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**DETERMINATION OF
 FOAM DENSITY**

BDX-613-180

October, 1970

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Prepared By:
 C. B. Pettie
 Department 834

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Technical Communications

**Kansas City
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This report was

Prepared by:

C. B. Pettie
C. B. Pettie
D/834

Approved by:

E. C. Johnson
E. C. Johnson
D/834

Mathematical Analysis

DXT Technology

Coordinators

J. R. Lembke
R. A. Koehler
J. S. Carson
D. M. Hashii
D. W. Drayer
C. B. Pettie
J. R. Lembke

KANSAS CITY DIVISION

BENDIX AEROSPACE-ELECTRONICS COMPANY

KANSAS CITY, MISSOURI

A prime contractor for the Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

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ABSTRACT

Methods for nondestructively determining the density variations within a block of polystyrene foam were investigated. Efforts were primarily focused on using an X-ray radiation guage (DXT), since there is no known method with better capabilities. The greater the number of DXT views, the better the approximation of the actual density variations within the billet. A Fortran IV program for computer simulation of DXT information based on random density variation was developed to permit the evaluation of the technique developed in this report without sectioning of actual material. The possibilities of using DXT equipment for this technique were explored mathematically and effects of beams with non-orthogonal orientation were calculated.

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Section 1

SUMMARY

This development effort was initiated to develop a nondestructive technique to determine the variation in density inside a block of polystyrene bead foam.

The intent was to find either a replacement for, or more precise ways to use, the commercially available X-ray radiation gauge, commonly referred to as the DXT (density times thickness) machine, since it measures the product of the average density and the total thickness of the sample at each location.

A literature search did not disclose testing methods and equipment better than the X-radiation gauge as an instrument to accurately measure the density characteristics of a polystyrene foam billet.

The commercial X-ray radiation absorption gauge compares unknown to standardized samples by measuring the attenuation of a constant-intensity X-ray beam.

The density distribution within the right cylindrical foam billets is symmetrical about the billet axis. A DXT scan across a diameter with the beam parallel to the axis and a DXT scan along an element with the beam perpendicular to the axis describes the DXT characteristics of a billet. When such billets have fixed patterns with variable density ranges, destructive test data can be correlated with DXT values to predict the density of each cubic inch of material in the billet. In a like manner cubes of material with fixed three dimensional patterns can be evaluated using an orthogonal system of scanning. If the density distributions are random, these density values cannot be predicted and the density of each cubic inch must be measured directly or calculated from measurements that average the density data from other cubic inches (subvolumes). The more measurements involving an individual subvolume the more accurate will be the calculated density of the subvolume. An N view DXT technique includes N measurements of each subvolume.

N-view DXT data from foam blocks with random density variations was synthesized and computer methods of solving for subvolume density values developed and evaluated.

The N view calculation methods were also applied to small blocks of foam using the data obtained from orthogonal DXT scans. The accuracy of the calculated densities was limited by the small number of views.

Application of the N-view techniques to large billets would require DXT equipment not available at the present time and require many hours of DXT scanning for each block.

Development of foam processing methods reduced the random density variations in polystyrene foam billets and made it possible to calculate the average density and density range from axial and diametrical DXT traces. This data will define the density of polystyrene billets adequately for existing requirements.

Section 2

DISCUSSION

DIRECT MEASUREMENT OF DENSITIES

Direct measurement of the density of internal subvolumes of a foam billet requires one of two radiation conditions, or a combination of both:

- o Generation of a penetrating radiation in a subvolume that exits the subvolume without being changed by the material surrounding the subvolume, or,
- o Generation of penetrating radiation that penetrates a foam billet but is affected only by the subvolume being measured.

X-radiation in contrast to the ideal radiations described above is attenuated by all the matter that is in its path and the attenuation of a transmitted beam is a measure of the total amount of material. DXT equipment uses this type of measurement and is more accurate than equipment that operates with microwaves and ultra sonic radiation.

A survey of current technical literature and the activities of nondestructive testing laboratories disclosed one phenomena that might be usable for measuring the density of internal subvolumes of a polystyrene billet. There is a small possibility that the change in dielectric properties of polystyrene when irradiated with gamma rays could be used to measure the density of internal subvolumes.

This technique involves scanning the foam billet with intersecting microwave and gamma radiation beams. If the cross section of each beam is restricted to one inch square, then a volume of one inch cube would be involved in the measurement. The transparency of polystyrene to microwaves and gamma radiation would make it possible to measure a small change in the dielectric characteristics of an individual cubic inch.

The technique would require laborious scanning methods of large volumes of foam, using precision measuring devices, and would produce data of limited accuracy.

APPROXIMATE DETERMINATIONS OF DENSITY

An alternative to direct measurement is to make measurements of the density characteristics of the entire polystyrene billet and then use these measurements to calculate the variations in density inside the foam block. If every billet of foam has an individual density distribution, the adequate

methods of measurement and calculation would need to be developed for complete evaluation of each billet. However, if the degree of randomness is low and all the blocks have similar density variation patterns, data on previous blocks can be combined with individual measurements to predict nondestructively the density variations in each block.

DXT machines are capable of making precision measurements of the areal density of a material by transmission methods. If a one inch square X-ray beam is used, the areal density is equal to the sum of the densities of the one inch cube subvolumes. The density pattern of a foam cube can readily be described by a set of equations relating the average of the densities of the row and columns of subvolumes to the individual DXT values. These sets of equations are unsolvable since the number of unknowns exceeds the independent equations in all but very small samples.

If the test sample is a cube n inches on a side, the number of unknown cubic inches would be n^3 , while the number of equations would be $3n^2$. Any cube larger than three inches would then contain more unknowns than relationships expressed in equations. A computer method of calculating approximate solutions to these equations was developed and evaluated.

Verification tests were made on small blocks of foam by making DXT measurements in three mutually perpendicular directions through each cubic volume and comparing the approximate values to the bulk density values determined by cutting the blocks into cubes (Appendix A).

The differences between the weight volume densities and the calculated densities approached the amount of density variation in the block.

The N-view technique was evaluated as a method of increasing the accuracy of the statistical approximations derived from the three-view technique. Theoretical models composed of randomized numbers with selected standard deviations were set up on a computer. The DXT process was synthesized by selection of sets of random numbers to represent subvolumes involved in DXT measurement. The possibilities of using DXT equipment for the N-view technique were explored mathematically and the effects of beams with other than mutually perpendicular orientation were calculated (Appendices B, C, and D).

ANALYSIS OF DENSITY DISTRIBUTION CHARACTERISTICS

The absence of established nondestructive testing methods for direct measurement of internal densities and the complexity of the N-view X-ray method made it necessary to analyze the density characteristics of polystyrene bead foam to supplement other methods of measuring or calculating densities. The basic density characteristics required to evaluate a piece

of foam are the density mean and density range. The location and quantity of material near the extreme ends of the density range could be usable information.

The large beads used in early foam processing were recognized as a source of observable density fluctuations. The functional effect of these density variations was considered and a lower limit of density resolution of one cubic inch was adopted. The large bead foam also exhibited density variations due to lack of blending of unlike beads and non-uniform thermal cycles in addition to the minor variations due to bead density variation.

Use of small beads virtually eliminated bead-caused density variations and accented density fluctuations caused by loading practices and density patterns caused by the molding process.

Density patterns caused by layered loading of non-uniform beads are best demonstrated by radiographs of thin slabs of material. Figure 1 illustrates the density striations resulting from loading by mixing colored beads with the white beads. The patterns change in size as the loading technique changes, and increase in density variation as the bead difference increases. Blending of beads lowers the density contrast between the layers. The amplitude of the density variations can be measured by making a DXT trace across the streaks in a thin slab of foam using a one-inch X-ray beam. The DXT traces in Figure 2 illustrate variations due to streaks in blended and unblended manually loaded foam. The current loading practice is to blend the beads as they are loaded into a mold with a pneumatic blender. DXT traces in Figure 3 illustrate the density variations in 0.05 and 0.10 g/cc foam typical of the pneumatic blender and loader. This process apparently is more capable of consistent blending than manual methods.

The virtual elimination of striations and coarse beads as sources of density fluctuations left molding as the controlling factor for density variation.

Current molding processes for 0.05 g/cc foam produces billets with very little density variation. The axial and diametrical DXT traces are slight catenaries (Figure 4) while the billets have a density range of two times the DXT range. The density variations follow a fixed pattern of high density perimeter with another high density area in the center of the block that varies in size and intensity. The changes in the high density area are measurable by the axial and diametrical traces of the 42-inch by 28-inch billet. With the present process controls the density range of a billet can be predicted from destructive test data and axial and diametrical DXT traces with an accuracy comparable to the accuracy that could be developed in direct measurement of subvolume measurements or calculated from multiscan DXT methods.

Figure 1-A. White and Colored Beads Mixed. 2 Blend, 10 Quart

Figure 1-B. White and Colored Beads Mixed. 4 Blend, 5 Gallon

Figure 1-C. White and Colored Beads Mixed. 3 Blend, 5 Gallon

Figure 1-D. White and Colored Beads Mixed. 3 Blend, 5 Gallon, Wire Screen

Figure 2-A. Variations Due to Streaks, Block 5-R-605

Figure 2-B. Variations Due to Streaks, Block 5-R-740

Figure 3. Density Variations in 0.05 and 0.10 g/cc Foam
Typical of the Pneumatic Blender and Loader

Figure 4-A. Block 5-E-924, Axial Trace

Figure 4-B. Block 5-E-924, Diametrical Trace

Figure 4-C. Block 5-R-894, Axial Trace

Figure 4-D. Block 5-R-894, Diametrical Trace

Section 3

CONCLUSIONS AND RECOMMENDATIONS

The exploratory phase of this project produced two feasible approaches to the determination of the density variation inside a block of foam. Development of these processes would have been necessary if the density variation of polystyrene had remained predominantly random in nature.

Improvements in processing have produced foam with density variations that conform to fixed patterns and do not require a density measurement for each cubic inch of foam to determine the density variation.

Appendix A

EVALUATION AND OPTIMIZATION OF THREE-VIEW X-RAY TECHNIQUES:

Three five inch styrofoam cubes of 0.1 g/cc density were scanned at one inch intervals from three directions with DXT equipment. The DXT strip chart data for two blocks was reduced to digital form for computer manipulation, and each block was cut into 125 incremental volumes. The increments were weighed and measured to establish actual incremental densities.

DXT data from block RL-1 was analyzed by computer, using a program designed to average the three independent density estimates of each incremental cube. Output of this program was in coded form, indicating only relative density. Figure A-1 is a scatter diagram showing correlation between computer output and actual density.

Analysis of the N-view technique (Appendix B) showed the way for improvements in the program for the three-view technique. DXT data from block RL-2 was analyzed by an improved program. Results are plotted in Figure A-2. In this case, computed density is in absolute form (i.e., g/cc).

Another comparison of actual and computed density is shown in Figure A-3, in which block RL-2 is divided into five layers. The density of each of the 25 incremental volumes in each layer is indicated by a shade of gray, with lighter grays corresponding to lower densities. The similarity of the computed density patterns to the actual density patterns is evident, although there are many points of disagreement.

The various estimating techniques which were used to compute densities within blocks RL-1 and RL-2 resulted in correlation coefficients between computed and actual data in the range of 0.75 to 0.81. The standard error in the density computation for block RL-2, using the latest program, is 0.005 g/cc. These results indicate the technique has definite possibilities of providing useful results, but some means must be found to reduce the standard error. This is expected to be a more serious problem when a larger number of incremental volumes is considered.

Figure A-1. Actual Versus Computed Density for 125 Incremental Volumes in Block RL-1

Figure A-2. Actual Versus Computed Density for 125 Incremental Volumes in Block RL-2

Figure A-3. Actual Versus Computed Density for 125 Incremental Volumes in Block RL-2

Appendix B

PRELIMINARY ANALYSIS OF N-VIEW X-RAY TECHNIQUE FOR DENSITY DETERMINATION

Assuming the block to be measured is of some shape which can be described conveniently by algebraic statements, with respect to some reference coordinate system, then matrices exist which will transform the description into any other desired coordinate system. Any particular incremental volume within the block can be located in another coordinate system by means of these same matrices.

Let the desired transformations (i. e., the new coordinate systems) be defined by the directions of exposure for several radiographs of the block. Specifically, let the x-y plane of each new coordinate system be perpendicular to the direction of the X-ray beam, let the origin of the coordinate systems remain fixed, and restrict the x-axis of the original coordinate system to the x-z plane in any new coordinate system. The actual coordinate system determination is arbitrary, but this arrangement is convenient for the present discussion.

Call the coordinates in the jth system x_j , y_j , and z_j . The jth radiograph has a film density, d_j , which is a function of x_j and y_j ; $d_j = f_1(x_j, y_j)$. The thickness of the part in the z_j direction is $t_j = f_2(x_j, y_j)$.

Number the incremental volumes from 1 to N in the reference coordinate system. Then the coordinates of the center of the nth incremental volume in the jth coordinate system are x_{jn} , y_{jn} , z_{jn} . The corresponding thickness and film density are t_{jn} and d_{jn} .

Assume the incremental volumes are cubes with sides of length a. In any coordinate system, we can imagine the nth incremental volume to be rotated about its center so that its sides are aligned with the coordinate axes, and assume that the variation in average mass density of the incremental volume due to this rotation is negligible. In general, the incremental volumes (other than the nth) in the columns of material parallel to z_j will not correspond precisely to incremental volumes in the reference coordinate system.

If M is the actual mass of the entire block, and m_i is the actual mass of the ith incremental volume, we can write

$$M = \sum_{i=1}^N m_i \quad (1)$$

The actual mass of the column of material parallel to z_j and containing the n th incremental volume (which we will call column C_{jn}) is

$$M_{jn} = \sum_{i=1}^{t_{jn}/a} m_i \quad (2)$$

where t_{jn}/a is the number of incremental volumes in C_{jn} and the index i now indicates the order of the incremental volumes in C_{jn} . If the n th incremental volume in the reference coordinate system is the k_{jn} th incremental volume in C_{jn} , then

$$M_{jn} = m_n + \sum_{\substack{i=1 \\ i \neq k_{jn}}}^{t_{jn}/a} m_i \quad (3)$$

The average value of M_{jn} in J different coordinate systems is

$$(M_n) = m_n + \frac{1}{J} \sum_{j=1}^J \sum_{\substack{i=1 \\ i \neq k_{jn}}}^{t_{jn}/a} m_i \quad (4)$$

The actual mass of the parts of C_{jn} external to the n th incremental volume is

$$M'_{jn} = \sum_{\substack{i=1 \\ i \neq k_{jn}}}^{t_{jn}/a} m_i \quad (5)$$

The average value of M'_{jn} in J different coordinate systems is

$$(M'_n) = \frac{1}{J} \sum_{j=1}^J \sum_{\substack{i=1 \\ i \neq k_{jn}}}^{t_{jn}/a} m_i \quad (6)$$

(M'_n) is the actual average mass of J different columns passing through the n th incremental volume, not including the mass of the n th incremental volume itself.

The average volume occupied by each of the J columns C_{jn}, but not including the nth incremental volume, is

$$(V_n') = \frac{a^2}{J} \sum_{j=1}^J (t_{jn} - a) \quad (7)$$

The actual average mass density of the J columns passing through but excluding the nth incremental volume is

$$(R_n') = \frac{(M_n')}{(V_n')} \quad (8)$$

If J is large, and if the various coordinate systems are arranged so that C_{jn} sweeps nearly the entire volume of the block as j is varied, then (R_{n'}) is approximately equal to the actual average density of the entire block, external to the nth incremental volume, which we will call R_{n'}.

But if the incremental volume is small compared to the block volume, and if the percentage variation in density throughout the block is not very large, the nth incremental volume cannot have much influence on the total block density. Therefore,

$$(R_n') \approx R_n' \approx R \quad (9)$$

$$\text{and } (M_n') \approx R(V_n') = \frac{Ra^2}{J} \sum_{j=1}^J (t_{jn} - a) \quad (10)$$

From (4) and (6),

$$(M_n) = m_n + (M_n') \quad (11)$$

Combining (10) and (11), we get

$$(M_n) = m_n + \frac{Ra^2}{J} \sum_{j=1}^J (t_{jn} - a) \quad (12)$$

$$\text{or } m_n = (M_n) - \frac{Ra^2}{J} \sum_{j=1}^J (t_{jn} - a) \quad (13)$$

If r_n is the actual average mass density of the nth incremental volume, then

$$r_n = \frac{m_n}{a^3} = \frac{(M_n)}{a^3} - \frac{R}{J} \sum_{j=1}^J [(t_{jn}/a) - 1] \quad (14)$$

Neglecting measurement errors, d_{jn} is linearly related to M_{jn} /

$$M_{jn} = C_1 d_{jn} + C_2 \quad (15)$$

$$\text{and } (M_n) = C_1 (d_{jn}) + C_2 = C_1 \frac{1}{J} \sum_{j=1}^J d_{jn} + C_2 \quad (16)$$

$$\text{Therefore, } r_n = \frac{C_1}{Ja^3} \sum_{j=1}^J d_{jn} + \frac{C_2}{a^3} - \frac{R}{J} \sum_{j=1}^J [(t_{jn}/a) - 1]$$

$$\text{or } r_n = \frac{C_2}{a^3} + R + \frac{1}{aJ} \sum_{j=1}^J \left(\frac{C_1}{a} d_{jn} - Rt_{jn} \right) \quad (17)$$

Appendix C

EVALUATION OF N-VIEW X-RAY TECHNIQUE

A Fortran IV program for computer simulation of DXT information was developed to permit evaluation of the N-view technique without extensive X-ray and sectioning of actual material.

The program performs three functions:

1. It generates a simulated foam slab characterized by a random density distribution, with specified mean density and standard deviation.
2. It generates any desired number of simulated DXT views of the simulated slab, with the X-ray beam in the plane of the slab.
3. It computes an estimate of the density distribution in the block, using the simulated DXT data from Function 2.

The computed estimate of density distribution (Function 3) can then be compared with the actual density distribution (Function 1) to determine the degree of success of the estimation technique.

The program was used with 14 different combinations of three independent variables (i.e., number of DXT views, actual density distribution, and dimensions of the slab in terms of the dimensions of the assumed DXT beam). In each case, the computed density distribution was compared with the actual density distribution and the simple correlation coefficient between the two sets of data was computed. These correlation coefficients were used as figures of merit in comparing the various results.

The slabs were assumed to be squares, M length units on a side, where a length unit is the width of the DXT beam. Since the slabs are assumed to be one unit thick, a volume of one cubic unit is the lower limit of resolution for the estimate of density distribution. All DXT measurements are taken from the edge of the slabs, so a block of any thickness could be treated as a stack of thin slabs.

Figure C-1 shows that the correlation coefficient improves as the number of DXT views is increased. The two curves are for slabs 5 and 10 units square, respectively. The vertical line at the 10-view position on the M-10 curve indicates that five computer runs were made for this set of conditions. The only difference between these runs was the set of random numbers used to generate the actual density distribution, and the calculated correlation coefficients varied between 0.799 and 0.829.

Also shown in Figure C-1 are three isolated points showing correlation coefficients for $M=4$, $M=8$, and $M=12$, when 10 DXT views were used.

It is interesting to compare the results of the N-view analysis with those of the three-view analysis which was used initially. Actual five-inch foam blocks were measured earlier, using the three-view technique, with volume resolution of one cubic inch. This corresponds to a stack of five slabs, with $M=5$, or a total of 125 incremental volumes. The correlation coefficients for this technique were in the range of 0.75 to 0.81. With the N-view technique, the same measurements could now be made with correlation of about 0.91. Even more significant, a cube with 1000 incremental volumes could now be measured with correlation of about 0.81, using 12 DXT views. This is an eight-fold improvement in resolution, with no decrease in correlation.

Computer time of over 30 minutes was required on an IBM/360, Model 50, for analysis of the 12 by 12 inch slab, but this includes simulation of the slab and of the DXT data as well as computation of the density estimate. Also, large improvements in computer time can be expected by optimization of the program, and by elimination of double-precision computations.

Figure C-1. Correlation Coefficient Versus Number of DXT Views

Program for Evaluating N-View X-Ray Technique

COMPILER OPTIONS - NAME=EPSP51,OPT=00,LINECNT=55,SOURCE,EBCDIC,NOLIST,NODECK,LO

```

1SN 0002      IMPLICIT REAL*8(A-H,O-Z),INTEGER(I-N)
1SN 0003      DIMENSION S(10,150), T(10,150), SR(10,10), RHO(32,32), X(32,32)
1SN 0004      EQUIVALENCE (X(1,1), RHO(1,1))
1SN 0005      COMMON XBAR(32), XVAR(32)

```

C

C

GEORGE'S PROGRAM LEADS THE WAY

```

1SN 0006      SUM=0.0
1SN 0007      SUMSQ=0.0
1SN 0008      N=32
1SN 0009      M=32
1SN 0010      RNUM1=3*3*5
1SN 0011      RNUM2=7*11*29
1SN 0012      SD=0.007
1SN 0013      TMV=0.1
1SN 0014      CALL VARGEN(M,N,SD,TMV,RNUM1,RNUM2,X)
1SN 0015      EN=M*N
1SN 0016      DO 11 I=1,M
1SN 0017      DO 11 J=1,N
1SN 0018      SUM = SUM+X(J,I)
1SN 0019      11 SUMSQ = SUMSQ+X(J,I)**2
1SN 0020      AMEAN = SUM/EN
1SN 0021      VAREN = (SUMSQ-SUM*SUM/EN)/(EN-1.0)
1SN 0022      N=EN
1SN 0023      999 CONTINUE

```

C

**** PART II ****

C

**** COMPUTATION SCHEME FOR SIMULATED X-RAY DATA ****

C

**** SIMULATED SLAB, CHARACTERIZED BY ****

C

**** CELL DIMENSION, L, USED IN PGM AS XL ****

C

**** NUMBER OF CELLS VERTICALLY, M, USED AS VM AND M ****

C

**** NUMBER OF CELLS HORIZONTALLY, N, USED AS HN AND N ****

C

C

**** X-RAY INCREMENTING PARAMETERS ****

C

**** NUMBER OF ANGULAR INCREMENTS, CAP. Q, USED IN PGM AS BQ ****

C

**** NUMBER OF LINEAR INCREMENTS PER CELL, P, USED IN PGM AS P ****

C

C

```

ISN 0024      60 FORMAT(2X,5(D6.3,1X))
ISN 0025      61 READ(1,60)XL,HN,VM,Q,P
C      ****
C      **** X, USED IN PGM AS XX      ****
C      **** Y, USED IN PGM AS YY      ****
C      **** ANGLE THE1A, USED IN PGM AS THE1R      ****
C      **** ANGLE ALPHA, USED IN PGM AS ALPHR      ****
C      *****
C      ****

ISN 0026      M = VM
ISN 0027      N = HN
ISN 0028      D = XL/P
ISN 0029      PART = 0.0
ISN 0030      XX = HN*XL
ISN 0031      YY = VM*XL
ISN 0032      P1 = 3.141592653DC
ISN 0033      THE1R = DATAN(YY/XX)
ISN 0034      DALPHR = P1/Q

ISN 0035      GC1 = P1/2.DC
ISN 0036      GC2 = DSQRT(XX*XX + YY*YY)
ISN 0037      GC3 = 1.D0/D
ISN 0038      GC4 = P1 - THE1R
ISN 0039      BQ = 1.D0
ISN 0040      IN1 = 0
C      *****
C      **** THIRD LOOP, WORKING WAY OUT, RULED BY BQ AND Q      ****
C      **** BQ1 RUNS FROM 0 TO Q-1      ****
C      **** INDICES FOR PART II      ****
C      **** SMALL Q USED AS LQ, CAP. K USED AS LK      ****
C      ****

ISN 0041      1000 LQ = BQ
ISN 0042      IN1 = IN1 + 1
ISN 0043      9998 FORMAT(1H1,10X,'S(LQ,LK) IS',8X,'LQ IS',8X,'LK IS'//)
ISN 0044      WRITE(3,9998)
ISN 0045      INJ = 0

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ISN 0046      BC1 = BQ - 1.00
ISN 0047      ALPHR = DALPHR*BC1
ISN 0048      IF(ALPHR.EQ.0.0)GO TO 1002
ISN 0050      C = D/DSIN(ALPHR)
ISN 0051      GO TO 1003
ISN 0052      1002 C = 2.004
ISN 0053      1003 IF(ALPHR.EQ.0.0)GO TO 1004
ISN 0055      TEM1 = DCOS(ALPHR)
ISN 0056      TEM2 = DABS(TEM1)
ISN 0057      E = D/TEM2
ISN 0058      GO TO 1200
ISN 0059      1004 E = 2.004
ISN 0060      1200 IF(ALPHR.LT.0.01)GO TO 1210
ISN 0062      IF(ALPHR.LT.PI)GO TO 1220
ISN 0064      1210 KMAX = GC3*(GC2*DSIN(ALPHR + THETR))
ISN 0065      GO TO 1230
ISN 0066      1220 KMAX = GC3*(GC2*DSIN((PI + THETR) - ALPHR))
ISN 0067      1230 BKMAX = KMAX
ISN 0068      BK = 1.00
C *****
C **** SECOND LOOP, WORKING WAY OUT, RULED BY BK AND BKMAX ****
C **** BK RUNS FROM 1 TO KMAX ****
C ****
ISN 0069      2000 LK = BK
ISN 0070      INK = 0
ISN 0071      INJ = INJ + 1
ISN 0072      A = C*(LK-0.500)
ISN 0073      B = E*(BK-0.500)
ISN 0074      2001 IF(ALPHR.LT.JHE1R)GO TO 2110
ISN 0076      IF(ALPHR.LT.GC1)GO TO 2210
ISN 0076      IF(ALPHR.LT.GC4)GO TO 2310
ISN 0080      IF(ALPHR.LT.PI)GO TO 2410
ISN 0082      GO TO 900
ISN 0083      2110 IF(A.LT.XX)GO TO 2011
ISN 0085      2120 IF(B.LL.YY)GO TO 2012
ISN 0087      GO TO 2013
ISN 0088      2210 IF(B.LI.YY)GO TO 2021
ISN 0090      2220 IF(A.LE.XX)GO TO 2022

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ISN 0092      GO TO 2023
ISN 0093      2310 IF(B.LT.YY)GO TO 2031
ISN 0095      2320 IF(A.LE.XX)GO TO 2032
ISN 0097      GO TO 2033
ISN 0098      2410 IF(A.LT.XX)GO TO 2041
ISN 0100      2420 IF(B.LE.YY)GO TO 2042
ISN 0102      GO TO 2043

C *****
ISN 0103      2011 T(LQ,LK) = B/DSIN(ALPHR)
ISN 0104      INDEX = 1
ISN 0105      GO TO 2500
ISN 0106      2012 T(LQ,LK) = XX/DCOS(ALPHR)
ISN 0107      INDEX = 1
ISN 0108      GO TO 2500
ISN 0109      2013 T(LQ,LK) = (YY - ((A-XX)*DTAN(ALPHR)))/DSIN(ALPHR)
ISN 0110      INDEX = 2
ISN 0111      GO TO 2500
ISN 0112      2021 T(LQ,LK) = B/DSIN(ALPHR)
ISN 0113      INDEX = 1
ISN 0114      GO TO 2500
ISN 0115      2022 T(LQ,LK) = YY/DSIN(ALPHR)
ISN 0116      INDEX = 2
ISN 0117      GO TO 2500
ISN 0118      2023 T(LQ,LK) = (YY - ((A-XX)*DTAN(ALPHR)))/DSIN(ALPHR)
ISN 0119      INDEX = 2
ISN 0120      GO TO 2500
ISN 0121      2031 T(LQ,LK) = B/DSIN(ALPHR)
ISN 0122      INDEX = 3
ISN 0123      GO TO 2500
ISN 0124      2032 T(LQ,LK) = YY/DSIN(ALPHR)
ISN 0125      INDEX = 3
ISN 0126      GO TO 2500
ISN 0127      2033 T(LQ,LK) = (YY + ((A-XX)*DTAN(ALPHR)))/DSIN(ALPHR)
ISN 0128      INDEX = 4
ISN 0129      GO TO 2500
ISN 0130      2041 T(LQ,LK) = B/DSIN(ALPHR)
ISN 0131      INDEX = 3

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ISN 0132      GO TO 2500
ISN 0133      2042 I(LQ,LK) = -XX/DCOS(ALPHR)
ISN 0134      INDEX = 4
ISN 0135      GO TO 2500
ISN 0136      2043 I(LQ,LK) = (YY + ((A-XX)*DTAN(ALPHR)))/DSIN(ALPHR)
ISN 0137      INDEX = 4
ISN 0138      2500 IF(PART.EQ.3.)GO TO 3100
ISN 0140      MAXG = I(LQ,LK)/D +.500
ISN 0141      S(LQ,LK) = 0.0
ISN 0142      GC5 = 0.500
C *****
C ***** INNER LOOP, FROM 3000 TO 3999, RULED BY INK AND MAXG *****
C ***** SMALL GMAX USED AS MAXG *****
C ***** INK RUNS FROM I TO MAXG *****
C *****
ISN 0143      3000 G = GC5 * D
ISN 0144      INK = INK + 1
ISN 0145      GO TO(3100,3200,3300,3400), INDEX

ISN 0146      3100 I = ((B-(G*DSIN(ALPHR)))/XL) + 1.00
ISN 0147      J = ((G*DCOS(ALPHR))/XL) + 1.00
ISN 0148      GO TO 3500
ISN 0149      3200 I = ((YY-(G*DSIN(ALPHR)))/XL) + 1.00
ISN 0150      J = (((G*DCOS(ALPHR)) + ((B-YY)/DTAN(ALPHR)))/XL) + 1.00
ISN 0151      GO TO 3500
ISN 0152      3300 I = ((YY-(G*DSIN(ALPHR)))/XL) + 1.00
ISN 0153      J = ((A + (G*DCOS(ALPHR)))/XL) + 1.00
ISN 0154      GO TO 3500
ISN 0155      3400 I = (((YY-(G*DSIN(ALPHR))) + ((A-XX)*DTAN(ALPHR)))/XL) + 1.00
ISN 0156      J = ((XX + (G*DCOS(ALPHR)))/XL) + 1.00
ISN 0157
ISN 0158      3500 S(LQ,LK) = S(LQ,LK) + D*D*XL*RHO(I,J)
ISN 0159      GC5 = GC5 + 1.00
ISN 0160      3999 IF(INK.LT.MAXG)GO TO 3000
C *****
C ***** END OF INNER LOOP *****

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ISN 0162      90 FORMAT(4X,D16.9,8X,I3,8X,I3)
ISN 0163      WRITE(3,90)S(LQ,LK), LQ, LK
ISN 0164      BK = BK + 1.00
ISN 0165      2999 IF(BK.LE.BKMAX)GO TO 2000
C *****
C ***** END OF SECOND LOOP *****
ISN 0167      BQ = BQ + 1.00
ISN 0168      1999 IF(BQ.LE.Q)GO TO 1000
C *****
C ***** END OF THIRD LOOP *****
C *****
C ***** PART III *****
C ***** COMPUTATION SCHEME FOR DENSITY VARIATION *****
C ***** FILM DENSITY DISTRIBUTION IS IN S(LQ,LK) *****
C ***** SMALL S USED AS SS, SMALL T USED AS ST, SMALL L USED AS SL *** *
C ***** CAP. S USED AS BIGS, CAP. T USED AS BIGT *****
C ***** SUMMATION OF CAP. T IS IN SUMBT *****
C ***** SUMMATION OF CAP. S IS IN SUMBS *****
C *****
ISN 0170      4000 LT = 1.00
ISN 0171      C2 = 0.0
ISN 0172      PART = 3.00
ISN 0173      ALPHR = 0.0
ISN 0174      LQ3 = 1
ISN 0175      SS = 0.0
ISN 0176      LK3 = C
C *****
C ***** NEW KMAX FOR BEGINNING LOOP OF PART III *****
C ***** BEGINNING LOOP, RULED BY LK3 AND KMAX3 *****
C *****
ISN 0177      KMAX3 = YY/D
ISN 0178      4001 LK3 = LK3 + 1.00
ISN 0179      SS = SS + S(LQ3,LK3)
ISN 0180      IF(LK3.LT.KMAX3)GO TO 4001
ISN 0182      R = SS/(XX*YY*XL)
ISN 0183      I = 0
C *****
C ***** INDICES FOR SMALL R(I,J) *****

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C **** I RUNS FROM 1 TO M, J RUNS FROM 1 TO N ****
C **** SMALL N USED AS KS ****
C **** SMALL KMAX USED AS LKMAX ****
C ****
C *****
C **** FOURTH LOOP, WORKING WAY OUT, RULED BY I ****
ISN 0184 5000 I = I + 1
ISN 0185 X1 = 1
ISN 0186 X1 = X1 - .500
ISN 0187 J = 0
ISN 0188 9996 FORMAT(1H1,10X,'SMALL R(I,J) IS',4X,'I IS',6X,'J IS'//)
ISN 0189 WRITE(3,9996)
C *****
C **** THIRD LOOP, WORKING WAY OUT, RULED BY J ****
ISN 0190 6000 J = J + 1
ISN 0191 XJ = J
ISN 0192 XJ = XJ - .500
ISN 0193 SUMBS = 0.0
ISN 0194 SUMBT = 0.0
ISN 0195 BQ = 0.0
C *****
C **** SECOND LOOP, WORKING WAY OUT, RULED BY Q AND BQ ****
C ****
ISN 0196 7000 BQ = BQ + 1.00
ISN 0197 LQ = BQ
ISN 0198 BQ3 = BQ - 1.00
ISN 0199 ALPHR = D*ALPHR*BQ3
ISN 0200 IF(ALPHR.EQ.0.0)GO TO 7002
ISN 0201 C = D/DSIN(ALPHR)
ISN 0202 GO TO 7003
ISN 0203 7002 C = 2.004
ISN 0204 7003 IF(ALPHR.EQ.0.0)GO TO 7004
ISN 0205 TEM71 = DCOS(ALPHR)
ISN 0206 TEM72 = DABS(TEM71)
ISN 0207 E = D/TEM72
ISN 0208 GO TO 7050
ISN 0209 7004 E = 2.004
ISN 0210 7050 SS = 0.0
ISN 0211 ST = 0.0
ISN 0212 IF(ALPHR.LT.0.0)GO TO 7054
ISN 0213
ISN 0214

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ISN 0216      IF(ALPHR.LT.PI)GO TO 7058
ISN 0218      GO TO 900
ISN 0219      7054 KS = P*(X1*DCOS(ALPHR) + XJ*DSIN(ALPHR) - .3D0) + .5D0
ISN 0220      GO TO 7064
ISN 0221      7058 KS = P*((X1 - (YY/XL))*DCOS(ALPHR) + XJ*DSIN(ALPHR) - .3D0) + .5D0
ISN 0222      7064 LKMAX = KS + .6D0*P + .5D0
ISN 0223      CC6 = LKMAX - KS + 1
C *****
C ***** INNER LOOP, RULED BY LK AND LKMAX *****
C ***** LK RUNS FROM KS TO LKMAX *****
C *****
ISN 0224      LK = KS - 1
ISN 0225      8000 LK = LK + 1
ISN 0226      BR3 = LK
ISN 0227      A = C*(BR3 - .5D0)
ISN 0228      B = E*(BR3 - .5D0)
ISN 0229      GO TO 2001
ISN 0230      8100 ST = ST + T(LQ,LK)
ISN 0231      SS = SS + S(LQ,LK)
ISN 0232      IF(LK.LI.LKMAX)GO TO 8000
C ***** END OF INNER LOOP *****
C *****
ISN 0234      BIGT = ST/CC6
ISN 0235      BIGS = SS/CC6
ISN 0236      SUMBS = SUMBS + BIGS*P
ISN 0237      SUMBT = SUMBT + BIGT
ISN 0238      IF(BQ.LT.Q)GO TO 7000
C ***** END OF SECOND LOOP *****
C *****
ISN 0240      SR(I,J) = ((C2/(XL**3)) + R + ((C1/((XL**3)*Q))*SUMBS) - ((R/(XL*Q**
1))*SUMBT))
ISN 0241      WRITE(5,90)SR(I,J), I, J
ISN 0242      IF(J.LI.N)GO TO 6000
C ***** END OF THIRD LOOP *****
C *****
ISN 0244      IF(I.LI.M)GO TO 5000
C ***** END OF FOURTH LOOP *****
C *****
ISN 0246      30 900 STOP
ISN 0247      END

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Computer Model of Foam Block

COMPILER OPTIONS - NAME=EPSP51,OPT=00,LINECNT=55,SOURCE,EBCDIC,NOLIST,NODECK

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ISN 0002      SUBROUTINE VARGEN(M,N,SD,TMV,RNUM1,RNUM2,X)
ISN 0003      IMPLICIT REAL*8(A-H,O-Z),INTEGER(I-N)
ISN 0004      DIMENSION X(32,32)
ISN 0005      COMMON XBAR(32), XVAR(32)
ISN 0006      EN=N
ISN 0007      DO 1 I=1,M
ISN 0008      XBAR(I) = 0.0
ISN 0009      1 XVAR(I) = 0.0
ISN 0010      DO 2 I=1,M
ISN 0011      DO 2 J=1,N
ISN 0012      2 X(J,I)=0.0
ISN 0013      DO 3 I=1,M
ISN 0014      XSUM = 0.0
ISN 0015      XSUMSQ = 0.0
ISN 0016      DO 4 J=1,N
ISN 0017      RNEW = 99991.0*RNUM1-51380151.0
ISN 0018      IF(RNEW)5,5,6
ISN 0019      5 RNEW = RNEW+99991.0*134217728.0
ISN 0020      6 RNEW = DMOD(RNEW,134217728.0)
ISN 0021      R1 = RNEW/134217727.0
ISN 0022      RNUM1 = RNEW
ISN 0023      RNEW = 99991.0*RNUM2-51380151.0
ISN 0024      IF(RNEW)7,7,8
ISN 0025      7 RNEW = RNEW+99991.0*134217728.0
ISN 0026      8 RNEW = DMOD(RNEW,134217728.0)
ISN 0027      R2 = RNEW/134217727.0
ISN 0028      RNUM2 = RNEW
ISN 0029      X(J,I) = ((-2.0*DLOG(R1))**0.5*DCOS(6.283185*R2))*SD+TMV
ISN 0030      XSUM = XSUM+X(J,I)
ISN 0031      4 XSUMSQ = XSUMSQ+X(J,I)**2
ISN 0032      XBAR(I) = XSUM/EN
ISN 0033      XVAR(I) = (XSUMSQ-(XSUM)**2/EN)/(EN-1.0)
ISN 0034      3 CONTINUE
ISN 0035      RETURN
ISN 0036      END

```

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