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ATOMICS INTERNATIONAL <small>A Division of North American Aviation, Inc.</small>		NAA SR TDR NO 10961		APPROVALS	
TECHNICAL DATA RECORD		PAGE 1 OF 22			
AUTHOR R. W. Winson		DEPT & GROUP NO 727-753		DATE 3-2-65	
TITLE Thermal Model for Use in SNAP System Simulation		GO NO 7569		<i>K. E. Buttrey</i>	
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				AUTHORIZED CLASSIFIER SIGNATURE <i>K. E. Buttrey</i>	
				DATE 5/3/65	
STATEMENT OF PROBLEM Develop a thermal model to describe the heat transfer within the reactor and various heat exchanger components used in a SNAP reactor system.					
ABSTRACT A thermal model, in transfer function form, is developed to describe the heat transfer within either a fluid to fluid or fluid to solid heat exchanger. The model is primarily intended for use as a four terminal network for use in the simulation of complex systems such as a SNAP reactor and its primary loop. In the form presented, it is an accurate thermal representation of the exchanger using a minimum mathematical representation. The model can also be used, in model form, to accurately determine the time dependent temperature distribution within the heat exchanger. An approximation of the model is also presented which in many cases simplifies the simulation of the equations on analog equipment. Two digital subroutines used in simulating the thermal model and its approximation on a digital computer is presented.					

I. INTRODUCTION

In order to analytically predict the transient response of SNAP reactors, under startup or accident conditions it is necessary to mathematically represent the many complex relationships in the various components comprising the entire system. For example, in order to evaluate SNAP 8 PCS startup, it is necessary to simulate the reactor kinetics and heat transfer, the control drums and controller, the NaK-Hg boiler, auxiliary heat exchanger, parasitic load resistor, pump, and thermal line losses. These elements comprise only the primary loop and in a detailed analysis it may prove necessary to include the secondary loop as well.

In order to determine the response of these complex systems, commensurate with reasonable digital computation time or with a reasonable amount of analog components, it is necessary to develop models which accurately represent the system characteristics and yet minimize simulation complexity.

This paper presents the development of a mathematical model which, in its general form can be used to represent the heat transfer within the reactor, boiler, and heat exchanger.

II. MODEL DEVELOPMENT

Figure 1.

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Figure 1 represents an increment and illustrates a coolant flowing past a mass at some average temperature $\bar{T}_m$. It is assumed that flow is incompressible and that the heat transfer coefficient u does not vary along the length X . The temperature of the coolant can be written as

$$\rho A c_p \frac{\partial T}{\partial t} = -\dot{W} c_p \frac{\partial T}{\partial X} - uc (T - \bar{T}_m) \dots (1)$$

where:

ρ = Coolant density in lb/in.³

A = Coolant channel cross section area in in.²

c_p = Coolant specific heat in BTU/lb-°F

$\dot{W}$ = Coolant flow rate in lb/sec

u = Heat transfer coefficient in BTU/sec-in.²-°F

c = Heat transfer periphery in inches

If we define the following

$$\alpha = \rho A c_p$$

$$\beta = \dot{W} c_p$$

$$\gamma = uc$$

and take the Laplace transform of Equation (1), ignoring initial conditions, we obtain

$$\alpha s T(X, s) = -\beta \frac{dT(X, s)}{dx} - \gamma [T(X, s) - \bar{T}_m(s)]$$

Rewriting, we obtain

$$\beta \frac{dT(X, s)}{dx} = \gamma [\bar{T}_m(s) - T(X, s)] - \alpha s T(X, s) \dots (2)$$

Taking the transform of Equation (2) with respect to the space variable, we obtain

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$$\beta [PT(P, s) - T(O, s)] = \gamma \left[\frac{\bar{T}_m(s)}{P} - T(P, s) \right] - s \propto T(P, s) \dots (3)$$

Defining

$$A = \gamma + s \propto \dots (3a)$$

we have

$$\beta PT(P, s) + AT(P, s) = \frac{\gamma \bar{T}_m(s)}{P} + \beta T(O, s)$$

$$T(P, s) \left[\frac{\beta}{A} P + 1 \right] = \frac{\gamma \bar{T}_m(s)}{PA} + \frac{\beta T(O, s)}{A}$$

or

$$T(P, s) = \frac{\gamma \bar{T}_m(s)}{PA(\frac{\beta}{A} P + 1)} + \frac{\beta T(O, s)}{A(\frac{\beta}{A} P + 1)} \dots (4)$$

Taking the inverse transform of Equation (4), we have

$$T(X, s) = \frac{\gamma \bar{T}_m(s)}{A} (1 - e^{-\frac{XA}{\beta}}) + T(O, s) e^{-\frac{XA}{\beta}} \dots (4a)$$

or

$$T(X, s) = \frac{\gamma \bar{T}_m(s)}{s \propto + \gamma} \left[1 - e^{-\frac{X}{\beta} (\gamma + \propto s)} \right] + T(O, s) e^{-\frac{X}{\beta} (\propto + \gamma s)}$$

Defining

$$T_1 = \frac{X \propto}{\beta} = \frac{\rho A C_p X}{\dot{W} C_p} \dots (5)$$

$$T_2 = \frac{\propto}{\gamma} = \frac{\rho A C_p}{uc} \dots (6)$$

$$K = \frac{X \gamma}{\beta} = \frac{X uc}{\dot{W} C_p} = \frac{T_1}{T_2} \dots (7)$$

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we have

$$T(X, S) = \frac{\bar{T}_m(S)}{1+T_2S} - \frac{\bar{T}_m(S)e^{-T_1S}}{1+T_2S} + T(O, S)e^{-T_1S} \dots \quad (8)$$

Inspection of Equation (8) shows that it is not necessary to rigorously transform it into the time domain since the form is recognized as pure lags and time delays. If $F(t-T)$ is defined as the functional notation representing a pure time delay and $\frac{F(t)}{1+TS}$ is understood as an operational equation defining a time dependent variable passing through a first order lag, we can write

$$T(X, t) = \frac{\bar{T}_m(t)}{1+T_2S} - \frac{\bar{T}_m(t-T_1)e^{-K}}{1+T_2S} + T(O, t-T_1)e^{-K} \dots \quad (9)$$

Equation (9) defines the instantaneous value of the coolant outlet temperature in terms of $\bar{T}_m(t)$ and the coolant inlet temperature $T(O, t)$. It should be noted that in Equation (9) both $\bar{T}_m(t)$ and $T(O, t)$ have been assumed to be arbitrary functions of time. In real systems, the value of $\bar{T}_m(t)$ is strongly dependent on the temperature in the coolant. In order to readily couple $\bar{T}_m(t)$ to the coolant temperature it is necessary to determine the mean coolant temperature which is defined by

$$\bar{T}(t) = \frac{\int_0^L T(X, t) dx}{\int_0^L dx} \dots \quad (10)$$

or

$$\bar{T}(S) = \frac{\int_0^L T(X, S) dx}{\int_0^L dx}$$

Utilizing Equation (4a), it can be seen that

$$L\bar{T}(s) = -\frac{\beta}{\Lambda} T(0, s)e^{-\frac{LA}{\beta}} + \frac{\gamma}{\Lambda} \bar{T}_m(s)L + \frac{\gamma}{\Lambda} \frac{\beta}{\Lambda} \bar{T}_m(s)e^{-\frac{AL}{\beta}} \\ + \frac{\beta}{\Lambda} T(0, s) - \frac{\gamma}{\Lambda} \frac{\beta}{\Lambda} \bar{T}_m(s) \dots \dots \dots (11)$$

From Equation (4a), it is seen that

$$\frac{\beta}{\Lambda} (T(0, s)e^{-\frac{LA}{\beta}} - \frac{\gamma}{\Lambda} \bar{T}_m(s)e^{-\frac{AL}{\beta}}) = \frac{\beta}{\Lambda} (T(L, s) - \frac{\gamma}{\Lambda} \bar{T}_m(s)). \dots (12)$$

Substituting Equation (12) into Equation (11) we obtain

$$\bar{T}(s) = \frac{1}{\Lambda} \left[\gamma \bar{T}_m(s) + \frac{\beta}{L} (T(0, s) - T(L, s)) \right]$$

Utilizing Equations (3a), (6), and (7) we have

$$\bar{T}(s) = \frac{1}{T_2 s + 1} \left[\bar{T}_m(s) + \frac{1}{K} (T(0, s) - T(L, s)) \right] \dots \dots \dots (13)$$

Again defining $\frac{F(t)}{1+Ts}$ as an operational equation defining a first order lag, we have

$$\bar{T}(t) = \frac{1}{T_2 s + 1} \left[\bar{T}_m(t) + \frac{1}{K} (T(0, t) - T(L, t)) \right] \dots \dots \dots (14)$$

III. DISCUSSION OF THERMAL MODEL

Equations (9) and (14) represent a mathematical description of a fluid passing through a heat exchanger. The model is completed when the thermal description of the variation of $\bar{T}_m$ with time is presented.

Figure 2.

Figure 2 illustrates a heat exchanger of any length. For the sake of convenience, Equations (9) and (14) may be rewritten as

$$T_o = \frac{\bar{T}_m}{1+T_2S} - \frac{\bar{T}_m(t-T_1)e^{-K}}{1+T_2S} + T_{in}(t-T_1)e^{-K} \dots (15)$$

$$\bar{T} = \frac{1}{1+T_2S} \left[\bar{T}_m + \frac{1}{K} (T_{in} - T_o) \right] \dots (16)$$

where

$$T_1 = \frac{\rho AL}{\dot{W}} \dots (17)$$

$$T_2 = \frac{\rho A C_p}{uc} \dots (18)$$

$$K = \frac{L uc}{\dot{W} C_p} \dots (19)$$

Equations (15) and (16) permit representation of the heat exchanger coolant temperature with a single pair of equations. If the temperature distribution within the exchanger is of no particular interest, as is usually the case in a complex system simulation, these equations represent a single node model which accurately and simply describes the heat transfer.

Since a time delay and a first order lag are both linear and may be considered to be operators, it is of no importance as to the sequence in which they are coupled. If we define $(\frac{1}{1+TS})$ and $(t-T_1)$ as linear operators defining a time lag and a time delay respectively, the computational representation of Equation (15) may be simplified.

Defining:

$$A = \bar{T}_m \left(\frac{1}{1+T_2S} \right) \dots (20)$$

$$B = (T_{in} - A)(t-T_1) \dots (21)$$

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we have

$$T_o = A + Be^{-K} \dots \dots \dots (22)$$

In the form represented by Equations (20), (21), and (22) one time delay and one lag has been eliminated from the simulation.

Two digital subroutines have been written to expedite the simulation of the heat exchanger on a digital computer. They are called DELAY and LAGGER, and a listing of these subroutines are included in the appendix of this report. Subroutine DELAY digitally simulates a pure time delay. This subroutine, in the form presented, will handle ten different variable time delays. The delays are variable in order to simulate variable flow rates, which manifest themselves as variable transport delays through the system. By simply altering the dimension statement in the subroutine, the number of delays can be increased.

Subroutine LAGGER was written to digitally simulate a first order lag. It can also be used as a method of integration (Reference 1).

IV. DIGITAL SIMULATION

In order to simulate the coolant channel on a digital computer, it is assumed that the system is initially at steady state and is responding to some perturbation in either T_{in} or $\bar{T}_m$. It is necessary to first load the time delay with its past history (a constant when the system has been at steady state for at least T_1 seconds). The following FORTRAN statements are used to represent the equations (initial conditions).

A = TBARM

B = TIN - A

TBAR = A + (TIN - T_o)/AK

TIME = 0.0

CALL DELAY (1, B, TAU1, TIME, 1.0)

If it is assumed that $\bar{T}_m$, $\frac{d\bar{T}_m}{dt}$, T_{in} , and $\frac{dT_{in}}{dt}$ are known input functions of time, the coolant temperature may be digitally represented by the following FORTRAN statements.

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```
TIME = TIME + DELT
CALL LAGGER (DELT, TAU2, A, TBARM, DTBARM)
B      = TIN - A
CALL DELAY (1, B, TAU1, TIME, 0.0)
DTØ    = TØ
TØ     = A + B* EXPF (-AK)
DTØ    = (TØ + DTØ)/2.0
```

(the above equation is used to approximate the average rate of change of the coolant outlet temperature)

```
Z      = TBARM + (TIN - TØ)/AK
DZ     = DTBARM + (DTIN - DTØ)/AK
CALL LAGGER (DELT, TAUZ, TBAR, Z, DZ)
```

In the above equations the following identities hold true.

```
t      = TIME
T̄      = TBARM
T̄_m    = TBAR
K̄      = AK
dT̄_m   = DTBARM
dt
T_in   = TIN
dT̄_in  = DTIN
dt
T_1    = TAU1
T_2    = TAU2
T_o    = TØ
t      = DELT
```

LAGGER is used to generate a first order lag operation on any arbitrary function of time if the magnitude of the function and its first derivative are known.

FIG 3

Figure 3 is a block diagram of what LAGGER simulates where $A(t)$ is the value of the function $F(t)$ after it has been lagged. If A is the value of $A(t)$ at time zero, F is the magnitude of the function $F(t)$ at time zero and DF is the rate of change of the function at time zero, LAGGER transfers in the values of A, T, F , and DF and transfers back the new value A after a time step of Δt seconds. The value of A is equivalent to $A(t + \Delta t)$. The following call statement is used to effect this calculation.

CALL LAGGER (DELT, TAU, A, F, DF)

V. DISCUSSION

Equations (15) and (16) are used to describe the coolant temperature within a heat exchanger. In order to complete the thermal model, equations describing the non-coolant side must be written. Two models will be presented.

If the heat exchanger is either a parallel or counter flow device, Equations (15) and (16) may be used to completely describe the system.

FIG 4

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Figure 4 illustrates a counter flow heat exchanger with two incompressible working fluids. Let the following be defined:

SIDE A

ρ_a = coolant density

c_{p_a} = coolant specific heat

$\dot{W}_a$ = coolant flow rate

A_a = coolant cross sectional flow area

$$\tau_{A_1} = \frac{\rho_a A_a L}{\dot{W}_a}$$

$$\tau_{A_2} = \frac{\rho_a A_a c_{p_a}}{uc}$$

$$K_a = \frac{Luc}{\dot{W}_a c_{p_a}}$$

where

L = length of heat exchanger

c = heat transfer periphery

u = heat transfer coefficient

SIDE B

ρ_b = coolant density

c_{p_b} = coolant specific heat

$\dot{W}_b$ = coolant flow rate

A_b = coolant cross sectional flow area

$$\tau_{B_1} = \frac{\rho_b A_b L}{\dot{W}_b}$$

$$\tau_{B_2} = \frac{\rho_b A_b c_{p_b}}{uc}$$

$$K_b = \frac{Luc}{\dot{W}_b c_{p_b}}$$

The thermal equations describing the system may then be written as:

$$TA_o = \frac{\overline{TB}}{1+TA_2} - \frac{\overline{TB}(t-TA_1)e^{-Ka}}{1+TA_2} + TA_{in}(t-TA_1)e^{-Ka} \dots (23)$$

$$\overline{TA} = \frac{1}{1+TA_2} \left[\overline{TB} + \frac{1}{Ka} (TA_{in} - TA_o) \right] \dots (24)$$

$$TB_o = \frac{\overline{TA}}{1+TB_2} - \frac{\overline{TA}(t-TB_1)e^{-K_b}}{1+TB_2} + TB_{in}(t-TB_1)e^{-K_b} \dots (25)$$

$$\overline{TB} = \frac{1}{1+TB_2} \left[\overline{TA} + \frac{1}{K_b} (TB_{in} - TB) \right] \dots (26)$$

Equations (23), (24), (25), and (26) represent a four-terminal network completely describing the heat exchanger.

When simulating the heat transfer within a reactor core, Equations (15) and (16) may be used to represent the coolant. The following equations may be used to describe the temperature of a single fuel node.

$$W C_p \frac{d\overline{TF}}{dt} = Q - ucL (\overline{TF} - \overline{T}) \dots (27)$$

where

W = fuel weight

C_p = fuel specific

Q = power generation rate in BTU/sec

The coolant temperatures are given by Equations (15) and (16) when $\overline{TF}$ is substituted for $\overline{T}_m$.

When it is desired to determine the temperature distribution within the reactor, Equations (27), (15), and (16) may be written as nodal equations and used directly. If the reactor is divided into N nodes, N sets of thermal equations are necessary to describe the system. It is possible to take advantage of the nodal representation and use first order lags to approximate the transport delay through each node. In a multinode model, this approximation will result in the overall coolant transport delay through the core being represented by N first order lags in cascade.

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For N greater than 5, this is an excellent approximation and only the high frequency response of the system could be effected. Due to the high heat transfer characteristics of the core, it is physically impossible to pass unattenuated high frequency perturbations in inlet coolant temperature through the core. Therefore, despite the mathematical discrepancy involved in representing a true time delay by N cascaded lags, the response of the model accurately represents the physical response of the reactor. As the number of nodes goes up, the transport time through a coolant node goes down in direct proportion and a first order lag more closely approximates the delay. The nodal response is therefore more accurate as the number of nodes increases. It should be noted that the use of a lag is always an approximation, and if the high frequency thermal response is desired, the number of nodes required could get excessive. In most systems however, only the fundamental frequency response of the reactor is necessary and the approximation may be used without any appreciable change in the dynamic response of the reactor or the nodal temperatures.

Figure 4.

Figure 4 represents a nodal model of a reactor core. If the core is divided into N nodes, each node x long, the following nodal equations may be written:

$$T_1(I) = \frac{\rho A(I) x}{W} \dots \dots \dots (28)$$

$$T_2(I) = \frac{\rho A(I) C_p}{uc(I)} \dots \dots \dots (29)$$

$$K(I) = \frac{x_{uc}(I)}{\dot{W} C_p} \dots \dots \dots (30)$$

$$\dot{W}(I) C_p \bar{T}_f(I) = Q(I) - uc(I) x (\bar{T}_f(I) - \bar{T}(I)) \dots \dots \dots (31)$$

$$T_o(I) = \frac{\bar{T}_f(I)}{1+\bar{T}_2(I)S} + \frac{\bar{T}_f(I)e^{-K(I)}}{(1+\bar{T}_1(I)S)(1+\bar{T}_2(I)S)} + \frac{T_{in}(I)e^{-K(I)}}{1+\bar{T}_1(I)S} \dots \dots (32)$$

$$T_{in}(I+1) = T_o(I) \dots \dots \dots (33)$$

$$\bar{T}(I) = \frac{1}{1+\bar{T}_2(I)S} \left[\bar{T}_f(I) + \frac{1}{K(I)} (T_{in}(I) - T_o(I)) \right] \dots \dots \dots (34)$$

In the above equations $uc(I)$, $Q(I)$, and $A(I)$ may all be a function of position along the reactor. The approximation

$$F(t-T) \approx \frac{F(t)}{1+TS}$$

has been used in Equation (32).

VI. CONCLUSIONS

A thermal model has been developed which can be used to determine the thermal response of various types of heat exchangers. The model when used as a single node representation of a heat exchanger is as accurate as a multinode model using the conventional thermal Equations (35) and (36).

$$\dot{W} C_p \dot{T}_c = ua(\bar{T}_f - T_c) + \dot{W} C_p(T_{in} - T_o) \dots \dots \dots (35)$$

$$T_o = 2T_c - T_{in} \dots \dots \dots (36)$$

These equations are subject to anomalies in the output temperature T_o for rapidly varying inlet temperature perturbations. These anomalies are present regardless of the number of nodes used in representing the heat exchanger and is due to the algebraic Equation (36) which couples

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the outlet temperature to the inlet temperature. Examination of this equation will show that for a step change in inlet temperature T_{in} , the outlet temperature will instantaneously drop by the magnitude of the step. In simulating reactor cores such as SNAP 2/10 and 8, this anomaly is unacceptable due to the coupling between coolant outlet temperature and the reactor kinetics through the grid plate coefficient. The anomalies can cause rapid changes in reactor power which will invalidate the transient.

If it is desired to determine the temperature distribution in a heat exchanger, Equations (15) and (16) can be used in the nodal model. If the high frequency response characteristics are not of importance, the approximate model given by Equations (31) and (32) can be used. In either case, no anomalies in the outlet temperature will be effected by perturbations in the coolant inlet temperature.

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REFERENCES:

1. R. W. Winson, "A Technique for Solving Dynamics Problems by Digital Computation," NAA SR 10692

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SUBROUTINE DELAY(I,A,TAU,TIME,SET)	00011000
DIMENSION DELAYT(10,10),SUM(10)	00011010
I=I	00011020
IF (SET) 25,25,10	00011030
10 DO 20 J=1,10	00011050
20 DELAYT(I,J)=A	00011060
SUM(I)=TIME	00011062
RETURN	00011065
25 IF (TAU) 120,110,30	00011066
30 DELTIM=TAU/10.0	00011070
IF (TAU-TIME+SUM(I)) 135,135,35	00011075
35 TIMSUM=TIME-SUM(I)	00011080
40 IF (TIMSUM-DELTIM) 100,50,50	00011090
50 JD0=TIMSUM/DELTIM	00011100
AD0=JD0	00011105
SUM(I)=SUM(I)+ AD0*DELTIM	00011110
ID0=10-JD0	00011115
KA=ID0	00011120
DO 60 J=1,ID0	00011125
K=11-J	00011130
DELAYT(I,K)=DELAYT(I,KA)	00011135
60 KA=KA-1	00011140
DO 70 J=1,JD0	00011145
70 DELAYT(I,J)=A	00011150
100 A=DELAYT(I,10)	00011160
110 RETURN	00011162
120 WRITE OUTPUT TAPE 6,130,TAU,I	00011164
130 FORMAT (26H1NEGATIVE TIME DELAY. TAU=1PE14.7,13H DELAY NUMBER I2)	00011168
CALL EXIT	00011170
135 SUM(I)=TIME	00011171
DO 140 J=1,10	00011172
140 DELAYT(I,J)=A	00011173
GO TO 110	00011174
END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)	

STORAGE NOT USED BY PROGRAM

DEC OCT
375 00567

DEC OCT
32561 77461

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE STATEMENTS

DEC OCT
DELAYT 364 00554

DEC OCT
SUM 374 00566

DEC OCT

DEC OCT

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATEMENTS

DEC OCT
ADD 264 00410
J 260 00404

DEC OCT
DELTIM 263 00407
KA 259 00403

DEC OCT
IDD 262 00406
K 258 00402

DEC OCT
JDD 261 00405
TIMSUM 257 00401

SYMBOLS AND LOCATIONS FOR SOURCE PROGRAM FORMAT STATEMENTS

EFN LOC
8142 130 00367

EFN LOC

EFN LOC

EFN LOC

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

DEC OCT
1) 248 00370
A1101 201 00311
C1102 254 00376
D120C 166 00246
E15 83 00123

DEC OCT
2) 227 00343
A1102 214 00326
C1103 255 00377
D130C 165 00245
E110D 171 00253

DEC OCT
3) 231 00347
C160 252 00374
C1201 256 00400
D1408 135 00207

DEC OCT
6) 232 00350
C1101 253 00375
D110D 169 00251
D1608 134 00206

LOCATIONS OF NAMES IN TRANSFER VECTOR

DEC OCT
EXIT 2 00002

DEC OCT
(FIL) 1 00001

DEC OCT
(STH) 0 00000

DEC OCT

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXIT (FIL) (STH)

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN	IFN	L0C	EFN	IFN	L0C	EFN	IFN	L0C	EFN	IFN	L0C
10	7	00102	20	8	00104	25	12	00117	30	13	00124
35	15	00135	40	16	00140	50	17	00145	60	25	00221
70	27	00237	100	28	00247	110	29	00254	120	31	00260
135	34	00277	140	36	00303						

```
SUBROUTINE LAGGER (DELT,TAU,X,Y,DY)
  AT=DELT/TAU
  IF (AT-0.005) 30,1,1
  1 IF (AT-10.0) 5,40,40
  5 APEX=1.0-EXP(-AT)
    IF (DY) 10,20,10
  10 APEX1=TAU*(AT-APEX)
    X=X+APEX*(Y-X) + APEX1*DY
    GO TO 60
  20 X=X+APEX*(Y-X)
    RETURN
  30 X=X+(Y-X)*AT
    GO TO 60
  40 X=Y+DY*(DELT-TAU)
  60 RETURN
  END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```

```
01000000
01000010
01000015
01000018
01000020
01000025
01000030
01000040
01000050
01000052
01000054
01000056
01000058
01000060
01000070
```

11/04/24

STORAGE NOT USED BY PROGRAM

DEC OCT
120 00170DEC OCT
32561 77461

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATEMENTS

DEC OCT
APEX1 119 00167DEC OCT
APEX 118 00166DEC OCT
AT 117 00165

DEC OCT

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

DEC OCT
1) 114 00162DEC OCT
3) 105 00151DEC OCT
6) 108 00154

DEC OCT

LOCATIONS OF NAMES IN TRANSFER VECTOR

DEC OCT
EXP 0 00000

DEC OCT

DEC OCT

DEC OCT

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXP

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN IFN LOC
1 5 00055
30 14 00127EFN IFN LOC
5 6 00061
40 16 00136EFN IFN LOC
10 8 00072
60 17 00145EFN IFN LOC
20 11 00114

3-2-65

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BEGIN LOADING 25

13-29-24

11/04/24

*PROGRAM DECK NO. 3W715 FILED BY

MARV HOFFMAN

05-01-64

MISSING SUBROUTINES, JOB DELETED

MAXI

NAME LOAD ENTRY

NAME LOAD ENTRY

NAME LOAD ENTRY

NAME LOAD ENTRY

000000 00200 00206

BOILER 00512 00532

LAGGER 06464 06471

DELAY 06654 06663

FGEN 07316 07326

AICRT3 10564 10611

GRAB 13220 13220

SORT 13344 13350

LOWEST COMMON LOC. (77461)8 HIGHEST PROGRAM LOC.(13464)8

STORAGE NOT USED BY PROGRAM. (63774)8