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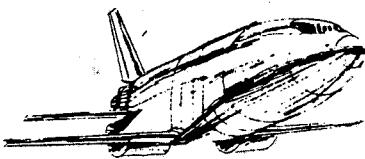
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CONTROL OF A FLEXIBLE

SPACE SHUTTLE VEHICLE

Contract No. NAS8-25708

CONTROL OF A FLEXIBLE
SPACE SHUTTLE VEHICLE

by

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FEBRUARY 1973

FOREWORD

This is the final report on Contract NAS8-25708, "Controller Design Technology for the Space Shuttle Vehicle", for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center.

Dr. S. W. Winder of the Dynamics and Control Division of the Aero-Astro-dynamics Laboratory served as technical monitor for the contract. The study was performed in the Research Department of the Systems and Research Division of Honeywell Inc.

Two interim reports have been issued previously. The first, Honeywell Report 12238-IR1, "Controller Design Technology for the Space Shuttle Vehicle", July 1971, summarized the work performed during the first year of the contract. Significant achievements described therein were in the areas of controller simplification, insensitivity to parameter variations, and the sensor-choice problem. During the remainder of the contract period the goal of the program was to apply the techniques and results developed in the first year to the design of a controller for a flexible space shuttle vehicle. A major part of this effort was spent developing a mathematical model. The second interim report, Honeywell Document 12238-IR2, "Mathematical Model of a Flexible Space Shuttle Vehicle", December 1972, describes the model developed.

This final report describes the application of the controller synthesis technique to the mathematical model developed. This portion of the study was conducted by Dr. C. A. Harvey as principal investigator with the assistance of Mr. T. Yam. Dr. E. E. Yore served as program manager.

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SECTION I

INTRODUCTION AND SUMMARY

This report describes the application of optimal control technology to the design of a controller for the space shuttle vehicle during ascent. An earlier phase of this program was devoted to developing the necessary technology. Accomplishments during that phase are reported in Reference 1.

The objectives of applying the technology to a specific space shuttle vehicle were to

- Ascertain the quality of performance which could be expected of a controller

- Determine any inadequacies in the technology requiring further research

- Discover any special problems associated with vehicle flexure

- Examine the significance of parameter uncertainty

We planned to accomplish these objectives by designing an optimal controller and a simplified controller, and to examine the effects of parameter variations for a realistic shuttle problem. As the realistic problem we chose control of the lateral motion during ascent of a flexible space shuttle vehicle defined in the Space Shuttle Phase B Program. Unfortunately, data to represent a flexible space shuttle vehicle was not available at the conclusion of the Space Shuttle Phase B Program. So our plans had to be modified. We could restrict our plans to a rigid vehicle and eliminate all possibility of answering the flexure question, or we could develop the necessary representation of a flexible vehicle and then proceed with the original plan as far as contract funds would permit. The second alternative was chosen. The required model was developed. Reference 2 summarizes that development and gives the quantitative data used for the controller described in this report.

The lateral motion of the space shuttle vehicle consists of bending, rotations, and translation caused by side gusts and rolling gusts and controlled with engine gimbal and aerodynamic surface deflections. A stochastic constrained-response design technique was shown to be applicable to such controller design problems in References 3 and 4. In this technique the problem is formulated on a finite time interval with time-varying dynamics. Gusts and vehicle responses are modeled as stochastic processes. An optimal control minimizes the likelihood* that any responses exceed their desired constraints.

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*Actually the optimal control minimized an upper bound on the likelihood.

The optimal control was shown to be optimal for a quadratic performance index. The weighting matrices in the performance index were adjusted through iteration to achieve minimization of the likelihood of exceeding constraints. In this study we used a slight variation on this theme. Here the weighting matrices were adjusted through iteration to reduce response peaks defined as mean magnitude plus three sigma values. The optimal control is a linear control with feedbacks of the complete state of the system and a deterministic input. Details of the synthesis technique are given in Section II.

Design of the optimal control is summarized in Section III. One significant difference was found in the design of the optimal controller for this problem from that of previous studies. In previous studies (References 3, 4, and 5) it had sufficed to use the same quadratic weighting matrices for design of the deterministic component of the controller as was used for the covariance component of the controller. For the problem at hand this was not the case. The optimal controller is again the sum of a deterministic component and a covariance component. But two different weighting matrices were required to define the two components.

A total of 15 iterations of the quadratic weighting matrices were required to define the optimal controller.

The primary response variables considered for this study were δp, δr, δa, $\bar{q}\beta$, ϕ, ψ, and a_y. These variables were defined in Reference 2. Brief physical descriptions of these variables along with design limits in parentheses follow.

δp (± 0.175 rad) denotes a fictitious gimbal actuator which provides pure rolling moment

δr (± 0.175 rad) denotes a fictitious gimbal actuator which provides pure yawing moment

δa (± 0.524 rad) denotes booster aileron actuator position

$\bar{q}\beta$ (± 4800 psf deg) is an aerodynamic load indicator with $\bar{q}$ denoting dynamic pressure and β denoting sidelsip angle

ϕ (± 0.524 rad) denotes roll angle

ψ (± 0.524 rad) denotes yaw angle

a_y (± 32 ft/sec^2) denotes lateral acceleration at the orbiter cockpit

The times of occurrence of peak values of the mean responses and covariance responses for the optimal controller were generally different as shown in Table 1. The only exception was $\bar{q}\beta$. The peak values of $\overline{q\beta}$ and $\sigma_{\overline{q\beta}}$ occurred at 70 seconds. The last column in Table 1 shows the peak value and time of occurrence for the composite mean-plus-three-sigma response, $|\bar{r}| + 3\sigma_r$. In terms of these peak responses there is no difference between the two cases of only the side gust as input or both side-gust and rolling-gust inputs. This supported our conjecture that rolling-gust effects were secondary. In fact the controller was designed by neglecting the rolling-gust input during iterations of the quadratic weights. Then this rolling-gust input was included in the final evaluation of the optimal controller. The only significant change in optimal controller gains was the definition of non-zero gains for the rolling-gust states. Neglecting the rolling gusts during the early iterations of quadratic weights is highly recommended since their inclusion adds 30 percent to the computer time required to compute an optimal controller and evaluate its responses.

Table 1. Peak Response Summary of Optimal Controller

Response	Peak of Mean Response	Peak of Sigma Response	Peak of Mean-Plus -Three-Sigma Response
δp (rad)	- 0.134 at 70 sec	0.022 at 75 sec	0.196 at 70 sec
δr (rad)	0.059 at 75 sec	0.014 at 80 sec	0.101 at 77 sec
δa (rad)	- 0.386 at 71 sec	0.069 at 76 sec	0.568 at 71 sec
$\bar{q}\beta$ (psf rad)	26.1 at 70 sec	19.7 at 70 sec	85.1 at 70 sec
ϕ (rad)	- 0.148 at 77 sec	0.167 at 61 sec	0.546 at 76 sec
ψ (rad)	0.093 at 46 sec	0.036 at 156 sec	0.142 at 86 sec
a_y (ft/sec^2)	7.86 at 75 sec	5.47 at 85 sec	23.9 at 80 sec

The controllers were computed and evaluated as sampled-data controllers in a sampled-data system. That is, controller inputs and disturbance inputs were assumed to be constant within each sample interval, and responses and states were evaluated only at endpoints of the sample intervals. For purposes of design a sample frequency had to be chosen a priori. Computer time required for controller analysis and synthesis is directly proportional to sample frequency. But controller performance capability is generally a decreasing function of sample frequency. So a compromise had to be made. We chose a rate of 20 samples per second even though the maximum frequency associated with flexure was approximately 7 Hz.

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This proved to be a satisfactory choice as indicated by a single check on the sensitivity of controller performance capability with respect to sampling frequency. For comparison one optimization and response evaluation was made with a sample rate of 50 samples per second. Only minor changes were found in the major contributors to the value of the performance index, even though significant changes were observed in some gains and in the flexure responses.

It was believed that gust penetration effects could be significant for the flexible vehicle. A simple representation of gust penetration was included in the model. But we noted that the gust penetration seemed to play a minor role in the optimization. We also noted that computer time could be reduced by 35 percent if penetrating effects were neglected. So we compared the optimal controllers designed with and without gust penetration in the model. There was no significant difference. This may, of course, be due to the fact that no responses such as bending moments at particular stations were considered.

Thus, these effects were neglected in the design of a simplified controller.

The unanticipated modeling effort caused a severe reduction in the effort to design a simplified controller and eliminated the analysis of parameter uncertainty effects.

An initial simplified controller was determined. This controller was based on a measurement vector consisting of 12 sensor outputs and contained no sensor compensator dynamics. One iteration of the gradient method was successfully completed. Choice of the step-size was found to be critical, especially during the time of occurrence of high dynamic pressure.

During the second iteration the method was modified so that step-size variations over sub-intervals and time-varying step-sizes could economically be studied. For the controller configuration chosen even this did not help us in achieving significant improvement in performance. Limited resources did not permit investigating the effectiveness of adding sensors or repositioning the present ones.

The design of the simplified controller is summarized in Section IV.

SECTION II
SYNTHESIS TECHNIQUE

Modern controller synthesis may be viewed as consisting of a mathematical model of the physical system, a mathematical representation of quality of performance, computational techniques for evaluating performance and for computing controllers that provide satisfactory performance, and application of the computational techniques. In this section we describe qualitatively the first three of these components for this space shuttle controller design. The fourth component, application of the computational techniques, is described in Sections III and IV.

MATHEMATICAL MODEL

The physical problem of interest is the control of the lateral motion of a flexible space shuttle vehicle during ascent. The specific vehicle for which numerical data were derived was the North American Rockwell Phase B study vehicle identified as the 161C-B9U, "a piggy-back" configuration. Reference 2 describes in detail the derivation of the mathematical model used in this study. Here we will describe only the nature of the model and introduce appropriate nomenclature.

The system is modeled as a linearized (vector) differential equation

$$\dot{\chi}(t) = A(t)\chi(t) + B_1(t)u(t) + B_2(t)\bar{v}(t) + B_3(t)n(t), \quad \chi(0) = \chi^*_o \tag{1}$$

a response vector, r, defined as

$$r(t) = H_1(t)\chi(t) + D_1(t)u(t) + D_2(t)\bar{v}(t) \tag{2}$$

and a measurement vector, m, defined as

$$m(t) = M(t)\chi(t) + N(t)\bar{v}(t) \tag{3}$$

The state vector, χ, in the most general form considered consists of six "rigid-body" states, eight flexure states, three actuator positions, three side-gust penetration states, two side-gust states, one rolling-gust penetration state, and one rolling-gust state. The six "rigid-body" states describe the motion of a fictitious undeflected vehicle. The states chosen are "body" roll rate, p, "body" yaw rate, r, "body" side velocity, v, roll angle, ϕ, yaw angle, ψ, and inertial side displacement, y, where a pitch, roll, yaw system of Euler angles relates the "body" reference frame to the inertial (earth) reference frame. The eight flexure states are η_i and $\dot{\eta}_i$ for i = 1,2,3,4.

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*The time, t = 0, represents the time of lift-off, and χ_o indicates the state at lift-off.

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The deflection of the vehicle is described by $\sum\limits_{i=1}^{4} \eta_i(t)Y_i(x)$ where $Y_i(x)$ denotes the ith natural mode shape for the free vehicle. The actuator positions are a booster aileron actuator position, δa, and two fictitious gimbal actuator positions. These fictitious gimbal actuators represent combinations of specific engine gimbals. The first combination, δp, produces maximum rolling moment with no yawing moment about the velocity vector. Similarly, the second combination, δr, produces maximum yawing moment with no rolling moment. The side gust, $v_w(x,t)$, where x denotes position along the vehicle centerline, is represented by

$$v_w(x,t) = \sum\limits_{i=1}^{3} x_i(t) f_i(x)$$

The states $x_i(t)$ for $i = 1,2,3$ are the side-gust penetration states. These states are driven by the side gust at the nose of the vehicle $v_w(t)$. This gust, $v_w(t)$, is assumed to be

$$v_w(t) = \bar{v}(t) + \sigma_w(t)\omega(t)$$

where $\bar{v}(t)$ is a mean wind and ω is one state of a second-order linear filter[*] driven by Gaussian white noise n_1. The other state of the filter is called x. The rolling gust is treated similarly with a mean value of zero, a single penetration state x_4, driven by p_g, the output of a first-order linear filter driven by a second Gaussian white noise n_2.

The control inputs, u_i, $i = 1,2,3$, represent inputs to first-order actuators. Thus u_1, u_2, and u_3 may be considered as δp, δr, and δa commands, respectively.

Fourteen responses make up the response vector. These responses consist of roll angle, ϕ, side displacement, y, the actuator positions, δp, δr, and δa, a measure of aerodynamic loading, $\bar{q}\beta$, lateral acceleration of the orbiter cockpit, a_y, and the time derivatives of these responses. In actuality the time derivative of $\bar{q}\beta$ is replaced by $\bar{q}\dot{\beta}$, and the $\dot{u}$ terms are neglected in computing $\dot{a}_y$.

The measurement vector consists of actuator positions and outputs of ideal sensors. The sensors are ideal in the sense that their dynamics are neglected. Optimal "complete state" controllers may be included in this formulation by assuming that M is the identity matrix and N is zero in Equation (3).

For computational purposes the system is modeled as a discrete system. The differential equation (1) is transformed to the difference equation

$$\chi(k+1) = A(k)\chi(k) + B_1(k)u(k) + B_2(k)\bar{v}(k) + B_3(k)n(k), \quad \chi(0) = \chi_0 \quad (4)$$

The numerical values of the elements of the coefficient matrices in Equations (1)-(3) used in this study as well as descriptions of the methods used to compute them and the coefficients in Equation (4) are given in Reference (2).

[*]The equations for this filter are given on page 18 of Reference 2.

Controls in this study are constrained to be linear. Thus, in the discrete form we assume that

$$u(k) = K(k)m(k) + f(k) \tag{5}$$

This assures that the controlled system is Gaussian and hence is completely characterized by its means and covariances.

The mean state, $\bar{\chi}(k) = E\{\chi(k)\}$, is the solution of

$$\bar{\chi}(k+1) = \left[A(k) + B_1(k)K(k)M(k)\right]\bar{\chi}(k) + [B_1(k)f(k)]$$
$$+ \left[B_1(k)N(k) + B_2(k)\right]\bar{v}(k), \quad \bar{\chi}(0) = \bar{\chi}_o \tag{6}$$

The state covariance matrix, $X(k) = E\left\{\left[\chi(k) - \bar{\chi}(k)\right]\left[\chi(k) - \bar{\chi}(k)\right]'\right\}$, is the solution of

$$X(k+1) = \left[A(k) + B_1(k)K(k)M(k)\right]X(k)\left[A(k) + B_1(k)K(k)M(k)\right]'$$
$$+ B_3(k)W(k)B_3'(k), \quad X(0) = X_o \tag{7}$$

where ′ indicates transpose and

$$E\{n(j)n'(k)\} = W(k)\delta_{jk} \tag{8}$$

Means and covariances of controls, responses, and measurements may readily be computed in terms of the mean state and state covariance matrix. Thus, the mean control is

$$\bar{u}(k) = K(k)\bar{m}(k) + f(k) \tag{9}$$

where

$$\bar{m}(k) = M(k)\bar{\chi}(k) + N(k)\bar{v}(k)$$

Then the mean response is

$$\bar{r}(k) = H_1(k)\bar{\chi}(k) + D_1(k)\bar{u}(k) + D_2(k)\bar{v}(k) \tag{10}$$

The response covariance matrix, denoted by $S(k)$, is

$$S(k) = \left[H_1(k) + D_1(k)K(k)M(k)\right]X(k)\left[H_1(k) + D_1(k)K(k)M(k)\right]' \tag{11}$$

Equations (6) through (11) comprise the analytical model of the system. The transformation of these equations and appropriate numerical data to operational computer programs yields the ultimate quantitative model for this study.

PERFORMANCE INDEX

According to our mathematical model the system is completely characterized by state and response means and covariances. So our mathematical representation of quality of performance must be some function of these means and covariances. We use a quadratic performance index of the form

$$J = tr\left\{Q(T)S(T) + V(T)R(T) + \int_0^T [Q(t)S(t) + V(t)R(t)] \, dt\right\} \qquad (12)$$

where tr indicates trace. This choice is based on the following rationale.

In Reference (3), Skelton introduced the likelihood of mission failure as a performance index for a launch-vehicle control problem during ascent. Mission failure was defined as the event that some response exceeds its limit during the flight or at the terminal time. An explicit expression for an upper bound for the likelihood of mission failure in terms of means responses and response covariances was derived. Then Skelton introduced the concept of quadratic equivalence. This yields an equivalent quadratic performance index with the property that minimization of the upper bound on the likelihood of mission failure is equivalent to minimization of a quadratic performance index.

Knowledge of real physical limits is requisite to the meaningfulness of the likelihood of mission failure performance index. For this study these limits are not known, especially the structural load limits. In fact, the study vehicle is one of many configurations considered in the conceptual and preliminary design phases. In these design phases results from control system studies such as this could influence the final design and hence the final values for response limits. Thus, instead of choosing artificial limits and taking the resulting upper bound on mission failure as a performance index, a quadratic performance index was chosen. The responses included in the performance index were chosen as those that would typically occur in a quadratic performance index derived as equivalent to an upper bound index. For example, if $r_i(t)$ represents a response that is constrained, then the response $r_i(t)$ and its time derivative $\dot{r}_i(t)$ must be included in the upper bound index and hence in the equivalent quadratic index.

Specific responses considered to be constrained in this study are roll angle, ϕ; lateral displacement, y; roll gimbal actuator position, δp; yaw gimbal actuator position, δr; aileron actuator position, δa; an aerodynamic load indicator, $\bar{q}\beta$; and lateral acceleration of the orbiter cockpit, a_y.

These responses along with their time derivatives comprise the response vector. The actuator positions and their rates are the only responses for which physical limits are known, and even these constraints could be modified.

Therefore, the goal of the controller synthesis was defined to be minimization of the magnitude of $\bar{q}\beta$ within the constraint of satisfactory magnitudes of terminal lateral displacement and in-flight roll angle, actuator positions and rates, and lateral acceleration. For this purpose the in-flight magnitude of a response variable, $r_i(t)$, is taken to be

$$(r_i) \text{ peak} = \max_t \left\{ |r_i(t)| + 3\sigma_{r_i}(t) \right\} \tag{13}$$

Similarly, the peak value of terminal lateral displacement is

$$y(T) \text{ peak} = |y(T)| + 3\sigma_y(T) \tag{14}$$

The quadratic weighting matrices, Q and V, in Equation (12) are adjusted in the controller synthesis to yield satisfactory response peaks as defined by Equations (13) and (14).

A similar performance index was used in the previous shuttle control system study reported in Reference (4).

One calculation was performed to yield a quantitative comparison of predictions of likelihoods of a response exceeding its limit. For the optimal controller with complete state feedback the peak value of the response δa occurs at 71 seconds. There $\bar{\delta a} = -0.3865$ and $\sigma_{\delta a} = 0.0605$ rad. Taking the aileron limits to be ± 0.5236 rad (30 deg), we compute the probability

$$\text{Pr}\left\{ |\delta a(71)| \geq 0.5236 \right\} = 0.012$$

The upper bound of Reference (3) on the likelihood that $|\delta a(t)| \geq 0.5236$ for some $t \in [0, 210]$ is the expected number of times that $[\delta a(t)] \geq 0.5236$, which for the same controller was found to be 0.102.

These figures appear to be in good agreement considering that the first corresponds to a single-time point and that the second corresponds to an upper bound and to an interval of time. This single comparison is viewed as support for the use of the quadratic performance index with interpretation of constraint exceedance in terms of peak magnitudes exceeding constraints.

It had sufficed to choose Q and V, the covariance and mean response weighting matrices, to be identical in previous studies (References 3, 4, and 5). This did not occur here so that the mean and covariance controllers are optimal relative to different weights and hence performance indices.

The performance index for the controller simplification was shown to be dependent on the controller configuration in Reference 1. This requires variation in the quadratic weights as gradient steps are taken.

However, the variation can only be computed accurately after sufficient nearness to the optimal controller is attained. The variation is based on the non-quadratic performance index. The controller simplification performed on this program stopped short of the variation in the performance index. Therefore, the single quadratic performance index was used for the simplification task.

COMPUTATIONAL TECHNIQUES

The solution of the optimization problem formulated for a time-varying linear system driven by white Gaussian noise with a quadratic performance index on a finite time interval is straightforward. The necessary equations are derived in References 3, 5, and 6. A program to solve these equations is documented in Reference 6, Volume 2.

The equations which define the optimal (complete state feedback) control for the problem defined by Equations (2) through (5) and the discrete version of (12) are [assuming $M(k)$ is the identity matrix and $N(k) = 0$ and taking n as the independent discrete variable running from 0 to N] :

$$K(n) = K_Q(n)$$

$$f(n) = [K_V(n) - K_Q(n)]\,\bar{\chi}(n) + f_V(n)$$

$$P_V(N) = H_1(N)'\,V(N)H_1(N)$$

$$g(N) = H_1(N)'\,V(N)D_2(N)\bar{v}(N)$$

$$K_V(n) = -[B_1(n)'\,P_V(n+1)B_1(n)+\Delta t D_1(n)'\,V(n)D_1(n)]^{-1}$$

$$\cdot [B_1(n)'\,P_V(n+1)A(n) + \Delta t D_1(n)'\,V(n)H_1(n)]$$

$$f_V(n) = -[B_1(n)'\,P_V(n+1)B_1(n) + \Delta t D_1(n)'\,V(n)D_1(n)]^{-1}$$

$$\cdot \{B_1(n)'[g(n+1) + P_V(n+1)B_2(n)\bar{v}(n)] + \Delta t D_1(n)'\,V(n)D_2(n)\bar{v}(n)\}$$

$$P_V(n) = [A(n) + B_1(n)K_V(n)]'\,P_V(n+1)[A(n) + B_1(n)K_V(n)]$$

$$+ \Delta t [H_1(n) + D_1(n)K_V(n)]'\,V(n)[H_1(n) + D_1(n)K_V(n)]$$

$$g(n) = [A(n) + B_1(n)K_V(n)]' [g(n+1) + P_V(n+1)(B_1(n)f(n) + B_2(n)\bar{v}(n))]$$

$$+ \Delta t[H_1(n) + D_1(n)K_V(n)]' \, V(n)[D_2(n)\bar{v}(n) + D_1(n)f(n)]$$

The gain $K_Q(n)$ is the solution to the above where $V(n)$ is replaced by $Q(n)$.

$$\bar{\chi}(n+1) = A(n)\bar{\chi}(n) + B_1(n)K_V(n)\bar{\chi}(n) + B_2(n)\bar{v}(n) + B_1(n)f(n), \quad \bar{\chi}(0) = 0 \qquad (15)$$

These equations may be solved on a digital computer using the program DISCOP of Reference 6.

For a given weighting matrix, V, the optimal control may be computed. Then the corresponding mean state and state covariance may be computed and in turn the mean response and response covariance using DISCOP. The weighting matrix V may be modified and the process repeated. In this fashion iterations of the quadratic weights may be made to enforce desired response characteristics.

The gradient technique for controller simplification was developed and demonstrated during the first year of this contract. Those results are reported in Reference 1. If we assume perfect knowledge of the model, it is only necessary to derive a simplified covariance controller.

The original mean controller can be mechanized with any simplified controller by appropriate modification of the deterministic input. Suppose that Equation (15) yields the optimal mean state and $\bar{u}(n) = K_V(n)\bar{\chi}(n) + f(n)$ is the optimal mean control input. Consider a measurement vector $m(n)$ with $M(n)$ not necessarily the identity and $N(n)$ not necessarily zero. Let $K_S(n)$ denote a "simplified" gain matrix and $f_S(n)$ denote the deterministic input to be used in conjunction with $K_S(n)$; i.e., let

$$u_S(n) = K_S(n)[M(n)\bar{\chi}(n) + N(n)\bar{v}(n)] + f_S(n)$$

Setting

$$f_S(n) = f(n) + [K_V(n) - K_S(n) M(n)] \, \bar{\chi}(n) - K_S(n)N(n)\bar{v}(n) \qquad (16)$$

assures that the mean state and mean control are the optimal mean state and mean control, respectively. Thus, it suffices to simplify only the covariance controller.

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The simplification of the covariance controller consists of choosing a measurement vector and finding an initial controller of the desired configuration; starting with this controller, use the gradient method to minimize the Hamiltonian defined below.

The gradient method for optimizing the simplified controller is depicted in Figure 1. The Hamiltonian for the kth iteration is defined therein to be:

$$H_k = tr \sum_{n=o}^{N} Q(n) [H_1(n)+D_1(n)K_k(n)M(n)] X_k(n)[H_1(n)+D_1(n)K_k(n)M(n)]'$$

$$+ (\Delta t)^{-1} tr \sum_{n=o}^{N-1} P_k(n+1) [X_k(n+1) - X_k(n)]$$
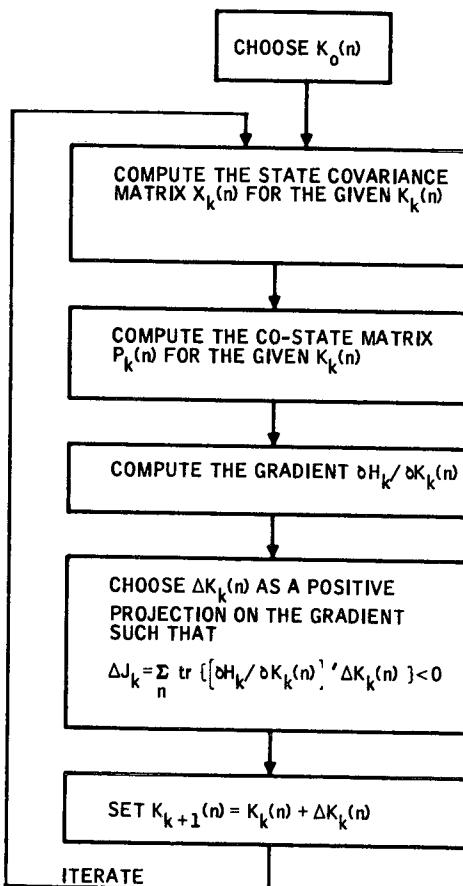
Figure 1. The Gradient Method

CHOOSE $K_o(n)$

COMPUTE THE STATE COVARIANCE MATRIX $X_k(n)$ FOR THE GIVEN $K_k(n)$

COMPUTE THE CO-STATE MATRIX $P_k(n)$ FOR THE GIVEN $K_k(n)$

COMPUTE THE GRADIENT $\delta H_k/\delta K_k(n)$

CHOOSE $\Delta K_k(n)$ AS A POSITIVE PROJECTION ON THE GRADIENT SUCH THAT

$\Delta J_k = \sum_n tr \{[\delta H_k/\delta K_k(n)]' \Delta K_k(n) \} < 0$

SET $K_{k+1}(n) = K_k(n) + \Delta K_k(n)$

ITERATE

where

$$P_k(n) = [A(n) + B_1(n)K_k(n)M(n)]' \, P_k(n+1)[A(n) + B_1(n)K_k(n)M(n)] \quad (17)$$

$$+ \Delta t[H_1(n) + D_1(n)K_k(n)M(n)]' \, Q(n)[H_1(n) + D_1(n)K_k(n)M(n)]$$

with $P_k(N) = H_1(N)' Q(N)H_1(N)$. Equation 7 may be used to compute $X_k(n)$ and Equation (17) used to compute $P_k(n)$. The gradient is given by

$$\partial H_k/\partial K_k(n) = 2[B_1(n)]' \, P_k(n+1)[A(n)+B_1(n)K_k(n)M(n)] \, X_k(n)[M(n)]'(\Delta t)^{-1}$$

$$+ 2[D_1(n)]' \, Q(n)[H_1(n)+D_1(n)K_k(n)M(n)] \, X_k(n)[M(n)]' \quad (18)$$

with $\partial H_k/\partial K_k(N) = 0$. The total computer program for implementing the gradient method uses basically the same subroutines for computing $X_k(n)$ and $P_k(n)$. Engineering judgement plays a significant role in the choice of a proper step-size and the choice of ΔK for each iteration.

This gradient method was described in Reference 1. There it was shown to be an iterative approach to satisfying the necessary conditions for optimality of the simplified controller. In this context these conditions are

$$\dot{X} = \frac{\partial H}{\partial P}, \quad \dot{P} = -\frac{\partial H}{\partial X}, \quad \frac{\partial H}{\partial K} = 0$$

For the case of incomplete measurement, i.e., the rank of M less than n, these three equations are coupled. Furthermore, the boundary conditions, X(0) and P(T), are given. So the problem is in reality a two-point boundary-value problem. The gradient method is a convergent numerical method for solving such a problem with the property of monotone improvement in the performance index.

In summary, the synthesis technique may be viewed as

- Starting with some subjective assumptions in deriving the mathematical model

- Using an objective procedure to find an optimal controller (optimal with respect to a performance index derived with engineering judgment)

- And deriving simplified controllers with the aid of engineering judgment and objective computational procedures.

SECTION III
OPTIMAL CONTROLLER DESIGN

The first task of the design was definition of quantitative performance goals.
Then quadratic weights were adjusted to attempt to achieve these goals.
Sensitivity to rolling gusts, sampling frequency, and gust penetration was
examined and found to be small. These tasks are summarized in this section.
Quantitative characteristics of the optimal controller are given in Appendix A.

PERFORMANCE GOALS

The primary performance goal was to minimize the aerodynamic load as
measured by $\bar{q}\beta$, subject to the constraint that actuator positions and rates
remained within their limits. Secondary goals were to achieve lateral accel-
eration responses of less than 1 g, terminal displacements of less than
10,000 ft, and acceptable roll and yaw angles. The most difficult and prob-
ably most demanding of these secondary goals is the roll angle requirement.
It is essential for the validity of the linearized analysis that roll angle be
kept sufficiently small. No attempt was made to define an accurate upper
bound for acceptable roll angle. Instead an arbitrary goal of 30 deg was
chosen.

The limits on actuator displacements and rates were assumed to be ±0.175 rad
(10 deg) for δp and δr, ±0.175 rad/sec for $\delta \dot{p}$ and $\delta \dot{r}$, ±0.524 rad (30 deg)
for δa, and 0.436 rad/sec (25 deg/sec) for $\delta \dot{a}$. These limits on the actuators
δp and δr were imposed with the aim of constraining the 24 actual engine
gimbals. Inclusion of each of the individual engine gimbals as a response
would more than double the dimension of the response vector. This did not
seem to be worthwhile. Also, it is believed that a gimbal logic could be
defined to blend the individual engine gimbals together to achieve the magni-
tudes of δp and δr called for by the optimal controller defined by constraining
only δp and δr.

With these performance goals defined, the optimal controller was designed
with the techniques described in Section II. The specific iterations and some
of the reasoning involved is described below. The degree to which the
optimal controller achieved the desired goals is summarized in Table 2.
The peak values of δp and δa are slightly larger than their limits. This was
accepted for two reasons. First, it is considered a matter of "fine-tuning"
with the quadratic weights to reduce these peaks to their limits. The second
reason is a conjecture that actual imposition of these constraints in the real
system in the form of hard-overs would not cause severe deterioration in the
other responses from that displayed in Table 2.

Table 2. Optimal Controller Performance versus Goals

Response r	Response Limit, γ	Peak Response, Max $\{|\bar{r}|+3\sigma_r\}$	Time of Peak Occurrence (sec)
δp (deg)	10	11.2	70
δr (deg)	10	5.8	77
δa (deg)	30	32.5	71
$\dot{\delta p}$ (deg/sec)	10	3.7	75
$\dot{\delta r}$ (deg/sec)	10	8.3	81
$\dot{\delta a}$ (deg/sec)	25	8.7	75
$\bar{q}\beta$ (psf deg)	4800	4876.0	70
ϕ (deg)	30	31.3	76
a_y (ft/sec^2)	32	23.9	86
η_1 (ft)	--	0.43	76
η_2 (ft)	--	0.63	84
η_3 (ft)	--	0.02	81
η_4 (ft)	--	0.47	77

The normalized modal deflections, η_i, i = 1,2,3,4, are included in Table 2 even though no direct attempt was made to control them. That is, they were not taken to be elements of the response vector. Their magnitudes do appear to be significant. These state variables may be interpreted as the following physical deflections: η_1 denotes deflection of the booster nose, η_3 denotes deflection of the booster tail, and η_2 and η_4 each denote deflection of the orbiter nose. From Figures 5, 6, 9, and 10 of Reference 2 it may be seen that η_2, η_3, and η_4 represent points of maximum deflections of their respective modes at the times of peak occurrences. However, for the first mode the point of maximum deflection at the time of peak occurrence is the nose of the orbiter. The deflection at that point is approximately four times η_1. Thus, we see significant first mode bending taking place.

ITERATIONS OF QUADRATIC WEIGHTS

The initial set of quadratic weights was chosen as follows. The weighting matrix was chosen to be diagonal with constant elements for the in-flight portion of the index. The weight q_{ii} (t) was defined by

$$q_{ii}(t) = (r_i^*)^{-2}$$

where

$$r_i^* = \sum_{j=1}^{4} \max_t |\bar{r}_{ij}(t)| + \max_t 3\sigma_{r_{ij}}(t)$$

with r_{ij} denoting the ith response for the jth controller of Reference 4. The terminal weights on y and $\dot{y}$ were defined in the same fashion. In the controllers of Reference 4 the ailerons were constrained to be inactive, so the corresponding r_i* was undefined. The weights for δa and $\delta \dot{a}$ were chosen to be smaller than the weights for δr and $\delta \dot{r}$ since the limits on δa and $\delta \dot{a}$ were larger than the limits for δr and $\delta \dot{r}$.

The succeeding four sets of weights were constrained to be constant. In each of these iterations the weight on $\bar{q}\beta$ was increased. Relative weights on δp and δa were varied. The major conclusion from these iterations was that constant weights would be inadequate. These iterations also served as "debugging" runs for the computer program and numerical model.

Time-varying weights were introduced in the sixth set of weights. A "normal" curve, centered at 75 sec,

$$e_1(t) = \exp[-(t-75)^2/145]$$

was multiplied by a constant and added to the weight on δp. The same modification, with different constants, was made to the δa and $\bar{q}\beta$ weights. At this point, we discovered that aileron data had not been converted from degrees to radians. Incorporating this correction, the next set of weights was chosen to reduce the weights on δp and δa and increase the weight on $\bar{q}\beta$. The time varying exponential was changed to

$$e_2(t) = \exp[-(t-75)^2/578]$$

The resulting controller reduced $\bar{q}\beta$ to far below its expected limit at the expense of excessively exceeding actuator constraints.

The next five sets of weights were chosen to reduce actuator responses and permit $\bar{q}\beta$ to increase. The controller from the twelfth iteration exhibited a satisfactory mean response with the exception of the roll response, $\bar{\phi}$. Two succeeding iterations were made to reduce the roll response without significantly modifying the other responses.

For the first of these two iterations the "somewhat arbitrarily" chosen exponential

$$e_3(t) = \exp[-(t-65)^2/140]$$

was used to add weight to roll angle response. The roll responses from this thirteenth iteration and the previous iteration were then plotted as shown in Figure 2. The time varying weight on roll angle,

$$q_\phi(t)_{13} = 10 + 30\ e_3(t)*$$

is superimposed on the responses. We noted that the exponential weight caused a nearly perfect reflection or inversion of the peak in the variance,

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*The subscript 13 denotes iteration number.
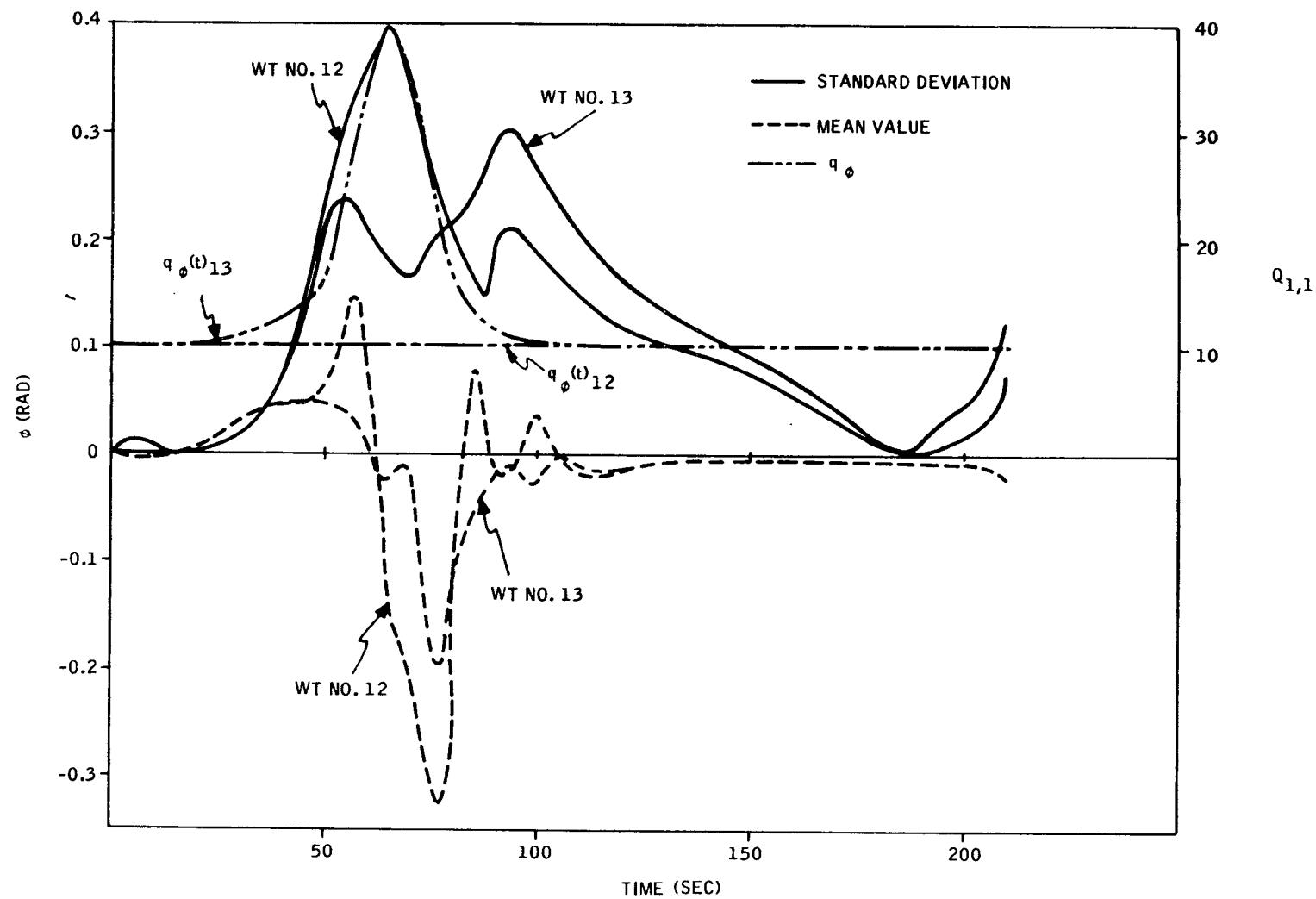
Figure 2. Effect of First Roll Weight on Roll Response

σ_ϕ. We then decided a much better fit to the original variance $\sigma_\phi(t)_{12}$ would be

$$q_\phi(t)_{14} = 10 + 30\, e_4(t) + 15 e_5(t)$$

where

$$e_4(t) = \exp[-(t-65)^2/300]$$

and

$$e_5(t) = \exp[-(t-95)^2/140]$$

This weighting function is superimposed on the roll responses of the twelfth and fourteenth iterations in Figure 3. This figure clearly indicates the desired effectiveness of the second exponential in the weighting function in reducing $\sigma_\phi(t)$. In addition the mean response $\bar{\phi}(t)$ was significantly improved. Its magnitude was reduced by more than a factor of two, and this mean response was deemed acceptable. In this iteration one other modification of the weights was made. The mean responses of $\bar{q}\beta$, δp, and δa had peak magnitudes at approximately 70 sec in the twelfth and thirteenth iterations. Thus, the peak of the exponential function used to weight these responses was shifted from 75 to 70 sec; i.e., $e_2(t)$ was replaced by

$$e_6(t) = \exp[-(t-70)^2/578]$$

The changes in peak responses of $\bar{q}\beta$, δp, δr, and δa were almost imperceptible.

All of the mean responses of the fourteenth iteration were acceptable. But the covariance responses for this iteration, when combined with the mean responses, were not acceptable. In particular, the responses σ_ϕ, $\sigma_{\delta p}$, $\sigma_{\delta r}$, $\sigma_{\delta a}$, and σ_{a_y} were too large. Exponentials were added to the corresponding weights for the fifteenth and final iteration. Desired covariance responses were achieved. However, the mean responses deteriorated from the fourteenth iteration to unacceptable levels in combination with the fifteenth iteration covariance responses. The combination of fourteenth iteration mean responses and fifteenth iteration covariance responses was acceptable. The corresponding controller was considered to be optimal even though "fine-tuning" of the weights could have given slightly improved results.

Detailed quantitative data for the iterations are given in Tables 3 and 4. The quadratic weights are listed in Table 3. Mean responses and response standard deviations are briefly summarized in Table 4.

The optimal controller may be written as the sum of a mean controller and a covariance controller in the form

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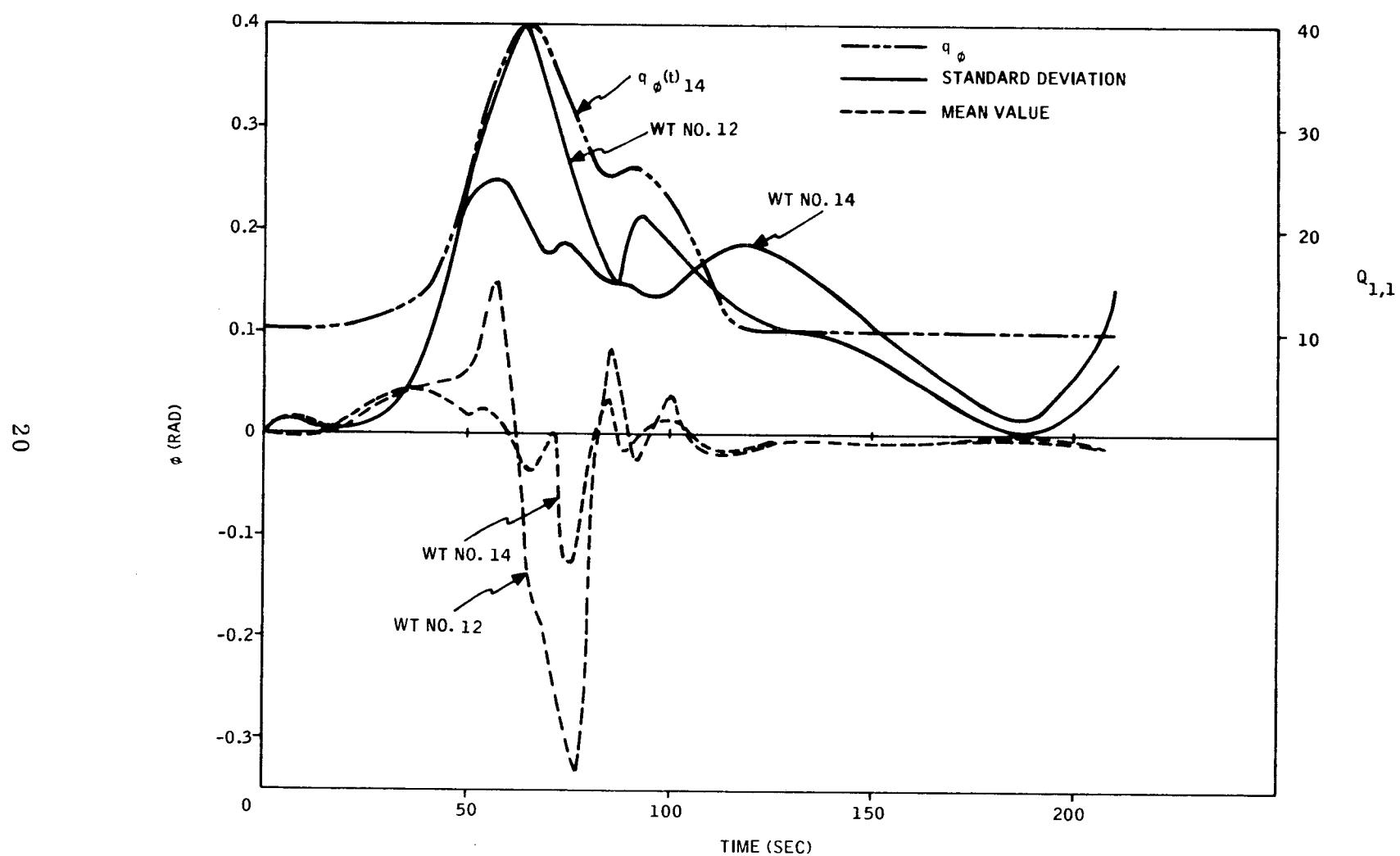
Figure 3. Effect of Second Roll Weight on Roll Response

Table 3. Quadratic Weights for Iteration 1 to 15

In-Flight Weights

| Response \ Iteration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
φ	100	100	100	100	100	10	10	10	10	10	10	40	$10+30e_3(t)$	$10+30e_4(t)+15e_5(t)$	$10+30e_4(t)+15e_5(t)+10e_7(t)$
$\dot{\varphi}$	80	80	80	100	100	10	10	10	10	10	10	40	10	10	10
y	0	10^{-12}	10^{-12}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}
$\dot{y}$	0	10^{-12}	10^{-12}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}	10^{-14}
δ_p	0.7	0.7	1.4	5	50	$50+100e_1(t)$	$50+100e_2(t)$	$50+100e_2(t)$	$50+100e_2(t)$	$200+400e_2(t)$	$2000+4000e_2(t)$	$8000+16000e_2(t)$	$2000+4000e_2(t)$	$2000+4000e_6(t)$	$2000+4000e_6(t)+20000e_8(t)$
$\dot{\delta}_p$	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	50	200	2000	8000	2000	2000	2000
δ_r	5	5	5	5	5	5	5	5	5	20	200	800	200	200	200
$\dot{\delta}_r$	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	5	20	200	800	$200+200e_2(t)$	$200+220e_6(t)$	$200+220e_6(t)+80e_1(t)$
δ_a	1	10^{-2}	0.25×10^{-2}	0.05	0.1	$0.02+100e_1(t)$	$0.2+0.4e_2(t)$	$20+40e_2(t)$	$10+20e_2(t)$	$40+80e_2(t)$	$400+800e_2(t)$	$1600+3200e_2(t)$	$400+800e_2(t)$	$400+800e_6(t)$	$400+800e_6(t)+4000e_8(t)$
$\dot{\delta}_a$	10^{-3}	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10	40	400	1600	400	400	400
$\bar{q}\beta$	10^{-5}	2×10^{-5}	4×10^{-5}	10^{-4}	10^{-3}	$10^{-3}+100e_1(t)$	$10^{-3}+30e_2(t)$	$10^{-3}+30e_2(t)$	$10^{-3}+0.3e_2(t)$	$10^{-3}+0.3e_2(t)$	$10^{-3}+0.3e_2(t)$	$4\times10^{-3}+1.2e_2(t)$	$10^{-3}+0.3e_2(t)$	$10^{-3}+0.3e_6(t)$	$10^{-3}+0.3e_6(t)$
$\bar{q}\dot{\beta}$	10^{-5}	2×10^{-5}	2×10^{-5}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-5}	10^{-6}	10^{-6}	10^{-6}
a_y	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	$2\times10^{-4}+10^{-3}e_9(t)$
$\dot{a}_y$	2×10^{-7}	2×10^{-7}	2×10^{-7}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-8}

$$e_1(t)=e^{\frac{-(t-75)^2}{140}} \quad e_3(t)=e^{\frac{-(t-65)^2}{140}} \quad e_5(t)=e^{\frac{-(t-95)^2}{140}} \quad e_7(t)=e^{\frac{-(t-55)^2}{200}}$$

$$e_2(t)=e^{\frac{-(t-75)^2}{578}} \quad e_4(t)=e^{\frac{-(t-65)^2}{300}} \quad e_6(t)=e^{\frac{-(t-70)^2}{578}} \quad e_8(t)=e^{\frac{-(t-70)^2}{300}} \quad e_9(t)=e^{\frac{-(t-185)^2}{140}}$$

Terminal Weights

Response \ Iteration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
y	4×10^{-10}	4×10^{-8}	4×10^{-8}	4×10^{-8}	4×10^{-8}	4×10^{-6}	4×10^{-6}	4×10^{-7}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
$\dot{y}$	6×10^{-6}	6×10^{-4}	6×10^{-4}	10^{-4}	10^{-4}	10^{-2}	10^{-2}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
a_y	0	0	0	0	0	0	0	0	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
$\dot{a}_y$	0	0	0	0	0	0	0	0	10^{-8}	10^{-8}	10^{-8}	2×10^{-8}	10^{-8}	10^{-8}	10^{-8}

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Table 4. Peak Response Values for Iterations 5 to 15

Iterations	Responses	φ rad	$\dot\varphi$ rad/sec	y ft	$\dot y$ ft/sec	δp rad	$\delta\dot p$ rad/sec	δr rad	$\delta\dot r$ rad/sec	δa rad	$\delta\dot a$ rad/sec	$\bar q\beta$ psf rad	$\bar q\dot\beta$ psf rad/sec	a_y^* ft/sec^2	$\dot a_y$ ft/sec^3
5	$\bar R$	0.1838E-2	0.9284E-3	-0.2629E+4	-0.4835E+2	-0.1233E+0	0.1280E-1	0.2787E-1	0.9859E-2	-0.6995E+0	0.7660E-1	0.5120E+2	-0.2072E+1	-0.8225E+1	-0.2228E+2
	$T_{\bar R}$	70	210	120	71	76	87	80	210	77	91	71	75	210	210
	$\bar\sigma_R$	0.2531E-2	0.1622E-2	0.2342E+4	0.3482E+2	0.3449E-1	0.2754E-1	0.8788E-2	0.6916E+1	0.2131E+0	0.1046E+0	0.2223E+2	0.4108E+1	0.9946E+1	0.2665E+2
	$T_{\bar\sigma_R}$	75	76	172	121	76	76	80	76	85	85	71	80	210	210
6	$\bar R$	-0.3982E+0	-0.9802E-1	-0.2253E+4	-0.4467E+2	-0.1276E+0	0.1520E-1	0.2806E-1	0.2310E-1	-0.3549E+0	0.4329E-1	0.5219E+2	-0.2109E+1	-0.1807E+2	-0.5059E+2
	$T_{\bar R}$	77	71	95	56	75	90	80	210	75	95	70	75	210	210
	$\bar\sigma_R$	0.1645E+0	0.3693E-1	0.2244E+4	0.4999E+2	0.4912E-1	0.1916E+0	0.3307E-1	0.4890E+0	0.1454E+0	0.3400E+0	0.2111E+2	0.6556E+1	0.1233E+3	0.4718E+3
	$T_{\bar\sigma_R}$	72	78	142	175	75	75	210	80	85	75	70	80	210	80
7	$\bar R$	0.2056E+0	0.8750E-1	-0.7381E+4	-0.1681E+3	0.2002E-1	-0.3570E-1	0.8345E-1	-0.7531E-1	-0.1044E+1	0.1538E+0	0.4259E+1	0.3266E+1	0.5743E+2	0.1731E+3
	$T_{\bar R}$	84	82	92	60	98	100	70	31	71	71	157	85	210	210
	$\bar\sigma_R$	0.9781E+0	0.6670E+0	0.1012E+5	0.2655E+3	0.3526E+0	0.2446E+1	0.2645E+0	0.1432E+2	0.8048E+1	0.2524E+3	0.1683E+2	0.2666E+2	0.1624E+4	0.4723E+4
	$T_{\bar\sigma_R}$	54	75	156	182	210	75	75	75	75	75	152	75	210	210
8	$\bar R$	0.1997E+0	-0.5984E-1	-0.7239E+4	-0.1652E+3	-0.3354E+0	0.6683E-1	0.8300E-1	-0.8054E-1	-0.4798E+0	0.8433E-1	0.4537E+1	0.3508E+1	0.3414E+2	0.9470E+2
	$T_{\bar R}$	84	85	91	60	70	85	70	31	70	95	157	95	210	210
	$\bar\sigma_R$	0.9483E+0	0.1821E+0	0.1429E+5	0.2475E+3	0.1870E+0	0.6111E+1	0.3737E+0	0.2019E+2	0.3329E+0	0.8963E+1	0.1701E+2	0.2386E+2	0.5809E+3	0.2244E+5
	$T_{\bar\sigma_R}$	55	31	162	139	70	76	75	75	85	85	153	75	75	75
9	$\bar R$	-0.6722E-1	-0.3167E-1	-0.7070E+4	-0.1639E+3	-0.2246E+0	0.3505E-1	0.8113E-1	-0.1344E-1	-0.6644E+0	0.7528E-1	0.3558E+1	0.3330E+1	0.1076E+2	-0.1313E+2
	$T_{\bar R}$	76	73	91	60	70	72	70	96	70	72	147	95	95	70
	$\bar\sigma_R$	0.4360E+0	0.6524E-1	0.1186E+5	0.2746E+3	0.7932E-1	0.5860E-1	0.4631E-1	0.5347E+0	0.2533E+0	0.1618E+0	0.2368E+2	0.1425E+2	0.6105E+2	0.7354E+3
	$T_{\bar\sigma_R}$	58	51	148	179	70	70	75	75	70	70	138	75	76	75
10	$\bar R$	-0.1091E+0	-0.4145E-1	-0.6714E+4	-0.1574E+3	-0.2125E+0	0.3180E-1	0.7711E-1	-0.1029E-1	-0.6239E+0	0.6494E-1	0.4698E+1	0.3204E+1	0.1048E+2	-0.1292E+2
	$T_{\bar R}$	76	74	91	60	70	73	75	86	70	72	70	90	95	65
	$\bar\sigma_R$	0.4382E+0	0.6009E-1	0.1029E+5	0.2397E+3	0.7416E-1	0.5035E-1	0.3726E-1	0.3169E+0	0.2332E+0	0.1332E+0	0.1812E+2	0.1254E+2	0.4484E+2	0.5093E+3
	$T_{\bar\sigma_R}$	58	52	150	181	70	70	75	75	70	70	138	75	76	76

Table 4. Peak Response Values for Iterations 5 to 15 (Concluded)

Responses / Iterations		φ rad	$\dot{\varphi}$ rad/sec	y ft	$\dot{y}$ ft/sec	δp rad	$\delta\dot{p}$ rad/sec	δr rad	$\delta\dot{r}$ rad/sec	δa rad	$\delta\dot{a}$ rad/sec	$\bar{q}\beta$ psf rad	$\bar{q}\dot{\beta}$ psf rad/sec	a_y* ft/sec^2	$\dot{a}_y$ ft/sec^3
11	$\bar{R}$	-0.3380E+0	0.9796E-1	-0.4741E+4	-0.1082E+3	-0.1328E+0	0.1684E-1	0.5906E-1	-0.7606E-2	-0.3830E+0	0.3020E-1	0.2632E+2	0.2909E+1	0.9425E+1	-0.1106E+2
	$T_{\bar{R}}$	77	81	92	58	70	85	75	88	71	84	70	95	95	73
	$\bar{\sigma}_R$	0.4103E+0	0.4984E-1	0.4833E+4	0.1133E+3	0.4468E-1	0.2761E-1	0.2242E-1	0.9437E-1	0.1373E+0	0.6874E-1	0.1349E+2	0.8518E+1	0.2163E+2	0.1687E+3
	$T_{\bar{\sigma}_R}$	64	61	155	187	70	70	75	76	71	71	70	80	188	80
12	$\bar{R}$	-0.2002E+0	0.9785E-1	-0.4775E+4	-0.1086E+3	-0.1327E+0	0.1682E-1	0.5909E-1	-0.7606E-2	-0.3831E+0	0.3016E-1	0.2632E+2	0.2919E+1	0.9462E+1	-0.1413E+2
	$T_{\bar{R}}$	69	81	92	58	70	85	75	88	71	84	70	95	95	71
	$\bar{\sigma}_R$	0.3959E+0	0.4746E-1	0.6373E+4	0.9988E+2	0.4479E-1	0.2754E-1	0.2259E-1	0.9561E-1	0.1376E+0	0.6839E-1	0.1345E+2	0.8569E+1	0.3030E+2	0.1760E+3
	$T_{\bar{\sigma}_R}$	64	61	162	126	70	70	75	76	71	70	70	80	195	81
13	$\bar{R}$	-0.2140E+0	0.7543E-1	-0.4880E+4	-0.1133E+3	-0.1335E+0	0.1676E-1	0.5935E-1	-0.7718E-2	-0.3852E+0	0.3047E-1	0.2631E+2	-0.2889E+1	0.9100E+1	-0.1456E+2
	$T_{\bar{R}}$	77	81	92	60	70	85	75	88	71	84	70	72	95	71
	$\bar{\sigma}_R$	0.2962E+0	0.4066E-1	0.6050E+4	0.1414E+3	0.4437E-1	0.2631E-1	0.2162E-1	0.7125E-1	0.1362E+0	0.6545E-1	0.1374E+2	0.8212E+1	0.2682E+2	0.1252E+3
	$T_{\bar{\sigma}_R}$	90	51	155	187	70	71	75	76	71	71	70	80	188	81
14	$\bar{R}$	-0.1477E+0	0.5094E-1	-0.4898E+4	-0.1130E+3	-0.1343E+0	0.1668E-1	0.5929E-1	-0.7813E-2	-0.3865E+0	0.3154E-1	0.2610E+2	-0.2815E+1	0.9059E+1	-0.1085E+2
	$T_{\bar{R}}$	77	80	90	59	70	84	75	88	71	83	70	72	95	74
	$\bar{\sigma}_R$	0.2533E+0	0.3948E-1	0.7060E+4	0.1651E+3	0.4446E-1	0.2662E-1	0.2141E-1	0.6838E-1	0.1358E+0	0.6523E-1	0.1371E+2	0.8090E+1	0.3136E+2	0.1164E+3
	$T_{\bar{\sigma}_R}$	55	51	155	187	70	70	75	76	71	70	70	76	188	80
15	$\bar{R}$	-0.2661E+0	0.7984E-1	-0.2948E+4	-0.6420E+2	-0.6166E-1	0.1073E-1	0.3574E-1	-0.5922E-2	-0.1896E+0	0.1559E-1	0.3814E+2	-0.2968E+1	0.7865E+1	-0.1276E+2
	$T_{\bar{R}}$	77	81	82	72	75	85	77	88	75	90	75	75	75	71
	$\bar{\sigma}_R$	0.1669E+0	0.3674E-1	0.4175E+4	0.8506E+2	0.2168E-1	0.1763E-1	0.1382E-1	0.4649E-1	0.6868E-1	0.4470E-1	0.1966E+2	0.6445E+1	0.5474E+1	0.8283E+2
	$T_{\bar{\sigma}_R}$	61	80	153	189	75	75	80	80	76	75	70	81	85	85

$\bar{R}$ = Peak mean response

$T_{\bar{R}}$ = Time of peak mean response occurrence

$\bar{\sigma}_R$ = Peak standard deviation

$T_{\bar{\sigma}_R}$ = Time of peak standard deviation occurrence

*The values for the responses a_y and $\dot{a}_y$ listed for the first 14 iterations were computed incorrectly. The terms $u_o r - w_o p - g (\psi s\theta_o + \phi c\theta_o) + (\bar{x}_1 - 110) Q_o p + (\bar{z}_1 - 40) Q_o r$ were omitted from the expression for a_y during these iterations.

$$u_o(n) = \bar{u}(n) + K_{15}(n)\left[\chi(n) - \bar{\chi}(n)\right]$$

where

$$\bar{u}(n) = K_{14}(n)\,\bar{\chi}(n) + f_{14}(n) \text{ and}$$

$K_{14}(n)$ denotes the gain of the fourteenth iteration

$K_{15}(n)$ denotes the gain of the fifteenth iteration

$(\bar{\chi}n)$ denotes the mean state of the fourteenth iteration

Computer plots of the gain $K_{15}(n)$, the mean controller - $\bar{u}(n)$, and the responses $\bar{r}(n)$ and $\sigma_r(n)$ are given in Appendix A. Computer listing of the mean state $\bar{\chi}(n)$ also appear in Appendix A.

SENSITIVITY TO MODELING ASSUMPTIONS

Three assumptions made during the above iterations were (1) rolling gusts would have a second-order effect on controller design and optimal performance, (2) a sampling frequency of 20 samples per second was sufficient for design, and (3) gust penetration could play a major roll in controllers designed for flexible vehicles. Sensitivity of the controller design to each of these assumptions was investigated. It was found that the first two assumptions were valid, but that gust penetration could be ignored.

The computer time for one iteration in the optimization process is directly proportional to sampling frequency and proportional to the cube of the order of the system. For our problem the model without rolling gusts is of twenty-second order including three side-gust penetration states. Increasing the order of the model from 22 to 24 to include rolling gusts represents an increase of 30 percent in computation time. Decreasing the order from 22 to 19 by eliminating side-gust penetration yields a decrease of 36 percent in computation time. Thus, these issues significantly effect the computation cost of the controller design.

To test the first assumption we added the rolling gusts to the model and performed the optimization with the fifteenth weight set. The mean rolling gust was zero, so that only covariances would change. The gains for the twenty-fourth order system agreed to within 1 percent of those for the twenty-second order system, except that new gains were defined for the rolling gust and rolling-gust penetration states. There were some changes in the responses and states. The major changes were changes in $\sigma_{\dot{\eta}i}$ of up to 120 percent and a 32 percent change in σ_{a_y}. Actual changes in the other response standard deviations were less than 1 percent. Thus, it is sufficient to neglect rolling gusts for controller synthesis via iterations on quadratic weights for this vehicle. Accurate analysis seems to require, however, the inclusion of rolling gusts.

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The second assumption was tested by performing controller optimization with a sample rate of 50 samples per second for the fifteenth set of quadratic weights and with rolling gust excluded. General agreement with the 20 samples per second results was found. But there were some significant differences. For example, some flexure gains were markedly different. Even the roll feedback to the yaw rate actuator and the yaw rate feedback to the aileron displayed significant differences for the two sample rates. The responses also differed. But these differences were slight (less than 10 percent) even though some flexure standard deviations changed by as much as 40 percent. The rate of 20 samples per second appears sufficient for controller synthesis* and implementation since the major contributors to the value of the performance index showed little change. This conclusion must be considered as tentative since it is based on only two data points. Verification of this conclusion or a priori determination of minimum adequate sample rate should be pursued in the future. Quantitative data computed with the two sample rates are displayed in Appendix B.

We performed the following test to examine the importance of the gust penetration. A nineteenth order system was constructed from the twenty-second order system by eliminating the gust penetration from the model. An optimal controller was computed for the resulting nineteenth order system with the fifteenth set of quadratic weights and the sample frequency of 20 samples per second. The gains on rigid-body, flexure and actuator states for this system were within 5 percent of the corresponding gains for the twenty-second order system. Similar agreement was found for the wind-state gains and the deterministic inputs of the nineteenth order system with corresponding gains and inputs computed from the twenty-second order system gains and the assumption of no gust penetration.** The responses for the derived nineteenth

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*Adequacy of this low sample rate for synthesis for the problem considered is contingent on the use of an accurate difference equation representation for the system.

**The assumption of no gust penetration for the twenty-second order system is that

$$x_i = \bar{v} + \sigma_w \omega, \ i = 1, 2, 3$$

Thus the appropriate modification of the controller is to replace

$k_{i,20}$ by $k_{i,20} + \sigma_w \sum_{j=i}^{3} k_{i,j+17}$ and to replace f_i by $f_i + \bar{v} \sum_{j=i}^{3} k_{i,j+17}$

since ω is the twentieth state and x_i is the $(i+17)^{th}$ state.

order system differed by less than 10 percent from the corresponding responses of the twenty-second order system. The corresponding peaks of the actuator responses and $\bar{q}\beta$ response differed by less than 4 percent. We concluded from these agreements that for this vehicle gust penetration effects were negligible.

These investigations of sensitivity of the controller design to modeling assumptions indicate that rolling gusts are of second-order importance as expected, that the sample frequency of 20 sample per second was adequate, and surprisingly that gust penetration is of second-order importance. Questions of

- What is an a priori minimum sample frequency that is adequate for controller synthesis and analysis? and

- For what problems can rolling gusts and or gust penetration be neglected in controller synthesis?

have not been answered. This study has provided only some data points related to these questions. But their strong influence on the cost as well as the validity of the controller synthesis clearly recommend them as areas for future study.

SECTION IV

SIMPLIFIED CONTROLLER DESIGN

The goal of this phase of the design task is to choose a realistic sensor complement which provides a measurement vector,

$$m = M\chi + N\bar{v} \tag{19}$$

and find a controller of the form

$$u_s = K_s m + f_s \tag{20}$$

which minimizes the performance index. A sensor complement was chosen, an initial controller of the proper form was found, and initial application of the gradient method was performed. We demonstrated with one gradient step that improvement could be achieved. Choice of the proper step-size was found to be critical. Therefore, we concluded our study by investigating the use of a time-varying step-size. Investigation of the proper time-varying step-size by restricting attention to subintervals of the total interval of flight did significantly reduce the computer time required. But our results indicated that additional accelerometers would be required to realize approximately optimal performance. The contract resources did not permit further investigation in this direction.

THE MEASUREMENT VECTOR

An initial set of measurements was chosen to consist of the three actuator positions; the inertial side displacement, y; its rate, ẏ; roll angle, φ; its rate, φ̇; and outputs of yaw and yaw rate gyros and a lateral accelerometer. The accelerometer, the yaw gyro, and the yaw rate gyro were assumed located in the booster cockpits at the point $(91.7', 0, 4.2')$ in the No. 1 coordinate system of Reference 2. As shown in Figures 5-10 of Reference 2, the normalized bending mode displacements and slopes are generally quite large at this point. The major exception is that the displacement and slope of the fourth bending mode are small during the early portion of flight.

This measurement vector was augmented with three additional sensor outputs. These sensors were a lateral accelerometer, a yaw gyro, and a yaw rate gyro. The gyros were located in the booster at the point $(222.2', 0, 0)$. The lateral accelerometer was located at the point $(166.6', 0, 0)$. These points are given in the No. 1 coordinate system of Reference 2. These locations were chosen to provide small mode displacements at the accelerometer location and small mode slopes at the location of the gyros.

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The resulting measurement vector may be written as

$$m = MX + N\bar{v}$$

where the M matrix for the nineteenth order system and the N vector are:

p	r	v	φ	ψ	y	$\dot{\eta}_1$	η_1	$\dot{\eta}_2$	η_2	$\dot{\eta}_3$	η_3	$\dot{\eta}_4$	η_4	δp	δr	δa			$\bar{v}$
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	$-w_o$	u_o	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	$-Q_o$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	$m_{8,8}$	0	$m_{8,10}$	0	$m_{8,12}$	0	$m_{8,14}$	0	0	0	0	0	0
0	1	0	Q_o	0	0	$m_{9,7}$	0	$m_{9,9}$	0	$m_{9,11}$	0	$m_{9,13}$	0	0	0	0	0	0	0
$m_{10,1}$	$m_{10,2}$	$m_{10,3}$	$m_{10,4}$	$m_{10,5}$	0	$m_{10,7}$	$m_{10,8}$	$m_{10,9}$	$m_{10,10}$	$m_{10,11}$	$m_{10,12}$	$m_{10,13}$	$m_{10,14}$	$m_{10,15}$	$m_{10,16}$	$m_{10,17}$	0	$m_{10,19}$	n_{10}
0	0	0	0	1	0	$m_{11,7}$	$m_{11,8}$	0	$m_{11,10}$	0	$m_{11,12}$	0	$m_{11,14}$	0	0	0	0	0	0
0	1	0	Q_o	0	0	$m_{12,7}$	0	$m_{12,9}$	0	$m_{12,11}$	0	$m_{12,13}$	0	0	0	0	0	0	0
$m_{13,1}$	$m_{13,2}$	$m_{13,3}$	$m_{13,4}$	$m_{13,5}$	0	$m_{13,7}$	$m_{13,8}$	$m_{13,9}$	$m_{13,10}$	$m_{13,11}$	$m_{13,12}$	$m_{13,13}$	$m_{13,14}$	$m_{13,15}$	$m_{13,16}$	$m_{13,17}$	0	$m_{13,19}$	n_{13}

The coefficients of the flexure states in the gyro outputs are

$$m_{8+3j,\,6+2i} = m_{9+3j,\,5+2i} = \frac{\partial Y_i}{\partial x_1} \quad \text{for } i = 1,\,2,\,3,\,4,\quad j = 0,\,1$$

with the partial derivatives evaluated at $x_1 = 91.7'$ and $z_1 = 0$ for $j = 0$ and at $x_1 = 222.2'$ and $z_1 = 0$ for $j = 1$. The coefficients in the accelerometer outputs are:

$$m_{10+3j} = [z_1 - \bar{z}_1,\ \bar{x}_1 - x_1,\ 1, 0, 0, 0, Y_1, 0, Y_2, 0, Y_3, 0, Y_4, 0, 0, 0, 0, 0, 0]A$$

$$+ [-w_o + Q_o(\bar{x}_1 - x_1),\ u_o + Q_o(\bar{z}_1 - z_1),\ 0, -gc\theta_o, -gs\theta_o, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]$$

$$n_{10+3j} = [z_1 - \bar{z}_1,\ \bar{x}_1 - x_1,\ 1, 0, 0, 0, Y_1, 0, Y_2, 0, Y_3, 0, Y_4, 0, 0, 0, 0, 0, 0]B_2$$

with $x_1 = 91.7'$, $z_1 = 4.2'$ for $j = 0$, and $x_1 = 166.6'$ and $z_1 = 4.2'$ for $j = 1$, where A and B_2 are the coefficient matrices of the state vector differential equations of motion (1). The remaining notation is consistent with the definitions in Reference 2. The terms $\bar{x}_1$ and $\bar{z}_1$ denote coordinates of the center of mass; u_o, w_o, Q_o, and θ_o denote trajectory parameters; $c\theta_o$ and $s\theta_o$ denote $\cos\theta_o$ and $\sin\theta_o$; and Y_i denotes the ith normalized bending mode shape.

Numerical values for the coefficients are listed in Appendix C. For computational convenience the matrix M was slightly modified. The states φ, δp, δr, and δa are each assumed to be measured independently. The contributions of these states to the other measurements were eliminated by setting the corresponding coefficients to zero. The modified matrix was denoted by M_o.

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This matrix is equivalent to the original matrix M in the sense that a controller of the form

$$u = KM\chi + KN\bar{v}$$

may be written as

$$u = K_o M_o \chi + K_o N\bar{v}$$

The relation between K_o and K is

$$(K_o)_{ij} = (K)_{ij} \quad \text{for } i = 1, 2, 3; \; j \neq 6, 15, 16, 17$$

$$(K_o)_{i6} = \sum_{\ell=1}^{13} (K)_{i\ell} (M)_{\ell 4}, \quad i = 1, 2, 3$$

$$(K_o)_{ij} = \sum_{\ell=1}^{13} (K)_{i\ell} (M)_{\ell, j+14}, \quad i = 1, 2, 3; \; j = 1, 2, 3$$

This set of equations may be inverted to provide K as a function of K_o. Thus, simplification with respect to the measurement $m_o = M_o\chi + N_o\bar{v}$ is equivalent to simplification with respect to the measurement $m = M\chi + N\bar{v}$.

CHOICE OF INITIAL SIMPLIFIED CONTROLLER

The first attempt to find a simplified controller was made with the first 10 measurements. A gain matrix for this set of measurements was computed as a "least-square" fit to the gain matrix of the optimal controller. This may be stated mathematically as follows.

Let K* denote the gain matrix of the optimal controller, and let M and K denote the measurement matrix and associated gain matrix, respectively. Then the "least-square" fit to K* is

$$K = K^* M' (MM')^{-1} \tag{21}$$

This gain matrix K minimizes the "square-of-the-error"

$$e^2 = \text{tr} \left[(KM - K^*) (KM - K^*)' \right]$$

The closed-loop system was found to be violently unstable when computation of the response covariance matrix was attempted.

The measurement vector was augmented with three more sensors. A "least-square" gain matrix of the form (21) was computed for the resulting thirteenth-order measurement vector. The eigenvalues of the closed-loop matrix were computed for five points along the trajectory. The points correspond to times of 10, 45, 75, 145, and 210 sec after liftoff. Rigid body instabilities were apparent at the 145- and 210-sec points. Eigenvalues of the closed-loop system with the gain matrix reduced uniformly by a factor of two exhibited similar characteristics. The extent of instability was less, but still intolerable.

At this point the gain matrix for the simplified controller was chosen to be of the form

$$K_o M_o = K_1 M_1 + \alpha \hat{K} \tilde{M} \tag{22}$$

where M_1 is the 4 x 19 matrix consisting of the first four rows of M, α is a scalar parameter, and $\tilde{M}$ is the last m-4 rows of the (m x 19) M_o matrix. The matrix, K_1, was chosen such that the gains on the displacement, y, and the three actuators, δp, δr, and δa, for the simplified controller were equal to the corresponding gains of the optimal controller. For $\alpha = 0$, the closed-loop system exhibited slight instabilities at all time points considered.

Attempting to find a suitably stable initial controller, we tried eliminating the "feed-forward" gain on the wind state, ω, from the least-square fitting, i.e., we set

$$K = K* \hat{M}' \ (\hat{M} \hat{M}')^{-1} \tag{23}$$

with $\hat{M}$ derived from $\tilde{M}$ by setting the nineteenth column of $\tilde{M}$ to zero.

This is equivalent to choosing $\hat{K}$ to minimize the "square-of-the-error"

$$e^2 = tr \ (K \tilde{M} - K*) \ W \ (K \tilde{M} - K*)'$$

with $W = \begin{bmatrix} I_{18} & 0 \\ 0 & 0 \end{bmatrix}$. The closed-loop system with $\alpha = 0.5$ was highly unstable at t = 145 and 210 sec.

Comparison of $K_o M_o$ with K* showed that the gains on the rigid body state, v, differed most significantly. There was little difference in the first 40 sec of flight. But after that the difference grew larger throughout the flight. This was attributed to the velocity term, u_o, appearing as the coefficient of r in the fifth measurement. The fifth measurement was eliminated, and the

resulting $\hat{K}$ was computed according to Equation (23). This gain gave a satisfactorily stable controller with $\alpha = 1.0$. The resulting controller served as the initial controller for the gradient method.

A similar attempt with the last three measurements deleted gave a satisfactorily stable controller at $\alpha = 0.3$. But for $\alpha = 0.7$ and $\alpha = 1.0$, the resulting controllers exhibited severe instabilities.

GRADIENT RESULTS

The state and response covariance matrices, the quadratic cost, and the gradient of the cost with respect to the (3x12) simplified gain matrix at the 43 five-second time points were computed. The quadratic cost of the initial simplified controller was 4792.5 compared to the corresponding cost of 3064 for the optimal controller. The peak value of $\sigma_{\bar{q}\beta}$ was 25.72 (psf rad) at 75 sec for the initial simplified controller, compared to 19.66 for the optimal controller.

An incremental gain, ΔK_O, was computed based on the gradient as follows:

$$(\Delta K_O)_{ij} = -\gamma_{ij} \left| (K)_{ij} \right| \frac{\partial H}{\partial K_{ij}}$$

with γ_{ij} taken to be a positive normalizing factor. Then gains in the "gradient direction" were computed with a step-size of ϵ as

$$K_{k+1, \epsilon} = K_k + \epsilon \, \Delta K_k \tag{24}$$

with the subscript k denoting the gradient iteration index. Controllers corresponding to $\epsilon = 1, 2, 10, 12, 20, 30$, and 60 were evaluated. Quantitative results for these controllers are given in Table 5. Steps with $\epsilon = 1$ and $\epsilon = 2$ were computed first. The value of 60 was the predicted minimum of the cost index assumed to be quadratic in ϵ. At $\epsilon = 60$ the vehicle hardly got off the ground. Based on this information, we tried $\epsilon = 10$ which gave slightly improved performance over that of the initial controller. Seeking larger improvement, we tried $\epsilon = 20$ which gave improved performance through the first 75 sec but much worse performance at 85 and 95 sec.

The value of $\epsilon = 12$ gave very minor improvement over that for $\epsilon = 10$. We chose this gain corresponding to $\epsilon = 12$ as the starting point for a new gradient direction with the hope that step-size choice might not be so critical in this iteration. However, the choice in the new direction was just as critical.

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Table 5. Performance as a Function of Step-Size

ε	J	$\sigma_{\ddot{q}\beta}$ (75) psf rad
0	4792.5	25.72
1	4792.3	25.72
2	4792.1	25.72
10	4787.7	25.70
12	4786.6	25.70
20	864213.2	25.66
30	Unstable at 80 sec	
60	Unstable at 5 sec	

For the second iteration, after experiencing instabilities near 75 sec, we decided to use a time-varying ε. In this way we could set ε equal to some value for $0 \le t \le 60$ and then change it on the interval $60 < t \le 90$. For $t > 90$ we could neglect the cost contribution if proper system behavior could be achieved on the interval between 60 and 90 sec. The gain was incremented with ε = 100 for the first 60 sec. The corresponding state and response covariances were computed on this interval. Investigation of step-size choice on the interval from 60 to 90 sec could then be performed using the covariance matrices at 60 sec as the initial values. However, even with a time varying ε we were unable to realize noticeable improvement in performance.

The major changes in gains occur in those associated with the accelerometers. These measurements have strong contributions from flexure states and rigid-body states. They also are the only measurements containing contributions from the wind states. It was concluded that the coupling of all these states in two accelerometer signals severely limits the capability of this simplified controller.

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APPENDIX A
QUANTITATIVE CHARACTERISTICS OF THE OPTIMAL CONTROLLER

This appendix consists of a graphical and tabular summary of the optimal controller characteristics. Figures A1 through A14 show the mean responses depicted with 0's and the response standard deviations depicted with X's.

Figures A15 through A77 display the gains for the covariance controller. These gains correspond to the system without side-gust penetration. Thus, $KV(i,j)$ denotes the $(i,j)^{th}$ element of the gain matrix, K. Such an element is the gain on the jth state for the ith actuator input for $j \leq 17$. The correspondence on actuators is $\delta p \sim 1$, $\delta r \sim 2$, and $\delta a \sim 3$. For $j > 17$, the gains correspond to the states: x for $j = 18$, ω for $j = 19$, x_4 for $j = 23$ and p_g for $j = 24$.

The remaining figures show the mean controller inputs, $\bar{u}$. The optimal control may be represented in terms of $\bar{u}$ and K as

$$u = \bar{u} + K(\chi - \bar{\chi})$$

Numerical values of $\bar{u}$ and $\bar{\chi}$ are given in Tables A1 and A2.

The final table in this appendix lists the eigenvalues of the closed-loop matrix $A + BK$ at five time points along the trajectory. This table indicates that the controller would yield stable "frozen-point" systems at the times considered.

Figure A1. Graph of ϕ versus Time
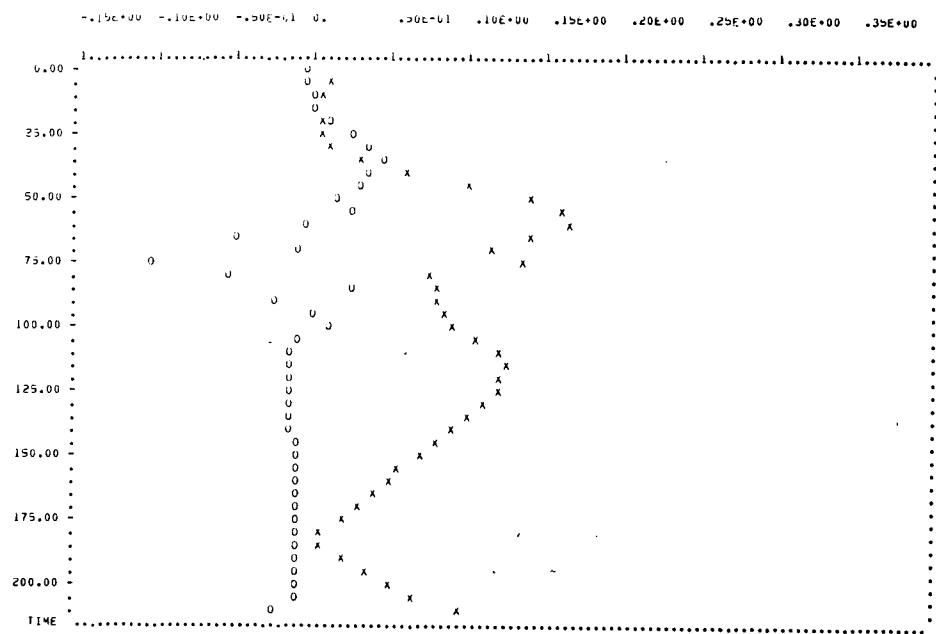
Figure A2. Graph of $\dot{\phi}$ versus Time
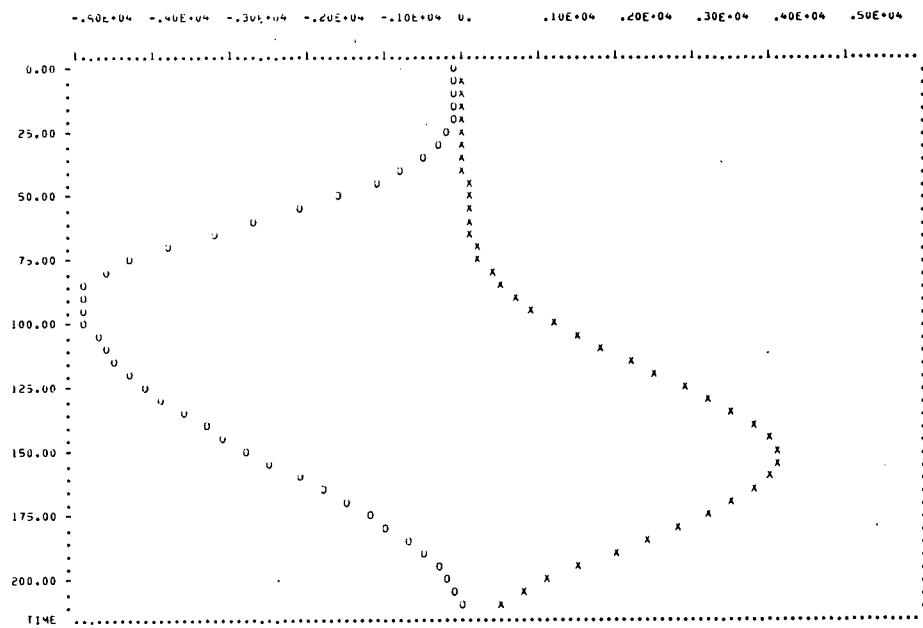
Figure A3. Graph of y versus Time
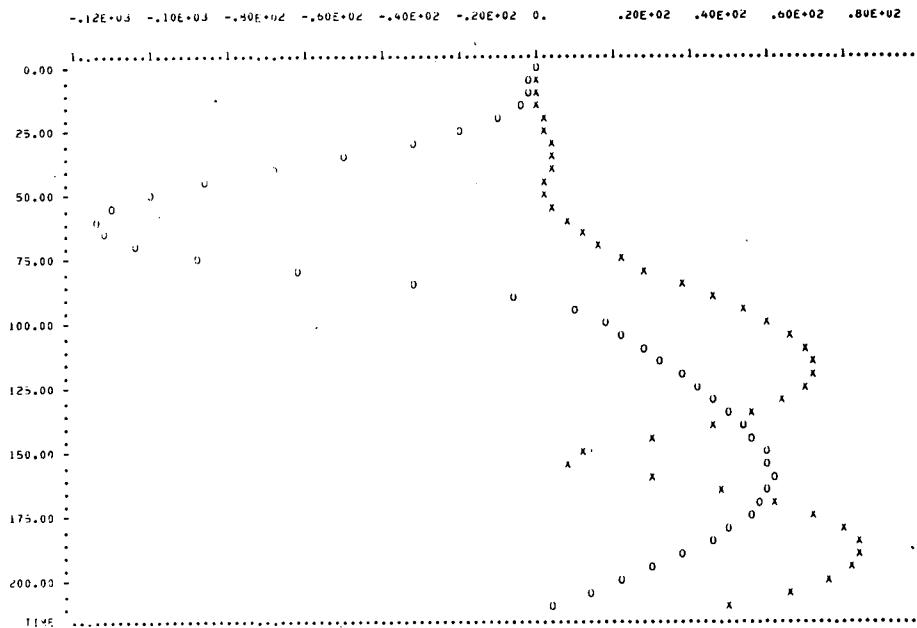

Figure A4. Graph of ẏ versus Time
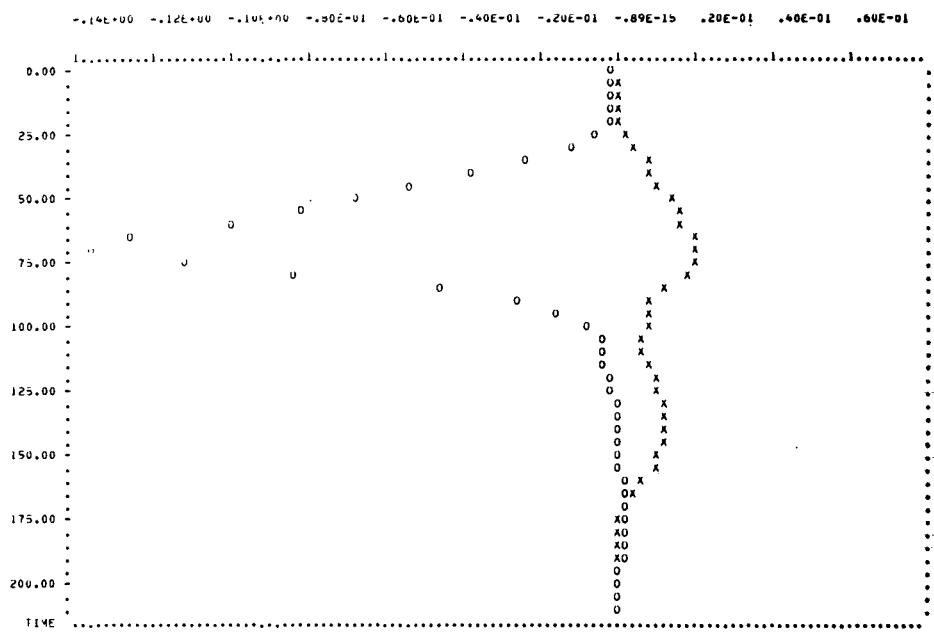
Figure A5. Graph of δp versus Time

Figure A6. Graph of δp versus Time

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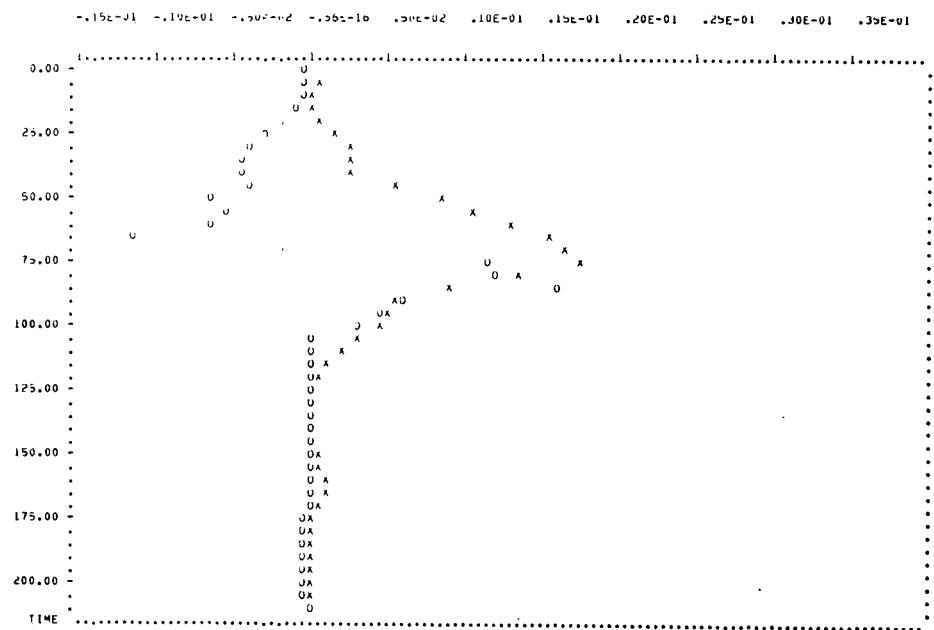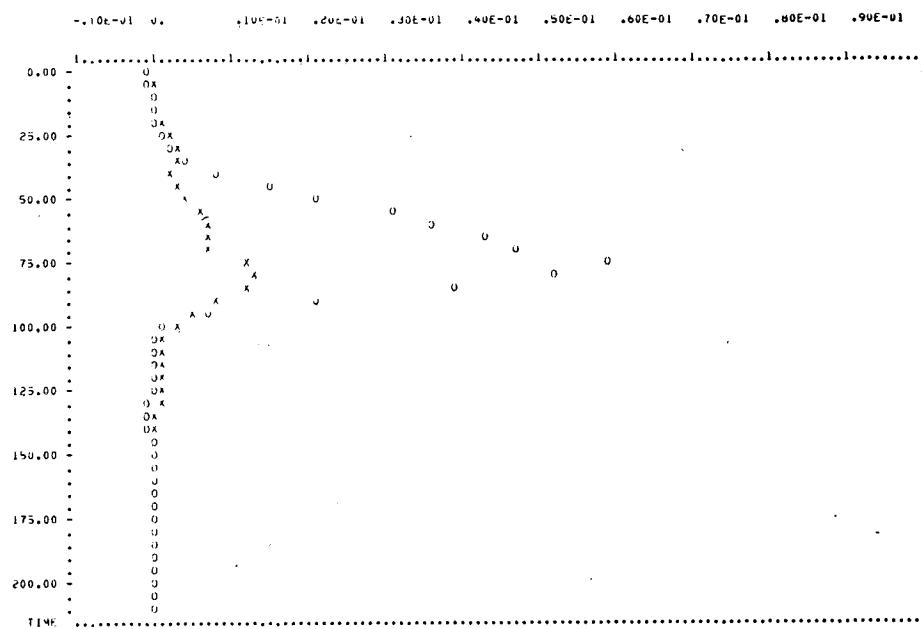
Figure A7. Graph of δr versus Time
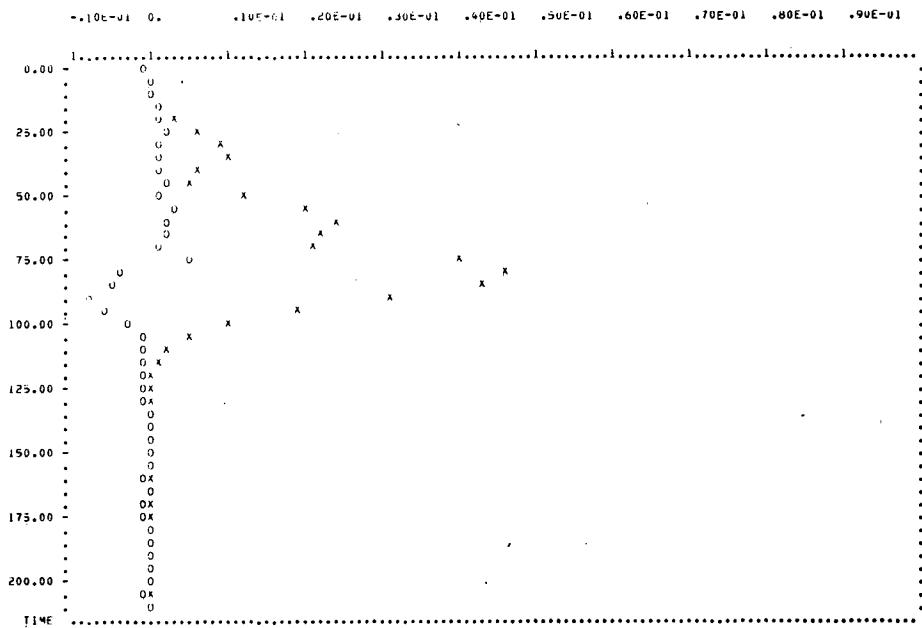
Figure A8. Graph of δr versus Time

Figure A9. Graph of δa versus Time
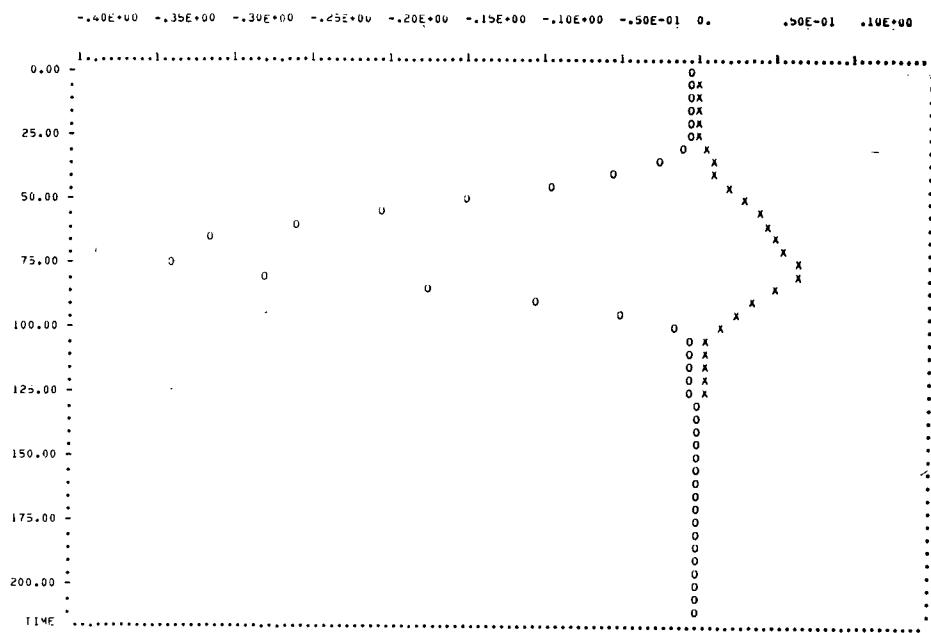
Figure A10. Graph of $\dot{\delta a}$ versus Time
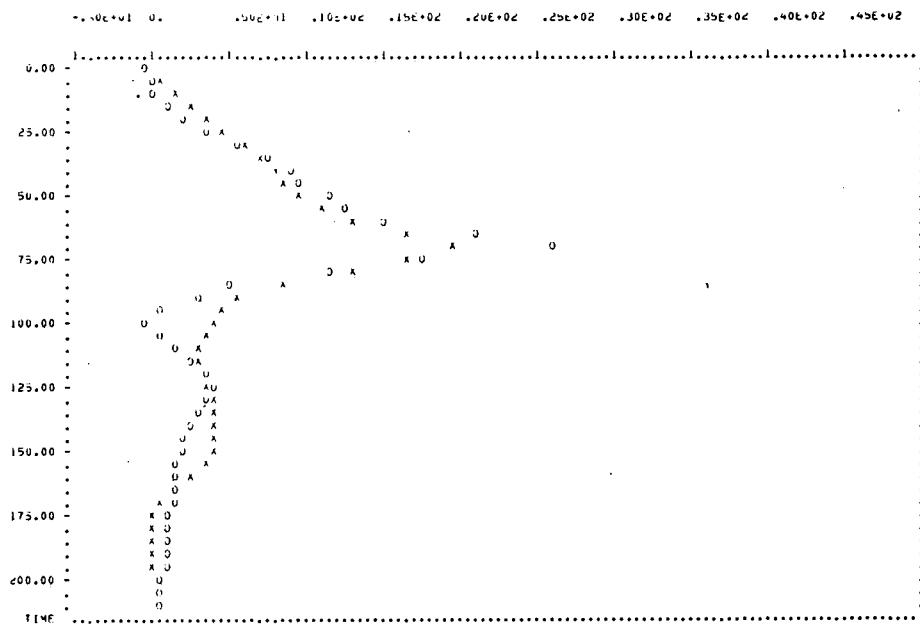
Figure A11. Graph of q̄β versus Time

Figure A12. Graph of q̄β versus Time

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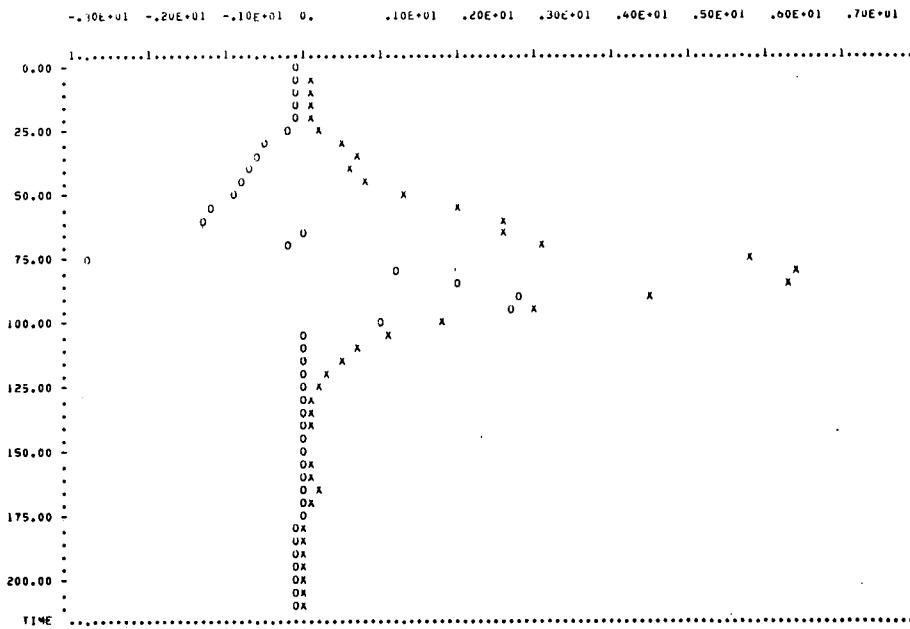
```
       I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........
  0.00 -    X
       .    0  X
       .    0X
       .    X
       .    0X
 25.00 -     0X
       .      0  X
       .      0X
       .      X    0
       .      X
 50.00 -      X        X         U
       .          X
       .             X      0
       .            X              0
       .            X                    0
 75.00 -            X           X                    0      0           U
       .                                   X   X0                            U
       .                      X      0       X
100.00 -       0          U        X
       .       0
       .        0   X
       .       U   X
125.00 -       0    X
       .       0    X
       .       0    X
       .       0      X
150.00 -       0      X
       .       0     X
       .       0  X
       .       0  X
175.00 -       0  X
       .       0  X
       .       0  X
       .       0  X
200.00 -       0  X
       .       U  X
       .        0X
  TIME .........................................................................................................
```
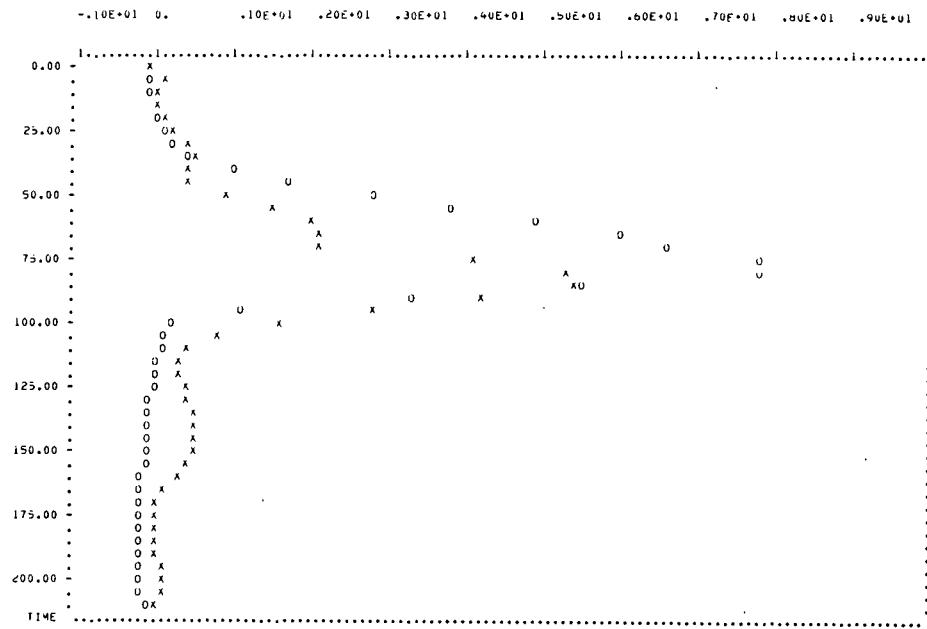
Figure A13. Graph of a_y versus Time

```
       I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........
  0.00 -         0X
       .         0X
       .         0X
       .         0X
       .         0  X
 25.00 -         0    X
       .         0       X
       .         0         X
       .        0       X
 50.00 -        0       X
       .      0   0          X
       .       0 0              X
       .     0                   X  X
 75.00 -     0                      X  X
       .     0                         X
       .        0              X                  X
       .          0                          X              X    X
100.00 -          U
       .          0        X            X
       .         0    X
       .         0  X
       .         0 X
125.00 -         0X
       .         X
       .         X
       .         U  X
       .         0  X
150.00 -         0X
       .         0X
       .         0X
       .         0X
       .         0X
175.00 -         0X
       .         0X
       .         0X
       .         0X
       .         0X
200.00 -         0X
       .         0X
       .         0X
  TIME .........................................................................................................
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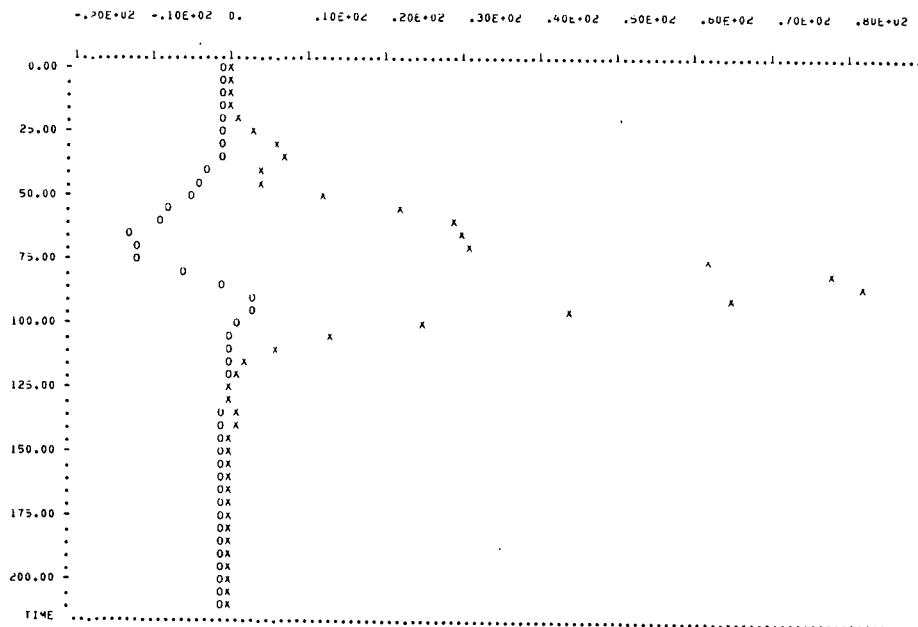
Figure A14. Graph of $\dot{a}_y$ versus Time

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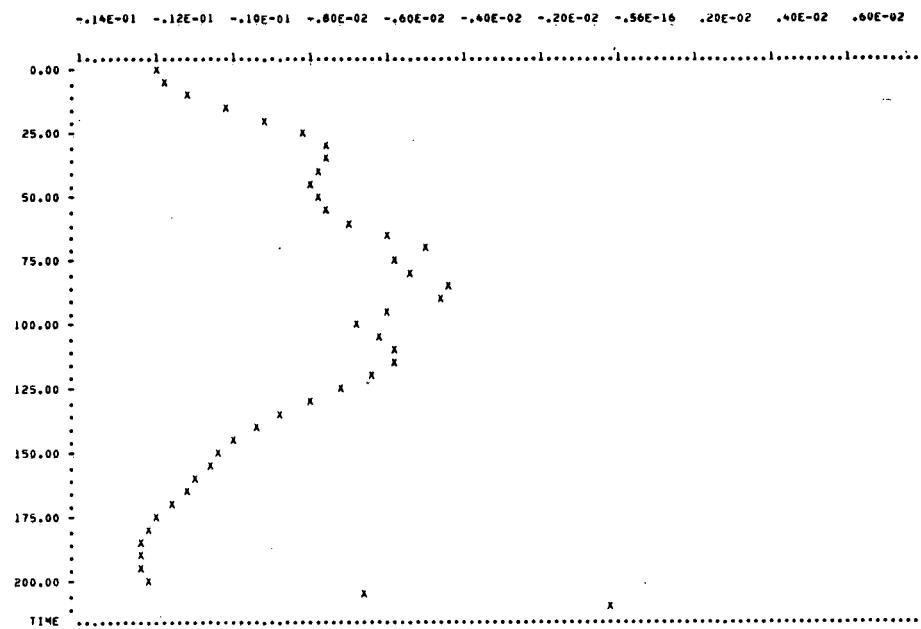
Figure A15. Graph of KV(1,1) versus Time
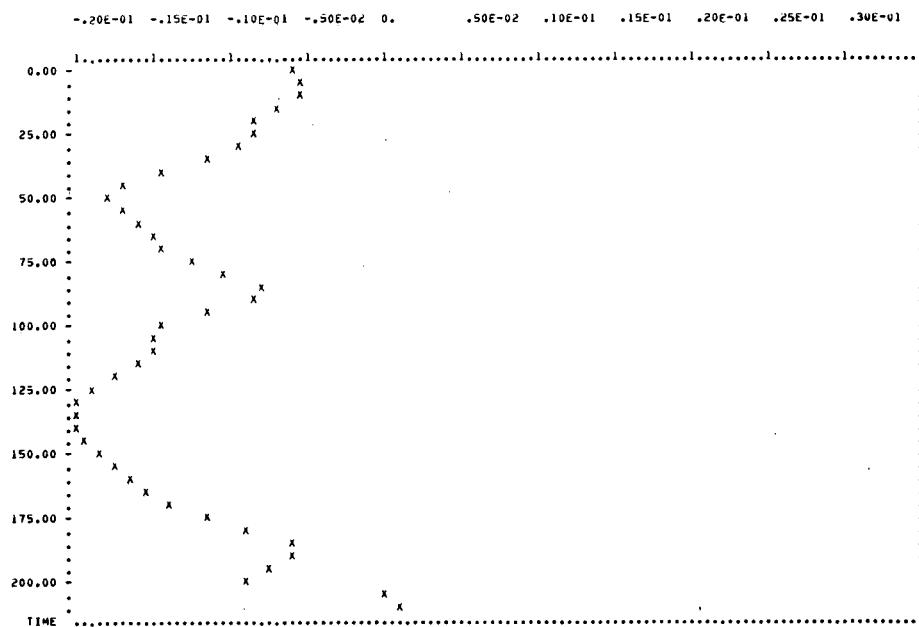
Figure A16. Graph of KV(1,2) versus Time
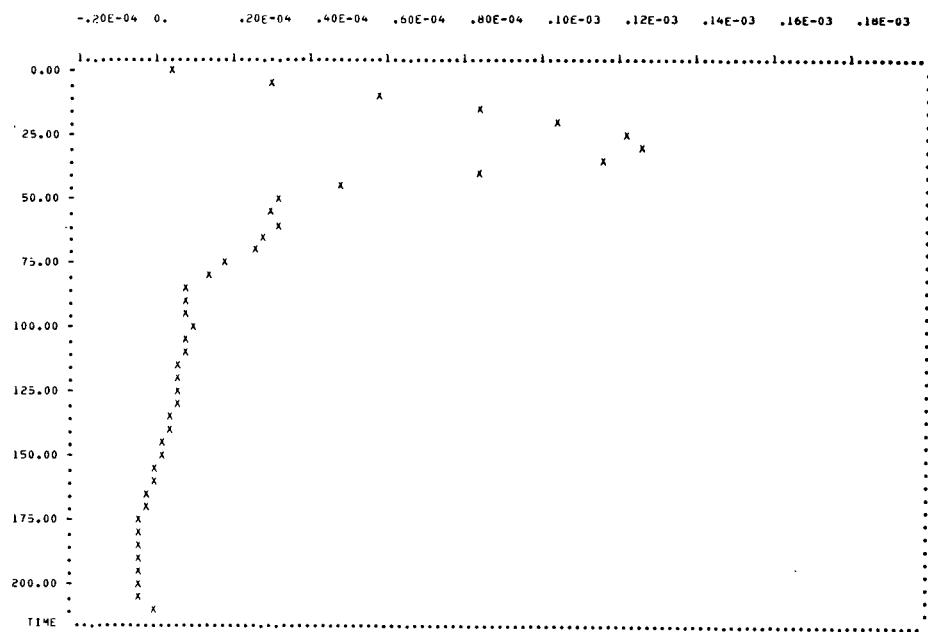
Figure A17. Graph of KV(1,3) versus Time
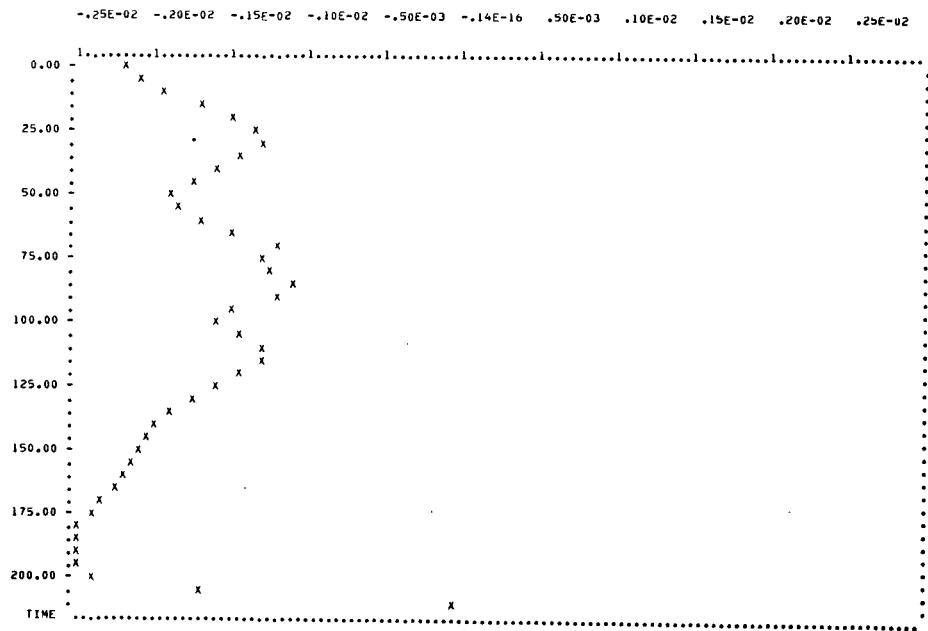
Figure A18. Graph of KV(1,4) versus Time
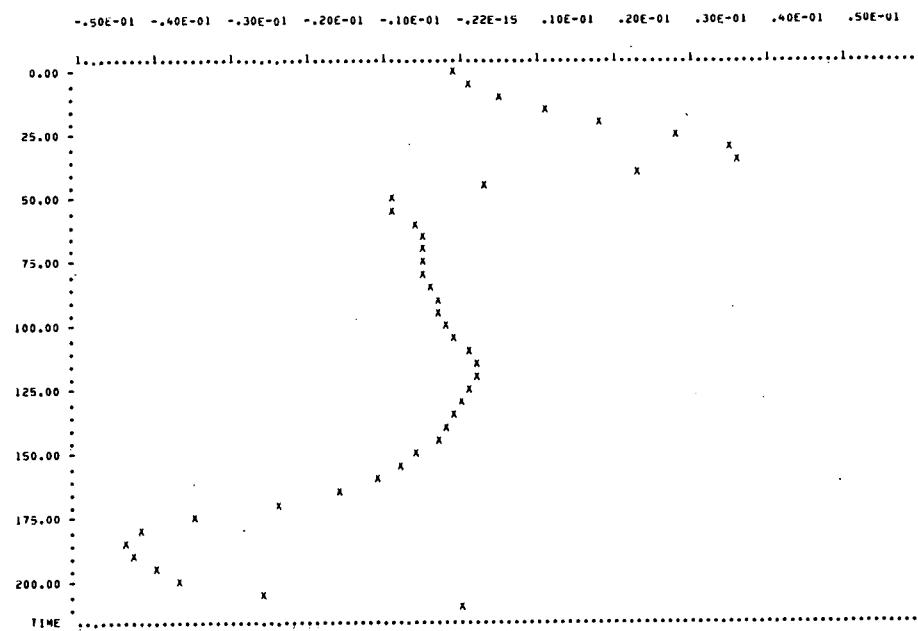
Figure A19. Graph of KV(1,5) versus Time
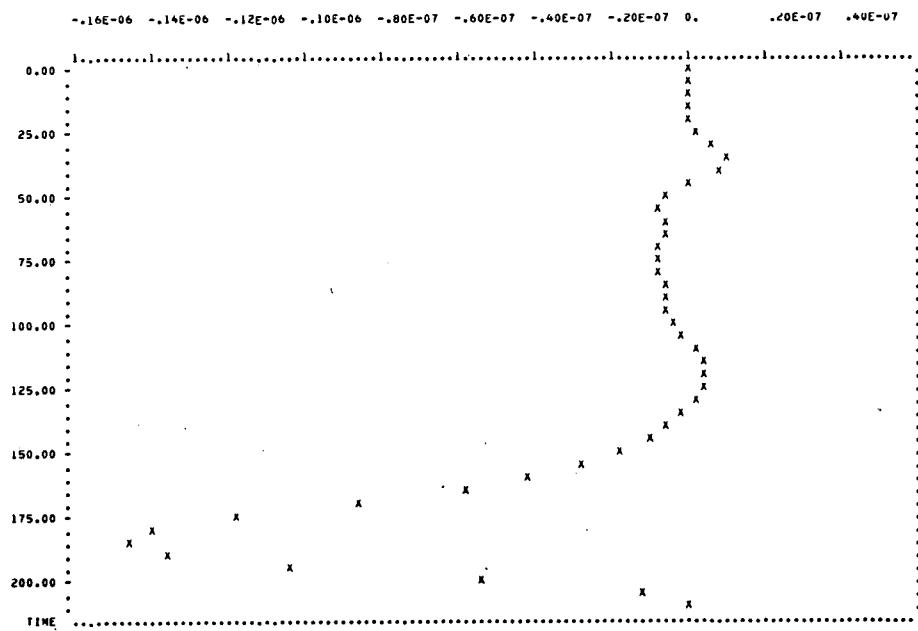
Figure A20. Graph of KV(1,6) versus Time
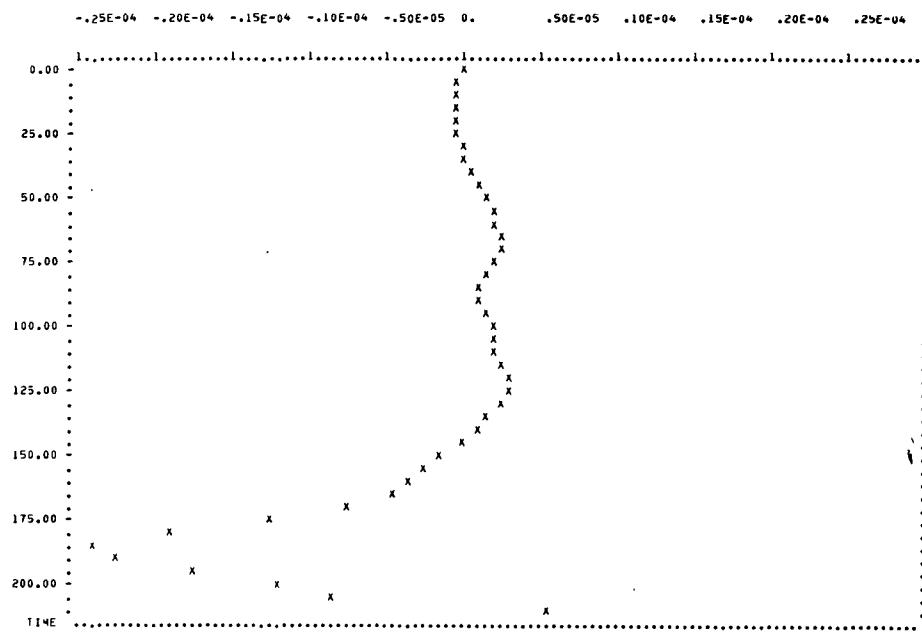
Figure A21. Graph of KV(1,7) versus Time
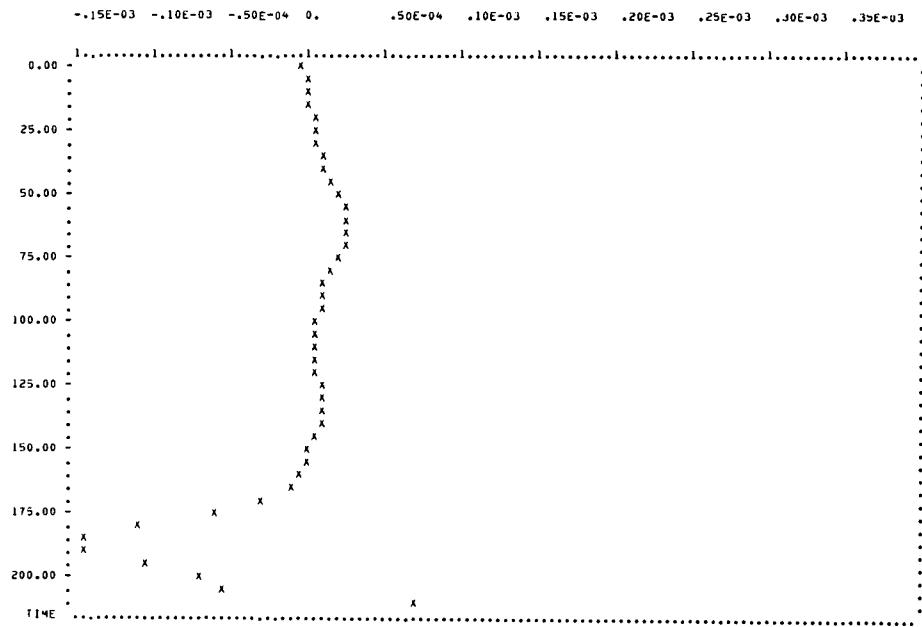
Figure A22. Graph of KV(1,8) versus Time

```
         1..........1.........1.........1.........1.........1.........1.........1.........1.........1.........
  0.00 -                           X
       .                             X
       .                              X
 25.00 -                             X
       .                              X
       .                             X
 50.00 -                       X   X
       .                    X   X
       .                X  X
 75.00 -             X  X
       .              X
       .                X
100.00 -          X                X
       .           X
       .            X
125.00 -         X         X
       .                 X           X
150.00 -                          X   X
       .                            X  X
175.00 -                               X  X
       .                              X
200.00 -                   X   X
  TIME ...........................................................................................
```
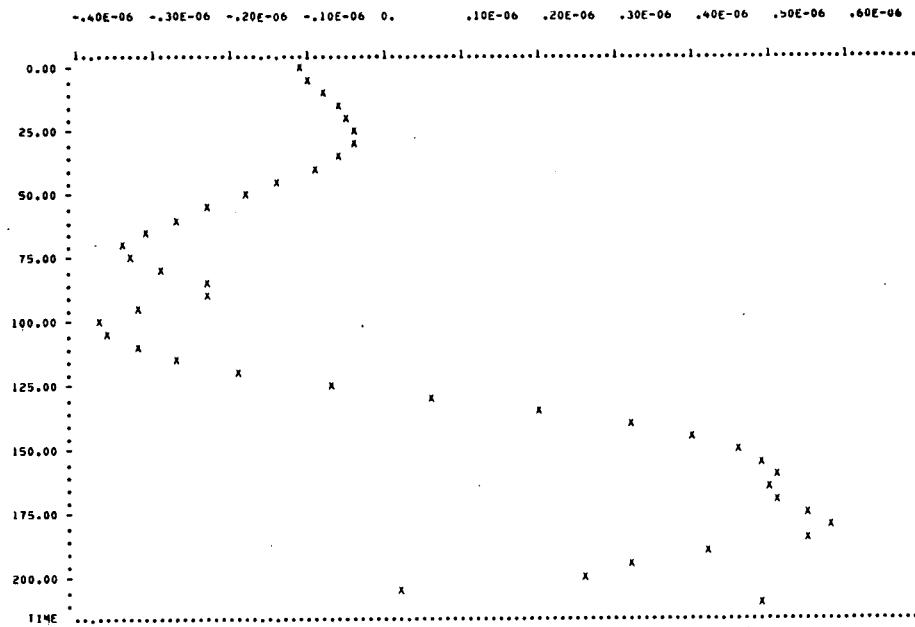
Figure A23. Graph of KV(1,9) versus Time

```
         1..........1.........1.........1.........1.........1.........1.........1.........1.........1.........
  0.00 -                             X
       .                             X
       .                            X
 25.00 -                          X
       .                        X
       .                      X  X
 50.00 -                   X  X
       .                X  X
       .              X
 75.00 -             X  X
       .               X
       .                 X
100.00 -          X
       .          X
       .           X
125.00 -         X
       .                X
150.00 -                  X
       .                    X  X
175.00 -                       X
       .                          X
200.00 -                  X
  TIME ...........................................................................................
```
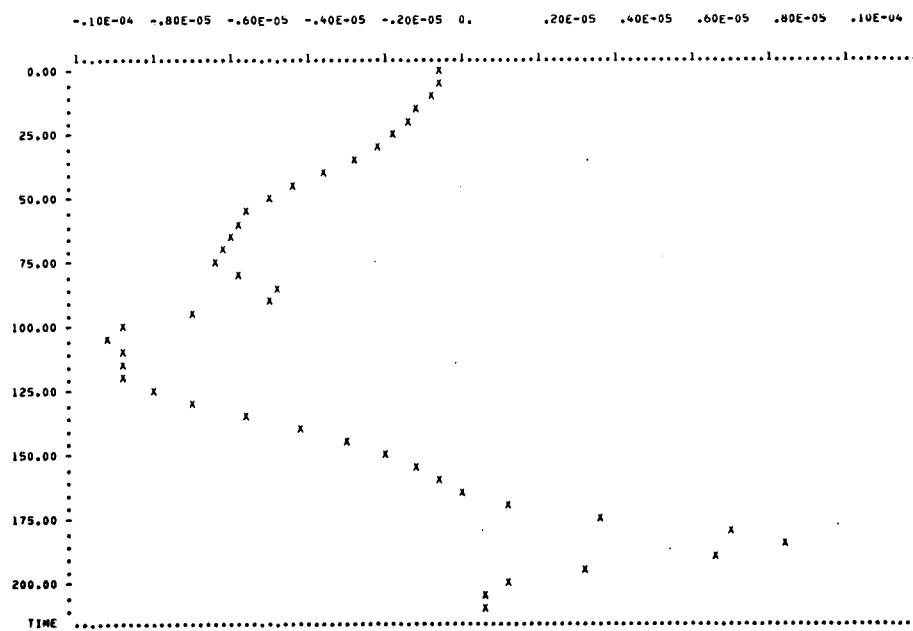
Figure A24. Graph of KV(1,10) versus Time
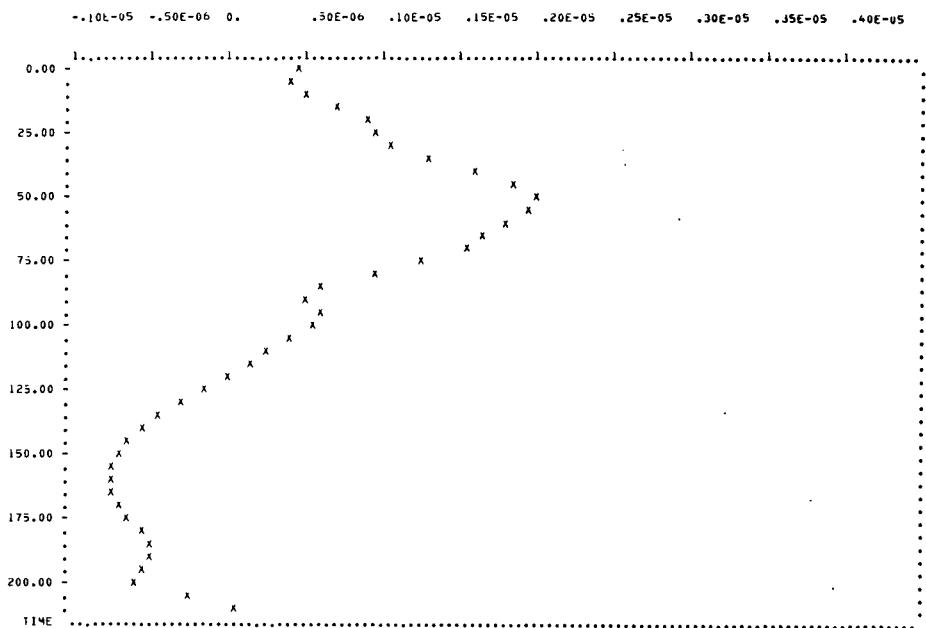
Figure A25.   Graph of KV(1,11) versus Time
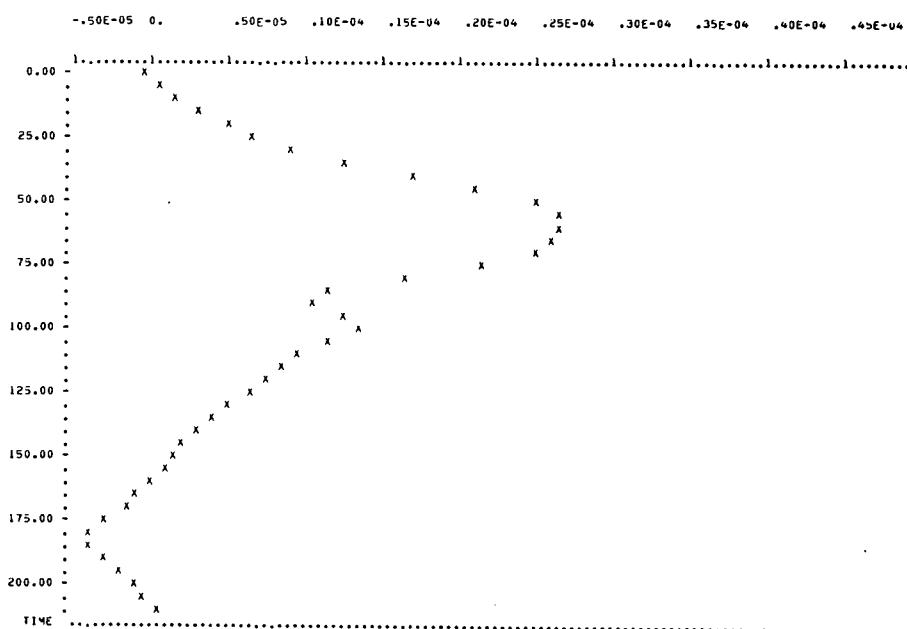
Figure A26.   Graph of KV(1,12) versus Time
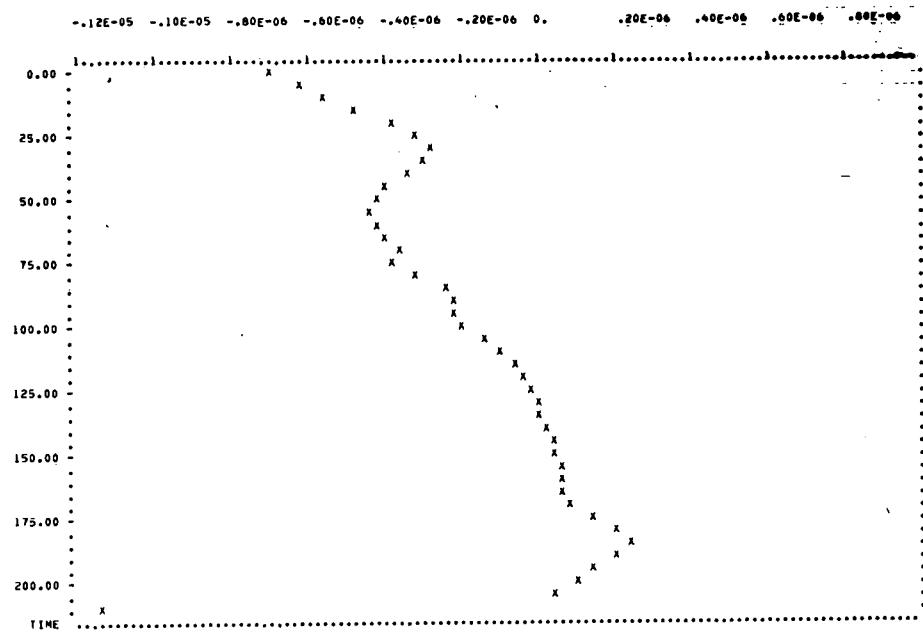
Figure A27. Graph of KV(1, 13) versus Time
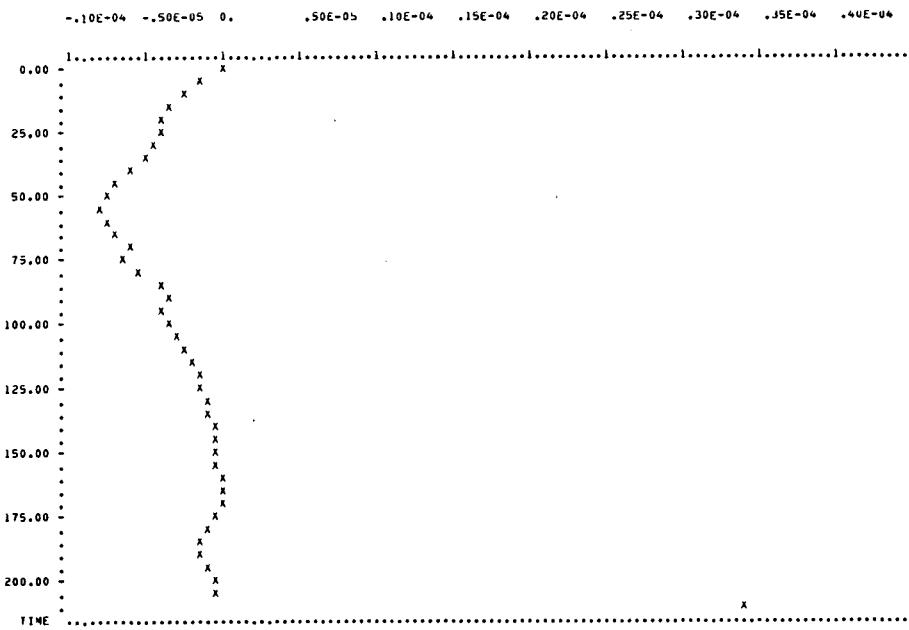
Figure A28. Graph of KV(1, 14) versus Time

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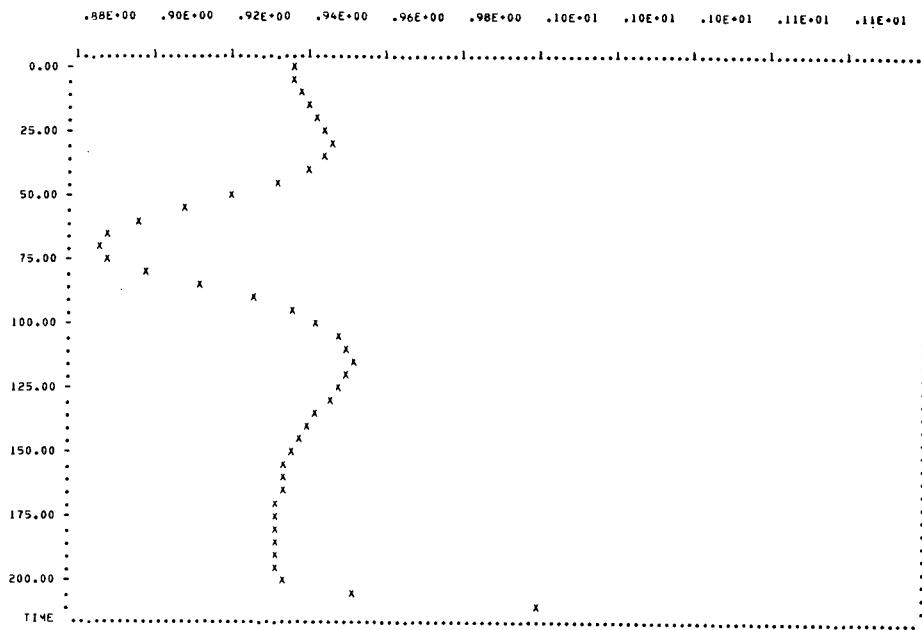
Figure A29. Graph of KV(1,15) versus Time
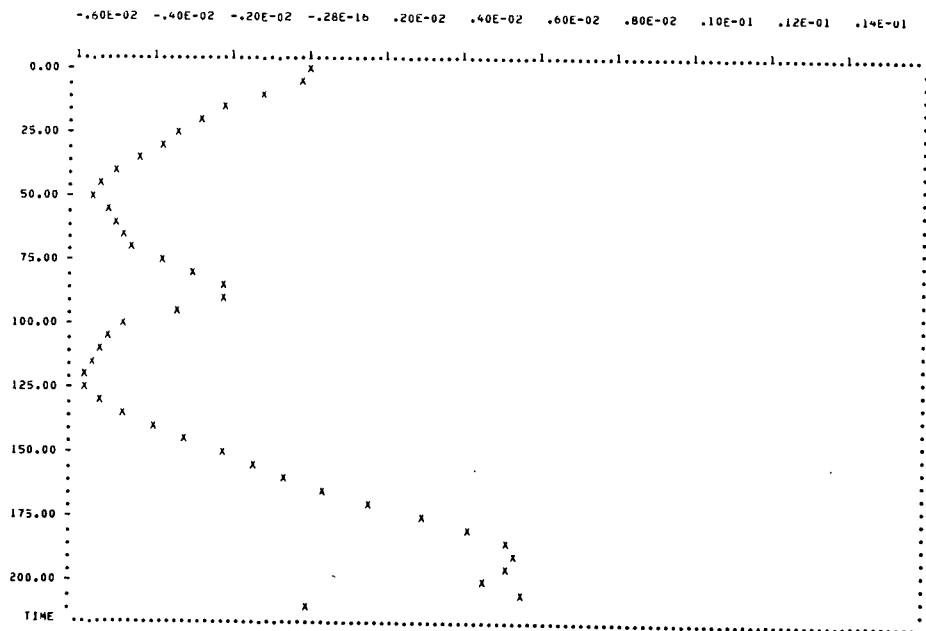
Figure A30. Graph of KV(1,16) versus Time
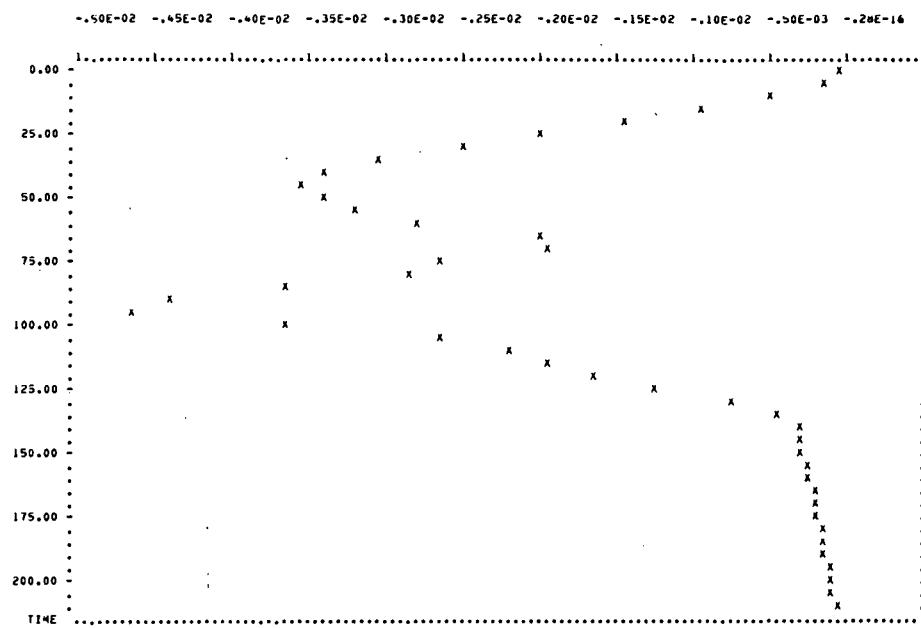
Figure A31. Graph of KV(1, 17) versus Time
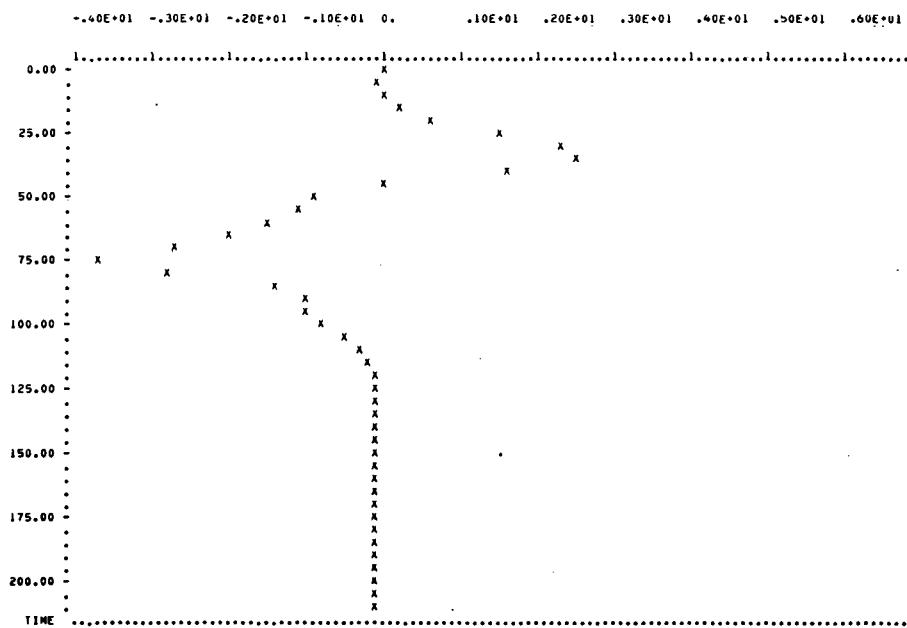
Figure A32. Graph of KV(1, 18) versus Time
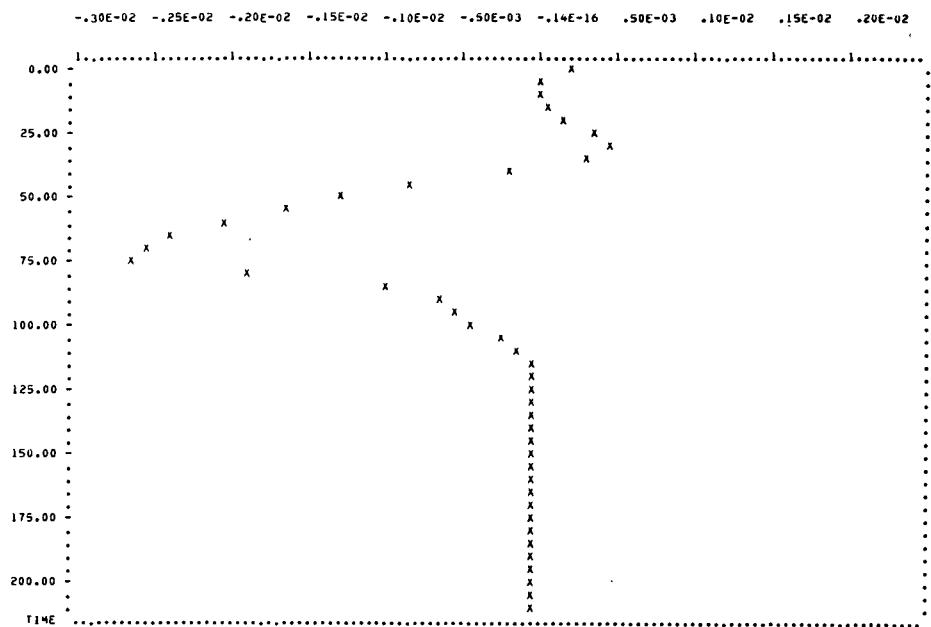
Figure A33. Graph of KV(1,19) versus Time
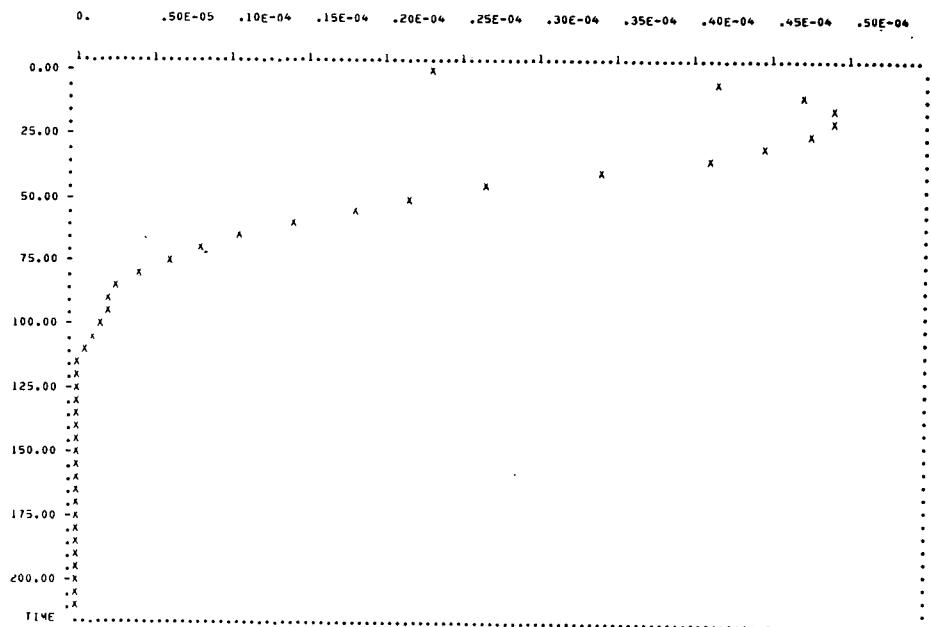
Figure A34. Graph of KV(1,23) versus Time
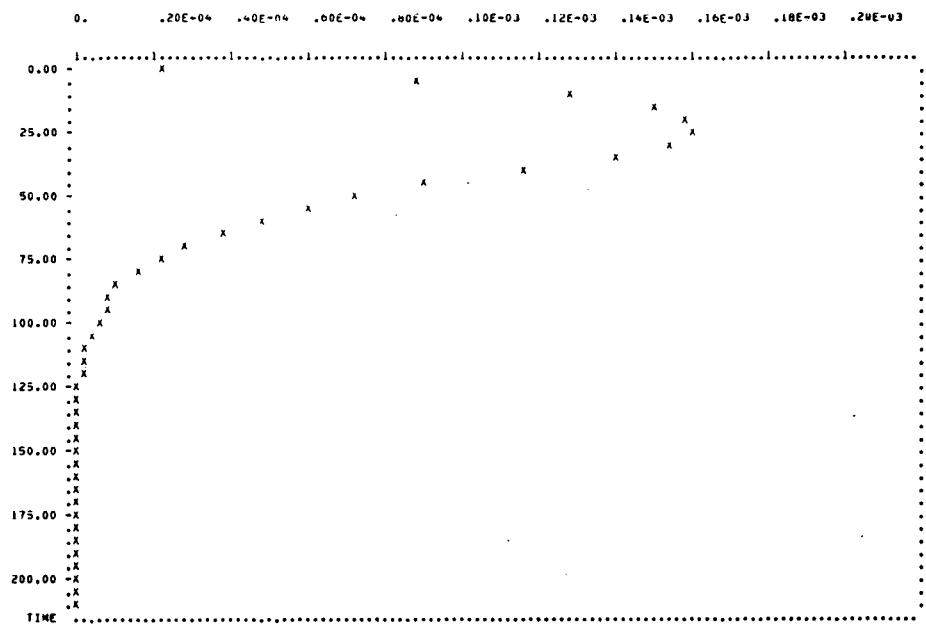
Figure A35. Graph of KV(1,24) versus Time
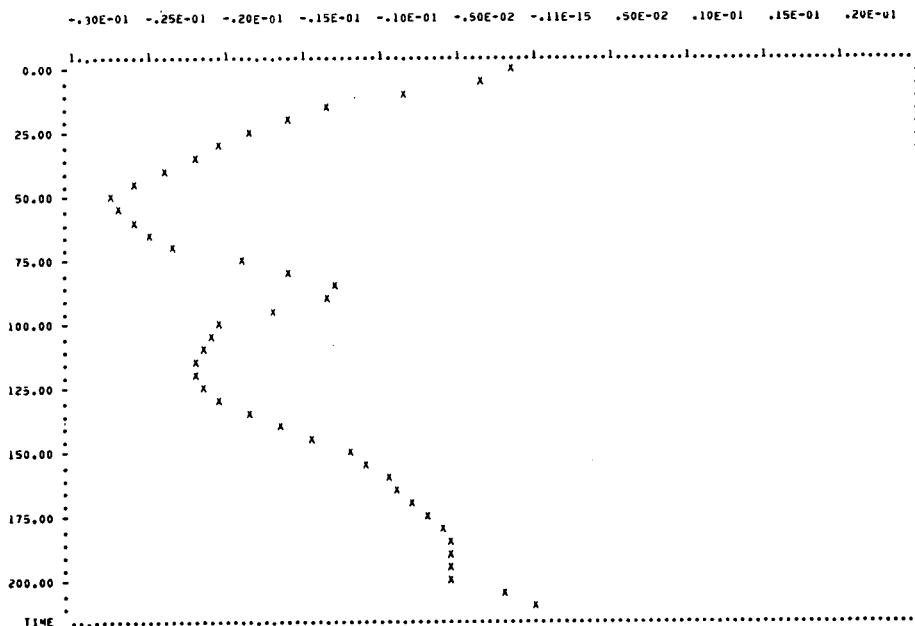
Figure A36. Graph of KV(2,1) versus Time
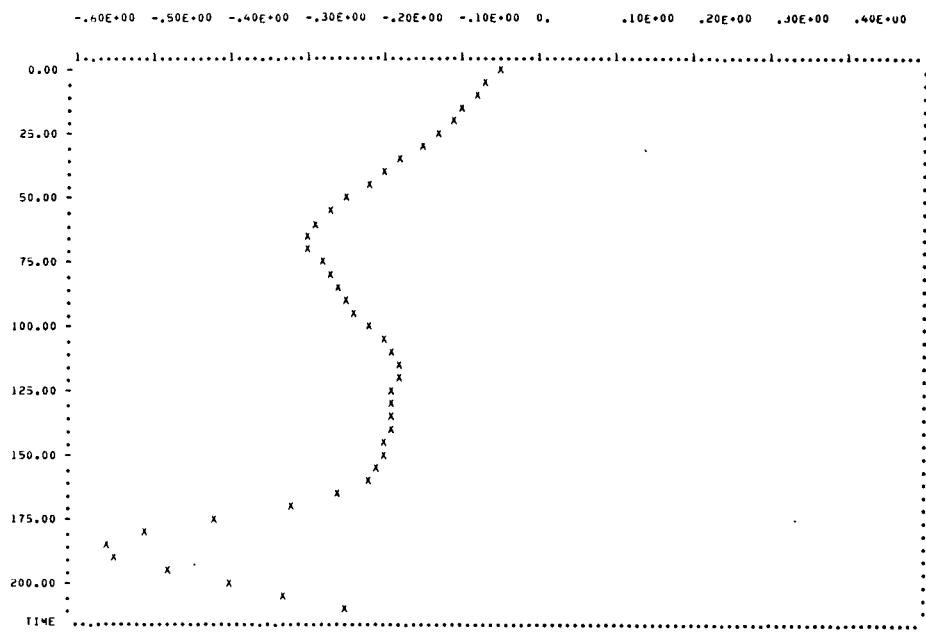
Figure A37. Graph of KV(2,2) versus Time
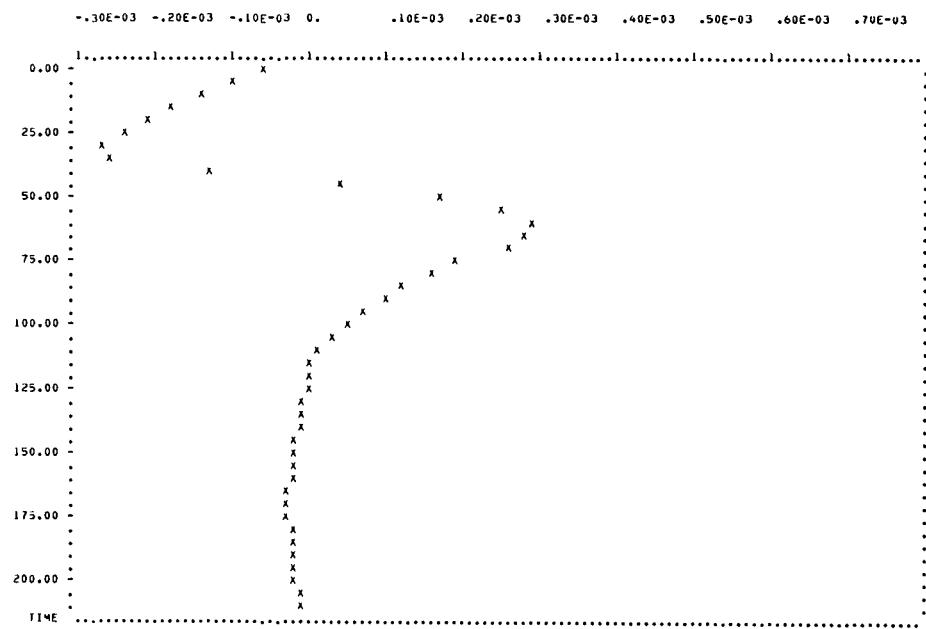
Figure A38. Graph of KV(2,3) versus Time

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-.45E-02 -.40E-02 -.35E-02 -.30E-02 -.25E-02 -.20E-02 -.15E-02 -.10E-02 -.50E-03 -.28E-16   .50E-03
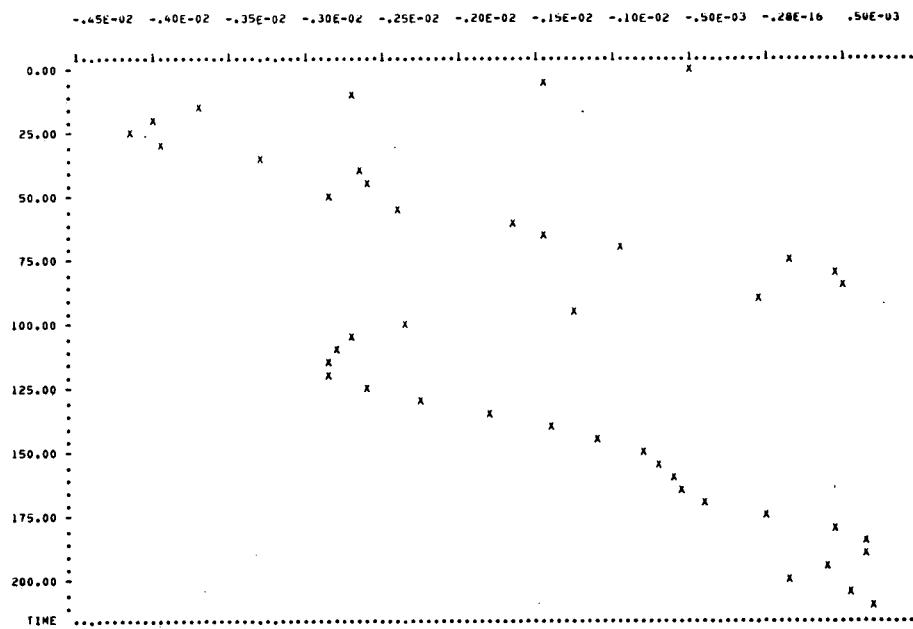
Figure A39. Graph of KV(2,4) versus Time

-.25E+00 -.20E+00 -.15E+00 -.10E+00 -.50E-01 -.89E-15   .50E-01   .10E+00   .15E+00   .20E+00   .25E+00
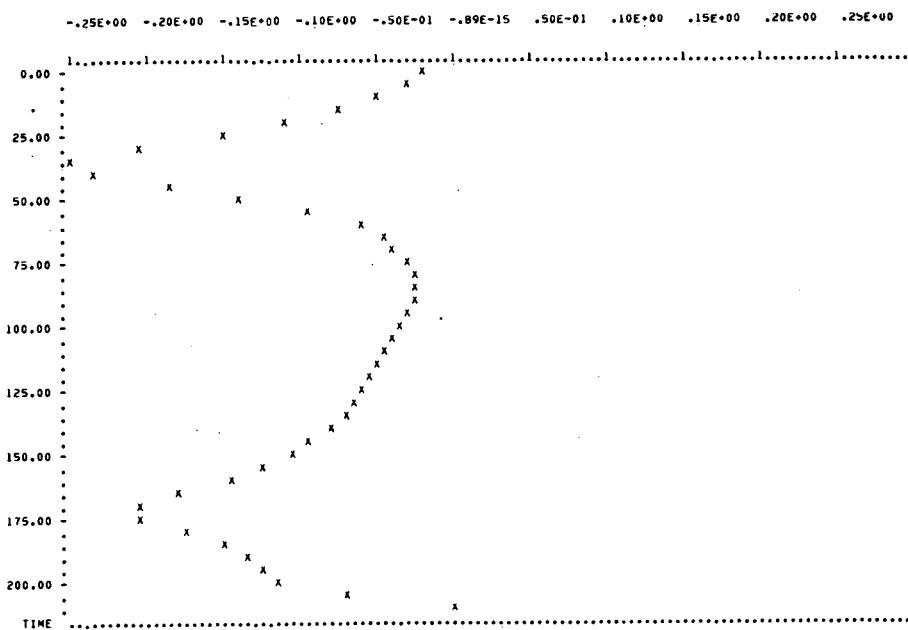
Figure A40. Graph of KV(2,5) versus Time
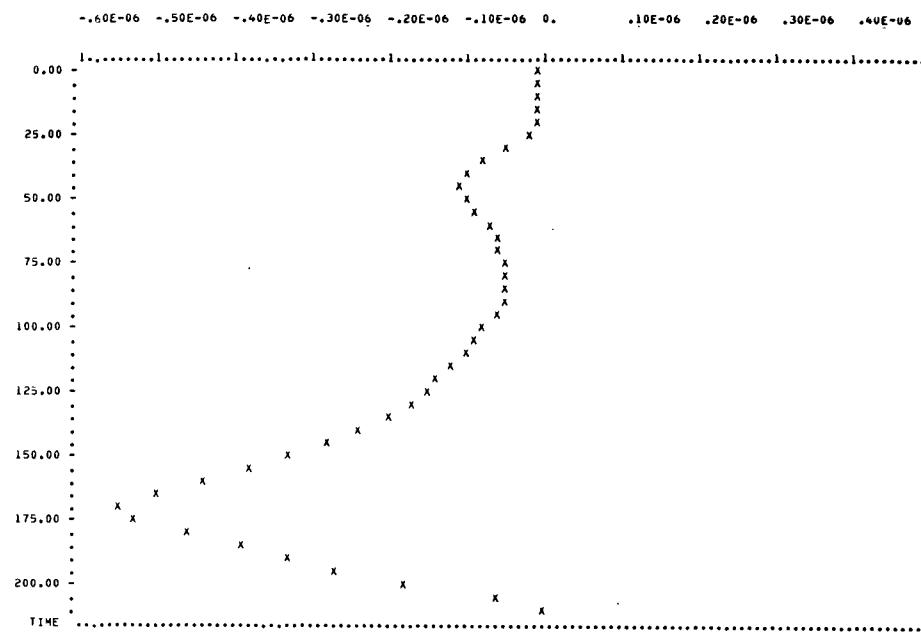
Figure A41. Graph of KV(2,6) versus Time
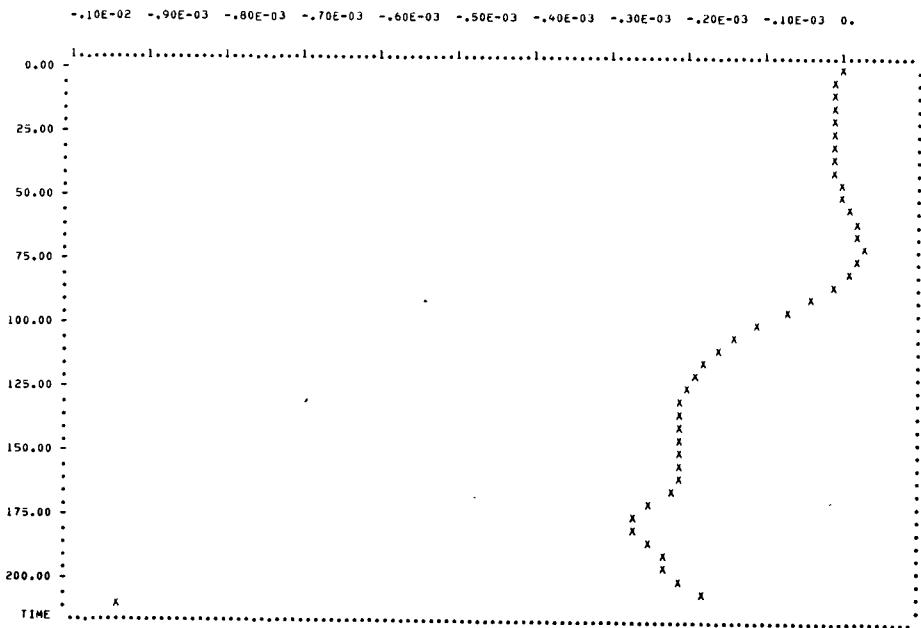

Figure A42. Graph of KV(2,7) versus Time
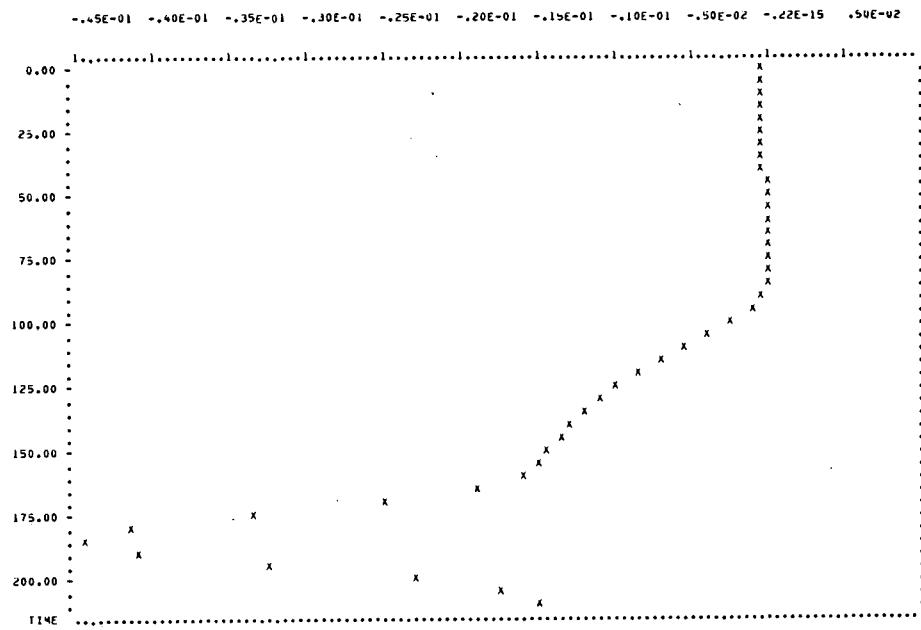
Figure A43. Graph of KV(2,8) versus Time
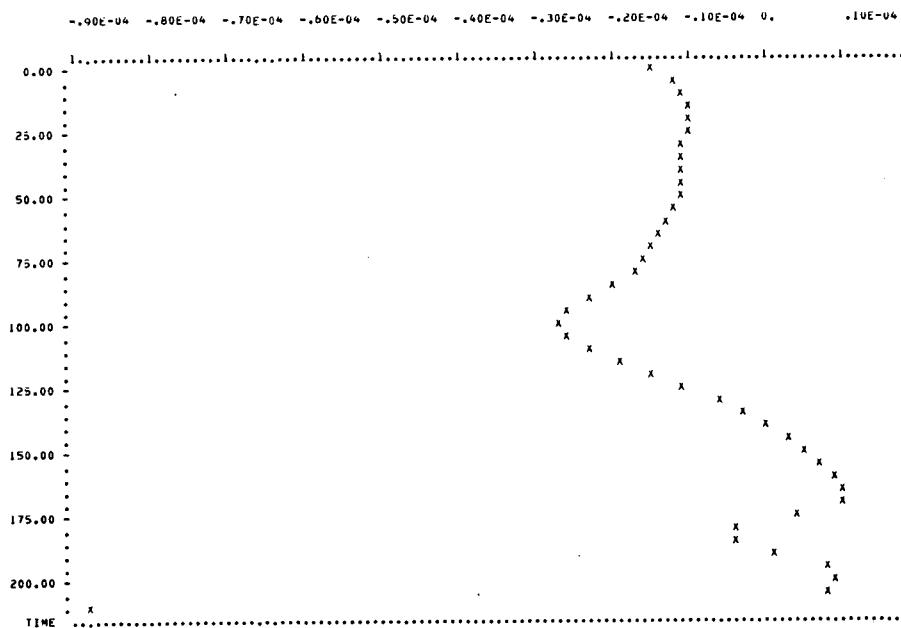
Figure A44. Graph of KV(2,9) versus Time
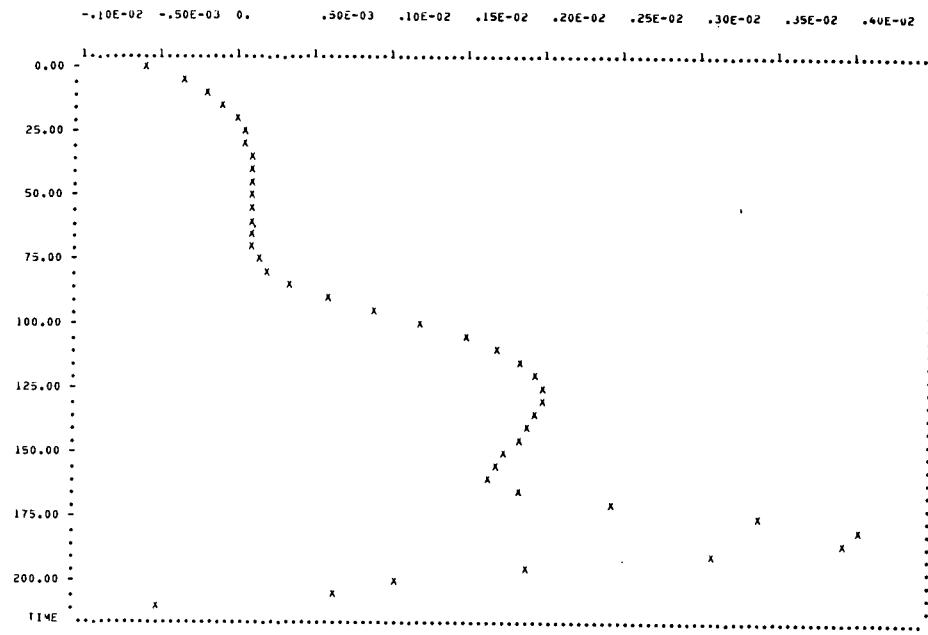
Figure A45. Graph of KV(2,10) versus Time
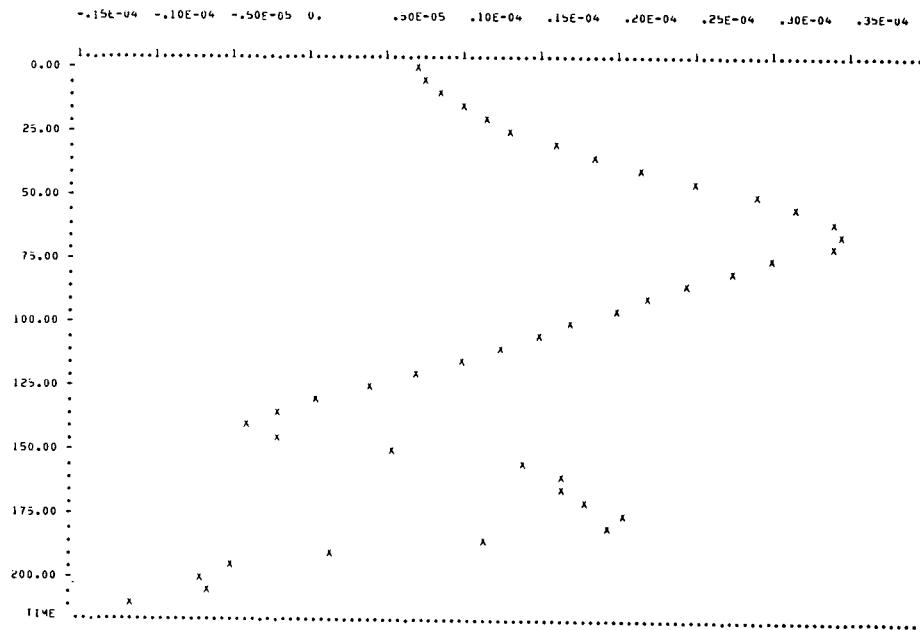
Figure A46. Graph of KV(2,11) versus Time

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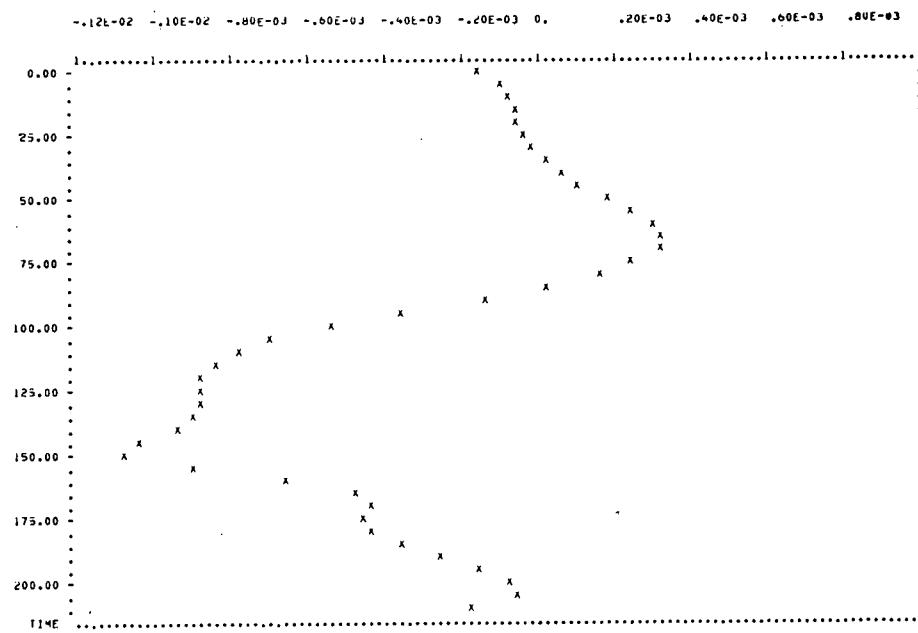
Figure A47. Graph of KV(2,12) versus Time
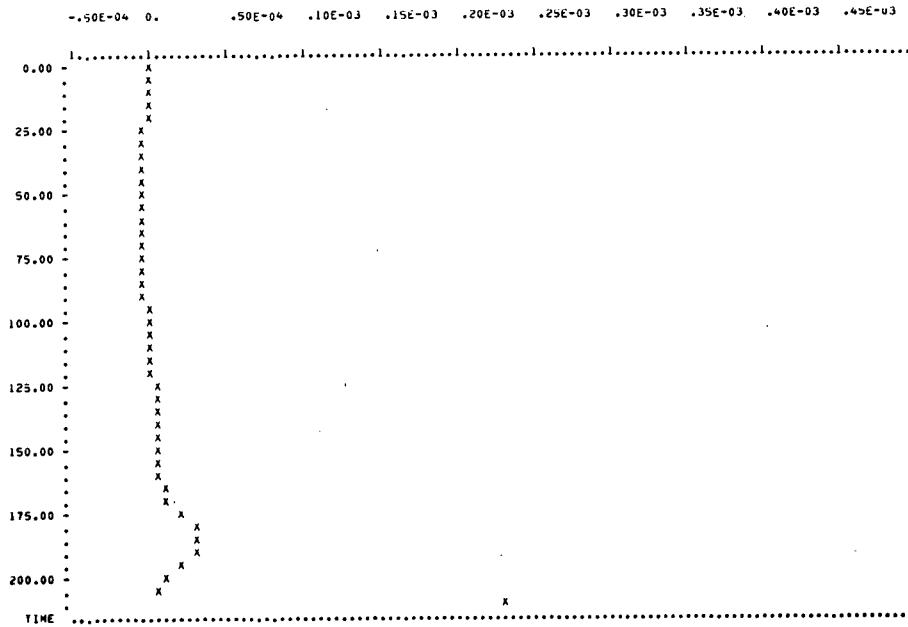
Figure A48. Graph of KV(2,13) versus Time
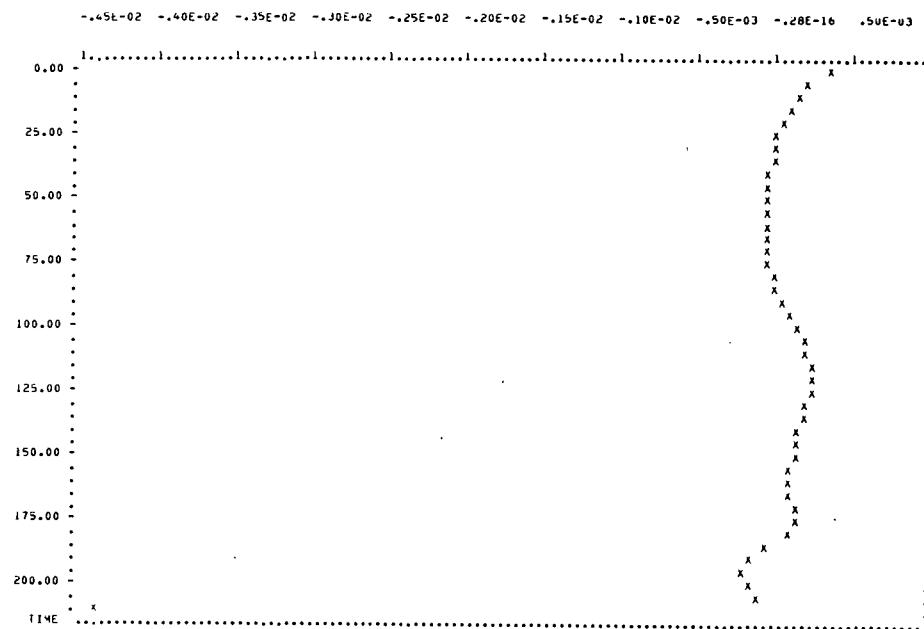
Figure A49. Graph of KV(2,14) versus Time
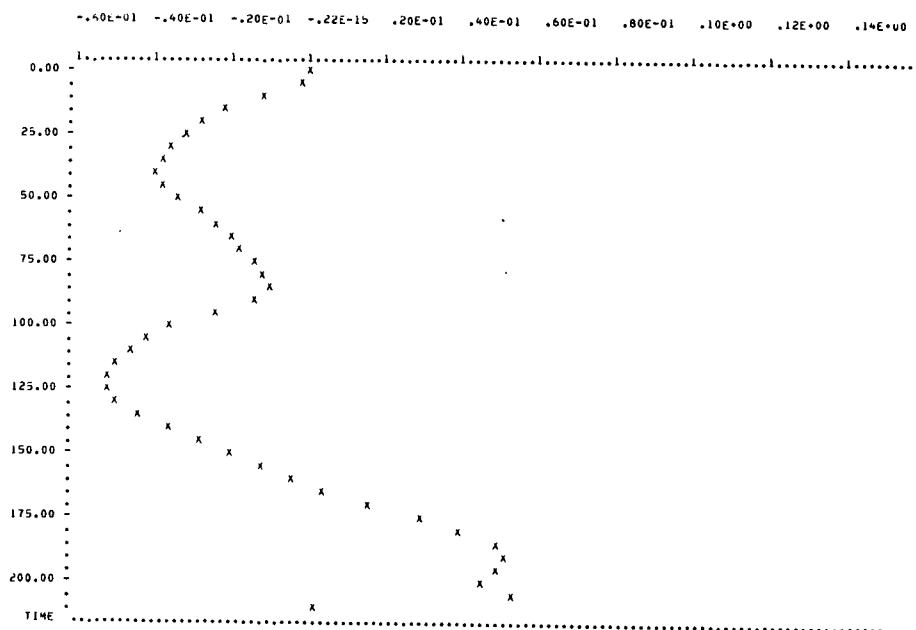
Figure A50. Graph of KV(2,15) versus Time
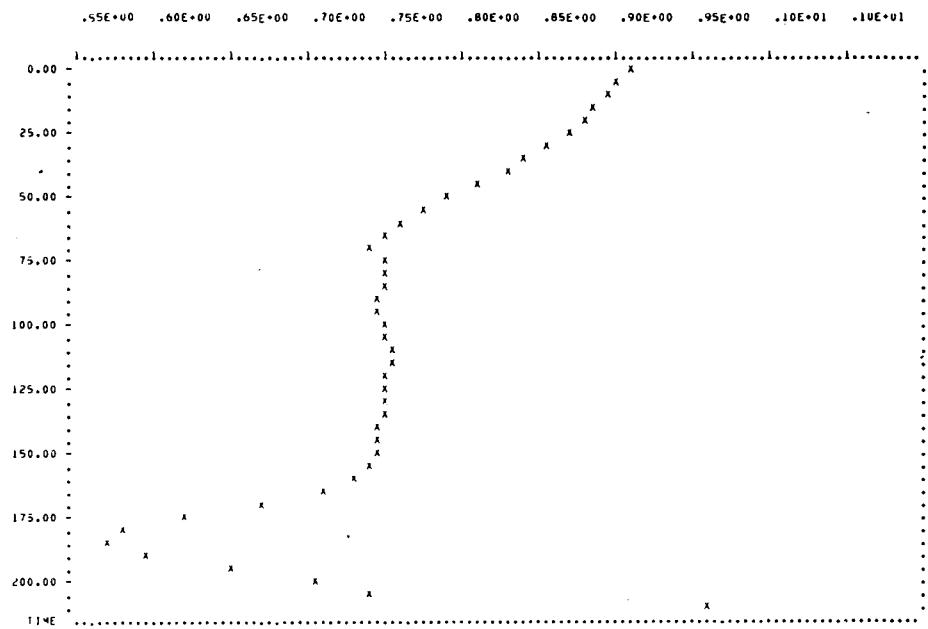
Figure A51. Graph of KV(2,16) versus Time
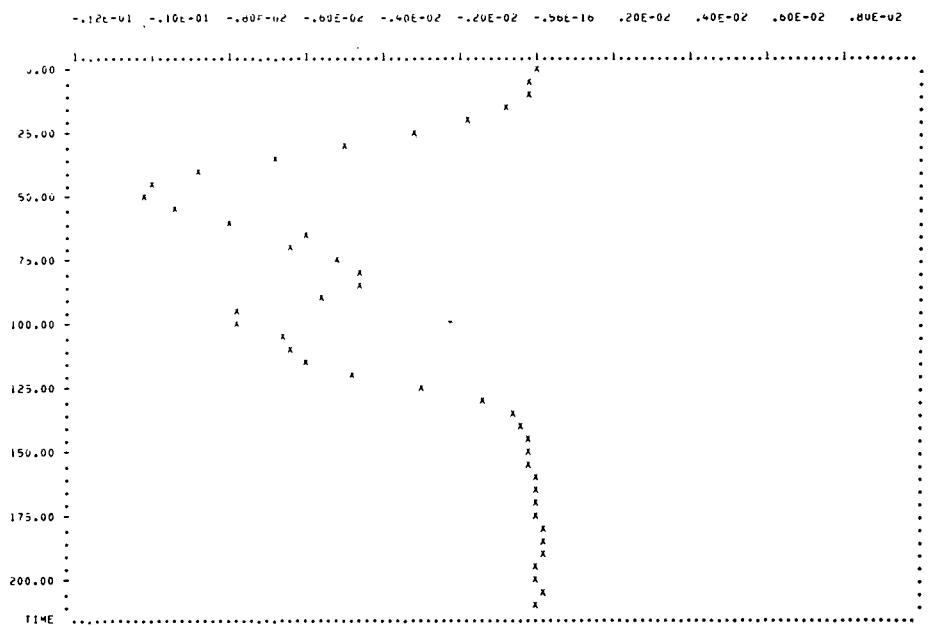
Figure A52. Graph of KV(2,17) versus Time

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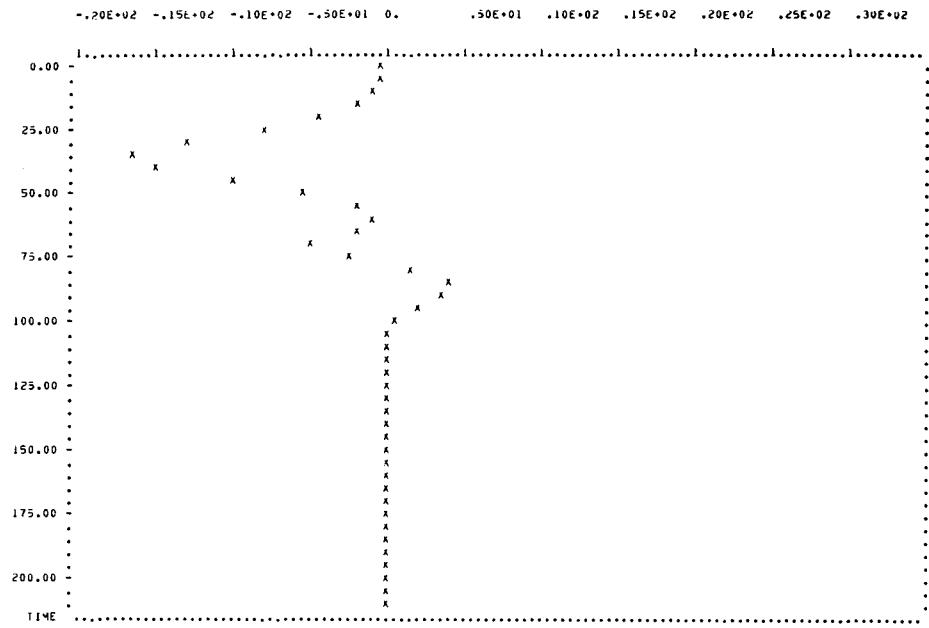
Figure A53.   Graph of KV(2,18) versus Time
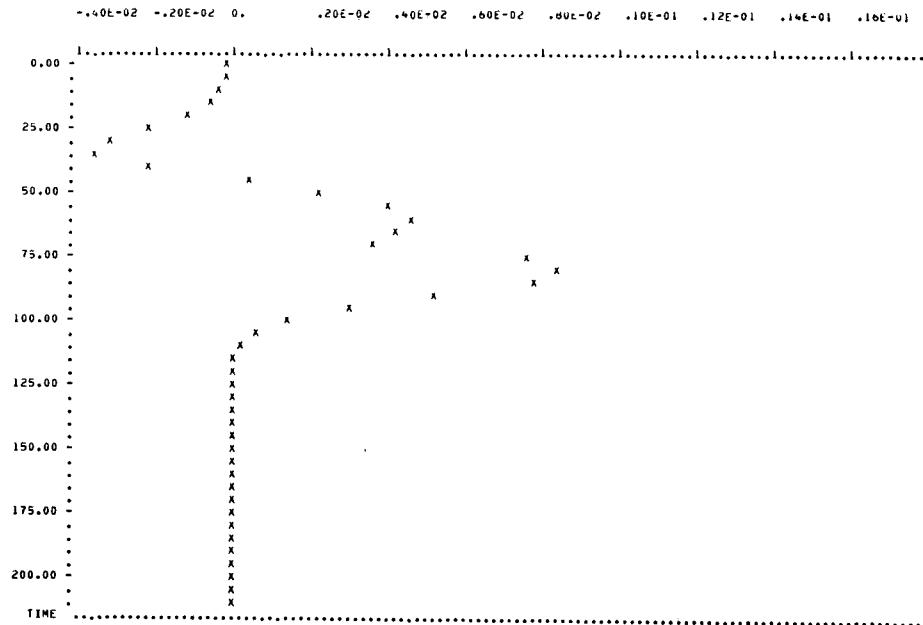
Figure A54.   Graph of KV(2,19) versus Time
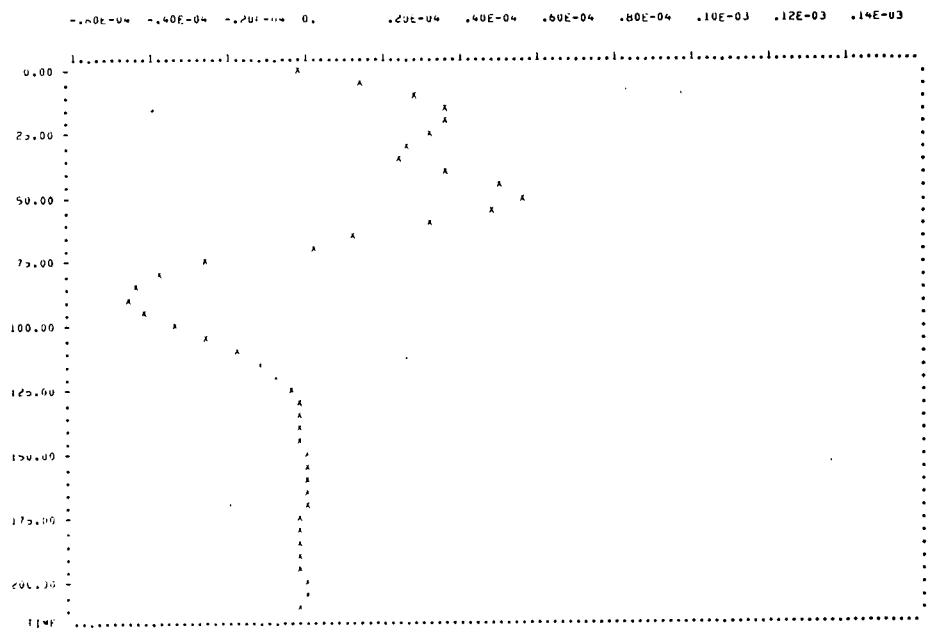
Figure A55. Graph of KV(2,23) versus Time
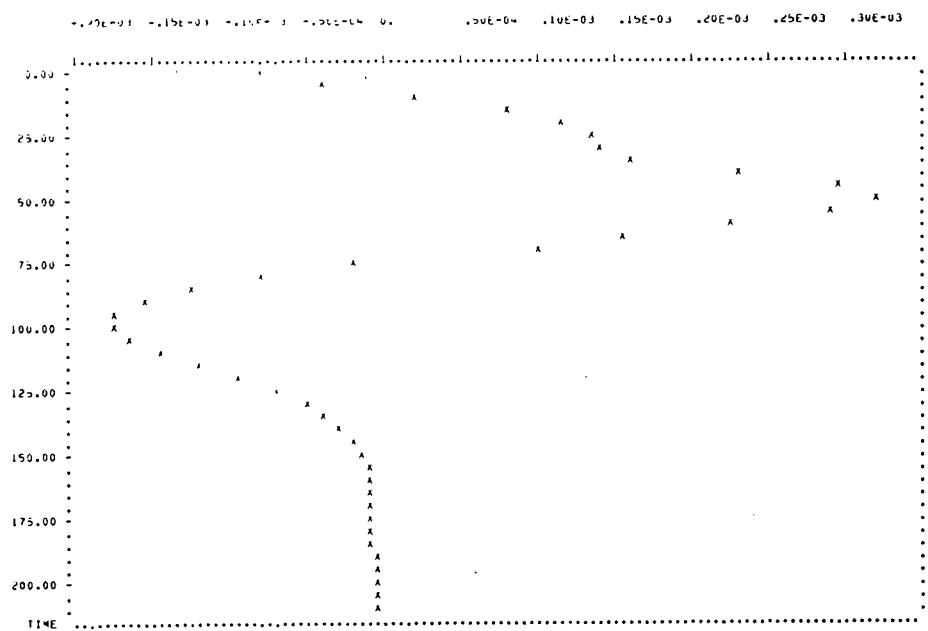
Figure A56. Graph of KV(2,24) versus Time

-.70E-01 -.60E-01 -.50E-01 -.40E-01 -.30E-01 -.20E-01 -.10E-01 -.44E-15   .10E-01   .20E-01   .30E-01

```
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........
  0.00 -                                                               X                                  .
                                                                     X                                    .
                                                                  X                                       .
 25.00 -                                                      X                                           .
                                                          X                                               .
                                                    X                                                     .
 50.00 -                              X                                                                   .
            X    X                                                                                        .
              X                                                                                           .
 75.00 -          X          X                                                                            .
                    X                                                                                     .
          X     X                                                                                         .
100.00 -          X                    X                                                                  .
                                          X                                                               .
                                            X                                                             .
125.00 -                                       X                                                          .
                                                 X                                                        .
                                                 X                                                        .
150.00 -                                         X                                                        .
                                                 X                                                        .
                                                 X                                                        .
175.00 -                                         X                                                        .
                                                 X                                                        .
                                                 X                                                        .
200.00 -                                         X                                                        .
                                                 X                                                        .
  TIME  .........................................................................................
```
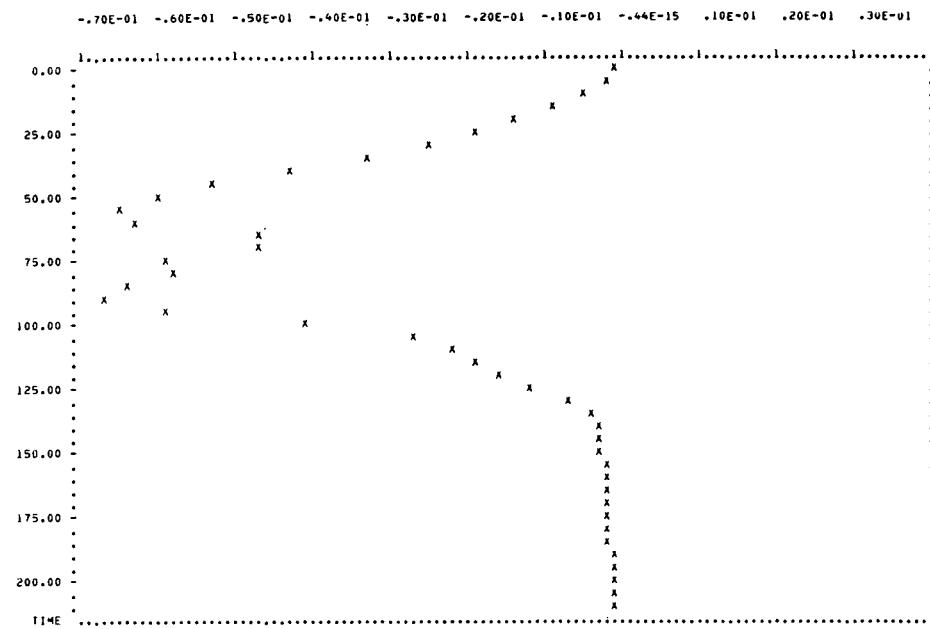
Figure A57. Graph of KV(3,1) versus Time

-.16E+00 -.14E+00 -.12E+00 -.10E+00 -.80E-01 -.60E-01 -.40E-01 -.20E-01   0.   .20E-01   .40E-01

```
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........
  0.00 -                                                                     X                            .
                                                                             X                            .
                                                                           X                              .
 25.00 -                                                                 X                                .
                                                                     X                                    .
                                                              X                                           .
 50.00 -                         X                                                                        .
            X    X                                                                                        .
              X                                                                                           .
 75.00 -          X    X                                                                                  .
                    X                                                                                     .
                    X                                                                                     .
100.00 -          X              X                                                                        .
                                     X                                                                    .
                                       X                                                                  .
125.00 -                                   X                                                              .
                                              X                                                           .
                                                  X                                                       .
150.00 -                                                X                                                 .
                                                          X                                               .
                                                          X                                               .
175.00 -                                                  X                                               .
                                                          X                                               .
                                                          X                                               .
200.00 -                                                  X                                               .
                                                          X                                               .
  TIME  .........................................................................................
```
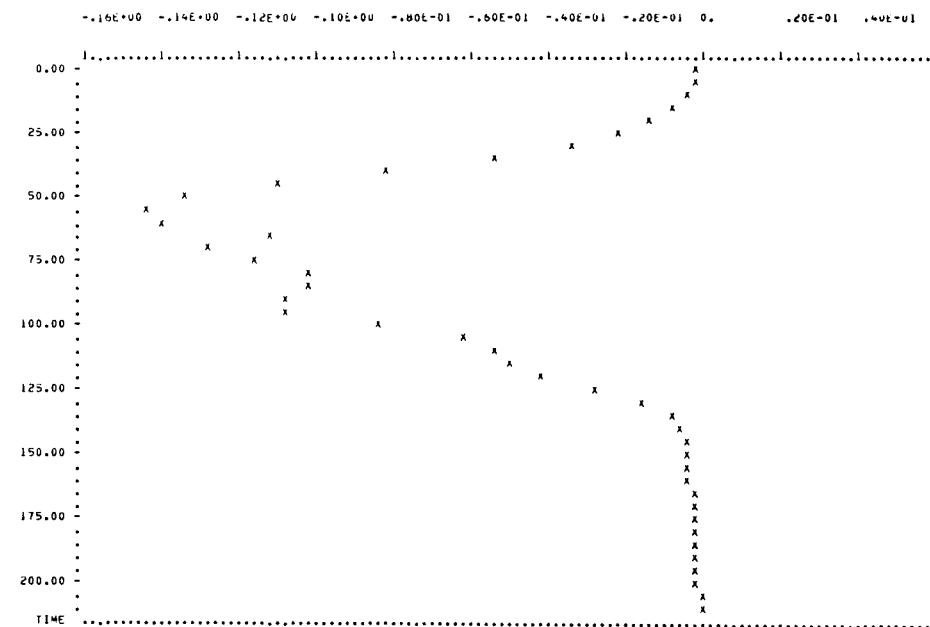
Figure A58. Graph of KV(3,2) versus Time
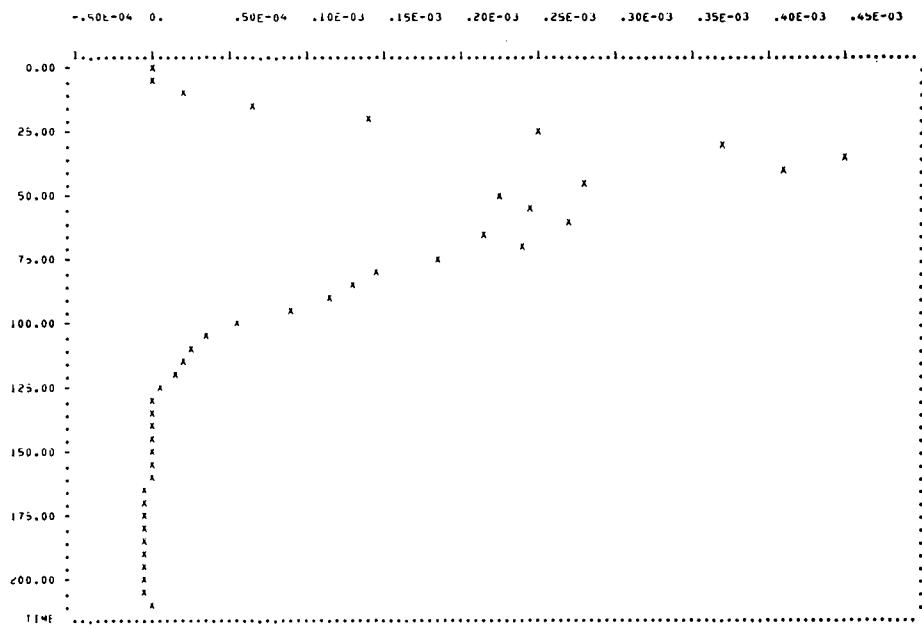
Figure A59. Graph of KV(3,3) versus Time
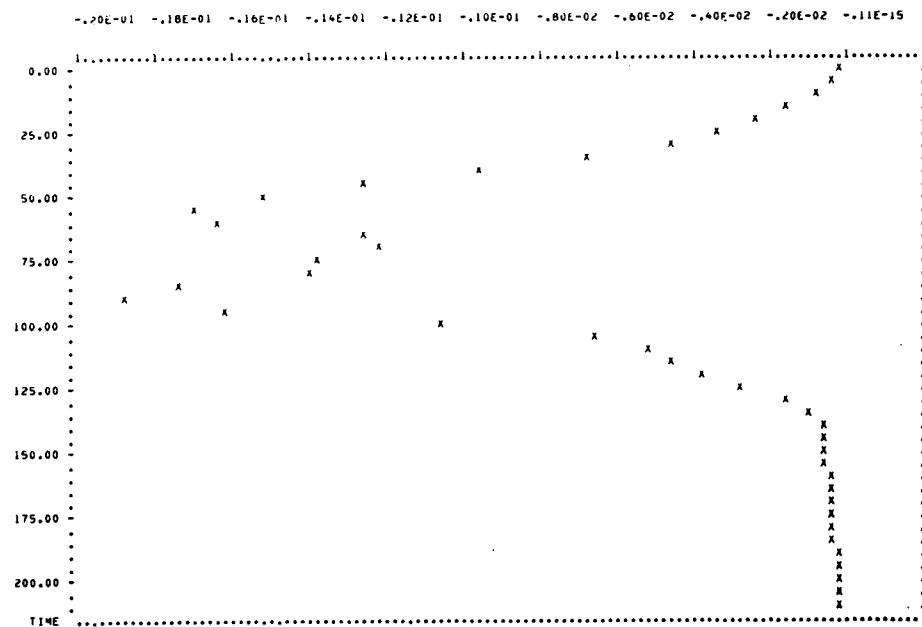
Figure A60. Graph of KV(3,4) versus Time
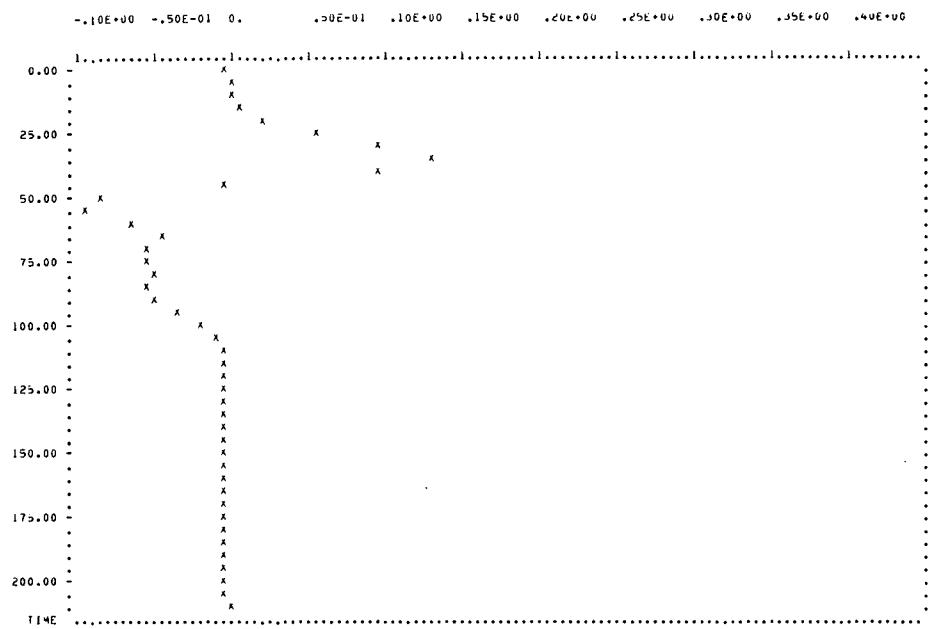
Figure A61. Graph of KV(3, 5) versus Time
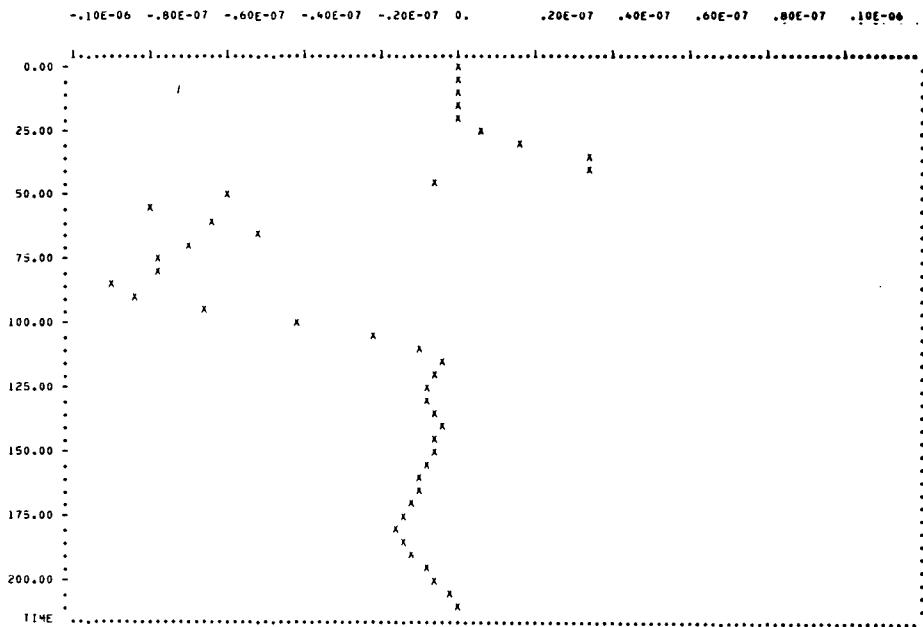
Figure A62. Graph of KV(3, 6) versus Time
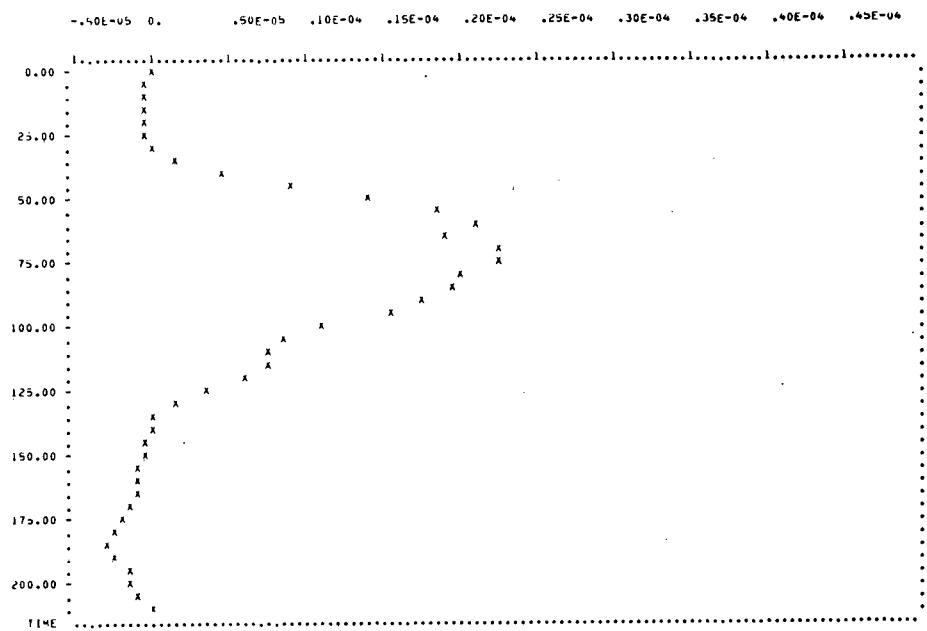
Figure A63. Graph of KV(3, 7) versus Time
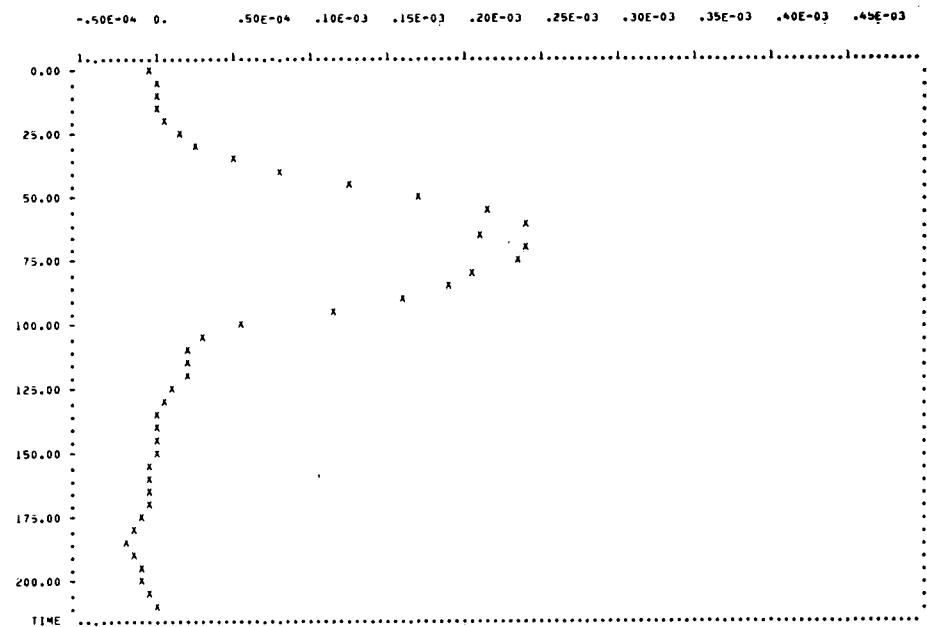
Figure A64. Graph of KV(3, 8) versus Time
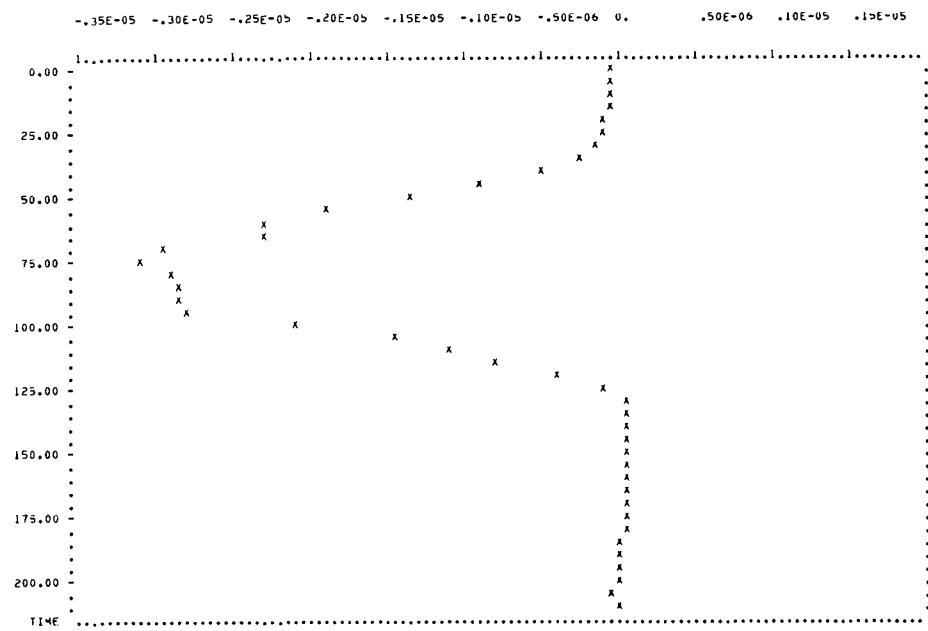
Figure A65. Graph of KV(3,9) versus Time
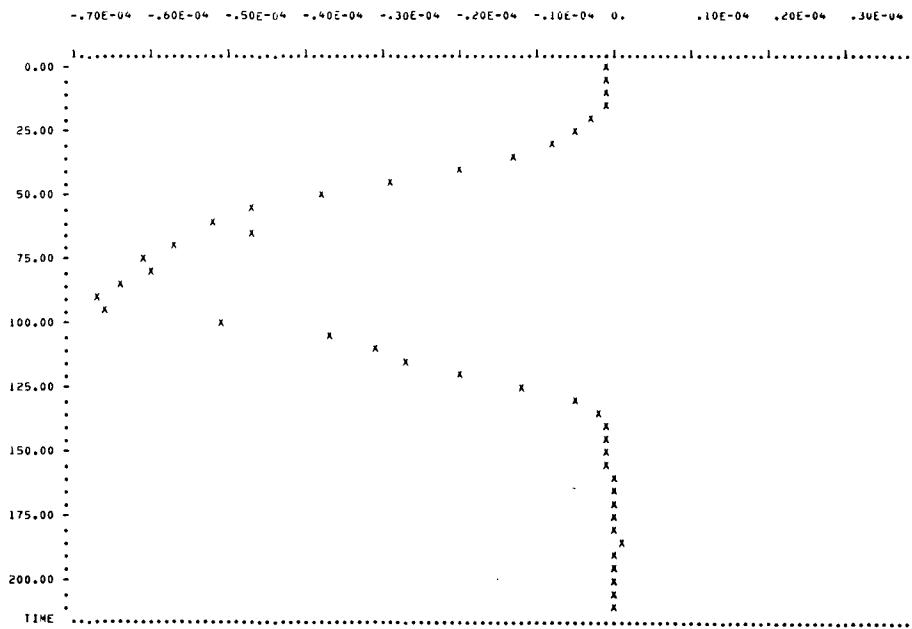
Figure A66. Graph of KV(3,10) versus Time
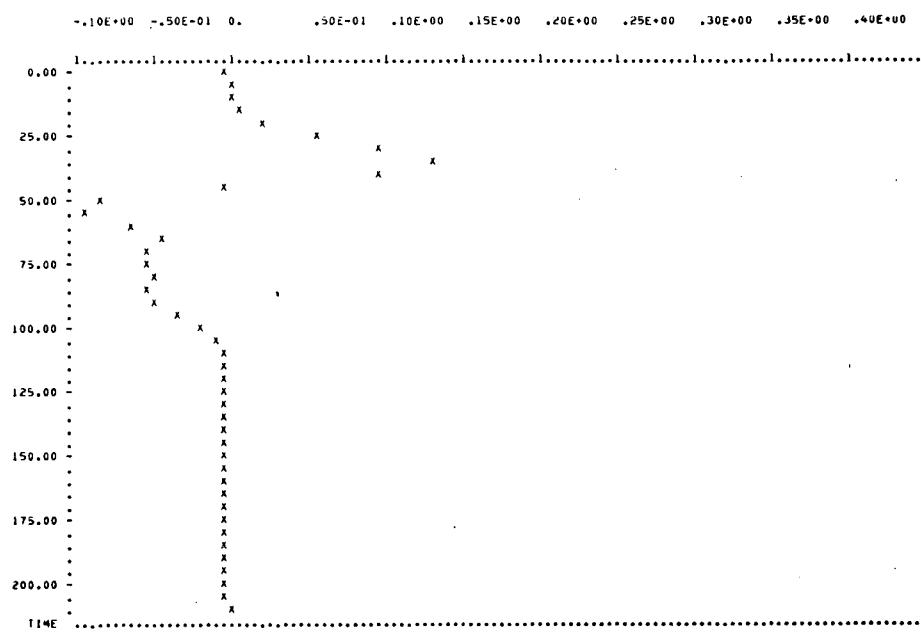
Figure A67. Graph of KV(3,11) versus Time
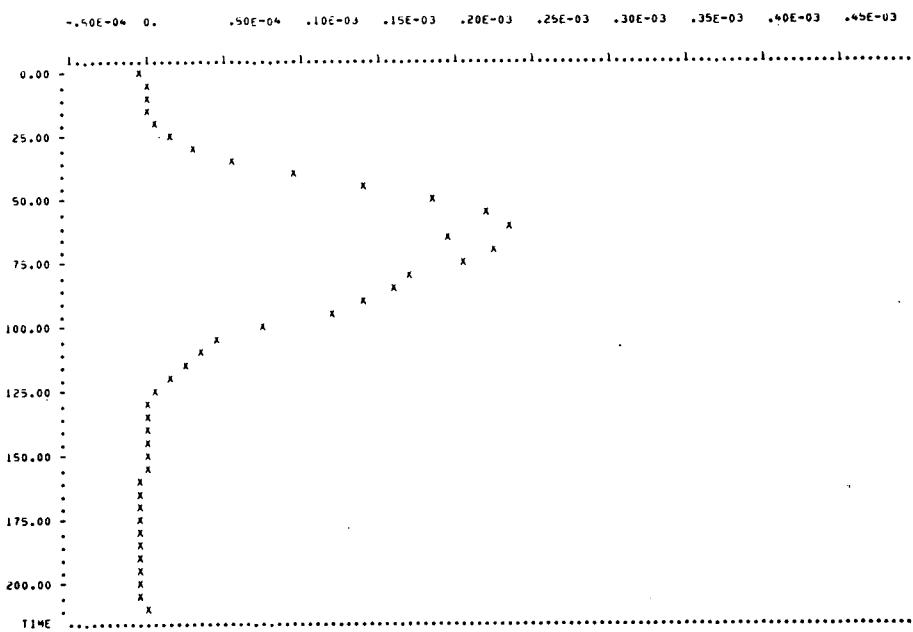
Figure A68. Graph of KV(3,12) versus Time
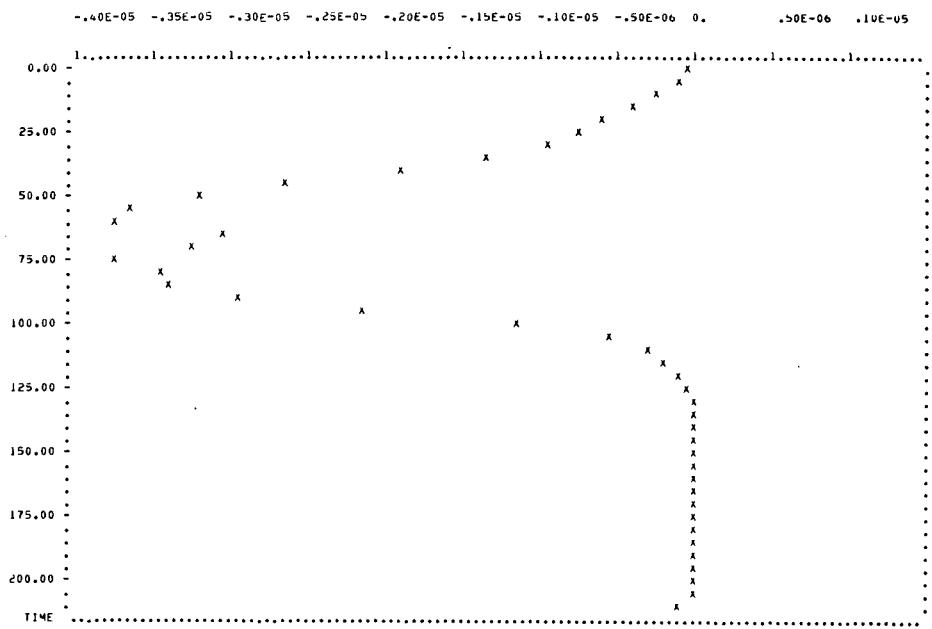
Figure A69. Graph of KV(3,13) versus Time
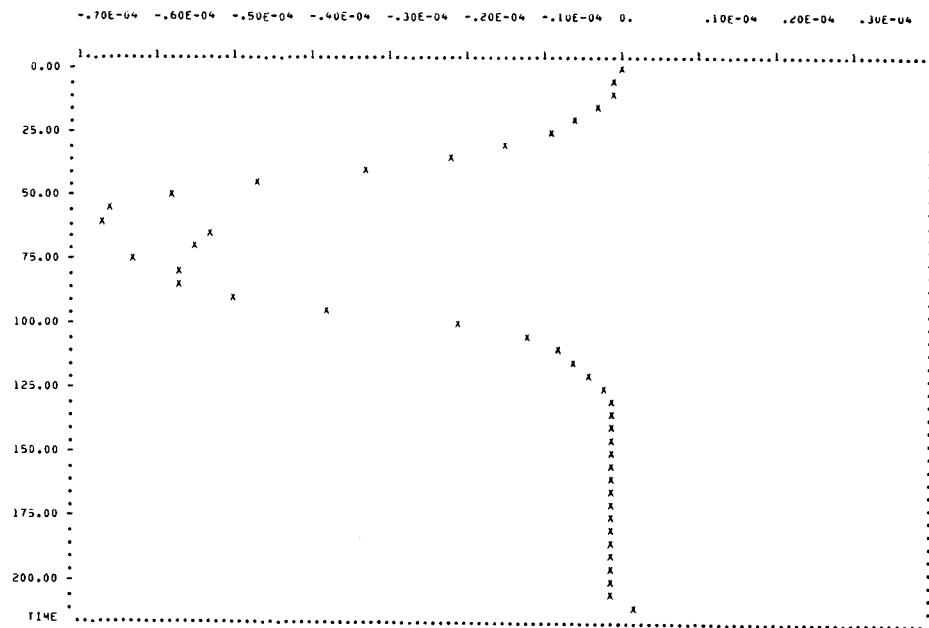
Figure A70. Graph of KV(3,14) versus Time

-.12E+00 -.10E+00 -.80E-01 -.60E-01 -.40E-01 -.20E-01 -.44E-15   .20E-01   .40E-01   .60E-01   .80E-01
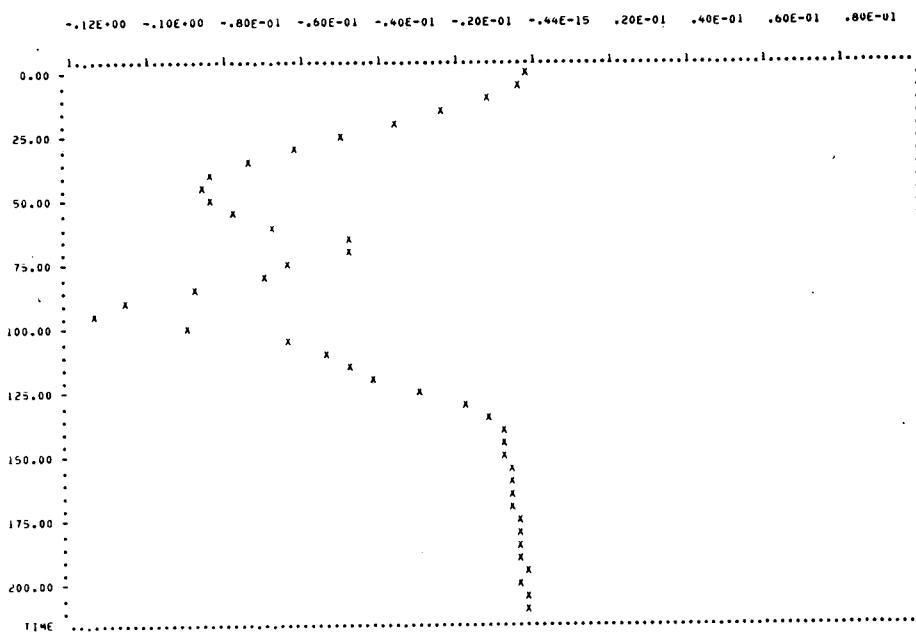
Figure A71. Graph of KV(3,15) versus Time

-.45E-01 -.40E-01 -.35E-01 -.30E-01 -.25E-01 -.20E-01 -.15E-01 -.10E-01 -.50E-02 -.22E-15   .50E-02
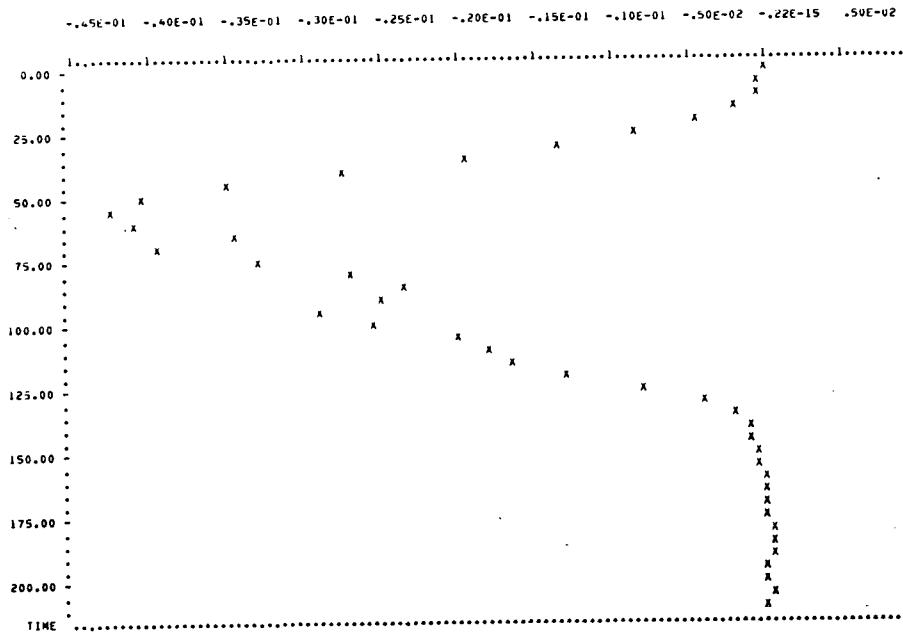
Figure A72. Graph of KV(3,16) versus Time

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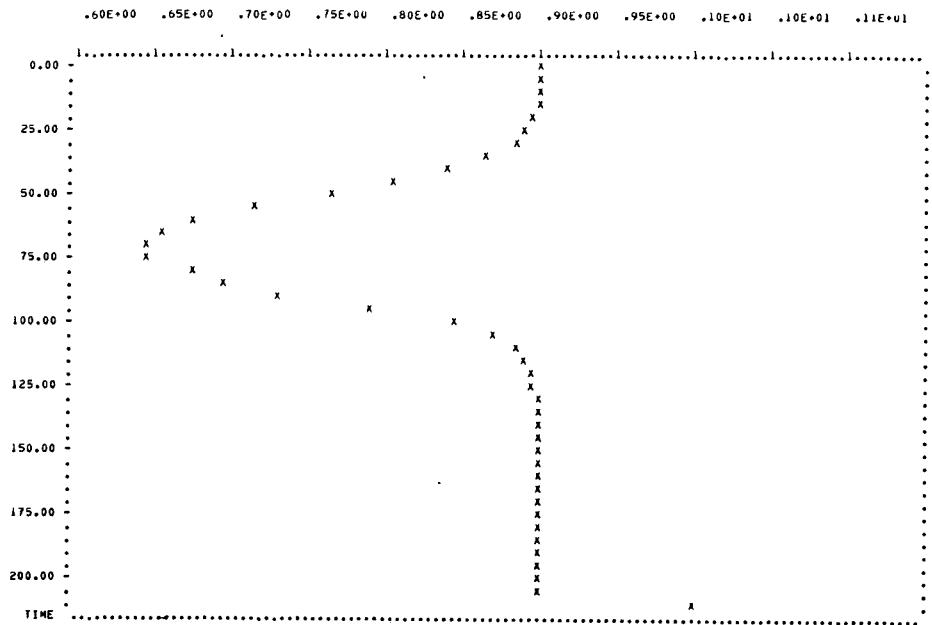
Figure A73. Graph of KV(3,17) versus Time
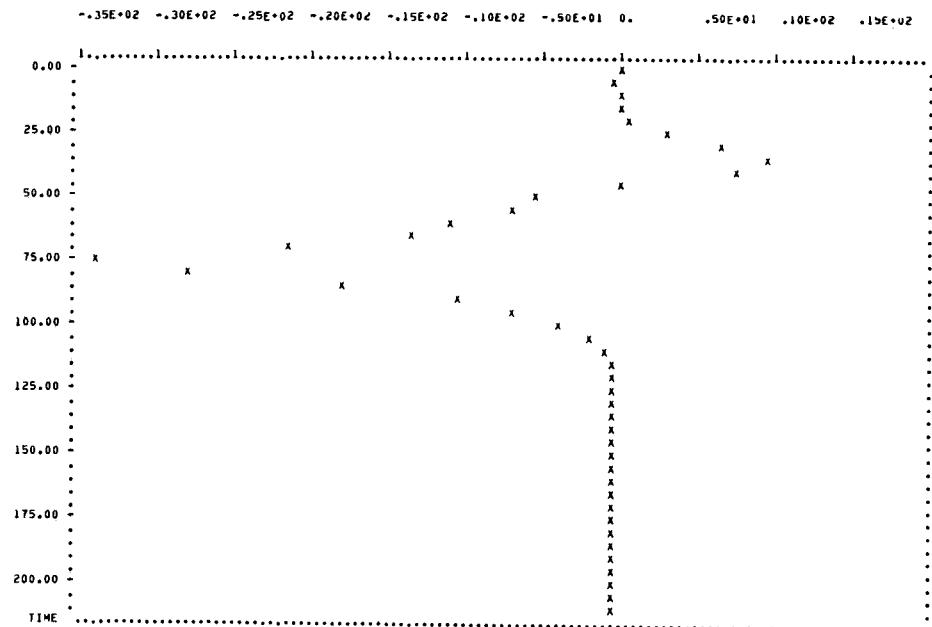

Figure A74. Graph of KV(3,18) versus Time
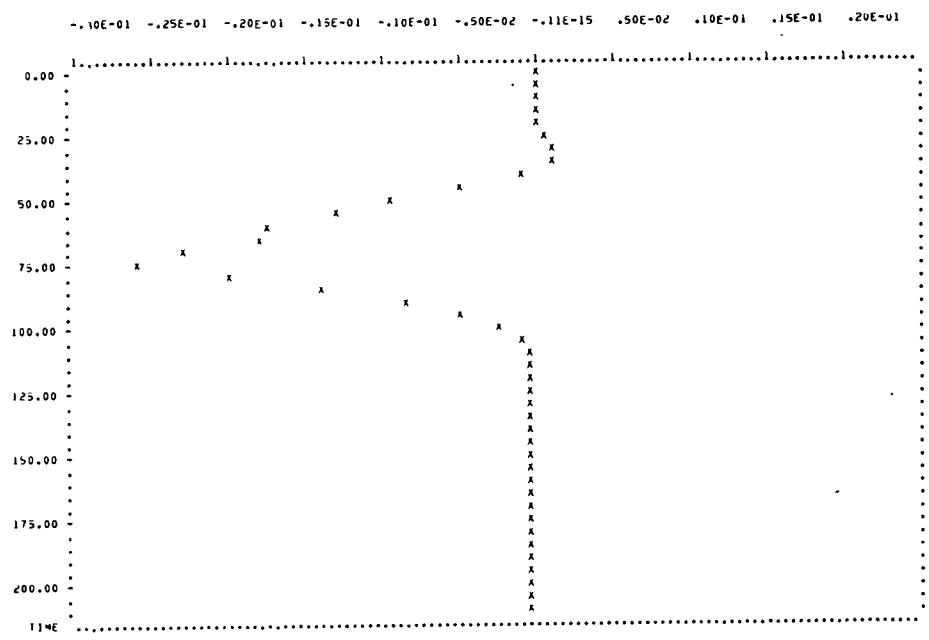
Figure A75. Graph of KV(3,19) versus Time
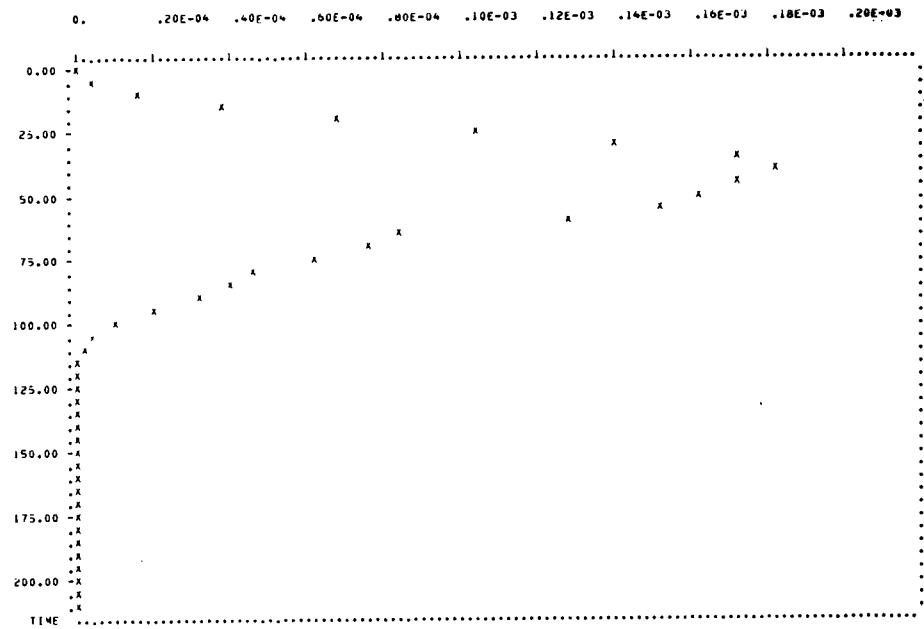
Figure A76. Graph of KV(3,23) versus Time
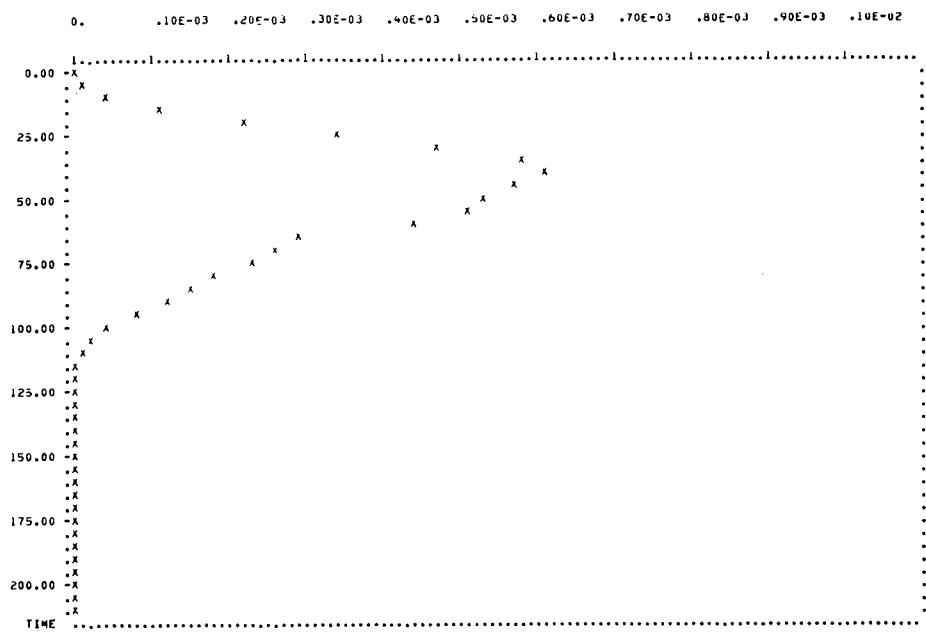
Figure A77. Graph of KV(3,24) versus Time
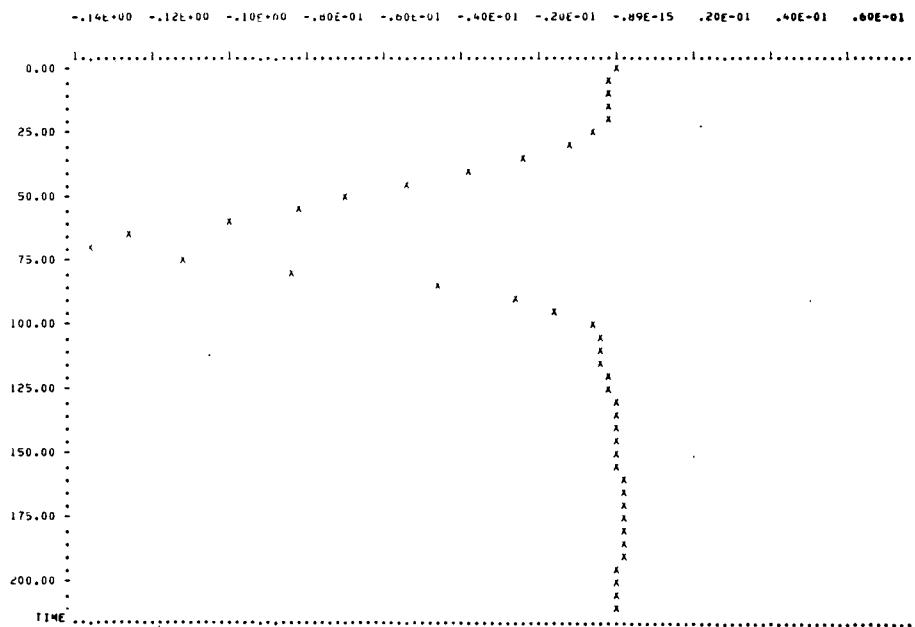
Figure A78. Graph of ū(1) versus Time

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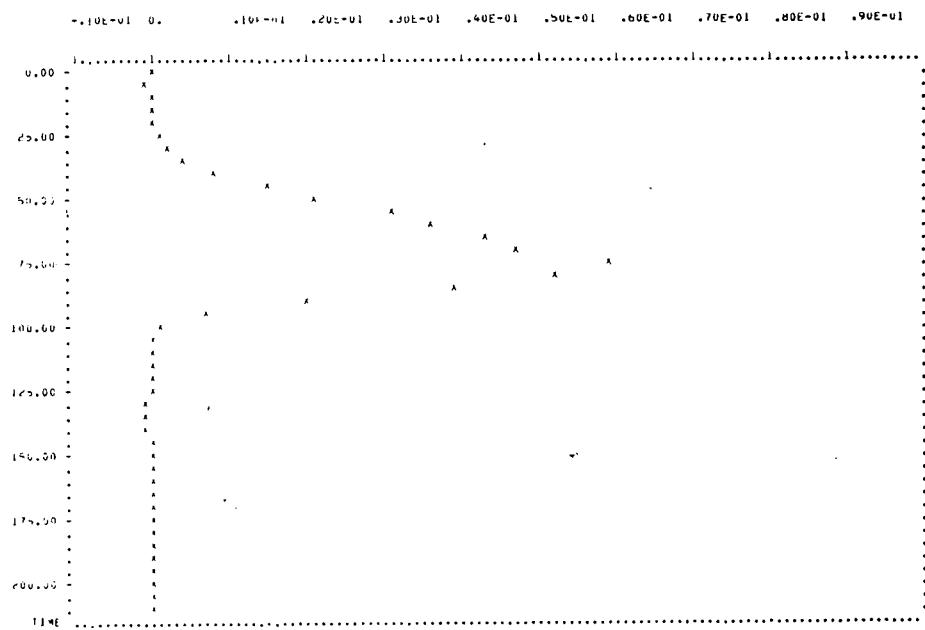
Figure A79. Graph of ū(2) versus Time
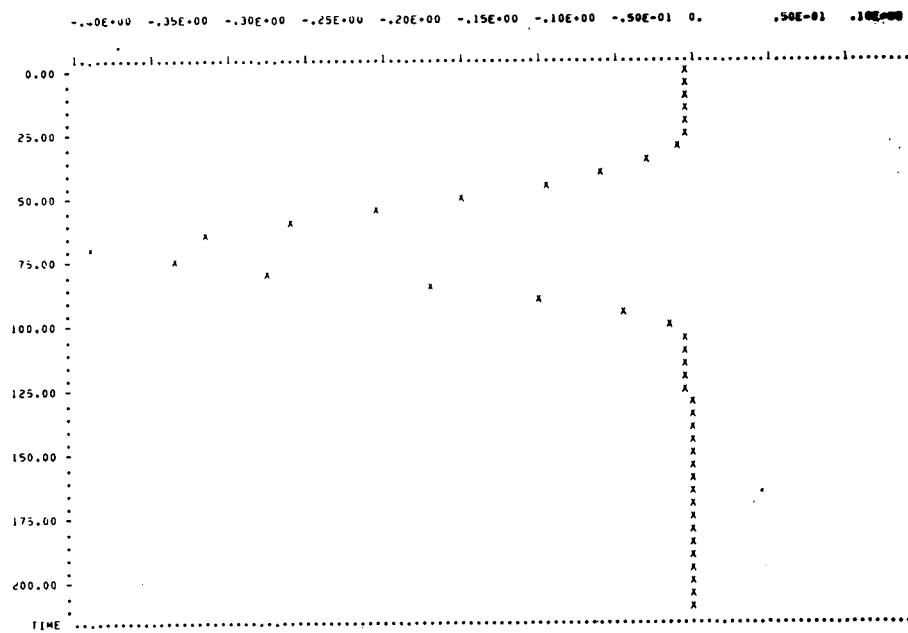
Figure A80. Graph of ū(3) versus Time

Table A1. Optimal Mean Control Input

TIME	U (1) (RAD)	U (2) (RAD)	U (3) (RAD)
0.	.2281E-06	.3232E-05	-.3551E-08
5.	-.5027E-04	-.9043E-04	-.2580E-05
10.	-.1899E-03	.1263E-03	-.2292E-04
15.	-.7066E-03	.3555E-03	-.1529E-03
20.	-.1984E-02	.8559E-03	-.6820E-03
25.	-.5018E-02	.1675E-02	-.2708E-02
30.	-.1154E-01	.2918E-02	-.9184E-02
35.	-.2276E-01	.4687E-02	-.2537E-01
40.	-.3747E-01	.8865E-02	-.5502E-01
45.	-.5229E-01	.1554E-01	-.9470E-01
50.	-.6825E-01	.2164E-01	-.1493E+00
55.	-.8193E-01	.3150E-01	-.2039E+00
60.	-.9914E-01	.3681E-01	-.2594E+00
65.	-.1260E+00	.4393E-01	-.3147E+00
70.	-.1344E+00	.4767E-01	-.3881E+00
75.	-.1105E+00	.5960E-01	-.3334E+00
80.	-.8203E-01	.5208E-01	-.2742E+00
85.	-.4464E-01	.3953E-01	-.1678E+00
90.	-.2485E-01	.2079E-01	-.9804E-01
95.	-.1413E-01	.7004E-02	-.4361E-01
100.	-.5878E-02	.1563E-02	-.1108E-01
105.	-.2986E-02	.8325E-03	-.3460E-02
110.	-.2881E-02	.5761E-03	-.2907E-02
115.	-.2359E-02	.3835E-03	-.2071E-02
120.	-.1408E-02	.1547E-03	-.9843E-03
125.	-.4152E-03	.1105E-04	-.2126E-03
130.	.3259E-03	-.4623E-04	.6829E-04
135.	.7847E-03	-.4599E-04	.9816E-04
140.	.1106E-02	-.1667E-04	.8349E-04
145.	.1385E-02	.5530E-05	.8323E-04
150.	.1617E-02	.8090E-04	.8694E-04
155.	.1840E-02	.1142E-03	.9033E-04
160.	.2024E-02	.1351E-03	.8769E-04
165.	.2130E-02	.2370E-03	.7905E-04
170.	.2206E-02	.2458E-03	.7169E-04
175.	.2244E-02	.2408E-03	.6581E-04
180.	.2238E-02	.3335E-03	.5903E-04
185.	.2170E-02	.3882E-03	.5159E-04
190.	.2058E-02	.4480E-03	.4060E-04
195.	.1938E-02	.4993E-03	.3111E-04
200.	.1748E-02	.5943E-03	.3320E-04
205.	.1123E-02	.4484E-03	.2173E-04
210.	.1338E-02	.5467E-03	.3221E-04

Table A2. Optimal Mean State

TIME (SEC)	$\bar{P}$ (RAD/SEC)	$\bar{r}$ (RAD/SEC)	$\bar{V}$ (FT/SEC)	$\bar{\phi}$ (RAD)	$\bar{\psi}$ (RAD)	$\bar{Y}$ (FT)	$\dot{\bar{\eta}}_1$ (FT/SEC)	$\bar{\eta}_1$ (FT)	$\dot{\bar{\eta}}_2$ (FT/SEC)	$\bar{\eta}_2$ (FT)
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	-.1027E-03	-.1105E-04	.531HE-03	-.3992E-04	-.6882E-06	.1404E-03	.2423E-02	.1049E-02	.6710E-03	.4023E-03
2.	-.2541E-03	-.1257E-03	.3324E-02	-.2222E-03	-.5877E-04	.1505E-02	.1139E-02	.3494E-02	.5412E-03	.1148E-02
3.	-.2575E-03	-.3363E-03	.7873E-02	-.4994E-03	-.2848E-03	.2968E-02	.6137E-03	.4501E-02	-.6623E-04	.1384E-02
4.	.1934E-04	-.5544E-03	.1096E-01	-.6404E-03	-.7338E-03	-.5142E-02	-.1315E-02	.3677E-02	-.4529E-03	.1053E-02
5.	.4180E-03	-.6830E-03	.6464E-02	-.4152E-03	-.1353E-02	-.4338E-01	-.2521E-02	.1872E-02	-.6128E-03	.5001E-03
6.	.5647E-03	-.7629E-03	-.7367E-02	.1027E-03	-.2076E-02	-.1400E+00	.6088E-02	.4318E-02	.9142E-03	.9226E-03
7.	.4751E-03	-.1039E-02	-.2214E-01	.6279E-03	-.2960E-02	-.3235E+00	.1561E-02	.8094E-02	.2835E-03	.1547E-02
8.	.4878E-03	-.1413E-02	-.3148E-01	.1096E-02	-.4189E-02	-.6280E+00	-.2919E-02	.7939E-02	-.6607E-03	.1330E-02
9.	.5979E-03	-.1641E-02	-.4637E-01	.1631E-02	-.5740E-02	-.1107E+01	-.4671E-02	.3923E-02	-.6557E-03	.6187E-03
10.	.3884E-03	-.1564E-02	-.7241E-01	.2147E-02	-.7374E-02	-.1828E+01	-.5136E-02	-.1491E-02	-.4996E-03	-.4142E-05
11.	.2197E-05	-.1417E-02	-.1887E+00	.2296E-02	-.8838E-02	-.2868E+01	.1365E-01	.4286E-02	.7659E-03	.5078E-03
12.	.2331E-03	-.1810E-02	-.2911E+00	.2343E-02	-.1041E-01	-.4286E+01	.4730E-02	.1369E-01	-.7168E-05	.8819E-03
13.	.7633E-03	-.2452E-02	-.3530E+00	.2810E-02	-.1255E-01	-.6145E+01	-.5025E-02	.1428E-01	-.3866E-03	.5711E-03
14.	.1109E-02	-.2801E-02	-.3941E+00	.3750E-02	-.1523E-01	-.8536E+01	-.9231E-02	.6735E-02	-.3167E-04	.3126E-03
15.	.8244E-03	-.2559E-02	-.4909E+00	.4738E-02	-.1797E-01	-.1158E+02	-.8827E-02	-.3122E-02	.4120E-03	.5221E-03
16.	.2562E-03	-.2191E-02	-.7052E+00	.5178E-02	-.2030E-01	.1541E+02	.2369E-01	.7308E-02	-.1527E-02	.7598E-04
17.	.7700E-03	-.2808E-02	-.9229E+00	.5526E-02	-.2274E-01	.2012E+02	.7006E-02	.2281E-01	-.9981E-03	-.1296E-02
18.	.2023E-02	-.3791E-02	-.1019E+01	.6834E-02	-.2608E-01	.2580E+02	-.1043E-01	.2171E-01	.7533E-03	-.1629E-02
19.	.2793E-02	-.4143E-02	-.1049E+01	.9230E-02	-.3015E-01	.3261E+02	-.1603E-01	.7780E-02	.2115E-02	-.1633E-03
20.	.2205E-02	-.3478E-02	-.1205E+01	.1173E-01	-.3401E-01	.4073E+02	-.1156E-01	-.7119E-02	.2211E-02	-.2174E-02
21.	.1119E-02	-.2712E-02	-.1621E+01	.1316E-01	-.3712E-01	.5035E+02	.3438E-01	.9847E-02	-.6153E-02	-.5716E-03
22.	.1981E-02	-.3468E-02	-.2050E+01	.1438E-01	-.4017E-01	.6159E+02	.7916E-02	.3059E-01	-.2081E-02	-.4900E-02
23.	.3826E-02	-.4597E-02	-.2256E+01	.1707E-01	-.4432E-01	.7457E+02	-.1570E-01	.2643E-01	.3292E-02	-.4388E-02
24.	.4669E-02	-.4729E-02	-.2347E+01	.2120E-01	-.4921E-01	.8947E+02	-.1921E-01	.7957E-02	.5099E-02	.2981E-04
25.	.3640E-02	-.3625E-02	-.2714E+01	.2518E-01	-.5361E-01	-.1065E+03	-.8967E-02	-.7047E-02	.3246E-02	.4496E-02
26.	.2044E-02	-.2557E-02	-.3477E+01	.2755E-01	-.5675E-01	-.1259E+03	.3609E-01	.1312E-01	-.1063E-01	-.1100E-02
27.	.2386E-02	-.3169E-02	-.4292E+01	.2919E-01	-.5971E-01	-.1478E+03	.6973E-02	.3410E-01	-.2426E-02	-.7895E-02
28.	.3624E-02	-.4053E-02	-.4847E+01	.3175E-01	-.6360E-01	-.1723E+03	-.1480E-01	.2901E-01	.5142E-02	-.6275E-02
29.	.3894E-02	-.3904E-02	-.5330E+01	.3512E-01	-.6795E-01	-.1996E+03	-.1344E-01	.1372E-01	.5568E-02	-.4824E-03
30.	.2974E-02	-.2807E-02	-.6101E+01	.3803E-01	-.7155E-01	-.2298E+03	-.5727E-03	.6404E-02	.1156E-02	.3051E-02
31.	.2136E-02	-.1875E-02	-.7249E+01	.3988E-01	-.7425E-01	-.2632E+03	.2304E-01	.2179E-01	-.9274E-02	-.2757E-02
32.	.2220E-02	-.2020E-02	-.8576E+01	.4131E-01	-.7650E-01	-.2998E+03	.7508E-02	.3677E-01	-.2967E-02	-.9029E-02
33.	.2422E-02	-.2384E-02	-.9713E+01	.4292E-01	-.7913E-01	-.3397E+03	-.2033E-02	.3860E-01	.1169E-02	-.9651E-02
34.	.2041E-02	-.2346E-02	-.1078E+02	.4440E-01	-.8196E-01	-.3830E+03	.2083E-03	.3722E-01	.3268E-03	-.8704E-02
35.	.1500E-02	-.2051E-02	-.1192E+02	.4528E-01	-.8463E-01	-.4297E+03	.5549E-02	.4029E-01	-.2356E-02	-.9849E-02
36.	.5239E-03	-.1202E-02	-.1325E+02	.4553E-01	-.8688E-01	-.4801E+03	-.1575E-01	.2600E-01	.9147E-02	-.1597E-02
37.	-.1853E-02	.3937E-02	-.1518E+02	.4387E-01	-.8775E-01	-.5342E+03	.2238E-01	.3310E-01	-.1188E-01	-.4487E-02
38.	-.2288E-02	.6609E-03	-.1750E+02	.4051E-01	-.8756E-01	-.5920E+03	.2425E-01	.5955E-01	-.1329E-01	-.1896E-01
39.	.3293E-03	-.4144E-02	-.1949E+02	.3828E-01	-.8785E-01	-.6533E+03	.6392E-02	.7494E-01	-.3309E-01	-.2756E-01
40.	.4051E-02	-.1582E-02	-.2081E+02	.3938E-01	-.8936E-01	-.7182E+03	-.3586E-02	.7527E-01	.2683E-02	-.2733E-01
41.	.4916E-02	-.1051E-02	-.2181E+02	.4326E-01	-.9149E-01	-.7867E+03	-.3379E-01	.3951E-01	.2271E-01	-.3757E-01
42.	.4066E-02	.1337E-02	-.2370E+02	.4493E-01	-.9188E-01	-.8589E+03	.2813E-01	.4361E-01	-.1928E-01	-.5829E-02
43.	-.3154E-02	.1872E-02	-.2634E+02	.4208E-01	-.9065E-01	-.9347E+03	.2562E-01	.7526E-01	-.1751E-01	-.2755E-01
44.	-.3709E-02	.7912E-03	-.2860E+02	.3728E-01	-.8980E-01	-.1014E+04	.2524E-02	.8851E-01	-.1655E-02	-.3693E-01
45.	-.3625E-02	-.2102E-02	-.3015E+02	.3243E-01	-.9002E-01	-.1097E+04	-.3390E-02	.8662E-01	.2393E-02	-.3562E-01
46.	-.4476E-02	.3914E-03	-.3145E+02	.2731E-01	-.9059E-01	-.1182E+04	-.1518E-01	.6089E-01	.1225E-01	-.1602E-01
47.	-.5595E-02	.2041E-02	-.3364E+02	.2086E-01	-.8960E-01	-.1272E+04	.3068E-01	.7715E-01	-.2482E-01	-.2856E-01
48.	-.2876E-02	.1898E-02	-.3618E+02	.1511E-01	-.8773E-01	-.1364E+04	.1488E-01	.1027E+00	-.1163E-01	-.4900E-01
49.	.1761E-02	.1178E-02	-.3820E+02	.1343E-01	-.8640E-01	-.1459E+04	.1725E-02	.1091E+00	-.1191E-02	-.5424E-01
50.	.4671E-02	.9815E-03	-.3975E+02	.1574E-01	-.8555E-01	-.1557E+04	.5034E-02	.1120E+00	-.4904E-02	-.5703E-01
51.	.3299E-02	.1892E-02	-.4131E+02	.1908E-01	-.8453E-01	-.1658E+04	-.1391E-01	.9041E-01	.1253E-01	-.3872E-01
52.	.6620E-03	.3247E-02	-.4375E+02	.1974E-01	-.8208E-01	-.1761E+04	.1569E-01	.9997E-01	-.1519E-01	-.4785E-01
53.	.2095E-02	.3094E-02	-.4639E+02	.1981E-01	-.7908E-01	-.1867E+04	-.2547E-02	.1074E+00	.2788E-02	-.5477E-01
54.	.4834E-02	.2859E-02	-.4860E+02	.2238E-01	-.7641E-01	-.1974E+04	-.7184E-02	.1009E+00	.7435E-02	-.4840E-01

Table A2. Optimal Mean State (Continued)

TIME (SEC)	$\bar{P}$ (RAD/SEC)	$\bar{r}$ (RAD/SEC)	$\bar{V}$ (FT/SEC)	$\bar{\phi}$ (RAD)	$\bar{\psi}$ (RAD)	$\bar{Y}$ (FT)	$\bar{\dot{\eta}}_1$ (FT/SEC)	$\bar{\eta}_1$ (FT)	$\bar{\dot{\eta}}_2$ (FT/SEC)	$\bar{\eta}_2$ (FT)
55.	.5936E-02	.3019E-02	-.5059E+02	.2703E-01	-.7378E-01	-.2083E+04	-.3452E-02	.9578E-01	.3448E-02	-.4336E-01
56.	.4194E-02	.3604E-02	-.5243E+02	.3157E-01	-.7086E-01	-.2193E+04	.1192E-01	.9941E-01	-.1344E-01	-.4813E-01
57.	-.1384E-02	.4102E-02	-.5496E+02	.3238E-01	-.6737E-01	-.2305E+04	.1280E-01	.1123E+00	-.1519E-01	-.6336E-01
58.	-.8687E-02	.4270E-02	-.5740E+02	.2660E-01	-.6353E-01	-.2417E+04	.1118E-01	.1241E+00	-.1425E-01	-.7830E-01
59.	-.1554E-01	.4245E-02	-.5945E+02	.1358E-01	-.5951E-01	-.2530E+04	.1082E-01	.1351E+00	-.1433E-01	-.9284E-01
60.	-.2004E-01	.4077E-02	-.6237E+02	-.5597E-02	-.5540E-01	-.2643E+04	.1026E-01	.1456E+00	-.1403E-01	-.1073E+00
61.	-.1652E-01	.2279E-02	-.6408E+02	-.2624E-01	-.5181E-01	-.2756E+04	-.3004E-01	.1461E+00	.3262E-01	-.1100E+00
62.	-.7405E-02	.1166E-02	-.6428E+02	-.3852E-01	-.4989E-01	-.2868E+04	-.3241E-01	.1060E+00	.3671E-01	-.6510E-01
63.	-.2731E-02	.1493E-02	-.6439E+02	-.4393E-01	-.4804E-01	-.2980E+04	-.1561E-01	.8435E-01	.1719E-01	-.4136E-01
64.	.1475E-03	.1566E-02	-.6472E+02	-.4575E-01	-.4591E-01	-.3091E+04	-.1932E-01	.6692E-01	.2219E-01	-.2205E-01
65.	.2368E-02	.1616E-02	-.6503E+02	-.4503E-01	-.4374E-01	-.3202E+04	-.1914E-01	.4720E-01	.2265E-01	.8335E-03
66.	.1113E-02	.2548E-02	-.6571E+02	-.4350E-01	-.4117E-01	-.3311E+04	.5183E-02	.3426E-01	-.6907E-02	.1616E-01
67.	.2637E-02	.2770E-02	-.6713E+02	-.4272E-01	-.3783E-01	-.3420E+04	-.3469E-02	.3825E-01	.4690E-02	.1046E-01
68.	.9095E-02	.2625E-02	-.6826E+02	-.3749E-01	-.3455E-01	-.3527E+04	-.8380E-02	.3027E-01	-.1110E-01	.2094E-01
69.	.1576E-01	.2903E-02	-.6923E+02	-.2540E-01	-.3149E-01	-.3633E+04	-.4863E-02	.2376E-01	.6217E-02	.2950E-01
70.	.2043E-01	.3300E-02	-.7022E+02	-.7313E-02	-.2818E-01	-.3737E+04	-.4858E-02	.1879E-01	.6018E-02	.357RE-01
71.	-.1410E-02	.6931E-02	-.7279E+02	-.6496E-02	-.2349E-01	-.3838E+04	.4119E-01	.3260E-02	-.5661E-01	.5597E-01
72.	-.2516E-01	.8115E-02	-.7927E+02	-.1013E-01	-.1547E-01	-.3938E+04	.1816E-01	.4738E-01	-.2426E-01	-.7446E-02
73.	-.3082E-01	.7238E-02	-.8551E+02	-.3405E-01	-.7578E-02	-.4034E+04	.1326E-02	.5028E-01	-.1093E-01	-.1057E-01
74.	-.3332E-01	.7368E-02	-.9140E+02	-.7111E-01	.3953E-03	-.4127E+04	.1346E-01	.5876E-01	-.2013E-01	-.2223E-01
75.	-.3873E-01	.7506E-02	-.9875E+02	-.1067E+00	.8961E-02	-.4216E+04	.1408E-01	.7225E-01	-.2243E-01	-.4272E-01
76.	-.2267E-01	.3148E-02	-.1043E+03	-.1410E+00	.1659E-01	-.4300E+04	-.1833E-01	.1231E+00	.2150E-01	-.1186E+00
77.	.7768E-02	.4172E-03	-.1017E+03	-.1473E+00	.1957E-01	-.4379E+04	-.1700E-01	.8278E-01	.2193E-01	-.5654E-01
78.	.2704E-01	.1457E-02	-.1028E+03	-.1290E+00	.2230E-01	-.4453E+04	.1177E-01	.8740E-01	-.2256E-01	-.6622E-01
79.	.4109E-01	.1879E-02	-.1023E+03	-.9431E-01	.2541E-01	-.4522E+04	.7156E-03	.9212E-01	-.5428E-02	-.7748E-01
80.	.5100E-01	.2575E-02	-.1016E+03	-.4742E-01	.2851E-01	-.4585E+04	.2104E-02	.9280E-01	-.8444E-02	-.8338E-01
81.	.4902E-01	.2541E-02	-.1007E+03	.4501E-02	.3151E-01	-.4643E+04	.2448E-02	.1087E+00	-.1400E-01	-.1138E+00
82.	.2807E-01	.2506E-02	-.9858E+02	.4471E-01	.3360E-01	-.4694E+04	-.6319E-03	.1044E+00	-.9030E-02	-.1141E+00
83.	.5841E-01	.2660E-02	-.9640E+02	.5428E-01	.3558E-01	-.4739E+04	.2047E-02	.1066E+00	-.1275E-01	-.1264E+00
84.	-.1935E-01	.2049E-02	-.9455E+02	.4937E-01	.3728E-01	-.4778E+04	-.3952E-02	.1049E+00	-.1224E-02	-.1316E+00
85.	-.2672E-01	.1212E-02	-.9205E+02	.2571E-01	.3845E-01	-.4811E+04	-.5511E-02	.9948E-01	.2818E-02	-.1294E+00
86.	-.1878E-01	.8473E-04	-.8897E+02	.2322E-02	.3899E-01	-.4839E+04	.1388E-02	.1046E+00	-.886RE-02	-.1418E+00
87.	-.8544E-02	-.7566E-03	-.8443E+02	-.1044E-01	.3863E-01	-.4861E+04	.1343E-03	.1035E+00	-.6496E-02	-.1439E+00
88.	-.4378E-02	-.1071E-02	-.7945E+02	-.1601E-01	.3798E-01	-.4878E+04	.2238E-02	.1054E+00	-.1056E-01	-.1525E+00
89.	-.3918E-02	-.1528E-02	-.7438E+02	-.1954E-01	.3690E-01	-.4890E+04	-.1123E-02	.1057E+00	-.4710E-02	-.1591E+00
90.	-.4463E-02	-.2069E-02	-.6862E+02	-.2333E-01	.3526E-01	-.4898E+04	-.3566E-02	.1029E+00	-.1658E-03	-.1606E+00
91.	-.1039E-02	-.2395E-02	-.6226E+02	-.2615E-01	.3323E-01	-.4901E+04	-.1139E-01	.8747E-01	.1782E-01	-.1358E+00
92.	.4319E-02	-.2397E-02	-.5606E+02	-.2414E-01	.3117E-01	-.4901E+04	-.5996E-02	.7982E-01	.7177E-01	-.1252E+00
93.	.8672E-02	-.2842E-02	-.4945E+02	-.1714E-01	.2880E-01	-.4897E+04	-.1038E-01	.7098E-01	.1474E-01	-.1127E+00
94.	.1041E-01	-.3259E-02	-.4195E+02	-.7059E-02	.2594E-01	-.4889E+04	-.1071E-01	.6008E-01	.1523E-01	-.9673E-01
95.	.9607E-02	-.3689E-02	-.3360E+02	.3393E-02	.2243E-01	-.4880E+04	-.1110E-01	.4908E-01	.1615E-01	-.8069E-01
96.	.5244E-02	-.2402E-02	-.2542E+02	.1153E-01	.1896E-01	-.4868E+04	-.7338E-02	.2095E-01	.1504E-01	-.3064E-01
97.	-.2188E-03	-.5970E-03	-.2158E+02	.1387E-01	.1755E-01	-.4854E+04	.8379E-02	.2567E-01	-.1771E-01	-.4147E-01
98.	-.6955E-03	-.1020E-02	-.1889E+02	.1328E-01	.1668E-01	-.4838E+04	-.6234E-02	.2570E-01	.9369E-02	-.4311E-01
99.	.2038E-03	-.1457E-02	-.1511E+02	.1323E-01	.1527E-01	-.4821E+04	-.6254E-02	.1873E-01	.9840E-02	-.3142E-01
100.	.1848E-03	-.1645E-02	-.1022E+02	.1347E-01	.1359E-01	-.4802E+04	-.4407E-02	.1362E-01	.6633E-02	-.2326E-01
101.	-.2179E-02	-.9170E-03	-.4809E+01	.1313E-01	.1198E-01	-.4782E+04	-.4080E-02	.9648E-03	.8446E-02	.1908E-03
102.	-.5836E-02	.3655E-03	-.5835E+01	.9048E-02	.1170E-01	-.4762E+04	.6646E-02	.3869E-02	-.1402E-01	-.6060E-02
103.	-.6349E-02	.3450E-03	-.6339E+01	.2815E-02	.1207E-01	-.4740E+04	.4700E-03	.7687E-02	-.1670E-02	-.1355E-01
104.	-.4907E-02	.6520E-04	-.6543E+01	-.2809E-02	.1226E-01	-.4718E+04	-.1257E-02	.6863E-02	.2246E-02	-.1199E-01
105.	-.3516E-02	-.2124E-05	-.6432E+01	-.6929E-02	.1233E-01	-.4694E+04	-.2803E-03	.6050E-02	.4533E-03	-.1048E-01
106.	-.2346E-02	.5995E-05	-.6365E+01	-.9717E-02	.1240E-01	-.4670E+04	-.8527E-04	.5760E-02	.2267E-03	-.9920E-02
107.	-.1479E-02	.3119E-04	-.6416E+01	-.1150E-01	.1252E-01	-.4645E+04	.1443E-03	.5792E-02	-.3611E-03	-.9990E-02
108.	-.8274E-03	.3620E-04	-.6545E+01	-.1252E-01	.1266E-01	-.4619E+04	.2616E-04	.5865E-02	-.1702E-03	-.1016E-01
109.	-.3822E-03	.3971E-04	-.6702E+01	-.1299E-01	.1281E-01	-.4591E+04	-.1493E-04	.5845E-02	-.7205E-04	-.1016E-01

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Table A2. Optimal Mean State (Continued)

TIME (SEC)	$\bar{P}$ (RAD/SEC)	$\bar{r}$ (RAD/SEC)	$\bar{V}$ (FT/SEC)	$\bar{\phi}$ (RAD)	$\bar{\psi}$ (RAD)	$\bar{Y}$ (FT)	$\dot{\bar{\eta}}_1$ (FT/SEC)	$\bar{\eta}_1$ (FT)	$\dot{\bar{\eta}}_2$ (FT/SEC)	$\bar{\eta}_2$ (FT)
110.	-.1370E-03	.5289E-04	-.6892E+01	-.1312E-01	.1297E-01	-.4564E+04	.9348E-05	.5816E-02	-.1130E-03	-.1016E-01
111.	.5301E-04	.2873E-04	-.7096E+01	-.1305E-01	.1314E-01	-.4535E+04	.1035E-03	.6126E-02	-.1906E-03	-.1077E-01
112.	.2260E-03	-.3558E-04	-.7151E+01	-.1279E-01	.1324E-01	-.4505E+04	-.3701E-03	.5928E-02	.6536E-03	-.1039E-01
113.	.2266E-03	-.5607E-04	-.7079E+01	-.1244E-01	.1330E-01	-.4474E+04	-.3672E-03	.5505E-02	.5625E-03	-.9620E-02
114.	.7872E-04	-.4877E-04	-.6996E+01	-.1217E-01	.1335E-01	-.4442E+04	-.2405E-03	.5195E-02	.3571E-03	-.9084E-02
115.	-.1154E-03	-.4482E-04	-.6936E+01	-.1208E-01	.1340E-01	-.4409E+04	-.2230E-03	.4952E-02	.3383E-03	-.8681E-02
116.	-.1992E-03	-.6944E-04	-.6862E+01	-.1215E-01	.1344E-01	-.4376E+04	-.7535E-04	.4929E-02	.1004E-03	-.8680E-02
117.	-.1083E-03	-.1277E-03	-.6655E+01	-.1220E-01	.1344E-01	-.4341E+04	-.3606E-03	.4682E-02	.5681E-03	-.8255E-02
118.	.1894E-04	-.1711E-03	-.6246E+01	-.1214E-01	.1339E-01	-.4305E+04	-.4600E-03	.4238E-02	.7575E-03	-.7474E-02
119.	.1113E-03	-.1941E-03	-.5814E+01	-.1197E-01	.1329E-01	-.4268E+04	-.4323E-03	.3781E-02	.7152E-03	-.6680E-02
120.	.1673E-03	-.2097E-03	-.5277E+01	-.1173E-01	.1318E-01	-.4231E+04	-.4290E-03	.3341E-02	.7065E-03	-.5926E-02
121.	.2085E-03	-.2262E-03	-.4680E+01	-.1144E-01	.1305E-01	-.4192E+04	-.4696E-03	.2889E-02	.8121E-03	-.5133E-02
122.	.2078E-03	-.2337E-03	-.4031E+01	-.1114E-01	.1290E-01	-.4152E+04	-.4582E-03	.2407E-02	.7740E-03	-.4284E-02
123.	.1643E-03	-.2357E-03	-.3358E+01	-.1086E-01	.1274E-01	-.4112E+04	-.4191E-03	.1963E-02	.7096E-03	-.3512E-02
124.	.1101E-03	-.2410E-03	-.2664E+01	-.1064E-01	.1258E-01	-.4070E+04	-.3984E-03	.1552E-02	.6735E-03	-.2799E-02
125.	.7445E-04	-.2530E-03	-.1931E+01	-.1046E-01	.1240E-01	-.4028E+04	-.4000E-03	.1149E-02	.6922E-03	-.2099E-02
126.	.5924E-04	-.2607E-03	-.1145E+01	-.1031E-01	.1221E-01	-.3985E+04	-.4677E-03	.6662E-03	.8349E-03	-.1231E-02
127.	.1536E-04	-.2478E-03	-.3644E+00	-.1019E-01	.1202E-01	-.3940E+04	-.3435E-03	.2575E-03	.6043E-03	-.5030E-03
128.	-.3836E-04	-.2367E-03	.3740E+00	-.1013E-01	.1185E-01	-.3895E+04	-.2715E-03	-.4171E-04	.4682E-03	-.1900E-04
129.	-.7479E-04	-.2366E-03	.1098E+01	-.1011E-01	.1167E-01	-.3849E+04	-.2583E-03	-.3046E-03	.4594E-03	.4786E-03
130.	-.8343E-04	-.2452E-03	.1846E+01	-.1012E-01	.1150E-01	-.3803E+04	-.2532E-03	-.5586E-03	.4504E-03	.9263E-03
131.	-.7904E-04	-.2508E-03	.2638E+01	-.1014E-01	.1131E-01	-.3755E+04	-.3202E-03	-.8863E-03	.5961E-03	.1518E-02
132.	-.9678E-04	-.2427E-03	.3427E+01	-.1016E-01	.1112E-01	-.3706E+04	-.2310E-03	-.1157E-02	.4107E-03	.2003E-02
133.	-.1116E-03	-.2391E-03	.4196E+01	-.1020E-01	.1094E-01	-.3657E+04	-.1922E-03	-.1359E-02	.3640E-03	.2361E-02
134.	-.1081E-03	-.2449E-03	.4977E+01	-.1025E-01	.1076E-01	-.3607E+04	-.1958E-03	-.1548E-02	.3642E-03	.2702E-02
135.	-.8261E-04	-.2578E-03	.5807E+01	-.1028E-01	.1057E-01	-.3556E+04	-.1987E-03	-.1740E-02	.3793E-03	.3052E-02
136.	-.5941E-04	-.2662E-03	.6701E+01	-.1029E-01	.1036E-01	-.3505E+04	-.2521E-03	-.1997E-02	.4917E-03	.3525E-02
137.	-.5880E-04	-.2643E-03	.7614E+01	-.1030E-01	.1015E-01	-.3452E+04	-.1773E-03	-.2201E-02	.3237E-03	.3893E-02
138.	-.5340E-04	-.2674E-03	.8539E+01	-.1030E-01	.9940E-02	-.3399E+04	-.1568E-03	-.2358E-02	.3189E-03	.4180E-02
139.	-.3074E-04	-.2784E-03	.9509E+01	-.1029E-01	.9721E-02	-.3346E+04	-.1619E-03	-.2511E-02	.3205E-03	.4461E-02
140.	.1057E-04	-.2949E-03	.1056E+02	-.1025E-01	.9488E-02	-.3291E+04	-.1622E-03	-.2665E-02	.3221E-03	.4751E-02
141.	.3810E-04	-.3074E-03	.1170E+02	-.1018E-01	.9237E-02	-.3236E+04	-.2062E-03	-.2869E-02	.4097E-03	.5125E-02
142.	.2827E-04	-.3129E-03	.1289E+02	-.1010E-01	.8977E-02	-.3180E+04	-.1463E-03	-.3032E-02	.2868E-03	.5414E-02
143.	.7209E-05	-.3227E-03	.1414E+02	-.1004E-01	.8709E-02	-.3124E+04	-.1365E-03	-.3164E-02	.2715E-03	.5654E-02
144.	-.1025E-04	-.3388E-03	.1547E+02	-.9998E-02	.8427E-02	-.3067E+04	-.1354E-03	-.3292E-02	.2859E-03	.5886E-02
145.	-.1694E-04	-.3601E-03	.1692E+02	-.9974E-02	.8124E-02	-.3009E+04	-.1319E-03	-.3416E-02	.2679E-03	.6116E-02
146.	-.1824E-04	-.3796E-03	.1850E+02	-.9954E-02	.7799E-02	-.2951E+04	-.2552E-03	-.3646E-02	.5201E-03	.6546E-02
147.	-.2288E-04	-.3892E-03	.2017E+02	-.9941E-02	.7459E-02	-.2892E+04	-.1837E-03	-.3851E-02	.3830E-03	.6918E-02
148.	-.9629E-05	-.4031E-03	.2192E+02	-.9927E-02	.7108E-02	-.2833E+04	-.1738E-03	-.4018E-02	.3420E-03	.7230E-02
149.	.2713E-04	-.4241E-03	.2379E+02	-.9890E-02	.6738E-02	-.2773E+04	-.1762E-03	-.4183E-02	.3693E-03	.7539E-02
150.	.8505E-04	-.4503E-03	.2581E+02	-.9807E-02	.6344E-02	-.2713E+04	-.1747E-03	-.4347E-02	.3685E-03	.7853E-02
151.	.1023E-03	-.4632E-03	.2799E+02	-.9679E-02	.5925E-02	-.2652E+04	-.2265E-03	-.4584E-02	.4516E-03	.8294E-02
152.	.6011E-04	-.4600E-03	.3022E+02	-.9573E-02	.5503E-02	-.2591E+04	-.1175E-03	-.4734E-02	.2891E-03	.8559E-02
153.	.1874E-04	-.4640E-03	.3248E+02	-.9513E-02	.5081E-02	-.2530E+04	-.1071E-03	-.4834E-02	.2242E-03	.8740E-02
154.	-.3139E-05	-.4764E-03	.3462E+02	-.9488E-02	.4649E-02	-.2468E+04	-.9464E-04	-.4923E-02	.2078E-03	.8904E-02
155.	-.3653E-05	-.4945E-03	.3728E+02	-.9476E-02	.4200E-02	-.2406E+04	-.8064E-04	-.4998E-02	.1860E-03	.9048E-02
156.	-.1428E-04	-.5059E-03	.3988E+02	-.9466E-02	.3734E-02	-.2344E+04	-.1859E-03	-.5170E-02	.3728E-03	.9367E-02
157.	-.4103E-04	-.5044E-03	.4254E+02	-.9482E-02	.3264E-02	-.2282E+04	-.8405E-04	-.5284E-02	.2550E-03	.9567E-02
158.	-.4464E-04	-.5081E-03	.4524E+02	-.9516E-02	.2793E-02	-.2219E+04	-.7334E-04	-.5350E-02	.1848E-03	.9687E-02
159.	-.2087E-04	-.5182E-03	.4802E+02	-.9541E-02	.2315E-02	-.2157E+04	-.5334E-04	-.5401E-02	.1369E-03	.9779E-02
160.	.2214E-04	-.5322E-03	.5091E+02	-.9535E-02	.1823E-02	-.2094E+04	-.3530E-04	-.5432E-02	.9144E-04	.9841E-02
161.	.4578E-04	-.5422E-03	.5394E+02	-.9490E-02	.1317E-02	-.2032E+04	-.1975E-03	-.5594E-02	.3885E-03	.1015E-01
162.	.3507E-04	-.5379E-03	.5701E+02	-.9446E-02	.8085E-03	-.1970E+04	-.1049E-03	-.5726E-02	.3013E-03	.1039E-01
163.	.3383E-04	-.5368E-03	.6011E+02	-.9411E-02	.3029E-03	-.1907E+04	-.9844E-04	-.5814E-02	.2603E-03	.1055E-01
164.	.5157E-04	-.5412E-03	.6327E+02	-.9370E-02	-.2052E-03	-.1845E+04	-.8200E-04	-.5891E-02	.2236E-03	.1070E-01

Table A2. Optimal Mean State (Continued)

TIME (SEC)	$\bar{P}$ (RAD/SEC)	$\bar{r}$ (RAD/SEC)	$\bar{V}$ (FT/SEC)	$\bar{\phi}$ (RAD)	$\bar{\psi}$ (RAD)	$\bar{Y}$ (FT)	$\dot{\bar{\eta}}_1$ (FT/SEC)	$\bar{\eta}_1$ (FT)	$\dot{\bar{\eta}}_2$ (FT/SEC)	$\bar{\eta}_2$ (FT)
165.	.8431E-04	-.5491E-03	.6651E+02	-.9304E-02	-.7202E-03	-.1783E+04	-.7022E-04	-.5954E-02	.1772E-03	.1083E-01
166.	.8143E-04	-.5465E-03	.6992E+02	-.9218E-02	-.1240E-02	-.1722E+04	-.7619E-04	-.6031E-02	.1011E-03	.1098E-01
167.	.4650E-04	-.5377E-03	.7314E+02	-.9159E-02	-.1754E-02	-.1661E+04	.1749E-06	-.6048E-02	.7233E-04	.1100E-01
168.	.2080E-04	-.5331E-03	.7645E+02	-.9133E-02	-.2261E-02	-.1600E+04	-.4747E-05	-.6040E-02	.5925E-04	.1098E-01
169.	.1057E-04	-.5315E-03	.7979E+02	-.9125E-02	-.2766E-02	-.1540E+04	.2496E-04	-.6016E-02	.2296E-04	.1094E-01
170.	.1282E-04	-.5313E-03	.8317E+02	-.9123E-02	-.3271E-02	-.1480E+04	.4093E-04	-.5970E-02	-.2832E-04	.1086E-01
171.	.3563E-05	-.5294E-03	.8659E+02	-.9123E-02	-.3775E-02	-.1420E+04	-.4407E-04	-.5978E-02	.3419E-04	.1087E-01
172.	-.1337E-04	-.5240E-03	.9002E+02	-.9140E-02	-.4276E-02	-.1362E+04	.2092E-04	-.5973E-02	.2340E-04	.1085E-01
173.	-.1502E-04	-.5188E-03	.9346E+02	-.9158E-02	-.4772E-02	-.1303E+04	.1437E-04	-.5946E-02	.4480E-05	.1080E-01
174.	.5205E-06	-.5135E-03	.9691E+02	-.9190E-02	-.5264E-02	-.1246E+04	.4562E-04	-.5903E-02	-.2933E-04	.1072E-01
175.	.2779E-04	-.5077E-03	.1004E+03	-.9191E-02	-.5750E-02	-.1189E+04	.5897E-04	-.5839E-02	-.7483E-04	.1061E-01
176.	.4491E-04	-.5061E-03	.1038E+03	-.9158E-02	-.6232E-02	-.1134E+04	-.6604E-04	-.5848E-02	.7468E-04	.1063E-01
177.	.3617E-04	-.5025E-03	.1073E+03	-.9142E-02	-.6714E-02	-.1078E+04	-.2092E-04	-.5879E-02	.8511E-04	.1068E-01
178.	.1825E-04	-.4953E-03	.1108E+03	-.9133E-02	-.7190E-02	-.1024E+04	-.3092E-04	-.5896E-02	.7482E-04	.1072E-01
179.	.2236E-05	-.4859E-03	.1143E+03	-.9141E-02	-.7658E-02	-.9711E+03	-.6595E-05	-.5902E-02	.5557E-04	.1074E-01
180.	-.7839E-05	-.4747E-03	.1177E+03	-.9153E-02	-.8117E-02	-.9188E+03	.4043E-06	-.5895E-02	.2613E-04	.1074E-01
181.	-.1458E-04	-.4654E-03	.1211E+03	-.9195E-02	-.8564E-02	-.8676E+03	.9562E-05	-.5861E-02	-.6017E-04	.1067E-01
182.	-.1622E-04	-.4627E-03	.1244E+03	-.9230E-02	-.9007E-02	-.8175E+03	.1911E-04	-.5835E-02	-.1682E-05	.1063E-01
183.	-.1902E-04	-.4557E-03	.1278E+03	-.9270E-02	-.9445E-02	-.7685E+03	.1572E-04	-.5811E-02	-.3936E-05	.1058E-01
184.	-.1991E-04	-.4438E-03	.1311E+03	-.9312E-02	-.9875E-02	-.7206E+03	.3723E-04	-.5772E-02	-.2489E-04	.1052E-01
185.	-.9638E-05	-.4280E-03	.1344E+03	-.9350E-02	-.1029E-01	-.6740E+03	.4954E-04	-.5718E-02	-.5456E-04	.1042E-01
186.	.3027E-05	-.4168E-03	.1375E+03	-.9375E-02	-.1049E-01	-.6296E+03	.1764E-04	-.5661E-02	-.8285E-04	.1032E-01
187.	.1727E-05	-.4121E-03	.1407E+03	-.9394E-02	-.1109E-01	-.5845E+03	.3220E-04	-.5625E-02	-.1438E-04	.1025E-01
188.	-.1776E-04	-.4016E-03	.1439E+03	-.9424E-02	-.1147E-01	-.5417E+03	.2195E-04	-.5593E-02	-.7623E-05	.1019E-01
189.	-.3847E-04	-.3854E-03	.1468E+03	-.9477E-02	-.1185E-01	-.5003E+03	.4168E-04	-.5549E-02	-.2118E-04	.1012E-01
190.	-.4666E-04	-.3652E-03	.1497E+03	-.9546E-02	-.1220E-01	-.4603E+03	.4990E-04	-.5495E-02	-.4793E-04	.1003E-01
191.	-.3008E-04	-.3503E-03	.1525E+03	-.9611E-02	-.1254E-01	-.4217E+03	.6183E-04	-.5407E-02	-.1075E-03	.9862E-02
192.	.7190E-05	-.3453E-03	.1552E+03	-.9649E-02	-.1287E-01	-.3847E+03	.5204E-04	-.5343E-02	-.4219E-04	.9744E-02
193.	.5532E-04	-.3350E-03	.1579E+03	-.9643E-02	-.1319E-01	-.3491E+03	.5349E-04	-.5283E-02	-.4891E-04	.9637E-02
194.	.1220E-03	-.3195E-03	.1604E+03	-.9591E-02	-.1350E-01	-.3151E+03	.6537E-04	-.5213E-02	-.7332E-04	.9513E-02
195.	.2141E-03	-.2998E-03	.1629E+03	-.9440E-02	-.1380E-01	-.2826E+03	.7697E-04	-.5133E-02	-.1055E-03	.9370E-02
196.	.3192E-03	-.2858E-03	.1652E+03	-.9198E-02	-.1407E-01	-.2518E+03	.4159E-04	-.5057E-02	-.1029E-03	.9231E-02
197.	.3904E-03	-.2778E-03	.1675E+03	-.8855E-02	-.1434E-01	-.2225E+03	.5458E-04	-.4999E-02	-.4283E-04	.9131E-02
198.	.4224E-03	-.2654E-03	.1697E+03	-.8491E-02	-.1459E-01	-.1949E+03	.4365E-04	-.4944E-02	-.2779E-04	.9037E-02
199.	.4365E-03	-.2507E-03	.1718E+03	-.8076E-02	-.1484E-01	-.1690E+03	.5057E-04	-.4887E-02	-.3849E-04	.8942E-02
200.	.4555E-03	-.2335E-03	.1738E+03	-.7655E-02	-.1507E-01	-.1448E+03	.5264E-04	-.4828E-02	-.6112E-04	.8844E-02
201.	.4594E-03	-.2131E-03	.1756E+03	-.7217E-02	-.1528E-01	-.1222E+03	.1312E-03	-.4712E-02	-.2544E-03	.8624E-02
202.	.3348E-03	-.1972E-03	.1773E+03	-.6630E-02	-.1547E-01	-.1014E+03	.1585E-03	-.4554E-02	-.2442E-03	.8328E-02
203.	.2700E-03	-.1825E-03	.1788E+03	-.5657E-02	-.1555E-01	-.8226E+02	.1609E-03	-.4390E-02	-.2575E-03	.8017E-02
204.	-.4639E-03	-.1703E-03	.1803E+03	-.5484E-02	-.1592E-01	-.6487E+02	.1651E-03	-.4217E-02	-.2840E-03	.7694E-02
205.	-.1123E-02	-.1625E-03	.1816E+03	-.7687E-02	-.1597E-01	-.4924E+02	.1738E-03	-.4041E-02	-.3053E-03	.7363E-02
206.	-.1905E-02	-.1516E-03	.1828E+03	-.9222E-02	-.1612E-01	-.3539E+02	.3382E-04	-.3949E-02	-.1003E-03	.7195E-02
207.	-.2586E-02	-.1323E-03	.1838E+03	-.1151E-01	-.1625E-01	-.2337E+02	.5473E-04	-.3898E-02	-.3189E-04	.7106E-02
208.	-.3025E-02	-.1143E-03	.1846E+03	-.1436E-01	-.1635E-01	-.1323E+02	.3356E-04	-.3852E-02	-.2262E-04	.7029E-02
209.	-.3209E-02	-.9670E-04	.1850E+03	-.1752E-01	-.1644E-01	-.5013E+01	.6547E-04	-.3795E-02	-.8343E-04	.6934E-02
210.	-.3194E-02	-.7768E-04	.1852E+03	-.2075E-01	-.1650E-01	.1220E+01	.9650E-04	-.3711E-02	-.1648E-03	.6785E-02

Table A2. Optimal Mean State (Continued)

TIME (SEC)	$\dot{\overline{\eta}}_3$ (FT/SEC)	$\overline{\eta}_3$ (FT)	$\dot{\overline{\eta}}_4$ (FT/SEC)	$\overline{\eta}_4$ (FT)	$\overline{\delta p}$ (RAD)	$\overline{\delta r}$ (RAD)	$\overline{\delta a}$ (RAD)	$\overline{x}_1$	$\overline{x}_2$	$\overline{x}_3$
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	.3718E-04	.1674E-04	-.4223E-03	-.2274E-03	-.3051E-06	-.5793E-04	-.2371E-06	.1403E-02	.1609E-02	-.213AE-02
2.	.1748E-04	.5186E-04	-.3009E-03	-.7130E-03	-.2811E-05	-.1831E-03	-.6901E-06	.4841E-02	.7465E-02	-.4295E-02
3.	-.3511E-06	.6579E-04	-.1064E-03	-.9243E-03	-.9040E-05	-.2415E-03	-.1203E-05	.9543E-02	.1940E-01	.1182E-02
4.	-.2107E-04	.5109E-04	.3127E-03	-.7574E-03	-.2500E-04	-.2040E-03	-.1798E-05	.1472E-01	.3388E-01	.1809E-01
5.	-.341AE-04	.2031E-04	.495AE-03	-.3564E-03	-.4869E-04	-.9826E-04	-.2490E-05	.1945E-01	.4079E-01	.3680E-01
6.	.8751E-04	.5842E-04	-.1074E-02	-.867AE-03	-.4499E-04	-.2348E-03	.5444E-06	.2319E-01	.3465E-01	.4030E-01
7.	.2756E-04	.1190E-03	-.4049E-03	-.1654E-02	-.2309E-04	-.4589E-03	.5257E-05	.2575E-01	.2643E-01	.297AE-01
8.	-.4549E-04	.1146E-03	.5606E-03	-.1614E-02	-.2593E-04	-.4569E-03	.5229E-05	.2726E-01	.2737E-01	.2567E-01
9.	-.7709E-04	.4996E-04	.1075E-02	-.746AE-03	-.7564E-04	-.228AE-03	-.3032E-05	.2801E-01	.2975E-01	.2932E-01
10.	-.7999E-04	-.3465E-04	.1172E-02	.4510E-03	-.1A14E-03	.1049E-03	-.2020E-04	.2828E-01	.283AE-01	.2895E-01
11.	.2005E-03	.5834E-04	-.2415E-02	-.6699E-03	-.2145E-03	-.2103E-03	-.4430E-05	.2972E-01	.3120E-01	.2917E-01
12.	.7826E-04	.2067E-03	-.1069E-02	-.2590E-02	-.174AE-03	-.7572E-03	.3250E-04	.3264E-01	.3586E-01	.3478E-01
13.	-.8566E-04	.2125E-03	.1070E-02	-.2617E-02	-.200AE-03	-.7883E-03	.3777E-04	.3578E-01	.3820E-01	.3732E-01
14.	-.157AE-03	.3650E-04	.2125E-02	-.9205E-03	-.3603E-03	-.3313E-03	-.1463E-04	.3865E-01	.4078E-01	.4009E-01
15.	-.1430E-03	-.7685E-04	.2157E-02	.1341E-02	-.6809E-03	.3155E-03	-.1335E-03	.4113E-01	.4277E-01	.4228E-01
16.	.3893E-03	.1021E-03	-.4132E-02	-.5707E-03	-.8612E-03	-.2223E-03	-.1206E-03	.4318E-01	.4439E-01	.4397E-01
17.	.1135E-03	.3632E-03	-.1442E-02	-.3607E-02	-.8533E-03	-.1098E-02	.2275E-05	.44A6E-01	.4583E-01	.4543E-01
18.	-.1A49E-03	.338AE-03	.2276E-02	-.3172E-02	-.9472E-03	-.1029E-02	.1812E-04	.4628E-01	.4706E-01	.4671E-01
19.	-.2794E-03	.9581E-04	.3639E-02	-.3087E-04	-.1297E-02	-.1957E-03	-.1739E-03	.4750E-01	.4813E-01	.4787E-01
20.	-.1835E-03	-.1602E-03	.3125E-02	.3560E-02	-.1932E-02	.7998E-03	-.6100E-03	.4855E-01	.490AE-01	.4891E-01
21.	.6035E-03	.1510E-03	-.5810E-02	.6674E-03	-.2432E-02	.2733E-04	-.7549E-03	.4986E-01	.505AE-01	.5025E-01
22.	.1299E-03	.5217E-03	-.1213E-02	-.3054E-02	-.2654E-02	-.1072E-02	-.612AE-03	.5132E-01	.5196E-01	.5164E-01
23.	-.2903E-03	.4415E-03	.363AE-02	-.1661E-02	-.3043E-02	-.7962E-03	-.7219E-03	.5267E-01	.5321E-01	.5292E-01
24.	-.3431E-03	.105AE-03	.4559E-02	.2757E-02	-.3755E-02	.3932E-03	-.1327E-02	.53A7E-01	.5432E-01	.5410E-01
25.	-.1359E-03	-.1576E-03	.3342E-02	.6951E-02	-.4930E-02	.1612E-02	-.2517E-02	.5494E-01	.5532E-01	.5519E-01
26.	.6825E-03	.2404E-03	-.5315E-02	.4300E-02	-.6172E-02	.8624E-03	-.3516E-02	.5664E-01	.5736E-01	.5704E-01
27.	.1190E-03	.6435E-03	.3910E-04	.1537E-02	-.7255E-02	-.3739E-04	-.4146E-02	.5864E-01	.5930E-01	.5896E-01
28.	-.2945E-03	.5494E-03	.4391E-02	.407AE-02	-.8401E-02	.5364E-02	-.5051E-02	.6049E-01	.6106E-01	.6075E-01
29.	-.2374E-03	.2671E-03	.4535E-02	.8851E-02	-.9759E-02	.1816E-02	-.6561E-02	.6217E-01	.6267E-01	.6242E-01
30.	.3214E-04	.1504E-03	.285AE-02	.1267E-01	-.1143E-01	.2869E-02	-.8839E-02	.6370E-01	.6414E-01	.6399E-01
31.	.4A4E-03	.48A6E-03	-.1403E-02	.1250E-01	-.1355E-01	.2727E-02	-.1172E-01	.6539E-01	.6589E-01	.6564E-01
32.	.1606E-03	.8145E-03	.1657E-02	.1267E-01	-.1596E-01	.2584E-02	-.1479E-01	.6707E-01	.6754E-01	.6726E-01
33.	-.2817E-04	.9763E-03	.3491E-02	.1553E-01	-.1832E-01	.3178E-02	-.1796E-01	.6862E-01	.6905E-01	.6879E-01
34.	.3720E-04	.8774E-03	.3230E-02	.1904E-01	-.2055E-01	.4002E-02	-.2128E-01	.7004E-01	.7044E-01	.7022E-01
35.	.1556E-03	.9755E-03	.2514E-02	.2203E-01	-.2253E-01	.4654E-02	-.2489E-01	.7135E-01	.7172E-01	.7158E-01
36.	-.2753E-03	.7247E-03	.9010E-02	.2944E-01	-.2532E-01	.6583E-02	-.3013E-01	.7308E-01	.7358E-01	.7332E-01
37.	.5536E-03	.9480E-03	.1671E-02	.3394E-01	-.2871E-01	.7653E-02	-.3670E-01	.7491E-01	.7536E-01	.7507E-01
38.	.59A2E-03	.1581E-02	.1531E-02	.3524E-01	-.3206E-01	.7629E-02	-.4323E-01	.7660E-01	.7700E-01	.7672E-01
39.	.174E-04	.1951E-02	.3976E-02	.3820E-01	-.3501E-01	.7950E-02	-.4920E-01	.7817E-01	.7851E-01	.7829E-01
40.	-.6636E-04	.2004E-02	.4664E-02	.4249E-01	-.3735E-01	.8805E-02	-.5441E-01	.7962E-01	.7991E-01	.7978E-01
41.	-.7014E-03	.1263E-02	.1200E-01	.5498E-01	-.4006E-01	.1193E-01	-.6161E-01	.8058E-01	.8073E-01	.8056E-01
42.	.7509E-03	.1455E-02	.1629E-02	.6093E-01	-.4350E-01	.1341E-01	-.7084E-01	.8132E-01	.8148E-01	.8126E-01
43.	.7027E-03	.2264E-02	.2709E-02	.6257E-01	-.4689E-01	.1345E-01	-.7980E-01	.8201E-01	.8215E-01	.8194E-01
44.	.1107E-03	.2632E-02	.5954E-02	.5737E-01	-.4985E-01	.1420E-01	-.8762E-01	.8263E-01	.8276E-01	.8260E-01
45.	-.6353E-04	.2639E-02	.5663E-02	.7355E-01	-.5217E-01	.1546E-01	-.9399E-01	.8320E-01	.8331E-01	.8325E-01
46.	-.3021E-03	.2101E-02	.9692E-02	.8478E-01	-.5450E-01	.1826E-01	-.1021E+00	.8461E-01	.8492E-01	.8469E-01
47.	.8696E-03	.2606E-02	.2109E-02	.8947E-01	-.5774E-01	.1915E-01	-.1131E+00	.A618E-01	.8647E-01	.8621E-01
48.	.4946E-03	.3325E-02	.5041E-02	.9305E-01	-.6122E-01	.1945E-01	-.1250E+00	.A764E-01	.8791E-01	.8765E-01
49.	.1205E-03	.3567E-02	.6365E-02	.9942E-01	-.6474E-01	.2052E-01	-.1368E+00	.8900E-01	.8924E-01	.8904E-01
50.	.1756E-03	.3722E-02	.4779E-02	.1053E+00	-.6805E-01	.2159E-01	-.1479E+00	.9026E-01	.9048E-01	.9038E-01
51.	-.2A05E-03	.3276E-02	.1063E-01	.1165E+00	-.7092E-01	.2435E-01	-.1582E+00	.9111E-01	.9125E-01	.9108E-01
52.	.5401E-03	.3654E-02	.6157E-02	.1236E+00	-.7360E-01	.2582E-01	-.1687E+00	.9181E-01	.9194E-01	.9173E-01
53.	.8562E-04	.3960E-02	.953E-02	.1318E+00	-.7633E-01	.2735E-01	-.1799E+00	.9245E-01	.9257E-01	.9237E-01
54.	-.8639E-04	.3890E-02	.9654E-02	.1420E+00	-.7910E-01	.2944E-01	-.1914E+00	.9303E-01	.9313E-01	.9300E-01

TIME (SEC)	$\dot{\bar{\eta}}_3$ (FT/SEC)	$\bar{\eta}_3$ (FT)	$\dot{\bar{\eta}}_4$ (FT/SEC)	$\bar{\eta}_4$ (FT)	$\bar{\delta p}$ (RAD)	$\bar{\delta r}$ (RAD)	$\bar{\delta a}$ (RAD)	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_3$
55.	-.2576E-04	.3854E-02	.8548E-02	.1512E+00	-.8177E-01	.3138E-01	-.2025E+00	.9357E-01	.9364E-01	.9362E-01
56.	.4239E-03	.4067E-02	.4890E-02	.1579E+00	-.8496E-01	.3268E-01	-.2148E+00	.9477E-01	.9496E-01	.9479E-01
57.	.4647E-03	.4544E-02	.5124E-02	.1630E+00	-.8864E-01	.3360E-01	-.2272E+00	.9604E-01	.9622E-01	.9599E-01
58.	.4376E-03	.4997E-02	.5639E-02	.1696E+00	-.9224E-01	.3464E-01	-.2384E+00	.9722E-01	.9738E-01	.9715E-01
59.	.4366E-03	.5433E-02	.5741E-02	.1744E+00	-.9556E-01	.3571E-01	-.2486E+00	.9832E-01	.9846E-01	.9828E-01
60.	.4224E-03	.5866E-02	.5800E-02	.1804E+00	-.9894E-01	.3675E-01	-.2582E+00	.9934E-01	.9945E-01	.9938E-01
61.	-.8347E-03	.5947E-02	.9679E-02	.1857E+00	-.1031E+00	.3756E-01	-.2686E+00	.1001E+00	.1002E+00	.1000E+00
62.	-.9548E-03	.4788E-02	.7886E-02	.1962E+00	-.1094E+00	.3993E-01	-.2799E+00	.1008E+00	.1009E+00	.1007E+00
63.	-.4545E-03	.4191E-02	.4760E-02	.2019E+00	-.1141E+00	.4127E-01	-.2911E+00	.1014E+00	.1015E+00	.1013E+00
64.	-.5591E-03	.3684E-02	.5747E-02	.2072E+00	-.1199E+00	.4248E-01	-.3022E+00	.1019E+00	.1020E+00	.1019E+00
65.	-.5603E-03	.3095E-02	.5722E-02	.2130E+00	-.1256E+00	.4385E-01	-.3133E+00	.1024E+00	.1025E+00	.1025E+00
66.	.1896E-03	.2724E-02	.1874E-02	.2172E+00	-.1294E+00	.4498E-01	-.3249E+00	.1030E+00	.1032E+00	.1030E+00
67.	-.9678E-04	.2899E-02	.4267E-02	.2195E+00	-.1311E+00	.4536E-01	-.3383E+00	.1036E+00	.1038E+00	.1036E+00
68.	-.2137E-03	.2673E-02	.4609E-02	.2240E+00	-.1323E+00	.4626E-01	-.3534E+00	.1042E+00	.1043E+00	.1041E+00
69.	-.8993E-04	.2494E-02	.3569E-02	.2277E+00	-.1334E+00	.4698E-01	-.3695E+00	.1047E+00	.1048E+00	.1046E+00
70.	-.1194E-03	.2366E-02	.3419E-02	.2309E+00	-.1344E+00	.4763E-01	-.3860E+00	.1051E+00	.1052E+00	.1051E+00
71.	.1397E-02	.1964E-02	.3260E-02	.2403E+00	-.1324E+00	.5041E-01	-.3860E+00	.1052E+00	.1052E+00	.1051E+00
72.	.7451E-03	.3685E-02	.1300E-01	.2452E+00	-.1276E+00	.5123E-01	-.3732E+00	.1052E+00	.1053E+00	.1051E+00
73.	.3371E-03	.3950E-02	.1575E-01	.2604E+00	-.1222E+00	.5426E-01	-.3602E+00	.1052E+00	.1052E+00	.1051E+00
74.	.7656E-03	.4451E-02	.1367E-01	.2741E+00	-.1166E+00	.5688E-01	-.3479E+00	.1052E+00	.1052E+00	.1051E+00
75.	.7375E-03	.5173E-02	.1458E-01	.2877E+00	-.1109E+00	.5943E-01	-.3351E+00	.1051E+00	.1051E+00	.1051E+00
76.	-.3652E-03	.7129E-02	.5506E-02	.2845E+00	-.1051E+00	.5728E-01	-.3223E+00	.1020E+00	.1017E+00	.1017E+00
77.	-.5928E-03	.5539E-02	-.2950E-02	.2891E+00	-.9956E-01	.5812E-01	-.3108E+00	.9861E-01	.9837E-01	.9827E-01
78.	.3538E-03	.5822E-02	-.2807E-02	.2802E+00	-.9414E-01	.5591E-01	-.2993E+00	.9532E-01	.9511E-01	.9501E-01
79.	.4413E-04	.5050E-02	-.6342E-02	.2719E+00	-.8841E-01	.5389E-01	-.2877E+00	.9215E-01	.9194E-01	.9190E-01
80.	.2279E-03	.5121E-02	-.7036E-02	.2643E+00	-.8242E-01	.5219E-01	-.2758E+00	.8908E-01	.8888E-01	.8893E-01
81.	.2091E-03	.6712E-02	-.1219E-01	.2494E+00	-.7637E-01	.4888E-01	-.2620E+00	.8436E-01	.8405E-01	.8405E-01
82.	-.1204E-03	.6477E-02	-.1254E-01	.2365E+00	-.6958E-01	.4671E-01	-.2426E+00	.7960E-01	.7933E-01	.7927E-01
83.	-.1709E-04	.6526E-02	-.1236E-01	.2222E+00	-.6179E-01	.4422E-01	-.2188E+00	.7502E-01	.7476E-01	.7471E-01
84.	-.1629E-03	.6415E-02	-.1097E-01	.2095E+00	-.5350E-01	.4194E-01	-.1939E+00	.7061E-01	.7036E-01	.7034E-01
85.	-.1904E-03	.6149E-02	-.1097E-01	.1975E+00	-.4515E-01	.3968E-01	-.1706E+00	.6638E-01	.6611E-01	.6618E-01
86.	.7905E-04	.6281E-02	-.1534E-01	.1810E+00	-.3890E-01	.3603E-01	-.1542E+00	.6171E-01	.6145E-01	.6144E-01
87.	-.8366E-04	.6149E-02	-.1639E-01	.1641E+00	-.3471E-01	.3237E-01	-.1421E+00	.5716E-01	.5692E-01	.5689E-01
88.	.1743E-04	.6165E-02	-.1710E-01	.1457E+00	-.3137E-01	.2845E-01	-.1293E+00	.5279E-01	.5256E-01	.5253E-01
89.	-.7947E-04	.6116E-02	-.1659E-01	.1277E+00	-.2821E-01	.2464E-01	-.1152E+00	.4859E-01	.4835E-01	.4835E-01
90.	-.1832E-03	.5926E-02	-.1649E-01	.1102E+00	-.2505E-01	.2101E-01	-.1000E+00	.4454E-01	.4430E-01	.4436E-01
91.	-.7161E-04	.5095E-02	-.1284E-01	.9683E-01	-.2234E-01	.1851E-01	-.8758E-01	.3914E-01	.3883E-01	.3886E-01
92.	-.4079E-03	.4649E-02	-.1371E-01	.8239E-01	-.2025E-01	.1554E-01	-.7798E-01	.3379E-01	.3351E-01	.3351E-01
93.	-.5439E-03	.4140E-02	-.1303E-01	.6843E-01	-.1837E-01	.1269E-01	-.6842E-01	.2865E-01	.2839E-01	.2839E-01
94.	-.5739E-03	.3517E-02	-.1344E-01	.5458E-01	-.1643E-01	.9951E-02	-.5769E-01	.2372E-01	.2347E-01	.2349E-01
95.	-.6596E-03	.2877E-02	-.1372E-01	.4047E-01	-.1428E-01	.7178E-02	-.4531E-01	.1900E-01	.1874E-01	.1879E-01
96.	-.7335E-03	.1364E-02	-.8219E-02	.3410E-01	-.1220E-01	.6803E-02	-.3497E-01	.1571E-01	.1555E-01	.1557E-01
97.	.3710E-03	.1577E-02	-.4033E-02	.2483E-01	-.1047E-01	.4702E-02	-.2807E-01	.1267E-01	.1253E-01	.1254E-01
98.	-.2530E-03	.1551E-02	-.4047E-02	.1914E-01	-.8959E-02	.3393E-02	-.2258E-01	.9764E-02	.9630E-02	.9635E-02
99.	-.3201E-03	.1145E-02	-.4606E-02	.1475E-01	-.7508E-02	.2620E-02	-.1736E-01	.6970E-02	.6839E-02	.6852E-02
100.	-.3091E-03	.8340E-03	-.5126E-02	.9621E-02	-.5980E-02	.1629E-02	-.1182E-01	.4289E-02	.4161E-02	.4181E-02
101.	-.4273E-03	.1026E-03	-.2030E-02	.4207E-02	-.4667E-02	.1881E-02	-.7623E-02	.4150E-02	.4159E-02	.4153E-02
102.	.3874E-03	.2704E-03	-.2231E-02	.5704E-02	-.3835E-02	.1246E-02	-.5498E-02	.4239E-02	.4249E-02	.4240E-02
103.	.1644E-03	.4931E-03	-.1945E-04	.4716E-02	-.3353E-02	.8323E-03	-.4420E-02	.4322E-02	.4332E-02	.4323E-02
104.	-.4836E-04	.4477E-03	.2945E-04	.4404E-02	-.3104E-02	.8632E-03	-.3855E-02	.4401E-02	.4408E-02	.4402E-02
105.	-.3718E-04	.4047E-03	-.2864E-03	.4619E-02	-.2990E-02	.8379E-03	-.3499E-02	.4475E-02	.4478E-02	.4478E-02
106.	-.2547E-04	.3905E-03	-.2046E-03	.4390E-02	-.2941E-02	.7837E-03	-.3278E-02	.4986E-02	.5015E-02	.5006E-02
107.	.2257E-04	.3952E-03	-.1554E-03	.4171E-02	-.2919E-02	.7178E-03	-.3164E-02	.5514E-02	.5545E-02	.5532E-02
108.	.2210E-04	.4029E-03	-.8556E-04	.3498E-02	-.2908E-02	.6596E-03	-.3086E-02	.6018E-02	.6049E-02	.6035E-02
109.	.5650E-05	.4065E-03	-.7610E-04	.3845E-02	-.2898E-02	.6168E-03	-.3010E-02	.6501E-02	.6528E-02	.6517E-02

Table A2. Optimal Mean State (Continued)

TIME (SEC)	$\dot{\bar{\eta}}_3$ (FT/SEC)	$\bar{\eta}_3$ (FT)	$\dot{\bar{\eta}}_4$ (FT/SEC)	$\bar{\eta}_4$ (FT)	$\bar{\delta p}$ (RAD)	$\bar{\delta r}$ (RAD)	$\bar{\delta a}$ (RAD)	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$
110.	.1103E-05	.4113E-03	-.7844E-04	.3746E-02	-.2883E-02	.5784E-03	-.2920E-02	.6962E-02	.6982E-02	.6979E-02
111.	.1209E-04	.4353E-03	-.1482E-03	.3544E-02	-.2843E-02	.5074E-03	-.2809E-02	.7606E-02	.7641E-02	.7631E-02
112.	-.1624E-04	.4247E-03	-.1264E-03	.3383E-02	-.2756E-02	.4783E-03	-.2669E-02	.8239E-02	.8279E-02	.8263E-02
113.	-.1790E-04	.3995E-03	-.1794E-03	.3200E-02	-.2656E-02	.4604E-03	-.2500E-02	.8845E-02	.8885E-02	.8868E-02
114.	-.1357E-04	.3825E-03	-.1970E-03	.2978E-02	-.2522E-02	.4258E-03	-.2308E-02	.9425E-02	.9458E-02	.9446E-02
115.	-.1130E-04	.3705E-03	-.1836E-03	.2753E-02	-.2369E-02	.3860E-03	-.2098E-02	.9979E-02	.1000E-01	.9999E-02
116.	-.7228E-06	.3712E-03	-.2253E-03	.2519E-02	-.2201E-02	.3245E-03	-.1885E-02	.1088E-01	.1093E-01	.1092E-01
117.	-.2101E-04	.3552E-03	-.1899E-03	.2292E-02	-.2019E-02	.2788E-03	-.1674E-02	.1177E-01	.1182E-01	.1181E-01
118.	-.3058E-04	.3251E-03	-.2205E-03	.2052E-02	-.1828E-02	.2437E-03	-.1460E-02	.1262E-01	.1268E-01	.1266E-01
119.	-.3106E-04	.2936E-03	-.2608E-03	.1793E-02	-.1629E-02	.2025E-03	-.1240E-02	.1344E-01	.1349E-01	.1347E-01
120.	-.2996E-04	.2628E-03	-.2607E-03	.1504E-02	-.1421E-02	.1575E-03	-.1013E-02	.1422E-01	.1425E-01	.1425E-01
121.	-.3549E-04	.2290E-03	-.2273E-03	.1250E-02	-.1216E-02	.1230E-03	-.8149E-03	.1470E-01	.1474E-01	.1473E-01
122.	-.3350E-04	.1922E-03	-.2107E-03	.1030E-02	-.1018E-02	.9561E-04	-.6534E-03	.1514E-01	.1519E-01	.1517E-01
123.	-.3213E-04	.1580E-03	-.2134E-03	.8030E-03	-.8218E-03	.6655E-04	-.5061E-03	.1556E-01	.1561E-01	.1559E-01
124.	-.3208E-04	.1257E-03	-.2041E-03	.5845E-03	-.6250E-03	.3809E-04	-.3654E-03	.1595E-01	.1599E-01	.1598E-01
125.	-.3275E-04	.9331E-04	-.1934E-03	.3764E-03	-.4277E-03	.1255E-04	-.2296E-03	.1633E-01	.1635E-01	.1634E-01
126.	-.4043E-04	.5294E-04	-.1617E-03	.2096E-03	-.2459E-03	.7890E-05	-.1244E-03	.1624E-01	.1627E-01	.1626E-01
127.	-.2915E-04	.1817E-04	-.1637E-03	.4556E-04	-.8811E-04	-.1043E-05	-.5601E-04	.1612E-01	.1616E-01	.1614E-01
128.	-.2379E-04	-.8009E-05	-.1551E-03	-.1146E-03	.5530E-04	-.1839E-04	-.5756E-05	.1599E-01	.1603E-01	.1602E-01
129.	-.2374E-04	-.3169E-04	-.1427E-03	-.2597E-03	.1896E-03	-.3380E-04	.3364E-04	.1587E-01	.1590E-01	.1589E-01
130.	-.2434E-04	-.5525E-04	-.1336E-03	-.3933E-03	.3179E-03	-.4558E-04	.6483E-04	.1574E-01	.1574E-01	.1574E-01
131.	-.3155E-04	-.8580E-04	-.1135E-03	-.5032E-03	.4339E-03	-.4099E-04	.8546E-04	.1565E-01	.1567E-01	.1567E-01
132.	-.2313E-04	-.1117E-03	-.1194E-03	-.6124E-03	.5341E-03	-.4075E-04	.9669E-04	.1556E-01	.1560E-01	.1559E-01
133.	-.2004E-04	-.1322E-03	-.1112E-03	-.7184E-03	.6238E-03	-.4579E-04	.1020E-03	.1547E-01	.1550E-01	.1550E-01
134.	-.2088E-04	-.1521E-03	-.1039E-03	-.8146E-03	.7063E-03	-.4790E-04	.1027E-03	.1537E-01	.1540E-01	.1539E-01
135.	-.2260E-04	-.1731E-03	-.9772E-04	-.9048E-03	.7839E-03	-.4620E-04	.9893E-04	.1527E-01	.1528E-01	.1527E-01
136.	-.2755E-04	-.2000E-03	-.9741E-04	-.9878E-03	.8567E-03	-.3392E-04	.9487E-04	.1504E-01	.1505E-01	.1505E-01
137.	-.2113E-04	-.2222E-03	-.1060E-03	-.1076E-02	.9242E-03	-.2853E-04	.9295E-04	.1479E-01	.1482E-01	.1482E-01
138.	-.1947E-04	-.2407E-03	-.1018E-03	-.1154E-02	.9872E-03	-.2724E-04	.9112E-04	.1455E-01	.1458E-01	.1458E-01
139.	-.2003E-04	-.2595E-03	-.9942E-04	-.1248E-02	.1046E-02	-.2353E-04	.8837E-04	.1432E-01	.1433E-01	.1433E-01
140.	-.2151E-04	-.2792E-03	-.9518E-04	-.1330E-02	.1102E-02	-.1714E-04	.8415E-04	.1408E-01	.1408E-01	.1407E-01
141.	-.2497E-04	-.3033E-03	-.1094E-03	-.1416E-02	.1157E-02	-.6279E-05	.8110E-04	.1386E-01	.1387E-01	.1387E-01
142.	-.2089E-04	-.3236E-03	-.1162E-03	-.1509E-02	.1212E-02	-.2190E-05	.8076E-04	.1365E-01	.1366E-01	.1367E-01
143.	-.1967E-04	-.3417E-03	-.1186E-03	-.1602E-02	.1268E-02	-.9912E-06	.8147E-04	.1343E-01	.1345E-01	.1346E-01
144.	-.1942E-04	-.3599E-03	-.1142E-03	-.1695E-02	.1324E-02	.1491E-05	.8243E-04	.1322E-01	.1323E-01	.1324E-01
145.	-.2052E-04	-.3787E-03	-.1135E-03	-.1789E-02	.1382E-02	.5263E-05	.8317E-04	.1301E-01	.1301E-01	.1301E-01
146.	-.3318E-04	-.4080E-03	-.1177E-03	-.1878E-02	.1438E-02	.2504E-04	.8416E-04	.1281E-01	.1282E-01	.1283E-01
147.	-.2752E-04	-.4348E-03	-.1248E-03	-.1972E-02	.1491E-02	.4063E-04	.8550E-04	.1261E-01	.1262E-01	.1264E-01
148.	-.2562E-04	-.4587E-03	-.1313E-03	-.2048E-02	.1539E-02	.5162E-04	.8658E-04	.1242E-01	.1243E-01	.1244E-01
149.	-.2664E-04	-.4831E-03	-.1258E-03	-.2163E-02	.1580E-02	.6462E-04	.8712E-04	.1223E-01	.1223E-01	.1224E-01
150.	-.2704E-04	-.5086E-03	-.1209E-03	-.2259E-02	.1615E-02	.7988E-04	.8701E-04	.1204E-01	.1204E-01	.1204E-01
151.	-.3228E-04	-.5412E-03	-.1463E-03	-.2360E-02	.1655E-02	.1029E-03	.8743E-04	.1186E-01	.1186E-01	.1187E-01
152.	-.2343E-04	-.5643E-03	-.1456E-03	-.2469E-02	.1703E-02	.1090E-03	.8872E-04	.1169E-01	.1169E-01	.1170E-01
153.	-.1995E-04	-.5828E-03	-.1468E-03	-.2574E-02	.1751E-02	.1094E-03	.8989E-04	.1151E-01	.1151E-01	.1152E-01
154.	-.1938E-04	-.6007E-03	-.1378E-03	-.2672E-02	.1797E-02	.1114E-03	.9050E-04	.1134E-01	.1134E-01	.1135E-01
155.	-.1934E-04	-.6178E-03	-.1230E-03	-.2756E-02	.1837E-02	.1141E-03	.9040E-04	.1117E-01	.1117E-01	.1117E-01
156.	-.3002E-04	-.6450E-03	-.1434E-03	-.2859E-02	.1890E-02	.1307E-03	.9050E-04	.1101E-01	.1101E-01	.1101E-01
157.	-.2164E-04	-.6654E-03	-.1448E-03	-.2953E-02	.1925E-02	.1365E-03	.9094E-04	.1086E-01	.1085E-01	.1086E-01
158.	-.1643E-04	-.6813E-03	-.1390E-03	-.3041E-02	.1967E-02	.1362E-03	.9083E-04	.1070E-01	.1070E-01	.1070E-01
159.	-.1517E-04	-.6958E-03	-.1317E-03	-.3123E-02	.1999E-02	.1361E-03	.8987E-04	.1055E-01	.1054E-01	.1055E-01
160.	-.1510E-04	-.7087E-03	-.1113E-03	-.3199E-02	.2023E-02	.1352E-03	.8799E-04	.1039E-01	.1039E-01	.1039E-01
161.	-.3419E-04	-.7360E-03	-.1254E-03	-.3271E-02	.2049E-02	.1598E-03	.8641E-04	.1025E-01	.1025E-01	.1025E-01
162.	-.2551E-04	-.7595E-03	-.1313E-03	-.3337E-02	.2078E-02	.1809E-03	.8545E-04	.1011E-01	.1011E-01	.1011E-01
163.	-.2002E-04	-.7788E-03	-.1187E-03	-.3397E-02	.2104E-02	.1972E-03	.8417E-04	.9972E-02	.9969E-02	.9974E-02
164.	-.1892E-04	-.7973E-03	-.1030E-03	-.3447E-02	.2121E-02	.2157E-03	.8221E-04	.9835E-02	.9833E-02	.9836E-02

Table A2. Optimal Mean State (Concluded)

TIME (SEC)	$\dot{\bar{\eta}}_3$ (FT/SEC)	$\bar{\eta}_3$ (FT)	$\dot{\bar{\eta}}_4$ (FT/SEC)	$\bar{\eta}_4$ (FT)	$\bar{\delta p}$ (RAD)	$\bar{\delta r}$ (RAD)	$\bar{\delta a}$ (RAD)	$\bar{X}_1$	$\bar{X}_2$	$\dot{\bar{X}}_3$
165.	-.1903E-04	-.8147F-03	-.7907F-04	-.3489E-02	.2129E-02	.2357E-03	.7945E-04	.9697E-02	.9698E-02	.9700E-02
166.	-.1744E-04	-.8323E-03	-.1155F-03	-.3545E-02	.2142E-02	.2493E-03	.7735E-04	.9574E-02	.9571E-02	.9573E-02
167.	-.1422F-04	-.8418F-03	-.1245F-03	-.3597F-02	.2154E-02	.2496E-03	.7631E-04	.9451E-02	.9446E-02	.9447E-02
168.	-.9348E-05	-.8489E-03	-.1129F-03	-.3639E-02	.2195E-02	.2490E-03	.7530E-04	.9329E-02	.9323E-02	.9323E-02
169.	-.5342F-05	-.8543E-03	-.9274E-04	-.3671E-02	.2200E-02	.2482E-03	.7389E-04	.9208E-02	.9201E-02	.9202E-02
170.	-.4000F-05	-.8573F-03	-.6241F-04	-.3695E-02	.2206E-02	.2460E-03	.7197E-04	.9087E-02	.9081E-02	.9082E-02
171.	-.1274F-04	-.8657F-03	-.8834E-04	-.3729E-02	.2215E-02	.2476E-03	.7050E-04	.8978E-02	.8971E-02	.8970E-02
172.	-.1191E-04	-.8718F-03	-.9973F-04	-.3736E-02	.2231E-02	.2482E-03	.6972E-04	.8869E-02	.8863E-02	.8861E-02
173.	-.6543F-05	-.8757F-03	-.9424F-04	-.3775E-02	.2244E-02	.2472E-03	.6897E-04	.8761E-02	.8756E-02	.8754E-02
174.	-.1747E-05	-.8776F-03	-.7596F-04	-.3745F-02	.2249E-02	.2451E-03	.6767E-04	.8654E-02	.8650E-02	.8648E-02
175.	-.1020E-07	-.8771F-03	-.4404F-04	-.3786E-02	.2244E-02	.2412E-03	.6604E-04	.8546E-02	.8544E-02	.8544E-02
176.	-.1620E-04	-.8857F-03	-.5821F-04	-.3799E-02	.2240E-02	.2502E-03	.6450E-04	.8449E-02	.8447E-02	.8445E-02
177.	-.1760E-04	-.8968F-03	-.6721F-04	-.3802E-02	.2241E-02	.2697E-03	.6329E-04	.8353E-02	.8351E-02	.8348E-02
178.	-.1298E-04	-.9067F-03	-.6310E-04	-.3797E-02	.2244E-02	.2897E-03	.6211E-04	.8256E-02	.8255E-02	.8253E-02
179.	-.8849E-05	-.9154E-03	-.4637E-04	-.3795E-02	.2244E-02	.3106E-03	.6078F-04	.8161E-02	.8160E-02	.8158E-02
180.	-.7864E-05	-.9226E-03	-.1635E-04	-.3744E-02	.2239E-02	.3321E-03	.5924E-04	.8065E-02	.8065E-02	.8065E-02
181.	-.3398F-05	-.9242E-03	-.3903E-04	-.3756E-02	.2229E-02	.3361E-03	.5768E-04	.7978E-02	.7978E-02	.7976E-02
182.	-.8683F-05	-.9268F-03	-.4707E-04	-.3740E-02	.2218E-02	.3463E-03	.5624E-04	.7891E-02	.7891E-02	.7889E-02
183.	-.6579E-05	-.9298E-03	-.4655F-04	-.3717E-02	.2206E-02	.3608E-03	.5484E-04	.7804E-02	.7805E-02	.7802E-02
184.	-.2604E-05	-.9310F-03	-.3259F-04	-.3648E-02	.2191E-02	.3745E-03	.5339E-04	.7718E-02	.7718E-02	.7716E-02
185.	-.1014E-06	-.9303F-03	-.3328F-05	-.3650E-02	.2171E-02	.3874E-03	.5180E-04	.7632E-02	.7632E-02	.7630E-02
186.	-.4780F-06	-.9275F-03	-.1641F-04	-.3625E-02	.2146E-02	.3871E-03	.4994E-04	.7553E-02	.7554E-02	.7552E-02
187.	-.6678E-05	-.9279E-03	-.2975E-04	-.3591E-02	.2121E-02	.3987E-03	.4762E-04	.7475E-02	.7477E-02	.7475E-02
188.	-.4703E-05	-.9287F-03	-.3104F-04	-.3550E-02	.2099E-02	.4148E-03	.4540E-04	.7398E-02	.7399E-02	.7397E-02
189.	-.7713E-06	-.9293F-03	-.1526F-04	-.3503E-02	.2079E-02	.4309E-03	.4318E-04	.7320E-02	.7321E-02	.7320E-02
190.	.1494F-05	-.9262F-03	.1561F-04	-.3449E-02	.2059E-02	.4469E-03	.4090E-04	.7243E-02	.7243E-02	.7244E-02
191.	.6212F-05	-.9174E-03	.1153F-04	-.3407E-02	.2036E-02	.4446E-03	.3870E-04	.7171E-02	.7173E-02	.7173E-02
192.	-.4427F-07	-.9130F-03	-.1748F-04	-.3357F-02	.2012F-02	.4549E-03	.3672E-04	.7101E-02	.7104E-02	.7103E-02
193.	.6719F-06	-.9049F-03	-.1727F-04	-.3303E-02	.1989E-02	.4701E-03	.3490E-04	.7030E-02	.7033E-02	.7032E-02
194.	.3542E-05	-.9033F-03	.2217F-05	-.3244F-02	.1966F-02	.4846E-03	.3312E-04	.6960E-02	.6963E-02	.6962E-02
195.	.5903F-05	-.8962F-03	.2844F-04	-.3179E-02	.1940E-02	.4985E-03	.3134E-04	.6889E-02	.6892E-02	.6891E-02
196.	.4372F-05	-.8885F-03	.1030F-04	-.3125F-02	.1900E-02	.5048E-03	.3009E-04	.6825E-02	.6828E-02	.6827E-02
197.	-.5055F-07	-.8837F-03	-.8054F-05	-.3066F-02	.1853E-02	.5221E-03	.2986E-04	.6761E-02	.6764E-02	.6764E-02
198.	.6075F-06	-.8793F-03	.1409F-05	-.3003E-02	.1811E-02	.5434E-03	.3043E-04	.6697E-02	.6700F-02	.6701E-02
199.	.2521E-05	-.8747F-03	.1574F-04	-.2935E-02	.1777F-02	.5668E-03	.3155E-04	.6633E-02	.6636E-02	.6637E-02
200.	.3462F-05	-.8694F-03	.3534F-04	-.2863E-02	.1749E-02	.5926E-03	.3300E-04	.6569E-02	.6571E-02	.6573E-02
201.	.2020F-04	-.8546F-03	.1129E-04	-.2807E-02	.1675E-02	.5825E-03	.3245E-04	.6510E-02	.6512E-02	.6513E-02
202.	.1949F-04	-.8324F-03	-.4045E-05	-.2750E-02	.1547F-02	.5535E-03	.2986E-04	.6451E-02	.6453E-02	.6454E-02
203.	.2051F-04	-.8044F-03	.6726F-05	-.2690F-02	.1407E-02	.5212E-03	.2703E-04	.6393E-02	.6394E-02	.6395E-02
204.	.2299F-04	-.7836F-03	.1225E-04	-.2627E-02	.1268E-02	.4869E-03	.2442F-04	.6334E-02	.6334E-02	.6335E-02
205.	.2497F-04	-.7577F-03	.3268E-04	-.2551E-02	.1132E-02	.4508E-03	.2203E-04	.6276E-02	.6275E-02	.6274E-02
206.	.3654F-05	-.7452F-03	.2259F-04	-.2494E-02	.1086E-02	.4500E-03	.2239E-04	.6221E-02	.6221E-02	.6220E-02
207.	.1296F-05	-.7390F-03	.2061F-04	-.2431E-02	.1145E-02	.4737E-03	.2537E-04	.6167E-02	.6167E-02	.6166E-02
208.	.3174F-05	-.7335F-03	.2775F-04	-.2356E-02	.1232E-02	.5035E-03	.2862E-04	.6113E-02	.6112E-02	.6111E-02
209.	.7853F-05	-.7267F-03	.3375F-04	-.2279E-02	.1306E-02	.5314E-03	.3114F-04	.6059E-02	.6058E-02	.6056E-02
210.	.1408F-04	-.7150F-03	.5067F-04	-.2290F-02	.1338E-02	.5464E-03	.3221E-04	.6005E-02	.6004E-02	.6001E-02

Table A3. Eigenvalues of Optimal Closed-Loop Sampled-Data System with Δt = 0.05 second

EIGEN VALUES AT TIME   =   10.00

REAL	IMAGINARY	MAGNITUDE
.9995E+00	.3873E-03	.9995E+00
.9995E+00	-.3873E-03	.9995E+00
.9613E+00	0.	.9613E+00
.9886E+00	0.	.9886E+00
.9620E+00	0.	.9620E+00
.9732E+00	0.	.9732E+00
.1000E+01	0.	.1000E+01
.9881E+00	.1558E-01	.9882E+00
.9881E+00	-.1558E-01	.9882E+00
.9830E+00	.2626E-01	.9834E+00
.9830E+00	-.2626E-01	.9834E+00
.8420E+00	.5027E+00	.9806E+00
.8420E+00	-.5027E+00	.9806E+00
.7031E+00	.6856E+00	.9827E+00
.7031E+00	-.6856E+00	.9827E+00
.3735E+00	.9114E+00	.9850E+00
.3735E+00	-.9114E+00	.9850E+00
.1887E+00	.9580E+00	.9764E+00
.1887E+00	-.9580E+00	.9764E+00

EIGEN VALUES AT TIME   =   45.00

REAL	IMAGINARY	MAGNITUDE
.9973E+00	.2095E-02	.9973E+00
.9973E+00	-.2095E-02	.9973E+00
.9568E+00	0.	.9568E+00
.9990E+00	0.	.9990E+00
.9999E+00	0.	.9999E+00
.9815E+00	.1547E-01	.9817E+00
.9815E+00	-.1547E-01	.9817E+00
.9337E+00	0.	.9337E+00
.9272E+00	0.	.9272E+00
.9595E+00	.6900E-01	.9621E+00
.9595E+00	-.6900E-01	.9621E+00
.7832E+00	.5058E+00	.9329E+00
.7832E+00	-.5058E+00	.9329E+00
.6469E+00	.7093E+00	.9600E+00
.6469E+00	-.7093E+00	.9600E+00
.3708E+00	.9114E+00	.9839E+00
.3708E+00	-.9114E+00	.9839E+00
.9091E-01	.9453E+00	.9497E+00
.9091E-01	-.9453E+00	.9497E+00

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Table A3. Eigenvalues of Optimal Closed-Loop Sampled-Data System with Δt = 0.05 second (Continued)

EIGEN VALUES AT TIME   =   75.00

REAL	IMAGINARY	MAGNITUDE
.9953E+00	.3651E-02	.9953E+00
.9953E+00	-.3651E-02	.9953E+00
.9167E+00	0.	.9167E+00
.1000E+01	.2827E-03	.1000E+01
.1000E+01	-.2827E-03	.1000E+01
.9838E+00	.1594E-01	.9839E+00
.9838E+00	-.1594E-01	.9839E+00
.8999E+00	0.	.8999E+00
.8723E+00	0.	.8723E+00
.9410E+00	.1072E+00	.9471E+00
.9410E+00	-.1072E+00	.9471E+00
.7447E+00	.5345E+00	.9167E+00
.7447E+00	-.5345E+00	.9167E+00
.5973E+00	.7439E+00	.9540E+00
.5973E+00	-.7439E+00	.9540E+00
.3692E+00	.9113E+00	.9837E+00
.3692E+00	-.9113E+00	.9837E+00
.9924E-02	.9450E+00	.9451E+00
.9924E-02	-.9450E+00	.9451E+00

EIGEN VALUES AT TIME   =   145.00

REAL	IMAGINARY	MAGNITUDE
.9937E+00	.4877E-02	.9937E+00
.9937E+00	-.4877E-02	.9937E+00
.9614E+00	0.	.9614E+00
.9996E+00	.7700E-03	.9996E+00
.9996E+00	-.7700E-03	.9996E+00
.9884E+00	0.	.9884E+00
.9725E+00	0.	.9725E+00
.9864E+00	.1728E-01	.9865E+00
.9864E+00	-.1728E-01	.9865E+00
.9306E+00	.6378E-01	.9328E+00
.9306E+00	-.6378E-01	.9328E+00
.6897E+00	.6703E+00	.9618E+00
.6897E+00	-.6703E+00	.9618E+00
.3648E+00	.9150E+00	.9851E+00
.3648E+00	-.9150E+00	.9851E+00
.3897E+00	.8937E+00	.9749E+00
.3897E+00	-.8937E+00	.9749E+00
-.1591E+00	.9613E+00	.9743E+00
-.1591E+00	-.9613E+00	.9743E+00

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Table A3. Eigenvalues of Optimal Closed-Loop Sampled-Data System with Δt = 0.05 second (Concluded)

EIGEN VALUES AT TIME   =   210.00

REAL	IMAGINARY	MAGNITUDE
.9951E+00	.3798E-02	.9951E+00
.9951E+00	-.3798E-02	.9951E+00
.1000E+01	0.	.1000E+01
.1000E+01	0.	.1000E+01
.1000E+01	0.	.1000E+01
.9983E+00	0.	.9983E+00
.1000E+01	.1697E-02	.1000E+01
.1000E+01	-.1697E-02	.1000E+01
.1002E+01	0.	.1002E+01
.9903E+00	.1102E+00	.9964E+00
.9903E+00	-.1102E+00	.9964E+00
.6789E+00	.7027E+00	.9771E+00
.6789E+00	-.7027E+00	.9771E+00
.3596E+00	.9171E+00	.9851E+00
.3596E+00	-.9171E+00	.9851E+00
.2251E+00	.9585E+00	.9846E+00
.2251E+00	-.9585E+00	.9846E+00
-.4389E+00	.8592E+00	.9737E+00
-.4389E+00	-.8592E+00	.9737E+00

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APPENDIX B
EFFECTS OF VARIATION OF SAMPLE RATE

Representative data from sample rates of 20 and 50 samples per second comprise this appendix. Figures B1 through B23 display the gains for the first control input, δp. The gains for the 50-sample-per-second are marked with X. Vertical bars mark the 20-sample-per-second gains.

The mean states computed with the two sample rates do not exhibit any noticeable difference. The largest difference in the state standard deviations for the two sample rates is in $\mathring{\eta}_4$. The difference is shown in Figure B24. In this figure 0's mark the mean state, X's the standard deviation for 20 samples per second, and vertical bars mark the standard deviation for 50 samples per second.
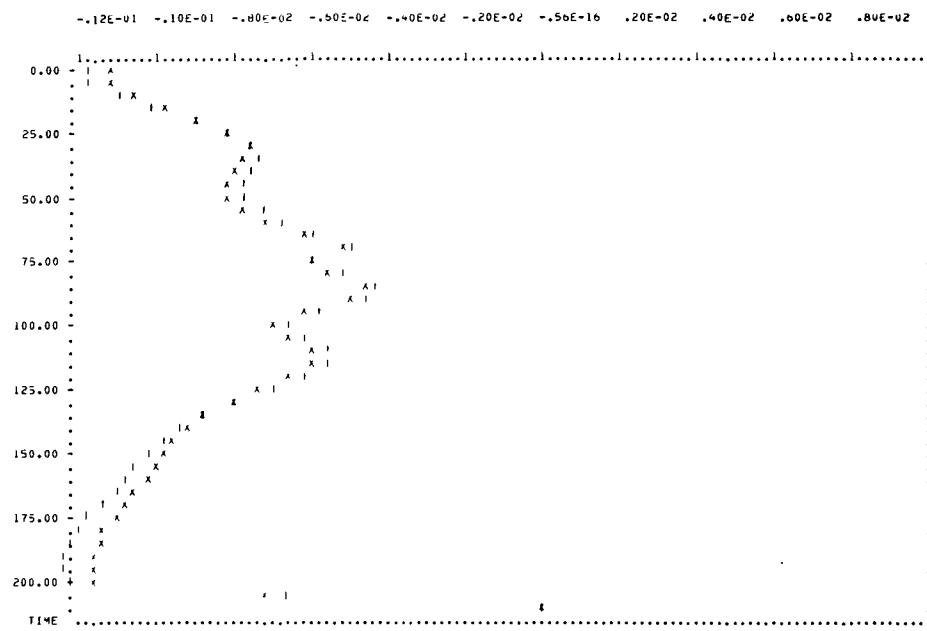
Figure B1. Graph of KV (1, 1) versus Time
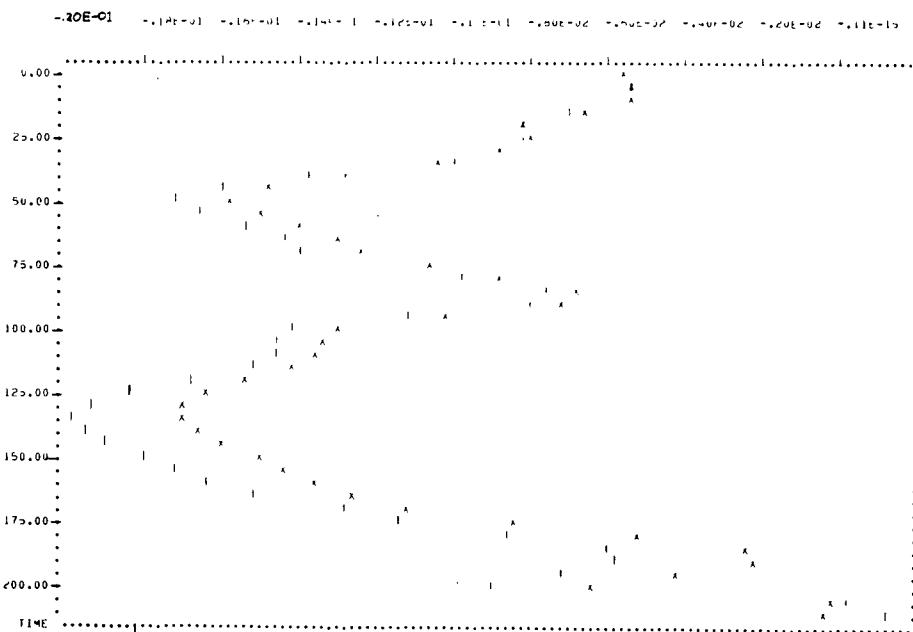
Figure B2. Graph of KV (1, 2) versus Time
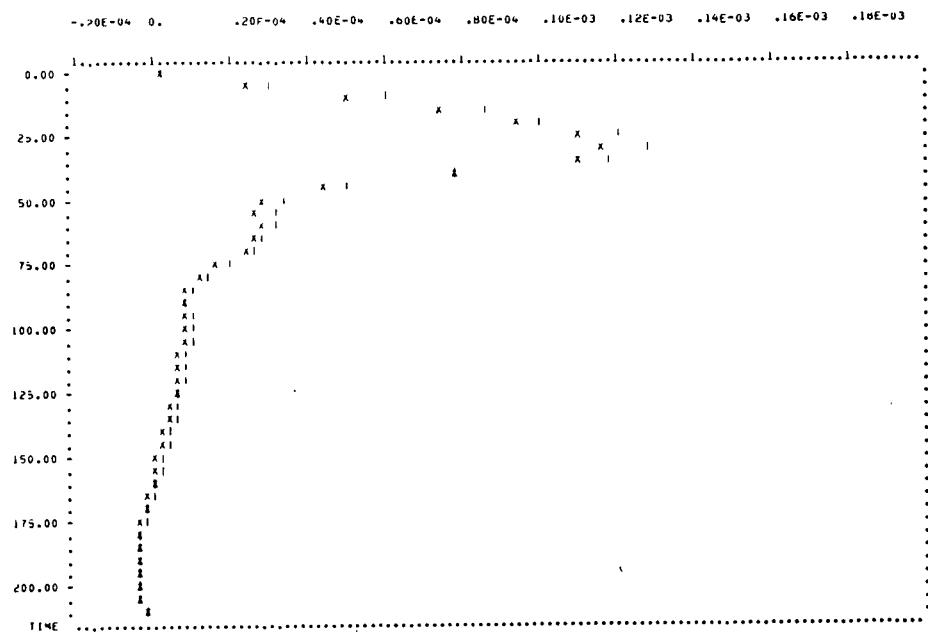
Figure B3. Graph of KV (1, 3) versus Time
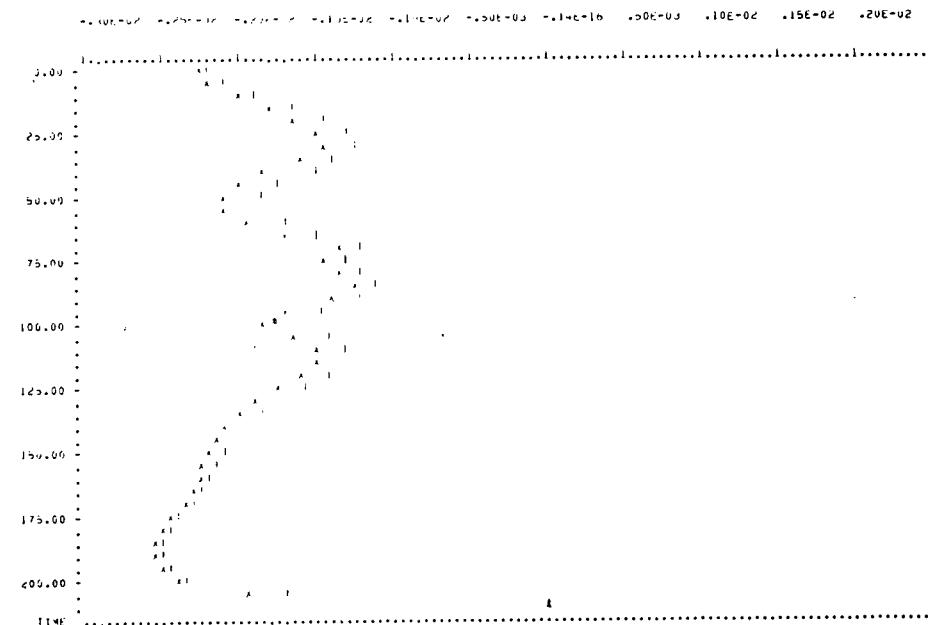
Figure B4. Graph of KV (1, 4) versus Time
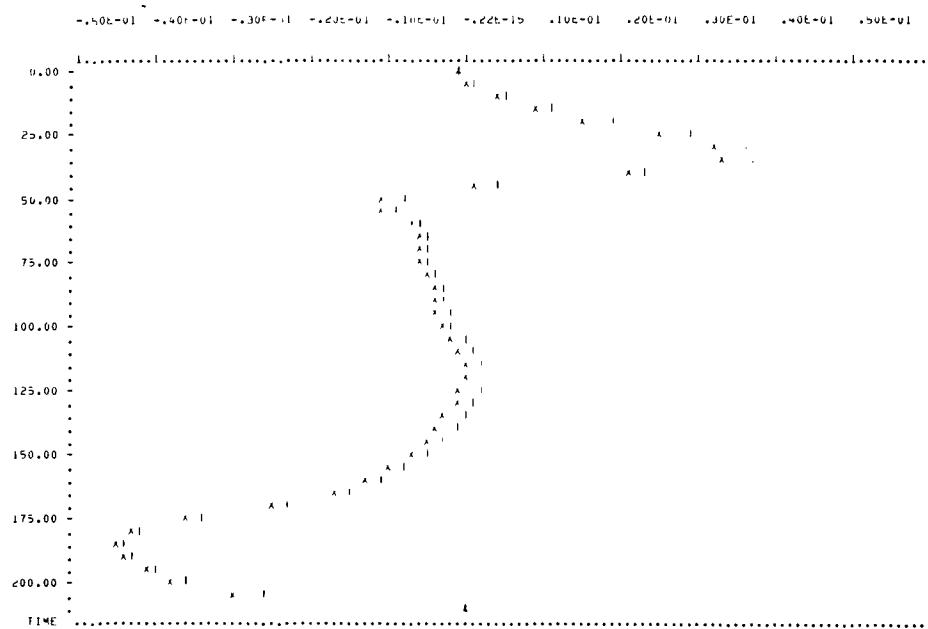
Figure B5. Graph of KV (1, 5) versus Time
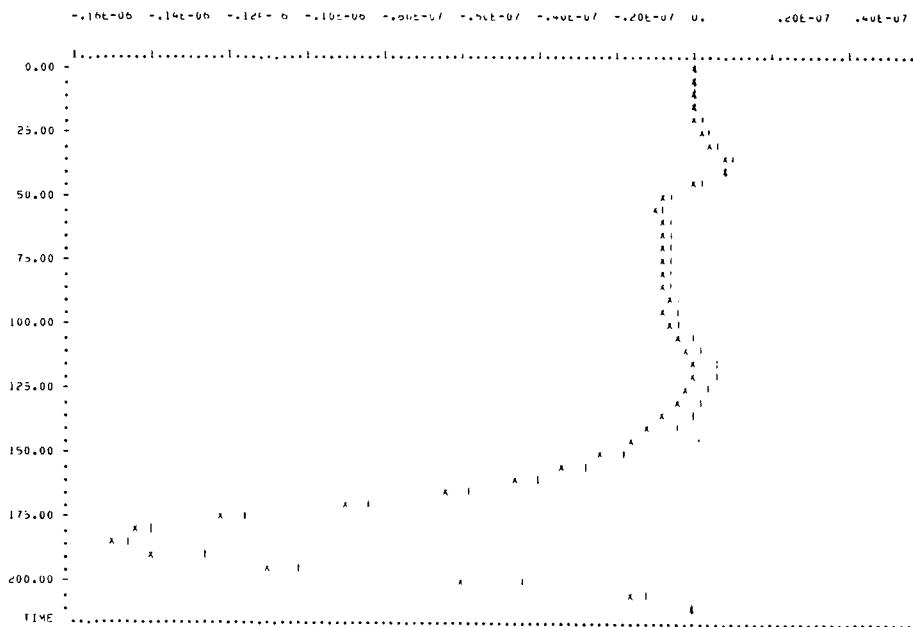
Figure B6. Graph of KV (1, 6) versus Time
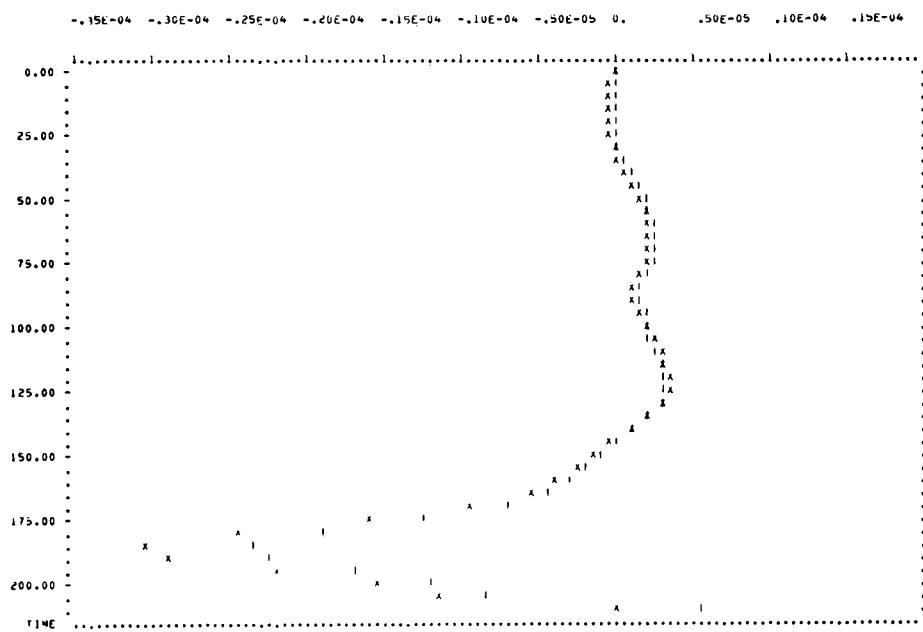
Figure B7.   Graph of KV (1, 7) versus Time
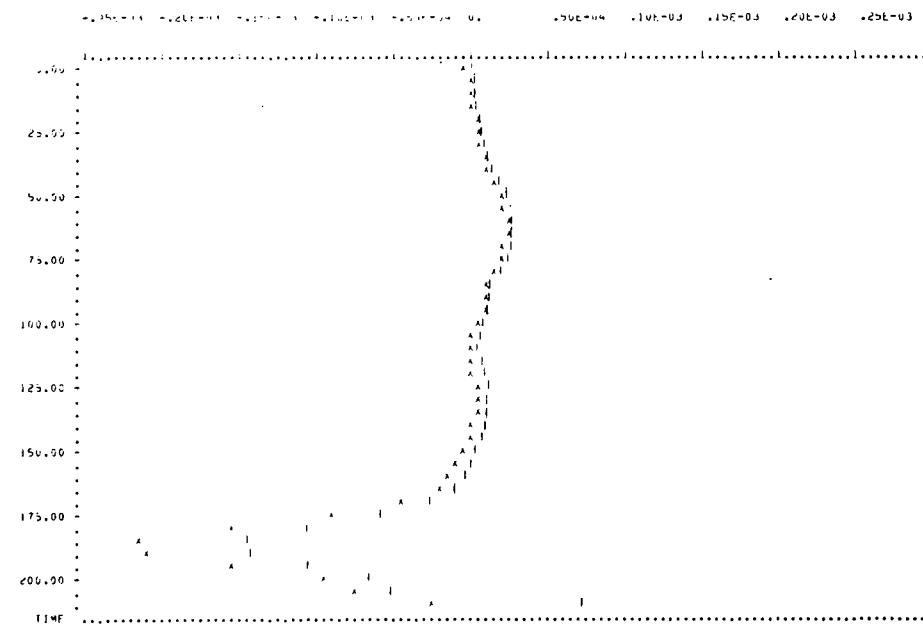
Figure B8.   Graph of KV (1, 8) versus Time
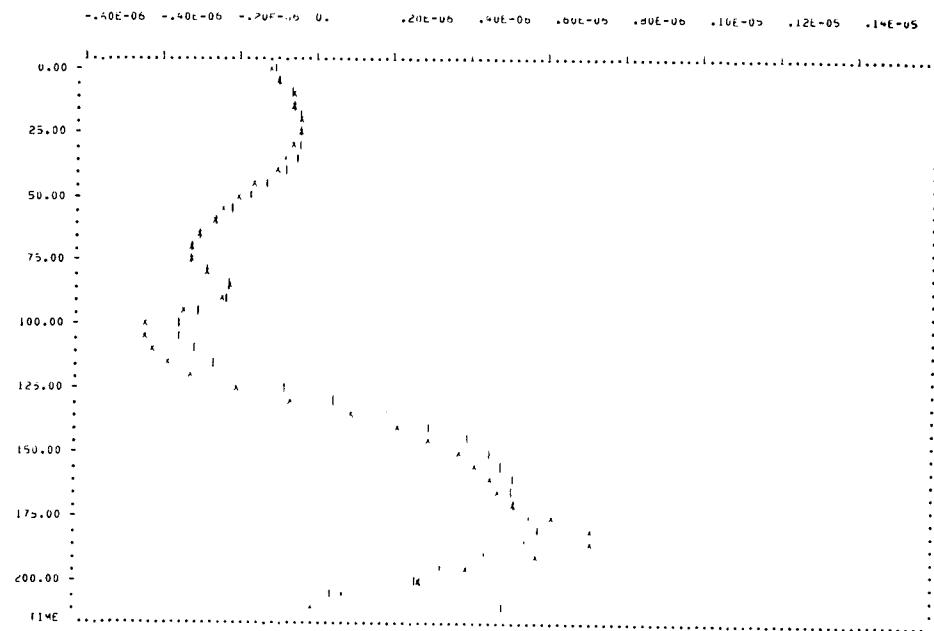
Figure B9.   Graph of KV (1, 9) versus Time
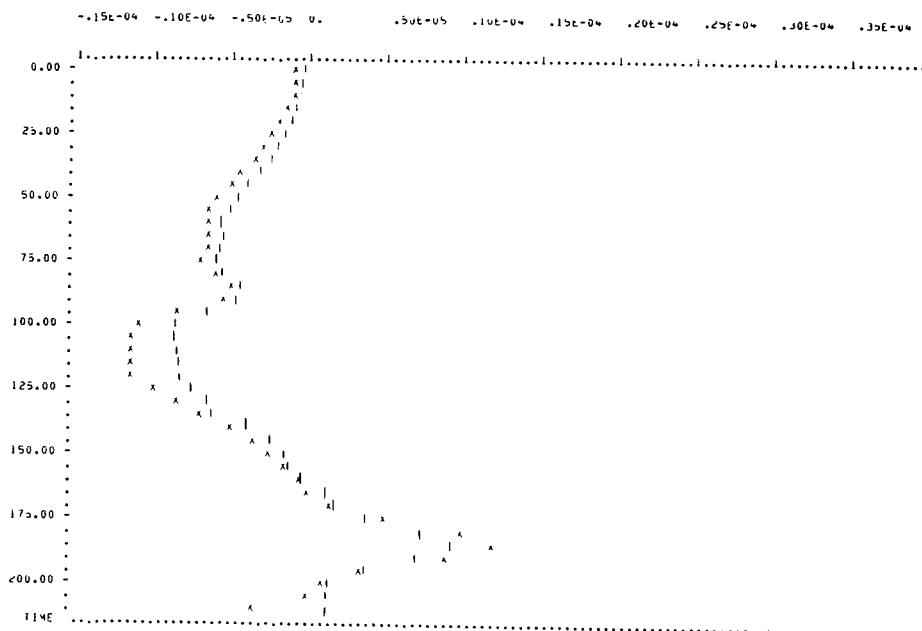
Figure B10.   Graph of KV (1, 10) versus Time
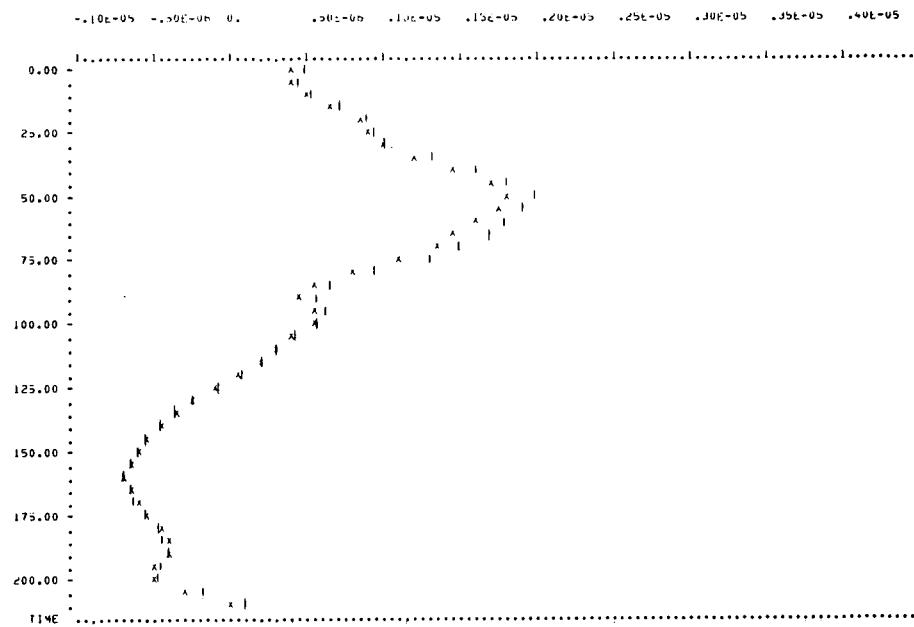
Figure B11.   Graph of KV (1,11) versus Time
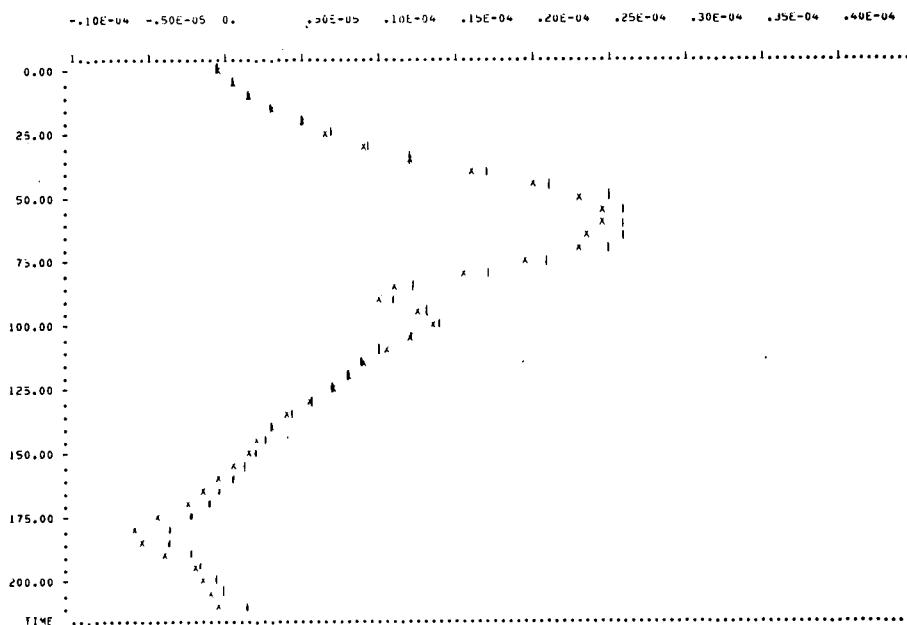
Figure B12.   Graph of KV (1,12) versus Time
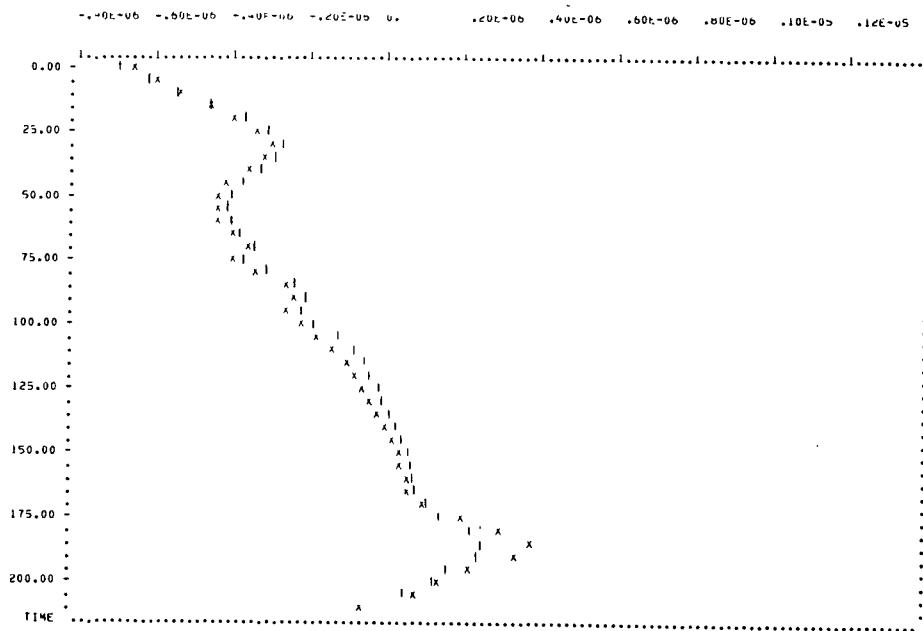
Figure B13.　Graph of KV (1,13) versus Time
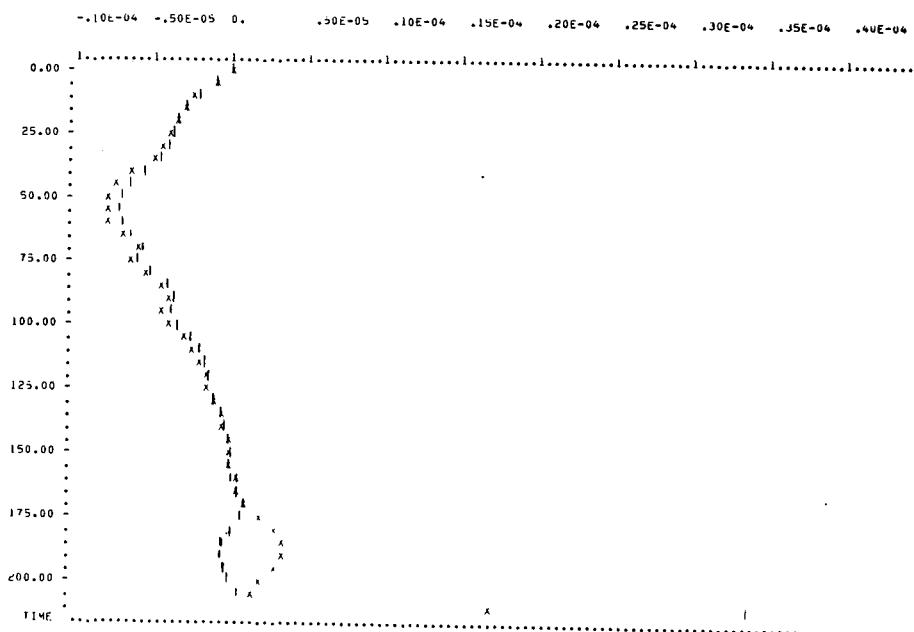
Figure B14.　Graph of KV (1,14) versus Time

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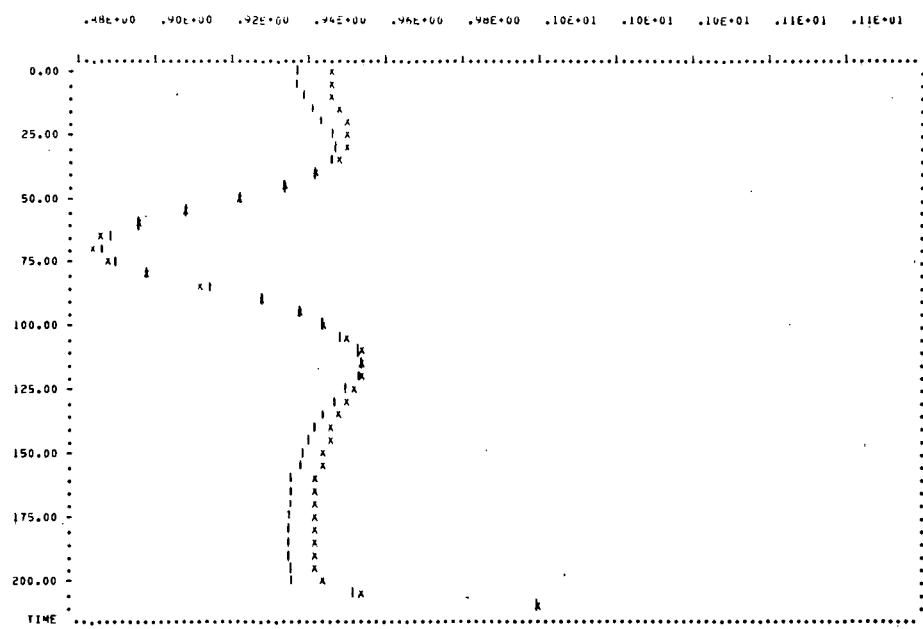
Figure B15.   Graph of KV (1, 15) versus Time
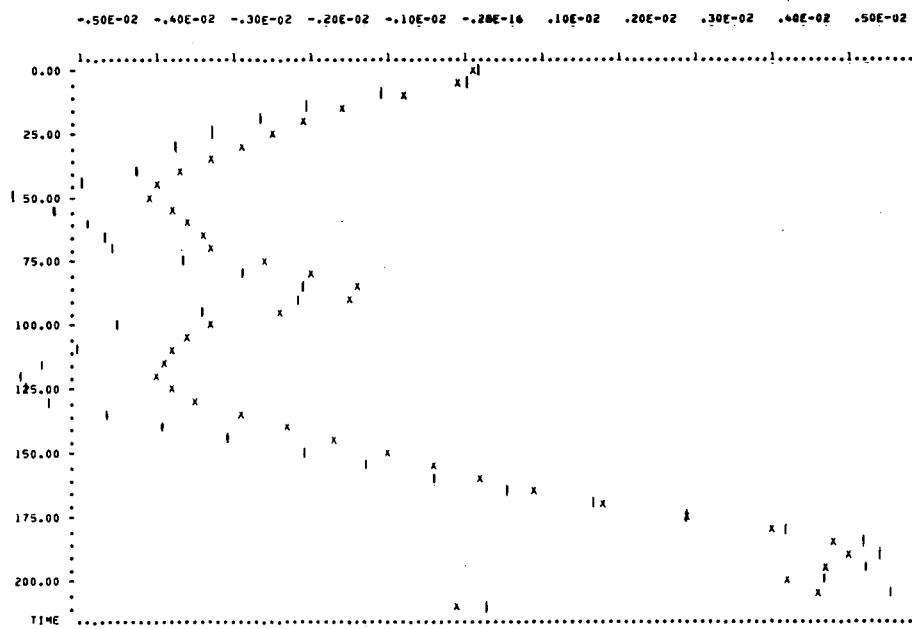
Figure B16.   Graph of KV (1, 16) versus Time
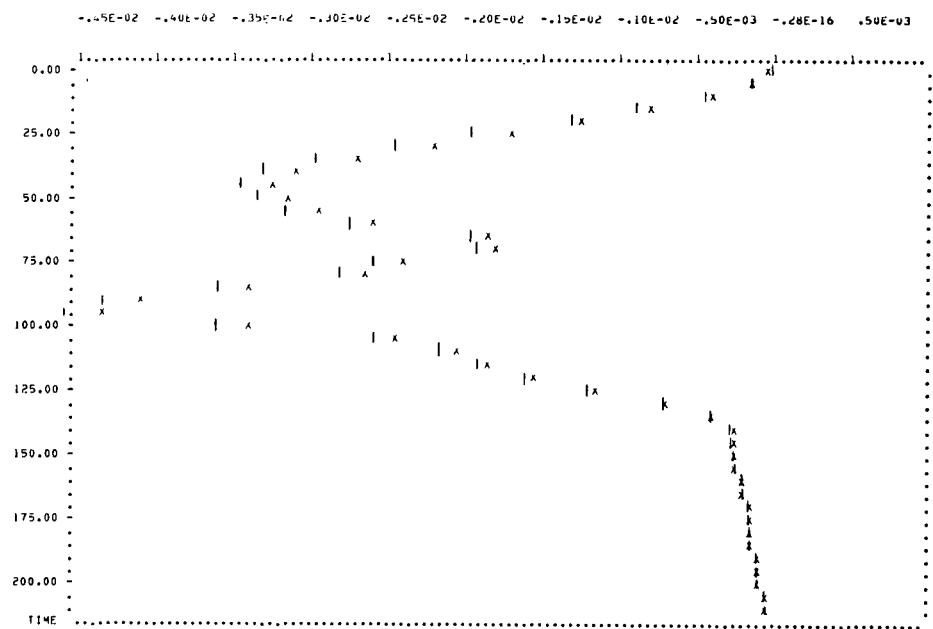
Figure B17.   Graph of KV (1, 17) versus Time
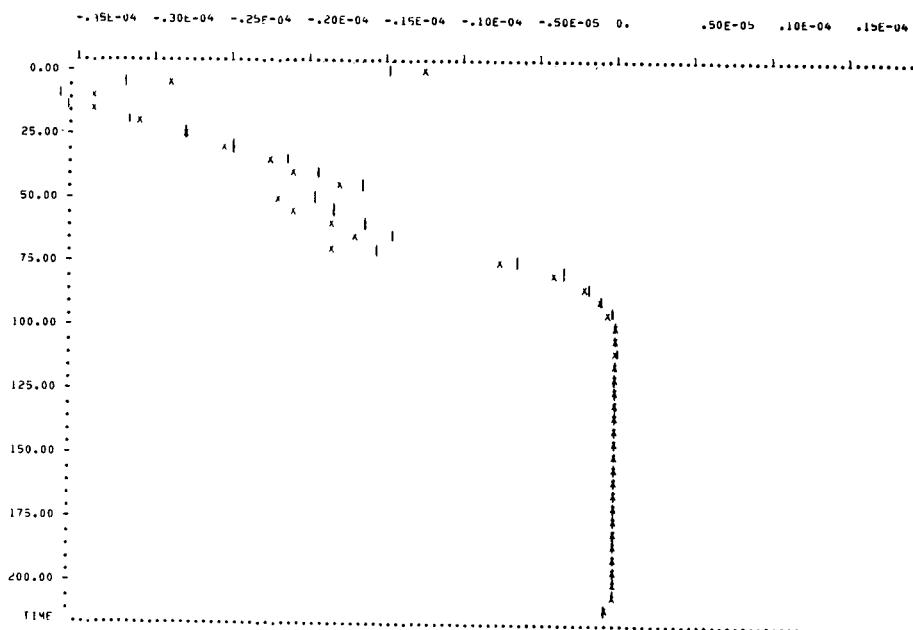
Figure B18.   Graph of KV (1, 18) versus Time
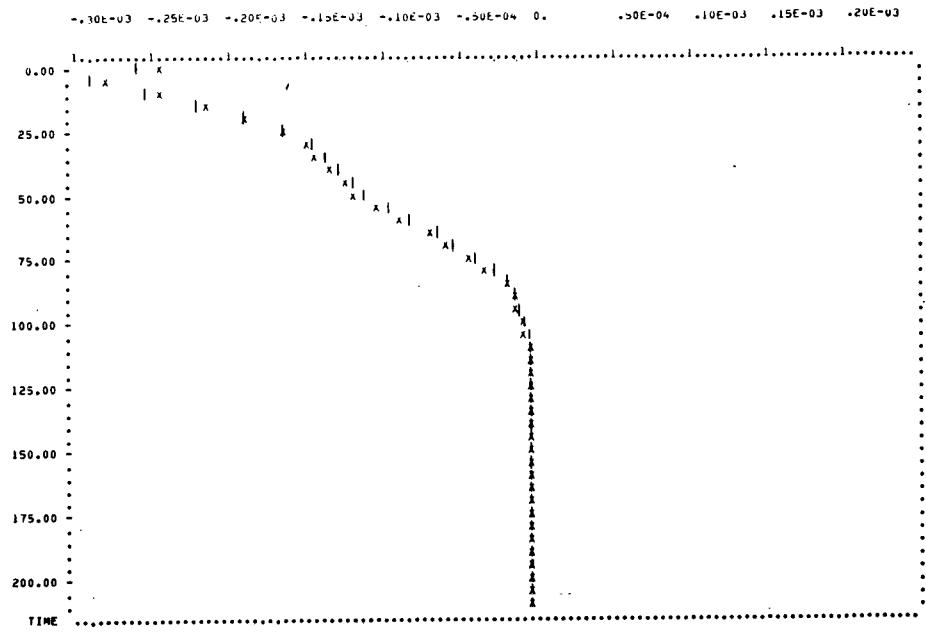
Figure B19. Graph of KV (1, 19) versus Time
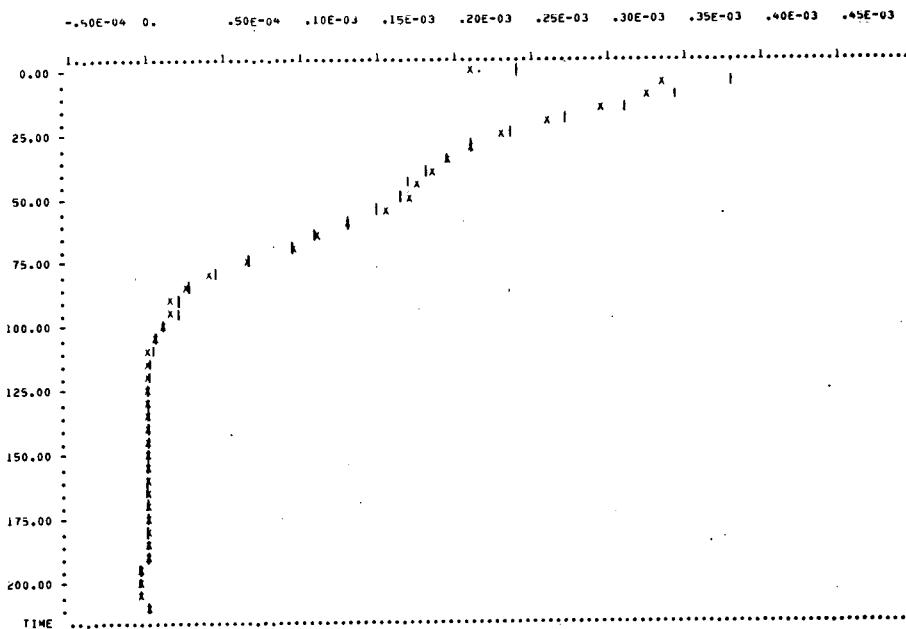
Figure B20. Graph of KV (1, 20) versus Time
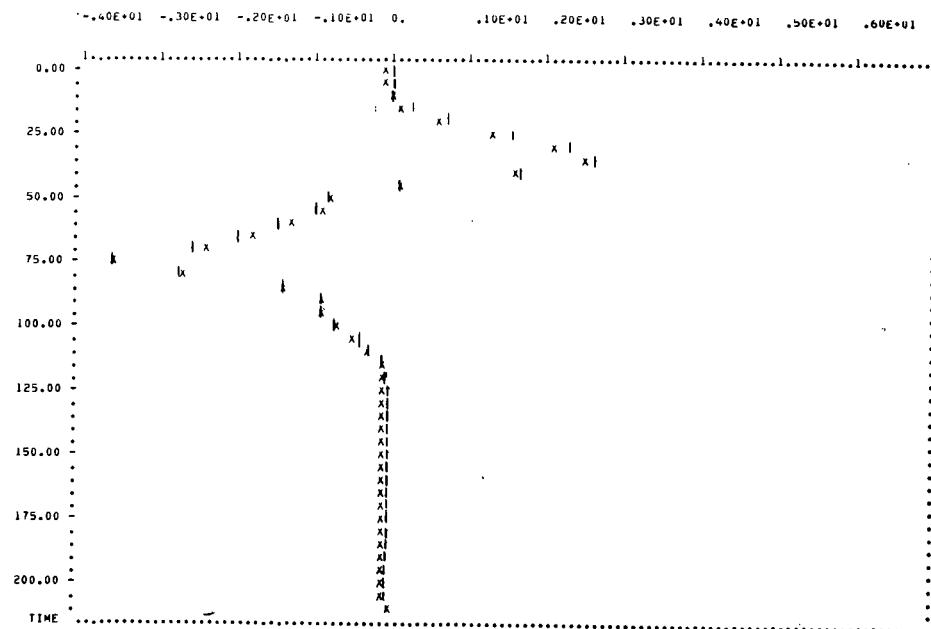
Figure B21. Graph of KV (1,21) versus Time
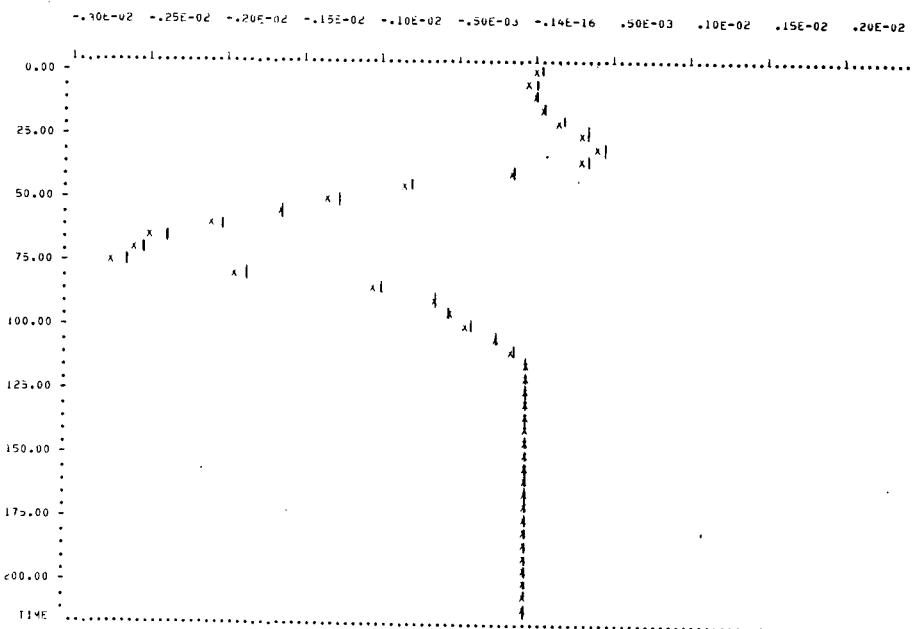
Figure B22. Graph of KV (1,22) versus Time

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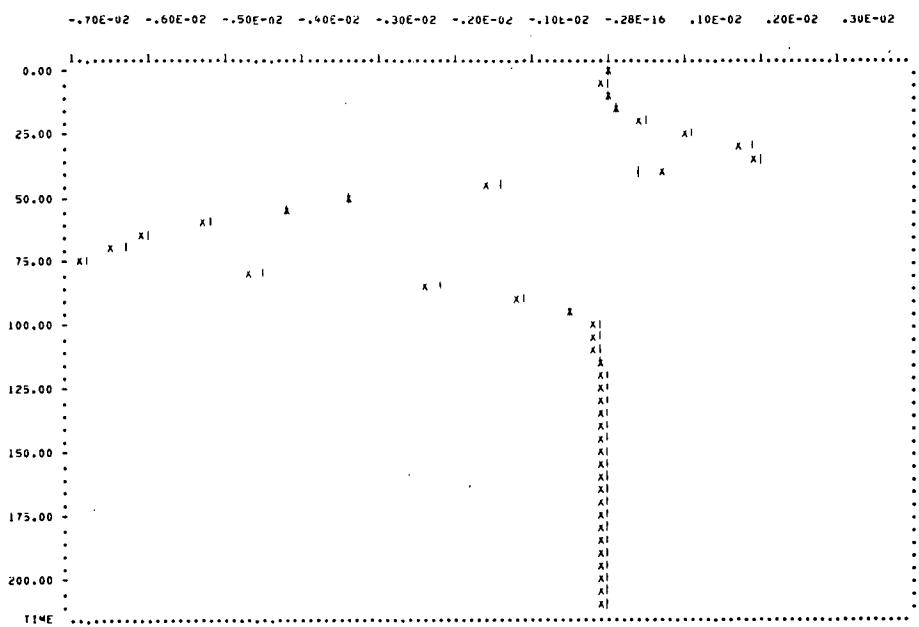
Figure B23. Graph of KV (1,25)* versus Time
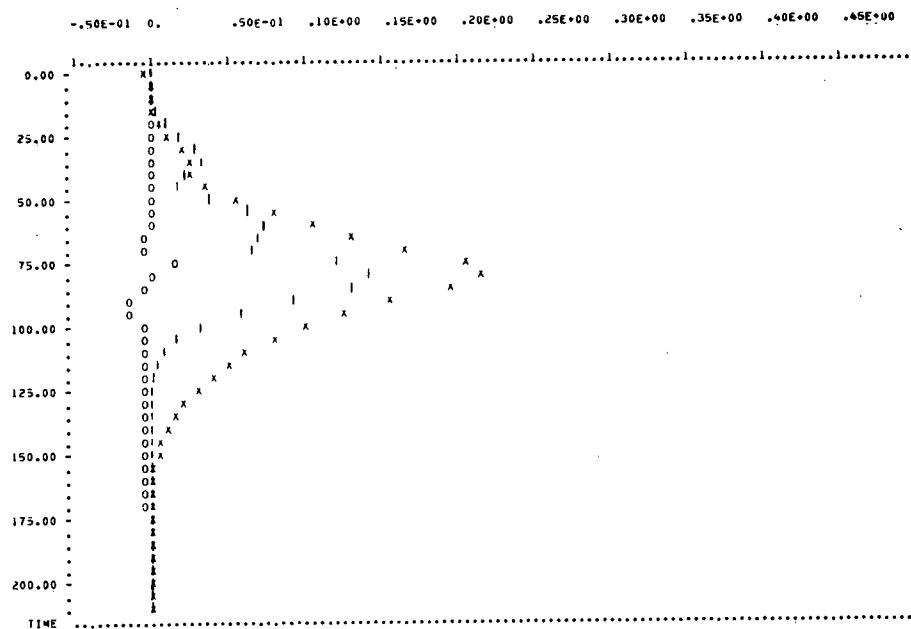
Figure B24. Graph of $\dot{\eta}_4$ versus Time

*KV(1, 25) denotes the deterministic input to δp

APPENDIX C
SIMPLIFIED CONTROLLER DATA

Data for the (13 x 19) measurement matrix is listed in Table C1. Only the non-zero elements are listed.

The fifth measurement was eliminated from this measurement matrix in defining an initial simplified controller. The remaining measurements were renumbered from 1 to 12, keeping them in the same order. Figures C1 through C27 display the initial simplified gains that correspond to a modified measurement matrix. This modified matrix was obtained by eliminating the actuator position and roll angle contributions from the rate gyro and accelerometer outputs. The actuator feedbacks for the simplified controller were essentially unchanged from the optimal controller, and hence they are not shown. Gains after the first gradient iteration are plotted. In the cases (i, j) equal to (2, 9) and (3, 9) the gain changes actually exceeded the scales at a few data points, although they are plotted as if they saturated.

The responses of major interest are shown in Figures C28 through C34 for the simplified controller.

Table C1. Measurement Matrix

TIME	M(1,15)	M(2,16)	M(3,17)	M(4, 6)	M(5, 3)	M(5, 4)	M(5, 5)	M(6, 4)	M(7, 1)	M(7, 5)
0.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	0.	0.	.1000E+01	.1000E+01	0.
5.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.2891E-01	.5103E+02	.1000E+01	.1000E+01	.3286E-03
10.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.3671E+00	.1056E+03	.1000E+01	.1000E+01	.2096E-02
15.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.2612E+00	.1630E+03	.1000E+01	.1000E+01	.2597E-02
20.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.1080E+01	.2239E+03	.1000E+01	.1000E+01	.3749E-02
25.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.4889E+00	.2888E+03	.1000E+01	.1000E+01	.6494E-02
30.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.8085E+00	.3580E+03	.1000E+01	.1000E+01	.8494E-02
35.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.1221E+01	.4321E+03	.1000E+01	.1000E+01	.1063E-01
40.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.1725E+01	.5125E+03	.1000E+01	.1000E+01	.1264E-01
45.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.2195E+01	.6001E+03	.1000E+01	.1000E+01	.1366E-01
50.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.2474E+01	.6940E+03	.1000E+01	.1000E+01	.1303E-01
55.	.1000E+01	.1000E+01	.1000E+01	.1000F+01	.1000E+01	-.2544E+01	.8008E+03	.1000E+01	.1000E+01	.1203E-01
60.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.3154E+01	.9145E+03	.1000E+01	.1000E+01	.1236E-01
65.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.3746E+01	.1034E+04	.1000E+01	.1000E+01	.1307E-01
70.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.4132E+01	.1160E+04	.1000E+01	.1000E+01	.1283E-01
75.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.4487E+01	.1294E+04	.1000E+01	.1000E+01	.1266E-01
80.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.4920E+01	.1442E+04	.1000E+01	.1000E+01	.1265E-01
85.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5194E+01	.1607E+04	.1000E+01	.1000E+01	.1224E-01
90.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5427E+01	.1789E+04	.1000E+01	.1000E+01	.1157E-01
95.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5611E+01	.1992E+04	.1000E+01	.1000E+01	.1081E-01
100.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5746E+01	.2214E+04	.1000E+01	.1000E+01	.9997E-02
105.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5887E+01	.2455E+04	.1000E+01	.1000E+01	.9302E-02
110.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6115E+01	.2716E+04	.1000E+01	.1000E+01	.8709E-02
115.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6283E+01	.2995E+04	.1000E+01	.1000E+01	.8116E-02
120.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6297E+01	.3292E+04	.1000E+01	.1000E+01	.7417E-02
125.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6292E+01	.3608E+04	.1000E+01	.1000E+01	.6676E-02
130.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6271E+01	.3940E+04	.1000E+01	.1000E+01	.6114E-02
135.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6259E+01	.4291E+04	.1000E+01	.1000E+01	.5576E-02
140.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6236E+01	.4659E+04	.1000E+01	.1000E+01	.5093E-02
145.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6196E+01	.5045E+04	.1000E+01	.1000E+01	.4628E-02
150.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6141E+01	.5449E+04	.1000E+01	.1000E+01	.4246E-02
155.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.6071E+01	.5872E+04	.1000E+01	.1000E+01	.3834E-02
160.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5990E+01	.6313E+04	.1000E+01	.1000E+01	.3457E-02
165.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5940E+01	.6765E+04	.1000E+01	.1000E+01	.3176E-02
170.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5854E+01	.7219E+04	.1000E+01	.1000E+01	.2897E-02
175.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5765E+01	.7675E+04	.1000E+01	.1000E+01	.2628E-02
180.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5671E+01	.8133E+04	.1000E+01	.1000E+01	.2389E-02
185.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5577E+01	.8594E+04	.1000E+01	.1000E+01	.2180E-02
190.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5481E+01	.9055E+04	.1000E+01	.1000E+01	.1983E-02
195.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5386E+01	.9519E+04	.1000E+01	.1000E+01	.1806E-02
200.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5292E+01	.9984E+04	.1000E+01	.1000E+01	.1631E-02
205.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5198E+01	.1045E+05	.1000E+01	.1000E+01	.1424E-02
210.	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	-.5108E+01	.1092E+05	.1000E+01	.1000E+01	.1417E-02

Table C1. Measurement Matrix (continued)

TIME	M(8, 5)	M(8, 8)	M(8,10)	M(8,12)	M(8,14)	M(9, 2)	M(9, 4)	M(9, 7)	M(9, 9)	M(9,11)
0.	.1000E+01	-.1728E-01	.1784E-02	-.4929E-02	-.1465E-01	.1000E+01	0.	-.1723E-01	.1744E-02	-.4929E-02
5.	.1000E+01	-.1715E-01	.2033E-02	-.4862E-02	-.1348E-01	.1000E+01	-.3286E-03	-.1715E-01	.2033E-02	-.4862E-02
10.	.1000E+01	-.1702E-01	.2272E-02	-.4791E-02	-.1228E-01	.1000E+01	-.2096E-02	-.1702E-01	.2272E-02	-.4791E-02
15.	.1000E+01	-.1688E-01	.2512E-02	-.4717E-02	-.1105E-01	.1000E+01	-.2597E-02	-.1688E-01	.2512E-02	-.4717E-02
20.	.1000E+01	-.1675E-01	.2748E-02	-.4643E-02	-.9828E-02	.1000E+01	-.3749E-02	-.1675E-01	.2748E-02	-.4643E-02
25.	.1000E+01	-.1662E-01	.2989E-02	-.4571E-02	-.8606E-02	.1000E+01	-.6494E-02	-.1662E-01	.2939E-02	-.4571E-02
30.	.1000E+01	-.1649E-01	.3232E-02	-.4503E-02	-.7430E-02	.1000E+01	-.8494E-02	-.1649E-01	.3232E-02	-.4503E-02
35.	.1000E+01	-.1637E-01	.3486E-02	-.4440E-02	-.6291E-02	.1000E+01	-.1063E-01	-.1637E-01	.3486E-02	-.4440E-02
40.	.1000E+01	-.1626E-01	.3748E-02	-.4386E-02	-.5232E-02	.1000E+01	-.1264E-01	-.1626E-01	.3748E-02	-.4386E-02
45.	.1000E+01	-.1616E-01	.4026E-02	-.4341E-02	-.4245E-02	.1000E+01	-.1366E-01	-.1616E-01	.4026E-02	-.4341E-02
50.	.1000E+01	-.1608E-01	.4317E-02	-.4310E-02	-.3372E-02	.1000E+01	-.1303E-01	-.1608E-01	.4317E-02	-.4310E-02
55.	.1000E+01	-.1601E-01	.4631E-02	-.4292E-02	-.2610E-02	.1000E+01	-.1203E-01	-.1601E-01	.4631E-02	-.4292E-02
60.	.1000E+01	-.1597E-01	.4962E-02	-.4292E-02	-.1993E-02	.1000E+01	-.1236E-01	-.1597E-01	.4962E-02	-.4292E-02
65.	.1000E+01	-.1594E-01	.5322E-02	-.4310E-02	-.1525E-02	.1000E+01	-.1307E-01	-.1594E-01	.5322E-02	-.4310E-02
70.	.1000E+01	-.1595E-01	.5705E-02	-.4348E-02	-.1234E-02	.1000E+01	-.1283E-01	-.1595E-01	.5705E-02	-.4348E-02
75.	.1000E+01	-.1598E-01	.6122E-02	-.4414E-02	-.1107E-02	.1000E+01	-.1266E-01	-.1598E-01	.6122E-02	-.4414E-02
80.	.1000E+01	-.1602E-01	.6562E-02	-.4519E-02	-.1064E-02	.1000E+01	-.1265E-01	-.1602E-01	.6562E-02	-.4519E-02
85.	.1000E+01	-.1606E-01	.7036E-02	-.4686E-02	-.1003E-02	.1000E+01	-.1224E-01	-.1606E-01	.7036E-02	-.4686E-02
90.	.1000E+01	-.1610E-01	.7531E-02	-.4926E-02	-.8278E-03	.1000E+01	-.1157E-01	-.1610E-01	.7531E-02	-.4926E-02
95.	.1000E+01	-.1612E-01	.8052E-02	-.5246E-02	-.4931E-03	.1000E+01	-.1081E-01	-.1612E-01	.8052E-02	-.5246E-02
100.	.1000E+01	-.1614E-01	.8563E-02	-.5582E-02	-.1524E-03	.1000E+01	-.9997E-02	-.1614E-01	.8563E-02	-.5582E-02
105.	.1000E+01	-.1619E-01	.9049E-02	-.5874E-02	.1752E-04	.1000E+01	-.9302E-02	-.1619E-01	.9049E-02	-.5874E-02
110.	.1000E+01	-.1627E-01	.9490E-02	-.6090E-02	-.4420E-04	.1000E+01	-.8709E-02	-.1627E-01	.9490E-02	-.6090E-02
115.	.1000E+01	-.1620E-01	.1012E-01	-.6683E-02	.1003E-02	.1000E+01	-.8116E-02	-.1620E-01	.1012E-01	-.6683E-02
120.	.1000E+01	-.1620E-01	.1065E-01	-.7105E-02	.1549E-02	.1000E+01	-.7417E-02	-.1620E-01	.1065E-01	-.7105E-02
125.	.1000E+01	-.1626E-01	.1113E-01	-.7378E-02	.1644E-02	.1000E+01	-.6676E-02	-.1626E-01	.1113E-01	-.7378E-02
130.	.1000E+01	-.1638E-01	.1152E-01	-.7506E-02	.1319E-02	.1000E+01	-.6114E-02	-.1638E-01	.1152E-01	-.7506E-02
135.	.1000E+01	-.1656E-01	.1187E-01	-.7504E-02	.6008E-03	.1000E+01	-.5576E-02	-.1656E-01	.1197E-01	-.7504E-02
140.	.1000E+01	-.1678E-01	.1215E-01	-.7385E-02	-.4598E-03	.1000E+01	-.5093E-02	-.1678E-01	.1215E-01	-.7385E-02
145.	.1000E+01	-.1704E-01	.1238E-01	-.7156E-02	-.1854E-02	.1000E+01	-.4628E-02	-.1704E-01	.1238E-01	-.7156E-02
150.	.1000E+01	-.1735E-01	.1256E-01	-.6834E-02	-.3513E-02	.1000E+01	-.4246E-02	-.1735E-01	.1256E-01	-.6834E-02
155.	.1000E+01	-.1769E-01	.1271E-01	-.6424E-02	-.5444E-02	.1000E+01	-.3834E-02	-.1769E-01	.1271E-01	-.6424E-02
160.	.1000E+01	-.1806E-01	.1282E-01	-.5947E-02	-.7566E-02	.1000E+01	-.3457E-02	-.1806E-01	.1282E-01	-.5947E-02
165.	.1000E+01	-.1844E-01	.1290E-01	-.5416E-02	-.9837E-02	.1000E+01	-.3176E-02	-.1844E-01	.1290E-01	-.5416E-02
170.	.1000E+01	-.1883E-01	.1296E-01	-.4860E-02	-.1216E-01	.1000E+01	-.2897E-02	-.1883E-01	.1296E-01	-.4860E-02
175.	.1000E+01	-.1922E-01	.1299E-01	-.4292E-02	-.1449E-01	.1000E+01	-.2628E-02	-.1922E-01	.1299E-01	-.4292E-02
180.	.1000E+01	-.1961E-01	.1302E-01	-.3717E-02	-.1682E-01	.1000E+01	-.2389E-02	-.1961E-01	.1302E-01	-.3717E-02
185.	.1000E+01	-.1999E-01	.1304E-01	-.3152E-02	-.1910E-01	.1000E+01	-.2180E-02	-.1999E-01	.1304E-01	-.3152E-02
190.	.1000E+01	-.2036E-01	.1306E-01	-.2598E-02	-.2133E-01	.1000E+01	-.1983E-02	-.2036E-01	.1306E-01	-.2598E-02
195.	.1000E+01	-.2071E-01	.1307E-01	-.2068E-02	-.2346E-01	.1000E+01	-.1806E-02	-.2071E-01	.1307E-01	-.2068E-02
200.	.1000E+01	-.2105E-01	.1309E-01	-.1554E-02	-.2554E-01	.1000E+01	-.1631E-02	-.2105E-01	.1309E-01	-.1554E-02
205.	.1000E+01	-.2138E-01	.1311E-01	-.1074E-02	-.2749E-01	.1000E+01	-.1424E-02	-.2138E-01	.1311E-01	-.1074E-02
210.	.1000E+01	-.2168E-01	.1314E-01	-.6249E-03	-.2933E-01	.1000E+01	-.1417E-02	-.2168E-01	.1314E-01	-.6249E-03

Table C1. Measurement Matrix (continued)

TIME	M(9,13)	M(10, 1)	M(10, 2)	M(10, 3)	M(10, 4)	M(10, 5)	M(10, 7)	M(10, 8)	M(10, 9)	M(10,10)
0.	-.1465E-01	0.	-.1832E+01	0.	-.1027E+00	-.2848E+01	-.2547E+00	-.1291E+03	.3658E-01	.2363E+02
5.	-.1348E-01	.6908E+00	.1420E+02	-.2065E+00	-.1059E+00	-.2967E+01	-.3566E+00	-.1300E+03	.6249E-01	.2749E+02
10.	-.1228E-01	.9551E+00	.3432E+02	-.4223E+00	-.1313E+00	-.3183E+01	-.4850E+00	-.1305E+03	.9417E-01	.3131E+02
15.	-.1105E-01	.6351E+00	.5940E+02	-.6432E+00	-.1866E+00	-.3406E+01	-.6391E+00	-.1306E+03	.1308E+00	.3530E+02
20.	-.9828E-02	-.4364E+00	.8892E+02	-.8688E+00	-.2465E+00	-.3604E+01	-.8195E+00	-.1307E+03	.1719E+00	.3944E+02
25.	-.8606E-02	-.1955E+01	.1228E+03	-.1095E+01	-.3586E+00	-.3776E+01	-.1025E+01	-.1303E+03	.2177E+00	.4384E+02
30.	-.7430E-02	-.4188E+01	.1602E+03	-.1318E+01	-.5146E+00	-.3875E+01	-.1251E+01	-.1297E+03	.2675E+00	.4851E+02
35.	-.6291E-02	-.7083E+01	.1949E+03	-.1534E+01	-.7124E+00	-.3917E+01	-.1498E+01	-.1286E+03	.3227E+00	.5355E+02
40.	-.5232E-02	-.1048E+02	.2394E+03	-.1733E+01	-.9416E+00	-.3878E+01	-.1762E+01	-.1270E+03	.3839E+00	.5896E+02
45.	-.4245E-02	-.1430E+02	.2794E+03	-.1916E+01	-.1183E+01	-.3763E+01	-.2037E+01	-.1253E+03	.4524E+00	.6489E+02
50.	-.3372E-02	-.1816E+02	.3155E+03	-.2081E+01	-.1387E+01	-.3559E+01	-.2317E+01	-.1232E+03	.5284E+00	.7121E+02
55.	-.2610E-02	-.2215E+02	.3483E+03	-.2214E+01	-.1544E+01	-.3323E+01	-.2594E+01	-.1207E+03	.6135E+00	.7825E+02
60.	-.1993E-02	-.2595E+02	.3744E+03	-.2326E+01	-.1634E+01	-.3033E+01	-.2850E+01	-.1186E+03	.7040E+00	.8597E+02
65.	-.1525E-02	-.2907E+02	.3915E+03	-.2373E+01	-.1689E+01	-.2704E+01	-.3063E+01	-.1167E+03	.7969E+00	.9467E+02
70.	-.1234E-02	-.3091E+02	.3942E+03	-.2381E+01	-.1705E+01	-.2364E+01	-.3217E+01	-.1156E+03	.8861E+00	.1043E+03
75.	-.1107E-02	-.3348E+02	.3963E+03	-.2373E+01	-.1660E+01	-.2020E+01	-.3305E+01	-.1154E+03	.9702E+00	.1154E+03
80.	-.1064E-02	-.3428E+02	.3819E+03	-.2299E+01	-.1566E+01	-.1676E+01	-.3322E+01	-.1165E+03	.1041E+01	.1282E+03
85.	-.1003E-02	-.3398E+02	.3570E+03	-.2149E+01	-.1412E+01	-.1334E+01	-.3253E+01	-.1182E+03	.1092E+01	.1434E+03
90.	-.8278E-03	-.3267E+02	.3216E+03	-.1932E+01	-.1213E+01	-.1021E+01	-.3096E+01	-.1208E+03	.1116E+01	.1615E+03
95.	-.4931E-03	-.3029E+02	.2760E+03	-.1651E+01	-.9941E+00	-.7396E+00	-.2850E+01	-.1247E+03	.1108E+01	.1836E+03
100.	-.1524E-03	-.2684E+02	.2296E+03	-.1361E+01	-.7802E+00	-.5189E+00	-.2540E+01	-.1308E+03	.1067E+01	.2086E+03
105.	.1752E-04	-.2321E+02	.1898E+03	-.1127E+01	-.6096E+00	-.3662E+00	-.2238E+01	-.1372E+03	.1015E+01	.2352E+03
110.	-.4420E-04	-.1956E+02	.1570E+03	-.9329E+00	-.4710E+00	-.2479E+00	-.1947E+01	-.1444E+03	.9536E+00	.2624E+03
115.	.1003E-02	-.1762E+02	.1323E+03	-.7502E+00	-.3538E+00	-.1768E+00	-.1747E+01	-.1468E+03	.9371E+00	.2980E+03
120.	.1549E-02	-.1523E+02	.1112E+03	-.6122E+00	-.2794E+00	-.1256E+00	-.1544E+01	-.1514E+03	.9044E+00	.3329E+03
125.	.1644E-02	-.1271E+02	.4365E+02	-.5021E+00	-.2135E+00	-.7987E-01	-.1347E+01	-.1573E+03	.8616E+00	.3664E+03
130.	.1319E-02	-.1033E+02	.7965E+02	-.4143E+00	-.1626E+00	-.5522E-01	-.1168E+01	-.1640E+03	.8173E+00	.3982E+03
135.	.6008E-03	-.8264E+01	.6980E+02	-.3465E+00	-.1231E+00	-.3743E-01	-.1014E+01	-.1708E+03	.7782E+00	.4246E+03
140.	-.4598E-03	-.6585E+01	.6223E+02	-.2937E+00	-.9458E-01	-.2843E-01	-.8851E+00	-.1776E+03	.7464E+00	.4566E+03
145.	-.1854E-02	-.5249E+01	.5544E+02	-.2526E+00	-.7058E-01	-.1991E-01	-.7795E+00	-.1835E+03	.7230E+00	.4834E+03
150.	-.3513E-02	-.4235E+01	.5133E+02	-.2208E+00	-.5713E-01	-.1480E-01	-.6947E+00	-.1889E+03	.7063E+00	.5075E+03
155.	-.5444E-02	-.3473E+01	.4942E+02	-.1956E+00	-.4833E-01	-.1134E-01	-.6272E+00	-.1936E+03	.6957E+00	.5305E+03
160.	-.7556E-02	-.2894E+01	.4732E+02	-.1752E+00	-.3547E-01	-.8598E-02	-.5739E+00	-.1976E+03	.6889E+00	.5511E+03
165.	-.9837E-02	-.2468E+01	.4630E+02	-.1586E+00	-.3459E-01	-.5748E-02	-.5310E+00	-.2012E+03	.6852E+00	.5705E+03
170.	-.1216E-01	-.2133E+01	.4609E+02	-.1436E+00	-.2849E-01	-.4690E-02	-.4931E+00	-.2042E+03	.6827E+00	.5877E+03
175.	-.1449E-01	-.1876E+01	.4635E+02	-.1309E+00	-.1910E-01	-.3250E-02	-.4721E+00	-.2066E+03	.6816E+00	.6032E+03
180.	-.1682E-01	-.1685E+01	.4704E+02	-.1204E+00	-.1848E-01	-.2405E-02	-.4522E+00	-.2089E+03	.6820E+00	.6182E+03
185.	-.1910E-01	-.1521E+01	.4910E+02	-.1102E+00	-.1836E-01	-.2367E-02	-.4356E+00	-.2107E+03	.6822E+00	.6318E+03
190.	-.2133E-01	-.1377E+01	.4990E+02	-.1006E+00	-.1038E-01	-.2008E-02	-.4216E+00	-.2119E+03	.6827E+00	.6447E+03
195.	-.2346E-01	-.1232E+01	.5076E+02	-.9134E-01	-.1570E-01	-.1250E-02	-.4099E+00	-.2131E+03	.6837E+00	.6577E+03
200.	-.2554E-01	-.1131E+01	.5296E+02	-.8276E-01	-.1547E-01	-.1433E-02	-.4003E+00	-.2144E+03	.6851E+00	.6705E+03
205.	-.2749E-01	-.1027E+01	.5898E+02	-.7449E-01	-.1053E-01	-.4160E-03	-.3919E+00	-.2152E+03	.6871E+00	.6832E+03
210.	-.2933E-01	-.9368E+00	.5829E+02	-.6672E-01	-.1164E-01	-.5981E-03	-.3845E+00	-.2159E+03	.6892E+00	.6957E+03

Table C1.   Measurement Matrix (continued)

TIME	M(10,11)	M(10,12)	M(10,13)	M(10,14)	M(10,15)	M(10,16)	M(10,17)	M(10,19)	M(11, 5)	M(11, 8)
0.	-.8501E-01	-.8041E+02	-.3671E+00	-.4584E+03	.5267E+01	-.4128E+03	0.	.2883E+00	.1000E+01	.4779E-02
5.	-.1482E+00	-.7407E+02	-.4053E+00	-.4335E+03	.4588E+01	-.5197E+03	.1781E-01	.3132E+00	.1000E+01	.4669E-02
10.	-.2304E+00	-.6589E+02	-.4285E+00	-.4071E+03	.4186E+01	-.6565E+03	.6947E-01	.3310E+00	.1000E+01	.4557E-02
15.	-.3354E+00	-.5700E+02	-.4326E+00	-.3807E+03	.3684E+01	-.7825E+03	.1423E+00	.3459E+00	.1000E+01	.4442E-02
20.	-.4652E+00	-.4806E+02	-.4159E+00	-.3546E+03	.3108E+01	-.8789E+03	.2151E+00	.3745E+00	.1000E+01	.4327E-02
25.	-.6201E+00	-.3941E+02	-.3772E+00	-.3285E+03	.2455E+01	-.1051E+04	.2745E+00	.4085E+00	.1000E+01	.4212E-02
30.	-.7961E+00	-.3154E+02	-.3175E+00	-.3036E+03	.1728E+01	-.1204E+04	.2790E+00	.4473E+00	.1000E+01	.4103E-02
35.	-.9911E+00	-.2461E+02	-.2381E+00	-.2792E+03	.8854E+00	-.1366E+04	.1895E+00	.5013E+00	.1000E+01	.3997E-02
40.	-.1199E+01	-.1890E+02	-.1445E+00	-.2563E+03	.8435E-01	-.1528E+04	.1065E-01	.5424E+00	.1000E+01	.3900E-02
45.	-.1413E+01	-.1469E+02	-.4012E-01	-.2350E+03	-.7450E+00	-.1703E+04	-.2868E+00	.6167E+00	.1000E+01	.3811E-02
50.	-.1625E+01	-.1207E+02	.6708E-01	-.2161E+03	-.2140E+01	-.1880E+04	-.9377E+00	.7233E+00	.1000E+01	.3733E-02
55.	-.1827E+01	-.1081E+02	.1717E+00	-.2000E+03	-.3075E+01	-.2069E+04	-.1557E+01	.8405E+00	.1000E+01	.3668E-02
60.	-.2004E+01	-.1140E+02	.2646E+00	-.1877E+03	-.4260E+01	-.2249E+04	-.2355E+01	.9844E+00	.1000E+01	.3618E-02
65.	-.2138E+01	-.1384E+02	.3385E+00	-.1798E+03	-.5506E+01	-.2432E+04	-.2625E+01	.1165E+01	.1000E+01	.3585E-02
70.	-.2222E+01	-.1826E+02	.3854E+00	-.1771E+03	-.6752E+01	-.2612E+04	-.3892E+01	.1454E+01	.1000E+01	.3570E-02
75.	-.2254E+01	-.2477E+02	.4065E+00	-.1792E+03	-.8167E+01	-.2794E+04	-.5038E+01	.1132E+01	.1000E+01	.3573E-02
80.	-.2237E+01	-.3434E+02	.4129E+00	-.1822E+03	-.9691E+01	-.2983E+04	-.6281E+01	.9175E+00	.1000E+01	.3587E-02
85.	-.2167E+01	-.4821E+02	.4156E+00	-.1808E+03	-.1106E+02	-.3208E+04	-.9567E+01	.6644E+00	.1000E+01	.3601E-02
90.	-.2047E+01	-.6731E+02	.4205E+00	-.1698E+03	-.1316E+02	-.3417E+04	-.1119E+02	.4271E+00	.1000E+01	.3607E-02
95.	-.1878E+01	-.9219E+02	.4204E+00	-.1473E+03	-.1539E+02	-.3653E+04	-.8904E+01	.2871E+00	.1000E+01	.3602E-02
100.	-.1670E+01	-.1191E+03	.3688E+00	-.1246E+03	-.1742E+02	-.3852E+04	-.5934E+01	.1951E+00	.1000E+01	.3604E-02
105.	-.1467E+01	-.1434E+03	.3262E+00	-.1162E+03	-.1948E+02	-.4008E+04	-.4487E+01	.1329E+00	.1000E+01	.3636E-02
110.	-.1269E+01	-.1633E+03	.2398E+00	-.1260E+03	-.2150E+02	-.4073E+04	-.4221E+01	.8877E-01	.1000E+01	.3703E-02
115.	-.1176E+01	-.1965E+03	.2872E+00	-.5435E+02	-.2317E+02	-.4313E+04	-.4079E+01	.6018E-01	.1000E+01	.3615E-02
120.	-.1063E+01	-.2222E+03	.2726E+00	-.1994E+02	-.2534E+02	-.4472E+04	-.3428E+01	.4131E-01	.1000E+01	.3597E-02
125.	-.9423E+00	-.2411E+03	.2227E+00	-.1944E+02	-.2725E+02	-.4523E+04	-.2788E+01	.2763E-01	.1000E+01	.3643E-02
130.	-.8262E+00	-.2532E+03	.1480E+00	-.5107E+02	-.2931E+02	-.4542E+04	-.1344E+01	.1905E-01	.1000E+01	.3748E-02
135.	-.7206E+00	-.2588E+03	.5148E-01	-.1147E+03	-.3189E+02	-.4482E+04	-.7256E+00	.1313E-01	.1000E+01	.3908E-02
140.	-.6279E+00	-.2586E+03	-.6275E-01	-.2081E+03	-.3425E+02	-.4393E+04	-.4747E+00	.8967E-02	.1000E+01	.4117E-02
145.	-.5467E+00	-.2527E+03	-.1952E+00	-.3332E+03	-.3661E+02	-.4312E+04	-.4269E+00	.6217E-02	.1000E+01	.4372E-02
150.	-.4763E+00	-.2422E+03	-.3404E+00	-.4865E+03	-.3932E+02	-.4222E+04	-.4252E+00	.4293E-02	.1000E+01	.4664E-02
155.	-.4140E+00	-.2274E+03	-.5000E+00	-.6716E+03	-.4200E+02	-.4130E+04	-.4150E+00	.2998E-02	.1000E+01	.4996E-02
160.	-.3582E+00	-.2068E+03	-.6690E+00	-.8842E+03	-.4507E+02	-.4024E+04	-.3898E+00	.2127E-02	.1000E+01	.5353E-02
165.	-.3077E+00	-.1878E+03	-.8445E+00	-.1121E+04	-.4640E+02	-.3750E+04	-.3421E+00	.1535E-02	.1000E+01	.5731E-02
170.	-.2618E+00	-.1653E+03	-.1020E+01	-.1375E+04	-.5033E+02	-.3473E+04	-.3227E+00	.1085E-02	.1000E+01	.6113E-02
175.	-.2203E+00	-.1420E+03	-.1195E+01	-.1642E+04	-.5262E+02	-.3243E+04	-.3109E+00	.7748E-03	.1000E+01	.6495E-02
180.	-.1821E+00	-.1181E+03	-.1371E+01	-.1921E+04	-.5429E+02	-.3037E+04	-.2829E+00	.5711E-03	.1000E+01	.6876E-02
185.	-.1467E+00	-.9456E+02	-.1543E+01	-.2207E+04	-.5835E+02	-.2798E+04	-.2826E+00	.4128E-03	.1000E+01	.7246E-02
190.	-.1137E+00	-.7157E+02	-.1712E+01	-.2496E+04	-.6082E+02	-.2685E+04	-.2431E+00	.2922E-03	.1000E+01	.7609E-02
195.	-.8326E-01	-.4906E+02	-.1874E+01	-.2785E+04	-.6413E+02	-.2486E+04	-.1783E+00	.1997E-03	.1000E+01	.7955E-02
200.	-.5482E-01	-.2748E+02	-.2033E+01	-.3077E+04	-.6585E+02	-.2345E+04	-.2543E+00	.1303E-03	.1000E+01	.8293E-02
205.	-.2893E-01	-.7309E+01	-.2184E+01	-.3363E+04	-.6946E+02	-.2192E+04	-.2758E+00	.7681E-04	.1000E+01	.8611E-02
210.	-.5287E-02	.1157E+02	-.2326E+01	-.3639E+04	-.7199E+02	-.2089E+04	-.2399E+00	.3793E-04	.1000E+01	.8913E-02

Table C1. Measurement Matrix (continued)

TIME	M(11,10)	M(11,12)	M(11,14)	M(12, 2)	M(12, 4)	M(12, 7)	M(12, 9)	M(12,11)	M(12,13)	M(13, 1)
0.	-.5575E-04	.4919E-02	.5518E-02	.1000E+01	0.	.4779E-02	-.5575E-04	.4919E-02	.5518E-02	0.
5.	-.8253E-04	.4830E-02	.5172E-02	.1000E+01	-.3286E-03	.4669E-02	-.8253E-04	.4830E-02	.5172E-02	-.5116E-01
10.	-.1101E-03	.4739E-02	.4820E-02	.1000E+01	-.2096E-02	.4557E-02	-.1101E-03	.4739E-02	.4820E-02	.1549E-01
15.	-.1387E-03	.4647E-02	.4459E-02	.1000E+01	-.2597E-02	.4442E-02	-.1387E-03	.4647E-02	.4459E-02	.2842E+00
20.	-.1671E-03	.4555E-02	.4101E-02	.1000E+01	-.3749E-02	.4327E-02	-.1671E-03	.4555E-02	.4101E-02	.7828E+00
25.	-.1953E-03	.4463E-02	.3743E-02	.1000E+01	-.6494E-02	.4212E-02	-.1953E-03	.4463E-02	.3743E-02	.1399E+01
30.	-.2222E-03	.4374E-02	.3397E-02	.1000E+01	-.8494E-02	.4103E-02	-.2222E-03	.4374E-02	.3397E-02	.2275E+01
35.	-.2480E-03	.4287E-02	.3060E-02	.1000E+01	-.1063E-01	.3997E-02	-.2480E-03	.4287E-02	.3060E-02	.3321E+01
40.	-.2713E-03	.4204E-02	.2745E-02	.1000E+01	-.1264E-01	.3900E-02	-.2713E-03	.4204E-02	.2745E-02	.4565E+01
45.	-.2924E-03	.4124E-02	.2447E-02	.1000E+01	-.1366E-01	.3811E-02	-.2924E-03	.4124E-02	.2447E-02	.5944E+01
50.	-.3101E-03	.4051E-02	.2179E-02	.1000E+01	-.1303E-01	.3733E-02	-.3101E-03	.4051E-02	.2179E-02	.7550E+01
55.	-.3243E-03	.3983E-02	.1940E-02	.1000E+01	-.1203E-01	.3668E-02	-.3243E-03	.3983E-02	.1940E-02	.9046E+01
60.	-.3341E-03	.3923E-02	.1738E-02	.1000E+01	-.1236E-01	.3616E-02	-.3341E-03	.3923E-02	.1738E-02	.1040E+02
65.	-.3394E-03	.3871E-02	.1574E-02	.1000E+01	-.1307E-01	.3585E-02	-.3394E-03	.3871E-02	.1574E-02	.1161E+02
70.	-.3392E-03	.3828E-02	.1457E-02	.1000E+01	-.1283E-01	.3570E-02	-.3392E-03	.3828E-02	.1457E-02	.1277E+02
75.	-.3319E-03	.3793E-02	.1381E-02	.1000E+01	-.1266E-01	.3573E-02	-.3319E-03	.3793E-02	.1381E-02	.1164E+02
80.	-.3115E-03	.3755E-02	.1331E-02	.1000E+01	-.1265E-01	.3587E-02	-.3115E-03	.3755E-02	.1331E-02	.1097E+02
85.	-.2705E-03	.3701E-02	.1282E-02	.1000E+01	-.1224E-01	.3601E-02	-.2705E-03	.3701E-02	.1282E-02	.9948E+01
90.	-.2030E-03	.3621E-02	.1212E-02	.1000E+01	-.1157E-01	.3607E-02	-.2030E-03	.3621E-02	.1212E-02	.8570E+01
95.	-.1046E-03	.3507E-02	.1104E-02	.1000E+01	-.1081E-01	.3602E-02	-.1046E-03	.3507E-02	.1104E-02	.7041E+01
100.	.1137E-04	.3379E-02	.9728E-03	.1000E+01	-.9997E-02	.3604E-02	.1137E-04	.3379E-02	.9728E-03	.5604E+01
105.	.1340E-03	.3255E-02	.8300E-03	.1000E+01	-.9302E-02	.3636E-02	.1340E-03	.3255E-02	.8300E-03	.4459E+01
110.	.2518E-03	.3147E-02	.6900E-03	.1000E+01	-.8709E-02	.3703E-02	.2518E-03	.3147E-02	.6900E-03	.3538E+01
115.	.4163E-03	.2942E-02	.5038E-03	.1000E+01	-.8116E-02	.3615E-02	.4163E-03	.2942E-02	.5038E-03	.2702E+01
120.	.5593E-03	.2782E-02	.3389E-03	.1000E+01	-.7417E-02	.3597E-02	.5593E-03	.2782E-02	.3389E-03	.2102E+01
125.	.6857E-03	.2658E-02	.1899E-03	.1000E+01	-.6676E-02	.3643E-02	.6857E-03	.2658E-02	.1899E-03	.1636E+01
130.	.7937E-03	.2573E-02	.5907E-04	.1000E+01	-.6114E-02	.3748E-02	.7937E-03	.2573E-02	.5907E-04	.1277E+01
135.	.8874E-03	.2519E-02	-.5817E-04	.1000E+01	-.5576E-02	.3908E-02	.8874E-03	.2519E-02	-.5817E-04	.9936E+00
140.	.9659E-03	.2496E-02	-.1603E-03	.1000E+01	-.5093E-02	.4117E-02	.9659E-03	.2496E-02	-.1603E-03	.7692E+00
145.	.1033E-02	.2500E-02	-.2512E-03	.1000E+01	-.4628E-02	.4372E-02	.1033E-02	.2500E-02	-.2512E-03	.6034E+00
150.	.1087E-02	.2529E-02	-.3300E-03	.1000E+01	-.4246E-02	.4664E-02	.1087E-02	.2529E-02	-.3300E-03	.4644E+00
155.	.1132E-02	.2579E-02	-.3999E-03	.1000E+01	-.3834E-02	.4996E-02	.1132E-02	.2579E-02	-.3999E-03	.3525E+00
160.	.1168E-02	.2647E-02	-.4606E-03	.1000E+01	-.3457E-02	.5353E-02	.1168E-02	.2647E-02	-.4606E-03	.2717E+00
165.	.1197E-02	.2729E-02	-.5137E-03	.1000E+01	-.3176E-02	.5731E-02	.1197E-02	.2729E-02	-.5137E-03	.1962E+00
170.	.1219E-02	.2820E-02	-.5596E-03	.1000E+01	-.2897E-02	.6113E-02	.1219E-02	.2820E-02	-.5596E-03	.1442E+00
175.	.1236E-02	.2915E-02	-.5999E-03	.1000E+01	-.2628E-02	.6495E-02	.1236E-02	.2915E-02	-.5999E-03	.1053E+00
180.	.1250E-02	.3014E-02	-.6365E-03	.1000E+01	-.2349E-02	.6876E-02	.1250E-02	.3014E-02	-.6365E-03	.7005E-01
185.	.1262E-02	.3112E-02	-.6701E-03	.1000E+01	-.2180E-02	.7240E-02	.1262E-02	.3112E-02	-.6701E-03	.4232E-01
190.	.1273E-02	.3209E-02	-.7021E-03	.1000E+01	-.1943E-02	.7609E-02	.1273E-02	.3209E-02	-.7021E-03	.2161E-01
195.	.1284E-02	.3301E-02	-.7328E-03	.1000E+01	-.1806E-02	.7955E-02	.1284E-02	.3301E-02	-.7328E-03	.2104E-01
200.	.1295E-02	.3390E-02	-.7637E-03	.1000E+01	-.1631E-02	.8293E-02	.1295E-02	.3390E-02	-.7637E-03	-.5212E-02
205.	.1307E-02	.3473E-02	-.7944E-03	.1000E+01	-.1424E-02	.8611E-02	.1307E-02	.3473E-02	-.7944E-03	-.1679E-01
210.	.1320E-02	.3548E-02	-.8258E-03	.1000E+01	-.1417E-02	.8913E-02	.1320E-02	.3548E-02	-.8258E-03	-.3075E-01

Table C1.   Measurement Matrix (continued)

TIME	M(13, 2)	M(13, 3)	M(13, 4)	M(13, 5)	M(13, 7)	M(13, 8)	M(13, 9)	M(13,10)	M(13,11)	M(13,12)
0.	-.1877E+01	0.	.5147E-01	.1517E+01	.7814E-01	.4069E+02	.1790E-02	.1171E+01	.2632E-01	.2560E+02
5.	-.1126E+02	.7064E-01	.5088E-01	.1500E+01	.1224E+00	.4091E+02	.1438E-02	.7666E+00	.6096E-01	.2338E+02
10.	-.2195E+02	.1406E+00	.6056E-01	.1527E+01	.1738E+00	.4083E+02	.9883E-04	.3339E+00	.9999E-01	.2031E+02
15.	-.3315E+02	.2075E+00	.8150E-01	.1539E+01	.2318E+00	.4061E+02	-.2322E-02	-.1326E+00	.1435E+00	.1729E+02
20.	-.4533E+02	.2710E+00	.1031E+00	.1546E+01	.2968E+00	.4034E+02	-.5873E-02	-.6073E+00	.1920E+00	.1431E+02
25.	-.5791E+02	.3283E+00	.1425E+00	.1522E+01	.3681E+00	.3993E+02	-.1078E-01	-.1087E+01	.2446E+00	.1151E+02
30.	-.7014E+02	.3781E+00	.1949E+00	.1491E+01	.4446E+00	.3943E+02	-.1717E-01	-.1550E+01	.3006E+00	.8954E+01
35.	-.8293E+02	.4169E+00	.2580E+00	.1432E+01	.5268E+00	.3882E+02	-.2540E-01	-.1990E+01	.3592E+00	.6663E+01
40.	-.9339E+02	.4502E+00	.3229E+00	.1343E+01	.6124E+00	.3815E+02	-.3557E-01	-.2385E+01	.4167E+00	.4888E+01
45.	-.1018E+03	.4705E+00	.3836E+00	.1227E+01	.7009E+00	.3751E+02	-.4802E-01	-.2727E+01	.4724E+00	.3543E+01
50.	-.1096E+03	.4813E+00	.4319E+00	.1112E+01	.7902E+00	.3690E+02	-.6263E-01	-.2998E+01	.5256E+00	.2570E+01
55.	-.1137E+03	.4863E+00	.4458E+00	.9710E+00	.8754E+00	.3644E+02	-.7919E-01	-.3193E+01	.5693E+00	.2168E+01
60.	-.1154E+03	.4711E+00	.4515E+00	.8400E+00	.9524E+00	.3627E+02	-.9673E-01	-.3303E+01	.6042E+00	.2200E+01
65.	-.1140E+03	.4712E+00	.4462E+00	.7144E+00	.1013E+01	.3649E+02	-.1139E+00	-.3329E+01	.6249E+00	.2703E+01
70.	-.1103E+03	.4607E+00	.4161E+00	.5884E+00	.1049E+01	.3740E+02	-.1286E+00	-.3302E+01	.6276E+00	.3874E+01
75.	-.1031E+03	.4057E+00	.3877E+00	.4773E+00	.1060E+01	.3899E+02	-.1398E+00	-.3246E+01	.6141E+00	.5500E+01
80.	-.9533E+02	.3614E+00	.3427E+00	.3722E+00	.1038E+01	.4140E+02	-.1453E+00	-.3090E+01	.5827E+00	.7545E+01
85.	-.8300E+02	.3115E+00	.2924E+00	.2809E+00	.9794E+00	.4450E+02	-.1440E+00	-.2784E+01	.5316E+00	.9868E+01
90.	-.6755E+02	.2465E+00	.2366E+00	.1974E+00	.8845E+00	.4815E+02	-.1349E+00	-.2265E+01	.4629E+00	.1222E+02
95.	-.5251E+02	.1872E+00	.1755E+00	.1361E+00	.7651E+00	.5209E+02	-.1192E+00	-.1369E+01	.3850E+00	.1413E+02
100.	-.3687E+02	.1348E+00	.1227E+00	.8672E-01	.6436E+00	.5642E+02	-.9918E-01	-.1996E+00	.3071E+00	.1567E+02
105.	-.2452E+02	.9025E-01	.8058E-01	.4993E-01	.5474E+00	.6051E+02	-.7991E-01	.1381E+01	.2447E+00	.1646E+02
110.	-.1427E+02	.5726E-01	.5199E-01	.3615E-01	.4721E+00	.6470E+02	-.6206E-01	.3170E+01	.1955E+00	.1692E+02
115.	-.5002E+01	.3707E-01	.4152E-01	.1685E-01	.3883E+00	.6665E+02	-.4724E-01	.5616E+01	.1487E+00	.1538E+02
120.	.1510E+01	.2135E-01	.1996E-01	.6413E-02	.3318E+00	.6910E+02	-.3399E-01	.8153E+01	.1155E+00	.1408E+02
125.	.6375E+01	.9735E-02	.1055E-01	.9982E-02	.2927E+00	.7232E+02	-.2203E-01	.1077E+02	.9074E-01	.1314E+02
130.	.1020E+02	.2037E-02	.5829E-02	.6113E-02	.2664E+00	.7633E+02	-.1155E-01	.1339E+02	.7274E-01	.1262E+02
135.	.1437E+02	-.4368E-02	.4287E-02	.4772E-02	.2498E+00	.8121E+02	-.2332E-02	.1605E+02	.5969E-01	.1246E+02
140.	.1778E+02	-.8508E-02	.2810E-02	.9943E-03	.2402E+00	.8703E+02	.5663E-02	.1863E+02	.5044E-01	.1274E+02
145.	.1966E+02	-.1100E-01	.4964E-02	.9346E-03	.2358E+00	.9357E+02	.1244E-01	.2122E+02	.4382E-01	.1338E+02
150.	.2239E+02	-.1290E-01	.2420E-02	.2196E-03	.2354E+00	.1009E+03	.1825E-01	.2369E+02	.3929E-01	.1438E+02
155.	.2589E+02	-.1361E-01	-.5851E-03	-.3247E-03	.2384E+00	.1090E+03	.2331E-01	.2610E+02	.3641E-01	.1569E+02
160.	.2811E+02	-.1379E-01	-.3377E-03	-.3764E-03	.2438E+00	.1177E+03	.2758E-01	.2851E+02	.3472E-01	.1725E+02
165.	.3057E+02	-.1399E-01	-.2558E-02	.4784E-03	.2510E+00	.1267E+03	.3123E-01	.3089E+02	.3393E-01	.1897E+02
170.	.3316E+02	-.1344E-01	-.1803E-02	.7846E-04	.2592E+00	.1358E+03	.3430E-01	.3311E+02	.3388E-01	.2078E+02
175.	.3565E+02	-.1282E-01	.3413E-02	.4524E-03	.2682E+00	.1450E+03	.3690E-01	.3522E+02	.3427E-01	.2270E+02
180.	.3810E+02	-.1240E-01	.7723E-03	.5132E-03	.2780E+00	.1542E+03	.3920E-01	.3738E+02	.3496E-01	.2455E+02
185.	.4164E+02	-.1174E-01	-.1885E-02	-.6089E-04	.2878E+00	.1631E+03	.4122E-01	.3939E+02	.3590E-01	.2640E+02
190.	.4368E+02	-.1105E-01	.3734E-02	-.1824E-03	.2974E+00	.1720E+03	.4302E-01	.4134E+02	.3693E-01	.2825E+02
195.	.4558E+02	-.1027E-01	-.3621E-02	.1963E-03	.3070E+00	.1806E+03	.4467E-01	.4331E+02	.3797E-01	.2995E+02
200.	.4866E+02	-.9568E-02	-.5132E-02	-.2858E-03	.3166E+00	.1892E+03	.4623E-01	.4533E+02	.3904E-01	.3164E+02
205.	.5541E+02	-.8756E-02	-.1705E-02	.4946E-03	.3259E+00	.1973E+03	.4770E-01	.4729E+02	.4006E-01	.3318E+02
210.	.5533E+02	-.7936E-02	-.4110E-02	.1244E-03	.3346E+00	.2050E+03	.4910E-01	.4929E+02	.4099E-01	.3456E+02

Table C1. Measurement Matrix (concluded)

TIME	M(13,13)	M(13,14)	M(13,15)	M(13,16)	M(13,17)	M(13,19)
0.	.1050E+00	.1297E+03	-.5262E+01	.3312E+03	0.	-.5789E-01
5.	.1035E+00	.1181E+03	-.5647E+01	.3596E+03	-.2187E-01	-.1106E+00
10.	.9704E-01	.1062E+03	-.5969E+01	.3965E+03	-.9738E-01	-.1116E+00
15.	.8474E-01	.9399E+02	-.6360E+01	.4207E+03	-.2437E+00	-.1113E+00
20.	.6649E-01	.8173E+02	-.6818E+01	.4306E+03	-.4853E+00	-.1151E+00
25.	.4201E-01	.6919E+02	-.7245E+01	.4738E+03	-.8200E+00	-.1202E+00
30.	.1218E-01	.5673E+02	-.7672E+01	.5082E+03	-.1267E+01	-.1264E+00
35.	-.2250E-01	.4409E+02	-.8146E+01	.5455E+03	-.1846E+01	-.1366E+00
40.	-.6013E-01	.3167E+02	-.8514E+01	.5788E+03	-.2491E+01	-.1428E+00
45.	-.9957E-01	.1932E+02	-.8808E+01	.6148E+03	-.3184E+01	-.1573E+00
50.	-.1396E+00	.7486E+01	-.9645E+01	.6547E+03	-.4144E+01	-.1792E+00
55.	-.1757E+00	-.3850E+01	-.1002E+02	.6913E+03	-.5019E+01	-.2024E+00
60.	-.2084E+00	-.1420E+02	-.1060E+02	.7250E+03	-.5815E+01	-.2303E+00
65.	-.2347E+00	-.2364E+02	-.1130E+02	.7576E+03	-.5357E+01	-.2639E+00
70.	-.2529E+00	-.3174E+02	-.1197E+02	.7844E+03	-.6876E+01	-.3203E+00
75.	-.2627E+00	-.3866E+02	-.1283E+02	.8095E+03	-.7890E+01	-.2361E+00
80.	-.2627E+00	-.4482E+02	-.1376E+02	.8294E+03	-.8902E+01	-.1811E+00
85.	-.2518E+00	-.5106E+02	-.1452E+02	.8456E+03	-.1255E+02	-.1228E+00
90.	-.2304E+00	-.5793E+02	-.1597E+02	.8421E+03	-.1357E+02	-.7288E-01
95.	-.2024E+00	-.6585E+02	-.1757E+02	.8310E+03	-.1016E+02	-.4440E-01
100.	-.1770E+00	-.7502E+02	-.1905E+02	.8048E+03	-.6487E+01	-.2729E-01
105.	-.1627E+00	-.8622E+02	-.2071E+02	.7798E+03	-.4769E+01	-.1674E-01
110.	-.1578E+00	-.9929E+02	-.2250E+02	.7504E+03	-.4405E+01	-.1006E-01
115.	-.1318E+00	-.1033E+03	-.2385E+02	.6881E+03	-.4198E+01	-.5936E-02
120.	-.1219E+00	-.1110E+03	-.2584E+02	.6459E+03	-.3496E+01	-.3592E-02
125.	-.1227E+00	-.1223E+03	-.2764E+02	.6093E+03	-.2421E+01	-.2119E-02
130.	-.1311E+00	-.1373E+03	-.2961E+02	.5869E+03	-.1358E+01	-.1288E-02
135.	-.1448E+00	-.1563E+03	-.3213E+02	.5685E+03	-.7310E+00	-.7537E-03
140.	-.1616E+00	-.1788E+03	-.3444E+02	.5587E+03	-.4773E+00	-.4159E-03
145.	-.1814E+00	-.2056E+03	-.3677E+02	.5567E+03	-.4287E+00	-.2149E-03
150.	-.2027E+00	-.2358E+03	-.3945E+02	.5597E+03	-.4266E+00	-.8354E-04
155.	-.2259E+00	-.2704E+03	-.4210E+02	.5666E+03	-.4160E+00	-.1627E-04
160.	-.2504E+00	-.3086E+03	-.4515E+02	.5757E+03	-.3905E+00	.1903E-04
165.	-.2755E+00	-.3499E+03	-.4646E+02	.5592E+03	-.3426E+00	.3915E-04
170.	-.3006E+00	-.3930E+03	-.5038E+02	.5460E+03	-.3230E+00	.4132E-04
175.	-.3256E+00	-.4379E+03	-.5267E+02	.5352E+03	-.3112E+00	.3858E-04
180.	-.3510E+00	-.4843E+03	-.5433E+02	.5194E+03	-.2831E+00	.3568E-04
185.	-.3758E+00	-.5314E+03	-.5838E+02	.5027E+03	-.2827E+00	.3044E-04
190.	-.4004E+00	-.5788E+03	-.6084E+02	.5029E+03	-.2432E+00	.2525E-04
195.	-.4240E+00	-.6261E+03	-.6415E+02	.4850E+03	-.1783E+00	.1965E-04
200.	-.4473E+00	-.6738E+03	-.6587E+02	.4708E+03	-.2544E+00	.1444E-04
205.	-.4698E+00	-.7207E+03	-.6948E+02	.4564E+03	-.2759E+00	.9534E-05
210.	-.4910E+00	-.7658E+03	-.7200E+02	.4440E+03	-.2399E+00	.5196E-05
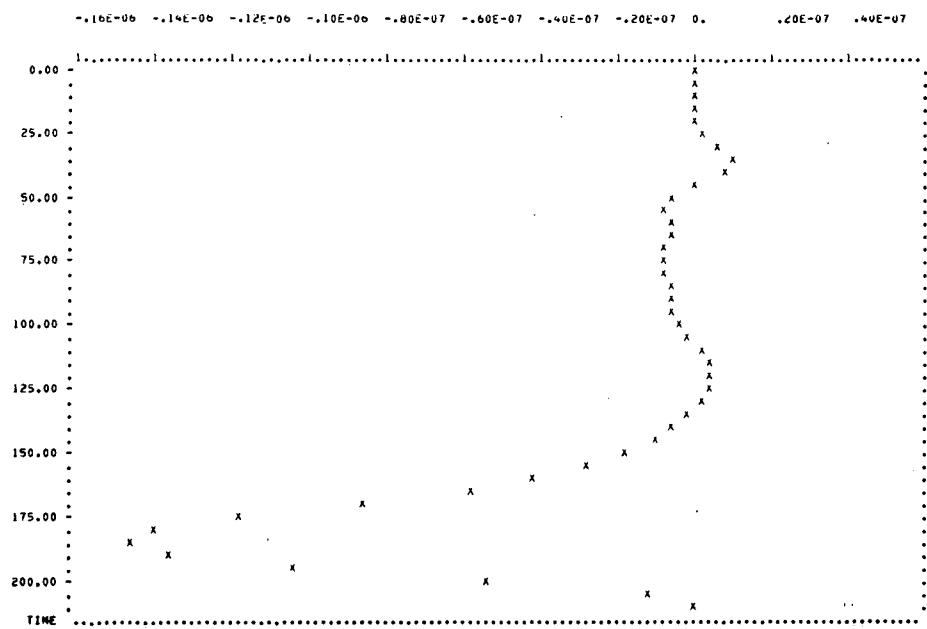
Figure C1. Graph of KV (1, 4) versus Time
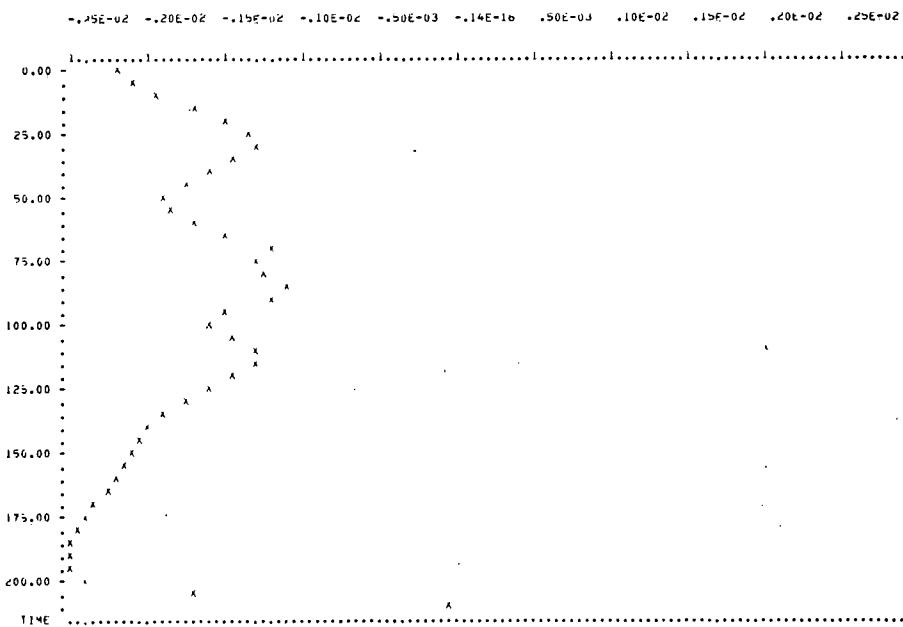
Figure C2. Graph of KV (1, 5) versus Time
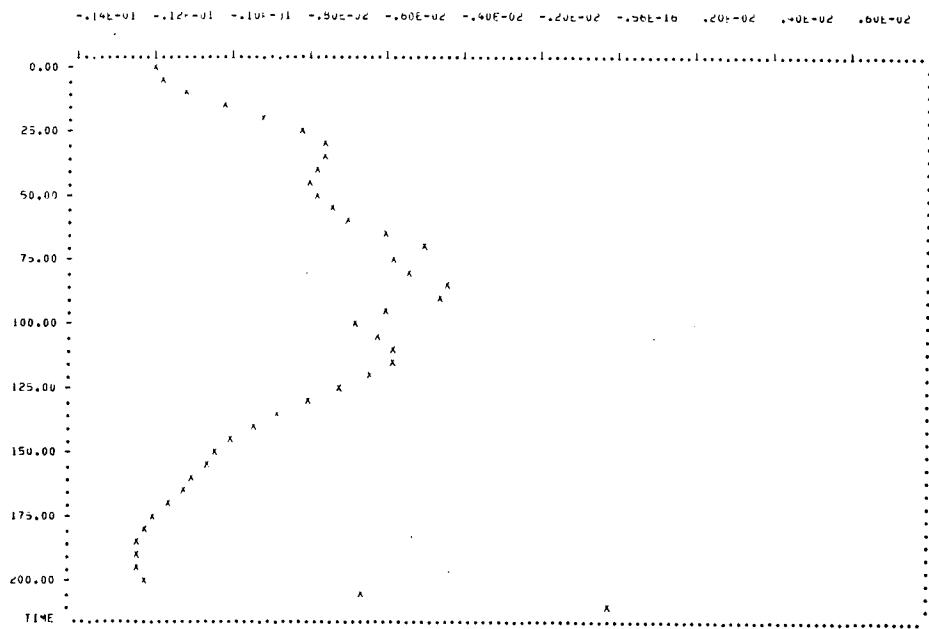
Figure C3.   Graph of KV (1,6) versus Time
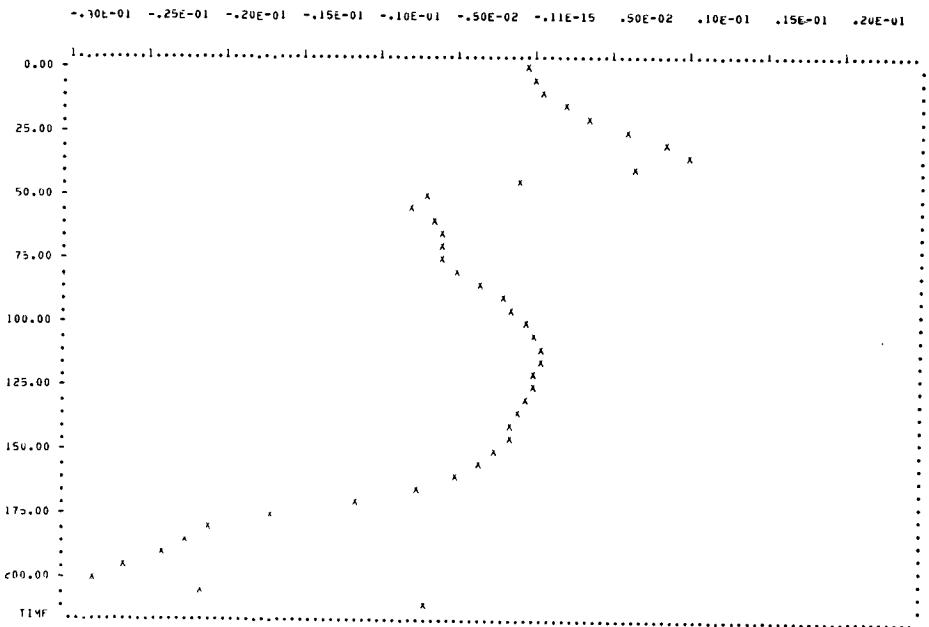
Figure C4.   Graph of KV (1,7) versus Time
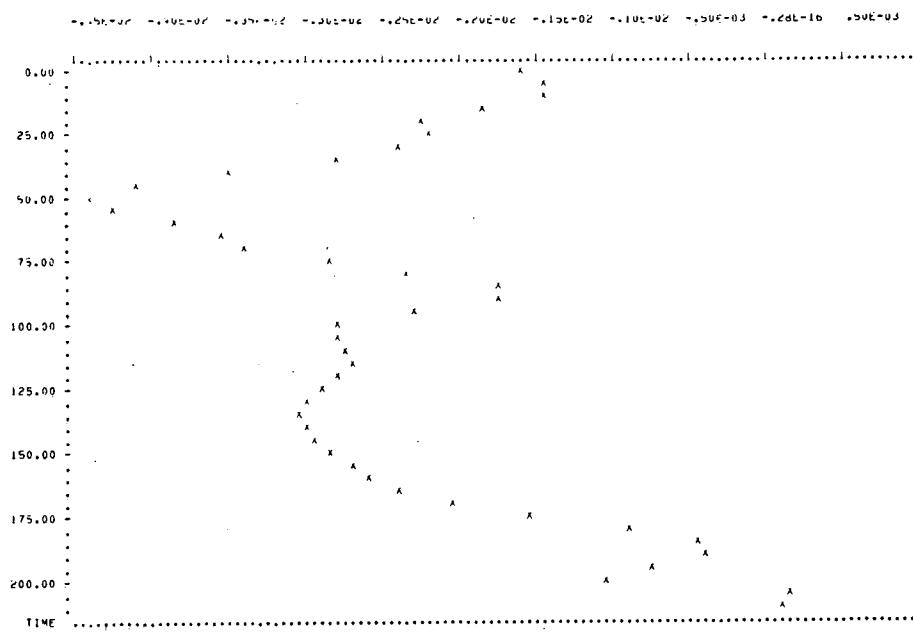
Figure C5.   Graph of KV (1, 8) versus Time
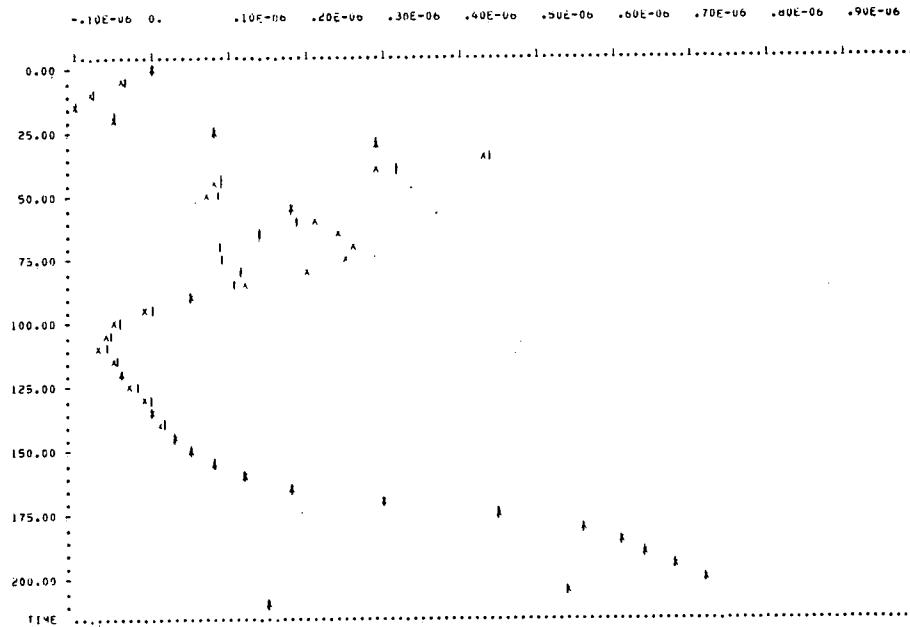
Figure C6.   Graph of KV (1, 9) versus Time
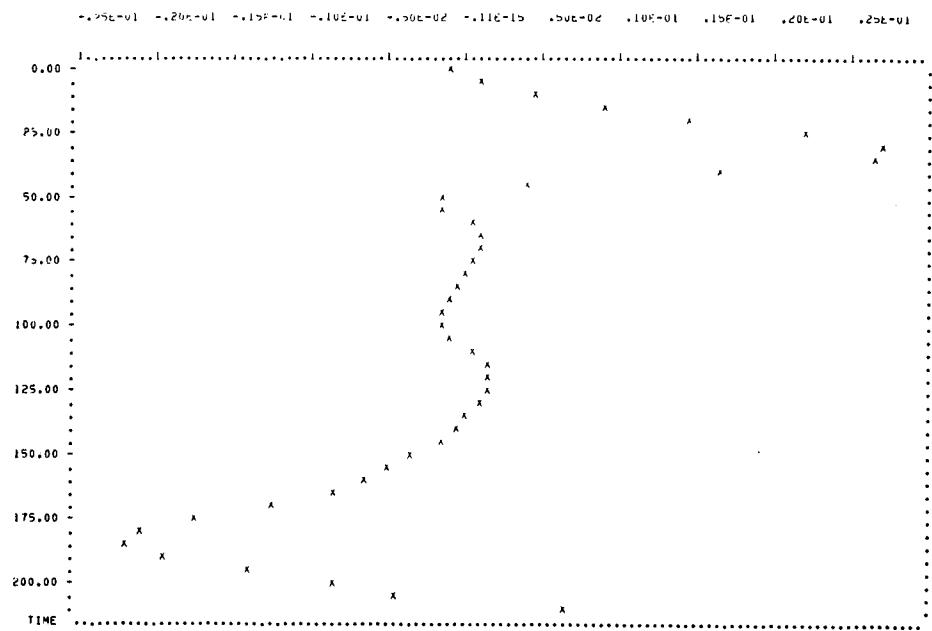
Figure C7.   Graph of KV (1, 10) versus Time
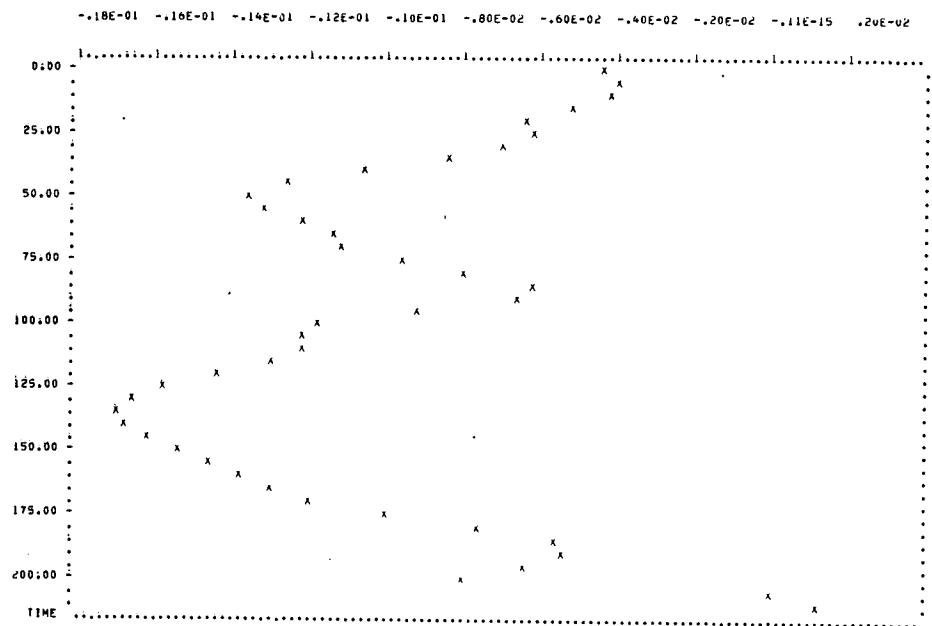
Figure C8.   Graph of KV (1, 11) versus Time
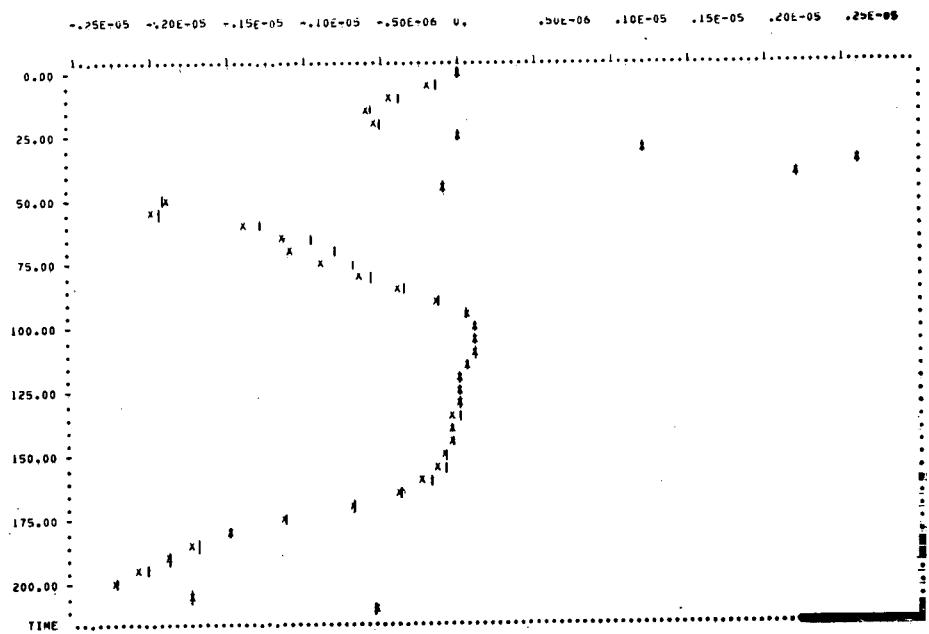
Figure C9. Graph of KV (1,12) versus Time
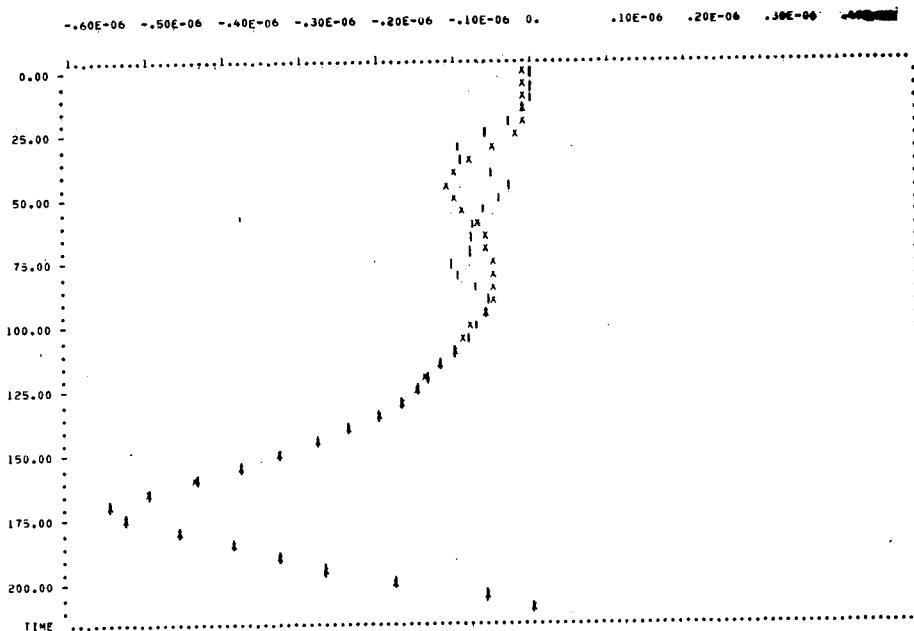
Figure C10. Graph of KV (2,4) versus Time
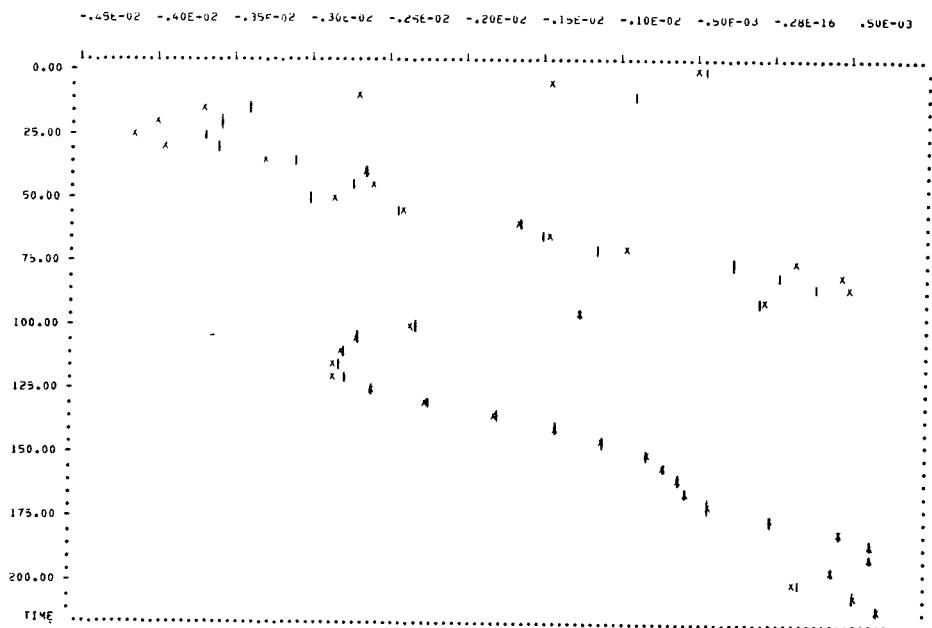
Figure C11.   Graph of KV (2,5) versus Time
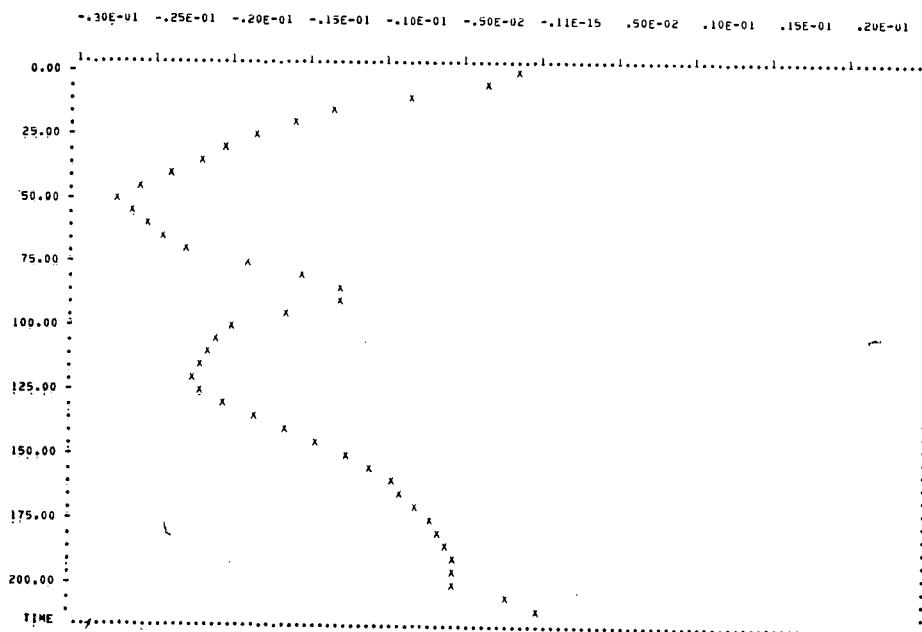
Figure 12.   Graph of KV (2,6) versus Time

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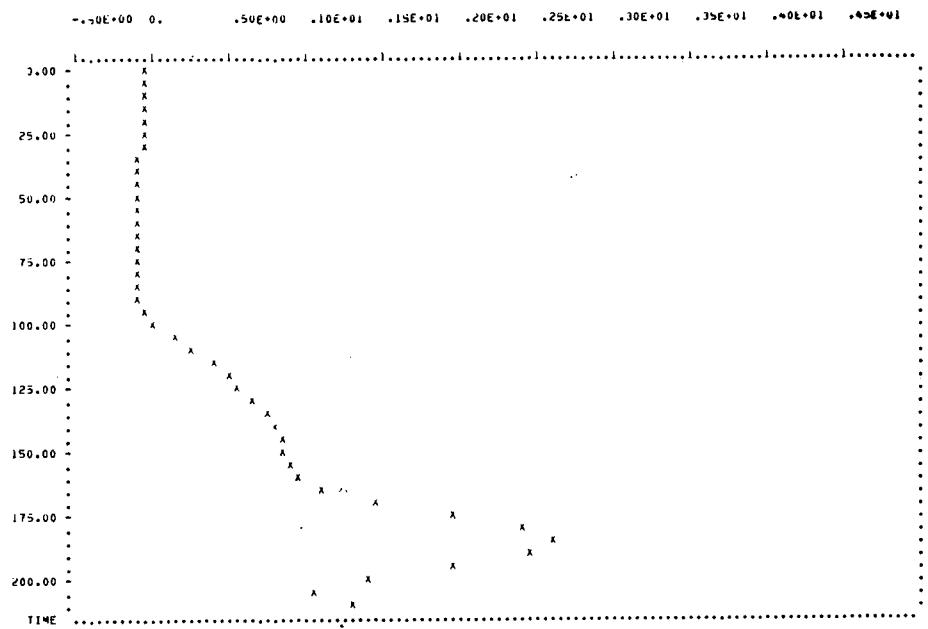
Figure C13.   Graph of KV (2,7) versus Time
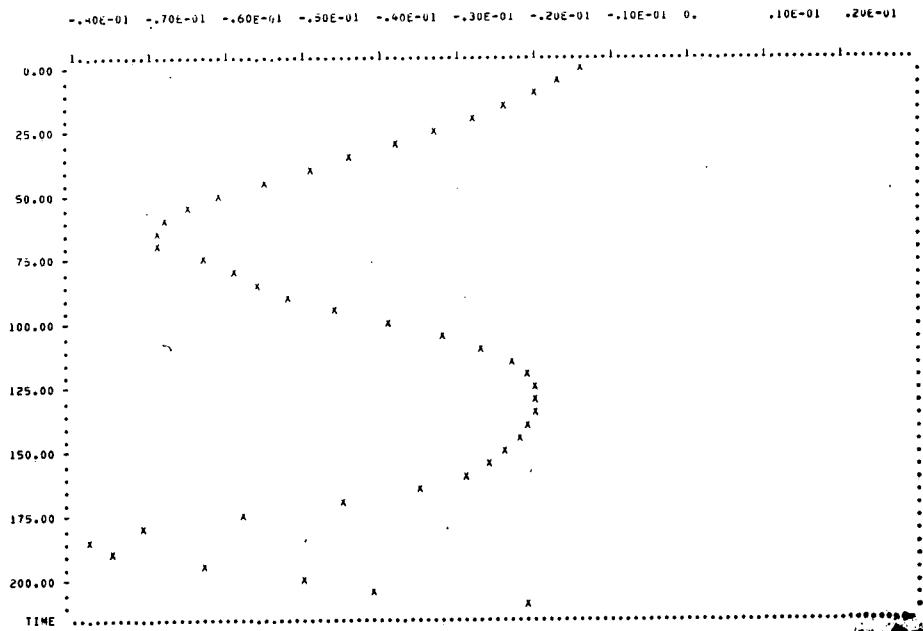
Figure C14.   Graph of KV (2,8) versus Time

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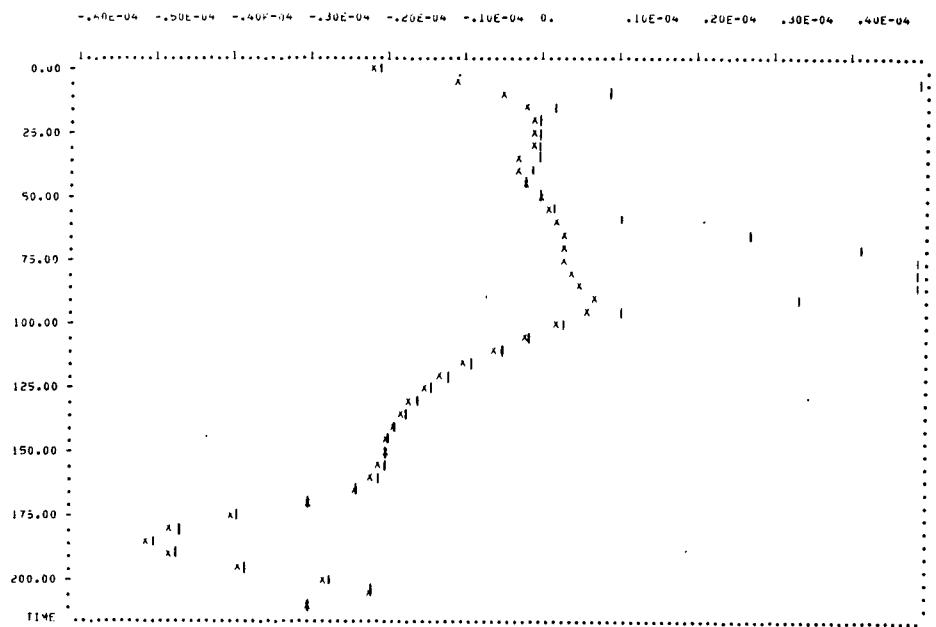
Figure C15.   Graph of KV (2,9) versus Time
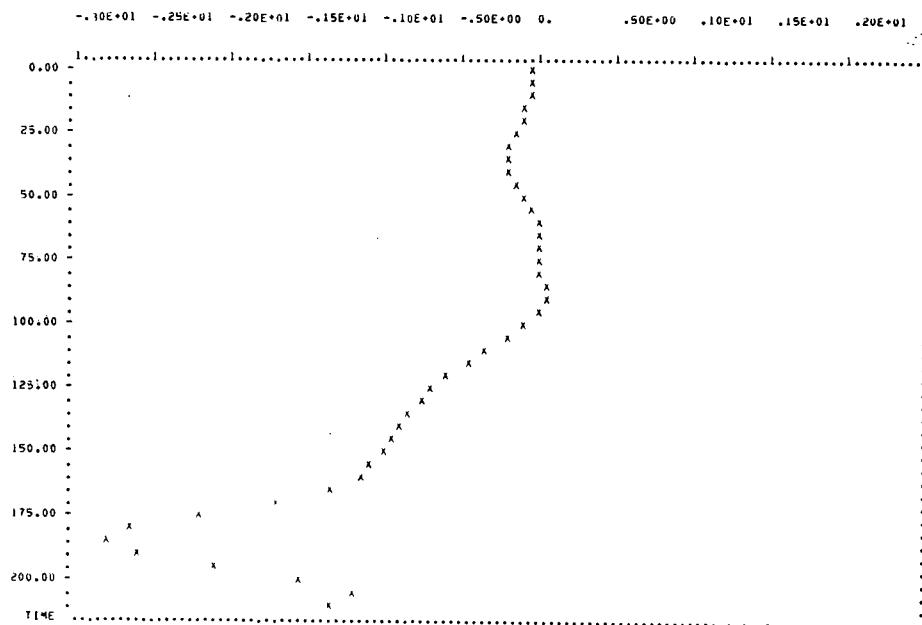
Figure C16.   Graph of KV (2,10) versus Time
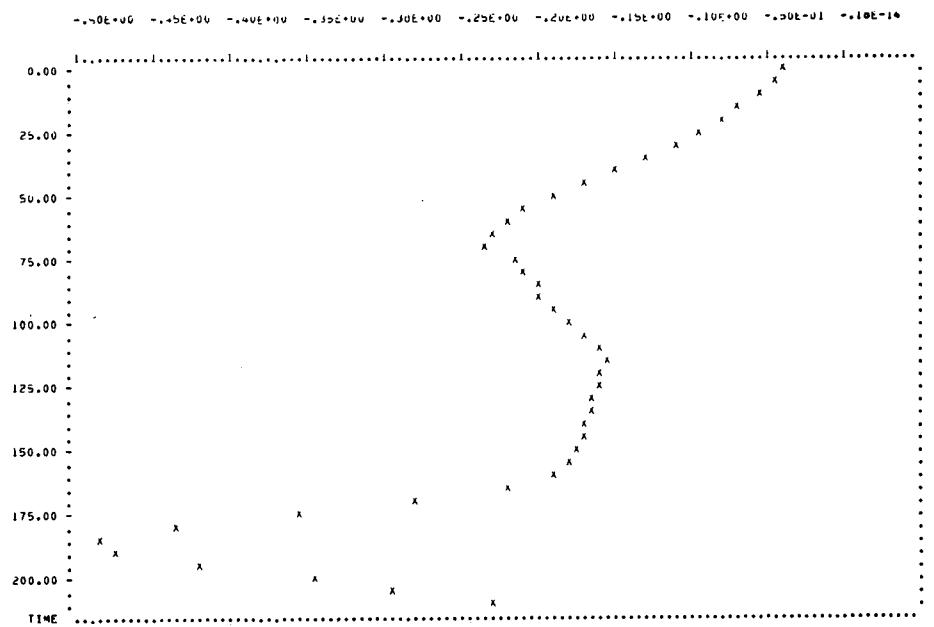
Figure C17.   Graph of KV (2,11) versus Time
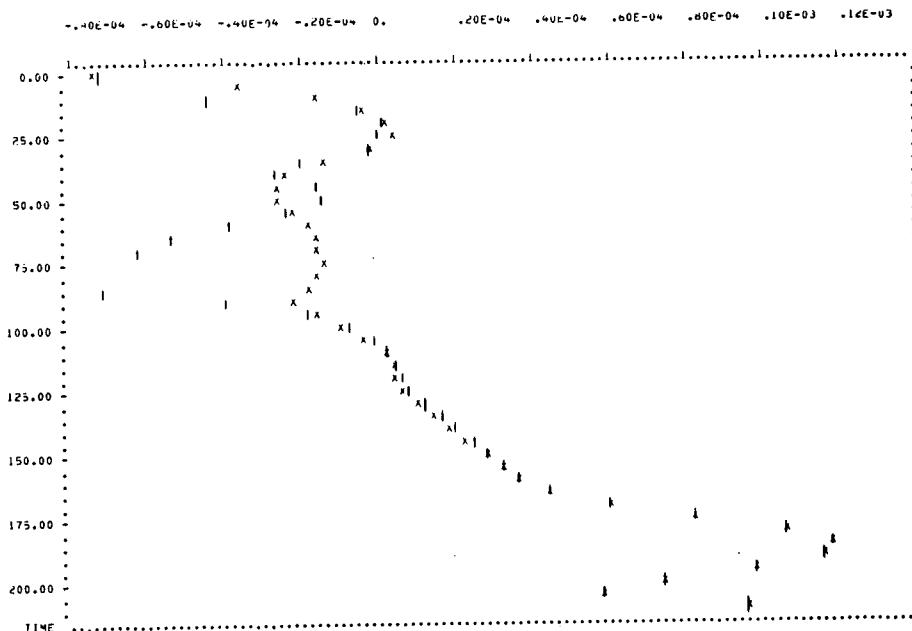
Figure C18.   Graph of KV (2,12) versus Time
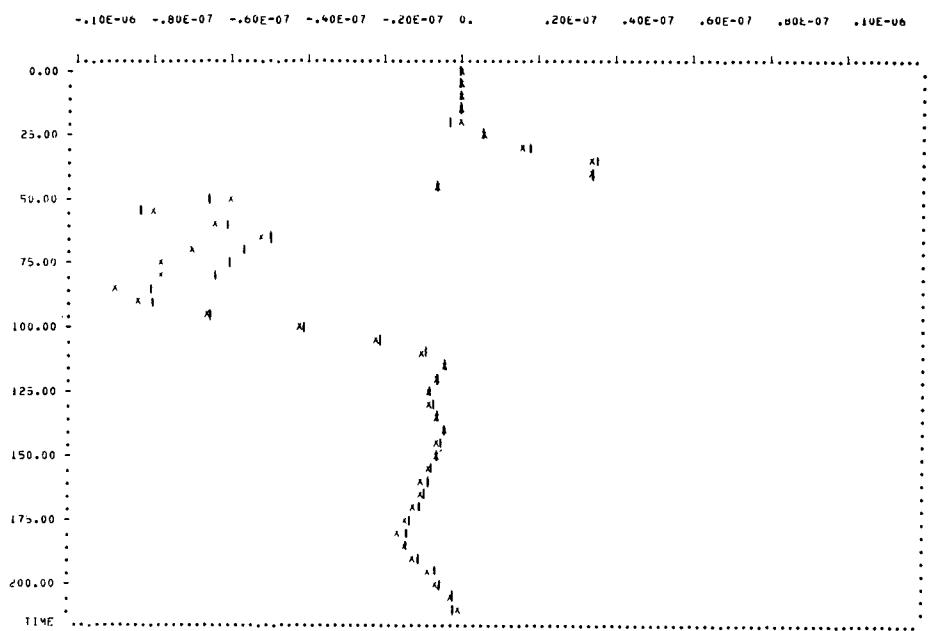
Figure C19. Graph of KV (3,4) versus Time
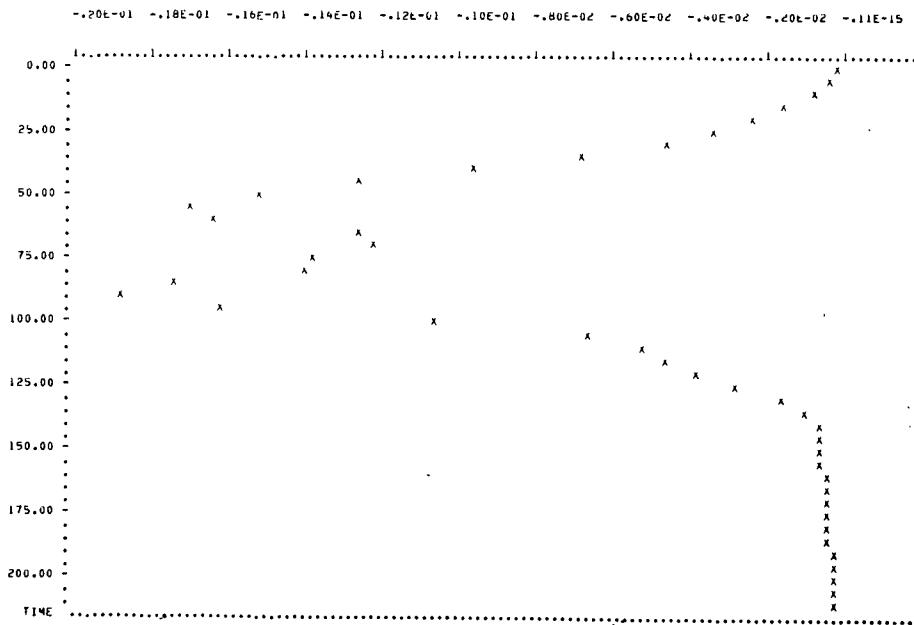
Figure C20. Graph of KV (3,5) versus Time

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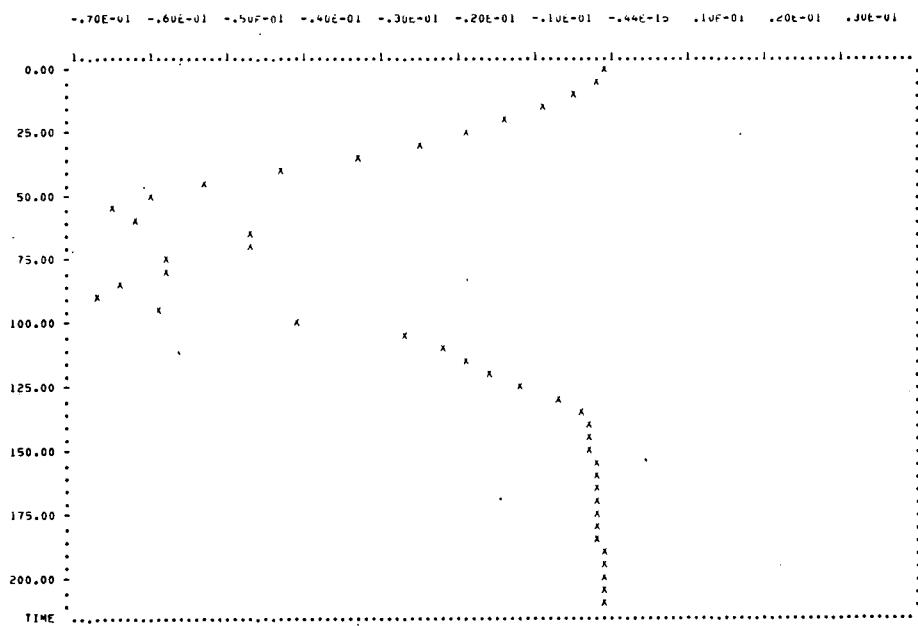
Figure C21.   Graph of KV (3,6) versus Time
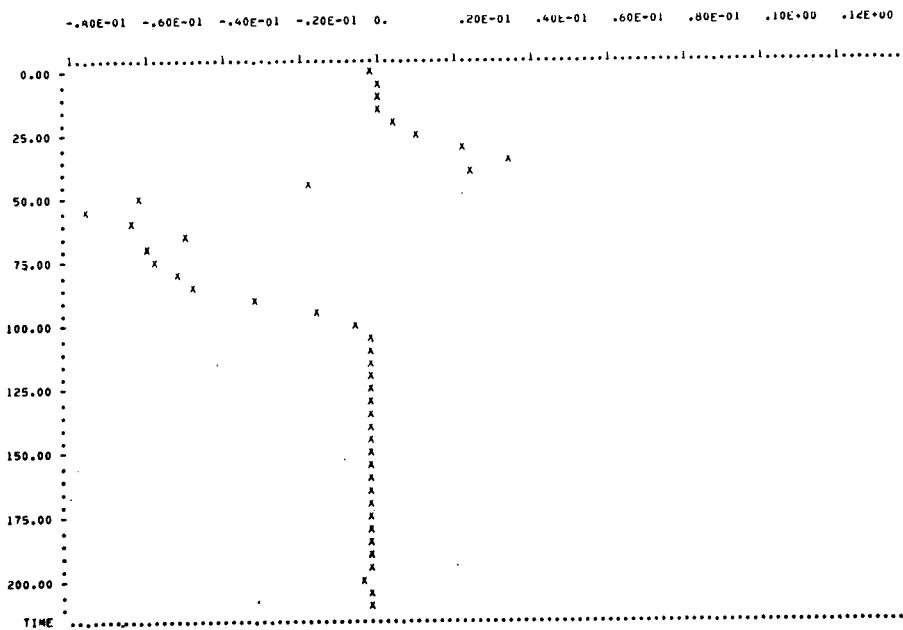
Figure C22.   Graph of KV (3,7) versus Time
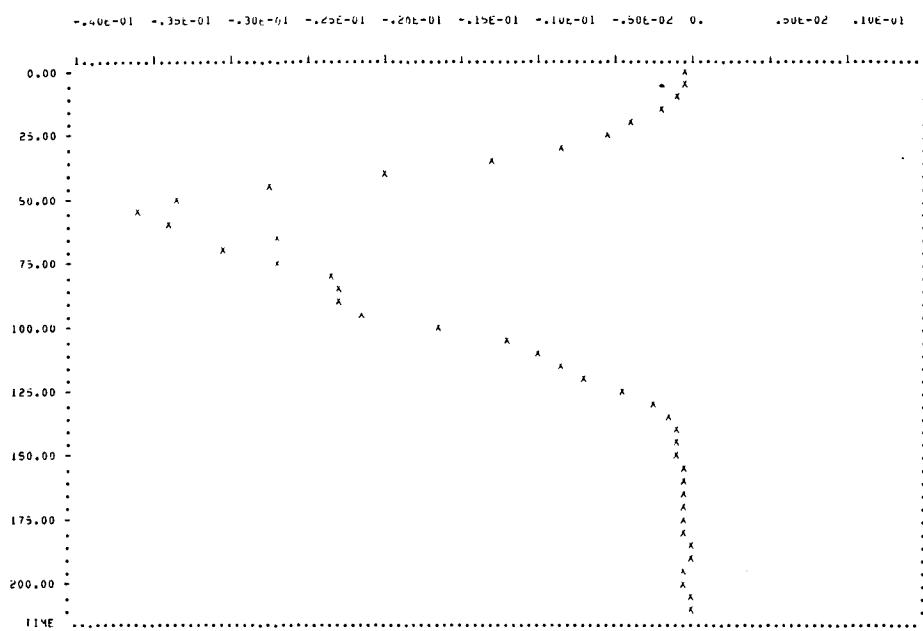
Figure C23. Graph of KV (3, 8) versus Time
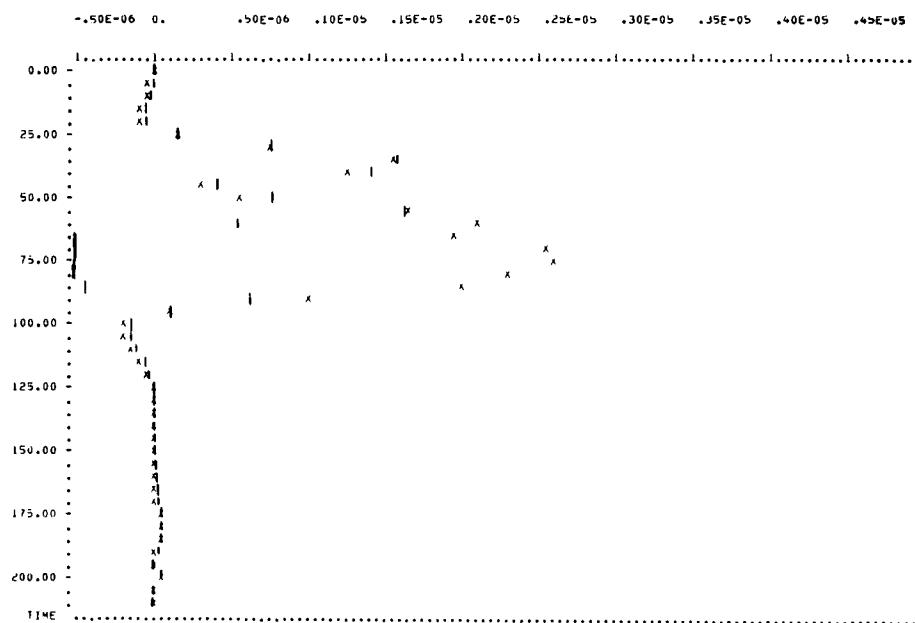
Figure C24. Graph of KV (3, 9) versus Time
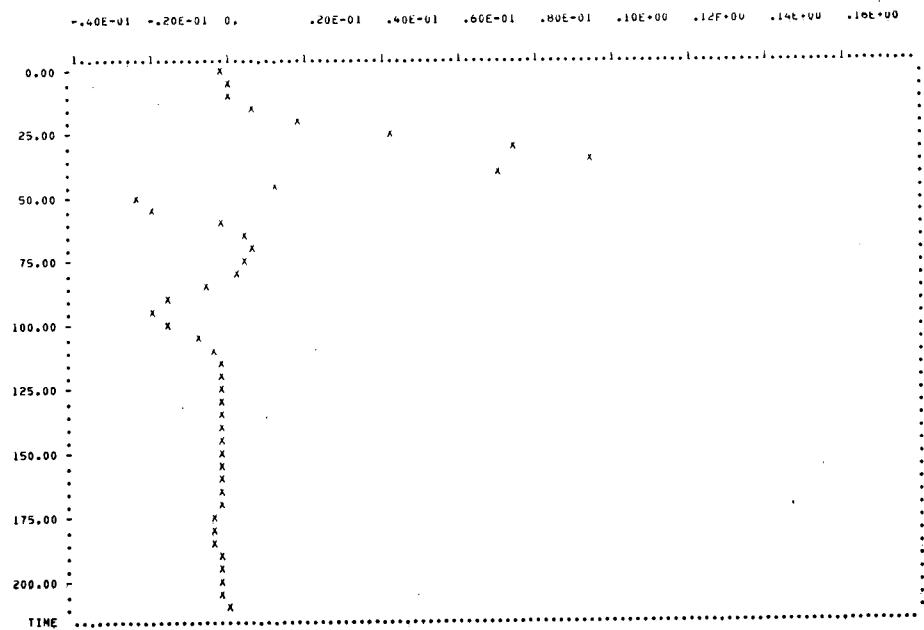
Figure C25. Graph of KV (3,10) versus Time
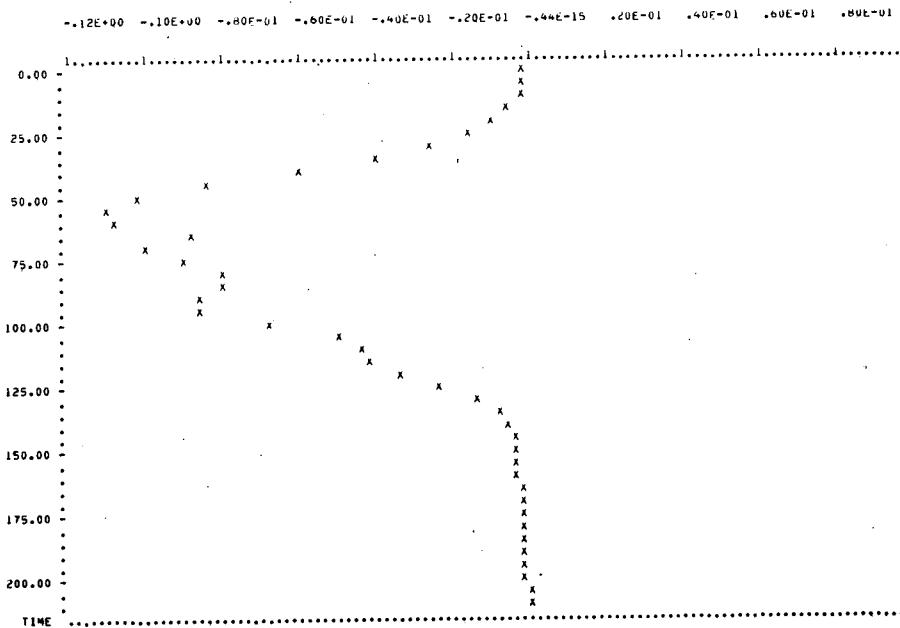
Figure C26. Graph of KV (3,11) versus Time

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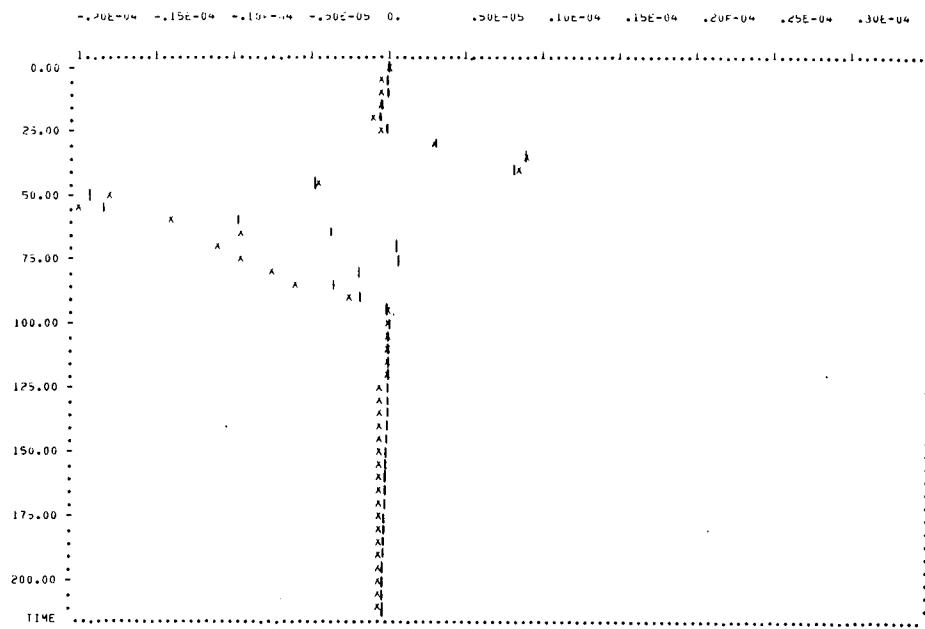
Figure C27. Graph of KV (3,12) versus Time
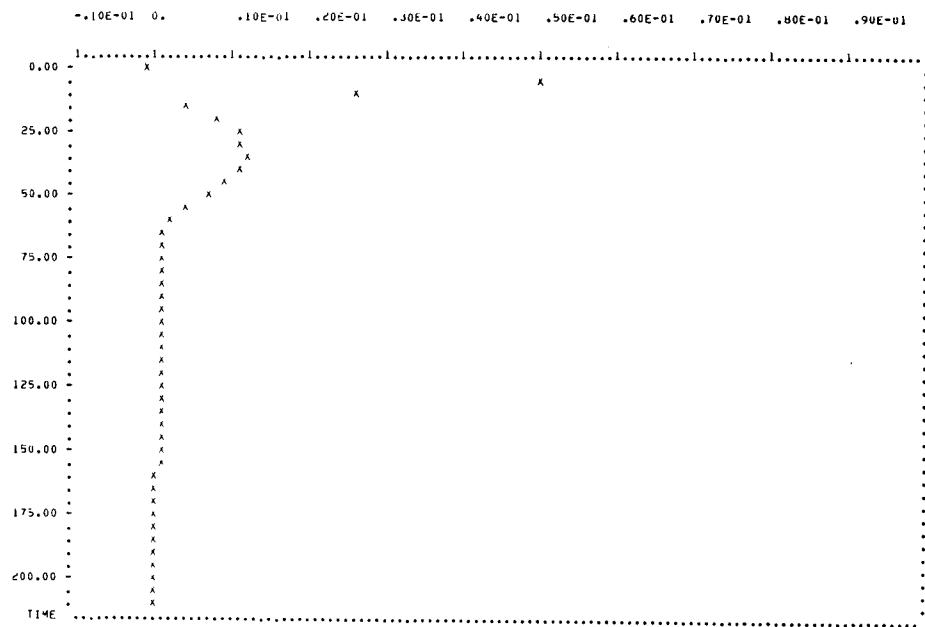
Figure C28. Graph of ϕ versus Time

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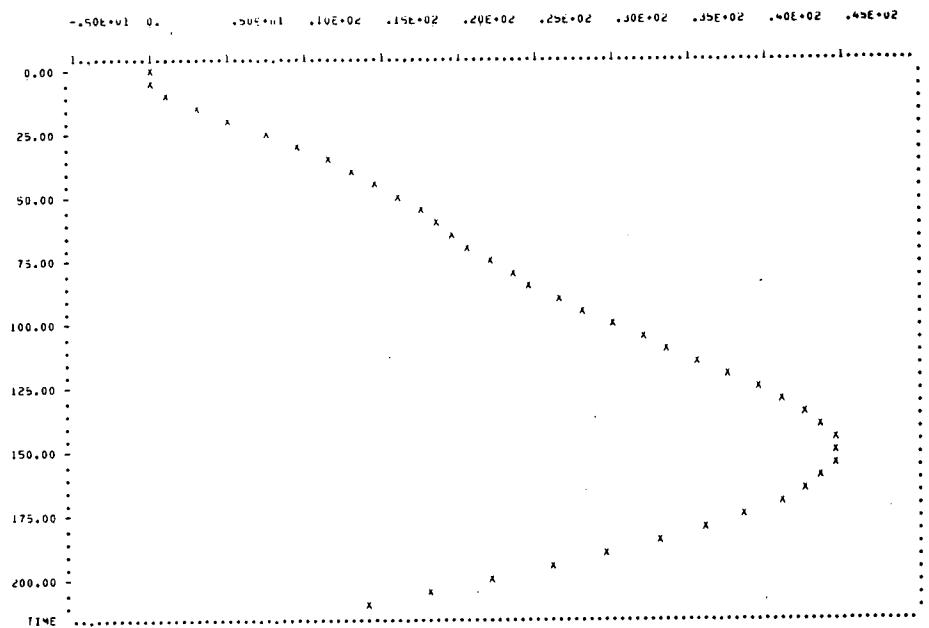
Figure C29. Graph of y versus Time
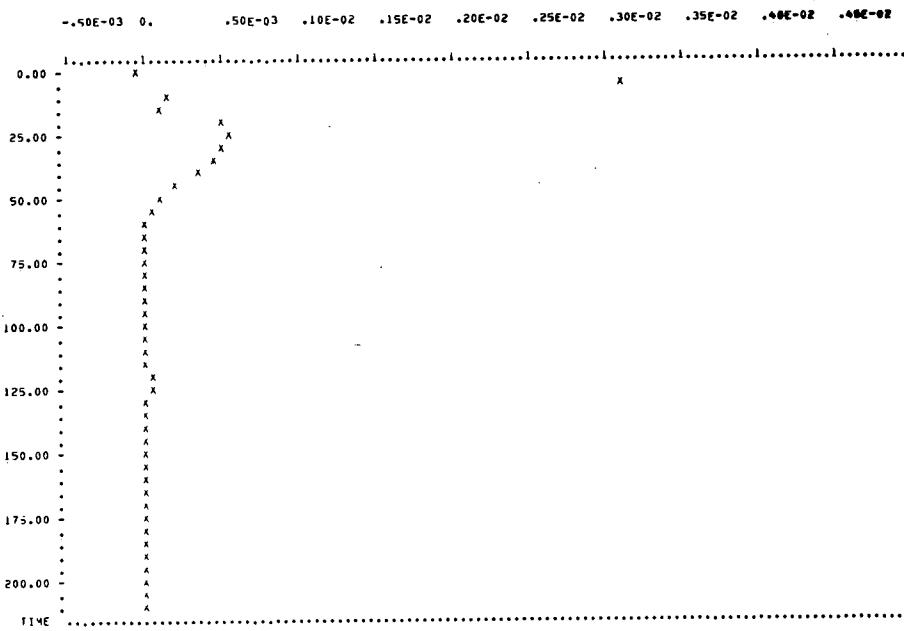
Figure C30. Graph of δp versus Time
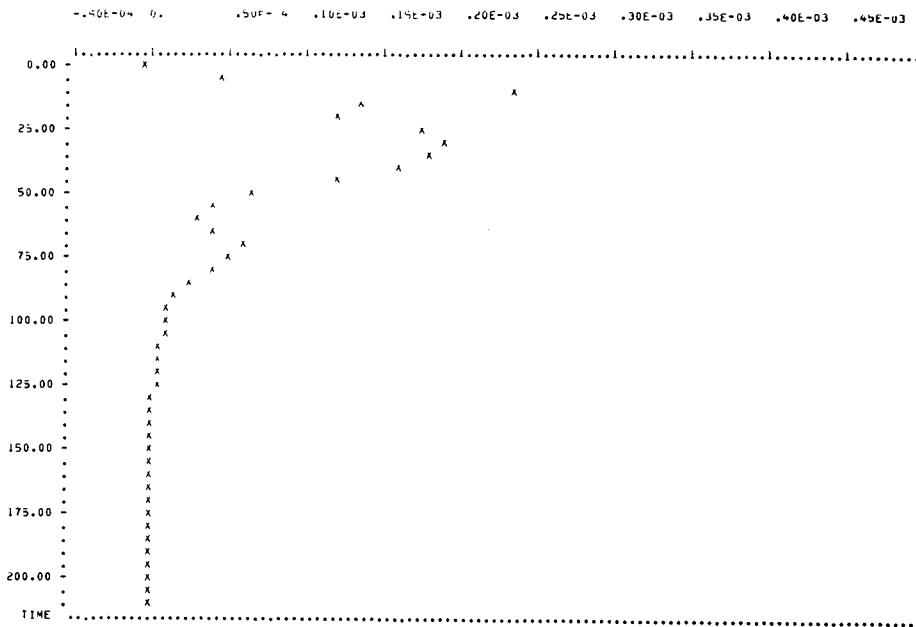
Figure C31.   Graph of δr versus Time
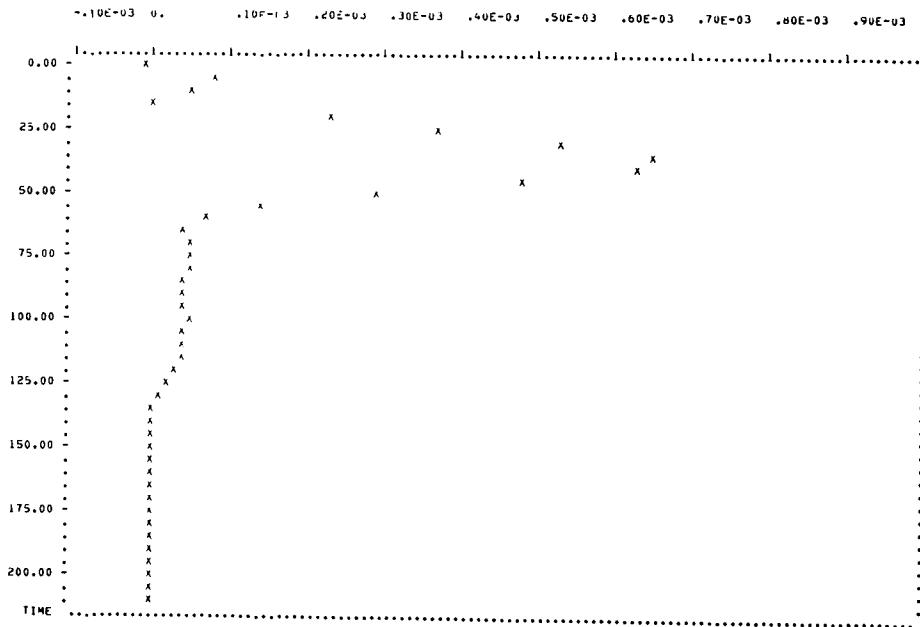
Figure C32.   Graph of δa versus Time
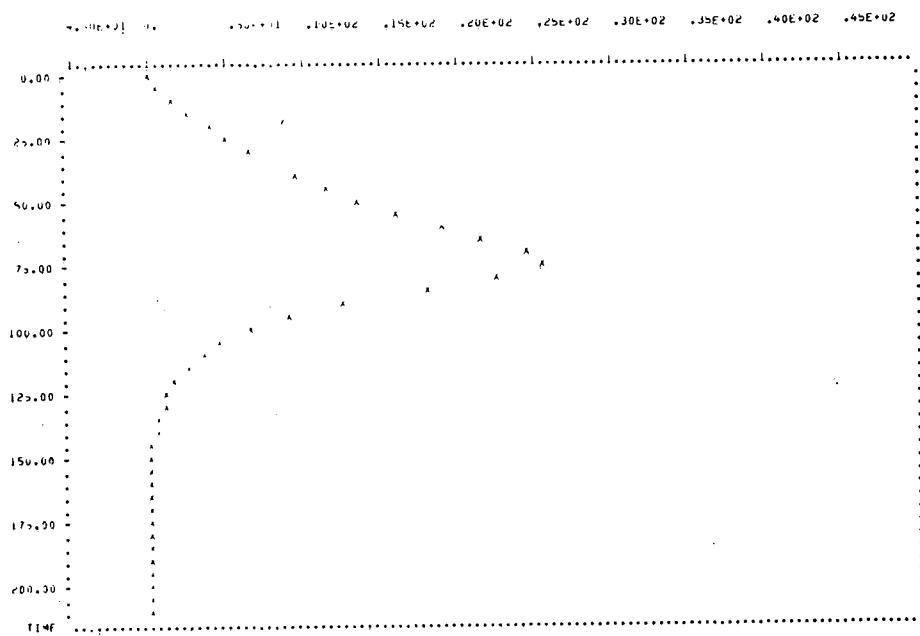
Figure C33. Graph of $\bar{q}\beta$ versus Time
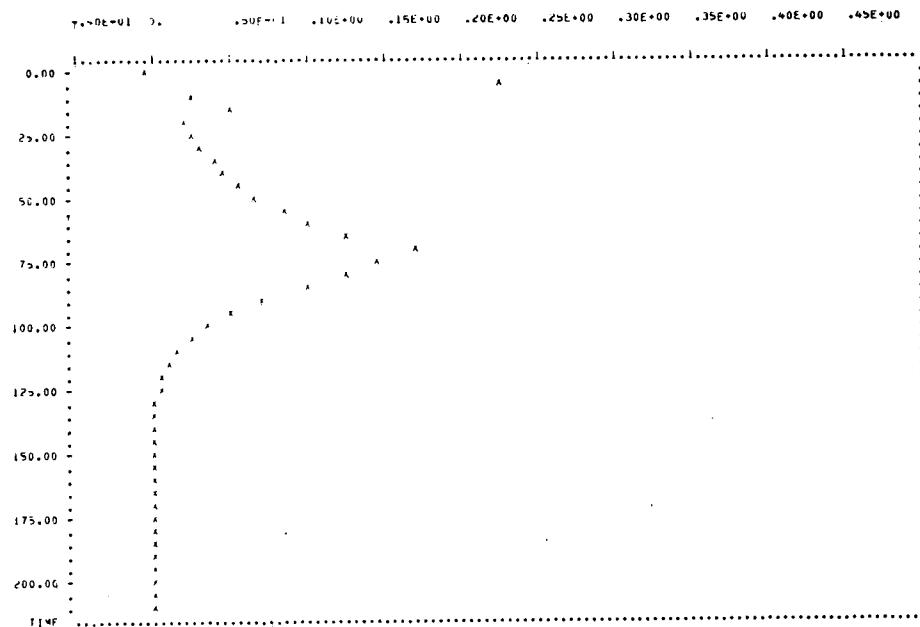
Figure C34. Graph of a_y versus Time

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