NRL MODIFIED VERSION OF CINDA-3G PROGRAM

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Washington, D. C.

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<td>ABSTRACT (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)</td>
<td>A programming manual has been prepared for the thermal analyzing program, CINDA. The program's options offer the user a variety of methods for solution of thermal analog models presented to it in a network format. The network representation of the thermal problem is unique in that it has a one-to-one correspondence to both the physical model and the mathematical model. This analogy enables engineers quickly to construct mathematical models of complex</td>
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thermophysical problems and prepare them for program input. In addition, the program contains numerous subroutines for handling interrelated complex phenomena such as sublimation; diffuse radiation within enclosures; simultaneous, one-dimensional, incompressible fluid flow including valving and transport delay effects; etc. It can handle all three types of heat transfer—conduction, convection, and radiation. The optional combinations of these capabilities, in conjunction with the model size allowable (4000 nodes on a 65k-core machine), make CINDA an extremely potent analytical tool for thermal systems analysis in the hands of a competent engineer analyst. Its uses include determining temperatures of structures such as bridges, rockets, and buildings; finding cooling requirements for electric circuits; and studying the thermal properties of adverse thermal systems such as nuclear reactors and automobile engines.

The programs on pp. 104, 105, 106 are adaptations of similar programs published in "MITAS User Information Manual (Martin Marietta Thermal Analyzer System)," CYBERNET Publications Division, Control Data Corporation, Copyright 1972.
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I. INTRODUCTION

Background

When it was recognized that a thermal analyzing system was needed at the Naval Research Laboratory, the Chrysler Numerical Differencing Analyzer for third-generation computers (CINDA-3G)* was obtained for use on the CDC-3800 computer. CINDA-3G was developed by the Thermodynamic Section of the Aerospace Physics Branch of the Chrysler Corporation Space Division at NASA's Michoud Assembly Facility. A major portion of this work was done as a NASA-funded project from the Manned Spacecraft Center in Houston, Texas.

CINDA was programmed in FORTRAN V for the Univac 1108. Because of differences between the computers, modifications to the program were necessary before it could be usable on the CDC-3800. The task of conversion required compensating for compiler differences (FORTRAN V vs 3800 FORTRAN), rewriting some routines in COMPASS, and in general, adapting CINDA to the Drum SCOPE system. Documentation supplied with the Univac version of CINDA was a most useful aid in the conversion process. This NRL report represents the CDC-3800 version of CINDA-3G, and is partly a rewrite of the original Chrysler document. While most of the sections have been only slightly modified, the section on tape usage and deck setups is strictly applicable to CDC-3800 software. The external plotting package in Section VI for the CALCOMP plotter replaces plotting routines used by the Univac 1108 for the SC-4020.

Overview

This programming manual deals with the CINDA system in two general categories—the logic and data needed in setting up the problem data deck, and the actual structure of the operating system.

The logic in constructing a problem for CINDA involves developing a lumped-parameter representation of the physical problem. This model simulates the elements of heat transfer, and the user must supply the corresponding network data, which will be used by one or more routines selected from a large subroutine library. The user must determine which routines are needed and the order in which they are to be activated. This information and the other related logic are entered in a modified FORTRAN language. The major routines involved use various iterative techniques for solutions, with the program-formed compute sequences minimizing the required operations.

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CINDA is not merely a single execution program, but is an operating system in itself. It consists of two software packages of its own (the preprocessor and subroutine library file) and is also quite dependent on the computer's system software (at NRL, the CDC-3800's Drum SCOPE system). This dependence is largely due to language and allocating differences of FORTRAN compilers, as well as computer work size and assembly language routines. The preprocessor reads and processes the two types of user data—the network data and the logic data. From the former, its output is a binary data file, and from the latter, it generates five FORTRAN subroutines which, when compiled, are referred to as the processor. The processor makes user-requested calls to subroutines in the library file, executing the binary data output from the preprocessor. The user's logic controls the processor until the end of the job. For any particular problem the arrays in the processor are dimensioned exactly as needed by the preprocessor. This feature, together with user-controlled output, saves computer time and money.

II. DISCUSSION

Lumped-Parameter Representation

The key to utilizing a network-type analysis program lies in the users' ability to develop a lumped-parameter representation of the physical problem. Once this is done, superimposing the network mesh is a mechanical task at most and the numbering of the network elements is simple although perhaps tedious. It might be said that the network representation is a "crutch" for the engineer, but it does simplify the data logistics and allow easy preparation of data input to the program. In addition, it allows the user to identify uniquely any element in the network and modify its value or function during the analysis as well as sense any potential or current flow in the network. Another feature of the network is that it has a one-to-one correspondence to the mathematical model as well as the physical model.

Perhaps the most critical aspect of the lumped-parameter approach is determining the lump size. There are methods for optimizing the lump size, but they usually involve more analytical effort and computer time than the original analysis. One must also keep in mind that for a transient problem, time is being lumped as well as space. Of prime importance is what information is being sought from the analysis. If spot temperatures are being sought, nodes must at least fall on the spots and not include much more physically than would be expected to exist at a relatively similar temperature. Nodes must fall at end points when a temperature gradient is sought. Of necessity, lumping must be fairly fine where isotherms are sought. Lumping should be coarse in areas of high thermal conductivity. When nonlinear properties are being evaluated, the lumping should be fine enough so that extreme gradients are not encountered. The lumping is also dependent on the severity of the nonlinearity.

To reduce round-off error, the explicit stability criteria of the lump (the capacitance value divided by the summation of conductor values into the node) should be held fairly constant. The value \( C/\Sigma G \) is directly proportional to the square of the distance between nodes. Although refining the lumped-parameter representation will yield more accurate answers, halving the distance between nodes decreases the stability criteria by a factor of four and increases the number of nodes by a factor of two, four, or eight depending upon whether the problem is one, two, or three dimensional. For the explicit case,
halving the distance between nodes increases the machine time for transient analysis by a factor of 8, 16, or 32, respectively. The increase in solution time for the implicit methods is somewhat less but proportional.

When lumping the time space, consideration must be given to the frequency of the boundary conditions. A time step must not step over boundary excitation points or they will be missed. Do not step over pulses; rather, rise and fall with them. Generally the computation interval for the explicit methods is sufficiently small so that frequency effects can be ignored. However, care must be exercised when specifying the time step for implicit methods. If only a small portion of a transient analysis involves frequency considerations, the time step used may be selectively restricted for that interval. By setting the maximum time step allowed as a function of time, we may utilize an interpolation call to vary it accordingly.

One must also realize that the problem being solved is linearized over the time step. Heating rate calculations are usually computed for a time point and then applied to a time space. If the rates are nonlinear, a certain amount of error is introduced, particularly with radiation. These nonlinear effects may cause almost any method of solution to diverge. A brute force method for forcing convergence is to limit the temperature change allowed over the time space. Consideration of the factors mentioned above, coupled with some experience in using the program, will aid the observant analyst in choosing lump sizes that will yield answers of sufficient engineering accuracy with a reasonable amount of computer time.

Figure 1 shows the lumped-parameter representation and network superposition of a one-dimensional heat transfer problem.

The "node" points are centered within the lumps, and temperatures at the nodes are considered uniform throughout the lump. The capacitors hung from the nodes indicate the ability of the lump to store thermal energy. Capacitance values are calculated as lump volume times density times specific heat. The conductors (electrical symbol G) represent the capability for transmitting thermal energy from one lump to another. Conductor values for energy transmission through solids are calculated as thermal conductivity times the energy cross-sectional flow area divided by path length (distance between nodes). Conductor values for convective heat transfer are calculated as the convection coefficient times the energy cross-sectional flow area. Conductors representing energy transfer by radiation are usually indicated by crossed arrows over the conductor symbol. Radiation transfer is nonlinear; it is proportional to the difference of the absolute temperatures raised to the fourth power. Utilization of the Fahrenheit system allows easy automation of this nonlinear transfer function by the program and reduces the radiation conductor value to the product of the Stephan-Boltzmann constant times the surface area times the net radiant interchange factor (script $F$).
Basics of Finite Differencing

The concept of network superposition on the lumped-parameter representation of a physical system is easy to grasp. Describing the network to the program is also quite straightforward. Having described a network to the program, what information have we really supplied and what does the program do with it? Basically, we desire the solution to a simultaneous set of partial differential equations of the diffusion type; i.e.,

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + S, \quad \nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}. \quad (1)$$

That the diffusivity ($\alpha = k/\rho C_p$) may be temperature varying or nonlinear radiation transfer occurring is immaterial at this point. Of importance is how Eq. (1) is finite differenced and its relationship to the network and energy flow equations more commonly utilized by the engineer. The partial of the T-state variable with respect to time is finite differenced across the time space as follows:

$$\frac{\partial T}{\partial t} \approx \frac{T' - T}{\Delta t}, \quad (2)$$

where the prime indicates the new T value after passage of the $\Delta t$ time step.

The right side of Eq. (1) could be written with T primed to indicate implicit "backward" differencing or unprimed to indicate explicit "forward" differencing. The following equation is illustrative of how "backward" and "forward" combinations may be obtained.

$$\frac{\partial T}{\partial t} = \beta (\alpha \nabla^2 T + S) + (1 - \beta)(\alpha' \nabla^2 T' + S'), \quad 0 \leq \beta \leq 1. \quad (3)$$

Any value of $\beta$ less than 1 yields an implicit set of equations which must be solved in a simultaneous manner (more than one unknown exists in each equation). Any value of $\beta$ equal to or less than 1/2 yields an unconditionally stable set of equations or in other words, any time step desired may be used. Values of $\beta$ greater than 1/2 invoke stability criteria or limitations on the magnitude of the time step. A value of $\beta$ equal to 1/2 yields an unconditionally stable implicit set of equations commonly known as "forward-backward" differencing or the Crank-Nicholson method. Various transformations or first order integration applied to Eq. (1) generally yield an implicit set of equations similar to Eq. (3) with $\beta$ equal to 1/2. The following finite difference approach generally applies to transformed equations.

Let us consider the right side of Eq. (3) with $\beta = 1$ and rewrite it as follows:

$$\alpha \nabla^2 T + S \approx \frac{\alpha}{\Delta x} \left( \frac{\partial T}{\partial x^-} - \frac{\partial T}{\partial x^+} \right) + \frac{\alpha}{\Delta y} \left( \frac{\partial T}{\partial y^-} - \frac{\partial T}{\partial y^+} \right) + \frac{\alpha}{\Delta z} \left( \frac{\partial T}{\partial z^-} - \frac{\partial T}{\partial z^+} \right) + S. \quad (4)$$

The minus or plus signs on the first partial terms indicate that they are taken on the negative or positive side, respectively, of the point under consideration and always in the
same direction. If we consider three consecutive points (1, 2, and 3) ascending in the x direction we can complete the finite difference of the x portion of Eq. (4) as follows:

\[
\frac{\alpha}{\Delta x} \left( \frac{\partial T_y}{\partial x} - \frac{\partial T_x}{\partial x} \right) \approx \frac{\alpha}{\Delta x} \left( \frac{T_1 - T_2}{\Delta x^-} + \frac{T_3 - T_2}{\Delta x^+} \right). \tag{5}
\]

Applying the above step to the y and z portions of Eq. (4) yields the common denominator of volume \( V = \Delta x \Delta y \Delta z \). Using Eq. (3) with \( \beta = 1 \), finite differencing with the steps used for Eqs. (3), (4), and (5), substituting \( \alpha = k/\rho C_p \), and multiplying both sides by \( \rho V C_p \) yield

\[
\frac{\rho V C_p}{\Delta t} (T_0' - T_0) = \frac{k A}{\Delta x^-} (T_1 - T_0) + \frac{k A}{\Delta x^+} (T_2 - T_0) + \frac{k A}{\Delta y^-} (T_3 - T_0) + \frac{k A}{\Delta y^+} (T_4 - T_0) + \frac{k A}{\Delta z^-} (T_5 - T_0) + \frac{k A}{\Delta z^+} (T_6 - T_0) + Q, \tag{6}
\]

where \( A_x = \Delta y \Delta z, A_y = \Delta x \Delta z, A_z = \Delta x \Delta y \) and \( Q = \rho V C_p S \).

\( x, y, \) and \( z \) correspond to the coordinates of Fig. 2a.

Fig. 2—Network of a three-dimensional system
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The numbering system corresponds to a three-dimensional network, shown in Fig. 2b. It should be obvious that the network capacitance value is \( \rho V C_p \), that the \( G_1 \) value is \( kA x/Ax^- \), etc. Equation (6) may then be written as

\[
C_0(T_0 - T_0)/\Delta t = G_1(T_1 - T_0) + G_2(T_2 - T_0) + G_3(T_3 - T_0) + G_4(T_4 - T_0) \\
+ G_5(T_5 - T_0) + G_6(T_6 - T_0) + Q_0, \tag{7}
\]

or in engineering terminology, the rate of change of temperature with respect to time is proportional to the summation of heat flows into the node.

It should be noted that Fig. 2 is essentially superimposed on a lumped-parameter cube of a physical system and is the network representation of Eq. (1). Since Eq. (7) is written in explicit form, only one unknown \( T_0 \) exists and all of the information necessary for its solution is contained in the network description. If it had been formulated implicitly, it would have to be solved in a simultaneous manner. No matter what method of solution is requested of the program, the information necessary has been conveyed by the network description. When an implicit set is used with \( \beta > 0 \), the energy flows based on old temperatures are added to the \( Q \) term and the equations are then treated in the same manner as for \( \beta = 0 \);

\[
\alpha \gamma^2 T + S = 0. \tag{8}
\]

The solution of Poisson's equation (8) is the solution utilized for steady state analysis. It is extremely important because virtually all of the unconditionally stable implicit methods reduce to it. If Eq. (7) had all the right side values primed and the left side was subtracted from both sides, we could think of \( C_0/\Delta t \) as a \( G_0 \) term and \( T_0 \) (old) would then become a boundary node. In a manner of speaking, the capacitor we look at in three dimensions becomes a conductor in four dimensions. We could draw a four-dimensional network, but since there is no feedback in time it is senseless to take more than one time step at a time. However, various time-space transformations can be utilized such that a one-dimensional "transient" yields the solution to a two-dimensional steady state problem, etc. This is analogous to the "Particle in Cell" method developed in the nuclear field for following shock-wave propagation.

Iterative Techniques

Now that we have discussed the correlation between the physical, network, and mathematical models, let's investigate the commonality of the various methods of solution. By describing the network of Fig. 1 to the program, we have supplied it with five temperatures, five capacitors, five sources (four not specified and therefore zero), four conductors, and the adjoining node numbers of the conductors. An explicit formulation such as Eq. (6) has only one unknown. Its solution is easily obtainable as long as any associated stability criteria are continuously satisfied. A more interesting formulation would be a set of implicit equations as follows:
If the above had been formulated as partly explicit and implicit, the known explicit portion would have been calculated and added to the $Q$ terms, then the $\beta$ factor would have been divided into the $Q$ terms and multiplied by the $\Delta t$ term.

If we divide the $\Delta t$ term into the $C$ terms and indicate this by priming $C$, we can reformulate Eq. (9) as follows:

\[
(C_1' + G_1) T_1' = Q_1' + C_1' T_1 + G_1 T_2'
\]
\[
(C_2' + G_1 + G_2) T_2' = Q_2' + C_2' T_2 + G_1 T_1' + G_2 T_3'
\]
\[
(C_3' + G_2 + G_3) T_3' = Q_3' + C_3' T_3 + G_2 T_2' + G_3 T_4'
\]
\[
(C_4' + G_3 + G_4) T_4' = Q_4' + C_4' T_4 + G_3 T_3' + G_4 T_5'
\]
\[
(C_5' + G_4) T_5' = Q_5' + C_5' T_5 + G_4 T_4'.
\]

This equation can be generalized as

\[
T_i' = \frac{C_i' T_i + \sum G_a T_a' + Q_i'}{C_i' + \sum G_a},
\]

where the subscript a indicates connection to adjoining nodes. A $C'$ value of zero yields the standard steady state equation, the conductor weighted mean of all the surrounding nodes. We see here that the $C'$ can be thought of as a conductor to the old temperature value and therefore Eq. (11), although utilized to obtain transient solutions, can be considered as a steady state equation in four dimensions. By rewriting Eqs. (10) in the form of Eq. (11) we are in a position to discuss iterative techniques. By assuming all old values on the right hand side of Eq. (10), we could calculate a new set of temperatures on the left which, although wrong, are closer to the correct answer. This single set of calculations is termed an iteration. By replacing all of the old temperatures with those just calculated, we can then perform another iteration. This process is called “block” iteration. A faster method is to utilize only one location for each temperature. This way, the newest temperature available is always utilized. This method is termed “successive point” iteration and is generally 25% faster than “block” iteration. The iterative process is continued a fixed (set by user) number of times or until the maximum absolute difference between the new and old temperature values is less than some prespecified value (set by user).
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Although the above operations are similar to a relaxation procedure, there is a slight difference. We are performing a set of calculations in a fixed sequence. A relaxation procedure would continuously seek the node with the maximum temperature difference between old and new and calculate it. Programmingwise, as much work is required in the seeking operation, which must be consecutive, as in the calculation. For this reason it would be wasteful to code a true relaxation method.

In addition to the iterative approach, several solution subroutines utilize an acceleration feature and/or a different convergence criteria. Once it can be determined that the temperatures are approaching the steady state value, an extrapolation is applied in an attempt to accelerate convergence. This convergence criterion is the maximum absolute temperature change allowed between iterations. This criteria, however, is generally one sided and any associated errors are accumulative. In order to obtain greater accuracy, some subroutines are coded to perform an energy balance on the entire system (a type of Green's function) and apply successively more severe convergence criteria until the system energy balance (energy in minus energy out) is within some prespecified tolerance.

Pseudo-Compute Sequence

A set of simultaneous equations such as Eqs. (10) is quite often treated by matrix methods and formulated as follows:

\[
[A] \{T'\} = \{B\},
\]

where

\[
(A) = \begin{bmatrix}
(C'_1 + G_1) & -G_1 & 0 & 0 & 0 \\
-G_1 & (C'_2 + G_1 + G_2) & -G_2 & 0 & 0 \\
0 & -G_2 & (C'_3 + C_2 + G_3) & -G_3 & 0 \\
0 & 0 & -G_3 & (C'_4 + G_3 + G_4) & -G_4 \\
0 & 0 & 0 & -G_4 & (C'_5 + G_4)
\end{bmatrix}
\]

and

\[
\begin{align*}
T'_1 &= \frac{Q'_1 + C'_1 T_1}{T_1} \\
T'_2 &= \frac{Q'_2 + C'_2 T_2}{T_2} \\
T'_3 &= \frac{Q'_3 + C'_3 T_3}{T_3} \\
T'_4 &= \frac{Q'_4 + C'_4 T_4}{T_4} \\
T'_5 &= \frac{Q'_5 + C'_5 T_5}{T_5}
\end{align*}
\]

\[
\begin{align*}
\{T'\} = \begin{bmatrix}
T'_1 \\
T'_2 \\
T'_3 \\
T'_4 \\
T'_5
\end{bmatrix} = \begin{bmatrix}
Q'_1 + C'_1 T_1 \\
Q'_2 + C'_2 T_2 \\
Q'_3 + C'_3 T_3 \\
Q'_4 + C'_4 T_4 \\
Q'_5 + C'_5 T_5
\end{bmatrix} = \{B\}
\]

The inverse of \([A]\) is then calculated and the solution obtained by matrix multiplication;
\[ \{T'\} = [A]^{-1} \{B\}. \] (14)

It should be noted that the one-dimensional problem has no more than three finite values in any row or column of the coefficient matrix \([A]\). A three-dimensional problem would generally have no more than seven finite values in any row or column. It is easy to see that a 1000-node, three-dimensional problem would require one million data locations, of which approximately 993,000 would contain zero. The inverse might require an additional one million data locations. Aside from exceeding computer core area, the computer time required to calculate the inverse is proportional to the cube of the problem size, and large problems soon become uneconomical to solve.

The explicit and iterative implicit methods previously discussed are well suited for optimizing the data storage area required. Note the adjoining node numbers associated with the conductors of Fig. 1:

\[
\begin{align*}
1,1,2 & \rightarrow \text{G1 between nodes 1 and 2} \\
2,2,3 & \rightarrow \text{G2 between nodes 2 and 3} \\
3,3,4 & \rightarrow \text{G3 between nodes 3 and 4} \\
4,4,5 & \rightarrow \text{G4 between nodes 4 and 5}.
\end{align*}
\] (15)

Note also the row and column position of conductor values off the main diagonal in the \([A]\) coefficient matrix, Eq. (13). By retaining the adjoining node numbers for each conductor we are able to identify its element position in the coefficient matrix. As a consequence we need store only the finite values. The main diagonal term in a composite of the node capacitance and conductor values off the main diagonal.

The program operates on the adjoining node numbers to form what is termed the pseudo-compute sequence (PCS). The nodes are to be calculated sequentially in ascending order, so the adjoining nodes are searched until the number 1 is found. When this occurs the conductor number and the adjoining node number are stored as a doublet value. The search is continued until all nodes one are located and the conductor number for the last receives a minus sign. The process is then continued for node two, etc., until all the node numbers have been processed. The pseudo-compute sequence formed (LPCS) is shown below left. A slight variation to this operation is to place a minus sign on the original other adjoining node number so that it is not recognized when it is searched for. The resulting pseudo-compute sequence thus formed (SPCS) is shown below right.

\[
\begin{array}{ll}
\text{LPCS} & \text{SPCS} \\
-1,2 & -1,2 \\
1,1 & -2,3 \\
-2,3 & -3,4 \\
2,2 & -4,5 \\
-3,4 & -0,0 \\
3,3 & \\
-4,5 & \\
-1,4 & \\
\end{array}
\]
The above pseudo-compute sequences are termed long (LPCS) and short (SPCS), respectively. By starting at the top of the pseudo-compute sequence, we are operating on node 1. The two values identify the conductor into the node (the position of the conductor value in an array of conductor values) and the adjoining node (the position of the temperature, capacitor, and source values in arrays of temperature, capacitor, and source values, respectively). The node being operated on starts as one and is advanced by one each time a negative conductor number is passed.

It is easy to see that the LPCS identifies the element position and value locations of all the off-diagonal elements of the row being operated on. It takes complete advantage of the sparsity of the coefficient matrix. It is well suited for "successive point" iteration of the implicit equations because all elements in a row are identified. When a row is processed and the new T value obtained, the new T can then be used in the calculation procedure of succeeding rows.

The SPCS identifies each conductor only once and in this manner takes advantage of the symmetry of the coefficient matrix as well as the sparsity. It is well suited for explicit methods of solution. The node being operated on and the adjoining node number reveal their temperature value locations and their source value locations. The explicit solution subroutines calculate the energy flow through the conductor, add it to the source location of the node being worked on, and subtract it from the source location for the adjoining node. However, if the short pseudo-compute sequence were utilized for implicit methods of solution, they would require the use of slower "block" iterative procedures. The succeeding rows do not have all of the elements defined, and the energy rates passed ahead were based on old temperature values.

Data Logistics

The pseudo-compute sequence formulated as shown above allow the program to store only the finite values in the coefficient matrix, thereby taking advantage of its sparsity. In addition, the SPCS takes advantage of any symmetry which may exist. Multiply-connected conductors which will be covered in the next section allow the user to take advantage of similarity as well. The foregoing is fairly easy to follow, especially if the nodes and conductors start with the number 1 and continue sequentially with no missing numbers. This restriction is too limiting for general use on large network models. To overcome this restriction the program assigns relative numbers (sequential and ascending) to the incoming node data, conductor data, constants data, and array data in the order received. Any numbers missing in the actual numbering system set up by the user are packed out, thereby requiring only as much core space as is actually necessary.

All solution (Execution) subroutines require three locations for diffusion node data (temperature, capacitance, and source) and one location for each conductor value. They also may require from zero to three extra locations per node for intermediate data storage. Each node in a three-dimensional network has essentially six conductors connected to it but only three are unique; i.e., each additional node requires only three more conductors. Hence, each node in a three-dimensional system requires from six to nine storage locations for data values (temperature, capacitance, source, three conductors, and up to three intermediate locations). The two integer values that make up a doublet of the PCS are packed into a single core location. Hence, for a three-dimensional network,
each node requires approximately three locations for data addressing for the short and six locations for the long pseudo-compute sequence. The number of core locations required for node can vary from 9 to 15.

The program requires the user to allocate an array of data locations to be used for intermediate data storage and initialize array start and length indicators. Each subroutine that requires intermediate storage area has access to this array and the start and length indicators. They check to see that there is sufficient space, update the start and length indicators, and continue with their operations. If they call upon another subroutine requiring intermediate storage, the secondary subroutine repeats the check and update process. Whenever any subroutine terminates its operations it returns the start and length indicators to their entry values. This process is termed dynamic storage allocation and allows subroutines to share a common working area.

Order of Computation

A problem data deck consists of data and operations blocks which are preprocessed by CINDA and passed on to the system FORTRAN compiler. The operations blocks are named EXECUTION, VARIABLES 1, VARIABLES 2 and OUTPUT CALLS. The FORTRAN compiler constructs these blocks as individual subroutines with the entry names EXECTN, VARBL1, VARBL2 and OUTCAL, respectively. After a successful compilation, control is passed to the EXECUTION subroutine. Therefore, the order of computation depends on the sequence of subroutine calls placed in the EXECUTION block by the program user. No other operations blocks are performed unless called upon by the user either directly by name or indirectly from some subroutine which internally calls upon them. The network execution subroutines listed on page internally call upon VARBL1, VARBL2, and OUTCAL. Their internal order of computation is quite similar; the primary difference being the analytical method by which they solve the network. Figure 3 represents a flow diagram of all the network solution subroutines; the subroutine writeups contain the comparisons made at the various check points and the routings taken.

Systems Programming

CINDA is actually an operating system rather than an applications program. Two programs are run and executed, the second program being the product of the first. The initial program, the preprocessor, operates in an integral fashion with a large library of assorted subroutines which can be called in any sequence desired. It reads all of the input data, packs them, assigns relative numbers, forms the pseudo-compute sequence, and writes the data onto two different peripheral units. One unit contains FORTRAN source language generated from the operations blocks, with all of the data values dimensioned exactly in name COMMON. This program, the processor, is then compiled and executed, using as input the data from the first-mentioned peripheral unit. The FORTRAN allocator has access to the CINDA subroutine library and loads only those subroutines referred to by the problem being processed.

Due to this type of operation, CINDA is extremely dependent on the system software supplied. However, once the program has been made operational on a particular machine, the problem data deck prepared by the user can be considered as machine independent.
START

CTS

VARBL1

1

SN

A

B

VARBL2

2

3

MTC

OUTCAL

4

5

6

END

OPERATION | DESCRIPTION
---------|------------------
CTs | Calculate time step
VARBL1 | Variables 1 operations
SN | Solve network
VARBL2 | Variables 2 operations
OUTCAL | Output calls operations
MTC | Modify time control
EI | Erase iteration

Check

1 | Reverse direction if
2 | Backup nonzero
3 | Relaxation criteria not met
4 | Time or temperature change too large
5 | Backup nonzero
6 | Not time to print
7 | Problem stop time not reached

Fig. 3—Basic flowchart for network solution subroutines
III. DATA INPUT REQUIREMENTS

A CINDA problem data deck consists of both data and instruction cards. The card-
reading subroutines for CINDA do not utilize a fixed format type of input; but instead
use a free-form format. The type of data is designated by a mnemonic code in columns
8, 9, and 10. This is followed by the data field which consists of columns 12-80 or the
instruction field which consists of columns 12-72. Although blanks are allowed before
or after numerical data they may not be contained within. The number 1.234 is fine,
but 1. 234 will cause the program to abort. The program processes the problem data
into FORTRAN common data and reforms instructions into FORTRAN source language
which are then passed on to the system FORTRAN compiler. Instruction cards which
contain an F in column 1 are passed on exactly as received. Any instruction card with
or without an F in column 1 may contain a statement or sequence number in columns
25 which is passed on to and used by the FOPTRAN compiler.

The most frequently used mnemonic code is three blanks. The data following this
blank mnemonic code may be one or more integers, floating-point numbers (with or without
the E exponent designation) or alphanumeric words of up to six characters each.
The reading of a word or number continues until a comma is encountered and then the
next word or number is read. As many numbers or words as desired may be placed on
a card, but they may not be broken between cards. A new card is equivalent to starting
with a comma and therefore no continuation designation is required. All blanks are
ignored and reading continues until the terminal column is reached or a dollar sign en-
countered. Comments pertinent to a data card may be placed after a dollar sign and are
not processed by the program. If sequential commas are encountered, floating-point zero
values are placed between them.

The next most frequently used code is BCD (for binary-coded decimal) which must
be followed by an integer 1 through 9 in column 12. The integer designates the number
of 6-character words immediately following it. Blanks are retained and only the desig-
nated number of 6-character words are read from the card. The mnemonic code END is
utilized to designate the end of a block of input to the program. The code REM serves
the same function as a FORTRAN comment card; it is not processed by the program
but allows the user to insert nondata for clarification purposes. The special codes CGS,
CGD, and GEN will be discussed later in this section.

The data deck prepared by a program user consists of various input blocks contain-
ing either data or instructions. A fixed sequence of block input is required, and each
block must start with a BCD 3 header card and terminate with an END card (mnemonic
codes). Specific details about these blocks follows.

Title Block

The first card of a problem data deck is the title block header card. It conveys in-
formation to the program as to the type of problem, which data blocks follow, and how
they should be processed. The three options presently available are
The GENERAL indicates that a non-network problem follows and therefore no node or conductor data is present. The THERMAL cards indicate that a conductor-capacitor (CG) network description follows and that either a short (SPCS) or long (LPCS) pseudo-compute sequence should be constructed. The title block header card may be followed by as many BCD cards as desired. However, the first 20 words (six characters each) are retained by the program and used as a page heading by the user-designated output routines. The block must be terminated by an END card and is then followed by node data for a CG network problem or constants data for a non-network problem.

Node Data Block

As discussed in Section II, there are three types of nodes: diffusion, arithmetic, and boundary. Diffusion nodes are those nodes with a positive capacitance and have the ability to store energy. Their future values are calculated by a finite difference representation of the diffusion partial differential equation. Arithmetic nodes are designated by a negative capacitance value; they have no physical capacitance and are unable to store energy. Their future values are calculated by a finite difference representation of Poisson's partial differential equation. This is a steady state calculation which always utilizes the latest diffusion node values available. Boundary nodes are designated by a minus sign on the node number; they refer to the mathematical boundary, not necessarily the physical boundary. Their values are not changed by the network solution subroutines but may be modified as desired by the user.

A diffusion node causes three core locations to be utilized, one each for temperature, capacitance, and a source location. An arithmetic node receives core locations only for temperature and source and a boundary node receives only a temperature location. The program user is required to group his node data into the above three classes and submit them in that order. Node data input with the three-blank mnemonic code always consists of three values—the integer node number followed by the floating-point initial temperature and capacitance values. A negative capacitance value is used to designate an arithmetic node while a negative node number designates a boundary node. Although the capacitance value of a boundary node is meaningless, it must be included so as to maintain the triplet format.

All nodes are renumbered sequentially (from one on) in the order received. The user input number is termed the actual node number while the program assigned number is termed the relative node number. This relative numbering system allows sequential packing of the data and does not require a sequential numbering system on the part of the program user. It is worth noting that the pseudo-compute sequence is based on the relative numbering system. Hence, the computational sequence of the nodes is identical with their input sequence. If a user desired to reorder the computations in order to aid boundary propagation, he needs merely to reorder his nodal input data.
The mnemonic codes CGS, CGD, and GEN may be used. The CGS and CGD codes are used when one or two materials, respectively, with temperature-varying properties are to be considered. For a single material the node number and initial temperature remain the same but instead of a capacitance value, the user may input the starting location (integer count) or a doublet array of the temperature-varying property followed by the actual (literal) multiplying factor value to complete the calculation or a constants location containing it. For a node consisting of two materials, the node number and initial temperature remain the same but the user would use two array addresses and multiplying factors with a CGD code. These codes would look as follows:

\[\text{CGS N#,TI,A1,F1}\]
\[\text{or CGD N#,TI,A1,F1,A2,F2}\]

where N= is the integer node number and Ti is the floating-point initial temperature. The A arguments refer to doublet arrays of temperature-varying Cp or \(\rho \cdot \text{Cp}\), and the F arguments may be or refer to a constant location containing the weight or volume, respectively. The CGS code causes the product of the interpolated value times the F factor to be used as the capacitance value. The CGD code uses the sum of the separate interpolations times the factor products as the capacitance value.

To input a group of sequential nodes, the following code is available:

\[8\]
\[\downarrow\]
\[\text{GEN N#,N1,TI,X,Y,Z,W}\]

where

N= is the starting node number
N is the total number of nodes desired (integer)
IN is an increment for the generated nodes (integer)
Ti is the initial temperature for all nodes,

and the capacitance value is calculated as the produce of X times Y times Z times W. If this product is negative, arithmetic nodes will be generated. If N= is negative, boundary nodes will be generated. A sample node data block could be as follows:

\[8\]
\[12\]
\[\downarrow\]
\[\text{BCD 3NODE DATA}\]
\[1,80,1,2,2,80,1,3\]
\[\text{TWO DIFFUSION NODES}\]
\[\text{CGS 3,80,A1,4.63}\]
\[\text{SINGLE MATERIAL NODE}\]
\[\text{CGD 4,80,A1,2.31,A2,4.76}\]
\[\text{DOUBLE MATERIAL NODE}\]
\[\text{GEN 5,10,1,80,4,63,1,1,1,1,1,1}\]
\[\text{GENERATE 10 NODES, 5-14}\]
\[\text{15,80,-1,16,80,-1,1,1}\]
\[\text{TWO ARITHMETIC NODES}\]
\[\text{-18,-460,0}\]
\[\text{ONE BOUNDARY NODE}\]

15
The above does not correspond to a problem; it just represents data input. Note that the nodes are input in the order: diffusion, arithmetic and boundary. The factor portion of the CGS and CGD codes may be a literal (actual value) as shown or reference a constant's location containing the value. Either one (not both) of the array arguments on the CGD code may be a literal if the property is constant. Both codes set up linear interpolation calls which utilize the node temperature as the independent variable and interpolate a dependent value which is then multiplied by the factor to obtain the capacitance value. The CGD call causes two interpolations and multiplications to be performed and sums the products to obtain the capacitance value. These interpolations are performed each iteration during the transient analysis.

The GEN code expects values in the following order; starting node number, number of nodes to be generated, an increment for indexing the generated node numbers, the initial temperature for all nodes, and four floating point numbers, the product of which is the capacitance value.

Conductor Data Block

Two basic types of conductors may be used, regular or radiation, and either may utilize temperature-varying properties in calculating the conductance value. When utilizing the blank mnemonic code a regular conductor consists of the integer conductor number followed by two integer adjoining node numbers and the floating-point conductance value. If more than one conductor has the same constant value, they may share the same conductor number and value. This is accomplished by placing two or more pairs of integer adjoining node numbers between the conductor number and value. The CGS and CGD mnemonic codes may also be utilized for conductors. They would appear as follows:

```
8
↓
CGS G#, NA, NB, A1, F1
or
CGD G#, NA, NB, A1, F1, A2, F2
```

where

- G# is the integer conductor number
- NA is one adjoining node number
- NB is the other adjoining node number.

The A arguments refer to doublet arrays of temperature-varying thermal conductivity $k(T)$, and the F arguments may be or refer to a constant location containing the cross sectional area divided by path length.

For CGS with F1 positive

$$G = k_1(T_m) \cdot F_1, \quad T_m = (T_a + T_b)/2.0. \quad (16)$$

For CGS with F1 negative

$$G = k_1(T_a) \cdot |F_1|. \quad (17)$$
For CGD

\[ G = \frac{1.0}{1.0 + \frac{1.0}{k_1(T_a)*F_1} + \frac{1.0}{k_2(T_b)*F_2}}. \]  

(18)

The CGS mnemonic code may be utilized for either regular or radiation conductors. The data consist of the integer conductor number and one pair only of integer adjoining node numbers, and are followed by an array address and multiplying factor. A regular conductor would normally utilize the CGS code where the addressed array would be thermal conductivity vs temperature, and the multiplying factor would consist of the cross-sectional area divided by path length. A surface radiation conductor would utilize the CGS code for a temperature-varying array of emissivity with the multiplying factor being the product of surface area times the Stephan-Boltzmann constant \( F = 1.0 \).

The CGD code may be utilized for regular conductors passing through two materials. In this case two temperature-varying property arrays and multiplying factors are input. Two conductance values are calculated and one over the summation of their inverses is returned as the conductor value. Either of the array addresses may be a literal if one of the properties is a constant. The GEN code is also available for conductors and is input as follows:

8  
|  
| GEN G#, #G, IG, MA, INA, NB, INB, X, Y, Z, N  

where

- \( G = \) is the starting conductor number
- \( =G \) is the total number of conductors desired (integer)
- \( IG \) is an increment for the generated conductors (integer)
- \( NA \) and \( NB \) are initial adjoining node numbers (integers)
- \( INA \) and \( INB \) are increments for the generated adjoining nodes (integers),

and all generated conductors receive the same conductance value of \( X \) times \( Y \) times \( Z \) divided by \( W \). A negative \( G = \) will cause radiation conductors to be generated.

The GEN code may be used to generate sequential conductors, either radiation or regular. The data consist of the integer conductor number, an integer for the number of conductors to be generated, an integer increment for indexing the generated conductors, the first integer adjoining node number, an integer increment for indexing the first adjoining node number, the second integer adjoining node number, an integer increment for indexing the second adjoining node number, and finally four floating-point numbers; the product of the first three divided by the fourth is the constant conductance value. For example:

8  
|  
| GEN 1, 2, 1, 1, 1, 2, 1, 2, 2, 2, 2  
| GEN -3, 3, 0, 1, 1, 0, 0, 1, 1, 1, 1, E+15  

is equivalent to

17
An additional feature of the program is the one-way conductor. This is a conductor value which enters into the temperature calculation of only one of its adjoining nodes and is indicated by placing a minus sign on the unaffected node. The CGS, CGD, and GEN codes may be used for one-way conductors. Physically this occurs in incompressible fluid flow, and therefore the upstream node would receive the minus sign.

A program idiosyncrasy which should be mentioned is that while a single-valued conductor with as many adjoining node pairs as desired may be used, extending several cards if necessary, an adjoining node pair must not be split between cards. In addition, the CGS, CGD, and GEN card may have more than one set of data on a card, but a set of data may not be broken between cards. All regular conductors must be entered prior to any radiation conductors. The following is illustrative of the various conductor input options.

8

<table>
<thead>
<tr>
<th>BCD 3CONDUCTOR DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,1,2,1,2,2,3,1,7</td>
</tr>
<tr>
<td>3,3,4,4,5,5,6,1,5</td>
</tr>
<tr>
<td>4,-7,8,-8,9,7,6</td>
</tr>
<tr>
<td>CGS 5,10,11,A3,4,6</td>
</tr>
<tr>
<td>CGD 6,12,13,A3,4,1,A4,7,6</td>
</tr>
<tr>
<td>GEN 7,3,1,1,1,9,1,1,6,4,0,1,,1</td>
</tr>
<tr>
<td>-10,1,99,1,E-15</td>
</tr>
<tr>
<td>CGS -11,2,99,A5,1,E-14</td>
</tr>
<tr>
<td>GEN -12,4,1,3,1,99,0,1,E-14,1,,1,1</td>
</tr>
</tbody>
</table>

The first GEN card is equivalent to the following:

12

<table>
<thead>
<tr>
<th>$TWU REGULAR CONDUCTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
</tr>
<tr>
<td>7,1,9,6,4,8,2,10,6,4,9,3,11,6,4</td>
</tr>
</tbody>
</table>

and the second GEN card is equivalent to

12

<table>
<thead>
<tr>
<th>$DOUBLE PLACED ONE-WAY COND.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
</tbody>
</table>

If the second GEN card had incremented the conductor number by zero, it would have been equivalent to

12

<table>
<thead>
<tr>
<th>$DOUBLE PLACED ONE-WAY COND.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
<tr>
<td>$DOUBLE PLACED ONE-WAY COND.</td>
</tr>
</tbody>
</table>

If the second GEN card had incremented the conductor number by zero, it would have been equivalent to
Once the node and conductor data have been read by the program, construction of the pseudo-compute sequence is performed. Any errors encountered cause an appropriate error message to be printed and a "do not execute" switch to be set. However, the program will continue to process input data and attempt to discover any and all recognizable errors. Items checked for are no duplicate node or conductor numbers, all conductor adjoining nodes must have been specified in node data, and all diffusion and arithmetic nodes must have at least one conductor into them. A missing comma will dislocate the data input sequence causing pages of error messages. If over 200 error messages are printed, the program gives up and immediately terminates.

Constants Data Block

Constants data are always input as doublets, the constant name or number followed by its value. They are divided into two types, control constants and user constants, and may be intermingled within the block. Control constants (≈ 50) have alphanumeric names while user constants receive a number. User constants are simply data storage locations which may contain integers, floating-point numbers, or up to 6-character alphanumeric words. It is up to the program user to place data in user constant locations as needed and supply the location addresses to subroutines as arguments.

Control constant values are communicated through program COMMON to specific subroutines which require them. However, any control constant name desired can be used as a subroutine argument. Wherever possible, control constant values not specified are set to some acceptable value. If a required control constant value is not specified, an appropriate error message is printed and the program terminated. It is up to the user to check the writeups of subroutines he is using to determine control constant requirements. A list of control constant names and brief description of each follows; check subroutine writeups for exact usage.

ARLXCA The maximum arithmetic relaxation change allowed.
ARLXCC The maximum arithmetic relaxation change calculated.
ATMPCA The maximum arithmetic temperature change allowed.
ATMPCC The maximum arithmetic temperature change calculated.
BACKUP If nonzero, the time step just done is erased and redone.
BALENG User-specified system energy balance to be maintained.
CSGFA5 Stability criteria multiplication/division factor.
CSGMAX Maximum stability criteria for the network. \( (C/\Sigma G) \) max and min.
CSGMIN Minimum stability criteria for the network. \( (C/\Sigma G) \) max and min.
CSGRAL Stability criteria range allowed.
CSGRCL Stability criteria range calculated.
DAMPA Arithmetic node damping factor.
DAMPD Diffusion node damping factor.
DRLXCA The maximum diffusion relaxation change allowed.
DRLXCC The maximum diffusion relaxation change calculated.
DTIMEH Highest time step allowed (maximum).
DTIMEI Input time step for implicit solutions.
MARY E. GEALY

DTIMEL  Lowest time step allowed (minimum).
DTIMEU  Time step used for all transient network problems.
DTMFCA  The maximum diffusion temperature change allowed.
DTMPCC  The maximum diffusion temperature change calculated.
ENGBAL  The calculated energy balance of the system.
IDCNT   A counter for STOREP and RECALL identification (integer).
LAXFAC  Number of iterations before radiation conductor is linear (integer).
LINECT  A line counter location for program output.
LØØFCT  Program count of iteration loops performed (integer).
NLØØP  User input number of iteration loops desired (integer).
ØPEITR  Causes output each iteration if set nonzero.
ØOUTPUT Time interval for activating OUTPUT CALLS.
PAGECT  A page counter location for program output.
TIMEM   Mean time for the computation interval.
TIMEN   New time at the end of the computation interval.
TIMEND  Problem stop time for transient analysis.
TIMEØ   Old time at the start of the computation interval, also used as problem
        start time, may be negative.

ITEST, JTEST, KTEST, LTEST, MTEST are dummy control constants with integer
names.
RTEST, STEST, TTEST, UTEST, VTEST are dummy control constants with noninteger
names.

The following is representative of a constants data block:

    8
   /   
BCD 3CONSTANTS "DATA
    TIMEND,10,C,OUTPUT,1.0
    1,10,2,3,3,7,4,8
    5,1,6,1.E3,7,1.E-3
    8,TEMP,9,ALPHA
END

Array Data Block

Array data are exceedingly simple to enter. The user inputs an array number, se-
quentially lists his information, and terminates it with an END (data END, not mnemonic).
Numerous subroutines (interpolation, matrix, etc.) require that the exact number of values
in an array be specified as an integer. In order to reduce the number of subroutine argu-
ments and chance of error, the CINDA preprocessor counts the number of values in an
array and supplies this integer count as the first value in the array. The writeup of any
subroutine whose array arguments require the array integer count will list the array argu-
ment as A(IC). Subroutines whose array arguments require the first data value rather
than the integer count will list the array argument as A(DV). When a user inputs the
array number as positive, the integer count is calculated by the preprocessor and supplied
as the first value in the array. For example,
The above array (Array 1) contains three data values and was input as a positive array. By addressing A1 as a subroutine argument the integer count 3 would be the first value followed by 1.6, 2.4 and 3.8. If the user wanted the 1.6 data value to be addressed the argument should be A1+1. The user has the option of placing a minus sign on the input array number. In this event the integer count of data values in the array is not calculated or stored and addressing the array as A1 obtains the first data value. For example:

```
12
1,1.6,2.4,3.8,END
```

Entering the argument A2 would address the 1.6 data value; the integer count is not available. The following is an example of various types of arrays.

```
8
4
BCD 3ARRAY DATA
1,1.6,2.4,3.8,END $FLOATING POINT NUMBERS
2,TMP1,TMP2,END $ALPHANUMERIC
3
BCD 3TEMPERATURE STUDY
END
-4,SPACE,100,END $SPACE OPTION
END
```

Two types of alphanumeric inputs are shown above. The first allows each word to be separated by a comma, requires each word to start with a letter, and does not allow the use of blanks. The second requires use of the BCD mnemonic code and the integer word count. It allows use of letters, numbers, or characters anywhere and retains blanks. The space option is an easy way for the user to specify a large number of locations which are initialized by the preprocessor as floating-point zeros. The space option requires the word SPACE followed by the number of locations to be initialized. It may be used anywhere in an array and as many times as desired as long as total available core space is not exceeded.

**Program Control**

Aside from the title block, there are either two or four data blocks depending upon whether the problem is GENERAL or THERMAL, respectively. No matter which, there are also four operations blocks entitled EXECUTION, VARIABLES 1, VARIABLES 2, and OUTPUT CALLS. The operations or instructions called for in these blocks determine the program control. They are preprocessed by CINDA and passed on to the system FORTRAN compiler as four separate subroutines entitled EXECTN, VARBL1, VARBL2, and OUTCAL, respectively. When the FORTRAN compilation is successfully completed, control is passed to the EXECTN subroutine which sequentially performs the operations.
in the same order as entered by the user in the EXECUTION block. None of the operations specified in the other three blocks will be performed unless they are called for, either directly by name in the EXECUTION block or internally by some other called-for subroutine.

No operations will be performed unless requested by the user, and, no control constants will be utilized unless some subroutine calls for them. Network solution subroutines internally call upon VARBL1, VARBL2, and OUTCAL (see Fig. 3). They also use numerous control constants, but their individual writeups in Section VIII must be consulted to determine which ones and their exact usage. Network solution subroutines require no arguments but most others do. These arguments may be addresses which refer to the location of data or they may be literals; i.e., the actual data value. All of the input data can be addressed by using alphanumeric arguments of the following form.

TN for the temperature location of node N
CN for the capacitance location of node N
QN for the source location of node N
GN for the conductance location of conductor N
KN for the value location of constant N
AN for the starting location of array N

and control constants utilize their individual names.

When addressing arrays the user must be cautious as to the use of positive and negative arrays and address them accordingly. However, the user may uniquely address any item in an array. For instance, the one-hundredth value in a positive array may be uniquely addressed as A10+100. This plus option is available only in arrays. If, for instance, a user desired to address the 20 BCD words for the title block which were retained as output page headings, he could do so by using the arguments.

Dynamic Storage Allocation is a unique feature of the "INFX3G" program, though not carried to the ultimate, all arguments which require working space generally obtain it from a common working array. However, it is up to the user to specify information about this array to the program. To do so, the user must include two or three cards at the start of the Execution block, the first of which must appear before the third EXECUTION card. For example,

1    7   21   25
F   1
F DIMENSION X(100)
F BCD 3EXECUTION
F NDIM = 100
F NTH = 0

In the DIMENSION card, columns 21-25 must be reserved for the array name, which must be in an 15 format. The names used must be exactly as specified on the card for the program to recognize. If no working locations are needed, the integer 100 may be changed as desired (but not DIMX, NDIM, and NDIM). If no working locations are required, the cards should be omitted.
An F in column 1 indicates to the preprocessor that the card is FORTRAN and should be passed on as received. This F option allows the user to program FORTRAN operations directly into the operations blocks. However, the CINDA arguments listed above are not FORTRAN compatible with the exception of the control constant names. Therefore, it is recommended that the program user utilize CINDA subroutine calls wherever possible. This is impossible however when logical operations are required. In this case it is recommended that the user place CINDA data values as needed into the available dummy control constant names allowed for that purpose. Then, FORTRAN logical operations can be utilized with the dummy control constant names as arguments. FORTRAN statement numbers for routing purposes may be placed in columns 2-5 on any operations cards.

The data field for node, conductor, constant, and array data consists of columns 12-80. However, the data field of operations cards ends with column 12. In a manner of speaking, a CINDA subroutine call is a special array and should terminate with a data END. In order to simplify input for the user, the operations read subroutines recognize two special characters; the left and right parentheses. The left parenthesis is accepted as a comma, while the right parenthesis is accepted as a comma followed by a data END. This allows what would have been

```
12
\downarrow
ADD(K1,K2,K3,END)
```

to be more aesthetically formatted as

```
12
\downarrow
ADD(K1,K2,K3)
```

which is almost identical to a FORTRAN subroutine call.

**Execution Operations Block**

An Execution operation block might be as follows:

```
1 7 12 21 2b
\downarrow \downarrow \downarrow \downarrow \downarrow \downarrow
F DIMENSION X(25)
 F UCD 3EXECUTION
 F NDIM = 25
 F NTH = 0
 F 10 TIMEND = TIMEND + 1.0
 CNFRND
 S$\text{IF}(\text{TEST LE. } 100.) \text{GO TO 10 END}$
```

\$\text{EXPLICIT FORWARD DIFFERENCING}$

\$\text{PLACE } 10 \text{ INTO DUMMY CC}$
The above indicates a transient thermal problem in which the user desires to terminate the analysis when the temperature at node 20 exceeds 100°F. The problem must have been fairly small because only 25 working locations were dimensioned and CNFRWD requires one per node. It does demonstrate the use of both CINDA calls and FORTRAN operations and that control constants are referred to by name in either. Another example might be

```
1     8    21   25
↓  ↓  ↓  ↓  ↓
F   DIMENSION X(500)
    BCD 3EXECUTION
F   NDIM =500
F   NTH =0
    CINDSL $STEADY STATE (USES LPCS)
F   TIMEND =10.0
    CNFRMD $TRANSIENT ANALYSIS (USES SPCS)
END
```

In this case the user desires to have a steady state analysis performed on the network and then a transient analysis performed utilizing the steady state answer as initial conditions. However, the two-network solution subroutines referred to are incompatible in their PCS requirements and the program would be terminated with an appropriate error message. A further example might be

```
8    12
↓  ↓
BCD 3EXECUTION
    INVERSE(A1,A2) $SEE MATRIX SUBROUTINE
    MULT(A2,A3) $WRITEUPS FOR OPERATIONS
    LIST(A2,K1,17) $PERFORMED
    LIST(A3,K2,17)
END
```

The above problem consists entirely of matrix operations and therefore is run as a GENERAL. The subroutines do not require any working space so none have been dimensioned. Furthermore, no reference, direct or indirect, is made to VARBL1, VARBL2, or OUTCAL, and those operations blocks should be empty. Even though they may be empty or not referred to, their blockheader and mnemonic END cards must still be entered.

There is no end to the variety of examples that could be generated. In reality, the program user is actually programming, although it is somewhat disguised as data input. However, the program does simplify the task of data logistics, and it automates data input and output, construction of the PCS, loading the subroutine library, and other systems features, thereby greatly lessening the programming knowledge which might otherwise be required of a user.

A point well worth considering is proper initialization. All instructions contained in the other three operations blocks are performed each iteration or on the output interval. If an operation being performed in Variables 1 is utilizing and producing nonchanging constants, it should be placed in the Execution block (prior to the network solution call) so that it will be performed only once. Input arrays requiring postinterpolation multiplication
for units conversion only could be prescaled, thereby deleting and multiplication process. Complex functions of a single independent variable requiring several interpolation values which are then combined in a multiplicative fashion can be precalculated vs the independent variable. Such a precalculated complex function reduces the amount of work performed during the transient analysis. A great many operations of this type can be performed in the Execution block prior to call for a transient analysis. Also, output operations to be performed once the transient analysis is completed may be placed directly into the Execution block following the transient network solution call.

Variables 1 Operations Block

The statement that this program solves nonlinear partial differential equations of the diffusion type is not quite accurate. In reality the program only solves linear equations. However, nonlinearities are evaluated at each computation interval and in this manner generally yield acceptable answers to nonlinear problems. This method is more properly termed quasilinearization. The Variables 1 operation block allows a point in the computational sequence at which the user can specify the evaluation of nonlinear network elements, coefficients, and boundary values (see Fig. 3). The CGS and CGD mnemonic codes utilized for node and conductor data cause the construction of various subroutine calls which are placed in this block by the CINDA preprocessor. The user must specify any additional subroutine calls necessary to completely define the network prior to entering the network solution phase.

Prior to inclusion of the CGS and CGD mnemonic codes, the Variables 1 operations block primarily consisted of linear interpolation subroutine calls input by the user for the evaluation of temperature varying properties. While these linear interpolation calls are automated through use of the CGS and CGD codes, it is up to the program user to specify any required bivariate or trivariate interpolations or other functional evaluations necessary. Just prior to performing the Variables 1 operations, all network solution subroutines zero out all source locations. Therefore, the user is required to specify constant as well as variable or nonlinear impressed sources in this block. A Variables 1 operations block could be as follows:

```plaintext
1     8  12
B  C  B  C

BCD 3VARIABLES 1
STFSEP(10,0,0,17)  $CONSTANT IMPRESSED SOURCE
D1DEGI(TIMEN,A8,0,19)  $TIME VARYING SOURCE
D2DIM(T18,TIMEN,A19,7,63,A18)  $BIVARIATE FUNCTION

F  TTEST=11.6
F  IF (TIMEN .GT. 10.) TTEST =0.0
STFSEP(TTEST,0,27)  $VARIABLE SOURCE
END
```

The first call above places a constant heating rate of 10.0 into the source location of node 17. The second call causes a linear interpolation to be performed on array 8 using mean time as the independent variable to obtain a time-varying heating rate for node 19. The third call uses mean time and the temperature at node 18 as independent variables to perform a bivariate interpolation. The interpolated answer is then multiplied by 7.63.
and placed as the conductance value of conductor 18. The next two cards are FORTRAN
and allow a value of 11.6 to be placed into control constant TTEST until TIMEN exceeds
10.0, after which a value of 0.0 is placed into TTEST. This amounts to a single step in
a "staircase" function. The last card places the value from TTEST into the source loca-
tion for node 27. Another sample Variables 1 block might look as follows:

8 12
↓ ↓
BCD 3VARIABLES 1
BDARY(A12+1,T1,T7,T3,T4) $CONSTRUCT VECTOR
D1DEG1(T7,A19,A13+2) $INTERPOLATION
IRRADE(A7,A13,A10,A12) $IR RADIOSITY EXPLICIT
BRKARY(A12+1,Q1,Q7,Q3,Q4) $DISTRIBUTE Q RATES
D1D1WM(TIMEM,A9,0.35,TTEST) $ADD TWO RATES
END

The first call causes the construction of an array of four temperature values necessary as
input to an infrared radiosity subroutine (third card). The second call causes the linear
interpolation of a temperature-varying property from array 19 to be placed into array
13 + 2 which is the second array argument for the radiosity call. This second argument
must be an array of surface emissivities for the surfaces under consideration; therefore
array 19 must be an array of temperature-varying emissivity. The BRKARY call takes
data values from array 12 + 1, 2, 3, and 4 and places them into the source locations for
nodes 1, 7, 3, and 4, respectively. The fifth call performs linear interpolation on array 9
using TIMEM as the independent variable, multiplies the result by 0.35 and places it in
control constant TTEST. This might be a time-varying solar heating rate where 0.35 is the
solar absorptivity. The ADD call adds this rate to what is already contained in the source
location for node 1. Each node has one and only one source location. If a user desires
to impress more than one heating rate on a node, he must sum the rates and supply the
value to the single source location available per node.

The Variables 1 operations block is the logical point in the network computational
sequence for the calculation of impressed sources whether they are due to internal dissipa-
tion of power components, radiation deposition, aerodynamic heating, or orbital
heating. If a desired subroutine is not available, the user may always add his own; data
communication is obtained through subroutine arguments as in any other subroutine.

Variables 2 Operations Block

With regard to the network solution, the Variables 1 operations may be thought of
as presolution operations and the Variables 2 operations as postsolution operations. In
Variables 1 the network was completely defined with respect to nonlinear elements and
boundary conditions. Variables 2 allows the user to look at the network just solved. He
may meter and integrate flow rates, make corrections in order to account for material
phase changes, or compare answers just calculated with test data in order to derive em-
pirical relationships. A simple Variables 2 operations block might be as follows:

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The first call measures the heat flow from node 1 to node 2 through regular conductor 1 and stores the result in constant location 1. The second call performs a simple integration with respect to time and sums the result into constants location 2. The third call measures heat flow through a radiation conductor which is then integrated by the fourth call. The sum of the two integrations is obtained by the fifth call. Another Variables 2 operations block might be as follows:

```
8 12
↓ ↓
BCD 3VARIABLES 2
QINTEG(K2,DTIMEU,K2) $INTEGRATE HEAT FLOW
RDTNQS(T5,T1,G8,K3) $METER RADIANT FLOW
QINTEG(K3,DTIMEU,K4) $INTEGRATE RADIANT FLOW
ADD(K2,K4,K5) $METER HEAT FLOW
END
```

Phase change subroutines such as the above are unique in that they perform automatic corrector operations. Node 15 has been solved by the network solution subroutine as though no ablative existed. The ABLATS subroutine then corrects the temperature at node 15 to account for the ablative material. It does this by calculating the average heating rate to node 15 over the time step just performed and utilizes it as an inner-surface boundary condition for the internally constructed one-dimensional network representation of the ablative material. The correctness of this analytical approach can be rigorously substantiated for use with explicit network solution subroutines. However, when used with large time step implicit methods it yields a controlled instability and the results may be questionable. It is up to the user to determine the solution accuracy by whatever means available. A more complicated Variables 2 operations block could be as follows:

```
1 5 8 12
↓ ↓
BCD 3VARIABLES 2
D1DEGI(TI1EN,A10,K8) $GET TEST TEMPERATURE
SUB(T8,K8,TTEST) $OBTAIN TEMP DIFFERENCE
F IF(TTEST.LE.2.0)GO TO 10
MLTPLY(G7,0.99,G7) $REDUCE CONDUCTANCE
5 STFSEP(-1.0,BACKUP) $SET BACKUP NON-ZERO
F GO TO 20
F 10 IF(TTEST.GE.-2.0) GO TO 15
MLTPLY(G7,1.01,G7) $INCREASE CONDUCTANCE
F 15 QMETER(T8,T15,K9) $METER HEAT FLOW
QINTEG(K9,DTIMEU,K10)
F 20 CONTINUE
END
```

27
This corresponds to a portion of a network such as shown in Fig. 4.

Array 10 is a time-temperature test history of node 8, and node 15 is a known boundary reference temperature. The problem is to calculate the value of conductor 7 which will yield a calculated temperature at node 8 that is within ±2.0 degrees of the test history. The above Variables 2 operations will attempt to modify conductor 7 so that it will meet the constraints on temperature 8. It is quite “brute force” and unsophisticated. However, the corrector operations are at the discretion of the user. If the tolerances were too severe or the correction operations too strong, the correction for one tolerance could lead to dissatisfaction of the other and an impasse result. If the reference temperature at node 15 were incorrect, possibly no value of conductor 7 would satisfy the constraints. The end result of such a study would be to produce a plot of conductance 7 vs time which could be used to derive an empirical relationship with other parameters. Too wide a tolerance would cause the plot to resemble a staircase function. Please note that either condition being unsatisfied causes control constant BACKUP to be nonzero and the iteration to be redone with the corrected conductor 7 value. Only when all criteria are met are the metering and integration operations performed.

Output Calls Operations Block

This operations block could have been entitled Variables 3 but Output Calls seemed more appropriate. In it a user may call upon any desired subroutine. However, its contents are performed on the output interval (see Fig. 3), so it is only logical that it would primarily contain instructions for outputting information. There is a variety of output subroutines offering the user several format options. A very simple Output Calls block would be as follows:

```
  S  12
  \ /  \\
 BCD 3OUTPUT CALLS
      PRNTMP
      END
```

The above call will output certain time control information and the temperature of every node in the network under consideration. The node temperatures will correspond to the relative node numbers set up by the preprocessor, not the actual node numbers set by
the user. The preprocessor lists out all of the input data. Immediately after the
input node data a dictionary of relative node numbers vs actual node numbers is
listed. By utilizing it a user can correlate the relative node temperatures with his
actual numbers.

The Output Calls will be performed at problem start time and on the output inter-
val until problem stop time is reached. For example, a 100-min transient analysis
with an output interval of 5 min would cause the Output Calls operations to be per-
formed 21 times.

The above data and operations blocks constitute a problem data deck which must be
terminated by the following card:

```
8 12
BD 3END OF DATA
```

Parameter Runs

Parametric analyses which do not involve network of operations changes to the
original problem may be performed on the same computer run. Only data values such
as output page heading, temperatures, capacitances, conductances, constants, and arrays
may be changed. The data change blocks must all be specified whether changes occur
in the block or not, and the data input is identical to the preceding discussion with the
exception of conductors. When specifying new conductances, the adjoining node infor-
mation is deleted; only the conductor number and value are required. The only mnemon-
ics allowed are the three blanks and BCD. When changing an array, the entire new array
must be entered and be exactly the length of its original. No new arrays or numbered
constants may be defined.

Two parametric run options are available, INITIAL and/or FINAL, and they may
be used several times within the problem data deck. The problem data deck as initially
entered is referred to as the original problem. Any and all INITIAL parameter runs refer
to it exactly as it was put in. The FINAL parameter run refers to the problem just com-
pleted exactly as terminated. When two INITIAL parameter runs are attached to the end
of a problem data deck, they both refer to the original problem at start time. However,
when two FINAL parameter runs are attached to the end of a problem data deck, the
first refers to the original as terminated, and the second refers to the first FINAL param-
eter run as completed. The CINDA control cards necessary to specify a parameter run
are as follows:
The parameter run decks are inserted in the problem data deck immediately preceding the BCD 3END OF DATA card. After the BCD parameter card, the user may insert additional BCD data to replace the original problem output page heading. Parameter runs conserve machine time mainly because the PCS does not have to be reformed. If a user desires, he may accomplish FINAL parameter runs by calling the network execution subroutine twice in the Execution block and inserting the necessary calls to modify data values between them.

**Store and Recall Problem Options**

The purpose of the store and recall options is to provide the user with the means to interrupt his program at any point, store the current data values on tape, and continue processing. While the parameter run capability is useful for performing parametric analyses in the same run, the store and recall capability allows an indefinite time lapse between parametric analyses. In addition, long duration problems may be broken into several short duration runs. If a parametric analysis is such that the first portion of the runs are identical, then the problem can be run for the constant portion, stored and then recalled as many times as necessary.

The store problem feature is achieved by a user initiated subroutine call which is as follows:

```
12
STOREP(KX)
```

where KX refers to a constant location containing an alphanumeric identification name for the stored problem. The call may be used as many times as desired, but each activation must reference a unique name. To allow the STOREP call to be placed in a loop, the programmer must use the control constant IDCNT. By incrementing this constant within the loop (not to exceed 999), a unique combination of KX and IDCNT will be available to identify the problem.

The recall problem feature is a CINDA preprocessor option, which is activated by the following card:
where AAAAAA is the alphanumeric identification name of the stored problem, and NNN is the integer IDCNT. (If IDCNT was not used with STOREP, NNN = 0). This single card replaces the blank card preceding the problem data deck and must be followed by a BCD 3INITIAL PARAMETERS data deck. The stored problem identified will be searched for and brought into core from the two storage tapes. Any data changes specified will be performed and the control is passed to the first subroutine call in the EXECUTION block.

The problem is stored on logical unit 22 and recalled from unit 21; the processor (tape 40) must be saved in a store run and remounted on a recall run. The user must remember that the recalled problem contains the STOREP call. Because of this feature, the user has the option whether or not to store the problem again. Logical unit 22 is equipped depending on this option. Section VII should be consulted for details concerning deck setups, tape usage, and Job Request forms.

Data Printing Option

At times, the user may wish to see what is being stored on the data tapes during preprocessing (i.e., LUT1, LUT2, LUT3, LUT4, and LB3D). A printout will occur if an asterisk is put in column 80 of the first BCD card (the GENERAL, THERMAL, INITIAL PARAMETERS, or FINAL PARAMETERS card). After each block of the problem deck is printed, there will be a listing of the appropriate data (most of which will be binary).

IV. ERROR MESSAGES

Due to the variety of subroutines available and the variable number of arguments which some of them have, no check is made to determine if a subroutine call has the correct number of arguments. An incorrect number of arguments on a subroutine call will generally cause job termination immediately after successful compilation, usually without any error message. If the above occurs, the user should closely check the number of arguments for his subroutine calls.

Numerous error messages can be put out by the preprocessor. These error messages are listed below and are grouped according to various preprocessor functions. All error messages are preceded by three asterisks, which have been deleted below. Self-explanatory messages are not enlarged upon.

Processing Data Blocks—

DATA BLOCKS IN IMPROPER ORDER OR ILLEGAL BLOCK DESIGNATION ENCOUNTERED.
AN IMBEDDED BLANK HAS BEEN ENCOUNTERED IN THE LAST LINE.
BLANK COUNT OF 10 HAS BEEN EXCEEDED.
INTEGER FIELD EXCEEDS 10.
REAL NUMBER FIELD EXCEEDS 20.
ALPHAMERIC FIELD EXCEEDS 6.
MULTIPLE DECIMAL POINTS HAVE BEEN ENCOUNTERED.
NODES MUST BE ORDERED - DIFFUSION, ARITHMETIC, BOUNDARY.
CONDUCTORS MUST BE ORDERED - REGULAR, RADIATION.
NODE NUMBER, XXXXX, IS THE DUPLICATE OF THE XXXXXTH NODE.
CONDUCTOR NUMBER, XXXXX, IS THE DUPLICATE OF THE XXXXXTH CONDUCTOR.
CONSTANT NUMBER, XXXXX, IS THE DUPLICATE OF THE XXXXXTH CONSTANT.
ARRAY NUMBER, XXXXX, IS THE DUPLICATE OF THE XXXXXTH ARRAY.
FIXED CONSTANT NAME NOT IN LIST.
NUMBER OF GEN ARGUMENTS, XXX, EXCEEDS NUMBER REQUIRED.
STORAGE ALLOTTED FOR THIS DATA BLOCK HAS BEEN EXCEEDED.
PROCESSING WILL RESUME WITH THE NEXT DATA BLOCK.

Forming PCS—

NODE, XXXXX, HAS NO MATCH IN THE NA-NB PAIRS.
ADJACENT NODE, XXXXX, OF NA-NB PAIR HAS NO MATCH IN THE NODAL BLOCK, CONDUCTOR IS NO., XXXXX

Processing Program Blocks—

EXECUTION BLOCKS IN IMPROPER ORDER OR ILLEGAL BLOCK DESIGNATION ENCOUNTERED.
Explanation: Some alpha character other than K or A has been used to reference a data block. In a thermal problem a designator other than G, K, or A is assumed to be referencing the nodal block.

MISSING NODE NUMBER, XXXXX.
MISSING CONDUCTOR NUMBER, XXXXX.
MISSING CONSTANT NUMBER, XXXXX.
MISSING ARRAY NUMBER, XXXXX.
FIXED CONSTANT NAME, AAAAA, NOT IN LIST.
NUMBER OF SUBROUTINES REQUESTED EXCEEDS 75.
Explanation: More than 75 unique subroutines have been called.

*Processing Parameter Changes*—The first five parameter change error messages are prefaced with the words: PARAMETER CHANGE ERROR.

NODE NUMBER, XXXXX, WAS NOT DEFINED IN THE ORIGINAL PROBLEM.
CONDUCTOR NUMBER, XXXXX, WAS NOT DEFINED IN THE ORIGINAL PROBLEM.
CONSTANT NUMBER, XXXXX, WAS NOT DEFINED IN THE ORIGINAL PROBLEM.
ARRAY NUMBER, XXXXX, WAS NOT DEFINED IN THE ORIGINAL PROBLEM.
CONSTANTS BLOCK WAS EMPTY IN THE ORIGINAL PROBLEM.
ARRAY BLOCK WAS EMPTY IN THE ORIGINAL PROBLEM.
ARRAY NUMBER XXXXX - DIMENSIONS NOT EQUAL. ORIGINAL, XXXXX, CHANGE, XXXXX.

*Terminations Due to Errors* (no preceding asterisks)—

THE ABOVE PARAMETER CHANGE WILL NOT BE EXECUTED.
ERROR TERMINATION - LOADING IS SUPPRESSED.

V. OPERATING SYSTEM DESCRIPTION

General

The CDC-3800 (FORTRAN IV) version of CINDA exists logically as a preprocessor, processor, and library. The operational continuity of these portions is made possible by the CDC Drum SCOPE system (see Fig. 5).

The function of the preprocessor is to operate on a user-supplied problem and produce the following items.

1. Processor Main Program—This small routine acts primarily as a communications link in providing addressing relationships between the operational user program and user data.

2. User Program—These FORTRAN source subroutines are operational equivalents of the user' Executon, Variables 1 and 2, and Output Calls blocks.

3. User Data—Binary data generated consists of definitions of parameters referenced in the various user data blocks and their corresponding values.
Fig. 5—Flow of CINDA operating system
The preprocessor and appropriate use of the CDC-3800 system control cards allows construction of the above from tape when the RECALL option is utilized.

The processor performs reading of the user data values prepared previously and calls the user program (i.e., Execution block).

The CINDA library contains a large number of various types of subprograms to accomplish most user requirements. Draw SCOPE's LIBEDIT provides simple, flexible methods for the maintenance of this library. In addition, it is not necessary that a subroutine be updated to the library prior to availability in the user problem.

Preprocessor

Operation of the Preprocessing Phase.—(See Fig. 6 for flowchart.) The main program PREPRO accomplishes the initialization of data values and tape units and defines the order of processing by calling seven subroutines.

1. If the problem being processed is a RECALL problem, subroutine SPLIT is called to read the recalled problem data and number definitions from the input tape and write these on the appropriate work tape. SPLIT calls SKIP if the input tape is not positioned at the problem being recalled (see Store and Recall Problems Options).

2. CODERD reads the title block and the block title cards. It then calls DATARD, which reads the free-form data cards in the four (or two, if General Problem) data blocks and any parameter change data. Each card is read, a format is constructed for it, and then it is reread. The data from each block are written on the data tape as one record. The number definitions of the data and the NA-NB pairs are written on work tapes.

3. PSEUDO reads the node number definitions and NA-NB pairs from work tape. The PCS (long or short) is constructed, packed by PACK43 and flagged by ORMIN, and written on the data tape. PACK43 and ORMIN call BIT, a COMPASS packing and unpacking routine.

4. GENLNK constructs the main program of the processor (LINKO), including COMMON and DIMENSION information. BLKCRD and STFFB are called upon to fill an array with FORTRAN source code, which is then written onto logical unit LB4P by WRTBLK. WRTSCOPE writes SCOPE at the end of LB4P after completion of the other four subroutines (EXECTN, VARBL1, VARBL2, and OUTCAL).

5. PRESUB reads the title cards of the four program blocks and initiates the construction of each new subroutine. CINDA4 converts the CINDA "calls" in the program blocks into FORTRAN subroutine calls. Data referenced by input number definition is changed to refer to its relative location in COMMON data arrays.

6. INITAL combines the original set of the data and the initial parameter changes and writes the updated set of data on the data tape.
7. FINAL converts final parameter change data (number definitions and values) to relative array locations and values and writes number-value records on the data tape.

VI. EXTERNAL PLOTTING PACKAGE

CINDA's plot package, for use on the CALCOMP plotter, is an external program that will plot a graph of time vs temperature for each problem node. The input to this program is an output file (unit 24) generated by TSAVE during a previous CINDA problem run. The program can be run separately from the CINDA problem using the tape from TSAVE as input, or it can be placed behind the CINDA problem in a single run. In the latter case, unit 24 may be either a drum unit or a tape equipped for later use.

The package, available as a binary deck, consists of three routines. The main program, PLOTTEMP, calls PLOTPREP, which rearranges the data from the input tape and writes it on unit 25. Unit 25 contains the actual node numbers, the time array, and the temperature profile for each node. PLOTTEMP then reads a set of data cards which give the plot heading, X- and Y-axis limits, and nodes to be plotted. The temperature array for each node is read, and if the node is to be plotted, PLOTT is called, which in turn activates CALCOMP routines. A separate set of axes is drawn for each node. When all temperatures have been read, the tape is rewound and a new set of data (if any) is read.

Data Set

A data set consists of at least three cards.

*CARD 1—TITLE

Columns 1-40 will be used as the plot heading.

*CARD 2—AXIS LIMITS and TEMPERATURE SCALE OPTION

Four floating-point values must be entered in an E9.2 format. The minimum and maximum times (X-axis) must be in fields 4-12 and 14-22, respectively; the minimum and maximum temperatures (Y-axis) must be in fields 24-32 and 34-42, respectively. Column 43 contains the temperature scale option. A blank indicates that the data will be plotted in Fahrenheit temperatures, and a 1 specifies Centigrade.

\[
\begin{array}{cccc}
4 & 12 & 22 & 32 \\
\downarrow & \downarrow & \downarrow & \downarrow \\
\text{nnnnnn.nn} & \text{nnnnnn.nn} & \text{nnnnnn.nn} & \text{nnnnnn.nn} \\
\text{(TIMEMIN)} & \text{(TIMEMAX)} & \text{(TEMPMIN)} & \text{(TEMPMAX)} \quad \text{(Centigrade scale)}
\end{array}
\]

*CARD 3—NODES and OPTION

Options:

Plot all nodes—card is blank.
Plot certain nodes—column 1 contains a $; nodes are listed.
MARY E. GEALY

Plot _all but_ certain nodes—column 1 contains any character but * or $; nodes are listed.

The nodes may be listed individually or in inclusive pairs. Each node must be followed by a comma except for the inclusive pair, which must be separated by a blank instead of a comma. (The second node of the pair must be followed by a comma, however.) An asterisk (*), instead of a comma, must follow the last node.

The node numbers must be in 14 format, right adjusted to columns 5, 10, 15, ..., 80. The commas or separating blanks go in columns 6, 11, 16, ..., 76. Data may be continued to a following card by putting a comma or blank in column 1 of that card. Data cards will be read until an asterisk is encountered (limit of nine cards).

**Examples**

1. 1 5 10 15 20
   ↓ ↓ ↓ ↓ ↓
   $ 10, 15, 25 30*
   
   Plot nodes 10, 15, 25, 26, 27, 28, 29, 30. (Pairs must be in ascending order; otherwise, order of magnitude isn’t important.)

2. 1 5 10 15 20 25
   ↓ ↓ ↓ ↓ ↓
   + 5, 8, 10 12, 15*
   
   Plot all nodes but 5, 8, 10, 11, 12, 15.

3. 1 5 10 15 20
   ↓ ↓ ↓ ↓ ↓
   (Card 1) $1050, 1060 1062, 1070, 1070, 2000, 2005
   (Card 2) 2007, 2012*
   

4. 1 5 10 15
   ↓ ↓ ↓ ↓
   (Card 1) + 30, 25 28, 100
   (Card 2) *
   
   Plot all but nodes 30, 25, 26, 27, 28, ..., 100.

Another set of data may follow the last node card, thus enabling the programmer to redefine the title and limits and to plot different nodes. Any number of data sets may be used.

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Diagnostics

Messages that may be encountered while plotting are listed below. The first two will not cause job termination.

1. *** SOME NODES TO BE PLOTTED WERE NOT FOUND ON INPUT TAPE, OR WERE DUPLICATED ON NODE CARD. ***

NODES ON INPUT TAPE—
(listing of nodes)

NODES TO BE PLOTTED—
(listing of nodes)

Cause: The number of nodes to be plotted is larger than the number of nodes actually plotted.

2. IN FOLLOWING NODE CARD, AN INCLUSIVE PAIR OF NODES IS FOLLOWED BY A BLANK—A COMMA IS ASSUMED AND PROCESSING IS CONTINUED.

3. ***** WRONG FORMAT USED ON FOLLOWING NODE CARD—PROCESS NEXT SET OF DATA, IF ANY.

Cause: A character other than a comma, blank, or asterisk has been found in a column intended for those characters only.

This error terminates the processing of a current data set, and processing continues to the next set if there is one. (Most data format errors will cause job termination by the system.)

VII. TAPE USAGE AND DECK SETUPS

This section shows deck setups and tape usage for various types of runs on the 3800 Drum SCOPE system.

CINDA Operating System

Table 1 lists the program and data files used in the preprocessor, processor, and library.

Units 15, 17, 18, 19, and 27 are preprocessing units only and are available as scratch units during processing. Units 16, 21, 22, 24, 30, 33, and 40 can also be used for that purpose if the corresponding options are not activated.
Table 1
CINDA Tape Usage

<table>
<thead>
<tr>
<th>Logical Unit</th>
<th>Program Variable</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>*9</td>
<td></td>
<td>CINDA Master tape; (file 1 contains preprocessor, file 2 contains Library).</td>
</tr>
<tr>
<td>12</td>
<td>LB3D</td>
<td>Data tape (original problem and all parameter changes).</td>
</tr>
<tr>
<td>14</td>
<td>LB4P</td>
<td>Program tape (contains generated FORTRAN routines LINK0, EXECTN, VARBL1, VARBL2, OUTCAL).</td>
</tr>
<tr>
<td>15</td>
<td>LUT7</td>
<td>Variables 1 calls generated from node and conductor data blocks.</td>
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<tr>
<td>**16</td>
<td></td>
<td>Matrix retrieval unit in library.</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>NA-NB pairs; data number definitions. (From parameter changes.)</td>
</tr>
<tr>
<td>18</td>
<td>LUT3</td>
<td>Copy of original problem data.</td>
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<tr>
<td>19</td>
<td>LUT4</td>
<td>Parameter Change data.</td>
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<tr>
<td>20</td>
<td>LUT1</td>
<td>Data number definitions.</td>
</tr>
<tr>
<td>**21</td>
<td></td>
<td>Problem recall data tape.</td>
</tr>
<tr>
<td>**22</td>
<td></td>
<td>Problem store data tape.</td>
</tr>
<tr>
<td>**24</td>
<td></td>
<td>Output from TSAVE.</td>
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<td>27</td>
<td>INTERN</td>
<td>Data conversion scratch tape.</td>
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<tr>
<td>**30</td>
<td>KRR</td>
<td>FORTRAN reread unit in preprocessor.</td>
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<tr>
<td>33</td>
<td></td>
<td>Scratch unit in STOREP.</td>
</tr>
<tr>
<td>**40</td>
<td></td>
<td>Binary program tape (processor) used with store and recall options.</td>
</tr>
</tbody>
</table>

* Equipped units.
** Equipped units depending on options. Matrix storage and retrieval requires equipping tapes 16 and 30. The STOREP option requires equipping tapes 40 and 22; the RECALL option requires 40 and 21 (and 22 if desired).

General deck structures for different kinds of CINDA runs are shown below. The character Δ denotes a 7 and 9 punch in the column, and a •Δ is for an 11(-), 0, 7, 9 punch. The number enclosed in parentheses in the job card (e.g., 5) may have to be increased if several tapes are used. The current label for tape unit 9 is CINDA MASTER, 1,1,999. The other tapes may be unlabeled. Corresponding job request forms are found in Fig. 7.
Fig. 7—Job Request forms (magnetic tape portions)
Fig. 8—Ordinary CINDA run
Not RECALL (Ordinary Run)—(See Fig. 8.)
\[\Delta R\theta B(5), \ldots\]
\[\Delta EQU\text{IP}, 9=\text{(label)}, R\theta, H\theta, D\theta\]
\[\Delta B\text{ANK}, (0), /4/\]
\[\Delta L\overline{O}\text{AD}, 9\]
\[\Delta R\text{UN}, t, l\]
blank card

problem data deck through BCD 3END $\emptyset$F DATA

\[\Delta L\text{IBRARY}, 9, L\text{CINDA}\]
\[\Delta F\text{TN}, l=14, L, X\]
\[\Delta L\overline{O}\text{AD}\]
binary decks, if any

\[\Delta R\text{UN}, t, l\]
$\emptyset$F

Not RECALL (STOREP run)
\[\Delta R\theta B(5), \ldots\]
\[\Delta EQU\text{IP}, 9=\text{(label)}, R\theta, H\theta, D\theta\]
\[\Delta EQU\text{IP}, 40=\text{(label)}, R\theta, H\theta, D\theta\]
\[\Delta EQU\text{IP}, 22=\text{(label)}, W\theta, H\theta, D\theta\]
\[\Delta B\text{ANK}, (0), /4/\]
\[\Delta L\overline{O}\text{AD}, 9\]
\[\Delta R\text{UN}, t, 1\]
blank card

problem data deck through BCD 3END $\emptyset$F DATA (includes at least one call to STOREP)

\[\Delta L\text{IBRARY}, 9, L\text{CINDA}\]
\[\Delta F\text{TN}, l=14, L, X=40\]
\[\Delta L\overline{O}\text{AD}, 40\]

binary decks, if any

\[\Delta R\text{UN}, t, l\]
$\emptyset$F
MARY E. GEALY

RECALL

\[ \Delta \text{JOB}(5), \ldots \]
\[ \Delta \text{EQUIP}, 9 = (\text{label}), \text{RO, HI, DA} \]
\[ \Delta \text{EQUIP}, 10 = (\text{label}), \text{RO, HI, DA} \]
\[ \Delta \text{EQUIP}, 21 = (\text{label}), \text{RO, HI, DA} \]
\[ *\Delta \text{EQUIP}, 22 = (\text{label}), \text{WO, HI, DA} \]
\[ \Delta \text{BANK}, 0, /4/ \]
\[ \Delta \text{LOAD}, 9 \]
\[ \Delta \text{RUN}, t, l \]

RECALL Card

.
.
.

INITIAL PARAMETERS blocks and BCD 3END OF DATA

.
.
.

\[ \Delta \text{LIBRARY}, 9, \text{LCINDA} \]
\[ \Delta \text{LOAD}, 40 \]

.
.
.

binary decks if any

.
.
.

\[ \Delta \text{RUN}, t, l \]
\[ \text{EOF} \]

For any other options using tapes, the tapes should be equipped as those shown above, using the appropriate logical unit number and label. The user must also designate whether the tape is read only (RO), only written on (WO), or both (RW). In the latter case, if the tape is written on first, the output block of the job request form is checked. If the tape is read, then written on, both the input and output blocks should be checked. (Check the Drum SCOPE manual for more details.)

Plot Package

Table 2 lists the files used in the plot packages.

*Optional—used only if problem is to be restored.
Table 2

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<tr>
<td>24</td>
<td>Output from TSAVE; Input to PLOTPREP</td>
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<tr>
<td>25</td>
<td>Output from PLOTPREP; Input to PLOTT</td>
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</tbody>
</table>

NOTE: Units 25 and 10 are drum units. Unit 24 is usually a tape, but can also be a drum unit if the plotting run follows the CINDA run in the same job.

Below are sample deck sets showing a CINDA run that generates the TSAVE tape, and a plotting run that uses the TSAVE tape as input. Figure 9 shows a job request form for the plotting run. Figure 10 displays the deck setup for a combined CINDA and plotting run.

Not RECALL (Generate TSAVE tape)

\[\Delta\text{JOB}(5), \ldots\]
\[\Delta\text{EQUIP},9=(\text{label}),\text{R}\emptyset,\text{HI},\text{DA}\]
\[\Delta\text{EQUIP},24=(\text{label}),\text{W}\emptyset,\text{HI},\text{DA}\]
\[\Delta\text{BANK},(0),/4/\]
\[\Delta\text{LOAD},9\]
\[\Delta\text{RUN},t,\ell\]
blank card
.
.
.
problem data deck through BCD 3END OF DATA (includes a call to TSAVE in Output Calls)
.
.
.
\[\Delta\text{LIBRARY},9,\text{LCINDA}\]
\[\Delta\text{FTN},t=14,\text{L},\text{X}\]
\[\Delta\text{LOAD}\]
.
.
.
binary decks, if any
.
.
\[\Delta\text{RUN},t,\ell\]
E\emptyset F

45
Plotting Run

\[ \Delta \text{JOB, ...} \]
\[ \Delta \text{EQUIP,24=(label),R0,H1,DA} \]

\[ \text{binary deck} \quad \begin{cases} \text{PL0TTEMP} \\ \text{PL0TPREP} \\ \text{PL0TT} \end{cases} \]

\[ \Delta \text{RUN,t,1} \]

plotting data

E0F
Fig. 10—Combined TSAVE and plot run
### VIII. ALPHABETIC LISTING OF AVAILABLE SUBROUTINES

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<th>Name</th>
<th>Page</th>
<th>Name</th>
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Execution Subroutines

Name

CINDSS (Steady state, block iteration)
CINDSL (Steady state, accelerated)
CINDSM (Steady state, accelerated, terminated)
CNFRWD (Explicit forward differencing)
CNFAST (Accelerated forward differencing)
CNEAPN (Explicit exponential prediction)
CNFWBK (Implicit forward-backward differencing)
CNBACK (Implicit backward differencing)

Execution Subroutine CINDSS

Purpose—This subroutine ignores the capacitance values of diffusion nodes to calculate the network steady state solution. Due to the SPCS requirement, diffusion nodes are solved by a "block" iterative method. However, if all diffusion nodes were specified as arithmetic nodes they would be calculated by a successive point iterative method. The user is required to specify the maximum number of iterations to be performed in attempting to reach the steady state solution (control constant NLOOP and the relaxation criterion which determines when it has been reached (DRLXCA for diffusion nodes and ARLXCA for arithmetic nodes). The subroutine will conduct the iterations until both of the above criteria is met. If the iteration count exceeds NLOOP, an appropriate message is printed. Variables 1 and Output Calls are performed at the end of each iteration. Input Calls are performed upon completion. If not specified, DAMPA is set to 1.0. They are used as multipliers times the new Vars or each node minus their value is used as multipliers times the old temperature in order to damp oscillations due to nonlinearity. These weighting of so much new and so much old is used for dampening oscillations due to newness. The may also be used to achieve operator control.

If a series of steady state solutions at various times is desired it is specified by specifying control constants TIMEND and OUTPUT. OUTPUT will be used both as the output interval and the computation interval. In this case it is necessary we have to be made in Variables 1 to modify boundary conditions adequately.

If desired, the CINDSS call can be followed by a call to one of the transient solution subroutines which has the same SPCS requirements. In that manner the steady state solution becomes the initial conditions for the transient analysis. However, this CINDSS utilizes control constants TIMEND and OUTPUT the user must specify trans or it in the execution block after the steady state call and prior to the transient analysis call.

Restrictions—The SPCS option is required. Diffusion nodes receive a "block" iteration, while arithmetic nodes receive a successive point iteration no acceleration features are utilized. Control constants NLOOP and DRLXCA and/or ARLXCA must be specified. Successive steady state solutions can be obtained by specifying control constants.
TIMEND and OUTPUT. Other control constants which are activated or used are LCOPT, DRLXCC and/or ARLXCC, TIMEN, TIMEM, TIMEO, DAMPD, DAMPA, DTIMEU, LINECT, and PAGECT. Control constant OPEITR is checked for output each iteration.

**Calling Sequence—CINDSS—** This subroutine utilizes one dynamic storage curve location for each diffusion node.

**Execution Subroutine CINDSL**

**Purpose—** This subroutine ignores the capacitance values of diffusion nodes to calculate the network steady state solution. Since this subroutine has the LPCS requirement, both diffusion and arithmetic nodes receive a successive point iteration. In addition, each third iteration a linear extrapolation is performed on the error function plot of each node in an attempt to accelerate convergence. The user is required to specify the maximum number of iterations to be performed in attempting to reach the steady state solution (control constant NLOOP) and the relaxation criterion, which determines when it has been reached (DRLXCA for diffusion nodes and/or ARLXCA for arithmetic nodes). The subroutine will continue to iterate until one of the above criteria is met. If the iteration count exceeds NLOOP an appropriate message is printed. Variables 1 and Output Calls are performed at the start, and Variables 2 and Output Calls are performed upon completion. If not specified, control constants DAMPD and DAMPA are set at 1.0. They are used as multipliers times the new temperatures while 1.0 minus their value is used as multipliers times the old temperatures in order to weight the returned answer. This weighting of so much new and so much old is useful for damping oscillations due to nonlinearities. They may also be used to achieve overrelaxation.

If a series of steady state solutions at various times is desired it can be accomplished by specifying control constants TIMEND and OUTPUT. OUTPUT will be used both as the output interval and the computation interval. In this case appropriate calls would have to be made in Variables 1 to modify boundary conditions with time.

If desired, the CINDSL call can be followed by a call to one of the transient solution subroutines which has the same LPCS requirement. In this manner the steady state solution becomes the initial conditions for the transient analysis. However, since CINDSL utilizes control constants TIMEND and OUTPUT the user must specify their values in the execution block after the steady state call and prior to the transient analysis call.

**Restrictions—** The LPCS option is required. Diffusion and arithmetic nodes receive a successive point iteration and an extrapolation method of acceleration. Control constants NLOOP and DRLXCA and/or ARLXCA must be specified. Successive steady state solutions can be obtained by specifying control constants TIMEND and OUTPUT. Other control constants which are activated or used are: LOOPCT, DRLXCC, and/or ARLXCC, TIMEN, TIMEM, TIMEO, DAMPD, DAMPA, DTIMEU, LINECT, and PAGECT. Control constant OPEITR is checked for output each iteration.
Calling Sequence—CINDSL—This subroutine utilizes two dynamic storage core locations for each diffusion and arithmetic node.

Execution Subroutine CINDSM

Purpose—This subroutine is designed to calculate the network steady state solution of moderately radiation-dominated problems. It is similar to CINDSL in that the LPCS option is required and that all nodes receive a successive point iteration and the same extrapolation method of acceleration. Other execution subroutines evaluate the nonlinear radiation conductors each time they are encountered during an iteration. CINDSR differs in that it linearizes the problem by calculating effective radiation conductors and solves the linearized problem. It then reevaluates the effective radiation conductors, solves the linear problem and continuously repeats the process. The user must specify the maximum number of iterations to perform in attempting to reach the steady state solution and the energy balance of the system to be satisfied as a criterion. This system energy balance is the difference between all energy into the system and all energy out and is specified as control constant BALENG. CINDSM internally calculates the iterative relaxation criteria damping factors and loopings to be performed in solving the linearized problem. It continuously increases the severity of the relaxation criteria until the BALENG criteria is met for two successive linearized problems with virtually no temperature change between the two. Systems with small energy transfer rates to the boundaries are difficult to solve. A reasonable rule is to set BALENG at 1% of the rate in or out. Successive steady state analyses may be performed and CINDSM may be followed by a call to a transient analysis routine with the same LPCS option requirement.

Restrictions—The LPCS option is required. Control constants NLOOP, LAXFAC, and BALENG must be specified and be greater than zero. DAMPD may be used. If it is not specified, the routine will set DAMPD to 1.0. Successive steady state solutions can be obtained by specifying control constants TIMEND and OUTPUT. Other control constants which are activated or used are LOOPCT, ENGBAL, and/or ARLXCC, TIMEN, TIMEM, TIMEO, DTIMEU, LINECT, and PAGECT. Control constant OPEITR is checked for output each iteration. Caution: Each radiation conductor must have a unique conductor number.

Calling Sequence—CINDSM—This subroutine utilizes three dynamic storage core locations for each diffusion and arithmetic node and one more for each radiation conductor.

Execution Subroutine CNFRWD

Purpose—This subroutine performs transient thermal analysis by the explicit forward-differencing method. The stability criterion of each diffusion node is calculated and the
minimum value is placed in control constant CSGMIN. The time step used (control constant DTIMEU) is calculated as 95% of CSGMIN divided by CSGFAC. Control constant CSGFAC is set at 1.0 unless specified larger by the user. A “look-ahead” feature is used when calculating DTIMEU. If one time step will pass the output time point, the time step is set to come out exactly on the output time point; if two time steps will pass the output time point, the time step is set so that two time steps will come out exactly on the output time point. DTIMEU is also compared to DTIMEH and DTIMEL. If DTIMEU exceeds DTIMEH it is set equal to it, if DTIMEU is less than DTIMEL the problem is terminated. If no input values are specified, DTIMEL is set at zero and DTIMEH it is set at infinity. The maximum temperature change calculated over an iteration is placed in control constant DTMPCC and/or ATMPCC. They are compared to DTMPCA and/or ATMPCA, respectively, and if larger cause DTIMEU to be modified so that they compare as equal to or less than DTMPCA and/or ATMPCA. If DTMPCA and/or ATMPCA are not specified they are set at infinity.

All diffusion nodes are calculated prior to solving the arithmetic nodes. The user may iterate the arithmetic node solution by specifying control constants NLOOP and ARLXCA. If the arithmetic node iteration count exceeds NLOOP, answers are accepted as is and the subroutine continues without any user notification. In addition the user may specify control constant DAMPA in order to dampen possible oscillations due to nonlinearities. The arithmetic nodes may be used to specify an incompressible pressure or radiosity network. In this manner they would be solved implicitly each time step, but evaluation of temperature varying properties would suffer a lag of one time step.

Restrictions—The SPCS option is required and control constants TIMEND and OUTPUT must be specified. Problem start time if other than zero may be specified as TIMEO. Other control constants used or activated are: TIMEN, TIMEM, CSGMIN, CSGFAC, DTIMEU, DTIMEL, DTIMEH, DTMPCA, ATMPCC, NLOOP, LOOPCT, DAMPA, ARLXCA, ARLXCC, OPEITR, BACKUP, LINECT, and PAGECT.

Calling Sequence—CNFRWD —This subroutine utilizes one dynamic storage core location for each diffusion and arithmetic node.

Execution Subroutine CNFAST

Purpose—This subroutine is a modified version of CNFRWD which allows the user to specify the minimum time step to be taken. The time step calculations proceed exactly as in CNFRWD until the check with DTIMEL is made. If DTIMEU is less than DTIMEL it is set equal to it. As each node is calculated its CSGMIN is obtained and compared to DTIMEU. If equal to or greater, the nodal calculation is identical to CNFRWD. If the CSGMIN for a node is less than DTIMEU the node receives a steady state calculation. If only a small portion of the nodes in a system receive the steady state calculation the answers are generally reasonable. However, as the number of nodes receiving steady state calculations increases, so do the solution inaccuracies.
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Restrictions—The SPCS option is required and control constants TIMEND and OUTPUT must be specified. The checks on control constants DTMPCA, ATMPCA and BACKUP are not performed. Other control constants which are used or activated are TIMEN, TIMEM, TIMEO, CSGMIN, CSGFAC, DTIMEU, DTIMEL, DTIMEH, DTMPCC, ATMPCC, DAMPA, ARLXCA, ARLXCC, NLOOP, LOOPCT, LINECT, and PAGECT.

Calling Sequence—CNFAST—This subroutine utilizes one dynamic storage core location for each diffusion node.

Execution Subroutine CNEXPN

Purpose—This subroutine performs transient thermal analysis by the exponential prediction method, and the solution equation is of the following form:

\[ T_j' = \left( \sum_{i} G_{ij} Q_i \right) \left( 1 - e^{-\frac{G_j \Delta t}{C_i}} \right) + T_j e^{-\frac{C_i \Delta t}{C_i}}. \]

This equation is unconditionally stable, no matter what size time step is taken, and it reduces to the steady state equation for an infinite time step. However, stability is not to be confused with accuracy. Time steps larger than would be taken with CNFRWD remain stable but tend to lose or gain energy in the system. For this reason this subroutine is not recommended where accuracy is sought. However, it is suitable for parametric analysis where trends are sought and a more accurate method will be utilized for a final analysis.

The inner workings of the subroutine are virtually identical to CNFRWD with the exception of the solution equation and the use of CSGFAC. The time step used (DTIMEU) is calculated as CSGMIN times CSGFAC. The look-ahead feature for calculating the time step is identical, as are the checks with DTIMEH, DTIMEL, and DTMPCA. The diffusion nodes are calculated prior to the arithmetic nodes, and the arithmetic nodes utilize NLOOP, ARLXCA, and DAMPA, exactly the same as CNFRWD.

Restrictions—The SPCS option is required and control constants TIMEND and OUTPUT must be specified. Problem start time if other than zero may be specified as TIMEO. Other control constants used or activated are TIMEN, TIMEM, CSGMIN, CSGFAC, DTIMEU, DTIMEL, DTIMEH, DTMPCA, DTMPCC, ATMPCA, ATMPCC, ARLXCA, ARLXCC, DAMPA, OPEITR, BACKUP, LINECT, and PAGECT.

Calling Sequence—CNEXPN—This subroutine utilizes one dynamic storage core location for each diffusion and arithmetic node.
Execution Subroutine CNFWBK

Purpose—This subroutine performs transient thermal analysis by implicit forward-backward differencing. The LPCS option is required and allows the simultaneous set of equations to be solved by "successive point" iterations. During the first iteration for a time step, the capacitance values are doubled and divided by the time step and the energy transfer rates based on old temperatures are added to the source locations. Upon completing the time step the capacitance values are returned to their original state. The iteration looping, convergence criteria and other control constant checks are identical to CNBACK. The time step checks and calculations and look ahead feature are identical to that used for CNBACK.

The automatic radiation transfer damping and extrapolation method of acceleration mentioned under the CNBACK subroutine writeup are also employed in this subroutine. Diffusion and/or arithmetic temperature calculations may be damped through use of DAMPD and/or DAMPA respectively. Control constants BACKUP and OPEITR are continuously checked. CNFWBK internally performs forward-backward differencing of boundary conditions. For this reason the user should utilize TIMEN as the appropriate independent variable in Variables 1 operations.

It is interesting to note that CNFWBK generally converges in 25% fewer iterations than CNBACK. The probable reason for this is that the boundary of the mathematical system is better defined. While every future temperature node under CNBACK is connected to its present temperature, under CNFWBK every future temperature node is also receiving an impressed source based on the present temperature.

Restrictions—The LPCS option is required. Control constants TIMEND, OUTPUT, DTIMEI, NLOOP and DRLXCA and/or ARLXCA must be specified. Other control constants which are used or activated are TIMEN, TIMEO, TIMEM, CSGMIN, DTIMEU, DTIMEH, DTMPCA, DTMCC, ATMPC, ATMPCC, DAMPD, DAMPA, DRLXCC and/or ARLXCC, LOOPCT, BACKUP, OPEITR, LINECT, and PAGECT.

Calling Sequence—CNFWBK—This subroutine utilizes three dynamic storage core locations for each diffusion node and one for each arithmetic and boundary node.

Execution Subroutine CNBACK

Purpose—This subroutine performs transient thermal analysis by implicit backward differencing. The LPCS option is required and allows the simultaneous set of equations to be solved by "successive point" iteration. Each third iteration, diffusion node temperatures which trace a continuous decreasing slope receive an extrapolation on their error function curve in an attempt to accelerate convergence. For convergence criteria the user is required to specify NLOOP and DRLXCA and/or ARLXCA. If the number of iterations during a time step exceeds NLOOP a message is printed but the problem proceeds.
Variables 1 is performed only once for each time step. Since this subroutine is implicit the user must specify the time step to be used as DTIMEI in addition to TIMEND and OUTPUT. The look ahead feature for the time step calculation in CNFRWD is used as are the checks for DTIMEH, DTMPCA and ATMPCA but not DTIMEL. Damping of the solutions can be achieved through use of control constants DAMPD and/or DAMPA. Control constants BACKUP and OPEITR are continuously checked.

Implicit methods of solution often oscillate at start up or for boundary step changes when radiation conductors are present. CNBACK contains an automatic damping feature which is applied to radiation conductors. The radiation transfer to a node is calculated for its present temperature and a temporary new temperature is calculated. Then the radiation transfer is recalculated and the final node temperature is calculated based on the arithmetic mean of the two radiation transfer calculations. This automatic radiation damping has proven to be quite successful and lessens the need for use of DAMPD and DAMPA.

Restrictions—The LPCS option is required. Control constants TIMEND, OUTPUT, DTIMEI, NLOOP and DRLXCA and/or ARLXCA must be specified. Other control constants which are used on activated are: TIMEN, TIMEO, TIMEM, CSGMIN, DTIMEV, DTIMEH, DTMPCA, DTMPCC, ATMPCA, ATMPC, DAMPD, DAMPA, DRLXCC and/or ARLXCC, LOOPCT, BACKUP, OPEITR, LINECT, and PAGECT.

Calling Sequence—CNBACK—This subroutine utilizes three dynamic storage core locations for each diffusion node and one for each arithmetic and boundary node.
Interpolation Subroutines

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Subroutine LAGRN or LGRNDA

Purpose—These subroutines perform Lagrangian interpolation of up to order 50. The first requires one doublet array of X, Y pairs while the second requires two singlet arrays, one of X's and the other of Y's. They contain an extrapolation feature such that if the X value falls outside the range of the independent variable the nearest dependent Y variable value is returned and no error is noted.

\[ Y = P_n(X) = \sum_{k=0}^{n} y_k \prod_{i=0, i \neq k}^{n} \frac{X - x_i}{x_k - x_i}, \quad r. = 1,2,3, \ldots, 50 \text{max.} \]

Restrictions—All values must be floating point except N which is the order of interpolation plus one and must be an integer. The independent variable values must be in ascending order.

Calling Sequence—LAGRN(X,Y,A(IC),N) or LGRNDA(X,Y,AX(IC),AY(IC),N)

NOTE: A doublet array is formed as follows:
IC, X1, Y1, X2, Y2, X3, Y3, ..., XN, YN
where IC = 2*N (set by program).

Singlet arrays are formed as follows:
IC, X1, X2, X3, ..., XN
IC, Y1, Y2, Y3, ..., YN
and IC = N (set by program).

Subroutine D1DEG1 or D1D1DA

Purpose—These subroutines perform single variable linear interpolation on doublet or singlet arrays respectively. They are self-contained subroutines that are called upon by virtually all other linear interpolation subroutines.

Restrictions—All values must be floating point numbers. The X independent variable values must be in ascending order.

Calling Sequence—D1DEG1(X,A(IC),Y) or D1D1DA(X,AX(IC),AY(IC),Y)

Subroutine D1D1WM or D11MDA

Purpose—These subroutines perform single-variable, linear interpolation by calling on D1DEG1 or D1D1DA, respectively. However, the interpolated answer is multiplied by the value addressed as Z prior to being returned as Y.
Restrictions—Same as D1DEG1 or D1D1DA, and Z must be a floating-point number.

Calling Sequence—D1D1WM(X,A(IC),Z,Y) or D11MDA(X,AX(IC),AY(IC),Z,Y)

Subroutine D1MDG1 or D1M1DA

Purpose—These subroutines use the arithmetic mean of two input values as the independent variable for linear interpolation. They require a doublet or two singlet arrays, respectively.

Restrictions—See D1DEG1 or D1D1DA as they are called on, respectively.

Calling Sequence—D1MDG1,X1,X2,A(IC),Y) or D1M1DA(X1,X2,AX(IC),AY(IC),Y)

Subroutine D1M1WM or D1M1MD

Purpose—These subroutines use the arithmetic mean of two input values as the independent variable for linear interpolation. The interpolated answer is multiplied by the Z value prior to being returned as Y.

Restrictions—Same as D1MDG1 or D1M1DA, and Z must be a floating-point number.

Calling Sequence—D1M1WM(X1,X2,A(IC),Z,Y) or D1M1MD(X1,X2,AX(IC),AY(IC),Z,Y)

Subroutine D1DEG2 or D1D2DA

Purpose—These subroutines perform single-variable parabolic interpolation. The first requires a doublet array of X, Y pairs while the second requires singlet arrays of X and Y values. They call on subroutines LAGRAN and LGRNDA, respectively.

Restrictions—See LAGRAN or LGRNDA.

Calling Sequence—D1DEG2(X,A(IC),Y) or D1D2DA(X,AX(IC),AY(IC),Y)

Subroutine D1D2WM or D12MDA

Purpose—These subroutines perform single-variable parabolic interpolation by calling on LAGRAN or LGRNDA, respectively. However, the interpolated answer is multiplied by the value addressed as Z prior to being returned as Y.

Restrictions—Same as LAGRAN or LGRNDA, and Z must be a floating-point number.
Calling Sequence—D1D2WM(X,A(IC),Z,Y) or
D12MDA(X,AX(IC),AY(IC),Z,Y)

Subroutine D1MDG2 or D1M2DA

Purpose—These subroutines use the arithmetic mean of two input values as the independent variable for parabolic interpolation. They require a doublet or two singlet arrays, respectively.

Restrictions—See LAGRAN or LGRNDA as they are called.

Calling Sequence—D1MDG2(X1,X2,A(IC),Y) or
D1M2DA(X1,X2,AX(IC),AY(IC),Y)

Subroutine D1M2WM or D1M2MD

Purpose—These subroutines use the arithmetic mean of two input values as the independent variable for parabolic interpolation. The interpolated answer is multiplied by the Z value prior to being returned as Y.

Restrictions—Same as D1MDG2 or D1M2DA, and Z must be a floating point number.

Calling Sequence—D1M2WM(X1,X2,A(IC),Z,Y) or
D1M2MD(X1,X2,AX(IC),AY(IC),Z,Y)

Subroutine D1DG1I or D1D1IM or D1D1MI

Purpose—These subroutines perform single-variable linear interpolation on an array of X’s to obtain an array of Y’s. D1D1IM multiplies all interpolated values by a constant Z value while D1D1MI allows a unique Z value for each X value. They all call on D1DEGI.

Restrictions—The number of input X’s must be supplied as the integer N and agree with the number of Y and Z locations where applicable. Z values must be floating-point numbers.

Calling Sequence—D1DG1I(N,X(DV),A(IC),Y(DV)) or
D1D1IM(N,X(DV),A(IC),Z(Y(DV)) or
D1D1MI(N,X(DV),A(IC),Z(DV),Y(DV))

Subroutine D11DAI or D11DIM or D11MDI

Purpose—These subroutines are virtually identical to D1DG1I, D1D1IM, and D1D1MI, respectively. The difference is that they require singlet arrays for interpolation and call on D1D1DA.
Restrictions—Same as D1DG1, D1D1I, and D1D1I.

Calling Sequence—D11DAI(N,X(DV),AX(IC),AY(IC),Y(DV)) or D11DIM(N,X(DV),AX(IC),AY(IC),Z,Y(DV)) or D11MDI(N,X(DV),AX(IC),AY(IC),Z(DV),Y(DV))

Subroutine D11CYL or DA11CY

Purpose—These subroutines reduce core storage requirements for cyclical interpolation arrays. The arrays need cover one period only, and the period (PR) must be specified as the first argument. Linear interpolation is performed, and the independent variable must be in ascending order.

Restrictions—All values must be floating point. Subroutine INTRFC is called on by both D11CYL and DA11CY, then D1DEG1 or D1D1DA, respectively.

Calling Sequence—D11CYL(PR,X,A(IC),Y) or DA11CY(PR,X,AX(IC),AY(IC),Y)

Subroutine D12CYL or DA12CY

Purpose—These subroutines are virtually identical to D11CYL and DA11CY, except that parabolic interpolation is performed.

Restrictions—See D11CYL and DA11CY. Subroutines LAGRAN and LGRNDA, respectively, are called on.

Calling Sequence—D12CYL(PR,X,A(IC),Y) or DA12CY(PR,X,AX(IC),AY(IC),Y)

Subroutine D11MCY or DA11MC

Purpose—These subroutines are virtually identical to D11CYL or DA11CY, except that the interpolated answer is multiplied by the floating-point Z value prior to being returned as Y.

Restrictions—Call on subroutines D1DEG1 and D1D1DA, respectively.

Calling Sequence—D11MCY(PR,X,A(IC),Z,Y) or DA11MC(PR,X,AX(IC),AY(IC),Y)

Subroutine D12MCY or DA12MC

Purpose—These subroutines are virtually identical to D11MCY and DA11MC except that parabolic interpolation is performed.
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Restrictions—Calls on subroutines LAGRAN and LGRNDA, respectively.

Calling Sequence—D12MCY(PR,X,A(IC),Z,Y) or DA12MC(PR,X,AX(IC),AY(IC),Z,Y)

Subroutine CVQ1HT or CVQ1WM

Purpose—These subroutines perform two single-variable linear interpolations. The interpolation arrays must have the same independent variable X and dependent variables of, say, R(X) and S(X). Additional arguments of Y, Z, and T complete the data values. The postinterpolation calculations are, respectively:

\[ Y = S(X)^*(R(X)-T) \]  or \[ Y = Z*S(X)(R(X)-T). \]

Restrictions—Interpolation arrays must be of the doublet type and have a common independent variable. All values must be floating-point numbers.

Calling Sequence—CVQ1HT(X,AR(IC),AS(IC),T,Y) or CVQ1WM(X,AR(IC),AS(IC),T,Z,Y)

Subroutine GSLOPE

Purpose—This subroutine will generate a slope array so that point slope interpolation subroutines can be used instead of standard linear interpolation subroutines. The user must address two singlet arrays, and a singlet slope array will be produced.

Restrictions—The X independent-variable array must be in ascending order. All arrays must be of equal length and contain floating-point numbers.

Calling Sequence—GSLOPE(AX(IC),AY(IC),AS(IC))

Subroutine PSINTR or PSNTWM

Purpose—These subroutines perform linear interpolation and require arrays of the Y points and slopes which correspond to the independent variable X array. All values must be floating-point numbers. PSNTWM multiplies the interpolated answer by Z prior to returning it as Y.

Restrictions—The independent X and dependent Y and slope arrays must be of equal length.

Calling Sequence—PSINTR(X,AX(IC),AY(IC),AS(IC),Y) or PSNTWM(X,AX(IC),AY(IC),AS(IC),Z,Y)
Bivariate Array Format, $Z = f(X,Y)$

Bivariate arrays must be rectangular and full and must be entered in the following row order:

\[ \begin{align*}
IC,N \quad X_1, X_2, X_3, \ldots, X_N \\
Y_1, Z_{11}, Z_{12}, Z_{13}, \ldots, Z_{1N} \\
Y_2, Z_{21}, Z_{22}, Z_{23}, \ldots, Z_{2N} \\
\vdots \\
YM, Z_{M1}, Z_{M2}, Z_{M3}, \ldots, Z_{MN}
\end{align*} \]

where $N$ is the integer number of $X$ variables. All other values must be floating-point numbers, and the $X$ and $Y$ values must be in ascending order.

Subroutine BVPSA or BVPSDA

**Purpose**—These subroutines use an input $Y$ argument to address a bivariate array and pull off a singlet array of $Z$'s corresponding to the $X$'s or pull off a doublet array of $X, Z$ values, respectively. The integer count for the constructed arrays must be exactly $N$ or $2N$, respectively. To use the singlet array for an interpolation call, reach the $X$ array by addressing the $N$ in the bivariate array.

**Restrictions**—As stated above, and all values must be floating point.

**Calling Sequence**—BVPSA($Y$, BA($IC$), AZ($IC$)) or BVSPDA($Y$, BA($IC$), AXZ($IC$))

Subroutine D2DEG1 or D2DEG2

**Purpose**—These subroutines perform bivariate linear and parabolic interpolation, respectively. The arrays must be formatted as shown for Bivariate Array Format.

**Restrictions**—For D2DEG1, $N \geq 2$, $M \geq 2$; See bivariate
For D2DEG2, $N \geq 3$, $M \geq 3$; array format

**Calling Sequence**—D2DEG1($X, Y$, BA($IC$), $Z$) or D2DEG2($X, Y$, BA($IC$), $Z$)

Subroutine D2D1WM or D2D2WM

**Purpose**—These subroutines perform bivariate linear or parabolic interpolation by calling on D2DEG1 or D2DEG2, respectively. The interpolated answer is multiplied by the $W$ value prior to being returned as $Z$.

**Restrictions**—Same as D2DEG1 or D2DEG2, and $W$ must be a floating-point value.

**Calling Sequence**—D2D1WM($X, Y$, BA($IC$), $W$, $Z$) or D2D2WM($X, Y$, BA($IC$), $W$, $Z$)
Subroutine D2MXD1 or D2MXD2

Purpose—These subroutines are virtually identical to D2DEG1 and D2DEG2 except that the arithmetic mean of two X values is used as the X-independent variable for interpolation.

Restrictions—Same as D2DEG1 or D2DEG2.

Calling Sequence—D2MXD1(X1,X2,Y,BA(IC),Z) or D2MXD2(X1,X2,Y,BA(IC),Z).

Subroutine D2MX1M or D2MX2M

Purpose—These subroutines are virtually identical to D2D1WM and D2D2WM except that the arithmetic mean of two X values is used as the X-independent variable for interpolation.

Restrictions—Same as D2D1WM and D2D2WM.

Calling Sequence—D2MX1M(X1,X2,Y,BA(IC),W,Z) or D2MX2M(X1,X2,Y,BA(IC),W,Z).

Trivariate Array Format, T = f(X,Y,Z)

Trivariate arrays may be thought of as two or more bivariate arrays, each bivariate array a function of a third independent variable Z. Trivariate arrays must be entered in row order and be constructed as follows:

\[
\begin{align*}
&IC,NX1,NY1, Z1, X 1, X 2, X 3, \ldots, X N \\
&Y1, T11, T12, T13, \ldots, T1N \\
&Y2, T21, T22, T23, \ldots, T2N \\
&\vdots
\end{align*}
\]

\[
\begin{align*}
&YM,TM1,TM2,TM3, \ldots, TMN \\
&NX2,NY2, Z2, X 1, X 2, X 3, \ldots, X J \\
&Y1, T11, T12, T13, \ldots, T1J \\
&Y2, T21, T22, T23, \ldots, T2J \\
&\vdots
\end{align*}
\]

\[
\begin{align*}
&YK,TK1,TK2,TK3, \ldots, TKJ \\
&NX3,NY3, Z3, \ldots \ldots \\
&\vdots
\end{align*}
\]

The trivariate array may consist of as many bivariate “sheets” as desired. The number of X and Y values in each sheet must be specified as integers (NX,NY). The “sheets” must be rectangular and full but need not be identical in size.
Subroutine D3DEGI or D3D1WM

**Purpose**—These subroutines perform trivariate linear interpolation. The interpolation array must be constructed as shown for the Trivariate Array Format. Subroutine D2DEGI is called on, which calls on D1DEGI. Hence, the linear extrapolation feature of these routines applies. Subroutine D3D1WM multiplies the interpolated answer by F prior to returning it as T.

**Restrictions**—See Trivariate Array Format. F must be a floating-point value.

**Calling Sequence**—D3DEGI(X,Y,Z,TA(IC),T) or D3D1WM(X,Y,Z,TA(IC),F,T)

Subroutine VARCSM or VARCCM or VARC1 or VARC2

**Purpose**—These are linear interpolation subroutines which are set up as Variables 1 calls by the preprocessor when processing the CGS and CGD mnemonic codes in the nodal data block. VARCSM is utilized for the CGS code. VARCCM is utilized for the CGD code when two array arguments appear. VARC1 and VARC2 are used for the CGD code when either the first or second respective array arguments are entered as a constant. The following mnemonic codes in the nodal block

```
8
|
CGS 1,80.,A1,10.2
CGD 2,80.,A1,10.2,A2,1.6
CGD 3,80.,1.4,5.1,A2,1.6
CGD 4,80.,A1,5.1,6.3,8.7
```

would cause the construction in Variables 1 of

```
12
|
VARCSM(T1,C1,A1,10.2)
VARCCM(F2,C2,A1,10.2,A2,1.6)
VARC1(T3,C3,1.4,5.1,A2,1.6)
VARC2(T4,C4,A1,5.1,6.3,8.7)
```

The second call causes the sum of two interpolations with multiplications to be used as the C2 value. The latter two cells only perform one interpolation but use the sum of the two products as the C value.

**Restrictions**—The array arguments must address the integer count.

**Calling Sequence**—VARCSM(T,C,A1(IC),F) or VARCCM(T,C,A1(IC),F1,A2(IC),F2) or VARC1(T,C,X,F1,A2(IC),F2) or VARC2(T,C,A1(IC),F1,X,F2)
Subroutine VARGSM or VARGCM or VARG1 or VARG2

Purpose—These are linear interpolation subroutines set up as Variables 1 calls by the preprocessor when processing the CGS and CGD mnemonic codes in the conductor data block. They are similar to the preceding four calls for the nodal data block except that the conductor argument is first followed by two temperature arguments. VARGSM is used for the CGS code. If the \( F \) value is positive, the mean of the two addressed temperatures is used for interpolation. If it is negative, only \( T_1 \) is used for interpolation and the absolute value of \( F \) is used as a multiplier. VARGCM, VARG1, and VARG2 perform the one or two interpolations required, multiply by the \( F \) values to obtain \( G_1 \) and \( G_2 \) components, and then calculate \( G \) as

\[
G = \frac{1.0}{(1.0/G_1 + 1.0/G_2)}.
\]

Restrictions—The array arguments must address the integer count.

Calling Sequence—VARGSM\((G,T_1,T_2,A(IC),F)\) or
VARGCM\((G,T_1,T_2,A1(IC),F1,A2(IC),F2)\) or
VARG1\((G,T_1,T_2,X,F1,A2(IC),F2)\) or
VARG2\((G,T_1,T_2,A1(IC),F1,X,F2)\)
Arithmetic Subroutines

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Subroutine FLOAT or FIX or INTRFC

*Purpose*—Subroutine FLOAT will convert an integer to a floating-point number. Subroutine FIX will convert a floating-point number to an integer. Subroutine INTRFC will fracture a floating-point number to yield the largest integer value possible and the remainder or fractional portion is a floating-point number. Their respective operations are

\[
\begin{align*}
X &= N \\
\text{or} \quad N &= X \\
\text{or} \quad N &= X \\
Y &= N \\
F &= X-Y
\end{align*}
\]

*Restrictions*—X and F arguments must address floating-point values and the N argument must address an integer.

*Calling Sequence*—FLOAT(N,X) or FIX(X,N) or INTRFC(X,N,F)

Subroutine SHFTV or SHFTVR or FLIP

*Purpose*—Subroutine SHFTV will shift a sequence of data from one array to another. Subroutine SHFTVR will shift a sequence of data from one array and place it in another array in reverse order. Subroutine FLIP will reverse an array in its own array location. Their respective operations are

\[
\begin{align*}
A(i) &= B(i), \quad i = 1, N \\
\text{or} \quad A(N-i+1) &= B(i), \quad i = 1, N \\
\text{or} \quad A(i)_{\text{new}} &= A(N-i+2)_{\text{old}}, \quad i = 2, N+1.
\end{align*}
\]

The answer array may not be overlayed into the input array.

*Restrictions*—The data values to be shifted or reversed in order may be anything. The N must be an integer.

*Calling Sequence*—SHFTV(N,B(DV),A(DV)) or SHFTVR(N,B(DV),A(DV)) or FLIP(A(IC))

Subroutine SETPLS or ARYPLS

*Purpose*—SETPLS will set the sign positive for a variable number of arguments while ARYPLS will set the sign positive for every data value in a specified length array.

*Restrictions*—The values addressed may be either integers or floating-point numbers. The number \((N)\) of data values in the array must be specified as an integer.
Calling Sequence—SETPLS(A,B,C,...) or ARYPLS(N,A(DV))

where N may be a literal integer or the address of a location containing an integer, and A(DV) addresses the first data value in the array.

Subroutine SETMNS or ARYMNS

Purpose—SETMNS will set the sign negative for a variable number of arguments, while ARYMNS will set the sign negative for every data value in a specified length array.

Restrictions—The values addressed may be either integers or floating-point numbers. The number (N) of data values in the array must be specified as an integer.

Calling Sequence—SETMNS(A,B,C,...) or ARYMNS(N,A(DV))

where N may be a literal integer or the address of a location containing an integer and A(DV) addresses the first data value in the array.

Subroutine ADD or ADDFIX

Purpose—To sum a variable number of floating-point or integer numbers, respectively.

\[ S = \sum X_i, \quad i = 1, 2, 3, \ldots, N, \quad N \geq 2 \]

Restrictions—Subroutine ADD is for floating-point numbers, while subroutine ADDFIX is for integers.

Calling Sequence—ADD(X1,X2,X3,...,XN,S) or ADDFIX(X1,X2,X3,...,XN,S)

Subroutine ADDARY or ARYADD

Purpose—Subroutine ADDARY will add the corresponding elements of two specified length arrays to form a third array. Subroutine ARYADD will add a constant value to every element in an array to form a new array. Their respective operations are

\[ A_i = B_i + C_i, \quad i = 1, N \]

or

\[ A_i = B_i + C, \quad i = 1, N. \]

The answer array may be overlayed into one of the input array areas.

Restrictions—All data values to be operated on must be floating-point numbers. The array length N must be an integer.

Calling Sequence—ADDARY(N,B(DV),C(DV),A(DV)) or ARYADD(N,B(DV),C,A(DV))
Subroutine SUB or SUBFIX

*Purpose*—To subtract a variable number of floating-point or integer numbers, respectively,

\[ R = Y - \sum_{i=1}^{N} X_i, \quad i = 1, 2, 3, \ldots, N, \quad N \geq 1 \]

*Restrictions*—Subroutine SUB is for floating-point numbers while subroutine SUBFIX is for integers.

*Calling Sequence*—SUB(Y,X1,X2,X3,\ldots,XN,R) or

\[ \text{SUBFIX}(Y,X1,X2,X3,\ldots,XN,R) \]

Subroutine SUBARY or ARYSUB

*Purpose*—Subroutine SUBARY will subtract the corresponding elements of one array from another to form a third array. Subroutine ARYSUB will subtract a constant value from every element in an array to form a new array. Their respective operations are

\[ A_i = B_i - C_i, \quad i = 1, N \]

or

\[ A_i = B_i - C, \quad i = 1, N \]

The answer array may be overlayed into one of the input array areas.

*Restrictions*—All data values to be operated on must be floating-point numbers. The array length N must be an integer.

*Calling Sequence*—SUBARY(N,B(DV),C(DV),A(DV)) or

\[ \text{ARYSUB}(N,B(DV),C,A(DV)) \]

Subroutine MLTPLY or MPYFIX

*Purpose*—To multiply a variable number of floating-point or integer numbers, respectively.

\[ P = X_1 * X_2 * X_3 * \ldots * X_N, \quad N \geq 2 \]

*Restrictions*—Subroutine MLTPLY is for floating-point numbers, while subroutine MPYFIX is for integers.

*Calling Sequence*—MLTPLY(X1,X2,X3,\ldots,XN,P) or MPYFIX(X1,X2,X3,\ldots,XN,P)

Subroutine MPYARY or ARYMPLY

*Purpose*—Subroutine MPYARY will multiply the corresponding elements of two arrays to form a third. Subroutine ARYMPLY will multiply a constant value times each element of an array to form a new array. Their respective operations are

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\[ A_i = B_i \times C_i, \quad i = 1, N \]

or \[ A_i = B_i / C_i, \quad i = 1, N \]

The answer array may be overlaid into one of the input array areas.

**Restrictions**—All data values to be operated on must be floating-point numbers. The array length \( N \) must be an integer.

**Calling Sequence**—MPYARY\((N,B(DV),C(DV),A(DV))\) or ARYMPY\((N,B(DV),C,A(DV))\)

Subroutine **DIVIDE** or **DIVFIX**

**Purpose**—These subroutines are used to perform a division of floating-point or integer numbers, respectively;

\[ Q = Y / \Sigma X_i, \quad i = 1, 2, 3, \ldots, N, \quad N \geq 1. \]

**Restrictions**—Subroutine **DIVIDE** is for floating-point numbers, while **DIVFIX** is for integers.

**Calling Sequence**—DIVIDE\((Y,X1,X2,X3,\ldots,XN,Q)\) or DIVFIX\((Y,X1,X2,X3,\ldots,XN,Q)\)

Subroutine **DIVARY** or **ARYDIV**

**Purpose**—Subroutine **DIVARY** will divide the elements of one array into the corresponding elements of another array to produce a third array. Subroutine **ARYDIV** will divide each element of an array by a constant value to produce a new array. Their respective operations are

\[ A_i = B_i / C_i, \quad i = 1, N \]

or \[ A_i = B_i / C, \quad i = 1, N. \]

The answer array may be overlaid into one of the input array areas.

**Restrictions**—All data values to be operated on must be floating-point numbers. The array length \( N \) must be an integer.

**Calling Sequence**—DIVARY\((N,B(DV),C(DV),A(DV))\) or ARYDIV\((N,B(DV),C,A(DV))\)

Subroutine **GENARY**

**Purpose**—This subroutine will generate an array of equally incremented ascending values. The user must supply the minimum value, maximum value, number of values in the array to be generated, and the space for the generated array.
MARY E. GEALY

Restrictions—All numbers must be floating point.

Calling Sequence—GENARY(B(DV),A(DV))

where:

\[
\begin{align*}
B(1) &= \text{minimum value} \\
B(2) &= \text{maximum value} \\
B(3) &= \text{length of array to be generated (floating point)}. \\
\end{align*}
\]

Subroutine BLDARY

Purpose—This subroutine will build an array from a variable number of arguments in the order listed. The operation performed is

\[ A_1 = X_1, \quad i = 1, N. \]

Restrictions—Data may be of any form. The subroutine obtains the integer array length N by counting the arguments.

Calling Sequence—BLDARY(A(DV),X1,X2,X3, \ldots ,XN)

Subroutine BRKARY or BKARAD

Purpose—These subroutines will distribute values from within an array to a variable number of arguments in the order listed. The first places the value into the location while the second adds it to what is in the location. Respective operations are

\[
\begin{align*}
X_i &= A_i, \quad i = 1, N \\
or \quad X_i &= X_i + A_i, \quad i = 1, N. \\
\end{align*}
\]

Restrictions—Floating-point numbers must be used for BKARAD. The integer array length N is obtained by the routines by counting the number of arguments.

Calling Sequence—BRKARY(A(DV),X1,X2,X3, \ldots ,XN) or BKARAD(A(DV),X1,X2,X3, \ldots ,XN)

Subroutine STFSEP or SCALE

Purpose—Subroutine STFSEP will place a constant value into a variable number of locations. Subroutine SCALE will utilize a constant value to multiply a variable number of arguments, each having a location for the product. The respective operations are

\[
\begin{align*}
X_i &= Y, \quad i = 1, 2, 3, \ldots , N \\
or \quad X_i &= Y * Z_i, \quad i = 1, 2, 3, \ldots , N. \\
\end{align*}
\]

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Restrictions—STFSEP may be used to move any desired value, but SCALE can only be used for floating-point numbers.

Calling Sequence—STFSEP(Y,X1,X2,X3,...,XN) or SCALE(Y,X1,Z1,X2,Z2,...,XN,ZN)

Subroutine STFSEQ or STFSQS

Purpose—Both subroutines will stuff a constant data value into a specified length array or group of sequential locations. STFSEQ expects the constant data value to be in the first array location, while STFSQS requires it to be supplied as an additional argument. The respective operations performed are

\[ A_i = A_1, \quad i = 2, N \]
\[ A_i = A, \quad i = 1, N. \]

Restrictions—N must be an integer, but the constant data value may be integer, either floating point or alphanumeric.

Calling Sequence—STFSEQ(A(DV),N) or STFSQS(B,N,A(DV))

Subroutine SUMARY

Purpose—SUMARY is used to sum an array of floating-point values:

\[ S = \sum A_i, \quad i = 1, N. \]

Restrictions—The values to be summed must be floating-point numbers and the array length N must be an integer.

Calling Sequence—SUMARY(N,A(DV),S)

Subroutine MAXDAR or MXDRAL

Purpose—These subroutines will obtain the absolute maximum difference between corresponding elements of two arrays of equal length N. The array values must be floating-point numbers. The operation performed is

\[ D = |A_i - B_i|_{\text{max}}; \quad i = 1, N. \]

Subroutine MXDRAL also locates the position P between 1 and N where the maximum occurs.

Restrictions—The N argument must be an integer. The D and P arguments are returned as floating-point numbers.

Calling Sequence—MAXDAR(N,A(DV),B(DV),D) or MXDRAL(N,A(DV),B(DV),D,P)
Subroutine ARYINV or ARINDV

_Purpose_—Subroutine ARYINV will invert each element of an array in its own location. Subroutine ARINDV will divide each element of an array into a constant value to form a new array. Their respective operations are

\[ A_i = \frac{1.0}{A_i}, \quad i = 1, N \]

or

\[ A_i = \frac{B}{C_i}, \quad i = 1, N. \]

_Restrictions_—All data values must be floating-point numbers. The array length \( N \) must be an integer.

_Calling Sequence_—ARYINV(\( N, A(DV) \)) or ARINDV(\( N, C(DV), B, A(DV) \))

The ARINDV answer array may be overlayed into the input array area.

Subroutine ADDINV or ADARIN

_Purpose_—Subroutine ADDINV will calculate one over the sum of the inverses of a variable number of arguments. Subroutine ADARIN will calculate one over the sum of inverses of an array of values. These subroutines are useful for calculating the effective conductance of series conductors. Their respective operations are

\[ Y = \frac{1.0}{\left(1./X_1 + 1./X_2 + \ldots + 1./X_N\right)}, \quad N > 2 \]

or

\[ Y = \frac{1.0}{\Sigma(1./X_i)}, \quad i = 1, N. \]

_Restrictions_—All data values must be floating-point numbers. The array length \( N \) must be an integer.

_Calling Sequence_—ADDINV(X1,X2,X3,...,XN,Y) or ADARIN(N,X(DV),Y)

Subroutine STOARY or ARYSTO

_Purpose_—These subroutines will place a value into or take a value out of a specific array location, respectively. Their respective operations are

\[ A_i = X, \quad i = N, \quad N > 0 \]

or

\[ X = A_i, \quad i = N, \quad N > 0. \]

_Restrictions_—The values may be anything, but \( N \) must be an integer.

_Calling Sequence_—STOARY(\( N, X, A(DV) \)) or ARYSTO(\( N, X, A(DV) \))
Subroutine SCLDEP or SCLIND

*Purpose*—These subroutines will multiply the dependent or independent variables of a doublet interpolation array, respectively. Their respective operations are

\[ A_i = X \times A_i, \quad i = 3, 5, 7, \ldots, N+1 \]

or

\[ A_i = X \times A_i, \quad i = 2, 4, \ldots, N. \]

*Restrictions*—All values must be floating point. The arrays must contain the length integer count as the first value, which must be even.

*Calling Sequence*—SCLDEP(A(IC),X) or SCLIND(A(IC),X)

Subroutine SLDARY or SLDARD

*Purpose*—These subroutines are useful for updating fixed-length interpolation arrays during a transient analysis. The array data values are moved back one or two positions, the first one or two values are discarded, and the last one or two values updated, respectively. The “sliding array” thus maintained can then be used with standard interpolation subroutines to simulate transport delay phenomena. Their respective operations are

\[ A_i = A_{i+1}, \quad i = 2, N \]

and

\[ A_i = X, \quad i = N + 1 \]

or

\[ A_i = A_{i+2}, \quad i = 2, N-1 \]

and

\[ A_i = X \text{ and } A_{i+1} = Y, \quad i = N. \]

*Restrictions*—The addressed arrays must have the array integer count \( N \) as the first value. For SLDARD, \( N \) must be even.

*Calling Sequence*—SLDARY(X,A(IC)) or SLDARD(X,Y,A(IC))

Subroutine SPLIT or JOIN

*Purpose*—These subroutines separate a doublet array into two singlet arrays or combine two singlet arrays into a doublet array respectively. Their respective operations are

\[ \bar{A}_i = A_{2i-1}, \quad i = 1, N \]

\[ C_i = A_{2i}, \quad i = 1, N \]

or

\[ A_{2i-1} = B_i, \quad i = 1, N \]

\[ A_{2i} = C_i, \quad i = 1, N. \]

*Restrictions*—The arrays may contain any values, but \( N \) must be an integer. \( N \) is the length of the \( B \) and \( C \) arrays, and the \( A \) array must be of length \( 2N \).

*Calling Sequence*—SPLIT(N,A(DV),B(DV),C(DV)) or JOIN(N,B(DV),C(DV),A(DV))

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Subroutine SPREAD

Purpose—This subroutine applies interpolation subroutine D1D1DA to two singlet arrays to obtain an array of dependent variables vs an array of independent variables. It is extremely useful for obtaining singlet arrays of various dependent variables with a corresponding relationship to one singlet independent variable array. The dependent variable arrays thus constructed can then be operated on by array manipulation subroutines in order to form composite or complex functions. Doublet arrays can first be separated with subroutine SPLIT and later reformed with subroutine JOIN.

Restrictions—All data values must be floating point except N, which must be the integer length of the array to be constructed. The arrays fed into D1D1DA for interpolation must start with the integer count. X is for independent and Y is for dependent. I is for input and O for output.

Calling Sequence—SPREAD(N,X(IC),Y(IC),XI(DV),YO(DV))

Subroutine QMETER or RDTNQS or QMTRI or QFORCE

Purpose—These subroutines are generally used for calculating flow rates. Their respective operations are

\[ A = B \times (C-D) \]
\[ A = B \times ((C+460.)^4 - (D+460.)^4) \]
\[ A_i = B_i \times (C_i-C_{i+1}), \quad i = 1, N \]
\[ A_i = B_i \times (D_i-D_{i+1}), \quad i = 1, N. \]

Restrictions—All values must be floating-point numbers except the array length N, which must be an integer.

Calling Sequence—QMETER(C,D,B,A) or RDTNQS(D,C,B,A) or QMTRI(N,C(DV),B(DV),A(DV)) or QFORCE(N,C(DV),D(DV),B(DV),A(DV))

Subroutine QINTEG or QINTGI

Purpose—These subroutines perform a simple integration. They are useful for obtaining the integrals of flow rates calculated by QMETER, RDTNQS, QMTRI, or QFORCE. Their respective operations are

\[ S = S + Q \times DT \]
\[ S_i = S_i + Q_i \times DT, \quad i = 1, N. \]

Restrictions—All values must be floating-point numbers except N which must be an integer. Control constant DTIMEU should be used for the step size when doing an integration with respect to time. These subroutines should be called in Variables 2.

Calling Sequence—QINTEG(Q,DT,S) or QINTGI(N,Q(DV),DT,S(DV))
Subroutine CINSIN or SINARY

Purpose—These subroutines obtain the sine function of an angle or an array of angles. Their respective operations are

\[ A = \sin(B) \]
\[ A_i = \sin(B_i), \quad i = 1, N. \]

Restrictions—All angles must be in radians. All values must be floating-point numbers except N, which must be an integer.

Calling Sequence—CINSIN(B,A) or SINARY(N,B(DV),A(DV))

Subroutine CINCOS or COSARY

Purpose—These subroutines obtain the cosine function of an angle or array of angles. Their respective operations are

\[ A = \cos(B) \]
\[ A_i = \cos(B_i), \quad i = 1, N. \]

Restrictions—All angles must be in radians. All values must be floating-point numbers except the array length N, which must be an integer.

Calling Sequence—CINCOS(B,A) or COSARY(N,B(DV),A(DV))

Subroutine CINTAN or TANARY

Purpose—These subroutines obtain the tangent function of an angle or array of angles. Their respective operations are

\[ A = \tan(B) \]
\[ A_i = \tan(B_i), \quad i = 1, N. \]

Restrictions—All angles must be in radians. All values must be floating point numbers except the array length N, which must be an integer.

Calling Sequence—CINTAN(B,A) or TANARY(N,B(DV),A(DV))

Subroutine ARCSIN or ASNARY

Purpose—These subroutines obtain the angle corresponding to a sine function value or array of sine values. Their respective operations are

\[ A = \sin^{-1}(B) \]
\[ A_i = \sin^{-1}(B_i), \quad i = 1, N. \]

Restrictions—The angles are returned in radians with the limits \(-\pi/2 \leq A \leq \pi/2\). All values must be floating point except for the array length N, which must be an integer.
Subroutine ARCCOS or ACSARY

Purpose—These subroutines obtain the angle corresponding to a cosine function value or array of cosine values. Their respective operations are

\[ A = \cos^{-1}(B) \]
\[ A_i = \cos^{-1}(B_i), \quad i = 1, N. \]

Restrictions—The angles are returned in radians with the limits \( 0 \leq A \leq \pi \). All values must be floating-point numbers except for the array length \( N \), which must be an integer.

Calling Sequence—ARCCOS(B,A) or ACSARY(N,B(DV),A(DV))

Subroutine ARCTAN or ATNARY

Purpose—These subroutines obtain the angle corresponding to a tangent function value of array of tangent values. Their respective operations are

\[ A = \tan^{-1}(B) \]
\[ A_i = \tan^{-1}(B_i), \quad i = 1, N. \]

Restrictions—The angles are returned in radians with the limits \(-\pi/2 \leq A \leq \pi/2 \). All values must be floating-point numbers except the array length \( N \), which must be an integer.

Calling Sequence—ARCTAN(B,A) or ATNARY(N,B(DV),A(DV))

Subroutine EXPNTL or ARYEXP or EXPARY

Purpose—These subroutines perform an exponential operation. Their respective operations are

\[ A = B^c \]
\[ A_i = B_i^c, \quad i = 1, N \]
\[ A_i = B_i^c, \quad i = 1, N. \]

Restrictions—All values must be positive floating-point numbers except \( N \), which must be an integer.

Calling Sequence—EXPNTL(C,B,A) or ARYEXP(N,C,B(DV),A(DV)) or EXPARY(N,C(DV),B(DV),A(DV))
Subroutine LOGT or LOGTAR

Purpose - These subroutines obtain the base 10 log function of a number or array of numbers. Their respective operations are

\[ A = \log_{10}(B) \]

or \[ A_i = \log_{10}(B_i), \quad i = 1, \ldots, N. \]

Restrictions - All values must be positive floating-point numbers except N, which must be an integer.

Calling Sequence - LOGT(B,A) or LOGTAR(N,B(DV),A(DV))

Subroutine LOGE or LOGEAR

Purpose - These subroutines obtain the base e log function of a number or array of numbers. Their respective operations are

\[ A = \log_e(B) \]

or \[ A_i = \log_e(B_i), \quad i = 1, \ldots, N. \]

Restrictions - All values must be positive floating-point numbers except N, which must be an integer.

Calling Sequence - LOGE(B,A) or LOGEAR(N,B(DV),A(DV))

Subroutine SQROOT or SQROTI

Purpose - These subroutines obtain the square root of a number or array of numbers, respectively. Their respective operations are

\[ A = \sqrt{B} \]

or \[ A_i = \sqrt{B_i}, \quad i = 1, \ldots, N. \]

Restrictions - The A and B values must be floating-point numbers. The N must be an integer.

Calling Sequence - SQROOT(B,A) or SQROTI(N,B(DV),A(DV))

Subroutine CMPXSIR or CSQRI

Purpose - These subroutines obtain the complex square root of a complex number or an array of complex numbers, respectively. Their respective operations are

\[ A + iB = \sqrt{C} + id, \quad i = 1 \]

or \[ A_j + iB_j = \sqrt{C_j} + id_j, \quad j = 1, \ldots, N \]

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Restrictions—All numbers must be floating-point except N, which must be an integer.

Calling Sequence—CMPXR(C,D,A,B) or CSQRI(N,C(DV),D(DV),A(DV),B(DV))

Subroutine CMPXR or CMPYI

Purpose—These subroutines will multiply two complex numbers or the corresponding elements of arrays of complex numbers. Their respective operations are

\[ A + iB = (C + iD)(E + iF), \quad \text{or} \quad A_j + iB_j = (C_j + iD_j)(E_j + iF_j), \quad j = 1, N \]

Restrictions—All numbers must be floating point except for N, which must be an integer.

Calling Sequence—CMPXR(C,D,E,F,A,B) or CMPYI(N,C(DV),D(DV),E(DV),F(DV),A(DV),B(DV))

Subroutine CMPXDV or CDIVI

Purpose—These subroutines will divide two complex numbers or the corresponding elements of arrays of complex numbers. Their respective operations are

\[ A + iB = (C + iD)/(E + iF), \quad \text{or} \quad A_j + iB_j = (C_j + iD_j)/(E_j + iF_j), \quad j = 1, N \]

Restrictions—All numbers must be floating point except for N, which must be an integer.

Calling Sequence—CMPXDV(C,D,E,F,A,B) or CDIVI(N,C(DV),D(DV),E(DV),F(DV),A(DV),B(DV))

Subroutine NEWTRT or NEWT4

Purpose—These subroutines utilize Newton’s method to obtain one root of a cubic or quartic equation, respectively. The root must be in the neighborhood of the supplied initial guess, and up to 100 iterations are performed in order to obtain an answer within the specified tolerance. If the tolerance is not met, an answer of 10^{-38} is returned. The respective equations are

\[ f(X) = A_1 + A_2 X + A_3 X^2 + A_4 X^3 = 0, 0 \pm T \]
\[ \text{or} \quad g(X) = A_1 + A_2 X + A_3 X^2 + A_4 X^3 + A_5 X^4 = 0, 0 \pm T \]

where X starts as the initial guess RI and finishes as the final answer RF. T is the tolerance.
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Restrictions—All data values must be floating-point numbers.

Calling Sequence—NEWRT(A(DV),T,RI,RF) or NEWRT4(A(DV),T,RI,RF)

Subroutine PLYNML or PLYARY

Purpose—These subroutines calculate Y from the following polynomial equation:

\[ Y = A_1 + A_2 X + A_3 X^2 + A_4 X^3 + \ldots + A_N X^{N-1}. \]

The number of terms is variable, but all the \( A \) coefficients must be entered no matter what their value.

Restrictions—All values must be floating-point numbers except the number of coefficients \( N \), which must be an integer.

Calling Sequence—PLYNML(XA1,A2,A3,\ldots,AN,Y) or PLYARY(N,X,A(DV),Y)

Subroutine SMPINT or TRPZD

Purpose—These subroutines perform area integrations by Simpson’s rule and the trapezoidal rule, respectively. Simpson’s rule requires that an odd number of points be supplied. If an even number of points is supplied, SMPINT will apply the trapezoidal rule to the last incremental area but Simpson’s rule elsewhere. The respective operations are

\[ A = DX*(Y_1 + 4Y_2 + 2Y_3 + 4Y_4 + \ldots + Y_N)/3 \]

or

\[ A = DX*(Y_1 + 2Y_2 + 2Y_3 + 2Y_4 + \ldots + Y_N)/2. \]

Restrictions—The DX increment must be uniform between all the Y points. All values must be floating point except \( N \), which must be an integer.

Calling Sequence—SMPINT(N,DX,Y(DV),A) or TRPZD(N,DX,Y(DV),A)

Subroutine TRPZDA

Purpose—This subroutine performs area integration by the trapezoidal rule. It should be used where the DX increment is not uniform between the Y values but the corresponding X value for each Y value is known. The operation performed is as follows:

\[ A = \frac{1}{2} \sum_{i=2}^{N} (X_i-X_{i-1})*(Y_i+Y_{i-1}), \quad i = 2, N. \]

Restrictions—All values must be floating-point numbers except the array length \( N \), which must be an integer.

Calling Sequence—TRPZDA(N,X(DV),Y(DV),A)
Subroutine PRESS or SPRESS

Purpose—These routines are useful for impressing nodal pressures in one-dimensional flow paths once the entry pressure \( P_1 \), path conductance \( G \), and flow rate \( W \) are known. The respective equations are

\[
P_2 = P_1 - \frac{W}{G} \\
\text{or } P_{i+1} = P_i - \frac{W}{G}, \quad i = 1, 2, 3, \ldots, N.
\]

Restrictions—For SPRESS, the pressures and conductors must be sequential and in ascending order; the number of pressure points to be calculated must be supplied as the integer \( N \).

Calling Sequence—PRESS\((P_1,W,G,P_2)\) or SPRESS\((N,P_1(DV),W,G(DV))\)

Subroutine EFFG

Purpose—Subroutine EFFG is a pressure network of the type in Fig. 11.

![Fig. 11](image)

Where the values of the identified elements are known, this subroutine will calculate the effective conductance \( G_E \) from \( P_1 \) to \( P_2 \). Any interconnections may occur in the space, but only \( P_2, P_3 \) and \( P_4 \) may be on the boundary and no elements may cross it. The equation utilized is

\[
G_E = \frac{(G_1*(P_1-P_3) + G_2*(P_1-P_4))/(P_1-P_2)}.
\]

Restrictions—See above. May not be used where capacitors appear on the internal nodes.

Calling Sequence—EFFG\((P_1,P_2,P_3,P_4,G_1,G_2,G_E)\)

Subroutine EFFEMS

Purpose—This subroutine calculates the effective emissivity \( E \) between parallel flat plates by the following equation:

\[
E = 1.0/(1.0/E_1 + 1.0/E_2 - 1.0),
\]

where \( E_1 \) and \( E_2 \) are the emissivities of the two surfaces under consideration.

Restrictions—Arguments must be floating-point numbers.

Calling Sequence—EFFEMS\((E_1,E_2,E)\)
Output Subroutines

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Subroutine STNDRD or PRNTMP

*Purpose*—Subroutine STNDRD causes a line of output to be printed giving the present time, the last time step used, the most recent CSGMIN value, the maximum diffusion temperature change calculated over the last time step, and the maximum relaxation change calculated over the last iteration. RNN refers to the relative node number on which something occurred. The line of output looks as follows:

```
* * * *
TIME DTIMEU CSGMIN(RNN) DTMPCC(RNN) ARLXCC(RNN)
```

Subroutine PRNTMP internally calls on STNDRD and also lists the temperature of every node in the network according to relative node number. The relative node number vs actual node number dictionary printed out with the input data should be consulted to determine temperature locations on the thermal network model.

*Restrictions*—No arguments are required or allowed. These subroutines should be used with network problems only.

*Calling Sequence*—STNDRD or PRNTMP

Subroutine PRINT or PRINTL

*Purpose*—These subroutines allow individual floating-point numbers to be printed out. The arguments may reference temperature, capacitance, source locations, conductors, constants, or unique array locations. In addition, subroutine PRINTL allows each value to be preceded or labeled by a 6-character alphanumeric word. The number of arguments is variable, but the “label” array used for PRINTL should contain a label for each argument.
MARY E. GEALY

Restrictions—These subroutines do not call on STNDRD. The user may call on it if he desires time control information. Any control constant may be addressed in order to see what its value is; integers must first be floated.

Calling Sequence—PRINT(T,C,Q,G,K,...,A+) or PRINTL(LA(DV),T,C,Q,G,K,...,A+)

Subroutine PRINTA

Purpose—This subroutine allows the user to print out an array of values, five to the line. The integer array length N and the first data value location must be specified. Each value receives an indexed label. The user must supply a 6-character alphanumeric word L to be used as a common label and an integer value M to begin the index count.

Restrictions—The array values to be printed must be floating-point numbers.

Calling Sequence—PRINTA(L,A(DV),N,M)

If the label was the work TEMP, N was 3, and M was 6, the line of output will look as follows:

TEMP ( 6) value TEMP ( 7)value TEMP ( 8)value

Subroutine PRNTMA

Purpose—This subroutine allows the user to print out up to 10 arrays in a column format. The individual elements are not labeled, but each column receives a 2-line heading of 12 alphanumeric characters each. The 2-line heading must be supplied as a single array of four words, six characters each. The user must supply the starting location of each label array and value array. The number of values in each value array must agree and be supplied as the integer N. The value arrays must contain floating-point numbers.

Restrictions—Labels must be alphanumeric, while values must be floating point. All floating-point-value arrays must contain the same number of values.

Calling Sequence—PRNTMA(N,LA1(DV),VA1(DV),LA2(DV),VA2(DV),...)

Subroutine PUNCHA

Purpose—This subroutine enables a user to punch out an array of data values in any desired format. The F argument must reference a FORTRAN format which has been input as an array, including the outer parentheses but deleting the word format. The second argument must address the first data value of the array of sequential values. The third argument N must be the integer number of data values in the array.

Restrictions—Punched cards must be asked for on the job request form.

Calling Sequence—PUNCHA(F(DV),A(DV),N)
Subroutine TPRINT

Purpose—Subroutine TPRINT makes a call to STNDRD, then lists the actual node number and corresponding temperature for every node in a network.

Restrictions—This subroutine may be called from any of the operations blocks.

Calling Sequence—TPRINT

Subroutine READ or WRITE

Purpose—These subroutines enable the user to read and write arrays of data as binary information on magnetic tape. The first argument L must be the integer number of the logical tape being addressed. The second argument X must address the first data value of the array to be written out or the starting location for data to be read into. The third argument N must be an integer. For WRITE it is the number of data values to be written on tape as a record. For READ it is the number of data values to be read in from tape from the next record, not necessarily the entire record.

Restrictions—The user should check section VII to determine which logical units are available and control card requirements. All processed information must be in binary.

Calling Sequence—READ(L,X(DV),N) or WRITE(L,X(DV),N)

Subroutine EOF or REWIND

Purpose—These subroutines enable the user to write end of file marks on magnetic tape and to rewind them. They are generally used in conjunction with subroutines READ and WRITE discussed above. The single argument L must be the integer logical tape number of the unit being activated.

Restrictions—The user should check section VII to determine available logical units.

Calling Sequence—EOF (L) or REWIND (L)
### Matrix Subroutines

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**NOTE:** All of the above subroutines require that matrices be entered as positive numbered arrays having the integer number of rows and columns as the first two data values followed by the floating-point element values in row order. The above package of subroutines is referred to as MOPAS, for Matrix Oriented Production Assembly System.
Subroutine ZERO or ONES

Purpose—These subroutines generate a matrix [Z] such that every element is zero or one, respectively.

Restrictions—The matrix to be generated must contain exactly enough space in addition to having the integer number of rows and columns as the first two data values. The NR and NC arguments are the integer number of rows and columns, respectively.

Calling Sequence—ZERO(NR, NC, Z(IC)) or ONES(NR, NC, Z(IC))

Subroutine UNITY or SIGMA

Purpose—These are square matrix generation subroutines. UNITY generates a square matrix such that the main diagonal elements are one and all other elements are zero. SIGMA generates a square matrix such that all elements on and below the main diagonal are one and the remaining elements are zero.

Calling Sequence—UNITY(N, Z(IC)) or SIGMA(N, Z(IC))

Restrictions—The matrix [Z] to be generated must contain exactly enough space in addition to having the integer number of rows and columns as the first two data values. The integer number of rows and columns are equal and must be input as the argument N.

Subroutine GENALP or GENCOL

Purpose—These are special matrix generation subroutines. GENALP will generate a matrix such that every element is equal to a constant C. GENCOL will generate a column matrix such that the first element is equal to X1 and the last element is equal to X2. The intermediate elements receive equally incremented values such that a linear relationship is established between row number and element value.

Restrictions—The NR and NC arguments refer to the integer number of rows and columns, respectively. X1, X2, and C must be floating-point values. The generated matrixes must contain exactly enough space in addition to having the integer number of rows and columns as the first two data values.

Calling Sequence—GENALP(NR, NC, C, Z(IC)) or GENCOL(X1, X2, NR, Z(IC))
Subroutine SHIFT or REFLCT

Purpose—These subroutines may be used to move an entire matrix from one location to another. SHIFT moves the matrix exactly as is and REFLCT moves it and reverses the order of the elements within each column. The last element in each column becomes the first and the first becomes the last, etc.

REFLCT uses three dynamic storage locations plus an additional one for each row.

Restrictions—The matrices must be of identical size, and the integer number of rows and columns must be the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) matrix.

Calling Sequence—\(\text{SHIFT}(A(IC),Z(IC))\) or \(\text{REFLCT}(A(IC),Z(IC))\)

Subroutine SHUFL

Purpose—This subroutine allows the user to reorder the size of a matrix as long as the total number of elements remains unchanged. The row order input matrix \([A]\) is transposed to achieve column order and then reformed as a vector by sequencing the columns in ascending order. This vector is then reformed into a column order matrix by taking a column at a time sequentially from the vector. The newly formed column matrix is then transposed and output as the row order matrix \([Z]\).

Restrictions—The matrices must be identical in size and have their respective integer number of rows and columns as the first two data values. The number of rows times columns for \([A]\) must equal the number of rows times columns of \([Z]\).

Calling Sequence—\(\text{SHUFL}(A(IC),Z(IC))\)

Subroutine COLMAX or COLMIN

Purpose—These subroutines search an input matrix to obtain the maximum or minimum values within each column, respectively. These values are output as a single row matrix \([Z]\) having as many columns as the input matrix \([A]\).

Restrictions—Each matrix must have its integer number of rows and columns as the first two data values.

Calling Sequence—\(\text{COLMAX}(A(IC),Z(IC))\) or \(\text{COLMIN}(A(IC),Z(IC))\)

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Subroutine ELEADD or ELESUB

*Purpose*—These subroutines add or subtract the corresponding elements of two matrices, respectively:

\[ [Z] = [A] \pm [B], \quad z_{ij} = a_{ij} \pm b_{ij}. \]

*Restrictions*—All matrices must be of identical size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) or \([B]\) matrix.

*Calling Sequence*—ELEADD(A(IC), B(IC), Z(IC)) or ELESUB(A(IC), B(IC), Z(IC))

Subroutine ELEMUL or ELEDIV

*Purpose*—These subroutines multiply or divide the corresponding elements of two matrices, respectively:

\[ [Z] = [A] \ast [B], \quad z_{ij} = a_{ij} \ast b_{ij}. \]

*Restrictions*—All matrices must be of identical size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) or \([B]\) matrix.

*Calling Sequence*—ELEMUL(A(IC), B(IC), Z(IC)) or ELEDIV(A(IC), B(IC), Z(IC))

Subroutine ELEINV

*Purpose*—This subroutine obtains the reciprocal of each element of the \([A]\) matrix and places it in the corresponding element location of the \([Z]\) matrix;

\[ z_{ij} = 1.0/a_{ij}. \]

*Restrictions*—The matrixes must be of identical size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) matrix.

*Calling Sequence*—ELEINV(A(IC), Z(IC))

Subroutine EFSIN or EFASN

*Purpose*—These subroutines perform elementary functions on all of the \([A]\) matrix elements as follows:

\[ z_{ij} = \sin(a_{ij}) \text{ or } z_{ij} = \arcsin(a_{ij}). \]
Restrictions—The matrices must be identical in size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) matrix.

Calling Sequence—EFSIN(A(IC),Z(IC)) or EFASN(A(IC),Z(IC))

Subroutine EFCOS or EFACS

Purpose—These subroutines perform elementary functions on all of the \([A]\) matrix elements as follows:

\[ z_{ij} = \cos (a_{ij}) \text{ or } z_{ij} = \arccos (a_{ij}). \]

Restrictions—The matrices must be identical in size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) matrix.

Calling Sequence—EFCOS(A(IC),Z(IC)) or EFACS(A(IC),Z(IC))

Subroutine EFTAN or EFATN

Purpose—These subroutines perform elementary functions on all of the \([A]\) matrix elements as follows:

\[ z_{ij} = \tan (a_{ij}) \text{ or } z_{ij} = \arctan (a_{ij}). \]

Restrictions—The matrices must be of identical size and have the integer number of rows and columns as the first two data values. The \([Z]\) matrix may be overlayed into the \([A]\) matrix.

Calling Sequence—EFTAN(A(IC),Z(IC)) or EFATN(A(IC),Z(IC))

Subroutine EFLOG or EFSQR

Purpose—These subroutines perform elementary functions on all of the \([A]\) matrix elements as follows:

\[ z_{ij} = \log_e (a_{ij}) \text{ or } z_{ij} = \sqrt{a_{ij}}. \]

Restrictions—The matrices must be identical in size and have the integer number of rows and columns as the first two data values. All elements in the \([A]\) matrix must be positive.

Calling Sequence—EFLOG(A(IC),Z(IC)) or EFSQR(A(IC),Z(IC))
Subroutine EFEXP or EFPOW

*Purpose*—These subroutines perform elementary functions on all of the [A] matrix elements as follows:

\[ z_{ij} = e^{a_{ij}} \text{ or } z_{ij} = a_{ij}^\alpha. \]

*Restrictions*—The matrices must be identical in size and have the integer number of rows and columns as the first two data values. The [Z] matrix may be overlayed into the [A] matrix. The exponent \( \alpha \) may be an integer or floating-point number. However, if any elements in [A] are negative then \( \alpha \) must be an integer.

*Calling Sequence*—EFEXP(A(IC),Z(IC)) or EFPOW(A(IC),\( \alpha \),Z(IC))

Subroutine MATRIX or SCALAR

*Purpose*—Subroutine MATRIX allows a constant to replace a specific matrix element, and subroutine SCALAR allows a specific matrix element to be placed into a constant location. The integers \( I \) and \( J \) designate the row and column position of the specific element:

\[ z_{ij} = C \text{ or } C = z_{ij}. \]

*Restrictions*—The matrix must have the integer number of rows and columns as the first two data values. Checks are made to insure that the identified element is within the matrix boundaries.

*Calling Sequence*—MATRIX(C,I,J,Z(IC)) or SCALAR(Z(IC),I,J,C)

Subroutine DISAS or ASSMBL

*Purpose*—These subroutines allow a user to operate on matrixes in a partitioned manner by disassembling a submatrix [Z] from a parent matrix [A] or assembling a submatrix [Z] into a parent matrix [A].

*Restrictions*—The \( I \) and \( J \) arguments are integers which identify (by row and column number, respectively) the upper left-hand corner position of the submatrix within the parent matrix. All matrices must have exactly enough space and contain the integer number of rows and columns as the first two data values. The \( NR \) and \( NC \) arguments are the integer number of rows and columns, respectively, of the disassembled submatrix. If the submatrix exceeds the bounds of the parent matrix an appropriate error message is written and the program terminated.

*Calling Sequence*—DISAS(A(IC),I,J,NR,NC,Z(IC)) or ASSMBL(Z(IC),I,J,A(IC))
MARY E. GEALY

Subroutine DIAG

Purpose—Given a 1*N or N*1 matrix [V], this subroutine forms a full square N*N matrix [Z]. The [V] values are placed sequentially on the main diagonal of [Z] and all off-diagonal elements are set to zero.

Restrictions—Both matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values.

Calling Sequence—DIAG(V(IC),Z(IC))

Subroutine COLMLT or ROWMLT

Purpose—to multiply each element in a column or row of matrix [A] by its corresponding element from the matrix [V] which is conceptually a diagonal matrix but stored as a vector; i.e., 1*N or N*1 matrix. The matrix [Z] is the product.

Restrictions—The matrixes must have exactly enough space and contain the integer number of rows and columns as the first two data values. The matrixes being multiplied must be conformable.

Calling Sequence—COLMLT(A(IC),V(IC),Z(IC)) or ROWMLT(V(IC),A(IC),Z(IC))

Subroutine ADDALP or ALPHAA

Purpose—These subroutines add a constant to or multiply a constant times every element in a matrix;

\[ z_{ij} = c + a_{ij} \quad \text{or} \quad z_{ij} = c \cdot a_{ij}. \]

Restrictions—The matrixes must have exactly enough space and contain the integer number of rows and columns as the first two data values. C and all elements must be floating-point numbers. The [Z] matrix may be overlayed into the [A] matrix.

Calling Sequence—ADDALP(C,A(IC),Z(IC)) or ALPHAA(C,A(IC),Z(IC))

Subroutine AABB

Purpose—to sum two scaled matrixes;

\[ [Z] = C_1 [A] + C_2 [B] \quad \text{and} \quad z_{ij} = c_1 a_{ij} + c_2 b_{ij}. \]

Restrictions—All matrixes must be of identical size, contain exactly enough space, and contain the integer number of rows and columns as the first two data values. The output matrix [Z] may be overlayed into either of the input matrixes.

Calling Sequence—AABB(C1,A(IC),C2,B(IC),Z(IC))
Subroutine BTAB

Purpose—To perform the following matrix operation:

\[ \begin{bmatrix} Z \end{bmatrix} = \begin{bmatrix} B \end{bmatrix} \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} B \end{bmatrix} \cdot \]

Restrictions—The matrixes must be conformable, contain exactly enough space, and contain the integer number of rows and columns as the first two data values. Subroutines MULT and TRANS are called on.

This subroutine (due to MULT and TRANS) uses \(2 \times m \times n + 6\) dynamic storage locations.

Calling Sequence—BTAB(A(IC),B(IC),Z(IC))

Subroutine INVRSE

Purpose—to invert a square matrix;

\[ \begin{bmatrix} Z \end{bmatrix} = \begin{bmatrix} A \end{bmatrix}^{-1} \cdot \]

This subroutine requires \(n\) dynamic storage locations.

Restrictions—The matrixes must be square, identical in size, and contain the integer number of rows and columns as the first two data values. The output matrix \(\begin{bmatrix} Z \end{bmatrix}\) may be overlayed into the \(\begin{bmatrix} A \end{bmatrix}\) matrix.

Calling Sequence—INVRSE(A(IC),Z(IC))

Subroutine MULT

Purpose—to multiply two conformable matrixes together;

\[ \begin{bmatrix} Z \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} B \end{bmatrix}, \quad z_{ij} = a_{ik} \times b_{kj}. \]

This subroutine requires \(n \times m\) dynamic storage locations.

Restrictions—The matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values. If \(\begin{bmatrix} A \end{bmatrix}\) and \(\begin{bmatrix} B \end{bmatrix}\) are square, \(\begin{bmatrix} Z \end{bmatrix}\) may be overlayed into either of them.

Calling Sequence—MULT(A(IC),B(IC'),Z(IC))
Subroutine TRANS

\[ m \times n \quad n \times m \]

**Purpose**—Given a matrix \([A]\), form its transpose as \([Z]\).

This subroutine requires \(n \times m\) dynamic storage locations.

**Restrictions**—Both matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values. The output matrix \([Z]\) may be overlayed into the \([A]\) matrix.

**Calling Sequence**—TRANS(A(IC),Z(IC))

Subroutine POLMLT

**Purpose**—This subroutine performs the multiplication of a given number of \(n\)th order polynomial coefficients by a similar number \(m\)th order polynomial coefficients. The polynomials must be input as matrixes with the number of rows equal, and each row receives the following operation:

\[
(c_1, c_2, c_3, \ldots, c_k) = (a_1, a_2, \ldots, a_n) \times (b_1, b_2, \ldots, b_m), \quad k = m + n - 1.
\]

**Restrictions**—The matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values.

**Calling Sequence**—POLMLT(A(IC),B(IC),D(IC))

Subroutine POLVAL

**Purpose**—Given a set of polynomial coefficients as the first row of matrix \([A]\), this subroutine evaluates the polynomial for the input complex number \(X+iY\). The answer is returned as \(U+iV\).

**Restrictions**—\([A]\) may be \(m \times n\), but only the first row is evaluated.

**Calling Sequence**—POLVAL(A(IC),X,Y,U,V)

Subroutine PLYEV

**Purpose**—Given a matrix \([A]\) containing an arbitrary number \(NRA\) of \(n\)th order polynomial coefficients and a column matrix \([X]\) containing an arbitrary number \(NRX\) of \(x\) values, this subroutine evaluates each polynomial for each \(x\) value. The answers are output as a matrix \([Z]\) of size \(NRX \times NRA\). Each set of polynomial coefficients in \([A]\) is a row in ascending order. An \(x\) value evaluated for the polynomials creates a row in \([Z]\) where the column number agrees with the polynomial row number.
Restrictions—The matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values.

Calling Sequence—PLYEVL(A(IC),Z(IC),Z(IC))

Subroutine POLSOV

Purpose—Given a set of polynomial coefficients as the first row in matrix [A], size (m,n+1), this subroutine calculates the complex roots which are returned as matrix [Z], size (n,2). Column 1 contains the real part and column 2 the imaginary part of the roots.

Restrictions—This subroutine presently is limited to n = 20. It internally calls on RTPOLY and utilizes some double precision.

Calling Sequence—POLSOV(A(IC),Z(IC))

Subroutine JACOBI

Purpose—This subroutine will find the eigenvalues [E] and eigenvector matrix [Z] associated with an input matrix [A];

\[ \begin{bmatrix} n^*n & n*n & n*1 \\ A & Z & [E] \end{bmatrix} \]

This subroutine requires 2*n*n+6 dynamic storage locations.

Restrictions—The matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values.

Calling Sequence—JACOBI(A(IC),E(IC),Z(IC))

Subroutine MODES

Purpose—This subroutine solves the dynamic vibration equation

\[ \begin{bmatrix} n^*n & n*n & n*n & n*1 \\ A & Z & [B] & [Z] \end{bmatrix} \]

where [A] is the input inertia matrix associated with the kinetic energy and [B] is the input stiffness matrix associated with the strain energy. [Z] is the output eigenvector matrix associated with the frequencies of vibration \( W_i \) which are output in rad/sec as [R] and in hertzes as [C]; both [R] and [C] are n*1 matrixes.

This subroutine requires 3*n*n+9 dynamic storage locations.
MARY E. GEALY

Restrictions—The matrixes must have exactly enough space and contain their integer number of rows and columns as the first two data values. Subroutine JACOBI is called on.

Calling Sequence—MODES(A(IC),B(IC),Z(IC),R(IC),C(IC))

Subroutine MASS

Purpose—If a dynamic vibration problem is referred to a set of coordinates consisting of the deflections $\dot{x}_i$ and the rotations $\dot{\theta}_i$ at N collocation points along the beam under consideration, then this subroutine generates the $2N \times 2N$ inertia matrix $[A]$ which appears in the following expression for kinetic energy.

$$T = \frac{1}{2} \left[ \begin{array}{c} \dot{x}_1 \ldots \dot{x}_N \dot{\theta}_1 \ldots \dot{\theta}_N \end{array} \right] [A] \left[ \begin{array}{c} \dot{x}_1 \\ \vdots \\ \dot{x}_N \\ \dot{\theta}_1 \\ \ldots \\ \dot{\theta}_N \end{array} \right]$$

Restrictions—The mass and inertia data inputs to this subroutine are to be supplied as piecewise continuous slices; however, these arrays may be of arbitrary size and different in length from each other. The number of collocation points $N$ which determines the ultimate size, $2N \times 2N$, of the output inertia matrix, is also chosen arbitrarily.

Calling Sequence—MASS(X(IC),DMPL(IC),RIPL(IC),CM(IC),A(IC))

Here

$X$ is an $N \times 1$ matrix of collocation points referred to an arbitrary origin.
$DMPL$ is an $NDM \times 4$ matrix of distributed mass per unit length slices, in which
Col 1 is the location of the rear of a slice.
Col 2 is the location of the front of a slice.
Col 3 is the mass value at the rear of the slice.
Col 4 is the mass value at the front of the slice.
$RIPL$ is an $NRI \times 4$ matrix of distributed rotary inertia per unit length slices. The columns here are similar to $DMPL$.
$CM$ is an $NCM \times 4$ matrix of concentrated mass items, where
Col 1 is the attach point location for each item.
Col 2 is the mass at this location.
Col 3 is the location of its center of gravity.
Col 4 is the amount of inertia about the center of gravity.
$A$ is a $2N \times 2N$ output inertia matrix.

NOTE: Since this applies to $DMPL$, $RIPL$, and $CM$, the location of the values may not go beyond the limits of the collocation points in either direction.
Subroutine STIFF

Purpose—If a dynamic vibration problem is referred to a set of coordinates consisting of the deflections $\xi_j$ and the rotations $\theta_j$ at $N$ collocation points along the beam under consideration, then this subroutine generates the $2N$ by $2N$ stiffness matrix $[K]$ which appears in the following expression for the strain energy $U$

$$U = \frac{1}{2} \begin{bmatrix} \xi_1 & \ldots & \xi_N \theta_1 & \ldots & \theta_N \end{bmatrix} \begin{bmatrix} [K] & \xi_1 \\ \vdots & \ddots & \vdots \\ \xi_N & \theta_1 & \ldots & \theta_N \end{bmatrix}$$

Restrictions—The stiffness and shear data inputs to this subroutine are to be supplied as piecewise continuous slices; however, these arrays may be of arbitrary size and different in length from each other. The number of collocation points $N$, which determine the ultimate size ($2N$ by $2N$) of the output stiffness matrix, is also chosen arbitrarily.

Calling Sequence—STIFF(X(IC),EI(IC),GA(IC),K(IC))

where

- $X$ is an $N$ by 1 matrix of collocation points referred to an arbitrary origin.
- $EI$ is an $NEI$ by 4 matrix of bending stiffness slices, where
  - Col 1 is the location of the rear of a slice.
  - Col 2 is the location of the front of a slice.
  - Col 3 is the stiffness value at the rear of a slice.
  - Col 4 is the stiffness value at the front of a slice.
- $GA$ is an $NGA$ by 4 matrix of shear stiffness slices, where the columns here are similar to those for the $EI$ distribution.
- $K$ is the output stiffness matrix size $2N$ by $2N$.

NOTE: Since this applies to $EI$ and $GA$, the location of the values may not go beyond the limits of the collocation points in either direction.

Subroutine LIST

Purpose—This subroutine prints out the elements of a matrix $[A]$ and identifies each by its row and column number. The user must supply an alphanumeric name $ALP$ and integer number $NUM$ to identify the matrix. This is to maintain consistency with subroutines FILE and CALL.

Restrictions—The matrix must have its integer number of rows and columns as the first two data values.

Calling Sequence—LIST(A(IC),ALP,NUM)
Mary E. Gealy

Subroutine PUNCH

Purpose—This subroutine punches out a matrix \([A]\), size \(n \times m\), one column at a time in any desired format. The argument FOR must reference a FORTRAN format statement that has been entered as a positive array. It must include the outer parenthesis but not the word FORMAT. The argument HEAD must be a single BCD word used to identify the matrix. Each column is designated and restarts use of the FORMAT statement.

This subroutine requires \(n+3\) dynamic storage locations.

Restrictions—The matrix \([A]\) must have exactly enough space and contain the integer number of rows and columns as the first two data values. Punched cards must be asked for on the job request form.

Calling Sequence—PUNCH(A(IC),HEAD,FOR(IC))

Matrix Data Storage and Retrieval

The ability to store and retrieve matrices from tape is easily achieved through the use of the FILE and CALL subroutines. Matrices are identified by an alphanumeric name, integer problem number, and the core address of or for the matrix. The CALL subroutine searches the matrix storage tape on logical 16 and brings the desired matrix into core. The FILE subroutine writes a matrix onto the logical 30 tape. Subroutine ENDMOP causes all matrices from the logical 30 tape to be updated onto the logical 16 tape. In case of duplicate matrices the one from logical 30 replaces the one on logical 16. A matrix which has been filed cannot be called until an ENDMOP operation has been performed. To create a new tape the user merely sets control constant NOCOPY nonzero and has a scratch tape mounted on logical 16. The user should check the section on control cards and deck setup to determine control card requirements.

Subroutine CALL or FILE

Purpose—To allow the user to retrieve or store matrixes on magnetic tape, see above. The H argument must be a 6-character alphanumeric word and N must be an integer number, both of which are used to identify the matrix.

Restrictions—See above. The matrix must have exactly enough space and contain the integer number of rows and columns as the first two data values.

Calling Sequence—CALL(H,N,A(IC)) or FILE(A(IC),H,N)

Subroutine ENDMOP or LSTAPE

Purpose—Subroutine ENDMOP should be used in conjunction with subroutines CALL and FILE, see above. It causes matrixes which have been filed by FILE on logical 30 to be updated onto logical 16. A call to subroutine LSTAPE will cause the output of the name, problem number, and size of every matrix stored on tape on logical 16.

Restrictions—See above.

Calling Sequence—ENDMOP or LSTAPE

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Subroutine SIMEQN

**Purpose**—This subroutine solves a set of up to 10 linear simultaneous equations by the factorized inverse method. The problem size and all input and output values are communicated as a single, specially formatted, positive input array. The array argument must address the matrix order \( N \) which is input by the user. The first data value must be the integer order of the set (or size of the square matrix) followed by the coefficient matrix \( [A] \) in column order, the boundary vector \( \{B\} \), and space for the solution vector \( \{S\} \):

\[
[A] \{S\} = \{B\}.
\]

**Restrictions**—The integer count and matrix size must be integers; all other values must be floating point. The coefficient matrix is not modified by SIMEQN. Hence, changes to \( \{B\} \) only allow additional solutions to be easily obtained.

**Calling Sequence**—SIMEQN(A(N))

where the array is formatted exactly as follows:

\[
IC, N, A(1,1), A(1,2), \ldots, A(N,N), B1, \ldots, BN, S1, \ldots, SN
\]

Subroutine LSTSQU

**Purpose**—This subroutine performs a least squares curve fit to an arbitrary number of \( X, Y \) pairs to yield a polynomial equation of up to order 10. Rather than using a double precision matrix inverse, this subroutine calls on subroutine SIMEQN to obtain a simultaneous solution.
MARY E. GEALY

This subroutine requires 2*M dynamic storage core locations.

Restrictions—All values must be floating-point numbers except N and M, which must be integers. N is the order of the polynomial desired and is one less than the number of coefficients desired. M is the array length of the independent X or dependent Y values.

Calling Sequence—LSTSQU(N,M,X(DV),Y(DV),A(DV))

Subroutine IRRADI or IRRADE

Purpose—These subroutines simulate a radiosity network* within a multiple gray surface enclosure containing a nonabsorbing media. The input is identical for both subroutines. However, IRRALE utilizes explicit equations to obtain the solution by relaxation, and IRRADI initially performs a symmetric matrix algebra inverse and thereafter obtains the exact solution implicitly by matrix multiplication. The relaxation criteria of IRRALE is internally calculated and severe enough so that both routines generally yield identical results. However, IRRALE should be used when temperature-varying emissivities are to be considered, and IRRADI should be used when the surface emissivities are constant. Both subroutines solve for the J-node radiosity, obtain the net radiant heat flow rates to each surface, and return them sequentially in the last array that was initially used to input the surface temperatures. The user need not specify any radiation conductors within the enclosure.

Restrictions—The Fahrenheit system is required. The arbitrary number of temperature arguments may be constructed by a preceding BLDARY call. The emissivity, area, temperature-Q and upper half-FA arrays must be in corresponding order and of exact length. The first data value of the FA array must be the integer number of surfaces and the second the Stephan-Boltzmann constant in the proper units and then the FA floating-point values in row order. The diagonal elements (even if zero) must be included. As many radiosity subroutine calls as desired may be used. However, each call must have unique array arguments. The user should follow the radiosity routine by SCALE, BRKARY, or BKARAD to distribute the Q’s to the proper source locations.

Calling Sequences—IRRADI(AA(IC),Ae(IC),AFA(IC),ATQ(IC)) or IRRADE(AA(IC),Ae(IC),AFA(IC),ATQ(IC))

The arrays are formatted as follows:

AA(IC),A1,A2,A3,A4,...,AN,END
Ae(IC),e1,e2,e3,e4,...,eN,END
AFA(IC),N,o,FA(1,1),FA(1,2),FA(1,3),FA(1,4),FA(1,5),... FA(1,N)
FA(2,2),FA(2,3),FA(2,4),FA(2,5),... FA(2,N)
FA(N-2,N-2),FA(N-2,N-1),FA(N-2,N)
FA(N-1,N-1),FA(N-1,N)
FA(N,N),END
ATQ(IC),T1,T2,T3,...TN,END

where FA(1,2) is defined as A(1) * F(1,2). After the subroutine has been performed the 
ATQ array is ATQ(IC),Q1,Q2,Q3,...QN,END.

Since FA1(1,2) = FA2(2,1) only the upper half triangle of the full FA matrix is 
required. IRRADI inverts this half-matrix in its own area; hence, approximately 300 
surfaces may be considered using CINDA on a 65k-core machine.

Subroutine SLRADI or SLRADE

Purpose—These subroutines are very similar to IRRADI and IRRADE but are 
designed to solve for the solar heating rates within an enclosure. SLRADI inverts half a 
symmetric matrix in order to obtain implicit solutions while SLRADE obtains solutions 
explicitly by relaxation. SLRADE should be used when temperature varying solar emissivi-
ties are to be considered. The second data value of the AFA array must be the solar con-
stant in the proper units. The AT array allows the user to input the angle (degrees) be-
tween the surface normal and the surface-sun line. The AI array allows the user to input 
an illumination factor for each surface which is the ratio from zero to one of the unshaded 
portion of the surface. The solar constant S, AT, and AI values may vary during the 
transient for both routines. No input surface temperatures are required. The absorbed 
heating rates are returned sequentially in the AQ array; the user may utilize SCALE, 
BRKARY, or BKARAD to distribute the heating rates to the proper source locations.

Restrictions—These routines are independent of the temperature system being used. 
All of the array arguments must reference the integer count set by the CINDA preproc-
essor and be of the exact required length. As many calls as desired may be made, but 
each call must have unique array arguments.

Calling Sequences—SLRADI(AA(IC),Ac(IC),AFA(IC),AT(IC),AI(IC),AQ(IC)) or 
SLRADE(AA(IC),Ac(IC),AFA(IC),AT(IC),AI(IC),AQ(IC))

Subroutine SCRPFA

Purpose—To obtain the script FA value for radiant transfer within an enclosure. 
The input arrays are formatted as shown for subroutines IRRADI and IRRADE. The 
second data value in the AFA array is used as a final multiplier. If 1.0 the script FA 
values are returned; if a then script a FA values are returned. The script FA values are 
returned in the ASFA array which is formatted identically to the AFA array and may 
overlay it.

Restrictions—All array arguments must reference the integer count set by the 
CINDA preprocessor, and all arrays must be exactly the required length.

Calling Sequence—SCRPF(AA(IC),Ac(IC),AFA(IC),ASFA(IC))

NOTE: Subroutine SYMLIST(AFA(IC)+3,AFA(IC)+1) may be called to list the matrix 
values and identify them by row and column number. This routine and the implicit 
radiosity routines finalize the half-symmetric-coefficient matrix and call on 
SYMINV(AFA(IC)+3,AFA(IC)+1) to obtain the symmetric inverse.
Subroutine ABLATS

Purpose—ABLATS provides a simple ablation (sublimation) capability for the CINDA user. The user constructs the three-dimensional network without considering the ablative. Then in Variables 2 he simulates one-dimensional ablative attachments by calling ABLATS. ABLATS constructs the one-dimensional network and solves it by implicit forward-backward differencing (Crank-Nicholson method) using the time step set by the execution subroutine. Separate ablation arrays (AA) must be used for each ABLATS call. Required working space is obtained from unused program COMMON. Several ABLATS calls thereby share unused COMMON. The user must call subroutine PNTABL(AA) in the OUTPUT CALLS to obtain the ablation totals and temperature distribution.

Restrictions—ABLATS must be called in Variables 2 and may be used with any execution subroutine. Subroutines D1DEG1, NEWTR4, and INTRFC are called. All units must be consistent. The Fahrenheit system is required. Temperature-varying material property arrays must not exceed 60 doublets. Bivariate material properties may be simulated by calling BVSPSA prior to ABLATS. Cross-sectional area is always considered unity. Thermal conductivity, Stephan-Boltzmann constant, and density units must agree in area and length units.

This subroutine requires 3*(L*NSL+1) dynamic storage core locations.

Calling Sequence—ABLATS(AA(IC),R,CP,G,T,C)

where

C is the capacitance location of the three-dimensional node.
T is the temperature location of the three-dimensional node.
G is the location of the material thermal conductivity or the starting location (integer count) of a doublet G vs T array.
CP is the location of the material specific heat or the starting location (integer count) of a doublet Cp vs T array.
R is the location of the material density or the starting location (integer count) of a doublet ρ vs T array.
AA(IC) is the starting location of the ablation array which must be formatted as follows:

AA(IC)+1—the ablative link number, a user-specified identification integer.
AA(IC)+2—integer number of sublayers (NSL) desired; ABLATS subtracts from this the number of sublayers ablated.
AA(IC)+3—the initial temperature of the material; ABLATS replaces this with the outer surface temperature, always in degrees F.
AA(IC)+4—the impressed outer surface heating rate per unit area, radiation rates not included.
AA(IC)+5—material thickness; this is replaced by the sublayer thickness.
AA(IC)+6—surface area of the three-dimensional node; need not be unity.
AA(IC)+7—ablation temperature, degrees F.
AA(IC)+8—heat of ablation.
AA(IC)+9—Stephan-Boltzmann constant in consistent units.
AA(IC)+10—surface emissivity.
Subroutine LQDVAP

Purpose—This subroutine allows the user to simulate the addition of liquid to a node. The network data is prepared as though no liquid exists at the node and is solved that way by the network execution subroutine. Then LQDVAP, which must be called from Variables 2, corrects the nodal solution in order to account for the liquid. If the nodal temperature exceeds the boiling point of the liquid, it is set to the boiling point.

The excess energy above that required to reach the boiling point is calculated and considered as absorbed through vaporization. If the liquid is completely vaporized the subroutine deletes its operations. The method of solution holds very well for explicit solutions, but may introduce some error when large time steps are used with implicit solutions.

Restrictions—This subroutine must be called from Variables 2.

Calling Sequence—LQDVAP(T,C,(A))

where

T is the temperature location of the node.
C is the capacitance location of the node.
A + 1 contains the initial liquid weight.
A + 2 contains the liquid specific heat.
A + 3 contains the liquid vaporization temperature.
A + 4 contains the liquid heat of vaporization.
A + 5 receives the liquid vaporization rate (weight/time).
A + 6 receives the liquid vaporization total (total weight).
A + 7 contains the liquid initial temperature.

Subroutine BIVLV

Purpose—This subroutine allows the user to specify the percentage flow rates through two parallel tubes with common end points. One tube must consist of a single flow conductor (G1) while the other tube may consist of one or more sequential flow conductors (G2(I), I = 1,N). The ratio of flow through G1 divided by the total flow may be calculated in any desired manner and must be supplied as the argument W. The conductor values of either one tube or the other are reduced in order to achieve the desired percentage flow rates regardless of the pressure drop.

Restriction—N must be an integer. G2 must address the first of the sequential conductors in that tube.

Calling Sequence—BIVLV(N,W,G1,G2(DV))
Subroutine LINE

Purpose—This subroutine computes the steady state changes in the thermodynamic and flow properties through a line of length L. The upstream properties must be defined and supplied. The following equations are simultaneously solved in an iterative fashion:

\[ \rho_u v_u = \rho_d v_d \] (one-dimensional conservation of mass),

where \( u \) denotes upstream and \( d \) denotes downstream;

\[ \frac{I_u + \frac{v_u^2}{2}}{W} = \frac{I_d + \frac{v_d^2}{2}}{W} \] (one-dimensional energy equation);

\[ P_u = P_d \] (momentum equation, simplified because of a very small pressure drop and low velocities);

\[ \rho = f(X,P,h) \]

\[ T = g(X,P,h) \] (equations of state);

\[ X_L = h(X,P,h) \]

\[ Q = h(W_p)L(T_w - T) \] (energy loss)

\[ R_e = W(4A/W_p)/A_\mu \] (\( R_e \) is the Reynolds number)

\[ P_r = C_p \mu/K \] (\( P_r \) is the Prandtl number)

\[ h = 0.332 (R_e^{0.5})(P_r^{0.333}) \text{ for } R_e < 2100 \text{ (laminar flow)} \]

\[ h = 0.023 (R_e^{0.8})(P_r^{0.4}) \text{ for } R_e > 2100 \text{ (turbulent flow)} \]

\( C_p, \mu, \) and \( K \) are obtained from subroutine TRNPR.T.

Restrictions—Subroutine LINE assumes that the flowing fluid is composed of a perfect noncondensable gas and a perfect condensable gas. This assumption involves the STATE subroutine which is called on. However, LINE does not need the variables \( X_L \) and \( T \) to evaluate the transport properties and the heat transfer coefficient \( h \) for the calculation of \( Q \). The thermodynamic property arguments are upstream properties when calling LINE, but the downstream thermodynamic properties are in the same locations.

Calling Sequence—
LINE(A,W,Wp,L,Tw,W,A1(IC),A2(IC),A3(IC),...A10(IC),P,T,X_L,X,I,V,\rho,Q)

where

\( A = \) flow area
\( W_p = \) wetted perimeter
\( L = \) tube length (floating point)
\( T_w = \) wall temperature
Subroutine STATE

Purpose — This subroutine computes the thermodynamic state for a mixture of an assumed noncondensable gas (hydrogen) and a condensable gas (water vapor). The subroutine establishes whether the mixture is superheated or saturated and gives its density ($\rho_m$), temperature ($T$), and liquid mass fraction ($X_L$). The hydrogen mass fraction ($X_h$), mixture pressure ($P_m$), and mixture enthalpy ($I_m$) are input. Vapor components are assumed to be perfect gases; that is,

$$\rho_v = \frac{P_v}{R_v T} \quad \rho_h = \frac{P_h}{R_h T}$$

$$I_v = C_{pv} T \quad I_h = C_{ph} T$$

where subscripts $h$ and $v$ refer to hydrogen and water vapor, respectively. The liquid constituent is assumed to have the following properties:

$$o_L = 62.4 \quad \text{and} \quad I_L = I_v - HV,$$

where

- $HV$ = heat of vaporization
- $C_p$ = specific heat at constant pressure
- $R$ = gas constant.

If the mixture is saturated, $P_v$ is related to $T$ by the saturation equation of subroutines FSOFTS and/or TSOFP. Mixture properties are obtained from the following equations:
MARY E. GEALY

\[ \rho_m = \frac{1.0}{\frac{X_h}{\rho_h} + \frac{(1 - X_h - X_L)}{\rho_v} + \frac{X_L}{\rho_L}} \]

and

\[ I_m = X_h I_h + (1 - X_L) I_v - X_L (HV). \]

Restrictions—The restrictions are those that are imposed for perfect gases and incompressible liquids. The pressures must be well below the critical point. \( A \) is a doublet interpolation array of \( HV \) as a function of temperature \( T \). \( I_m \) must be a floating-point number.

Calling Sequence—STATE(X,P,I,\( X_L \),T,\( A(1:IC) \))

Subroutine PSOFTS

Purpose—This subroutine computes the saturation pressure of water vapor as a function of gas temperature. The relationship used is

\[ \log_{10} \frac{P_c}{P} = \frac{x}{T_s} \left( \frac{A + Bx + Cx^2}{1 + Dx} \right), \]

where \( x = T_c - T_s \), \( A \), \( B \), \( C \), and \( D \) are constants, and \( P_c \) and \( T_c \) are critical points.

Restrictions—The gas temperature should be between 10° and 150° C.

Calling Sequence—PSOFTS(TS,P)

Subroutine TSOFP

Purpose—This subroutine computes gas temperature as a function of the saturation pressure of water vapor, using the same relation as in PSOFTS.

Restrictions—The same restrictions apply to TSOFP as to PSOFTS.

Calling Sequence—TSOFP(P,TS)

Subroutine TRNPRT

Purpose—This subroutine calculates the transport properties of a two-component gas mixture.

Restrictions—Only a two-component gas mixture is allowed, and the component properties must have already been evaluated at the desired temperature.
**NRL REPORT 7656**

*Calling Sequence*—TRNPRT(V1,V2,G1,G2,C1,C2,V,G,C,P1)

where

VN is the viscosity of component N.
GN is the thermal conductivity of component N.
CN is the specific heat of component N.
P1 is the percent (by weight) of component 1.
V, G, and C are the viscosity, thermal conductivity, and specific heat of the mixture.

Subroutine CSGDMP or LSTPCS or QMAP

*Purpose*—These routines are designed to aid in the checkout of thermal problem data decks by listing the pseudo-compute sequence. CSGDMP calls upon Variables 1 and then prints out each relative diffusion node number with the capacitance and CSGMIN value of the node. For each node, all three routines identify the attached conductors by relative conductor number and type, and by the relative number of the adjoining node. CSGDMP also lists the conductance of the attached conductor and the type of the adjoining node. Either the SPCS or the LPCS option may be used. While the LPCS option allows every conductor attached to a node to be identified, the SPCS option identifies only conductors for the first relative node number on which they occur. After the diffusion nodes are processed, the connection information for the arithmetic nodes is listed. After listing the above information, control passes to the next sequentially listed subroutine.

QMAP has all the properties of CSGDMP. In addition, it prints the temperatures of each node and adjoining node, and the flux between them.

*Restrictions*—These routines are generally called from EXECTN. CSGDMP and QMAP should never be called from Variables 1.

*Calling Sequence*—CSGDMP or LSTPCS or QMAP

Subroutine TSAVE

*Purpose*—This subroutine generates an external plotting data output file (unit 24) that can be used with the external plotting option to plot nodal temperature vs time. TSAVE records each nodal temperature at TIMEN and also saves the actual node numbers.

*Restrictions*—This routine should not be called more than 2000 times.

*Calling Sequence*—TSAVE
MARY E. GEALY

Internal Subroutines

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These subroutines are called from other routines and not normally by the user.

ACKNOWLEDGMENTS

The author would like to thank Mr. Richard Perlut of the Mechanical Engineering Branch, Engineering Services Division, for his suggestions and technical assistance.
Appendix A

SAMPLE PROBLEM 1A

ORIGINAL RUN

A perfectly insulated one-dimensional bar has a constant heating rate applied to one end. Obtain the 10-min transient temperature response, at half-minute intervals, of the bar ends and at points 1/4, 1/2, and 3/4 of the way along the bar. The bar is initially at 80°F and receives a constant heating rate of 3.0 Btu/min. The length of the bar is 4 in., and it has a cross-sectional area of 1 sq. in. It has the following material properties:

density = 172.8 lb/ft³
specific heat = 0.35 Btu/lb°F
thermal conductivity = 0.2 Btu/in.-min.-°F

Figure A1a shows a schematic of the physical problem with the nodes appropriately placed and the dashed lines indicating the lumping of the system for capacitance purposes. The network representation is illustrated in Fig. A1b.

![Diagram](image)

(a) Parameter lumping

(b) One-dimensional network

Fig. A1—Representation of a perfectly insulated bar

Capacitors receive the same number as the temperatures but with a C prefix. From the above information, we immediately calculate

\[ C_2 = C_3 = C_4 = \rho V C_p = 0.035 \text{ Btu/°F} \]
\[ C_1 = C_5 = C_2/2.0 = 0.0175 \text{ Btu/°F} \]
\[ G_1 = G_2 = G_3 = G_4 = k A c/\ell = 0.2 \text{ Btu/min/°F}, \]
where $V = \ell \times A_c$; length times cross-sectional area.

Since this is not a RECALL run, the first data card should be blank.

To apply explicit forward differencing to this problem, we must utilize the CNFRWD execution subroutine which requires the short pseudo-compute sequence. Hence, the title block is as follows:

```
8
| BCD 3THERMAL SPCS
| BCD 9SAMPLE PROBLEM NO. 1A
| END
```

The nodal block is next and requires the node number, initial temperature, and capacitance of each node be listed.

```
8
| BCD 3NODE DATA
| 1, 80, .0175, 5, .0175
| GEN 2, 3, .035, 1, 1, 1
| END
```

The conductor block requires that each conductor number be listed with the node numbers at either end, and the conductor value.

```
8
| BCD 3CONDUCTOR DATA
| GEN 1, 4, 1, 1, 2, l, 1, 1
| END
```

The only control constants required for CNFRWD are as follows:

```
8
| BCD 3CONSTANTS DATA
| TIMEND, 10, OUTPUT, 5, CSGFAC, 2
| END
```

There are no array data and only one execution call; hence,
There are no second variables operations, but we must apply the heating rate in the first variables;

The following completes the data input.

Since PRNTMP lists the relative node numbers, and not the actual ones, the node dictionary will have to be consulted for conversion of relative to actual.

The above problem data deck processed by the CINDA program on the CDC-3800 as a standard run produces the output as given in the following printouts.

NOTE: The only alternative to the BCD 3END OF DATA card is a parameter change. A new job would require another set of control cards.
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EXTERNAL SYMBOLS
- QBENTRY
- QDPICT
- INPUT
- EXECTN

00126 SYMBOLS
SUBROUTINE EXECTN
COMMON /TITLE/ M
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KONST/ K
COMMON /ARRAY/ A
COMMON /FIXCON/ TIMEN, DTIMEU, TIMEO, CSGFAC

DIMENSION M(20)
COMMON /PRINT/ NT
COMMON /XSPACE/ NDIM, NTH, X
EQUIVALENCE (K(1),XK(1))
DIMENSION T(1), C(1), G(1), K(1), A(1), XK(1), X(1)
NDIM = 100
NTH = 0
CALL CSGDMP
CALL CNGMPD
RETURN
END
SUBROUTINE VARBL1
COMMON /TITLE/ H
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ Q
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KINST/ K
COMMON /ARRAY/ A
COMMON /IACON/ TIMEN, DTIMEU, TIMEND, DAMP, CSGFAC
INLOOP, OPEITH, OTIMEH, DAMPA
IDAMP, ATMPGA, HACRUP, TTIMEO, TTIME1
IDTMPCC, ATMPCC, CSGMIN, OUTPUT, ARLXCA
LDOPCT, DTIME1, DTIMEI, CSGMAX, CSGCAL
LCGRCL, OPLCRA, OPLACC, LINECT, PAGECT
LRLACC, LSPCS, ENGRA, RALENG, NOCOPY
NCROG, NOUTMP, NARLKC, NARMP, ITEST
JTEST, KTEST, LTEST, MTEST, RTEST
ITEST, TTEST, UTTEST, VTEST, LARFAC
L, IDCNT
COMMON /DIMENS/ NNT, NND, NNC, NNG, NNGC, NAMY, LSEQ, DUM, NUM2
DIMENSION H(20)
COMMON /PRINTS/ NT
COMMON /SPACES/ NDM, NTM, X
EQUIVALENCE (K(1), KK(1))
DIMENSION T(1), C(1), Q(1), G(1), X(1), A(1), X(1), X(1)
1, CSEQ(1), NT(1)
CALL STFSEP(1, X(1))
RETURN
END
SUBROUTINE VARHLZ
COMMON /TITLE/ M
COMMON /TEMP/ I
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KONST/ K
COMMON /ARRAY/ A
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1AMLAC, LSPCS, ENGBAL, BALEG, NOCOPY,
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COMMON /SOURCE/ Q
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COMMON /CONST/ K
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1.OAMPO, ATWPCA, BACKUP, TIME0, TIMEN,
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1.UTEST, UTEST, LTEST, MTET, VTETEST,
1.UTEST, UTEST, VTEST, LAXFAC,
1. IDENT
COMMON /DIMENS/ NNT, NN0+NMC+NHR, NNG+NCON+NARY+LSEQ+DUM1+NUN
DIMENSION H(20)
COMMON /PRNT/ NT
COMMON /SPACE/ NOIM, NTM, X
EQUIVALENCE (K(1),XK(1))
DIMENSION T(1), G(1), Q(1), K(1), A(l) ,XK(1),X(1)
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RETURN
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This node was reprocessed.
### Sample Problem 40.1A

**Chrysler Improved Numerical Differentiating Analyzer - CO0045**

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<td>18.54017+001</td>
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<th>DTIMEU</th>
<th>21.40625+003</th>
<th>CSGMIN(1)</th>
<th>1) 87.50000+003</th>
<th>DTMPCC(1)</th>
<th>1) 45.87055+002</th>
<th>ARLXCC(1)</th>
<th>0) 00.00000+000</th>
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</tbody>
</table>
SAMPLE PROBLEM NO.1A

TIME 50.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 20.683036+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       17.683036+001  19.375053+001  18.633036+001
       17.687053+001

TIME 55.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 21.754444+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       18.754444+001  20.441986+001  19.504444+001
       18.941986+001

TIME 60.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 22.825893+001
   1) 87.50000-003 DTMPCR  3) 45.87056-002 ARLXCC1
       19.825893+001  21.513939+001  26.575893+001
       20.013939+001

TIME 65.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 23.97321+001
   1) 87.50000-003 DTMPCR  3) 45.87056-002 ARLXCC1
       20.97321+001  22.654821+001  21.647321+001
       21.084821+001

TIME 70.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 24.968750+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       21.968750+001  23.656250+001  22.718750+001
       22.156250+001

TIME 75.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 26.040179+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       23.040179+001  24.727679+001  23.790179+001
       23.227679+001

TIME 80.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 27.111607+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       24.111607+001  25.799107+001  24.861607+001
       24.299107+001

TIME 85.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 28.183036+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       25.183036+001  26.870536+001  25.933036+001
       25.370536+001

TIME 90.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 29.254444+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       26.254444+001  27.941986+001  27.004444+001
       26.441986+001

TIME 95.00000-001 DTIMEU 21.40625-003 CSQMINI
   1 THRU 5 30.325893+001
   1) 87.50000-003 DTMPCR  1) 45.87056-002 ARLXCC1
       27.325893+001  29.013939+001  28.075893+001
       27.513939+001
CHRYSLER IMPROVED NUMERICAL DIFFERENCING ANALYZER - C00045

SAMPLE PROBLEM 40.1A

TIME 10.00000+000 DTIME 21.40625+003 CSSH14
1) 87.50000+000 DMPCC1 1) 45.08754+002 ARLXCC1 0) 00.00000+000
1 THRU 5 31.397321+001 28.397321+001 30.084821+001 29.147321+001 28.584821+001

END OF DATA
This is an example of a TSAVE run that was made after the problem had been satisfactorily debugged and run. Since that run had produced printed output, all calls to output subroutines were removed from the deck to save processing time. Hence, the Execution block is now:

```
1 7 21 25
↓ ↓ ↓ ↓
F DIMENSION X(100)
   BCD 3EXECUTION
F NDIM = 100
F NTH = 0
END
```

TSAVE is the only subroutine in Output Calls.

```
8 12
↓ ↓
BCD 3OUTPUT CALLS
   TSAVE
END
```

Since the time and temperature limits were determined from the output in the previous run, it is possible to supply the plotting data so that the plot program can be run immediately after the CINDA problem (in the same job). This eliminates the need for equipping the TSAVE output tape (tape 24). The plotting data are as follows:

```
1 12 22 32 42
↓ ↓ ↓ ↓
card 1 CINDA SAMPLE PROBLEM 1A
 card 2 0.00 10.00 0.00 320.00
 card 3 (blank)
EOF
```

The above plot data and revised problem data deck for problem 1A produce the following output and plots when processed on the CDC-3800 and plotted on the CalComp 565 plotter (the actual dimensions of the X and Y axes are 7 and 9 in., respectively). Plots of the data (Fig. A2a-e) follow the printouts.
<table>
<thead>
<tr>
<th>PROGRAM NAMES</th>
<th>ENTRY POINTS</th>
<th>LABELLED COMMON</th>
<th>NUMBERED COMMON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 77672 SEARCH 000105</td>
<td>0 77777 SENTRY</td>
<td>1 76566 CROBLK 01015</td>
<td>0 23042 2</td>
</tr>
<tr>
<td>1 74272 SKIP 00322</td>
<td>1 74214 GENLKNK</td>
<td>1 75654 GLOGIC 00003</td>
<td>17500</td>
</tr>
<tr>
<td>1 7147 PACKA3 02010</td>
<td>1 72717 CODERO</td>
<td>1 75642 PLOGIC</td>
<td>1 00001</td>
</tr>
<tr>
<td>1 70673 WRTSCPE 00036</td>
<td>1 71497 BIT</td>
<td>1 75137 DIMARY 00434</td>
<td>1 17500</td>
</tr>
<tr>
<td>1 62141 PREPRO 00605</td>
<td>1 62657 SPM</td>
<td>1 64257 REAL</td>
<td>1 17500</td>
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<tr>
<td>0 51677 ION.</td>
<td>0 51676 BLKRD</td>
<td>0 50624 RSP.</td>
<td>1 17500</td>
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<tr>
<td>0 57005 ENI.</td>
<td>0 54546 EFT.</td>
<td>0 53662 REAL</td>
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<tr>
<td>0 53667 RE.</td>
<td>0 52342 QBENTRY</td>
<td>0 52342 QBENTRY</td>
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<td>1 17501 3</td>
<td>1 17506 3</td>
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<td>1 75657 SUBLST 00116</td>
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<td>0 52342 QBENTRY</td>
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<tr>
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<td>1 74272 SUBLST</td>
<td>1 17501 3</td>
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</tr>
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<tr>
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<td>1 74272 SUBLST</td>
<td>1 17501 3</td>
<td>1 17506 3</td>
</tr>
</tbody>
</table>

**EXECUTION STARTED AT 1832 -20**
BCD 3THERMAL SPCS
BCD 3SAMPLE PROBLEM NO.1A
END
BCD 3NODE DATA
100 1075 580 0075
GEN 7 9 10 11 12
END

RELATIVE NODE NUMBERS
ACTUAL NODE NUMBERS
1 5 2 3 4

BCD 3CONDUCTOR DATA
GEN 1 2 3
END

RELATIVE CONDUCTOR NUMBERS
ACTUAL CONDUCTOR NUMBERS
1 2 3 4

BCD 3CONSTANTS DATA
TIMEND 10 OUTPUT 5 CSGFAC 2
END

BCD 3ARRAY DATA
END

DIMENSION XI 100
HCD NEXECUTION
NDIM 100
NTH 0
CNFRWU
END

BCD 3VARAIBLES 1
STFSEP (3,*.01)
END

BCD 3VARAIBLES 2
END

BCD 3OUTPUT CALLS
TSAVE
END
PROGRAM LINK0
COMMON /TITLE/ H
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ Q
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KONST/ K
COMMON /ARRAY/ A
COMMON /FIRCON/ TIMEN, DTIME, DTIMEU, TIMEND, CS0FAC,
INLOOP: DTIMEP, DTIMEP, DTIMEP, DTIMEP, DTIMEP, DTIMEP,
TIMEP, TIMEP, TIMEP, TIMEP, TIMEP, TIMEP,
1DTIMEP, ATMPCC, CSGM, OUTPUT, ARXCA,
JDTIMEP, ATMPCC, CSGM, OUTPUT, ARXCA,
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JDTIMEP, ATMPCC, CSGM, OUTPUT, ARXCA,
SUBROUTINE EXECTN
COMMON /TITLE/ M
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KONST/ A
COMMON /ARRAY/ A
COMMON /FIXCON/ TIMEN, DTIMEU, TIMEND, CSQFAc
1NLQPC, ONPCC, OPEIR, DTIMEE, DAMPA
10TMPC, ONPCC, OPEIR, DTIMEE, DAMPA
10TMPC, ONPCC, OPEIR, DTIMEE, DAMPA
1CSQGCL, DLXKC, DLXKC, LINDEX, PAGENT
1ASQCL, LSPCS, ENQAL, BALEN, NOCOPY
1MCSCG, MHTMPC, MARCH, MATHPC, MTEST
1MTEST, MTEST, MTEST, MTEST, LARFAC
1. I0CNY
COMMON /DIMNS/ NNT, NNO, NNC, NRG, NNG, NCON, NARY, LSEQ, DUM1, DUM2
DIMENSION M(20)
COMMON /PRINT/ NT
COMMON /XSPACE/ NDIM, NTH, X
EQUIVALENCE (K(I), X(I))
DIMENSION T(I), C(I), Q(I), G(I), K(I), D(I), X(I), X(I)
1. CSQGCL, NT(I)
NDIM = 100
NTH = 0
CALL CNFRWD
RETURN
END
SUBROUTINE VARRL1
COMMON /TITLE/ M
COMMON /TEMP/ T
COMMON /C&P/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSQ
COMMON /XMON/ K
COMMON /ARRAY/ A
COMMON /FIXCOM/ TIMEN, DTIMEU, TIMEND, CSQFAC,

IDNPO, ATNPCA, GPEIKA, GTIMEM, GAMPAA,
1LMTPOCA, ATNPCA, BACKUP, TIMED, TIMEM,
1.0TMCPC, ATMCPC, CSQMIN, OUTPUT, ARLXCA,
ILOOPCT, OTIMEL, DTIMEL, CSQMAX, CSQRAL,
1CSQRCL, DALXCA, DALXCC, LINECT, PABECT,
1ARLACC, LSPCS, ENGRAL, BALENC, NOCOPY,
1NC504, N0TMCPC, HARLC, N0TMCPC, ITEST,
1JTEST, KTEST, MTEST, NTEST, ATEST,
1TEST, VTEST, VTEST, UTEST, LARFAC,
1ICDT,

COMMON /DIMENS/ NMT+ANG+NNC+ANG+ANG+ANG+NARY+NARY+LSQ+DUM1+NUM2
DIMENSION M(20)
COMMON /PRMT/ NT
COMMON /ASPACE/, NDIM, NTH, L
EQUIVALENCE (K(1),XK(1))
DIMENSION T(1), C(1), D(1), G(1), H(1), M(1), A(1), DXK(1), X(1)
1, CSEQ(1), NT(1)
CALL S77SEP(3,0(1))
RETURN
END
SUBROUTINE VARRLZ
COMMON /TITLE/ M
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /KONST/ K
COMMON /ARRA/ A
COMMON /FIXCON/ TIMEN, OTIMEU, TIMEND, CSGFAC

ILOOP, DTHPCA, OPEITA, DT enumerated
IDMPA, ATMPCA, MACHUP, TIMED, DMPA
IDTHPC, ATMPCC, CSMPA, OUTPUT, AMRCA

ILOOPCA, DTMEI, CSMPA, CSMAX, CSRGL
ICSRLCA, DMLRCA, DMRCC, LINECT, PAGECT

LATRCC, LSPCS, ENROAL, BALENG, NOCOPY
INCSPM, NTHPCA, NARFCL, NTMPCL, ITST
JTEST, KTEST, LTEST, MTST, ATST

JTEST, JTEST, UTEST, VTEST, LARFAC

COMMON /DIMENS/ NNT, NNO, NNAG, NNCG, NCON, NARY, LSEQ, DUX, NUX
DIMENSION H(20)
COMMON /PRINT/ NT
COMMON /SPACE/ NDIH, NTM, X
EQUVALENCE (K(1), XK(1))
DIMENSION T(1), C(1), G(1), K(1), A(1), BK(1), XK(1)

RETURN
END
Fig. A2—Time vs temperature profiles for CINDA Sample Problem 1A. Plots are shown in the order in which they are plotted. Time and temperature numbers will be in the E format, rather than in the F format as shown.
Fig. A2 (Cont'd)—Time vs temperature profiles for CINDA Sample Problem 1A. Plots are shown in the order in which they are plotted. Time and temperature numbers will be in the E format, rather than in the F format as shown.
Fig. A2 (Cont'd)—Time vs temperature profiles for CINDA Sample Problem 1A. Plots are shown in the order in which they are plotted. Time and temperature numbers will be in the E format, rather than in the F format as shown.
Appendix B

SAMPLE PROBLEM 1B

ORIGINAL RUN

Sample problem 1A was linear and can be rigorously solved by means of the Laplace transform. However, the introduction of nonlinearities makes rigorous solutions virtually impossible and makes the use of finite difference techniques mandatory. To demonstrate, apply the following nonlinearities to sample problem 1A and obtain the solution.

1. Both ends of the bar are uninsulated and allowed to radiate to absolute zero. The Stephan-Boltzmann constant is \( \sigma = 1.991 \times 10^{-13} \text{ Btu/min-in.}^2 \text{R}^{-4} \), and the emissivity varies linearly with temperature as follows:
   \[
   \begin{align*}
   \epsilon &= 0.4 \text{ at } -100^\circ F \\
   \epsilon &= 0.8 \text{ at } 300^\circ F.
   \end{align*}
   \]

2. The thermal conductivity of the bar varies with temperature as follows:
   \[
   \begin{align*}
   k &= 0.15 \text{ at } -100^\circ F \ (\text{Btu/in.-min.}^\circ F) \\
   k &= 0.25 \text{ at } 100^\circ F \\
   k &= 0.40 \text{ at } 200^\circ F \\
   k &= 0.60 \text{ at } 300^\circ F.
   \end{align*}
   \]

3. The density remains unchanged but the specific heat varies with temperature as follows:
   \[
   \begin{align*}
   C_p &= 0.3 \text{ at } -100^\circ F \ (\text{Btu/lb-}^\circ F) \\
   &= 0.39 \text{ at } 100^\circ F \\
   &= 0.49 \text{ at } 200^\circ F \\
   &= 0.65 \text{ at } 300^\circ F.
   \end{align*}
   \]

4. The heating rate is a function of time as follows:
   \[
   \begin{align*}
   q &= 3.0 \text{ at } 0 \text{ min (Btu/min)} \\
   q &= 4.0 \text{ at } 3 \text{ min} \\
   q &= 4.0 \text{ at } 7 \text{ min} \\
   q &= 3.0 \text{ at } 10 \text{ min}.
   \end{align*}
   \]

In addition, obtain the rate of heat loss and the integral of the radiation transfer from the unheated end of the bar. The network representation of this problem (shown in Fig. B1) differs only slightly from problem 1A. Now however, the capacitances are a function of temperature. We therefore require multiplying factors such that
Fig. B1—Network of a nonlinear bar

\[ C = \rho V C_p(T), \quad MF = \rho V \]
\[ MF = 0.1 \text{ for capacitors 2, 3, and 4} \]
\[ MF = 0.05 \text{ for capacitors 1 and 5.} \]

The conductors are now

\[ G = k(T_m)A_c/\ell, \quad MF = A_c/\ell, \text{ where } T_m \text{ is the mean of the end } T\text{'s.} \]
\[ MF = 1.0 \text{ for conductors 1, 2, 3, and 4.} \]

A radiation conductor requires the input value \( \sigma e FA \); however, \( FA = 1.0 \), hence

\[ \text{Grad} = \sigma e(T) \]
\[ MF = 1.991 \text{ Btu/min}^\circ \text{F}. \]

Also,

\[ q = q(T). \]

The capacitors and conductors will be specified with CGS and CGD calls.

A. Original Run

Since this is not a RECALL problem, the first card of the problem data deck will be blank. The rest of the deck may be constructed as follows:
NRL REPORT 7656

BCD 3THERMAL SPCS
BCD 9SAMPLE PROBLEM 1B
END

BCD 3NODE DATA
CGS 1,80.,A3,.05,2,60.,A3,.1,3,80.,A3,.1
CGS 4,80.,A3,.1,5,80.,A3,.05
-10,-460.,0
END

BCD 3CONDUCTOR DATA
CGS 1,1,2,A2,1.,2,2,3,A2,1.,3,3,4,A2,1.,4,4,5,A2,1.
CGS -11,1,10,A1,-1.991E-13,-12,5,10,A1,-1.991E-13
END

BCD 3CONSTANTS DATA
TIMEND,10.,OUTPUT,.5,CSGFAC,2.,4,0,5,0,6,STOR1,7,STOR2

END

BCD 3ARRAY DATA
1,-100.,4,300.,.0,8,END $ EPSILON VS T
2,-100.,15,100.,.25,200.,.4,300.,.6,END $ K VS T
3,-100.,3,100.,.39,200.,.49,300.,.65,END $ CP VS T
4,0.,3.,3.,4.,7.,4.,10.,3.,END $ 0 VS TIME
-5,QRATE,QTOTAL,END $ A LABEL ARRAY

END

F D I M E N S I O N  X ( 1 0 0 )

BCD 3EXECUTION
F NDIM = 100
F NTH = 0
STOREP (K6)
CNF + W
F IDCT = IDCT + 1
STOREP(K7)

END

BCD 3VARIABLES 1
D1DEG1(TIME,M,A4,01) $ APPLY HEATING RATE

END

BCD 3VARIABLES 2
RHEATST10,T5,G12,K4) $ SORTEAIN HEAT FLOW RATE
QINTEG(K4,DTIMEU,K5) $ INTEGRATE SAME

END

BCD 3OUTPUT CALLS
PRINT
PRINTL (A5,K4,K5)

END

BCD 3END OF DATA

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MARY E. GEALY

This problem will be stored twice on tape 22. The original data will be stored under the I.D. name, STØR1, and the number, 0 (IDCNT). The final values will be identified as STØR2, 1 because IDCNT was incremented. (It actually would not have been necessary to use IDCNT in this case, since neither call to STØREP was in a loop. The second call could have been uniquely identified as STØR2,0.) The binary constructed subroutines (processor) will be stored on tape 40. See Section VII for the proper deck setup and job request form.

The above problem data deck processed by the CDC-3800 version of CINDA produces output given in the following pages (original run).
SUBROUTINE EXECUTN
COMMON /TITLE/ H
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSEQ
COMMON /CONST/ K
COMMON /ARRAY/ A
COMMON /FIXCON/ TIMEN*, OTIMEU*, TIMEND*, CSOFAC*
INLOOP = THIPCA* OPRTA* TIMEN* DAMPA*
IDAMP = ATIPC* BACKUP* TIME0* TIMEN*
IDTPCC = ATIPC* CSMIN* OUTPUT* ARLCRA*
LOOPI. = TIMEL* OTIME* CSMAX* CSSPAN*
LCSGRL* ORLCA* ORLACL- LINC* PAGEXT*
JARLCC = LSPCS* ENSBAL* BALENG* NDOPY*
JNCSGH = NOTPCC* NARLAC* NATHPC* JTEST*
JTEST = XTEST* UTTEST* VTEST* ATEST*
JTEST = XTEST* UTTEST* VTEST* LARFAC
1 = IDCNT
COMMON /DIMENS/ NNT,NND,NNG,NGT,NCF,NARY+LSEQ+DOM1,NUM2
DIMENSION M(20)
COMMON /PRINT/ NT
COMMON /KSPACE/ NDIM*, NTH*, X
EQUIVALENCE (K(1)*XK(1))
DIMENSION T(1), C(1), G(1), K(1), A(1), S(XK(1),X(1))
NDIM = 100
NTH = 0
CALL STOREP(K(3))
CALL CMFPHD
IDCNT = IDCNT + 1
CALL STOREP(K(4))
RETURN
END
SUBROUTINE VARBL1
COMMON /TITLE/ N
COMMON /TEMP/ T
COMMON /CAP/ C
COMMON /SOURCE/ G
COMMON /COND/ G
COMMON /PCS/ CSQ
COMMON /KONST/ K
COMMON /ARRAY/ A
COMMON /FIXAC/ TIMEN, OTIMEU, TIMEND, CSOFAC
INLOOP = DTMPCA, OPEITN, DTIMEN, DAMPA
IAMP = ATMPCA, BACKUP, TIMED, TIMEN
IAPTPC = ATMPCA, CSOIMX, OUTPUT, ARLRCA
ICSRICL = ORLRCA, ORLRCC, LINC, PAEGCT
ICLRACC = LSRPC, ENOALC, BALENG, NOCOPY
INCSOH = NORTPC, MARLAC, NAPPLEC, ITST
ITEST = KTEST, LTEST, MTEST, RTEST
ITEST = OTEST, UTTest, VTEST, LARFAC
I, ICNT
COMMON /DIMENS/ NMT, NAD, NN, NRG, NNG, NCON, NARY, LSEG, DU1, NUN, Z
DIMENSION H(20)
COMMON /PRMT/ NT
COMMON /XSPACE/ MDIM, NMT, X
EQUIVALENCE (K(1),XX(1)), (G(1), K(1)), (A(1), XX(1), X(1))
CALL VARS1M(T(1), C(1), A(15), 9, 3)
CALL VARS1M(T(2), C(2), A(15), 9, 3)
CALL VARS1M(T(3), C(3), A(15), 9, 3)
CALL VARS1M(T(4), C(4), A(15), 9, 3)
CALL VARS1M(T(5), C(5), A(15), 9, 3)
CALL VARS1M(T(6), T(2), A(6), 1, 3)
CALL VARS1M(T(7), T(3), A(6), 1, 3)
CALL VARS1M(T(8), T(4), A(6), 1, 3)
CALL VARS1M(T(9), T(5), A(6), 1, 3)
CALL VARS1M(T(10), T(6), A(1), 1, 99E=13)
CALL VARS1M(T(11), T(6), A(1), 1, 99E=13)
CALL ODEQ1(TIMEN, A(2), 0(1))
RETURN
END
SUBROUTINE DUTCAL

COMMON /TITLE/ T
COMMON /CPL/ C
COMMON /SPU/ G
COMMON /CPLP/ G
COMMON /PSGS/ CSEQ
COMMON /DLST/ X
COMMON /ARRAY/ A
COMMON /FSIZE/ TIME: TIMEX: TIMEX: CSGFAC:

INLOOP: INWPCA: OPLTA: DTIME1: DTIME1: DAPA:
lo\p: hWPCA: ABAC: TME: TME:
lo\psec: hWPCA: CSN:
INLOOPC: OPLTA: DTIME1: CSGMAX: CSGFAC:
ICSPC: ORPCA: ORPCA: ORPCA: DTIM:
ALPCA: LSPCS: ENSP:
INCSG: NDTHPC: NLAPC: NLAPC: ITST:
ISTST: KST: LST: MTEST: ATEST:

IDNT: IDNT:
COMMON /DIME: NTNK: NTNK: NTNK:
DIMENSION H2(N2)
COMMON /PRNT/ NT
COMMON /SPACE/ HOM: HOM:

EQUIVALENCE (k1),x(k1)
DIMENSION T(1), L(1), G(1), G(1), R(1), A(1), X(1), X(1)

CALL PRNT
CALL PRINT((A(1),K1),X(1))
RETURN
END
SAMPLE PROBLEM 18

1) 70.36890 = 003 DTMPCC(1) 00.00000 = 000 ARLXCC(0) 00.00000 = 000
   3 = 00.00000 = 000 T 4 = 00.00000 = 000 T 5 = 00.00000 = 000 T 10 = 00.00000 = 001

2) 78.25181 = 003 DTMPCC(1) 68.11626 = 002 ARLXCC(0) 00.00000 = 000
   3 = 87.61895 = 000 T 4 = 93.87777 = 000 T 5 = 02.00624 = 000 T 10 = 00.00000 = 001

3) 97.99293 = 000 T 4 = 93.20244 = 000 T 5 = 91.58636 = 000 T 10 = 00.00000 = 001

4) 73.72196 = 003 DTMPCC(4) 38.60775 = 002 ARLXCC(0) 00.00000 = 000
   3 = 10.87716 = 001 T 4 = 10.37800 = 001 T 5 = 10.20570 = 001 T 10 = 00.00000 = 001

5) 71.49888 = 003 DTMPCC(5) 56.04585 = 002 ARLXCC(0) 00.00000 = 000
   3 = 11.97555 = 001 T 4 = 11.47887 = 001 T 5 = 11.30795 = 001 T 10 = 00.00000 = 001

6) 69.46924 = 003 DTMPCC(5) 72.10139 = 002 ARLXCC(0) 00.00000 = 000
   3 = 13.30902 = 001 T 4 = 12.60268 = 001 T 5 = 12.43351 = 001 T 10 = 00.00000 = 001

7) 14.7555 = 003 DTMPCC(7) 29.11089 = 003 ARLXCC(0) 00.00000 = 000
   3 = 12.43351 = 001 T 4 = 12.60268 = 001 T 5 = 12.43351 = 001 T 10 = 00.00000 = 001
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CHRYSLER IMPROVED NUMERICAL DIFFERENCING ANALYZER - CO0045  
(NRL EDITED)  

SIXTH PROBLEM 1B  

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<td>24.71160-001</td>
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</table>
CHRYSLER IMPROVED NUMERICAL DIFFERENCING ANALYZER - COD945

SAMPLE PROBLEM 18

TIME 40.00000=001 DTIMEU 22.28256+003 CSQMIN:

1) 56.15228=003 DTMPCG 5) 32.508615+002 ARLXCC:

T 1= 26.76715+001 T 2= 26.21810+001 T 3= 25.81131+001 T 4= 25.55891+001 T 5= 25.46874+001 T 10= 40.00000+001

GRATE 39.18499+003 QTOTAL 19.91642=002

TIME 95.00000+000 DTIMEU 23.95381+003 CSQMIN:

2) 55.76676+003 DTMPCG 5) 32.59281+002 ARLXCC:

T 1= 27.37665+001 T 2= 26.86785+001 T 3= 26.49106+001 T 4= 26.25722+001 T 5= 26.17326+001 T 10= 44.00000+001

GRATE 41.13322+003 QTOTAL 21.92705=002

TIME 10.00000+000 DTIMEU 25.43501+003 CSQMIN:

3) 55.42083+003 DTMPCG 5) 32.16639+002 ARLXCC:

T 1= 27.94356+001 T 2= 27.47203+001 T 3= 27.12314+001 T 4= 26.90650+001 T 5= 26.82824+001 T 10= 46.00000+001

GRATE 43.01397+003 QTOTAL 24.03348+002

END OF DATA
The stored original problem of sample 1B is used to illustrate the RECALL option. The initial data will be taken and given a new TIMEND of 5.0 min, as well as a negative heating rate.

The first card in the problem data deck is

```
1  13  22
1  1  1
RECALL STOR1 0
```

The title block is changed to

```
8
BCD 3INITIAL PARAMETERS
BCD 3SAMPLE PROBLEM 1B---RECALL
END
```

Since there are no temperature or conductor data changes, the nodal and conductor blocks are blank.

```
8
BCD 3NODE DATA
END
BCD 3CONDUCTOR DATA
END
```

The change in TIMEND produces the following constants block:

```
8
BCD 3CONSTANTS DATA
    TIMEND, 5.0
END
```

Array 4 is changed to induce a negative heating rate.

```
8
BCD 3ARRAY DATA
    4, 0, -3, 3, -4, 7, 4, 10, -3, 9, 0 VS TIME
END
```

Since no operations block changes are allowed in parameter runs, the data deck is terminated by

```
8
BCD 3END OF DATA
```
The binary program tape (processor) was stored during the original run, so recompilation of the constructed subroutines is not necessary. Since the STOREP calls are still in the processor, the original and final data of this RECALL problem are stored on drum unit 22. The unit was not equipped in this example, however. See Section VII for the correct deck setup.

The processed problem printouts of the second run follow.
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<th>3 = 80.00000+000</th>
<th>T</th>
<th>6 = 80.00000+000</th>
<th>T</th>
<th>5 = 80.00000+000</th>
<th>T</th>
<th>10 = 6.00000+001</th>
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<td>1 = 53.68590+000</td>
<td>2 = 65.16701+000</td>
<td>3 = 72.30302+000</td>
<td>T</td>
<td>4 = 76.05116+000</td>
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<td>5 = 77.17596+000</td>
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CHRYSLER IMPROVED NUMERICAL DIFFERENCING ANALYZER - 600045 (NRL EDITED)

SAMPLE 1B - RECALL

| TIME 30.000000-001 DTIMEU 31.5876003 CGSMIN1 | 5) 84.365280-003 DTNPCB1 | 1) 10.33833-001 ARLXCC1 | 0) 00.00000+000 |
| T | 1=18.11003=000 T | Z=41.82308=002 T | 3=11.51046+000 T | T = 18.40611+000 T | 5= 26.64749+000 T | 10=46.00000+001 |
| RATE | 55.01477+004 QTOTAL | 23.70579=003 |

| TIME 35.000000-001 DTIMEU 28.27367-003 CGSMIN | 5) 65.71831-003 DTNPCB1 | 1) 89.41939-002 ARLXCC1 | 0) 00.00000+000 |
| T | 1=33.9862=000 T | Z=15.68103+000 T | 3=28.20476+001 T | T = 45.84702+001 T | 5= 88.93648+001 T | 10=46.00000+001 |
| RATE | 48.03297+004 QTOTAL | 26.27884+003 |

| TIME 40.000000-001 DTIMEU 44.59518-003 CGSMIN1 | 5) 87.21536-003 DTNPCB1 | 1) 79.26287+002 ARLXCC1 | 0) 00.00000+000 |
| T | 1=49.93476+000 T | Z=30.59536+000 T | 3=17.44109+000 T | T = 98.14308+001 T | 5= 73.24506+001 T | 10=46.00000+001 |
| RATE | 41.24798-004 QTOTAL | 28.69637-003 |

| TIME 45.000000-001 DTIMEU 41.56380-003 CGSMIN1 | 5) 68.78902-003 DTNPCB1 | 1) 13.73111-001 ARLXCC1 | 0) 00.00000+000 |
| T | 1=66.25569+000 T | Z=46.03567+000 T | 3=32.33825+000 T | T = 24.41424+000 T | 5= 21.82787+000 T | 10=46.00000+001 |
| RATE | 35.18335-004 QTOTAL | 30.39969+003 |

| TIME 50.000000-001 DTIMEU 37.54882+003 CGSMIN1 | 5) 90.59414-003 DTNPCB1 | 1) 12.76855+001 ARLXCC1 | 0) 00.00000+000 |
| T | 1=83.02761+000 T | Z=61.70634+000 T | 3=47.52776+000 T | T = 39.28323+000 T | 5= 36.59361+000 T | 10=46.00000+001 |
| RATE | 29.72409-004 QTOTAL | 31.99057+003 |

END OF DATA
TSAVE AND PLOT RUN

This run and the plots are similar to the TSAVE run of sample 1A. The following data were used.

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| CINDA SAMPLE PROBLEM 1B | 0.00 | 10.00 | 80.00 | 280.00 |
| CINDA SAMPLE PROBLEM 1B | * 10* | 0.00 | 10.00 | -470.00 | -450.00 |

The printed output from the plot run are as follows.

CINDA SAMPLE PROBLEM 18

X-AXIS LIMITS -- 0.00*000; 1.00*000

Y-AXIS LIMITS -- 8.00*001; 2*80*002

ALL NODES BUT THE FOLLOWING WILL BE PLOTTED ---

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CINDA SAMPLE PROBLEM 18

X-AXIS LIMITS -- 0.00*000; 1.00*000

Y-AXIS LIMITS -- -4.70*002; -450.000

THE FOLLOWING NODES WILL BE PLOTTED ---

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The plots are given in Fig. B2.
Fig. B2—Time vs temperature plots for CINDA Sample Problem 1B. Plots are shown in the order in which they are plotted. Time and temperature values will be in the E format, rather than in the F format as shown.
Fig. B2 (Cont'd)—Time vs temperature plots for CINDA Sample Problem 1B. Plots are shown in the order in which they are plotted. Time and temperature values will be in the E format, rather than in the F format as shown.
Fig. B2 (Cont'd)—Time vs temperature plots for CINDA Sample Problem 1B. Plots are shown in the order in which they are plotted. Time and temperature values will be in the $E$ format, rather than in the $F$ format as shown.