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A COMPUTER PROGRAM TO MODEL THE DYNAMIC THERMAL BEHAVIOR OF A NUCLEAR WARHEAD SECTION ADAPTATION KIT IN AN ACCIDENTAL FIRE ENVIRONMENT

FRED A. MULLER

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A Computer Program to Model the Dynamic Thermal Behavior of a Nuclear Warhead Section Adaption Kit in an Accidental Fire Environment

Fred A. Muller

Nuclear Development & Engineering Directorate
Picatinny Arsenal, Dover, NJ

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A method for modeling the thermal behavior of a warhead section adaption kit in an accidental fire environment has been described in detail. A Control Data Corporation Model 6600 computer operating under SCOPE version 3.4.2 and utilizing the dynamic simulator called CSSL-3 is used. The model permits study of the temperature versus time of a few points within a three-dimensional system. The effects of radiation, conduction and convection are included, as well as changes in heat paths due to melting of some parts. 

**Key Words**: Computer modeling, Multiple (78) simultaneous differential equations, Computer simulation, Accidental fire, Three-D thermal analysis, CSSL-3, Adaption kit modeling.
TABLE OF CONTENTS

Introduction .......................................................... 1

Modeling Method ....................................................... 1

Mathematical Approach .............................................. 4

1. General .............................................................. 4
2. Terminology ......................................................... 4
3. Conduction ........................................................... 5
4. Radiation ............................................................. 6
5. Convection ........................................................... 7

System Simulator ....................................................... 7

1. General .............................................................. 7
2. Tabular Functions .................................................. 8
3. Macros ................................................................. 9
4. Procedurals .......................................................... 9
5. Data Inputted ....................................................... 10
6. Fitting the Model to Heat Test Results ....................... 11
7. Computer Program ............................................... 13

Using the Model ...................................................... 13

References ............................................................ 16

Appendix ............................................................... 37

Distribution List ...................................................... 59

Table

1 Designations of test thermocouples (TC) and computer model temperatures (T) 17
Figures

1. Cover 18
2. Base 19
3. Deck 20
4. Conductivity model 21
5. Deck plate thermal fit 22
6. Computer model T50 and test thermocouple TC 25 23
7. Computer model T52 and test thermocouple TC 24 24
8. Computer model T56 and test thermocouple TC 22 25
9. Computer model T19 and test thermocouple TC 27 26
10. Computer model T45 and test thermocouple TC 12 27
11. Computer model T58 and test thermocouple TC 15 28
12. Computer model T90 and test thermocouple TC 21 29
13. Computer model T07 and test thermocouple TC 26 30
14. Computer model heat source at 1800°F 31
15. Computer model heat source at 1450°F 32
16. Computer model heat source at 1800°F (to top only) 33
17. Computer model heat source at 5500°F 34
18. Heat paths to element 45 35
INTRODUCTION

Picatinny Arsenal Technical Report #4831 entitled "Dynamic Thermal Modeling of the Behavior of a Nuclear Warhead Section Adaption Kit in an Accidental Fire Environment" treated the problem of a safety analysis based on dynamic thermal modeling. The purpose of this report is to provide potential users with a description of the thermal modeling method itself and the details of the computer programming method developed.

It was pointed out in Picatinny Arsenal Technical Report #4831 that unknown effective emissivities and convective film coefficients would be determined empirically by performing one or a few simulated fire tests run under closely controlled conditions, and then fitting the model temperatures versus time to the test thermocouple results.

The general lumped-constant (lumped-parameter) method for solving complex dynamic engineering problems is well known (Reference 1). The method of analysis developed here for the thermal behavior of a warhead section adaption kit is of this type.

MODELING METHOD

The specific device which was modeled is the Spartan Warhead Section Adaption Kit. It is comprised of some 26 different types of mechanical parts and electrical components. It is three-dimensional, involving several different materials, complex geometric shapes, and multipath heat flow patterns. Time is an essential part of the problem so the model must be a dynamic one.

The first step in the lumped-constant method is to divide the device to be modeled into a number of pieces called elements. The temperature of each element is the temperature of a single point within the element. In the model, there are no temperatures other than that of each of the elements. Heat is transferred from one element to another by conduction, radiation and/or convection. The model is a network made of the elemental points with heat paths between some pairs of points. The temperature of an element rises at a rate which depends on the net heat flow to that element and its heat capacity. All of the heat capacity associated with an element is assumed to be concentrated at the elemental point.

The simulation modeled here is based on a mental image of a possible accident scenario. If, before attaching the first stage to a Spartan missile, an organic fuel fire were to start, the Warhead Section
Adaption Kit cover could be exposed to the flames but its base, being mounted against the warhead, would not. Under worst case conditions such a fire is considered equivalent to exposure of the cover to an 1850°F black body source of heat. Average organic fire conditions would correspond to about 1450°F.

In this situation the cover will quickly heat up and radiate heat to components inside. There will also be conduction to the base and through the upright brackets to the deck. Convection will also convey heat from the cover to cooler surfaces inside. Dense smoke will be generated when plastic insulation and paint overheats and this may affect heat flow. It is expected that some of the aluminum and magnesium parts may melt since their melting points are well below the heat source temperature. If the exposed part of the deck melts, a new radiation path is created through the hole to the base below. Each of the effects described above was accounted for in the model.

The Spartan Warhead Section Adaption Kit was divided into 74 elements. (The number of elements chosen is arbitrary, but a large number becomes unwieldy whereas a small number may not include enough detail to accurately distinguish temperatures between the crucial points. The number of elements is limited by the number of representation statements required, which cannot exceed 685. The program described here has about 600.) The way in which the division was done was dictated by the results desired. In the case treated here, the temperature versus time was required for eight critical points in order to study several “thermal races”.

In a region where two such points are close together, the division has been made fairly fine while other regions are coarsely sectioned. The propellant activated battery has two critical points, a gas generator which turns it on, and a thermal release connector which disconnects it electrically from the rest of the circuit. (Actually, there are two gas generators and two thermal release connectors, but attention is concentrated on the set which is known to be most critical.) Because of the importance of the thermal race between these two points and the geometry in this region, the battery has been divided into 27 elements.

Elements are identified by a two digit number. Elements of the base plate are numbered 01 to 45, of the deck plate 50 to 64, uprights (which support the deck plate on the base plate) 80 to 89. The warhead thermal release connector 90 and the cover 97 to 99. The shroud which was used as a heat source surrounding the whole adaption kit is called element SH.
In the computer program to be described TC22 is a variable name, the value of which at any given time is the temperature of thermocouple number 22. Similarly, T56 is a variable name the value of which is the temperature of element number 56. All other thermocouples and elements have corresponding variable names.

Figures 1, 2 and 3 show in outline the important parts of the Spartan Warhead Section Adaption Kit which have been modeled. Figure 1 is a side view of a section through the center of the adaption kit. The cover and its three elements can be seen. Element 99 is the part of the cover below the flange. Element 98 is that part of the cover above the flange to the level of the deck plate. Element 97 is the rest of the cover. Elements 98 and 99, instead of representing a point within the cover, are represented by a line going around the cylinder halfway between the top and bottom of that part of the cover. Figure 1 also shows the base plate at the bottom and the deck plate part way between it and the top of the cover.

Figure 2 is a plan view of the base plate with its major components. The base plate is divided into 12 elements numbered as shown (01 through 12).

The battery (element numbers 19-45) occupies the major part of the lower half of the figure and a Burst Delay Timer (element numbers 13-18) the upper part. The prefixes to the element numbers (used only on the diagram) designate:

- T - Top
- B - Bottom
- U - Upper
- L - Lower
- M - Match (Propellant Element)
- S - Side

The elements 80 through 89 are the upright supports for the deck plate. The outer supports (80-86) are fastened to the cover with screws. Element 90 is the warhead connector.

Figure 3 is a plan view of the deck plate. Mounted on it are the IC Box and two arm-safe devices (ASD's). Element 56 is ASD Nr. 1 and corresponds to thermocouple TC22 as shown in Figure 3. The correspondence between other elements and thermocouple numbers in the heat test is given in the table on page 17.
MATHEMATICAL APPROACH

1. General.

The dynamic simulation implemented here is represented by 74 simultaneous differential equations:

\[ \frac{dT_n}{dt} = 10^{-9} \frac{Q_n F_n}{V_n} \text{°F/second} \quad (1) \]

in which:

\[ T_n = \text{temperature of n'th element in °F} \]
\[ t = \text{time in seconds} \]
\[ Q_n = \text{heat flux toward n'th element in erg/sec} \]
\[ V_n = \text{volume of n'th element in cubic inches} \]
\[ F_n = \frac{2.63}{C_n D_n} \]
\[ C_n = \text{specific heat of n'th element in Cal/g/°C} \]
\[ D_n = \text{density of n'th element in g/cc} \]

Each \( Q_n \) is the sum of several terms which represent the heat flux toward element \( n \) from each other element. These heat flux terms are of three types:

- conduction \( QC = f_1 (T_1 - T_n) \)
- radiation \( QR = f_2 (T_1^4 - T_n^4) \)
- convection (similar to conduction)

The conduction terms involve elements in contact. There is one such term for each pair of elements in contact.

Radiation terms involve elements between which there is a direct path for radiation. The only significant ones involve one very hot element and appreciable areas facing one another. Since these criteria also apply to convection, the same element pairs are used for both.

2. Terminology.

The rate of heat flow (in erg/sec) is designated \( Q \) in this report. This heat flux from element 01 to element 02, when it results from conduction, is called \( QC_{0102} \). For radiation from 99 to 01, the flux
is QR9901. The total flux toward an element 01 is called QO1. It is the algebraic sum of all terms which involve that element. For example:

\[
QO1 = QR9901 - QC0102
\]  

(2)

The second term is negative because the order of the element numbers indicates heat flow away from 01. (Eq. (2), which illustrates the terminology, is incomplete. The actual expression includes 12 more conduction terms and two more radiation terms. The complete equation is given in the Appendix.)

There is one such equation for each element of the model.

3. Conduction - (Ref 2).

Elements in contact have heat conduction terms between them (See Figure 4). The heat flux expression is of the form:

\[
QC0102 = KC*(T01-T02)/R \quad \text{(See Note below)} \quad (3)
\]

where R is the thermal resistance and KC is a constant for unit conversion (1.411 here). The resistance R in (3) is the sum of three terms, that within element 01 to the boundary, the contact resistance and that within 02 from the boundary to the elemental point. This can be expressed as:

\[
R = D01B/(K01*A01) + D02B/(K02*A02) + R0102C \quad (4)
\]

D01B = Distance heat must travel within element 01 to the boundary within element 01 in inches
A01 = Cross-sectional area for heat flow in element 01 (Sq inches)
K01 = Thermal conductivity of element 01 (erg/cm-sec-deg C)
D02B, A02, K02 similarly
R0102C = Contact resistance

NOTE: Equations in this text and in the computer program are written in the format of Fortran in which:
* signifies multiplication
/ signifies division
** signifies exponentiation
parentheses (multi-nested, if necessary) are used to resolve ambiguities.

3.48E-5 stands for 3.48 x 10^{-5}
In cases where the two elements are part of the same material, or welded together, the contact resistance is assumed to be zero. The distance within element 01 is the distance from the defined point to the boundary with 02. The cross-sectional area for conduction is an estimated average area between the point and the boundary. For an element which is a rectangular parallelepiped, it is the full cross-sectional normal to the direction of heat flow. This is justified on the basis that the conductive heat flow is not toward the point but rather is practically one dimensional. The temperature gradient is nearly uniform for the whole region. Since all the heat conduction paths (except the three to the battery explosive actuator) are metallic, it becomes evident when analyzing the actual test data that all of the gradients are quite small so the linear approximation is believed to be reasonable.

If we substitute (4) into (3) and use width times thickness for cross-sectional area, we get:

\[
Q_{C01O2} = 1.411 \times \frac{(T_{01} - T_{02})}{(D_{01}/(K_{01} \times W_{01} \times T_{01}) + D_{02}/(K_{02} \times W_{02} \times T_{02}) + R_{0102c})}
\]

which is another of the basic equations used in the computer program. There is one such equation for each pair of elements in contact.

4. Radiation - (Ref 3 and 4).

In the terms we are using in this analysis, radiative heat flow is of the form:

\[
Q_{R9901} = K_R \times ((T_{99} + 459.7)^2 - (T_{01} + 459.7)^2) \times G \times A_{01} \times V_{9901}
\]

\[
K_R = \text{Stefan-Boltzmann constant and a factor for units (3.48E-5 Here)}
\]

\[
A_{01} = \text{Area of element 01 in square inches}
\]

\[
V_{9901} = \text{Effective view factor}
\]

\[
G = \frac{1}{1/(E_{01} + 1/E_{99} - 1)} \quad \text{(See Ref 4, P74, Eq. (4.7))}
\]

\[
E_{01} \text{ and } E_{99} \text{ are effective emissivities and both elements are assumed to be gray bodies.}
\]

G has a value between zero and one. It is like a composite emissivity. (Ref 3, P76, Eq at bottom of page is similar. In this case one body is a total enclosure so its emissivity is 1 in which case (7) reduces to G = E).
V9901 is the view factor or configuration factor. It has a value between 0 and 1 which represents the fraction of element 99 which is "seen" by 01 and vice versa.

Equation (7) assumes the absorptivity is equal to the emissivity and all reflection is diffuse. It takes into account radiation, absorption, reflection and reradiation.

Because of the fourth power of absolute temperatures, it is evident that the magnitude of radiative heat flux is very dependent on temperature. Only terms of which one of the elements is at high temperature need be considered. The only ones considered here are those in which one of the cover elements is included. By the time any other element reaches a comparable temperature, some melting occurs. The most exposed areas inside the cover are the deck plate and the IC Box, which melt at 1110 and 1150 degrees, respectively.

5. Convection.

The convective heat flux is expressed as:

\[ Q = hA \Delta t \]  

(Ref 5, page 3) (8)

where

- \( h \) = coefficient of heat transfer
- \( A \) = Area of Surface
- \( \Delta t \) = Temperature Difference

The whole subject of convective heat transfer is very complex and quantitative results are difficult to compute. But for the present purpose, it has been assumed that convective heat flux is proportional to the temperature difference with the constant of proportionality determined empirically. It is also assumed that only those element pairs involved in radiative heat flow may also include the effects of convection. This simplifies the coding considerably, without, it is believed, detracting from the utility of the program.

SYSTEM SIMULATOR

1. General.

The digital computer program used as a system simulator was written in CSSL 3 (Continuous System Simulator Language). A detailed understanding of the program requires familiarity with CSSL 3, which is described in the User's Manual, (Ref 6), and with FORTRAN. A brief
description of the CSSL 3 features which have been used will be given here.

Statements may be either in FORTRAN or CSSL 3 syntax. Most statements may be placed in any order within the program. A sort routine arranges the order of replacement statements so that all variables are defined before they are used. The programmer can force a fixed order for a group of statements by the use of a PROCEDURAL.

All statements (CSSL 3 or FORTRAN) are written in free format in which any column, from 1 through 72, may be used. A statement may be continued onto the next line by three periods before the end of the line. Blanks may be added freely.

At the beginning of a statement, a variable name (alphabetic) followed by one period denotes a logical control variable. If that variable is true at execution time, the statement will be executed; otherwise not. A statement which starts with the word CONSTANT indicates that the variable names which follow have the value given which is invariable with time (the only independent variable in the program) but which may be given a different value at execution time for a different run.

2. Tabular Functions.

A function may be inputted to the program as a series of points called a TABLE. For example, TABLE SHROUD, 1, 14, etc., means that a Table function has the name SHROUD, one dependent variable and 14 pairs of values (14 points) in which the next 14 values are of the independent variable in order of increasing value and the remaining 14 values are of the corresponding dependent variable. Interpolations between points are linear. Extrapolations are linear from the last two points. This function is used in the statement:

\[ \text{NX}. \text{TSH} = \text{SHROUD} \ (T) \]

which indicates that, for the present value of T, TSH is to be set to the corresponding value of the SHROUD function (if NX is TRUE).

Data for this table was obtained during the fire simulation test by digitally recording thermocouple voltages on computer tape. Tabular function SHROUD was used as the driving function of temperature versus time for the differential equation set. Similarly, the eight other sets of thermocouple data were inputted as table functions to facilitate comparisons with model results.
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2. Tabular Functions.

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\[ \text{NX.TSH = SHROUD (T)} \]

which indicates that, for the present value of T, TSH is to be set to the corresponding value of the SHROUD function (if NX is TRUE).

Data for this table was obtained during the fire simulation test by digitally recording thermocouple voltages on computer tape. Tabular function SHROUD was used as the driving function of temperature versus time for the differential equation set. Similarly, the eight other sets of thermocouple data were inputted as table functions to facilitate comparisons with model results.
3. Macros.

CSSL 3 allows the usage of a MACRO function. A MACRO is created by a statement MACRO MACRO followed by a MACRO name and a dummy variable name. It ends with a statement MACRO END. In between, the MACRO is defined with the dummy variable subscripted with digits indicating the order of the parameters in the call. An example from our program will illustrate.

```plaintext
MACRO MACRO COND Q
   Q(1) = 1.411E+7 * (Q(2)-Q(3))/(Q(4) etc
   MACRO END
```

if called by -

```
COND QC0102, T01, T02, 4.9 etc.
```

will result in -

```
QC102 = 1.411E+7*(T01-T02)/(4.9, etc
```

being inserted into the program.

Three CSSL 3 MACRO's were written. The first called COND and used in the example above produces heat flux values at each time step due to conduction between elements pairs using the form of Eq. (5). The second, called, RAD, similarly produces heat flux due to radiation and convection using the form of Eqs. (6) and (8). The third, called DT, produces equations of the form of Eq. (1).

4. Procedurals.

A PROCEDURAL BLOCK is used to force a fixed order of execution for some statements. This begins with, for example, PROCEDURAL (M52, M58, M19, M56,) etc., and ends with END. This block is sorted so that all variables to the right of the equal sign come before the block and those to the left come afterwards. This particular PROCEDURAL simulates the melting of elements 52, 58, 19 and 56 (see the complete program listing in Appendix). For these four elements, in addition to the variables TS2, etc., two more were set up for each element.
<table>
<thead>
<tr>
<th>Element Temp</th>
<th>Element Melting Point</th>
<th>Melted</th>
</tr>
</thead>
<tbody>
<tr>
<td>T52</td>
<td>MP52</td>
<td>M52</td>
</tr>
<tr>
<td>T58</td>
<td>MP58</td>
<td>M58</td>
</tr>
<tr>
<td>T19</td>
<td>MP19</td>
<td>M19</td>
</tr>
<tr>
<td>T56</td>
<td>MP56</td>
<td>M56</td>
</tr>
</tbody>
</table>

Each M-variable such as M52 is set to zero unless the corresponding temperature T52 is equal to or greater than the melting point of element 52, MP52 in which case M52 is set to one. M52 is used as a multiplier for terms which are to be added when melting has occurred, such as radiation from element 97 to element 01 through the void. The expression (1 - M52) is used as a multiplier for the heat flux to element 52 and also for each other term which should be dropped at this time such as conduction to adjacent elements.

Another PROCEDURAL BLOCK is used to switch the SHROUD temperature versus time from the tabular function to an exponential function with controllable parameters.

The third PROCEDURAL BLOCK is for the simulation of the effect of smoke on radiative heat flux. (The reason for introducing this effect is given in the subsequent section "Fitting the Model to Heat Test Results").

A fourth PROCEDURAL allows switching off the heat input to elements 98 and/or 99 to simulate the situation when the whole cover is not exposed to heat.

5. Data Inputted.

Data is inputted to the program in the form of constants, MACRO call parameters or table values.

Data inputted as program constants include:

- Coefficient of Convective Heat Transfer
- View Factor
- Emissivity
- Melting Points
- Contact Resistances
- Specific Heat & Density via Factor F (See Mathematical Approach General)
Data inputted as MACRO call parameters are:

<table>
<thead>
<tr>
<th>MACRO</th>
<th>PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>COND</td>
<td>Distance for conductive heat flow</td>
</tr>
<tr>
<td></td>
<td>Width</td>
</tr>
<tr>
<td></td>
<td>Thickness  For cross-sectional area for conduction</td>
</tr>
<tr>
<td></td>
<td>Conductivity</td>
</tr>
<tr>
<td>RAD</td>
<td>Emissivity</td>
</tr>
<tr>
<td></td>
<td>Area Exposed to Radiation</td>
</tr>
<tr>
<td></td>
<td>View Factor</td>
</tr>
<tr>
<td>DT</td>
<td>Specific Heat &amp; Density via Factor F</td>
</tr>
<tr>
<td></td>
<td>Volume of Element</td>
</tr>
</tbody>
</table>

The only data inputted by table values are temperatures versus time obtained from physical testing. Nine such tables were used in the program.

6. Fitting the Model to Heat Test Results.

Once all of the known physical and thermal data have been inputted to the model, the next step is to find values for the various unknowns (such as convective heat coefficients) which make the model correspond to the test results reasonably well. There are eight thermocouple temperature versus time curves derived from the test, each of which correspond to an element of the model. Values are arbitrarily chosen for each unknown constant and the eight curves produced by the model are compared with the test curves. On the first guess most of the model curves differ considerably from the test curves. Because some model curves are influenced more by some constants than others, it is not difficult to make the general trend of the curves match the test curves in about 20 runs. (Incidentally, these runs do not require the complete CSSL cycle. The first part produces and compiles a FORTRAN program which takes substantial computer time. But this does not have to be redone if the program itself is not changed. It is only necessary to change some of the "constant" values and this can be done at run time. Each run itself then takes very little time.)

After getting the curves to generally fit overall temperature rise, the next step is to attempt to get the shape of the curves right by balancing the contributions due to radiation, convection and conduction. All curves were matched reasonably well in this way except for thermocouple TC22 in the test which corresponds to element T56 in the model.
This thermocouple is on the deck plate not covered by the IC Box and is thus exposed to radiation and convection from the two upper parts of the cover. The conduction from the cover through the deck plate itself allows the use of only one arbitrary unknown constant which is the cover to deck plate contact resistance. But, even with this at zero, the contribution to temperature rise from conduction is very small. This means that the heating of the deck plate is mainly by radiation and/or convection. To find out how much of each may be required, two sets of runs were made. In the first set, convection was set at zero and radiation increased and decreased until the latest significant point (the occurrence of melting) is matched. The resultant curve is shown on Figure 5. In the second set radiation was eliminated to the deck plate and with only convection the end point was again matched. That curve is also shown on Figure 5, together with the curve for the test result. The problem is evident in the Figure. Combinations of radiation and convection can only give curves between the two extremes whereas the test curve is outside. Therefore, the actual phenomenon is not merely heating by radiation and convection (with conduction, too, of course). Something else is going on.

During the test it was observed that a large volume of dense smoke was evolved. It was felt that this smoke may affect heat flow. If so, it would have an effect which changes with time. This could affect the heating curve in the way observed, with the heating rate higher in the beginning and decreasing with time. To simulate this a smoke function (S) was introduced. The precise manner in which smoke is generated is, of course, unknown. It seemed reasonable to assume that smoke will begin to form when the temperature is high enough for some materials to start burning. Four hundred degrees Fahrenheit was chosen as the temperature at which smoking begins. The value chosen is probably not critical since the temperatures rise rapidly. It was also felt that the rate of smoke generation increases more rapidly than proportional to temperature so a square function was used. The amount of smoke present is cumulative so the rate-of-smoke generation DS is integrated outside the PROCEDURAL to give S. The effective net emissivity GV is then made a simple inverse function of S.

Using this smoke function the arbitrary constants K1, K2 and K3 were adjusted to make T56 match TC22 while keeping all other curves reasonably well-matched. Figures 6 through 13 are the eight pairs of curves for the model output compared with the thermocouple readings when the empirical curve-matching was concluded.
7. Computer Program.

The Appendix has a complete source listing of both the main program, which must be run once each time the model is changed, and of a typical parameter-alteration run.

The main program is in three contiguous parts. The first part (lines 100-230) is the control deck for the SCOPE operating system. The second part (lines 250-7030) is the CSSL 3 source deck. The third part (lines 7050-7180) is the CSSL 3 run time control deck.

Execution proceeds in several steps. First, CSSL 3 reads the CSSL 3 source deck, sorts the statements, makes MACRO substitutions, interprets statements which are in CSSL 3 format and produces a FORTRAN source program on a file called TAPE7. This is then compiled with the machine code written on a file named LGO. Compiled subroutines on a permanent file are loaded into central memory along with LGO for execution as the last step. Total time for execution of the main program is typically 250 CPU seconds.

A parameter alteration run is illustrated by the second source listing in the Appendix. Any defined constants in the main program (see lines 430-520) may have new values assigned for this type of run. The time step and ending time may be reset by redefining CI and TE respectively. The constant XX, initially set to zero, makes the shroud temperature equal to the table function which is the measured shroud thermocouple values as a function of time. If reset to 1 an exponential temperature rise is used with a maximum temperature and time constant of TMAX and TAU respectively. Similarly, the constants X98 and TBC can be used as switches to turn on or off the radiation to elements T93 and T99 respectively. The values of any variable versus time may be outputted and/or plotted during a parameter alteration run. This allows detailed study of heat flow within the model. Execution of a parameter alteration run uses 5 to 10 seconds CPU time.

USING THE MODEL

There are several ways in which the model can now be used. One of these is to assume a different heat input. The most interesting heat input is a shroud temperature which is a fast exponential rise to a steady 1850°F. This corresponds to a worst-case organic fuel fire. The result of using such an input on TS2 is shown in Figure 14. As expected, of course, the rate of heating is greater than was experienced in the test, but in addition, details such as the time of melting can probably best be estimated by the use of a model like this. The change
to the program which is required to get this result is to input a value for XX of 1 instead of 0. This makes the logical variable X true through PROCEDURAL (X,NX = XX) which acts as a switch to change the definition of TSH, the temperature of the shroud versus time. With XX = 0, TSH is the SHROUD tabular function of thermocouple readings whereas when XX = 1, TSH equals an exponential function of time. TMAX is set to 1850° and TAU is 10 (seconds) within the program.

Figure 15 was gotten in the same way but the maximum shroud temperature (TMAX) was set to 1450°F which is considered to be typical of an organic fuel fire rather than worst-case.

Another configuration which was considered is 1850°F heat only to the top of the cover, which could occur if the missile were lying on the ground with a fuel fire nearby. The resulting T52 is shown in Figure 16. To simulate this condition two switches were reset in the program. The constant TBC was reset to 2000, and X98 was reset to 1. TBC is in the program as the time at which the missile ballistic case melts. Prior to TBC there is no heat input to element T99 because of the shielding effect of the ballistic case. By setting TBC = 0, we have heat input to T99 all the time whereas by setting it high the heat never gets inputted to T99. Constant X98 is used only to allow switching off the heat input to element T98.

Temperature T52 for the case of heat input to the whole top and with a maximum input temperature of 5500°F to correspond to a propellant fire is given in Figure 17. In a case like this, which differs so widely from the conditions under which the model parameters were derived, the results must be interpreted with a great deal of caution. Nevertheless, such results may be better than a simplified calculation or estimate.

Another use for the model is in the analysis of heat flow paths. As an example, consider how the battery match gets heated.

T45 gets heated by conduction from T32, T34, and T42, which three elements form a bottom corner of the battery case. Since any variable can be outputted (not only the state variables used in the integration routines) all that is needed is to output some of the QC's and QR's and compare these to find the main heat flow patterns.

Figure 18 is a diagram of all major (> 10^7 erg/sec) heat flow paths feeding elements 32, 34 and 42 at the time 240 seconds. It is seen that elements 32 and 34 are receiving more heat by radiation than conduction. Element 42 receives heat only by conduction. There are several more heat flow paths, such as radiative and conductive flux from 98 to 99 to 01 and 02 which are not shown. Also, everything
changes with time. All of this information is available to use, keeping in mind that the interpretation must be a reasonable consequence of the data put into the model.

Knowledge of the heat flow paths allows the designer to incorporate conductors and insulators to obtain desired performance. It may be desirable to insulate a battery gas generator for example while increasing the conduction to the thermal release connector.
REFERENCES


<table>
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<tr>
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<tbody>
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<td>T50</td>
<td>Deck, under IC Box</td>
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<tr>
<td>TC 24</td>
<td>T52</td>
<td>Deck, exposed part</td>
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<tr>
<td>TC 22</td>
<td>T56</td>
<td>Arm Safe Device Number 1</td>
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<td>TC 27</td>
<td>T19</td>
<td>Battery TRC</td>
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<tr>
<td>TC 12</td>
<td>T45</td>
<td>Battery explosive gas generator</td>
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<tr>
<td>TC 15</td>
<td>T58</td>
<td>IC Box top</td>
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<tr>
<td>TC 21</td>
<td>T90</td>
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<tr>
<td>TC 26</td>
<td>T07</td>
<td>Base between BDT and battery</td>
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Fig 4  Conductivity model
Fig. 6: Computer model T50 and test thermocouple TC 25.
Fig 7  Computer model T52 and test thermocouple TC 24
Fig 8 Computer model T56 and test thermocouple TC 22
T45 (SOLID) & TC12 (DOTTED) VS TIME

Fig 10  Computer model T45 and test thermocouple TC 12
Fig 12: Computer model T90 and test thermocouple TC 21
Fig 15 Computer model heat source at 1450°F
Fig 16 Computer model heat source at 1800°F (to top only)
Numbers in boxes are element numbers. Other numbers are heat values in millions of ergs per second at 240 seconds.

Fig 18  Heat paths to element 45
PROGRAM HEAT CALCULATIONS

** COMMENT **

*** WRITTEN BY - FRED A MILLER ***

*** JULY 1976 ***

***

COMMENT 2-D HEAT ANALYSIS OF SEADAN IV

COMMENT TCH = TEMP OF SHIELD (FIFIC F)

COMMENT ALL DIMENSIONS ARE IN INCHES

MASS TG7=0.0, T98=0.0, T99=0.0

KFRP = TG7=0.0, T98=1.0, T99=1.0

TARE SHOWN=1.14, 1.8, 0.48, 0.72, 1.14, 1.14, 0.72, 0.72, 0.72, 0.72

28.8, 44.8, 52.8, 60.0, 60.0

60.0, 60.0, 111.7, 111.7, 111.7, 111.7, 111.7, 111.7

1.94, 1.94, 1.94, 1.94, 1.94

CONSTANT **

H = 0.05, VR = 0.19, CSE = 0.20

HA = 0.00, VA = 0.00, CCA = 0.00

HC = 0.20, VC = 0.20, CSE = 0.20

HTC = 0.15, VS1 = 0.15, CSE = 0.15

HS = 2.0, VS2 = 0.15, VP19 = 20.0

10.0, TF = 11.0
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<tr>
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<td>680</td>
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<tr>
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ATTN: Nuclear Safety Dept 1650
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