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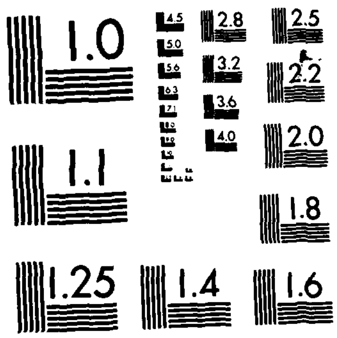

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COLOR POST-PROCESSOR FOR THE EPIC-2 COMPUTER PROGRAM

Thomas M. Sherrick

June 1985

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US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The Color Post-Processor for the Epic-2 Computer Program is an extensive modification of the original Post-Processor for the Epic-2 Computer Program. This report documents modifications made to the State Plots Program in the Post-Processor and the implementation of color graphics into the Post-Processor. The State Plots Program represents the voluminous amount of numerical data generated by the Epic-2 Computer Program as Deformed Geometry, Stress Field, Pressure Field, Strain Field and Velocity Vector Plots. The color graphics incorporated into the Post-Processor illustrate shading and color contours of

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20. Continued...

the respective plots in the State Plots Program. Detailed instructions for using the Color Post-Processor are included.

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I. INTRODUCTION

This report documents enhancements made to the EPIC-2 post-processor and the implementation of color into the post-processor. Reference 1 describes the EPIC-2 program and contains a user's manual for the program and post-processor. This report can be utilized as documentation for the original EPIC-2 post-processor, STPLOTPL, by merely neglecting the information pertaining to color graphics.

Plotting information for the post-processor is written on two tapes by the EPIC-2 program at user-specified intervals. One tape contains all the flow field variables at preselected times. The other contains time histories of flow field variable at preselected times and locations.

As described in [1], EPIC-2 is a two-dimensional computer program for impact and explosive detonation problems. The capability to treat spinning projectiles is also included. The numerical technique is based on a Lagrangian finite element formulation in which the equations of motion are integrated directly rather than through the traditional stiffness matrix approach. Triangular elements are formulated for large strains and displacements, and nonlinear material strength compressibility effects are included to account for elastic plastic flow and wave propagation.

II. THE POST-PROCESSOR

The EPIC-2 post-processor is a plotting program which reads data from previously generated tapes in an EPIC-2 calculation. The post-processor can produce state plots and time plots.

The state plots are broken down into five types:

1. Deformed geometry plots - plots composed of triangular or triangle in quadilateral elements.

2. Stress field plots - plots the lines of constant equivalent stress given by the following equation;

$$\bar{\sigma} = \sqrt{3/2\ (s_r^2 + s_z^2 + s_\theta^2) + 3\ (\tau_{rz}^2 + \tau_{r\theta}^2 + \tau_{z\theta}^2)}\ . \qquad (1)$$

3. Pressure field plots - plots net pressure, that is, hydrostatic pressure plus artificial viscosity.

4. Strain field plots - plots equivalent plastic strain given by the following equation;

$$\bar{\varepsilon}_p^{\,t + \Delta t} = \bar{\varepsilon}_p^{\,t} + \dot{\bar{\sigma}}\,\Delta t \qquad (2)$$

---

[1] *Johnson, G. R., "EPIC-2, A Computer Program for Elastic-Plastic Impact Computations in Two Dimensions Plus Spin," ARBRL-CR-00373, June 1978 (ADA058786).*

where

$$\dot{\bar{\varepsilon}} = \sqrt{2/9\ [(\dot{\varepsilon}_r - \dot{\varepsilon}_z)^2 + (\dot{\varepsilon}_r - \dot{\varepsilon}_\theta)^2 + (\dot{\varepsilon}_z - \dot{\varepsilon}_\theta)^2 + 3/2\ (\dot{\gamma}_{rz}^2 + \dot{\gamma}_{r\theta}^2 + \dot{\gamma}_{z\theta}^2)]}\ . \quad (3)$$

5. Velocity field plots - plots velocity vectors based on the position, velocity, and direction of the velocity of the nodes.

In the above, the symbols s_r, s_z, s_θ represent deviatoric stresses, $\tau_{rz}, \tau_{r\theta}, \tau_{z\theta}$ represent shear stresses, $\bar{\varepsilon}_p$ equivalent plastic strain and $\dot{\bar{\varepsilon}}$ strain rate; $\dot{\varepsilon}_r, \dot{\varepsilon}_z, \dot{\varepsilon}_\theta$ represent strain rates in the coordinate directions while the

$\dot{\gamma}_{rz}, \dot{\gamma}_{r\theta}, \dot{\gamma}_{z\theta}$ represent shear strain rates.

The time plots program, TMPLOT, generates plots of the following variables as a function of time. Each plot contains data for the projectile, target and the total system:

1. center of gravity
2. kinetic energy
3. internal energy
4. total energy
5. plastic work
6. axial momentum
7. axial velocity
8. spin momentum (r momentum for plane strain)
9. spin velocity (r velocity for plane strain)
10. maximum axial coordinate
11. minimum axial coordinate.

The post-processing program, as received, proved to be very inefficient. Changes were made to various sections of the state plot portion of the post-processor. At the same time, color capability was also added as the result of acquisition of Tektronix 4027 color graphics terminals. These changes are described below. Modification of the time plot portion of the post-processor will be described in a future report.

III. CODE MODIFICATIONS

Subroutine EDGE proved to be the most time-consuming part of the original EPIC-2 post-processor. This subroutine plots the outline of the figure being plotted. It was modified by incorporating a sort/merge routine into the edge subroutine, thus reducing the computing costs by 33% to 50%. This subroutine is used in a large portion of the post-processor, that is, it is used for deformed geometry plots, pressure field plots, stress field plots and velocity field plots.

A unit conversion subroutine was added to the post-processor. In this subroutine, SIUNIT, variables are converted from Engineering Units to Standard International Units. There is also an entry point in the subroutine, EGUNIT, which converts Standard International Units to Engineering Units. This subroutine is invoked by setting ICONV to some integer value on the second input card. This card is explained in more detail in the input instructions section of this report.

Material selection and density parameters were added to the pressure, stress, strain, shear and velocity field plots. The material selection parameter allows for the plotting of contours or velocity vectors for a user specified material when working with a multi-material calculation. For example, for the case of a projectile penetrating a target of different material, material selection permits the contours to be displayed in either the projectile or the target or both. The density parameter, IDEN, determines the number of symbols to be plotted on the contour itself, or the number of velocity vectors to be plotted. The IDEN parameter is explained more fully in the input instructions section. These features are illustrated in Figures 1-4.

A feature incorporated into the velocity vector subroutine is the addition of arrowheads to the velocity vectors in order to show direction. Figure 5 is a typical example of a velocity vector plot.

In each of the subroutines PPLOT, SPLOT, EPLOT, and CSHEAR, there is a process which performs four tasks:

1. Checks the elements to see if they are beyond the extreme coordinates or completely failed.

2. Determines if the pressure, stress, shear or strain contour is present between each pair of nodes in the element.

3. Calculates the position of the pressure, stress, shear or strain contour intersection on a line between a pair of nodes.

4. Fills arrays RP and ZP for drawing the pressure, stress, shear or strain contour.

Basically, this algorithm loops through the elements and determines the nodes associated with each element. The algorithm then averages the pressures of the elements surrounding each node and linearly interpolates between the nodes to find where the contour intersects the element boundary. The process has now been incorporated into a subroutine called CONPLOT, thus making the program more maintainable and less time consuming.

FIGURE 1--Pressure Contours for material 1 only (Projectile) with IDEN = 0

FIGURE 2--Pressure Contours for Material 2 only (Target) with IDEN = 5

FIGURE 3--Velocity Vectors with IDEN = 0

FIGURE 4--Velocity Vectors with IDEN = 5

FIGURE 5--Velocity Vector Plot

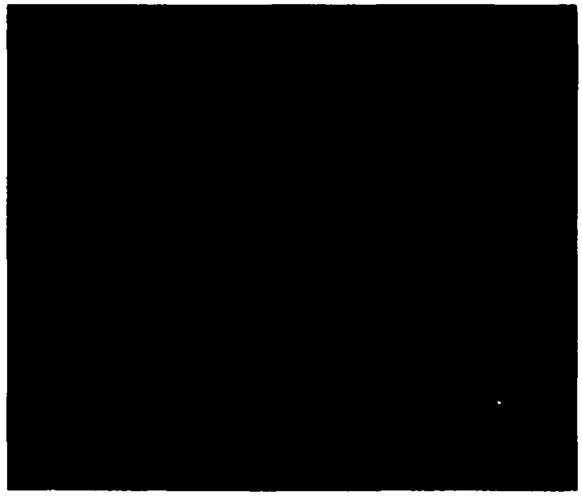

FIGURE 6--Axial Load Plot

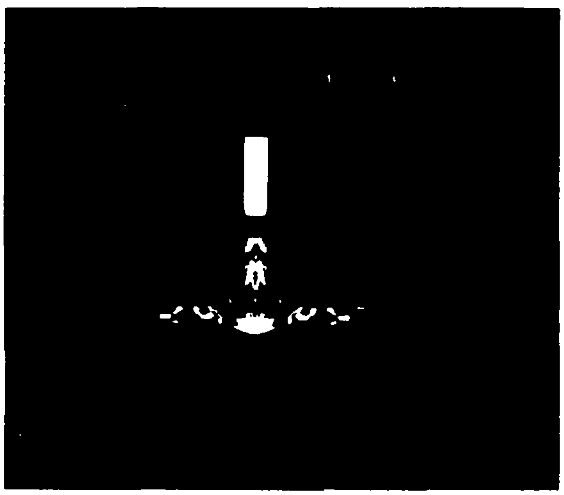

FIGURE 7--Stress Color Shaded Plot

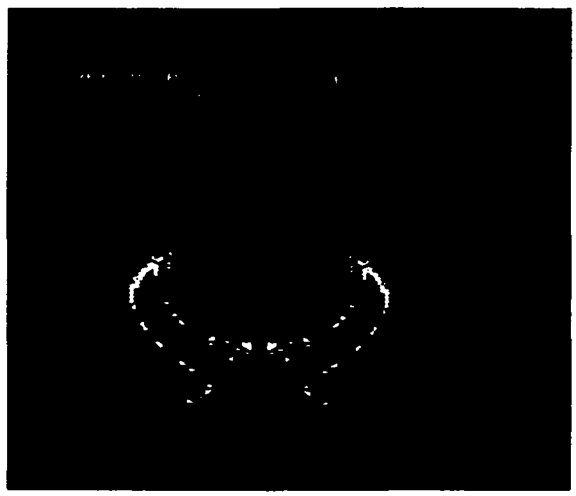

FIGURE 8--Pressure Color Shaded Plot

In addition, this subroutine calculates the maximum value of stress, strain, pressure and shear using the standard FORTRAN intrinsic, min-max function routines. After finding the maximum value, five contour lines are set up plotting 98%, 80%, 60%, 40%, and 20%, respectively, of the maximum constant stress, pressure, strain or shear.

Subroutine LOAD was also added to the post-processor. This subroutine calculates and plots the axial load in the projectile. This is accomplished by calculating the force in the rings of elements of the projectile, multiplying pressure times area. This can be obtained only along the centerline and is only meaningful for normal impacts. Axial load can be an especially useful feature for situations involving long rod impacts. An example of axial load plots for an L/D = 25 steel projectile striking a rigid barrier is shown in Figure 6.

Principal stress and maximum shear contours may also be plotted by the EPIC-2 post-processor. This is a color contour representation. The following equations are evaluated in the READ 2 subroutine in the post-processor:

1. Maximum shear:

$$t = \sqrt{\left(\frac{\sigma_{rr} - \sigma_{zz}}{2}\right)^2 + \left(\sigma_{rz}\right)^2} \qquad (4)$$

2. Principal stresses:

$$\sigma_{r,z} = \frac{\sigma_{rr} + \sigma_{zz}}{2} \pm t \qquad (5)$$

STRESSES ARE FOR THE (r-z) PLANE.

To implement the shear capability, another block of storage, called SHEAR, was added to the common block /ELEM/. Care must be taken so as not to exceed the common block length. This is dependent upon the memory capacity of the machine running the program.

In order to incorporate color into the velocity vector plotting capability of the EPIC-2 post-processor, it was necessary to make some changes to the subroutine VPLOT. The velocity vectors are scaled so as to give a vector one inch long to represent the maximum velocity in the grid for both raster and vector terminals. On the Tektronix 4027 terminal one inch is equivalent to 64 rasters. The scaling is done in the following manner:

XT = R(I) XT, YT represent the coordinates of the tail of the velocity vector. R(I) IS THE RADIAL COORDINATE OF THE NODE.

YT = Z(I) Z(I) IS THE AXIAL COORDINATE OF THE NODE.

Call GTSCAL (SFX, SFY) - this routine obtains the proper scale factor and converts the R, Z values to user units per raster.

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VI. SUMMARY

The EPIC-2 post-processor color program is currently available at the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. It is set up to run with the EPIC-2 computer program on the Cyber 7600. The output is displayed on the Tektronix 4027 color graphics terminal and hard copy is obtained from a Matrix color hard copy recording system, model 4007.

Future plans include modification of the time plots program and implementing color into this capability.

V. SUMMARY OF INPUT DATA

BLANK CARD

State plot identification card. One required for each type of plot desired (2I5, 2I1, 3X, 4F10.0).

TYPE CYCLE ICAL ICONV ZMAX ZMIN RMAX RMIN

Deformed geometry plot card. Type = 1 (3A6, 2X, 5I5).

TITLE EDGE IE ID IF IM

Stress, pressure, strain or shear plot card. Type = 2, 3, 4, or 6. Two cards required. (Contour plots)

Card #1 (3A6, 2X, 2I5, 5F10.0)

TITLE EDGE NLINE PARAM(1) PARAM(2) PARAM(3) PARAM(4) PARAM(5)

Card #2 (2I5)

IDEN IMAT

Stress, pressure, strain or shear plot card. Type = 7, 8, 9 or 10. Two cards are required. (Shaded plots)

Card #1 (3A6)

TITLE

Card #2 (5X, I5)

IMAT

Velocity vector plot card. Type = 5 (3A6, 2X, 2I5, F10.0, I5)

TITLE EDGE NSTRT VSCALE IDEN

Axial load plot card. Type = 11. Only state plot identification card required.

Card #1 (3A6, 2X, 2I5, 5F10.0)

TITLE (3A6) - Title to be written on the plot. Presently there is no need for the remainder of the fields on this card. The EDGE subroutine is not required because the shaded plots generate their own edge. Also, the NLINE value and PARAM(I) values are unnecessary, because the shading subroutines generate their own degrees of shading. The format remains the same for further development.

Card #2 (2I5)

The IDEN parameter, the first I5 field on this card, is not needed since no symbols are plotted on the shaded plots.

IMAT (I5) - Plot shaded areas for IMAT, if IMAT = 0, all materials are plotted.

Present only if TYPE = 5

Velocity vector plot card (3A6, 2X, 2I5, F10.0, I5)

This type of plot generates velocity vectors based on the position, velocity and direction of the velocity of the nodes.

TITLE (3A6) - The title which is written on the plot.

EDGE (I5) - Number to indicate type of outline to be plotted, same as those described for the geometry plot.

NSTRT (I5) - The node number to start plotting the velocity vectors, if NSTRT = 0 all nodal velocity vectors are plotted.

VSCALE (F10.0) - That velocity vector which produces a velocity vector of length 1.0 inch.

IDEN (I5) - Density control parameter for velocity vectors, for IDEN = 0 all velocity vectors are plotted. This is based on the same type modulo function as the other IDEN parameters.

EDGE = -1 plots an outline of the mirror image of the actual geometry for axisymmetric cases.

EDGE = 2 plots an outline of both actual geometry and the mirror of actual geometry.

EDGE = 3 plots an outline of the entire image without showing the elements.

IE(I5) - = 1 prints E in those elements which are in the elastic range.

ID(I5) - = 1 prints P in those elements which are in the plastic flow range.

IF(I5) - = 1 prints F in those elements which have failed.

IM(I5) - = 1 prints material number inside elements. Effective only if IE = ID = IF = 0 or are left blank.

Present only if TYPE = 2, 3, 4, and 6. These types give plots of constant equivalent stress, net pressure, equivalent plastic strain or shear contours.

There are two cards required for each of these plots.

Card #1 (3A6, 2X, 2I5, 5F10.0)

TITLE (3A6) - Title to be written on the plot.

EDGE (I5) - Number to indicate type of outline to be plotted. (Same as those described for the geometry plot.)

NLINE (I5) - The number of contour lines to be plotted. Must be 1, 2, 3, 4 or 5.

PARAM (I) - I = 1, NLINE (F10.0) Specific contour values of stress, net pressure, equivalent plastic strains or shear. There is an algorithm which will automatically calculate 98%, 80%, 60%, 40%, and 20%, respectively, of the maximum value of the chosen variable. If this capability is chosen, then 0.0 is entered in the first (F10.0) field of the five and the remaining four fields are left blank.

Card #2 (2I5)

IDEN (I5) - Density of contour label symbols. If (MOD (Node Number/Element Number, IDEN)) is 0, a label symbol will be plotted.

IMAT (I5) - Plot contours only for IMAT, material selection parameter, if IMAT = 0, all materials are plotted.

Present only if TYPE = 7, 8, 9, and 10. These plots give shaded areas of Stress, Pressure, Strain, or Shear. The areas are determined by the respective subroutines as mentioned earlier in the report.

Again, two cards are required for each of these plots.

TYPE = 7 plots a shaded stress field

TYPE = 8 plots a shaded pressure field

TYPE = 9 plots a shaded strain field

TYPE = 10 plots a shaded shear field

TYPE = 11 plots the axial load distribution in the projectile.

CYCLE (I5) - The cycle number which is to be plotted. The printed output of the main program gives the cycle numbers of the data written on tape 2.

ICAL (I1) - This is a CALCOMP option and, in this instance, will always be 0.

ICONV (I1) - If ICONV = 0, the output (coordinates, velocities, stresses and pressures) will be in SI units. If ICONV is greater than 0, the output will be in Engineering units.

ZMAX (F10.0) - The maximum axial Z coordinate on the plot. The Z axis is 10 inches long and is divided into 10 equal increments from ZMAX to ZMIN. ZMAX represents the maximum Z coordinate of the physical problem analyzed by EPIC-2. Ignored for TYPE = 11 plots.

ZMIN (F10.0) - The minimum Z coordinate on the plot. Ignored for TYPE = 11 plots.

RMAX (F10.0) - The maximum radial R-coordinate on the plot. The R axis (RMAX to RMIN) can be any length and the scale is equal to that of the Z axis. RMAX represents the maximum R-coordinate of the physical problem analyzed with EPIC-2.

RMIN (F10.0) - The minimum R coordinate on the plot. Ignored for TYPE = 11 plots.

The next card required describes, with more detail, the type of plot chosen by the first card. The format is dependent upon the type of plot chosen.

Present only if TYPE = 1

Deformed geometry plot card (3A6, 2X, 5I5)

TITLE (3A6) - The title which is written on the plot. The time and cycle number are also written on the plot using data previously read by the post-processor subroutines.

EDGE (I5) - A number to specify if an outline of the geometry should be plotted.

EDGE = 0 plots no outline.

EDGE = 1 plots an outline of the actual geometry.

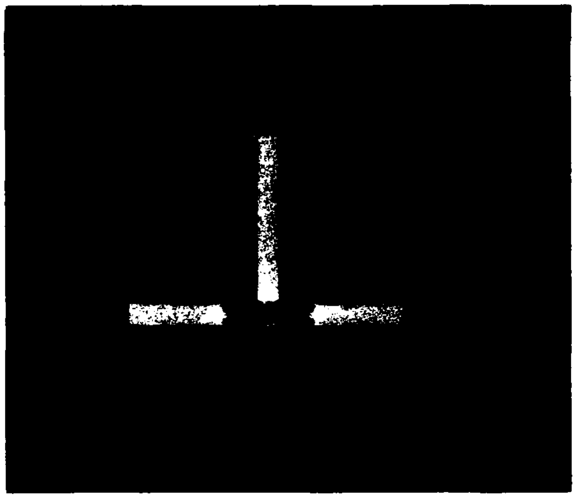

FIGURE 9--Strain Color Shaded Plot

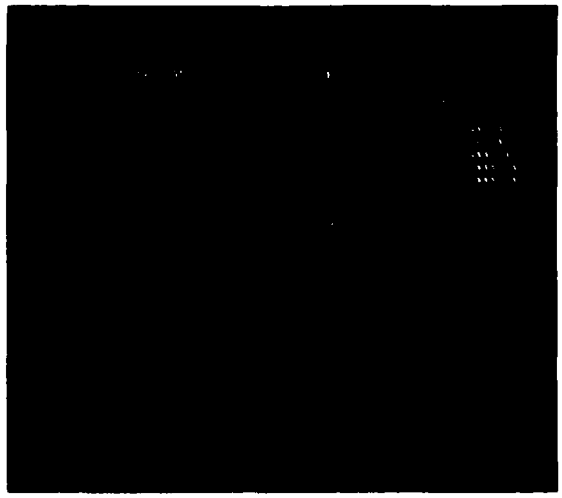

FIGURE C-1--Stress Color Contour Plot

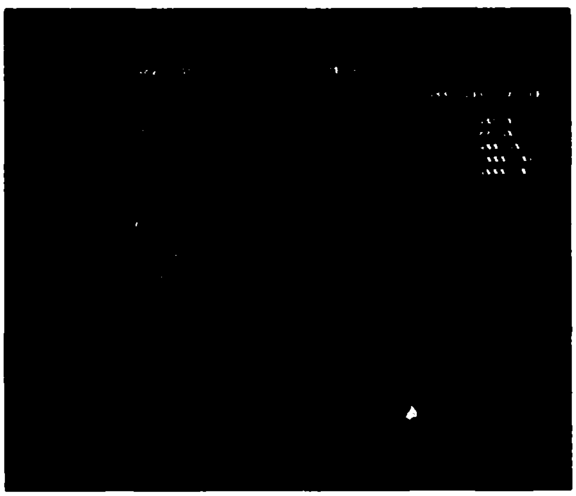

FIGURE C-2--Pressure Color Contour Plot

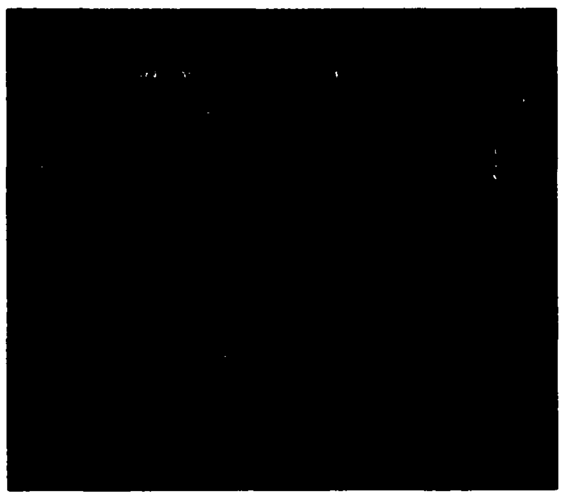

FIGURE C-3--Strain Color Contour Plot

set up, the ranges in the algorithm are;

```
IF (FAC .GE. .5) ICOLOR = 1

IF (.36 .LE. FAC .AND. FAC .LT. .5)  ICOLOR = 2

IF (.25 .LE. FAC .AND. FAC .LT. .36)  ICOLOR = 3

IF (.14 .LE. FAC .AND. FAC .LT. .25)  ICOLOR = 4

IF (.036 .LE. FAC .AND. FAC .LT. .14)  ICOLOR = 5

IF (.002 .LE. FAC .AND. FAC .LT. .036)  ICOLOR = 6

IF (FAC .LT. .002)  ICOLOR = 0
```

where FAC is the normalized value.

2. In the second algorithm, threshold values of pressure, stress or shear are used as the limiting factor. For example, consider the handling of compression and tension with respect to a shaded pressure PLOT, one color can represent all positive pressures, compression, another could represent all negative pressures, tension, finally a third could represent those pressures which are essentially zero. This algorithm uses the actual values of the pressure from the tape generated by the EPIC-2 program. These values are not normalized. The shaded plot capability is shown in figures 7-9.

IV. PROGRAM USER INSTRUCTIONS

The input required for the color processor is similar to that of the old post-processor. However, for the sake of completeness, it is worth reviewing all the input. Some portions of the following are taken directly from the old post-processor description found in [1].

The first card is blank. This card is used for CALCOMP information and is not used by the color processor. However, it is required.

The next card is a state plot identification card. The format is (2I5, 2I1, 3X, 4F10.0) representing:

TYPE (I5) - a number indicating the type of plot desired.

TYPE = 1 plots a geometry plot i.e. element connectivity

TYPE = 2 plots stress field contours

TYPE = 3 plots pressure field contours

TYPE = 4 plots strain field contours

TYPE = 5 plots a velocity field

TYPE = 6 plots shear field contours

15. SUBROUTINE DELAY (IMSEC) - causes the 4027 to wait at least /IMSEC/ milliseconds.

16. SUBROUTINE BELL27 - sounds the 4027 bell.

17. SUBROUTINE BAUD (ITR, IR) - sets the transmit and receive Baud.

18. SUBROUTINE RMAP (ICOLOR, IHUE, ILIGHT, ISAT) - changes color /ICOLOR/ by relative values of hue, lightness and saturation.

19. SUBROUTINE RPOL (IX, IY, NPTS) - creates a polygon with vertices given in relative coordinates.

20. SUBROUTINE RVE (IX, IY, NPTS) - draws a vector in relative coordinates.

21. SUBROUTINE JUMP (IROW, ICOLM) - moves the workspace Alpha cursor to row /IROW/ and columns /ICOLM/ of the workspace.

22. SUBROUTINE GRA (IROW1, IROW2, ICOLM1, ICOLM2) - creates a graphic area in the workspace containing rows /IROW1/ through /IROW2/ of columns /ICOLM1/ through /ICOLM2/.

23. SUBROUTINE ANWORD (NCHAR, IWORD) - this subroutine outputs up to 2 alphanumeric words to the CRT.

24. SUBROUTINE DISPNO (FNUMB, IDEC) - displays the values for the contours.

25. SUBROUTINE SHRINK - shrinks graph address so that the 4027 can emulate a 4010 terminal.

26. SUBROUTINE COPY27 (ITYPE) - this subroutine directs the 4027 to copy a host file to the 4924 tape drive with simultaneous display, ITYPE = 0, or without display, ITYPE = 1.

A major contribution to the color post-processor is the creation of the shaded state plots for stress, pressure, strain and shear fields. The subroutines are basically similar, hence, the description of one subroutine is sufficient to demonstrate the process involved.

The subroutine begins by setting the eight basic colors, which can be plotted simultaneously occupying distinct regions, to the values of whichever colors are desired. The 4027 has eight basic colors, C0 through C7 which are white, red, green, blue, yellow, cyan, magenta and black, respectively. By using subroutine MAP these colors can be changed to any of the 128 colors capable of being produced by the 4027 color terminal. The maximum value of stress, pressure, strain or shear is then calculated using the standard FORTRAN intrinsic, min-max function routines. Finally, one of two algorithms is employed to determine the amount of shading desired. The two algorithms are:

1. The first algorithm normalizes all the values for pressure, stress, strain or shear by dividing by the maximum value obtained from the maximizing function. Ranges of values are then set up which can produce as many or as few colors as desired. For example, the way the program is currently

XH = XT + (RDOT(I)/VSCALE) * 64. * SFX , RDOT is radial velocity of the node.

YH = YT + (ZDOT(I)/VSCALE) * 64. * SFY , ZDOT is axial velocity of the node.
VSCALE is the velocity scaling factor.
XH, YH represent the coordinates of the head of the velocity vector; these values are scaled to fit the 4027 color terminal.

After scaling is completed, a test is performed to check if the vector length is less than .05 inches. If so, it is not plotted. Finally an arrowhead is placed on the vector denoting its direction and the scale for the vector is displayed on the screen.

In implementing color into the post-processor, a color library was created. It is composed of subroutines completed with PLOT10 and the Tektronix 4027 color graphics terminal. The library subroutines are written in FORTRAN and allow the user control of the 4027 color terminal with simple CALL commands. The library contains the following subroutines:

1. SUBROUTINE DRWLIN - draws a line.

2. SUBROUTINE DRWARR - draws lines.

3. SUBROUTINE CIR(IR) - draws a circle with radius IR.

4. SUBROUTINE COL(ICOLOR) - sets the current vector and polygon to ICOLOR.

5. SUBROUTINE ERA - erases the workspace, monitor or graphics region.

6. SUBROUTINE ERASEG (ICOLOR) - erases the contents of the graphic area with ICOLOR.

7. SUBROUTINE LIN(ITYPE) - select line type, i.e., solid, dashed, etc.

8. SUBROUTINE MAP (ICOLOR, IHUE, ILIGHT, ISAT) - sets color, ICOLOR, to hue, lightness, and saturation levels contained in /IHUE/, /ILIGHT/, and /ISAT/, respectively.

9. SUBROUTINE MIX (ICOLOR, IRED, IGREEN, IBLUE) - sets color, ICOLOR, to a given color value expressed as percentages of red, green, and blue.

10. SUBROUTINE PIE (IR, ISTART, ISTOP) - draws a pie with a radius, IR, fills in the pie area between /ISTART/ and /ISTOP/, which are expressed in in degrees.

11. SUBROUTINE POL (IX, IY, NPTS) - color fills a polygon with /NPTS/ vertices.

12. SUBROUTINE VEC (IX, IY, NPTS) - draws a vector in the graphics region.

13. SUBROUTINE ENA - places the 4027 in the Gin (GRAPHIC INPUT) mode.

14. SUBROUTINE DISA - causes the 4027 to exit the Gin mode.

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