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TWO DIGITAL COMPUTER PROGRAMS FOR FLYER PLATE-CAPACITOR BANK ANALYSIS

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ABSTRACT

Two programs have been developed to aid in magnetically driven flyer-plate analysis and design. Both programs, FLYER and ANALOG, are digital programs. FLYER operates on the CDC 6600, and ANALOG operates on the GE time-shared terminal in AREA III.

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TWO DIGITAL COMPUTER PROGRAMS FOR FLYER PLATE-CAPACITOR BANK ANALYSIS

Introduction

Two programs, FLYER and ANALOG, have been developed to aid in magnetically driven flyer-plate analysis and design. FLYER computes the performance of flyers capable of producing a cosine surface load. ANALOG computes the performance of flat flyers.

ANALOG is composed of a master program, ANALG$, written by General Electric, and a flow diagram connection program, A15677, developed for flyer plates. ANALG$ is a digital computer simulation of an analog computer.[1] All that is necessary to use it is to describe any time-dependent nonlinear system by integrodifferential equations. These equations are then put in a form suitable for solution on an analog computer. A computer flow diagram is then constructed, and the information from this diagram is fed into the master program. A derivation of the flyer equations and discussion of ANALOG is given in the following section.

FLYER is a straightforward circuit solution of a multiloop circuit, representing the flyer, connected to an RLC circuit, representing the capacitor bank. The program accounts for the nonlinear inductance due to flyer motion, but it neglects any resistance change due to heating. A derivation of the circuit equations, required inputs, outputs, and how to use FLYER is given in the final section of this report.

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[1] For operating details of ANALG$, refer to GE publioation, "Analog Computer Simulation," X807233.

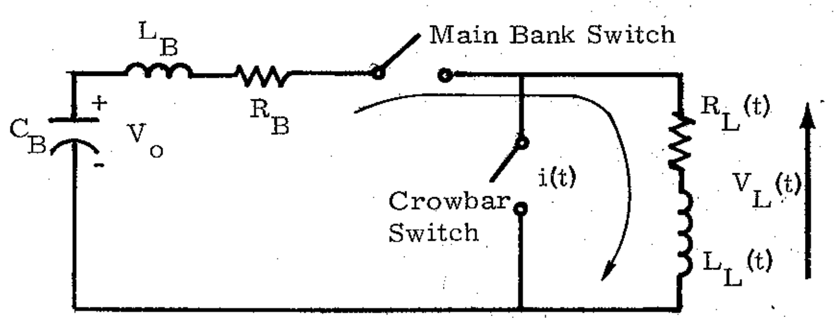
ANALOG

The master program, ANALG$, is not discussed here since its use is well documented by General Electric. The flow diagram program, A15677, will be derived, and several example problems will be explained to illustrate use of ANALOG.

The integrodifferential equations that govern flyer motion and heating are readily derived from the circuit model shown in Figure 1 and elementary field theory. The circuit equation for the model is obtained by summing voltages.

$$L_B \frac{di(t)}{dt} + R_B i(t) + \frac{1}{C_B} \int_o^t i(\tau)d\tau + R_L(t)i(t) + \frac{d}{dt}\left[L_L(t)i(t)\right] = V_o \,, \qquad (1)$$

where all quantities are defined in Figure 1.



C_B = Bank capacitance
L_B = Bank inductance
R_B = Bank resistance
$L_L(t)$ = Load inductance
$R_L(t)$ = Load resistance
V_o = Bank voltage
i(t) = Load current
$V_L(t)$ = Load voltage

Figure 1. Circuit model of flat flyer and capacitor bank

To put Equation (1) in analog computer form, it is necessary to solve for the highest derivative, di(t)/dt. Equation (2) is the result:

$$\frac{di(t)}{dt} = \frac{V_o - \left[R_B + R_L(t) + \frac{dL_L(t)}{dt}\right]i(t) - \frac{1}{C_B}\int_o^t i(\tau)d\tau}{L_B + L_L(t)} \,. \qquad (2)$$

The load voltage, $V_L(t)$, is found to be

$$V_L(t) = R_L(t)i(t) + d/dt\left[L_L(t)i(t)\right] . \tag{3}$$

In Equations (2) and (3), the load inductance and resistance are functions of time. These functions can be derived if one makes several assumptions. Assuming that the specific heat, C_p, of the flyer does not change and that no energy is radiated, an upper limit on the resistance can be derived. Equating the electrical power, $i^2(t)R_L(t)$, to the time rate of change of thermal energy, $mC_p\left[d\left(T(t) - T_R\right)/dt\right]$, where m is the mass of the flyer, T(t) the flyer temperature, and T_R the reference temperature, one obtains

$$mC_p\left[\frac{d\left(T(t) - T_R\right)}{dt}\right] = i^2(t)R_i(t) . \tag{4}$$

The temperature of the flyer is related to the resistance through the coefficient of resistivity, α_R.

$$\alpha_R = \frac{\dfrac{R_L(t) - R_{LR}}{R_{LR}}}{T(t) - T_R} , \tag{5}$$

where R_{LR} is the flyer reference resistance.

Solving Equations (4) and (5), one obtains the function that relates the load resistance to the current in the circuit

$$R_L(t) = R_{LR}\, e^{\frac{R_{LR}\alpha_R}{mC_p}\int_0^t i^2(\tau)d\tau} . \tag{6}$$

The relationship of load inductance to current can be derived from field theory. The inductance of the flyer-coil assembly, as pictured in Figure 2, is given by Equation (7).

$$L_L(t) = \left[\mu_o \ell / w \, s(t)\right], \quad (7)$$

where μ_o = 1250.6 nanohenries/m, ℓ and w are the flyer length and width, and s(t) is the flyer-coil separation. To find s(t), one must integrate the velocity of the flyer, v(t). From elementary field theory, the pressure, p(t), acting on the flyer due to the current flowing in the flyer and being returned by the coil is

$$p(t) = \frac{1}{2}\mu_o \left[\frac{i(t)}{w}\right]^2 . \quad (8)$$

The velocity can readily be found by equating the force to flyer mass times acceleration, and integrating. The resultant equation is

$$v(t) = \frac{\mu_o}{2\rho T w^2} \int_o^t i^2(\tau) d\tau , \quad (9)$$

where ρ is the flyer density and T is the flyer thickness. For composite flyers, a summation of the corresponding ρ's and T's must be used.

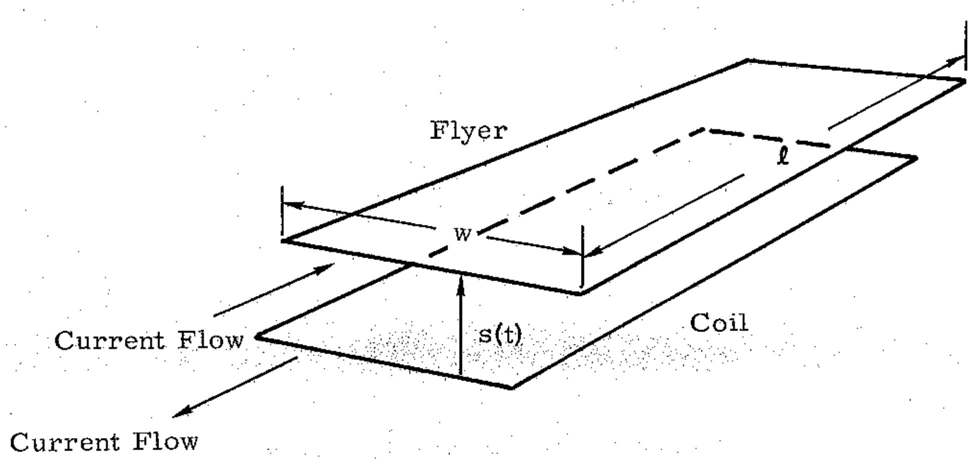


Figure 2. Flyer-coil assembly

Equations (2), (3), (6), (7), and (9) are the equations which govern the flyer. A flow diagram representing the above equations can now be drawn. However, with capacitor banks, another variable sometimes enters the problem--crowbarring. On high-inductance loads, the peak-to-peak voltage on the capacitors may exceed the manufacturer's rating. If this occurs, it is necessary to short the capacitor bank for protection against the high reversal. To accomplish this in the flow diagram, it is necessary to suddenly change Equation (2) at crowbar time, T_c, to simulate shorting the capacitor bank. This is accomplished by dropping the bank resistance, inductance, and capacitance terms. Equation (10) results:

$$\frac{di(t)}{dt} = \frac{-\left[R_L(t) + \frac{dL_L(t)}{dt}\right]i(t)}{L_L(t)} , \qquad (10)$$

with the initial condition on the load current, $i_L(t)$,

$$i_L(T_c^-) = i_L(T_c^+) . \qquad (11)$$

Figure 3 shows the flow diagram that solves the flyer equations with the option of crowbarring the bank. The derivation of this flow diagram is straightforward with the possible exception of the crowbar section blocks 67, 68, and 79 with relays 21, 66, and 72.

Blocks 68 and 79 are constant blocks. Number 68, set to a -1.0, causes the integrator, 67, to start counting down to zero from its initial condition, T_c. When the integrator's output is zero, the relays operate and switch from the normally closed position to the normally open position, which connects block 79. Block 79, containing zero, removes the desired quantities from Equation (2), yielding Equation (10).

The flow diagram also allows the option of eliminating the time-dependent resistance. This is done by setting α_R to zero.

Table I lists the inputs required for the flow diagram. A15677 was written so that it operates in the noncrowbarred, fixed load resistance mode, unless instructed otherwise. To use this mode, it is necessary to list only the data listed as Required in Table I. To operate in the crowbarred mode, one simply inputs the crowbar time

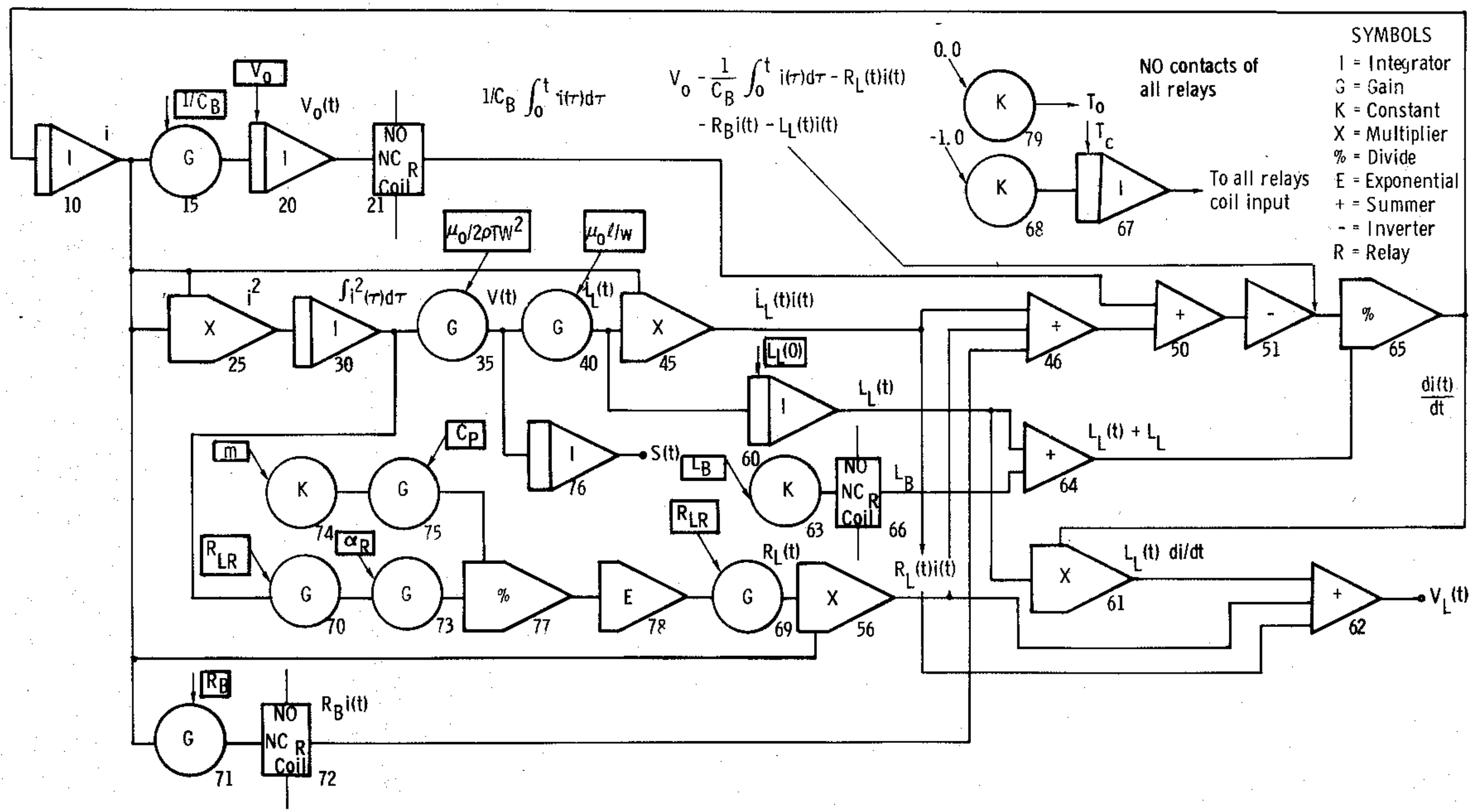


Figure 3. Flow diagram for Equations (2), (3), (6), (7), and (9)

into block 67. To select the time varying resistance problem, one is required to give the appropriate data for blocks 70, 73, 74, and 75. Table II lists the most useful data available from the program with the block numbers where each is available. All input data must be supplied in MKS units. Also, the program operates in and gives all output data in MKS units.

TABLE I

Input Parameters for Flow Diagram, A15677

Block Number	Parameter	Special Instructions
15	Inverse Capacitance, $1/C_B$	Required
20	Bank Voltage, V_o	Required
35	Velocity Multiplier, $\mu_o/2\rho T w^2$	Required
40	Inductance Multiplier, $\mu_o \ell/w$	Required
60	Initial Load Inductance, $L_L(0)$	Required
63	Bank Inductance, L_B	Required
67	Crowbar Time, T_C	Crowbar Only
69	Initial Load Resistance, $R_L(0)$	Required
70	Initial Load Resistance	Time Varying Resistance Only
71	Bank Resistance	Required
73	Coefficient of Resistivity, α_R	Time Varying Resistance Only
74	Mass of Flyer, m	Time Varying Resistance Only
75	Specific Heat of Flyer, C_p	Time Varying Resistance Only
76	Initial Spacing, s(0)	Required

Appendix A contains the listing of A15677 and three sample programs.

TABLE II

Useful Output Data

Data	Block Number
Current, i(t)	10
Capacitor Voltage, $V_o(t)$	20
Flyer Velocity, v(t)	35
Flyer Displacement, s(t)	76
Load Resistance, $R_L(t)$	69
Load Inductance, $L_L(t)$	60
Load Voltage, $V_L(t)$	62
$dL_L(t)/dt$	40

FLYER

After ANALOG was written and in use, Division 7342 requested that an existing digital program be modified to account for the nonlinear inductance of the flyer. The existing program, obtained from EG&G, did not allow the current to vary from an assumed damped sine wave. FLYER, the new program, makes no assumptions about the current waveform; it allows the circuit model to determine the waveform.

A stairstepped flyer is shown in Figure 4, with the circuit model shown in Figure 5. The flyer equations that were derived in the previous section are valid for the stairstepped flyer, if one uses the correct value of current. Each section of the flyer sees different pressures since the current is varying from section to section.

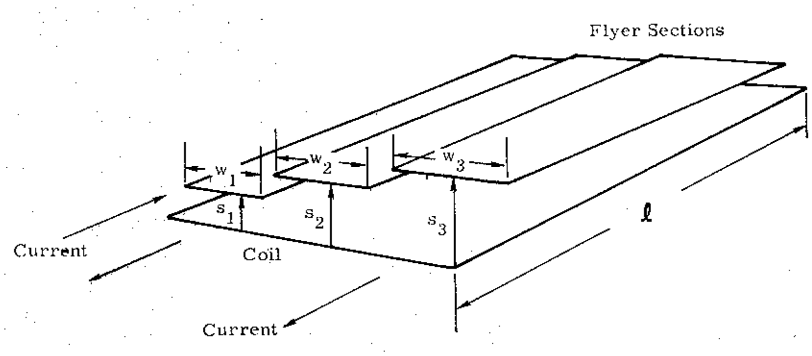


Figure 4.
A stairstepped flyer

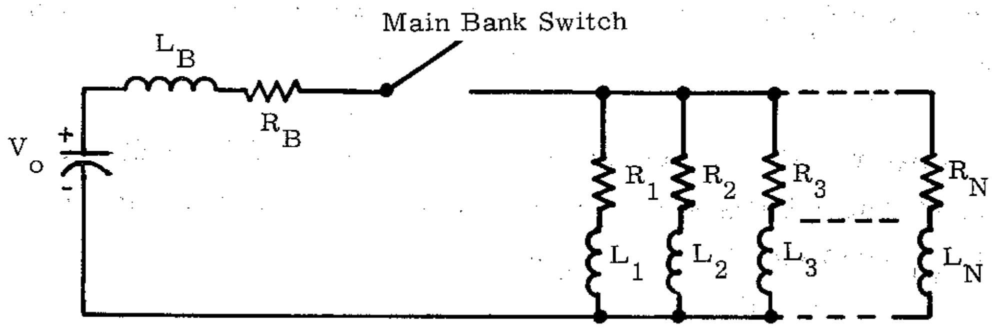


Figure 5. Circuit model of a stairstepped flyer-capacitor bank setup

Assuming that one can calculate each R_i and L_i, the circuit can be reduced to a simple RLC circuit. This is done by combining the sections of the flyer to get an equivalent flat flyer. The equivalent inductance and resistance are

$$R_{eq} = \frac{RE}{RE^2 + IM^2} , \tag{12}$$

and

$$L_{eq} = \frac{IM}{RE^2 + IM^2} , \tag{13}$$

where

$$RE = \sum_{i=1}^{n} \frac{R_i}{R_i^2 + \omega^2 L_i^2} , \tag{14}$$

and

$$IM = \sum_{i=1}^{n} \frac{\omega L_i}{R_i^2 + \omega^2 L_i^2} , \tag{15}$$

where each L_i and R_i may be functions of time, and ω is the instantaneous radian frequency.

The program makes use of the complex function, CMPLX, available on the CDC 6600, so that no terms are neglected. This was not the case with the EG&G program; L_{eq} was dropped from all calculations.

One now must consider each L_i and R_i and the determination of the instantaneous radian frequency. The inductance of a section can be found by applying Equation (7). Therefore,

$$L_i(t) = \mu_o S_i(t) \left[\ell_i / w_i \right] . \tag{16}$$

Since there is no current flowing at the first instant, the total inductance is computed by Equation (17).

$$L_{eq}(0) = \frac{1}{\sum_{i=1}^{n} \frac{1}{L_i(0)}} . \tag{17}$$

Using Equation (17), one may define an initial frequency, ω_o, as

$$\omega_o = \frac{1}{\sqrt{(L_{eq}(0) + L_B) \cdot C_B}} , \tag{18a}$$

where C_B is the bank capacitance and L_B is the bank inductance. In general, instantaneous frequency is determined using Equation (18b).

$$\omega = \frac{1}{\sqrt{(L_{eq}(t) + L_B) \cdot C_B}} . \tag{18b}$$

Using Equations (18a) and (18b) as the value of ω, the resistance of each section can now be determined using skin depth theory, provided that the flyer current is not skin depth limited.

To determine if the current is skin depth limited, the skin depth, δ, must be computed and compared to the actual flyer thickness, T_F. For sinusoidal excitation, the skin depth is

$$\delta = \sqrt{\frac{2}{\omega \mu_o \sigma}} , \tag{19}$$

where δ is given by Equation (18b) and σ is the conductivity of the flyer material. It can be shown that the difference between the skin depth for damped sine waves and sine waves is approximately 10 percent, with the damped wave having the greater value.

Using δ as given in Equation (19), the resistance, R_i, is found by

$$R_i = \frac{\delta \ell_i}{\sigma w_i} , \tag{20}$$

provided that $T_F > \delta$. For $T_F \leq \delta$, the value of R_i is computed using the standard resistance equation.

$$R_i = \frac{\ell_i}{\sigma w_i T_F} . \tag{21}$$

Equations (12) to (21) enable one to determine the flyer inductance and resistance as functions of time and the instantaneous frequency. Once these are known, the circuit equation can be solved. The circuit equation in terms of charge, q, is

$$\dot{q} R_T + \frac{d}{dt}\left(\dot{q} L_T(t)\right) + q/C_B = 0 , \tag{21}$$

where

$$R_T = R_B + R_{eq} , \tag{21a}$$

$$L_T(t) = L_{eq}(t) + L_B , \tag{21b}$$

where R_B is the bank resistance, and $\dot{q}$ is the current. The initial conditions on (21) are

$$q(0) = C_B V_o \, , \tag{22a}$$

$$\dot{q}(0) = 0 \, , \tag{22b}$$

and

$$L_T(0) = L_{eq}(0) + L_B \, , \tag{22c}$$

where V_o is the voltage. The current at time t_1, obtained from solving Equation (21), is the total current flowing in the circuit. The current in the K^{th} element of the flyer, $\dot{q}_K(t_1)$ is found by Equation (23).

$$\dot{q}_K(t_1) = \dot{q}(t_1) Z(t_1) / Z_K(t_1) \, , \tag{23a}$$

where

$$Z(t_1) = R_{eq}(t_1) + R_B + jw\left(L_B + L_{eq}(t_1)\right) \, , \tag{23b}$$

and

$$Z_K(t_1) = R_K(t_1) + j\omega(t_1) L_K(t_1) \, . \tag{23c}$$

The current in each section can then be used to calculate the velocity of each section at time t_1. The above equations were used to write the new program FLYER. The program was written by R. E. Domres, 9422, with inputs from R. A. Benham, 7342, J. L. Cawlfield, 7342, and W. K. Tucker, 7345.

Table III lists the inputs and the units of each that are in FLYER. Table IV lists the outputs and the units of each that the program gives. Appendix B illustrates the format of flyer with a sample set of input and output data. For the data listed in

Table III, some special consideration must be given to Items 12 and 13. For Item 13, the distance information is the actual distance from the coil to the flyer. The internal inductance is calculated in the program, and it is not necessary to include a correction factor for this.

TABLE III

Required Inputs and Their Units for the Program FLYER

1. Number of sections of the flyer.
2. Integration step size in microseconds.
3. Print internal in microseconds.
4. Print stop time in microseconds.
5. Bank capacitance in microfarads.
6. Bank inductance in nanohenries.
7. Bank resistance in milliohms.
8. Bank voltage in kilovolts.
9. Conductivity of the flyer and the coil in reciprocal ohm-centimeters.
10.* Density of the components of the flyer in grams/cubic centimeter.
11. Thickness of the components of the flyer in mils.
12. Width and length of each section in inches.
13. Distance from the coil to the flyer in mils at each section.
14. Separation of the coil from the test object in mils.

*If desired, the wings of the flyer can be fixed by having a variable density at those sections.

TABLE IV

Outputs and Their Units from the Program FLYER

1. Total circuit current in megamperes at time t_1 in microseconds.
2. Velocity in millimeters/microsecond, impulse in dyne-second/centimeter squared, and distance from leading edge of the flyer to the coil in mils at each section.
3. Time of arrival in microseconds and velocity at time of arrival of flyer at test object at each section.

For conical shapes, the width for Item 12 is the actual width of the flyer at the point where flyer performance is to be evaluated. The length for Item 12 is the equivalent length of a rectangular shape. This length is determined by equating the inductance of the actual tapered section to the inductance of assumed rectangular section. Equation (24) is used to calculate the equivalent length, ℓ_{eq}.

$$\ell_{eq} = \frac{w_a}{w_2 - w_1} \ell n \frac{w_2}{w_1} , \tag{24}$$

where w_2 and w_1 are the widths of the tapered section, ℓ is the length of the tapered section, and w_a is the width of the assumed rectangular shape, which is equal to the actual width at the point of interest.

Conclusions

FLYER is a much improved flyer plate design tool. The EG&G program was limited in that one had to guess at a design, build the flyer, and fire the bank to get a current record. With FLYER, one still has to guess at a design; but then FLYER, using known bank parameters, computes the performance. Additionally, the output data format has been improved for easier reading.

ANALOG is a design tool for use when first designing flyers. An equivalent flat plate model is designed, and then ANALOG is used to predict performance as well as computing bank behavior. The crowbar feature allows one to see what effect this will have on the flyer performance.

APPENDIX A

A15677 LISTING AND SAMPLE PROGRAM

A15677 LISTING AND SAMPLE PROGRAM

Table A-I lists the program A15677. Tables II through IV contain the three sample programs. Figure A-1 illustrates the use of the plotting routine available on the time shared terminal.

The sample program in Table A-II is a noncrowbarred fixed load resistance problem. Table III is the same problem with the load resistance allowed to vary. To accomplish this, it is only necessary to give the time-varying resistance data since the remaining data is stored in the temporary file. Table A-IV is again the same problem but with the addition of a crowbar. It is only necessary to supply the crowbar time since all other input data has been retained in the temporary file.

Figure A-1 contains a plot of the current, velocity, displacement, and load voltage for the crowbarred, variable load resistance problem.

TABLE A-I

Listing of Flow Diagram Information for A15677

```
A15677          08:02          03/27/70

10 10,I,65,0,0
15 15,G,10,0,0
20 20,I,15,0,0
21 21,R,67,20,79
25 25,X,10,10,0
30 30,I,25,0,0
35 35,G,30,0,0
40 40,G,35,0,0
45 45,X,40,10,0
46 46,+,45,56,72
50 50,+,21,46,0
51 51,-,50,0,0
56 56,X,10,69,0
60 60,I,40,0,0
61 61,X,60,65,0
62 62,+,45,56,61
63 63,K,0,0,0
64 64,+,60,66,0
65 65,/,51,64,0
66 66,R,67,63,79
67 67,I,68,0,0
68 68,K,0,0,0
69 69,G,78,0,0
70 70,G,30,0,0
71 71,G,10,0,0
72 72,R,67,71,79
73 73,G,70,0,0
74 74,K,0,0,0
75 75,G,74,0,0
76 76,I,35,0,0
77 77,/,73,75,0
78 78,E,77,0,0
79 79,K,0,0,0
80 0,0,0,0,0
85 10,0,0,0
90 15,0,0,0
95 20,0,0,0
100 30,0,0,0
105 35,0,0,0
110 40,0,0,0
115 60,0,0,0
120 63,0,0,0
124 69,0,0,0
125 70,0,0,0
126 73,0,0,0
127 74,1,0,0
128 75,1,0,0
130 71,0,0,0
140 76,0,0,0
145 79,0,0,0
150 67,1.0,0,0
155 68,-1.0,0,0
```

TABLE A-II

Noncrowbarred, Fixed-Load Resistance Problem

```
ANALGS        08:04       03/27/70

FILENAME=?A15677
CØNFIGURATIØN DESCRIPTIØN (YES ØR NØ)?NØ
CØMMAND?START/BL/PARA
INTEGRATIØN INT.,PRINT INT.,TIME=?.05E-06,.2E-06,1.0E-06
BLØCK,PAR1,PAR2,PAR3=?15,.21186E+04,0,0
BLØCK,PAR1,PAR2,PAR3=?20,.33E+05,0,0
BLØCK,PAR1,PAR2,PAR3=?35,.317E-06,0,0
BLØCK,PAR1,PAR2,PAR3=?40,.312E-05,0,0
BLØCK,PAR1,PAR2,PAR3=?60,.159E-08,0,0
BLØCK,PAR1,PAR2,PAR3=?63,.215E-08,0,0
BLØCK,PAR1,PAR2,PAR3=?69,.12E-02,0,0
BLØCK,PAR1,PAR2,PAR3=?71,.6E-03,0,0
BLØCK,PAR1,PAR2,PAR3=?76,.51E-03,0,0
BLØCK,PAR1,PAR2,PAR3=?0,0,0,0
ØUTPUTS-ØUT1,ØUT2,ØUT3,ØUT4=?10,35,76,62
```

TIME	ØUTPUT 10	ØUTPUT 35	ØUTPUT 76	ØUTPUT 62
.	0.	0.	0.51000E-03	-0.14029E+05
.2000E-06	-0.16761E+07	0.60993E-01	0.51000E-03	-0.14605E+05
.4000E-06	-0.31621E+07	0.44878E+00	0.51005E-03	-0.14815E+05
.6000E-06	-0.44430E+07	0.13827E+01	0.51022E-03	-0.14694E+05
.8000E-06	-0.55092E+07	0.29701E+01	0.51064E-03	-0.14279E+05
.1000E-05	-0.63563E+07	0.52192E+01	0.51145E-03	-0.13610E+05

TABLE A-III

Noncrowbarred, Variable-Load Resistance Problem

```
CØMMAND?START/BL/PARA
INTEGRATIØN INT.,PRINT INT.,TIME=?.05E-06,.2E-06,1.0E-06
BLØCK,PAR1,PAR2,PAR3=?70,.12E-02,0,0
BLØCK,PAR1,PAR2,PAR3=?73,.395E-02,0,0
BLØCK,PAR1,PAR2,PAR3=?74,.56E+01,0,0
BLØCK,PAR1,PAR2,PAR3=?75,.3854E+03,0,0
BLØCK,PAR1,PAR2,PAR3=?0,0,0,0
ØUTPUTS-ØUT1,ØUT2,ØUT3,ØUT4=?10,35,76,69
```

TIME	ØUTPUT 10	ØUTPUT 35	ØUTPUT 76	ØUTPUT 69
.	0.	0.	0.51000E-03	0.12000E-02
.2000E-06	-0.16761E+07	0.60993E-01	0.51000E-03	0.12005E-02
.4000E-06	-0.31619E+07	0.44875E+00	0.51005E-03	0.12037E-02
.6000E-06	-0.44413E+07	0.13822E+01	0.51022E-03	0.12115E-02
.8000E-06	-0.55031E+07	0.29673E+01	0.51064E-03	0.12249E-02
.1000E-05	-0.63405E+07	0.52085E+01	0.51145E-03	0.12441E-02

TABLE A-IV

Crowbarred Variable-Load Resistance Problem

```
CØMMAND?START/BL/PARA

INTEGRATIØN INT.,PRINT INT.,TIME=?.05E-06,1.0E-06,4.0E-06

BLØCK,PAR1,PAR2,PAR3=?67,2.8E-06,0,0

BLØCK,PAR1,PAR2,PAR3=?0,0,0,0

ØUTPUTS-ØUT1,ØUT2,ØUT3,ØUT4=?10,35,76,21
```

TIME	ØUTPUT 10	ØUTPUT 35	ØUTPUT 76	ØUTPUT 21
.	0.	0.	0.51000E-03	0.33000E+05
.1000E-05	-0.63405E+07	0.52085E+01	0.51145E-03	0.25356E+05
.2000E-05	-0.73156E+07	0.21890E+02	0.52465E-03	0.10004E+05
.3000E-05	-0.44198E+07	0.34023E+02	0.55351E-03	0.
.4000E-05	-0.17497E+07	0.36825E+02	0.58935E-03	0.

```
CØMMAND?PLØT

NUMBER ØF BLØCKS IN PLØT=?4

CØMMAND?START/BL

INTEGRATIØN INT.,PRINT INT.,TIME=?.05E-06,.2E-06,10.0E-06

ØUTPUTS-ØUT1,ØUT2,ØUT3,ØUT4=?10,35,76,21
```

BLØCK	SYMBØL	LEFT	RIGHT	INCREMENT
10	+	-0.75217E+07	0.	0.12536E+06
35	*	0.	0.37379E+02	0.62298E+00
76	X	0.51000E-03	0.81329E-03	0.50549E-05
21	Ø	-0.92391E+03	0.33000E+05	0.56540E+03

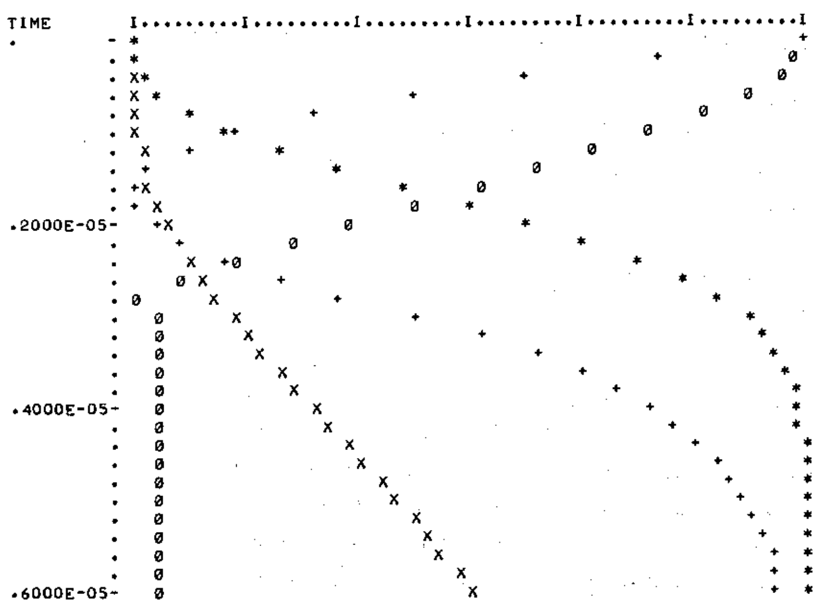


Figure A-1.

Plot of Current, Velocity, Displacement, and Load Voltage for the Crowbarred Variable-Load Resistance Problem

APPENDIX B

FLYER FORMAT LISTING

FLYER FORMAT LISTING

Table B-I lists a sample set of required data for FLYER and the necessary card order for insertion in the program. Table B-II illustrates the tabular output data available from FLYER.

Figures B-1 through B-6 illustrate the six plots available. Figure B-1 contains the plot of total current versus time and is used to compare computer results against integrated di/dt data. Figures B-2, derivative of the inductance, and B-3, instantaneous radian frequency, are used for checking capacitor bank-flyer plate performance. Figures B-4, velocity at each section versus time, B-5, velocity at each section versus distance, and B-6, flyer distance versus time are used for flyer plate design.

TABLE B-I

Sample Set of Input Data Required for FLYER

(Card 2)

COPPER FLYER RUN 15000

(Card 1)

NUMBER	DELTAH	DELTAU	TAUEND
10	.01000	1.00000	50.00000

(Card 3)

CAPACITANCE (MICRO-FD)	INDUCTANCE (NANO-HEN)	RESISTANCE (MILLI-OHMS)	VOLTAGE(0) (K-VOLTS)	SIGMA COIL (1/OHM-CM)
4.72000E+02	2.20000E+00	6.00000E-01	1.65000E+01	3.76000E+05

(Card 4)

RHO(C) (GM/CM3)	RHO(S) (GM/CM3)	THICK(C) (MILS)	THICK(S) (MILS)	SIGMA FLYER (1/OHM-CM)
8.89000E+00	2.70000E+00	4.20000E+01	0.	5.82000E+05

(Cards 5, 6, ..., to Complete Data for N Sections)

WIDTH (IN)	LENGTH (IN)	DISTANCE (MILS)	SEPARATION (MILS)	DENSITY (GM/CM3)
7.50000E-01	8.00000E+00	1.40000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	1.50000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	1.60000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	1.75000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	2.00000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	2.30000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	2.60000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	3.10000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	3.80000E+01	1.25000E+02	8.89000E+00
3.70000E-01	8.00000E+00	4.40000E+01	1.25000E+02	8.89000E+00

NOTES: Computer printout reverses Cards 1 and 2.
All cards are repeated for each run desired.
Last card is blank.

TABLE B-II

Sample Set of Output Data Required for FLYER

TIME (U-SEC)	CURRENT (AMPS)	K	VELOCITY (MM/U-SEC)	IMPULSE (DYNE-SEC/CM2)	TOTAL DISTANCE (MILS)	CAP.VOLTS (KVOLTS)
0.000	0.	1	1.000E-55	0.	5.600E+01	1.650E+01
		2	1.000E-55	0.	5.700E+01	
		3	1.000E-55	0.	5.800E+01	
		4	1.000E-55	0.	5.950E+01	
		5	1.000E-55	0.	6.200E+01	
		6	1.000E-55	0.	6.500E+01	
		7	1.000E-55	0.	6.800E+01	
		8	1.000E-55	0.	7.300E+01	
		9	1.000E-55	0.	8.000E+01	
		10	1.000E-55	0.	8.600E+01	
1.000	-4.145E+06	1	1.732E-02	1.643E+03	5.619E+01	1.163E+01
		2	1.605E-02	1.522E+03	5.717E+01	
		3	1.490E-02	1.413E+03	5.816E+01	
		4	1.338E-02	1.269E+03	5.964E+01	
		5	1.130E-02	1.071E+03	6.212E+01	
		6	9.352E-03	8.870E+02	6.510E+01	
		7	7.853E-03	7.447E+02	6.808E+01	
		8	6.030E-03	5.719E+02	7.306E+01	
		9	4.364E-03	4.139E+02	8.005E+01	
		10	3.424E-03	3.247E+02	8.604E+01	

SECTION	MYLAR SPACING(MILS)	ARRIVAL TIME(U SEC)	VELOCITY(MM/USEC)
1	14.000	13.945	.160
2	15.000	14.357	.154
3	16.000	14.763	.148
4	17.500	15.359	.140
5	20.000	16.317	.128
6	23.000	17.404	.114
7	26.000	18.419	.103
8	31.000	19.922	.088
9	38.000	21.541	.072
10	44.000	22.391	.060

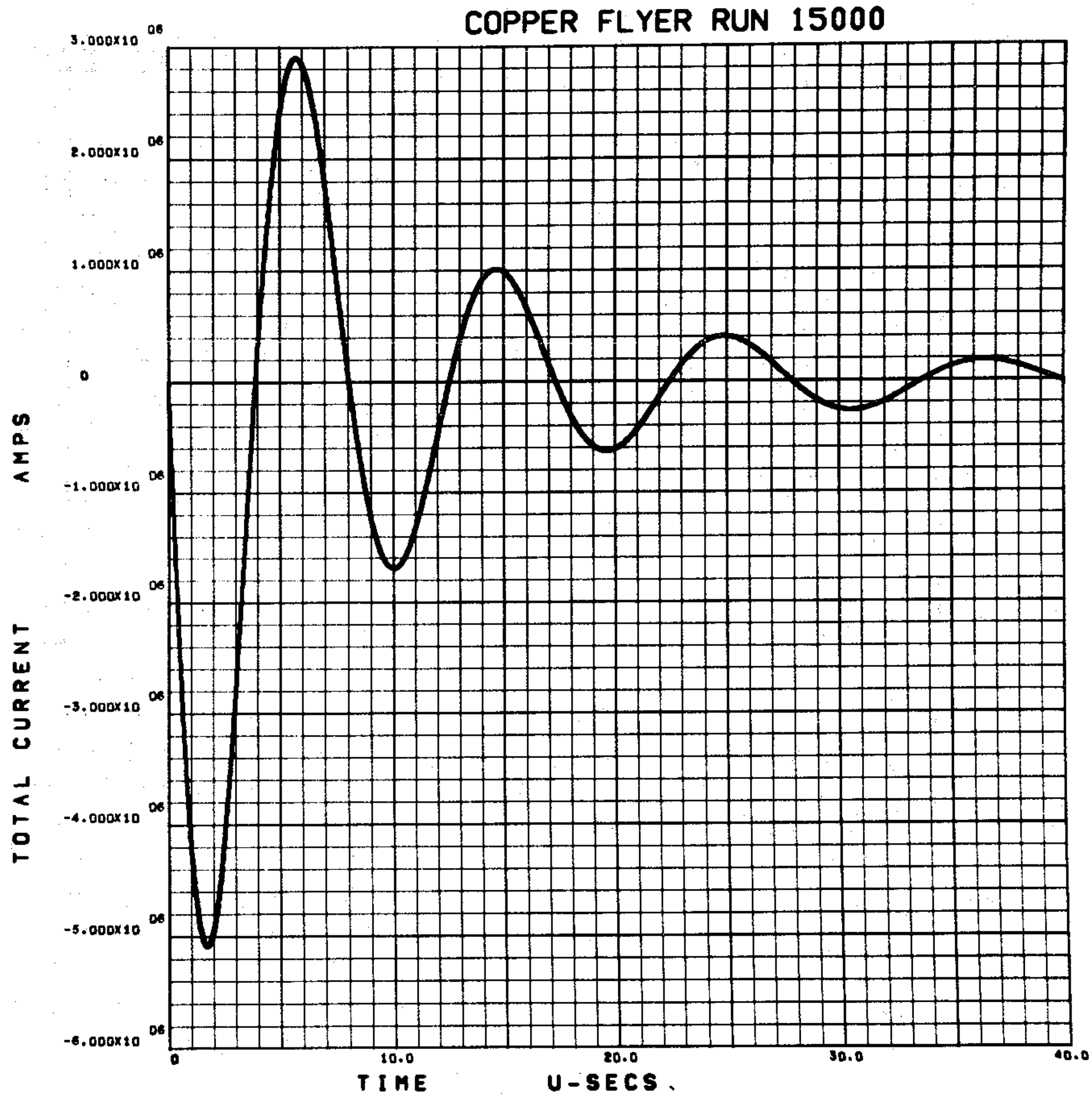


Figure B-1. Total Capacitor Bank Current Versus Time

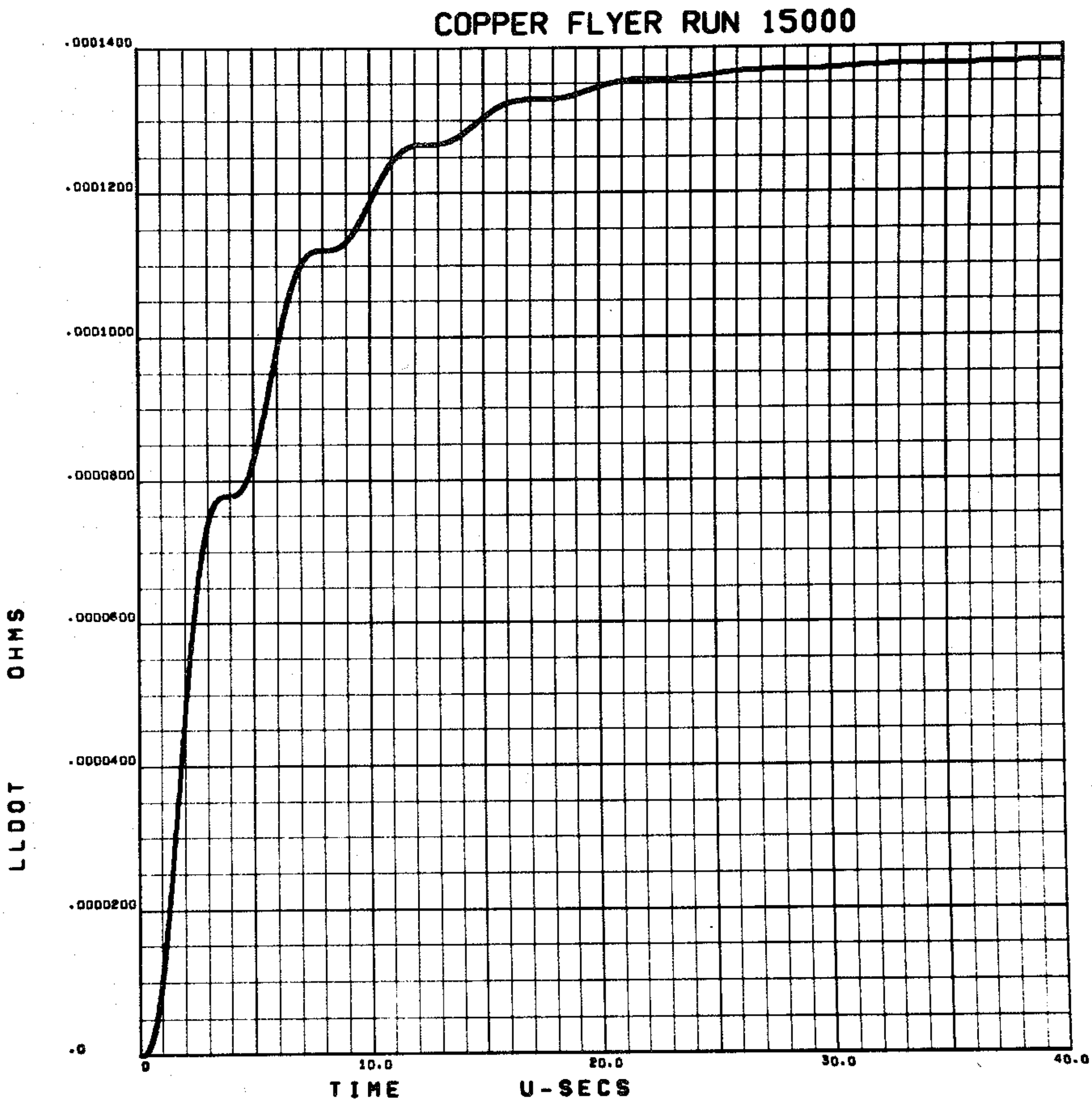


Figure B-2. Derivative of Load Inductance Versus Time

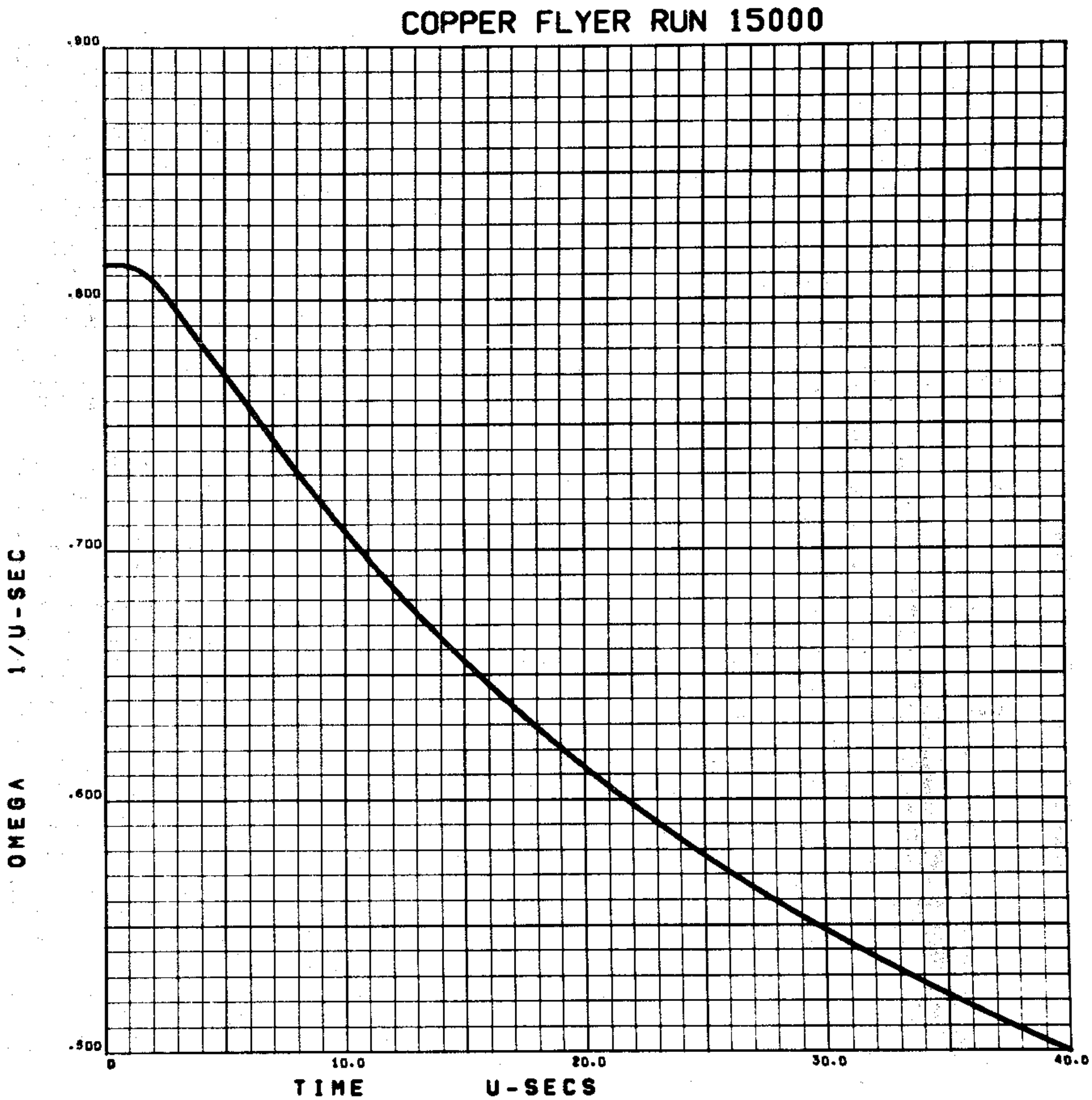


Figure B-3. Instantaneous Radian Frequency Versus Time

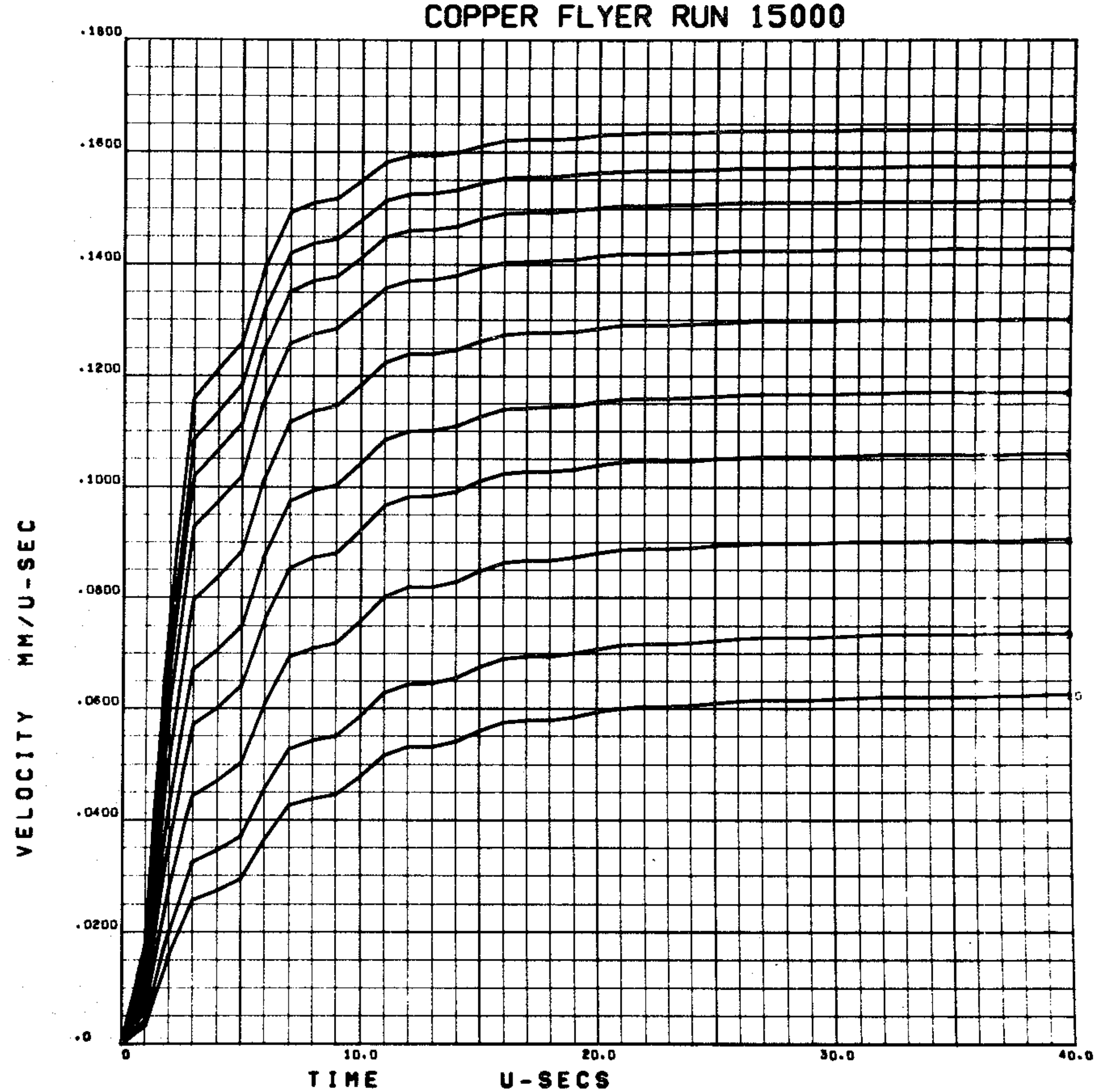


Figure B-4. Flyer Velocity at Each Section Versus Time

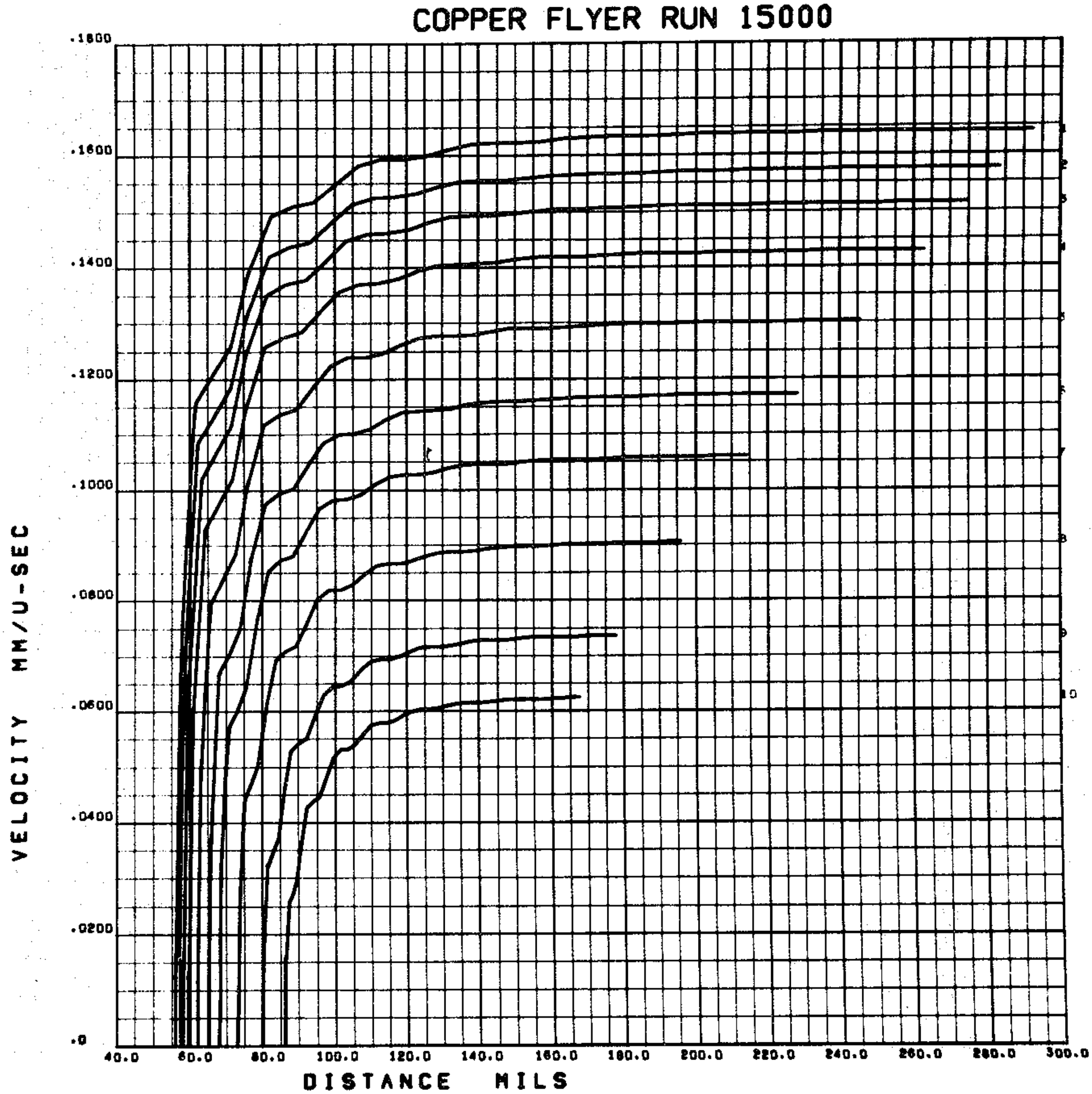


Figure B-5. Flyer Velocity at Each Section Versus Flyer Displacement at Each Section

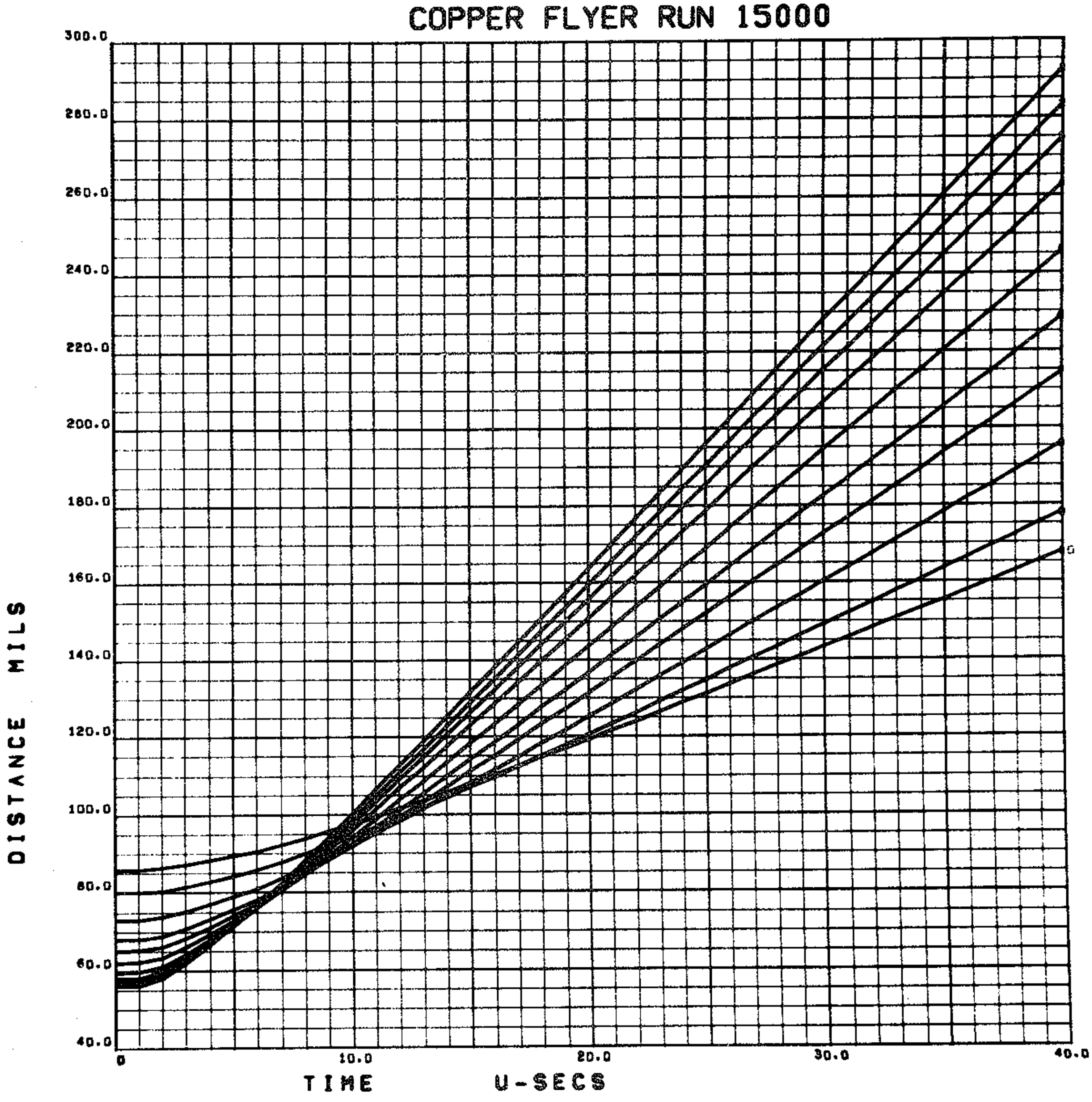


Figure B-6. Flyer Displacement at Each Section Versus Time

DISTRIBUTION:
L. C. Guynes, 1000 (3)
F. H. Mathews, 7342
R. A. Benham, 7342
J. L. Cawlfield, 7342
H. C. Walling, 7342
J. D. Patrick, 7345
W. K. Tucker, 7345
S. G. Cain, 8343
G. J. Rohwein, 8343
R. S. Gillespie, 3411
G. C. McDonald, 3416 (3)
B. F. Hefley, 8232
C. H. Sproul, 3428-1 (15)