MASTER

FLOW SIMULATION THROUGH GRAPHICS: A HIGH-SPEED INTERPRETATION
OF REACTOR BLOWDOWN CALCULATIONS

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ABSTRACT

This paper discusses the various techniques of graphic representation which should be considered when attempting to produce motion pictures portraying fluid motion. Also, a detailed description of a method used to produce motion picture flow representation in a reactor primary loop is presented.

INTRODUCTION

Nuclear safety calculations are of necessity usually conducted with complex computer codes that produce large quantities of information. This information must be interpreted in order to assess the safety factor inherent in a given nuclear plant design. The natural restraints of time and money may cause some information to remain uninterpreted unless a convenient method of summarizing this information is available.

This paper discusses the use of computer-generated motion pictures for high speed interpretation of thermal and hydraulic coolant code output. These motion pictures can portray the coolant motion through the reactor primary loops determined by a reactor blowdown calculation. This motion picture summary of a loss-of-coolant accident can be used to determine the portion of the blowdown calculation that should be investigated in detail. For example, through use of a computer-generated motion picture, flow stagnation points which can cause localized hot regions can be determined and followed throughout the accident. After a safety analysis has been completed the motion pictures can be used to summarize the investigation to other persons not familiar with the particular safety analysis.

This paper summarizes some methods that can be used to generate a motion picture of flow in reactor primary loops. The method developed by the authors is described in detail.

DESCRIPTION OF METHODS AVAILABLE

The methods which can be used to generate motion pictures of flow in reactor primary loops can be summarized by considering the process required to generate a motion picture. A method is employed to map a three-dimensional piping network (which has crossovers, intersections, and obstructing views) onto a two-dimensional plane. Density, velocity, pressure waves, and temperatures of the fluid and surfaces can be represented. Methods of flow representation consist of velocity vectors, particle motion, shading of points on a continuous sweep (as a TV screen), and contour plots. Visual features that can be varied are line or particle widths, shading and color. Particle motion can be calculated from either velocity or mass flow information and some mapping function is then used to move the particles within the straight piping, elbows and tees in the loops.

The method described in detail in this paper provides a general mapping of three-dimensional reactor primary loops onto a two-dimensional plane. It represents the density and velocity of the fluid as well as pressure waves associated with large fluid displacements. A random distribution of points is used to represent the fluid. The localized point density is proportional to the mass density. Motion of individual points is controlled by two-dimensional mappings consistent with calculated junction flows and conservation of mass. The method allows for point motion by considering each junction with its associated inlet and outlet volumes. The method is general and places no restrictions on the number of junctions under consideration.

QUANTITIES WHICH CAN BE REPRESENTED IN A MOTION PICTURE

The quantities which are of interest in thermal and hydraulics problems are density, flow, temperature, and pressure of the fluid. In addition, it may be desirable to represent some surface temperatures which are in contact with the fluid. Visual features which can be varied are line or particle widths, shading, and color. It is also possible to use different symbols to represent some of these features.

Shading would be useful in representing fluid densities. Color would be useful in representing temperatures. The blackbody radiation distribution can be used to relate temperature to color. However, this requires equipment which is capable of portraying all the colors on a tristimulus diagram. The characteristics of the graphic equipment which would be necessary to portray both shading and color would be the capability to specify intensity of illumination and three colors (such as red, green, and blue). These capabilities could be combined to yield any color and intensity. These characteristics are not available on existing computer peripheral equipment at the present time.

Various methods of flow representation are described in the following section. In addition to the actual flow, it is of interest to follow the path of a certain portion of the fluid. For example, it is of interest to track the fluid, initially in the accumulators in the reactor primary coolant loop, during a loss-of-coolant accident. This fluid could be differentiated from the other fluid in the system by using a different symbol or a different color to represent it.

Pressures are difficult to portray particularly in a one-dimensional problem. The best method may be the representation of the pressure on a graph as a function of time and position. This is difficult to do, however, when a loop is being described.

METHODS OF FLOW REPRESENTATION

The motion of a fluid can be represented in several different ways. The methods discussed here consist of velocity vectors, particle motion, shading of points on a continuous sweep, and contour plots.

VELOCITY VECTOR REPRESENTATION

In this type of representation, the direction and magnitude of the velocity vector at selected fixed points in space are pictured. This method is used to advantage where the motion of the fluid is small but the magnitude of the velocity is sufficient. An example^[1] of velocity vector representation is shown in Figure 1. This figure is a computer generated frame from a two-dimensional fluid dynamics code, CHARM, written by Westinghouse. This code has been used to show

Figure 1. Typical flow pattern inside the core.

that motion occurs in a reactor vessel due to density gradients even when there is no flow into or out of the vessel and that the stagnation point moves about.

This figure illustrates several characteristics of the method. There is a relation between the number of points at which the velocity can be represented and the maximum length of any vector. If the maximum length of a vector is equal to the minimum spacing between points, then the vectors will not intersect. Vectors which are much larger than the minimum spacing between points can cause a confusing picture. The arrowheads and the angle of the vector indicate the flow direction. Absence of the arrowheads leaves confusion about the flow direction. The size of the arrowheads is proportional to the length of the vector to eliminate difficulty in using a large size arrowhead even with a zero velocity. The end of the vector without the arrowhead represents the point for which the velocity vector is being drawn.

In this type of representation, it is difficult to get a feeling of motion of the general flow pattern. Since the velocity vectors are scaled by some representative velocity (such as the maximum velocity in the computer run), the velocity vectors may appear quite large but the actual motion of the fluid might be very small. This fact can be used to advantage, however, to illustrate the effects of pressure waves in an almost stationary fluid. In this instance, the fluid motion is very small and the motion of points might be imperceptible in a motion picture, yet velocity vectors would exhibit these waves quite clearly since the instantaneous velocity can be large. The method has the disadvantage that the maximum velocity must be known before the movie is generated.

A motion picture of the one-dimensional motion which appears in many places in a reactor loop is not especially interesting when velocity vectors are used although they may be unavoidable in some cases. A series of frames^[2] is shown in Figure 2 which represent a compressible flow problem. It shows the effect of a blast wave on a bomb shelter access tunnel. It is seen that the velocity vectors (without arrowheads) from point to point connect and give the impression of a continuous straight line due to the fact that the flow is essentially one-dimensional. The motion of the fluid is so small in this problem, however, that no motion at all might be observed if particle motion were used. The points are quite close together relative to the size of the figure which adds to the difficulty in interpreting this representation.

PARTICLE MOTION REPRESENTATION

There are several different methods of representing the existence of a transparent fluid (either liquid or gas). The difficulty associated with fluid representation is closely linked with the difficulty of experimental flow visualization. One method of flow visualization^[3] consists of distributing small particles within the fluid and observing the motion of these particles. An example of selected frames taken from a movie^[2] based upon particle motion is shown in Figure 3. The motion of these particles is calculated with a two-dimensional fluid dynamics code, MAC, where the local velocity of the fluid was used to calculate the position of these points. This figure represents the motion of a fluid encountering an obstruction after a dam has been removed. It is seen that this type of representation is a very natural one which is easy for the mind to associate with water flow.

The initial fluid configuration consists of uniformly placed particles. Since a different velocity is available from the computer code for each location, each particle moves independently. It should be noted, however, that due to the initial uniformity of points, the later frames exhibit lines of particles. In the two-dimensional case, these lines do not detract from flow representation. In a one-dimensional flow situation, which occurs in many places in a loop code, these lines cause considerable detracting. This is illustrated in Figure 4.

a.

b.

c.

d.

Figure 2. Blast wave effect.

a.

b.

c.

d.

e.

f.

Figure 3. Dam removal.

Figure 4 a represents a water filled pipe which is initially at a subcooled state. The RELAP3^[5] computer code was used to calculate the flow when one end of the pipe was broken. RELAP3 is a loop code that is used as a one-dimensional code in this case to describe the flow from the pipe. It is assumed in this calculation that steam and water move at the same velocity. Initially, the density of fluid in the pipe is 50 lbs/ft³. At the end of the blowdown the pipe will be filled with steam which has a representative density of about 0.07 lbs/ft³. Twenty-seven regions were used to perform the calculations with RELAP3. This made 28 uniformly spaced boundaries where the time dependent velocities were available for determining the motion of the particles in the pipe. Linear interpolation was used to obtain the velocity $U(x,t)$ at any location in the pipe. A simple step method was used to find the location, x , of a particle at the new time.

$$x(t + \Delta t) = x(t) + U(x(t),t) \cdot \Delta t$$

The resultant motion leaves much to be desired. It appears that lines are moving rather than particles. In Frame f the section near the unbroken end of the pipe appears to be devoid of fluid yet the density is still about 5 lbs/ft³.

The difficulty can be circumvented by generating particle coordinates randomly. Figure 5 illustrates the type of results obtained when particles are placed randomly in the pipe. No change has been made in the computational procedure with the exception of particle distribution. This representation presents a much more realistic model of the fluid. Since the particles are placed randomly, each particle has a different initial position and is thus moved independently. In the previous figure each row of particles, with 21 particles per row, represented the velocity of only one point in the fluid. Each particle in Figure 5 represents a different point in the fluid. Frame f of Figure 5 corresponds to a much later time than Frame f of Figure 4. Less than 50 particles remain in the frame, yet the fluid representation is more reasonable than the former which has 210 particles remaining.

Several features of the blowdown process are illustrated in Figure 5. A pressure gauge has been situated on the pipe at the location where the pressure is being plotted. Frame b shows the particle positions just after the first pressure wave has passed the midpoint of the pipe. Frame c shows the pressure remaining constant at a saturation pressure for a period of time. The second pressure wave has only progressed one quarter of the way down the pipe. Frame d shows the pressure decreasing just as the pressure wave passes the midpoint of the pipe. Frame e shows the pressure remaining essentially constant until a reflected wave from the closed end passes back to the midpoint of the pipe. The last frame shows the time when the blowdown is almost over.

A further consideration should be made in the case where fluid leaves a system. The motion in this case must be defined since it is no longer calculated with the computer code. Some technique must be employed for moving the particles from the system to the edge of the film frame. If the particles leaving the system just disappear (i.e., are no longer plotted), this seriously detracts from the continuity of motion. In Figures 4 and 5 the positions of the points outside the system were calculated by arbitrarily assigning the exit velocity to these particles.

SHADING OF POINTS ON A CONTINUOUS SWEEP

A television screen uses a continuous sweep of an electron beam which causes desired points on the screen to be illuminated. Each of these points may be illuminated with a different intensity. The composite of these illuminated points forms the picture on the screen. The ability to obtain a range of intensities is quite important for this type of representation. It is extremely

a.

b.

c.

d.

e.

f.

Figure 4. Broken pipe.

a.

b.

c.

d.

e.

f.

Figure 5. Random distribution of points.

difficult and time consuming to obtain this shading capability on present day computer peripheral equipment. Present day devices are oriented toward directing the motion of the electron beam and turning it on and off rather than varying the beam intensity while it is undergoing a predetermined sweep.

It may or may not be of advantage to represent velocity vectors or particle motion in this manner. However, the major advantage of this method might be in representing another quantity such as density. If the density were represented in a system this would give a feeling of motion (except in incompressible flow problems). This method has not been investigated to any great extent because of the limitations of present day equipment.

CONTOUR PLOTS, STREAMLINES, AND STREAKLINES

Contour plots may be used to represent almost any physical quantity associated with the fluid. An example^[4] of a contour plot of the pressure field for flow behind an obstacle (von Kármán vortex streak) is shown in Figure 6 a. (Note: Flow is from left to right.) As usual, contour plots exhibit curves with some property (pressure in this case) maintained a constant. Equal intervals of the property are maintained between contour lines. This type of representation does not give a feeling of realism. In steady state flow, there would be no motion at all. One-dimensional flow would result in a series of straight lines and thus this representation would not be reasonable.

Figure 6 b illustrates the use of streamlines^[4]. This is also a representation of flow behind an object. Streamlines are formed by a curve which is tangent to the velocity vector field at a given time. The same comments may be made about this type of representation as about the contour plot. Streamlines are closely associated with velocity vector plots. Streamlines can be sketched on a diagram of velocity vectors.

Figure 6 c illustrates the use of "streaklines"^[4] for the same problem as Figure 6 b. Strictly speaking, streaklines are shown on a single photograph which has been formed by exposing the film for a certain period of time. Streaks (or short lines) appear on the photograph due to the motion of particles during that time period. Thus, Figure 6 c is actually a particle plot. Rather than initially filling the field with particles, this frame was formed by adding a particle in eight locations at the left boundary at each time step. This technique has limited utility in one and two-dimensional flow since information is presented in only a certain portion of the flow field. This does result in a saving of computer time, however. The real utility of this method might be in three-dimensional flow representations (projected on a two-dimensional surface). The motion of particles in a three-dimensional space projected on a two-dimensional surface would confuse the viewer. However, the judicious introduction of a limited number of particles might indicate the flow field quite clearly.

METHOD OF FLOW REPRESENTATION

This section describes a graphic modeling technique which simulates the coolant motion through a reactor primary loop determined by a reactor blowdown calculation. The main motivation for this technique is the need for rapid assessment of the massive amounts of data inherent to nuclear safety calculations.

a.

b.

c.

Figure 6. Contour plot, Streamlines and Streaklines.

TWO-DIMENSIONAL REACTOR LOOP REPRESENTATION

The constraints imposed by the computing hardware require that a simple representation of the actual nuclear plant be used. Figure 7 is representative of a four-loop nuclear plant. For purposes of illustration the four accumulators have been omitted. Figure 8 is a two-dimensional scheme for nuclear plant representation. Here the two loops have been separated, cut, and portrayed independently. Figure 9 differs from Figure 8 with respect to the cutting of the loops, although the loops themselves are still portrayed independently. Figure 10 indicates all components properly connected. However, the illustration has been abstracted until component identification becomes difficult. Figure 11 is a good two-dimensional representation of a four-loop nuclear plant. Here the three unbroken loops are lumped together as one loop and the loop under investigation is portrayed separately.

An acceptable two-dimensional representation of the nuclear plant must necessarily consider the several constraints imposed by the realities of the situation. The requirements considered are the following:

1. The representation must be simple. This requirement is imposed by two considerations; the restrictions of computing hardware, and a finished product that is not so complex that observation becomes difficult.
2. Power plant components and junctions between components must be represented.
3. There must be no restrictions on the number of components and junctions.
4. Conservation of mass of the fluid in the plant must be observed.
5. The information provided for fluid motion is junction information only.

The following mapping was chosen with the above constraints in mind.

The representation of each reactor component shall be rectangular and have the property that its area be proportional to the actual volume of the component. The constant of proportionality shall be the same for all components under consideration.

The rectangular component representation was picked because the testing required for fluid containment within the various components is greatly simplified. Requiring areas proportional to component volumes provides for conservation of mass of the fluid. Imposing only the restriction of area on the component representations affords the desired degree of flexibility insofar as properly connecting the components is concerned. For example, a pipe representation can be elongated and narrowed or shortened and widened in order to provide the proper connections. This additional flexibility points up to a shortcoming, however. Junction areas are no longer conserved. Hence any use of junction velocity information would require the use of a separate scaling factor for each junction in order for the representation to remain compatible with the requirement of conservation of mass. This consideration was circumvented by using the mass flux information at the junctions. An illustration of a two-loop nuclear plant representation is given in Figure 12.

THE GRAPHIC SETUP

For ease of user input preparation, a working subject space with dimensions 8-1/2 x 11 units was selected. The space coincides with a standard sheet of graph

Figure 7. Four-loop reactor plant.

Figure 8. Two-loop plant with loops cut and represented separately.

Figure 9. Two-loop plant with loops represented separately.

Figure 10. Two-loop plant with loops connected.

Figure 11. Four-loop reactor plant.

Figure 12. Two-loop plant with loops connected and component areas proportional to actual volumes.

paper and is easily scaled such that its image exactly fills a 16 mm film frame.

Each nuclear plant component representation is referred to as a region in the subject space. The junctions between regions are ordered in the same manner as in the computer code RELAP3[5]. Each junction has two associated regions, an input region and an output region. A junction classification is with respect to the initial flow direction through the junction. If fluid enters a junction from a region this region is called an input region with respect to the junction. If fluid enters a region from a junction this region is called an output region with respect to the junction.

Each junction is initially identified by the following parameters:

1. Junction identification number (RELAP3 number)
2. Input region number (RELAP3 number)
3. Input region side (side on which junction occurs)
4. Output region number (RELAP3 number)
5. Output region side (side on which junction occurs)
6. Minimum junction coordinate (x or y) in subject space units
7. Maximum junction coordinate (x or y) in subject space units.

Note: With rectangular regions the junctions lie parallel to either the x or y axes and the reference in (6) and (7) to minimum and maximum coordinates is a reasonable one.

Figure 13 illustrates a junction with its associated regions.

Each region is identified by the following parameters:

1. Region identification number (RELAP3 number)
2. Minimum x-coordinate
3. Maximum x-coordinate
4. Minimum y-coordinate
5. Maximum y-coordinate
6. Volume of actual component which region represents.

The fluid in each region is represented by a set of points which has the following properties:

1. The number of points in a region is proportional to the fluid density in the component and the same constant of proportionality is used for every region.
2. The point density is uniform throughout the region.
3. The points are randomly distributed throughout the region.

Figure 13. Junction and region representation.

The first requirement is necessary for conservation of mass. The second is necessary for continuous motion and the third is necessary to avoid "patterning" of points which can cause a violation of the uniformity requirement.

The proportionally constant is determined by computing hardware requirements and a desire for a reasonable visual representation.

The criteria (2) and (3) are provided for by subdividing each region into almost square cells with the property that the number of cells can intergally divide the number of points at least once and at most twice. This is done by the following:

The area of the region is divided by the number of points to be placed in the region to determine the area per point. The square root is taken to find the side of a square which has this area. The greatest integral divisor of both the length and the width of the region by the side of the square (NX, NY) is taken to determine the number of cells to be formed. This leads to the inequality.

$$\text{Number of Cells} = NX * NY \leq \text{Number of Points} < (NX+1)(NY+1)$$

$$\text{But } (NX+1)(NY+1) \leq 3NX * NY \text{ whenever } NX \text{ or } NY \text{ is greater than 1.}$$

$$\text{Since } NX > 1 \text{ or } NY > 1$$

$$\Rightarrow NX < NX * NY \text{ or } NY < NX * NY$$

$$\Rightarrow NX + NY + 1 \leq 2NX * NY$$

$$\Rightarrow (NX+1)(NY+1) \leq 3NX * NY$$

$$\Rightarrow \text{Number of Points} < 3NX * NY$$

The condition $NX > 1$ or $NY > 1$ is easily met by requiring more than one point per unit area in each region. The number of points equal to the integral part of the quotient (1 or 2) are placed in each cell. An actual point location is determined using a random number generator to produce the x and y coordinates of the point within a particular cell. The random number generator is not re-initialized for each point in order to avoid "patterning" the points. To place the remaining points a linear ordering is induced on the cells. The random number generator is used to choose the cells in which the remaining points are placed. When a point is placed in a cell, the cell is flagged to insure no remaining points are placed there. In this way the difference in the number of points between any pair of cells within a region can be at most one.

DETERMINATION OF THE NUMBER OF POINTS TO MOVE

The requirement of conservation of mass implies that the point densities in each region be proportional to the densities within the actual components. Initially this is provided by setting

$$NP_i = K p_i \text{Vol}_i, \text{ where } i=1, \text{ number of components, } p_i \text{ is}$$

the density of the i th component, Vol_i is the volume, K is the proportionality constant, and NP_i is the number of points to be placed in the i th region.

In order for the regional point densities to remain proportional at later times it is necessary for the point motion through the junctions to be consistent with the junction flow rates provided by RELAP3. To this end the following method has been derived.

The number of points to be moved through a junction during a time Δt is given by

$$P_j = KW_j \Delta t, \text{ where } W_j \text{ is the RELAP3 flow rate for the } j\text{th}$$

junction and Δt is the RELAP3 time step. The above equation will yield a non-integer while point motion requires that an integral number of points be moved through a junction at a given time step. Any attempt to truncate or round P_j leads to serious disagreement with the conservation of mass requirement when the truncation or rounding is carried over many time steps. The difficulty is circumvented by accumulating totals of the points which should be moved versus the points which are actually moved through each junction and for each flow direction relative to the junction. Input and output regions for a particular junction are assigned by assuming the initial flow through the junction to be positive. One set of totals are accumulated for this flow direction, and in the event the flow direction changes, (W_j changes sign) the roles of the input and output regions are reversed and another set of totals are accumulated for the new flow direction. The process for the accumulation and comparisons of the totals is as follows.

$$A_{j,1}^T = \sum_{n=1}^T P_j = \sum_{n=1}^T KW_{j,1}^n \Delta t^n, \text{ where } W_{j,1}^n \text{ is the mass}$$

flow through junction j during the n th time step in the positive direction (1) and $A_{j,1}^T$ is the total number of points which should pass through the j th junction in the positive direction by time step T .

The total number of points actually moved through the j th junction in the positive direction by the $T-1$ time step is

$$B_{j,1}^{T-1} = \sum_{n=2}^{T-1} L_{j,1}^n, \text{ where } L_{j,1}^n \text{ is the actual number of points}$$

moved through the j th junction in the positive direction at the n th time step.

The number of points which should be moved through the junction at time T is

$$U = \text{sgn}(A_{j,1}^T) = B_{j,1}^{T-1}, \text{ where } \text{sgn} \text{ is the greatest integer}$$

function. Then

$$L_{j,1}^T = U \text{ if } U > 0.$$

and

$$L_{j,1}^T = 0 \text{ if } U \leq 0.$$

In the event the proper number of points is moved through the junction at each time step the above technique insures that the total point movement will be within one point mass of the actual mass flow through an time interval. The method used for actual point motion cannot guarantee the proper number of points will be moved through a junction at a particular time step due to the random nature of the point positions. However, over several time steps the above appears to give good agreement with the conservation of mass.

In order to insure conservation of mass it is necessary to choose Δt such that no attempt is made to move all the points from a region. The stability restriction from the RELAP3 program is

$$\Delta t \sum_{i=1}^K |W_i| < M$$

where the summation is taken over all junctions of the component and M is its mass. Hence, by taking Δt to be the same as the RELAP3 time step, nonempty regions are insured.

METHOD OF POINT MOTION

Mass flow rates are provided only at junctions and are not available for locations internal to the regions. The following method has been developed to provide for relatively continuous flow between the junctions of a region and at the same time maintain a good uniformity of density within the region.

A junction is assumed to divide each of its input and the output regions into three subregions which are defined by the boundaries of the junction. Figure 14 a provides an illustration of the subregion division. In the event any of the subregions are empty (a junction boundary coincides with a vertex of the region), they are ignored. This is illustrated in Figure 14 b.

The actual motion of the points with respect to the junction is provided in four steps. first the desired number of points is moved from the second subregion of the input region. A uniform point density is then formed in the second subregion of the output region which includes the added points. The last two steps provide for a uniform point density over the three subregions of the input region and the three subregions of the output region which completes the point motion for the junction.

More precisely, consider a junction J with input region I. Suppose the four vertices of the region are (x_1, y_1) , (x_2, y_1) , (x_2, y_2) , (x_1, y_2) and that the junction is positioned on side 4 with end points ab such that the region is divided into three nonempty subregions as in Figure 14 a. Suppose further that n_{pm} points are to be moved through the junction and that subregion 2 contains n_{i2} points. For the moment suppose $n_{pm} < n_{i2}$. Since the point density is essentially uniform the unknown dimension for the area which contains the points to be moved through the junction is given by

$$\frac{d_1}{x_2 - x_1} = \frac{n_{pm}}{n_{i2}} \quad \text{or} \quad d_1 = \frac{n_{pm}}{n_{i2}}(x_2 - x_1).$$

The scale factor required for point motion is then

$$s_1 = \frac{x_2 - x_1}{x_2 - x_1 - d_1}$$

and the new x-coordinate for a point in subregion 2 is given by

$$x' = (x - x_1)s_1 + x_1.$$

Since the junction is positioned on side 4 and point motion will be parallel to the x-axis and in the positive direction. For motion in the positive y-direction x and y are interchanged in the above. For motion in the negative x-direction the scale factor is unchanged but the new x-coordinate is given by

$$x' = (x - x_2)s_1 + x_2.$$

For motion in the negative y-direction x and y are interchanged. The distance a point on the junction boundary will be moved is

$$ds = s_1 \cdot d_1.$$

a. Subregions formed by junction.

b. Subregion 1 empty

Figure 14.

For inducing a uniform point density in the second subregion of the output region two areas must be found whose sum is the area of a subregion and such that the point density of the added points with respect to the first area is equal to the point density of the original points with respect to the second area, or each density is equal to the new density of the subregion.

Suppose the original number of points in the subregion is $no2$. Then since npm points have been moved into the subregion, the unknown dimension for the area is given by

$$\frac{d_2}{x_2 - x_1} = \frac{npm}{no2 + npm}$$

or

$$d_2 = \frac{npm}{no2 + npm}(x_2 - x_1) \quad (\text{Figure 15})$$

Since a point on the junction boundary was moved a distance ds , the scaling factor for the first area is

$$s_2 = d_2/ds.$$

The points moved through the junction boundary are now scaled with s_2 by

$$x' = (x - x_1)s_2 + x_1.$$

The scaling factor s_3 which will move the original points into the second area is the ratio

$$s_3 = \frac{no2}{no2 + npm}$$

and in a similar manner the new position of an original point is given by

$$x' = (x - x_2)s_3 + x_2.$$

The density is now uniform within the center subregion of the output region. For flow in the negative x -direction and for flow parallel to the y -axis, the same considerations must be taken as in the case of moving points from the input region.

For the purpose of forming a uniform point density over the three subregions after points have been gained or lost, suppose subregions 1, 2, and 3 contain $N1$, $N2$, and $N3$ points, respectively. Then the required condition is

$$\frac{N1}{a' - y_1} = \frac{N2}{b' - a'} = \frac{N3}{y_2 - b'} \quad (\text{Figure 16})$$

Substitution yields

$$a' = \frac{(N2 + N3)}{(N1 + N2 + N3)} y_1 + \frac{N1}{(N1 + N2 + N3)} y_2$$

and

$$b' = \frac{N3}{(N1 + N2 + N3)} y_1 + \frac{(N1 + N2)}{(N1 + N2 + N3)} y_2$$

The new point positions with each subregion is

Figure 15. Junction J and output region

Figure 16. Uniformity over all subregions after a gain or loss of points.

$$y' = (y-y_1) \frac{(a'-y_1)}{(a-y_1)} + y_1$$

$$y' = (y-a) \frac{(b'-a')}{(b-a)} + a'$$

$$y' = (y-b) \frac{(y_2-b')}{(y_2-b)} + b'$$

for subregions 1, 2, and 3, respectively. For flow parallel to the y-axis the x and y-coordinates are interchanged in the above.

A final case to consider is the problem of insufficient points in the second subregion of the input region to satisfy the junction flow. In this instance all points are moved from the center subregion through the junction, the densities in the input and output regions are made uniform, and the process is repeated until the required number of points are moved through the junction.

The ordering used on the junctions is the same as the RELAP3 ordering. For the time step under consideration each junction is analyzed in turn until the list of junctions is exhausted. The film frames are generated at a uniform rate with respect to time and the RELAP3 time increments may differ from the film time increments. To insure that the required information is available at each film time step, the film time increment is chosen as a subset of the RELAP3 time increment. In the event the two time increments coincide, the results are output to a film frame.

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