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KEG, An Eulerian Configuration Generator for BBC and VOA

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PREFATORY NOTE

This manuscript fully describes the use of KEG and CONDUMP, and supersedes any and all previous documentation related to them. Those who have used these codes before should note the following changes:

- 1) The polynomial equations of state have been completely revised. The older forms of input will no longer be valid.
- 2) The HY, D, EN and TN input cards have been modified.
- 3) New features have been added which relate to setting up the region boundaries (E4 and M4 cards), physical attributes (VORTEX card), equations of state (RM card), boundary conditions (title and WALL cards), and lower bounds on the attributes (FLOOR card).
- 4) The options on the execute line have been modified slightly.
- 5) A PL (for plasma) card has been added for VOA users.
- 6) Because of 1), TLU no longer exists. A more up-to-date version is in preparation, and will operate independently of the restart dump.
- 7) Pages 23 and 25 may be reproduced for convenience.
- 8) CONDUMP's capability has been expanded to include other BBC peripheral output files.

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I. INTRODUCTION

A. Brief Generalities

From time to time in the calculation of a computer-simulated hydrodynamics problem, the running code may pause to dump out onto a storage disk a file containing all the physical variables of the problem relevant to the calculation at the time of dumping. If these variables are suitably arranged in the file so that the running code can accept them as input to resume the calculation anew, the file is called a restart dump.

The first restart dump - the one from which the calculation is originally begun - can be made any number of ways. A generator code can produce this first restart dump directly from suitable input information. A link code can copy the results of a calculation done by another hydrodynamics code, and make up a restart dump from this information; the problem physics can thus be modified (intentionally or otherwise) in this linking process. All other procedures merely involve mixing these two methods in varying degrees. For example, a restart dump produced in the usual course of running the calculation can be modified, and so serve as an initial restart dump to begin a variation on the original problem. Depending on one's semantic taste, this could be referred to as a regeneration, a rezoning, or a self-link.

KEG is an extremely flexible generator for BBC, a two-dimensional multifluid Eulerian hydrodynamics code,⁽¹⁾ and for VOA,⁽²⁾ a plasma version of BBC. It produces the initial restart dump file from which the code's calculation can begin. KEG is user-oriented; it is initiated and run by the user at the teletype. It requires as input some information on the

TTY execute line, and the contents of a card-image disk file obtained by reading the generator input deck into the machine. The output consists of the restart dump and two or more printer files.

In this document we describe the operating details for the use of KEG, the contents of the input deck required to set up a problem to be calculated on the BBC or VOA, and other miscellanea related to output and file handling. Matters relevant to the actual calculations of the hydrodynamics will be found in references (1) and (2).

B. Eulerian Grid & Conventions

In the two-dimensional Eulerian hydrodynamic calculation for which KEG is the generator, space is partitioned into contiguous cells defined by a fixed, stationary, rectangular grid of lines. The calculation proceeds by determining at each time step how much and in what condition mass enters and leaves each of those cells.

The cells are set up in two ways, depending on the type of symmetry required by the problem.

(1) Two-dimensional planar slab. All fluid motion is confined to the plane, on which a rectangular coordinate system (r,z) is established. The r -axis is taken positive upward with the z -axis positive to the right.

A fixed, finite rectangular grid is set up in the plane, defined by the lines

$$\begin{aligned} r &= R(\ell), & \ell &= \text{Lagrangian horizontal line index} = 1, 2, \dots, \ell_{\max} \\ z &= Z(k), & k &= \text{Lagrangian vertical line index} = 1, 2, \dots, k_{\max} \end{aligned}$$

The grid limits are therefore

$$\begin{aligned} R(1) &\leq r \leq R(\ell_{\max}) \\ Z(1) &\leq z \leq Z(k_{\max}) \end{aligned}$$

and the plane is partitioned into $(k_{\max}-1)(\ell_{\max}-1)$ cells. These cells have unit thickness in the direction normal to the plane. The locations of the grid lines are monotonically increasing in k and ℓ , viz.:

$$R(l) < R(l+1)$$

$$Z(k) < Z(k+1)$$

Mass motion is defined by flux of mass through the interface between adjacent cells. Associated with each interface, therefore, is a mean mass velocity normal to it in the r or z direction as appropriate.

Each cell is identified by the Lagrange index pair (k,l) of its upper right hand corner. These conventions are summarized in Figure 1, on the next page.

(2) Two-dimensional cylinder of rotation. The fluid motion calculation is symmetric about an axis of rotation - i.e. it possesses cylindrical symmetry. The Eulerian grid in this case is obtained by rotating the mesh of Fig. 1 about the z -axis ($r = 0$). The contiguous cells here are now concentric toroids of rectangular cross-section, as shown in Fig. 2. Except for the obvious cylindrical differences, the same labeling and sign conventions apply here as for the planar slab. In the case where $R(1) > 0$, the Eulerian grid when rotated about the z -axis will form a hollow cylinder. The same labels, etc. above also apply. The interface flux velocities are normal to the interfaces: u_z is the velocity through the appropriate annulus in the z -direction, and u_r is the radially outward velocity through the appropriate strip of curved surface.

Figure 1

Figure 2

C. Material Properties

Since the coordinate system in an Eulerian type calculation is assumed fixed, the physical state of a problem being calculated would ideally be defined by density, velocity and temperature distributions as continuous functions of r , z and time.* In machine calculations this is not possible: instead, these attributes are specified by assigning at every time step some average value to the fluid within each cell of the Eulerian grid. Thus, for example, if a grid cell of volume V contains at time t a mass of material m , then a mean density $\rho(r_c, z_c, t) = m/V$ is assigned to the cell, where r_c and z_c locate the midpoint of the cell. All material attributes are cell-centered, except for fluxes and velocities, which are interface-centered.

KEG, at the user's direction, assigns mean values of intensive material attributes to every cell and mean mass velocities to every cell interface. If more than one type of material is in a problem, then this attribute assignment is done separately for each type of material. Cells containing more than one type of material will generally be the rule, rather than the exception.

From this initial ("time-zero") configuration of the problem the actual hydrodynamics calculation begins.

*In VOA, nonequilibrium moments of the corresponding distribution functions are also used. See reference (2).

D. Geometrical Conventions

As there appears to be little, if any precedent for the way in which KEG assigns materials to cells, and since it seems that very few potential users of KEG have had experience with generating an Eulerian-type calculation, it is necessary to go into some detail to explain how KEG sets up its material and attribute assignments. Without this explanation, little of the generator input will make sense. Code users accustomed to two-dimensional Lagrangian-type generators with their input foibles will find themselves in strange territory indeed. It is hoped that these users will find the ensuing discussion especially helpful.

We assume the Eulerian grid has been set up, which covers a rectangular portion of (r,z) space given by the limits $R(1) \leq r \leq R(\ell_{\max})$ and $Z(1) \leq z \leq Z(k_{\max})$. In a problem, this domain is partitioned into material regions, each region containing one type of material. The boundaries of each region, or rather, the interfaces which separate one region from another, are closed, piecewise continuous, sectionally smooth curves in (r,z) space. An example of a three-material problem is shown in Figure 3.

Figure 3

Region boundaries in KEG are currently assembled with segments of straight lines and conic sections.* These boundary curve specifications are independent of the grid lines. Once KEG knows where these curves are, it proceeds to assign to each cell covered by the region the material for that region. Multifluid cells arise naturally when the curves do not coincide with the grid lines. For example, as shown in Figure 4, more than half the volume of the (k,l) cell indicated by a corner dot contains material 2, with the remainder consisting of material 1. Situations producing 3,4,..... n-fluid cells should be obvious.

Figure 4

There are two distinctly different methods of handling the geometric assignment of materials to cells in KEG: the overlay mode, described immediately below, and the direct mode, treated further on. Using the same input for either mode indiscriminately may sometimes cause problems. The relative merits of each mode will be discussed in Part V, Section D.

* Other geometrical forms may be used, once the appropriate coding has been put into KEG.

E. Overlay Mode

KEG in the overlay mode contains what is perhaps a unique recipe for easily handling a problem containing many regions, so as to minimize the amount of input data required. This recipe is based on the Lagrange-to-Euler mapping algorithm described in detail in reference (3). Accordingly, the following rules and conventions have been build into the code.

KEG RULE #1: Every material region is uniquely and completely specified solely by an oriented boundary. This boundary may be one or more closed contours, made up of one or more continuous curves, and does not cross itself. Regions can be specified to exist in two or more pieces, each piece with its "own" closed boundary.

KEG RULE #2: Every material region is uniquely labeled by a non-zero positive integer, so that no two distinct material regions can have the same region number.

KEG RULE #3: (Overlay rule) If two or more numerically distinct regions are deliberately made to overlap, their intersection (in the usual Boolean sense) belongs to the region labeled with the higher region number. An example of this is shown in Figure 5.

Figure 5

These rules permit one to construct fairly complex spatial regions from a minimum collection of simple boundary curves. In a sense, we are laying down successive regions, one on top of another, using overlays to construct the final result. This construction of regions is analogous to that of an oil painting: each successive application of paint (a region with a higher index number) may or may not cover part of the layers already applied.*

With the overlay rule, one can use the boundary contours of one region to automatically define part of the boundary of another. (For example, see Figure 5.) Thus, if two concentric circles were used to specify two regions, the smaller circle would automatically define the inner boundary of the annulus, etc.

The possibility does exist where regions are specified with no cells. Such cases arise when the region lies completely off the grid, or when the overlay arrangement wipes out a region completely. Since every region described in the input is used, we have the following caveat:

KEC RULE #4: No material region can be specified in such a way that it is eliminated from the problem, intentionally or otherwise.

A number of useful and flexible features for setting up the problem geometry have been incorporated into KEG, and are detailed herewith, along with a few caveats and comments.

(a) The region numbers used for labeling need not be sequential. However, they must be properly ordered for purposes of doing the region

* Regions may also be laid down next to one another without overlaps or gaps, but only with some risk. See warnings in Part V, Section D, and reference (3).

overlays correctly. (Rule #3).

(b) With one exception, any region specification partly outside the limits of the Eulerian grid is simply ignored. For example, if a closed circular boundary is specified with center near one of the grid sides, only that part of the region within the grid is made part of the problem. This is shown in Figure 6. Because of this feature, one is at liberty to shift the grid without changing the contour input.

Figure 6

The one exception is that region contours directly above the grid are used, even though their shapes are not counted in the assignment. The reasons for this are outlined in Part V, Section C.

(c) If the complete configuration does not completely fill every cell in the grid, the calculation will be aborted and error messages sent.

(d) Multiply connected regions are permitted: two or more spatially separate portions of the (r,z) plane can be assigned to the same material region, and therefore have the same region number.

(e) If the boundary curve (or curves) is to be specified by piecewise continuous segments, all such segments must be connected, leaving no gaps. Since the input for any curved segment in KEG involves its endpoints, it should be a fairly easy matter to ensure that this happens.

F. Direct Mode

In this mode, the overlay feature (Rule #3) no longer holds, and the material regions must be assigned to the cells in patchwork quilt fashion. This means that if two regions have a common boundary segment, this segment must be specified twice - once for each region on either side.

As described in Part III on card input to KEG, one can not only specify the shape of a boundary curve segment, but also on which side of this segment the region lies. This is done by orienting the segment input, so that on going from the first entered segment point to the last, the region lies to the left of the segment. These concepts are illustrated by example in Figure 7. These regions within the grid are defined by 12 boundary segments, each of which is indicated by an arrow.

Figure 7

Except for the overlay rule, all the caveats and comments that applied to the overlay mode also apply to the direct mode. Thus, the restriction that the material label numbers be in a particular order is completely relaxed, and the specification of two or more regions to overlap will produce errors. Also, KEG will abort generation if unspecified gaps between regions are detected.

Conceptually, the direct mode is easier to implement than the overlay mode, but it requires almost four times as much input.

II. USER OPERATION OF KEG

A. KEG in the BBC System

KEG is presently set up specifically for the Eulerian codes BBC⁽¹⁾ and VOA⁽²⁾ and runs only on the CDC 7600 in the Livermore Time Sharing System. It produces initial restart dumps from which BBC can begin calculations. Another code, MEL, has also been written to produce initial BBC restart dumps from a link from Lagrangian type calculations.⁽⁴⁾ MEL and KEG are similar, differing only in that MEL requires the Eulerian zonal configuration data as input, while KEG calculates this data.

These restart dumps may be converted to the hexadecimal format required to run BBC from them on the CDC STAR by using an utility code, CONDUMP, as discussed in Section D.

Figure 8 is a schematic flow diagram of the current BBC code system, showing the relation of KEG and MEL to the other codes and disk files. All communication between codes is by way of teletype execution and disk files, except where noted in the BBC manual.⁽¹⁾ A similar flow chart in reference(4) contains more detail related to MEL.

BBC and its plotting routines reside in the 7600 public library file BBC. KEG, MEL, CORK, LEG and CONDUMP reside in the 7600 public library file KEG. Both KEG and BBC may be executed directly from the teletype; the other codes have to be pulled out of their respective libraries (using X, EXE, IIX, etc.) prior to their usage.

UIB is a B-division code which, like LEG, produces Eulerian configuration data from the B-division Lagrange-to-Euler link system for input to MEL.⁽⁴⁾

Figure 8

B. Teletype Dialogue

On typing in

KEG / t v

the code will produce message prompts at the TTY for more information to be entered.

The full execute line is

KEG *filename options* / t v

where *filename* is the name of the input card deck containing the Eulerian configuration information, as described in Part III, and *options* is a list of one or more ASCII symbols describing what desired system actions the code may take at execute time. These symbols follow *filename* and may be in any order or omitted completely. Their meanings are listed in the following table.

Option	Action Taken
(none)	Both long and short edit files (packed ASCII) are left on disk to be disposed of as the user sees fit. The disk names of these files are <i>filenamePn</i> for the short edit, and <i>filenameHn</i> for the long edit, where $n = 0, 1, 2, \dots$ depending on the amount of output generated.
0 (zero)	All edit files are sent to microfiche when KEG ends.
1	The long edit file is sent to the high speed printer, and the short edit file is sent to the on-line printer.

2	Same as using both 0 and 1
NR	KEG will execute without producing a restart dump and any of the associated I/O. This fast "dry run" option allows the user to check out his input geometry and equations of state with a minimum of execution time. Some input cards will not be read by KEG in this mode.
EDIT	KEG will put out on the long edit all the zone-by-zone details of the Eulerian configuration generated. For large problems (~ 10K cells or greater) a substantial amount of output is generated.

BBC users will note that the style of the KEG and MEL execute lines are not quite the same as those for BBC.

On successfully reading the input deck, KEG will first respond with the card image of the title card, the machine identification and the current date and time. A variety of messages will then be sent, some of which are as follows.

KEG WILL RUN IN DIRECT MODE - if the direct mode was chosen.

GEOMETRY OK - when all geometrical calculations required to assign materials to cells have been successfully completed.

CREATED *filename/K* NN - a restart dump disk file with this name and length NN(octal) has been created, but not yet written onto.

GEN DONE - restart dump has been successfully written, closed, and made read-only. It is now ready to be used by BBC on the 7600.

Self-explanatory TTY messages will result from either KEG input errors or system troubles, the latter needing no elaboration. KEG has built

into it a fairly comprehensive system of error checks and diagnostic messages.* These are included in both the long and short edits. Hopefully, these built-in error checks will eliminate (by catching them beforehand) situations that provoke system (e.g.: ORDERLIB, etc.) errors.

Most KEG input errors will be fatal: when found, the calculation will be terminated with appropriate prose. The input will have to be corrected before using KEG again to obtain a restart dump.

* However, in some situations, Murphy's Law may prevail.

C. Drop Files and other Disk Files

Depending on the size of the problem and the options chosen, KEG will run under a variety of drop file names, and create and destroy disk files as needed. Should the machine go down or the problem be otherwise interrupted by breaking out, the calculation can always be resumed by executing the current drop file. These are -KEG, +KEG1, +KEG2, etc. Each of these drop files represents KEG with a different code size and 7600 large core memory (LCM) arrangement. The differing names serve as a debug aid should the calculation crash for no immediately obvious reason.

In addition to on-line printer and high speed printer files, KEG creates two disk files for temporary storage of variables which are labeled *filenameFV* and *filenameES*. They are normally destroyed when the generator ends successfully. Otherwise, when the problem is aborted, they are left on disk.

Finally, KEG will create and write a restart dump, labeled *filename/K*.

If another KEG problem with the same input file name is started, any disk files left on disk by previous calculation with the labels *filenameFV*, *filenameES* or *filename/K* will be destroyed automatically, and new ones created. However, if any printout disk files with labels *filenameHn* and *filenamePn* were left on disk from a previous run, they will not be destroyed. If a new problem is generated with the same name, new printer files will be created and written with new problem data. These files will be labeled with (n+1) instead of (n) as the rightmost character.

D. Converting Restart Dumps to STAR Format (and back)

CONDUMP is a mildly interactive BBC utility code which runs only on the 7600, and will do a number of things. These are as follows:

1. Convert any BBC restart dump file from 7600 60-bit octal format to STAR 64-bit hexadecimal format.
2. Do the same as 1. in reverse, i.e., convert BBC restart dumps from STAR to 7600 format.
3. Convert any BBC plot-type disk file (see reference (1)) that has been generated on the STAR to octal format for use on the 7600.
4. Operate 1., 2., or 3. in "familied-files" mode, on request.

CONDUMP is obtained by pulling it out of public library file KEG using X, LIX, etc. On the typing of

```
CONDUMP / t v
```

a number of prompts for the desired information will be printed at the TTY. The full execute line is

```
CONDUMP infile outfile outmode filetype / t v
```

where the line entries have the following significance: (next page)

infile is the name of the disk file to be converted. If no such file exists on disk, the TTY prompts will be repeated.

outfile is the desired name of the converted disk file.

outmode is HEX if conversion is from 7600 to STAR, or is OCT if conversion is from STAR to 7600.

filetype may be omitted (or RSD used) if a BBC restart dump is to be converted. For conversion of a fractional volume dump, FV is used, and for conversion of a snapshot dump, SS is used.

If a family of such disk files is present on disk, CONDUMP will prompt the user for more information at the TTY after converting the first one. The user should respond according to the prompt, depending on whether he wants the remainder of the family also converted, or not.

CONDUMP will only read the *infile* disk files, and not alter or destroy them. As each file is processed, CONDUMP will notify the user of the successful conversion at the TTY, or print error messages if anomalies are found.

During the conversion process, CONDUMP will create and write information into a printer file HXCONDUMP0, (or HXCONDUMPn, n = 1, 2,, etc. if HXCONDUMP0 already exists on disk). This file contains information useful for debugging purposes should a crash occur for no obvious reason. In normal usage of CONDUMP, these files may be ignored.

Users who wish to examine the contents of a hexadecimal file* may use public file DKSTAR on it, in a manner similar to the old utility routine DUMP. The execute line is DKSTAR DUMP / t v after which the routine will prompt the user for more information.

* on the 7600

III. INPUT

A. Input Deck

The first card of the KEG input deck or file is always the problem title card. The remaining data cards are each identified by alphameric mnemonics and suitable numbers punched thereon, and generally may be in any order whatever. (There are certain exceptions to this which will be mentioned further on.)

The data cards after the title card are read in what is essentially "field-free" format. Each entry (i.e., field) on any data card is not restricted to a particular format, but the entries must be separated by at least one blank space. Zeros must explicitly be entered when called for, as blank spaces have no numerical meaning. (Commas (,) may also be used as data entry delimiters; however, they are treated as blank spaces and simply ignored. Therefore, use of commas is not recommended.)

The general arrangement of the entered items on the data cards is as follows:

<u>Field</u>	<u>Information</u>
1	Region number (fixed point) if required, or may be omitted if not needed.
2	<u>Alphameric mnemonic</u> describing the function of this card.
3, 4, etc.	<u>Numerical</u> data (either fixed or floating)

Each data card is completely self-contained: only one card function mnemonic is allowed per card. The code will check the entries on each card to make sure that the first entry is an integer (unless omitted), the second entry is alphameric, and the remaining entries are fixed or floating numbers as required.

B. Title Card

The first card identifies the problem, user's box number, and miscellaneous global sentinels. It is currently read in a fixed columnar format, which is laid out as follows.*

<u>Column</u>	<u>Information</u>
1	(not used)
2	Symmetry sentinel: 1 for planar slab, zero or blank for cylinder of revolution (Part I, Section B)
3	(not used)
4 upper	Eulerian grid edge boundary condition sentinels, as described more fully in Section D., following. 0 = vacuum, 1 = rigid wall, 2 = continuation, 3 = periodic, 4 and 5 indicate BBC-controlled flow across boundary.
5 lower	
6 left	
7 right	
8	(not used)
9	Number of integration interval subdivisions to be used in repeated applications of Gauss-Legendre quadrature. (May be left blank.)**
10	Mode of region assignment: zero or blank for overlay mode (Part I, Section E), 1 for direct mode (Part I, Section F).
11 - 13	BOX
14	blank
15 - 17	Three character alphameric output box number
18 - 47	Thirty columns of prose to title and identify problem, which will appear on appropriate pages of all subsequent printed output. (For generated problems destined for the STAR, use only columns 18-41, viz., 24 columns.)

* Plans for eliminating this fixed format are in progress.

** See reference (3), page 8.

C. Input Card Summary

The current input card repertoire for KEG is summarized on the next page. Each card type (after the title card) is identified by an alphameric mnemonic thereon, and required cards are indicated in the table by notes in parentheses. KEG will abort if any of these required cards are missing.

In the table, region numbers are symbolized by N, coordinates by words whose first letter is R or Z, grid line indices by words whose first letter is K or L, and the other entries are explained in the succeeding text. The page numbers listed at the right are for the corresponding card descriptions.

No card can have more than 25 separate items on it. Unless clearly obvious from the context, dropouts of entries from the right are allowed, viz.: successively last entries on each card can be omitted if they are each zero.

All numerical labels and grid line or other indices must be input as fixed point integers. All other obviously non-integer numbers may be input in either E or F format.

CARD INPUT FOR KEG

PAGE

TITLE CARD (REQUIRED)

23,31

EULERIAN GRID (K AND L CARDS REQUIRED)

K	K1	Z(K1)	K2	Z(K2)		(UP TO 11 K,Z PAIRS)	26
L	L1	R(L1)	L2	R(L2)		(UP TO 11 L,R PAIRS)	26
KVAR	K1	K2	ALPHA				28
LVAR	L1	L2	BETA				28
WALL	K1	K2	L1	L2			32

GEOMETRY DATA FOR REGION BOUNDARIES (ONE CARD PER REGION REQUIRED)

N	EC	ZCENTER	RCENTER	A	B	ANGLE		33
N	CE	ZCENTER	RCENTER	A	B	ANGLE		33
N	C1	ZCENTER	RCENTER	ZRIM	RRIM			34
N	C3	Z1	R1	Z2	R2	Z3	R3	35
N	E4	Z1	R1	Z2	R2	Z3	R3	36
N	M3	ZTAIL	RTAIL	ZMID	RMID	ZHEAD	RHEAD	37
N	M4	ZTAIL	RTAIL	ZMID	RMID	ZHEAD	RHEAD	38
N	M2	Z1	R1	Z2	R2	Z3	R3	39
N	KL	K1	K2	L1	L2	FV		41
	SLOP	FVTOL1	FVTOL2					43

PHYSICAL ATTRIBUTES FOR MATERIALS (HY CARD REQUIRED PER REGION)

N	HY	DENS	TEMP	MASS	ENRG					49
N	D	K1	K2	L1	L2	D1	D2	D3	D4	52
N	EN	K1	K2	L1	L2	E1	E2	E3	E4	52
N	TN	K1	K2	L1	L2	T1	T2	T3	T4	52
N	V	ZVEL	RVEL	ZCENTER	RCENTER	OMEGA	RDOT	K1	K2	54
	VORTEX	ZC	RC	VPEAK	RPEAK	RMAX	DENS	PRES	ZVEL	58

EQUATIONS OF STATE (ES CARD REQUIRED PER REGION)

N	ES	IEOS	PMULT	EMULT	0.	PSCL	ESCL			44
	AEOS	IEOS	ITYPE	DENS	ENRG	DMIN	DMAX	EMIN	EMAX	45
	AEOS	IEOS	ITYPE	DENS	ENRG	DMIN	DMAX	EMIN	EMAX	45
	COEF	IEOS	I1	J1	A(I1,J1)	I2	J2	A(I2,J2)		45
	COEF2	IEOS	I1	J1	A(I1,J1)	I2	J2	A(I2,J2)		45
	RM	PMULT	EMULT							48

BBC RUN CARDS

ST	TSTART	TSTOP	DYSTART	DTFLOOR	NCYCLESTOP	59
FLOOR	TEMPFLOOR	DENSFLOOR	FVFLOOR	ENRGFLOOR		59

PLASMA SENTINELS (FOR VOA, A PLASMA VERSION OF BBC, SEE REF. [2])

PL NOMAT NZMMOM IBEAM IZPER IRPER JPBCT JPBCB JPBCL JPBCR

(MAY 1977)

D. Eulerian Grid Cards (Mnemonics: K,L,KVAR,LVAR)

The grid input consists of specifying a collection of $R(l)$ and $Z(k)$ lines, between pairs of which a linear interpolation over l or k is performed to obtain the remaining lines. The entries on the cards are as follows:

<u>Field</u>	<u>k line input</u>	<u>l line input</u>
1	none	none
2	K	L
3	k_1 (fixed point)	l_1
4	$Z(k_1)$	$R(l_1)$
5	k_2 (fixed point)	l_2
6	$Z(k_2)$	$R(l_2)$
.	.	.
.	.	.
.	.	.
. etc.	.	.
.	.	.

Up to eleven number pairs (Lagrangian index and line location) are presently allowed per card. These pairs may be in any order, and as many cards as needed may be input. KEG will unscramble and properly order the data, so that the interpolation will be done between closest pairs of lines.

Data for $k=1$ and $l=1$ must always be entered. If the problem is cylindrically symmetric, then $R(1)$ must never be negative. The maximum k and l found on these cards will be the $k_{\max}$ and $l_{\max}$ for the grid. More than one entry of the same grid line will cause errors.

An example is shown at the top of Figure 9, next page.

Input: K 1 0.0 11 5.0 17 20.0
 L 1 0.0 5 4.0 15 8.0

Resulting Grid:

Input: Same as above, but with addition of
 KVAR 5 15 1.25

Resulting Grid:

Figure 9

Once the grid has been set up, a further altering of the already specified grid line locations can be made, such that between any two selected lines the spacing between adjacent lines is adjusted to vary exponentially. That is, in the z-direction, the condition

$$\frac{Z(k+1) - Z(k)}{Z(k) - Z(k-1)} = \alpha = \text{constant}$$

is imposed, while the r-direction the condition would be

$$\frac{R(\ell+1) - R(\ell)}{R(\ell) - R(\ell-1)} = \beta = \text{constant}$$

The cards needed to do this are as follows:

<u>Field</u>	<u>z-direction</u>	<u>r-direction</u>
1	blank	blank
2	KVAR	LVAR
3	k_1	ℓ_1
4	k_2	ℓ_2
5	α	β

The line index pairs (k_1, k_2) or (ℓ_1, ℓ_2) select the z or r interval over which this exponentially varying spacing is to be imposed. Generally, α and β are $1. \pm \epsilon$ where ϵ is a small amount. An example is shown at the bottom of Figure 9, on the previous page.

The following short discussion is given to aid in choosing appropriate values of α and β . For simplicity of discussion, let either grid line coordinate be denoted by X_n , $n=0, 1, 2, \dots, N$, and let

$\Delta X_n = X_n - X_{n-1}$. Then if the ratio between adjacent zone widths is α , we have, for any n , spacings between adjacent grid points given by

$$\begin{aligned}\Delta X_n &= \alpha \Delta X_{n-1} \\ &= \alpha^{n-1} \Delta X_1\end{aligned}$$

If $L = X_N - X_0$ is the length of the interval, then

$$L = \left(\frac{1 - \alpha^N}{1 - \alpha} \right) \Delta X_1$$

From the above and some algebraic manipulation,

$$\alpha = \frac{L - \Delta X_1}{L - \Delta X_N}$$

$$N = 1 + \frac{\log (\Delta X_N / \Delta X_1)}{\log \alpha}$$

(Natural logarithms are used here.) Thus, given any three of the quantities $(L, \Delta X_1, \Delta X_N, \alpha)$ one can calculate the fourth one. If α is very close to 1, the following sequence of approximation is quite good:

$$\alpha' \approx 1 + \frac{\Delta X_N - \Delta X_1}{L}$$

$$N' \approx 1 + \frac{1}{\alpha' - 1} \log \left(\frac{\Delta X_N}{\Delta X_1} \right)$$

WARNING: The KVAR and LVAR cards will be processed in the order they appear in the deck. If the intervals on two KVAR or two LVAR cards do not overlap (even if they happen to have a common endpoint), this will not matter. However, if there is overlap, then this ordering does matter. Everytime a KVAR (or LVAR) card is processed, the grid is altered. Any subsequent KVAR (or LVAR) card will perform alterations on this new grid, and not on the grid set up by just the K and L cards.

E. Boundary Conditions (Title card, WALL card)

Numerical entries in columns 4, 5, 6 and 7 of the title card will specify the hydrodynamic boundary conditions to be imposed at the four edges of the Eulerian grid during a BBC run.⁽¹⁾ There are currently six such sentinel values, which are tabulated as follows:

<u>Sentinel Value</u>	<u>Grid Edge Boundary Condition Imposed</u>
0 or blank	Vacuum: allows material to flow freely outward across the boundary, as for example occurs with a rarefaction wave.
1	Rigid wall: this is just what it says.
2	"Continuation": sets up a row of exterior zones outside the grid, whose contents (material, volume, mass, energy) are identical to those of the immediately adjacent interior zone.
3	"Periodic Wall": similar to 2 except the contents of the exterior zones are set identical to those of the interior boundary zones adjacent to the <u>opposite</u> edge of the grid. (The strip of exterior zones on the left edge would have the same contents as the strip of corresponding interior zones at the right edge, and conversely. The same would also be true for the upper and lower edge of the grid.)
4	Indicates to BBC that exterior boundary zone density, energy and perpendicular velocity control will be specified at run time, by input to BBC.
5	Same as 4, but without the velocity control.

Sentinels 2, 3, 4 and 5 allow material flow across the Eulerian grid edge in either direction during a BBC run. One immediately apparent result

of using them is that KEG will generate a larger restart dump than if 0 or 1 were used, because exterior boundary zones were created.

In addition to the above, provision is available for making any side of any Eulerian cell into a rigid wall, so that no material can move across this side. Such specification is indicated by using a WALL card whose entries contain the k and ℓ line limits of this condition, and is set up as follows:

<u>Field</u>	<u>Entry</u>
1	(none)
2	WALL
3	k_1
4	k_2
5	ℓ_1
6	ℓ_2

For example, to set up a rigid wall condition along a segment of a grid k line from ℓ_1 to ℓ_2 , set $k_1=k_2$ and $\ell_1 \neq \ell_2$. One may thus partition the Eulerian configuration into hydrodynamically isolated regions in this manner, by using different WALL cards to define the periphery of these regions.

If $k_1 \neq k_2$ and $\ell_1 \neq \ell_2$, then a rigid wall condition will be specified for all four sides of every zone that lies between these crossed pair of grid lines. These lines would then define the edges of a "rigid block".

As many WALL cards as desired may be used.

F. Region Geometry Cards (Mnemonics: EC,CE,C1,C3,M2,M3,M4,E4)

These cards specify the shape of the boundary of a material region by entries which indicate whether a closed conic section (ellipse or circle) or connected segments of a conic are called for. Field 1 on the card has the region number, and field 2 contains the appropriate mnemonic. The remaining fields contain the necessary data for the curve. As many cards as needed to completely specify a boundary for each region may be used.

Closed Ellipse or Circle (EC,CE)

<u>Field</u>	<u>Data</u>
1	region number
2	EC (or CE)
3	Z_{center}
4	R_{center}
	} center of ellipse or circle
5	length of semi-axis A
6	length of semi-axis B
7	tilt angle θ in degrees which semi-axis A makes with z-axis, positive CCW

If the mnemonic is CE, exactly the same type of geometrical calculation is done, except that the ellipse/circle so generated is regarded as being traversed in the opposite sense. That is, this curve will be the inner boundary of an extended region.

This is shown in Figure 10. If $A = B$, or $B = 0$, the curve will be treated as a circle with radius A.

Figure 10

Closed Circle (C1)

This card specifies a closed circle by its center and one point on the circumference.

<u>Field</u>	<u>Data</u>
1	region number
2	C1
3	Z_{center}
4	R_{center}
5	Z_{rim}
6	R_{rim}
	center of circle
	point on rim.

This is shown in Figure 11.

Figure 11

Closed Circle (C3)

This card specifies a closed circle by any three points on its circumference.

<u>Field</u>	<u>Data</u>
1	region number
2	C3
3	Z_1 }
4	R_1 }
5	Z_2 }
6	R_2 }
7	Z_3 }
8	R_3 }

The Z_i , R_i are the coordinates of the three points on the rim.
This is shown in Figure 12; the points need be in no particular order,
but must not coincide.

Figure 12

Closed Ellipse (E4)

This card specifies a closed ellipse by its center and any three points on it. No three of these four data points can be collinear, else errors result. (The EC card should be used instead.)

<u>Field</u>	<u>Data</u>
1	region number
2	E4
3	Z_1 }
4	R_1 }
5	Z_2 }
6	R_2 }
7	Z_3 }
8	R_3 }
9	Z_{center} }
10	R_{center} }

Figure 13

Circular Arc (M3)

A segment of a circular arc is specified by giving the coordinates of its two endpoints and any other point on the arc itself, but in a particular order. This ordering indicates on which side of the curve the region lies, as follows: as you go from the "tail" endpoint to the "head" endpoint, the region lies to the left of the segment. This is shown in Figure 14: the region is shaded. The card entries are as follows:

<u>Field</u>	<u>Data</u>
1	region number
2	M3
3	Z_{tail}
4	R_{tail}
5	Z_{mid}
6	R_{mid}
7	Z_{head}
8	R_{head}

tail endpoint
any midpoint on the arc
head endpoint

In specifying a region boundary which includes these segments, the endpoints must be connected, leaving no gaps, and the entries must be properly ordered.

Figure 14

Elliptic Arc (M4)

A segment of an elliptic arc is specified exactly the same way as a circular arc (previous page) but with the addition of the coordinates of the center of the ellipse. The card entries are:

<u>Field</u>	<u>Data</u>
1	region number
2	M4
3	Z_{tail}
4	R_{tail}
5	Z_{mid}
6	R_{mid}
7	Z_{head}
8	R_{head}
9	Z_{center}
10	R_{center}
	tail endpoint
	any point on the arc
	head endpoint
	center of defining ellipse

Note: The same collinear caveat for the E4 card also applies here.

Figure 15

Straight Lines and Polygons (M2)

A boundary made up of connected straight line segments can be specified by entering the points that define it, in a particular order: starting with the "tail" endpoint, each successive point is entered, ending with the "head" endpoint. For such a boundary traversed in this manner, the region is defined to lie to the left. This is shown in Figure 16. For closed polygons the head and tail endpoints are identical.* Whether this polygon forms the inner or outer boundary of a region will depend on the way the entered points are ordered.

The card entries are as follows (for n points, where n=11 is the maximum allowed per card):

<u>Field</u>	<u>Data</u>	
1	region number	
2	M2	
3	Z_1	} tail endpoint (for this card)
4	R_1	
5	Z_2	} intermediate vertex points
6	R_2	
⋮	⋮	
⋮	⋮	
2n+1	Z_n	} head endpoint (for this card)
2n+2	R_n	

As many M2 cards as needed may be used.

* and both must be entered!

Figure 16

Zonewise Boundary Input (Mnemonic: KL)

Special provision is made for specifying a region by cells, rather than by boundary contours. The input consists of designating two pairs of crossed grid lines to denote the outer boundary of the region: all cells within this rectangular area are assigned to the region with a specified fractional volume. This type of geometry input differs from all the previous ones in two respects:

(1) The region boundary is grid-dependent, since the grid lines form parts of the boundary.

(2) For this card, and this card only, overlaps of regions with the same region number are permitted.* That is, for a given region, a portion of (r,z) space specified by its KL card can be made to overlap any other portion, whether defined by another KL card or any of the geometry cards. Figure 17 on the next page shows an example of such a situation.

The card entries are as follows:

<u>Field</u>	<u>Data</u>	
1	region number	
2	KL	
3	k_1	$\left. \begin{array}{l} k_1 \\ k_2 \\ l_1 \\ l_2 \end{array} \right\}$ k and l limits. The region zones lie within the rectangle bounded by $Z(k_1)$, $Z(k_2)$, $R(l_1)$ and $R(l_2)$ (fixed point).
4	k_2	
5	l_1	
6	l_2	
7	f	fractional volume to be applied to these zones for this region. If omitted, then $f=1$ is assumed.

* regardless of whether direct or overlay mode is used.

Input of two KL specifications;

Result:

Figure 17

It should be emphasized that the totality of outer K-line and L-line segments of the KL-specified region is part of the region boundary and may be treated as such in either overlay or direct mode. CARE SHOULD BE EXERCISED IN RE-USING THESE CARDS IF THE EULERIAN GRID IS CHANGED.

One useful aspect of this card is that "holes" may be put into a region by specifying a KL card with a fractional volume less than δ_2 of the SLOP card (see next page). If more than one KL card is used for the same region, but with different f's, then the order in which these

cards appear in the deck' is important for such k,l regions that happen to overlap: the last KL card given in the deck for that region will take precedence in assigning f's to the zones in common.

Tolerance Card (Mnemonic: SLOP)

Before using this card, the user should have read reference (3) for the relevant background, and in particular, Section IV.

It sometimes happens that the cells of the Eulerian grid are improperly filled, for reasons which have to do with roundoff error or machine noise. Such usually non-fatal errors are represented by fractional volumes of the order of $\delta = 10^{-14}$, or fractional volume cell sums like $1. \pm \delta$, where δ is of the order of 10^{-14} . In KEG, a default tolerance of $\delta_1 = 10^{-6}$ is allowed for the fractional volume assignment of individual regions during the geometrical calculations, and a default tolerance of $\delta_2 = 10^{-12}$ is permitted for the total fractional volume in each cell. The code will abort with error messages if these tolerances are exceeded. These internal tolerances can be changed if needed by use of the following card:

<u>Field</u>	<u>Data</u>
1	(none)
2	SLOP
3	δ_1
4	δ_2

Note: This card has nothing to do with the entries on the FLOOR card.

G. Equation of State Cards (Mnemonics: ES, AEOS, BEOS, COEF, COEF2, RM)

These cards specify the equations of state to be assigned to each material region of the problem. Two types of equation of state are available: one is obtained from a table lookup of the data in the LLL equation of state library, and the other is obtained by specifying one of a number of polynomial expressions to be used, and giving the coefficients for it as input. For both cases, the ES card is required, one per region, as follows:

<u>Field</u>	<u>Data</u>
1	region number
2	ES
3	equation of state number (fixed point)
4	pressure multiplier
5	energy multiplier
6	Ø. (zero)
7	ρ scaler for pressure
8	ρ scaler for energy

The multipliers and scalers are assumed to be 1. if omitted. If the LLL equation of state lookup is to be used, the equation of state number must correspond to one of those in the LLL library. Otherwise this number is an arbitrary label.

If it is desired to use a rational polynomial expression instead, then additional cards are required. Their presence tells KEG not to use the LLL library for all equations of state for the problem. These cards and their entries are described on the next few pages.

There are four kinds of cards to be used for specifying the polynomial equation of state; not all are needed, as the ensuing discussion will show. These cards are summarized by the following information sequence that goes on each card (the first item is the mnemonic):

AEOS	M	N	ρ_0	ϵ_0	$\rho_{\min}$	$\rho_{\max}$	$\epsilon_{\min}$	$\epsilon_{\max}$	$\bar{A}$	$\bar{Z}$
BEOS	M	N	ρ_0	ϵ_0	$\rho_{\min}$	$\rho_{\max}$	$\epsilon_{\min}$	$\epsilon_{\max}$	$\bar{A}$	$\bar{Z}$
COEF	M	I_1	J_1	$A(I_1, J_1)$	I_2	J_2	$A(I_2, J_2) \dots \text{etc.}$			
COEF2	M	I_1	J_1	$B(I_1, J_1)$	I_2	J_2	$B(I_2, J_2) \dots \text{etc.}$			

M is the EOS number as entered on the ES card, and N denotes the analytic type desired. There are five types available at present writing.

<u>N</u>	<u>Description</u>
1	γ -law: $P = (\gamma - 1)\rho\epsilon$
2	Polynomial in ρ , ϵ (or μ , E as the case may be)
3	Ratio of two polynomials
4	Split-range polynomial: one polynomial is used for $\rho \geq \rho_0$, and another is used for $\rho < \rho_0$
5	Same as 4, but splitting of range is over ϵ , where ϵ_0 similarly divides the range.

All these types require accompanying COEF cards. Types 3, 4 and 5 require COEF2 cards in addition.

AEOS is used when polynomials of the form

$$P(\rho, \epsilon) = \sum_{i,j} a_{ij} \epsilon^i \rho^j \quad (\text{or a ratio of such polynomials})$$

are to be employed.

BEOS is used when polynomials of the form

$$P(\mu, E) = \sum_{i,j} a_{ij} E^i \mu^j \quad (\text{or a ratio of such polynomials})$$

are to be employed. Here, $\mu = \frac{\rho}{\rho_0} - 1$, $E = \rho_0 \epsilon$, and ρ_0 is the reference density.

The COEF card is used to input non-zero coefficients (coefficients that are zero need not be input at all) for these polynomials, for either AEOS or BEOS types. I is the power of ϵ or E, and J is the power of ρ or μ of the associated coefficient, which is input as A(I,J). The numbers used for these coefficients must be consistent with the forms indicated by the choice of AEOS or BEOS. If a non-zero coefficient has a zero power, that is, I or J are either or both zero, these zeros must explicitly be entered. For example, the constant term coefficient of the polynomial would be represented by the numerical triple (0 0 a_{00}) on the COEF card.

The COEF2 card is similarly used to input the coefficients for the second polynomial as required by types 3, 4 and 5. In type 3 coefficient input, the coefficients on both the COEF and COEF2 cards must be consistent with the ratio of the two polynomials.

The second group four entries on the AEOS and BEOS cards are limits on the validity of the polynomial. These may be used in BBC to check on excursions outside the range implied by them. $\bar{A}$ and $\bar{Z}$ may currently be omitted.

As many coefficients data triplets (I,J,A) or (I,J,B) as needed may be input; there is no limit, except that dictated by common sense. The storage carved out on the restart dump and in BBC memory is $(I_{\max} + 1) * (J_{\max} + 1)$ for each polynomial. There is a limit of seven triplets per card, and as many COEF and COEF2 cards as needed may be input. However, there can be only one AEOS or BEOS card for each ES card used. Both AEOS and BEOS cards can be used in the same problem.

I,J,M and N are input as fixed point integers. The remaining numbers may be input in E or F floating point format, as desired.

There is no restriction on the way the input cards are ordered in the deck, as usual.

When inputting type 1 data (gamma law), the expected input is for a single COEF card with just one coefficient triplet; viz:

```
COEF  M  I  J  gamma
```

where I and J can be any fixed point value except blank. They are ignored. Anything else produces errors.

The coefficients are printed out in both printer files* in matrix form, consistent with the coefficients and AEOS type polynomials. If BEOS types are input, the information is converted accordingly before being printed out.

* see page 60

In certain physical regimes, such as are found in astrophysical situations (stellar interiors, supernovae, etc.) the pressures and energies involved may contain blackbody radiation components.⁽⁵⁾ In these cases it becomes useful to alter the equations of state so that these components may be suitably simulated. One such alteration as used by KEG and BBC is to add to the pressure and energy calculated from the equations of state the corresponding blackbody values of

$$\mu_e \frac{a\theta^4}{\rho} \text{ for energy,}$$

and

$$\mu_p \frac{a\theta^4}{3} \text{ for pressure,}$$

where θ is the temperature, ρ is the density, a is a constant, and the μ 's are multiplicative factors. The inclusion of these terms is specified by use of a card whose format is as follows:

<u>Field</u>	<u>Data</u>
1	blank
2	mnemonic: RM
3	μ_p
4	μ_e

The default value for the μ 's if this card is omitted is 1. If one desires to run the calculations without these radiant contributions to the equations of state, then this card must be used, with zero (0.) entered for the μ 's. (When the polynomial equations of state are called for, the appropriate coefficients can be set up directly for them instead.)

H. Attribute Cards (Mnemonics: HY,D,TN,EN,V,VORTEX)

These cards set the initial zonal densities, temperatures, energies and cell interface velocities in the Eulerian configuration, after the geometry has been successfully determined.

<u>Field</u>	<u>Data</u>
1	region number
2	HY
3	density of region
4	temperature of region
5	mass of region (overrides density if entered)
6	specific internal energy (must be entered if polynomial EOS used)(energy/unit mass of region)

This card specifies the values of the attributes entered to apply uniformly throughout the region. Zero entries will be understood to have the values given on the FLOOR card (or their defaults if that card is not part of the input for the problem). If a non-zero mass for the region is entered, the code will derive the density from this and the volume of the region and ignore what was entered for the density. The specific internal energy (per unit mass) is required if the polynomial equations of state are employed.

Attribute Variation Cards (Optional)

A limited facility for input of spatially varying densities, energies, and temperatures has been provided in the code by the following recipe. In a rectangular region bounded by the lines k_1 , k_2 , ℓ_1 , and ℓ_2 , let Q_i ($i = 1, 2, 3, 4$) be values of a physical quantity Q given at the four corner zones of this region as shown in Figure 18. Then within this rectangle the spatially varying values of Q in each cell are calculated by the following bivariate interpolation scheme:

$$Q(R,Z) = (Q_1 - Q_2 + Q_3 - Q_4)fg + (Q_2 - Q_3)f + (Q_4 - Q_3)g + Q_3$$

where f and g are given by

$$f(Z) = \left(\frac{Z - Z_1}{Z_2 - Z_1} \right)^\alpha$$

$$g(R) = \left(\frac{R - R_1}{R_2 - R_1} \right)^\beta$$

and the R_i and Z_i are derived from the coordinates of the midpoints of the corner zones. That is, from Figure 18,

$$Q(R_2, Z_2) = Q_1$$

$$Q(R_1, Z_2) = Q_2$$

$$Q(R_1, Z_1) = Q_3$$

$$Q(R_2, Z_1) = Q_4$$

Also, the values of Q so generated for the remaining zones within the rectangle are calculated for R and Z at the midpoint of those zones.

α and β are positive exponents. When both are 1, this recipe is a bilinear interpolation over R and Z from the corner values.

Figure 18

To specify an attribute to take on this spatial variation, the following card format is used:

Field	Data	
1	Region number or blank. If blank, this attribute variation is made to apply to <u>all</u> regions of the problem, within the limits set <u>below</u> . If the region number is input, only those zones of that region which fall within these limits will be affected.	
2	Mnemonic: D for density, TN for temperature, EN for energy per unit mass if analytic EOS is used.	
3	k_1 } k_2 } ℓ_1 } ℓ_2 }	k, ℓ edges of rectangle. This defines a window for application of the variation. (fixed point)
4		
5		
6		
7	Q_1 } Q_2 } Q_3 } Q_4 }	Corner values. (See text and Figure 18.) Zeros imply default floor values unless given by FLOOR card.
8		
9		
10		
11	α } β }	Exponent. Default value = 1.
12		

This attribute variation will override any entries given on the regional HY cards in those zones for which the variation is designated. Zones not so designated will have "flat" attribute values given by the appropriate HY card entries.

WARNING: These attribute variation cards will be processed for each region in the order which they appear in the deck. If the rectangular extents of two similar (same region, same attribute) cards happen to overlap, the latter one will override the former for those zones common to both.

Velocities (Mnemonic: V)

Material velocities are set up by assigning values through each horizontal and vertical cell interface as follows: a continuous velocity field is constructed with suitable input parameters, as described below, and then the velocity field value occurring at the midpoint of and normal to a cell interface is assigned to that interface.

The velocity field is set up as a vector sum of spatially uniform translations, rotations, and expansions, that is:

$$\vec{v}(r,z) = \vec{v}_0 + \vec{\omega} \times \vec{r}' + \vec{r}''$$

where:

$\vec{v}_0$ = uniform velocity component

$\vec{\omega}$ = uniform angular velocity (rotating disk model)

$\vec{r}'$ = radius vector to (r,z) from some center of rotation

$\vec{r}''$ = velocity vector representing uniform motion radially outward from some center of expansion (uniform expansion model)

This velocity field can be applied just to those cells for a given material region, or it can be applied to the whole grid, or to part of the grid. The data card entries are listed below and illustrated in Figure 19. As many cards as needed to specify a velocity field may be used; the resultant velocity field will be the vector sum of all the velocity components on these cards for that region. One may, if desired, input different velocity components on separate cards.

At present there is no momentum mapping in KEG. Thus, the problem arises as to how to properly assign velocities to cell interfaces in the case where a region boundary crosses an interface, and different velocities are assigned to the regions on either side of this boundary. The following recipe is currently being used: where a cell interface involves two or more regions, the velocity applied to the region with the highest region number will be given to that interface.

The card entries for input of velocities are listed below; Figure 19 which illustrates these concepts is on the next page.

<u>Field</u>	<u>Data</u>
1	region number of blank. If blank, the velocity components will be applied to every interface in the mesh and added to any regional velocities input.
2	V
3	z-component of $\vec{v}_0$
4	r-component of $\vec{v}_0$
5	Z_{center}
6	R_{center}
	} coordinates of center of rotation and/or expansion for this card
7	angular velocity CCW about $(Z_{\text{center}}, R_{\text{center}})$ in degrees/time unit
8	radial velocity positive outward from $(Z_{\text{center}}, R_{\text{center}})$
9	k_1
10	k_2
11	ℓ_1
12	ℓ_2
	} window for application of velocities (optional)

Figure 19

Vortex Condition Input

One or more vortex-type configurations may be set up anywhere on the Eulerian grid if desired. These initial hydrodynamic conditions in KEG are imposed regardless of material region boundaries, and are given by the following sets of equations, which were taken from reference (6).

$$v_{\text{tangential}} = \begin{cases} \frac{v_p r}{R_p} & \text{for } 0 < r < R_p \\ \frac{v_p R_p}{r} & \text{for } R_p < r < R_{\text{max}} \end{cases}$$

$$v_{\text{radial}} = -\mu |v_{\text{tangential}}|$$

define the velocity field of the vortex, and

$$\rho = \rho_o - \frac{[\rho_o v_p]^2}{2P_o} f(r)$$

where

$$f(r) = \begin{cases} 2 - \frac{r^2}{R_p^2} & \text{for } 0 < r < R_p \\ \frac{R_p^2}{r^2} & \text{for } R_p < r < R_{\text{max}} \end{cases}$$

defines the spatial variation of the material density in the vortex region.

Here, the symbols have the following meaning:

r is the radial distance measured outward from the center of the vortex.

R_{max} is the radius of the vortex region, beyond which the above specifications no longer hold. (This is not to be confused with the grid limit $R(l_{\text{max}})$).

V_p is the peak tangential velocity of the vortex, and is positive for counter-clockwise rotation.

R_p is the radius (from the vortex center) at which this peak tangential velocity occurs. (Note that it is quite permissible to set things up so that $R_p > R_{\max}$; what will then happen is that part of the above specification will be cut off at $R_{\max}$.)

ρ_0 and P_0 are reference values of density and pressure.

Depending on the multiplier μ , the radial velocity component will be directed inward or outward, regardless of the sign of V_p .

These velocity fields are superposed on any other velocity that may be specified in the problem. The density field, however, overrides any density given by the HY or D cards.

The velocities are assigned to the midpoints of the Eulerian cell sides in exactly the same fashion as indicated for the velocity cards given previously. (With suitable changes in notation, the diagram at the top in Figure 19 also applies here.)

Generally speaking, this type of input is more suited for planar slab geometry. However, if it is used in problems having cylindrical symmetry, this input will describe a rotating toroid, such as one finds when blowing smoke rings.

On the next page, we give the card format needed to specify a vortex.

<u>Field</u>	<u>Data</u>	
1	blank	
2	VORTEX	
3	Z_{center}	} coordinates of center of vortex
4	R_{center}	
5	V_p	peak tangential velocity in "rest frame" of vortex (CCW)
6	R_p	distance from center of vortex to where peak tangential velocity occurs
7	R_{max}	radius of extent of vortex field
8	ρ_o	reference density
9	P_o	reference pressure
10	v_z	} components of optional translational velocity superposed on the vortex region
11	v_r	
12	μ	radial/tangential velocity proportion

Notes:

P_o should be consistent with ρ_o , the EOS used, and the temperature (or energy) on the appropriate HY cards. The code will check that $P_o > \rho_o v_p^2$ and abort generation if this condition is not met.

R_p may be larger or smaller than R_{max} , as desired.

v_z and v_r are the translational velocity components of the vortex that may be superposed on it as desired.

The defaults for the last three items are zero if omitted.

J. Miscellaneous Other Cards

Attribute floor card (FLOOR)

<u>Field</u>	<u>Data</u>
1	blank
2	FLOOR
3	temperature floor (default = 10^{-20})
4	density floor (default = 10^{-30})
5	fractional volume floor (default = 10^{-8})
6	specific energy floor (default = 10^{-21})

BBC problem timing card (ST)

<u>Field</u>	<u>Data</u>
1	none (Blank)
2	ST
3	start time (default = 0.)
4	stop time (default = 10^{20})
5	initial Δt (default = .001)
6	floor Δt (default = 0.)
7	stop cycle (default = 10^6)

PL card - Refer to VOA description in reference (2).

IV. PRINTED OUTPUT FROM KEG

Two edit files are generated, for on-line and high-speed type printers. These are similar except as noted below. Generation information is printed out in blocks of data, each of which may take up a single page or more, depending on the size of the problem generated. The blocks are:

Identification: Machine, date and time of problem, ditto for current compilation of code. Card images of and card numbers for input deck. Running time parameters.

Eulerian Grid: Cards used to set up grid, grid k, l and r, z limits, and table of grid lines.

Region Geometry: Running record of processing of region contour information, by region, starting with the region having the highest region number, and proceeding in inverse sequence to the lowest. Items pertinent to the user are the input cards used, the volume of the region, and miscellaneous remarks referring to the segment of the contour, since for coding purposes every curve treated is broken into monotonic, single-valued segments.⁽³⁾ All other information is used for debugging purposes.

Material Attributes: Material attribute cards, as they are processed. Edits of the physical attributes will appear on the high speed printer file if asked for on execution.

Problem Summary: A table of mass-averaged attributes is printed out for each region. This is largely self-explanatory.

Material Map: A logical material map is printed, showing at a glance which cells contain which material, and where the multfluid zones are. A key is provided to aid in interpreting the map.

Other Remarks: Error messages reflecting mistakes made in setting up the problem will always be printed. In some cases of trouble a full mesh print of cell fractional volumes for the offending region in the problem will be made.

When requested, the physical and geometrical variables for the problem are each printed out in panels of data, sized so that each panel just fits onto a printed page. Each panel contains 50 lines and may contain anywhere up to 50 columns of data, all arrayed in the same logical order as they appear in the mesh. In the output from KEG, this information is printed to 4 significant figures in either E or I format, depending on the nature of the variable. In BBC, this decimal accuracy can be controlled by one of the BBC input cards; for this situation the number of columns per panel (page) is a function of the desired decimal accuracy.⁽¹⁾ For instance, if it is desired to print the data out in E format to 4 significant figures (e.g., 1.234E-65), then eleven columns would be used. Each of these panels is sufficiently well labeled so that little difficulty should be experienced in locating data.

V. HINTS, KINKS & TRICKS

This section is a collection of useful miscellanea related to generating problems with KEG.

A. Setting Up Problems

The following procedure is suggested for preparing input decks.

1. Draw up a detailed plan of the hydrodynamic configuration, including all relevant dimensions.
2. Decide whether to use the overlay mode or the direct mode, and number the regions in the problem accordingly. In the overlay mode, it may be useful to assign region numbers that are multiples of 5 or 10, so that subsequent insertion of additional regions can be made without shifting the original region numbers.
3. Make up the necessary region contour geometry cards, using the configuration plan to help with the bookkeeping. In the direct mode, every boundary common to two adjacent regions has to be specified twice.
4. Afterwards decide on the number and location of the Eulerian grid lines. These should be placed so that areas of interest in the problem are sufficiently well detailed. Experience with the running code will show whether this choice of detail provides reasonably good hydrodynamic resolution. Every Eulerian cell must be accounted for.
5. Grid-dependent cards can now be completed, along with the necessary material attribute cards.
6. Run KEG with the NR option on the execute line to check the geometry until satisfied with the results. (For small problems this may not really be necessary.) See Part II, section B.

B. Debugging Input Errors

Errors arising from mispunched, missing or spurious cards are fairly easy to detect and correct. However, those produced by bad geometry input, particularly in the overlay mode, are not usually so trivial. We detail herewith some comments and suggestions to aid in correcting them.

Bad fractional volumes for a region arise when one or more cells are not properly filled. The total volume fraction in the cell could be negative, or different from 1. Look for crossed or missing boundary curves, or gaps between endpoints of connected segments, and also check for the possibility of duplicate overlapping region numbers. In the direct mode, check for "holes" or "overlaps" in the patchwork. It is not always true that the region with the bad cell or cells is at fault -- one of the adjoining regions may have been badly set up. As a debugging aid, a logical map of the fractional volumes for the bad region will appear on the long output.

Regions with no zones can arise when the region boundary lies wholly outside the grid limits, or, in the overlay mode, when one region completely overlays another. In the latter case, simply renumbering the regions properly is usually all that is needed. If this situation arose during a problem change because an extra region was left in the input, it suffices to remove all cards referring to that region.

If KL cards are used, check to see if they are indeed properly specifying their regions.

C. Some Useful Tricks or An Advanced Users Guide to Bending Rules

The details of the way in which KEG assigns regions and cells is given in reference (3). These features of the coding permit useful short cuts in setting up the geometry for boundaries made up of connected segments.

These are:

(a) Vertical straight line segments are ignored, and may be left out of the input.

(b) Horizontal straight line segments coinciding with the bottom line of the grid (i.e., $r = R(1)$) are likewise ignored.

(c) Similarly, segments which lie entirely to the right, left or are entirely below the grid are ignored, and need not be input. However, this is not true for segments which lie entirely above the grid: their specification is needed if they are legitimate parts of a boundary.

If one wants to input a "background" region in the overlay mode, the usual way to do this is to lay down the first region over the entire grid, using, say, the KL cards. The same purpose can be served by using an M2 card to define the boundary of this first region as a properly oriented straight line located above the entire top edge of the grid. In this way a background specification would not be dependent on the actual grid line count.

D. Choosing Between Direct and Overlay Modes

Making a choice between using the direct or using the overlay mode depends on the nature of the problem to be generated. In some cases the direct mode may indeed turn out to be the easiest way to set up a problem. As a general rule of thumb, we suggest the following guides.

If the configuration is well described as a collection of nested or overlaid regions, then the overlay mode is clearly recommended. Thus, a series of concentric shells can be handled most easily by an overlay of successively smaller circles or ellipses. (As another example, see the case displayed in Part VI, which follows.) If N geometry cards are required for this overlay, one would expect about $4N$ cards to be needed in the direct mode for the same configuration set up as a patchwork.

If the configuration is better described as a literal patchwork, then the direct mode is indicated. The reasoning is that it may be far easier and safer to do the double curve boundary bookkeeping required by the direct mode than to try to implement an extremely complicated overlay scheme to create the patchwork. (For example, see Figure 7, and following paragraph.)

Finally, we note that while geometrical input set up in patchwork fashion (as if for the direct mode) could be used in the overlay mode, this way of doing things should be avoided in certain problems. The reason is that the overlay mode as presently coded will sometimes do a poor job at a boundary which has been set up like a patchwork seam, and allow "chinks" in the "seam" where cells have not been completely filled.⁽³⁾ This will almost always produce error messages. Otherwise, one way to tell when this situation has occurred is to check the logical material map for multifluid zones with more fluids in the zone than were expected.

VI. EXAMPLE

As an illustration of KEG input and results, an input deck was punched, from which a problem was generated, and results shown on the next four pages. On page 67 a listing is shown of the input cards and the TTY dialogue for execution of KEG. On page 68 the logical material map for the problem is displayed. Letters indicate one-fluid cells, and numbers indicate cells with that many fluids in them. Plus signs denote the outer edges of the grid. Page 69 contains the material and multifluid key for interpreting the map. These latter two pages are reproductions of the printer output from KEG. Page 70 shows a partial example of the output produced from BBCPLOT⁽¹⁾ when the KEG restart dump was used to plot material boundaries.

The grid in this particular example consists of rectangular cells all the same size and shape.

11111 BOX G14 SCENE
60 ES 878
60 KL 33 38 10 12
60 KL 38 41 10 15
60 KL 26 28 7 11
70 ES 879 2. 1. 0. 3. 4.
ST 0. 100. 2.6E-4 0. 1500
10 HY 1. 2.
30 M2 30. 14. 12. 27. 6. 18. 1. 21. -10. 8.
40 M2 30. 4. 13. 17. -10. 0.
50 M2 30. 6. -10. 5.
60 KL 30 33 3 17
60 KL 28 30 7 9
K 1 -10. 51 30.
70 M3 2. 5. -3. 9.6 -8. 5.
70 M3 -8. 5. -3. 4. 2. 5.
10 ES 878
20 ES 878
30 ES 879
40 ES 878
50 ES 879 1. 2.
20 HY 3. 4.
30 HY 5. 6.
40 HY 6. 7.
50 HY 1.E-2 3.
70 HY 3.14159 2.71828
60 HY 5. 6. 0. 0. 18.
L 1 0. 41 30.
10 KL 1 51 1 41
20 EC 3. 17. 9..

FILES / 4 5
116D TST

ALL DONE

KEG TST / 4 5

11111 BOX G14 SCENE

R 06/27/74 16:44:52

GEOMETRY OK

MAX FV SUM ERROR = 7.1054E-15

CREATED TST/K 00033551

GEN DONE

HSP AND PRINTER OUTPUT ON DISK, FAMILY IS

TSTH0

TSTP0

ALL DONE

FILES / 4 5

116D TST

33551R TST/K

13004D TSTH0

5004D TSTP0

ALL DONE

PANEL 1 OF 1 (COLUMN 1 ROW 1)

L

[illegible] $K =$

1 10 20 30 40 50

MATERIAL KEY

70 = A 60 = B 50 = C 40 = D 30 = E 20 = F 10 = G

MULTIFLUID ZONE TALLY

L	K	FLUIDS				
37:	28-EG	29-EG	30-EG			
36:	14-FG	15-FG	16-FG	17-FG	18-FG	19-FG
36:	20-FG	21-FG	28-EG	30-EG	31-EG	32-EG
35:	12-FG	13-FG	14-FG	21-FG	22-FG	23-FG
35:	27-EG	28-EG	32-EG	33-EG		
34:	11-FG	12-FG	23-FG	24-FG	25-FG	27-EG
34:	33-EG	34-EG				
33:	10-FG	11-FG	25-FG	26-EG	34-EG	35-EG
32:	9-FG	10-FG	25-EF	26-EG	35-EG	36-EG
32:	37-EG					
31:	8-FG	9-FG	25-EF	37-EG	38-EG	
30:	8-FG	24-EF	25-EF	38-EG	39-EG	
29:	7-FG	8-FG	14-EF	15-EF	16-EF	17-EF
29:	23-EF	24-EF	39-EG	40-EG	41-EG	
28:	7-FG	14-EF	17-EF	18-EF	23-EF	41-EG
28:	42-EG					
27:	7-FG	13-EF	14-EF	18-EF	19-EF	20-EF
27:	22-EF	23-EF	42-EG	43-EG		
26:	7-FG	12-EF	13-EF	20-EF	21-EF	22-EF
26:	43-EG	44-EG	45-EG			
25:	7-FG	11-EF	12-EF	45-EG	46-EG	
24:	7-FG	10-EF	11-EF	29-DE	30-DE	31-DE
24:	46-EG	47-EG				
23:	7-FG	10-EF	28-DE	29-DE	31-DE	32-DE
23:	47-EG	48-EG				
22:	7-FG	9-EF	10-EF	27-DE	28-DE	32-DE
22:	33-DE	34-DE	48-EG	49-EG	50-EG	
21:	7-FG	8-EF	9-EF	26-DE	27-DE	34-DE
21:	35-DE	50-EG	51-EG			
20:	7-EFG	8-EF	24-DE	25-DE	26-DE	35-DE
20:	36-DE	51-EG				
19:	7-EG	23-DE	24-DE	36-DE	37-DE	
18:	6-EG	7-EG	22-DE	37-DE	37-DE	38-DE
17:	5-EG	6-EG	21-DE	22-DE	38-DE	39-DE
17:	40-DE					
16:	4-EG	5-EG	19-DE	20-DE	21-DE	40-DE
16:	41-DE					
15:	3-EG	4-EG	18-DE	19-DE	42-DE	
14:	3-EG	7-AE	8-AE	9-AE	10-AE	11-AE
14:	12-AE	13-AE	17-DE	18-DE	42-DE	43-DE
13:	2-EG	3-EG	6-AE	7-AC	13-AE	14-AE
13:	15-AE	16-DE	17-DE	43-DE	44-DE	45-DE
12:	2-EG	5-AE	6-AE	15-AE	45-DE	46-DE
11:	5-AE	15-AD	16-AD	46-DE	47-DE	
10:	4-AE	5-AE	16-AD	47-DE	48-DE	
9:	4-AE	16-AD	17-CD	18-CD	19-CD	20-CD
9:	21-CD	22-CD	23-CD	24-CD	25-CD	26-CD
9:	34-CD	35-CD	36-CD	37-CD	38-CD	39-CD
9:	40-CD	41-CD	42-CD	43-CD	44-CD	45-CD
9:	46-CD	47-CD	48-CDE	49-CE	50-CE	51-CE
8:	2-CE	3-CE	4-ACE	5-AE	6-AE	15-AC
8:	16-AC					
7:	6-AC	7-AC	8-AC	9-AC	10-AC	11-AC
7:	12-AC	13-AC	14-AC	15-AC		

MAX FV SUM ERROR = 7.1054E-15
 GEOMETRY OK
 CREATED TST/K 00033551

A 70
 B 60
 C 50
 D 40
 E 30
 F 20
 G 10

TEST R 04/25/77 10551152

C=

8.7

-0.

MATERIAL BOUNDARIES AT FRACTIONAL VOLUME OF .5

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