NUMERICAL PREDICTIONS OF THE MOTION OF MAGNETICALLY ACCELERATED FLYER PLATES

R. W. Reynolds
Simulation Division 8343
R. S. Jacobson
Experimental Mechanics Division 8122
Sandia Laboratories, Livermore

July 1969

ABSTRACT

A numerical solution predicts the motion of a magnetically accelerated flat flyer plate. Results obtained with the solution agree closely with experimental data.
ACKNOWLEDGMENT

The authors wish to thank K. D. Marx, Analytical Division 8341, for his assistance in the theoretical portion of this report, W. B. Vandermolen, Experimental Mechanics Division and R. E. Johnson, Simulation Division 8343, who conducted the flyer experiments.
CONTENTS

Introduction  9
Theory  9
Application of Theory to Flat Flyer Geometry  13
Numerical Solution of the Differential Equations  16
Computer Predictions and Experimental Results  17
Conclusion  22
REFERENCES  23/24
APPENDIX -- PROGRAM  25/26

ILLUSTRATIONS

Figure  Page
1. Schematic Representation of Flyer Plate and Capacitor Bank  10
2. Actual Flat Flyer Fixture  13
3. Flyer Inductance as a Function of Distance  15
4. Flyer Velocity Versus Displacement  19
5. Flyer Velocity Versus Displacement  20
6. Flyer Displacement and Total Current Against a Common Time Axis  21
NUMERICAL PREDICTIONS OF THE MOTION OF MAGNETICALLY ACCELERATED FLYER PLATES

Introduction

Capacitor banks have been successfully used to accelerate flyer plates for impulse testing. The predictions of the motion of the flyer plate should be of considerable assistance in the design of capacitor banks and flyer plates.

In this report, the motion of the flyer plate is studied with the aid of a circuit equation and an equation of motion. These two equations are derived in general, applied to a flat flyer geometry, and then solved numerically using a Runge-Kutta technique. A series of experimental tests was conducted with a capacitor bank at Sandia Laboratories, Livermore; the results of these tests were in very good agreement with the numerical predictions.

Theory

The model used to obtain the circuit equation for the flyer-bank system is shown in Figure 1. The flyer and its return path are represented by an inductance \( L_F \), which is a function of the separation of the flyer and its return path \( X \), and a constant resistance \( R_F \). If the total inductance is \( L \) and the total resistance is \( R \), \( L_B \) and \( R_B \) can be defined such that

\[
L_B = L(x) - L_F(x) \tag{1}
\]

\[
R_B = R - R_F \tag{2}
\]

where \( L_B \) and \( R_B \) can be considered to be the total remaining inductance and resistance.
The circuit equation can be written directly as follows

\[
\frac{d}{dt} (LI) + RI + \int_0^t \frac{I}{C} dt = V_0
\]  

(3)

where \( V_0 \) is the initial voltage on the capacitor \( C \), \( I \) is the current flowing in the circuit, and \( t \) is time. Since the switch is closed at \( t = 0 \),

\[
I(0) = 0 .
\]  

(4)

By differentiation,

\[
\frac{d^2}{dt^2} (LI) + R \frac{dI}{dt} + \frac{I}{C} = 0
\]  

(5)

where

\[
\frac{d}{dt} (LI) \Big|_{t=0} = V_0
\]  

(6)

The equation of motion can be solved from virtual energy considerations. Considering the inputs to the flyer plate section of the equivalent circuit, energy conservation requires that
\[ V_F I \delta t = R_F I^2 \delta t + \delta \left( \frac{1}{2} L_F I^2 \right) + f \delta x \] (7)

where

\[ V_F \]
= voltage across flyer equivalent circuit

\[ f \]
= force acting on the flyer

\[ V_F I \delta t \]
= total energy into the flyer equivalent circuit

\[ R_F I^2 \delta t \]
= energy lost by resistive heating

\[ \delta \left( \frac{1}{2} L_F I^2 \right) \]
= change in energy stored in the magnetic field

\[ f \delta x \]
= mechanical work done in moving the flyer plate

From circuit considerations,

\[ V_F = \frac{d\phi}{dt} + R_F I \] (8)

where \( \phi \), the magnetic flux, \( = L_F I \). Equation (8) may be expressed in virtual form as

\[ V_F \delta t = \delta \left( L_F I \right) + R_F I \delta t \] (9)

Using this result Equation (7) can be rewritten as

\[ \left[ \delta \left( L_F I \right) + R_F I \delta t \right] I = R_F I^2 \delta t + \delta \left( \frac{1}{2} L_F I^2 \right) + f \delta x, \] (10)

thereby obtaining

\[ f \delta x = \frac{1}{2} I^2 \delta L_F \]

or

\[ f = \frac{1}{2} I^2 \frac{dL_F}{dx} \] (11)
Knowing \( f = m \frac{d^2 x}{dt^2} \), where \( m \) = flyer mass, we obtain

\[
\frac{d^2 x}{dt^2} = \frac{l^2}{2m} \frac{dL_F}{dx} .
\] 

(12)

Since the initial displacement is \( x_0 \) and the initial velocity is zero,

\[
x(0) = x_0
\] 

(13)

\[
\frac{dx}{dt} \bigg|_{t=0} = 0
\] 

(14)

The inductance of the flyer can be expressed as

\[
L_F(x) = \int_{x_0}^{x} \left( \frac{dL_F}{dx} \right) dx + L_F(x_0)
\] 

(15)

where \( L_F(x_0) \) is the inductance of the flyer at its initial distance \( x_0 \).

Thus, Equation (1) becomes

\[
L(x) = L_B + \int_{x_0}^{x} \left( \frac{dL_F}{dx} \right) dx + L_F(x_0)
\] 

(16)

or

\[
L(x) = L_B + \int_{0}^{x} \left( \frac{dL_F}{dx} \right) dx
\]

At this point, Equations (5), (12), and (16) are sufficient to predict flyer plate characteristics. These equations can be applied to any one dimensional geometry if \( \frac{dL_F}{dx} \) can be calculated or measured.
Application of Theory to Flat Flyer Geometry

Since much of the flyer testing at Sandia Laboratories, Livermore has been done with a flat-flyer geometry, the remainder of this report will deal with that geometry. The analysis to be discussed can easily be extended to other geometries.

The value of \( \frac{dL_F}{dx} \) for the flat flyer can be calculated by first obtaining the magnetic flux density between the flyer plate and the return plate. Using Ampere's Law, it can be determined that

\[
B = \frac{\mu I}{w}
\]

(17)

where \( w \) is the width of the plates and \( \mu \) is the permeability of free space.

Figure 2. Actual Flat Flyer Fixture
The flyer inductance is then given by

\[ L_F = \mu I \int_0^x \int_0^l B dx dy \]

where \( l \) is the length of the plates. Differentiating this expression gives

\[ \frac{dL_F}{dx} = \frac{\mu l}{w} \]

which is independent of \( x \).

Since this simple analysis neglects fringing and skin effects, \( \frac{dL_F}{dx} \) was measured experimentally by mounting the flyer in its holder and using an inductance bridge to measure the inductance as a function of displacement. In this procedure, the flyer was manually moved away from the return plate, and \( L_F \) was measured at each new position. To include an estimate of the inductive skin effect, the bridge frequency was set at the ring frequency of the bank.

The results of these measurements are shown in Figure 3. In this particular case, a straight line fit yields \( \frac{dL_F}{dx} = 5.12 \mu \text{h/m} \), while Equation (18) gives \( \frac{dL_F}{dx} = 6.40 \mu \text{h/m} \). Equation (16) then becomes

\[ L(x) = L_B + \kappa x \]

(19)

where \( K \) is a constant and can be determined from Equation (18) or Figure 3.

By eliminating \( L \) in Equation (5) and \( \frac{dL_F}{dx} \) in Equation (12), two differential equations are left:
$L_F$ calculated \( \frac{dL_F}{dx} = 6.40 \ \mu h/m \)

$L_F$ measured \( \frac{dL_F}{dx} = 5.12 \ \mu h/m \)

(normalized to first calculated point)

Figure 3. Flyer Inductance as a Function of Distance
\[
\frac{d^2}{dt^2} \left[ (L_B + \kappa x) I \right] + R \frac{dI}{dt} + \frac{I}{C} = 0 \quad (20)
\]

\[
\frac{d^2 x}{dt^2} = \frac{I^2}{2\mu} \kappa \quad (21)
\]

subject to the boundary conditions

\[
\frac{d}{dt} \left[ (L_B + \kappa x) I \right] \bigg|_{t=0} = V_0 \quad (22)
\]

\[I(0) = 0 \quad (23)\]

\[
\frac{dx}{dt} \bigg|_{t=0} = 0 \quad (24)
\]

and

\[x(0) = x_0 \quad (25)\]

Numerical Solution of the Differential Equations

The two linked, second-order differential equations (20 and 21) can now be solved numerically. These two second-order equations were reduced to four first-order equations with the independent variables \( I, x, \frac{dI}{dt}, \) and \( \frac{dx}{dt} \). A program was then written for the CDC 6600 computer to numerically solve these four equations. The heart of the program was a modified Runge-Kutta method which is described by Gill in Reference 1.

The program, given in the Appendix, was designed to run a given flyer plate and bank at four different initial voltages. The resulting currents, displacements, and velocities were calculated as a function of time and compared with experimental values.
Computer Predictions and Experimental Results

To check the accuracy of the program, the capacitor bank at Sandia Laboratories, Livermore, was fired at four different voltages using four, identical, flat, aluminum flyer plates. The parameters of the system were:

- \( R = 7.4 \text{ m\Omega} \)  
  Total resistance

- \( C = 108.5 \mu\text{F} \)  
  Total capacitance

- \( L_B + \kappa x_0 = 101.5 \text{ nh} \)  
  Total initial inductance

- \( V_0 = 5, 9, 12, 16 \text{ Kv} \)  
  Initial bank voltages

- \( \rho = 2.71 \text{ grams/cc} \)  
  Flyer density

- \( \ell = 15.0 \text{ cm} \)  
  Flyer length

- \( w = 2.94 \text{ cm} \)  
  Flyer width

- \( \text{th} = .0313 \text{ cm} \)  
  Flyer thickness

- \( x_0 = .0254 \text{ cm} \)  
  Initial displacement of flyer

A record of flyer displacement versus time was determined with the aid of a streaking camera. The velocity of the flyer was determined from the slope of these records, and the current information was determined from photographs of oscilloscope traces. For more information concerning the experimental procedure, see Reference 2.

The computer program was inputted with the above values in mks units. The program also requires \( T_{\text{max}} \) (the maximum time calculated), \( X_{\text{lim}} \) (the maximum displacement plotted), and \( \frac{dL_F}{dx} \). These parameters were input as:

- \( T_{\text{max}} = 5.0 \times 10^{-5} \text{ seconds} \)
- \( X_{\text{lim}} = 3.0 \times 10^{-3} \text{ meters} \)
- \( \frac{dL_F}{dx} = \kappa = 5.12 \times 10^{-6} \text{ henries/meter} \)
This value of \( \frac{dL_F}{dx} \) was obtained experimentally. The computer program was then rerun with \( \frac{dL_F}{dx} = 6.40 \times 10^{-6} \) henries/meter, which was calculated from Equation (18).

The results of these two computer runs are shown in Figures 4, 5, and 6. The results from the four experimental shots are included in these plots as data points. The displacement shown in these graphs was measured from the initial position of the flyer, \( x_0 \).

Figure 4 shows a plot of flyer velocity versus displacement for four voltages based upon the experimentally determined \( \frac{dL_F}{dx} \). The experimental values of velocity are within ten percent of the predicted values. Since the accuracy of experimental measurements was estimated to be only ten percent, these results are considered satisfactory.

Figure 5 is similar to Figure 4, with the exception that the \( \frac{dL_F}{dx} \) was used in the computer run. Calculated velocities were all higher than those obtained experimentally, the worst result being high by 15 percent. This is the natural result of using too high a value of \( \frac{dL_F}{dx} \) (see Equation 11).

The last graph shows a theoretical plot of the current and displacement curves based on the measured \( \frac{dL_F}{dx} \). The experimental points which correspond to the same initial voltage are also plotted on this graph and show close agreement. The unevenness of the experimental plots gives an indication of the error in the data reduction process.
\[
\frac{dL_F}{dx} = 5.12 \, \mu h/m \text{ (MEASURED VALUE)}
\]

EXPERIMENTAL POINTS

- 16 KV
- 12 KV
- 9 KV
- 5 KV

Figure 4. Flyer Velocity Versus Displacement
Figure 5. Flyer Velocity Versus Displacement
Figure 6. Flyer Displacement and Total Current Against a Common Time Axis
Conclusion

The numerical results obtained using the mathematical model of the flat flyer described in this report correlate well with experimental data. These results show that for the most accurate predictions, the value of \( \frac{dL_F}{dx} \) should be measured, although fair predictions of flyer motion can be made using the calculated value. It is suspected that for greater width-to-spacing ratios, as would exist with larger flyers, the calculated value of \( \frac{dL_F}{dx} \) would correspond more closely to the measured value.

This program has been used to investigate the effects of varying flyer plate and bank parameters. The results of these studies (Reference 3) are useful in flyer plate and bank design.
REFERENCES


APPENDIX -- PROGRAM
PROGRAM MOTION (INPUT, OUTPUT, TAPE99)
COMMON /OUT/ TMAT(300), XMAT(300,4), CMAT(300,4), PMAT(300,4), V(4)
COMMON /VAR/ R, CAP, K1, K2, K3, L, XN, AREA, M, MU, PI
REAL L, K1, K2, K3
REAL MU, M
COMMON /MUTS/ H, HMIN, HMAX, XLIML, INTCON, N, TMAX, DELPR, XLIMR, NPL

THERE ARE FOUR DATA CARDS
ALL VARIABLES ARE IN MKS UNITS
IF DL/DX = 0, PROGRAM CALCULATES VALUE
ALL VARIABLES REQUIRE 10 SPACES
ALL VARIABLES USE E FORMATS EXCEPT TYPE VARIABLE ON SECOND CARD
THE TYPE VARIABLE DESCRIBES THE TYPE OF FLYER MATERIAL (H FORMAT)
FIRST CARD $$$$ THE FOUR DIFFERENT BANK VOLTAGES IN INCREASING ORDER
SECOND CARD $$$$ FLYER LENGTH, WIDTH, THICKNESS, INITIAL SPACING,
FLYER DENSITY, FLYER MATERIAL (H FORMAT)
THIRD CARD $$$$ TOTAL R, TOTAL L, TOTAL C, TOTAL TIME
FOURTH CARD $$$$ FLYER DL/DX, MAXIMUM DISPLACEMENT

COMMON TYPE, XLIM
CALL APERTUR
CALL REFSYM
READ 210, (V(I), I = 1, 4)
210 FORMAT (4E10.4)
READ 211, AL, BW, TH, XN, RHO, TYPE
211 FORMAT (5E10.4, A10)
READ 212, R, L, CAP, TMAX
212 FORMAT (4E10.4)
READ 214, K1, XLIM
214 FORMAT (2E10.4)
PI = 3.141592654
MU = 4.*PI*1.E-7
IF (K1.EQ.0.) K1 = MU*AL/BW
K2 = L - XN*K1
PRINT 40, L, TMAX
PRINT 213, TYPE
213 FORMAT (*0THIS FLYER IS A *,A10,* FLAT FLYER*//*)
    HMAX = TMAX/299.,
    DELPR = HMAX
    HMIN = HMAX/1000.,
    H = HMIN
    AREA = AL*BW
    M = TH AREA*RHO
    K3 = K1/(Z*M)
    DO 30 I=1,4
      PRINT 10,R,CAP,K1,K2,K3,V(I)
10  FORMAT (*OR =*,E12.3*4X,*CAP =*,E12.3*4X,*K1 =*,E12.3*4X*,
          1 *K2 =*,E12.3*4X,*K3 =*,E12.3*4X,*V =*,E12.3 )
      PRINT 20,XN,RHO,AL,BW,TH,M
20  FORMAT(*0XN =*,E12.3*4X,*RHO =*,E12.3*4X,*AL =*,E12.3*4X*,
          1 *BW =*,E12.3*4X,*TH =*,E12.3*4X,*M =*,E12.3//)
      CALL CONTROL(I)
      EN = V(4)*V(4)*CAP/2.
30  CONTINUE
      CALL MAP(EN)
      CALL OUTPUT(AL,BW,TH,EN,XN)
100  CALL ENDPLOT
      STOP
      END
SUBROUTINE CONTROL (IND)
REAL M,MU
REAL K1,K2,K3
COMMON /VAR/ R,CAK,K1,K2,K3, L,XN,AREA,M,MU,PI
COMMON /RKG/ YD(5),Y(5),XK(5,4),Q(5)
COMMON /OUT/ TMAT(300),XMAT(300,4),CMAT(300,4),PMAT(300,4),V(4)
COMMON /NUTS/ H,HMIN,HMAX,XLIML,INTON,N,TMAX,DELPR,XLIMR,NPL
DIMENSION YS(5),OS(5)

CMAT IN MEGAMPS
TMAT IN MICROSECONDS
XMAT IN MM
PMAT (VELOCITY IN CM/USEC)

C
C Y(1) = IDOT
C Y(2) = XDOT
C Y(3) = I
C Y(4) = X
C Y(5) = TIME

C
C X(0) = XN
C XDOT(0) = 0
C IDOT(0) = V/(K1*XN+K2)
C I(0) = 0

C
C
C XLMR = 5.
C XLMIL = 1.
C Y(1) = V(IND)/(K1*XN+K2)
C Y(2) = 0.
C Y(3) = 0.
C Y(4) = XN
C Y(5) = 0.
C TMAT(1) = Y(5)*1.E+6
C XMAT(1*IND) = 1.E+3 *Y(4)
C CMAT(1,IND) = Y(3)*1.E-6
C PMAT(1,IND) = Y(2)*1.E-4
NPL = 1
NIN = 4
IEND = 1
ICON = 1
N = -NIN
NX = NIN + 1
TIME = DELPR
20 CALL RKG
   GO TO (25,34,34), ICON
25 TEST = TMAX - Y(NX)
   IF (TEST) 30,50,55
30 HS = H
   H = TEST
   INTCON = 1
   ICON = 2
   IEND = 2
   GO TO 20
34 H = HS
35 CONTINUE
   NPL = NPL + 1
   TMAT(NPL) = Y(5)*1.E+6
   XMAT(NPL,IND) = 1.E+3*Y(4)
   CMAT(NPL,IND) = Y(3)*1.E-6
   PMAT(NPL,IND) = Y(2)*1.E-4
   GO TO (70,45), IEND
45 PRINT 15
15 FORMAT (1HO)
   RETURN
C
50 IEND = 2
   GO TO 35
55 TEST = TIME - Y(NX)
   IF (TEST) 60,60,20
60 DO 65 I=1,NX
   YS(I) = Y(I)
   QS(I) = Q(I)
65 CONTINUE
   INTS = INTCON
   HS = H
H = TEST
ICON = 3
INTCON = 1
70 DO 75 = 1, NX
    Y(I) = YS(I)
75 CONTINUE
H = HS
INTCON = INTS
80 GO TO 20
END
SUBROUTINE RKG

DIMENSION A(4), B(4), C(4)

COMMON /OUT/ TMAT(300), XMAT(300), CMAT(300), PMAT(300), V(4)
COMMON /NUTS/ H, HMIN, HMAX, XLIML, INTCIN, N, TMAX, DELPR, XLIMR, NPL
COMMON /RKG/ YD(5), Y(5), XK(5), Q(5)
COMMON /VAR/ R, CAP, K1, K2, K3, L, XN, AREA, M, MU, PI

C
C       N      - ORDER OF SYSTEM TO BE SOLVED (NEGATIVE ON FIRST CALL)
C       Y(I)   - FUNCTION VALUES - TIME IS AUTOMATICALLY IN Y(N+1)
C       YD(I)  - FUNCTION DERIVATIVES
C       XK(I)  - STORAGE FOR INTERVAL CONTROL INFORMATION
C       H      - STEP SIZE
C       HMIN   - MINIMUM PERMITTED STEP SIZE
C       HMAX   - MAXIMUM PERMITTED STEP SIZE
C       XLIML  - MINIMUM TOLERANCE FOR DOUBLING (PERCENTAGE)
C       XLIMR  - MAXIMUM TOLERANCE FOR DOUBLING (PERCENTAGE)

C
C       INITIALIZATION PHASE WHEN N IS NEGATIVE OR ZERO.
C

C
IF (N) 1, 10

1 NX = 1 - N
A(1) = .5
A(2) = 1. - SORT(.5)
A(3) = 1. + SORT(.5)
A(4) = 1. / 6.
B(1) = 2.
B(2) = 1.
B(3) = B(2)
B(4) = B(1)
C(1) = A(1)
C(2) = A(2)
C(3) = A(3)
C(4) = C(1)
N = - N
YD(NX) = 1.
DO 5 I = 1, NX
   Q(I) = 0.
5 CONTINUE
INTCON = 1
* ENTER HERE WITH N POSITIVE AND CONTINUE INTEGRATION
* TEST FOR POSSIBLE INTERVAL MODIFICATION
  * INTCON = 1 - NORMAL, DO NOT CHANGE H
  * INTCON = 2 - DO NOT PERMIT DOUBLING, SET INTCON TO 1
  * INTCON = 3 - HALVE H, SET INTCON = 2
  * INTCON = 4 - DOUBLE H, SET INTCON = 1

10 GO TO (50, 20, 15, 25), INTCON

* HALVE H

15 H = 0.5 * H
INTCON = 2
GO TO 30

* RESET NO DOUBLING INTERLOCK

20 INTCON = 1
GO TO 30

* DOUBLE H

25 H = H + H
INTCON = 1

* TEST H FOR BEING BETWEEN HMIN AND HMAX

30 IF (H - HMIN) 35, 50, 40
35 H = HMIN
GO TO 50
40 IF (HMAX - H) 45, 50, 50
45 H = HMAX

* INTEGRATE ONE TIME STEP
C

50 IF (H) 52, 90, 52
52 DO 60 J = 1, 4
   CALL DFRV
   DO 55 I = 1, NX
      TEMP = A(J) * (YD(I) - R(J) * Q(I))
      W = Y(I)
      Y(I) = Y(I) + H * TEMP
      TEMP = (Y(I) - W) / H
      Q(I) = Q(I) + 3.0 * TEMP - C(J) * YD(I)
      XK(I,J) = YD(I)
   55 CONTINUE
60 CONTINUE

C

C * TEST RESULTS FOR INTERVAL MODIFICATION
C

C * DO 85 I = 1, N
C TEMP = ABSF(XK(I,2) - XK(I,1))
C XL = XLIML * TEMP * 0.01
C XR = XLIIMR * TEMP * 0.01
C TEMP = ABSF(XK(I,3) - XK(I,2))
C IF (XR - TEMP) 65, 70, 70
65 INTCON = 3
   GO TO 90
70 GO TO (75, 85, 90, 85), INTCON
75 IF (TEMP - XL) 80, 85, 85
80 INTCON = 4
85 CONTINUE
90 RETURN
END
SUBROUTINE DERV
REAL M,MU
COMMON /OUT/ TMAT(300),XMAT(300,4),CMAT(300,4),PMAT(300,4),V(4)
COMMON /NUTS/ H,HMIN,HMAX,XLIML,INTCON,N,NMAX,DELPR,XLIMR,NPL
COMMON /VAR/ R,CAP,K1,K2,K3, L,XN,AREA,M,MU,PI
REAL L,K1,K2,K3
COMMON /RKG/ YD(5),Y(5),XK(5,4),Q(5)
TEMP = -R*A(1) - Y(3)/CAP - K1*K3*Y(3)**3 - 2*K1*Y(1)*Y(2)
YD(1) = TEMP/(K1*Y(4) + K2)
YD(2) = K3*Y(3)*Y(3)
YD(3) = Y(1)
YD(4) = Y(2)
RETURN
END
SUBROUTINE MAP (EN)
COMMON /OUT/ TMAT(300), XMAT(300,4), CMAT(300,4), PMAT(300,4), V(4)
COMMON /NUTS/ H, HMIN, HMAX, XLMIL, INTCON, N, Tmax, DELPR, XLMR, NPL
COMMON /VAR/ R, CAP, K1, K2, K3, L, XN, AREA, M, MU, PI
REAL L, K1, K2, K3, M, MU, M
REAL LT, KE

THE NEW X IS MEASURED FROM THE INITIAL SPACING OF THE FLYER

PRINT 5, FN
5 FORMAT (*THE INITIAL STORED ENERGY =*, E12.3, *JOULES*)
DO 20 J=1, 4
PRINT 10, V(J)
10 FORMAT (*1*, 10X, *VOLTAGE =*, E12.3) //
1 *0 I *, 12X, *X (MM), 14X, *TIME (US), 9X, *IMPULSE (TAPS), 8X,
K = 0
DO 25 I=1, 300
K = K + 1
KF = .5*M*(PMAT(I,J)*1.E+4)**2
LT = (K1*XMAT(I,J)*1.E-3 + K2)*1.E+6
P = PMAT(I,J)*10.1.E+4*M/AREA
X = XMAT(I,J) - XN*1.E+3
PRINT 15, I, X, TMAT(I), P, PMAT(I,J), LT, KE
15 FORMAT (* *, I3, 6E20.3)
IF (I*.GE.*300) GO TO 25
IF (K*.EQ..50) PRINT 10, V(J)
IF (K*.EQ..50) K = 0
25 CONTINUE
20 CONTINUE
RETURN
END
SUBROUTINE OUTPUT (AL,BW,TH,EN,XN)
COMMON TYPE,XLIM
COMMON /OUT/ TMAT(300),XMAT(300,4),CMAT(300,4),PMAT(300,4),V(4)
COMMON /NUTS/ H+HMIN,HMAX,XLIML,INTCON,N,TMAX,DELPR,XLIMR,NPL
DATA(A1(I),I=1,2) = 20HDISPLACEMENT (MM)
DATA(A2(I),I=1,2) = 20HVFLocity (CM/SEC)
DATA(A3(I),I=1,2) = 20H TIME (S)
DATA(A4(I),I=1,2) = 20H CURRENT (MFGAMPS)
DIMENSION IV(4)
DIMENSION NPMAT(4)
COMMON/ PLOTTER/ F(75)
REAL MAX

THIS SUBROUTINE PROVIDES PLOTTED OUTPUT OF MATRIXED VALUES

C
C F(1) = XMIN OF GRID
F(2) = YMIN OF GRID
F(3) = XMAX OF GRID
F(4) = YMAX OF GRID
DO 7 I=1,4
  IV(I) = V(I)*1.E-3+.5
7 CONTINUE
ENC lDE(80,41,A5(0)) (IV(I),I=1,4)
DO 85 J1=1,4
DO 80 I=1,300
XMAT(I,J1) = XMAT(I,J1) - XN*1.E+3
80 CONTINUE
85 CONTINUE
IE = EN*1.E-3+.5
ENC lDE(80,40,A5) IE,AL,BW,TH,TYPE
FORMAT (13,11HKJ BANK FOR,E11,3,4H M X,E11,3,8H M FLA
1T ,A10,7H FLYERS)
NP1 = 300*4
NP2 = 300
J = 20
CALL AUXY(2)
DO 10 I=1,4
ISYM = 59 + I
K = NP2*I - NP2 + 1
CALL SEARCH (I,NP)
CALL MINMAX (XMAT(K),NP,XMIN,XMAX,1)
CALL MINMAX (CMAT(K),NP,CMIN,CMAX,1)
CALL MINMAX (PMAT(K),NP,PMIN,PMAX,1)
XMIN = 0.
CMIN = -3.*CMAX
PMIN = 0.
CALL MINMAX (TMAT,NP,TMIN,MAX,1)
LARGEST X,P,C MATRICIES MUST BE LAST CALLED

NPMAT(I) = NP
CALL QUICK (2,TMAT,PMAT(K),NP,ISYM,A3,J,A2,J,TMIN,MAX,PMIN,PMAX)
F2 = F(4) + .14
F1 = F(4) + .42
CALL SYMBOL (F(1),F1,.14,A5,0,.80)
CALL SYMBOL (F(1),F2,.14,A5(9),0,.80)
ISYM = 56
CALL AUXXML (1,1,TMAT,XMAT(K),NP,ISYM,A1,J,XMIN,XMAX)
ISYM = 35
CALL AUXXML (2,1,TMAT,CMAT(K),NP,ISYM,A4,J,CMIN,CMAX)
10 CONTINUE
CALL AUXY(0)
CALL MINMAX (PMAT,NP1,P1,P2,1)
DO 30 I=1,4
L = 0
IF(I.EQ.1) L=2
ISYM = 59 + I
K = NP2*I - NP2 + 1
CALL QUICK (L,TMAT,PMAT(K),300,ISYM,A3,J,A2,J,TMAT(1),TMAT(300),
1 P1,P2)
30 CONTINUE
CALL SYMBOL (F(1),F2,.14,A5(9),0,.80)
CALL SYMBOL (F(1),F1,.14,A5,0,.80)
DO 20 I=1,4
L = 0
IF (I .EQ. 1) L = 2
K = NP2*1 - NP2 + 1
ISYM = 59 + I
CALL QUICK (L, XMAT(K), PMAT(K), NPMAT(I), ISYM, A1, J, A2, J, XMIN, XMAX,
1 PMIN, PMAX)
20 CONTINUE
CALL SYMBOL (F(1), F1, 14, A5, 0, 80)
CALL SYMBOL (F(1), F2, 14, A5(9), 0, 80)
PRINT 75
75 FORMAT (1H1)
RETURN
END
SUBROUTINE SEARCH (I, NP)
COMMON /OUT/ TMAT(300), XMAT(300, 4), CMAT(300, 4), PMAT(300, 4), V(4)
COMMON /VAR/ R, CAP, K1, K2, K3, L, XN, AREA, M, MU, PI
COMMON TYPE, XLM

C XLIMIT AND XMAT IN MM

XLIMIT = XLM*1.0E+3
DO 10 K = 1, 300
   TEST = XMAT(K, I) - XLIMIT
   NP = K
   IF (TEST .GT. 0.) GO TO 20
10 CONTINUE
20 RETURN
END
DISTRIBUTION:

Don Keller  
General Research Corp.  
Santa Barbara, Calif.  
Attn: M. E. Graham

T. F. Meagher  
Kaman Nuclear,  
Colorado Springs, Colo.

CDR. L. J. Ratto  
LMSC,  
Sunnyvale, Calif.  
Attn: R. R. Taylor

L. W. Woodruff, LRL, L125  
Q. C. Johnson, LRL, L404  
Technical Information Division, LRL, L3  
T. B. Lane, 1540  
R. G. Clem, 1730  
S. J. Buchsbaum, 5000  
O. E. Jones, 5130  
L. W. Davison, 5133  
W. Herrmann, 5160  
D. E. Munson, 5163; Attn: R. P. Reed  
A. W. Snyder, 5220  
E. H. Beckner, 5240  
M. Cowan, 5261  
L. M. Berry, 5430  
L. E. Lamkin, 7300  
W. T. Moffat, 7330  
M. McWhirter, 7340  
F. Mathews, 7342  
J. D. Patrick, 7335; Attn: W. K. Tucker  
T. B. Cook, Jr., 8000  
L. Gutierrez, 8100  
J. W. Pearce, 8120  
J. D. Benton, 8121  
R. S. Jacobson, 8122 (2)  
W. D. Zinke, 8122  
D. J. Bohrer, 8123  
C. M. Potthoff, 8124  
R. M. Hargreaves, 8125  
D. E. Gregson, 8130  
L. E. Davies, 8150  
G. L. Scholer, 8153  
R. D. Cozine, 8154
J. S. Anderson, 8155
R. A. Baroody, 8160
G. E. Brandvold, 8170
P. D. Gildea, 8174
J. C. King, 8300
J. M. Brierly, 8311
D. R. Adolphson, 8312
J. W. Weihe, 8320
G. W. Anderson, Jr., 8330
A. R. Willis, 8335
C. M. Robinson, Jr., 8336
C. S. Hoyle, 8337
J. L. Wirth, 8340
J. A. Mogford, 8341; Attn: K. Marx
H. R. Sheppard, 8342
S. G. Cain, 8343
R. W. Reynolds, 8343 (6)
AEC/DTI, Oak Ridge, Tenn. (3)
Technical Information Division III, 3413
Acquisitions and Cataloging Division, 3421
Subsequent Distribution and Records Depository, 3428-2 (3)
M. J. Connors, 8216
D. L. Rasmussen, 8231/Central Technical File, 8232-2
B. F. Hefley/E. Bodie, 8232
Central Technical File, 8232-2 (3)

Subsequent Distribution: 1/19/70 -- Central Technical File, 8232-2 (25)