FPN 14

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THEORETICAL ANALYSIS OF TWO-DIMENSIONAL MAGNETIC FLYER PLATES (U)

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1. INTRODUCTION

Kaman Nuclear (KN) is currently engaged in a substantial program to propel, instrument, and understand two-dimensional, magnetically driven flyer sheets (MDFS). This effort has been sponsored by the Strategic Systems Projects Office of the Navy, and it has evolved as a natural extension of our work on one-dimensional flyer plates. Since the problems of the two-dimensional flyer are clearly far greater than those incurred in flat flyer research, a strong theoretical approach is necessary to aid in choosing the proper design for any particular experiment. For example, if a cosine-uniform impulse loading on a nose cone is an objective, the selection of the best set of conditions (capacitor bank voltage, backstrap-to-flyer initial separation distances, backstrap shape, etc.) cannot be wisely made without rather sophisticated analytical modeling. This report is a complete review of the theoretical effort at KN for this modeling; it is also concerned with the presentation of a new related computer code, MULTIFL.

MULTIFL is a finite difference code which endeavors to predict the motion and electric magnetic state of MDFS. It is the result of a "second generation" effort at KN since it follows the one-dimensional code MAGFL[(1)] and since the modeling includes many more corrections and options. MULTIFL can monitor a flyer sheet of arbitrary initial shape from its original position to times after impact allowing for non-simultaneity of contact and nonuniformity of the driving forces. The equations of motion are nonlinear in that they contain resistors and inductors which change values during the problem and in that some skin-depth corrections are made.

The subject of two-dimensional magnetic flyer simulations and the code MULTIFL are presented in this report by first outlining the derivation of the basic electromagnetic equations of motion in Section 2. These equations can be solved by the methods discussed in Section 3. Section 4 illustrates the current agreement between this theory and KN experiments. Finally several appendices are necessary to aid in the presentation of the complex subject matter.

2. BASIC THEORY

The physical phenomena associated with MDFS are very diverse. First there are intense electromagnetic fields and high current densities to understand. Second the flyers can heat to the point of melting, and thus thermal effects must be considered. Finally the flyers are structural elements with highly nonuniform body forces that can conceivably buckle or mechanically deform. All three effects are closely coupled and an understanding of each is necessary.

The logical starting point of studying MDFS is with the description of the main circuit.

2.1 Circuit Description

A schematic diagram of the basic circuit is shown in Figure 1.

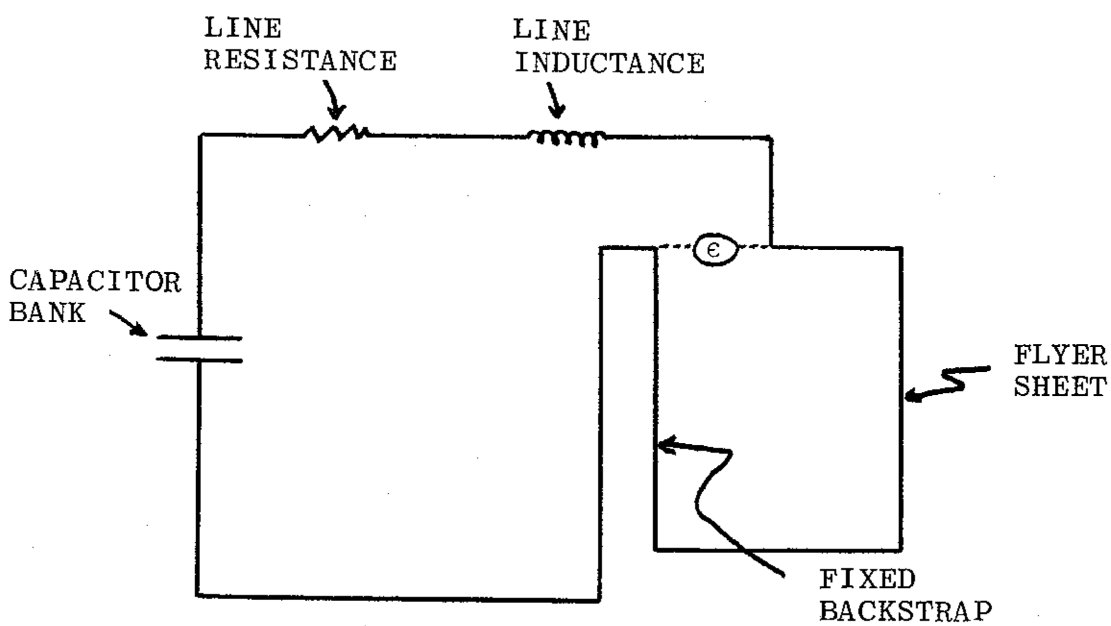


FIGURE 1
BASIC CIRCUIT

The driving component of the circuit is, of course, the capacitor bank which will be represented in MULTIFL as a linear element (charge stored is proportional to instantaneous voltage). It is not completely clear that this assumption is adequate. Many of the modern banks (i.e., our 50 kilojoule Maxwell) were designed to discharge as quickly as possible. Some significant inductance and resistance may be in series with the parallel capacitive parts. If this is the case, the bank should be represented by something resembling a transmission line, rather than a simple element. Currently standardization experiments are being performed at KN to ascertain if the need exists to evaluate the appropriate transmission line parameters.

The line resistance in Figure 1 represents a composite of the internal resistance of the bank, the backstrap resistance, and any other resistance which may be consistently present in the hardware. This resistance is characterized in MULTIFL by two constants, R_{ob} and G_b which are the room temperature resistance and the proportionality constant between additional resistance and the energy deposited by Joule heating.

$$R_b = R_{ob} + G_b \cdot E_b \qquad (1)$$

The line inductance (L_b) is also a composite except that it is assumed to be constant throughout the problem and it does not include a contribution from the backstrap.

The backstrap and the flyer sheet form a complicated inductor whose value depends on the spacial distribution of the current density, the position and shape of the sheet relative to the backstrap, and the relative velocity of the sheet. In addition, the MDFS have a skin depth sensitive resistance which must be considered. Most of the analysis in this report is related to the study of this inductive element. Further details are presented in Section 2 and the appendices.

Sequentially the bank begins to discharge with a current that is dependent upon the impedance of the complete circuit. In reaction to the current the resistors and the MDFS begin to heat, and the flyer begins to feel Lorentz type magnetic forces. This heating creates more resistance, and the forces produce flyer motion which in turn changes the inductance of the backstrap, flyer element. Clearly the circuit is nonlinear; nonetheless, it can be represented by the Kirchhoff equation

$$q/C + L_b \frac{di}{dt} + i R_b + \epsilon = 0 \qquad (2)$$

where ϵ is the voltage across the variable inductor

q = charge on the capacitor

$i = \frac{dq}{dt}$ = main circuit current

C = capacitance of the bank

Since R_b is a function of the Joule heat E_b this quantity must be monitored. At any time t

$$E_b = \int_0^t i^2 R_b \, dt \qquad (3)$$

All that is now required to solve differential equation (2) is the functional form of ϵ. Sections 2.2, 3.1 are aimed at deducing this function.

2.2 General Element Equations

The calculation of the voltage drop across the variable inductor is in most practical cases very difficult. The energy absorbed by the element is dependent upon its total current, its physical dimensions, its material properties and the relative velocities of any of its parts. The more complex the geometry, the more difficult the calculation becomes.

A general procedure for approaching the problem is the following:

$$\epsilon = \frac{\text{energy added to the element}}{\text{charge transferred through}} = \frac{dW}{dt}/i \tag{4}$$

W = stored energy

$$= W_B + W_{K.E.} + W_H \tag{5}$$

W_B = magnetostatic field energy

$W_{K.E.}$ = kinetic energy of MDFS

W_H = Joule heat

Joule heating effects are relatively easy to handle.

$$\frac{dW_H}{dt} = i^2R \tag{6}$$

where the evaluation of R is somewhat complicated by cases that consider nonuniform current densities. In the simplest example, uniform d.c. current flowing in a rectangular sheet, the resistance is

R = (resistivity)(length)/(cross-sectional area)

As current densities are perturbed by frequency and edge effects, the need for more complicated analysis arises and a review of some of the KN effort in this direction is presented in Appendix B. Temperature changes are introduced in the calculations by allowing the resistivity to vary with heating.

The rate of change of magnetic field energy and kinetic energy is known in terms of the inductance (L) by Faraday's Law

$$\frac{dW_B}{dt} + \frac{dW_{K.E.}}{dt} = i \frac{d}{dt} (Li) \tag{7}$$

where L must be defined from the following electromagnetic theory. The magnetostatic field energy (W_B) can be written in two equivalent forms

$$W_B = (1/2)\ Li^2 = (1/2) \int_\tau \vec{J} \cdot \vec{A}\ d\tau \tag{8}$$

with

$\vec{J}$ = current density vector (amps/m^2)

τ = volume of space containing current

$\vec{A}$ = vector potential = $\frac{\mu_o}{4\pi} \int_\tau \frac{\vec{J}\ d\tau}{r}$

μ_o = magnetic permeability of free space

r = distance from current source point to the field point

Equations (8) and (9) imply that if the current density for all space is known, the field energy is known; and since the current is related to the current density by

$$i = \int_a \vec{J} \cdot d\,\vec{S} \tag{10}$$

S = surface vector

L can be found by performing the indicated integrations. If $\vec{J}$ is not known, it must be deduced. In Appendices A,B and C inductance calculations are made for three geometries, two which have postulated current densities and one which uses a derived $\vec{J}$. Once L has been evaluated as a function of the possible positions of the flyer sheet, the ε voltage is determined by Equation (4).

The position of the flyer can be predicted by considering the mechanical equations of motion and structural response of the flyer sheet. Finding the magnetic body forces is the first step. From Equation (7) and the time derivative of (8)

$$\frac{dW_{K.E.}}{dt} = (i^2/2)\,\frac{dL}{dt} \tag{11}$$

If the flyer is translating as a rigid body with a velocity of v, the inductance is a function of its three position coordinates and the chain rule implies that

$$\frac{dL}{dt} = \nabla L \cdot \vec{v} \qquad (12)$$

∇L = gradient of L

From basic mechanics $\frac{dW_{K.E.}}{dt} = \vec{F} \cdot \vec{v}$ and therefore the magnetic force on the flyer is

$$F = (i^2/2) \cdot \nabla L \qquad (13)$$

For motions more complicated than translation the forces and coordinates become generalized in the classical mechanics sense and the resulting motion becomes very complex. A study of these constrained cases will not be attempted here.

3. MULTIFL

3.1 Model Assumptions

Correct calculations of resistance and inductance for any curved flyer sheet are almost impossible at the present time. For example equations (8) and (9) imply the 6 integrations must be performed for every conceivable flyer position and current density. Similarly the mechanical response of the flyer cannot be readily discussed even in the realm of "thin" shell theory. Therefore, approximations are necessary. For MULTIFL the procedure used is the following:

1. The flyer and its backstrap are divided into subelements. Each subelement consists of a flat, rectangular flyer sheet and a corresponding backstrap area.

2. Each subelement is assumed to be mechanically uncoupled. Initially they may have different backstrap, flyer separations and in time they may have different velocities and accelerations.

3. Each subelement is assumed to have a self inductance and a resistance. Mutual inductances are ignored.

4. The subelements are joined together by their positions in the current flow. For example, the curved flyer may be divided into 10 subdivisions in series to simulate a nonuniform

loading of a ring. In loading a nose cone, however, it may also be necessary to vary initial separation distances in the direction transverse to the current flow. Here elements are assumed to be in series and in parallel. To illustrate the model the circuit diagram of MULTIFL is represented in Figure 2.

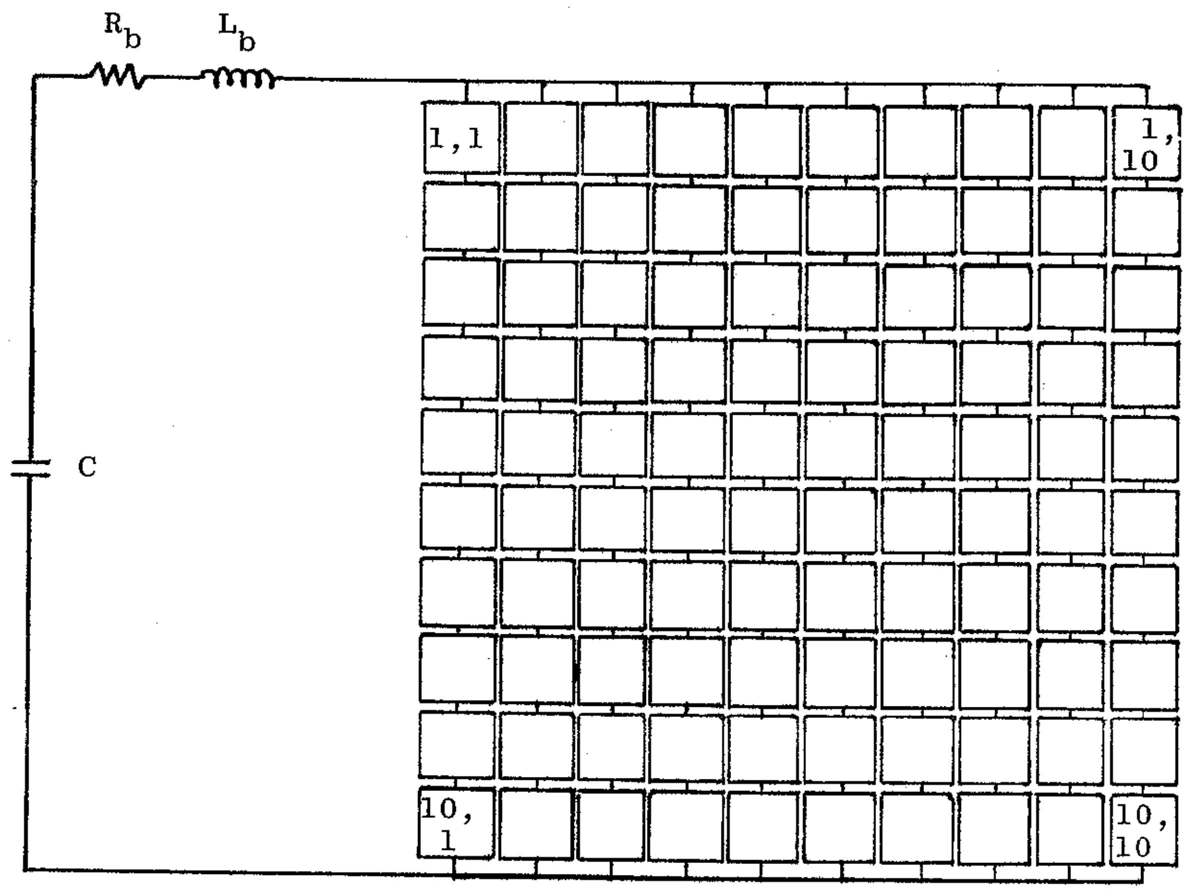
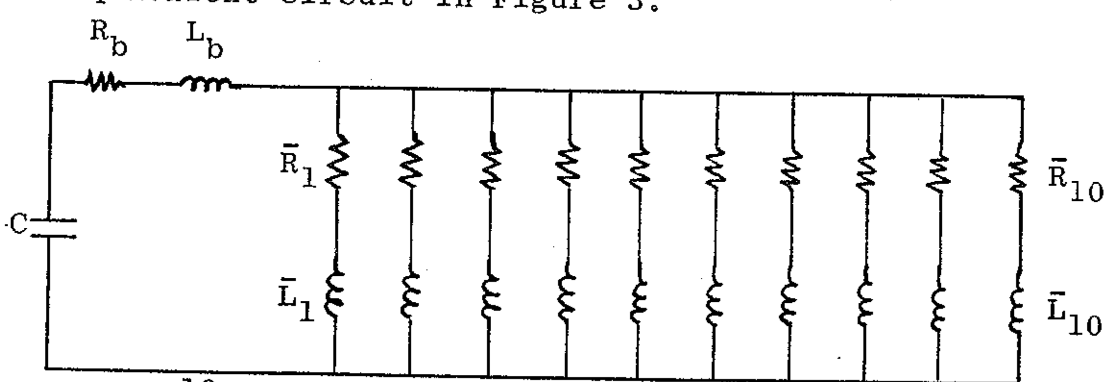


FIGURE 2
MULTIFL CIRCUIT DIAGRAM
EACH SQUARE IS A PARALLEL SHEET INDUCTOR AND RESISTOR

The errors introduced by these hypotheses are not entirely understood. An error from dividing the flyer into zones should be made smaller by increasing the number of subelements. Assuming rigid body translation for each subelement ignores the bending resistance and membrane forces of the flyer. But since the material is very soft aluminum and the magnetic pressure is usually an order of magnitude higher than the yield point, the assumption is workable for the present level of the theory. The lack of mutual inductances is a small error when the subelements have large dimensions as compared with backstrap-flyer separation distances.

The MULTIFL circuit shown in Figure 2 contains 202 resistors and inductors attached in series and parallel. In order to deduce the transient response of these elements when the capacitor is discharged, the circuit equations must be derived. First resistances and inductances in series add. Therefore, the circuit Figure 2 can be replaced by an equivalent circuit in Figure 3.



$$\bar{R}_m = \sum_{J=1}^{10} R_{jm} \qquad \bar{L}_m = \sum_{J=1}^{10} L_{jm}$$

FIGURE 3

SIMPLIFIED CIRCUIT DIAGRAM

Next the current (i) coming out of the line inductor splits into 10 separate currents (i_m). The junction equations are

$$i = \sum_{m=1}^{10} i_m \tag{14}$$

$$\frac{di}{dt} = \sum_{m=1}^{10} \frac{di_m}{dt} \tag{15}$$

Voltage equations are found from summing voltages around closed loops.

$$q/c + i\ R_b + L_b \frac{di}{dt} + i_1 R_1 + \frac{d(\bar{L}_1 i_1)}{dt} = 0 \tag{16}$$

$$i_m R_m + \frac{d(\bar{L}_m i_m)}{dt} - i_{m+1}\ \bar{R}_{m+1} + \frac{d(\bar{L}_{m+1} i_{m+1})}{dt} = 0 \tag{17}$$

$$m = 1, 2, \ldots 9$$

If the resistances and inductances were constants in time and known, equations (14), (16), and (17) would describe 11 differential equations in 12 unknowns $(i, q, i_1, i_2, \ldots i_{10})$. The necessary extra equation comes from a simple differentiation

$$i = \frac{dq}{dt} \tag{18}$$

In MULTIFL the resistors and inductors have known intital values, but they change in time. Thus, more equations must be coupled into the set above. The resistances change by heating

$$\bar{R}_m = \sum_{r=1}^{10} R_{rm} = \sum_{r=1}^{10} R_{rmo}\ (1 + \beta_{rm}\ E_{rm}) \tag{19}$$

$$m = 1, 2, \ldots 10$$

The 10 equations of (19) contain 200 time independent constants. R_{rmo} is the initial d.c. resistance of the r,m element. β_{rm} is a resistance per energy deposited coefficient. E_{rm} is the total internal energy in r,m, and it is time dependent. The constants are found by assuming that for the r,m element length (ℓ_{rm}) and width (b_{rm}) are known. Also it is assumed that all of the flyers are the same thickness (d) and have the same temperature sensitive resistivity (ρ)

$$\rho = \rho_o (1 + \alpha \Delta T)$$

α = coefficient of resistivity

ΔT = temperature change
$= E_{rm}/(C_v \ell_{rm} b_{rm} d)$

C_v = specific heat

$$R_{rmo} = (\rho_o \ell_{rm}/b_{rm} d) \tag{20}$$

$$\beta_{rm} = (\alpha/c_v \ell_{rm} b_{rm} d) \tag{21}$$

With these assumptions the resistances R_{rm} are known as a function of E_{rm} and the E_{rm} are determined by the Joule heating integral equations. Thus

$$R_{rm} = R_{rmo} (1 + \beta_{rm} \int_o^t i^2{}_m R_{rm} dt) \tag{22}$$

In (22) 100 new equations are added to the circuit equations and 100 new time dependent variables (R_{rm}) are added to the list of unknowns.

The inductances change in time by the motion of the MDFS. Equation (13) and the approximation that each sub-element flyer translates perpendicular to the flyer imply that the acceleration (A_{rm}) of the r,m flyer is

$$A_{rm} = i_m^2 \frac{\partial L_{rm}}{\partial D_{rm}} / 2M_{rm} \qquad (23)$$

with

D_{rm} = separation distance of r,m element

M_{rm} = mass of r,m flyer

Integrations of (23) yield the velocities (v_{rm}) and positions

$$v_{rm} = \int_o^t A_{rm} \, dt \qquad (24)$$

$$D_{rm} = \int_o^t v_{rm} \, dt + D_{rmo} \qquad (25)$$

Changing values of D_{rm} lead to new values of the inductances.

3.2 Numerical Procedure

The equations outlined in the last section are large in number and nonlinear in difficulty. Some carefully considered steps must be taken in any finite difference scheme to insure that the results are stable. For MULTIFL the procedure is given below.

1. Assume that the circuit equations are only slightly nonlinear. Solve the circuit equations as if they were linear, and then specify that "small" corrections in resistances and inductances can be made after each time step. The initial circuit resonant frequency is used for specifying the magnitude of the time step.

2. The currents are updated in each circuit loop simultaneously or on the same time step. Equations (16) and (17) must be treated such that the current derivatives are the only unknowns. When these equations are solved for these unknowns, the results are

$$\frac{di}{dt} = \frac{-(1/L_b)}{(1/L_b) + \sum_{m=1}^{10} (1/\bar{L}_m)} \cdot \sum_{m=1}^{10} (q/C + iR_b + i_m\bar{R}_m)/\bar{L}_m \quad (26)$$

$$\frac{di_m}{dt} = -\left(\frac{L_b}{\bar{L}_m}\right) \frac{di}{dt} - (q/C + iR_b + i_m\bar{R}_m)/\bar{L}_m \quad (27)$$

Equation (26) can be finite differenced by replacing $\frac{di}{dt}$ by

$$\frac{di}{dt} = (i_{new} - i_{old})/\Delta t \qquad (28)$$

and thus i_{new} is known in terms of the old circuit parameters. The right side of (26) can be substituted into (27) and similarly $\frac{di_m}{dt}$ can be differenced. Thus all new currents are determined.

3. The new accelerations, velocities, and positions are then found from (23), (24) and (25). New resistances and inductances are deduced from (22) and the inductance model discussed in Appendix E.

4. Stored energies are calculated and an energy balance is periodically recorded to insure that the time step has been acceptable.

4. PRELIMINARY EXPERIMENTAL VERIFICATION

The final proof of MULTIFL must be made by assessing its ability to predict experimental measurements. At this time, considerable correlation has been made with the computational simulation and flat flyer experiments. Since MULTIFL must not contradict one-dimensional results, this is a logical first step. The next step will be correlation with curved flyer plate tests. When the two-dimensional data become available, the final checking can be completed.

The two basic types of experiments that have been accomplished are (1) fixed flyer circuit measurements, and (2) flyer sheet velocity determinations. Experiment (1) is useful in evaluating the bank characteristics and the change in inductance of the flyer with position. Experiment (2) is the important proof test. It utilizes a high speed framing camera to watch the flyer progress and flyer-target collision. Approximately 10 to 15 frames can usually be exposed in the critical time region. From these pictures fairly repeatable impact velocities can be deduced. Figure 4 shows a specific comparison between a group of these experimental velocities (for various capacitor voltages) and the values that MULTIFL predicts. The graph is restricted to experiments on our 20 kilojoule bank with a .012" x 2.040" x 11.0" flyer and a constant flyer to target distance of .238".

The characteristics of this capacitor bank as determined by type (1) experiments are

$$C = 1.66 \times 10^{-5} \text{ farads}$$

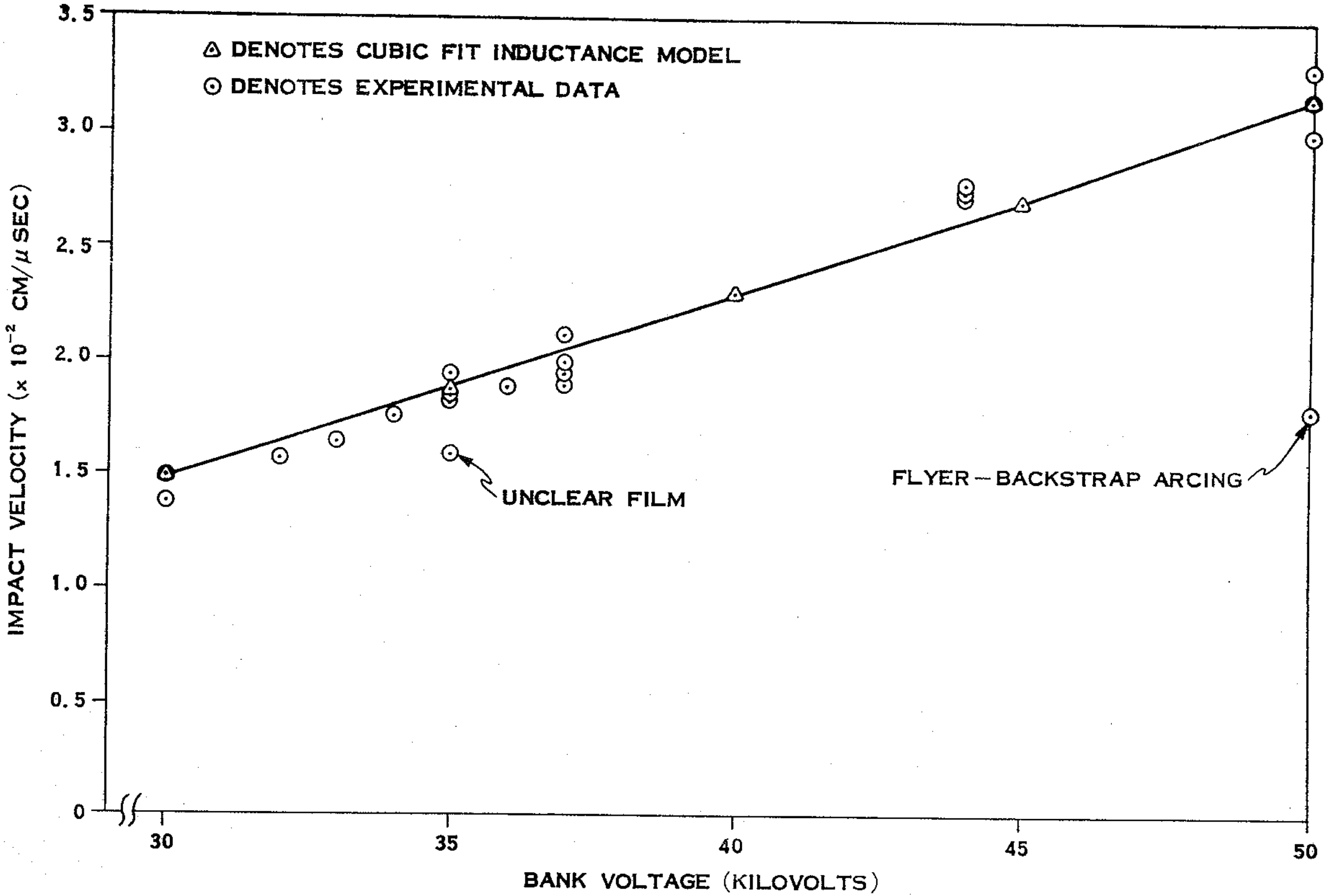
$$R_b = 1.036 \times 10^{-2} \text{ ohms}$$

$$G_b = 6. \times 10^{-8} \text{ ohms/joule}$$
$$L_b = 2.21 \times 10^{-7} \text{ henry,}$$

and the input properties of the flyer as determined by standard handbooks are

$$\alpha = 3.9 \times 10^{-3}/^{o}C$$
$$C_v = 2.59 \times 10^{6} \text{ joule}/(^{o}C \cdot m^3)$$
$$p = 2.71 \times 10^{3} \text{ kg}/m^3.$$

The agreement between the derived and measured data is remarkable. Apparently the one-dimensional flyer is predictable by MULTIFL.



PROGRAM MULTIFL—THEORY/EXPERIMENT COMPARISON (SRD)

5. SUMMARY

MULTIFL is a computer program which is designed to study the motion and condition of two-dimensional, magnetically driven flyer plates. This document has outlined the basic capacitor bank circuit, the components in the circuit, and the response mechanisms of each component. Most of the analysis reported in the appendices is related to the response of various types of parallel surface inductor sheets, which are very important in determining the course of the current flow and the final impact velocities.

MULTIFL considers a wide variety of nonlinear effects. For example, the resistors change value during any problem via Joule heating and skin-depth changes. The inductors change value via position and velocity changes in the parallel plates and skin-depth variations. Nonetheless, MULTIFL has a reasonable central processing time and is convenient to determine its inputs. It should be a very useful tool for aiding in designing magnetic flyer experiments.

The utilization of MULTIFL for two-dimensional experiments is in its initial stages. However, a sample problem is presented in Appendix F which shows a possible backstrap-flyer configuration to simulate cosine loading on a ring. There is no experimental data to compare the results, but the numbers intuitively appear to be reasonable.

REFERENCES

1. L.D. Webster, "Three Analytical Studies Pertinent to Structural Testing", KN-69-202(R), May 1969, Kaman Nuclear

2. W.R. Smythe, Static and Dynamic Electricity, 3rd Edition, page 371, McGraw Hill Book Company

3. R.W. Reynolds and R.S. Jacobson, "Numerical Predictions of the Motion of Magnetically Accelerated Flyer Plates", SCL-DR-69-44, July 1969, Sandia Laboratories

APPENDIX A

Thin, Infinite Sheet Inductor

A pair of parallel current sheets may be modeled in the simplest manner by assuming that the sheets are very long and very wide in comparison with sheet thickness and sheet-to-sheet separation distance. In this case edge effects and skin-depth effects are ignored. The model assumes a uniform current density vector at each point on either sheet.

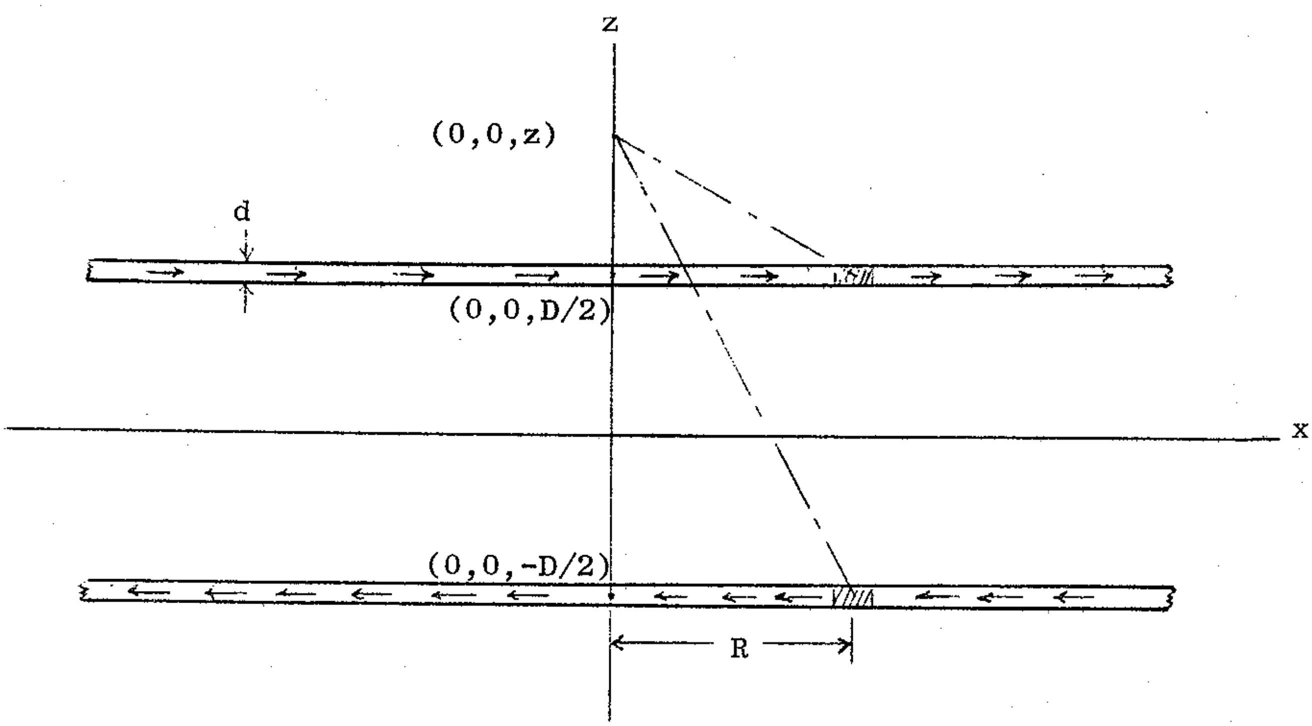


Figure A1

$\vec{J} = j\,\vec{1}_x$ on the upper sheet and $\vec{J} = -j\,\vec{1}_x$ on the lower. The electromagnetic vector potential ($\vec{A}$) defined in Equation (9) can be evaluated by a series of integrations. Due to symmetry the field quantities cannot depend upon their x, y coordinates; thus the integrations in cylindrical form are

$$\vec{A}(z) = (\mu_o/4\pi) \cdot j \cdot \vec{1}_x \int_{-d/2}^{+d/2} \int_0^{2\pi} \int_0^{\infty} \left\{ 1/\sqrt{R^2 + (z-D/2)^2} - 1/\sqrt{R^2 + (z + D/2)^2} \right\} R dR\, d\theta\, dz \qquad \text{(A1)}$$

$$\vec{A}(z) = (\mu_o jd/2)\ \vec{1}_x\ (|z + D/2| - |z - D/2|) \qquad \text{(A2)}$$

By definition the magnetic induction vector ($\vec{B}$) is the curl of $\vec{A}$. Therefore

$$\begin{aligned} \vec{B} = \nabla \times \vec{A} &= (\mu_o jd)\ \vec{1}_y && \text{between the sheets} \\ &= 0 && \text{otherwise} \end{aligned} \qquad \text{(A3)}$$

Equation (8) can be used to determine the inductance of the element. First the cartesian coordinate integrations are

$$W_B = (1/2)\ (\mu_o jd/2) j \int_{-d/2}^{+d/2} \int_{-b/2}^{+b/2} \int_{-\ell/2}^{+\ell/2} [2D]\ dx\ dy\ dz$$

$$= (1/2)\ \mu_o j^2 d^2\ b\ \ell\ D \qquad \text{(A4)}$$

Second the definition $i = \int_{-d/2}^{+d/2}\int_{-b/2}^{+b/2} j \, dx \, dy$

allows $i = j \, b \, d$ (A5)

and thus from (A4)

$$W_B = (1/2) \; (\mu_o \ell D/b) \; i^2 \tag{A6}$$

Equation (8) compares with (A6) if $L = \mu_o \ell D/b$ (A7)

Finally the force on either sheet can be found when (A7) is combined with (13)

$$F = (i^2/2) \; (\mu_o \ell/b) \tag{A8}$$

APPENDIX B

Skin-Depth Corrections

In Appendix A the current density is treated as a constant throughout the volume of the conductor. For some MDFS this is not a good approximation, since time varying currents tend to interact with a free surface to produce "skin" effects. The exact analysis of this phenomena for the transient, nonlinear problem at hand is very difficult, and it will not be attempted. However, a simple model is presented in the hope that it will improve the calculations in MULTIFL.

The most elementary skin-depth calculation assumes that a semi-infinite (one surface) conductor is excited with an electric field which is sinusoidal in time. This model leads to the conclusion that the current density has an exponential distribution; maximum current is at the surface (z=0)

$$\vec{J} = j_o e^{-z/\delta} \, \vec{1}_x \tag{B1}$$

The skin depth is defined to be δ and

$$\delta = (2\rho/\mu_o\omega)^{1/2} \tag{B2}$$

ω = angular frequency

Smythe(2) discusses this model in detail. He derives that the semi-infinite conductor has a total resistance equal to that of a d.c. resistor if the thickness is assumed as one skin-depth.

In MULTIFL there is no single ω and ρ is temperature dependent. The simple model is not easy to apply. Good conductors, however, damp out perturbations very quickly. This leads one to evaluate a "local time" ω and ρ and then assume the current density of (B1).

The effect of (B1) on the inductance of two parallel conductors must be considered. It is assumed that the mutual interference effects of one conductor on the other will not change the current density of (B1). This approximation is probably the most severe of any that have been presented in this appendix, but a more sophisticated model is not currently available. Figure B1 shows the geometry and coordinate system for the inductance calculation. The current density vectors are

$$\vec{J} = -j_u e^{-(z-D/2)/\delta_u} \vec{1}_x \quad \text{in upper region} \qquad \text{(B3)}$$

$$\vec{J} = j_\ell e^{(z+D/2)/\delta_\ell} \vec{1}_x \quad \text{in lower region} \qquad \text{(B4)}$$

ℓ, u = subscripts for lower and upper

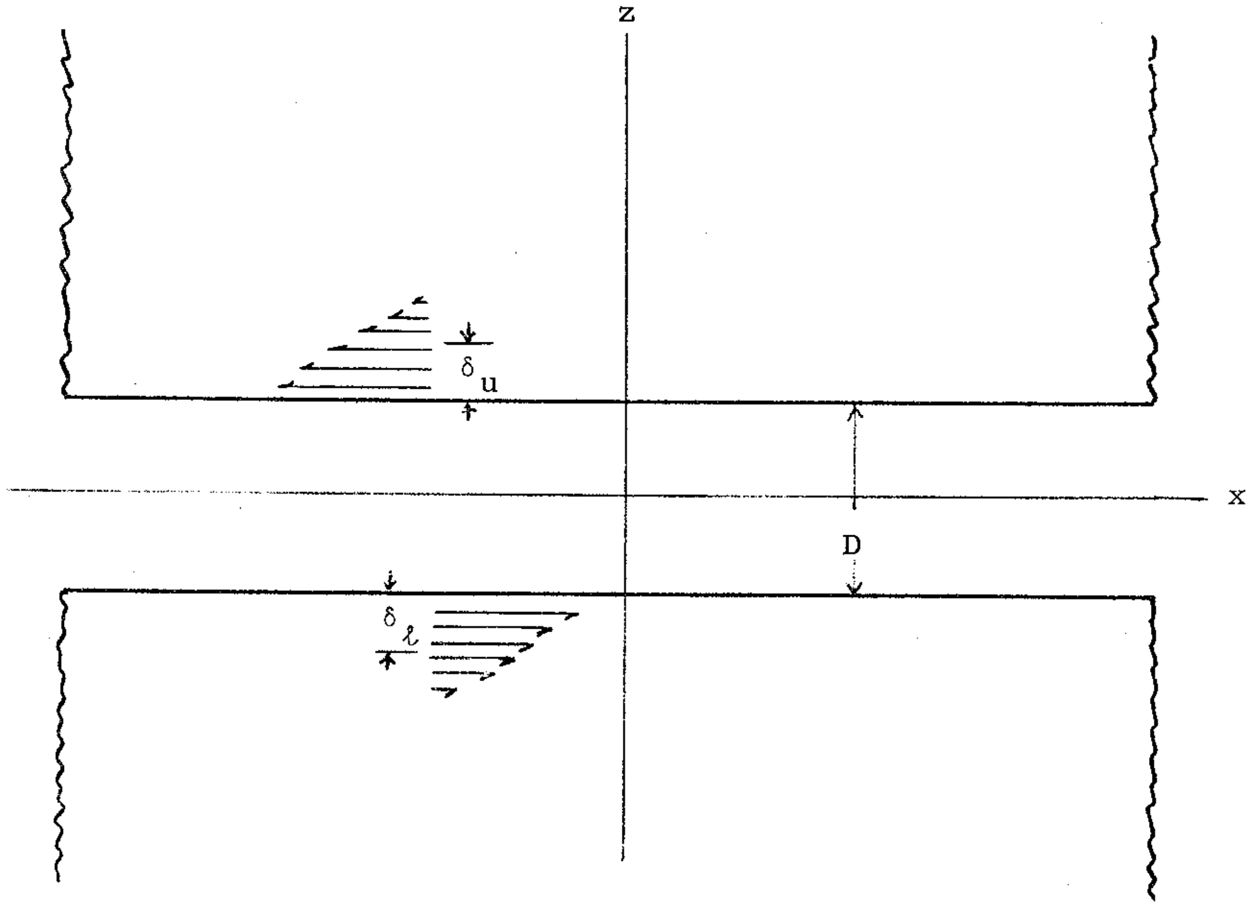


Figure B1

From Equation (10) the total current flowing in the circuit is

$$i = bj_u \int_{D/2}^{\infty} \left[e^{-(z-D/2)/\delta_u} \right] dz = bj_u\delta_u \tag{B5}$$

$$= bj_\ell \delta_\ell \tag{B6}$$

Appropriate substitution and integration into Equation (9) yields the vector potential

$$\vec{A}(z) = (\mu_o i/2b)\,\vec{1}_x \begin{cases} -D - \delta_u - \delta_\ell + 2\delta_u e^{(D/2-z)/\delta_u} & z > D/2 \\ +D + \delta_u + \delta_\ell - 2\delta_\ell e^{(D/2+z)/\delta_\ell} & z < -D/2 \end{cases}$$

Equation (8) then leads to the inductance

$$L = (\mu_o \ell / b)\ (D + [\delta_u + \delta_\ell]/2) \qquad \text{(B7)}$$

The interpretation of (B7) is very simple: the effective separation distance of the two current flows is D plus the average skin depth.

APPENDIX C

Finite Width Inductor

The next logical step in the inductance calculations is to improve the models in Appendices A and B by forcing a finite width to the current sheets. This begins the study of edge effects which should be important when the flyer-backstrap separation distance is about equal to or greater than the width. The mathematical procedures are very similar to the earlier examples, but the integrations are considerably harder, and the current density function is not intuitively obvious.

Figure C1 shows the basic geometry.

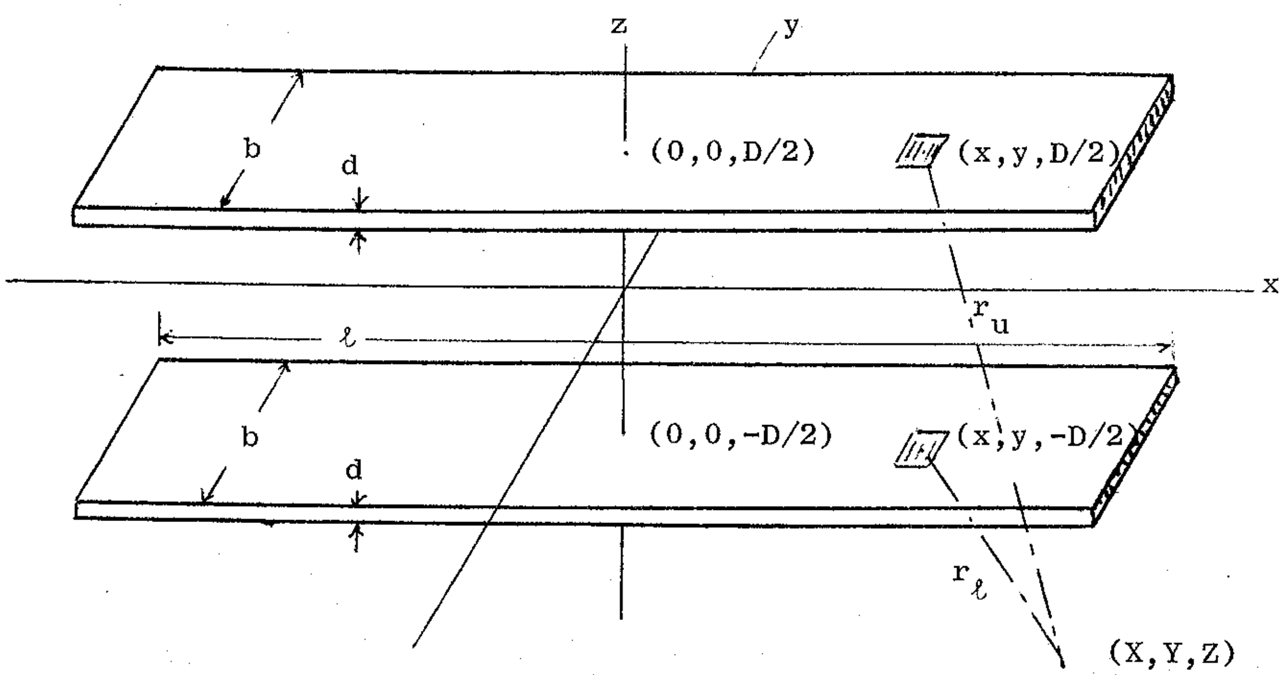


Figure C1

In order to evaluate the vector potential the form of the current density can be assumed as

$$\vec{J}_u = j(y)\ \vec{1}_x \tag{C1}$$

$$\vec{J}_\ell = -j(y)\ \vec{1}_x \tag{C2}$$

This implies that all current is "downstream" and not changing with x. j(y) is, as yet, unknown. The upper and lower distances from source point to field point are

$$r_u = \sqrt{(X-x)^2 + (Y-y)^2 + (Z-D/2)^2}$$

$$r_\ell = \sqrt{(X-x)^2 + (Y-y)^2 + (Z+D/2)^2}$$

and $d\tau = d(dx)(dy)$

$$i = d \int_{-b/2}^{+b/2} j(y)\ dy \tag{C3}$$

Therefore

$$\vec{A}(X,Y,Z) = (\mu_o d/4\pi)\vec{1}_x \int_{-b/2}^{+b/2} j(y) \int_{-\ell/2}^{+\ell/2} \Big[1/\sqrt{(X-x)^2+(Y-y)^2+(Z-D/2)^2}$$

$$- 1/\sqrt{(X-x)^2+(Y-y)^2+(Z+D/2)^2}\Big]\ dx\ dy \tag{C4}$$

The integration in the x-direction can be simplified by allowing ℓ to become very large, i.e.

$$\text{as } \ell \to \infty \int_{-\ell/2}^{+\ell/2} \frac{dx}{\sqrt{(X-x)^2 + C^2}} \to \log (\ell/c)^2$$

$$\vec{A} \to \vec{A}(Y,Z) = (\mu_o d/4\pi)\vec{1}_x \int_{-b/2}^{+b/2} j(y) \log \left\{ \frac{(Y-y)^2 + (Z+D/2)^2}{(Y-y)^2 + (Z-D/2)^2} \right\} dy \tag{C4}$$

Equation (8) again defines the inductance

$$L = (\mu_o \ell/2\pi) \frac{\int_{-b/2}^{+b/2} j(Y) \int_{-b/2}^{+b/2} j(y) \log \left[\frac{(Y-y)^2 + D^2}{(Y-y)^2} \right] dy \, dY}{\left[\int_{-b/2}^{+b/2} j(y) \, dy \right]^2} \tag{C5}$$

j(y) can be determined by application of an appropriate condition. One condition could be that the magnetostatic force on any current element in the y-direction must be zero and therefore $B_z=0$ on sheets. This condition could be imposed by summing all contributions to B_z in terms of j(y). The result is a messy singluar integral with j(y) as the unknown. Another approach is to determine j(y) by minimizing the field energy or minimizing L in (C5). This second method appears to have computational advantages and to be equivalent to the force formulation.

The mechanics of minimizing L are the following:

1. change to dimensionless variables by substituting $y' = y/b$, $Y' = Y/b$, $D' = D/b$, into (C5)

2. drop primes

3. assume a Taylor expansion for $j(by)$

$$j(by) = \sum_{n=0}^{\infty} J_n y^n \tag{C6}$$

4. integrate the integral in the denominator of (C5)

$$\Delta = \left[\int_{-1/2}^{+1/2} j(by)\,dy\right]^2 = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{J_m J_n [1-(-1)^{m+1}]\,[1-(-1)^{n+1}]}{(m+1)\,(n+1)\,(2)^{m+n+2}} \tag{C7}$$

5. substitute (C6) into numerator of (C5) and interchange the order of integration and summation

$$L = (\mu_o \ell/2\pi\Delta) \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} J_m J_n \,[F_{mn}(D) - F_{mn}(0)] \tag{C8}$$

where

$$F_{mn}(D) = \int_{-1/2}^{+1/2} Y^m \int_{-1/2}^{+1/2} y^n \log\,[(Y-y)^2 + D^2]\,dy\,dY \tag{C9}$$

After considerable algebraic manipulation, the $F_{mn}(D)$ functions can be integrated in closed form. This is an essential feature of the minimization plan due to the fact that numerical integration of either (C9) or (C5) is very difficult; there is integrable singularity at Y=y and and D=0. A review of the necessary algebra for evaluation of (C9) will be deferred to Appendix D.

Equation (C8) may be thought of as the definition of L as a function of the vector $(J_1, J_2, \ldots)$. Mathematically this vector must be chosen to minimize L. In order to perform this operation a small computer code FININD is also presented in Appendix D. FININD evaluates the $F_{mn}(D)$ functions and performs the minimization by a numerical "gradient" method. If the current density is forced to be a constant, no minimization is required and L has a closed form solution

$$L = (\mu_o \ell / 2\pi)\left[(1-D^2)\log(1+D^2) + D^2 \log D^2 + 4D \tan^{-1}(1/D)\right] \qquad \text{(C10)}$$

Equation (C10) asymtotically approaches equation (A7) as $D \to 0$ and the inductance of two parallel wires as $D \to \infty$. Table C1 compares the zeroth approximation $[j(y) = J_o]$ with the second order approximation $[j(y) = J_o + J_2 y^2]$ and the fourth order approximation. Conclusions of this comparison are (1) there are significant edge effects when $D/b > .1$, (2) the inductance is not extremely sensitive to the current density distribution, (3) the differences between the second order and fourth order approximations are small enough to ignore higher orders.

Table C1

Comparison of Model Inductances

$L/l \times 10^7$ (h/m)

D/b	Infinite Sheet Appendix A	Zeroth Order Model	Second Order	Fourth Order
.02	.252	.243	.243	.243
.04	.504	.474	.472	.471
.06	.756	.694	.690	.687
.08	1.01	.905	.897	.893
.10	1.26	1.11	1.10	1.09
.20	2.52	2.02	1.98	
.40	5.04	3.48	3.37	3.33
.60	7.56	4.62	4.44	4.40
.80	10.1	5.53	5.32	5.27
1.00	12.6	6.30	6.06	6.00
2.00	25.2	8.88	8.57	8.51
4.00	50.4	11.6	11.3	11.2
6.00	75.6	13.1	12.9	12.8
8.00	101.	14.4	14.0	14.0
10.0	126.	15.3	14.9	14.9

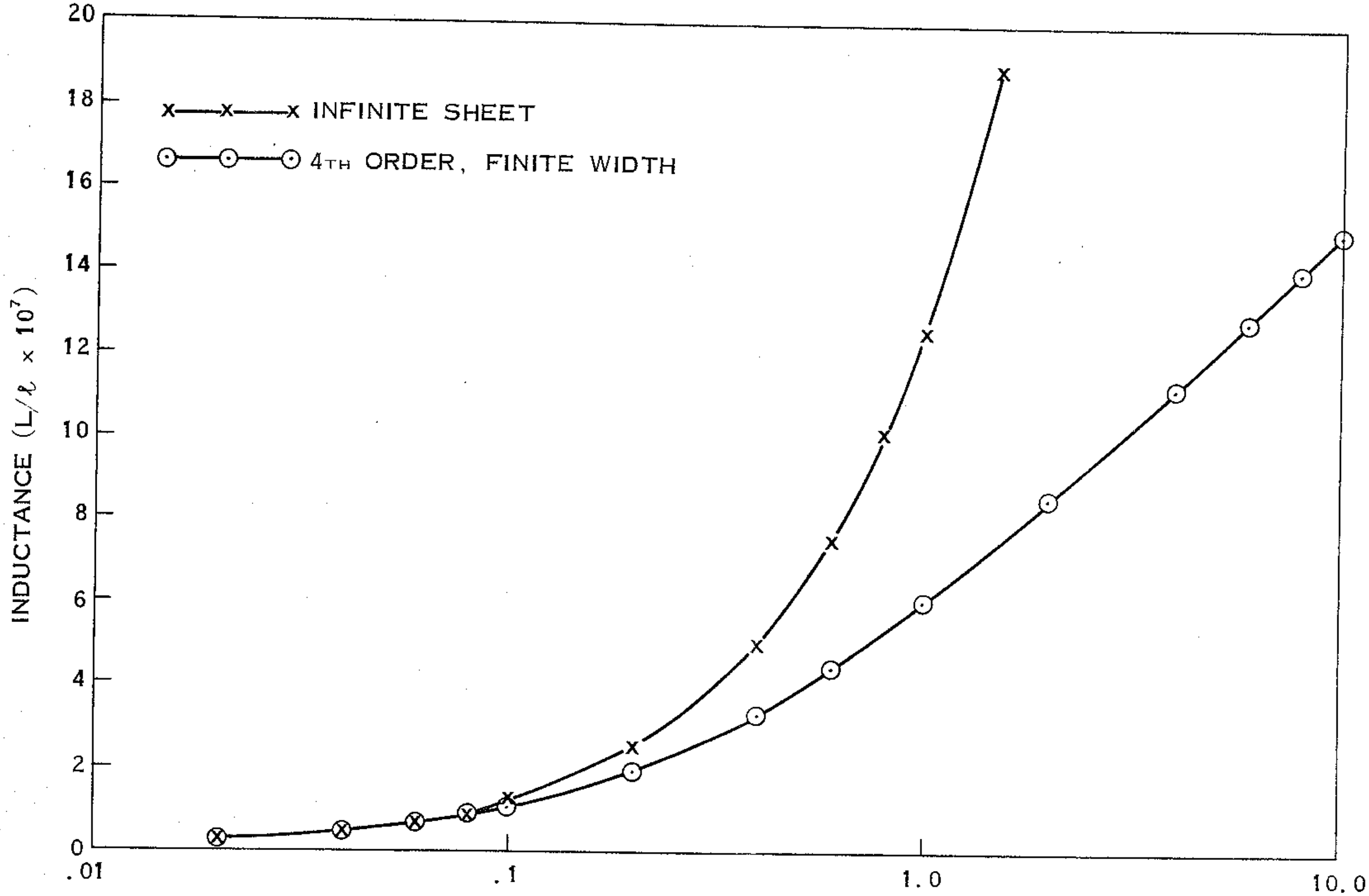


FIGURE C2

INDUCTANCE VS D/b

The shapes of the current distributions are plotted in Figures C3-C6. When D/b = .01 the distribution is nearly uniform. At D/b = 1. there is a strongly nonuniform current which does not differ very much from the distribution at D/b = 10. The actual forms of these curves are important, because the uneven currents lead to uneven magnetic forces and nonplanar flyers. As an example when D/b = 1., the current density is 3.7 times stronger at the edge than at the center. Since the force is proportional to i^2, the ratio of the corresponding forces is 13.7. The practical limit for D/b due to the warping effects of nonuniform forces has not yet been determined, but the input body forces can be calculated with the model described in this section.

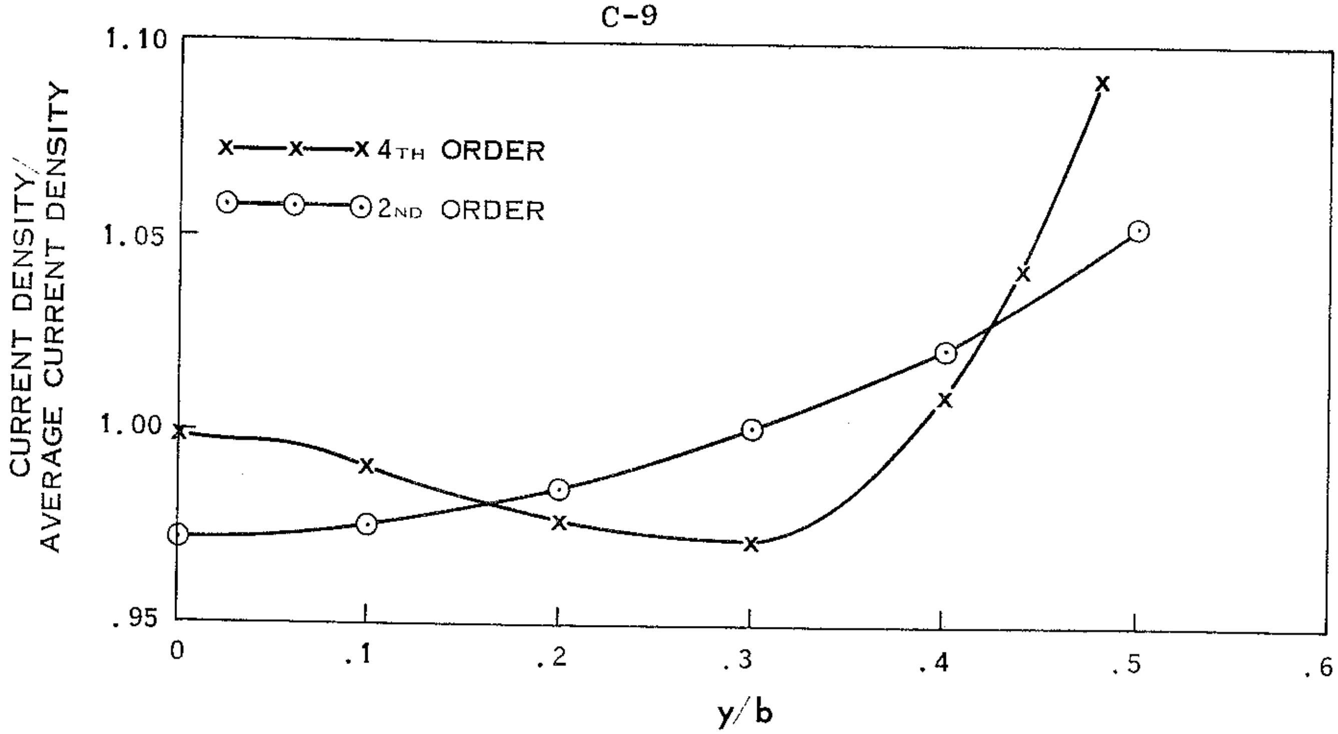


FIGURE C3

CURRENT DENSITY VS POSITION (D/b = .01)

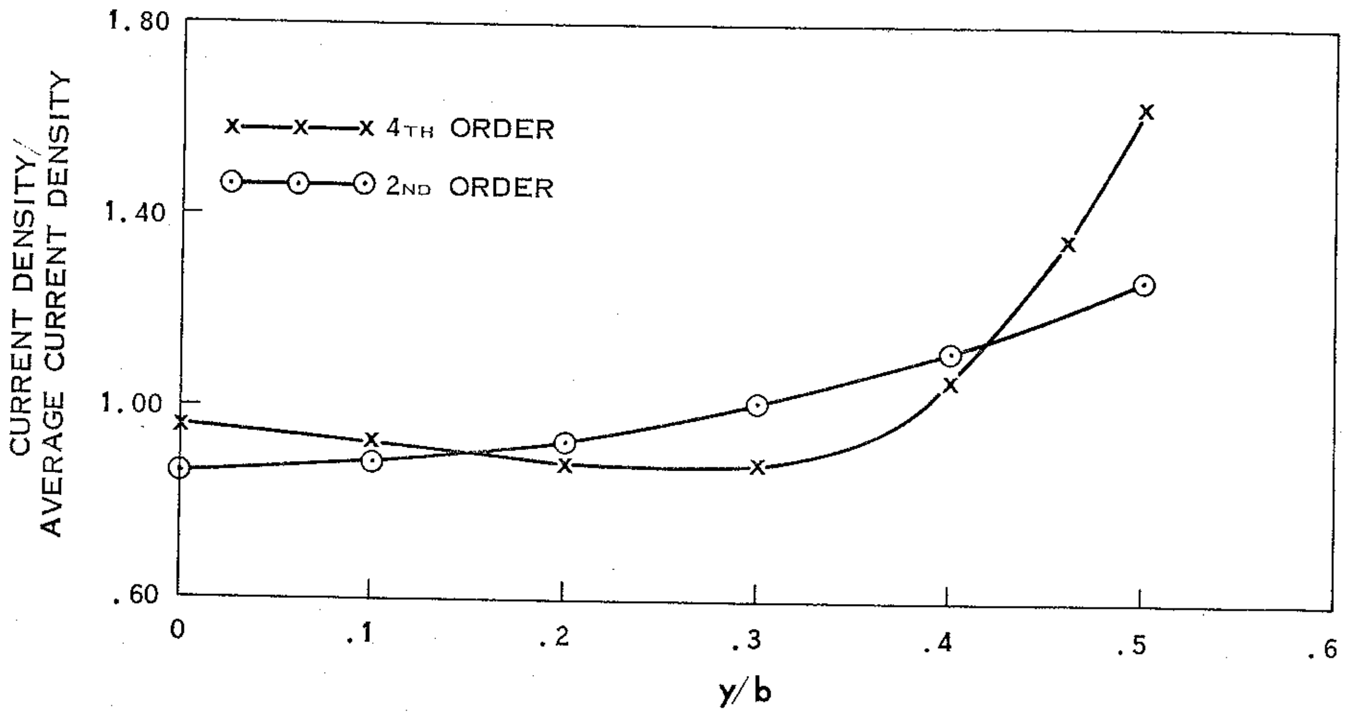


FIGURE C4

CURRENT DENSITY VS POSITION (D/b = .1)

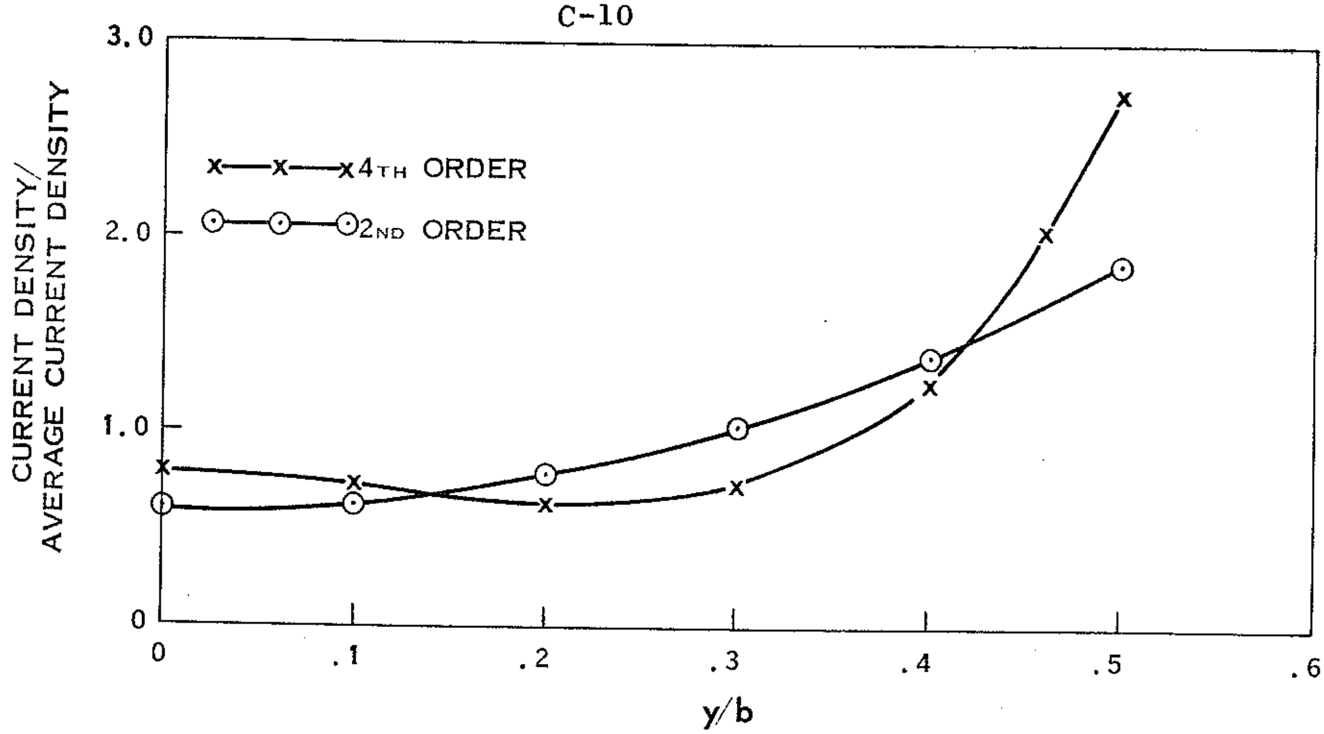


FIGURE C5

CURRENT DENSITY VS POSITION (D/b = 1.0)

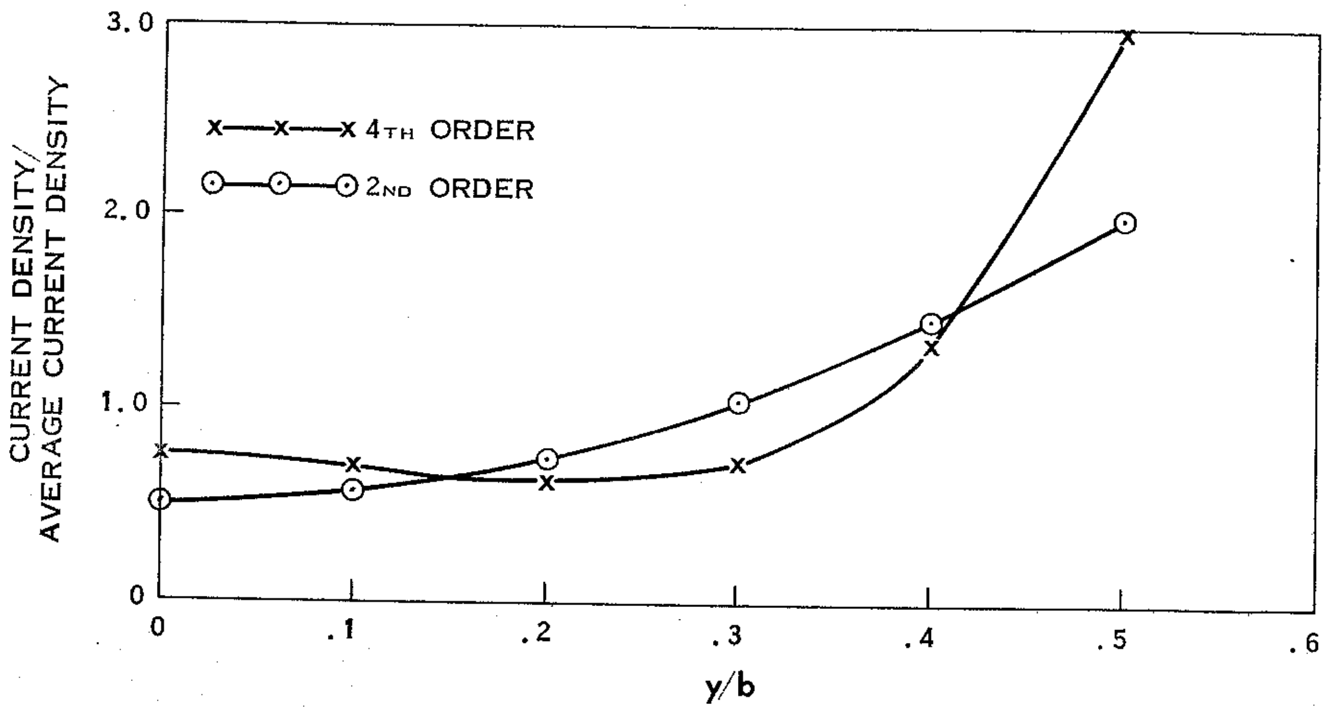


FIGURE C6

CURRENT DENSITY VS POSITION (D/b = 10.0)

APPENDIX D

Program FININD

This appendix discusses the evaluation of the functions $F_{mn}(D)$ of (C9) and the evaluation of the appropriate value of L for any D. First $F_{mn}(D)$ can be broken up and integrated by the following recipe.

$$F_{mn}(D) = \int_{-1/2}^{+1/2} Y^m F_n (Y,D) \, dY \tag{D1}$$

where

$$F_n(Y,D) = \int_{-1/2}^{+1/2} y^n \log [(Y-y)^2 + D^2] \, dy \tag{D2}$$

The integral in Equation (D2) can be divided up into two integrals by integrating from -1/2 to Y and Y to +1/2. After substitutions of y = Y-p in the first integral and y = Y+p in the second, $F_n(Y,D)$ becomes

$$F_n(Y,D) = G_n(Y,D) + (-1)^n G_n(-Y,D) \tag{D3}$$

where

$$G_n(Y,D) = \int_0^{1/2 + Y} (Y-p)^n \log (p^2+D^2) \, dp \tag{D4}$$

Combination of (D3) and (D1) lead to

$$F_{mn}(D) = [1 + (-1)^{n+m}] \int_{-1/2}^{+1/2} Y^m G_n(Y,D)\, dy \qquad \text{(D5)}$$

Equation (D5) is an improvement over (D1) only in that the $G_n(Y,D)$ function is easier to obtain than the $F_n(Y,D)$. Equation (D5) must be modified again; let $q = 1/2 + Y$

$$F_{mn}(D) = [1 + (-1)^{n+m}] \int_0^1 (q - 1/2)^m G_n \left([q - 1/2],D\right) dq \qquad \text{(D6)}$$

Let the binomial coefficients be denoted by

$$\binom{n}{k} = n!/\left((n-k)!k!\right)$$

and expand $(q - 1/2)^m$ in (D6) and $(q - p - 1/2)^n$ in $G_n\left([q - 1/2],D\right)$. Then (D6) becomes

$$F_{mn}(D) = [1 + (-1)^{n+m}] \sum_{R=0}^{n} \binom{n}{k} (-1)^{n-k} \sum_{j=0}^{m+k} \binom{m+k}{j} (-1/2)^{m+k-j}\, \overline{\overline{M}}_{j,n-k} \qquad \text{(D7)}$$

where

$$\overline{\overline{M}}_{j,n-k} = \int_0^1 q^j \int_o^q p^{n-k} \log [p^2 + D^2] \qquad \text{(D8)}$$

The next task is to integrate the set of functions $\overline{\overline{M}}_{m,n}$. In order to perform these operations a series of definitions and recursion relations must be introduced.

<u>Definitions</u>

$$N_n(q) = \int_o^q [p^n/(p^2 + D^2)]\, dp \tag{D9}$$

$$M_n(q) = \int_o^q p^n \log (p^2 + D^2)\, dp \tag{D10}$$

$$Q_n(q) = \int_o^q p^n \tan^{-1} (p/D)\, dp \tag{D11}$$

$$\overline{N}_n = N_n(1) \tag{D12}$$

$$\overline{M}_n = M_n(1) \tag{D13}$$

$$\overline{Q}_n = Q_n(1) \tag{D14}$$

$$\overline{\overline{N}}_{m,n} = \int_0^1 q^m N_n(q)\, dq \tag{D15}$$

$$\overline{\overline{M}}_{m,n} = \int_0^1 q^m M_n(q)\, dq \tag{D16}$$

Actual Integrations

$$N_0(q) = (1/D)\ \tan^{-1}\ (q/D) \tag{D17}$$

$$N_1(q) = (1/2)\ \log\ (1 + q^2/D^2) \tag{D18}$$

$$\overline{\overline{N}}_{m,o} = (1/D)\ \overline{Q}_m \tag{D19}$$

Recursion Relations (by parts integration)

$$\left.\begin{aligned} N_n(q) &= q^{n-1}/(n-1) - D^2 N_{n-2}(q) \\ \overline{N}_n &= 1/(n-1) - D^2 \overline{N}_{n-2} \end{aligned}\right\}\quad n\geq 2 \tag{D20}$$

$$\overline{Q}_n = [\tan^{-1}(1/D) - D\ \overline{N}_{n+1}]/(1+n) \qquad n\geq 2 \tag{D21}$$

$$\overline{\overline{N}}_{m,1} = (1/2)\ M_m - \log D/(m+1) \tag{D22}$$

$$\overline{\overline{N}}_{m,n} = [1/(n-1)(n+m)] - D^2\ \overline{\overline{N}}_{m,n-2} \qquad n\geq 2 \tag{D23}$$

$$\overline{M}_n = [\log\ (1+D^2) - 2\overline{N}_{n+2}]/(n+1) \qquad n\geq 0 \tag{D24}$$

$$\overline{\overline{M}}_{m,n} = [M_{m+n+1} - 2\overline{\overline{N}}_{m,n+2}]/(n+1) \qquad n\geq 0 \tag{D25}$$

The sequence of calculations is the following:

1. all $\overline{N}_n$ are determined by combination of (D17), (D18) and (D20)

2. all $\overline{\overline{M}}_n$ are then found from (D24)

3. all $\overline{Q}_n$ are evaluated from (D21)

4. all $\overline{\overline{N}}_{m,n}$ follow from (D19), (D22), and (D23)

5. Equation (25) then calculates $\overline{\overline{M}}_{m,n}$

The program FININD finds $F_{mn}(D)$ for any D and all $m \leq 10$, $n \leq 10$. Then the inductance is produced via Equation (C8) and an assumed current density function. A FININD subroutine MINMD minimizes the inductance by properly choosing the current function.

Listed below is a FORTRAN glossary and the program statements.

FORTRAN VARIABLE	DEFINITION
D	plate separation distance
DE	D increment
ANJ, NJ	order of current density
PLØT, IPLØT	flag
DS	dummy D
BNØ, BN(I)	$\overline{N}_n$
BMØ, BM(I)	$\overline{M}_n$

QBØ, QB(I)	$\overline{Q}_n$
DDNØØ, DDNXØ(I), DDNØX(I), DDN(I,J)	$\overline{\overline{N}}_{m,n}$
DDMØØ, DDMXØ(I), DDMØX(I), DDM(I,J)	$\overline{\overline{M}}_{m,n}$
F(N)	N!
C(N,M)	$\binom{N}{M}$ binomial coefficients
FBØØ, FBXØ(I), FBØX(I), FB(I,J)	$F_{mn}(D)$
CJ(I)	J_n
RATIØ	ratio of inductance to infinite sheet inductance

```
      PROGRAM FININD(INPUT,OUTPUT)
      COMMON FBOO,FBOX(10),FBXO(10),FB(10,10),NJ
      DIMENSION CJ(20),BN(33),BM(31),QB(20),DDNOX(12),DDN(20,12),DDNXO(2
     12),DDMOX(10),DDMXO(20),DDM(20,10),F(20),C(20,20),FDXO(10),FDOX(10)
     2,FD(10,10),TIT1(5),TIT2(5),APR(20),APD(20),API(20),DELTA(10)
      EXTERNAL AINDUCT
      DATA(TIT1(1)=8HINDUCTAN),(TIT1(2)=8HCE VS D/),(TIT1(3)=8HB       )
      DATA(TIT2(1)=8HRATIO OF),(TIT2(2)=8H L/L OF ),(TIT2(3)=8HINFINITE)
     1 ,(TIT2(4)=8H SHEET  ),(TIT2(5)=8H VS D/B )
C
C       INPUT     ANJ MUST BE LESS THAN 11
C
      READ 1000,D,DE,ANJ,PLOT
      IPLOT=PLOT
C      IPLOT=0  CORRESPONDS TO NO PLOTS
      NJ=ANJ
      KZ=0
      CJO=1.
      DS=D
      D=1.E-10     $    NNP=0
      IK=1
C
C
C       NBAR CALCULATIONS  I.E.   BN(N)=
C
5     BNO=ATAN(1./D)/D
      BN(1)=ALOG(1.+1./D**2)/2.
      BN(2)=1.-(D**2)*BNO
      DO 10 N=3,33
      AN=N
      BN(N)=1./(AN-1.)-(D**2)*BN(N-2)
10    CONTINUE
C
C        MBAR CALCULATIONS
C
      BMO=ALOG(1.+D**2)-2.*BN(2)
      DO 20 N=1,31
      AN=N
      BM(N)=(ALOG(1.+D**2)-2.*BN(N+2))/(AN+1.)
20    CONTINUE
C
C      QBAR CALCULATIONS
C
C
      QBO=ATAN(1./D)-D*BN(1)
      DO 30 N=1,20
      AN=N
      QB(N)=(ATAN(1./D)-D*BN(N+1))/(AN+1.)
30    CONTINUE
C
C
C       NDOUBLEBAR CALCULATIONS
C
      DDNOO=QBO/D
      DO 40 N=1,20
      DDNXO(N)=QB(N)/D
40    CONTINUE
```

```
      DDNOX(1)=BM0/2.-ALOG(D)
      DO 50 N=1,20
      AN=N
      DDN(N,1)=BM(N)/2.-ALOG(D)/(AN+1.)
   50 CONTINUE
      DO 70 N=2,12
      AN=N
      IF(N.EQ.2) DUM=DDNOO
      IF(N.NE.2) DUM=DDNOX(N-2)
      DDNOX(N)=(1./((AN-1.)*AN))-(D**2)*DUM
      DO 60 M=1,20
      AM=M   $  IF(N.EQ.2) DUM=DDNXO(M)
      IF(N.NE.2) DUM=DDN(M,N-2)
      DDN(M,N)=1./((AN-1.)*(AN+AM))-(D**2)*DUM
   60 CONTINUE
   70 CONTINUE
C
C
C     MDOUBLEBAR CALCULATIONS
      DDMOO=BM(1)-2.*DDNOX(2)
      DO 80 N=1,10
      AN=N
      DDMOX(N)=(BM(N+1)-2.*DDNOX(N+2))/(AN+1.)
   80 CONTINUE
      DO 90 M=1,20
      DDMXO(M)=BM(M+1)-2.*DDN(M,2)
   90 CONTINUE
      DO 99 N=1,10
      AN=N
      DO 95 M=1,20
      DDM(M,N)=(BM(M+N+1)-2.*DDN(M,N+2))/(AN+1.)
   95 CONTINUE
   99 CONTINUE
      PRINT 2010,D
      PRINT 2999,KZ,(I,I=1,10)
      PRINT 3000,KZ,DDMOO,(DDMOX(M),M=1,10)
      PRINT 3000,(M,DDMXO(M),(DDM(M,N),N=1,10),M=1,20)
C
C
C      BINOMIAL COEFFICIENTS
C
      F(1)=1.
      DO 100 N=2,20
      AN=N
      F(N)=AN*F(N-1)
  100 CONTINUE
      DO 110 N=1,20
      DO 105 M=1,N
      IF(N.EQ.M) GO TO 103
      C(N,M)=F(N)/(F(N-M)*F(M))
      GO TO 105
  103 C(N,M)=1.
  105 CONTINUE
  110 CONTINUE
      COO=1.
      C1O=1.
C
```

```
C
C        FB(M,N)    CALCULATIONS
C
C
         FB00=2.*DDM00
         DO 210 M=1,10
         FBX0(M)=(.5**M)*DDM00
         DO 205 J=1,M
         IF(M.EQ.J) DUM=1.
         IF(M.NE.J) DUM=(.5)**(M-J)
         FBX0(M)=FBX0(M)+C(M,J)*DUM*((-1.)**J)*DDMX0(J)
 205     CONTINUE
         FBX0(M)=FBX0(M)*(1.+(-1.)**M)
 210     CONTINUE
         DO 250 N=1,10
         FB0X(N)=DDM0X(N)
         DO 240 K=1,N
         IF(K.EQ.N) DUM=DDM00
         IF(K.NE.N) DUM=DDM0X(N-K)
         FB0X(N)=FB0X(N)+C(N,K)*(.5**K)*DUM
         DO 230 J=1,K
         IF(K.EQ.J) DUM1=1.
         IF(K.NE.J) DUM1=(.5**(K-J))
         IF(K.EQ.N) DUM2=DDMX0(J)
         IF(K.NE.N) DUM2=DDM(J,N-K)
         FB0X(N)=FB0X(N)+C(N,K)*C(K,J)*DUM1*((-1.)**J)*DUM2
 230     CONTINUE
 240     CONTINUE
         FB0X(N)=FB0X(N)*(1.+(-1.)**N)
 250     CONTINUE
C
C
         DO 300 M=1,10
         DO 290 N=1,10
         FB(M,N)=(.5**M)*DDM0X(N)
         DO 260 J=1,M
         IF(M.EQ.J) DUM=1.
         IF(M.NE.J) DUM=(.5**(M-J))
         FB(M,N)=FB(M,N)+ C(M,J)*DUM*((-1.)**J)*DDM(J,N)
 260     CONTINUE
         DO 280 K=1,N
         MK=M+K
         IF(N.EQ.K) DUM=DDM00
         IF(N.NE.K) DUM=DDM0X(N-K)
         FB(M,N)=FB(M,N)+C(N,K)*(.5**(MK))*DUM
         DO 270 J=1,MK
         IF(MK.EQ.J) DUM=1.
         IF(MK.NE.J) DUM=(.5**(MK-J))
         IF(N.EQ.K) DUM2=DDMX0(J)
         IF(N.NE.K) DUM2=DDM(J,N-K)
         FB(M,N)=FB(M,N)+C(N,K)*C(MK,J)*DUM*((-1.)**J)*DUM2
 270     CONTINUE
 280     CONTINUE
         FB(M,N)=FB(M,N)*(1.+(-1.)**(M+N))
 290     CONTINUE
 300     CONTINUE
         PRINT 2020,D
```

```
      PRINT 2999,KZ,(I,I=1,10)
      PRINT 3000,KZ,FBOO,(FBOX(M),M=1,10)
      PRINT 3000,(M,FBXO(M),(FB(M,N),N=1,10),M=1,10)
      IF(IK.EQ.2) GO TO 310
      FDOO=FBOO
      DO 303 M=1,10
303   FDXO(M)=FBXO(M)
      DO 304 N=1,10
304   FDOX(N)=FBOX(N)
      DO 305 M=1,10
      DO 306 N=1,10
      FD(M,N)=FB(M,N)
306   CONTINUE
305   CONTINUE
      IK=2
      D=DS
      GO TO 5
310   FBOO=FBOO-FDOO
      DO 311 M=1,10
311   FBXO(M)=FBXO(M)-FDXO(M)
      DO 312 N=1,10
312   FBOX(N)=FBOX(N)-FDOX(N)
      DO 314 M=1,10
      DO 313 N=1,10
      FB(M,N)=FB(M,N)-FD(M,N)
313   CONTINUE
314   CONTINUE
      DO 3 I=1,10
3     CJ(I)=0.
      AI=AINDUCT(CJ)
      RATIO=AI/((1.26E-6)*D)
      PRINT 2030,(CJ(I),I=1,10)
      PRINT 2040,AI,RATIO
      AIO=AI
      TEST=AI/(1.E+10)
      DO 320 I=1,NJ
320   DELTA(I)=.1
325   CALL MIN MD(NJ,1,DELTA,CJ,AINDUCT,TEST)
      PRINT 2030,(CJ(I),I=1,10)
      AI=AINDUCT(CJ)
      RATIO=AI/((1.26E-6)*D)
      PRINT 2040,AI,RATIO
      IF(ABS((AI-AIO)/AI).LT..00001) GO TO 330
      AIO=AI
      DO 326 I=1,NJ
326   DELTA(I)=(.1)*DELTA(I)
      GO TO 325
330   IF(IPLOT.EQ.0) STOP
      NNP=NNP+1
      API(NNP)=AI
      APR(NNP)=RATIO
      APD(NNP)=D
      D=D+DE
      IF(NNP.EQ.20) GO TO 350
      GO TO 5
350   CALL PLOT CT1(APD,API,NNP,10.,8.,1H*,TIT1,3)
      CALL PLOT CT1(APD,APR,NNP,10.,8.,1H*,TIT2,5)
```

```
      STOP
1000  FORMAT(8E10.3)
2010  FORMAT(*1 THE M DOUBLEBAR ARRAY FOR D=*,E10.3//)
2020  FORMAT(///*  THE F ARRAY FOR D = *,E10.3//)
2030  FORMAT(*        THE CURRENT DENSITY HAS THE FORM J0=1.  AND J(1)
     1THRU J(10) =*/,10E12.3//)
2040  FORMAT(/*  INDUCTANCE =*,E12.3,* HENRYS  AND THE RATIO OF THIS IND
     1UCTANCE TO THE INFINITE SHEET VALUE IS*,E12.3)
3000   FORMAT(3X,I2,2X,11E11.3 )
2999  FORMAT(2X,11I11/)
      END
```

```
      SUBROUTINE MIN MD(NV,KK,DLT,X,FOX,TEST)
      DIMENSION DLT(1),XNEW(20),XNOW(20),X(1),DEL(20)
C
      XNEW(4)=XNOW(4)=X(4)
      TST=TEST
      NX=NV
      NK=KK
      DO 5 I=1,NX
      XNOW(I)=X(I)
      XNEW(I)=X(I)
    5 DEL(I)=DLT(I)
   10 FNOW=FOX(XNOW)
   15 FOLD=FNOW
   20 DO 30 I=1,NX
      A=XNEW(I)
      XNEW(I)=XNOW(I)+DEL(I)
      FNEW=FOX(XNEW)
      IF(FNEW.GE.FNOW) GO TO 25
      FNOW=FNEW
      A=XNEW(I)
   25 XNEW(I)=XNEW(I)-2.*DEL(I)
      FNEW=FOX(XNEW)
      IF(FNEW.GE.FNOW) GO TO 30
      FNOW=FNEW
      A=XNEW(I)
   30 XNEW(I)=A
      IF(FNOW.GT.FOLD) GO TO 35
      IF((FOLD-FNOW).GT.TST) GO TO 50
   35 DO 40 I=1,NX
   40 DEL(I)=DEL(I)/10.
      NK=NK-1
      IF(NK.GT.0) GO TO 20
      DO 45 I=1,NX
   45 X(I)=XNOW(I)
      RETURN
   50 DO 55 I=1,NX
      T = XNOW(I)
      XNOW(I) = XNEW(I)
   55 XNEW(I)=2.*XNEW(I)-T
      FNEW=FOX(XNEW)
      IF(FNEW.GE.FNOW) GO TO 60
      IF((FNOW-FNEW).LT.TST) GO TO 60
      FNOW=FNEW
      GO TO 50
   60 DO 65 I=1,NX
   65 XNEW(I)=XNOW(I)
      GO TO 15
      END
```

```
      FUNCTION AINDUCT(CJ)
      COMMON FBOO,FBOX(10),FBXO(10),FB(10,10),NJ
      DIMENSION CJ(1)
      DATA ( AMU=1.26E-6)
      SUM=FBOO  $   DEL=1.
      DO 10 M=1,NJ
      AM=M
      DEL=DEL+CJ(M)*(1.-(-1.)**(M+1))/((AM+1.)*(2.**(M+1)))
   10 SUM=SUM+CJ(M)*FBXO(M)
      DO 12 N=1,NJ
      AN=N
      DEL=DEL+CJ(N)*(1.-(-1.)**(N+1))/((AN+1.)*(2.**(N+1)))
   12 SUM=SUM+CJ(N)*FBOX(N)
      DO 14 M=1,NJ
      DO 13 N=1,NJ
      AN=N   $   AM=M
      DEL=DEL+CJ(M)*CJ(N)*(1.-(-1.)**(M+1))*(1.-(-1.)**(N+1))/
     1((AM+1.)*(AN+1.)*2.**(M+N+2))
      SUM=SUM+FB(M,N)*CJ(M)*CJ(N)
   13 CONTINUE
   14 CONTINUE
      AINDUCT=AMU*SUM/(DEL*2.*3.14159)
      RETURN
      END
```

APPENDIX E

Experimental Verification of MULTIFL Inductance Model

Perhaps the best inductance model that can be used in MULTIFL is a hybrid of the two models presented in Appendices B and C. One model corrects for frequency effects and the other for edge effects. However, to correct for both simultaneously it would be necessary to perform more complicated integrations than those in Equation (C5). This cannot be done at the present time; another approximation must be made. The approximation is the following:

1. assume the d.c. inductance is given by the fourth order calculations of Table C1.

2. fit the data of 1. to a polynominal function

$$L/\ell = 1.257 \times 10^{-6} (D/b) - 1.910 \times 10^{-6} (D/b)^2$$

for $0 \le D/b \le .1$

$$= 1.069 \times 10^{-7} + 8.779 \times 10^{-7} (D/b-.1) - 3.921 \times 10^{-7} (D/b-.1)^2$$

for $.1 < D/b \le 1.$

$$= 5.794 \times 10^{-7} + 1.722 \times 10^{-7} (D/b-1.)^2 - 9.819 \times 10^{-9} (D/b-1.)^2$$

for $1. < D/b \le 10.$

3. correct the formula of 2. for frequency effects by changing the true D/b to the "effective" separation distance of $D/b + (\delta_u + \delta_\ell)/2b$

The accuracy of this procedure cannot be completely ascertained. The fourth order inductances are probably accurate to within 1%. The fit of (2) has only 3 independent parameters; the first coefficient is μ_o, and the curve and its derivative are continuous at the two transition points. Using 3 coefficients to fit a function over a range 4 orders of magnitude is a difficult problem and the result quoted in (2) is not better than 3%. The validity of the correction of (3) is hard to assess. There isn't a true frequency or a steady state in MULTIFL. In practice a "local time" frequency is defined by

$$\omega = \sqrt{\left| \frac{di}{dt} / q(t) \right|}$$

and transient effects are ignored.

The best check on this inductance model should rest with experiments. Sandia Laboratories [3] have used an inductance bridge to measure the change in inductance due to a change in separation distance on a particular element. They converted these relative inductances to absolute values by using the infinite sheet formula (Equation (A7)) on a very small D/b. They did not consider skin-depth effects explicitly, but they did measure the inductances at a frequency of about 50 Kc which is the resonant frequency of their capacitor bank facility. Their data (read off a graph) is recorded in columns (1) and (3) of Table E1.

Table E1

Inductance Comparisons, Theory and Experiment

(1) True Separation Distance D(cm)	(2) D/b	(3) Measured Inductance L(nh)	(4) L/ℓ (nh/m)	(5) L/ℓ + 14.8	(6) Average Current Separation $D/b + \delta_n$	(7) L/ℓ From Eqn.	(8) Percent Difference [(5)-(7)]/(7)
.118	.0402	6.7	44.7	69.5	.0620	70.8	1.8
.223	.0759	11.7	78.0	92.8	.0877	95.8	3.1
.328	.112	15.9	106.	121.	.124	126.	3.9
.432	.147	19.8	132.	157.	.159	157.	-

width = b = 2.94 cm   length = ℓ = 15.0 cm   flyer thickness = d = .0313 cm

L/ℓ skin-depth correction = 14.8 nh/m   skin depth = δ = .0377 cm

$\delta_n = (d+\delta)/2b = .0118$

In order to compare these experimental numbers with the MULTIFL model several modifications have to be made. Columns (2) and (4) are simple normalizations to compare with the more generalized forms. Column (5) is the result of applying a skin-depth correction to column (4). These are the inductances that would have been measured if formula (B7) had been used to peg the absolute inductance rather than (A7). In detail, aluminum at 50 Kc has a skin-depth of .0377 cm. The thickness of the flyer is .0313 cm. Therefore the average skin depth in the flyer and backstrap is about .0345 cm and at D=0 the inductance should be

$$L/\ell = \mu_o (.0345 \text{ cm}/b) = 14.8 \text{ nh/m}$$

rather than 0. Column (6) is the true separation distance plus the average skin depth and column (7) is the final MULTIFL model prediction. The comparison of columns (5) and (7) are the comparison between theory and experiment in the limited range $0 < D/b < .15$. Agreement is better than should be expected.

The discussion presented above verifies the inductance theory for a single, isolated, finite-width element. MULTIFL can operate on such an element or it can treat several such elements in series and in parallel. For the more complicated case it is not clear how edge effects should be treated. It may be that elements which are completely surrounded by other elements should be treated by the infinite sheet approximation (B7). Final judgments on this point have not been made, but several possibilities have been acknowledged by allowing model options in MULTIFL.

APPENDIX F

Program MULTIFL

Input to Program MULTIFL is in the form of 10 or more data cards per problem. By stacking their data decks sequentially, several problems may be solved in one computer run. A blank card read as the first card of a data deck will terminate execution of the program. All data cards are read in a (10X, 7E10.3) format; all matrices are input by rows. A label describing the contents of a particular card may be punched in columns 1-10. Definitions of input variables will be found in the Glossary of FORTRAN variables on Page F-25. For a given problem, data cards and input variables must be read in the following order:

1. One card containing: VC, C, RB, GB, ALB
2. One card containing: TP, DTC
3. One card containing: ANI, ANJ, ANPL
4. At least one card containing: DØ (I,J)
5. At least one card containing: DMAX (I,J)
6. At least one card containing: B (I,J)
7. At least one card containing: ALENG (I,J)

8. At least one card containing: AMØDL (I,J)

9. One to six cards, each containing: AIP, AJP

10. Once card containing: RESV, ARES, CV, RHØ, TH, RESB, ADEL

Should the Polynominal Fit inductance model be used for any flyer segment, two additional data cards are required. They are:

11. One card containing: C11, C12, C13, DØB1, C21, C22, C23

12. One card containing: DØB2, C31, C32, C33.

Test Problem

The test problem presented here is intended primarily to illustrate the form of the standard input and output for a multi-segemented flyer. Physically, it represents a flyer configuration which will approximate a cosine impulse load on a circular sample. One means of obtaining a load of the form

$$\text{Impulse} \simeq I_{max} \cos(\theta), \; -\frac{\pi}{2} \le 0 \le \frac{\pi}{2} \qquad \text{(F1)}$$

is to observe that

$$\text{Current density} \propto \text{width}$$

and

$$\text{Force} \propto (\text{Current})^2 \qquad \text{(F2)}$$

In the test problem, the input values of B(1,J) produce the load defined in Equation (F1). The input data deck appears on page F-3, followed by the MULTIFL printed output.

```
LINE PROP  4.500E+04 5.400E-05 5.730E-03 0.000E+00 3.000E-08
TIMES      2.800   -5 2.500   -3
NT,NJ      1.000E+01 1.000E+00 5.000E+00
D          4.064E-04 4.064E-04 4.064E-04 4.064E-04 4.064E-04 4.064E-04 4.064E-04
D          4.064E-04 4.064E-04 4.064E-04
DMAX       1.460E-02 1.460E-02 1.460E-02 1.460E-02 1.460E-02 1.460E-02 1.460E-02
DMAX       1.460E-02 1.460E-02 1.460E-02
B          8.330E-02 6.860E-02 5.790E-02 5.080E-02 4.720E-02 4.720E-02 5.080E-02
B          5.790E-02 6.860E-02 8.330E-02
L          2.060E-02 2.060E-02 2.060E-02 2.060E-02 2.060E-02 2.060E-02 2.060E-02
L          2.060E-02 2.060E-02 2.060E-02
MODEL      3.000   +0 3.000   +0 3.000   +0 3.000   +0 3.000   +0 3.000   +0 3.000   +0
MODEL      3.000   +0 3.000   +0 3.000   +0
PRINT I,J  1.000E+00 1.000E+00
PRINT I,J  2.000E+00 1.000E+00
PRINT I,J  3.000E+00 1.000E+00
PRINT I,J  4.000E+00 1.000E+00
PRINT I,J  5.000E+00 1.000E+00
FLYER      2.824E-08 3.900E-03 2.590E+06 2.700E+03 3.040E-04 2.824   -8 1.000   +0
CUBIC FIT  0.        1.257   -6 -1.910  -6 1.000   -1 1.069   -7 8.779   -7 -3.921  -7
CUBIC FIT  1.        5.794   -7 1.722   -7 -9.819  -9
```

CAPACITOR VOLTAGE= 4.500E+04(VOLTS) CAPACITANCE= 5.400E-05(FARADS)
LINE RESISTANCE= 5.730E-03(OHMS) AND LINE G= 0. (OHMS/JOULE)
LINE INDUCTANCE= 3.000E-04(HENRYS)

PROBLEM RUNNING TIME= 2.800E-05(SEC) DTC= 2.500E-03 CALCULATED TIME STEP= 2.000E-09(SEC)

FLYER CHARACTERISTICS
RESISTIVITY= 2.824E-08(OHMS-METER) COEFFICIENT OF RESISTIVITY= 3.900E-03(/C)
SPECIFIC HEAT= 2.590E+06(JOULES/C-METERS3) DENSITY= 2.700E+03(KG/METER3)
THICKNESS= 3.040E-04(METERS)

BACKSTRAP CHARACTERISTICS:
RESISTIVITY= 2.824E-08 (OHMS-METER)

INITIAL VALUES OF MATRIX ELEMENTS--
ROW, COLUMN, WIDTH, LENGTH, SEPARATION DISTANCE, MAXIMUM SEPARATION DISTANCE, AND INDUCTANCE MODEL

1	1	8.330E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
2	1	6.860E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
3	1	5.790E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
4	1	5.080E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
5	1	4.720E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
6	1	4.720E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
7	1	5.080E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
8	1	5.790E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
9	1	6.860E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT
10	1	8.330E-02	2.060E-02	4.064E-04	1.460E-02	CUBIC FIT

COEFFICIENTS FOR CUBIC FIT:

C11 =	0.	C12 =	1.257E-06	C13 =	-1.910E-06	(D/B) AT FIRST CHANGE =	1.000E-01
C21 =	1.069E-07	C22 =	8.779E-07	C23 =	-3.921E-07	(D/B) AT SECOND CHANGE =	1.000E+00
C31 =	5.794E-07	C32 =	1.722E-07	C33 =	-9.819E-09		

SKIN DEPTH EFFECT: YES

TIME= 0. (USEC) CAPACITOR VOLTAGE= 4.500E+04(VOLTS) LINE CURRENT= 2.833E+03(AMPS) CYCLE NO.= 0

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
2.83E+03

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	1.60E+01	0.	0.	0.	7.10E-06	2.30E-05	1.99E-10
2	1	1.60E+01	0.	0.	0.	1.04E-05	2.79E-05	2.41E-10
3	1	1.60E+01	0.	0.	0.	1.45E-05	3.31E-05	2.85E-10
4	1	1.60E+01	0.	0.	0.	1.88E-05	3.77E-05	3.24E-10
5	1	1.60E+01	0.	0.	0.	2.17E-05	4.05E-05	3.48E-10
6	1	1.60E+01	0.	0.	0.	2.17E-05	4.05E-05	3.48E-10
7	1	1.60E+01	0.	0.	0.	1.88E-05	3.77E-05	3.24E-10
8	1	1.60E+01	0.	0.	0.	1.45E-05	3.31E-05	2.85E-10
9	1	1.60E+01	0.	0.	0.	1.04E-05	2.79E-05	2.41E-10
10	1	1.60E+01	0.	0.	0.	7.10E-06	2.30E-05	1.99E-10

BANK FREQUENCY = 7.635E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.423E-04 METERS BACKSTRAP SKIN DEPTH = 2.423E-04 METERS

TIME= 1.410E+00(USEC) CAPACITOR VOLTAGE= 2.392E+04(VOLTS) LINE CURRENT= 1.385E+06(AMPS) CYCLE NO.= 705

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
1.38E+06

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	1.79E+01	1.24E-02	4.70E+00	1.02E+03	1.69E+00	2.50E-05	2.26E-10
2	1	1.88E+01	1.82E-02	7.08E+00	1.50E+03	2.47E+00	3.15E-05	2.82E-10
3	1	2.00E+01	2.54E-02	1.02E+01	2.09E+03	3.44E+00	3.93E-05	3.45E-10
4	1	2.11E+01	3.28E-02	1.36E+01	2.69E+03	4.44E+00	4.71E-05	4.07E-10
5	1	2.19E+01	3.78E-02	1.61E+01	3.11E+03	5.12E+00	5.26E-05	4.47E-10
6	1	2.19E+01	3.78E-02	1.61E+01	3.11E+03	5.12E+00	5.26E-05	4.47E-10
7	1	2.11E+01	3.28E-02	1.36E+01	2.69E+03	4.44E+00	4.71E-05	4.07E-10
8	1	2.00E+01	2.54E-02	1.02E+01	2.09E+03	3.44E+00	3.93E-05	3.45E-10
9	1	1.88E+01	1.82E-02	7.08E+00	1.50E+03	2.47E+00	3.15E-05	2.82E-10
10	1	1.79E+01	1.24E-02	4.70E+00	1.02E+03	1.69E+00	2.50E-05	2.26E-10

BANK FREQUENCY = 5.677E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.810E-04 METERS BACKSTRAP SKIN DEPTH = 2.810E-04 METERS

TIME= 2.820E+00(USEC) CAPACITOR VOLTAGE=-1.211E+04(VOLTS) LINE CURRENT= 1.120E+06(AMPS) CYCLE NO.= 1410

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
1.12E+06

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	3.34E+01	4.13E-02	1.82E+01	3.39E+03	1.09E+00	3.31E-05	3.23E-10
2	1	4.14E+01	6.03E-02	2.95E+01	4.95E+03	1.58E+00	4.79E-05	4.64E-10
3	1	5.14E+01	8.36E-02	4.68E+01	6.87E+03	2.17E+00	7.06E-05	6.52E-10
4	1	6.15E+01	1.07E-01	6.92E+01	8.81E+03	2.73E+00	1.01E-04	8.57E-10
5	1	6.84E+01	1.23E-01	8.78E+01	1.01E+04	3.10E+00	1.27E-04	1.00E-09
6	1	6.84E+01	1.23E-01	8.78E+01	1.01E+04	3.10E+00	1.27E-04	1.00E-09
7	1	6.15E+01	1.07E-01	6.92E+01	8.81E+03	2.73E+00	1.01E-04	8.57E-10
8	1	5.14E+01	8.36E-02	4.68E+01	6.87E+03	2.17E+00	7.06E-05	6.52E-10
9	1	4.14E+01	6.03E-02	2.95E+01	4.95E+03	1.58E+00	4.79E-05	4.64E-10
10	1	3.34E+01	4.13E-02	1.82E+01	3.39E+03	1.09E+00	3.31E-05	3.23E-10

BANK FREQUENCY = 9.883E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.130E-04 METERS BACKSTRAP SKIN DEPTH = 2.130E-04 METERS

TIME= 4.230E+00(USEC) CAPACITOR VOLTAGE=-2.811E+04(VOLTS) LINE CURRENT= 9.372E+04(AMPS) CYCLE NO.= 2115

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
9.37E+04

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	5.91E+01	4.82E-02	2.19E+01	3.96E+03	7.44E-03	3.31E-05	5.29E-10
2	1	7.89E+01	7.03E-02	3.61E+01	5.77E+03	1.06E-02	4.81E-05	8.11E-10
3	1	1.03E+02	9.72E-02	5.84E+01	7.98E+03	1.40E-02	7.18E-05	1.19E-09
4	1	1.28E+02	1.24E-01	8.83E+01	1.02E+04	1.69E-02	1.04E-04	1.60E-09
5	1	1.44E+02	1.42E-01	1.14E+02	1.17E+04	1.85E-02	1.33E-04	1.88E-09
6	1	1.44E+02	1.42E-01	1.14E+02	1.17E+04	1.85E-02	1.33E-04	1.88E-09
7	1	1.28E+02	1.24E-01	8.83E+01	1.02E+04	1.69E-02	1.04E-04	1.60E-09
8	1	1.03E+02	9.72E-02	5.84E+01	7.98E+03	1.40E-02	7.18E-05	1.19E-09
9	1	7.89E+01	7.03E-02	3.61E+01	5.77E+03	1.06E-02	4.81E-05	8.11E-10
10	1	5.91E+01	4.82E-02	2.19E+01	3.96E+03	7.44E-03	3.31E-05	5.29E-10

BANK FREQUENCY = 6.752E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.577E-04 METERS BACKSTRAP SKIN DEPTH = 2.577E-04 METERS

TIME= 5.640E+00(USEC) CAPACITOR VOLTAGE=-1.996E+04(VOLTS) LINE CURRENT=-6.234E+05(AMPS) CYCLE NO.= 2820

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-6.23E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	8.61E+01	5.02E-02	2.30E+01	4.12E+03	3.20E-01	3.23E-05	7.36E-10
2	1	1.18E+02	7.31E-02	3.80E+01	6.00E+03	4.43E-01	4.66E-05	1.15E-09
3	1	1.58E+02	1.01E-01	6.18E+01	8.27E+03	5.64E-01	6.90E-05	1.71E-09
4	1	1.97E+02	1.28E-01	9.39E+01	1.05E+04	6.58E-01	1.00E-04	2.28E-09
5	1	2.24E+02	1.47E-01	1.21E+02	1.21E+04	7.47E-01	1.27E-04	2.68E-09
6	1	2.24E+02	1.47E-01	1.21E+02	1.21E+04	7.47E-01	1.27E-04	2.68E-09
7	1	1.97E+02	1.28E-01	9.39E+01	1.05E+04	6.58E-01	1.00E-04	2.28E-09
8	1	1.58E+02	1.01E-01	6.18E+01	8.27E+03	5.64E-01	6.90E-05	1.71E-09
9	1	1.18E+02	7.31E-02	3.80E+01	6.00E+03	4.43E-01	4.66E-05	1.15E-09
10	1	8.61E+01	5.02E-02	2.30E+01	4.12E+03	3.20E-01	3.23E-05	7.36E-10

BANK FREQUENCY = 5.208E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.934E-04 METERS BACKSTRAP SKIN DEPTH = 2.934E-04 METERS

TIME= 7.050E+00(USEC) CAPACITOR VOLTAGE=-1.059E+03(VOLTS) LINE CURRENT=-7.255E+05(AMPS) CYCLE NO.= 3525

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-7.26E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	1.16E+02	5.75E-02	2.72E+01	4.72E+03	4.22E-01	4.16E-05	9.15E-10
2	1	1.62E+02	8.31E-02	4.55E+01	6.82E+03	5.70E-01	6.56E-05	1.46E-09
3	1	2.17E+02	1.13E-01	7.51E+01	9.29E+03	6.92E-01	1.07E-04	2.16E-09
4	1	2.73E+02	1.43E-01	1.16E+02	1.18E+04	8.63E-01	1.68E-04	2.91E-09
5	1	3.10E+02	1.64E-01	1.53E+02	1.34E+04	9.72E-01	2.24E-04	3.44E-09
6	1	3.10E+02	1.64E-01	1.53E+02	1.34E+04	9.72E-01	2.24E-04	3.44E-09
7	1	2.73E+02	1.43E-01	1.16E+02	1.18E+04	8.63E-01	1.68E-04	2.91E-09
8	1	2.17E+02	1.13E-01	7.51E+01	9.29E+03	6.92E-01	1.07E-04	2.16E-09
9	1	1.62E+02	8.31E-02	4.55E+01	6.82E+03	5.70E-01	6.56E-05	1.46E-09
10	1	1.16E+02	5.75E-02	2.72E+01	4.72E+03	4.22E-01	4.16E-05	9.15E-10

BANK FREQUENCY = 1.478E+06 RADIANS/SEC. FLYER SKIN DEPTH = 1.742E-04 METERS BACKSTRAP SKIN DEPTH = 1.742E-04 METERS

TIMF= 8.460E+00(USEC)   CAPACITOR VOLTAGE= 1.398E+04(VOLTS)   LINE   CURRENT=-3.834E+05(AMPS)   CYCLE NO.= 4230

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-3.83E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	1.49E+02	6.22E-02	3.05E+01	5.10E+03	1.13E-01	3.67E-05	1.17E-09
2	1	2.10E+02	8.92E-02	5.17E+01	7.32E+03	1.48E-01	5.62E-05	1.85E-09
3	1	2.82E+02	1.21E-01	8.72E+01	9.92E+03	1.88E-01	8.96E-05	2.71E-09
4	1	3.56E+02	1.53E-01	1.38E+02	1.25E+04	2.31E-01	1.40E-04	3.65E-09
5	1	4.05E+02	1.74E-01	1.84E+02	1.43E+04	2.58E-01	1.87E-04	4.31E-09
6	1	4.05E+02	1.74E-01	1.84E+02	1.43E+04	2.58E-01	1.87E-04	4.31E-09
7	1	3.56E+02	1.53E-01	1.38E+02	1.25E+04	2.31E-01	1.40E-04	3.65E-09
8	1	2.82E+02	1.21E-01	8.72E+01	9.92E+03	1.88E-01	8.96E-05	2.71E-09
9	1	2.10E+02	8.92E-02	5.17E+01	7.32E+03	1.48E-01	5.62E-05	1.85E-09
10	1	1.49E+02	6.22E-02	3.05E+01	5.10E+03	1.13E-01	3.67E-05	1.17E-09

BANK FREQUENCY = 6.451E+05 RADIANS/SEC.   FLYER SKIN DEPTH = 2.636E-04 METERS   BACKSTRAP SKIN DEPTH = 2.636E-04 METERS

TIME= 9.870E+00(USEC)   CAPACITOR VOLTAGE= 1.815E+04(VOLTS)   LINE   CURRENT= 5.624E+04(AMPS)   CYCLE NO.= 4935

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
5.62E+04

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	1.84E+02	6.27E-02	3.09E+01	5.15E+03	2.35E-03	3.57E-05	1.40E-09
2	1	2.60E+02	8.99E-02	5.24E+01	7.38E+03	2.95E-03	5.40E-05	2.21E-09
3	1	3.50E+02	1.22E-01	8.85E+01	9.99E+03	3.92E-03	8.53E-05	3.23E-09
4	1	4.41E+02	1.54E-01	1.40E+02	1.26E+04	4.77E-03	1.32E-04	4.35E-09
5	1	5.02E+02	1.76E-01	1.87E+02	1.44E+04	5.25E-03	1.76E-04	5.14E-09
6	1	5.02E+02	1.76E-01	1.87E+02	1.44E+04	5.25E-03	1.76E-04	5.14E-09
7	1	4.41E+02	1.54E-01	1.40E+02	1.26E+04	4.77E-03	1.32E-04	4.35E-09
8	1	3.50E+02	1.22E-01	8.85E+01	9.99E+03	3.92E-03	8.53E-05	3.23E-09
9	1	2.60E+02	8.99E-02	5.24E+01	7.38E+03	2.95E-03	5.40E-05	2.21E-09
10	1	1.84E+02	6.27E-02	3.09E+01	5.15E+03	2.35E-03	3.57E-05	1.40E-09

BANK FREQUENCY = 5.349E+05 RADIANS/SEC.   FLYER SKIN DEPTH = 2.895E-04 METERS   BACKSTRAP SKIN DEPTH = 2.895E-04 METERS

TIME= 1.128E+01(USEC) CAPACITOR VOLTAGE= 1.235E+04(VOLTS) LINE CURRENT= 3.543E+05(AMPS) CYCLE NO.= 5640

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
3.54E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	2.19E+02	6.34E-02	3.14E+01	5.21E+03	8.93E-02	3.52E-05	1.63E-09
2	1	3.10E+02	9.08E-02	5.33E+01	7.46E+03	1.15E-01	5.32E-05	2.55E-09
3	1	4.18E+02	1.23E-01	9.01E+01	1.01E+04	1.51E-01	8.37E-05	3.74E-09
4	1	5.27E+02	1.55E-01	1.43E+02	1.28E+04	1.81E-01	1.29E-04	5.03E-09
5	1	5.75E+02	0.	1.91E+02	0.	2.00E-01	1.73E-04	5.73E-09
6	1	5.75E+02	0.	1.91E+02	0.	2.00E-01	1.73E-04	5.73E-09
7	1	5.27E+02	1.55E-01	1.43E+02	1.28E+04	1.81E-01	1.29E-04	5.03E-09
8	1	4.18E+02	1.23E-01	9.01E+01	1.01E+04	1.51E-01	8.37E-05	3.74E-09
9	1	3.10E+02	9.08E-02	5.33E+01	7.46E+03	1.15E-01	5.32E-05	2.55E-09
10	1	2.19E+02	6.34E-02	3.14E+01	5.21E+03	8.93E-02	3.52E-05	1.63E-09

BANK FREQUENCY = 4.508E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.153E-04 METERS

TIME= 1.269E+01(USEC) CAPACITOR VOLTAGE= 1.633E+03(VOLTS) LINE CURRENT= 4.286E+05(AMPS) CYCLE NO.= 6345

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
4.29E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	2.55E+02	6.55E-02	3.28E+01	5.37E+03	1.25E-01	3.66E-05	1.84E-09
2	1	3.61E+02	9.35E-02	5.59E+01	7.67E+03	1.66E-01	5.62E-05	2.87E-09
3	1	4.87E+02	1.26E-01	9.50E+01	1.04E+04	2.15E-01	8.99E-05	4.23E-09
4	1	5.75E+02	0.	1.52E+02	0.	2.59E-01	1.41E-04	5.39E-09
5	1	5.75E+02	0.	2.04E+02	0.	2.92E-01	1.90E-04	5.72E-09
6	1	5.75E+02	0.	2.04E+02	0.	2.92E-01	1.90E-04	5.72E-09
7	1	5.75E+02	0.	1.52E+02	0.	2.59E-01	1.41E-04	5.39E-09
8	1	4.87E+02	1.26E-01	9.50E+01	1.04E+04	2.15E-01	8.99E-05	4.23E-09
9	1	3.61E+02	9.35E-02	5.59E+01	7.67E+03	1.66E-01	5.62E-05	2.87E-09
10	1	2.55E+02	6.55E-02	3.28E+01	5.37E+03	1.25E-01	3.66E-05	1.84E-09

BANK FREQUENCY = 5.495E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.856E-04 METERS BACKSTRAP SKIN DEPTH = 2.856E-04 METERS

TIME= 1.410E+01(USEC) CAPACITOR VOLTAGE=-8.183E+03(VOLTS) LINE CURRENT= 2.953E+05(AMPS) CYCLE NO.= 7050

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
2.95E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	2.92E+02	6.71E-02	3.42E+01	5.51E+03	5.68E-02	3.76E-05	2.05E-09
2	1	4.13E+02	9.57E-02	5.86E+01	7.85E+03	7.72E-02	5.83E-05	3.21E-09
3	1	5.58E+02	1.29E-01	1.00E+02	1.06E+04	9.90E-02	9.46E-05	4.73E-09
4	1	5.75E+02	0.	1.62E+02	0.	1.23E-01	1.51E-04	5.39E-09
5	1	5.75E+02	0.	2.18E+02	0.	1.39E-01	2.05E-04	5.72E-09
6	1	5.75E+02	0.	2.18E+02	0.	1.39E-01	2.05E-04	5.72E-09
7	1	5.75E+02	0.	1.62E+02	0.	1.23E-01	1.51E-04	5.39E-09
8	1	5.58E+02	1.29E-01	1.00E+02	1.06E+04	9.90E-02	9.46E-05	4.73E-09
9	1	4.13E+02	9.57E-02	5.86E+01	7.85E+03	7.72E-02	5.83E-05	3.21E-09
10	1	2.92E+02	6.71E-02	3.42E+01	5.51E+03	5.68E-02	3.76E-05	2.05E-09

BANK FREQUENCY = 5.775E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.786E-04 METERS BACKSTRAP SKIN DEPTH = 2.786E-04 METERS

TIME= 1.551E+01(USEC) CAPACITOR VOLTAGE=-1.286E+04(VOLTS) LINE CURRENT= 5.490E+04(AMPS) CYCLE NO.= 7755

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
5.49E+04

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	3.29E+02	6.75E-02	3.45E+01	5.54E+03	1.90E-03	3.68E-05	2.27E-09
2	1	4.67E+02	9.62E-02	5.93E+01	7.90E+03	2.62E-03	5.67E-05	3.55E-09
3	1	5.75E+02	0.	1.02E+02	0.	3.39E-03	9.16E-05	4.85E-09
4	1	5.75E+02	0.	1.64E+02	0.	4.24E-03	1.45E-04	5.40E-09
5	1	5.75E+02	0.	2.22E+02	0.	4.80E-03	1.97E-04	5.73E-09
6	1	5.75E+02	0.	2.22E+02	0.	4.80E-03	1.97E-04	5.73E-09
7	1	5.75E+02	0.	1.64E+02	0.	4.24E-03	1.45E-04	5.40E-09
8	1	5.75E+02	0.	1.02E+02	0.	3.39E-03	9.16E-05	4.85E-09
9	1	4.67E+02	9.62E-02	5.93E+01	7.90E+03	2.62E-03	5.67E-05	3.55E-09
10	1	3.29E+02	6.75E-02	3.45E+01	5.54E+03	1.90E-03	3.68E-05	2.27E-09

BANK FREQUENCY = 5.097E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.965E-04 METERS BACKSTRAP SKIN DEPTH = 2.965E-04 METERS

TIME= 1.692E+01(USEC) CAPACITOR VOLTAGE=-1.116E+04(VOLTS) LINE CURRENT=-1.739E+05(AMPS) CYCLE NO.= 8460

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-1.74E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	3.67E+02	6.76E-02	3.46E+01	5.55E+03	1.89E-02	3.65E-05	2.48E-09
2	1	5.20E+02	9.64E-02	5.94E+01	7.91E+03	2.58E-02	5.61E-05	3.88E-09
3	1	5.75E+02	0.	1.02E+02	0.	3.40E-02	9.03E-05	4.85E-09
4	1	5.75E+02	0.	1.64E+02	0.	4.25E-02	1.43E-04	5.40E-09
5	1	5.75E+02	0.	2.22E+02	0.	4.81E-02	1.94E-04	5.73E-09
6	1	5.75E+02	0.	2.22E+02	0.	4.81E-02	1.94E-04	5.73E-09
7	1	5.75E+02	0.	1.64E+02	0.	4.25E-02	1.43E-04	5.40E-09
8	1	5.75E+02	0.	1.02E+02	0.	3.40E-02	9.03E-05	4.85E-09
9	1	5.20E+02	9.64E-02	5.94E+01	7.91E+03	2.58E-02	5.61E-05	3.88E-09
10	1	3.67E+02	6.76E-02	3.46E+01	5.55E+03	1.89E-02	3.65E-05	2.48E-09

BANK FREQUENCY = 4.679E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.095E-04 METERS

TIME= 1.833E+01(USEC) CAPACITOR VOLTAGE=-4.756E+03(VOLTS) LINE CURRENT=-2.936E+05(AMPS) CYCLE NO.= 9165

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-2.94E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	4.04E+02	6.83E-02	3.51E+01	5.60E+03	5.32E-02	3.67E-05	2.69E-09
2	1	5.74E+02	9.73E-02	6.04E+01	7.98E+03	7.20E-02	5.66E-05	4.21E-09
3	1	5.75E+02	0.	1.04E+02	0.	9.70E-02	9.14E-05	4.86E-09
4	1	5.75E+02	0.	1.68E+02	0.	1.21E-01	1.45E-04	5.41E-09
5	1	5.75E+02	0.	2.27E+02	0.	1.37E-01	1.97E-04	5.74E-09
6	1	5.75E+02	0.	2.27E+02	0.	1.37E-01	1.97E-04	5.74E-09
7	1	5.75E+02	0.	1.68E+02	0.	1.21E-01	1.45E-04	5.41E-09
8	1	5.75E+02	0.	1.04E+02	0.	9.70E-02	9.14E-05	4.86E-09
9	1	5.74E+02	9.73E-02	6.04E+01	7.98E+03	7.20E-02	5.66E-05	4.21E-09
10	1	4.04E+02	6.83E-02	3.51E+01	5.60E+03	5.32E-02	3.67E-05	2.69E-09

BANK FREQUENCY = 3.619E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.519E-04 METERS

TIME= 1.974E+01(USEC) CAPACITOR VOLTAGE= 2.916E+03(VOLTS) LINE CURRENT=-2.702E+05(AMPS) CYCLE NO.= 9870

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-2.70E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	4.42E+02	6.92E-02	3.60E+01	5.68E+03	4.46E-02	3.91E-05	2.88E-09
2	1	5.75E+02	0.	6.20E+01	0.	6.10E-02	6.16E-05	4.20E-09
3	1	5.75E+02	0.	1.07E+02	0.	8.22E-02	1.02E-04	4.84E-09
4	1	5.75E+02	0.	1.74E+02	0.	1.03E-01	1.65E-04	5.39E-09
5	1	5.75E+02	0.	2.36E+02	0.	1.16E-01	2.27E-04	5.72E-09
6	1	5.75E+02	0.	2.36E+02	0.	1.16E-01	2.27E-04	5.72E-09
7	1	5.75E+02	0.	1.74E+02	0.	1.03E-01	1.65E-04	5.39E-09
8	1	5.75E+02	0.	1.07E+02	0.	8.22E-02	1.02E-04	4.84E-09
9	1	5.75E+02	0.	6.20E+01	0.	6.10E-02	6.16E-05	4.20E-09
10	1	4.42E+02	6.92E-02	3.60E+01	5.68E+03	4.46E-02	3.91E-05	2.88E-09

BANK FREQUENCY = 6.379E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.651E-04 METERS BACKSTRAP SKIN DEPTH = 2.651E-04 METERS

TIME= 2.115E+01(USEC) CAPACITOR VOLTAGE= 8.361E+03(VOLTS) LINE CURRENT=-1.330E+05(AMPS) CYCLE NO.=10575

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
-1.33E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	4.81E+02	6.96E-02	3.64E+01	5.72E+03	1.07E-02	3.77E-05	3.09E-09
2	1	5.75E+02	0.	6.28E+01	0.	1.48E-02	5.87E-05	4.21E-09
3	1	5.75E+02	0.	1.08E+02	0.	1.99E-02	9.61E-05	4.85E-09
4	1	5.75E+02	0.	1.76E+02	0.	2.49E-02	1.55E-04	5.40E-09
5	1	5.75E+02	0.	2.40E+02	0.	2.81E-02	2.12E-04	5.73E-09
6	1	5.75E+02	0.	2.40E+02	0.	2.81E-02	2.12E-04	5.73E-09
7	1	5.75E+02	0.	1.76E+02	0.	2.49E-02	1.55E-04	5.40E-09
8	1	5.75E+02	0.	1.08E+02	0.	1.99E-02	9.61E-05	4.85E-09
9	1	5.75E+02	0.	6.28E+01	0.	1.48E-02	5.87E-05	4.21E-09
10	1	4.81E+02	6.96E-02	3.64E+01	5.72E+03	1.07E-02	3.77E-05	3.09E-09

BANK FREQUENCY = 5.191E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.938E-04 METERS BACKSTRAP SKIN DEPTH = 2.938E-04 METERS

TIME= 2.256E+01(USEC) CAPACITOR VOLTAGE= 9.517E+03(VOLTS) LINE CURRENT= 4.416E+04(AMPS) CYCLE NO.=11280

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
4.42E+04

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	5.20E+02	6.97E-02	3.64E+01	5.72E+03	1.17E-03	3.72E-05	3.29E-09
2	1	5.75E+02	0.	6.29E+01	0.	1.63E-03	5.77E-05	4.21E-09
3	1	5.75E+02	0.	1.09E+02	0.	2.19E-03	9.41E-05	4.85E-09
4	1	5.75E+02	0.	1.77E+02	0.	2.74E-03	1.51E-04	5.40E-09
5	1	5.75E+02	0.	2.40E+02	0.	3.10E-03	2.06E-04	5.73E-09
6	1	5.75E+02	0.	2.40E+02	0.	3.10E-03	2.06E-04	5.73E-09
7	1	5.75E+02	0.	1.77E+02	0.	2.74E-03	1.51E-04	5.40E-09
8	1	5.75E+02	0.	1.09E+02	0.	2.19E-03	9.41E-05	4.85E-09
9	1	5.75E+02	0.	6.29E+01	0.	1.63E-03	5.77E-05	4.21E-09
10	1	5.20E+02	6.97E-02	3.64E+01	5.72E+03	1.17E-03	3.72E-05	3.29E-09

BANK FREQUENCY = 4.824E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.048E-04 METERS

TIME= 2.397E+01(USEC) CAPACITOR VOLTAGE= 6.429E+03(VOLTS) LINE CURRENT= 1.800E+05(AMPS) CYCLE NO.=11985

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
1.80E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	5.58E+02	6.98E-02	3.65E+01	5.73E+03	1.91E-02	3.73E-05	3.50E-09
2	1	5.75E+02	0.	6.31E+01	0.	2.70E-02	5.79E-05	4.21E-09
3	1	5.75E+02	0.	1.09E+02	0.	3.64E-02	9.44E-05	4.85E-09
4	1	5.75E+02	0.	1.78E+02	0.	4.56E-02	1.52E-04	5.40E-09
5	1	5.75E+02	0.	2.42E+02	0.	5.15E-02	2.07E-04	5.73E-09
6	1	5.75E+02	0.	2.42E+02	0.	5.15E-02	2.07E-04	5.73E-09
7	1	5.75E+02	0.	1.78E+02	0.	4.56E-02	1.52E-04	5.40E-09
8	1	5.75E+02	0.	1.09E+02	0.	3.64E-02	9.44E-05	4.85E-09
9	1	5.75E+02	0.	6.31E+01	0.	2.70E-02	5.79E-05	4.21E-09
10	1	5.58E+02	6.98E-02	3.65E+01	5.73E+03	1.91E-02	3.73E-05	3.50E-09

BANK FREQUENCY = 4.379E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.199E-04 METERS

TIME= 2.538E+01(USEC) CAPACITOR VOLTAGE= 9.498E+02(VOLTS) LINE CURRENT= 2.223E+05(AMPS) CYCLE NO.=12690

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
2.22E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	5.75E+02	0.	3.69E+01	0.	2.91E-02	3.74E-05	3.58E-09
2	1	5.75E+02	0.	6.39F+01	0.	4.13E-02	5.82F-05	4.22E-09
3	1	5.75E+02	0.	1.10E+02	0.	5.56E-02	9.52E-05	4.85E-09
4	1	5.75E+02	0.	1.80E+02	0.	6.95E-02	1.53E-04	5.40E-09
5	1	5.75F+02	0.	2.46E+02	0.	7.86E-02	2.10E-04	5.74E-09
6	1	5.75E+02	0.	2.46E+02	0.	7.86E-02	2.10E-04	5.74E-09
7	1	5.75E+02	0.	1.80E+02	0.	6.95E-02	1.53E-04	5.40E-09
8	1	5.75E+02	0.	1.10E+02	0.	5.56E-02	9.52E-05	4.85F-09
9	1	5.75E+02	0.	6.39E+01	0.	4.13E-02	5.82E-05	4.22E-09
10	1	5.75E+02	0.	3.69E+01	0.	2.91E-02	3.74E-05	3.58E-09

BANK FREQUENCY = 3.743E+05 RADIANS/SEC. FLYER SKIN DEPTH = 3.040E-04 METERS BACKSTRAP SKIN DEPTH = 3.460E-04 METERS

TIME= 2.679E+01(USEC) CAPACITOR VOLTAGE=-4.283E+03(VOLTS) LINE CURRENT= 1.639E+05(AMPS) CYCLE NO.=13395

PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ
1.64E+05

ROW I	COLUMN J	SEPARATION DISTANCE (MILS)	VELOCITY (CM/USEC)	SPECIFIC ENERGY (CAL/GRAM)	IMPULSE (TAPS)	MAGNETIC PRESSURE (KB)	RESISTANCE (OHMS)	INDUCTANCE (HENRYS)
1	1	5.75E+02	0.	3.73E+01	0.	1.58E-02	3.85E-05	3.58E-09
2	1	5.75E+02	0.	6.46E+01	0.	2.24E-02	6.06E-05	4.21E-09
3	1	5.75E+02	0.	1.12E+02	0.	3.03E-02	1.00E-04	4.84E-09
4	1	5.75E+02	0.	1.83E+02	0.	3.78E-02	1.63E-04	5.39E-09
5	1	5.75E+02	0.	2.50E+02	0.	4.28E-02	2.24E-04	5.72E-09
6	1	5.75E+02	0.	2.50E+02	0.	4.28E-02	2.24E-04	5.72E-09
7	1	5.75E+02	0.	1.83E+02	0.	3.78E-02	1.63E-04	5.39E-09
8	1	5.75E+02	0.	1.12E+02	0.	3.03E-02	1.00E-04	4.84E-09
9	1	5.75E+02	0.	6.46E+01	0.	2.24E-02	6.06E-05	4.21F-09
10	1	5.75E+02	0.	3.73E+01	0.	1.58E-02	3.85F-05	3.58E-09

BANK FREQUENCY = 5.498E+05 RADIANS/SEC. FLYER SKIN DEPTH = 2.855E-04 METERS BACKSTRAP SKIN DEPTH = 2.855E-04 METERS

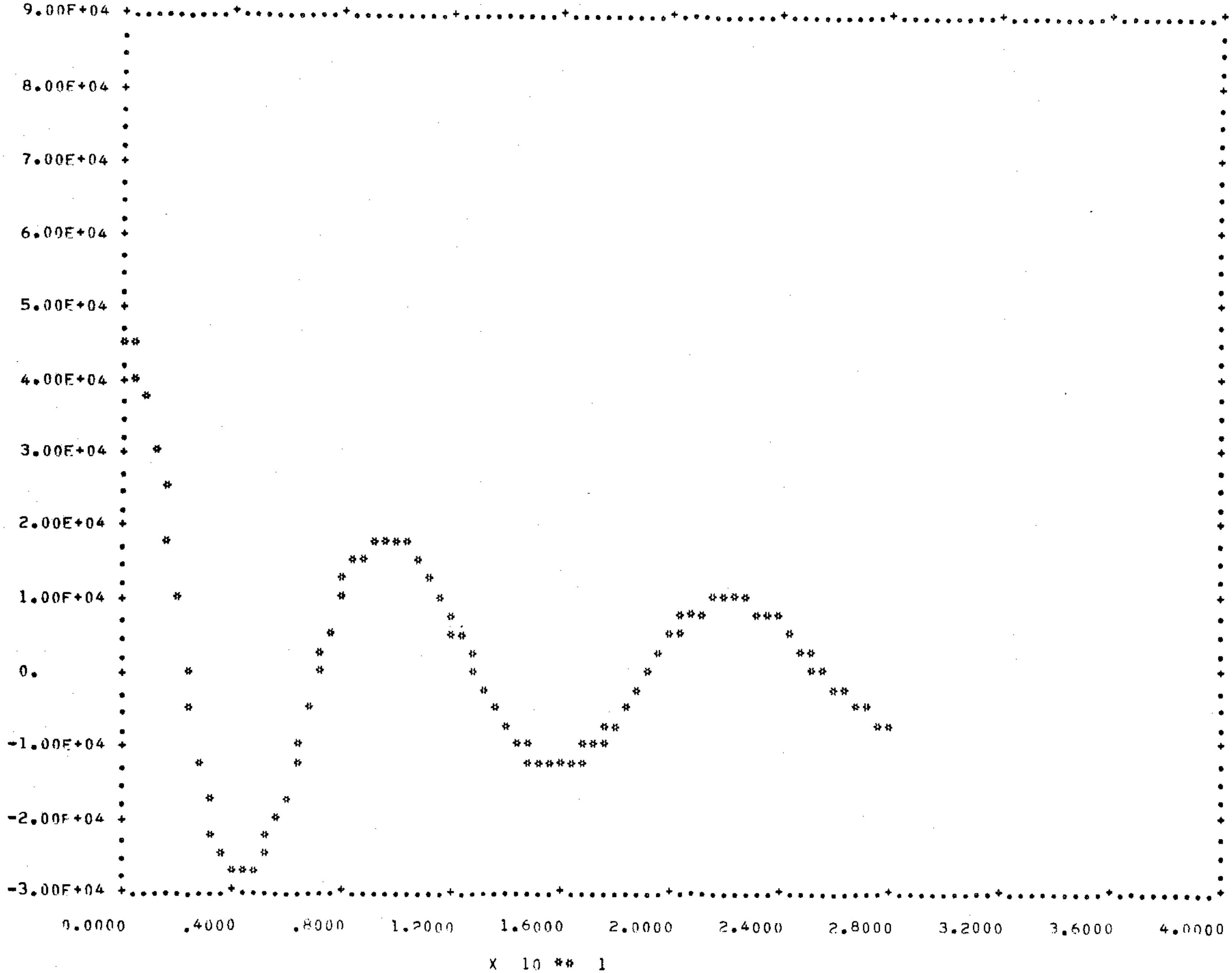
TIME (USEC)	CAPACITOR VOLTAGE	BANK CURRENT (AMPS)	ENERGY BALANCE	EFFICIENCY	SEPARATION (MILS) I= 1 J= 1	IMPULSE (TAPS) I= 1 J= 1	SEPARATION (MILS) I= 2 J= 1	IMPULSE (TAPS) I= 2 J= 1
0.	4.50E+04	2.83E+03	1.00E+00	0.	1.60E+01	0.	1.60E+01	0.
2.82E-01	4.40E+04	3.77E+05	1.00E+00	8.04E-07	1.60E+01	1.20E+01	1.60E+01	1.76E+01
5.64E-01	4.11E+04	7.15E+05	1.00E+00	4.56E-05	1.61E+01	8.93E+01	1.61E+01	1.31E+02
8.46E-01	3.66E+04	1.00E+06	1.00E+00	4.40E-04	1.63E+01	2.77E+02	1.64E+01	4.06E+02
1.13E+00	3.08E+04	1.23E+06	1.00E+00	2.01E-03	1.69E+01	5.91E+02	1.73E+01	8.66E+02
1.41E+00	2.39E+04	1.38E+06	1.00E+00	6.00E-03	1.79E+01	1.02E+03	1.88E+01	1.50E+03
1.69E+00	1.65E+04	1.46E+06	1.01E+00	1.34E-02	1.97E+01	1.53E+03	2.14E+01	2.24E+03
1.97E+00	8.76E+03	1.47E+06	1.01E+00	2.44E-02	2.21E+01	2.06E+03	2.49E+01	3.02E+03
2.26E+00	1.23E+03	1.41E+06	9.93E-01	3.79E-02	2.52E+01	2.58E+03	2.95E+01	3.77E+03
2.54E+00	-5.82E+03	1.28E+06	9.96E-01	5.21E-02	2.90E+01	3.03E+03	3.51E+01	4.43E+03
2.82E+00	-1.21E+04	1.12E+06	9.98E-01	6.48E-02	3.34E+01	3.39E+03	4.14E+01	4.95E+03
3.10E+00	-1.75E+04	9.28E+05	9.98E-01	7.47E-02	3.81E+01	3.65E+03	4.84E+01	5.32E+03
3.38E+00	-2.18E+04	7.20E+05	9.99E-01	8.13E-02	4.32E+01	3.82E+03	5.58E+01	5.57E+03
3.67E+00	-2.50E+04	5.07E+05	9.99E-01	8.51E-02	4.84E+01	3.91E+03	6.34E+01	5.70E+03
3.95E+00	-2.71E+04	2.95E+05	9.99E-01	8.67E-02	5.38E+01	3.95E+03	7.11E+01	5.75E+03
4.23E+00	-2.81E+04	9.37E+04	9.99E-01	8.71E-02	5.91E+01	3.96E+03	7.89E+01	5.77E+03
4.51E+00	-2.81E+04	-9.31E+04	9.99E-01	8.71E-02	6.45E+01	3.96E+03	8.67E+01	5.77E+03
4.79E+00	-2.72E+04	-2.61E+05	9.99E-01	8.74E-02	6.98E+01	3.97E+03	9.46E+01	5.78E+03
5.08E+00	-2.54E+04	-4.07E+05	9.99E-01	8.85E-02	7.52E+01	3.99E+03	1.02E+02	5.82E+03
5.36E+00	-2.30E+04	-5.28E+05	9.99E-01	9.04E-02	8.06E+01	4.05E+03	1.10E+02	5.89E+03
5.64E+00	-2.00E+04	-6.23E+05	1.00E+00	9.34E-02	8.61E+01	4.12E+03	1.18E+02	6.00E+03
5.92E+00	-1.65E+04	-6.93E+05	1.00E+00	9.73E-02	9.18E+01	4.22E+03	1.27E+02	6.14E+03
6.20E+00	-1.28E+04	-7.36E+05	1.00E+00	1.02E-01	9.76E+01	4.34E+03	1.35E+02	6.30E+03
6.49E+00	-8.87E+03	-7.55E+05	1.00E+00	1.07E-01	1.04E+02	4.47E+03	1.44E+02	6.47E+03
6.77E+00	-4.92E+03	-7.51E+05	1.00E+00	1.12E-01	1.10E+02	4.60E+03	1.52E+02	6.65E+03
7.05E+00	-1.06E+03	-7.26E+05	9.98E-01	1.18E-01	1.16E+02	4.72E+03	1.62E+02	6.82E+03
7.33E+00	2.62E+03	-6.80E+05	9.98E-01	1.22E-01	1.22E+02	4.83E+03	1.71E+02	6.97E+03
7.61E+00	6.02E+03	-6.21E+05	9.99E-01	1.26E-01	1.29E+02	4.93E+03	1.80E+02	7.09E+03
7.90E+00	9.08E+03	-5.50E+05	9.99E-01	1.30E-01	1.36E+02	5.01E+03	1.90E+02	7.20E+03
8.18E+00	1.17E+04	-4.70E+05	9.99E-01	1.32E-01	1.43E+02	5.06E+03	2.00E+02	7.27E+03
8.46E+00	1.40E+04	-3.83E+05	9.99E-01	1.34E-01	1.49E+02	5.10E+03	2.10E+02	7.32E+03
8.74E+00	1.58E+04	-2.93E+05	9.99E-01	1.35E-01	1.56E+02	5.13E+03	2.20E+02	7.36E+03
9.02E+00	1.70E+04	-2.02E+05	9.99E-01	1.36E-01	1.63E+02	5.14E+03	2.30E+02	7.37E+03
9.31E+00	1.79E+04	-1.13E+05	9.99E-01	1.36E-01	1.70E+02	5.15E+03	2.40E+02	7.38E+03
9.59E+00	1.82E+04	-2.58E+04	9.99E-01	1.36E-01	1.77E+02	5.15E+03	2.50E+02	7.38E+03
9.87E+00	1.82E+04	5.62E+04	9.99E-01	1.36E-01	1.84E+02	5.15E+03	2.60E+02	7.38E+03
1.02E+01	1.77E+04	1.32E+05	9.99E-01	1.36E-01	1.91E+02	5.15E+03	2.70E+02	7.39E+03
1.04E+01	1.68E+04	2.00E+05	9.99E-01	1.37E-01	1.98E+02	5.16E+03	2.80E+02	7.39E+03
1.07E+01	1.56E+04	2.60E+05	9.99E-01	1.37E-01	2.05E+02	5.17E+03	2.90E+02	7.41E+03
1.10E+01	1.41E+04	3.11E+05	1.00E+00	1.38E-01	2.12E+02	5.18E+03	3.00E+02	7.43E+03
1.13E+01	1.23E+04	3.54E+05	1.00E+00	1.38E-01	2.19E+02	5.21E+03	3.10E+02	7.46E+03
1.16E+01	1.04E+04	3.88E+05	1.00E+00	1.39E-01	2.26E+02	5.23E+03	3.20E+02	7.49E+03
1.18E+01	8.32E+03	4.11E+05	1.00E+00	1.40E-01	2.33E+02	5.27E+03	3.30E+02	7.53E+03
1.21E+01	6.13E+03	4.26E+05	1.00E+00	1.41E-01	2.40E+02	5.30E+03	3.40E+02	7.58E+03
1.24E+01	3.88E+03	4.32E+05	1.00E+00	1.42E-01	2.48E+02	5.34E+03	3.50E+02	7.63E+03
1.27E+01	1.63E+03	4.29E+05	1.00E+00	1.43E-01	2.55E+02	5.37E+03	3.61E+02	7.67E+03
1.30E+01	-5.77E+02	4.16E+05	9.99E-01	1.43E-01	2.62E+02	5.41E+03	3.71E+02	7.72E+03
1.33E+01	-2.70E+03	3.96E+05	9.99E-01	1.44E-01	2.70E+02	5.44E+03	3.82E+02	7.76E+03
1.35E+01	-4.70E+03	3.68E+05	9.99E-01	1.45E-01	2.77E+02	5.47E+03	3.92E+02	7.80E+03
1.38E+01	-6.54E+03	3.34E+05	9.99E-01	1.45E-01	2.84E+02	5.49E+03	4.03E+02	7.83E+03

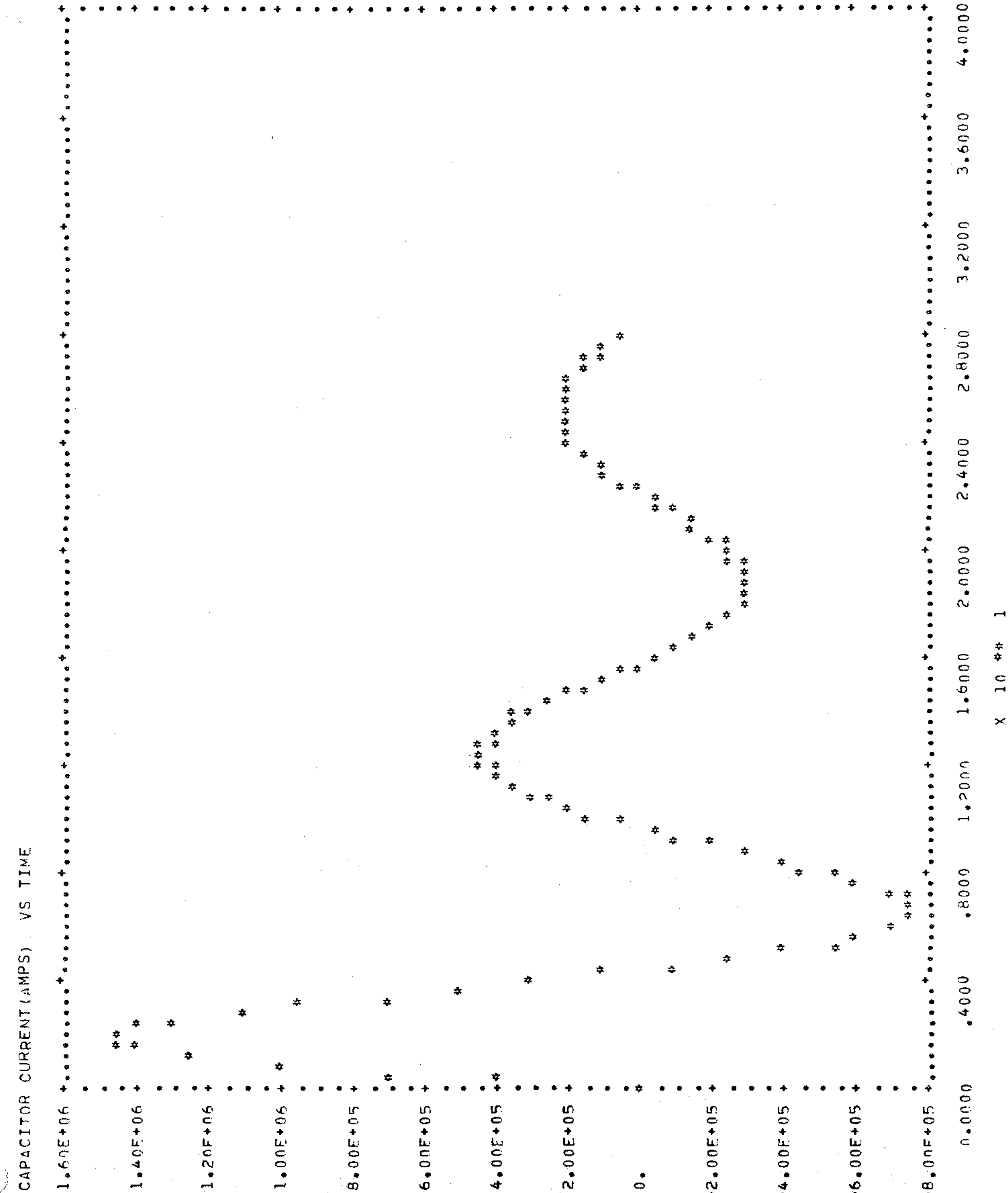
TIME (USEC)	CAPACITOR VOLTAGE	BANK CURRENT (AMPS)	ENERGY BALANCE	EFFICIENCY	SEPARATION (MILS) I= 1 J= 1	IMPULSE (TAPS) I= 1 J= 1	SEPARATION (MILS) I= 2 J= 1	IMPULSE (TAPS) I= 2 J= 1
1.41E+01	-8.18E+03	2.95E+05	9.99E-01	1.45E-01	2.92E+02	5.51E+03	4.13E+02	7.85E+03
1.44E+01	-9.61E+03	2.52E+05	9.99E-01	1.46E-01	2.99E+02	5.52E+03	4.24E+02	7.87E+03
1.47E+01	-1.09E+04	2.05E+05	1.00E+00	1.46E-01	3.07E+02	5.53E+03	4.35E+02	7.88E+03
1.49E+01	-1.18E+04	1.56E+05	1.00E+00	1.46E-01	3.14E+02	5.54E+03	4.45E+02	7.89E+03
1.52E+01	-1.24E+04	1.06E+05	1.00E+00	1.46E-01	3.22E+02	5.54E+03	4.56E+02	7.90E+03
1.55E+01	-1.29E+04	5.49E+04	1.00E+00	1.46E-01	3.29E+02	5.54E+03	4.67E+02	7.90E+03
1.58E+01	-1.30E+04	4.45E+03	1.00E+00	1.46E-01	3.37E+02	5.54E+03	4.77E+02	7.90E+03
1.61E+01	-1.29E+04	-4.45E+04	1.00E+00	1.46E-01	3.44E+02	5.54E+03	4.88E+02	7.90E+03
1.64E+01	-1.26E+04	-9.11E+04	1.00E+00	1.46E-01	3.52E+02	5.54E+03	4.99E+02	7.90E+03
1.66E+01	-1.20E+04	-1.34E+05	1.00E+00	1.46E-01	3.59E+02	5.54E+03	5.09E+02	7.90E+03
1.69E+01	-1.12E+04	-1.74E+05	1.00E+00	1.46E-01	3.67E+02	5.55E+03	5.20E+02	7.91E+03
1.72E+01	-1.02E+04	-2.09E+05	1.00E+00	1.46E-01	3.74E+02	5.56E+03	5.31E+02	7.92E+03
1.75E+01	-8.99E+03	-2.38E+05	1.00E+00	1.46E-01	3.82E+02	5.56E+03	5.42E+02	7.93E+03
1.78E+01	-7.68E+03	-2.63E+05	1.00E+00	1.46E-01	3.89E+02	5.57E+03	5.52E+02	7.95E+03
1.80E+01	-6.26E+03	-2.81E+05	1.00E+00	1.46E-01	3.97E+02	5.59E+03	5.63E+02	7.96E+03
1.83E+01	-4.76E+03	-2.94E+05	1.00E+00	1.47E-01	4.04E+02	5.60E+03	5.74E+02	7.98E+03
1.86E+01	-3.20E+03	-3.01E+05	1.00E+00	1.47E-01	4.12E+02	5.62E+03	5.75E+02	0.
1.89E+01	-1.63E+03	-3.02E+05	1.00E+00	1.47E-01	4.20E+02	5.63E+03	5.75E+02	0.
1.92E+01	-6.18E+01	-2.97E+05	9.99E-01	1.47E-01	4.27E+02	5.65E+03	5.75E+02	0.
1.95E+01	1.46E+03	-2.86E+05	1.00E+00	1.47E-01	4.35E+02	5.66E+03	5.75E+02	0.
1.97E+01	2.92E+03	-2.70E+05	1.00E+00	1.47E-01	4.42E+02	5.68E+03	5.75E+02	0.
2.00E+01	4.28E+03	-2.50E+05	1.00E+00	1.47E-01	4.50E+02	5.69E+03	5.75E+02	0.
2.03E+01	5.52E+03	-2.25E+05	1.00E+00	1.47E-01	4.58E+02	5.70E+03	5.75E+02	0.
2.06E+01	6.63E+03	-1.97E+05	1.00E+00	1.47E-01	4.66E+02	5.71E+03	5.75E+02	0.
2.09E+01	7.58E+03	-1.66E+05	1.00E+00	1.47E-01	4.73E+02	5.71E+03	5.75E+02	0.
2.11E+01	8.36E+03	-1.33E+05	1.00E+00	1.47E-01	4.81E+02	5.72E+03	5.75E+02	0.
2.14E+01	8.96E+03	-9.80E+04	1.00E+00	1.47E-01	4.89E+02	5.72E+03	5.75E+02	0.
2.17E+01	9.38E+03	-6.21E+04	1.00E+00	1.47E-01	4.96E+02	5.72E+03	5.75E+02	0.
2.20E+01	9.61E+03	-2.60E+04	1.00E+00	1.47E-01	5.04E+02	5.72E+03	5.75E+02	0.
2.23E+01	9.66E+03	9.66E+03	1.00E+00	1.47E-01	5.12E+02	5.72E+03	5.75E+02	0.
2.26E+01	9.52E+03	4.42E+04	1.00E+00	1.47E-01	5.20E+02	5.72E+03	5.75E+02	0.
2.28E+01	9.20E+03	7.69E+04	1.00E+00	1.47E-01	5.27E+02	5.72E+03	5.75E+02	0.
2.31E+01	8.72E+03	1.07E+05	1.00E+00	1.47E-01	5.35E+02	5.72E+03	5.75E+02	0.
2.34E+01	8.09E+03	1.35E+05	1.00E+00	1.47E-01	5.43E+02	5.72E+03	5.75E+02	0.
2.37E+01	7.32E+03	1.59E+05	1.00E+00	1.47E-01	5.51E+02	5.73E+03	5.75E+02	0.
2.40E+01	6.43E+03	1.80E+05	1.00E+00	1.47E-01	5.58E+02	5.73E+03	5.75E+02	0.
2.43E+01	5.44E+03	1.97E+05	1.00E+00	1.47E-01	5.66E+02	5.74E+03	5.75E+02	0.
2.45E+01	4.38E+03	2.09E+05	1.00E+00	1.47E-01	5.74E+02	5.75E+03	5.75E+02	0.
2.48E+01	3.26E+03	2.18E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.51E+01	2.11E+03	2.22E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.54E+01	9.50E+02	2.22E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.57E+01	-2.02E+02	2.18E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.59E+01	-1.32E+03	2.09E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.62E+01	-2.38E+03	1.98E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.65E+01	-3.38E+03	1.82E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.68E+01	-4.28E+03	1.64E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.71E+01	-5.09E+03	1.43E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.74E+01	-5.77E+03	1.20E+05	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.76E+01	-6.34E+03	9.52E+04	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.
2.79E+01	-6.77E+03	6.92E+04	1.00E+00	1.47E-01	5.75E+02	0.	5.75E+02	0.

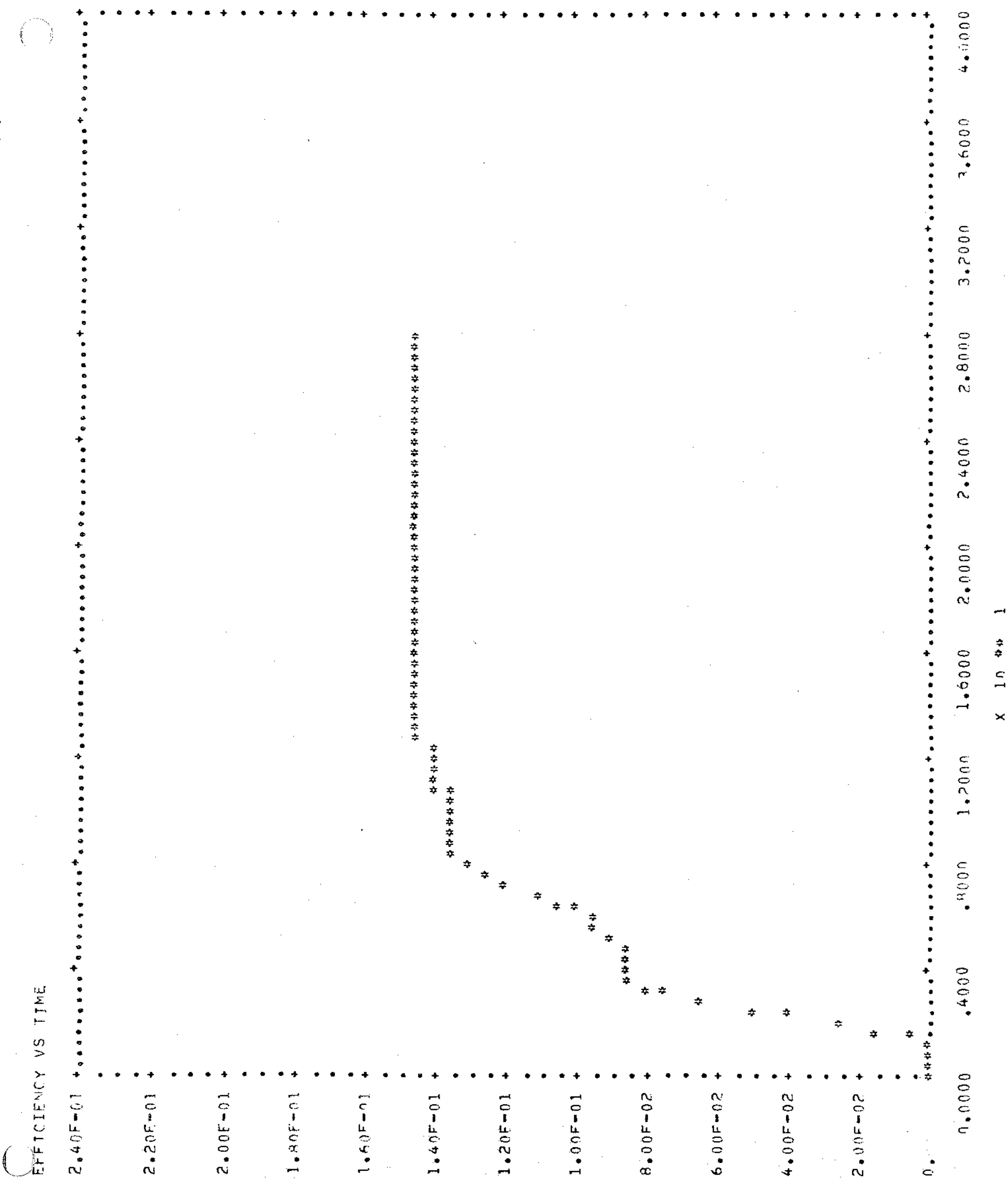
TIME (USEC)	SEPARATION (MILS) I= 3 J= 1	IMPULSE (TAPS) I= 3 J= 1	SEPARATION (MILS) I= 4 J= 1	IMPULSE (TAPS) I= 4 J= 1	SEPARATION (MILS) I= 5 J= 1	IMPULSE (TAPS) I= 5 J= 1	SEPARATION (MILS) I= 0 J= 0	IMPULSE (TAPS) I= 0 J= 0
0.	1.60E+01	0.	1.60E+01	0.	1.60E+01	0.		
2.82E-01	1.60E+01	2.46E+01	1.60E+01	3.17E+01	1.60E+01	3.67E+01		
5.64E-01	1.61E+01	1.83E+02	1.62E+01	2.36E+02	1.62E+01	2.73E+02		
8.46E-01	1.66E+01	5.66E+02	1.68E+01	7.32E+02	1.69E+01	8.45E+02		
1.13E+00	1.78E+01	1.21E+03	1.83E+01	1.56E+03	1.86E+01	1.80E+03		
1.41E+00	2.00E+01	2.09E+03	2.11E+01	2.69E+03	2.19E+01	3.11E+03		
1.69E+00	2.35E+01	3.12E+03	2.57E+01	4.02E+03	2.71E+01	4.64E+03		
1.97E+00	2.84E+01	4.20E+03	3.20E+01	5.41E+03	3.45E+01	6.24E+03		
2.26E+00	3.48E+01	5.25E+03	4.03E+01	6.75E+03	4.40E+01	7.76E+03		
2.54E+00	4.25E+01	6.15E+03	5.02E+01	7.90E+03	5.54E+01	9.08E+03		
2.82E+00	5.14E+01	6.87E+03	6.15E+01	8.81E+03	6.84E+01	1.01E+04		
3.10E+00	6.10E+01	7.38E+03	7.39E+01	9.45E+03	8.26E+01	1.08E+04		
3.38E+00	7.12E+01	7.70E+03	8.70E+01	9.86E+03	9.76E+01	1.13E+04		
3.67E+00	8.18E+01	7.88E+03	1.00E+02	1.01E+04	1.13E+02	1.15E+04		
3.95E+00	9.25E+01	7.96E+03	1.14E+02	1.02E+04	1.29E+02	1.16E+04		
4.23E+00	1.03E+02	7.98E+03	1.28E+02	1.02E+04	1.44E+02	1.17E+04		
4.51E+00	1.14E+02	7.98E+03	1.42E+02	1.02E+04	1.60E+02	1.17E+04		
4.79E+00	1.25E+02	7.99E+03	1.56E+02	1.02E+04	1.76E+02	1.17E+04		
5.08E+00	1.36E+02	8.04E+03	1.69E+02	1.03E+04	1.92E+02	1.18E+04		
5.36E+00	1.47E+02	8.13E+03	1.83E+02	1.04E+04	2.08E+02	1.19E+04		
5.64E+00	1.58E+02	8.27E+03	1.97E+02	1.05E+04	2.24E+02	1.21E+04		
5.92E+00	1.69E+02	8.45E+03	2.12E+02	1.07E+04	2.41E+02	1.23E+04		
6.20E+00	1.81E+02	8.65E+03	2.27E+02	1.10E+04	2.57E+02	1.26E+04		
6.49E+00	1.92E+02	8.87E+03	2.42E+02	1.13E+04	2.75E+02	1.29E+04		
6.77E+00	2.05E+02	9.09E+03	2.57E+02	1.15E+04	2.92E+02	1.32E+04		
7.05E+00	2.17E+02	9.29E+03	2.73E+02	1.18E+04	3.10E+02	1.34E+04		
7.33E+00	2.30E+02	9.47E+03	2.89E+02	1.20E+04	3.28E+02	1.37E+04		
7.61E+00	2.43E+02	9.63E+03	3.05E+02	1.22E+04	3.47E+02	1.39E+04		
7.90E+00	2.56E+02	9.75E+03	3.22E+02	1.23E+04	3.66E+02	1.41E+04		
8.18E+00	2.69E+02	9.85E+03	3.39E+02	1.25E+04	3.85E+02	1.42E+04		
8.46E+00	2.82E+02	9.92E+03	3.56E+02	1.25E+04	4.05E+02	1.43E+04		
8.74E+00	2.96E+02	9.96E+03	3.73E+02	1.26E+04	4.24E+02	1.44E+04		
9.02E+00	3.09E+02	9.98E+03	3.90E+02	1.26E+04	4.43E+02	1.44E+04		
9.31E+00	3.23E+02	9.99E+03	4.07E+02	1.26E+04	4.63E+02	1.44E+04		
9.59E+00	3.36E+02	9.99E+03	4.24E+02	1.26E+04	4.82E+02	1.44E+04		
9.87E+00	3.50E+02	9.99E+03	4.41E+02	1.26E+04	5.02E+02	1.44E+04		
1.02E+01	3.63E+02	9.99E+03	4.58E+02	1.26E+04	5.22E+02	1.44E+04		
1.04E+01	3.77E+02	1.00E+04	4.75E+02	1.27E+04	5.41E+02	1.44E+04		
1.07E+01	3.90E+02	1.00E+04	4.92E+02	1.27E+04	5.61E+02	1.45E+04		
1.10E+01	4.04E+02	1.01E+04	5.09E+02	1.27E+04	5.75E+02	0.		
1.13E+01	4.18E+02	1.01E+04	5.27E+02	1.28E+04	5.75E+02	0.		
1.16E+01	4.31E+02	1.01E+04	5.44E+02	1.28E+04	5.75E+02	0.		
1.18E+01	4.45E+02	1.02E+04	5.61E+02	1.29E+04	5.75E+02	0.		
1.21E+01	4.59E+02	1.02E+04	5.75E+02	0.	5.75E+02	0.		
1.24E+01	4.73E+02	1.03E+04	5.75E+02	0.	5.75E+02	0.		
1.27E+01	4.87E+02	1.04E+04	5.75E+02	0.	5.75E+02	0.		
1.30E+01	5.01E+02	1.04E+04	5.75E+02	0.	5.75E+02	0.		
1.33E+01	5.15E+02	1.05E+04	5.75E+02	0.	5.75E+02	0.		
1.35E+01	5.29E+02	1.05E+04	5.75E+02	0.	5.75E+02	0.		
1.38E+01	5.43E+02	1.06E+04	5.75E+02	0.	5.75E+02	0.		

TIME (USEC)	SEPARATION (MILS) I= 3 J= 1	IMPULSE (TAPS) I= 3 J= 1	SEPARATION (MILS) I= 4 J= 1	IMPULSE (TAPS) I= 4 J= 1	SEPARATION (MILS) I= 5 J= 1	IMPULSE (TAPS) I= 5 J= 1	SEPARATION (MILS) I= 0 J= 0	IMPULSE (TAPS) I= 0 J= 0
1.41E+01	5.59E+02	1.06E+04	5.75E+02	0.	5.75E+02	0.		
1.44E+01	5.72E+02	1.06E+04	5.75E+02	0.	5.75E+02	0.		
1.47E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.49E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.52E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.55E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.58E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.61E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.64E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.66E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.69E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.72E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.75E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.78E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.80E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.83E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.86E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.89E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.92E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.95E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
1.97E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.00E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.03E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.06E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.09E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.11E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.14E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.17E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.20E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.23E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.26E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.28E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.31E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.34E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.37E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.40E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.43E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.45E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.48E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.51E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.54E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.57E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.59E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.62E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.65E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.68E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.71E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.74E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.76E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		
2.79E+01	5.75E+02	0.	5.75E+02	0.	5.75E+02	0.		

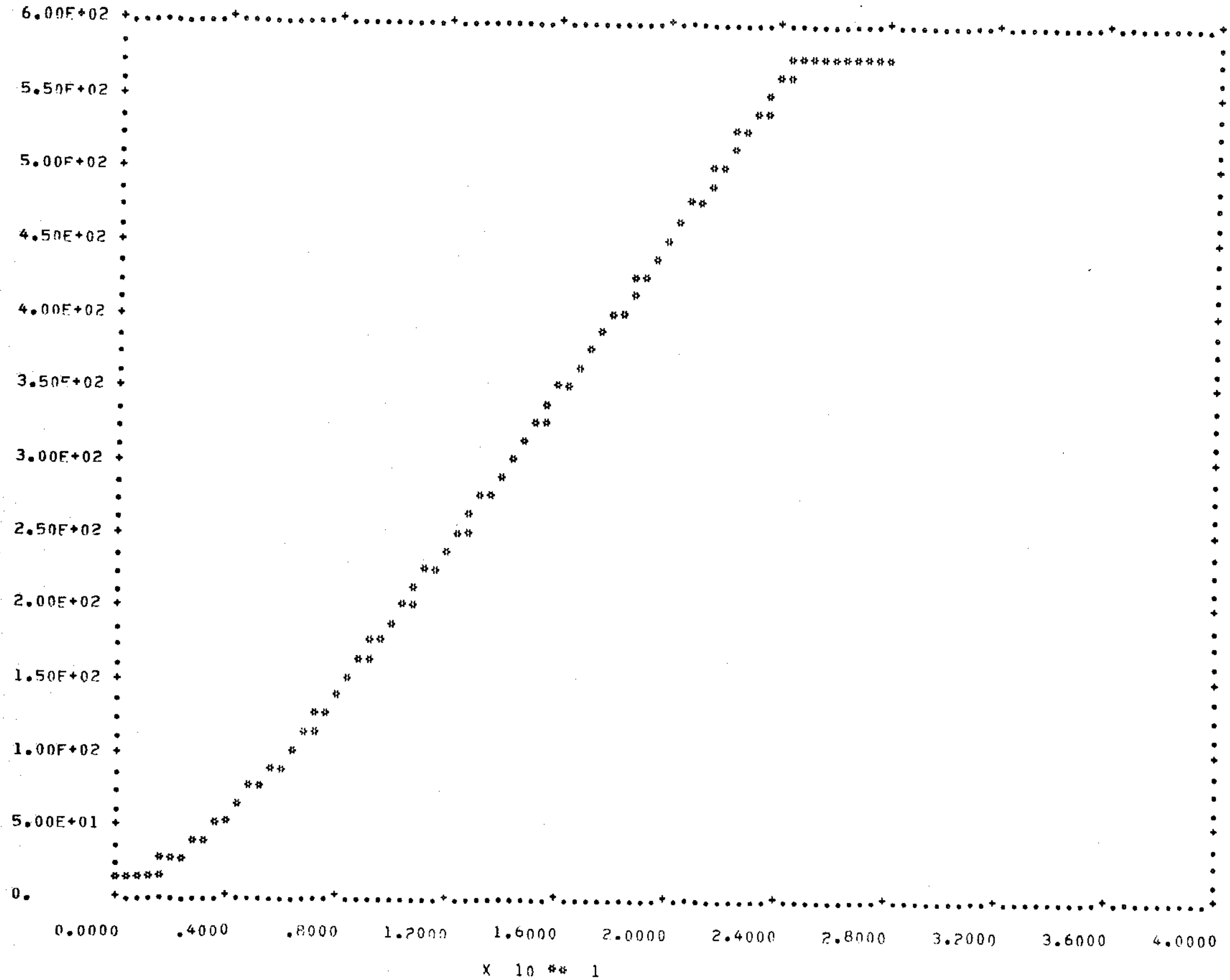
CAPACITOR VOLTAGE VS TIME (USEC)




CAPACITOR CURRENT(AMPS) VS TIME
1.60E+06
1.40E+06
1.20E+06
1.00E+06
8.00E+05
6.00E+05
4.00E+05
2.00E+05
0.
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
0.0000
.4000
.8000
1.2000
1.6000
2.0000
2.4000
2.8000
3.2000
3.6000
4.0000
X 10 ** 1

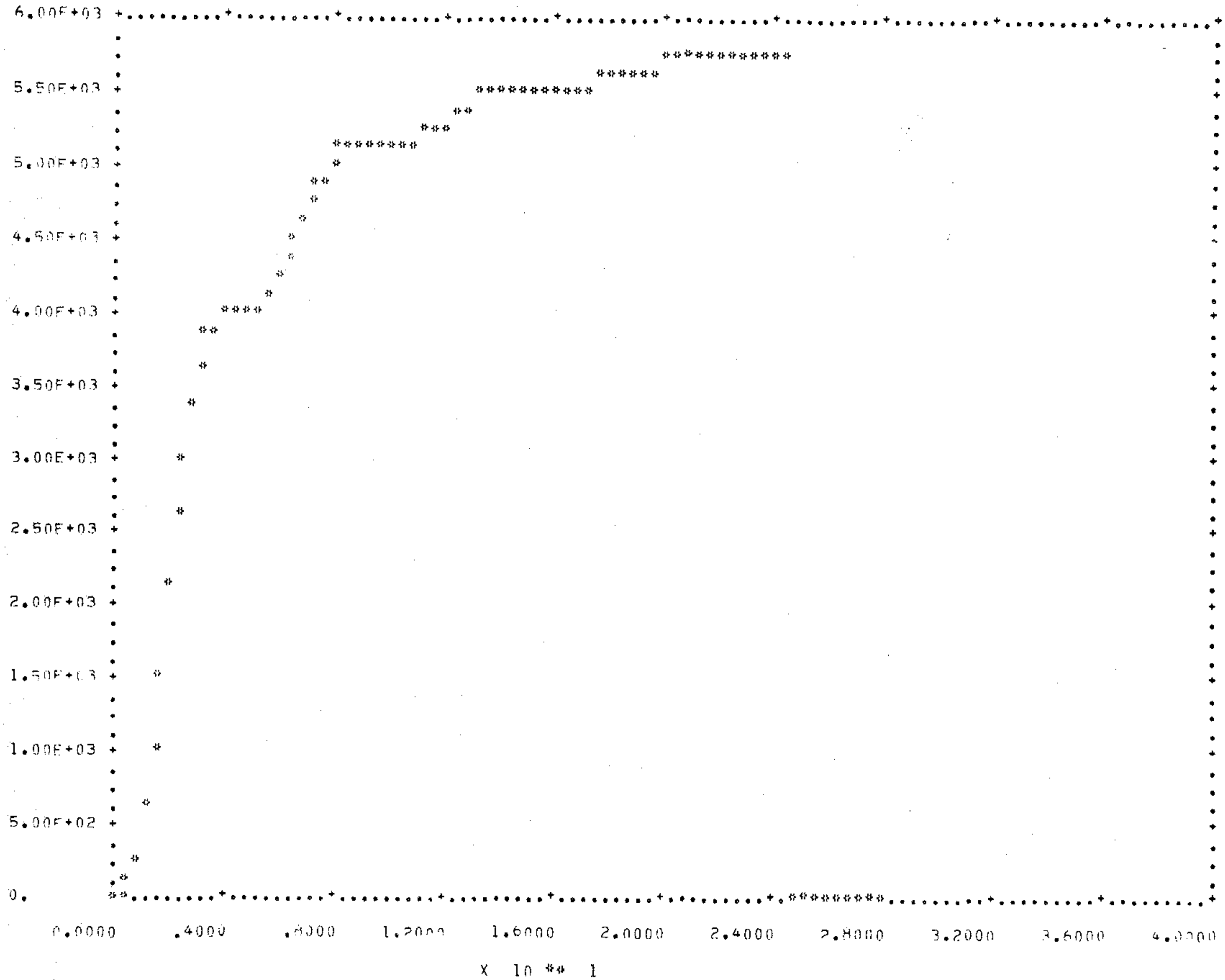

EFFICIENCY VS TIME
2.40E-01
2.20E-01
2.00E-01
1.80E-01
1.60E-01
1.40E-01
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.
0.0000
.4000
.8000
1.2000
1.6000
2.0000
2.4000
2.8000
3.2000
3.6000
4.0000
X 10 ** 1

SEPARATION DISTANCE (MILS) OF I,J ELEMENT VS TIME (USEC)



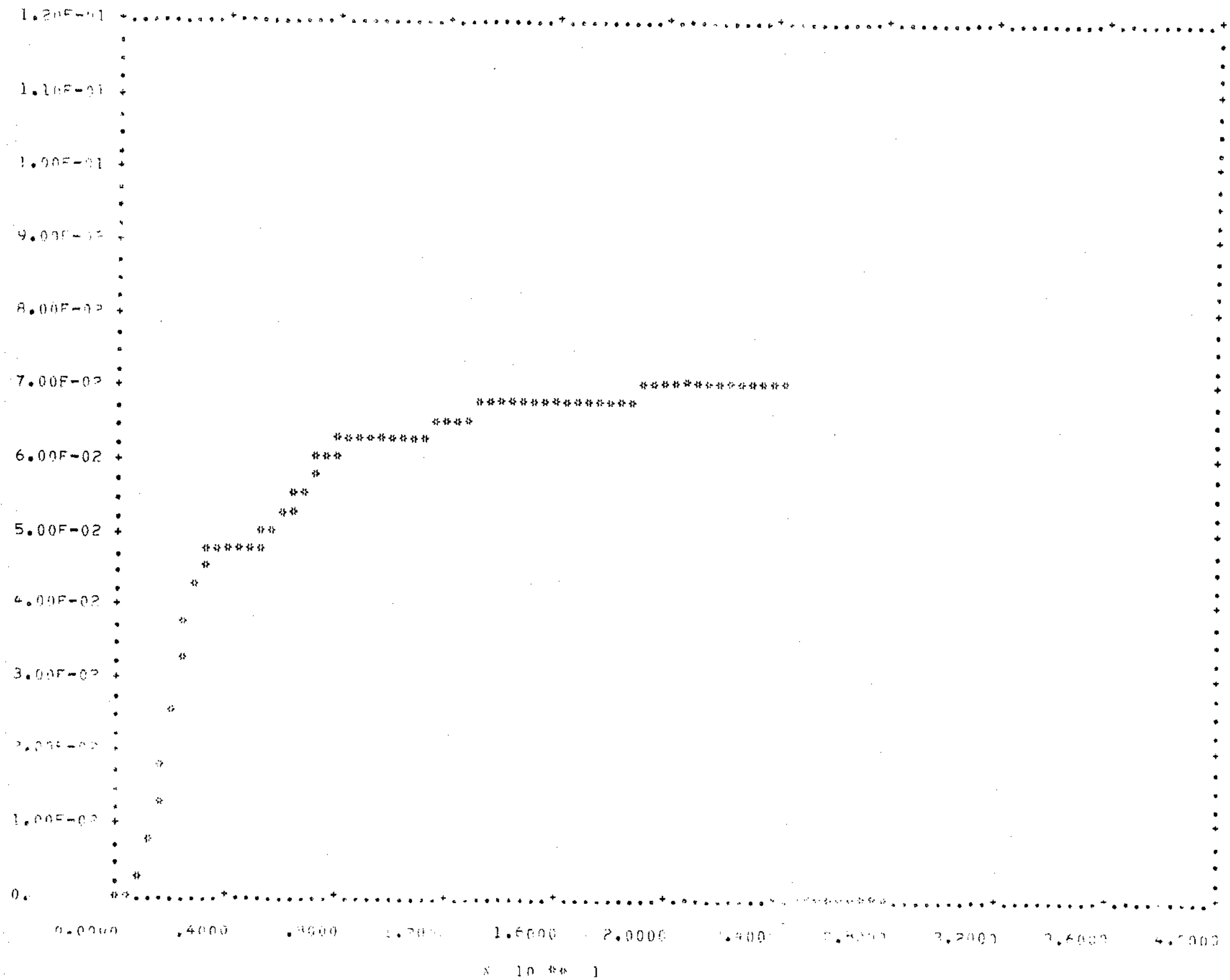
PLOT REPRESENTS ELEMENT IN ROW= 1 AND COLUMN= 1

IMPULSE (TAPS) OF I,J ELEMENT VS TIME (USEC)



PLOT REPRESENTS ELEMENT IN ROW= 1 AND COLUMN= 1

VELOCITY (CM/USEC) VS TIME (USEC)



PLOT REPRESENTS ELEMENT IN ROW= 1 AND COLUMN= 1

Glossary of FORTRAN Variables

AINDUCT	- Function subprogram which computes the time-dependent inductance of the (I,J) element
ADEL, IDEL	- Skin depth effect flag
AIJN(J)	- New current in J'th line
AIJØ(J)	- Old current in J'th line
AIN	- New current in main line
AIØ	- Old current in main line
AIP	- Row index of closely monitored element (input)
AJP	- Column index of closely monitored element (input)
ALB	- Bank inductance
ALENG(I,J)	- Length of (I,J) element
ALEQ	- Equivalent inductance of circuit
ALL(J)	- Total inductance of J'th line
AMASS(I,J)	- Mass of (I,J) element
AMØDL(I,J), MØDEL(I,J)	- Inductance model associated with (I,J) element = 1 for infinite sheet model = 2 for closed form model = 3 for polynominal fit model

AMU	- μ_o
ANCPP, NCPP	- Number of time cycles per edit
ANI, NI	- Maximum number of rows in flyer model
ANJ, NJ	- Maximum number of columns in flyer model
ANPL, NPL	- Number of elements to be monitored closely
ARES	- Thermal coefficient of resistance
B(I,J)	- Width of (I,J) element
C	- Capacitance
CHK	- Minimum initial (D/b), for use with closed form inductance model
CV	- Specific heat of flyer material, (joules/^{o}C·m^3)
C11	-
C12	-
C13	-
C21	- Coefficients used in polynominal fit inductance model
C22	-
C23	-
C31	-
C32	-
C33	-

DELB	- Skin depth in backstrap
DELF	- Skin depth in flyer
DELTA	- Average skin depth
DIDT	- Time derivative of bank current
DIJDT	- Time derivative of J'th line current
DLDD	- $\frac{\partial L}{\partial D}$
DMAX(I,J)	- Maximum allowable separation distance of (I,J) element
DN(I,J)	- Updated separation distance of (I,J) element
DØ(I,J)	- Old separation distance of (I,J) element, read in as initial separation distance
DØB1	- (D/b) at first change-over point in polynominal fit inductance model
DØB2	- (D/b) at second change-over point in polynominal fit inductance model
DPLØT(JJ,M)	- Stores separation distances for plotting
DT	- Time increment
DTC	- Zoning parameter
DTRAN	- Translated separation distance due to skin depth effect

E(I,J)	-	Energy deposited in (I,J) element (joules)
EBAL(M)	-	Stores energy balance for plotting
EK	-	Total kinetic energy of flyer
ELØST	-	Kinetic energy removed from problem as flyer segments impact the sample
EØTH	-	Total energy in bank
EQR(J)	-	Equivalent resistance, in J'th line, due to flyer velocity
EQRFV	-	Function subprogram which returns the equivalent resistance due to flyer velocity of the (I,J) element
ERB	-	Energy deposited in bank resistor
ET	-	Total energy of flyer
FØRCE	-	Function subprogram which computes the force on the (I,J) element
GB	-	Resistance increase per unit increase in deposited energy for bank
GØR	-	ARES/CV or α/C_V
I	-	Row index
IP(JJ)	-	Stores row indices of closely monitored elements
J	-	Column index
JP(JJ)	-	Stores column indices of closely monitored elements

L(I,J)	-	Inductance of (I,J) element
M	-	Plot storage index
N	-	Time increment index
NY	-	Print index
ØMEGA	-	Bank frequency
ØVERL	-	Sum of reciprocal inductances
PE(M)	-	Ratio of total kinetic energy to initial inergy
PI	-	π
PPLØ(M)	-	Plot storage
QN	-	Updated charge on capacitor
QØ	-	Old value of charge on capacitor
Q0	-	Initial charge on capacitor
R(I,J)	-	Initial resistance of (I,J) element
RB	-	Resistance of capacitor bank and transmission line
RBØ	-	Old value of bank resistance
RESB	-	Resistivity of backstrap
RESV	-	Resistivity of flyer
RHØ	-	Mass density of flyer

RJ(J) - Total resistance of J'th line

RØ(I,J) - Old value of resistance of (I,J) element

RT - $1/\sqrt{\omega}$

SIPLØT(JJ,M) - Stores, for plotting, impulse of closely monitored elements

T - Time

TH - Thickness

TIT, TIT1, TIT2, TIT3, TIT4, TIT5 - Plot title storage

TP - Problem running time

TT(M) - Stores time coordinates for plotting

VC - Initial capacitor voltage

VN(I,J) - Updated velocity of (I,J) element

VØ(I,J) - Old value of velocity of (I,J) element

VØLT(M)	-	Stores values of voltages on capacitor for plotting
VPLØT(JJ,M)	-	Stores, for plotting, velocity of closely monitored elements
W0	-	Initial bank frequency (used in time step calculation only)

PROGRAM MULTIFL
FØRTRAN SOURCE DECK LISTING

```
      PROGRAM MULTIFL(INPUT,OUTPUT)
      COMMON IP(6),JP(6),AIJO(10),AIJN(10),ALL(10),RJ(10),EQR(10),TT(101
     1),VOLT(101),PE(101),EBAL(101),AIPL(101),PPLO(101),DO(10,10),DN(10,
     210),B(10,10),ALENG(10,10),E(10,10),VO(10,10),VN(10,10),R(10,10),
     3RO(10,10),AMASS(10,10),L(10,10),DPLOT(6,101),VPLOT(6,101),SIPLOT(6
     4,101),DMAX(10,10)
      DIMENSION TIT(9),TIT1(9),TIT2(9),TIT3(9),TIT4(9),TIT5(9)
      DATA (TIT(1)=8HCAPACITO),(TIT(2)=8HR VOLTAG),(TIT(3)=8HE VS TIM),
     1 (TIT(4)=8HE (USEC))
      DATA (TIT1(1)=8HCAPACITO),(TIT1(2)=8HR CURREN),(TIT1(3)=8HT(AMPS)
     1),(TIT1(4)=8H VS TIME)
      DATA (TIT2(1)=8HEFFICIEN),(TIT2(2)=8HCY VS TI),(TIT2(3)=8HME
     1)
      DATA (TIT3(1)=8HSEPARATI),(TIT3(2)=8HON DISTA),(TIT3(3)=8HNCE (MIL
     1),(TIT3(4)=8HS) OF I,),(TIT3(5)=8HJ ELEMEN),(TIT3(6)=8HT VS TIM),
     2 (TIT3(7)=8HE (USEC))
      DATA (TIT4(1)=8HIMPULSE ),(TIT4(2)=8H(TAPS) O),(TIT4(3)=8HF I,J EL
     1),(TIT4(4)=8HEMENT VS),(TIT4(5)=8H TIME (U),(TIT4(6)=8HSEC)      )
      DATA (TIT5(1)=8HVELOCITY),(TIT5(2)=8H (CM/USE),(TIT5(3)=8HC) VS TI
     1),(TIT5(4)=8HME (USEC),(TIT5(5)=8H)        )
      REAL  L
      COMMON /FCTN/ C11,C12,C13,DOB1,C21,C22,C23,DOB2,C31,C32,C33,AMU,
     1CON1,DELTA,I,J,MODEL(10,10)
      DIMENSION AMODL(10,10)
      EQUIVALENCE (AMODL,MODEL)
      DATA AMU,CHK,PI/1.26E-6,1.E-5,3.14159265358979З/
C
C
C     INPUT SECTION
C
C
630   READ 1000,VC,C,RB,GB,ALB
      IF (VC.LE.0.) STOP10
      READ 1000,TP,DTC
      READ 1000,ANI,ANJ,ANPL
      NI=ANI  $  NJ=ANJ   $    NPL=ANPL
      READ 1000, ((DO (I,J),J=1,NJ),I=1,NI)
      READ 1000,((DMAX(I,J),J=1,NJ),I=1,NI)
      READ 1000, ((B(I,J),J=1,NJ),I=1,NI)
      READ 1000, ((ALENG(I,J),J=1,NJ),I=1,NI)
      READ 1000, ((AMODL(I,J), J=1,NJ), I=1,NI)
C
C     NPL MUST NOT EQUAL 0
      DO 1 JJ=1,6
      IF(JJ-NPL) 2,2,4
2     READ 1000,AIP,AJP
      IP(JJ)=AIP    $JP(JJ)=AJP
      GO TO 1
4     IP(JJ)=0     $JP(JJ)=0
1     CONTINUE
      READ 1000, RESV,ARES,CV,RHO,TH,RESR,ADEL
      IDEL=ADEL
      CON2=10HNO
      IF (IDEL.NE.0) CON2=10HYES
      DO 32 I=1,NI
      DO 32 J=1,NJ
      MODEL(I,J)=IFIX(AMODL(I,J))
```

```
      K=MODEL(I,J)
      GO TO (21,22,23), K
21    VN(I,J)=10HINF. SHEET
      GO TO 24
22    VN(I,J)=10HCLOSE FORM
      GO TO 24
23    VN(I,J)=10HCUBIC FIT
24    IF (MODEL(I,J).NE.2) GO TO 32
      IF (DO(I,J)/B(I,J).GT.CHK) GO TO 32
      PRINT 31, I,J,CHK
      STOP6
32    CONTINUE
      IPF=0
      DO 33 I=1,NI
      DO 33 J=1,NJ
      IF (MODEL(I,J).NE.3) GO TO 33
      READ 1000, C11,C12,C13,DOB1,C21,C22,C23
      READ 1000, DOB2,C31,C32,C33
      IPF=1
      GO TO 34
33    CONTINUE
C
C
C     INITIALIZATION
C
34    CON1=0.5*AMU/PI
      CON3=SQRT(2.*RESB/AMU)
      CON4=SQRT(2.*RESV/AMU)
      DELF=TH
      DELTA=0.
C
      ANP=99.
      T=0.      $ ERR=0.    $  M=1    $   NP=0
      QO=-C*VC   $  AIO=0.   $  N=0
      RBO=RB
      NY=60
      Q0=QO
      OVERL=0.
      GOR=0.
      IF (CV.GT.0.) GOR=ARES/CV
3     DO 8  J=1,NJ
      RJ(J)=0.    $  ALL(J)=0.
      EQR(J)=0.
      AIJO(J)=0.
      DO 5  I=1,NI
      E(I,J)=0.
      VO(I,J)=0.
      RO(I,J)=RESV*ALENG(I,J)/(TH*B(I,J))
      RJ(J)=RJ(J)+RO(I,J)
      AMASS(I,J)=RHO*TH*B(I,J)*ALENG(I,J)
      R(I,J)=RO(I,J)
      L(I,J)=AINDUCT(ALENG(I,J),DO(I,J),B(I,J))
      ALL(J)=ALL(J)+L(I,J)
5     CONTINUE
      OVERL=OVERL+1./ALL(J)
8     CONTINUE
      ALEQ=1./OVERL+ALB
```

```
      OVERL=OVERL+1./ALB
C
C          TIME STEP CALCULATION
C
      W0=(ALEQ*C)**(-.5)
      DT=DTC/W0
      DT = 0.8*DT
      IAP=0
30    IF(DT-1.0) 40,50,50
40    IAP=IAP+1
      DT=DT*10.0
      GO TO 30
50    CONTINUE
      ID=DT
      DT=ID
      DT=DT*10.0**(-IAP)
      ANC=TP/DT
      ANCPP=ANC/ANP
      NCPP=ANCPP
      IF(NCPP.LT.10) NCPP=10
C
C          INITIAL   PRINTING
C
      PRINT 1020,VC,C,RB,GB,ALB
      PRINT 1030,TP,DTC,DT
      PRINT 1040,RESV,ARES,CV,RHO,TH,RESP
      PRINT 1050
      PRINT 1060, ((I,J,R(I,J),ALENG(I,J),DO(I,J),DMAX(I,J),VN(I,J),
     1 J=1,NJ), I=1,NI)
      IF (IPF.NE.0) PRINT 1062, C11,C12,C13,DOB1,C21,C22,C23,DOB2,C31,
     1C32,C33
      PRINT 1063, CON2
C
C           BEGINNING  OF  TIME  CYCLE
C
C
      ELOST=0.
100   AIN=0.  $  ET=0.  $  EK=0.
C
C           UPDATING OF POSITIONS,VELOCITIES,CURRENTS,ENERGIES,VOLTAGES
C         AND CHARGES
C
      DIDT=0.
      DO 120 J=1,NJ
      DIDT=DIDT-(Q0/C+AIO*RBO+AIJO(J)*(RJ(J)+EQR(J)))/(ALL(J)*OVERL*ALB)
120   CONTINUE
      AIN=AIO+DIDT*DT
      IF (IDEL.EQ.0) GO TO 41
      OMEGA=SQRT(ABS(DIDT/Q0))
      RT=1./SQRT(OMEGA)
      DELB=CON3*RT
      DELF=CON4*RT
      IF (DELF.GT.TH) DELF=TH
      DELTA=0.5*(DELB+DELF)
41    DO 200 J=1,NJ
      DIJDT=-DIDT*ALB/ALL(J)-(Q0/C+AIO*RBO+AIJO(J)*(RJ(J)+EQR(J)))/
     1ALL(J)
```

```
      AIJN(J)=AIJO(J)+DT*DIJDT
      DO 150 I=1,NI
      VN(I,J)=VO(I,J)+DT*FORCE(ALENG(I,J),B(I,J),AMASS(I,J),AIJO(J),
     1 DO(I,J))
      DN(I,J)=DO(I,J)+DT*VO(I,J)
      IF(DN(I,J).LT.DMAX(I,J)) GO TO 130
      ELOST=ELOST+.5*AMASS(I,J)*(VN(I,J)**2)
      VN(I,J)=0.
130   E(I,J)=E(I,J) +(AIJO(J)**2)*RO(I,J)*DT
      ET=ET +E(I,J) +.5*AMASS(I,J)*VO(I,J)**2 +.5*L(I,J)*AIJO(J)**2
      EK=EK +.5*AMASS(I,J)*VO(I,J)**2
150   CONTINUE
200   CONTINUE
      ERB=ERB+(AIO**2)*RBO*DT
      QN=QO +DT*AIO
      EOTH= ERB + .5*(QO**2)/C + .5*(AIO**2)*ALB
C
C         UPDATING  OF  RESISTANCES AND INDUCTORS AND OLD TO NEW CHANGES
C
      RBO=RB+GB*ERB
      OVERL=0.
      DO 250 J=1,NJ
      RJ(J)=0.    $  ALL(J)=0.
      EQR(J)=0.
      AIJO(J)=AIJN(J)
      DO 225 I=1,NI
      RO(I,J)=R(I,J)*(1.+GOR*E(I,J)/(B(I,J)*DELF*ALENG(I,J)))
      RJ(J)=RJ(J)+RO(I,J)
      L(I,J)=AINDUCT(ALENG(I,J),DN(I,J),B(I,J))
      ALL(J)=ALL(J)+L(I,J)
      VO(I,J)=VN(I,J)   $   DO(I,J)=DN(I,J)
      EQR(J)=EQR(J)+EQRFV(ALENG(I,J),VN(I,J),B(I,J),DN(I,J))
225   CONTINUE
      OVERL=OVERL+1./ALL(J)
250   CONTINUE
      OVERL=OVERL+1./ALB
      QO=QN
      VLO=VLN
      AIO=AIN
C
C          CHECK FOR PRINTING
C
      IF(T.GE.TP) GO TO 600
      IF( MOD(N,NCPP).EQ.0) GO TO 500
      T=T+DT
      N=N+1
      GO TO 100
C
C
C
500   TT(M)=T*(10.**(+6))
      VOLT(M)=-QN/C
      PE(M)=C*2*(EK+ELOST)/(QO**2)
      EBAL(M)=(ET+EOTH+ELOST)*2*C/(QO**2)
      DO 510 JJ=1,NPL
      IPP=IP(JJ)
      JPP=JP(JJ)
```

```
      DPLOT(JJ,M)= DN(IPP,JPP)*(10.**5)/2.54
      VPLOT(JJ,M)= VN(IPP,JPP)*(10.**(-4))
      SIPLOT(JJ,M)= AMASS(IPP,JPP)*VN(IPP,JPP)/(B(IPP,JPP)*ALENG(IPP,JPP
     1))*(10.)
510   CONTINUE
      AIPL(M)=AIN
      IF(MOD(M,5).NE.1) GO TO 550
      MN=12+NI*NJ
      MM=60-NY
      IF(MM.LT.MN) GO TO 512
       PRINT 2001,TT(M),VOLT(M),AIPL(M),N
      GO TO 513
512   PRINT 2000,TT(M),VOLT(M),AIPL(M),N
      NY=0
513    PRINT 2005
      PRINT 2010,(AIJN(J),J=1,NJ)
      PRINT 2020
      NY=NY+12
      DO 520 I=1,NI
      DO 515 J=1,NJ
      NY=NY+1  $  IF(MOD(NY,60).EQ.0) PRINT 2021
      NY=MOD(NY,60)
      PLDN=DN(I,J)*(10.0**5)/2.54
      PLVN=VN(I,J)*(10.0**(-4))
      PLE =E(I,J)/(AMASS(I,J)*4.186*(10.0**3))
      PLIMP =AMASS(I,J)*VN(I,J)*(10.0)/(B(I,J)*ALENG(I,J))
      FF=FORCE(ALENG(I,J),B(I,J),AMASS(I,J),AIJN(J),DN(I,J))
      PLPR=(FF*TH*RHO)*(10.0**(-8))
      PRINT 2030,I,J,PLDN,PLVN,PLE,PLIMP,PLPR,RO(I,J),L(I,J)
515   CONTINUE
520   CONTINUE
      IF (IDEL.NE.0) PRINT 2110, OMEGA,DELF,DELB
C
C
C
550   T=T+DT
      M=M+1
      N=N+1
      GO TO 100
C
C
600   PRINT 2040
      M=M-1
      IF(NPL.NE.1) GO TO 620
      PRINT 2050,IP(1),JP(1),IP(1),JP(1)
      DO 610 K=1,M
      PRINT 2060,TT(K),VOLT(K),AIPL(K),EBAL(K),PE(K),DPLOT(1,K),SIPLOT(1
     1,K)
      IF(K.NE.50) GO TO 610
      PRINT 2040
      PRINT 2050,IP(1),JP(1),IP(1),JP(1)
610   CONTINUE
620   IF(NPL.LT.2) GO TO 630
      PRINT 2070,IP(1),JP(1),IP(1),JP(1),IP(2),JP(2),IP(2),JP(2)
      DO 625 K=1,M
      PRINT 2060,TT(K),VOLT(K),AIPL(K),EBAL(K),PE(K),DPLOT(1,K),SIPLOT(1
     1,K),DPLOT(2,K),SIPLOT(2,K)
```

```
      IF(K.NE.50) GO TO 625
      PRINT 2040
      PRINT 2070,IP(1),JP(1),IP(1),JP(1),IP(2),JP(2),IP(2),JP(2)
 625  CONTINUE
 630  IF(NPL.LE.2) GO TO 660
      PRINT 2080
      PRINT 2090,IP(3),JP(3),IP(3),JP(3),IP(4),JP(4),IP(4),JP(4),IP(5),
     1JP(5),IP(5),JP(5),IP(6),JP(6),IP(6),JP(6)
      DO 640 K=1,M
      IF(NPL.EQ.3) PRINT 2060,TT(K),DPLOT(3,K),SIPLOT(3,K)
      IF(NPL.EQ.4) PRINT 2060,TT(K),DPLOT(3,K),SIPLOT(3,K),DPLOT(4,K),
     1 SIPLOT(4,K)
      IF(NPL.EQ.5) PRINT 2060,TT(K),DPLOT(3,K),SIPLOT(3,K),DPLOT(4,K),
     1 SIPLOT(4,K) ,DPLOT(5,K),SIPLOT(5,K)
      IF(NPL.EQ.6) PRINT 2060,TT(K),DPLOT(3,K),SIPLOT(3,K),DPLOT(4,K),
     1 SIPLOT(4,K) ,DPLOT(5,K),SIPLOT(5,K),DPLOT(6,K),SIPLOT(6,K)
      IF(K.NE.50) GO TO 640
      PRINT 2080
      PRINT 2090,IP(3),JP(3),IP(3),JP(3),IP(4),JP(4),IP(4),JP(4),IP(5),
     1JP(5),IP(5),JP(5),IP(6),JP(6),IP(6),JP(6)
 640  CONTINUE
 660  CALL PLOT CT1(TT,VOLT,M,10.,8.,1H*,TIT,4)
      CALL PLOT CT1(TT,AIPL,M,10.,8.,1H*,TIT1,4)
      CALL PLOT CT1(TT,PF,M,10.,8.,1H*,TIT2,3)
      DO 670 JJ=1,NPL
      DO 665 K=1,M
 665  PPLO(K)=DPLOT(JJ,K)
      CALL PLOT CT1(TT,PPLO,M,10.,8.,1H*,TIT3,7)
      PRINT 2100,IP(JJ),JP(JJ)
      DO 666 K=1,M
 666  PPLO(K)=SIPLOT(JJ,K)
      CALL PLOT CT1(TT,PPLO,M,10.,8.,1H*,TIT4,6)
      PRINT 2100,IP(JJ),JP(JJ)
      DO 667 K=1,M
 667  PPLO(K)=VPLOT(JJ,K)
      CALL PLOT CT1(TT,PPLO,M,10.,8.,1H*,TIT5,5)
      PRINT 2100,IP(JJ),JP(JJ)
 670  CONTINUE
      GO TO 680
C
 31   FORMAT (*0ERROR STOP.  INITIAL (D/B) OF*,2I3,* ELEMENT MUST BE GRE
     1ATER THAN*,E10.3)
 1000 FORMAT(10X,7E10.3)
 1020 FORMAT(//*1CAPACITOR VOLTAGE=*,E10.3,*(VOLTS)  CAPACITANCE=*,E10.3
     1,*(FARADS)*/* LINE RESISTANCE=*,E10.3,*(OHMS) AND LINE G=*,E10.3,
     2*(OHMS/JOULE)*/* LINE INDUCTANCE=*,E10.3,*(HENRYS )*///)
 1030 FORMAT(* PROBLEM RUNNING TIME=*,E10.3,*(SEC)  DTC=*,E10.3,*   CALC
     1ULATED TIME STEP=*,E10.3,*(SEC)*//)
 1040 FORMAT(* FLYER CHARACTERISTICS*/* RESISTIVITY=*,E10.3,*(OHMS-METER
     1)  COEFFICIENT OF RESISTIVITY=*,E10.3,*(/C)*/* SPECIFIC HEAT=*,E10
     2.3,*(JOULES/C-METERS3)   DENSITY=*,E10.3,*(KG/METER3)*/* THICKNESS
     3=*,E10.3,*(METERS)*/*0BACKSTRAP CHARACTERISTICS:*/* RESISTIVITY=*,
     4E10.3,* (OHMS-METER)*//)
 1050 FORMAT (* INITIAL VALUES OF MATRIX ELEMENTS--*/* ROW, COLUMN, WIDT
     1H, LENGTH, SEPARATION DISTANCE, MAXIMUM SEPARATION DISTANCE, AND I
     2NDUCTANCE MODEL*/)
 1060 FORMAT (1X,2I5,4E13.3,5X,A10)
```

```
 1062 FORMAT (*0COEFFICIENTS FOR CUBIC FIT:*/* C11 =*,E13.3,5X,*C12 =*,
     1E13.3,5X,*C13 =*,E13.3,5X,*(D/B) AT FIRST CHANGE =*,E13.3/* C21 =*
     2,E13.3,5X,*C22 =*,E13.3,5X,*C23 =*,E13.3,5X,*(D/B) AT SECOND CHANG
     3E =*,E12.3/* C31 =*,E13.3,5X,*C32 =*,E13.3,5X,*C33 =*,E13.3)
 1063 FORMAT (*0SKIN DEPTH EFFECT:  *,A10)
 2000 FORMAT(//*1 TIME=*,E10.3,*(USEC)   CAPACITOR VOLTAGE=*,F10.3,*(VOL
     1TS)  LINE  CURRENT=*,E10.3,*(AMPS)    CYCLE NO.=*,I5,/)
 2001 FORMAT(//*  TIME=*,E10.3,*(USEC)   CAPACITOR VOLTAGE=*,F10.3,*(VOL
     1TS)  LINE  CURRENT=*,E10.3,*(AMPS)    CYCLE NO.=*,I5,/)
 2005 FORMAT(* PARALLEL CURRENTS IN AMPS FROM J=1 TO J=NJ*)
 2010 FORMAT(10X,10E12.2)
 2020 FORMAT(//*        ROW          COLUMN        SEPARATION       VELOCITY
     1SPECIFIC         IMPULSE         MAGNETIC        RESISTANCE        INDUCTANC
     2E*/*             I             J             DISTANCE          (CM/USEC)        ENERG
     3Y            (TAPS)          PRESSURE           (OHMS)            (HENRYS)*/,28X
     4,*(MILS)*,22X,*(CAL/GRAM)*,19X,*(KB)*/)
 2030 FORMAT(I7,I10,10X,E9.2,5X,E9.2,5X,E9.2,4X,F9.2,4X,E9.2,7X,E9.2,6X,
     1E9.2)
 2021 FORMAT(//*1       ROW          COLUMN        SEPARATION       VELOCITY
     1SPECIFIC         IMPULSE         MAGNETIC        RESISTANCE        INDUCTANC
     2E*/*             I             J             DISTANCE          (CM/USEC)        ENERG
     3Y            (TAPS)          PRESSURE           (OHMS)            (HENRYS)*/,28X
     4,*(MILS)*,22X,*(CAL/GRAM)*,19X,*(KB)*/)
 2040 FORMAT(*1*,11X,*TIME           CAPACITOR         BANK            ENERGY
     1EFFICIENCY  SEPARATION        IMPULSE       SEPARATION        IMPULSE*/,11X
     2 *(USEC)           VOLTAGE         CURRENT           BALANCE*,19X,*(MILS)
     3  (TAPS)           (MILS)            (TAPS)*)
 2050 FORMAT(36X,*(AMPS)*,31X,*I=*,I2,* J=*,I2,4X,*I=*,I2,* J=*,I2/)
 2060 FORMAT(5X,9E13.2)
 2070 FORMAT(36X,*(AMPS)*,31X,4(*I=*,I2,* J=*,I2,4X)/)
 2080 FORMAT(*1*,10X,*TIME*,6X,*SEPARATION       IMPULSE      SEPARATION
     1 IMPULSE      SEPARATION        IMPULSE       SEPARATION        IMPULSE*/,11X
     2,*(USEC)*,6X,4(*(MILS)*,8X,*(TAPS)*,6X) )
 2090 FORMAT(21X,8(*I=*,I2,* J=*,I2,4X)/)
 2100 FORMAT(/*  PLOT REPRESENTS ELEMENT IN ROW=*,I3, *  AND COLUMN=*,
     1I3)
 2110 FORMAT (*0BANK FREQUENCY =*,E10.3,* RADIANS/SEC.*,5X,*FLYER SKIN D
     1EPTH =*,E10.3,* METERS*,5X,*BACKSTRAP SKIN DEPTH =*,E10.3,* METERS
     2*)
      END
```

```
      FUNCTION FORCE (FL,FB,FM,FI,FD)
      COMMON /FCTN/ C11,C12,C13,DOB1,C21,C22,C23,DOB2,C31,C32,C33,AMU,
     1CON1,DELTA,I,J,MODEL(10,10)
C
      K=MODEL(I,J)
      GO TO (10,20,30), K
C
10    FORCE= AMU*FL*(FI**2)/(2.*FB*FM)
      RETURN
C
20    DTRAN=FD+DELTA
      DBAR=DTRAN/FB
      DBAR2=DBAR*DBAR
      A=1.+DBAR2
      B=1.-DBAR2
      C=2.*DBAR
      DLDD=(CON1*FL/FB)*(C*(1.+(B-2.)/A+ALOG(DBAR2/A))+4.*ATAN(1./DBAR))
      FORCE=(0.5/FM)*FI*FI*DLDD
      RETURN
C
30    DTRAN=FD+DELTA
      RB=1./FB
      FACT1=DTRAN/FB
      FACT2=FACT1-DOB1
      IF (FACT2) 40,40,50
40    DLDD=(RB*(C12+2.*FACT1*C13))*FL
      GO TO 80
50    FACT3=FACT1-DOB2
      IF (FACT3) 60,60,70
60    DLDD=(RB*(C22+2.*FACT2*C23))*FL
      GO TO 80
70    DLDD=(RB*(C32+2.*FACT3*C33))*FL
80    FORCE=(0.5/FM)*FI*FI*DLDD
      RETURN
C
      END
```

```
      FUNCTION AINDUCT(FL,FD,FB)
      COMMON /FCTN/ C11,C12,C13,DOB1,C21,C22,C23,DOB2,C31,C32,C33,AMU,
     1CON1,DELTA,I,J,MODEL(10,10)
C
      DTRAN=FD+DELTA
      K=MODEL(I,J)
      GO TO (10,20,30), K
C
10    AINDUCT=AMU*FL*DTRAN/FB
      RETURN
C
20    DBAR=DTRAN/FB
      RDBAR=1./DBAR
      DBAR2=DBAR*DBAR
      A=1.+DBAR2
      B=1.-DBAR2
      AINDUCT=CON1*FL*(B*ALOG(A)+DBAR2*ALOG(DBAR2)+4.*DBAR*ATAN(RDBAR))
      RETURN
C
30    FACT1=DTRAN/FB
      FACT2=FACT1-DOB1
      IF (FACT2) 40,40,50
40    AINDUCT=(C11+FACT1*(C12+FACT1*C13))*FL
      RETURN
50    FACT3=FACT1-DOB2
      IF (FACT3) 60,60,70
60    AINDUCT=(C21+FACT2*(C22+FACT2*C23))*FL
      RETURN
70    AINDUCT=(C31+FACT3*(C32+FACT3*C33))*FL
      RETURN
C
      END
```

```
      FUNCTION EQRFV (FL,FV,FB,FD)
      COMMON /FCTN/ C11,C12,C13,DOB1,C21,C22,C23,DOB2,C31,C32,C33,AMU,
     1CON1,DELTA,I,J,MODEL(10,10)
C
      K=MODEL(I,J)
      GO TO (10,20,30), K
C
10    EQRFV=AMU*FL*FV/FB
      RETURN
C
20    DTRAN=FD+DELTA
      DBAR=DTRAN/FB
      DBAR2=DBAR*DBAR
      A=1.+DBAR2
      B=1.-DBAR2
      C=2.*DBAR
      DLDD=(CON1*FL/FB)*(C*(1.+(B-2.)/A+ALOG(DBAR2/A))+4.*ATAN(1./DBAR))
      EQRFV=DLDD*FV
      RETURN
C
30    DTRAN=FD+DELTA
      RB=1./FB
      FACT1=DTRAN/FB
      FACT2=FACT1-DOB1
      IF (FACT2) 40,40,50
40    DLDD=(RB*(C12+2.*FACT1*C13))*FL
      GO TO 80
50    FACT3=FACT1-DOB2
      IF (FACT3) 60,60,70
60    DLDD=(RB*(C22+2.*FACT2*C23))*FL
      GO TO 80
70    DLDD=(RB*(C32+2.*FACT3*C33))*FL
80    EQRFV=DLDD*FV
      RETURN
C
      END
```

```
      SUBROUTINE PLOT CT) (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)                    PLOT 570
      PRINT 1020,(XAXIS(J),J=1,NS2)                           PLOT 580
      IF(IFACT.NE.0) PRINT 1050,IFACT                         PLOT 590
      RETURN                                                  PLOT 600
 1000 FORMAT(E9.2)                                            PLOT 610
 1010 FORMAT(X,A9,X,121A1)                                    PLOT 620
 1020 FORMAT(/2X 13F10.4)                                     PLOT 630
 1030 FORMAT(2H1 ,10A8)                                       PLOT 640
 1040 FORMAT(1H )                                             PLOT 650
 1050 FORMAT(/A8X 8HX  10 ** I3)                              PLOT 660
      END                                                     PLOT 67-
```

```
      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
```