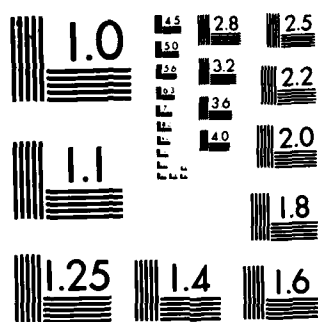


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A Users Guide to KLYSMA II: A Multifluid Transport Code

D. S. SPICER

*Geophysical and Plasma Dynamics Branch
Plasma Physics Division*

R. W. CLARK

*Plasma Radiation Branch
Plasma Physics Division*

June 14, 1984

This research was supported by the Defense Nuclear Agency under Subtask S99QMXBC,
work unit 00119 and work unit title "Early Time Dynamics."



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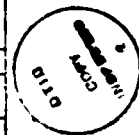
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A USERS GUIDE TO KLYSMA II: A MULTIFLUID TRANSPORT CODE

I. Introduction

This report documents a new one dimensional multifluid transport code, KLYSMA II, designed to study the cross-field transport of magnetized plasma in the presence of both anomalous and classical transport processes, radiation, and chemical reactions. Because the code was designed for research, as well as production purposes, versatility was incorporated at its conception. It is modular, well documented, and incorporates a variety of logical switches so that many physical processes may be switched on and off to study their effect on the problem under consideration. In addition the code, while built on a VAX-780, was constructed with vectorization in mind. We note that KLYSMA II differs from KLYSMA in many ways: better numerical algorithms are used (e.g., advanced FCT, implicitly solves the coupled set of ion and electron diffusion equations), new physics is incorporated (e.g., electrons and ions are thermally coupled, new instabilities are considered such as the lower-hybrid-drift instability), the code is vectorized, and the code is well-documented. In addition, very little physics is "hard wired" in KLYSMA II so that modifications and/or upgrades can be easily made as the need arises.

In section II we present the physical processes incorporated into KLYSMA II, the equations that describe these processes, the transport coefficients used, and the numerical algorithms utilized. In section III we present the structure of KLYSMA II and describe the purpose of each module. In section IV all the logical control parameters are defined as well as their purpose. Further a definition for each global array or parameter utilized by KLYSMA II will be given. Finally in section V we present a model run to illustrate the use of the code.

II. Basic Physical Processes and Numerical Algorithms

KLYSMA II is designed to study how the cross-magnetic field transport of a species of ions j with density n_j , temperature T_j and velocity $\underline{V}_j$ interacts one dimensionally with an ambient plasma of ion density n_k , ion temperature T_k , and velocity $\underline{V}_k$, electron density n_e , electron temperature T_e , and electron velocity $\underline{V}_e$ in the presence of a magnetic field $\underline{B}$. Because the heating and momentum coupling rates may be controlled by either collective ("anomalous") plasma processes and/or classical binary collisions, prescriptions for the computation of collective cross-field transport processes, as well as

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classical transport processes, are incorporated into KLYSMA II. The anomalous transport coefficients and the prescriptions for their use that are incorporated into KLYSMA II, with the exception of the lower hybrid drift instability (LHDI) and the drift cyclotron instability (DCI), can be found in Lampe et al (1975). The transport coefficients resulting from the LHDI and DCI, and the prescriptions for their use were obtained from Huba (1983). All classical transport coefficients utilized in KLYSMA II can be found in Braginskii (1965).

The following equations are solved:

$$\frac{\partial n_j}{\partial t} + \underline{v} \cdot (n_j \underline{v}_j) = 0, \quad (1)$$

ion continuity equation,

$$\begin{aligned} \frac{\partial}{\partial t} (m_j n_j \underline{v}_j) + \underline{v} \cdot (m_j n_j \underline{v}_j \underline{v}_j) = \\ - \underline{v} P_j + Z_j n_j e (\underline{E} + \frac{\underline{v}_j \times \underline{B}}{c}) + \underline{R}_j, \end{aligned} \quad (2)$$

ion momentum equation,

$$\frac{1}{(\gamma_j - 1)} \left[\frac{\partial P_j}{\partial t} + \underline{v}_j \cdot \underline{v} P_j \right] = - P_j \underline{v} \cdot \underline{v}_j - \underline{v} \cdot \underline{q}_j + Q_j \quad (3)$$

ion pressure equation,

$$\underline{E} = \frac{-\underline{v}_e \times \underline{B}}{c} - \frac{\underline{v} P_e}{en_e} + \underline{R}_e, \quad (4)$$

force balance on electrons,

$$\frac{1}{(\gamma_e - 1)} \left[\frac{\partial P_e}{\partial t} + \underline{v}_e \cdot \underline{v} P_e \right] = P_e \underline{v} \cdot \underline{v}_e - \underline{v} \cdot \underline{q}_e + Q_e, \quad (5)$$

electron pressure equation,

$$N_e = \sum_j Z_j N_j, \quad (6)$$

quasi-neutrality,

$$\nabla \times \underline{E} = - \frac{1}{c} \frac{\partial \underline{B}}{\partial t}, \quad (7)$$

Faraday's Equation,

$$\nabla \cdot \underline{B} = 0 \quad (8)$$

and

$$\underline{V}_e = \sum_j Z_j n_j \underline{V}_j - \frac{c}{4\pi n_e} \nabla \times \underline{B}, \quad (9)$$

Ampere's Equation,

where $P_j = n_j k_b T_j$, e is the magnitude of the electron charge, Z_j the charge state of the ion species j , m_j the mass of ion species j , and m_e the electron mass.

$\underline{R}_j$ represents the rate of momentum exchange between ion species k and j , and between ion species j and electrons, and has the general form

$$\underline{R}_j = \sum_{k=i,e} v_{jk} \frac{n_k m_k n_j m_j}{n_j m_j + n_k m_k} (\underline{V}_k - \underline{V}_j), \quad (10)$$

where v_{jk} represents the total effective collision frequency (both anomalous and classical) between species k and ion species j or the electrons. Q_j represents the rate at which ion species j is heated or cooled $\text{cm}^{-3}\text{s}^{-1}$ due to energy exchange between ion species j and the other plasma constituents and has the form

$$Q_j = \sum_k v_{jk} (\underline{V}_k - \underline{V}_j)^2 \frac{n_j m_j n_k m_k}{n_j m_j + n_k m_k} + \frac{3m_e}{m_j} \frac{n_e k_b}{\tau_{ej}} (T_e - T_j), \quad (11)$$

where the index k in the sum runs only over the ion species,

$$\tau_{ej} = \frac{3/m_e (k_b T_e)^{3/2}}{4\sqrt{2\pi} \lambda e^4 Z_j^2 n_j},$$

and λ is the Coulomb logarithm (Braginskii, 1965, p.215). $\underline{q}_j$ represents the perpendicular to $\underline{B}$ heat flux carried by the ion species j and has the form

$$\underline{q}_j = K_j^j \underline{V}_j (k_b T_j), \quad (12)$$

where

$$\kappa_j = \frac{n_j k_b T_j \tau_j}{m_j} \frac{(\alpha x^2 + \beta)}{(x^4 + \gamma x^2 + \delta)},$$

$$\tau_j = \text{MINIMUM} \left(\frac{3/m_j (k_b T_j)^{3/2}}{4\sqrt{\pi} e^4 Z_j^4 n_j}, \tau_{jan} \right),$$

τ_{jan} being the anomalous value of τ_j due to collective processes, $x = \Omega_{cj} \tau_j$, $\Omega_{cj} = Z_j e B / m_j c$, and $\alpha, \beta, \gamma, \delta$ are given by Braginskii (1965) according to the charge state of the ion species j .

q_e is the electron heat flux given by

$$\underline{q}_e = -K_j^e \underline{\nabla}_j (k_b T_e), \quad (13)$$

where

$$K_j^e = \frac{n_e k_b T_e \tau_{eff}}{m_e} \frac{(\gamma_1 y^2 + \gamma_0)}{(y^4 + \delta_1 x^2 + \delta_0)},$$

$\tau_{eff} = \text{MINIMUM} (\tau_e, \tau_{an})$, τ_{an} being the anomalous value of τ , $y = \Omega_{ce} \tau_{eff}$, $\Omega_{ce} = e B / m_e c$, and $\gamma_1, \gamma_0, \delta_1, \delta_0$ are given by Braginskii.

The quantity $\underline{R}_e$ and Q_e represent, respectively, the rate at which momentum and energy is gained or lost by electrons and have the form

$$\underline{R}_e = \sum_k m_e n_e v_{eff} (\underline{v}_k - \underline{v}_e) \quad (14)$$

and

$$\underline{Q}_e = \sum_k \left\{ m_e n_e v_{eff} (\underline{v}_k - \underline{v}_e)^2 + \frac{3 m_e n_e k_b}{m_k \tau_{ek}} (T_k - T_e) \right\} - R_{rad}, \quad (15)$$

where R_{rad} represents radiation losses.

These equations are solved in a time split fashion because of the wide range of time scales associated with the physical processes contained in equations (1) - (9). Momentum exchange between ion species, and electrons represented by $\underline{R}_j$ in (2), is treated implicitly, as are the thermal transport and the source and sink terms generically denoted by

$$-\nabla \cdot \mathbf{q} + Q$$

(16)

in equations (3) and (5). All other source terms in equations (2)-(5) are treated as explicit source terms for the appropriate calls to the explicit FCT module DSSFCT (Boris, 1976).

The module MULTIF performs all convective transport by splitting the integration into half and full time steps so as to achieve space and time centering. Module MULTIF calls MONTRN which implicitly exchanges momentum among the various plasma constituents. If the user selects LTCENT = .FALSE. the hydro timestep DT is split into many subcycles each with a time step DTC such that $DT = NTIME * DTC$. DTC is the time step associated with the shortest physical process contained in Q of (16). Under these circumstances the classical and anomalous transport coefficients are updated NTIME times with DIFFX3 being called after each update. DIFFX3 is an implicit module designed to be fully compatible with the FCT module. Physically subcyclng the heating, cooling, and equilibration terms in the pressure equations is fully justified because Q changes very rapidly on a hydro time scale making it necessary to update the flow quantities less frequently. However, in the event the user prefers a fully time centered run, which is less economical but nevertheless more accurate, taking LTCENT = .TRUE. will achieve this so that $DT = DTC$ and $NTIME = 1$. DIFFU3, which is called by DIFFX3, solves (implicitly the ion and electron) diffusion equations, together with equilibration and source terms, simultaneously utilizing the time step determined by DTSET and the condition of LTCENT. It incorporates a special finite differencing technique that requires the energy flux from the center of the cell I to the interface of the cell to equal the energy flux from the interface to the center of the cell I+1. This allows the temperature drop between cells to occur predominately in the cell with the smaller coefficient of thermal conduction, as would occur physically.

Subroutine REZONE allows the user to "window" the flow via a sliding rezone technique that uses the maximum and minimum velocity of ion specie 2 (the debris or "injected ion") to slide the window along with the flow if FLAG = 0.0, or a Lagrangian capability if FLAG = 1.0. The subroutine DTSET computes self-consistently the time-step necessary for numerical stability as

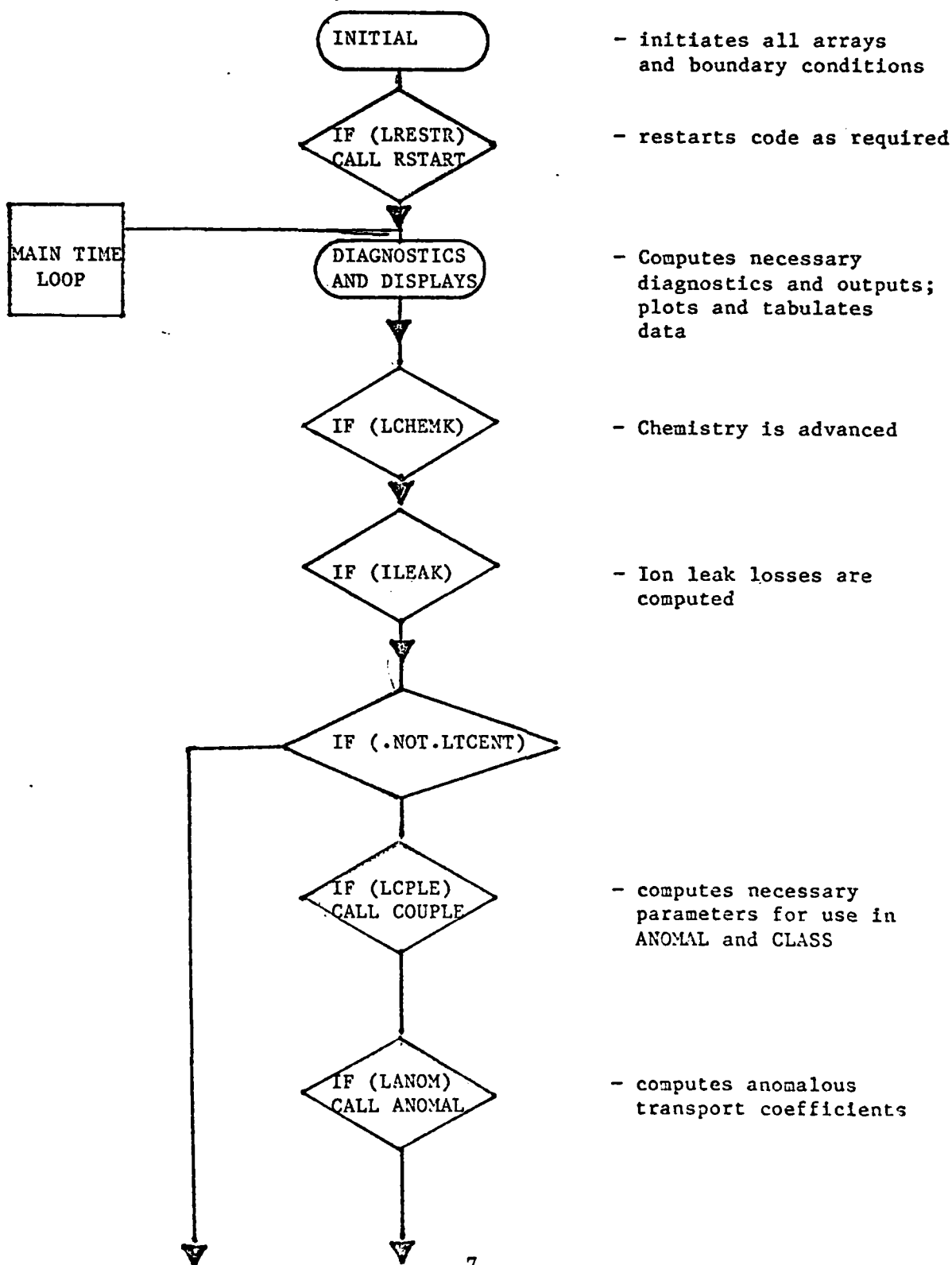
well as enforcing the condition that no physical quantity vary by more than $\sim 5\%$ in a timestep.

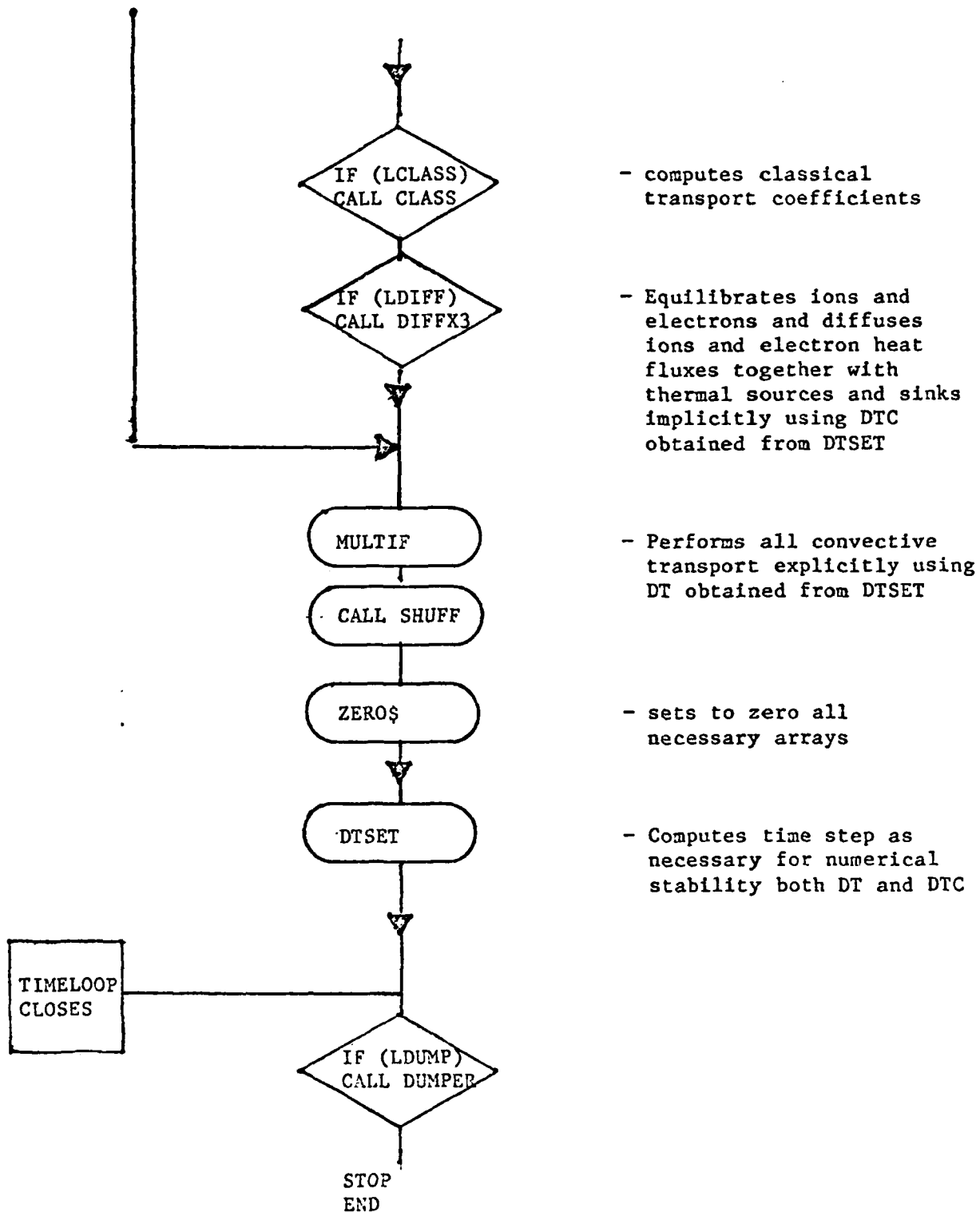
Ideally, debris (ion fluid 2) - air (ion fluid 1) coupling should be studied with a macroparticle or hybrid scheme which resolves the complex interaction of the two streams in velocity space. This is not always feasible for reasons which include economics and machine limitations. A compromise can be achieved through the use of a multi-fluid scheme. It permits the air and debris plasmas to maintain separate identities, and to interpenetrate. With a single fluid scheme, stagnation flow occurs at the debris-air interface and all local relative streaming energy is transformed into thermal energy. There is no way to study anomalous ion-ion coupling with the latter scheme, since the single fluid assumption implies a single fluid velocity at every point.

With as few as two fluids, a multifluid scheme can reproduce rather faithfully the configuration in phase space predicted by a macroparticle scheme. In one respect, however, it will eventually predict incorrect behaviour unless corrective measures are taken. Air plasma which has "coupled" via collisions, classical or collective, or via Larmor processes, to the expanding debris plasma subsequently moves along with the debris, i.e., it is picked up. This picked up air and debris mixture then interacts with the incoming upstream air plasma, via the same processes which earlier coupled the debris to the picked air, rather than stagnating and producing a shock. One way to deal with this pickup is to reassign some portions of the picked-up air fluid to the debris fluid. This is implemented in KLYSMA via SHUFF. SHUFF uses the assumption that both air and debris have Maxwellian radial velocity distributions. It then imposes a velocity cutoff, such that all plasma above the cutoff velocity is considered to be debris, and all plasma below it is taken to be air. In addition, conservation of mass, momentum, energy, and charge are imposed in the transfer process.

III. Code Structure

As noted in the introduction the code is modular, the code is driven from the main subroutine MAINMF, which is structured as follows:





SUBROUTINE INITIAL

This subroutine reads initial data, boundary conditions, and boundary condition factors off disc to initiate the run. In addition, it sets up the initial conditions. In general this fortran module will be the one most likely modified by the user.

SUBROUTINE RSTART

This subroutine restarts the run at the necessary time step by reading from disc the data written there by DUMPER. Subroutine DUMPER must be called at least once before calling RSTART. For example, the user may want to run the code first from 1 to the 2001 timestep, and then dump the data to disc for restarting. Thus initially LDUMP = .TRUE. and LRESTR = .FALSE. When restarting the code at timestep 2001 LRESTR must be .TRUE.. LDUMP may be .TRUE. or .FALSE. depending on whether the user wants to restart KLYSMA II again.

SUBROUTINE ZERO

This subroutine simply sets to zero all arrays that are used in summation processes.

SUBROUTINE COUPLE

This subroutine computes a variety of physical parameters needed to compute both the classical and anomalous transport coefficients. Both ANOMAL and CLASS are entries to COUPLE. COUPLE must be called prior to either ANOMAL or CLASS.

ENTRY ANOMAL

This entry into couple computes the cross-field anomalous transport coefficients based on Lampe et al (1975).

ENTRY CLASS

This entry into couple computes the cross-field classical transport coefficients obtained from Braginsky (1965).

SUBROUTINE PRNT

This subroutine prints all transported quantities as well as the individual source terms for the momentum and temperature equations. IPRNT determines the number of time cycles between calls to PRNT.

SUBROUTINE PAGEPL (CALCM)

This subroutine generates page plots (versatex plots using NCAR plot package) of the same quantities printed by PRNT. IPAGE determines the number of time cycles between calls to PAGEPL (CALCM).

SUBROUTINE DIAG

This subroutine generates a time (or ordinate) versus distance (abscissa) curve of the position of the coupling shell. The point at which the magnetic field has a maximum is used as the spatial position of the coupling shell at time t.

SUBROUTINE DTSET

This subroutine is designed to determine the maximum timestep permitted that will still be numerically stable. It computes both DTC and DT.

SUBROUTINE DIFFX3

This subroutine transports the thermal heat flux of the electrons and ions perpendicular to the attendant magnetic field as well as the thermal sources and sinks. It utilizes a special subroutine DIFFU3 that implicitly solves the coupled set of ion and electron diffusion equations and is designed to be fully compatible with the FCT Module DSSFCT. A call to DIFGE3 must be made prior DIFFU3 so that the updated metric coefficients needed in DIFFU3 are generated.

SUBROUTINE MULTIF

This subroutine is the heart of KLYSMA. It utilizes the FCT Module DSSFCT to solve the various fluid equations. Note that the transport coefficients used in these source terms are not time centered when LTCENT = .FALSE. However, when LTCENT = .TRUE. all of the transport coefficients,

anomalous and classical, are recomputed both at the half and the full time step. In addition, DIFFX3 is called at both the half and full time step if LTCENT = .TRUE.

MULTIF also calls a Subroutine REZONE that keeps the flow "windowed" spatially between the maximum and minimum values of the debris velocity.

SUBROUTINE SHUFF

This subroutine is designed to allow air (J=1 fluid) to be picked up by the faster moving debris (J=2 fluid) and for any deaccelerating debris to be converted to slower air. To accomplish this an algorithm is used that assumes both ion species are locally Maxwellian within a grid cell and drifting with a speed $VIX(I,J)$. In addition, it is assumed that whenever the air fluid velocity exceeds $V_D = (VIX(I,1) + VIX(I,2))/2$ that fraction of the air distribution that exceeds V_D becomes debris. In other words the fraction $\int_{V_D}^{\infty} f_{air} dv_x$ stays air and the fraction $\int_{-\infty}^{V_D} f_{air} dv_x$ becomes debris. Likewise for the debris. With these assumptions, together with the requirements that mass, momentum, energy and charge be conserved within a cell volume adjusted densities, velocities, temperatures, and charges are computed.

SUBROUTINE HANE\$

This subroutine contains three entries, HANE\$, SOLAR\$, and LASER\$, each of which computes the initial conditions for a HANE, SOLAR, or LASER Run.

SUBROUTINE ILEAK

This subroutine computes the total number of debris ions loss from the coupling shells, as well as, the total debris energy loss based on the loss cone instability.

IV. DEFINITIONS

The Module GLOBMF.FOR contains all the parameters global to KLYSMA. The following common blocks are included in GLOBMF. FOR.

COMMON/DIM/

NSPEC:	Number of ion species, presently dimensioned as MSPEC = 2 in the parameter statement
NCHEM:	Number of ionization levels followed for each ion species
NINSTE:	Number of electron-ion two stream instabilities, presently dimensioned as MINSTE = 4 in the parameter statement
NINSTI:	Numer of ion-ion two stream instabilities, presently dimensioned as MINSTI = 2 in the parameter statement

COMMON/PHYSIC/

NI (NPT, MSPEC):	ion number densities (particles cm^{-3})
TI (NPT, MSPEC):	ion temperatures (degrees Kelvin)
VIX (NPT, MSPEC):	ion drift velocities in x direction (cm/s)
VIY (NPT, MSPEC):	ion drift velocities in y direction (cm/s)
VIZ (NPT, MSPEC):	ion drift velocities in z direction (cm/s)
PI (NPT, MSPEC):	ion pressures (dynes/ cm^2)
RHO (NPT, MSPEC):	ion mass densities (grams cm^{-3})
RHOI (NPT, MSPEC):	inverse of RHO
NE (NPT):	electron number density (particles/ cm^3)
VEX (NPT):	electron drift velocity in x-direction (cm/s)
VEY (NPT):	electron drift velocity in y-direction (cm/s)
VEZ (NPT):	electron drift velocity in z-direction (cm/s)
BY (NPT):	Y-component of magnetic field (gauss)
BZ (NPT):	Z-component of magnetic field (gauss)
EX (NPT):	X-component of electric field (statvolts/cm)
EY (NPT):	Y-component of electric field (statvolts/cm)
EZ (NPT):	Z-component of electric field (statvolts/cm)
TE (NPT):	electron temperature (degrees Kelvin)
JY (NPT):	y component of current density (statamps/ cm^2)
JZ (NPT):	z component of current density (statamps/ cm^2)
PE (NPT):	electron pressure (dynes cm^{-2})

UNIT (NPT): array of which all elements are one
 ZERO (NPT): array of which all elements are zero
 PEDX (NPT): derivative of PE with respect to x

COMMON/CYCLE

MINSTP: index of STARTING VALUE of time loop
 MAXSTP: index of final value of time loop
 IDIAG: frequency of calls to DIAG
 IPRNT: frequency of calls to PRNT
 IPAGE: frequency of calls to PAGEPL
 IFlick: frequency of calls to FLICK (dummy at present)
 ISTEP: value of index corresponding to timestep
 IDUMP: frequency of intermediate dumps

COMMON/MESH/

XCOR (NPT): positions of cell centers
 XCORH (NPC): positions of cell interfaces
 NX: number of cells (or grid points)
 NX1: NX+1 number of cell interfaces
 NX2: NX+2
 ALPHA: Geometry chosen cartesian (ALPHA = 1), cylindrical
 (ALPHA = 2), or spherical (ALPHA = 3)
 FLAG: used if LAGRANGIAN code, FLAG = 0.0 Eulerian,
 FLAG = 1.0 Lagrangian, must be used in conjunction
 with LREZONE = .TRUE.
 DT: hydro time step (secs)
 TIME: TIME (secs)
 DTC: TIME STEP associated with shortest physical process
 modelled by code
 NTIME: NTIME = MAX (DT/DTC, 1)
 COURT: COURANT FACTOR

COMMON/PARA/

CS (NPT, MSPEC): ion sound speed (cm/s)
 WPI (NPT, MSPEC): ion plasma frequency (Hertz)

WCI (NPT, MSPEC): ion cyclotron frequency (Hertz)
 VTI (NPT, MSPEC): ion thermal speed (cm/s)
 VA (NPT, MSPEC): individual ion Alfven speed (cm/s)
 VDEIX (NPT, MSPEC): absolute value of ion-electron drift speeds in
 x-direction (cm/s)
 VDEIP (NPT, MSPEC): absolute value of ion-electron drift speeds
 perpendicular to B (cm/s)
 RCI (NPT, MSPEC): ion thermal Larmor radii
 GYRRAD (NPT, MSPEC): ion non-thermal Larmor radii
 UIJ (NPT): absolute value of ion-ion drift speed in
 in x-direction (cm/s)
 VTE (NPT): electron thermal speed (cm/s)
 WPE (NPT): electron plasma frequency (Hertz)
 WCE (NPT): electron cyclotron frequency (Hertz)

COMMON/BOUND/ see Boris NRL Memo Report (3237)

NIR (MSPEC): RIGHT ion density boundary condition factor
 NIL (MSPEC): LEFT ion density boundary condition factor
 NIRO (MSPEC): RIGHT ion density boundary value
 NILO (MSPEC): LEFT ion density boundary value
 VIXR (MSPEC): RIGHT ion x-velocity boundary condition factor
 VIXL (MSPEC): LEFT ion x-velocity boundary condition factor
 VIXRO (MSPEC): RIGHT ion x-velocity boundary value
 VIXLO (MSPEC): LEFT ion x-velocity boundary value
 VIYR (MSPEC): RIGHT ion y-velocity boundary condition factor
 UIYL (MSPEC): LEFT ion y-velocity boundary condition factor
 VIYRO (MSPEC): RIGHT ion y-velocity boundary value
 VIYLO (MSPEC): LEFT ion y-velocity boundary value
 TIR (MSPEC): RIGHT ion temperature boundary condition factor
 TIL (MSPEC): LEFT ion temperature boundary condition factor
 TIRO (MSPEC): RIGHT ion temperature boudary value
 TILO (MSPEC): LEFT ion temperature boundary value
 TER: RIGHT electron temperature boundary condition factor
 TEL: LEFT electron temperature boundary condition factor
 TERO: RIGHT electron temperature boundary condition
 TELO: LEFT electron temperature boundary condition

BZR: RIGHT z-component of B boundary condition factor
 BZL: LEFT z-component of B boundary condition factor
 BZRO: RIGHT z component of B boundary value
 BZLO: LEFT z-component of B boundary value

COMMON/CHEM/

RAD (NPT): Radiation Losses (ergs/cm³/s)
 NIZ (NPT, MSPEC, NCHEM): Particles cm⁻³ for each ionization state of a
 given ion specie

COMMON/TRANS/

VPIX (NPT, MSPEC, MINSTE): Phase velocities in x-direction for a given
 electron-ion two stream instability (cm/s)
 VPIEY (NPT, MSPEC, MINSTE): Phase velocities in y-direction for a given
 electron-ion two stream instability (cm/s)
 VEFF (NPT, MSPEC, MINSTE): effective collision frequencies resulting
 from a given electron-ion two stream instability (Hertz)
 VEFFII (NPT, MINSTI): effective ion-ion collision frequency resulting
 from a given ion-ion two stream instability (Hertz)
 VP II (NPT, MINSTI): phase velocities in x-direction for a given ion-ion
 two stream instability (cm/s)
 EQBIE (NPT, MSPEC): classical electron-ion equilibration frequencies
 (Hertz)
 VEI (NPT, MSPEC): classical electron-ion collisional frequencies (Hertz)
 COLJE (NPT, MSPEC): total effective electron-ion collision frequency,
 anomalous + classical (Hertz)
 KAPI (NPT, MSPEC): ion thermal conduction coefficient
 VII (NPT, MSPEC): classical ion-ion collision frequency (Hertz)
 EQBIK (NPT, MSPEC): classical ion-ion equilibration frequency (Hertz)
 COLKJ (NPT, MSPEC): classical ion-ion momentum exchange rate
 OFFLAR (NPT, MSPEC): binary switch used to turn off Larmor coupling
 terms if effective ion-ion collision frequency exceeds ion gyro frequency
 COLJK (NPT, MSPEC, MINSTI): anomalous ion-ion momentum exchange rate
 RESIS (NPT): classical resistivity (sec)
 KAPE (NPT): electron thermal conduction coefficient
 RSIZE: system size parallel to B field (cm)

COMMON/TIMSTP/

DRAG(NPT, 16, MSPEC): individual terms that result in ion acceleration or
drag (dynes)

IONH(NPT, 16, MSPEC): individual terms that result in ion cooling or
heating (ergs/cm³/s)

ELECH(NPT, 16): individual terms that result in electron heating or
cooling (ergs/cm³/s)

COMMON/CONST/ - all physical constants are c.g.s.

EC: Electron charge, ECI = 1.0/EC
BK: Boltzmann's constant, BKJ = 1.0/BK
C: Speed of light, CI = 1.0/C
PIE: 3.145927
PIE4: 4.0 * PIE
PIE8: 8.0 * PIE
EM: electron mass
EMEC: EM/EC
GAME: electron ratio of specific heats
GAME1: GAME-1
GAME2: GAME-2
GAMI ion ratio of specific heats
GAMI1: GAMI-1
GAMI2: GAMI-2
EVK: Conversion fractor from eV to degrees Kelvin

COMMON/ION/

MASS (MSPEC): ion masses (grams)
MASSI (MSPEC): inverse of MASS
MR (MSPEC): electron to ion mass ratio for each ion specie
SQMR (MSPEC): inverse of SQMR
SMASSI (MSPEC): square root of MASSI
Z(NPT, MSPEC): ion charge

COMMON/LOGIC/

LPAGE: control switch to call PAGEPL
LPRNT: control switch to call PRNT
LCPLE: control switch to call COUPLE
LANOM: control switch to call ANOMAL
LCLASS: control switch to call CLASS
LRESTR: control switch to call RSTART
LDUMP: control switch to call DUMPER
LNEU: control switch to call NEUTRALS (Dummy for now)
LRAD: control switch to call RADIAT (Dummy for now)
LDOAG: control switch to call DIAG
LIAI: switches on ion-acoustic instability if LANOM = TRUE
LBCI: switches on beam cyclotrm instability if LANOM = TRUE
LMTI: switches on modified two stream instability if LANOM = TRUE
LMII: switches on magnetized ion-ion instability if LANOM = TRUE
LUII: switches on unmagnetized ion-ion instability if LANOM = TRUE
LHDI: switches on unmagnetized lower hybrid drift instability
if LANOM = TRUE
LVISCO: switches on artificial viscosity
LDIFF: control switch for DIFFX3
LARMOR: switches on or off ion Larmor coupling
LSHUFF: control switch to call SHUFF
LILEAK: control switch to call ILEAK
LTCENT: if true transport is fully time and space centered
LSTION: control switch to call Supra thermal ion module
(dummy for now)
LBOHM: control switch to call BOHM (dummy for now)
LCHEM: control switch to call chemistry module
LJAC71: control switch to call JAC71 - not used
LHANE: control switch to call HANE
LSOLAR: control switch to call SOLAR
LLASER: control switch to call LASER
LECHO: control switch to call to give positions for module transfer
LSTOP: control switch to call to stop code
LFLICK: control switch to call FLICK (Dummy for now)
LREZON: control switch to call REZONE

LCALCM control switch to call CALCM
LPARTX control switch to call PARTX (Dummy for now)

COMMON/REZONE/

IMAX: index where VIX (1,2) has its maximum
IMIN: index where VIX (1,2) has its minimum
VNEW (NPT): see subroutine rezone
XOLD (NPT): old x-coordinates

COMMON/HANE/

HRA: hour of HANE, military time
LAT: latitude of HANE
DAY: day of year based on sequential numbering
ALT: altitude
YIELD: energy yield of HANE in megatons
WMASS: weapon mass in kilograms
RXRADN: ionization distance
BACKIZ: level of background ionization
NTOTAL: total number of debris ions
RMASS: Radius at a weapon mass of ambient plasma

COMMON/ILEAK/

NLOSS: total number of debris ions loss down field lines
ELOSS: total energy of debris ions loss down field lines
IFLUX (2000): debris ion flux (particles $\text{cm}^{-2} \text{sec}^{-1}$)

V. CASE RUN

The following initial data and boundary condition factors were used to initialize the run presented below.

The output for this run is presented below. No physical interpretation of this output will be presented here since the results are only presented for code documentation purposes. The initialization parameters given, while arbitrary, are designed to test the code performance. The run starts at time = 0.0 and runs up to 0.5 millisecs. Figure 1 illustrates the initial profiles selected (viz., densities, temperatures, pressures, electric fields, and magnetic field), while Figure 2 illustrates the formation of the debris-air interface $t \approx 0.5$ millisecs. Within this interface air is swept up by the debris, a laminar electric field capable of debris air acceleration is formed, and significant ion-electron heating occurs.

\$CYC

MINSTP = 1,
MAXSTP = 101,
IFLICK = 500,
IDIAG = 10,
IPRNT = 100,
IPAGE = 100,
IDUMP = 10,
NSPEC = 2.

\$END

\$BCI

NIR(1)	= 0.0,	NIR(2)	= 1.0,
NIL(1)	= 1.0,	NIL(2)	= 1.0,
NIRO(1)	= 5.504E7,	NIRO(2)	= 0.0,
NILO(1)	= 0.0,	NILO(2)	= 0.0,
VIXR(1)	= 1.0,	VIXR(2)	= 1.0,
VIXL(1)	= 1.0,	VIXL(2)	= 1.0,
VIXRO(1)	= 0.0,	VIXRO(2)	= 0.0,
VIXLO(1)	= 0.0,	VIXLO(2)	= 0.0,
VIYR(1)	= 1.0,	VIYR(2)	= 1.0,
VIYL(1)	= 1.0,	VIYL(2)	= 1.0,
VIYRO(1)	= 0.0,	VIYRO(2)	= 0.0,
VIYLO(1)	= 0.0,	VIYLO(2)	= 0.0,
VIZR(1)	= 1.0,	VIZR(2)	= 1.0,
VIZL(1)	= 1.0,	VIZL(2)	= 1.0,
VIZRO(1)	= 0.0,	VIZRO(2)	= 0.0,
VIZLO(1)	= 0.0,	VIZLO(2)	= 0.0,
TIR(1)	= 0.0,	TIR(2)	= 1.0,
TIL(1)	= 1.0,	TIL(2)	= 1.0,
TIRO(1)	= 1.161E7,	TIRO(2)	= 0.0,
TILO(1)	= 0.0,	TILO(2)	= 0.0,
PIR(1)	= 0.0,	PIR(2)	= 1.0,
PIL(1)	= 1.0,	PIL(2)	= 1.0,
PIRO(1)	= 8.81E-2,	PIRO(2)	= 0.0,
PILO(1)	= 0.0,	PILO(2)	= 0.0,
VIR(1)	= 0.0,	VIR(2)	= 0.0,
VIL(1)	= 0.0,	VIL(2)	= 0.0,

\$END

\$IOND

MASS(1) = 2.34E-23, MASS(2) = 4.51E-23,
ZZ(1) = 1.0, ZZ(2) = 1.0,
TIMIN(1) = 1.1605E4, TIMIN(2) = 0.0,
NIMIN(1) = 0.0, NIMIN(2) = 0.0,
TEMIN = 1.1605E4,

\$END

\$BCE

TER	= 0.0,	TEL	= 1.0,
TERO	= 1.161E6,	TELO	= 0.0,
PER	= 1.0,	PEL	= 1.0,
PERO	= 0.0,	PELO	= 0.0,
VER	= 0.0,	VEL	= 0.0,
BYR	= 1.0,	BYL	= 1.0,
BYRO	= 0.0,	BYLO	= 0.0,
BZR	= 0.0,	BZL	= 1.0,
BZRO	= 0.5,	BZLO	= 0.0,

\$END

\$CONTRL

LPAGE = F, LPRNT = T, LCPL = T, LCLASS = T,
LRESTR = F, LDUMP = T, LDIAG = T, LNEU = F,
LRAD = F, LANOM = T, LIAI = T, LBCI = T,
LMTI = T, LMII = T, LUII = T, LHDI = T,

LVISCO = T, LDIFF = T, LJOULE = F, LARMOR = T,
 LSHUFF = T, LILEAK = F, LTCENT = F, LSTION = F,
 LBOHM = F, LCHEM = T, LJAC71 = F, LHANE = T,
 LSOLAR = F, LLASER = F, LECHO = T, LSTOP = F,
 LFLICK = F, LREZON = T, LCAALCM = T,

\$END

\$INTDAT

XMIN = 1.0E5,
 XMAX = 1.0E6,
 NX = 99,
 DT = 1.0E-10,
 COURT = 0.2,
 ALPHA = 3,
 TIME0 = 0.0,
 BY0 = 0.0,
 BYMIN = 0.0,
 BZ0 = 0.5,
 BZMIN = 0.0,
 YSCALE = 0.0,
 ZSCALE = 0.0,
 VZERO = 2.0E8,
 NDZERO = 1.0E9,
 NAZERO = 1.0E8,
 TDZERO = 1.1605E7,
 TAZERO = 1.1605E4,
 TEZERO = 1.1605E6,
 RSIZE = 1.0E10,
 FLAG = 1.0,

\$END

\$HANE

HRA = 0.0,
 LAT = 40.0,
 DAY = 180,
 ALT = 400.0,
 YIELD = 1.2,
 WMASS = 1.0,
 TEH = 1.0E6,
 BZRH = 0.5

\$END

\$SOLAR

BETA = 1.0E-3,
 VSOLAR = 1.0E8,
 FMASS = 1.0E12,
 FENER = 5.0E27,
 TIAS = 1.0E6,
 TIDS = 1.0E4,
 TES = 1.0E6,
 NIAS = 1.0E10,
 NIDS = 1.0E12,
 BZRS = 1.0E2,

\$END

\$LASER

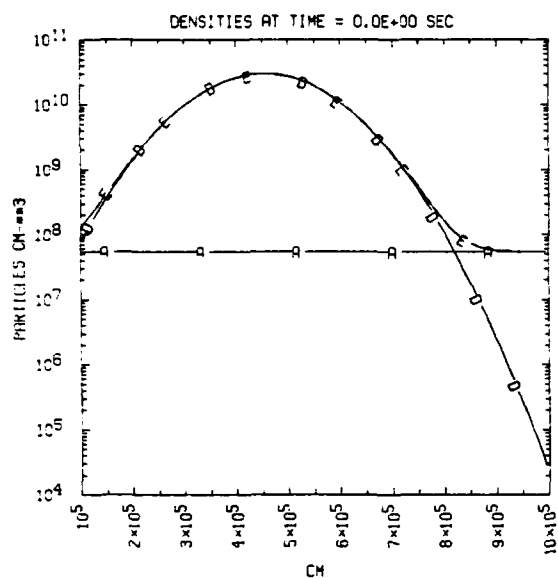
JOULES = 30.0,
 TMASS = 4.51E-7,

\$END

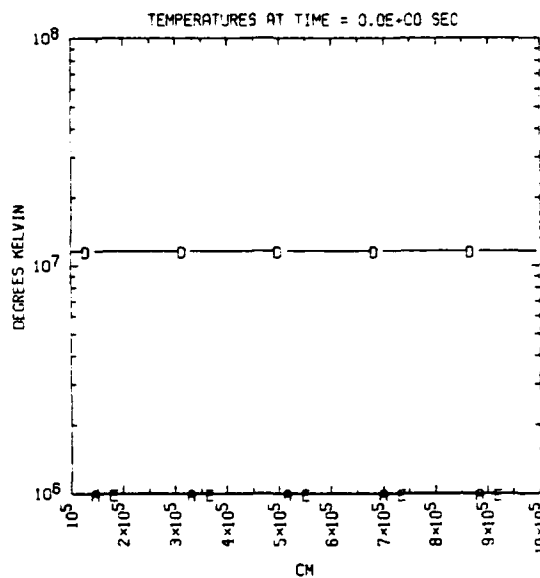
\$CHEM

NCHEM(1) = 6,
 NCHEM(2) = 9,
 ACHEM = 1.0,

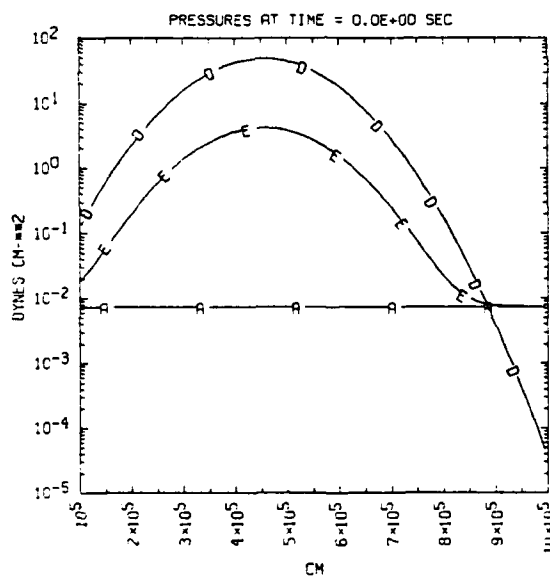
\$END



(a)

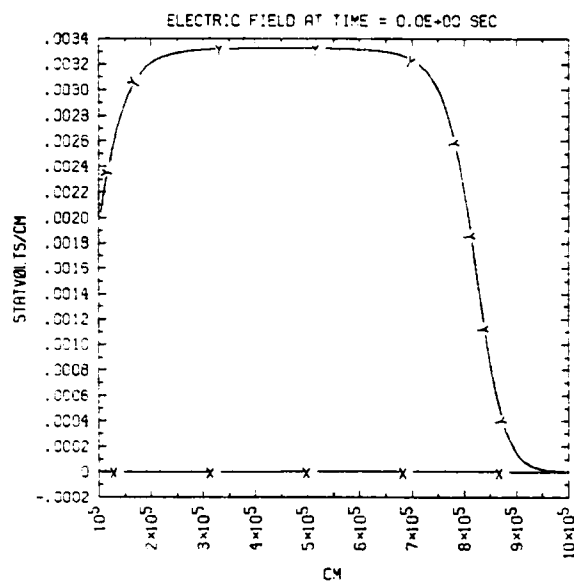


(b)

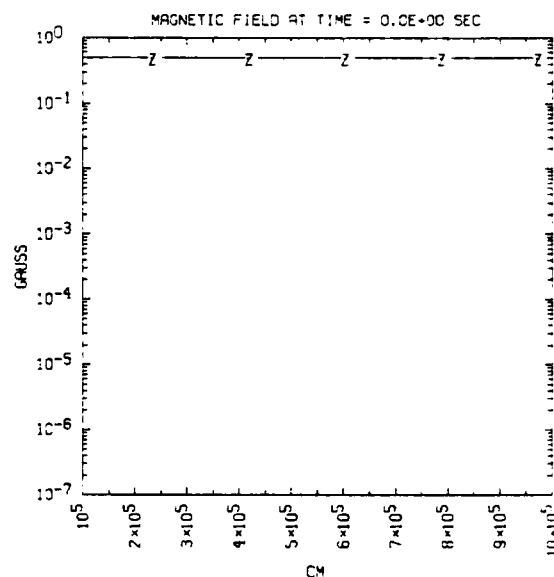


(c)

Figure 1. Initial conditions ($t = 0$). Shown are the (a) densities, (b) temperatures, (c) pressures, (d) electric fields, and (e) magnetic field profiles used to initialize the run.

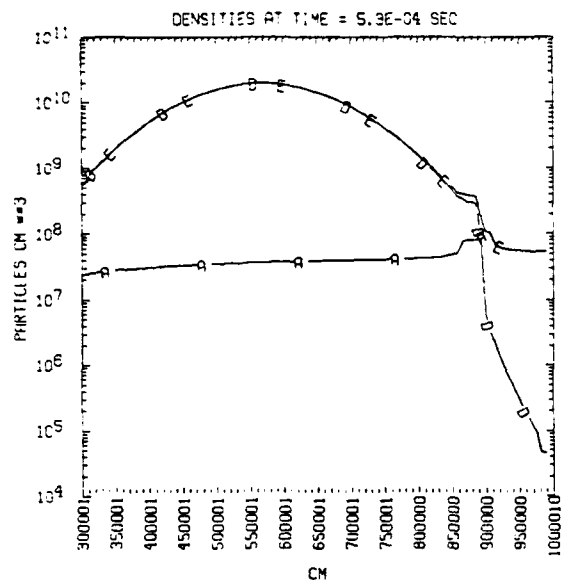


(d)

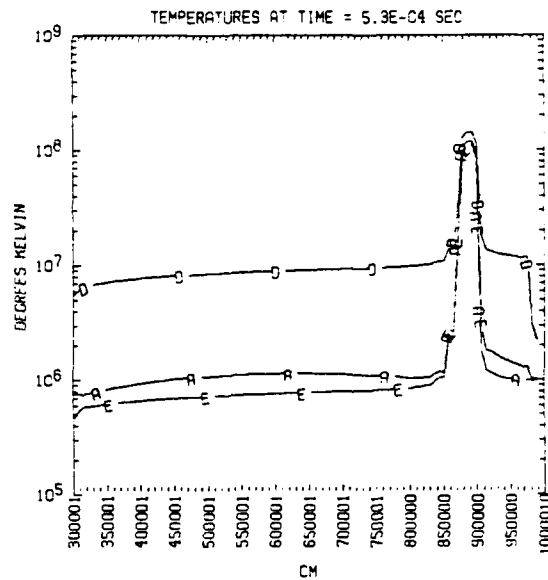


(e)

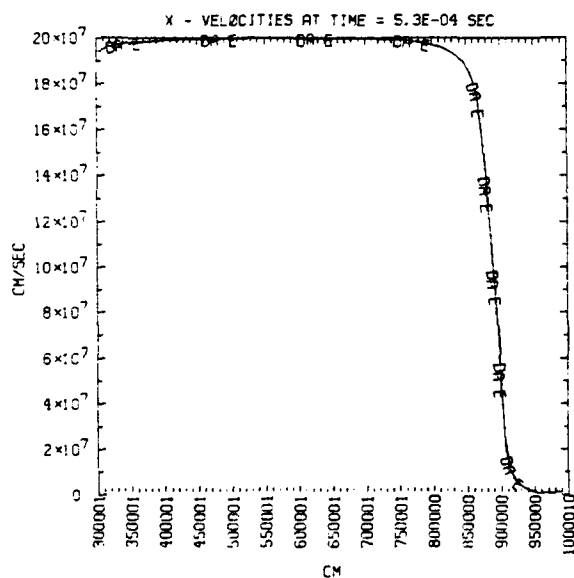
Figure 1. Initial conditions ($t = 0$). Shown are the (a) densities, (b) (cont'd.) temperatures, (c) pressures, (d) electric fields, and (e) magnetic field profiles used to initialize the run.



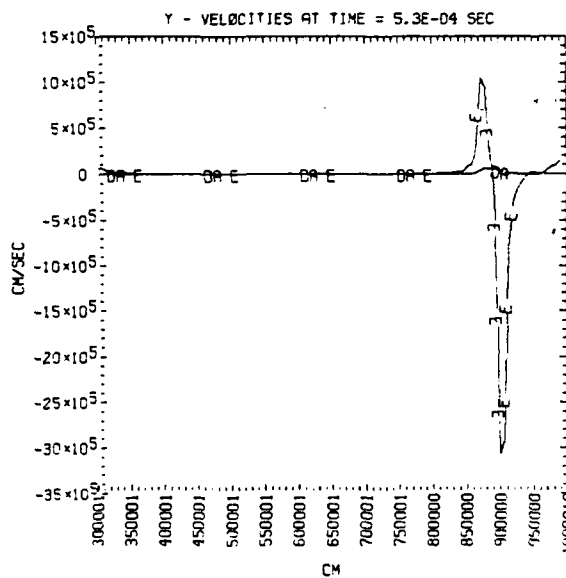
(a)



(b)

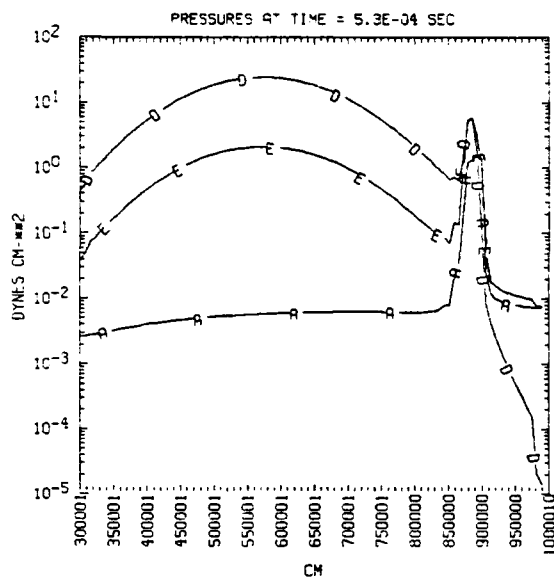


(c)

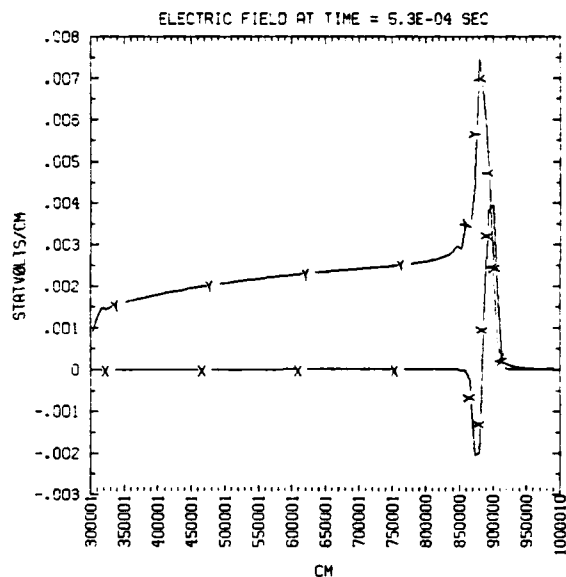


(d)

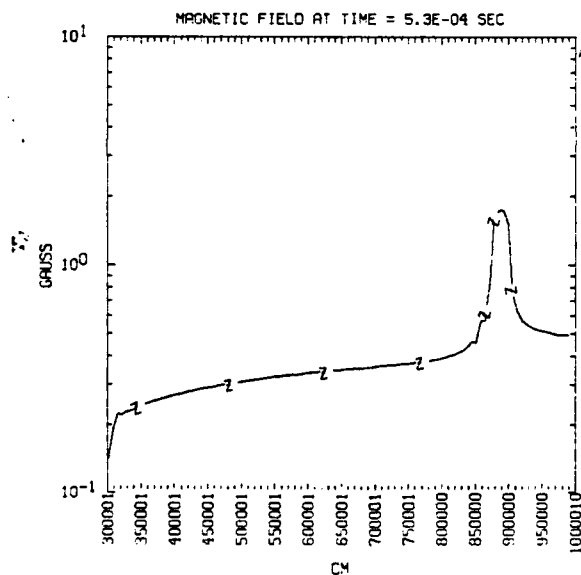
Figure 2. Final conditions ($t = 5.3 \times 10^{-4}$ sec). Shown are the (a) densities, (b) temperatures, (c) x velocity, (d) y velocity, (e) pressures, (f) electric fields, and (g) magnetic field profiles after approximately 0.5 milliseconds.



(e)



(f)



(g)

Figure 2. Final conditions ($t = 5.3 \times 10^{-4}$ sec). Shown are the (a) densities, (b) temperatures, (c) x velocity, (d) y velocity, (e) pressures, (f) electric fields, and (g) magnetic field profiles after approximately 0.5 millisecs.

Acknowledgments

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