FPN II

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Preliminary Analysis of Heating Effects and Velocity Response of Magnetically Driven Plates

PRELIMINARY ANALYSIS OF HEATING EFFECTS AND VELOCITY RESPONSE OF MAGNETICALLY DRIVEN PLATES

A. INTRODUCTION

The structural testing facilities of Kaman Nuclear include three rather large scale capacitor banks which, individually, are capable of driving practical size plates by magnetically generated forces. It is currently envisioned that each of these banks may be used for an assortment of input testing techniques. In order to assure a judicious choice of experimental inputs (capacitor voltage, flyer type, initial flyer separation distance, etc.) on any particular problem, it is necessary to develop a theoretical model(s) which will be able to predict at least some of the response behavior of the capacitor-flyer system. This report describes the initial steps taken to accomplish this goal.

The mathematical procedure to be outlined in the next section will be restricted in application to flat, thin flyer plates. The thin requirement implies that gradients across the plate thickness will be ignored. Both of these restrictions are rather severe and hopefully, they will eventually be removed. At present the judgment of the accuracy of this model can only be made by comparing its conclusions (i.e., flyer velocity, flyer heating) with experiments.

In Section B, the physical problem will be translated into a mathematical framework. Section C will consist of a discussion of the numerical solution technique, a detailed listing of a related Fortran computer program, and a sample problem.

B. DEVELOPMENT OF MAGNETIC FLYER THEORY

This discussion is divided into two distinct phases. The first phase delineates the model for simulating the fields, currents, and forces between two current carrying parallel plates. The second phase is concerned with incorporating the parallel plate element into the capacitor bank discharge circuit, and performing a circuit response analysis.

In phase I the starting point can be a standard representation of the electromagnetic vector potential ($\vec{A}$) at any field point due to a steady state current density $\vec{J}$ at other points. This representation is

$$\vec{A} = (\mu_o/4\pi) \int_\tau \vec{J} \frac{d\tau}{r} \tag{1}$$

where μ_o = permeability of free space

τ = volume of all space containing current

r = distance from source point to field point

For a thin infinite sheet of spacially uniform current, the $\vec{A}$ can be found rather easily. First let

$$\vec{J} = j\,\vec{1}_x \tag{2}$$

$\vec{1}_x$ = unit vector in x-direction

and consider the coordinate system shown in Figure 1.

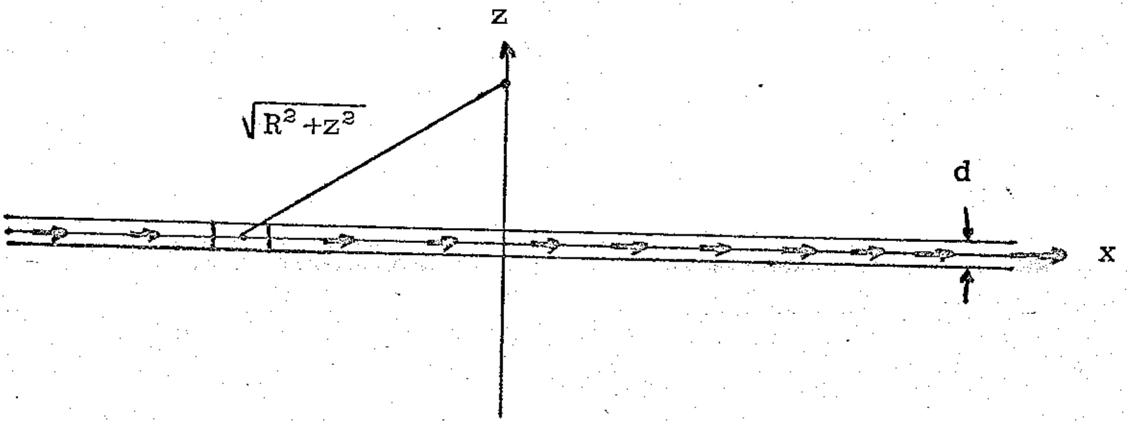

Figure 1

Integration of (1) over the current sheet can be accomplished in cylindrical coordinates. The $\vec{A}$ field at any point on the z-axis is

$$\vec{A} = (\mu_o/4\pi)\ j\ \vec{1}_x \int_{-d/2}^{+d/2} \int_0^{2\pi} \int_0^{R_L} \frac{R\ dR\ d\theta\ dz}{\sqrt{R^2 + z^2}} \qquad (3)$$

$$= (\mu_o j\ d/2)\ (R_L - |z|)\ \vec{1}_x \qquad (4)$$

where R_L is an extremely large radius.

The $\vec{A}$ field in the neighborhood of two parallel plates can be found by superposition. Let the upper plate coincide with the plane z=0 and its current density by $j\ \vec{1}_x$, and let the lower plate coincide with z= -D and its $\vec{J} = -j\ \vec{1}_x$. Then

$$\vec{A}\ (z) = (\mu_o\ j\ d/2)\ (|z + D| - |z|)\vec{1}_x \qquad (5)$$

Equation (5) implies that $\vec{A}$ is independent of z in the volumes above both plates or below both plates. Between the plates

$$\vec{A}\ (z) = (\mu_o\ j\ d)\ (z + D/2)\ \vec{1}_x \qquad (6)$$

The magnetic induction vector $\vec{B}$ and the electric field intensity $\vec{E}$ can be found from $\vec{A}$ by the standard relations

$$\vec{B} = \text{curl}\ \vec{A} \qquad (7)$$

$$\vec{E} = -\frac{\partial \vec{A}}{\partial t} \qquad (8)$$

Therefore, between the plates

$$B = \vec{1}_y \frac{\partial A_x}{\partial z} = (\mu_o\ jd)\ \vec{1}_y \qquad (9)$$

$$\vec{E} = -\frac{\partial}{\partial t}\Big((\mu_o j\ d/2)\ (2z + D)\Big)\ \vec{1}_x \qquad (10)$$

and $\vec{E}$ (0), $\vec{E}$ (-D) can be evaluated to deduce the voltage across the plates (assuming $\frac{dD}{dt}$ << speed of light)

$$\varepsilon = \oint \vec{E} \cdot d\ell = -\mu_o \ell d \frac{\partial}{\partial t} (Dj) \tag{11}$$

This relationship (11) can be the voltage-current law for the parallel plate element in an external circuit when the j is replaced by the full current on the sheets (i).

$$i = bdj \tag{12}$$

b = width of sheets

$$\mathcal{E} = -(\mu_o \ell/b) \frac{\partial}{\partial t} (Di) \tag{13}$$

$$= -\frac{\partial}{\partial t} (L_p \ i) \text{ if } L_p = \mu_o \ell \ D/b$$

The last step in phase I is concerned with the magnetic force exerted on one plate by its parallel counterpart. The Lorentz law can be used.

$$\vec{F} = i \ d\vec{\ell} \times \vec{B} \tag{14}$$

$\vec{F}$ = total force on plate

The $\vec{B}$ field in (14) is the $\vec{B}$ on one plate due to current in the other. Thus on the lower plate

$$\vec{B} \ (-D) = (\mu_o j \ d/2) \ \vec{1}_y$$

$$d\vec{\ell} = -\vec{1}_x \ dx$$

and then

$$\vec{F} = -(\mu_o \ell/2b) \ i^2 \ \vec{1}_z \tag{15}$$

Equations (13) and (15) give the voltage across the parallel plates and the force between the plates as a function of the total current.

Phase II can now be started. Consider the circuit diagram in Figure 2.

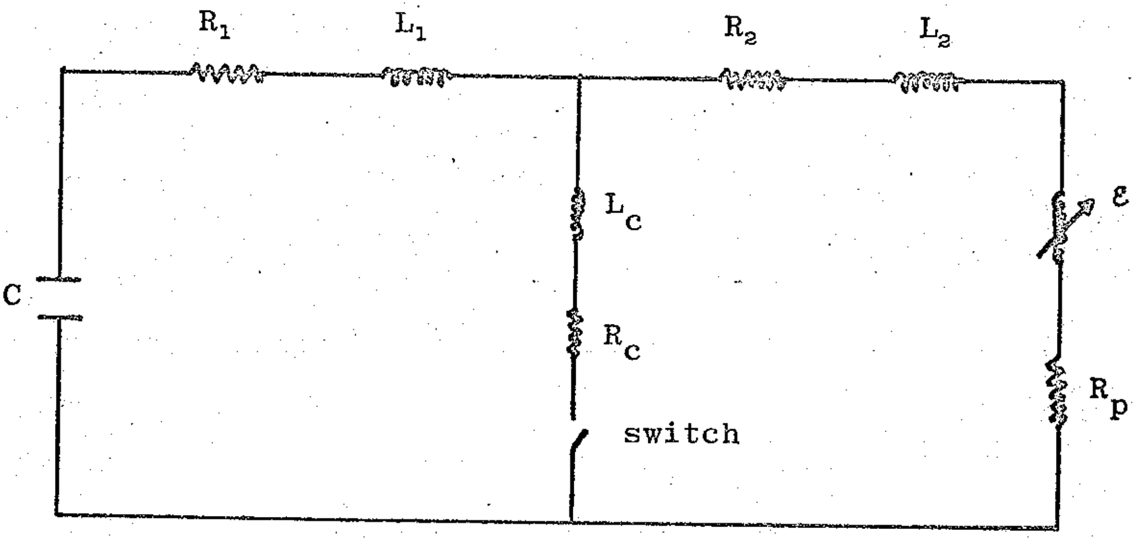

Figure 2

The subscripts on the symbols for resistance (R), inductance (L), and current i are 1 for loop 1 line quantities, 2 for loop 2, c for the L and R in the "crowbar" switch line, and p for parallel plate variables. This is a straight forward series circuit except for the crowbar line which is switched in at some specified time after the start of the capacitor discharge.

The parallel plate element has a nonlinear relationship between $\mathcal{E}$, i, and D when D is allowed to vary during the course of the discharge. Thus the more simple methods of circuit analysis (i.e., Laplace transforms) are not useful, and a finite difference approach is necessary. The governing circuit equations corresponding to Figure 2 will be formulated in terms of first order derivatives in order to facilitate this finite differencing.

Before the crowbar is switched in at time (t) = t_s, the sum of the voltage around the simple circuit is zero. Mathematically this is stated by

$$q/C + (L_1 + L_2)\frac{di}{dt} + (R_1 + R_2 + R_p)i + \frac{d}{dt}(L_p i) = 0 \qquad (16)$$

where

q = charge on capacitor
C = capacitance of bank

Equation (16) has 4 implied unknowns (q, i, D, and $\frac{dD}{dt}$) and thus 3 more equations are necessary to start a numerical procedure. These are

$$\frac{dq}{dt} = i \qquad (17)$$

$$\frac{dD}{dt} = \text{plate velocity} = v \qquad (18)$$

$$\frac{dv}{dt} = \frac{\text{force on plate}}{\text{mass of plate (M)}} = \frac{\mu_o \ell}{2bM} i^2 \qquad (19)$$

Before solution, equation (16) can be rearranged to a symmetrical form.

$$\frac{di}{dt} = -\{q/c + (R_1 + R_2 + R_p)i + (\mu_o \ell/b)vi\}/(L_1 + L_2 + L_p) \quad (20)$$

Since Equations (20), (21) are already nonlinear, it requires very little additional effort to allow all the resistances to vary with total heat generated in each. A way of formulating this behavior is to assume a linear dependence of resistance on deposited energy. For example let

$$R_2 = R_{20} + g_2 E_2 \tag{21}$$

where

$$E_2 = \int_o^t i^2 R_2 \, dt \tag{22}$$

g_2 = resistance/energy coefficient

R_{20} = initial resistance

The E_2 is a measure of time dependent temperature of the resistor. All equations are now complete except for a listing of the initial conditions of the dependent variables. These are

$$q(0) = -Q \tag{23}$$

$$i(0) = 0 \tag{24}$$

$$v(0) = 0 \tag{25}$$

$$D(0) = D_i \tag{26}$$

Equations (17) through (20) will be finite differenced in Section C.

After the switching time (t_s) a new set of similar equations with new initial conditions must be solved. Figure 2 shows two loop currents (i_1, i_2) and Kirchhoff's laws supply two loop equations. These loop equations can be written

$$\alpha_{11} \frac{di_1}{dt} + \alpha_{12} \frac{di_2}{dt} = \alpha_{13} \tag{27}$$

$$\alpha_{21} \frac{di_1}{dt} + \alpha_{22} \frac{di_2}{dt} = \alpha_{23} \tag{28}$$

with

$\alpha_{11} = L_1 + L_c$ $\qquad\qquad$ $\alpha_{12} = \alpha_{21} = -L_c$

$$\alpha_{22} = L_2 + L_p + L_c$$

$$\alpha_{13} = -q/c - (R_1 + R_c)i_1 + R_c i_2$$

$$\alpha_{23} = R_c i_1 - (R_2 + R_p + R_c + \mu_o \ell\ v/b)i_2 .$$

The derivatives in (27) and (28) can be isolated by solving two equations and two unknowns.

$$\frac{di_2}{dt} = \frac{\alpha_{11}\ \alpha_{23} - \alpha_{21}\ \alpha_{13}}{\alpha_{11}\ \alpha_{22} - \alpha_{21}\ \alpha_{12}} \tag{29}$$

$$\frac{di_1}{dt} = \frac{\alpha_{13}}{\alpha_{11}} - \frac{\alpha_{12}}{\alpha_{11}} \left(\frac{\alpha_{11}\ \alpha_{23} - \alpha_{21}\ \alpha_{13}}{\alpha_{11}\ \alpha_{22} - \alpha_{21}\ \alpha_{12}}\right) \tag{30}$$

and the other 3 equations are similarly

$$\frac{dq}{dt} = i_1 \tag{31}$$

$$\frac{dv}{dt} = (\mu_o \ell/2bM)i^2_2 \tag{32}$$

$$\frac{dD}{dt} = v \tag{33}$$

Initial conditions for this problem are

$$i_1\ (t_s) = i_2\ (t_s) = i\ (t_s)$$

$q(t)$, $v(t)$ and $D(t)$ continue from previous values.

Thus, the governing circuit equations are specified and available for numerical solution.

C. NUMERICAL ANALYSIS

The sets of coupled ordinary differential equations (17) through (20) and (29) through (33) can be solved by a rather simple procedure. First derivatives occurring on the left side of these equations can be replaced by finite difference approximations. As an example consider equation (17).

$$\frac{dq}{dt} = i(t)$$

$$\frac{\Delta q}{\Delta t} \cong i(t)$$

and

$$q_{new} = q_{old} + \Delta t \cdot L_{old}\,(t) \qquad (34)$$

A "new" q can be found from an "old" q and i. Equations (18) through (20) similarly provide "new" D, v, and i from "old" values. Thus, if initial values of q, D, v and i are specified, the finite difference equations such as (34) lead to a net of dependent variable values at fixed increments of time. Obviously a smaller values of Δt corresponds to smaller errors in advanced time quantities. The actual size of Δt, however, can be adjusted by trial and error until the energy for the system is "properly" conserved (to enough significant figures).

The Fortran program which performs this analysis and assists in plotting various output quantities is called MAGFL. To assist the interested reader in deciphering this program a dictionary of variables is listed below.

AN, NAA = number of problems

VC = initial capacitator voltage

C = bank capacitance

R10, R20, RP0, RCO = initial resistance of R_1, R_2, R_p, R_c

G1, G2, GP, GC = g_1, g_2, g_p, g_c resistance/energy coefficient

AL1, AL2, ALC = L_1, L_2, L_c inductance values

ALENG = plate length

B = plate width

AMASS = plate mass

D0 = initial plate separation distance

TP = maximum time in problem

TS = crowbar switching time

DTC = zoning parameter

AMU = μ_o

ANP = number of print outputs

DMAX = maximum allowable displacement

WO = initial angular frequency

DT = time increment

ANC = number cycles in problem

ANCPP, NCPP = number of cycles per printout

T = time

Q0 = initial capacitor charge

E1, E2, EP, EC = total energy deposited in 4 resistors

Q0, D0, V0, AI0 = "old" q, D, v, i

QN, DN, VN, AIN = "new" q, D, v, i

ALP = current inductance of plates

EOTH = energy sum parameter

R1, R2, RP, RC = instanteous resistances

IFLAG = 1 after $t=t_s$

TT (M) = time vector used in plotting subroutine

VOLT (M) = capacitor voltage

PE (M) = percent of initial energy in kinetic energy of flyer

D (M) = displacement

V (M) = flyer velocity

EPM (M) = heat deposited in parallel plates

RPM (M) = resistance of plates

EBAL (M) = 1.000 for appropriate zoning

SI (M) = top level of flyer

After the listing of MAGFL in the following pages a sample problem will be introduced.

```
    PROGRAM MAGFL(INPUT,OUTPUT)
    DIMENSION TT(100),VOLT(100),D(100),V(100),AI(100),EPM(100),RPM(100
   1),EOM(100),PE(100),EBAL(100),TIT1(4),TIT2(3),TIT3(3),SI(100),
   2TIT4(3),TIT5(4),TIT6(5),TIT7(5)
    DATA (TIT1(1)=8HCAPACITO),(TIT1(2)=8HR VOLTAG),(TIT1(3)=8HE VS TIM
   1),(TIT1(4)=8HE       )
    DATA (TIT2(1)=8HFLYER CU),(TIT2(2)=8HRRENT VS),(TIT2(3)=8H TIME
   1 )
    DATA (TIT3(1)=8HEFFICIEN),(TIT3(2)=8HCY VS TI),(TIT3(3)=8HME
   1 )
    DATA (TIT4(1)=8HFLYER VE),(TIT4(2)=8HLOCITY V),(TIT4(3)=8HS TIME
   1)
    DATA(TIT5(1)=8HFLYER VE),(TIT5(2)=8HLOCITY V),(TIT5(3)=8HS DISTAN)
   1,(TIT5(4)=8HCE       )
    DATA (TIT6(1)=8HDISTANCE),(TIT6(2)=8H VS TIME)
    DATA (TIT7(1)=8HD-IN MIL),(TIT7(2)=8HS VS TIM),(TIT7(3)=8HE
   1)
    READ 1000,AN
    NAA=AN
    DO 999  KK=1,NAA
C         READ CIRCUIT CHACTERISTICS
    READ 1000,VC,C,R10,G1,AL1,R20,G2,AL2
    READ 1000,RC0,GC,ALC
    READ 1000,ALENG,B,AMASS,RP0,GP,D0
    READ 1000,TP,TS
    AMU=.00000126
    DTC=.001
    ANP=99.
    DMAX=5.
    PRINT 2000
    PRINT 2010,R10,AL1,R20,AL2
    PRINT 2020,G1,G2
    PRINT 2030
    PRINT 2040
    PRINT 2040 $ PRINT 2040
    PRINT 2050
    PRINT 2060,RC0
    PRINT 2070,GC,RP0
    PRINT 2080,GP
    PRINT 2090 $ PRINT 2090
    PRINT 2100
    PRINT 2110,VC
    PRINT 2120
    PRINT 2130,ALC
    PRINT 2140,D0
    PRINT 2150,C,B
    PRINT 2160,ALENG
    PRINT 2170,AMASS
    PRINT 2040
    PRINT 2180
    PRINT 2190,TS
    PRINT 2040 $PRINT 2040 $ PRINT 2040 $ PRINT 2040
    PRINT 2200
    PRINT 2210
    AL=AL1+AL2+AMU*D0*ALENG/B
    W0=(AL*C)**(-.5)
    DT=DTC/W0
```

```
      ANC=TP/DT
      ANCPP=ANC/ANP
      NCPP=ANCPP
      IF(NCPP.LT.10) NCPP=10
      PRINT 1050,TP,DT,NCPP
      T=0.
      J=0
      P1=AMU*ALENG/(B*AMASS)
      P2=P1*AMASS
      QO=-C*VC
      QO=QO
      E1=0.
      E2=0.
      EP=0.  $EC=0.
      DO=D0
      M=1
      AIO=0.
      VO=0.
      DN=0.
      R2=R20
      R1=R10
      RC=RC0  $RP=RP0   $IFLAG=0
 100  IF(T.GT.TP) GO TO 600
      IF(T.GT.TS) GO TO 300
      IF(DN.GT.DMAX) GO TO 600
      QN=QO+AIO*DT
      DN=DO+VO*DT
      VN=VO+P1*(AIO**2)*DT       /2.
      E2=E2+(AIO**2)*R2*DT
      E1=E1+(AIO**2)*R1*DT
      EP=EP+(AIO**2)*RP*DT
      R2=R20+G2*E2
      R1=R10+G1*E1
      RP=RP0+GP*EP
      ALP=AMU*ALENG*DO/B
      AIN=AIO-DT*(QO/C+(R1+R2+RP)*AIO+P2*VO*AIO)/(AL1+AL2+ALP)
      EOTH=.5*(AL1+AL2+AMU*ALENG*DN/B)*(AIN**2)+.5*(QN**2)/C
      T=T+DT
      QO=QN
      DO=DN
      VO=VN
      AIO=AIN
      J=J+1
      IF(J.EQ.NCPP) GO TO 500
      GO TO 100
 300  AILO=AIO
      AIRO=AIO
      A11=AL1+ALC
      A21=-ALC
      A12=-ALC
 320  IF(T.GT.TP) GO TO 600
      QN=QO+DT*AILO
      DN=DO+VO*DT
      VN=VO+DT*P1*(AIRO**2)/2.
      E1=E1+(AILO**2)*R1*DT
      E2=E2+(AIRO**2)*R2*DT
      EP=EP+(AIRO**2)*RP*DT
      EC=EC+((AIRO-AILO)**2)*RC*DT
```

```
       R1=R10+G1*E1
       R2=R20+G2*E2
       RP=RP0+GP*EP
       RC=RC0+GC*EC
       A13=-Q0/C-(R1+RC)*AILO+RC*AIRO
       A23= RC*AILO-(R2+RP+RC+AMU*ALENG*VO/B)*AIRO
       A22=ALC+AL2+P2*DO
       BB=(A11*A23-A21*A13)/(A11*A22-A21*A12)
       AIRN=AIRO+DT*BB
       AILN=AILO+DT*(A13/A11-(A12/A11)*BB)
       EOTH=.5*(AL1)*(AILN**2)+.5*(AL2+P2*DN)*(AIRN**2)+.5*(ALC)*((AIRN
      1-AILN)**2)+.5*(QN**2)/C
       T=T+DT
       QO=QN
       DO=DN
       VO=VN
       AILO=AILN
       AIRO=AIRN
       J=J+1
       IFLAG=1
       IF(J.EQ.NCPP) GO TO 500
       GO TO 320
 500   TT(M)=T
       VOLT(M)=-QN/C
       PE(M)=C*AMASS*(VN**2)/(Q0**2)
       D(M)=DN
       V(M)=VN
       EPM(M)=EP
       RPM(M)=RP
       EOM(M)=EOTH
       EBAL(M)=C*(EOTH+E1+E2+EP+EC+.5*AMASS*(VN**2))/(.5*(Q0**2))
       SI(M)=AMASS*VN/(B*ALENG)
       IF(IFLAG.EQ.1) GO TO 550
       AI(M)=AIN
       M=M+1 $J=0 $GO TO 100
 550   AI(M)=AIRN
       M=M+1
       J=0
       GO TO 320
 600   MMAX=M-1
       PRINT 1005
       PRINT 1060
       PRINT 1070
       PRINT 1075
       DO 700 M=1,MMAX
       D(M)=D(M)*100.
       V(M)=.0001*V(M)
       TT(M)=1000000.*TT(M)
       SI(M)=10.*SI(M)
       IF(M.NE.50) GO TO 680
       PRINT 1005 $PRINT 1060$ PRINT 1070$   PRINT 1075
 680   PRINT 1080,TT(M),VOLT(M),AI(M),RPM(M),EPM(M),EOM(M),PE(M),EBAL(M),
      1D(M),V(M),SI(M)
 700   CONTINUE
       CALL PLOT CT1(TT,VOLT,MMAX,10.,8.,1H*,TIT1,4)
       CALL PLOT CT1(TT,AI,MMAX,10.,8.,1H*,TIT2,3)
       CALL PLOT CT1(TT,PE,MMAX,10.,8.,1H*,TIT3,3)
       CALL PLOT CT1(TT,V,MMAX,10.,8.,1H*,TIT4,3)
```

```
      CALL PLOT CT1(D,V,MMAX,10.,8.,1H*,TIT5,4)
      CALL PLOT CT1(TT,D,MMAX,10.,8.,1H*,TIT6,2)
      DO 720 M=1,MMAX
720   D(M)=D(M)/(.00254)
      CALL PLOT CT1(TT,D,MMAX,10.,8.,1HM,TIT7,3)
999   CONTINUE
      STOP
1000  FORMAT(8E10.3)
1005  FORMAT(///*1*)
1050  FORMAT(*      TIME MONITORED UNTIL =*,E10.3,*  WITH INCREMENT=*,E10
     1.3,* SEC    NUMBER OF CYCLES PER PLOT =*,I5//)
1060  FORMAT(8X,      *TIME       VOLTAGE     CURRENT      FLYER      HEAT IN
     1    STORED     EFFICIENCY  ENERGY      PLATE        PLATE      SPECIFI
     2C*)
1070  FORMAT(19X,*ON CAP      IN FLYER  RESISTANCE    FLYER     LC ENERGY  O
     1F SYSTEM    BALANCE   SEPARATION  VELOCITY      IMPULSE*)
1075  FORMAT(7X,*(USEC)           (VOLTS)      (AMPS)       (OHMS)      (JOULES)
     1(JOULES)*,26X,*(CM)          (CM/USEC)     (TAPS)*/)
1080  FORMAT(5X,11E11.2)
2000  FORMAT(*1*,38X,*CIRCUIT DIAGRAM*////)
2010  FORMAT(12X,*R10=*,E10.3,*  L1=*,E10.3,*         R20=*,E10.3,*  L2=*,
     1E10.3)
2020  FORMAT(13X,*G1=*,E10.3,22X,*G2=*,E10.3,/)
2030  FORMAT(9X,*-----RRRR-----LLLL-----------------------RRRR-----LLLL
     1---------*)
2040  FORMAT(9X,*-*,30X,*-*,30X,*-*)
2050  FORMAT(9X,*-*,30X,*R*,30X,*-*)
2060  FORMAT(9X,*-*,30X,*R   RCROWBAR=*,E10.3,8X,*-*)
2070  FORMAT(9X,*-*,30X,*R    GCBAR  =*,E10.3,8X,*R   RPLATES=*,E10.3)
2080  FORMAT(9X,*-*,30X,*R*,30X,*R    GPLATE=*,E10.3)
2090  FORMAT(9X,*-*,30X,*-*,30X,*R*)
2100  FORMAT(9X,*-   INITIAL CAPACITOR*,10X,*-*,30X,*-*)
2110  FORMAT(9X,*-    VOLTAGE =*,E10.3,7X,*-*,30X,*-*)
2120  FORMAT(8X,*CCC*,29X,*-*,30X,*-*)
2130  FORMAT(8X,*CCC*,29X,*L   LCROWBAR=*,E10.3,8X,*-*)
2140  FORMAT(9X,*-*,30X,*L*,30X,*E   D(0)=*,E10.3)
2150  FORMAT(9X,*-   CAPACITANCE=*,E10.3,5X,*L*,30X,*E   WIDTH=*,E10.3)
2160  FORMAT(9X,*-*,30X,*L*,30X,*E   LENGTH=*,E10.3)
2170  FORMAT(9X,*-*,30X,*-*,30X,*E   MASS=*,E10.3)
2180  FORMAT(9X,*-*,35X,*SWITCHING TIME*,12X,*-*)
2190  FORMAT(9X,*-*,31X,*/      =*,E10.3,13X,*-*)
2200  FORMAT(9X,*------------------------------------------------------------
     1--------*///)
2210  FORMAT(18X,*ALL UNITS OF THE ABOVE INPUT NUMBERS ARE CONSISTENT MK
     1S*)
      END
```

```
      SUBROUTINE PLOT CT1 (X,Y,NX,XLN,YLN,ISYM,TITLE,NT)
      DIMENSION X(1),Y(1),TITLE(1),IPLT(121),XAXIS(13)
      DATA (ISPC=1H ),(IPER=1H.),(IPLS=1H+)
      INTEGER YAXIS
C
      NS=XLN
      NS1=NS*10+1
      NS2=NS+1
      N=(YLN*6.)/4.
      NY=N*4+1
      ZN=N
      CALL SCALE(X,NX,XLN,XMN,XSCALE)
      CALL SCALE(Y,NX,ZN,YMN,YSCALE)
C
C         TITLE THE PLOT
C
      IF(NT.GT.0)  GO TO 30
      PRINT 1030
      GO TO 40
   30 PRINT 1030,(TITLE(I),I=1,NT)
   40 PRINT 1040
C
C         PRINT THE PLOT ONE ROW AT A TIME
C
      DO 200 I=1,NY
      DO 100 J=2,NS1
  100 IPLT(J) = ISPC
      IPLT(1) = IPER
      IPLT(NS1) = IPER
      YAXIS = ISPC
      J=(I-1)/4
      IF(J*4.NE.I-1) GO TO 150
      IPLT(1) = IPLT(NS1) = IPLS
      IF(I.NE.1.AND.I.NE.NY) GO TO 120
      DO 110 L=1,NS1
      IPLT(L) = IPER
      IF((L-1)/10*10.EQ.L-1) IPLT(L)=IPLS
  110 CONTINUE
  120 AL=(N-J)*YSCALE+YMN
      ENCODE(9,1000,YAXIS) AL
C
C         CALCULATE THE PLOT POSITIONS
C
  150 DO 180 K=1,NX
      YPOINT=(Y(K)-YMN)/YSCALE
      IY=YPOINT*4.+.5
      IY=NY-IY
      IF(IY.NE.I) GO TO 180
      IX = (X(K)-XMN)/XSCALE*10.+1.5
      IF(IX.GT.NS1) IX=NS1
      IPLT(IX) = ISYM
  180 CONTINUE
      PRINT 1010,YAXIS,(IPLT(J),J=1,NS1)
  200 CONTINUE
      IFACT=ALOG10(10.*XSCALE+XMN)
      DO 250 I=1,NS2
      B=I-1
```

```
  250 XAXIS(I)=(B*XSCALE+XMN)/(10.**IFACT)
      PRINT 1020,(XAXIS(J),J=1,NS2)
      IF(IFACT.NE.0) PRINT 1050,IFACT
      RETURN
 1000 FORMAT(E9.2)
 1010 FORMAT(X,A9,X,121A1)
 1020 FORMAT(/2X 13F10.4)
 1030 FORMAT(2H1 ,10A8)
 1040 FORMAT(1H )
 1050 FORMAT(/45X 8HX  10 ** I3)
      END
```

```
      SUBROUTINE SCALE(X,NX,S,XMIN,DX)
C
C           THIS SUBROUTINE FINDS MAXIMUM AND MINIMUM VALUE IN THE
C           ARRAY X.  IT THEN ADJUSTS  THESE TO OPTIMIZE THE PLOT WHILE
C           MAINTAINING REASONABLE VALUES FOR AXIS ANNOTATION.
C
C           ARGUEMENTS
C               X    - ARRAY TO BE SCALED FOR PLOTTING.
C               N    - NUMBER OF POINTS IN ARRAY X
C               S    - LENGTH OF THE AXIS OVER WHICH THESE NUMBERS ARE
C                      TO BE APPLIED.
C               XMIN - MINIMUM VALUE OF X
C               DX   - INCREMENT OF VARIABLE FOR ONE INCH TICK ALONG AXIS
C
      DIMENSION X(1),DXX(7)
      DATA (DXX=1.,2.,2.5,4.,5.,10.,20.)
C           DETERMINE MAXIMUM AND MINIMUM VALUES OF X
      XL = X
      XS = X
      DO 10 I=1,NX
      IF(XL.LT.X(I)) XL=X(I)
      IF(XS.GT.X(I)) XS=X(I)
 10   CONTINUE
      DS=(XL-XS)/S
      IF(DS.GT.0.) GO TO 20
      PRINT 100,(X(I),I=1,NX)
      STOP
C           DETERMINE VARIABLE INCREMENT.
   20 N=0
      ND=-1
      IF(DS.LT.1.) ND=1
   30 IF(DS.GE.1..AND.DS.LT.10.) GO TO 40
      N=N+ND
      DS=DS*10.**ND
      GO TO 30
   40 L=0
   50 L=L+1
      DX=DXX(L)
      IF(DS.GT.DX) GO TO 50
      DX=DX/10.**N
      IX=XS/DX
      IF(XS.LT.0. .AND. XS.NE.IX*DX) IX = IX-1
      XMIN=IX*DX
      IF(XMIN+S*DX.LT.XL*.99999) GO TO 50
      RETURN
  100 FORMAT(1H1,*ERROR IN INPUT ARRAY TO SCALE*/(1H ,E18.10))
      END
```

The sample problem is a very simple example which has previously been solved on an analog computer at Sandia Laboratories. The analog simulation considered only a simple series circuit with an effective line resistance, a capacitor, and a resistance less parallel plate flyer. Input numbers for this problem on MAGFL are

```
        /    AN    /          /          /          /          /          /          /
CARD 1  1.000E+00

        /    VC    /    C     /   R10    /    G1    /   AL1    /   R20    /    G2    /   AL2
CARD 2  4.000E+04  1.250E-03  4.000E-04  0.         0.         0.         0.         0.

        /   RCO    /    GC    /   ALC    /          /          /          /          /
CARD 3  0.         0.         0.

        /  ALENG   /    B     /  AMASS   /   RPO    /    GP    /    DO    /          /
CARD 4  1.270E+00  8.000E-01  4.480E+00  0.         0.         2.500E-04

        /    TP    /    TS    /          /          /          /          /          /
CARD 5  1.000E-05  1.000E-05
```

where all units are in MKS and all formats 8E10.3.

The output of MAGFL for this problem consists of 9 pages. On the first page appears a circuit diagram with all appropriate input parameters. The second and third pages consist of a table of various dependent variables for 100 different times. (The units are reported above the columns). The next six pages plot several combinations of these quantities that are listed in the tabular output.

Figure 3 is a reproduction of the analog computer output. However, this comparison cannot be construed to be a complete check of MAGFL due to the simplified nature of the check problem.

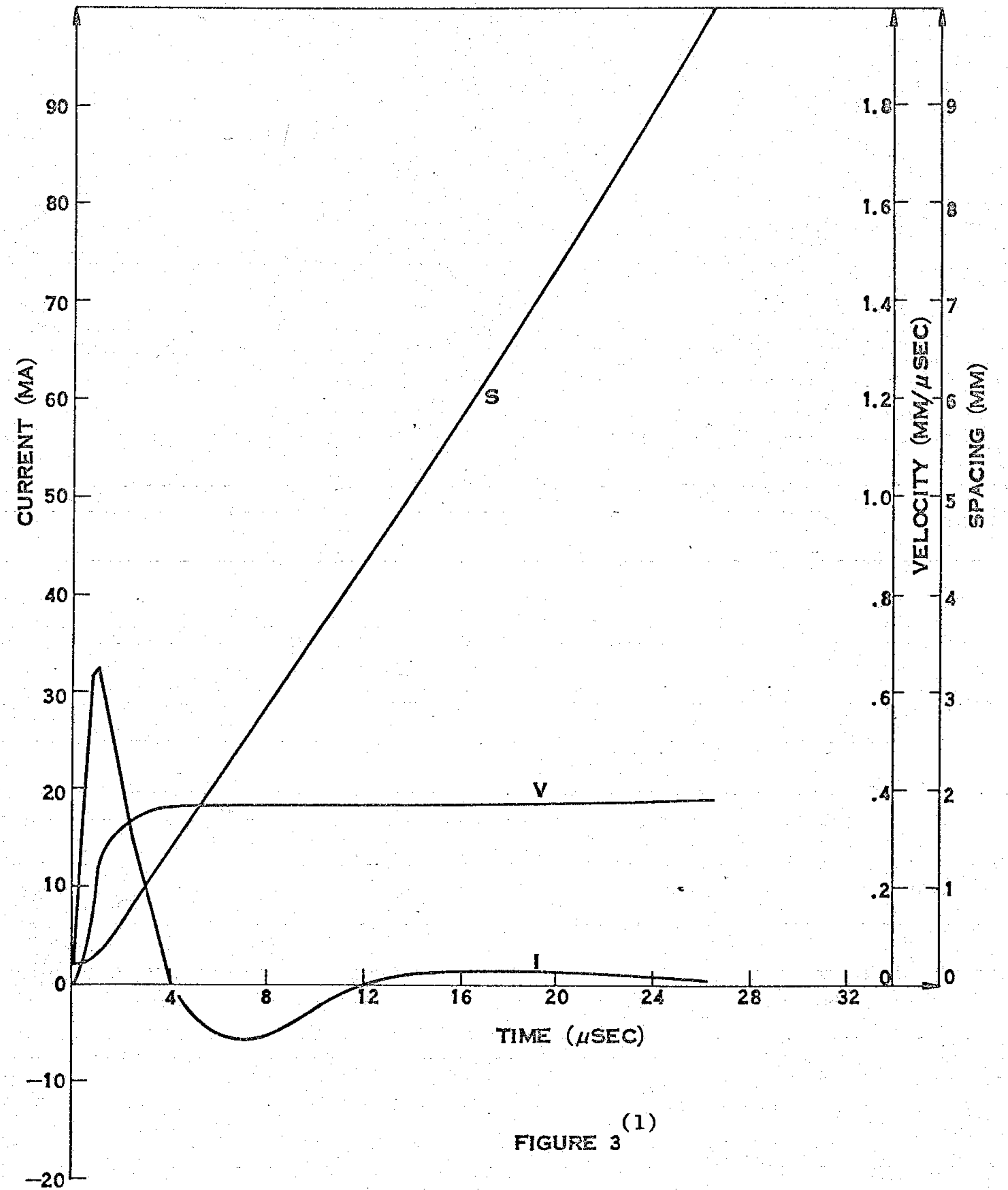

FIGURE 3(1)

SANDIA LABORATORIES

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1. SC-TM-69-106, "Analog Simulation of a Capacitor Bank Powered Flyer Plate", February 1969, Sandia Laboratories, Albuquerque, N. M.

```
                                    CIRCUIT DIAGRAM


        R10= 4.000E-04  L1= 0.                     R20= 0.          L2= 0.
         G1= 0.                                     G2= 0.
     -----RRRR-----LLLL------------------------RRRR-----LLLL---------
     -                              -                               -
     -                              -                               -
     -                              -                               -
     -                              R                               -
     -                              R   RCROWBAR= 0.                -
     -                              R    GCBAR   = 0.               R  RPLATES= 0.
     -                              R                               R   GPLATE= 0.
     -                              -                               R
     -                              -                               R
     -   INITIAL CAPACITOR          -                               -
     -    VOLTAGE = 4.000E+04       -                               -
    CCC                             -                               -
    CCC                             L   LCROWBAR= 0.                -
     -                              L                               E  D(0)= 2.500E-04
     -   CAPACITANCE= 1.250E-03     L                               E  WIDTH= 8.000E-01
     -                              L                               E  LENGTH= 1.270E+00
     -                              -                               E  MASS= 4.480E+00
     -                              -                               -
     -                                   SWITCHING TIME             -
     -                              /      = 1.000E-05              -
     -                              -                               -
     -                              -                               -
     -                              -                               -
     -                              -                               -
     ----------------------------------------------------------------

             ALL UNITS OF THE ABOVE INPUT NUMBERS ARE CONSISTENT MKS
TIME MONITORED UNTIL = 1.000E-05  WITH INCREMENT= 7.906E-10 SEC    NUMBER OF CYCLES PER PLOT =  127
```

```
  TIME     VOLTAGE   CURRENT     FLYER     HEAT IN    STORED   EFFICIENCY  ENERGY     PLATE       PLATE     SPECIFIC
            ON CAP   IN FLYER  RESISTANCE   FLYER   LC ENERGY  OF SYSTEM  BALANCE  SEPARATION  VELOCITY    IMPULSE
 (USEC)    (VOLTS)    (AMPS)    (OHMS)    (JOULES)  (JOULES)                          (CM)     (CM/USEC)    (TAPS)

1.00E-01   3.97E+04   7.70E+06   0.         0.       9.99E+05   4.49E-07  1.00E+00  2.50E-02   4.48E-05   1.97E+01
2.01E-01   3.88E+04   1.47E+07   0.         0.       9.94E+05   2.53E-05  1.00E+00  2.50E-02   3.36E-04   1.48E+02
3.01E-01   3.74E+04   2.08E+07   0.         0.       9.81E+05   2.49E-04  1.00E+00  2.51E-02   1.05E-03   4.65E+02
4.02E-01   3.55E+04   2.61E+07   0.         0.       9.58E+05   1.18E-03  1.00E+00  2.52E-02   2.30E-03   1.01E+03
5.02E-01   3.32E+04   3.03E+07   0.         0.       9.23E+05   3.75E-03  1.00E+00  2.56E-02   4.09E-03   1.81E+03
6.02E-01   3.06E+04   3.34E+07   0.         0.       8.77E+05   9.12E-03  1.00E+00  2.61E-02   6.38E-03   2.81E+03
7.03E-01   2.79E+04   3.53E+07   0.         0.       8.20E+05   1.83E-02  1.00E+00  2.69E-02   9.04E-03   3.99E+03
8.03E-01   2.50E+04   3.62E+07   0.         0.       7.55E+05   3.18E-02  1.00E+00  2.79E-02   1.19E-02   5.25E+03
9.04E-01   2.21E+04   3.61E+07   0.         0.       6.85E+05   4.94E-02  1.00E+00  2.92E-02   1.49E-02   6.55E+03
1.00E+00   1.92E+04   3.52E+07   0.         0.       6.13E+05   7.02E-02  1.00E+00  3.09E-02   1.77E-02   7.81E+03
1.10E+00   1.64E+04   3.38E+07   0.         0.       5.43E+05   9.30E-02  1.00E+00  3.28E-02   2.04E-02   8.99E+03
1.20E+00   1.38E+04   3.19E+07   0.         0.       4.76E+05   1.16E-01  1.00E+00  3.50E-02   2.28E-02   1.01E+04
1.31E+00   1.13E+04   2.99E+07   0.         0.       4.14E+05   1.39E-01  1.00E+00  3.74E-02   2.49E-02   1.10E+04
1.41E+00   9.00E+03   2.78E+07   0.         0.       3.59E+05   1.61E-01  1.00E+00  4.00E-02   2.68E-02   1.18E+04
1.51E+00   6.85E+03   2.57E+07   0.         0.       3.11E+05   1.81E-01  1.00E+00  4.27E-02   2.84E-02   1.25E+04
1.61E+00   4.87E+03   2.36E+07   0.         0.       2.69E+05   1.99E-01  1.00E+00  4.57E-02   2.98E-02   1.31E+04
1.71E+00   3.06E+03   2.16E+07   0.         0.       2.33E+05   2.14E-01  1.00E+00  4.87E-02   3.09E-02   1.36E+04
1.81E+00   1.40E+03   1.97E+07   0.         0.       2.02E+05   2.28E-01  1.00E+00  5.19E-02   3.19E-02   1.41E+04
1.91E+00  -1.08E+02   1.79E+07   0.         0.       1.77E+05   2.39E-01  1.00E+00  5.51E-02   3.27E-02   1.44E+04
2.01E+00  -1.48E+03   1.62E+07   0.         0.       1.55E+05   2.49E-01  1.00E+00  5.84E-02   3.33E-02   1.47E+04
2.11E+00  -2.72E+03   1.47E+07   0.         0.       1.38E+05   2.57E-01  1.00E+00  6.18E-02   3.39E-02   1.49E+04
2.21E+00  -3.84E+03   1.32E+07   0.         0.       1.23E+05   2.63E-01  1.00E+00  6.52E-02   3.43E-02   1.51E+04
2.31E+00  -4.85E+03   1.19E+07   0.         0.       1.11E+05   2.69E-01  1.00E+00  6.87E-02   3.46E-02   1.53E+04
2.41E+00  -5.75E+03   1.06E+07   0.         0.       1.02E+05   2.73E-01  1.00E+00  7.22E-02   3.49E-02   1.54E+04
2.51E+00  -6.55E+03   9.44E+06   0.         0.       9.43E+04   2.77E-01  1.00E+00  7.57E-02   3.52E-02   1.55E+04
2.61E+00  -7.27E+03   8.35E+06   0.         0.       8.83E+04   2.80E-01  1.00E+00  7.92E-02   3.53E-02   1.56E+04
2.71E+00  -7.90E+03   7.34E+06   0.         0.       8.36E+04   2.82E-01  1.00E+00  8.28E-02   3.55E-02   1.56E+04
2.81E+00  -8.45E+03   6.41E+06   0.         0.       8.01E+04   2.84E-01  1.00E+00  8.63E-02   3.56E-02   1.57E+04
2.91E+00  -8.93E+03   5.53E+06   0.         0.       7.73E+04   2.85E-01  1.00E+00  8.99E-02   3.57E-02   1.57E+04
3.01E+00  -9.34E+03   4.72E+06   0.         0.       7.54E+04   2.86E-01  1.00E+00  9.35E-02   3.57E-02   1.57E+04
3.11E+00  -9.69E+03   3.96E+06   0.         0.       7.39E+04   2.86E-01  1.00E+00  9.71E-02   3.58E-02   1.58E+04
3.21E+00  -9.98E+03   3.26E+06   0.         0.       7.29E+04   2.87E-01  1.00E+00  1.01E-01   3.58E-02   1.58E+04
3.31E+00  -1.02E+04   2.60E+06   0.         0.       7.23E+04   2.87E-01  1.00E+00  1.04E-01   3.58E-02   1.58E+04
3.41E+00  -1.04E+04   1.99E+06   0.         0.       7.19E+04   2.87E-01  1.00E+00  1.08E-01   3.58E-02   1.58E+04
3.51E+00  -1.05E+04   1.43E+06   0.         0.       7.16E+04   2.87E-01  1.00E+00  1.11E-01   3.58E-02   1.58E+04
3.61E+00  -1.06E+04   9.01E+05   0.         0.       7.15E+04   2.88E-01  1.00E+00  1.15E-01   3.58E-02   1.58E+04
3.72E+00  -1.07E+04   4.11E+05   0.         0.       7.15E+04   2.88E-01  1.00E+00  1.19E-01   3.58E-02   1.58E+04
3.82E+00  -1.07E+04  -4.30E+04   0.         0.       7.15E+04   2.88E-01  1.00E+00  1.22E-01   3.58E-02   1.58E+04
3.92E+00  -1.07E+04  -4.64E+05   0.         0.       7.15E+04   2.88E-01  1.00E+00  1.26E-01   3.58E-02   1.58E+04
4.02E+00  -1.06E+04  -8.54E+05   0.         0.       7.15E+04   2.88E-01  1.00E+00  1.29E-01   3.58E-02   1.58E+04
4.12E+00  -1.05E+04  -1.21E+06   0.         0.       7.14E+04   2.88E-01  1.00E+00  1.33E-01   3.58E-02   1.58E+04
4.22E+00  -1.04E+04  -1.55E+06   0.         0.       7.13E+04   2.88E-01  1.00E+00  1.37E-01   3.58E-02   1.58E+04
4.32E+00  -1.03E+04  -1.85E+06   0.         0.       7.10E+04   2.88E-01  1.00E+00  1.40E-01   3.58E-02   1.58E+04
4.42E+00  -1.01E+04  -2.14E+06   0.         0.       7.07E+04   2.88E-01  1.00E+00  1.44E-01   3.59E-02   1.58E+04
4.52E+00  -9.95E+03  -2.40E+06   0.         0.       7.03E+04   2.88E-01  1.00E+00  1.47E-01   3.59E-02   1.58E+04
4.62E+00  -9.75E+03  -2.63E+06   0.         0.       6.99E+04   2.88E-01  1.00E+00  1.51E-01   3.59E-02   1.58E+04
4.72E+00  -9.53E+03  -2.85E+06   0.         0.       6.93E+04   2.89E-01  1.00E+00  1.55E-01   3.59E-02   1.58E+04
4.82E+00  -9.29E+03  -3.04E+06   0.         0.       6.86E+04   2.89E-01  1.00E+00  1.58E-01   3.59E-02   1.58E+04
4.92E+00  -9.04E+03  -3.22E+06   0.         0.       6.79E+04   2.89E-01  1.00E+00  1.62E-01   3.59E-02   1.58E+04
```

```
   TIME       VOLTAGE     CURRENT      FLYER      HEAT IN      STORED     EFFICIENCY   ENERGY       PLATE        PLATE      SPECIFIC
               ON CAP    IN FLYER   RESISTANCE     FLYER     LC ENERGY    OF SYSTEM   BALANCE    SEPARATION    VELOCITY     IMPULSE
  (USEC)      (VOLTS)     (AMPS)      (OHMS)     (JOULES)    (JOULES)                              (CM)      (CM/USEC)     (TAPS)

  5.02E+00   -8.77E+03   -3.38E+06    0.          0.         6.70E+04    2.90E-01    1.00E+00    1.65E-01    3.60E-02    1.59E+04
  5.12E+00   -8.50E+03   -3.53E+06    0.          0.         6.61E+04    2.90E-01    1.00E+00    1.69E-01    3.60E-02    1.59E+04
  5.22E+00   -8.21E+03   -3.65E+06    0.          0.         6.52E+04    2.91E-01    1.00E+00    1.73E-01    3.60E-02    1.59E+04
  5.32E+00   -7.91E+03   -3.77E+06    0.          0.         6.41E+04    2.91E-01    1.00E+00    1.76E-01    3.60E-02    1.59E+04
  5.42E+00   -7.60E+03   -3.86E+06    0.          0.         6.30E+04    2.92E-01    1.00E+00    1.80E-01    3.61E-02    1.59E+04
  5.52E+00   -7.29E+03   -3.95E+06    0.          0.         6.18E+04    2.92E-01    1.00E+00    1.84E-01    3.61E-02    1.59E+04
  5.62E+00   -6.97E+03   -4.02E+06    0.          0.         6.06E+04    2.93E-01    1.00E+00    1.87E-01    3.61E-02    1.59E+04
  5.72E+00   -6.64E+03   -4.08E+06    0.          0.         5.94E+04    2.93E-01    1.00E+00    1.91E-01    3.62E-02    1.60E+04
  5.82E+00   -6.31E+03   -4.13E+06    0.          0.         5.81E+04    2.94E-01    1.00E+00    1.94E-01    3.62E-02    1.60E+04
  5.92E+00   -5.98E+03   -4.17E+06    0.          0.         5.68E+04    2.95E-01    1.00E+00    1.98E-01    3.63E-02    1.60E+04
  6.02E+00   -5.65E+03   -4.19E+06    0.          0.         5.54E+04    2.95E-01    1.00E+00    2.02E-01    3.63E-02    1.60E+04
  6.12E+00   -5.31E+03   -4.21E+06    0.          0.         5.41E+04    2.96E-01    1.00E+00    2.05E-01    3.63E-02    1.60E+04
  6.23E+00   -4.97E+03   -4.22E+06    0.          0.         5.27E+04    2.96E-01    1.00E+00    2.09E-01    3.64E-02    1.60E+04
  6.33E+00   -4.63E+03   -4.22E+06    0.          0.         5.13E+04    2.97E-01    1.00E+00    2.13E-01    3.64E-02    1.61E+04
  6.43E+00   -4.29E+03   -4.22E+06    0.          0.         5.00E+04    2.98E-01    1.00E+00    2.16E-01    3.65E-02    1.61E+04
  6.53E+00   -3.95E+03   -4.20E+06    0.          0.         4.86E+04    2.98E-01    1.00E+00    2.20E-01    3.65E-02    1.61E+04
  6.63E+00   -3.62E+03   -4.18E+06    0.          0.         4.73E+04    2.99E-01    1.00E+00    2.24E-01    3.65E-02    1.61E+04
  6.73E+00   -3.28E+03   -4.15E+06    0.          0.         4.59E+04    3.00E-01    1.00E+00    2.27E-01    3.66E-02    1.61E+04
  6.83E+00   -2.95E+03   -4.12E+06    0.          0.         4.46E+04    3.00E-01    1.00E+00    2.31E-01    3.66E-02    1.61E+04
  6.93E+00   -2.62E+03   -4.08E+06    0.          0.         4.33E+04    3.01E-01    1.00E+00    2.35E-01    3.67E-02    1.62E+04
  7.03E+00   -2.29E+03   -4.03E+06    0.          0.         4.20E+04    3.02E-01    1.00E+00    2.38E-01    3.67E-02    1.62E+04
  7.13E+00   -1.97E+03   -3.98E+06    0.          0.         4.08E+04    3.02E-01    1.00E+00    2.42E-01    3.67E-02    1.62E+04
  7.23E+00   -1.65E+03   -3.93E+06    0.          0.         3.96E+04    3.03E-01    1.00E+00    2.46E-01    3.68E-02    1.62E+04
  7.33E+00   -1.34E+03   -3.87E+06    0.          0.         3.84E+04    3.03E-01    1.00E+00    2.49E-01    3.68E-02    1.62E+04
  7.43E+00   -1.03E+03   -3.80E+06    0.          0.         3.73E+04    3.04E-01    1.00E+00    2.53E-01    3.68E-02    1.62E+04
  7.53E+00   -7.30E+02   -3.74E+06    0.          0.         3.62E+04    3.04E-01    1.00E+00    2.57E-01    3.69E-02    1.63E+04
  7.63E+00   -4.33E+02   -3.67E+06    0.          0.         3.51E+04    3.05E-01    1.00E+00    2.61E-01    3.69E-02    1.63E+04
  7.73E+00   -1.41E+02   -3.59E+06    0.          0.         3.41E+04    3.05E-01    1.00E+00    2.64E-01    3.69E-02    1.63E+04
  7.83E+00    1.44E+02   -3.52E+06    0.          0.         3.32E+04    3.06E-01    1.00E+00    2.68E-01    3.70E-02    1.63E+04
  7.93E+00    4.23E+02   -3.44E+06    0.          0.         3.22E+04    3.06E-01    1.00E+00    2.72E-01    3.70E-02    1.63E+04
  8.03E+00    6.96E+02   -3.36E+06    0.          0.         3.13E+04    3.07E-01    1.00E+00    2.75E-01    3.70E-02    1.63E+04
  8.13E+00    9.63E+02   -3.27E+06    0.          0.         3.05E+04    3.07E-01    1.00E+00    2.79E-01    3.70E-02    1.63E+04
  8.23E+00    1.22E+03   -3.19E+06    0.          0.         2.97E+04    3.08E-01    1.00E+00    2.83E-01    3.71E-02    1.63E+04
  8.33E+00    1.47E+03   -3.10E+06    0.          0.         2.89E+04    3.08E-01    1.00E+00    2.87E-01    3.71E-02    1.63E+04
  8.43E+00    1.72E+03   -3.01E+06    0.          0.         2.82E+04    3.08E-01    1.00E+00    2.90E-01    3.71E-02    1.64E+04
  8.53E+00    1.96E+03   -2.92E+06    0.          0.         2.75E+04    3.09E-01    1.00E+00    2.94E-01    3.71E-02    1.64E+04
  8.64E+00    2.19E+03   -2.83E+06    0.          0.         2.69E+04    3.09E-01    1.00E+00    2.98E-01    3.71E-02    1.64E+04
  8.74E+00    2.41E+03   -2.74E+06    0.          0.         2.63E+04    3.09E-01    1.00E+00    3.01E-01    3.71E-02    1.64E+04
  8.84E+00    2.63E+03   -2.65E+06    0.          0.         2.57E+04    3.09E-01    1.00E+00    3.05E-01    3.72E-02    1.64E+04
  8.94E+00    2.84E+03   -2.55E+06    0.          0.         2.52E+04    3.10E-01    1.00E+00    3.09E-01    3.72E-02    1.64E+04
  9.04E+00    3.04E+03   -2.46E+06    0.          0.         2.47E+04    3.10E-01    1.00E+00    3.13E-01    3.72E-02    1.64E+04
  9.14E+00    3.23E+03   -2.37E+06    0.          0.         2.42E+04    3.10E-01    1.00E+00    3.16E-01    3.72E-02    1.64E+04
  9.24E+00    3.42E+03   -2.27E+06    0.          0.         2.38E+04    3.10E-01    1.00E+00    3.20E-01    3.72E-02    1.64E+04
  9.34E+00    3.60E+03   -2.18E+06    0.          0.         2.34E+04    3.11E-01    1.00E+00    3.24E-01    3.72E-02    1.64E+04
  9.44E+00    3.77E+03   -2.08E+06    0.          0.         2.31E+04    3.11E-01    1.00E+00    3.28E-01    3.72E-02    1.64E+04
  9.54E+00    3.93E+03   -1.99E+06    0.          0.         2.28E+04    3.11E-01    1.00E+00    3.31E-01    3.73E-02    1.64E+04
  9.64E+00    4.09E+03   -1.89E+06    0.          0.         2.25E+04    3.11E-01    1.00E+00    3.35E-01    3.73E-02    1.64E+04
  9.74E+00    4.24E+03   -1.80E+06    0.          0.         2.22E+04    3.11E-01    1.00E+00    3.39E-01    3.73E-02    1.64E+04
  9.84E+00    4.38E+03   -1.71E+06    0.          0.         2.20E+04    3.11E-01    1.00E+00    3.43E-01    3.73E-02    1.64E+04
  9.94E+00    4.51E+03   -1.61E+06    0.          0.         2.18E+04    3.11E-01    1.00E+00    3.46E-01    3.73E-02    1.64E+04
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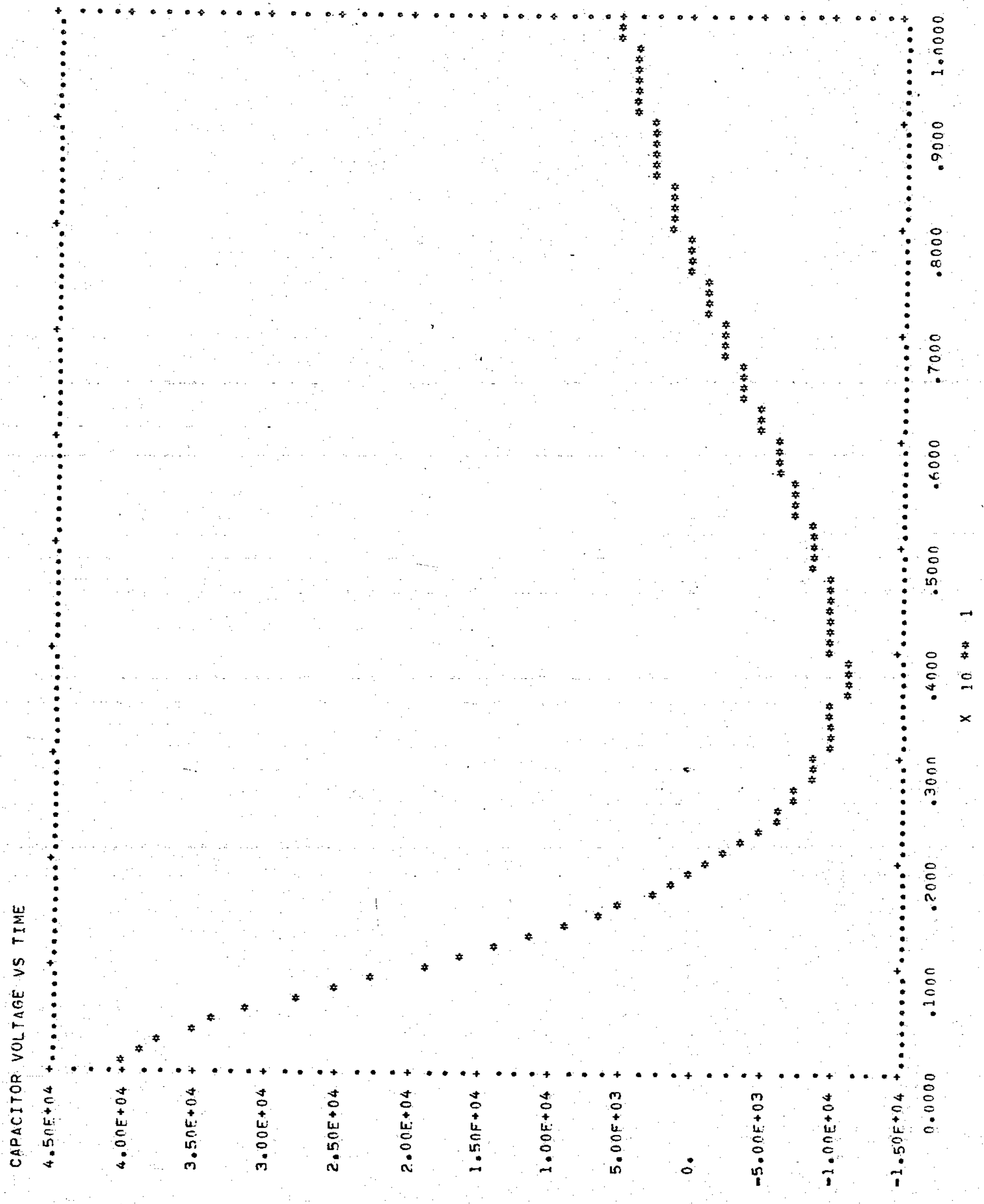
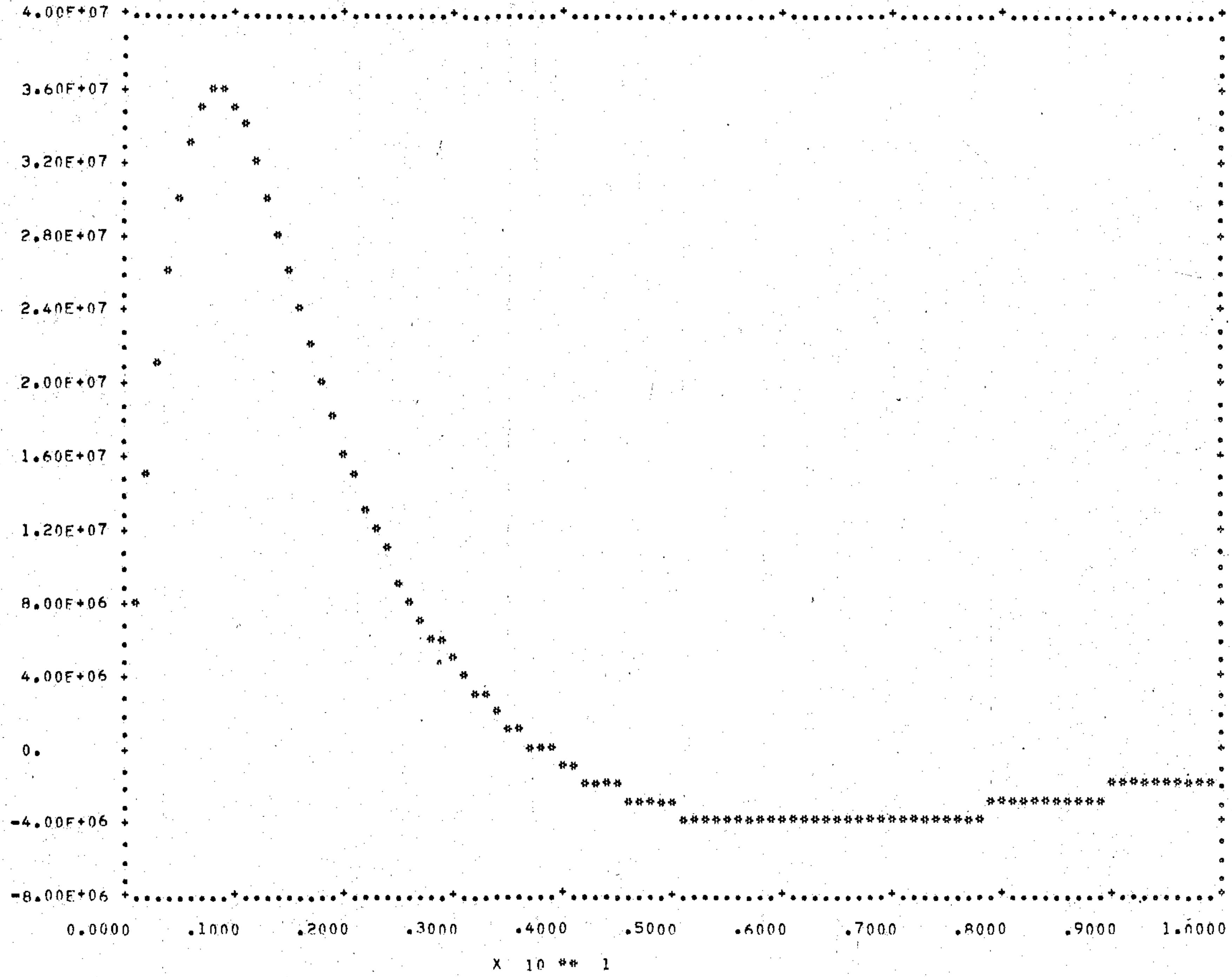
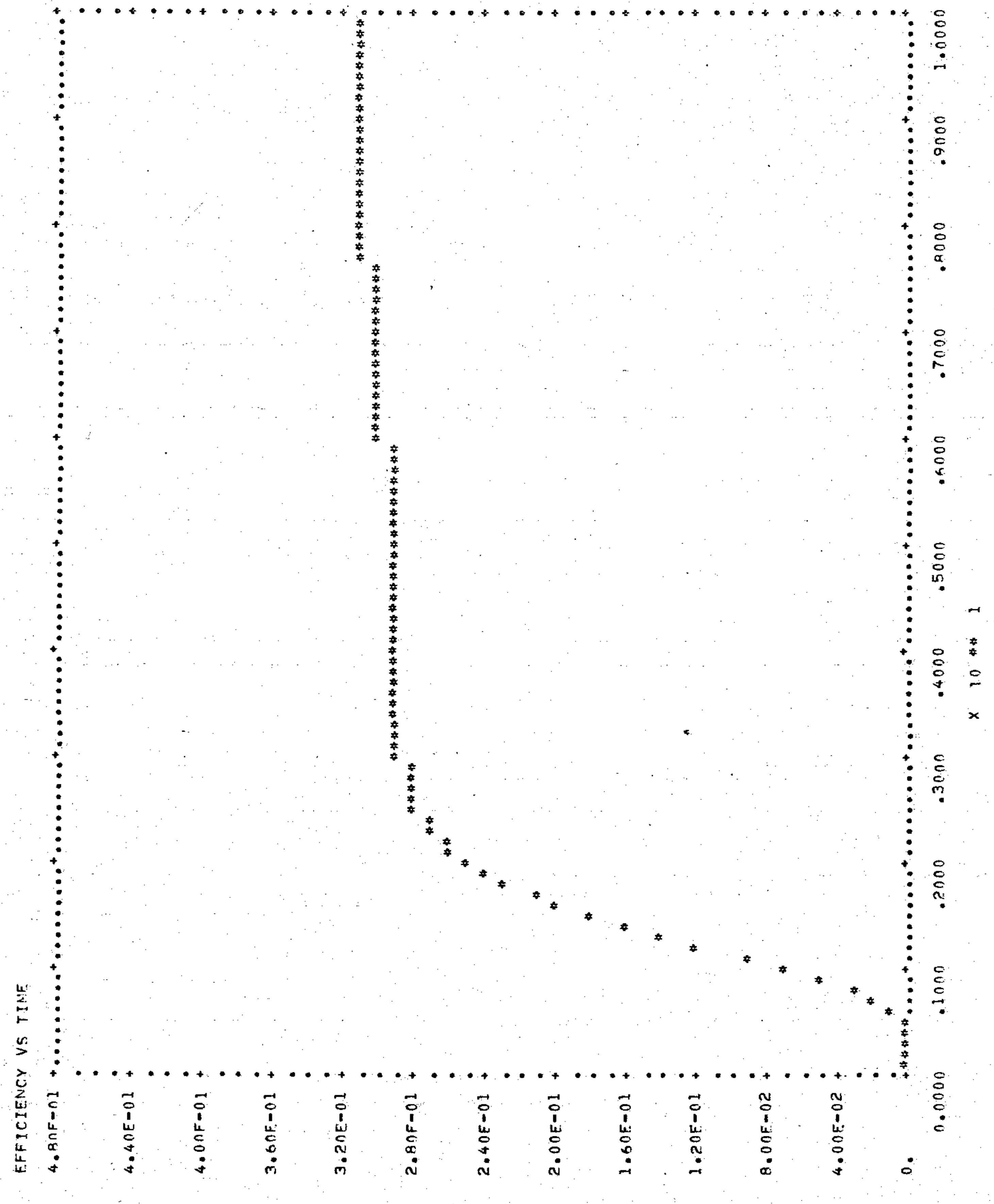


CAPACITOR VOLTAGE VS TIME

FLYER CURRENT VS TIME




EFFICIENCY VS TIME
4.80E-01
4.40E-01
4.00E-01
3.60E-01
3.20E-01
2.80E-01
2.40E-01
2.00E-01
1.60E-01
1.20E-01
8.00E-02
4.00E-02
0.
0.0000
.1000
.2000
.3000
.4000
.5000
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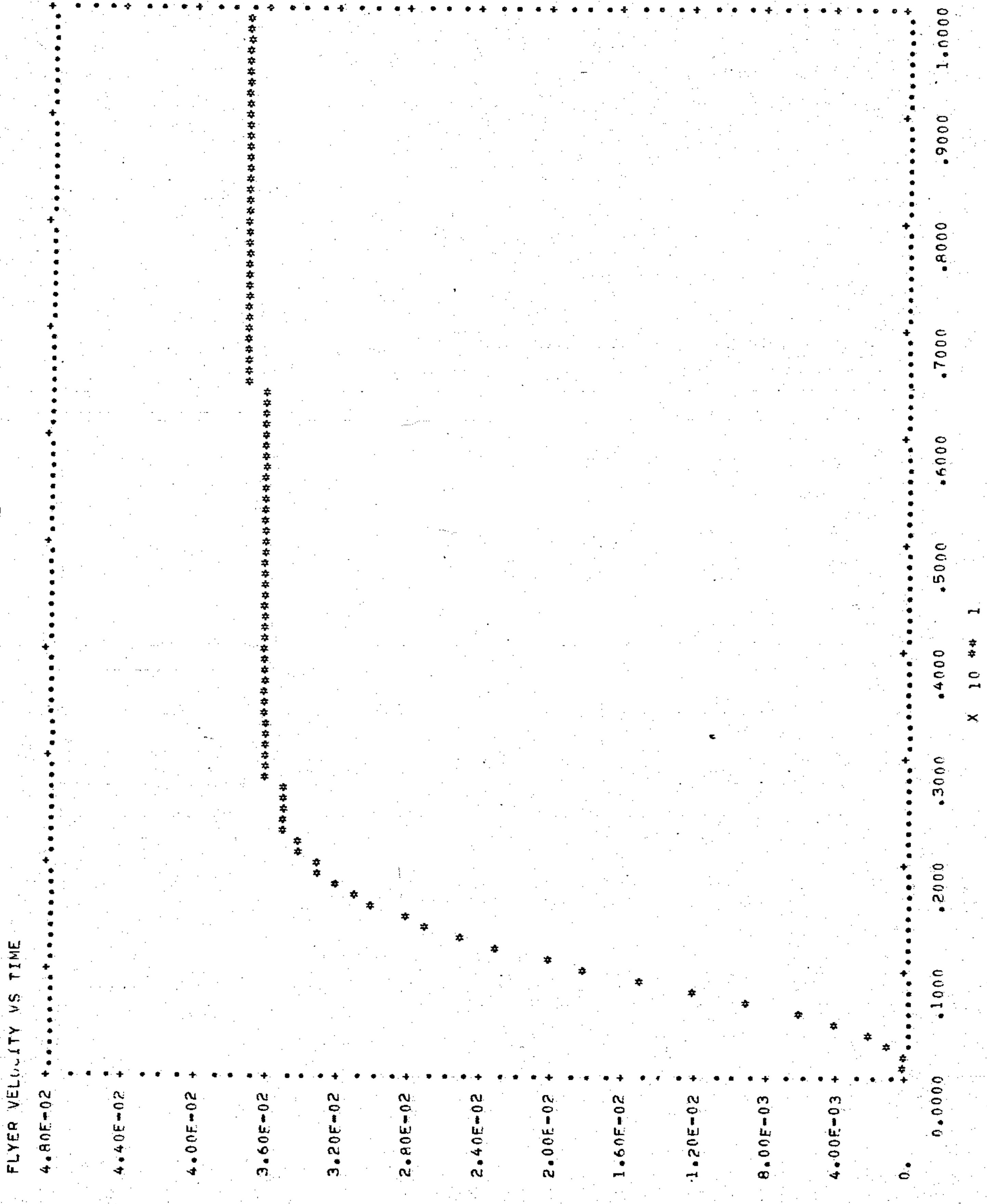
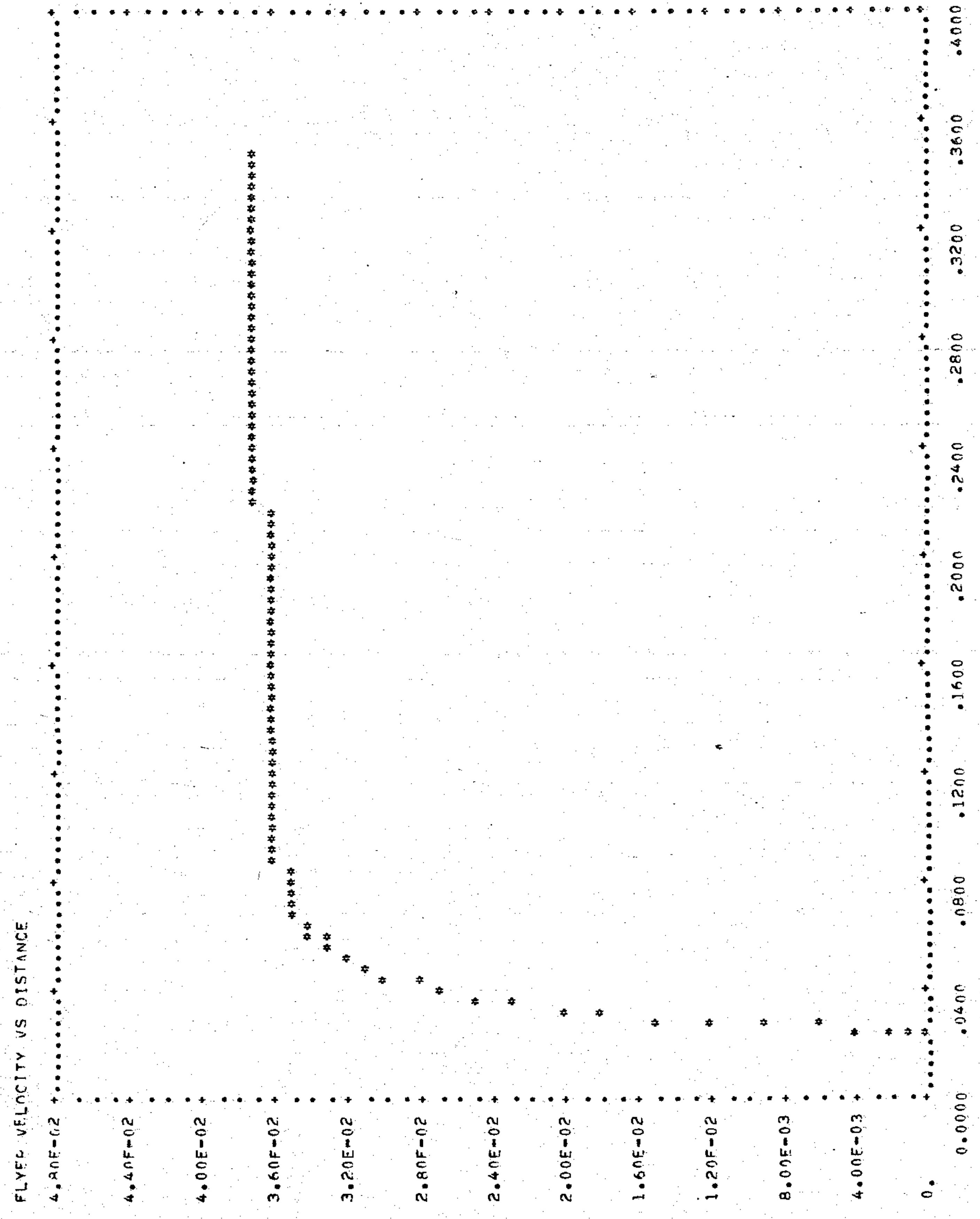
.7000
.8000
.9000
1.0000
X 10 ** 1



FLYER VELOCITY VS TIME


FLYER VELOCITY VS DISTANCE
4.80E-02
4.40E-02
4.00E-02
3.60E-02
3.20E-02
2.80E-02
2.40E-02
2.00E-02
1.60E-02
1.20E-02
8.00E-03
4.00E-03
0.
0.0000
.0400
.0800
.1200
.1600
.2000
.2400
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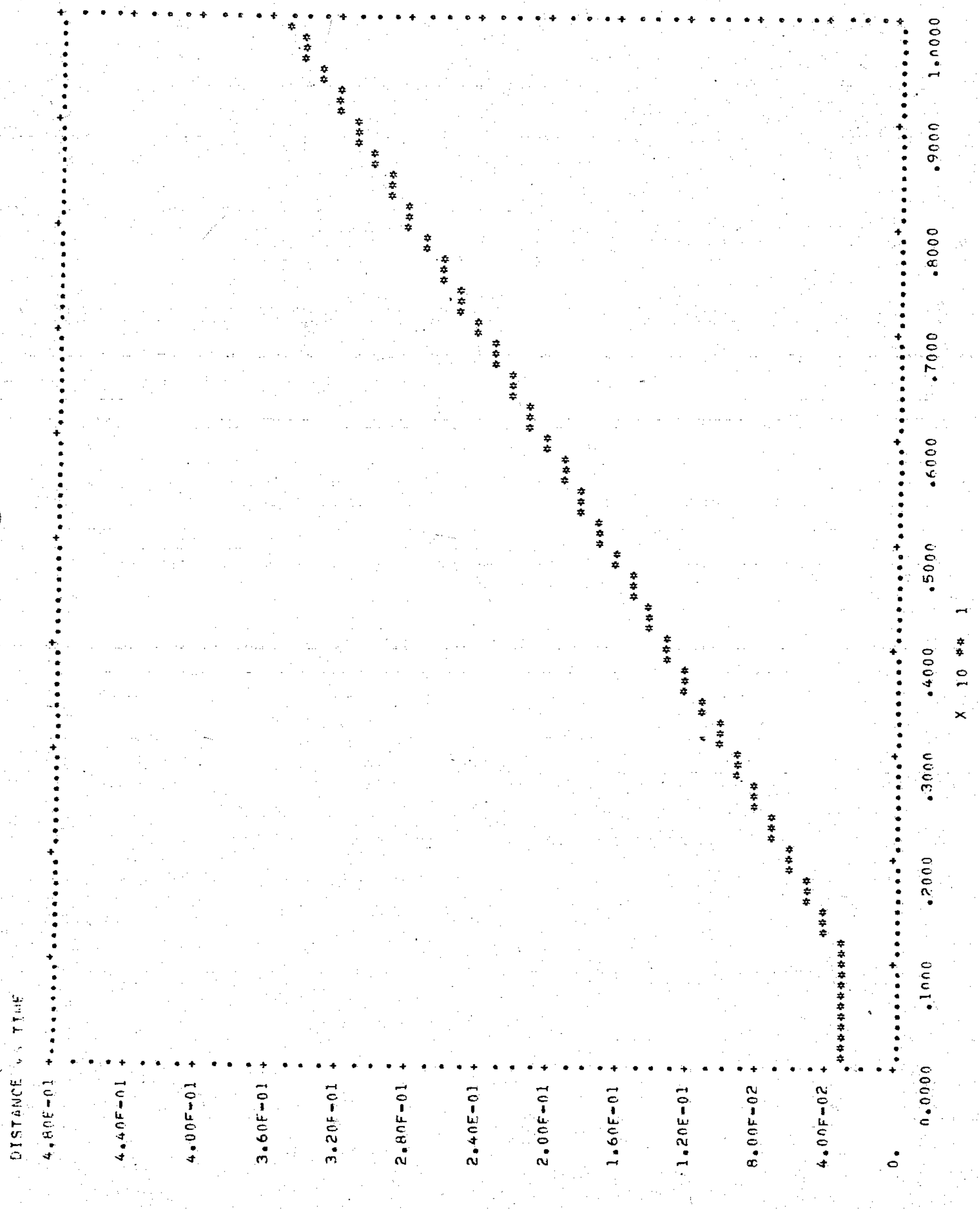
.4000


DISTANCE vs TIME
4.80E-01
4.40E-01
4.00E-01
3.60E-01
3.20E-01
2.80E-01
2.40E-01
2.00E-01
1.60E-01
1.20E-01
8.00E-02
4.00E-02
0.
0.0000
.1000
.2000
.3000
.4000
.5000
.6000
.7000
.8000
.9000
1.0000
X 10 ** 1