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TECHNICAL REPORT RG-80-25

DIGITAL SIMULATION FOR DESIGN OF A DISTURBANCE ABSORBING CONTROLLER FOR A FOURTH-ORDER PLANT WITH SECOND-ORDER DISTURBANCE AT INPUT

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12 May 1980

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A simulation is presented which utilizes user-input plant and state observer pole placement data to generate a disturbance-absorbing control component, u_c, which will cancel the effects of a disturbance which is entering the system at the plant input.

CONTENTS

I. INTRODUCTION

The Disturbance Accommodating Controller (DAC) design method was developed by Dr. C. D. Johnson (References 1-5) of the University of Alabama in Huntsville. This method uses a combination of waveform-mode disturbance modeling and state-variable control techniques and permits three primary modes of disturbance accommodation: (1) cancellation (absorption) of disturbance effects, (2) minimization of disturbance effects and, (3) utilization of disturbance effects as an aid in accomplishing the primary control task. This report, and the digital simulation presented herein, will deal with the methods associated with the first mode, i.e., absorption.

The plant considered is one which can be described by state equations of the Form

$$\begin{aligned} \dot{\underline{x}} &= \underline{A}\,\underline{x} + \underline{B}\,\underline{u} + \underline{F}\,\underline{w} \\ \underline{y} &= \underline{C}\,\underline{x} + \underline{E}\,\underline{u} + \underline{G}\,\underline{w} \end{aligned} \qquad (1)$$

where

$\underline{x}$ is the plant state vector

$\underline{u}$ is the plant control input vector

$\underline{w}$ is the vector of external disturbances acting on the plant

$\underline{y}$ is the system output vector, and

$\underline{A}$, $\underline{B}$, $\underline{F}$, $\underline{C}$, $\underline{E}$, $\underline{G}$ are appropriate size, known matrices which are not necessarily constant.

The disturbances considered are assumed to be described by the following general set of linear disturbance state equations:

$$\begin{aligned} \underline{w} &= \underline{H}\,\underline{z} + \underline{L}\,\underline{x} \\ \dot{\underline{z}} &= \underline{D}\,\underline{z} + \underline{M}\,\underline{x} + \underline{\sigma} \end{aligned} \qquad (2)$$

where

$\underline{z}$ is the disturbance "state" vector

$\underline{\sigma}$ is a sequence of randomly arriving vector impulses, and

$\underline{D}$, $\underline{H}$, $\underline{L}$, $\underline{M}$, are known, time-invarient matrices.

Since neither a complete set of plant state variables nor the various components of the disturbance are available for direct on-line measurement in most practical applications, the DAC is restricted to operate only on information in the available on-line measurements of the system outputs and commands and on any disturbance components which may actually be available for direct measurement. Since the plant and disturbance states ($\underline{x}$, $\underline{z}$) are required for a practical DAC implementation, the necessary data, if not available, must be generated via use of state reconstructors (observers) operating on real-time system outputs $\underline{y}$ and control inputs $\underline{u}$.

A full-dimensional observer which can be used to generate the plant and disturbance state estimates ($\hat{\underline{x}}$, $\hat{\underline{z}}$) for the equations of the form (1) and (2) is given in Reference 2 as

$$\begin{pmatrix} \dot{\hat{\underline{x}}} \\ \dot{\hat{\underline{z}}} \end{pmatrix} = \left[\begin{array}{c|c} \underline{A} + \underline{F}\,\underline{L} + \underline{K}_1\ (C + \underline{G}\,\underline{L}) & [\underline{F} + \underline{K}_1\,\underline{G}]\ \underline{H} \\ \hline \underline{M} + \underline{K}_2\ (\underline{C} + \underline{G}\,\underline{L}) & \underline{D} + \underline{K}_2\,\underline{G}\,\underline{H} \end{array}\right] \begin{pmatrix} \hat{\underline{x}} \\ \hline \hat{\underline{z}} \end{pmatrix}$$

$$- \begin{bmatrix} \underline{K}_1 \\ \underline{K}_2 \end{bmatrix} \underline{y}(t) + \begin{bmatrix} \underline{B} + \underline{K}_1\underline{E} \\ \underline{K}_2\ \underline{E} \end{bmatrix} \underline{u}(t) \qquad (3)$$

where

$\underline{K}_1$, $\underline{K}_2$ are gain matrices to be designed, and

$\underline{A}$, $\underline{F}$, $\underline{L}$, $\underline{C}$, $\underline{G}$, $\underline{H}$, $\underline{D}$, $\underline{M}$ are as previously defined.

For acceptable observer performance, the real-time estimation errors

$$\begin{aligned} \underline{\varepsilon}_x &= \underline{x} - \hat{\underline{x}} \\ \underline{\varepsilon}_z &= \underline{z} - \hat{\underline{z}} \end{aligned} \qquad (4)$$

must settle to zero rapidly in comparison to system settling times where $\underline{\varepsilon}_x$ and $\underline{\varepsilon}_z$ dynamics are governed by

$$\begin{pmatrix} \dot{\underline{\varepsilon}}_x \\ \dot{\underline{\varepsilon}}_z \end{pmatrix} = \left[\begin{array}{c|c} \underline{A} + \underline{F}\,\underline{L} + \underline{K}_1\ (\underline{C} + \underline{G}\,\underline{L}) & [\underline{F} + \underline{K}_1\,\underline{G}]\ \underline{H} \\ \hline \underline{M} + \underline{K}_2\ (\underline{C} + \underline{G}\,\underline{L}) & \underline{D} + \underline{K}_2\,\underline{G}\,\underline{H} \end{array}\right] \begin{pmatrix} \underline{\varepsilon}_x \\ \underline{\varepsilon}_z \end{pmatrix} + \begin{pmatrix} \underline{0} \\ \hline \sigma(t) \end{pmatrix} . \qquad (5)$$

II. PLANT MODEL

This simulation will model a fourth-order plant expressed in the form shown in Figure 1.

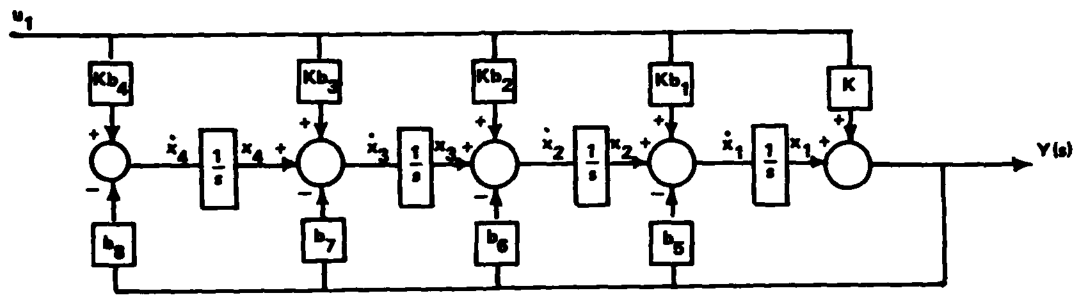

Figure 1. Plant model.

The transfer function across the plant is

$$\frac{y(s)}{u_1(s)} = \frac{K\left[S^4 + b_1 s^3 + b_2 s^2 + b_3 s + b_4\right]}{s^4 + b_5 s^3 + b_6 s^2 + b_7 s + b_8}$$

and this can be diagrammed as shown in Figure 2. As can be seen from Figure 2,

$$\begin{aligned}
\dot{x}_1 &= x_2 + Kb_1u_1 - b_5y \\
\dot{x}_2 &= x_3 + Kb_2u_1 - b_6y \\
\dot{x}_3 &= x_4 + Kb_3u_1 - b_7y \\
\dot{x}_4 &= Kb_4u_1 - b_8y \\
y &= x_1 + Ku_1 \quad .
\end{aligned} \tag{6}$$

For purposes of DAC design, equations (6) need to be expressed as functions of $\underline{x}$, $\underline{u}$, and $\underline{w}$. Therefore, since

$$\begin{aligned}
u_1 &= u + w, \text{ then} \\
y &= x_1 + K(u + w) \\
\dot{x}_1 &= - b_5x_1 + x_2 + K(u + w)\ (b_1 - b_5) \\
\dot{x}_2 &= - b_6x_1 + x_3 + K(u + w)\ (b_2 - b_6) \\
\dot{x}_3 &= - b_7x_1 + x_4 + K(u + w)\ (b_3 - b_7) \\
\dot{x}_4 &= - b_8x_1 + K(u + w)\ (b_4 - b_8)
\end{aligned} \tag{7}$$

In matrix form, Equations (7) can be written as

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{pmatrix} = \begin{bmatrix} -b_5 & 1 & 0 & 0 \\ -b_6 & 0 & 1 & 0 \\ -b_7 & 0 & 0 & 1 \\ -b_8 & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + K \begin{bmatrix} b_1 - b_5 \\ b_2 - b_6 \\ b_3 - b_7 \\ b_4 - b_8 \end{bmatrix} \underline{u} + K \begin{bmatrix} b_1 - b_5 \\ b_2 - b_6 \\ b_3 - b_7 \\ b_4 - b_8 \end{bmatrix} \underline{w} \tag{8}$$

$$\underline{y} = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + \begin{bmatrix} K \end{bmatrix} \underline{u} + \begin{bmatrix} K \end{bmatrix} \underline{w} \quad . \tag{9}$$

These correspond to Equations (1).

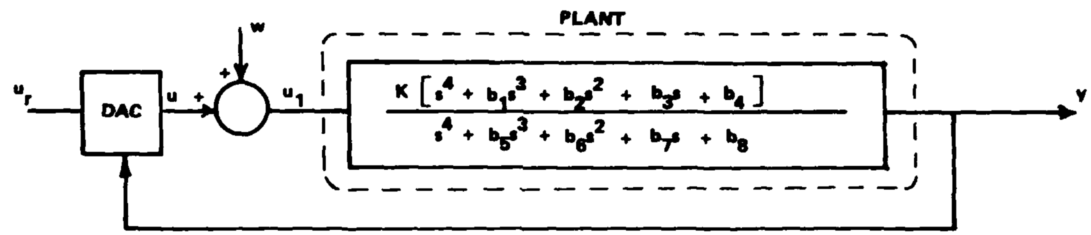

Figure 2. Plant state diagram.

III. DISTURBANCE MODEL

The general set of equations describing the disturbances were given in Equations (2). In this report, it is assumed that the disturbance is not dependent on the plant state, i.e., $\underline{L} \equiv \underline{M} \equiv \underline{0}$. Therefore, the disturbance modeled in the subroutine is

$$\begin{aligned} \underline{w} &= \underline{H}\,\underline{z} \\ \dot{\underline{z}} &= \underline{D}\,\underline{z} + \underline{\sigma}(t) \end{aligned} \qquad (10)$$

and it has been restricted to be a second-order model which can be represented as

$$\underline{w} = \underline{H}\,\underline{z} = (h_1\ h_2)\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} \qquad (11)$$

$$\dot{\underline{z}} = \underline{D}\,\underline{z} + \underline{\sigma} = \begin{bmatrix} d_1 & d_3 \\ d_2 & d_4 \end{bmatrix}\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} + \underline{\sigma} \quad . \qquad (12)$$

IV. DISTURBANCE ABSORBER CONTROL

For the complete absorption mode of DAC design, the object is to obtain a control vector which will completely cancel out the effects of the disturbance input. First, however, it must be verified that such a control exists for the particular case being considered.

It has been shown (Reference 1) that such a control vector, $\underline{u}_c$, will exist if, and only if,

$$\underline{F} \equiv \underline{B}\,\underline{\Gamma}$$

for some $\underline{\Gamma}$. With the disturbance summed at the plant input, as shown in Figure 1, we can see from the representation in Equation (8) that $\underline{F} \equiv \underline{B}\,\underline{\Gamma}$ for $\underline{\Gamma} = [1]$. Therefore, for this plant-disturbance model, $\underline{u}_c$ exists and is $\underline{u}_c = -\underline{\Gamma}\,\underline{w} = -\underline{w}$.

Since the disturbance states z_1 and z_2 cannot, in general, be measured, in order to implement the control $\underline{u}_c$ the state reconstructor given by Equation (3) must be used to provide $\hat{z}_1$ and $\hat{z}_2$. The DAC control for this configuration will then be given by

$$\underline{u}_c = -\underline{w} = -h_1\hat{z}_1 - h_2\hat{z}_2 \quad . \qquad (13)$$

V. STATE RECONSTRUCTOR DESIGN

In order to implement the state reconstructor, it is first necessary to design the gain matrices $\underline{K}_1$ and $\underline{K}_2$. This is done by using Equation (5) with

$$\underline{K}_1 = \begin{bmatrix} k_{11} \\ k_{21} \\ k_{31} \\ k_{41} \end{bmatrix} \qquad \underline{K}_2 = \begin{bmatrix} k_{12} \\ k_{22} \end{bmatrix} . \tag{14}$$

Substituting the appropriate values into the first term on the right-hand side of Equation (5) and performing the indicated matrix multiplications and additions will result in the relation

$$\begin{pmatrix} \dot{\underline{\varepsilon}}_x \\ \dot{\underline{\varepsilon}}_z \end{pmatrix} = \left[\begin{array}{cccc|cc} (k_{11} - b_5) & 1 & 0 & 0 & h_1K(b_1 - b_5 + k_{11}) & h_2K(b_1 - b_5 + k_{11}) \\ (k_{21} - b_6) & 0 & 1 & 0 & h_1K(b_2 - b_6 + k_{21}) & h_2K(b_2 - b_6 + k_{21}) \\ (k_{31} - b_7) & 0 & 0 & 1 & h_1K(b_3 - b_7 + k_{31}) & h_2K(b_3 - b_7 + k_{31}) \\ (k_{41} - b_8) & 0 & 0 & 0 & h_1K(b_4 - b_8 + k_{41}) & h_2K(b_4 - b_8 + k_{41}) \\ \hline k_{12} & 0 & 0 & 0 & (d_1 + Kh_1k_{12}) & (d_3 + Kh_2k_{12}) \\ k_{22} & 0 & 0 & 0 & (d_2 + Kh_1k_{22}) & (d_4 + Kh_2k_{22}) \end{array}\right] \underline{\varepsilon} + \begin{bmatrix} \underline{o} \\ \underline{\sigma} \end{bmatrix} . \tag{15}$$

For computation simplification, let this be

$$\dot{\underline{\varepsilon}} = \tilde{\underline{A}}\, \underline{\varepsilon} + \begin{bmatrix} \underline{o} \\ \underline{\sigma} \end{bmatrix} \tag{16}$$

and represent $\tilde{\underline{A}}$ as

$$\tilde{\underline{A}} = \begin{bmatrix} e_0 & 1 & 0 & 0 & e_6 & e_{12} \\ e_1 & 0 & 1 & 0 & e_7 & e_{13} \\ e_2 & 0 & 0 & 1 & e_8 & e_{14} \\ e_3 & 0 & 0 & 0 & e_9 & e_{15} \\ e_4 & 0 & 0 & 0 & e_{10} & e_{16} \\ e_5 & 0 & 0 & 0 & e_{11} & e_{17} \end{bmatrix} . \tag{17}$$

Now, $\tilde{\underline{A}}$ represents the characteristic matrix of the $\dot{\underline{\varepsilon}}$ dynamics. As stated earlier, it is desired that $\underline{\Sigma}(t) \rightarrow o$ "rapidly" for good reconstructor performance. This means that the roots of the characteristic equation,

$$\det\left[\tilde{\underline{A}} - \lambda \underline{I}\right] = 0,$$

should be "large" negative numbers. The next step, therefore, (and generally the most tedious), is to calculate

$$\det\left[\tilde{\underline{A}} - \lambda \underline{I}\right].$$

Remember that $\underline{\tilde{A}}$ has unknown gain components included and is not just an array of known numbers. Therefore, we have

$$\det\left[\underline{\tilde{A}} - \lambda \underline{I}\right] = \begin{vmatrix} (e_o - \lambda) & 1 & 0 & 0 & e_6 & e_{12} \\ e_1 & -\lambda & 1 & 0 & e_7 & e_{13} \\ e_2 & 0 & -\lambda & 1 & e_8 & e_{14} \\ e_3 & 0 & 0 & -\lambda & e_9 & e_{15} \\ e_4 & 0 & 0 & 0 & e_{10}-\lambda & e_{16} \\ e_5 & 0 & 0 & 0 & e_{11} & e_{17}-\lambda \end{vmatrix} = 0 \ .$$

Evaluating this gives

$$\begin{aligned} |A - \lambda \underline{I}| = \ & \lambda^6 - (e_o + e_{10} + e_{17})\lambda^5 + (e_0e_{10} + e_0e_{17} - e_{11}e_{16} + e_{10}e_{17} \\ & - e_1 - e_4e_6 - e_5e_{12})\lambda^4 + (e_0e_{11}e_{16} - e_0e_{10}e_{17} + e_1e_{10} \\ & + e_1e_{17} - e_2 + e_4e_6e_{17} - e_4e_{11}e_{12} - e_4e_7 - e_5e_6e_{16} + e_5e_{10}e_{12} \\ & - e_5e_{13})\lambda^3 + (e_1e_{11}e_{16} - e_1e_{10}e_{17} + e_2e_{10} + e_2e_{17} - e_3 \\ & + e_4e_7e_{17} - e_4e_{11}e_{13} - e_4e_8 - e_5e_7e_{16} + e_5e_{10}e_{13} - e_5e_{14})\lambda^2 \\ & + (e_2e_{11}e_{16} - e_2e_{10}e_{17} + e_3e_{10} + e_3e_{17} + e_4e_8e_{17} - e_4e_{11}e_{14} \\ & - e_4e_9 - e_5e_8e_{16} + e_5e_{10}e_{14} - e_5e_{15})\lambda + (-e_3e_{10}e_{17} \\ & + e_3e_{11}e_{16} + e_4e_9e_{17} - e_4e_{11}e_{15} - e_5e_9e_{16} + e_5e_{10}e_{15}) = 0 \ . \end{aligned} \quad (18)$$

If the desired roots of Equation (18) are λ_1, λ_2, λ_3, λ_4, λ_5, λ_6, then the desired characteristic equation is

$$(\lambda - \lambda_1)(\lambda - \lambda_2)(\lambda - \lambda_3)(\lambda - \lambda_4)(\lambda - \lambda_5)(\lambda - \lambda_6) = 0 \ . \quad (19)$$

Expanding Equation (19) and equating coefficients of like powers of λ between Equations (18) and (19) and substituting the proper symbols which the e_i represent results in the following:

(a) $k_{11} + Kh_1k_{12} + Kh_2k_{22} + (d_1 - b_5 + d_4) = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 = A_1$;

(b) $(d_1 + d_4)\, k_{11} + (- Kd_2h_2 + Kd_4h_1 - Kh_1b_1)\, k_{12} + (-Kd_3h_1 + Kd_1h_2$

$- Kb_1h_2)\, k_{22} - k_{21} + (- b_5d_1 - b_5d_4 - d_2d_3 - d_1d_4 + b_6)$

$$= \sum_{j=1}^{5} \sum_{j=i+1}^{6} \lambda_i\lambda_j = A_2 \quad ;$$

(c) $(d_3d_2 - d_1d_4)\, k_{11} + (Kh_1b_1d_4 - Kh_2b_1d_2 - Kh_1b_2)\, k_{12} + (- Kh_1b_1d_3$

$+ Kh_2b_1d_1 - Kh_2b_2)\, k_{22} + (d_1 + d_4)\, k_{21} - k_{31} + (- b_5d_3d_2$

$$+ b_5d_1d_4 - b_6d_1 - b_6d_4 + b_7) = -\left[\sum_{i=1}^{4} \sum_{j=i+1}^{5} \sum_{l=j+1}^{6} \lambda_i\lambda_j\lambda_l = -A_3 \quad ; \right]$$

(d) $(Kb_2h_1d_4 - Kb_2h_2d_2 - Kb_3h_1)\, k_{12} + (- Kb_2h_1d_3 + Kb_2h_2d_1 - Kb_3h_2)\, k_{22}$

$+ (d_3d_2 - d_1d_4)\, k_{21} + (d_1 + d_4)\, k_{31} - k_{41} + (- b_6d_3d_2 + b_6d_4d_1$

$$- b_7d_1 - b_7d_4 + b_8) = \left[\sum_{i=1}^{3} \sum_{j=i+1}^{4} \sum_{l=j+1}^{5} \sum_{n=l+1}^{6} \lambda_i\lambda_j\lambda_l\lambda_n = A_4 \quad ; \right]$$

(e) $(d_3d_2 - d_1d_4)\, k_{31} + (- d_3d_2b_7 + d_1d_4b_7 - d_1b_8 - d_4b_8) + (- Kh_1b_3d_3$

$+ Kh_2b_3d_1 + Kh_2b_4)\, k_{22} + (Kh_1b_3d_4 - Kh_2b_3d_2 - Kh_1b_4)\, k_{12} + (d_1 + d_4)\, k_{41}$

$= - \left[\lambda_1\lambda_2\lambda_3\lambda_4 (\lambda_5 + \lambda_6) + \lambda_1\lambda_2\lambda_5\lambda_6 (\lambda_3 + \lambda_4) + \lambda_3\lambda_4\lambda_5\lambda_6 (\lambda_1 + \lambda_2) \right]$

$= -A_5 \quad ;$

(f) $(- d_1d_4 + d_3d_2)\, k_{41} + (b_8d_1d_4 - b_8d_2d_3) + (Kh_1b_4d_4 - Kh_2b_4d_2)\, k_{12}$

$+ (- Kd_3b_4h_1 + Kd_1h_2b_4)\, k_{22} = \lambda_1\lambda_2\lambda_3\lambda_4\lambda_5\lambda_6 = A_6 \quad .$

For ease of manipulation, let us re-express (a) - (f) as

(a) $k_{11} + m_0k_{12} + m_1k_{22} + m_2 = A_1$

(b) $m_3k_{11} - k_{21} + m_4k_{12} + m_5k_{22} + m_6 = A_2$

(c) $m_7k_{11} + m_8k_{21} - k_{31} + m_9k_{12} + m_{10}k_{22} + m_{11} = - A_3$

(d) $m_{12}k_{21} + m_{13}k_{31} - k_{41} + m_{14}k_{12} + m_{15}k_{22} + m_{16} = A_4$

(e) $m_{17}k_{31} + m_{18}k_{41} + m_{19}k_{12} + m_{20}k_{22} + m_{21} = - A_5$

(f) $m_{22}k_{41} + m_{23}k_{12} + m_{24}k_{22} + m_{25} = A_6$

or, in matrix form,

$$\begin{bmatrix} 1 & 0 & 0 & 0 & m_0 & m_1 \\ m_3 & -1 & 0 & 0 & m_4 & m_5 \\ m_7 & m_8 & -1 & 0 & m_9 & m_{10} \\ 0 & m_{12} & m_{13} & -1 & m_{14} & m_{15} \\ 0 & 0 & m_{17} & m_{18} & m_{19} & m_{20} \\ 0 & 0 & 0 & m_{22} & m_{23} & m_{24} \end{bmatrix} \begin{bmatrix} k_{11} \\ k_{21} \\ k_{31} \\ k_{41} \\ k_{12} \\ k_{22} \end{bmatrix} = \begin{bmatrix} A_1 - m_2 \\ A_2 - m_6 \\ -A_3 - m_{11} \\ A_4 - m_{16} \\ -A_5 - m_{21} \\ A_6 - m_{25} \end{bmatrix} \qquad (20)$$

Therefore, we have $\underline{X}_m \begin{bmatrix} \underline{K}_1 \\ \underline{K}_2 \end{bmatrix} = \underline{R}$, where $\underline{K}_1 = \begin{bmatrix} k_{11} \\ k_{21} \\ k_{31} \\ k_{41} \end{bmatrix}$, $\underline{K}_2 = \begin{bmatrix} k_{12} \\ k_{22} \end{bmatrix}$. (21)

Solving for $\begin{bmatrix} \underline{K}_1 \\ \underline{K}_2 \end{bmatrix}$ gives $\begin{bmatrix} \underline{K}_1 \\ \underline{K}_2 \end{bmatrix} = \underline{X}_m^{-1}\underline{R}$ where $\underline{X}_m^{-1}$ denotes the inverse of the matrix $\underline{X}_m$. Since $\underline{X}_m$ is composed of known numbers when the desired values of λ_1 to λ_6 are substituted in, this matrix can be inverted via use of a matrix inversion subroutine.

Therefore, the components of the gain matrices $\underline{K}_1$ and $\underline{K}_2$ are determined as functions of the plant and disturbance parameters and the values of λ_1 through λ_6 chosen by the designer. It will usually be necessary to go through several iterations on values for the λ's before the desired observer performance is obtained.

Having these gains, it is now possible to construct the state observer, Equation (3), as

$$\begin{pmatrix} \dot{\hat{x}}_1 \\ \dot{\hat{x}}_2 \\ \dot{\hat{x}}_3 \\ \dot{\hat{x}}_4 \\ \dot{\hat{z}}_1 \\ \dot{\hat{z}}_2 \end{pmatrix} = \begin{bmatrix} (k_{11} - b_5) & 1 & 0 & 0 & h_1K(b_1 - b_5 + k_{11}) & h_2K(b_1 - b_5 + k_{11}) \\ (k_{21} - b_6) & 0 & 1 & 0 & h_1K(b_2 - b_6 + k_{21}) & h_2K(b_2 - b_6 + k_{21}) \\ (k_{31} - b_7) & 0 & 0 & 1 & h_1K(b_3 - b_7 + k_{31}) & h_2K(b_3 - b_7 + k_{31}) \\ (k_{41} - b_8) & 0 & 0 & 0 & h_1K(b_4 - b_8 + k_{41}) & h_2K(b_4 - b_8 + k_{41}) \\ k_{12} & 0 & 0 & 0 & (d_1 + Kh_1k_{12}) & (d_3 + Kh_2k_{12}) \\ k_{22} & 0 & 0 & 0 & (d_2 + Kh_1k_{22}) & (d_4 + Kh_2k_{22}) \end{bmatrix} \begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \\ \hat{x}_4 \\ \hat{z}_1 \\ \hat{z}_2 \end{pmatrix}$$

$$
- \begin{bmatrix} k_{11} \\ k_{21} \\ k_{31} \\ k_{41} \\ k_{12} \\ k_{22} \end{bmatrix} \underline{y}(t) + \begin{bmatrix} K(b_1 - b_5 + k_{11}) \\ K(b_2 - b_6 + k_{21}) \\ K(b_3 - b_7 + k_{31}) \\ K(b_4 - b_8 + k_{41}) \\ Kk_{12} \\ Kk_{22} \end{bmatrix} \underline{u}(t) \qquad (21)
$$

and thus obtain the disturbance state estimates, $\hat{z}_1$ and $\hat{z}_2$, required for the DAC control $\underline{u}_c$.

Figure 3 presents the overall block diagram for the composite plant-state reconstructor model. The symbols r_i, p_i, v_i relate to matrix elements from Equation 21 as shown in Table 1.

VI. DIGITAL SIMULATION

This simulation has been assembled, for use on a CDC 6600 digital computer, in order to permit the design of DAC's for systems of the type shown in Figure 1 without the necessity of having to go through the tedious task of expanding determinants by hand. This simulation can be used in a design process to determine the necessary gains for a given system and then simulate that system's operation for various disturbance conditions. Or, the simulation could be modified and used as a subroutine in a larger program to provide a necessary disturbance control value when called.

As a design tool used by itself, the simulation will perform the following tasks: (1) calculate the elements of the gain matrices $\underline{K}_1$ and $\underline{K}_2$ utilizing the plant and disturbance input parameters and the λ's input by the designer; (2) implement the state reconstructor; (3) calculate the DAC control vector;

$$\underline{u}_c = - h_1 z_1 - h_2 \hat{z}_2,$$

and (4) close the DAC control loop through the plant to provide output data showing the overall performance obtained.

As a subroutine, the necessary plant output and other data can be transferred in through a COMMON block; the gains can be updated, if required by changing plant parameters; the value for $\underline{u}_c$ can be determined; and then required data can be transferred out through a COMMON block.

An overall program dictionary is presented in Table 2. Table 3 lists the NAMELIST inputs for the program, and Table 4 lists the outputs. A System Library Line Printer Plot Routine is used to plot the output, Y, and the disturbance state estimates $\hat{z}_1$, $\hat{z}_2$.

A listing of the simulation is given in Appendix A and the results of several disturbance cases for a given plant are shown in Appendix B.

The line-plot and matrix inversion subroutines used in this simulation were taken from Reference 6.

TABLE 1. EQUIVALENCES FOR FIGURE 3 SYMBOLS

$r_1 = k_{11} - b_5$	$p_7 = Kh_2(b_1 - b_5 + k_{11})$
$r_2 = k_{21} - b_6$	$p_8 = Kh_2(b_2 - b_6 + k_{21})$
$r_3 = k_{31} - b_7$	$p_9 = Kh_2(b_3 - b_7 + k_{31})$
$r_4 = k_{41} - b_8$	$p_{10} = Kh_2(b_4 - b_8 + k_{41}$
$p_1 = Kh_1(b_1 - b_5 + k_{11})$	$p_{11} = d_3 + Kh_2k_{12}$
$p_2 = Kh_1(b_2 - b_6 + k_{21})$	$p_{12} = d_4 + Kh_2k_{22}$
$p_3 = Kh_1(b_3 - b_7 + k_{31})$	$v_1 = K(b_1 - b_5 + k_{11})$
$p_4 = Kh_1(b_4 - b_8 + k_{41})$	$v_2 = K(b_2 - b_6 + k_{21})$
$p_5 = d_1 + Kh_1k_{12}$	$v_3 = K(b_3 - b_7 + k_{31})$
$p_6 = d_2 + Kh_1k_{22}$	$v_4 = K(b_4 - b_8 + k_{41})$

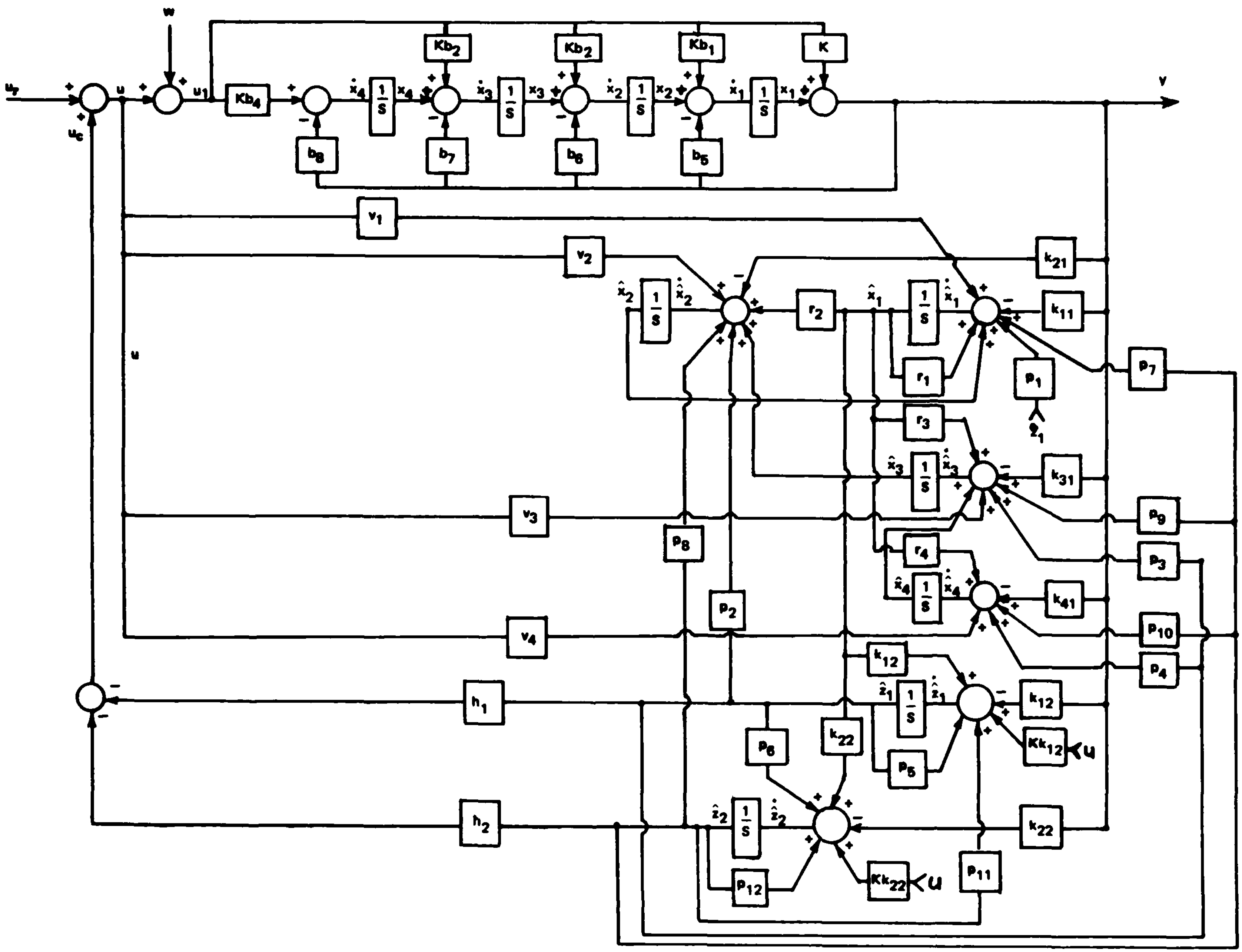

Figure 3. Composite plant - DAC block diagram.

TABLE 2. PROGRAM DICTIONARY

FORTRAN NAME	SYMBOL	DEFINITION
A	A_i	Coefficients of the desired characteristic equation associated with $[\tilde{\underline{A}} - \lambda \underline{I}]$ calculated using input eigenvalues.
AMO-AM25	m_i	Coefficients of the characteristic equation associated with $[\tilde{\underline{A}} - \lambda \underline{I}]$ calculated using actual plant and disturbance input parameters, factored according to components of the $\underline{K}_1$ and $\underline{K}_2$ matrices.
B	b_j	Coefficients in the plant transfer function.
CO, C1	C_o, C_1	Coefficients used in defining $\underline{w}(t)$.
C	K	Plant transfer function gain value.
CU1		Defined as $K \cdot U_1$.
CK	$\underline{K}_1$, $\underline{K}_2$	Array containing computed values for the gain matrices. CK(1) - CK(4) correspond to $\underline{K}_1$, CK(5) and CK(6) correspond to $\underline{K}_2$.
D	d_i	Array consisting of the elements of the $\underline{D}$ matrix associated with the disturbance state model.
DT	Δt	Integration step size.
H	h_i	Array consisting of elements of the $\underline{H}$ matrix associated with the disturbance state model.
KUTTA		Integration loop counter.
KU		Integration loop counter.
LM	λ_i	Eigenvalues of $\lvert \tilde{\underline{A}} - \lambda \underline{I} \rvert = 0$ chosen by designer to settle out state reconstructor response.
NX		Number of derivatives to be integrated.
PGO	u_r	Plant Input Command

TABLE 2. (CONCLUDED)

FORTRAN NAME	SYMBOL	DEFINITION
R	$\underline{R}$	Matrix used in solving for $\underline{K}_1$ and $\underline{K}_2$.
STPSZ		Used to define integration step size Δt = 1./STPSZ.
T		Intermediate terms, comprised of various combinations of the λ's, defined for use in later equations.
TIME	t	Total elapsed time (sec).
TSTOP	t_{stop}	Run end time (sec).
U1	u_1	Summation of u with disturbance magnitude, w.
U	u	Summation of plant input command, $\underline{u}_r$, DAC control term, $\underline{u}_c$, and plant output feedback, y.
UDA	$\underline{u}_c$	DAC control vector.
W	$\underline{w}(t)$	Disturbance vector.
X1 - X4	$x_1 - x_4$	Plant states.
XD1 - XD4	$\dot{x}_1 - \dot{x}_4$	Plant state derivatives.
XDH1 - XDH4	$\dot{\hat{x}}_1 - \dot{\hat{x}}_4$	State reconstructor state derivatives corresponding to $\dot{x}_1 - \dot{x}_4$.
XH1 - XH4	$\hat{x}_1 - \hat{x}_4$	State reconstructor states corresponding to $x_1 - x_4$.
XM		Array of elements of $\underline{X}_m$ matrix.
Y	y	Plant output.
Z		Intermediate terms, composed of various combinations of the λ's, defined for use in simplifying later equations.
ZDH1, ZDH2	$\dot{\hat{z}}_1, \dot{\hat{z}}_2$	State reconstructor disturbance state derivatives.
ZH1, ZH2	$\hat{z}_1, \hat{z}_2$	State reconstructor disturbance state estimates.

TABLE 3. NAMELIST INPUT VARIABLES

FORTRAN NAME	SYMBOL	DEFINITION
B	b_i	Array consisting of the coefficients, b_1 - b_8, of the plant transfer function y/u_1.
C	K	Plant transfer function gain value.
CO, C1	c_o, c_1	Coefficients used in defining $\underline{w}(t)$.
D	d_i	Array consisting of the elements of the $\underline{D}$ matrix associated with the disturbance state model. The elements are entered according to the subscripts shown in Equation (12).
H	h_i	Array consisting of elements of the $\underline{H}$ matrix associated with the disturbance model. The elements are entered according to the subscripts shown in Equation (11).
LM	λ_i	Array consisting of designer's choice of roots for the characteristic equation of $\|\tilde{A} - \lambda I\|$. The array permits input of complex conjugate values for the roots in the form $a \pm jb$. For this reason, the input format which must be used is: (RE_1, IM_1), (RE_2, IM_2), (RE_3, IM_3), (RE_4, IM_4), (RE_5, IM_5), (RE_6, IM_6).
NPRT	-	Used to control output print interval.
NUMBR	-	Used to control data storage for plots.
NX	-	Number of derivatives to be integrated by the Runge-Kutta integration subroutine.
PGO	u_r	Plant input command.
STPSZ	-	Used to define integration step size as, DT = 1./STPSZ (sec).
TSTOP	t_{STOP}	Run end time (sec).

TABLE 4. DIGITAL SIMULATION OUTPUT VARIABLES

FORTRAN NAME	SYMBOL	DEFINITION
PGO	$\underline{u}_r$	Plant input command
TIME	t	Total elapsed time since beginning of run (sec)
UDA	$\underline{u}_c$	DAC control vector
W	w	Disturbance magnitude as determined from differential equation used to describe it.
X1 - X4	$x_1 - x_4$	Plant states
XD1 - XD4	$\dot{x}_1 - \dot{x}_4$	Plant state derivatives
XDH1 - XDH4	$\dot{\hat{x}}_1 - \dot{\hat{x}}_4$	State reconstructor state derivatives corresponding to XD1 - XD4.
XH1 - XH4	$\hat{x}_1 - \hat{x}_4$	State reconstructor state estimates corresponding to X1 - X4.
Y	y	Plant output.
ZDH1, ZDH2	$\dot{\hat{z}}_1, \dot{\hat{z}}_2$	State reconstructor disturbance state derivatives.
ZH1, ZH2	$\hat{z}_1, \hat{z}_2$	State reconstructor disturbance state estimates.

REFERENCES

1. Johnson, C. D., "Accommodation of Disturbances in Optimal Control Problems," Int. Journal Control, Vol. 15, No. 2, 1972, pp. 209-231.

2. Johnson, C. D., "On Observers for Systems with Unknown and Inaccessible Inputs," Int. Journal Control, Vol. 21, No. 5, 1975, pp. 825-831.

3. Johnson, C. D., "Accommodation of External Disturbances in Linear Regulator and Servomechanism Problems," Institute of Electrical and Electronics Engineers Transactions on Automatic Control, Vol. AC-16, No. 6, December 1971.

4. Johnson, C. D., "Algebraic Solution of the Servomechanism Problem with External Disturbances," Transactions of American Society of Mechanical Engineers, Journal of Dynamics Systems, Measurements and Control, March 1974, pp. 25-35.

5. Johnson, C. D., "Theory of Disturbance-Accommodating Control," Chapter in Book, Control and Dynamic Systems; Advances in Theory and Applications, Vol. 12, Edited by C. T. Leondes, Academic Press, Inc., New York, 1976.

6. Sellers, W. R., Jr., and Gibbs, B. G., "Descriptions, General-Purpose Computer Subroutines," U.S. Army Missile Command, Report No. TR-WS-79, April 1979.

7. McCowan, W. L., "Investigation of Disturbance Accommodating Controller Application to a Missile Autopilot," U.S. Army Missile Research and Development Command Technical Report No. T-79-63, May 1979.

APPENDIX A

DIGITAL SIMULATION LISTING

```
      PROGRAM MAIN ( INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT )
C
      COMMON/DEFDAT/      ALF,          B ( 8 ),      BET,
     .    C,              CO,
     .    C1,             D ( 4 ),      H ( 2 ),      LM ( 6 ),
     .    NPRT,           NUMBR,        REC,          STPSZ,
     .    TSTOP
C
      COMMON/INTEG/       NX
C
      COMMON/OUTP/ AM0,   AM1,    AM2,    AM3,    AM4,
     .    AM5,     AM6,   AM7,    AM8,    AM9,    AM10,
     .    AM11,    AM12,  AM13,   AM14,   AM15,   AM16,
     .    AM17,    AM18,  AM19,   AM20,   AM21,   AM22,
     .    AM23,    AM24,  AM25
C
      COMMON/BLNK/        DT,           KUTTA
C
      COMMON/RUNKIN/
     .    XD1,     XD2,     XD3,     XD4,
     .    XDH1,    XDH2,    XDH3,    XDH4,    ZDH1,    ZDH2
C
      COMMON/BLNKOUT/
     .    X1,      X2,      X3,      X4,
     .    XH1,     XH2,     XH3,     XH4,     ZH1,     ZH2
C
      COMPLEX             LM,           T,            Z
C
      DIMENSION           A ( 6 ),      AM ( 26 ),    CK ( 6 ),
     .    HEAD ( 8 ),     IHLD ( [illegible] ),  P ( 6 ),  T ( 6 ),
     .    WORK ( 12 ),    XM ( 6, 12 ), XMT ( 6, 6 ), XT ( 1000 ),
     .    YT ( 1000 ),    Z ( 15 ),     Z1T ( 1000 ), Z2T ( 1000 )
C
      EQUIVALENCE  ( AM ( 1 ), AM0 )
C
C
      NAMELIST/INP/              ALF,      B,       BET,
     .    C,          CO,        C1,
     .    D,          H,         LM,       NPRT,    NUMBR,    NX,
     .    REC,        STPSZ,     TSTOP
C
      READ(5,100) HEAD
      READ(5,INP)
C
      WRITE(6,INP)
C
      WRITE(6,150) HEAD
C
      DO 10 I = 1, 6
      DO 10 J = 1, 12
   10 XM(I,J) = 0.0
      Z(1)    = LM ( 1 ) + LM ( 2 )
      Z(2)    = LM ( 1 ) + LM ( 3 )
      Z(3)    = LM ( 1 ) + LM ( 4 )
      Z(4)    = LM ( 1 ) + LM ( 5 )
      Z(5)    = LM ( 1 ) + LM ( 6 )
      Z(6)    = LM ( 2 ) + LM ( 3 )
```


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```
      Z(7)     = LM ( 2 ) * LM ( 4 )
      Z(8)     = LM ( 2 ) * LM ( 5 )
      Z(9)     = LM ( 2 ) * LM ( 6 )
      Z(10)    = LM ( 3 ) * LM ( 4 )
      Z(11)    = LM ( 3 ) * LM ( 5 )
      Z(12)    = LM ( 3 ) * LM ( 6 )
      Z(13)    = LM ( 4 ) * LM ( 5 )
      Z(14)    = LM ( 4 ) * LM ( 6 )
      Z(15)    = LM ( 5 ) * LM ( 6 )
      T(1)     = LM ( 3 ) + LM ( 4 ) + LM ( 5 ) + LM ( 6 )
      T(2)     = LM ( 4 ) + LM ( 5 ) + LM ( 6 )
      T(3)     = LM ( 5 ) + LM ( 6 )
      T(4)     = LM ( 3 ) + LM ( 4 )
      T(5)     = LM ( 1 ) + LM ( 2 )
      WRITE(6,300) T
      A(1)     = T ( 5 ) + T ( 4 ) + T ( 3 )
      A(2)     = Z ( 1 ) + Z ( 2 ) + Z ( 3 ) + Z ( 4 ) +
     .  Z ( 5 ) + Z ( 6 ) + Z ( 7 ) + Z ( 8 ) +
     .  Z ( 9 ) + Z ( 10 ) + Z ( 11 ) + Z ( 12 ) +
     .  Z ( 13 ) + Z ( 14 ) + Z ( 15 )
      A(3)     = Z ( 1 ) * T ( 1 ) + Z ( 2 ) * T ( 2 ) +
     .  Z ( 3 ) * T ( 3 ) + Z ( 4 ) * LM ( 6 ) +
     .  Z ( 6 ) * T ( 2 ) + Z ( 7 ) * T ( 3 ) +
     .  Z ( 8 ) * LM ( 6 ) + Z ( 10 ) * T ( 3 ) +
     .  Z ( 11 ) * LM ( 6 ) + Z ( 13 ) * LM ( 6 )
      A(4)     = Z ( 1 ) * ( Z ( 10 ) + Z ( 11 ) + Z ( 12 ) +
     .  Z ( 13 ) + Z ( 14 ) + Z ( 15 ) ) +
     .  Z ( 2 ) * ( Z ( 13 ) + Z ( 14 ) + Z ( 15 ) ) +
     .  Z ( 3 ) * Z ( 15 ) + Z ( 6 ) * ( Z ( 13 ) + Z ( 14 ) +
     .  Z ( 15 ) ) + Z ( 7 ) * Z ( 15 ) + Z ( 10 ) * Z ( 15 )
      A(5)     = Z ( 1 ) * Z ( 10 ) * T ( 3 ) +
     .  Z ( 1 ) * Z ( 15 ) * T ( 4 ) +
     .  Z ( 10 ) * Z ( 15 ) * T ( 5 )
      A(6)     = Z ( 1 ) * Z ( 10 ) * Z ( 15 )
      WRITE(6,400) A
      AM0      = C * H ( 1 )
      AM1      = C * H ( 2 )
      AM2      = D ( 1 ) - B ( 5 ) + D ( 4 )
      AM3      = D ( 1 ) + D ( 4 )
      AM8      = AM13 = AM18 = AM3
      AM4      = C * ( - D ( 2 ) * H ( 2 ) + D ( 4 ) * H ( 1 ) -
     .  H ( 1 ) * B ( 1 ) )
      AM5      = - C * ( D ( 3 ) * H ( 1 ) - D ( 1 ) * H ( 2 ) +
     .  H ( 2 ) * B ( 1 ) )
      AM7      = D ( 3 ) * D ( 2 ) - D ( 1 ) * D ( 4 )
      AM12     = AM17 = AM22 = AM7
      AM6      = - B ( 5 ) * AM3 + B ( 6 ) - AM7
      AM25     = - B ( 8 ) * AM7
      AM21     = - B ( 8 ) * AM3 - B ( 7 ) * AM7
      AM16     = - B ( 6 ) * AM7 - B ( 7 ) * AM3 + B ( 8 )
      AM11     = - B ( 5 ) * AM7 - B ( 6 ) * AM3 + B ( 7 )
      AM9      = C * ( H ( 1 ) * B ( 1 ) * D ( 4 ) -
     .  H ( 2 ) * B ( 1 ) * D ( 2 ) - H ( 1 ) * B ( 2 ) )
      AM10     = - C * ( H ( 1 ) * B ( 1 ) * D ( 3 ) -
     .  H ( 2 ) * B ( 1 ) * D ( 1 ) + H ( 2 ) * B ( 2 ) )
      AM14     = C * ( B ( 2 ) * H ( 1 ) * D ( 4 ) -
     .  H ( 2 ) * H ( 2 ) * D ( 2 ) - B ( 3 ) * H ( 1 ) )
```

```
      AM15     = -C * ( B ( 2 ) * H ( 1 ) * D ( 3 ) -
     .  B ( 2 ) * H ( 2 ) * D ( 1 ) + B ( 3 ) * H ( 2 ) )
      AM19     = C * ( H ( 1 ) * B ( 3 ) * D ( 4 ) -
     .  H ( 2 ) * B ( 3 ) * D ( 2 ) - H ( 1 ) * B ( 4 ) )
      AM20     = - C * ( H ( 1 ) * B ( 3 ) * D ( 3 ) -
     .  H ( 2 ) * B ( 3 ) * D ( 1 ) + H ( 2 ) * B ( 4 ) )
      AM23     = C * ( H ( 1 ) * B ( 4 ) * D ( 4 ) -
     .  H ( 2 ) * B ( 4 ) * D ( 2 ) )
      AM24     = C * ( - D ( 3 ) * B ( 4 ) * H ( 1 ) +
     .  D ( 1 ) * H ( 2 ) * B ( 4 ) )
      DO 30 I = 1, 25, 5
   30 WRITE(6,600) I, AM(I), I+1, AM(I+1), I+2, AM(I+2),I+3, AM(I+3)
     .  I+4, AM(I+4)
      WRITE(6,700) AM25
      B(1)     = A ( 1 ) - AM2
      B(2)     = A ( 2 ) - AM6
      B(3)     = - A ( 3 ) - AM11
      B(4)     = A ( 4 ) - AM16
      B(5)     = - A ( 5 ) - AM21
      B(6)     = A ( 6 ) - AM26
      WRITE(6,500) B
C-------------------COLUMN NO. 1  ---  ELEMENTS 1 THRU 6
      XM(1,1) = 1.0
      XM(2,1) = AM3
      XM(3,1) = AM7
      XM(4,1) = XM(5,1) = XM(6,1) = 0.0
C-------------------COLUMN NO. 2  ---  ELEMENTS 7 THRU 12
      XM(1,2) = 0.0
      XM(2,2) = -1.0
      XM(3,2) = AM8
      XM(4,2) = AM12
      XM(5,2) = XM(6,2) = 0.0
C-------------------COLUMN NO. 3  ---  ELEMENTS 13 THRU 18
      XM(1,3) = XM(2,3) = 0.0
      XM(3,3) = -1.0
      XM(4,3) = AM13
      XM(5,3) = AM17
      XM(6,3) = 0.0
C-------------------COLUMN NO. 4  ---  ELEMENTS 19 THRU 24
      XM(1,4) = XM(2,4) = XM(3,4) = 0.0
      XM(4,4) = -1.0
      XM(5,4) = AM18
      XM(6,4) = AM22
C-------------------COLUMN NO. 5  ---  ELEMENTS 25 THRU 30
      XM(1,5) = AM0
      XM(2,5) = AM4
      XM(3,5) = AM9
      XM(4,5) = AM14
      XM(5,5) = AM19
      XM(6,5) = AM23
C-------------------COLUMN NO. 6  ---  ELEMENTS 31 THRU 36
      XM(1,6) = AM1
      XM(2,6) = AM5
      XM(3,6) = AM10
      XM(4,6) = AM15
      XM(5,6) = AM20
      XM(6,6) = AM24
```

```
      DO 20 I = 1, 6
   20 WRITE(6,200) I, XM(I,1), I, XM(I,2), I, XM(I,3),
     .    I, XM(I,4), I, XM(I,5), I, XM(I,6)
C--------------------CALCULATE INVERSE OF MATRIX * XM *
      CALL SESOMI ( XM, 6, 6, 1, 6, DET, RA, E, WORK, IHLD, 1, 1, 1 )
      IF ( DET .EQ. 0.0 .OR. E .EQ. 1.0 ) GO TO 2200
      IF ( E .EQ. 2.0 ) WRITE(6, 5200)
      DO 40 I = 1, 6
   40 WRITE(6,200) I, XM(I,1), I, XM(I,2), I, XM(I,3),
     .    I, XM(I,4), I, XM(I,5), I, XM(I,6)
      WRITE(6,800) DET, RA, E
      DO 50 I = 1, 6
      DO 50 J = 1, 6
   50 XMI(I,J)= XM ( I, J )
      CALL MMPY ( XMI, B, CK, 6, 6, 1 )
      WRITE(6,900) CK
      XD1       = XD2 = XD3 = XD4 = 0.0
      X1        = X2 = X3 = X4 = 0.0
      XDH1      = XDH2 = XDH3 = XDH4 = ZDH1 = ZDH2 = 0.0
      XH1       = XH2 = XH3 = XH4 = ZH1 = ZH2 = 0.0
      DT        = 1.0 / STPSZ
      J         = 0
      TIME      = 0.0
      IP        = NPRT - 1
      ISTR      = STPSZ / NUMBR
      IPLT      = ISTR - 1
      NPTS      = 0
      YMAX      = -1000000.0
      YMIN      = 1000000.0
      YMAX1     = YMAX2 = -1000000.0
      YMIN1     = YMIN2 = 1000000.0
 1010 CONTINUE
      IF ( TIME .GE. TSTOP ) GO TO 1000
      J         = J + 1
      DO 2000 KU = 1, 4
      RUTTA     = KU
      W         = C0 + C1 * EXP( ALP * TIME )
      UDA       = H ( 1 ) * ZH1 + H ( 2 ) * ZH2
      U         = REF - UDA - Y
      U1        = U + W
      CU1       = C * U1
      XD4       = CU1 * B ( 4 ) - B ( 8 ) * Y
      XD3       = X4 + CU1 * B ( 3 ) - B ( 7 ) * Y
      XD2       = X3 + CU1 * B ( 2 ) - B ( 6 ) * Y
      XD1       = X2 + CU1 * B ( 1 ) - B ( 5 ) * Y
      Y         = X1 + CU1
      XDH1      = ( CK ( 1 ) - B ( 5 ) ) * XH1 + XH2 +
     .    C * ( B ( 1 ) - B ( 5 ) + CK ( 1 ) ) *
     .    ( H ( 1 ) * ZH1 + H ( 2 ) * ZH2 + U ) - CK ( 1 ) * Y
      XDH2      = ( CK ( 2 ) - B ( 6 ) ) * XH1 + XH3 +
     .    C * ( B ( 2 ) - B ( 6 ) + CK ( 2 ) ) *
     .    ( H ( 1 ) * ZH1 + H ( 2 ) * ZH2 + U ) - CK ( 2 ) * Y
      XDH3      = ( CK ( 3 ) - B ( 7 ) ) * XH1 + XH4 +
     .    C * ( B ( 3 ) - B ( 7 ) + CK ( 3 ) ) *
     .    ( H ( 1 ) * ZH1 + H ( 2 ) * ZH2 + U ) - CK ( 3 ) * Y
      XDH4      = ( CK ( 4 ) - B ( 8 ) ) * XH1 +
     .    C * ( B ( 4 ) - B ( 8 ) + CK ( 4 ) ) *
```

```
             .    ( H ( 1 ) * ZH1 + H ( 2 ) * ZH2 + U ) - CK ( 4 ) * Y
              ZDH1     = CK ( 5 ) * XH1 + ( D ( 1 ) + C * H ( 1 ) * CK ( 5 ) ) *
             .    ZH1 + ( D ( 3 ) + C * H ( 2 ) * CK ( 5 ) ) *
             .    ZH2 - CK ( 5 ) * Y + C * CK ( 5 ) * U
              ZDH2     = CK ( 6 ) * XH1 + ( D ( 2 ) + C * H ( 1 ) * CK ( 6 ) ) *
             .    ZH1 + ( D ( 4 ) + C * H ( 2 ) * CK ( 6 ) ) *
             .    ZH2 - CK ( 6 ) * Y + C * CK ( 6 ) * U
              GO TO ( 5000, 6000, 3000, 4000 ), KUTTA
         5000 CONTINUE
              IPLT     = IPLT + 1
              IF ( IPLT .NE. ISTR ) GO TO 2020
              IPLT     = 0
              NPTS     = NPTS + 1
              XT(NPTS)= TIME
              YT(NPTS)= Y
              YMAX     = AMAX1 ( YMAX, Y )
              YMIN     = AMIN1 ( YMIN, Y )
              Z1T(NPTS)= ZH1
              Z2T(NPTS)= ZH2
              YMAX1    = AMAX1 ( YMAX1, ZH1 )
              YMIN1    = AMIN1 ( YMIN1, ZH1 )
              YMAX2    = AMAX1 ( YMAX2, ZH2 )
              YMIN2    = AMIN1 ( YMIN2, ZH2 )
         2020 CONTINUE
              IP       = IP + 1
              IF ( IP .NE. NPRT ) GO TO 2030
              IP       = 0
              WRITE(6,550) TIME,     XD1,      XD2,      XD3,      XD4,
             .    X1,       X2,       X3,       X4,       XDH1,     XDH2,
             .    XDH3,     XDH4,     ZDH1,     ZDH2,     XH1,      XH2,
             .    XH3,      XH4,      ZH1,      ZH2,      POC,      W,
             .    UDA,      Y
         2030 CONTINUE
         3000 TIME     = TIME + 0.5 * DT
         4000 CONTINUE
         6000 CALL RUNGK
         2000 CONTINUE
              GO TO 1010
         1000 CONTINUE
              NPTS     = NPTS + 1
              XT(NPTS)= TIME
              YT(NPTS)= Y
              YMAX     = AMAX1 ( YMAX, Y )
              YMIN     = AMIN1 ( YMIN, Y )
              Z1T(NPTS)= ZH1
              Z2T(NPTS)= ZH2
              YMAX1    = AMAX1 ( YMAX1, ZH1 )
              YMIN1    = AMIN1 ( YMIN1, ZH1 )
              YMAX2    = AMAX1 ( YMAX2, ZH2 )
              YMIN2    = AMIN1 ( YMIN2, ZH2 )
              WRITE(6,550) TIME,     XD1,      XD2,      XD3,      XD4,
             .    X1,       X2,       X3,       X4,       XDH1,     XDH2,
             .    XDH3,     XDH4,     ZDH1,     ZDH2,     XH1,      XH2,
             .    XH3,      XH4,      ZH1,      ZH2,      POC,      W,
             .    UDA,      Y
              CALL LINPLT ( XT, YT, DUMM, DUMM, NPTS, 1, YMIN, YMAX, 0., 0.,
             .    0., 0. )
```

```
      CALL LINPLT ( XT, Z1T, Z2T, DUMM, NPTS, 2, YMIN1, YMAX1,
     .   YMIN2, YMAX2, 0., 0. )
      GO TO 2100
 2200 CONTINUE
      WRITE(6,5100)
 2100 CONTINUE
      CALL EXIT
  100 FORMAT(8A10)
  150 FORMAT(1H1,1X,13(2H* ),8A10,13(2H* ),/////)
  200 FORMAT(/,1X,3HXM(I1,4H,1)=,E12.6,1X,
     .   3HXM(I1,4H,2)=,E12.6,1X,3HXM(I1,4H,3)=,E12.6,1X,
     .   3HXM(I1,4H,4)=,E12.6,1X,3HXM(I1,4H,5)=,E12.6,1X,
     .   3HXM(I1,4H,6)=,E12.6)
  300 FORMAT(/,1X,*T(1)=*,2(E12.6,2X),1X,*T(2)=*,2(E12.6,2X),1X,
     .   *T(3)=*,2(E12.6,2X),/,1X,*T(4)=*,2(E12.6,2X),1X,
     .   *T(5)=*,2(E12.6,2X),/)
  400 FORMAT(/,1X,*A(1)=*E12.6,1X,*A(2)=*,E12.6,
     .   1X,*A(3)=*,E12.6,1X,*A(4)=*,E12.6,1X,
     .   *A(5)=*,E12.6,1X,*A(6)=*,E12.6,/)
  500 FORMAT(/,1X,*R(1)=*E12.6,1X,*R(2)=*,E12.6,
     .   1X,*R(3)=*,E12.6,1X,*R(4)=*,E12.6,1X,
     .   *R(5)=*,E12.6,1X,*R(6)=*,E12.6,/)
  550 FORMAT(/,4X,6HTIME =,E14.7,4X,6HXD1   =,E14.7,4X,
     .6HXD2   =,E14.7,4X,6HXD3   =,E14.7,4X,6HXD4   =,E14.7,/,
     .4X,6HX1    =,E14.7,4X,6HX2    =,E14.7,4X,6HX3    =,E14.7,4X,
     .6HX4    =,E14.7,4X,6HXDH1 =,E14.7,/,
     .4X,6HXDH2 =,E14.7,4X,6HXDH3 =,E14.7,4X,6HXDH4 =,E14.7,4X,
     .6HZDH1 =,E14.7,4X,6HZDH2 =,E14.7,/,4X,6HXH1   =,E14.7,4X,
     .6HXH2   =,E14.7,4X,6HXH3   =,E14.7,4X,6HXH4   =,E14.7,4X,
     .6HZH1   =,E14.7,/,4X,6HZH2   =,E14.7,4X,6HPEGC  =,E14.7,4X,
     .6HW     =,E14.7,4X,6HUDA   =,E14.7,4X,6HY     =,E14.7,//)
  600 FORMAT(/,5(1X,3HAM(,I2,2H)=,E12.6))
  700 FORMAT(/,1X,*AM(26)=*,E12.6,/)
  800 FORMAT(////,5X,*DET=*,E14.7,3X,*RA=*,E14.7,3X,*E=*,E14.7)
  900 FORMAT(/,1X,*K(1)=*E12.6,1X,*K(2)=*,E12.6,
     .   1X,*K(3)=*,E12.6,1X,*K(4)=*,E12.6,1X,
     .   *K(5)=*,E12.6,1X,*K(6)=*,E12.6,/)
 5100 FORMAT(/////,28X,10(2H**),4X,34HMATRIX IS SINGULAR, RUN IS ABORTE
     .,4X,10(2H**))
 5200 FORMAT(1X,68(2H**),//,35X,
     .56HSOLUTION IS ATTEMPTED BUT MATRIX MAY BE SINGULAR OR ILL ,
     .11HCONDITIONED,//,1X,68(2H**))
      END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

   ENTRY POINTS      DEF LINE      REFERENCES
    4114  MAIN              1

   VARIABLES      SN  TYPE            RELOCATION
    6153  A           REAL      ARRAY              REFS      29        92       129       130       131       132       133
                                                    134   DEFINED      73        74        78        83        88        91
       0  ALP         REAL                DEFDAT   REFS       3        37       208
       0  AM          REAL      ARRAY     OUTP     REFS      25        34     5*126
       0  AM0         REAL                OUTP     REFS      11        34       159   DEFINED        97
       1  AM1         REAL                OUTP     REFS      11       166   DEFINED        94
      12  AM10        REAL                OUTP     REFS      11       168   DEFINED       111
      13  AM11        REAL                OUTP     REFS      11       131   DEFINED       108
      14  AM12        REAL                OUTP     REFS      11       145   DEFINED       103
      15  AM13        REAL                OUTP     REFS      11       150   DEFINED        97
      16  AM14        REAL                OUTP     REFS      11       162   DEFINED       113
      17  AM15        REAL                OUTP     REFS      11       169   DEFINED       115
      20  AM16        REAL                OUTP     REFS      11       132   DEFINED       107
      21  AM17        REAL                OUTP     REFS      11       151   DEFINED       103
      22  AM18        REAL                OUTP     REFS      11       156   DEFINED        97
      23  AM19        REAL                OUTP     REFS      11       163   DEFINED       117
       2  AM2         REAL                OUTP     REFS      11       129   DEFINED        95
      24  AM20        REAL                OUTP     REFS      11       170   DEFINED       115
      25  AM21        REAL                OUTP     REFS      11       133   DEFINED       106
      26  AM22        REAL                OUTP     REFS      11       157   DEFINED       103
      27  AM23        REAL                OUTP     REFS      11       164   DEFINED       121
      30  AM24        REAL                OUTP     REFS      11       171   DEFINED       123
      31  AM25        REAL                OUTP     REFS      11       128       134   DEFINED       105
       3  AM3         REAL                OUTP     REFS      11        97       104       106       107       108       138
                                                 DEFINED     96
       4  AM4         REAL                OUTP     REFS      11       160   DEFINED        98
       5  AM5         REAL                OUTP     REFS      11       167   DEFINED       100
       6  AM6         REAL                OUTP     REFS      11       130   DEFINED       104
       7  AM7         REAL                OUTP     REFS      11       103       104       105       106       107       108
                                                    139   DEFINED     102
      10  AM8         REAL                OUTP     REFS      11       144   DEFINED        97
      11  AM9         REAL                OUTP     REFS      11       161   DEFINED       109
       1  B           REAL      ARRAY     DEFDAT   REFS       3        37        55        58       100     2*104       105
                                                  2*106   3*107     3*108     3*109     3*111     3*113     3*115     3*117
                                                  3*119   2*121     2*123     2*213     2*214     2*215     2*216     3*218
                                                  3*221   3*224     3*227
      11  BET         REAL                DEFDAT   REFS       3        37
      12  C           REAL                DEFDAT   REFS       3        37        93        94        98       100       109
                                                    111     113       115       117       119       121       123       212
                                                    218     221       224       227     3*230     3*233
    6161  CK          REAL      ARRAY              REFS      29       186       187     3*218     3*221     3*224     3*227
                                                  5*230   5*233
    6101  CL1         REAL                         REFS     213       214       215       216       217
                                                 DEFINED    212
      13  C0          REAL                DEFDAT   REFS       3        37       208
      14  C1          REAL                DEFDAT   REFS       3        37       208
      15  D           REAL      ARRAY     DEFDAT   REFS       3        37      2*55      2*56      2*58     2*100     4*102
                                                  2*109   2*111     2*113     2*115     2*117     2*119     2*121     2*123
                                                  2*230   2*233
    6055  DET         REAL                         REFS     176       177       182
```

```
VARIABLES       SN  TYPE            RELOCATION
    0  CT           REAL                  RUNK       REFS       17       262   DEFINED      192
 6102  DUMM         REAL                             REFS     2*284      286
 6057  F            REAL                             REFS      176       177      178       182
   21  H            REAL         ARRAY    DEFDAT     REFS        3        37       93        94      3*98     3*100     3*109
                                                    3*111    3*113     3*115    3*117     3*119     2*121     2*123     2*209
                                                    2*218    2*221     2*224    2*227     2*230     2*233
 6167  HEAD         REAL         ARRAY               REFS       29        47  DEFINED        42
 6053  I            INTEGER                          REFS       51    10*126   12*173    12*180     2*185
                                                  DEFINED       49       125      172       179       183
 6177  IHLD         INTEGER      ARRAY               REFS       29       176
 6061  IP           INTEGER                          REFS      253       254  DEFINED       195       253       255
 6063  IPLT         INTEGER                          REFS      238       239  DEFINED       197       238       240
 6062  ISTR         INTEGER                          REFS      197       239  DEFINED       196
 6054  J            INTEGER                          REFS       51     2*185      205   DEFINED        50       184       193
                                                      205
 6073  KU           INTEGER                          REFS      207   DEFINED      206
    1  KUTTA        INTEGER               RUNK       REFS       17       236  DEFINED       207
   23  LM           COMPLEX      ARRAY    DEFDAT     REFS        3        27       37      2*52      2*53      2*54      2*55
                                                     2*56     2*57      2*58     2*59      2*60      2*61      2*62      2*63
                                                     2*64     2*65      2*66     4*67      3*68      2*69      2*70      2*71
                                                     4*78
   37  NPRT         INTEGER               DEFDAT     REFS        3        37      195       254
 6064  NPTS         INTEGER                          REFS      241       242      243       246       247       268       269
                                                      270      273       274      284       286   DEFINED       198       241
                                                      268
   40  NUMBR        INTEGER               DEFDAT     REFS        3        37      196
    0  NX           INTEGER               INTEG      REFS        9        37
   41  PSC          REAL                  DEFDAT     REFS        3        37      210       256       275
 6205  R            REAL         ARRAY               REFS       29       135      186   DEFINED       129       130       131
                                                      132      133       134
 6056  RA           REAL                             REFS      176       182
   42  STPSZ        REAL                  DEFDAT     REFS        3        37      192       196
 6103  T            COMPLEX      ARRAY               REFS       27        29       72      3*73      6*78      3*88
                                                  DEFINED       67        68       69        70        71
 6060  TIME         REAL                             REFS      204       208      242       256       262       269       279
                                                  DEFINED      194       262
   43  TSTOP        REAL                  DEFDAT     REFS        3        37      204
 6076  U            REAL                             REFS      211       218      221       224       227       230       233
                                                  DEFINED      210
 6075  UCA          REAL                             REFS      210       256      279   DEFINED       209
 6100  U1           REAL                             REFS      212   DEFINED      211
 6074  W            REAL                             REFS      211       256      279   DEFINED       208
 6213  WORK         REAL         ARRAY               REFS       29       176
    4  XCH1         REAL                  RUNKIN     REFS       19       256      279   DEFINED       190       218
    5  XCH2         REAL                  RUNKIN     REFS       19       256      279   DEFINED       190       221
    6  XCH3         REAL                  RUNKIN     REFS       19       256      279   DEFINED       190       224
    7  XCH4         REAL                  RUNKIN     REFS       15       256      279   DEFINED       190       227
    0  XC1          REAL                  RUNKIN     REFS       19       256      279   DEFINED       188       216
    1  XC2          REAL                  RUNKIN     REFS       19       256      279   DEFINED       188       215
    2  XC3          REAL                  RUNKIN     REFS       19       256      279   DEFINED       188       214
    3  XC4          REAL                  RUNKIN     REFS       19       256      279   DEFINED       188       213
    4  XH1          REAL                  RUNKOUT    REFS       23       218      221       224       227       230       233
                                                      256      279   DEFINED      191
    5  XH2          REAL                  RUNKOUT    REFS       23       218      256       275   DEFINED       191
    6  XH3          REAL                  RUNKOUT    REFS       23       221      256       275   DEFINED       191
    7  XH4          REAL                  RUNKOUT    REFS       23       224      256       279   DEFINED       191
 6227  XM           REAL         ARRAY               REFS       29     6*173      176     6*180       185
```

```
VARIABLES      SN  TYPE            RELOCATION
                                             DEFINED     51     137     138      135    3*140    142    143
                                                144     145   2*146   2*148      149     150     151    152
                                              3*154     155     156     157      159     160     161    162
                                                163     164     166     167      168     165     170    171
  6337  XMI         REAL     ARRAY              REFS     29     186  DEFINED     185
  6403  XT          REAL     ARRAY              REFS     29     284     286  DEFINED     242     269
     0  X1          REAL             RUNKOUT    REFS     23     217     256      279  DEFINED     189
     1  X2          REAL             RUNKOUT    REFS     23     216     256      279  DEFINED     189
     2  X3          REAL             RUNKOUT    REFS     23     215     256      279  DEFINED     189
     3  X4          REAL             RUNKOUT    REFS     23     214     256      279  DEFINED     189
  6077  Y           REAL                        REFS    210     213     214      215     216     218    221
                                                224     227     230     233      243     244     245    256
                                                270     271     272     279  DEFINED     217
  6065  YMAX        REAL                        REFS    244     271     284  DEFINED     199     244    271
  6067  YMAX1       REAL                        REFS    248     275     286  DEFINED     201     248    275
  6070  YMAX2       REAL                        REFS    250     277     286  DEFINED     201     250    277
  6066  YMIN        REAL                        REFS    245     272     284  DEFINED     200     245    272
  6071  YMIN1       REAL                        REFS    249     276     286  DEFINED     202     249    276
  6072  YMIN2       REAL                        REFS    251     278     286  DEFINED     202     251    278
 10353  YT          REAL     ARRAY              REFS     29     284  DEFINED     243     270
  6115  Z           COMPLEX  ARRAY              REFS     27      29   15*74    10*78   21*83    6*88   3*91
                                             DEFINED     52      53      54       55      56      57     58
                                                 55      60      61      62       63      64      65     66
    10  ZCH1        REAL             RUNKIN     REFS     19     256     279  DEFINED     190     230
    11  ZCH2        REAL             RUNKIN     REFS     19     256     279  DEFINED     190     233
    10  ZH1         REAL             RUNKOUT    REFS     23     209     218      221     224     227    230
                                                233     246     248     249      256     273     275    276
                                                278 DEFINED     191
    11  ZH2         REAL             RUNKOUT    REFS     23     209     218      221     224     227    230
                                                233     247     250     251      256     274     277    278
                                                279 DEFINED     191
 12323  Z1T         REAL     ARRAY              REFS     29     286  DEFINED     246     273
 14273  Z2T         REAL     ARRAY              REFS     29     286  DEFINED     247     274

FILE NAMES          MODE
     0  INPUT
  2043  OUTPUT
     0  TAPE5       MIXED               READS     42      43
  2043  TAPE6       MIXED              WRITES     45      47      72      92      126     128     135    173
                                          178    180     182     187     256      279     290

EXTERNALS           TYPE    ARGS        REFERENCES
        EXIT                  0           282
        EXP         REAL      1 LIBRARY   208
        LINPLT               12           284     286
        MPEY                  6           186
        PUNCH                 0           264
        SESCMI               13           176

INLINE FUNCTIONS    TYPE    ARGS      DEF LINE  REFERENCES
        AMAX1       REAL      0  INTRIN          244     248     250     271     275     277
        AMIN1       REAL      0  INTRIN          245     249     251     272     276     278

NAMELISTS           DEF LINE      REFERENCES
        INP            37          43      45
```

```
STATEMENT LABELS                  DEF LINE   REFERENCES
     0  10                            51        49        50
     0  20                           173       172
     0  30                           126       125
     0  40                           180       179
     0  50                           185       183       184
  5616  100      FMT                 293        42
  5620  150      FMT                 294        47
  5625  200      FMT                 295       173       180
  5644  300      FMT                 299        72
  5661  400      FMT                 302        62
  5675  500      FMT                 305       175
  5711  550      FMT                 309       256       279
  5763  600      FMT                 317       126
  5767  700      FMT                 318       128
  5773  800      FMT                 319       182
  6001  900      FMT                 320       187
  5204  1000                         267       204
  4774  1010                         203       266
     0  2000                         265       206
  5170  2020                         252       239
  5175  2030                         261       254
  5240  2100                         291       288
  5236  2200                         289       177
  5175  3000                         262       276
  5200  4000                         263       236
  5140  5000                         237       236
  6015  5100     FMT                 323       250
  6025  5200     FMT                 325       178
  5200  6000                         264       236

LOOPS   LABEL    INDEX      FROM-TO      LENGTH     PROPERTIES
  4126  10      * I         49  51          4B                 NOT INNER
  4127  10        J         50  51          2B       INSTACK
  4544  30      * I        125 126         22B                 EXT REFS
  4662  20      * I        172 173         16B                 EXT REFS
  4714  40      * I        175 180         16B                 EXT REFS
  4734  50      * I        183 185          5B                 NOT INNER
  4735  50        J        184 185          3B       INSTACK
  5000  2000    * KL       206 265        204B                 EXT REFS

COMMON BLOCKS   LENGTH     MEMBERS - BIAS NAME(LENGTH)
        DEFDAT      36            0 ALP      (1)          1 B        (8)          9 BET      (1)
                                 10 C        (1)         11 C0       (1)         12 C1       (1)
                                 13 D        (4)         17 H        (2)         19 LP       (12)
                                 31 NFRT     (1)         32 NUMBR    (1)         33 REC      (1)
                                 34 STPSZ    (1)         35 TSTOP    (1)
        INTEG        1            0 NX       (1)
        OUTP        26            0 AM0      (1)          1 AM1      (1)          2 AM2      (1)
                                  3 AM3      (1)          4 AM4      (1)          5 AM5      (1)
                                  6 AM6      (1)          7 AM7      (1)          8 AM8      (1)
                                  9 AM9      (1)         10 AM10     (1)         11 AM11     (1)
                                 12 AM12     (1)         13 AM13     (1)         14 AM14     (1)
                                 15 AM15     (1)         16 AM16     (1)         17 AM17     (1)
                                 18 AM18     (1)         19 AM19     (1)         20 AM20     (1)
                                 21 AM21     (1)         22 AM22     (1)         23 AM23     (1)
                                 24 AM24     (1)         25 AM25     (1)
```

```
COMMON BLOCKS    LENGTH     MEMBERS - BIAS NAME(LENGTH)
       RUNK          2             0 CT      (1)         1 KUTTA   (1)
       RUNKIN       10             0 XD1     (1)         1 XD2     (1)         2 XD3     (1)
                                   3 XD4     (1)         4 XDH1    (1)         5 XDH2    (1)
                                   6 XDH3    (1)         7 XDH4    (1)         8 ZDH1    (1)
                                   9 ZDH2    (1)
       RUNKOUT      10             0 X1      (1)         1 X2      (1)         2 X3      (1)
                                   3 X4      (1)         4 XH1     (1)         5 XH2     (1)
                                   6 XH3     (1)         7 XH4     (1)         8 ZH1     (1)
                                   9 ZH2     (1)

EQUIV CLASSES    LENGTH     MEMBERS - BIAS NAME(LENGTH)
-MO    AMO          26             0 AM      (26)

STATISTICS
  PROGRAM LENGTH               12135B    5213
  BUFFER LENGTH                 4106B    2118
  CM LABELED COMMON LENGTH       125B      85
```

```
      BLOCK DATA A
C
      COMMON/DEFDAT/      ALP,          B ( 8 ),       BET,
     .    C,              C0,
     .    C1,             D ( 4 ),      H ( 2 ),       LM ( 6 ),
     .    NPRT,           NUMBR,        PGC,           STPSZ,
     .    TSTOP
C
      COMMON/INTEG/       NX
C
      COMPLEX             LM
      DATA                ALP           /1.0           /
      DATA                B
     .   /20.0,           -440.0,       -10800.0,      -54000.0,
     .    17.6816,        243.7748,     438.5048,      211.4116       /
      DATA                BET           /1.0           /
      DATA                C             /-0.03328      /
      DATA                C0            /0.0           /
      DATA                C1            /0.0           /
      DATA                D
     .   /0.0,            0.0,          1.0,           0.0            /
      DATA                H
     .   /1.0,            0.0           /
      DATA                LM
     .   /(-5.0,0.0),     (-6.0,0.0),   (-10.0,0.0),   (-10.0,0.0),
     .    (-12.0,0.0),    (-15.0,0.0)   /
      DATA                NPRT          /32            /
      DATA                NUMBR         /8             /
      DATA                NX            /10            /
      DATA                PGC           /1.0           /
      DATA                STPSZ         /32.0          /
      DATA                TSTOP         /10.0          /
      END
```

```
        SYMBOLIC REFERENCE MAP (R=3)

 VARIABLES      SN   TYPE            RELOCATION
      0  ALP          REAL                DEFDAT        REFS          3    DEFINED       12
      1  B            REAL         ARRAY  DEFDAT        REFS          3    DEFINED       13
     11  HET          REAL                DEFDAT        REFS          3    DEFINED       16
     12  C            REAL                DEFDAT        REFS          3    DEFINED       17
     13  CO           REAL                DEFDAT        REFS          3    DEFINED       18
     14  CI           REAL                DEFDAT        REFS          3    DEFINED       19
     15  D            REAL         ARRAY  DEFDAT        REFS          3    DEFINED       20
     21  H            REAL         ARRAY  DEFDAT        REFS          3    DEFINED       22
     23  LM           COMPLEX      ARRAY  DEFDAT        REFS          3        11   DEFINED     24
     37  NPRT         INTEGER             DEFDAT        REFS          3    DEFINED       27
     40  NUMPR        INTEGER             DEFDAT        REFS          3    DEFINED       28
      0  NX           INTEGER             INTEG         REFS          5    DEFINED       29
     41  PCC          REAL                DEFDAT        REFS          3    DEFINED       30
     42  STPSZ        REAL                DEFDAT        REFS          3    DEFINED       31
     43  TSTOP        REAL                DEFDAT        REFS          3    DEFINED       32

 COMMON BLOCKS    LENGTH     MEMBERS - BIAS NAME(LENGTH)
   DEFDAT             36               0 ALP      (1)          1 B      (8)          5 HET     (1)
                                      10 C        (1)         11 CO     (1)         12 CI      (1)
                                      13 D        (4)         17 H      (2)         15 LM      (12)
                                      31 NPRT     (1)         32 NUMPR  (1)         33 PCC     (1)
                                      34 STPSZ    (1)         35 TSTOP  (1)
   INTEG               1               0 NX       (1)

 STATISTICS
   PROGRAM LENGTH                   1B        0
   CM LABELED COMMON LENGTH        45B       37
```

```
      SUBROUTINE RUNGK
C
C
      COMMON/INTEG/     NX
C
C
C
      COMMON/RUNK/      DT,          KUTTA
C
C
C
C-------------------DERIVATIVES TO RUNGK
C                   DO NOT CHANGE THE ORDER OF THE MEMBERS
C
      COMMON/RUNKIN/
     .  XD1,       XD2,       XD3,       XD4,
     .  XDH1,      XDH2,      XDH3,      XDH4,      ZDH1,      ZDH2
C
C
C
C-------------------INTEGRALS FROM RUNGK
C                   DO NOT CHANGE THE ORDER OF THE MEMBERS
C
      COMMON/RUNKOUT/
     .  X1,        X2,        X3,        X4,
     .  XH1,       XH2,       XH3,       XH4,       ZH1,       ZH2
C
C
C
C
      DIMENSION          DX ( 10 ),     DXA ( 10 ),     XR ( 10 ),
     .  XA ( 10 )
C
C
C
      EQUIVALENCE  ( XR,       X1 ),  ( DX,     XD1  )
C
C
      GO TO (10,30,50,70),KUTTA
   10 DO 20 I=1,NX
      XA(I)    = XR ( I )
      DXA(I)=DT*DX(I)
   20 XR(I)    = XR ( I ) + 0.5 * DXA ( I )
      RETURN
   30 TDT=2.*DT
      HDT=.5*DT
      DO 40 I=1,NX
      DXA(I)=DXA(I)+TDT*DX(I)
   40 XR(I)    = XA ( I ) + HDT * DX ( I )
      RETURN
   50 DO 60 I=1,NX
      VDT=DT*DX(I)
      DXA(I)=DXA(I)+2.*VDT
   60 XR(I)    = XA ( I ) + VDT
      RETURN
   70 DO 80 I=1,NX
   80 XR(I)    = XA ( I ) + ( DXA ( I ) + DT * DX ( I ) ) / 6.0
```

```
      RETURN
      END
```

```
      SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS      DEF LINE     REFERENCES
    2 RUNGK              1        44         50        55        58

VARIABLES     SN  TYPE              RELOCATION
    0 DT          REAL                   RUNK          REFS         8        42        45        46        52        57
    0 DX          REAL          ARRAY    RUNKIN        REFS        31        36        42        48        49        52        57
  117 DXA         REAL          ARRAY                  REFS        31        43        48        53        57
                                                    DEFINED        42        48        53
  115 HDT         REAL                                 REFS        49   DEFINED        46
  113 I           INTEGER                              REFS      2*41      2*42      3*43      3*48      3*49        52      2*53
                                                       2*54      4*57   DEFINED        40        47        51        56
    1 KUTTA       INTEGER                RUNK          REFS         8        39
    0 NX          INTEGER                INTEG         REFS         4        40        47        51        56
  114 TDT         REAL                                 REFS        48   DEFINED        45
  116 VDT         REAL                                 REFS        53        54   DEFINED        52
  131 XA          REAL          ARRAY                  REFS        31        49        54        57   DEFINED        41
    4 XDH1        REAL                   RUNKIN        REFS        15
    5 XDH2        REAL                   RUNKIN        REFS        15
    6 XDH3        REAL                   RUNKIN        REFS        15
    7 XDH4        REAL                   RUNKIN        REFS        15
    0 XD1         REAL                   RUNKIN        REFS        15        36
    1 XD2         REAL                   RUNKIN        REFS        15
    2 XD3         REAL                   RUNKIN        REFS        15
    3 XD4         REAL                   RUNKIN        REFS        15
    4 XH1         REAL                   RUNKOUT       REFS        24
    5 XH2         REAL                   RUNKOUT       REFS        24
    6 XH3         REAL                   RUNKOUT       REFS        24
    7 XH4         REAL                   RUNKOUT       REFS        24
    0 XR          REAL          ARRAY    RUNKOUT       REFS        31        36        41        43   DEFINED        43        49
                                                         54        57
    0 X1          REAL                   RUNKOUT       REFS        24        36
    1 X2          REAL                   RUNKOUT       REFS        24
    2 X3          REAL                   RUNKOUT       REFS        24
    3 X4          REAL                   RUNKOUT       REFS        24
   10 ZDH1        REAL                   RUNKIN        REFS        15
   11 ZDH2        REAL                   RUNKIN        REFS        15
   10 ZH1         REAL                   RUNKOUT       REFS        24
   11 ZH2         REAL                   RUNKOUT       REFS        24

STATEMENT LABELS              DEF LINE    REFERENCES
   15 10                          40          39
    0 20                          43          40
   34 30                          45          39
    0 40                          49          47
   57 50                          51          39
    0 60                          54          51
   75 70                          56          39
    0 80                          57          56

LOOPS   LABEL     INDEX     FROM-TO     LENGTH     PROPERTIES
   16   20        I          40 43        14B          OPT
   43   40        I          47 49        12B          OPT
   60   60        I          51 54        13B          OPT
   76   80        I          56 57        10B          OPT
```

```
 SUBROUTINE LINPLT(XT,YT1,YT2,YT3,NX,NYTS,Y1MIN,Y1MAX,
1Y2MIN,Y2MAX,Y3MIN,Y3MAX)

 DESCRIPTION
     THIS ROUTINE GENERATES ON-LINE PRINTER PLOTS FOR
     1, 2, OR 3 CURVES. THE TABLE OF INDEPENDENT VARIABLES
     MUST BE EVENLY SPACED.

 INPUT
     1  YT        TABLE OF INDEPENDENT VALUES. MUST BE
                  EVENLY SPACED.
     2  YT1       TABLE OF DEPENDENT VALUES FOR FIRST CURVE.
     3  YT2       TABLE OF DEPENDENT VALUES FOR SECOND CURVE.
     4  YT3       TABLE OF DEPENDENT VALUES FOR THIRD CURVE.
     5  NX        NUMBER OF POINTS IN XT.
     6  NYTS      NUMBER OF CURVES TO BE PLOTTED.
                  (NYTS=1, 2, OR 3)
     7  Y1MIN     LOWER LIMIT OF YT1 SCALE.
     8  Y1MAX     UPPER LIMIT OF YT1 SCALE.
                  IF Y1MIN =Y1MAX , THIS ROUTINE WILL
                  CALCULATE SCALE VALUES.
     9  Y2MIN     LOWER LIMIT OF YT2 SCALE.
     10 Y2MAX     UPPER LIMIT OF YT2 SCALE.
                  IF Y2MIN =Y2MAX , THIS ROUTINE WILL
                  CALCULATE SCALE VALUES.
     11 Y3MIN     LOWER LIMIT OF YT3 SCALE.
     12 Y3MAX     UPPER LIMIT OF YT3 SCALE.
                  IF Y3MIN =Y3MAX , THIS ROUTINE WILL
                  CALCULATE SCALE VALUES.

 OUTPUT
     ON-LINE PRINTER PLOTS

 REMARKS
     IF A PLOT OF 1 CURVE OR A PLOT OF 2 CURVES IS
     DESIRED, THE VARIABLES NOT NEEDED MUST BE DUMMY
     VARIABLES IN THE  CALL  STATEMENT.
     EXAMPLE...TO PLOT 1 CURVE
     CALL LINPLT(XV1,YV1,DUMMY,DUMMY,100,1,-1.0,1.0,0.,0.,0.,0.)
```

```
      SUBROUTINE LINPLT(XT,YT1,YT2,YT3,NX,NYTS,Y1MIN,Y1MAX,
C    1Y2MIN,Y2MAX,Y3MIN,Y3MAX)
      DIMENSION XT(1),YT1(1),YT2(1),YT3(1),WRKARR(101)
      DIMENSION TT(4),DLM(3),SCA(3),SCALE(6),ABC(3)
      DIMENSION YMIN(3),YMAX(3),YLL(3),YUL(3)
      DATA BLK,DOT/1H ,1H./
      DATA ABC/1HA,1HB,1HC/
      DATA TT /1.0,2.0,5.0,10.0 /
C         INITIALIZE
      DO 200 II=1,3
      IF(II .GT. NYTS) GO TO 300
      GO TO (10,20,30), II
   10 YMN=Y1MIN
      YMX=Y1MAX
      GO TO 50
   20 YMN=Y2MIN
      YMX=Y2MAX
      GO TO 50
   30 YMN=Y3MIN
      YMX=Y3MAX
   50 YMIN(II)=1.0E+20
      YMAX(II)=-1.0E+20
      DO 60 I=1,NX
      IF(II .EQ. 1)  Y=YT1(I)
      IF(II .EQ. 2)  Y=YT2(I)
      IF(II .EQ. 3)  Y=YT3(I)
      YMIN(II)=AMIN1(YMIN(II),Y)
   60 YMAX(II)=AMAX1(YMAX(II),Y)
      IF(YMN .EQ. YMX)   GO TO 70
      YLL(II) = YMN
      YUL(II) = YMX
      GO TO 140
C     SET SCALES
   70 D=ABS(YMAX(II)-YMIN(II))
      IF(D .NE. 0.0) GO TO 72
      D = 0.01*ABS(YMAX(II))
      IF(D .EQ. 0.0) D = 1.0
   72 L1 = ALOG10(D)
      IF(D .LT. 1.0)    L1 = L1-1
      TEST = .5*10.0**(FLOAT(L1-8))
      DO 75 I=1,4
      R = TT(I) * 10.0**FLOAT(L1)
      IF(R .GE. D)   GO TO 80
   75 CONTINUE
   80 IF(YMIN(II) .NE. 0.0) GO TO 90
      YLL(II)=0.0
      YUL(II)=R
      GO TO 140
   90 IF(YMAX(II) .NE. 0.0) GO TO 100
   95 YUL(II)=0.0
      YLL(II)=-R
      GO TO 140
  100 P=.5*(YMIN(II)+YMAX(II))
      P = P+0.001*R*SIGN(1.0,P)
      L2 = 0
```

```
      IF(P .NE. 0.0)    L2 = ALOG10(ABS(P))
      IF(ABS(P) .LT. 1.0)  L2=L2-1
      IP=(P+.5*10.0**FLOAT(L2))/10.0**FLOAT(L2)
      IF(IP .LE. 0) IP=IP-1
  110 YLL(II)=FLOAT(IP)*10.0**FLOAT(L2)-.5*R
      IF(YLL(II) .GT. YMIN(II))  GO TO 125
      IF(YMIN(II) .GT. 0.0)    YLL(II)=AMAX1(0.0,YLL(II))
      YUL(II)=YLL(II)+R
      IF(YUL(II) .LT. YMAX(II)) GO TO 135
      IF(YMAX(II) .LT. 0.0 .AND. YUL(II) .GT. 0.0) GO TO 95
      IF(YUL(II)*YLL(II) .GE. 0.0) GO TO 130
      DO 120 I=1,10
      TMP1=YLL(II)+.1*R*FLOAT(I)
      IF(ABS(TMP1) .LE. TEST) GO TO 130
  120 CONTINUE
  125 IP=IP-1
      GO TO 110
  130 IF(YUL(II) .GE. YMAX(II)) GO TO 140
      IF(YMAX(II)-YUL(II) .LE. .005*R)  GO TO 140
  135 R = 2.0*R
      GO TO 110
  140 DLM(II)=(YUL(II)-YLL(II))/5.0
      SCA(II)=YLL(II)
C     PRINT CURVE MAX AND MIN VALUES
  150 IF(II .EQ.1) WRITE(6,160)
  160 FORMAT(1H1)
      WRITE(6,170) II,ABC(II),YMIN(II),YMAX(II)
  170 FORMAT(1X,7HCURVE Y,I1,1X,10HDENOTED BY,1X,A1,4X,4HMIN=1PE10.3,
     12X,4HMAX=1PE10.3)
  200 CONTINUE
C     PRINT CURVE SCALES
  300 WRITE(6,310)
  310 FORMAT(1H0)
      DO 350 II=1,3
      IF(II .GT. NYTS) GO TO 360
      SCALE(1)=SCA(II)
      DO 320 I=2,6
      SCALE(I)=SCALE(I-1)+DLM(II)
      IF(ABS(SCALE(I)) .LT. TEST) SCALE(I) = 0.0
  320 CONTINUE
  330 WRITE(6,340) ABC(II), (SCALE(I),I=1,6)
  340 FORMAT(1X,6HSCALE ,A1,10X,1PE10.3,10X,1PE10.3,10X,1PE10.3,10X,
     11PE10.3,10X,1PE10.3,10X,1PE10.3)
  350 CONTINUE
  360 NXP=NX+10
      WRITE(6,365)
  365 FORMAT(1HT)
      DX=XT(2)-XT(1)
      DO 800 I=1,NXP
      WRKARR(1)=DOT
      DO 375 JJ=2,101
      J=JJ
      WRKARR(J)=BLK
      IF(MOD((J-1),10).EQ.0) WRKARR(J)=DOT
      IF(I.EQ.1) WRKARR(J)=DOT
```

```
      IF(MOD((I-1),5).EQ.0) WRKARR(J)=DOT
  375 CONTINUE
      IF(I.GT.NX) GO TO 760
  400 DO 420 II=1,3
      IF(II .GT. NYTS) GO TO 720
      IF(II.EQ.1) Y=YT1(I)
      IF(II.EQ.2) Y=YT2(I)
      IF(II.EQ.3) Y=YT3(I)
      NP=100*(Y-YLL(II))/(YUL(II)-YLL(II))+1.5
      IF(NP .GT. 101) NP=101
      IF(NP .LT. 1) NP=1
      WRKARR(NP)=ABC(II)
  420 CONTINUE
C          PRINT LINE OF DESIRED PLOTS
  720 X=XT(I)
      IF(I.EQ.1) GO TO 740
      IF(MOD((I-1),10).EQ.0) GO TO 740
      WRITE(6,730) WRKARR
  730 FORMAT(20X,101A1)
      GO TO 800
  740 WRITE(6,750) X,WRKARR
  750 FORMAT(10X,1PE10.3,101A1)
      GO TO 800
  760 X=XT(NX)+FLOAT(I-NX)*DX
      IF(MOD((I-1),10).EQ.0) GO TO 820
      WRITE(6,730) WRKARR
  800 CONTINUE
      GO TO 830
  820 WRITE(6,750) X,WRKARR
  830 WRITE(6,835)
  835 FORMAT(1HS)
      RETURN
      END
```

```
SUBROUTINE SESOMI(X,N,NB,MS,MN1,D,R,E,WORK,IHLD,IC,ID,IS)

DESCRIPTION
    THIS SUBROUTINE WILL SOLVE AN N BY N SYSTEM OF SIMULTANEOUS
    EQUATIONS WITH AN ARBITRARY NUMBER OF RIGHT HAND SIDES OR
    INVERT A MATRIX OF ORDER N.  IN THE PROCESS, THE RANK OF
    THE MATRIX AND ITS DETERMINANT ARE EVALUATED.  THE METHOD
    USED IS THAT OF GAUSS-JORDAN WITH TOTAL PIVOTING IF DESIRED.

INPUT
    1  X        FIRST LOCATION OF INPUT COEFFICIENT MATRIX,X(1,1)
                AUGMENTED BY NB RIGHT HAND SIDES.  FOR MATRIX
                INVERSE, X IS FIRST LOCATION OF THE MATRIX TO BE
                INVERTED.  I.E. X(1,1).  X MUST BE DIMENSIONED
                TO (MN1,MN1+NB) IN THE CALLING PROGRAM IN EITHER
                CASE.
    2  N        NUMBER OF SIMULTANEOUS EQUATIONS TO BE SOLVED,
                OR ORDER OF MATRIX TO BE INVERTED.
    3  NB       NB = NUMBER OF RIGHT HAND SIDES FOR SIMULTANEOUS
                EQUATION SOLUTION.  NB = N FOR MATRIX INVERSE.
    4  MS       MS = 0 FOR SIMULTANEOUS EQUATION SOLUTION.
                MS = 1 FOR MATRIX INVERSE.
    5  MN1      ROW DIMENSION OF X AS DEFINED IN CALLING PROGRAM.
    6  WORK     WORKING ARRAY DIMENSIONED AS FOLLOWS IN CALLING
                PROGRAM... WORK(MN1+NB).
    7  IHLD     WORKING ARRAY DIMENSIONED AS FOLLOWS IN CALLING
                PROGRAM... IHLD(MN1).
    8  IC       IC=1, PIVOTING BY ROW ONLY. NORMALLY SUFFICIENT.
                IC=0, PIVOTING BY ROW AND COLUMN. RUNS LONGER.
    9  ID       ID=1, DETERMINANT CALCUALTED.
                ID=0, DETERMINANT NOT DESIRED.
   10  IS       IS=1, MATRIX IS NOT SCALED PRIOR TO MANIPULATION.
                IS=0, EACH MATRIX ELEMENT IS SCALED PRIOR TO MANIP.

OUTPUT
    1  X        X(1,1) THROUGH X(N,1) CONTAIN FIRST SOLUTION
                VECTOR.  X(1,2) THROUGH X(N,2) CONTAIN SECOND
                SOLUTION VECTOR, ETC.  FOR MATRIX INVERSE, THE
                ARRAY X CONTAINS THE INVERSE MATRIX.
    2  D        DETERMINANT OF INPUT X.
    3  R        RANK OF INPUT X.
    4  E        ERROR CHECK
                E=0 O.K.
                E=1 MATRIX OF COEFFICIENTS IS SINGULAR.
                E=2 SOLUTION IS ATTEMPTED BUT EQUATIONS MAY BE
                    SINGULAR OR ILL CONDITIONED.

REMARKS
    THIS SUBROUTINE WILL RUN FASTER WITH IC=1 AND IS=1. THE VALUE
    IC SHOULD BE SET TO 0 ONLY IN RARE CASES WHERE EXTREME ILL-
    CONDITIONING IS EVIDENT AND IS SHOULD BE SET TO 0 ONLY WHEN
    ELEMENTS OF ONE ROW OF THE MATRIX IS MUCH GREATER THAN THE
    ELEMENTS OF OTHER ROWS, CAUSING A FALSE E=2., INDICATOR.
```

```
      SUBROUTINE SESOMI(X,N,NB,MS,MN1,D,R,E,WORK,IHLD,IC,ID,IS)
      DIMENSION X(MN1,1),WORK(1),IHLD(1)
      DOUBLE PRECISION X,WORK,Y,D,SUM,X1
C     THE FOLLOWING 9 CARDS ARE TEMPORARY MODIFICATIONS TO ALLOW
C     EXISTING CALLS TO SESOMI (USING 10 ARGUMENTS) TO WORK PROPERLY.
C     ANY CALLS NOW MADE SHOULD INCLUDE ALL 13 ARGUMENTS.
C     J = LOCF(IC)
      IF(J .GT. 64 )GO TO 50
      IIC = 0
      IID = 1
      IIS = 0
      GO TO 51
   50 IIC = IC
      IID = ID
      IIS = IS
   51 X1 = 1.
      E=0.
      R=0.
      IF(IIC .NE. 0)GO TO 211
      DO 21 I=1,N
   21 IHLD(I)=I
  211 CONTINUE
      IF(MS)6,4,6
    6 NN=N+N
      NB=N
      MN=N+1
      DO 14 I=1,N
      DO 14 J=MN,NN
   14 X(I,J)=0.
      DO 15 I=1,N
      J=I+N
   15 X(I,J)=1.
      GO TO 16
    4 NN=N+NB
   16 JJ=NN
      NNN=N-1
      D=0.
      IF(IID .NE. 0)D=1.
      IF(IIS .NE. 0)GO TO 361
      DO 36 I=1,N
      Y=X(I,1)
      DO 35 J=2,N
      IF(ABS(Y).LT.ABS(X(I,J)))Y=X(I,J)
   35 CONTINUE
      D=D*Y
      DO 36 J=1,NN
   36 X(I,J)=X(I,J)/Y
  361 CONTINUE
      DO 5 I=1,N
      KK=N-I
      IF(KK)10,10,26
   26 IF(IIC .NE. 0)GO TO 261
      LL=KK+1
      IJJ=1
      L=I
```

```
      WORK(1)=X(1,1)
      DO 17 II=1,LL
      DO 17 J=1,LL
      IF(ABS(WORK(1))-ABS(X(II,J)))18,17,17
   18 WORK(1)=X(II,J)
      L=J+I-1
      IJJ=J
   17 CONTINUE
      IF(IJJ-1)2,2,19
   19 DO 20 II=1,N
      Y=X(II,1)
      X(II,1)=X(II,IJJ)
   20 X(II,IJJ)=Y
      IY=IHLD(I)
      IHLD(I)=IHLD(L)
      IHLD(L)=IY
      D=-D
  261 IJJ=1
      Y=X(1,1)
    2 DO 1 L=1,KK
      IF(ABS(Y)-ABS(X(L+1,1)))7,1,1
    7 IJJ=L+1
      Y=X(L+1,1)
    1 CONTINUE
      IF(IJJ.EQ.1) GO TO 10
      D=-D
      DO 9 J=1,JJ
      Y=X(1,J)
      X(1,J)=X(IJJ,J)
    9 X(IJJ,J)=Y
   10 JJ=JJ-1
      D=D*X(1,1)
      IF(X(1,1).EQ.0.)GO TO 8
   31 IF(ABS(ABS((X1-X(1,1))/X1)-1.).LT.1.E-7)E=2.
      X1=X(1,1)
   11 R=R+1.
      DO 12 J=1,JJ
   12 WORK(J)=X(1,J+1)/X(1,1)
      KK=JJ+1
      IF(NNN.EQ.0)GO TO 33
      DO 3 K=1,NNN
      DO 3 J=2,KK
    3 X(K,J-1)=X(K+1,J)-X(K+1,1)*WORK(J-1)
   33 DO 5 J=1,JJ
    5 X(N,J)=WORK(J)
      IF(IIC .NE. 0)GO TO 13
      NN=N-1
      IF(NN.EQ.0)GO TO 13
      DO 22 I=1,NN
      L=I+1
      DO 22 J=L,N
      IF(IHLD(I)-IHLD(J))22,22,23
   23 IY=IHLD(I)
      IHLD(I)=IHLD(J)
      IHLD(J)=IY
```

```
      DO 25 K=1,NB
      Y=X(I,K)
      X(I,K)=X(J,K)
   25 X(J,K)=Y
   22 CONTINUE
   13 RETURN
    8 E=1.
      RETURN
      END
```

APPENDIX B

SAMPLE RUNS

Several complete sample runs are presented in this Appendix in order to furnish examples of the output which results when this program is run on a stand-alone basis. The plant used for the examples is a simplified autopilot loop described by aerodynamic transfer function and compensator data taken at various times along a nominal trajectory (see Reference 7). For each case, the NAMELIST input section, the $\underline{X}_m$ matrix (before and after inversion), output data as listed in Table 3, and line printer plots showing output Y and disturbance state estimates $\hat{z}_1$, $\hat{z}_2$ are given.

The disturbances used in each run are as follows:

(a) Run 1: $w(t) = 1.$

(b) Run 2: $w(t) = 1. + 0.5t$

(c) Run 3: $w(t) = 1.5 + 0.5e^{.25t}$

For runs (a) and (b), where the disturbance is of the form $w(t) = C_o + C_1 t$, the disturbance is modeled as

$$\underline{w} = \underline{H}\,\underline{z} = (1,\ 0)\begin{pmatrix} z_1 \\ z_2 \end{pmatrix}$$

$$\dot{\underline{z}} = \underline{D}\,\underline{z} + \underline{\sigma} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} + \underline{\sigma}.$$

For run (c), the disturbance is of the form $w(t) = Co + c_1 e^{\alpha t}$ and is modeled as

$$\underline{w} = (1,\ 0)\begin{pmatrix} z_1 \\ z_2 \end{pmatrix}$$

$$\dot{\underline{z}} = \begin{bmatrix} 0 & 1 \\ 0 & \alpha \end{bmatrix}\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} + \underline{\sigma}.$$

RUN 1

```
*******************************************************************************************

$INP      RUN #1, INPUT

A         = .2E+02, .144E+02, -.1712E+04, -.856E+04, .1325916E+02, .5066242E+02,  .6554036E+02, .271441E+02,

C         = -.78847E-02,

C0        = .1E+01,

C1        = 0.0,

D         = 0.0, 0.0, .1E+01, 0.0,

M         = .1E+01, 0.0,

LM        = (-.3E+01,0.0), (-.4E+01,0.0), (-.7E+01,.2E+01), (-.7E+01,.2E+01),     (-.8E+01,0.0),
            (-.1E+02,0.0),

NPPT      = 128,

NUMBR     = 4,

NX        = 10,

PGO       = .1E+01,

STPSZ     = .32E+02,

TSTOP     = .1E+02,

$END
```

```
T(1)=-.320000E+02   .400000E+01   T(2)=-.250000E+02   .200000E+01   T(3)=-.180000E+02  0.
T(4)=-.140000E+02   .400000E+01   T(5)=-.700000E+01  0.

A(1)=-.390000E+02 A(2)= .613000E+03 A(3)=-.495300E+04 A(4)= .216340E+05 A(5)=-.483600E+05 A(6)= .432000E+05

AM( 1)=-.788470E-02 AM( 2)=0.          AM( 3)=-.132592E+02 AM( 4)=0.          AM( 5)= .157694E+00

AM( 6)= .788470E-02 AM( 7)= .506624E+02 AM( 8)=0.          AM( 9)=0.          AM(10)= .113540E+00

AM(11)= .157694E+00 AM(12)= .655404E+02 AM(13)=0.          AM(14)=0.          AM(15)=-.134986E+02

AM(16)= .113540E+00 AM(17)= .271441E+02 AM(18)=0.          AM(19)=0.          AM(20)=-.674930E+02

AM(21)=-.134986E+02 AM(22)=0.          AM(23)=0.          AM(24)=0.          AM(25)=-.674930E+02

AM(26)=0.

R(1)=-.257408E+02 R(2)= .562338E+03 R(3)= .488746E+04 R(4)= .216069E+05 R(5)= .483600E+05 R(6)= .432000E+05

XM(1,1)= .100000E+01 XM(1,2)=0.          XM(1,3)=0.          XM(1,4)=0.          XM(1,5)=-.788470E-02 XM(1,6)=0.

XM(2,1)=0.          XM(2,2)=-.100000E+01 XM(2,3)=0.          XM(2,4)=0.          XM(2,5)= .157694E+00 XM(2,6)= .788470E-02

XM(3,1)=0.          XM(3,2)=0.          XM(3,3)=-.100000E+01 XM(3,4)=0.          XM(3,5)= .113540E+00 XM(3,6)= .157694E+00

XM(4,1)=0.          XM(4,2)=0.          XM(4,3)=0.          XM(4,4)=-.100000E+01 XM(4,5)=-.134986E+02 XM(4,6)= .113540E+00

XM(5,1)=0.          XM(5,2)=0.          XM(5,3)=0.          XM(5,4)=0.          XM(5,5)=-.674930E+02 XM(5,6)=-.134986E+02

XM(6,1)=0.          XM(6,2)=0.          XM(6,3)=0.          XM(6,4)=0.          XM(6,5)=0.          XM(6,6)=-.674930E+02

XM(1,1)= .100000E+01 XM(1,2)=0.          XM(1,3)=0.          XM(1,4)=0.          XM(1,5)=-.116822E-03 XM(1,6)= .233645E-04

XM(2,1)=0.          XM(2,2)=-.100000E+01 XM(2,3)=0.          XM(2,4)=0.          XM(2,5)=-.233645E-02 XM(2,6)= .350467E-03

XM(3,1)=0.          XM(3,2)=0.          XM(3,3)=-.100000E+01 XM(3,4)=0.          XM(3,5)=-.168224E-02 XM(3,6)=-.200000E-02

XM(4,1)=0.          XM(4,2)=0.          XM(4,3)=0.          XM(4,4)=-.100000E+01 XM(4,5)= .200000E+00 XM(4,6)=-.416822E-01

XM(5,1)=0.          XM(5,2)=0.          XM(5,3)=0.          XM(5,4)=0.          XM(5,5)=-.148163E-01 XM(5,6)= .296327E-02

XM(6,1)=0.          XM(6,2)=0.          XM(6,3)=0.          XM(6,4)=0.          XM(6,5)=0.          XM(6,6)=-.148163E-01


   DET= -.4555309E+04    RA=  .6000000E+01    E= 0.

K(1)=-.303810E+02 K(2)=-.660188E+03 K(3)=-.505521E+04 K(4)=-.137355E+05 K(5)=-.588505E+03 K(6)=-.640066E+03

   TIME = 0.          XD1  = 0.          XD2  = 0.          XD3  = 0.          XD4  = 0.
   X1   = 0.          X2   = 0.          X3   = 0.          X4   = 0.          XDH1 = 0.
   XDH2 = 0.          XDH3 = 0.          XDH4 = 0.          ZDH1 = 0.          ZDH2 = 0.
   XH1  = 0.          XH2  = 0.          XH3  = 0.          XH4  = 0.          ZH1  = 0.
   ZH2  = 0.          PGO  =  .1000000E+01  W  = 0.          UDA  = 0.          Y    = 0.
```

```
TIME =  .1000000E+01   XD1  =  .6079224E+00   XD2  =  .6632977E+01   XD3  =  .1400536E+02   XD4  = -.1375049E+02
X1   =  .6423598E+00   X2   =  .9022833E+01   X3   =  .3874161E+02   X4   =  .5483239E+02   XDH1 =  .4965632E+00
XDH2 =  .4795033E+01   XDH3 =  .9727668E+00   XDH4 = -.4847177E+02   ZDH1 = -.1659993E+01   ZDH2 = -.2596457E+01
XH1  =  .6454718E+00   XH2  =  .9193399E+01   XH3  =  .3993056E+02   XH4  =  .5813855E+02   ZH1  =  .1288801E+01
ZH2  =  .6980323E+00   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1315429E+01   Y    =  .6402085E+00


TIME =  .2000000E+01   XD1  = -.1412598E+00   XD2  = -.1887715E+01   XD3  = -.7617743E+01   XD4  = -.8006926E+01
X1   =  .7642982E+00   X2   =  .1002667E+02   X3   =  .3687482E+02   X4   =  .3995333E+02   XDH1 = -.1205505E+00
XDH2 = -.1617378E+01   XDH3 = -.5666908E+01   XDH4 = -.2863760E+01   ZDH1 =  .1687666E+00   ZDH2 =  .9170375E-01
XH1  =  .7651376E+00   XH2  =  .1003512E+02   XH3  =  .3701793E+02   XH4  =  .4057109E+02   ZH1  =  .1051940E+01
ZH2  =  .9058734E-01   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1046360E+01   Y    =  .7631598E+00


TIME =  .3000000E+01   XD1  = -.2470653E-01   XD2  = -.1539012E+00   XD3  =  .9330406E+00   XD4  =  .4756761E+01
X1   =  .6632571E+00   X2   =  .8791909E+01   X3   =  .3337036E+02   X4   =  .3971393E+02   XDH1 = -.1967491E-01
XDH2 = -.5712742E-01   XDH3 =  .1546517E+01   XDH4 =  .6260982E+01   ZDH1 =  .5932165E-01   ZDH2 =  .6106235E-01
XH1  =  .6633364E+00   XH2  =  .8791295E+01   XH3  =  .3339693E+02   XH4  =  .3981397E+02   ZH1  =  .1004019E+01
ZH2  =  .4603071E-02   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1002723E+01   Y    =  .6606956E+00


TIME =  .4000000E+01   XD1  =  .5884867E-01   XD2  =  .7250972E+00   XD3  =  .2454174E+01   XD4  =  .1843567E+01
X1   =  .6960306E+00   X2   =  .9293857E+01   X3   =  .3586016E+02   X4   =  .4373116E+02   XDH1 =  .4908556E-01
XDH2 =  .5759456E+00   XDH3 =  .1378225E+01   XDH4 = -.1069909E+01   ZDH1 = -.1260938E+00   ZDH2 = -.1385628E+00
XH1  =  .6959843E+00   XH2  =  .9299099E+01   XH3  =  .3587676E+02   XH4  =  .4373348E+02   ZH1  =  .9988082E+00
ZH2  = -.1363391E-02   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1001237E+01   Y    =  .6934624E+00


TIME =  .5000000E+01   XD1  =  .6638800E-02   XD2  =  .3952231E-01   XD3  = -.2678063E+00   XD4  = -.1282243E+01
X1   =  .7289146E+00   X2   =  .9684745E+01   X3   =  .3688508E+02   X4   =  .4366933E+02   XDH1 =  .5234748E-02
XDH2 =  .1189737E-01   XDH3 = -.4448506E+00   XDH4 = -.1725676E+01   ZDH1 = -.1867377E-01   ZDH2 = -.2062317E-01
XH1  =  .7289162E+00   XH2  =  .9685282E+01   XH3  =  .3688128E+02   XH4  =  .4365440E+02   ZH1  =  .9997393E+00
ZH2  =  .8586540E-04   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1000091E+01   Y    =  .7267356E+00


TIME =  .6000000E+01   XD1  = -.1532339E-01   XD2  = -.1880282E+00   XD3  = -.6285549E+00   XD4  = -.4487033E+00
X1   =  .7201474E+00   X2   =  .9550771E+01   X3   =  .3622589E+02   X4   =  .4262903E+02   XDH1 = -.1277760E-01
XDH2 = -.1490362E+00   XDH3 = -.3477320E+00   XDH4 =  .3106168E+00   ZDH1 =  .3282118E-01   ZDH2 =  .3601964E-01
XH1  =  .7201550E+00   XH2  =  .9549421E+01   XH3  =  .3622180E+02   XH4  =  .4262920E+02   ZH1  =  .1000341E+01
ZH2  =  .4000739E-03   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .9997073E+00   Y    =  .7179584E+00


TIME =  .7000000E+01   XD1  = -.1372468E-02   XD2  = -.5982773E-02   XD3  =  .8355972E-01   XD4  =  .3422791E+00
X1   =  .7118403E+00   X2   =  .9452724E+01   X3   =  .3597556E+02   X4   =  .4266852E+02   XDH1 = -.1066562E-02
XDH2 =  .2864169E-03   XDH3 =  .1230360E+00   XDH4 =  .4399188E+00   ZDH1 =  .4089254E-02   ZDH2 =  .4568886E-02
XH1  =  .7118422E+00   XH2  =  .9452616E+01   XH3  =  .3597664E+02   XH4  =  .4267241E+02   ZH1  =  .1000062E+01
ZH2  = -.2737033E-04   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .9999849E+00   Y    =  .7095557E+00


TIME =  .8000000E+01   XD1  =  .4001100E-02   XD2  =  .4885060E-01   XD3  =  .1609761E+00   XD4  =  .1085754E+00
X1   =  .7143004E+00   X2   =  .9489646E+01   X3   =  .3615198E+02   X4   =  .4293716E+02   XDH1 =  .3334501E-02
XDH2 =  .3860712E-01   XDH3 =  .8732892E-01   XDH4 = -.9035699E-01   ZDH1 = -.8596019E-02   ZDH2 = -.9436067E-02
XH1  =  .7142971E+00   XH2  =  .9489998E+01   XH3  =  .3615342E+02   XH4  =  .4293703E+02   ZH1  =  .9999165E+00
ZH2  = -.1025433E-03   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1000076E+01   Y    =  .7120193E+00
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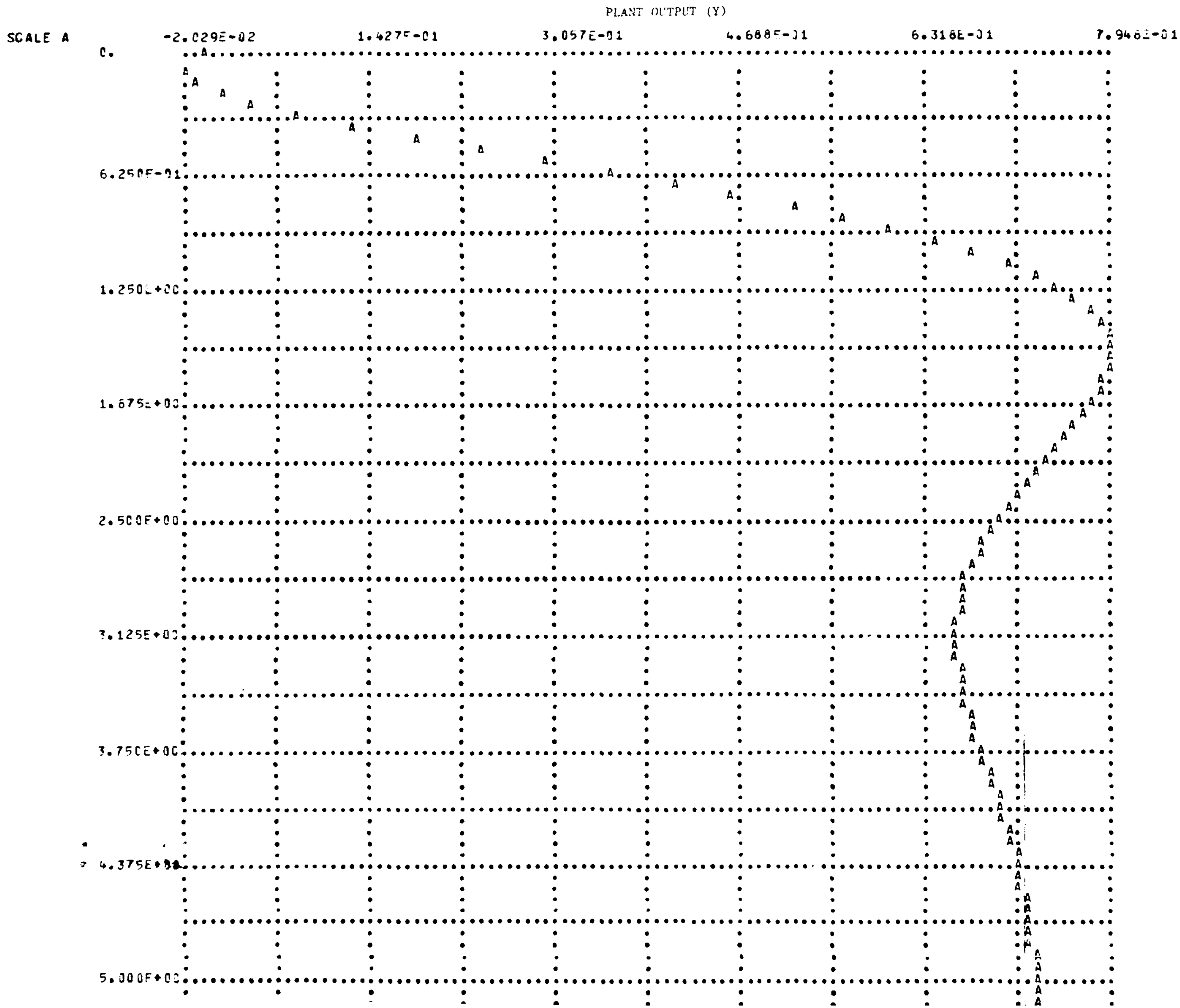
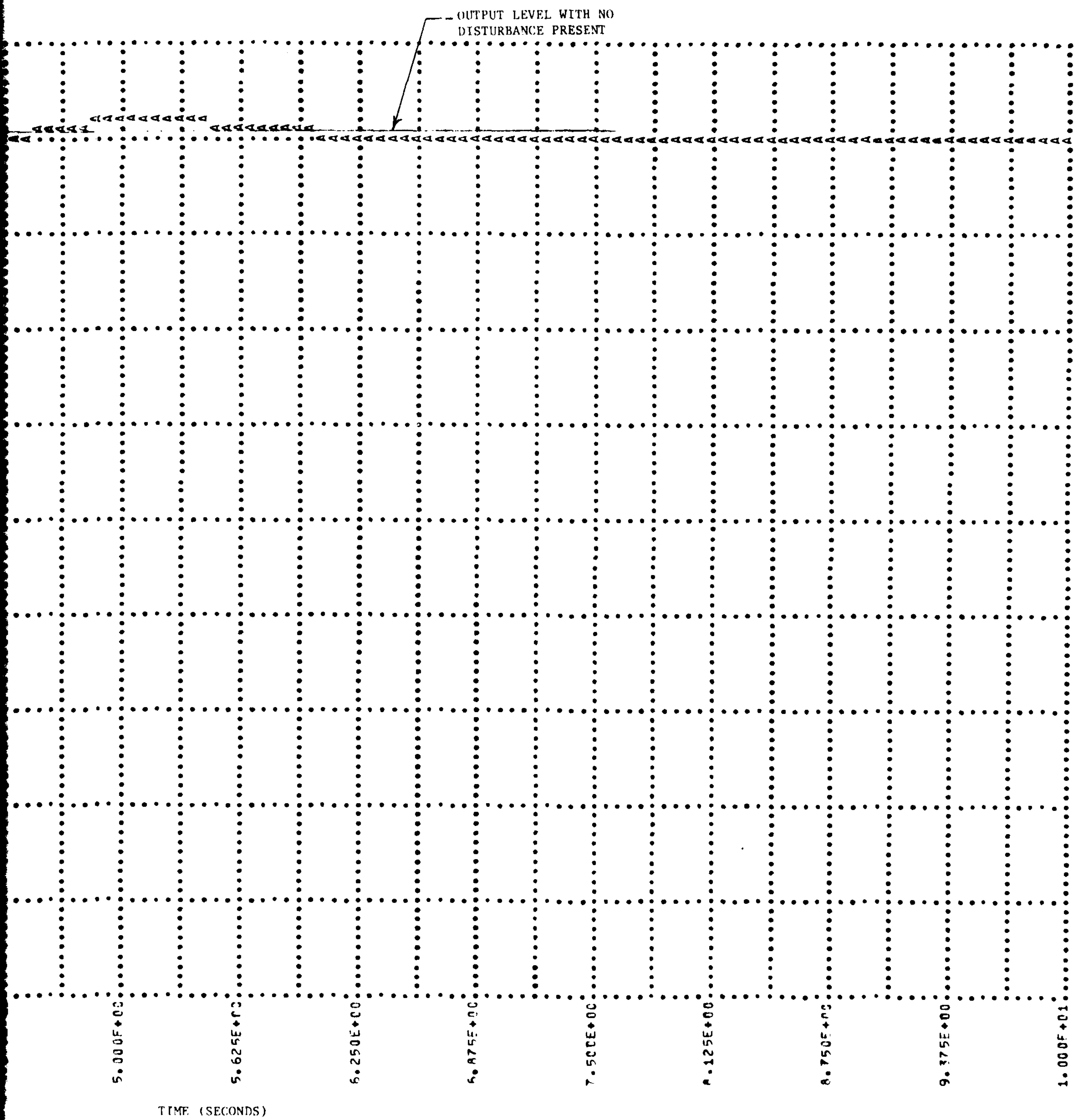
TIME =  .9000000E+01   XD1  =  .2659585E-03   XD2  =  .4558970E-03   XD3  = -.2525314E-01   XD4  = -.9110542E-01
X1   =  .7163962E+00   X2   =  .9514221E+01   X3   =  .3621288E+02   X4   =  .4292091E+02   XDH1 =  .2016352E-03
XDH2 = -.9388876E-03   XDH3 = -.3383116E-01   XDH4 = -.1119466E+00   ZDH1 = -.8669565E-03   ZDH2 = -.9724571E-03
XH1  =  .7163958E+00   XH2  =  .9514241E+01   XH3  =  .3621258E+02   XH4  =  .4291991E+02   ZH1  =  .9999861E+00
ZH2  =  .9437232E-05   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .1000002E+01   Y    =  .7141412E+00


TIME =  .1000000E+02   XD1  = -.1042501E-02   XD2  = -.1266567E-01   XD3  = -.4113742E-01   XD4  = -.2606685E-01
X1   =  .7157120E+00   X2   =  .9504105E+01   X3   =  .3616582E+02   X4   =  .4285168E+02   XDH1 = -.8603683E-03
XDH2 = -.9980703E-02   XDH3 = -.2186590E-01   XDH4 =  .2591632E-01   ZDH1 =  .2246341E-02   ZDH2 =  .2466327E-02
XH1  =  .7157128E+00   XH2  =  .9504014E+01   XH3  =  .3616555E+02   XH4  =  .4285174E+02   ZH1  =  .1000024E+01
ZH2  =  .2635707E-04   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .9999802E+00   Y    =  .7134554E+00

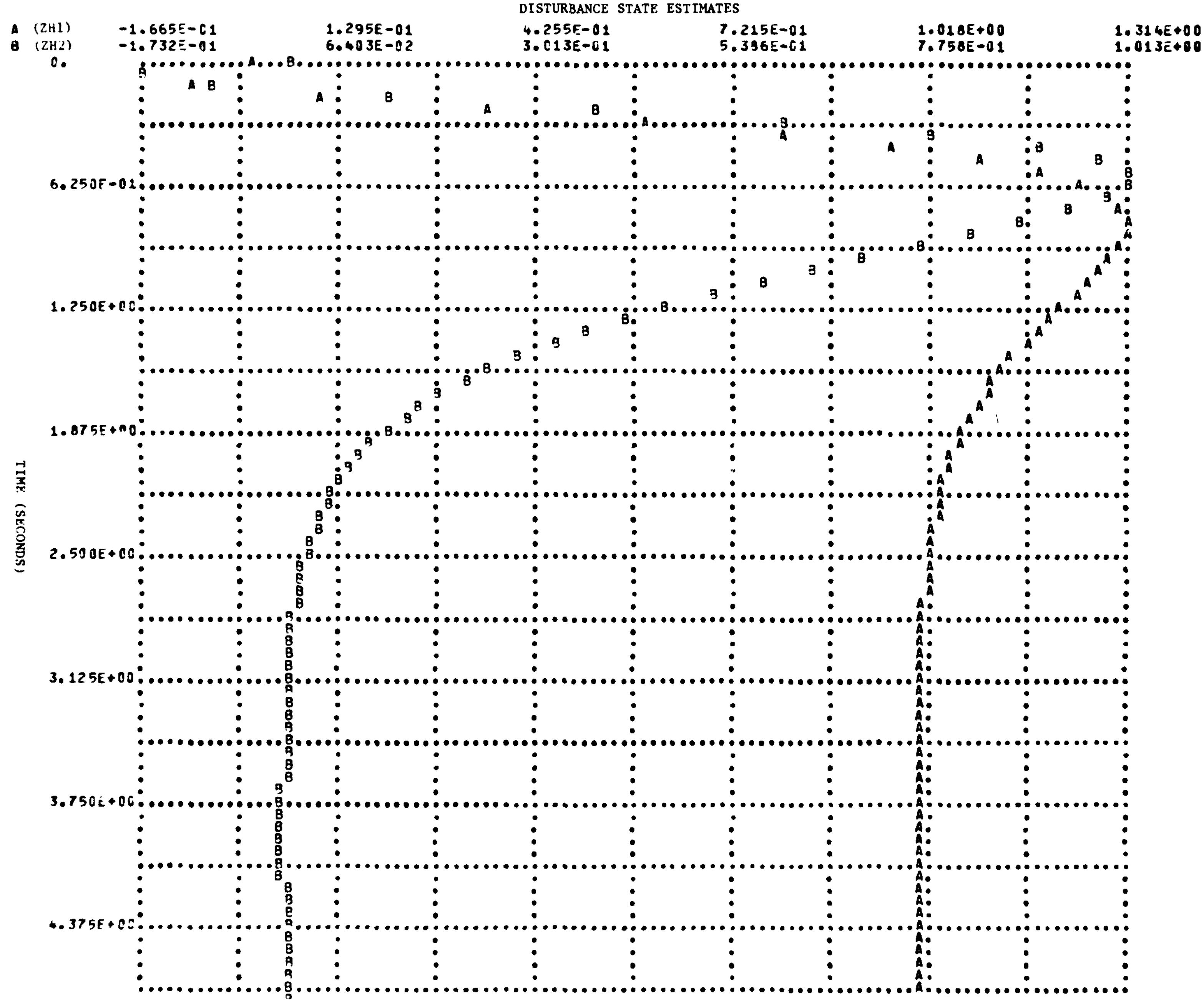

TIME =  .1000000E+02   XD1  = -.1042501E-02   XD2  = -.1266567E-01   XD3  = -.4113742E-01   XD4  = -.2606685E-01
X1   =  .7157120E+00   X2   =  .9504105E+01   X3   =  .3616582E+02   X4   =  .4285168E+02   XDH1 = -.8603683E-03
XDH2 = -.9980703E-02   XDH3 = -.2186590E-01   XDH4 =  .2591632E-01   ZDH1 =  .2246341E-02   ZDH2 =  .2466327E-02
XH1  =  .7157128E+00   XH2  =  .9504014E+01   XH3  =  .3616555E+02   XH4  =  .4285174E+02   ZH1  =  .1000024E+01
ZH2  =  .2635707E-04   PGO  =  .1000000E+01   W    =  .1000000E+01   UDA  =  .9999802E+00   Y    =  .7134554E+00
```

CURVE Y1 DENOTED BY A   MIN=-2.029E-02 MAX= 7.948E-01




OUTPUT LEVEL WITH NO DISTURBANCE PRESENT
5.000E+00
5.625E+00
6.250E+00
6.875E+00
7.500E+00
8.125E+00
8.750E+00
9.375E+00
1.000E+01
TIME (SECONDS)

CURVE Y1 DENOTED BY A   MIN=-1.665E-01 MAX= 1.314E+00
CURVE Y2 DENOTED BY B   MIN=-1.732E-01 MAX= 1.013E+00



RUN 2

```
-----------------------------------------------------------------------------------------

$INP    RUN #1, INPUT

B       = .2E+02, -.44E+03, -.108E+05, -.54E+05, .176816E+02, .2437748E+03,     .4385048E+03, .2114116E+03,

C       = -.3328E-01,

C0      = .1E+01,

C1      = .5E+00,

D       = 0.0, 0.0, .1E+01, 0.0,

H       = .1E+01, 0.0,

LM      = (-.5E+01,0.0), (-.6E+01,0.0), (-.1E+02,0.0), (-.1E+02,0.0),          (-.12E+02,0.0),
          (-.15E+02,0.0),

NPRT    = 128,

NUMBP   = 4,

NX      = 10,

PGO     = .1E+01,

STPSZ   = .32E+02,

TSTOP   = .1E+02,

$END
```

```
T(1)=-.470000E+02  0.          T(2)=-.370000E+02  0.          T(3)=-.270000E+02  0.
T(4)=-.200000E+02  0.          T(5)=-.110000E+02  0.

A(1)=-.580000E+02 A(2)= .136700E+04 A(3)=-.167300E+05 A(4)= .111900E+06 A(5)=-.387000E+06 A(6)= .540000E+06

AM( 1)=-.332800E-01 AM( 2)=0.           AM( 3)=-.176816E+02 AM( 4)=0.           AM( 5)= .665600E+00

AM( 6)= .332800E-01 AM( 7)= .243775E+03 AM( 8)=0.           AM( 9)=0.           AM(10)=-.146432E+02

AM(11)= .665600E+00 AM(12)= .438505E+03 AM(13)=0.           AM(14)=0.           AM(15)=-.359424E+03

AM(16)=-.146432E+02 AM(17)= .211412E+03 AM(18)=0.           AM(19)=0.           AM(20)=-.179712E+04

AM(21)=-.359424E+03 AM(22)=0.           AM(23)=0.           AM(24)=0.           AM(25)=-.179712E+04

AM(26)=0.

R(1)=-.403184E+02 R(2)= .112323E+04 R(3)= .162915E+05 R(4)= .111689E+06 R(5)= .387000E+06 R(6)= .540000E+06

XM(1,1)= .100000E+01 XM(1,2)=0.           XM(1,3)=0.           XM(1,4)=0.           XM(1,5)=-.332800E-01 XM(1,6)=0.

XM(2,1)=0.           XM(2,2)=-.100000E+01 XM(2,3)=0.           XM(2,4)=0.           XM(2,5)= .665600E+00 XM(2,6)= .332800E-01

XM(3,1)=0.           XM(3,2)=0.           XM(3,3)=-.100000E+01 XM(3,4)=0.           XM(3,5)=-.146432E+02 XM(3,6)= .665600E+00

XM(4,1)=0.           XM(4,2)=0.           XM(4,3)=0.           XM(4,4)=-.100000E+01 XM(4,5)=-.359424E+03 XM(4,6)=-.146432E+02

XM(5,1)=0.           XM(5,2)=0.           XM(5,3)=0.           XM(5,4)=0.           XM(5,5)=-.179712E+04 XM(5,6)=-.359424E+03

XM(6,1)=0.           XM(6,2)=0.           XM(6,3)=0.           XM(6,4)=0.           XM(6,5)=0.           XM(6,6)=-.179712E+04

XM(1,1)= .100000E+01 XM(1,2)=0.           XM(1,3)=0.           XM(1,4)=0.           XM(1,5)=-.185185E-04 XM(1,6)= .370370E-05

XM(2,1)=0.           XM(2,2)=-.100000E+01 XM(2,3)=0.           XM(2,4)=0.           XM(2,5)=-.370370E-03 XM(2,6)= .555556E-04

XM(3,1)=0.           XM(3,2)=0.           XM(3,3)=-.100000E+01 XM(3,4)=0.           XM(3,5)= .814815E-02 XM(3,6)=-.200000E-02

XM(4,1)=0.           XM(4,2)=0.           XM(4,3)=0.           XM(4,4)=-.100000E+01 XM(4,5)= .200000E+00 XM(4,6)=-.318519E-01

XM(5,1)=0.           XM(5,2)=0.           XM(5,3)=0.           XM(5,4)=0.           XM(5,5)=-.556446E-03 XM(5,6)= .111289E-03

XM(6,1)=0.           XM(6,2)=0.           XM(6,3)=0.           XM(6,4)=0.           XM(6,5)=0.           XM(6,6)=-.556446E-03


   DET= -.3229640E+07    RA=  .6000000E+01    E= 0.

K(1)=-.454851E+02 K(2)=-.123656E+04 K(3)=-.142182E+05 K(4)=-.514886E+05 K(5)=-.155248E+03 K(6)=-.333481E+03

   TIME  = 0.          XD1  = 0.           XD2  = 0.          XD3  = 0.          XD4  = 0.
   X1    = 0.          X2   = 0.           X3   = 0.          X4   = 0.          XDH1 = 0.
   XDH2  = 0.          XDH3 = 0.           XDH4 = 0.          ZDH1 = 0.          ZDH2 = 0.
   XH1   = 0.          XH2  = 0.           XH3  = 0.          XH4  = 0.          ZH1  = 0.
   ZH2   = 0.          PGO  =  .1000000E+01 W   = 0.          UDA  = 0.          Y    = 0.
```

```
TIME =  .1000000E+01   XD1  = -.3110706E+00   XD2  = -.5267632E+01   XD3  = -.7779523E+02   XD4  = -.2118939E+03
X1   =  .9280659E+00   X2   =  .1616113E+02   X3   =  .2222104E+03   X4   =  .3341483E+03   XDH1 = -.2426589E+00
XDH2 = -.3576046E+01   XDH3 = -.6288625E+02   XDH4 = -.1590423E+03   ZDH1 =  .5096986E+00   ZDH2 = -.4845186E+00
XH1  =  .9344028E+00   XH2  =  .1637174E+02   XH3  =  .2247700E+03   XH4  =  .3456251E+03   ZH1  =  .1580386E+01
ZH2  =  .7699491E+00   PGO  =  .1000000E+01   W    =  .1500000E+01   UDA  =  .1575371E+01   Y    =  .9291772E+00

TIME =  .2000000E+01   XD1  =  .8492381E-01   XD2  =  .1448084E+01   XD3  =  .1975917E+02   XD4  =  .4830117E+02
X1   =  .8793473E+00   X2   =  .1562612E+02   X3   =  .2126739E+03   X4   =  .3578829E+03   XDH1 =  .6172443E-01
XDH2 =  .7923703E+00   XDH3 =  .1323198E+02   XDH4 =  .1687306E+02   ZDH1 =  .4266095E+00   ZDH2 = -.1430763E+00
XH1  =  .8792531E+00   XH2  =  .1563597E+02   XH3  =  .2128274E+03   XH4  =  .3581694E+03   ZH1  =  .1999117E+01
ZH2  =  .4979180E+00   PGO  =  .1000000E+01   W    =  .2000000E+01   UDA  =  .2000441E+01   Y    =  .8749466E+00

TIME =  .3000000E+01   XD1  = -.1445108E-01   XD2  = -.2625927E+00   XD3  = -.3615202E+01   XD4  = -.1116329E+02
X1   =  .9033990E+00   X2   =  .1596963E+02   X3   =  .2177414E+03   X4   =  .3553265E+03   XDH1 = -.1076838E-01
XDH2 = -.1628931E+00   XDH3 = -.2638285E+01   XDH4 = -.7438893E+01   ZDH1 =  .5113105E+00   ZDH2 =  .2116658E-01
XH1  =  .9834218E+00   XH2  =  .1596826E+02   XH3  =  .2177163E+03   XH4  =  .3552581E+03   ZH1  =  .2500237E+01
ZH2  =  .5007838E+00   PGO  =  .1000000E+01   W    =  .2500000E+01   UDA  =  .2500025E+01   Y    =  .9001156E+00

TIME =  .4000000E+01   XD1  =  .1864373E-02   XD2  =  .3601191E-01   XD3  =  .5270227E+00   XD4  =  .2468038E+01
X1   =  .8976808E+00   X2   =  .1587154E+02   X3   =  .2162947E+03   X4   =  .3540633E+03   XDH1 =  .1443179E-02
XDH2 =  .2759861E-01   XDH3 =  .4277657E+00   XDH4 =  .2051724E+01   ZDH1 =  .4986647E+00   ZDH2 = -.2417530E-02
XH1  =  .8970788E+00   XH2  =  .1587175E+02   XH3  =  .2162990E+03   XH4  =  .3540826E+03   ZH1  =  .2999978E+01
ZH2  =  .4998662E+00   PGO  =  .1000000E+01   W    =  .3000000E+01   UDA  =  .3000002E+01   Y    =  .8935334E+00

TIME =  .5000000E+01   XD1  = -.8462174E-04   XD2  = -.3143971E-02   XD3  = -.4471175E-01   XD4  = -.4645352E+00
X1   =  .8984789E+00   X2   =  .1589444E+02   X3   =  .2166317E+03   X4   =  .3546580E+03   XDH1 = -.8397436E-04
XDH2 = -.3510325E-02   XDH3 = -.4937732E-01   XDH4 = -.4675960E+00   ZDH1 =  .5000137E+00   ZDH2 =  .4261572E-05
XH1  =  .8984707E+00   XH2  =  .1589442E+02   XH3  =  .2166311E+03   XH4  =  .3546535E+03   ZH1  =  .3499998E+01
ZH2  =  .5000163E+00   PGO  =  .1000000E+01   W    =  .3500000E+01   UDA  =  .3499998E+01   Y    =  .8949756E+00

TIME =  .6000000E+01   XD1  = -.4977684E-04   XD2  = -.4631205E-03   XD3  = -.5984299E-02   XD4  =  .7121517E-01
X1   =  .8982104E+00   X2   =  .1588988E+02   X3   =  .2165648E+03   X4   =  .3544828E+03   XDH1 = -.3134612E-04
XDH2 =  .1412873E-03   XDH3 =  .2334211E-03   XDH4 =  .9087346E-01   ZDH1 =  .5000520E+00   ZDH2 =  .1056317E-03
XH1  =  .8982106E+00   XH2  =  .1588988E+02   XH3  =  .2165648E+03   XH4  =  .3544837E+03   ZH1  =  .4000002E+01
ZH2  =  .4999996E+00   PGO  =  .1000000E+01   W    =  .4000000E+01   UDA  =  .4000001E+01   Y    =  .8947065E+00

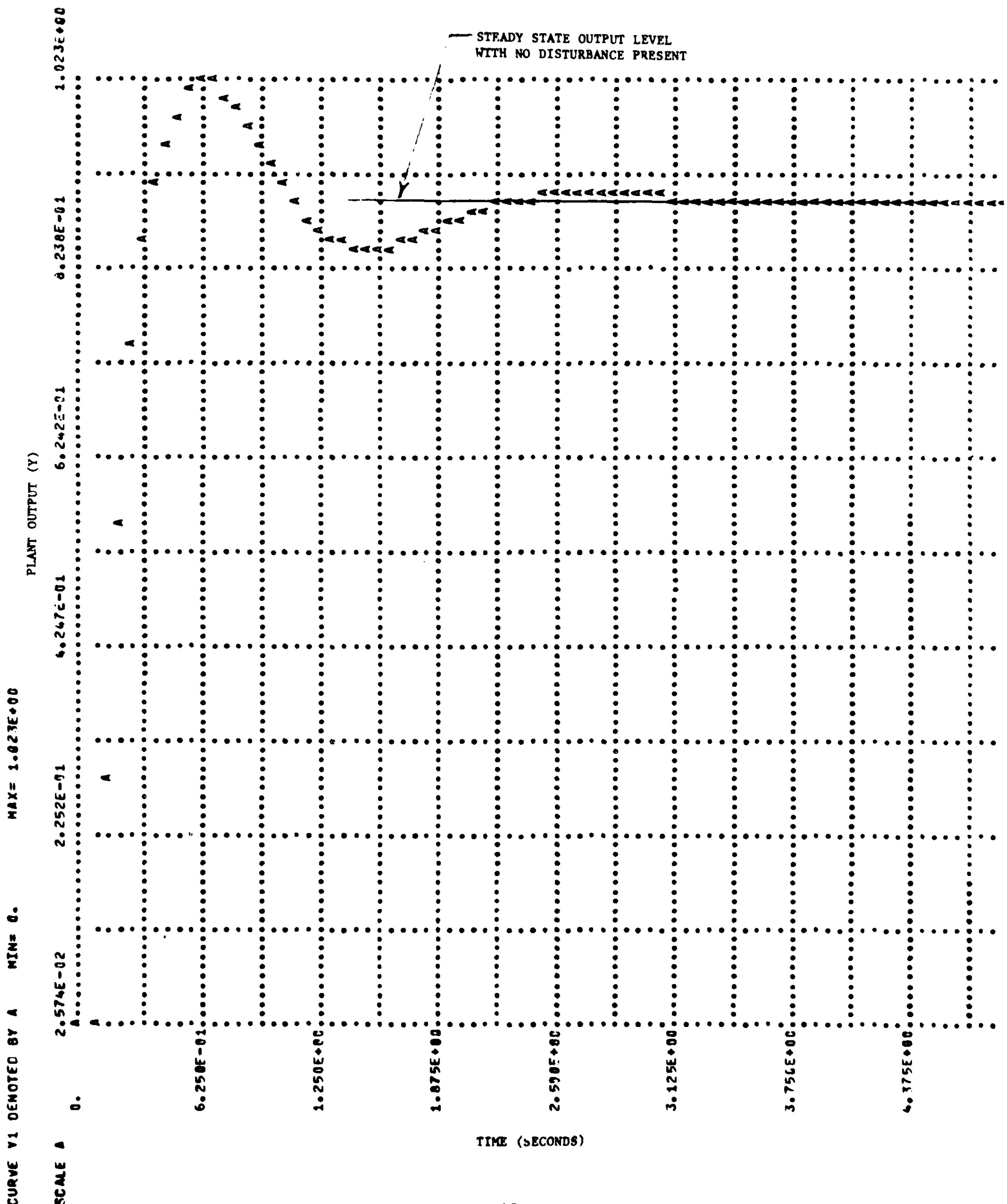
TIME =  .7000000E+01   XD1  =  .2311190E-04   XD2  =  .3195487E-03   XD3  =  .4310338E-02   XD4  = -.7894614E-02
X1   =  .8982501E+00   X2   =  .1589064E+02   X3   =  .2165758E+03   X4   =  .3545246E+03   XDH1 =  .1591521E-04
XDH2 =  .1807334E-03   XDH3 =  .2099094E-02   XDH4 = -.1460426E-01   ZDH1 =  .4999790E+00   ZDH2 = -.4127075E-04
XH1  =  .8982500E+00   XH2  =  .1589064E+02   XH3  =  .2165758E+03   XH4  =  .3545244E+03   ZH1  =  .4499999E+01
ZH2  =  .4999994E+00   PGO  =  .1000000E+01   W    =  .4500000E+01   UDA  =  .4500000E+01   Y    =  .8947472E+00

TIME =  .8000000E+01   XD1  = -.6780962E-05   XD2  = -.1037378E-03   XD3  = -.1410950E-02   XD4  = -.3991723E-03
X1   =  .8982462E+00   X2   =  .1589055E+02   X3   =  .2165745E+03   X4   =  .3545161E+03   XDH1 = -.4799465E-05
XDH2 = -.4544274E-04   XDH3 = -.8267198E-03   XDH4 =  .1649596E-02   ZDH1 =  .5000059E+00   ZDH2 =  .1136604E-04
XH1  =  .8982462E+00   XH2  =  .1589055E+02   XH3  =  .2165745E+03   XH4  =  .3545161E+03   ZH1  =  .5000000E+01
ZH2  =  .5000002E+00   PGO  =  .1000000E+01   W    =  .5000000E+01   UDA  =  .5000000E+01   Y    =  .8947433E+00
```

```
TIME = .9000000E+01   XD1  = .1612208E-05   XD2  = .2617325E-04   XD3  = .3575768E-03   XD4  = .4699875E-03
X1   = .8982460E+00   X2   = .1589055E+02   X3   = .2165745E+03   X4   = .3545175E+03   XDH1 = .1160746E-05
XDH2 = .1320583E-04   XDH3 = .2284290E-03   XDH4 = .6141907E-05   ZDH1 = .4999986E+00   ZDH2 = -.2590074E-05
XH1  = .8982460E+00   XH2  = .1589055E+02   XH3  = .2165745E+03   XH4  = .3545175E+03   ZH1  = .5500000E+01
ZH2  = .4999999E+00   PGO  = .1000000E+01   W    = .5500000E+01   UDA  = .5500000E+01   Y    = .8947430E+00

TIME = .1000000E+02   XD1  = -.3262775E-06  XD2  = -.5578414E-05  XD3  = -.7649155E-04  XD4  = -.1650428E-03
X1   = .8982462E+00   X2   = .1589055E+02   X3   = .2165746E+03   X4   = .3545174E+03   XDH1 = -.2385754E-06
XDH2 = -.3120550E-05  XDH3 = -.5217440E-04  XDH4 = -.7554712E-04  ZDH1 = .5000003E+00   ZDH2 = .5032409E-06
XH1  = .8982462E+00   XH2  = .1589055E+02   XH3  = .2165746E+03   XH4  = .3545174E+03   ZH1  = .6000000E+01
ZH2  = .5000000E+00   PGO  = .1000000E+01   W    = .6000000E+01   UDA  = .6000000E+01   Y    = .8947433E+00

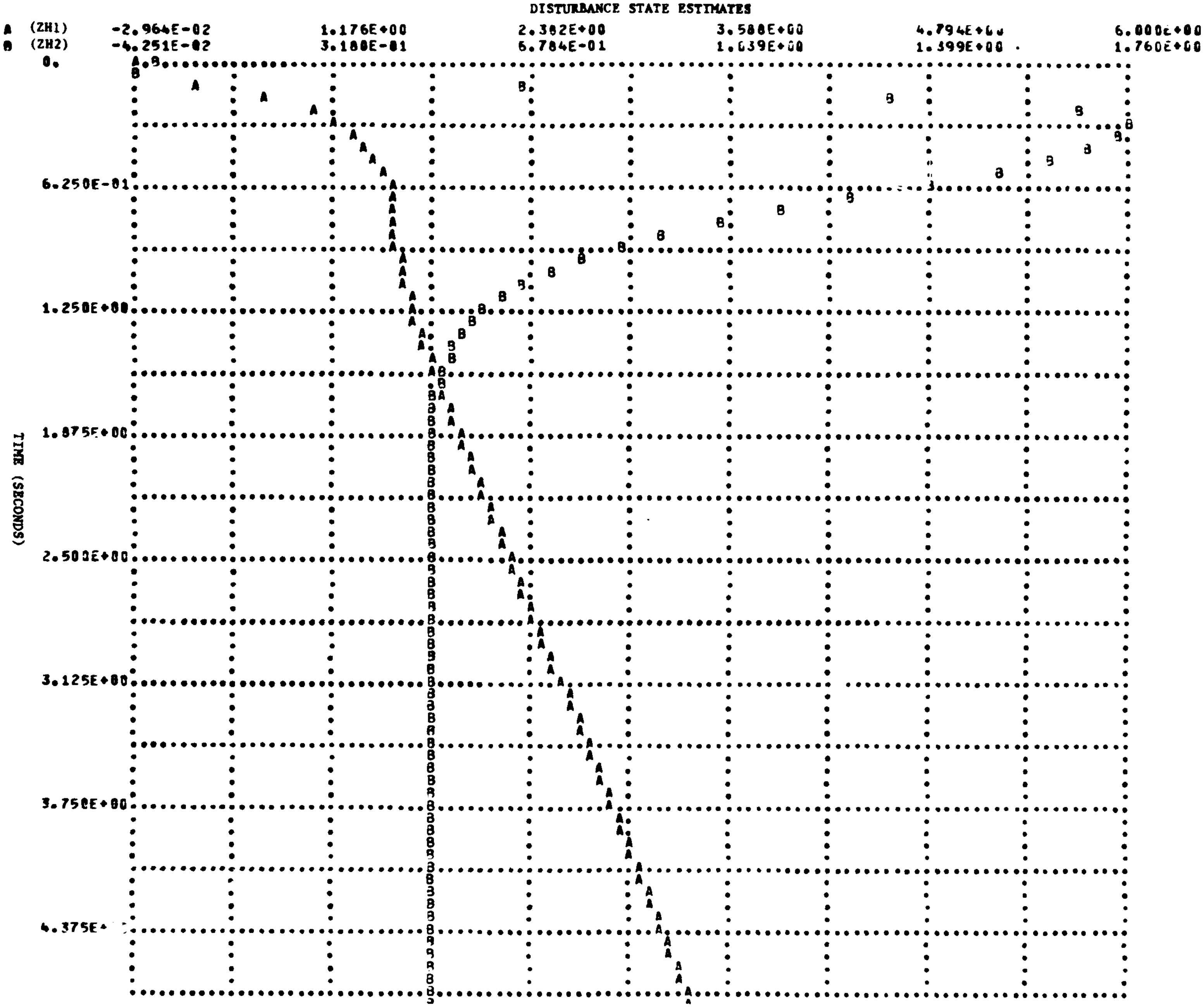
TIME = .1000000E+02   XD1  = -.3262775E-06  XD2  = -.5578414E-05  XD3  = -.7649155E-04  XD4  = -.1650428E-03
X1   = .8982462E+00   X2   = .1589055E+02   X3   = .2165746E+03   X4   = .3545174E+03   XDH1 = -.2385754E-06
XDH2 = -.3120550E-05  XDH3 = -.5217440E-04  XDH4 = -.7554712E-04  ZDH1 = .5000003E+00   ZDH2 = .5032409E-06
XH1  = .8982462E+00   XH2  = .1589055E+02   XH3  = .2165746E+03   XH4  = .3545174E+03   ZH1  = .6000000E+01
ZH2  = .5000000E+00   PGO  = .1000000E+01   W    = .6000000E+01   UDA  = .6000000E+01   Y    = .8947433E+00
```



STEADY STATE OUTPUT LEVEL
WITH NO DISTURBANCE PRESENT
CURVE V1 DENOTED BY A MIN= 0. MAX= 1.023E+00
SCALE A 0. 2.574E-02 2.252E-01 4.247E-01 6.242E-01 8.238E-01 1.023E+00
PLANT OUTPUT (Y)
6.250E-01
1.250E+00
1.875E+00
2.500E+00
3.125E+00
3.750E+00
4.375E+00
TIME (SECONDS)

CURVE Y1 DENOTED BY A   MIN=-2.964E-02   MAX= 6.000E+00
CURVE Y2 DENOTED BY B   MIN=-4.251E-02   MAX= 1.760E+00

SCALE A (ZH1)
SCALE B (ZH2)



RUN 3

```
$INP
ALP    = .25E+00,
F      = .2E+02, -.44E+07, -.108E+05, -.54E+05, .176P16E+02, .243774FE+03,     .4385048E+03, .2114111E+03,
FET    = .1E+01,
C      = -.3328E-01,
C0     = .15E+01,
C1     = .5F+00,
D      = 0.0, 0.0, .1E+01, .25E+00,
F      = .1E+01, 0.0,
LP     = (-.5F+01,0.0), (-.5E+01,0.0), (-.7F+01,.1E+02), (-.7E+01,-.1E+02),     (-.15E+02,0.0),
         (-.15E+02,0.0),
NFRT   = 16,
NUMBR  = 8,
NX     = 10,
PGO    = .1E+01,
STPSZ  = .32E+02,
TSTOP  = .2E+02,
$END
```

```
T(1)=-.440000E+02  0.          T(2)=-.370000E+02  -.100000E+02    T(3)=-.300000E+02  0.
T(4)=-.140000E+02  0.          T(5)=-.100000E+02  0.

A(1)=-.540000E+02 A(2)= .125900E+04 A(3)=-.166600E+05 A(4)= .129575E+06 A(5)=-.525750E+06 A(6)= .938125E+06

AM( 1)=-.332800E-01 AM( 2)=0.                 AM( 3)=-.174316E+02 AM( 4)= .250000E+00 AM( 5)= .657280E+00
AM( 6)= .332800E-01 AM( 7)= .239354E+03 AM( 8)=0.                 AM( 9)= .250000E+00 AM(10)=-.148096E+02
AM(11)= .665600E+00 AM(12)= .377561E+03 AM(13)=0.                 AM(14)= .250000E+00 AM(15)=-.355763E+03
AM(16)=-.146432E+02 AM(17)= .101785E+03 AM(18)=0.                 AM(19)= .250000E+00 AM(20)=-.170726E+04
AM(21)=-.359424E+03 AM(22)=-.528529E+02 AM(23)=0.                 AM(24)= .449280E+03 AM(25)=-.179712E+04
AM(26)=0.

R(1)=-.365684E+02 R(2)= .101565E+04 R(3)= .162824E+05 R(4)= .129473E+06 R(5)= .525503E+06 R(6)= .938125E+06

XM(1,1)= .100000E+01 XM(1,2)=0.            XM(1,3)=0.            XM(1,4)=0.            XM(1,5)=-.332800E-01 XM(1,6)=0.
XM(2,1)= .250000E+00 XM(2,2)=-.100000E+01 XM(2,3)=0.            XM(2,4)=0.            XM(2,5)= .657280E+00 XM(2,6)= .332800E-01
XM(3,1)=0.           XM(3,2)= .250000E+00 XM(3,3)=-.100000E+01 XM(3,4)=0.            XM(3,5)=-.148096E+02 XM(3,6)= .665600E+00
XM(4,1)=0.           XM(4,2)=0.            XM(4,3)= .250000E+00 XM(4,4)=-.100000E+01 XM(4,5)=-.355763E+03 XM(4,6)=-.146432E+02
XM(5,1)=0.           XM(5,2)=0.            XM(5,3)=0.            XM(5,4)= .250000E+00 XM(5,5)=-.170726E+04 XM(5,6)=-.359424E+03
XM(6,1)=0.           XM(6,2)=0.            XM(6,3)=0.            XM(6,4)=0.            XM(6,5)= .449280E+03 XM(6,6)=-.179712E+04
XM(1,1)= .100000E+01 XM(1,2)=-.275441E-06 XM(1,3)=-.110176E-05 XM(1,4)=-.440706E-05 XM(1,5)=-.176282E-04 XM(1,6)= .356114E-05
XM(2,1)= .250001E+00 XM(2,2)=-.100001E+01 XM(2,3)=-.223107E-04 XM(2,4)=-.892429E-04 XM(2,5)=-.356972E-03 XM(2,6)= .535946E-04
XM(3,1)= .624701E-01 XM(3,2)=-.245880E+00 XM(3,3)=-.959521E+00 XM(3,4)= .191679E-02 XM(3,5)= .766718E-02 XM(3,6)=-.152387E-02
XM(4,1)= .148738E-01 XM(4,2)=-.594953E-01 XM(4,3)=-.237981E+00 XM(4,4)=-.951925E+00 XM(4,5)= .152302E+00 XM(4,6)=-.307532E-01
XM(5,1)= .206912E-05 XM(5,2)=-.827648E-05 XM(5,3)=-.331059E-04 XM(5,4)=-.132424E-03 XM(5,5)=-.529694E-03 XM(5,6)= .107005E-03
XM(6,1)= .517280E-06 XM(6,2)=-.206912E-05 XM(6,3)=-.827648E-05 XM(6,4)=-.331059E-04 XM(6,5)=-.132424E-03 XM(6,6)=-.529694E-03

   DET= -.3392748E+07   RA= .6000000E+01   E= 0.

K(1)=-.434415E+02 K(2)=-.118349E+04 K(3)=-.138646E+05 K(4)=-.518806E+05 K(5)=-.285524E+03 K(6)=-.518002E+03

  TIME = 0.            XD1  = -.1996800E+01    XC2  =  .4392960E+02    XC3  =  .1078272E+04    XD4  =  .5391360E+04
  X1   = 0.            X2   = 0.               X3   = 0.               X4   = 0.               XDH1 = -.2968623E+01
  XDH2 = -.5601700E+02 XDH3 = -.5488076E+03    XDH4 = -.1649016E+04    ZDH1 = -.1374622E+02    ZDH2 = -.3447922E+02
  XH1  = 0.            XH2  = 0.               XH3  = 0.               XH4  = 0.               ZH1  = 0.
  ZH2  = 0.            PGO  =  .1000000E+01    W    =  .2000000E+01    UCA  = 0.               Y    = -.9984000E-01
```

```
TIME = .5000000E+00   XD1  =  .2653474E-01   XD2  =  .2167915E+01   XD3  = -.6556425E+02   XD4  = -.7163552E+03
X1   = .6437130E+00   X2   =  .1497192E+02   X3   =  .2147779E+03   X4   =  .4157082E+03   XDH1 =  .1162827E-01
XDH2 = .2661311E+ 1   XDH3 = -.5032006E+02   XDH4 = -.6164437E+03   ZDH1 = -.6246437E-01   ZDH2 = -.6359366E+01
XH1  = .6720937E+00   XH2  =  .1603361E+02   XH3  =  .2260339E+03   XH4  =  .4661151E+03   ZH1  =  .2510634E+01
ZH2  = .2746733E+01   FCC  =  .1000000E+01        =  .2066574E+01   UDA  =  .2510634E+01   Y    =  .8536357E+00

TIME = .1000000E+01   XD1  =  .3697638E-01   XD2  =  .1000960E+01   XD3  =  .1120186E+02   XD4  =  .1073415E+03
X1   = .7830443E+00   X2   =  .1369349E+02   X3   =  .1984369E+03   X4   =  .2979649E+03   XDH1 =  .2502802E-01
XDH2 = .4690739E+00   XDH3 =  .4334606E+01   XDH4 =  .7794809E+02   ZDH1 = -.1170431E+00   ZDH2 = -.1431068E+01
XH1  = .7884055E+00   XH2  =  .1411300E+02   XH3  =  .1511874E+03   XH4  =  .3086968E+03   ZH1  =  .2212788E+01
ZH2  = .5037211E+00   FCC  =  .1000000E+01   W    =  .2140013E+01   UDA  =  .2212788E+01   Y    =  .7780107E+00

TIME = .1500000E+01   XD1  =  .1572756E+00   XD2  =  .2085162E+01   XD3  =  .4225432E+02   XD4  =  .8133302E+02
X1   = .8553521E+00   X2   =  .1528477E+02   X3   =  .2077866E+03   X4   =  .3628092E+03   XDH1 =  .1782951E+00
XDH2 = .2978146E+01   XDH3 =  .4275185E+02   XDH4 =  .9104094E+02   ZDH1 =  .1767643E+00   ZDH2 = -.3254230E-01
XH1  = .8556717E+00   XH2  =  .1532665E+02   XH3  =  .2083525E+03   XH4  =  .3641771E+03   ZH1  =  .2232154E+01
ZH2  = .2107443E+00   FCC  =  .1000000E+01   W    =  .2227496E+01   UDA  =  .2232154E+01   Y    =  .8505178E+00

TIME = .2000000E+01   XD1  =  .7598750E-01   XD2  =  .4228396E+00   XD3  =  .6521887E+01   XD4  = -.2647126E+02
X1   = .9111736E+00   X2   =  .1615180E+02   X3   =  .2204168E+03   X4   =  .3719778E+03   XDH1 =  .4132667E-01
XDH2 = .4838473E+00   XDH3 =  .7005097E+01   XDH4 = -.2518115E+02   ZDH1 =  .2155716E+00   ZDH2 =  .6670283E-01
XH1  = .5111440E+00   XH2  =  .1615772E+02   XH3  =  .2204713E+03   XH4  =  .3717478E+03   ZH1  =  .2324298E+01
ZH2  = .2059895E+00   FCC  =  .1000000E+01   W    =  .2324361E+01   UDA  =  .2324298E+01   Y    =  .5081050E+00

TIME = .2500000E+01   XD1  = -.2473296E-01   XD2  = -.4555841E+00   XD3  = -.7309142E+01   XD4  = -.2368020E+02
X1   = .9090565E+00   X2   =  .1605719E+02   X3   =  .2190356E+03   X4   =  .3564092E+03   XDH1 = -.2857676E-01
XDH2 = -.5321597E+00  XDH3 = -.7587465E+01   XDH4 = -.2437010E+02   ZDH1 =  .2287046E+00   ZDH2 =  .4151143E-01
XH1  = .9051095E+00   XH2  =  .1605465E+02   XH3  =  .2189865E+03   XH4  =  .3562741E+03   ZH1  =  .2434705E+01
ZH2  = .2356415E+00   FCC  =  .1000000E+01   W    =  .2434123E+01   UDA  =  .2434705E+01   Y    =  .5059484E+00

TIME = .3000000E+01   XD1  = -.1168570E-01   XD2  = -.1670953E+00   XD3  = -.2714218E+01   XD4  =  .9961256E+00
X1   = .8974926E+00   X2   =  .1586625E+02   X3   =  .2162224E+03   X4   =  .3513143E+03   XDH1 = -.1350001E-01
XDH2 = -.1943808E+00  XDH3 = -.2821922E+01   XDH4 =  .5346734E+00   ZDH1 =  .2611499E+00   ZDH2 =  .5686083E-01
XH1  = .8971955E+00   XH2  =  .1586504E+02   XH3  =  .2162076E+03   XH4  =  .3513539E+03   ZH1  =  .2558763E+01
ZH2  = .2648814E+00   FCC  =  .1000000E+01   W    =  .2555500E+01   UDA  =  .2558763E+01   Y    =  .8539741E+00

TIME = .3500000E+01   XD1  =  .2556802E-02   XD2  =  .6457784E-01   XD3  =  .1017406E+01   XD4  =  .5020504E+01
X1   = .8958900E+00   X2   =  .1585198E+02   X3   =  .2160063E+03   X4   =  .3535618E+03   XDH1 =  .3469078E-02
XDH2 = .7459258E-01   XDH3 =  .1074232E+01   XDH4 =  .5074153E+01   ZDH1 =  .3001726E+00   ZDH2 =  .7650546E-01
XH1  = .8958948E+00   XH2  =  .1585232E+02   XH3  =  .2160141E+03   XH4  =  .3535575E+03   ZH1  =  .2655377E+01
ZH2  = .2095233E+00   FCC  =  .1000000E+01   W    =  [illegible]     UDA  =  .2699377E+01   Y    =  .8523036E+00

TIME = .4000000E+01   XD1  =  .2523702E-02   XD2  =  .4556278E-01   XD3  =  .7382021E+00   XD4  =  .6872056E+00
X1   = .8575811E+00   X2   =  .1586867E+02   X3   =  .2165456E+03   X4   =  .3550052E+03   XDH1 =  .3351270E-02
XDH2 = .5315770E-01   XDH3 =  .7706820E+00   XDH4 =  .7015742E+00   ZDH1 =  .3405517E+00   ZDH2 =  .8711554E-01
XH1  = .8575747E+00   XH2  =  .1586858E+02   XH3  =  .2165501E+03   XH4  =  .3550036E+03   ZH1  =  .2855775E+01
ZH2  = .3356759E+00   FCC  =  .1000000E+01   W    =  [illegible]     UDA  =  .2859077E+01   Y    =  .8544655E+00
```

```
X1    =  .[illegible]         X2    =  .[illegible]          X3    =  .21657466E+03        X4    =  .35451766E+03       XDH1 =  .7653017E-05
XDH2  =  .1[illegible]E-04    XDH3  =  .[illegible]E-03      XDH4  = -.[illegible]E-02     ZDH1  =  .10466177E+01       ZDH2 =  .26166661E+00
XH1   =  .[illegible]E+00     XH2   =  .[illegible]E+02      XH3   =  .21657466E+03        XH4   =  .35451777E+03       ZH1  =  .56664465E+01
ZH2   =  .174[illegible]E+01  RCC   =  .100[illegible]E+01         =  .[illegible]E+01     UDA   =  .56664465E+01       Y    =  .89474306E+00

TIME  =  .9[illegible]E+ 1    XD1   = -.7752[illegible]E-04  XD2   = -.[illegible]E-03     XD3   = -.16747566E-02       XD4  = -.53855566E-02
X1    =  .8[illegible]E+00    X2    =  .1[illegible]E+02     X3    =  .2[illegible]E+03    X4    =  .35451765E+03       XDH1 =  .1159[illegible]E-05
XDH2  = -.[illegible]E-04     XDH3  = -.[illegible]E-03      XDH4  = -.[illegible]E-02     ZDH1  =  .119[illegible]E+01 ZDH2 =  .2965047E+00
XH1   =  .[illegible]E+00     XH2   =  .1[illegible]E+02     XH3   =  .2165747[illegible]E+03  XH4 =  .35451775E+03      ZH1  =  .62436665E+01
ZH2   =  .11865647E+ 1        RCC   =  .100[illegible]E+01         =  .6[illegible]E+01    UDA   =  .6243[illegible]E+01  Y    =  .89474386E+00

TIME  =  .9500000E+ 1         XD1   = -.43177425E-04         XD2   = -.67397525E-03        XD3   = -.22537015E-02       XD4  = -.56858455E-02
X1    =  .89824655E+00        X2    =  .15890555E+02         X3    =  .21657466E+03        X4    =  .35451735E+03       XDH1 =  .5552[illegible]26E-06
XDH2  = -.4324226E-04         XDH3  = -.70046415E-03         XDH4  = -.34301555E-02        ZDH1  =  .1743[illegible]E+01 ZDH2 =  .33[illegible]E+00
XH1   =  .89824645E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451745E+03       ZH1  =  .68755[illegible]E+01
ZH2   =  .17438775E+01        RCC   =  .10000000E+01               =  .6875[illegible]E+01 UDA   =  .6875[illegible]E+01  Y    =  .89474366E+00

TIME  =  .1000000E+02         XD1   = -.4[illegible]E-04     XD2   = -.755[illegible]E-03  XD3   = -.24285545E-02       XD4  = -.6026742E-02
X1    =  .89824635E+00        X2    =  .15890555E+02         X3    =  .21657466E+03        X4    =  .35451735E+03       XDH1 =  .1120578E-05
XDH2  = -.35878645E-04        XDH3  = -.66205575E-03         XDH4  = -.34557466E-02        ZDH1  =  .15229157E+01       ZDH2 =  .36071925E+00
XH1   =  .89824630E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451745E+03       ZH1  =  .75912475E+01
ZH2   =  .15228127E+01        RCC   =  .10000000E+01               =  .75912475E+01        UDA   =  .75912475E+01       Y    =  .89474355E+00

TIME  =  .1050000E+02         XD1   = -.54753965E-04         XD2   = -.85744225E-03        XD3   = -.27025175E-02       XD4  = -.6840735E-02
X1    =  .89824635E+00        X2    =  .15890555E+02         X3    =  .21657456E+03        X4    =  .35451735E+03       XDH1 =  .1511594E-05
XDH2  = -.41677805E-04        XDH3  = -.6992575E-03          XDH4  = -.3523807E-02         ZDH1  =  .17255805E+01       ZDH2 =  .4314116E+00
XH1   =  .89824635E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451745E+03       ZH1  =  .84022875E+01
ZH2   =  .1725572[illegible]E+01  RCC =  .10000000E+01               =  .84022875E+01        UDA   =  .84022875E+01       Y    =  .89474355E+00

TIME  =  .1100000E+02         XD1   = -.62093695E-04         XD2   = -.96915975E-03        XD3   = -.30795175E-02       XD4  = -.7835107E-02
X1    =  .89824645E+00        X2    =  .15890555E+02         X3    =  .21657466E+03        X4    =  .35451735E+03       XDH1 =  .1655944E-05
XDH2  = -.44475035E-04        XDH3  = -.81032995E-03         XDH4  = -.45346615E-02        ZDH1  =  .19553385E+01       ZDH2 =  .46885345E+00
XH1   =  .89824645E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451755E+03       ZH1  =  .93217165E+01
ZH2   =  .19553295E+01        RCC   =  .10000000E+01               =  .93213165E+01        UDA   =  .93217165E+01       Y    =  .89474365E+00

TIME  =  .1150000E+02         XD1   = -.70413135E-04         XD2   = -.1[illegible]E-02    XD3   = -.35029555E-02       XD4  = -.8656057E-02
X1    =  .89824645E+00        X2    =  .15890555E+02         X3    =  .21657455E+03        X4    =  .35451735E+03       XDH1 =  .1916[illegible]E-05
XDH2  = -.55872825E-04        XDH3  = -.93186905E-03         XDH4  = -.51534195E-02        ZDH1  =  .2215[illegible]E+01 ZDH2 =  .55394345E+00
XH1   =  .89824645E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451755E+03       ZH1  =  .10362715E+02
ZH2   =  .22156786E+01        RCC   =  .10000000E+01               =  .10362715E+02        UDA   =  .10362715E+02       Y    =  .89474365E+00

TIME  =  .1200000E+02         XD1   = -.78787605E-04         XD2   = -.1[illegible]E-02    XD3   = -.39680415E-02       XD4  = -.10064555E-01
X1    =  .89824655E+00        X2    =  .15890555E+02         X3    =  .21657466E+03        X4    =  .35451735E+03       XDH1 =  .2[illegible]E-05
XDH2  = -.63223595E-04        XDH3  = -.10547135E-02         XDH4  = -.5[illegible]E-02    ZDH1  =  .25107[illegible]E+01 ZDH2 =  .62770015E+00
XH1   =  .89824645E+00        XH2   =  .15890555E+02         XH3   =  .21657466E+03        XH4   =  .35451755E+03       ZH1  =  .1154277E+02
ZH2   =  .[illegible]E+01     RCC   =  .1[illegible]E+01           =  .1154[illegible]E+02 UDA   =  .11540775E+02       Y    =  .89474375E+00

TIME  =  .1[illegible]E+02    XD1   = -.[illegible]E-04      XD2   = -.[illegible]E-02     XD3   = -.44937710E-02       XD4  = -.11395561E-01
X1    =  .89824655E+00        X2    =  .15890555E+02         X3    =  .21657466E+03        X4    =  .35451735E+03       XDH1 =  .2346231E-05
XDH2  = -.71432675E-04        XDH3  = -.11921166E-02         XDH4  = -.[illegible]E-02     ZDH1  =  .2845[illegible]E+01 ZDH2 =  .71127745E+00
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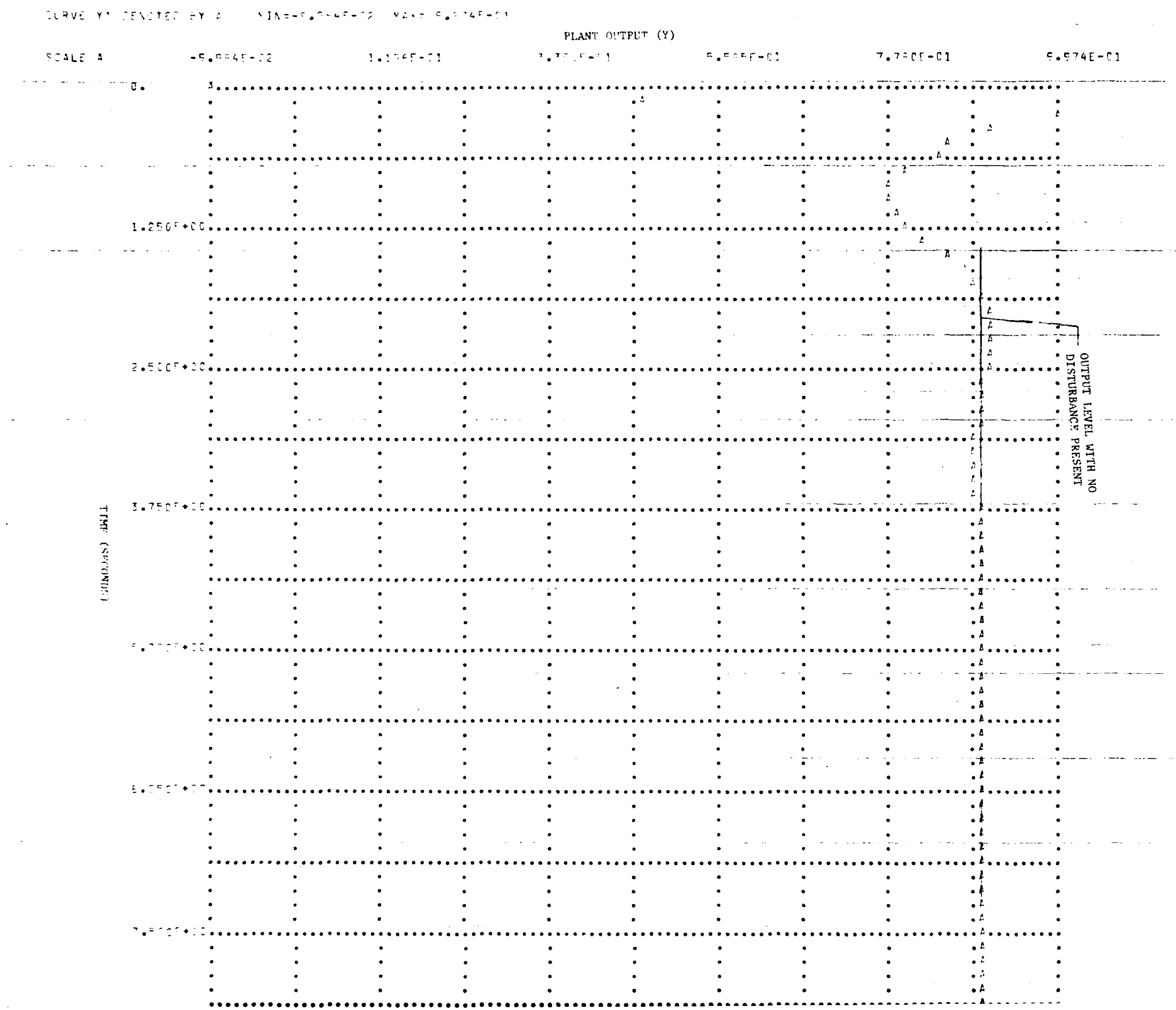
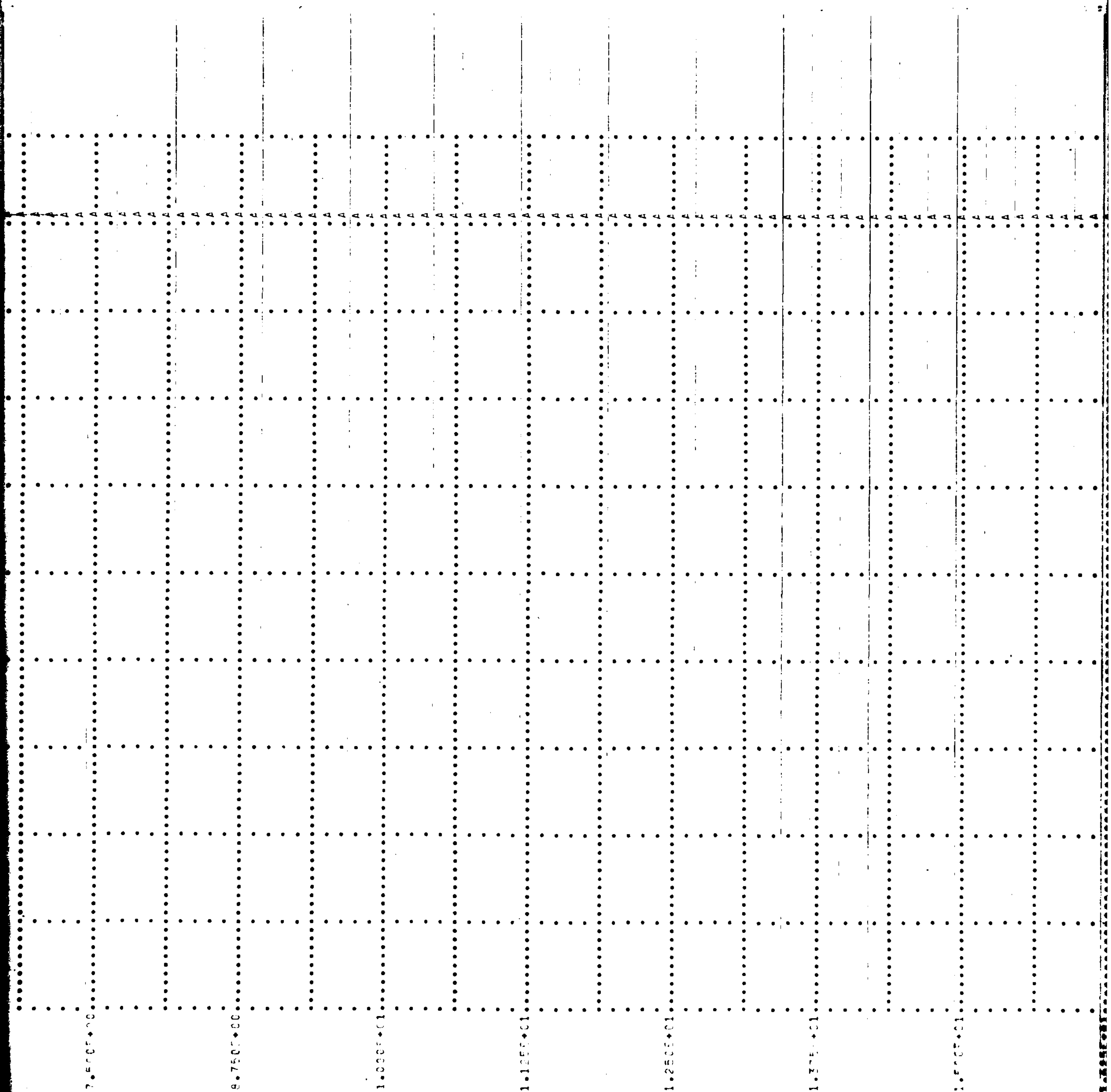
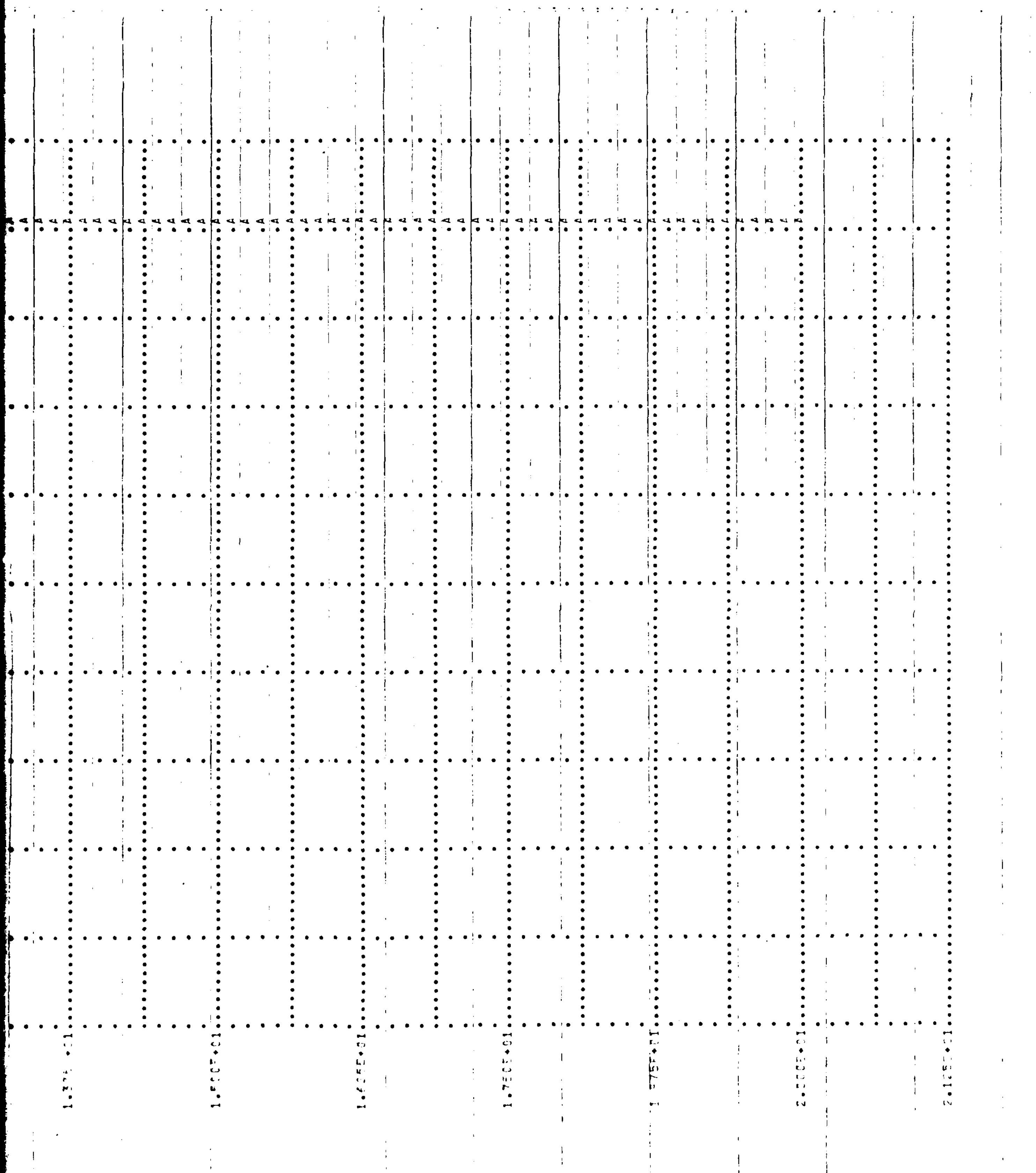
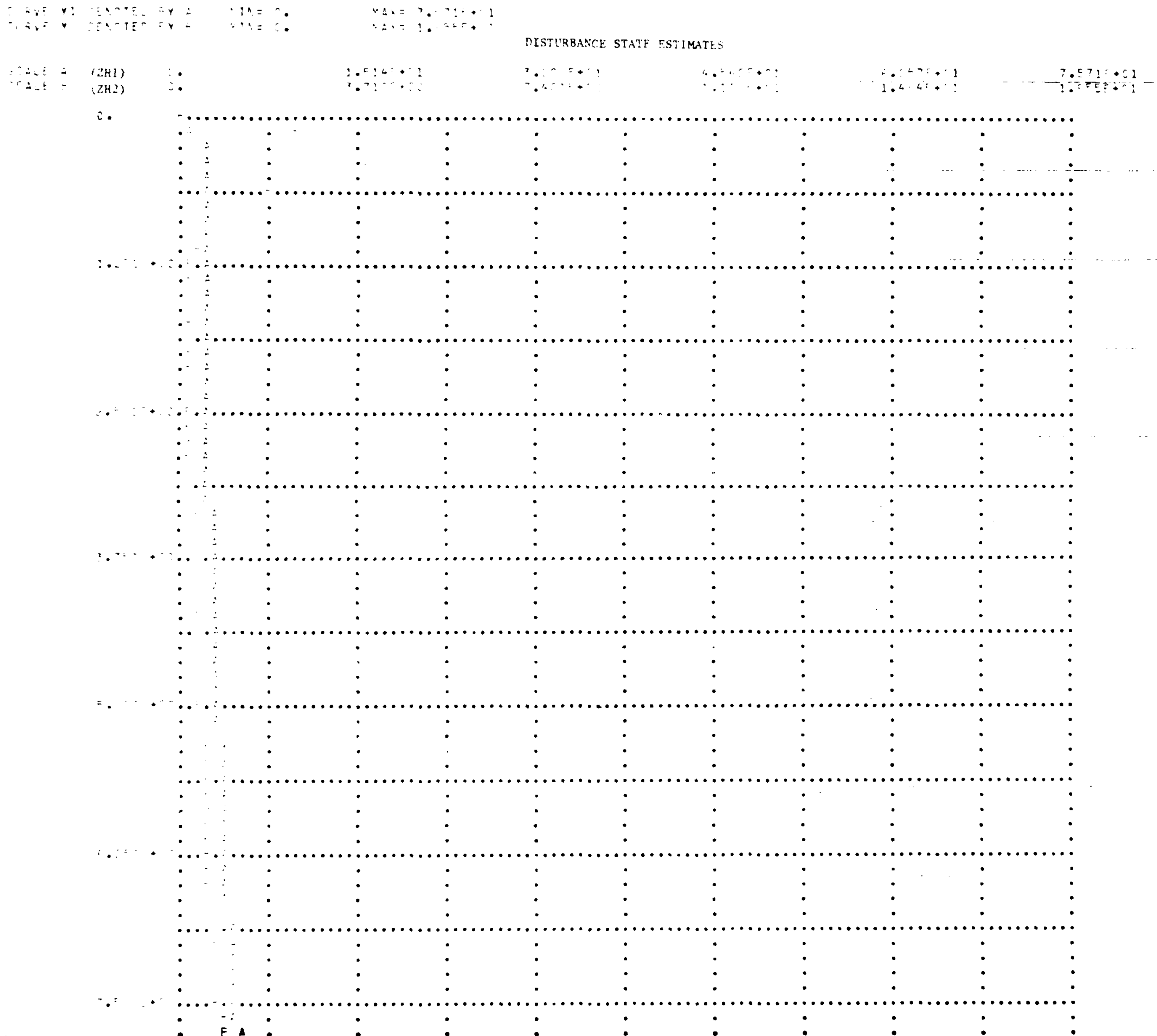


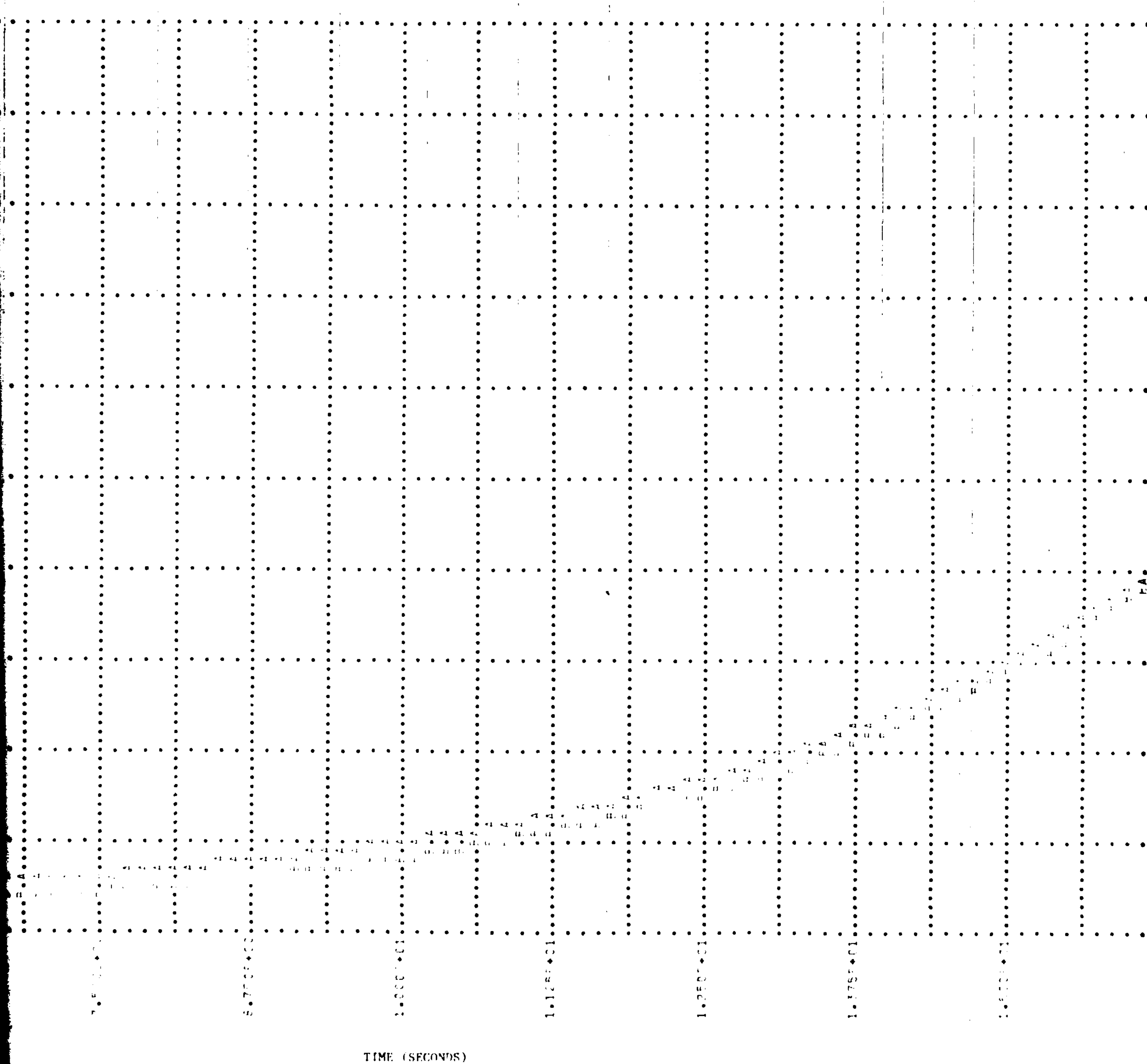
CURVE Y1 DENOTED BY A
PLANT OUTPUT (Y)
SCALE A
7.780E-01
9.574E-01
0.
1.250E+00
2.500E+00
3.750E+00
OUTPUT LEVEL WITH NO DISTURBANCE PRESENT
TIME (SECONDS)

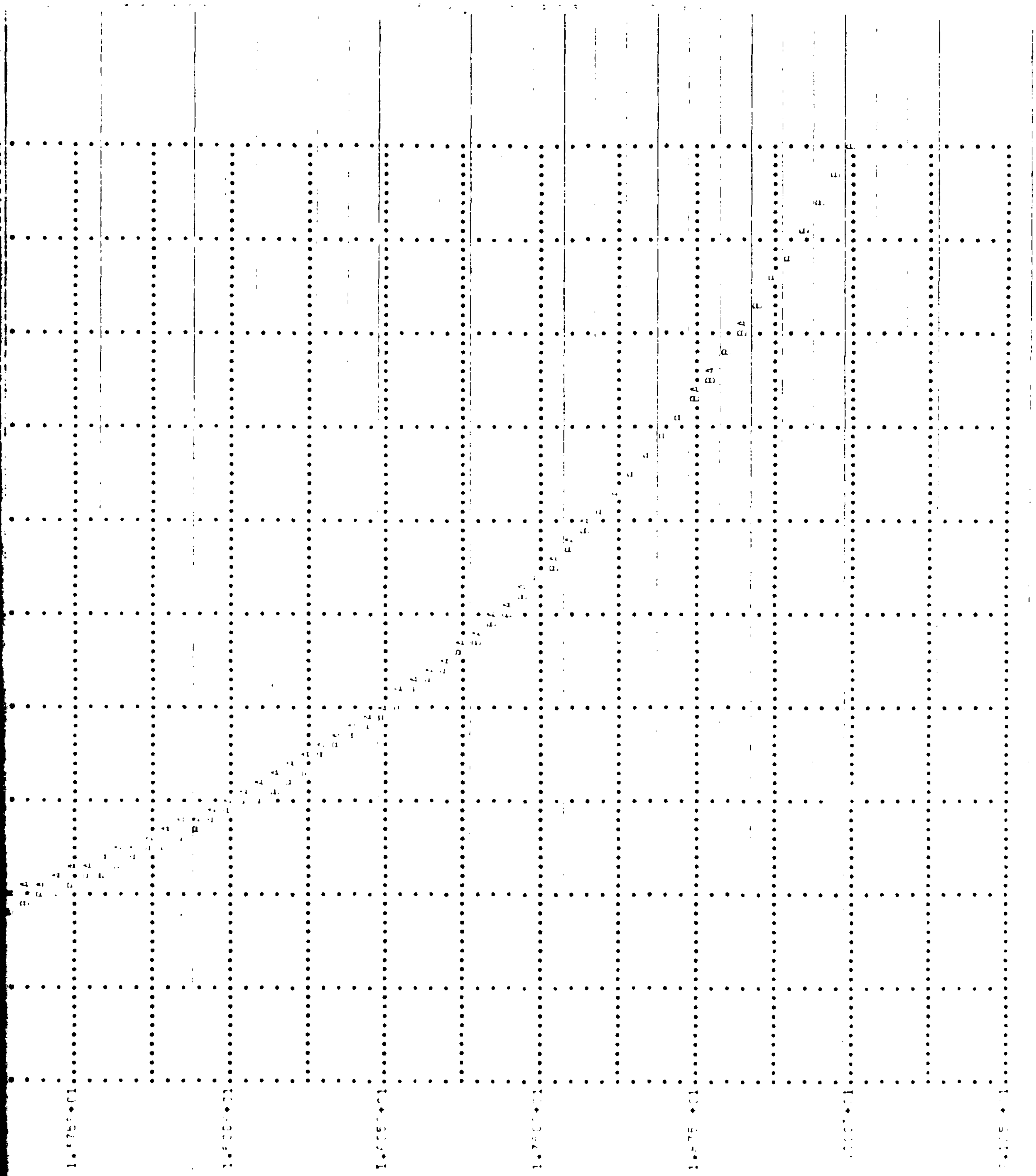

8.750E+00
1.000E+01
1.125E+01
1.250E+01



DISTURBANCE STATE ESTIMATES




TIME (SECONDS)



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