-06
IY=  2  -3.712E-06   1.534E-06   3.077E-06   3.282E-06   2.976E-06
IY=  1  -1.068E-05  -2.709E-06   1.470E-07   6.184E-08   1.068E-06
 IX=      1          5           9          13          17
IY=  6   1.951E-06
IY=  5   2.517E-06
IY=  4   3.033E-06
IY=  3   3.237E-06
IY=  2   1.748E-06
IY=  1   7.123E-06
 IX=     21
FIELD VALUES OF V1
IY=  5   1.724E-03   1.724E-03   1.724E-03   1.725E-03   1.725E-03
IY=  4   5.071E-03   5.072E-03   5.072E-03   5.073E-03   5.074E-03
IY=  3   1.052E-02   1.053E-02   1.053E-02   1.053E-02   1.053E-02
IY=  2   2.187E-02   2.187E-02   2.188E-02   2.188E-02   2.189E-02
IY=  1   4.119E-02   4.120E-02   4.121E-02   4.122E-02   4.122E-02
 IX=      1          5           9          13          17
IY=  5   1.726E-03
IY=  4   5.076E-03
IY=  3   1.053E-02
IY=  2   2.189E-02
IY=  1   4.121E-02
 IX=     21
FIELD VALUES OF W1
IY=  6   9.825E-01   9.824E-01   9.824E-01   9.824E-01   9.825E-01
IY=  5   1.004E+00   1.004E+00   1.004E+00   1.004E+00   1.004E+00
IY=  4   1.002E+00   1.002E+00   1.002E+00   1.002E+00   1.002E+00
IY=  3   1.008E+00   1.008E+00   1.008E+00   1.008E+00   1.008E+00
IY=  2   1.094E+00   1.093E+00   1.093E+00   1.093E+00   1.093E+00
IY=  1   1.515E+00   1.515E+00   1.515E+00   1.515E+00   1.515E+00
 IX=      1          5           9          13          17
IY=  6   9.825E-01
IY=  5   1.004E+00
IY=  4   1.002E+00
IY=  3   1.008E+00
IY=  2   1.094E+00
IY=  1   1.515E+00
 IX=     21
FIELD VALUES OF CH4
IY=  6   1.283E-08   1.385E-08   1.422E-08   1.425E-08   1.410E-08
IY=  5   2.472E-06   2.474E-06   2.475E-06   2.476E-06   2.477E-06
IY=  4   1.705E-04   1.706E-04   1.706E-04   1.707E-04   1.707E-04
IY=  3   6.103E-03   6.106E-03   6.107E-03   6.107E-03   6.109E-03
IY=  2   1.120E-01   1.121E-01   1.121E-01   1.121E-01   1.121E-01
IY=  1   9.973E-01   9.973E-01   9.973E-01   9.973E-01   9.973E-01
 IX=      1          5           9          13          17
IY=  6   1.368E-08
IY=  5   2.478E-06
IY=  4   1.708E-04
IY=  3   6.111E-03
IY=  2   1.121E-01
IY=  1   9.974E-01
 IX=     21
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FIELD VALUES OF AIR
IY=  6  2.459E-01  2.459E-01  2.459E-01  2.459E-01  2.459E-01
IY=  5  2.459E-01  2.459E-01  2.459E-01  2.459E-01  2.459E-01
IY=  4  2.458E-01  2.458E-01  2.458E-01  2.458E-01  2.458E-01
IY=  3  2.444E-01  2.444E-01  2.444E-01  2.444E-01  2.444E-01
IY=  2  2.183E-01  2.183E-01  2.183E-01  2.183E-01  2.183E-01
IY=  1  5.445E-04  5.453E-04  5.484E-04  5.475E-04  5.396E-04
 IX=      1          5          9         13         17
IY=  6  2.459E-01
IY=  5  2.459E-01
IY=  4  2.458E-01
IY=  3  2.444E-01
IY=  2  2.183E-01
IY=  1  5.275E-04
 IX=     21
FIELD VALUES OF MIXF
IY=  6  2.704E-05  2.704E-05  2.704E-05  2.704E-05  2.704E-05
IY=  5  2.949E-05  2.950E-05  2.950E-05  2.950E-05  2.950E-05
IY=  4  1.975E-04  1.976E-04  1.977E-04  1.977E-04  1.978E-04
IY=  3  6.130E-03  6.133E-03  6.134E-03  6.134E-03  6.136E-03
IY=  2  1.121E-01  1.121E-01  1.121E-01  1.121E-01  1.121E-01
IY=  1  9.973E-01  9.973E-01  9.973E-01  9.973E-01  9.974E-01
 IX=      1          5          9         13         17
IY=  6  2.704E-05
IY=  5  2.950E-05
IY=  4  1.979E-04
IY=  3  6.138E-03
IY=  2  1.121E-01
IY=  1  9.974E-01
 IX=     21
FIELD VALUES OF TMP1
IY=  6  2.993E+02  2.993E+02  2.993E+02  2.993E+02  2.993E+02
IY=  5  2.995E+02  2.995E+02  2.995E+02  2.995E+02  2.995E+02
IY=  4  3.078E+02  3.078E+02  3.078E+02  3.078E+02  3.078E+02
IY=  3  6.030E+02  6.031E+02  6.032E+02  6.032E+02  6.033E+02
IY=  2  8.938E+02  8.937E+02  8.937E+02  8.937E+02  8.937E+02
IY=  1  2.998E+02  2.998E+02  2.998E+02  2.998E+02  2.998E+02
 IX=      1          5          9         13         17
IY=  6  2.993E+02
IY=  5  2.995E+02
IY=  4  3.078E+02
IY=  3  6.034E+02
IY=  2  8.937E+02
IY=  1  2.997E+02
 IX=     21
FIELD VALUES OF RHO1
IY=  6  1.186E-05  1.186E-05  1.186E-05  1.186E-05  1.186E-05
IY=  5  1.185E-05  1.185E-05  1.185E-05  1.185E-05  1.185E-05
IY=  4  1.153E-05  1.153E-05  1.153E-05  1.153E-05  1.153E-05
IY=  3  5.883E-06  5.882E-06  5.881E-06  5.881E-06  5.880E-06
IY=  2  3.966E-06  3.966E-06  3.966E-06  3.966E-06  3.966E-06
IY=  1  1.183E-05  1.183E-05  1.183E-05  1.183E-05  1.183E-05
 IX=      1          5          9         13         17
IY=  6  1.186E-05
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IY=  5  1.185E-05
IY=  4  1.153E-05
IY=  3  5.879E-06
IY=  2  3.966E-06
IY=  1  1.183E-05
 IX=     21

************************************************************
TIME STP=    1 SWEEP NO=    35 ZSLAB NO=    16 ITERN NO=    1


FLOW FIELD AT ITHYD=  1, IZ=  16, ISWEEP=  35, ISTEP=   1
FIELD VALUES OF P1
IY=  6  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  5  1.021E+00  1.021E+00  1.021E+00  1.021E+00  1.021E+00
IY=  4  1.021E+00  1.021E+00  1.021E+00  1.021E+00  1.021E+00
IY=  3  1.023E+00  1.023E+00  1.023E+00  1.023E+00  1.023E+00
IY=  2  1.025E+00  1.025E+00  1.025E+00  1.025E+00  1.025E+00
IY=  1  1.027E+00  1.027E+00  1.027E+00  1.027E+00  1.027E+00
 IX=      1          5          9         13         17
IY=  6  1.020E+00
IY=  5  1.021E+00
IY=  4  1.021E+00
IY=  3  1.023E+00
IY=  2  1.025E+00
IY=  1  1.027E+00
 IX=     21
FIELD VALUES OF U1
IY=  6  3.832E-07  6.982E-08 -3.337E-07 -6.006E-07 -6.996E-07
IY=  5  4.823E-07  1.185E-07 -3.768E-07 -7.074E-07 -8.450E-07
IY=  4  6.312E-07  2.198E-07 -4.085E-07 -8.635E-07 -1.107E-06
IY=  3  1.466E-06  5.331E-07 -2.643E-07 -9.883E-07 -1.549E-06
IY=  2  5.136E-06  1.838E-06  7.441E-07 -7.793E-07 -2.507E-06
IY=  1  1.143E-05  9.598E-06  7.461E-06  1.777E-06 -6.490E-06
 IX=      1          5          9         13         17
IY=  6 -5.565E-07
IY=  5 -6.443E-07
IY=  4 -8.132E-07
IY=  3 -1.284E-06
IY=  2 -3.063E-06
IY=  1 -1.338E-05
 IX=     21
FIELD VALUES OF V1
IY=  5  3.671E-03  3.670E-03  3.670E-03  3.670E-03  3.670E-03
IY=  4  8.587E-03  8.586E-03  8.586E-03  8.586E-03  8.585E-03
IY=  3  1.563E-02  1.563E-02  1.563E-02  1.563E-02  1.563E-02
IY=  2  2.649E-02  2.648E-02  2.648E-02  2.648E-02  2.648E-02
IY=  1  3.701E-02  3.700E-02  3.700E-02  3.700E-02  3.700E-02
 IX=      1          5          9         13         17
IY=  5  3.670E-03
IY=  4  8.585E-03
IY=  3  1.563E-02
IY=  2  2.648E-02
IY=  1  3.700E-02
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 IX=    21
FIELD VALUES OF W1
IY=  6  9.959E-01  9.959E-01  9.959E-01  9.959E-01  9.959E-01
IY=  5  1.020E+00  1.020E+00  1.020E+00  1.020E+00  1.020E+00
IY=  4  1.022E+00  1.022E+00  1.022E+00  1.022E+00  1.022E+00
IY=  3  1.027E+00  1.027E+00  1.027E+00  1.027E+00  1.027E+00
IY=  2  1.047E+00  1.047E+00  1.047E+00  1.047E+00  1.047E+00
IY=  1  1.129E+00  1.129E+00  1.129E+00  1.129E+00  1.129E+00
 IX=     1          5          9          13         17
IY=  6  9.959E-01
IY=  5  1.020E+00
IY=  4  1.022E+00
IY=  3  1.027E+00
IY=  2  1.047E+00
IY=  1  1.129E+00
 IX=    21
FIELD VALUES OF CH4
IY=  6  5.166E-07  5.167E-07  5.170E-07  5.173E-07  5.175E-07
IY=  5  5.089E-05  5.089E-05  5.090E-05  5.091E-05  5.092E-05
IY=  4  1.885E-03  1.885E-03  1.885E-03  1.885E-03  1.886E-03
IY=  3  3.182E-02  3.182E-02  3.182E-02  3.182E-02  3.182E-02
IY=  2  2.488E-01  2.488E-01  2.488E-01  2.489E-01  2.489E-01
IY=  1  9.932E-01  9.932E-01  9.932E-01  9.932E-01  9.932E-01
 IX=     1          5          9          13         17
IY=  6  5.176E-07
IY=  5  5.093E-05
IY=  4  1.886E-03
IY=  3  3.183E-02
IY=  2  2.489E-01
IY=  1  9.933E-01
 IX=    21
FIELD VALUES OF AIR
IY=  6  2.447E-01  2.447E-01  2.447E-01  2.447E-01  2.447E-01
IY=  5  2.447E-01  2.447E-01  2.447E-01  2.447E-01  2.447E-01
IY=  4  2.442E-01  2.442E-01  2.442E-01  2.442E-01  2.442E-01
IY=  3  2.369E-01  2.369E-01  2.369E-01  2.369E-01  2.369E-01
IY=  2  1.835E-01  1.835E-01  1.835E-01  1.835E-01  1.835E-01
IY=  1  3.607E-04  3.611E-04  3.627E-04  3.616E-04  3.562E-04
 IX=     1          5          9          13         17
IY=  6  2.447E-01
IY=  5  2.447E-01
IY=  4  2.442E-01
IY=  3  2.369E-01
IY=  2  1.835E-01
IY=  1  3.484E-04
 IX=    21
FIELD VALUES OF MIXF
IY=  6  3.080E-04  3.080E-04  3.080E-04  3.080E-04  3.080E-04
IY=  5  3.583E-04  3.583E-04  3.583E-04  3.583E-04  3.584E-04
IY=  4  2.192E-03  2.192E-03  2.192E-03  2.193E-03  2.193E-03
IY=  3  3.212E-02  3.212E-02  3.213E-02  3.213E-02  3.213E-02
IY=  2  2.491E-01  2.492E-01  2.492E-01  2.492E-01  2.492E-01
IY=  1  9.935E-01  9.935E-01  9.935E-01  9.935E-01  9.936E-01
 IX=     1          5          9          13         17
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IY=  6   3.080E-04
IY=  5   3.584E-04
IY=  4   2.193E-03
IY=  3   3.214E-02
IY=  2   2.492E-01
IY=  1   9.936E-01
 IX=      21
FIELD VALUES OF TMP1
IY=  6   3.133E+02   3.133E+02   3.133E+02   3.133E+02   3.133E+02
IY=  5   3.158E+02   3.158E+02   3.158E+02   3.158E+02   3.158E+02
IY=  4   4.071E+02   4.071E+02   4.071E+02   4.071E+02   4.071E+02
IY=  3   1.896E+03   1.896E+03   1.896E+03   1.896E+03   1.897E+03
IY=  2   8.018E+02   8.018E+02   8.018E+02   8.018E+02   8.018E+02
IY=  1   3.023E+02   3.023E+02   3.023E+02   3.023E+02   3.023E+02
 IX=       1           5           9          13          17
IY=  6   3.133E+02
IY=  5   3.158E+02
IY=  4   4.071E+02
IY=  3   1.897E+03
IY=  2   8.017E+02
IY=  1   3.023E+02
 IX=      21
FIELD VALUES OF RHO1
IY=  6   1.134E-05   1.134E-05   1.134E-05   1.134E-05   1.134E-05
IY=  5   1.126E-05   1.126E-05   1.126E-05   1.126E-05   1.126E-05
IY=  4   8.741E-06   8.741E-06   8.741E-06   8.741E-06   8.741E-06
IY=  3   1.879E-06   1.879E-06   1.879E-06   1.879E-06   1.878E-06
IY=  2   4.451E-06   4.451E-06   4.451E-06   4.451E-06   4.451E-06
IY=  1   1.183E-05   1.183E-05   1.183E-05   1.183E-05   1.183E-05
 IX=       1           5           9          13          17
IY=  6   1.134E-05
IY=  5   1.126E-05
IY=  4   8.740E-06
IY=  3   1.878E-06
IY=  2   4.451E-06
IY=  1   1.183E-05
 IX=      21

************************************************************
TIME STP=     1 SWEEP NO=    35 ZSLAB NO=    20 ITERN NO=     1


FLOW FIELD AT ITHYD=   1, IZ=  20, ISWEEP=  35, ISTEP=    1
FIELD VALUES OF P1
IY=  6   1.014E+00   1.014E+00   1.014E+00   1.014E+00   1.014E+00
IY=  5   1.020E+00   1.020E+00   1.020E+00   1.020E+00   1.020E+00
IY=  4   1.022E+00   1.022E+00   1.022E+00   1.022E+00   1.022E+00
IY=  3   1.023E+00   1.023E+00   1.023E+00   1.023E+00   1.023E+00
IY=  2   1.024E+00   1.024E+00   1.024E+00   1.024E+00   1.024E+00
IY=  1   1.026E+00   1.026E+00   1.026E+00   1.026E+00   1.026E+00
 IX=       1           5           9          13          17
IY=  6   1.014E+00
IY=  5   1.020E+00
IY=  4   1.022E+00
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IY=  3  1.023E+00
IY=  2  1.024E+00
IY=  1  1.026E+00
 IX=    21
FIELD VALUES OF U1
IY=  6  6.034E-07 -2.239E-07 -7.925E-07 -1.724E-06 -2.462E-06
IY=  5  8.860E-07 -2.747E-07 -9.831E-07 -2.130E-06 -3.040E-06
IY=  4  9.588E-07 -3.250E-07 -1.285E-06 -2.705E-06 -3.814E-06
IY=  3  1.017E-06 -3.568E-07 -1.797E-06 -3.626E-06 -5.079E-06
IY=  2  1.356E-06 -3.992E-07 -2.771E-06 -5.467E-06 -7.672E-06
IY=  1  3.273E-06 -5.120E-07 -5.368E-06 -1.093E-05 -1.419E-05
 IX=     1         5         9        13        17
IY=  6 -2.027E-06
IY=  5 -2.605E-06
IY=  4 -3.425E-06
IY=  3 -4.652E-06
IY=  2 -6.491E-06
IY=  1 -1.122E-05
 IX=    21
FIELD VALUES OF V1
IY=  5  8.872E-03  8.872E-03  8.872E-03  8.872E-03  8.872E-03
IY=  4  5.784E-03  5.784E-03  5.784E-03  5.784E-03  5.784E-03
IY=  3  5.201E-03  5.201E-03  5.201E-03  5.201E-03  5.200E-03
IY=  2  5.209E-03  5.208E-03  5.207E-03  5.207E-03  5.205E-03
IY=  1  4.930E-03  4.928E-03  4.927E-03  4.926E-03  4.923E-03
 IX=     1         5         9        13        17
IY=  5  8.871E-03
IY=  4  5.783E-03
IY=  3  5.198E-03
IY=  2  5.202E-03
IY=  1  4.920E-03
 IX=    21
FIELD VALUES OF W1
FIELD VALUES OF CH4
IY=  6  1.716E-06  1.716E-06  1.716E-06  1.717E-06  1.717E-06
IY=  5  8.931E-05  8.931E-05  8.932E-05  8.933E-05  8.935E-05
IY=  4  2.555E-03  2.555E-03  2.555E-03  2.556E-03  2.556E-03
IY=  3  3.710E-02  3.710E-02  3.710E-02  3.710E-02  3.710E-02
IY=  2  2.652E-01  2.652E-01  2.652E-01  2.652E-01  2.652E-01
IY=  1  9.693E-01  9.693E-01  9.693E-01  9.693E-01  9.694E-01
 IX=     1         5         9        13        17
IY=  6  1.718E-06
IY=  5  8.936E-05
IY=  4  2.556E-03
IY=  3  3.711E-02
IY=  2  2.652E-01
IY=  1  9.694E-01
 IX=    21
FIELD VALUES OF AIR
IY=  6  2.387E-01  2.387E-01  2.387E-01  2.387E-01  2.387E-01
IY=  5  2.386E-01  2.386E-01  2.386E-01  2.386E-01  2.386E-01
IY=  4  2.380E-01  2.380E-01  2.380E-01  2.380E-01  2.380E-01
IY=  3  2.295E-01  2.295E-01  2.295E-01  2.295E-01  2.295E-01
IY=  2  1.734E-01  1.734E-01  1.734E-01  1.734E-01  1.734E-01
```

```
IY=  1  2.066E-04  2.069E-04  2.075E-04  2.067E-04  2.036E-04
 IX=     1          5          9         13         17
IY=  6  2.387E-01
IY=  5  2.386E-01
IY=  4  2.380E-01
IY=  3  2.295E-01
IY=  2  1.734E-01
IY=  1  1.994E-04
 IX=    21
FIELD VALUES OF MIXF
IY=  6  1.729E-03  1.729E-03  1.729E-03  1.729E-03  1.729E-03
IY=  5  1.817E-03  1.817E-03  1.817E-03  1.817E-03  1.817E-03
IY=  4  4.283E-03  4.283E-03  4.283E-03  4.283E-03  4.283E-03
IY=  3  3.883E-02  3.883E-02  3.883E-02  3.883E-02  3.883E-02
IY=  2  2.669E-01  2.669E-01  2.669E-01  2.669E-01  2.670E-01
IY=  1  9.711E-01  9.711E-01  9.711E-01  9.711E-01  9.711E-01
 IX=     1          5          9         13         17
IY=  6  1.729E-03
IY=  5  1.817E-03
IY=  4  4.284E-03
IY=  3  3.883E-02
IY=  2  2.670E-01
IY=  1  9.711E-01
 IX=    21
FIELD VALUES OF TMP1
IY=  6  3.840E+02  3.840E+02  3.840E+02  3.840E+02  3.840E+02
IY=  5  3.884E+02  3.884E+02  3.884E+02  3.884E+02  3.884E+02
IY=  4  5.111E+02  5.111E+02  5.111E+02  5.111E+02  5.111E+02
IY=  3  2.230E+03  2.230E+03  2.230E+03  2.230E+03  2.230E+03
IY=  2  7.898E+02  7.898E+02  7.898E+02  7.898E+02  7.898E+02
IY=  1  3.174E+02  3.174E+02  3.174E+02  3.174E+02  3.174E+02
 IX=     1          5          9         13         17
IY=  6  3.840E+02
IY=  5  3.884E+02
IY=  4  5.111E+02
IY=  3  2.230E+03
IY=  2  7.898E+02
IY=  1  3.174E+02
 IX=    21
FIELD VALUES OF RHO1
IY=  6  9.195E-06  9.195E-06  9.195E-06  9.195E-06  9.195E-06
IY=  5  9.144E-06  9.144E-06  9.144E-06  9.144E-06  9.144E-06
IY=  4  6.963E-06  6.963E-06  6.963E-06  6.962E-06  6.962E-06
IY=  3  1.598E-06  1.598E-06  1.598E-06  1.598E-06  1.598E-06
IY=  2  4.515E-06  4.515E-06  4.515E-06  4.515E-06  4.515E-06
IY=  1  1.125E-05  1.125E-05  1.125E-05  1.125E-05  1.125E-05
 IX=     1          5          9         13         17
IY=  6  9.195E-06
IY=  5  9.144E-06
IY=  4  6.962E-06
IY=  3  1.597E-06
IY=  2  4.515E-06
IY=  1  1.125E-05
 IX=    21
```

```
************************************************************
TIME STP=    1 SWEEP NO=   35 ZSLAB NO=    1 ITERN NO=    1


Whole-field residual sum(s) before solution
Resref values determined by EARTH
resfac  = 1.000E-03
 variable   resref  (res sum)/resref
   P1     1.573E-03   5.088E+01
   U1     1.861E-09   2.328E+05
   V1     6.252E-06   7.415E+05
   W1     7.860E-04   1.044E+04
   CH4    4.296E-05   6.372E+04
   AIR    1.962E-04   1.122E+04


Net source of U1   at patch named: INLTA    = 5.294E-23
Net source of U1   at patch named: INLTB    =-4.235E-22
Net source of U1   at patch named: OUTLT    = 2.181E-04
Net source of U1   at patch named: WALL     =-3.858E-07

Net source of V1   at patch named: INLTA    = 0.000E+00
Net source of V1   at patch named: INLTB    = 0.000E+00
Net source of V1   at patch named: OUTLT    =-7.229E-01

Net source of W1   at patch named: INLTA    = 8.968E+00
Net source of W1   at patch named: INLTB    = 1.099E+02
Net source of W1   at patch named: OUTLT    = 0.000E+00
Net source of W1   at patch named: WALL     =-1.487E+00

Net source of R1   at patch named: INLTA    = 5.307E+00
Net source of R1   at patch named: INLTB    = 1.099E+02
Net source of R1   at patch named: OUTLT    =-1.152E+02

Net source of CH4  at patch named: INLTA    = 5.307E+00
Net source of CH4  at patch named: INLTB    =-8.272E-25
Net source of CH4  at patch named: OUTLT    =-6.259E+00

Net source of AIR  at patch named: INLTA    = 0.000E+00
Net source of AIR  at patch named: INLTB    = 2.704E+01
Net source of AIR  at patch named: OUTLT    =-2.569E+01

************************************************************
spot values vs sweep or iteration number
  IXMON=    1   IYMON=    1   IZMON=    1 TIMESTEP=    1

Tabulation of abscissa and ordinates...
 ISWP       P1         U1         V1         W1        CH4
   1  1.000E-10  4.680E-11  5.830E-11  7.285E-01  5.000E-01
   2  1.000E-10  6.137E-05  8.615E-02  1.521E+00  7.500E-01
   3  8.701E-01 -5.508E-05  5.538E-02  1.579E+00  8.750E-01
   4  9.728E-01  3.140E-05  3.379E-02  1.621E+00  9.375E-01
   5  9.954E-01  2.463E-05  2.038E-02  1.648E+00  9.687E-01
```

```
  6  1.001E+00  2.565E-06  1.208E-02  1.665E+00  9.844E-01
  7  1.004E+00 -7.970E-06  6.941E-03  1.676E+00  9.922E-01
  8  1.006E+00 -8.004E-06  3.763E-03  1.682E+00  9.961E-01
  9  1.008E+00 -4.169E-06  1.821E-03  1.686E+00  9.980E-01
 10  1.010E+00 -7.945E-07  6.696E-04  1.689E+00  9.990E-01
 11  1.012E+00  7.898E-07  1.189E-05  1.690E+00  9.995E-01
 12  1.013E+00  1.052E-06 -3.405E-04  1.691E+00  9.998E-01
 13  1.015E+00  6.901E-07 -5.069E-04  1.691E+00  9.997E-01
 14  1.016E+00  3.100E-07 -5.638E-04  1.691E+00  9.996E-01
 15  1.017E+00  1.098E-07 -5.595E-04  1.691E+00  9.995E-01
 16  1.018E+00  6.899E-08 -5.223E-04  1.691E+00  9.994E-01
 17  1.018E+00  9.797E-08 -4.402E-04  1.691E+00  9.994E-01
 18  1.019E+00  1.447E-07 -3.413E-04  1.691E+00  9.995E-01
 19  1.020E+00  1.773E-07 -2.547E-04  1.690E+00  9.996E-01
 20  1.020E+00  1.920E-07 -1.860E-04  1.690E+00  9.997E-01
 21  1.020E+00  2.059E-07 -1.250E-04  1.690E+00  9.997E-01
 22  1.020E+00  2.142E-07 -8.265E-05  1.690E+00  9.998E-01
 23  1.021E+00  2.167E-07 -5.698E-05  1.690E+00  9.999E-01
 24  1.021E+00  2.195E-07 -4.137E-05  1.690E+00  9.999E-01
 25  1.021E+00  2.186E-07 -3.373E-05  1.690E+00  9.999E-01
 26  1.021E+00  2.113E-07 -3.211E-05  1.690E+00  9.999E-01
 27  1.021E+00  2.016E-07 -3.342E-05  1.690E+00  1.000E+00
 28  1.021E+00  1.891E-07 -3.565E-05  1.690E+00  1.000E+00
 29  1.021E+00  1.739E-07 -3.830E-05  1.690E+00  1.000E+00
 30  1.021E+00  1.585E-07 -4.056E-05  1.690E+00  1.000E+00
 31  1.021E+00  1.435E-07 -4.193E-05  1.690E+00  1.000E+00
 32  1.021E+00  1.285E-07 -4.266E-05  1.690E+00  1.000E+00
 33  1.021E+00  1.145E-07 -4.283E-05  1.690E+00  1.000E+00
 34  1.021E+00  1.022E-07 -4.250E-05  1.690E+00  1.000E+00
 35  1.021E+00  9.525E-08 -4.210E-05  1.690E+00  1.000E+00
ISWP      AIR
  1  2.314E-06
  2  1.157E-06
  3  5.897E-07
  4  2.988E-07
  5  1.502E-07
  6  7.494E-08
  7  3.728E-08
  8  1.853E-08
  9  9.208E-09
 10  4.575E-09
 11  2.274E-09
 12  9.146E-07
 13  4.555E-05
 14  9.051E-05
 15  1.209E-04
 16  1.355E-04
 17  1.348E-04
 18  1.223E-04
 19  1.039E-04
 20  8.424E-05
 21  6.497E-05
 22  4.819E-05
 23  3.497E-05
```

```
  24  2.523E-05
  25  1.856E-05
  26  1.446E-05
  27  1.225E-05
  28  1.129E-05
  29  1.129E-05
  30  1.129E-05
  31  1.129E-05
  32  1.129E-05
  33  1.129E-05
  34  1.129E-05
  35  1.129E-05
 VARIABLE        P1         U1         V1         W1         CH4
   MINVAL=  1.000E-10 -5.508E-05 -5.638E-04  7.285E-01  5.000E-01
   MAXVAL=  1.021E+00  6.137E-05  8.615E-02  1.691E+00  1.000E+00
   CELLAV=  9.528E-01  1.433E-06  6.187E-03  1.650E+00  9.713E-01
 VARIABLE        AIR
   MINVAL=  2.274E-09
   MAXVAL=  1.355E-04
   CELLAV=  3.292E-05

1.00 +V...+PP.CC.CC.CC.CC+CA.ACC.CC+CC.CC.CC.CC.CC+CC.CC
   .  W CC                           .
0.90 +  WC              A   A                  +
   . P                            .
0.80 +W                                   +
   .  CU                A                 .
0.70 +    U                               +
   .  V          A                       .
0.60 +                   A                 +
   .                                  .
0.50 +C    U      UU UU       A                +
   U          UU      UU UUU UU UU UU UU UU UU UU UU
0.40 +   V    UU                                 +
   .              A          A                 .
0.30 +                                      +
   .    V                    A              .
0.20 +                          A           +
   .     V                     A            .
0.10 +       V                     AA AA AA AA AA
   .        V V                             .
0.00 AA.AA+AA.AA.AA.AA.VV+VV.VVV.VV+VV.VV.VV.VV.VV+VV.VV
   0   .1   .2   .3   .4   .5   .6   .7   .8   .9  1.0
the abscissa is     ISWP.  min= 1.00E+00 max= 3.50E+01

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

*********************************************************
residuals vs sweep or iteration number

Tabulation of abscissa and ordinates...
 ISWP       P1         U1         V1         W1         CH4
    1  2.190E+06  4.210E+01  1.152E+00  1.189E+10  5.307E+08
    2  7.444E+04  5.554E+12  1.408E+15  1.780E+15  2.612E+15
```

```
 3  1.503E+04  5.809E+06  1.673E+06  1.408E+04  2.904E+06
 4  3.113E+03  8.336E+05  9.691E+05  9.387E+03  1.716E+06
 5  7.137E+02  3.594E+05  1.102E+06  9.244E+03  1.307E+06
 6  2.163E+02  5.659E+05  1.196E+06  9.352E+03  1.065E+06
 7  1.044E+02  1.672E+06  1.152E+06  9.459E+03  9.204E+05
 8  8.913E+01  8.619E+05  1.106E+06  9.515E+03  8.044E+05
 9  8.031E+01  4.267E+05  1.063E+06  9.576E+03  7.207E+05
10  7.339E+01  5.059E+05  1.006E+06  9.608E+03  6.479E+05
11  6.797E+01  1.493E+06  9.940E+05  9.676E+03  5.885E+05
12  6.413E+01  7.033E+05  9.693E+05  9.742E+03  5.352E+05
13  6.247E+01  3.673E+05  9.315E+05  9.768E+03  4.872E+05
14  5.844E+01  4.077E+05  9.373E+05  9.816E+03  4.437E+05
15  5.621E+01  6.529E+05  9.168E+05  9.883E+03  4.026E+05
16  5.605E+01  4.941E+05  9.013E+05  9.926E+03  3.652E+05
17  5.267E+01  3.780E+05  9.003E+05  9.953E+03  3.288E+05
18  5.169E+01  3.208E+05  8.784E+05  1.003E+04  2.963E+05
19  5.155E+01  3.026E+05  8.771E+05  1.007E+04  2.647E+05
20  4.914E+01  2.941E+05  8.717E+05  1.008E+04  2.370E+05
21  4.874E+01  2.922E+05  8.488E+05  1.016E+04  2.102E+05
22  4.821E+01  2.885E+05  8.534E+05  1.019E+04  1.874E+05
23  4.708E+01  2.793E+05  8.444E+05  1.019E+04  1.659E+05
24  4.679E+01  2.689E+05  8.258E+05  1.028E+04  1.477E+05
25  4.611E+01  2.614E+05  8.289E+05  1.030E+04  1.312E+05
26  4.586E+01  2.543E+05  8.167E+05  1.030E+04  1.172E+05
27  4.562E+01  2.479E+05  8.064E+05  1.036E+04  1.051E+05
28  4.541E+01  2.448E+05  8.029E+05  1.038E+04  9.501E+04
29  4.558E+01  2.421E+05  7.888E+05  1.037E+04  8.662E+04
30  4.554E+01  2.391E+05  7.834E+05  1.042E+04  7.962E+04
31  4.616E+01  2.376E+05  7.745E+05  1.044E+04  7.421E+04
32  4.665E+01  2.354E+05  7.605E+05  1.040E+04  6.966E+04
33  4.834E+01  2.323E+05  7.551E+05  1.045E+04  6.641E+04
34  5.088E+01  2.328E+05  7.415E+05  1.044E+04  6.372E+04
35  5.088E+01  2.328E+05  7.415E+05  1.044E+04  6.372E+04
ISWP      AIR
 1  2.704E+09
 2  1.209E+16
 3  2.867E+06
 4  1.766E+06
 5  1.313E+06
 6  1.056E+06
 7  8.869E+05
 8  7.644E+05
 9  6.703E+05
10  5.943E+05
11  5.303E+05
12  4.749E+05
13  4.254E+05
14  3.805E+05
15  3.391E+05
16  3.008E+05
17  2.651E+05
18  2.322E+05
19  2.018E+05
20  1.741E+05
```

```
   21  1.489E+05
   22  1.264E+05
   23  1.064E+05
   24  8.883E+04
   25  7.361E+04
   26  6.055E+04
   27  4.948E+04
   28  4.020E+04
   29  3.251E+04
   30  2.621E+04
   31  2.111E+04
   32  1.702E+04
   33  1.377E+04
   34  1.122E+04
   35  1.122E+04
  VARIABLE      P1        U1        V1        W1        CH4
   MINVAL=  3.816E+00  3.740E+00  1.416E-01  9.132E+00  1.106E+01
   MAXVAL=  1.460E+01  2.935E+01  3.488E+01  3.512E+01  3.550E+01
  VARIABLE      AIR
   MINVAL=  9.326E+00
   MAXVAL=  3.703E+01

 1.00 PA...+....+....+....+....+....+....+....+....+....+
      .                                            .
0.90 +                                              +
      .                                            .
0.80 +                                              +
      .                                            .
0.70 +P                                             +
      .                                            .
0.60 +                                              +
    W  P                                            .
0.50 +                                              +
    A  U                                            .
0.40 +  VV VV VV VV VV VV VV VVV VV VV VV VV VV VV VV VV
    C     UU    UU    UU  U UUU UU UU UU UU UU UU UU UU
0.30 +                                              +
   .    P                                          .
0.20 +  AA                                             +
   .  CC AA AA AA AA AA                                    .
0.10 +     CC CC CC CC CC AA AAA AA AA                   +
   .        P PP PP P   C CCC CC CC AA AA AA A       .
0.00 V..WW+WW.WW.WW.WW.WW+WW.WWW.WW+WW.WW.CC.CC.CA+AA.AA
    0   .1   .2   .3   .4   .5   .6   .7   .8   .9  1.0
the abscissa is      ISWP.  min= 1.00E+00 max= 3.50E+01

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

************************************************************
SATLIT RUN NUMBER =   1 ; LIBRARY REF.=   0
RUN COMPLETED AT 23:20:21 ON MONDAY, 01 MARCH 1993
MACHINE-CLOCK TIME OF RUN =       120 SECONDS.
TIME/(VARIABLES*CELLS*TSTEPS*SWEEPS*ITS) = 1.984E-04
************************************************************
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