Date: 4/4/77

Project Title: "Human Operator Control Strategy Model".

Project No: A-1979 (G-42-625/Psych/Ronan is sub-project.)

Project Director: Ms. E. L. ~~Burks~~ Davenport

Sponsor: Aeronautical Systems Division, Wright-Patterson AFB, Ohio 45433

Agreement Period: From ____4/1/77____   Until ~~5/31/78~~

Type Agreement: Contract No. F33615-77-C-0042

Amount: $63,778. (Partially funded at $30,000 through 9/30/77)   A-1979-000 $20,
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                                                                                    $30,(

Reports Required: R & D Status Reports, Cost & Performance Reports,
                    Final Technical Report.

Sponsor Contact Person (s):

        Technical Matters   Contractual Matters
                                                            (thru OCA)

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                                            Atlanta, Ga. 30332

                                                                    DD 250

Defense Priority Rating: D0-C9 under DMS Reg. 1

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CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 1/21/81

Project Title: "Human Operator Control Strategy Model"

Project No: A-1979

Project Director: Ms. E. L. Burks

Sponsor: Davenport &Green

Aeronautical Systems Division, Wright-Patterson AFB, Ohio 45433

Effective Termination Date: 10/31/80

Clearance of Accounting Charges: 10/31/80

Grant/Contract Closeout Actions Remaining:

- **X** Final Invoice and Closing Documents
- _ Final Fiscal Report
- **X** Final Report of Inventions
- **X** Govt. Property Inventory & Related Certificate
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CA—4 (1/79)

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

October 17, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Technical Memorandum
A-1979-000-11

TO: A-1979 File
FROM: Lee Burks
SUBJECT: Validation Experiment

INTRODUCTION

The experiments to be carried out in the initial attempt at validation of the model HOPE are described in this document. The HOPE (Human Operator Performance Emulator) is a computer simulation of the cognitive processes involved in psychomotor skill learning. The processes modelled include: perception of the task to be done now and of a preview of the future, association of control actions and their consequences, storing of these associations in long-term memory, prediction of the results of action taken, the generation and execution of sequences of motor commands, evaluation of actual and predicted performance, evaluation of prediction accuracy, and attention allocation. The task modelled is a one-dimensional preview tracking task. The model's control strategy is determined by parameters which control attention allocation and control patterns. Parameters include allowable error, minimum number of commands developed before the operator can leave the primary task, the degree of importance attached to new information, the degree of aggressiveness shown by the operator in new situations and the length of time over which one motor command is active. At present these quantities are not functions of external or internal events. They are parameters in the program which will be identified for each subject in the experiment. It is intended in follow-on efforts to correlate these parameters with variables like task difficulty, recent error rate, or even personality or ability variables.

The basic task for this set of validation experiments is a one-dimensional preview tracking task presented to the subject on digitally-refreshed graphics display. The track scrolls down from the top of the screen. The subject controls a cursor visible at the bottom of the screen. Control is in the horizontal dimension only.

Control is by means of a low friction, isotonic stick, with seven bits of position output--128 possible positions. Our simulation does not include the learning of the position of the control itself; rather, perfect perception of that position is assumed. Pre-training with the stick alone will be given to ensure subjects' knowledge of its position.

The relationship between stick motion and cursor position is called control or plant dynamics. The relationship embodies the characteristics of the vehicle being controlled. Because an important aspect of our model is learning of the characteristics of the plant being controlled, we wish to equate our subjects with respect to this type of learning. For this reason the controlled - element dynamics will be nonlinear--specifically, the element will be more responsive when the stick is near the middle of its travel than when it is near the extremes. Furthermore, the nonlinearity will be assymetric across the travel of the stick.

Identification of the subjects' control strategies will be made on the basis of the statistic MASE -- mean absolute state error. This statistic is based on the difference between subject's control stick output and the output of the model, and is computed as the sum of the absolute values of the instantaneous differences between position, first derivative, and second derivative of the two outputs.

Models which produce small MASE in a given interval will be considered 'matches'. "Small" is defined as a MASE value of no more than twenty percent of the possible range of motion of the stick.

The hypotheses to be tested in this initial set of experiments are discussed below. They are, in general, statements about control strategy as a concept, and are designed to test various aspects of this idea, with respect to its utility for use in simulation research.

HYPOTHESES

1.	The HOPE model matches human control output at better than chance level. There exist engineering models with time-varying coefficients, which produce excellent matches of human output. Even though our 'logic' model is in an embryonic stage, it is important that we demonstrate at least some degree of feasibility for the approach.

2.	Control strategy will be time-varying during the course of learning. The control strategy concept, if it is to be ultimately useful as we have defined it, should show changes during the course of learning. A qualitative analysis comparing the pattern of changes across time between individuals is important for assessment of the degree of individual differences to be expected among trainees. If the control strategy time variations for subjects in the same experimental conditions are more alike than are the variations for subjects in different experimental conditions, some evidence in favor of our assumption that control strategies are environmentally determined will be attained. The emphasis here is on the time variation of parameters. Hypotheses 3 and 4 (below) are directed towards examining parameters cross-sectionally during the latter portion of the learning curve.

3.	Control strategy will be more stable for a fixed task than for a varied task. This hypothesis is directed again at the question of the relationship of control strategy to the environment. That is, it seems reasonable that tasks with relatively constant average characteristics will result in relatively constant control strategies, and that tasks in which the average characteristics vary, will produce control strategies with variable characteristics. In this test, we will look specifically at the sensitivity of control strategy parameters to the contrast

between conditions in which the spectral content of the input forcing function is varied, and conditions in which it remains relatively constant.

4.   <u>The criterion applied by the human operator to his own actual or predicted performance depends upon the width of displayed guidelines on the track.</u>   Task performance is related to the criterion by which it is judged. Excellent performance under one criterion may be unacceptable under another. The standards may be explicitly or implicitly set, but in either case the human can be expected to respond to a task situation with some internal standard for performance. It is this standard, identified as the parameter ERRLIM in the model, which is the object of this manipulation. It is proposed here that human beings respond, consciously or unconsciously, to cues available to them as standards for performance. If the only available markers are quite stringent, the human may set his internal judgement at a more demanding level than if the only visible cues are not very demanding. The reason for our interest in implicitly set standards is that in most control situations of interest, the individual makes the decision about the level of performance to strive for. All subjects will be told to "track as accurately as you can...", and then given either a wide or narrow track boundary, which is described to them as a "guideline to help you track more accurately."

SUBJECTS

Subjects will be 16 men and 16 women, paid volunteers from campus ROTC units.

EXPERIMENTAL CONDITIONS

Subjects will be assigned at random within each sex to one of four cells of a two way factorial design. The factors are task variability and width of displayed error bounds.

There are two levels in the task factor--fixed and varied. The varied task will consist of varying the corner frequency in the track from 1/4 HZ to 3/4 HZ. The fixed task will consist of a constant 1/2 HZ corner frequency. Corner frequency is the frequency at which the power in the pseudo random input signal is attenuated to half-power by the 4th order Butterworth filter applied to limit the bandwidth of the signals the human has to deal with. 6dB/octave is the slope of this attenuation.

The width of the displayed error bounds factor also has two levels -- ten and twenty units wide.

Thus, there will be four groups of subjects:

> Group FN: fixed task, narrow guidelines
> Group FW: fixed task, wide guidelines
> Group VN: varied task, narrow guidelines
> Group VW: varied task, wide guidelines

TASK

The task will be to follow, using a low-friction isotonic control stick connected to an on-screen cursor, as accurately as possible, a filtered pseudo-random track with corner frequencies as described above, and with approximately 10 seconds of available preview. The task is fixed pace. It is anticipated that subjects will track for a total of 20 minutes, with one five minute rest period.

INSTRUCTIONS TO SUBJECTS

Subjects will be given the following instructions by the experimenter.

"The experiment you are participating in today involves using a control stick to control a cross-hair on this CRT screen. You are to control the cross-hair so as to stay as close as possible to the center line of a moving track you will see displayed in front of you. You will have two ten minute periods to learn this task, with a five minute break in between. The track will move down the screen from the top. The cursor you control is able to move only in the horizontal direction and will be located at the bottom of the screen. You will see guidelines displayed on each side of the track to help you track accurately.

Now I'd like you to get familiar with the positions available on this stick. Take hold of the stick and move it around until you think you're sure about where the center is, and where other positions on the handle are"....

"Do you think you're familar with it now? Good. Now without looking, place the stick in the zero position. Now the right extreme. Now the zero point."...

Continue this until the subject can reliably locate the zero point from most positions on the continuum.

"One last thing. The cursor - control stick 'machine' is different from any you have ever experienced. You may find it difficult to control at first, but it will get easier very shortly. At all times try to keep the cursor as close as possible to the center of the track.

Do you have any questions about the task you have to do?"...

"Now begin."

DEBRIEFING OF SUBJECTS

After each test session, subjects will be given a brief explanation of the project, as follows:

"We have a theory about how people learn to control vehicles such as cars and airplanes, or even how to hit a tennis ball properly. We believe you build up a special memory for the consequences of everything you do, and when you get back into the same, or a similar situation, you repeat actions that have been successful.

We have taken our theory, which is quite elaborate, and created a computer program which does part of what we believe all humans do when they learn a control task. We call the computer program HOPE, an acronym for Human

Operator Performance Emulator. We will take the recorded output from your control stick actions, and find the controlling parameter set which allows the HOPE output to best match your output for each 20 second interval in your tracking record. Then we will look at the values of the controlling parameters in the HOPE model of you in the "HOPE" of learning something about psychological processes involved in learning this task.

Do you have any questions?"...

"If you wish to know more about this study, please feel free to take a copy of this paper, which explains in more detail the scope and purpose of the project."

ANALYSIS PLAN

Preliminary Organization of the Data

1. The estimation of the best-fit HOPE model sets for each subject in the experiment. This procedure involves the division of each subject's control stick output into 60 20-second time intervals, and the identification for each interval of the HOPE output(s) which fall within the boundaries defined by 20 percent of the dynamic range of the control stick range of motion, using mean absolute state error (MASE) as the criterion mesure. This statistic is the unweighted sum of absolute position error (between model and human stick output) and its first two derivatives. The best two percent of the models for every time interval will be identified for further analysis in terms of their associated control strategy parameters, regardless of whether they meet the 20 percent criterion.

2. Computation of the learning curve for each subject, using mean absolute position error (between subject controlled-element output and input track) averaged across each 20 second time bin, as the criterion.

3. Preparation for each subject in the experiment of an N x P matrix, where N is equal to the top two percent of models, and P is about 60, the number of 20 second intervals in the tracking record. The contents of the ijth cell in the matrix will be the MASE values produced by the i th model (identified by its three control strategy parameter values) in the j th 20 second interval. With this matrix will be the learning curve for the subject--the 1 x N vector of performance scores in each 20 second interval --computed as the mean absolute position error between the input track and the controlled-element output. Thus, in a one page display, all the relevant data for each subject will be collected for qualitative (visual) and quantitative (statistical) examination.

This visual examination will be for the purpose of a qualitative comparison between control stategy stability and performance stability, for determination of the regions of asymptotic performance in order to do the comparisons of the responsiveness of control strategy parameters to the four experimental conditions, and for a qualitative comparison of the control strategy parameter graphs across individuals. The matrices described above will be grouped according to experimental condition, and by sex within each condition, to facilitate the qualitative assessment of the similarity within such groupings.

Test of the Hypotheses

1.　For at least 90 percent of the subjects, at least half of the 20 second bins will be matched by at least one HOPE model within the criterion boundary of 20% of the control stick range of motion.

2.　For at least 90 percent of the subjects, the variance of the control strategy parameters, as computed during the learning phase, will be significantly larger (F test) than the variance of the control strategy parameters computed during the period of performance asymptote.

3.　For at least one control strategy parameter, the mean absolute difference between the mean value of the parameter in the first section of track and a second section of track, for the varied task group, (groups VN and VW) will be significantly, (F-test) larger than the mean absolute difference between the mean values of the parameter in these two sections, for the fixed task groups (Groups FN and FW.)

4.　The mean value over subjects of the ERRLM parameters will be larger (F-test) in the groups shown 20 unit-wide guidelines (Group VW and FW) than in the groups shown 10-unit guidelines (Groups VN and FN.)

5.　The difference in the mean values for ERRLIM, COT, and ADJUST computed between the narrow and wide guideline conditions, for the fixed task groups, (Groups FN and FW) will not be significally different (F test) from the differences in the mean values for ERRLIM, COT, and ADJUST, computed between the narrow and wide guideline conditions, for the varied task groups, (Groups VN and VW). That is, $(\mu fn - \mu fw) - (\mu vn - \mu vw) = 0$. This is, of course, the test for interaction between the two independent variables.

Summary of Dependent Variables

1.　MASE value for each 20 second bin of tracking for each subject.

2.　The variance of each subject's control strategy parameter estimates, computed over all 20 second bins in which a match occurs. The best match in the bins will be used to compute this; once during learning, and once during performance asymptote.

3.　Absolute differences in mean values for each subject for each control strategy parameter averaged across two separate sections in the record--one about four minutes long beginning at about six minutes in; one about four minutes long beginning at about 15 minutes into the record. The averages of these differences within groups will be used to examine the effect of varying the task.

4.　Mean values of control strategy parameters for each subject, computed in item 3 for the differences, will be used to examine the effects on parameters of varying the displayed track guideline.

Measurement of Dependent Variables

　　　The three parameters of interest are ERRLIM, COT, and ADJUST. All will

be estimated by finding the model which best matches the data in a given segment, and assuming those parameter values which produce the best model, within the 20 percent stick range criterion, are the best estimates.

In future experiments, however, effort will be made to get alternate measures of these parameters. For example, COT might at some time be measured via electromyographic recordings of muscle potential. Adjust may be estimated by operator responses to experimenter-induced novelty. An alternate measure for ERRLIM, could be attained at the end of the training period. This could be accomplished by using the method of adjustment (Kling & Riggs, 1965). Briefly this method would require the subject, over approximately 50 trials, to adjust a symetrical pair of bars to a width within which he considers performance acceptable. The inital position of the bars varies randomly from trial to trial, and the average adjustment is used as the estimate of his ERRLIM. The values attained in this way would be compared to those attained through the model estimation procedure, and could be subjected to the between groups analysis required by hypothesis four. Such alternate measures will be important evidence for the validity of the constructs proposed here.

Contract F33615-77-0042

PRESENTATION OUTLINE

SUBJECT: HOPE REFINEMENTS--IMPLEMENTATION AND RESULTS

February 4, 1980

Wright-Patterson Air Force Base

   I. Review of Problems Suggesting Need for Refinements

  II. Refinement Procedures

 III. Criteria Used to Assess HOPE Refinements

  IV. Refinements Tested and Rejected

   V. Refinements Tested and Implemented

  VI. Results

 VII. Recommendations

I. REVIEW OF PROBLEMS SUGGESTING NEED FOR REFINEMENTS

A. Excessive Variation in Model Control Stick Posiiton

B. Poor Model Matches for Early Trials and Related Symptons

C. Problems in Best-Fit Model Identification Process

D. Poorer Matching 1/2 Hz Conditions

E. Clustering of Model Parameters at Edge of Parameter Space

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS
AND BEST-FIT MODEL CONTROL STICK RECORDS

1/4 Hz Track, Wide Guidelines
Old HOPE

Number of bins (20 seconds) out of 50 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
OP ID=1211 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.01 TR2 AVE= 1.78 TR3 AVE= 1.67 TR4 AVE= 1.58 TR5 AVE= 1.53	TOT AVE= 1.71
OP ID=1212 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.36 TR2 AVE= 2.48 TR3 AVE= 2.21 TR4 AVE= 1.86 TR5 AVE= 2.02	TOT AVE= 2.19
OP ID=1213 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 2.22 TR2 AVE= 1.79 TR3 AVE= 1.85 TR4 AVE= 1.75 TR5 AVE= 1.69	TOT AVE= 1.86
OP ID=1214 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.47 TR2 AVE= 1.74 TR3 AVE= 1.62 TR4 AVE= 1.52 TR5 AVE= 1.51	TOT AVE= 1.77
OP ID=1221 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.26 TR2 AVE= 1.97 TR3 AVE= 1.76 TR4 AVE= 1.79 TR5 AVE= 1.75	TOT AVE= 1.90
OP ID=1222 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.34 TR2 AVE= 2.02 TR3 AVE= 1.87 TR4 AVE= 1.92 TR5 AVE= 1.71	TOT AVE= 1.97
OP ID=1223 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 1.95 TR2 AVE= 1.62 TR3 AVE= 1.65 TR4 AVE= 1.60 TR5 AVE= 1.58	TOT AVE= 1.68
OP ID=1224 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.29 TR2 AVE= 1.97 TR3 AVE= 1.96 TR4 AVE= 1.68 TR5 AVE= 1.68	TOT AVE= 1.90

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS

AND BEST-FIT MODEL CONTROL STICK RECORDS

1/4 Hz Track, Narrow Guidelines

Old HOPE

Number of bins (20 seconds) out of 59 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
OP ID=1111 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.49 TR2 AVE= 2.68 TR3 AVE= 2.13 TR4 AVE= 2.01 TR5 AVE= 1.90	TOT AVE= 2.24
OP ID=1112 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.46 TR2 AVE= 2.35 TR3 AVE= 2.16 TR4 AVE= 2.26 TR5 AVE= 2.00	TOT AVE= 2.24
OP ID=1113 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.55 TR2 AVE= 2.38 TR3 AVE= 2.23 TR4 AVE= 2.03 TR5 AVE= 2.03	TOT AVE= 2.24
OP ID=1114 HAS 59 BINS WITH PMS <= 7.48	TR1 AVE= 2.45 TR2 AVE= 2.41 TR3 AVE= 2.09 TR4 AVE= 2.03 TR5 AVE= 1.99	TOT AVE= 2.21
OP ID=1121 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.19 TR2 AVE= 1.91 TR3 AVE= 1.83 TR4 AVE= 1.83 TR5 AVE= 1.84	TOT AVE= 1.93
OP ID=1122 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.47 TR2 AVE= 2.19 TR3 AVE= 2.11 TR4 AVE= 2.17 TR5 AVE= 2.16	TOT AVE= 2.21
OP ID=1123 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.46 TR2 AVE= 2.15 TR3 AVE= 1.92 TR4 AVE= 2.39 TR5 AVE= 1.93	TOT AVE= 2.17
OP ID=1124 HAS 59 BINS WITH PMS <= 7.48	TR1 AVE= 2.38 TR2 AVE= 1.86 TR3 AVE= 1.85 TR4 AVE= 1.90 TR5 AVE= 1.92	TOT AVE= 1.98

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS

AND BEST-FIT MODEL CONTROL STICK RECORDS

1/2 Hz Track, Narrow Guidelines

Old HOPE

| Number of bins (20 seconds) out of 50 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
OP ID=2111 HAS 24 BINS WITH RMS <= 7.48	TR1 AVE= 8.51 TR2 AVE= 7.64 TR3 AVE= 7.84 TR4 AVE= 7.48 TR5 AVE= 6.84	TOT AVE= 7.66
OP ID=2112 HAS 45 BINS WITH RMS <= 7.48	TR1 AVE= 6.07 TR2 AVE= 6.39 TR3 AVE= 6.10 TR4 AVE= 6.52 TR5 AVE= 6.09	TOT AVE= 6.23
OP ID=2113 HAS 54 BINS WITH RMS <= 7.48	TR1 AVE= 4.59 TR2 AVE= 4.85 TR3 AVE= 4.86 TR4 AVE= 5.09 TR5 AVE= 4.43	TOT AVE= 4.76
OP ID=2114 HAS 38 BINS WITH RMS <= 7.48	TR1 AVE= 7.98 TR2 AVE= 7.18 TR3 AVE= 7.47 TR4 AVE= 6.10 TR5 AVE= 6.42	TOT AVE= 7.04
OP ID=2121 HAS 57 BINS WITH RMS <= 7.48	TR1 AVE= 6.38 TR2 AVE= 5.23 TR3 AVE= 5.31 TR4 AVE= 5.17 TR5 AVE= 5.12	TOT AVE= 5.44
OP ID=2122 HAS 35 BINS WITH RMS <= 7.48	TR1 AVE= 6.35 TR2 AVE= 7.96 TR3 AVE= 6.16 TR4 AVE= 6.22 TR5 AVE= 6.76	TOT AVE= 6.79
OP ID=2123 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 4.59 TR2 AVE= 4.81 TR3 AVE= 4.90 TR4 AVE= 4.80 TR5 AVE= 5.08	TOT AVE= 4.84
OP ID=2124 HAS 58 BINS WITH RMS <= 7.48	TR1 AVE= 4.68 TR2 AVE= 4.81 TR3 AVE= 5.01 TR4 AVE= 4.62 TR5 AVE= 4.60	TOT AVE= 4.76

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS

AND BEST-FIT MODEL CONTROL STICK RECORDS

1/2 Hz Track, Wide Guidelines

Old HOPE

Number of bins (20 seconds) out of 59 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment

OP ID=2211 HAS 58 BINS WITH RMS <= 7.48   TR1 AVE= 6.41 TR2 AVE= 4.93 TR3 AVE= 4.69 TR4 AVE= 4.61 TR5 AVE= 4.40 TOT AVE= 5.01

OP ID=2212 HAS 52 BINS WITH RMS <= 7.48   TR1 AVE= 5.60 TR2 AVE= 6.20 TR3 AVE= 5.54 TR4 AVE= 5.48 TR5 AVE= 5.54 TOT AVE= 5.67

OP ID=2213 HAS 56 BINS WITH RMS <= 7.48   TR1 AVE= 4.01 TR2 AVE= 3.87 TR3 AVE= 4.25 TR4 AVE= 3.92 TR5 AVE= 4.93 TOT AVE= 4.20

OP ID=2214 HAS 56 BINS WITH RMS <= 7.48   TR1 AVE= 6.05 TR2 AVE= 5.42 TR3 AVE= 4.25 TR4 AVE= 4.47 TR5 AVE= 3.68 TOT AVE= 4.77

OP ID=2221 HAS 54 BINS WITH RMS <= 7.48   TR1 AVE= 5.03 TR2 AVE= 4.82 TR3 AVE= 5.36 TR4 AVE= 5.33 TR5 AVE= 4.34 TOT AVE= 4.99

OP ID=2222 HAS 59 BINS WITH RMS <= 7.48   TR1 AVE= 4.13 TR2 AVE= 3.22 TR3 AVE= 3.32 TR4 AVE= 3.61 TR5 AVE= 3.90 TOT AVE= 3.65

OP ID=2223 HAS 58 BINS WITH RMS <= 7.48   TR1 AVE= 4.81 TR2 AVE= 4.25 TR3 AVE= 3.98 TR4 AVE= 3.20 TR5 AVE= 3.80 TOT AVE= 4.13

OP ID=2224 HAS 55 BINS WITH RMS <= 7.48   TR1 AVE= 4.04 TR2 AVE= 5.83 TR3 AVE= 5.41 TR4 AVE= 5.60 TR5 AVE= 5.51 TOT AVE= 5.13

OPERATOR 1212, POINTS 2001-2500

T = Track

C = Cursor

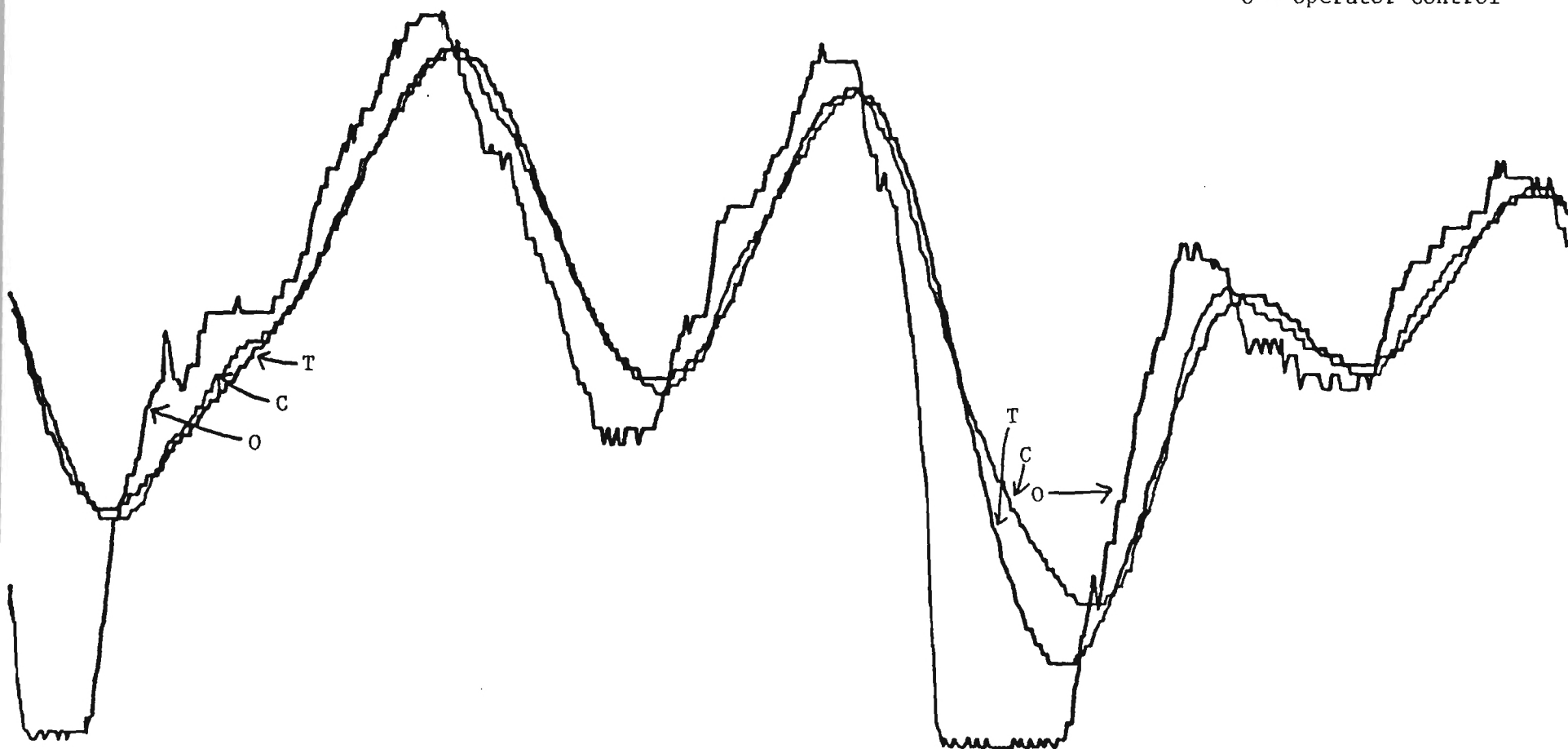O = Operator Control

T

C

O

T

C

O
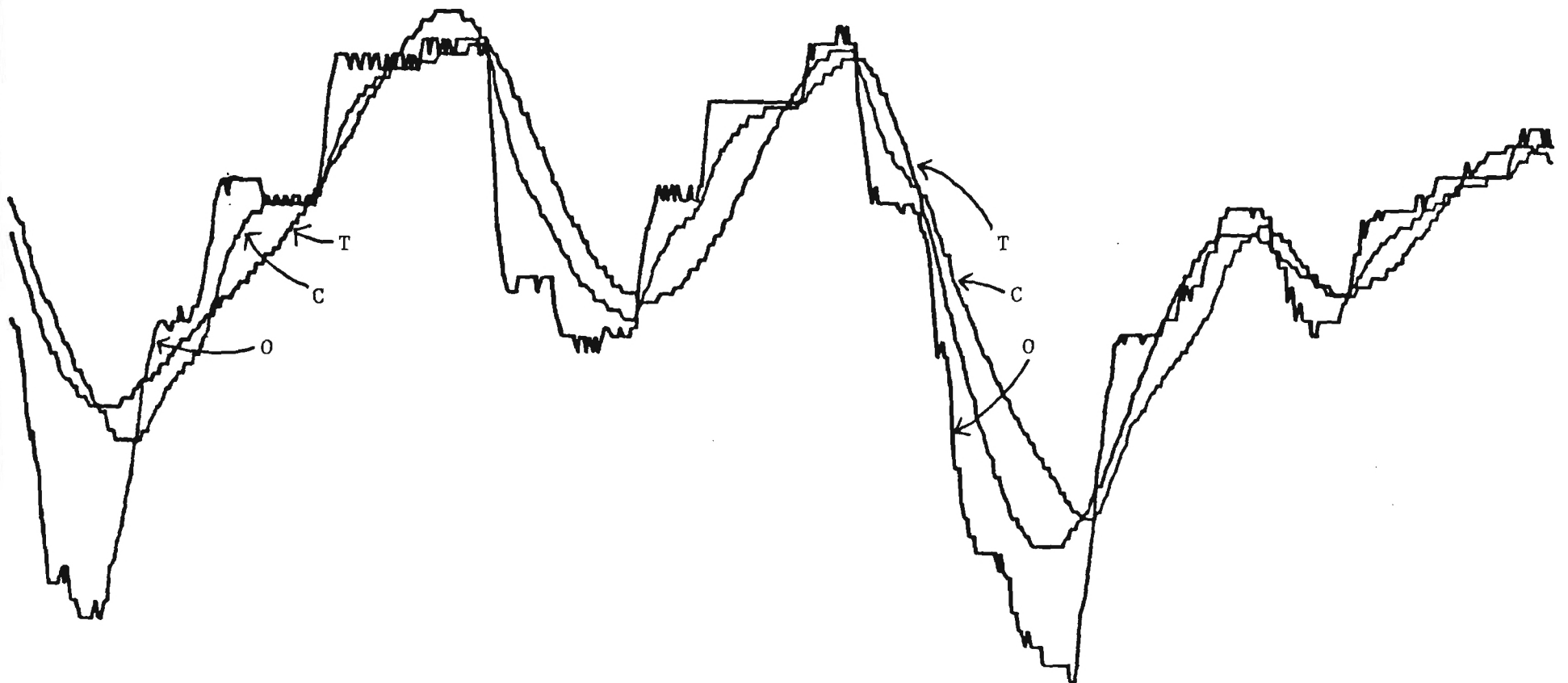
OPERATOR 1123, POINTS 26001-26500
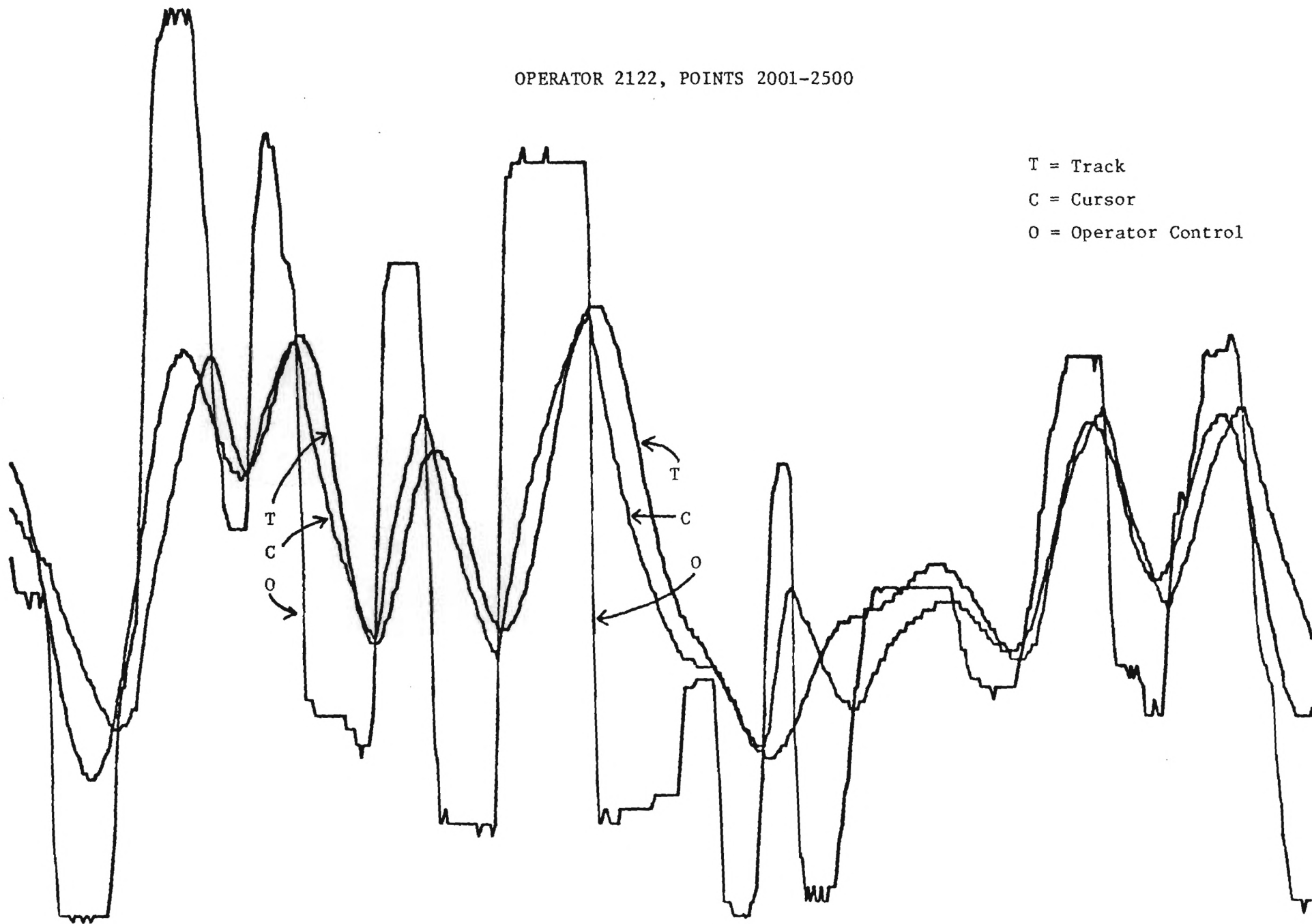
T = Track

C = Cursor

O = Operator Control

OPERATOR 2122, POINTS 2001-2500

T = Track

C = Cursor

O = Operator Control
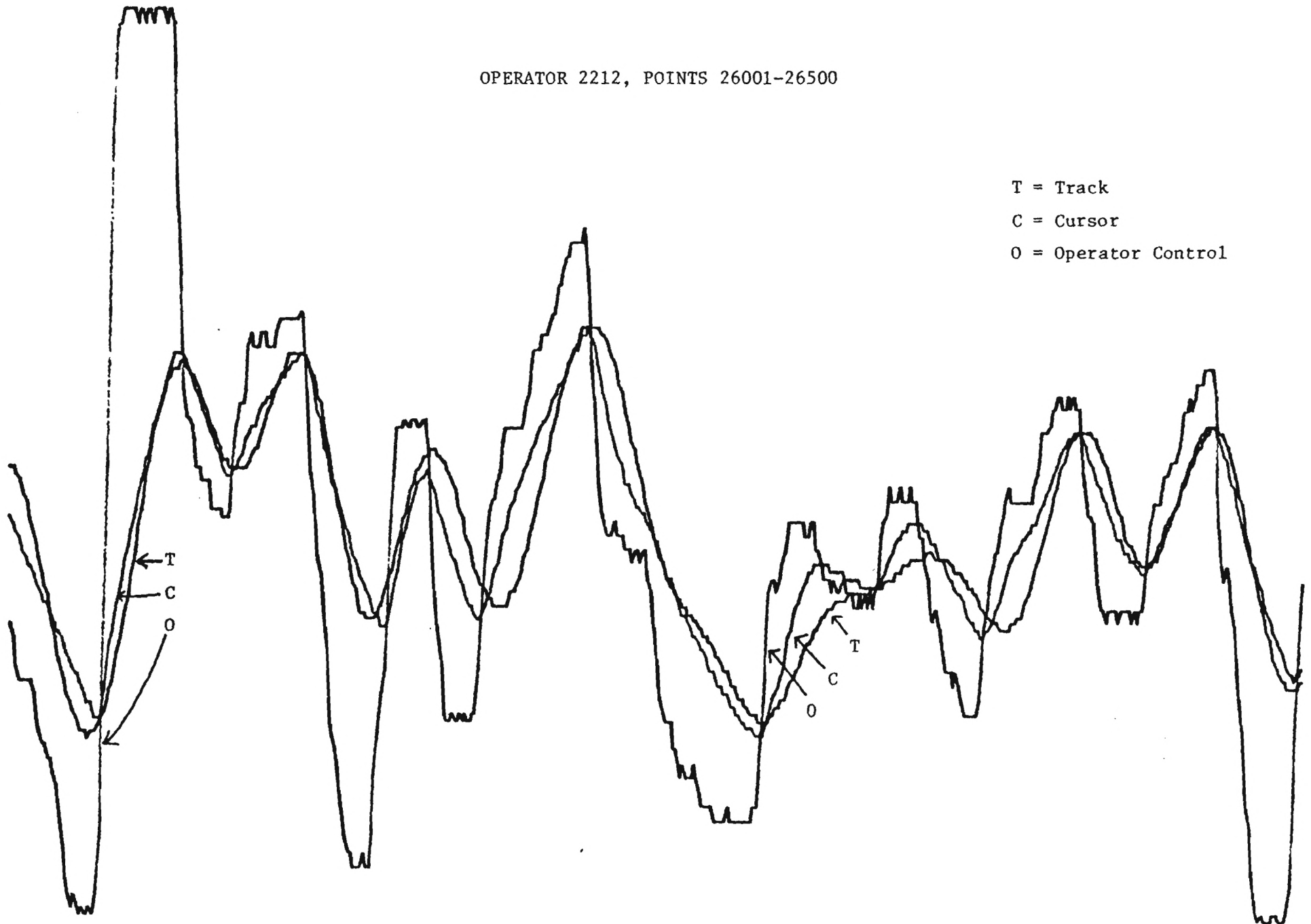
T

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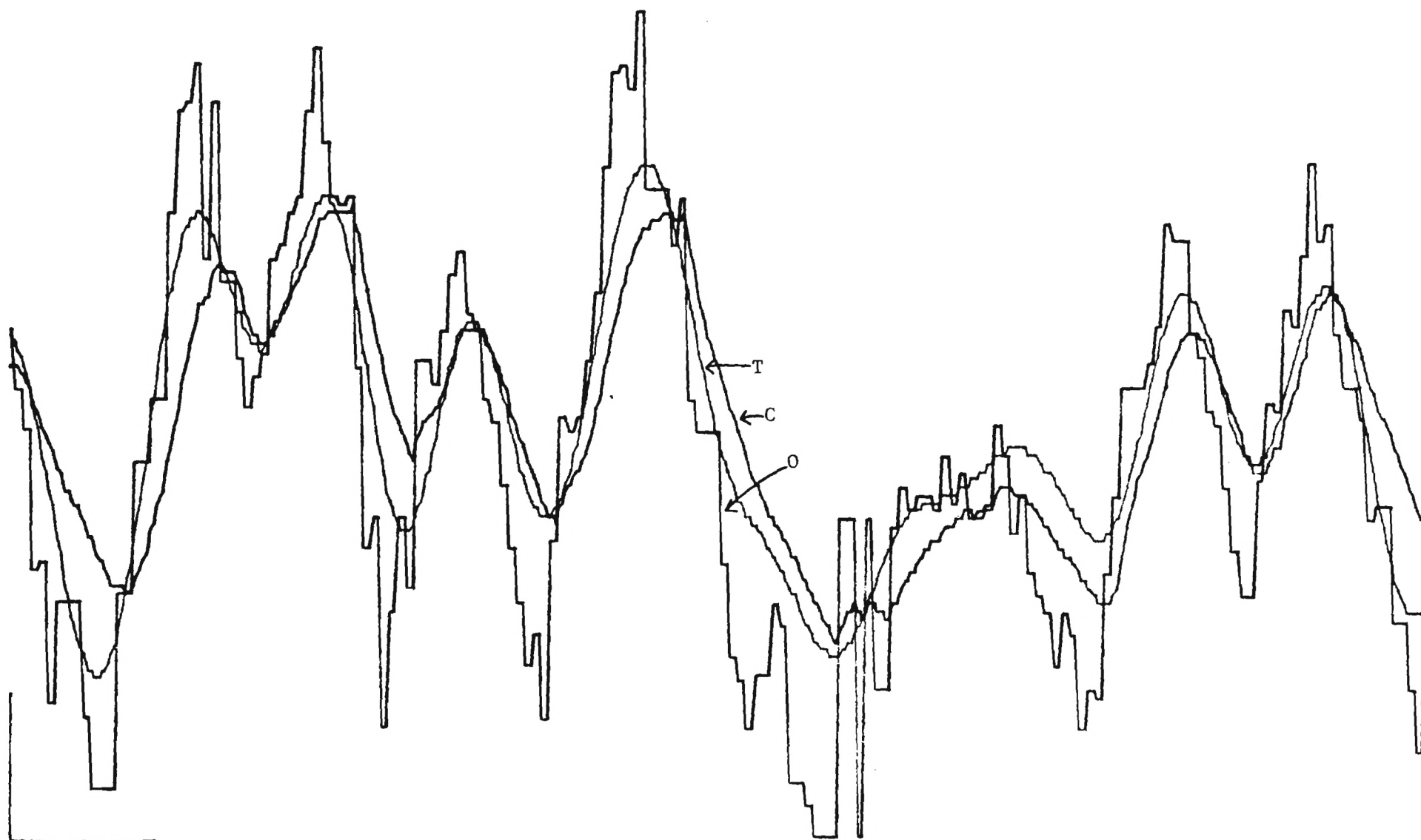
OPERATOR 2212, POINTS 26001-26500

T = Track

C = Cursor

O = Operator Control

OLD HOPE

Model 38
Points 26001-26500
1/4 Hz track, narrow
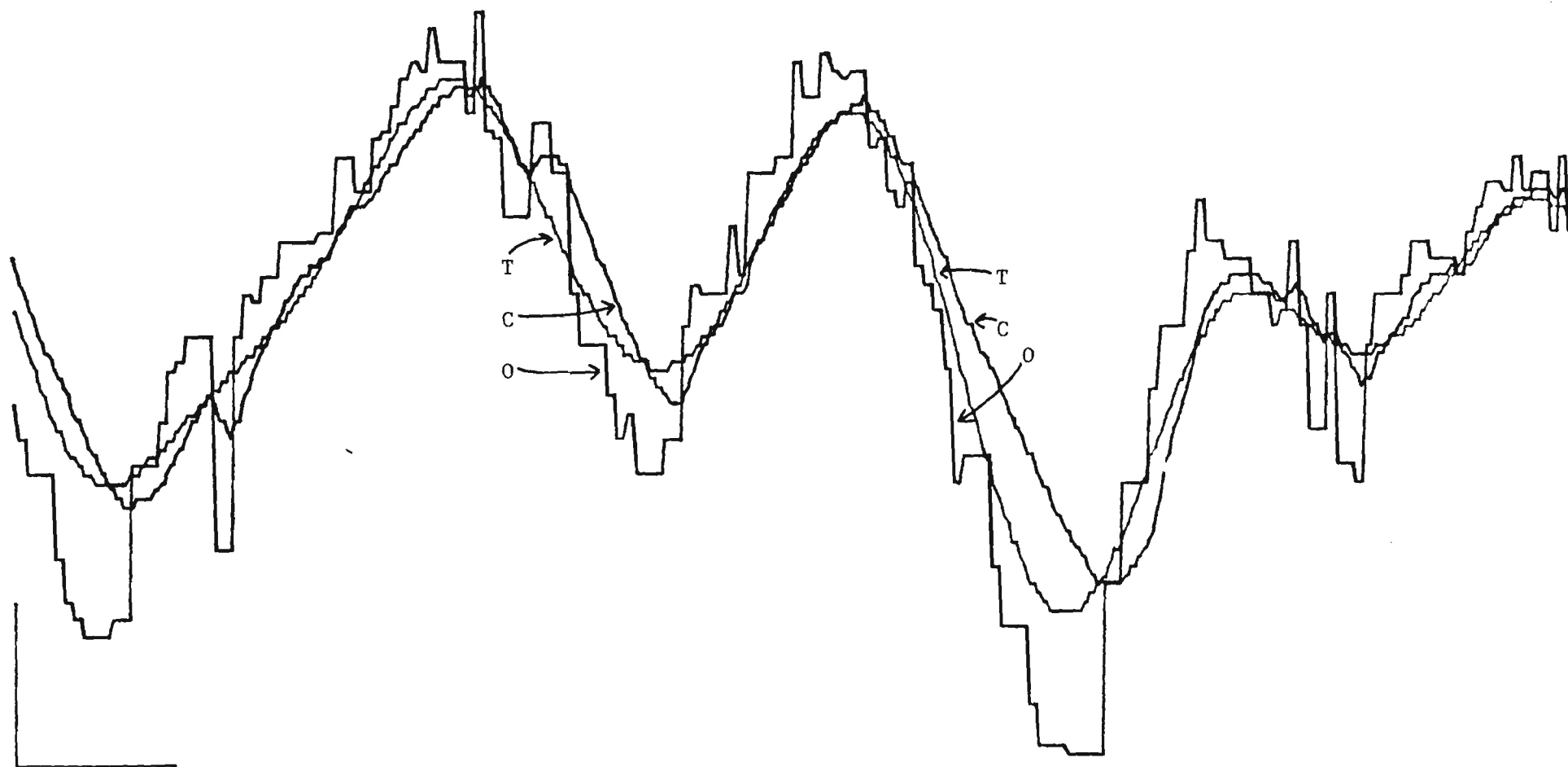
T = Track
C = Cursor
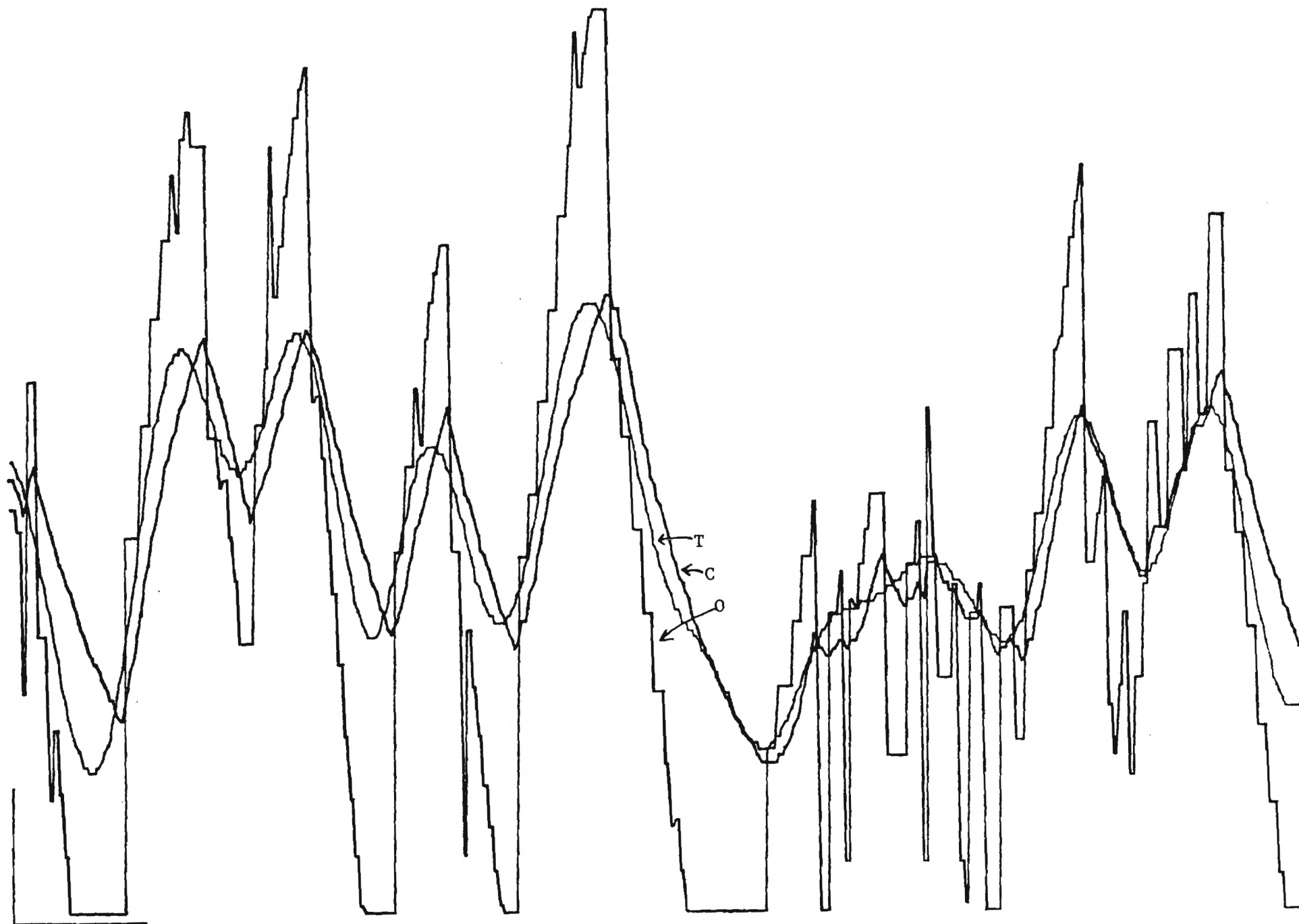O = Operator Control

OLD HOPE

Model 31
Points 2001–2500
1/4 Hz track, wide

T = Track
C = Cursor
O = Operator control
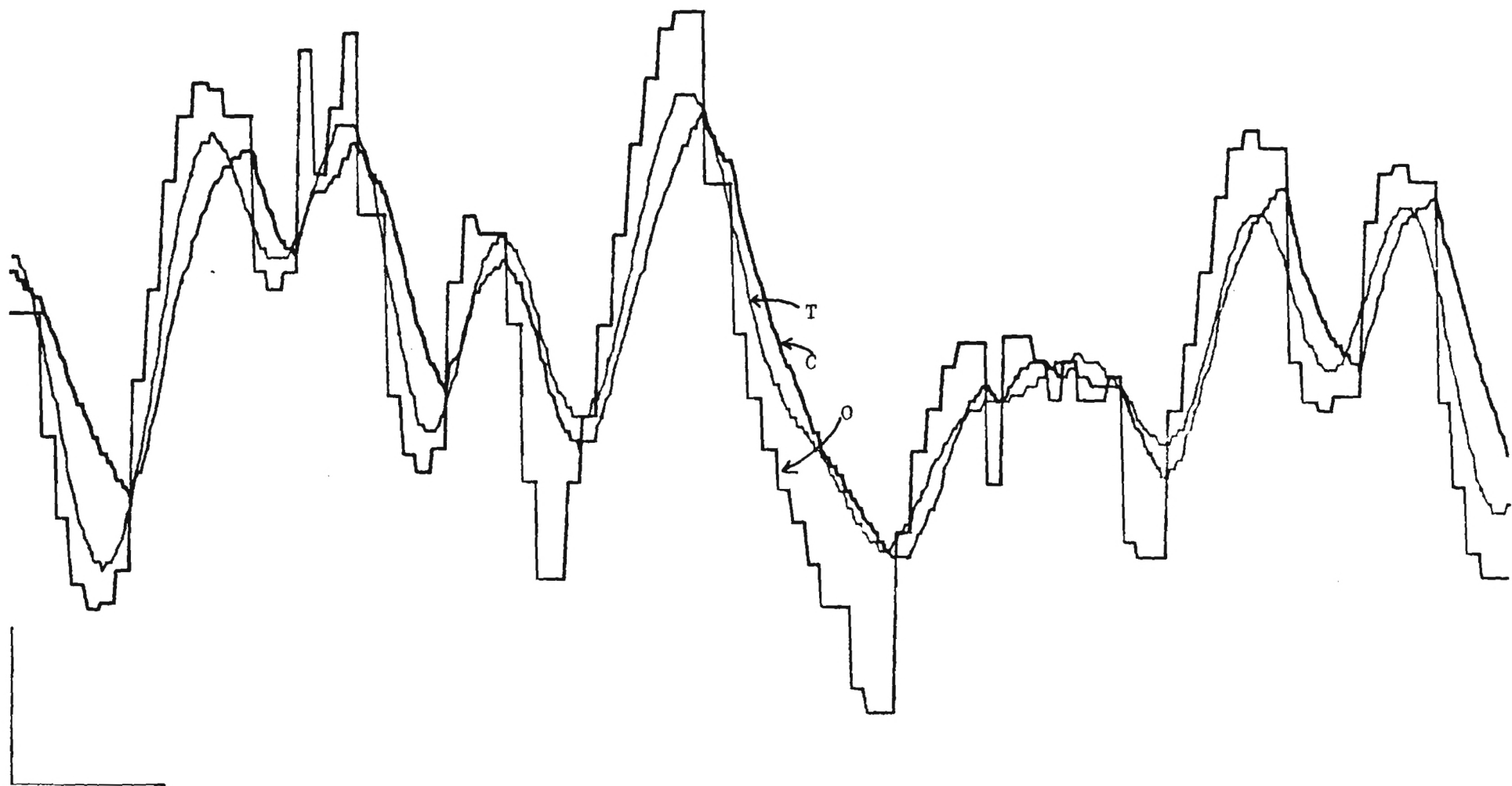
Model 17
Points 2001-2500
1/2 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

←T
←C
O

OLD HOPE

Model 61
Points 2001-2500
1/2 Hz track, wide

T = Track
C = Cursor
O = Operator Control

II. REFINEMENT PROCEDURES

A. Discussion

B. Coding and Check

C. Implementation

D. Plots and Diagnostics

E. Decision to Accept or Reject

F. Continue A-E on Next Refinement

D. PLOTS AND DIAGNOSTICS

1. 1/2 Hz, Early and Late

    a. 2, 2, 5

    al. 2, 16, 2

    b. 3, 16, 5

    c. 3, 2, 2

    d. 3, 8, 5

    e. 5, 2, 2
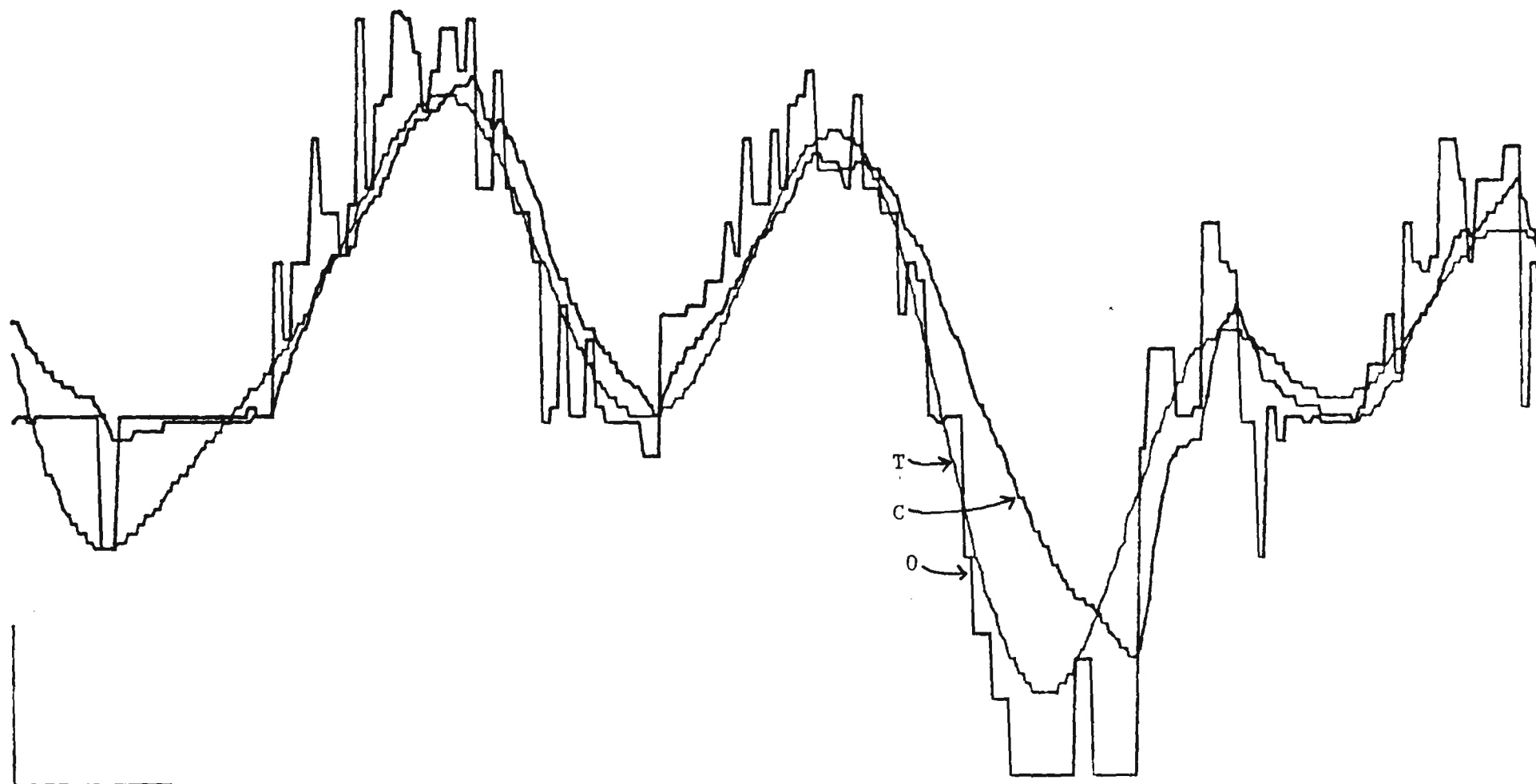

2. 1/4 Hz, Early and Late

    a. 2, 2, 5

    b. 3, 2, 2

    c. 3, 16, 5

    d. 4, 2, 2

    e. 5, 2, 2

OLD HOPE

Model 41
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

T

C

O

HOPE 3T(AERPC=3)

Model 41
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

HOPE 5

Model 41
Points 2001–2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

HOPE 5A

Model 41
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

HOPE 5B

Model 41
Points 2001-2500
1/4 Hz track, Narrow

T = Track
C = Cursor
O = Operator Control

HOPE 6

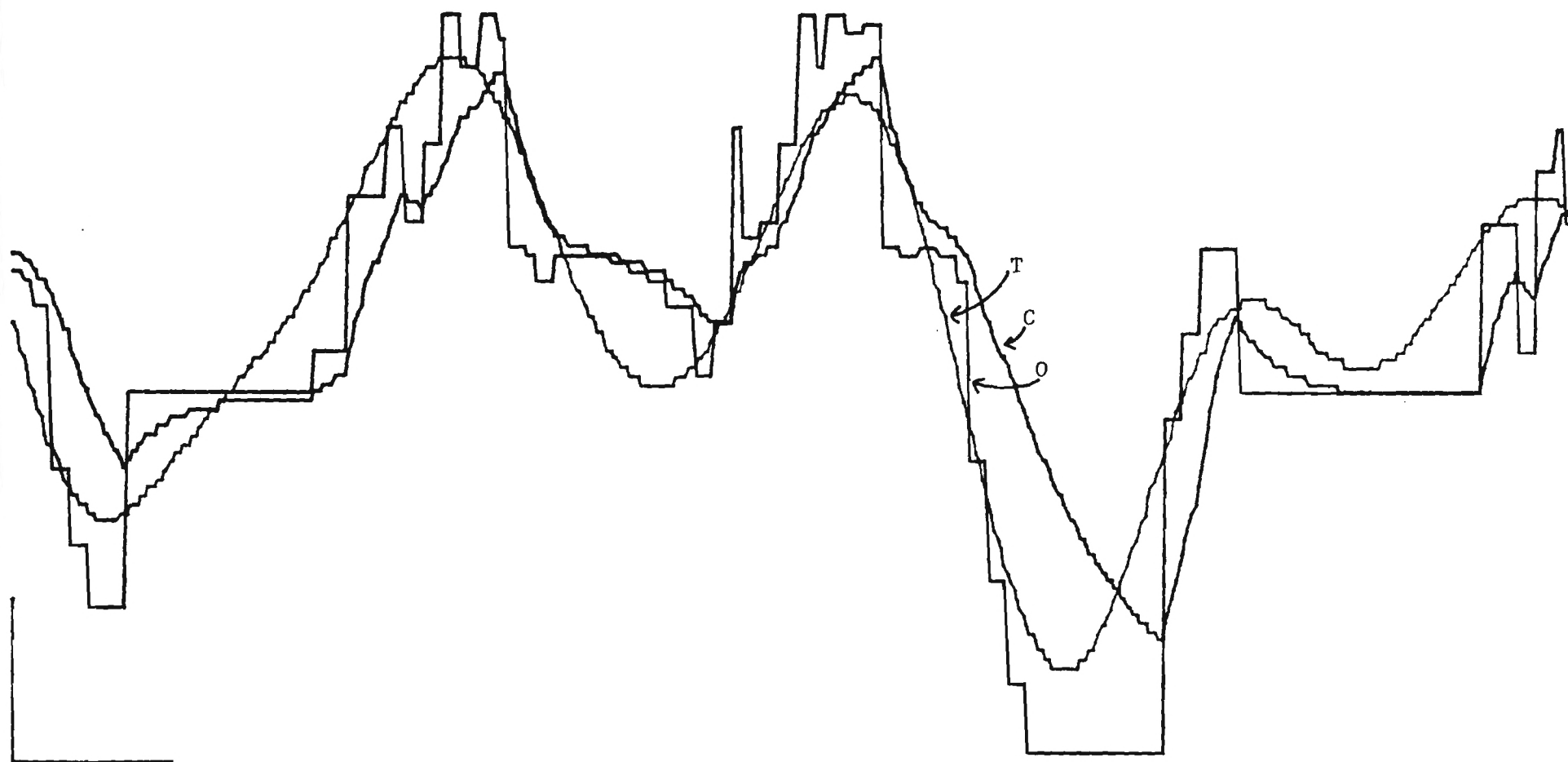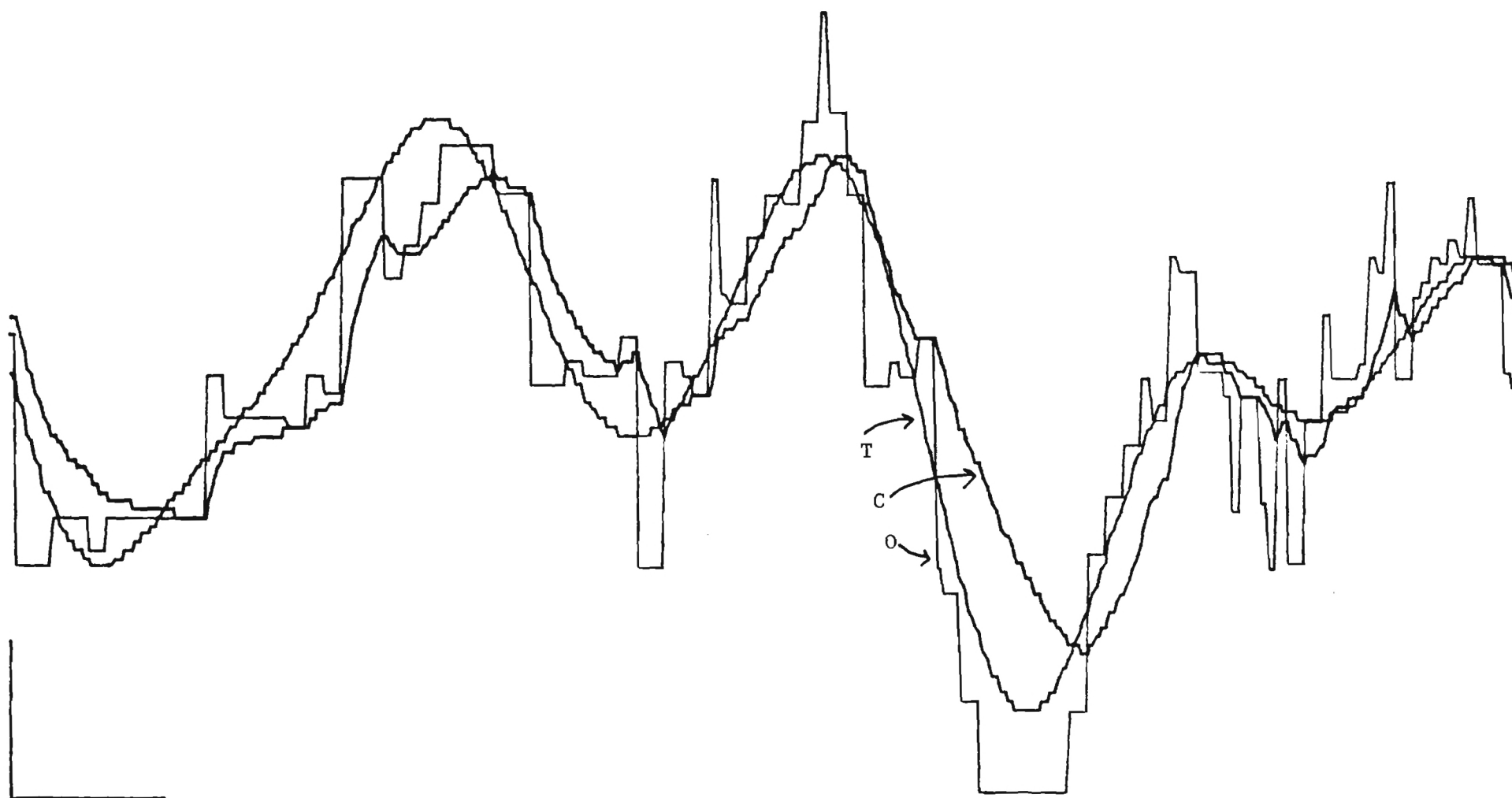Model 41
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control

HOPE 7

Model 41
Points 2001-2500
1/4 Hz track, narrow
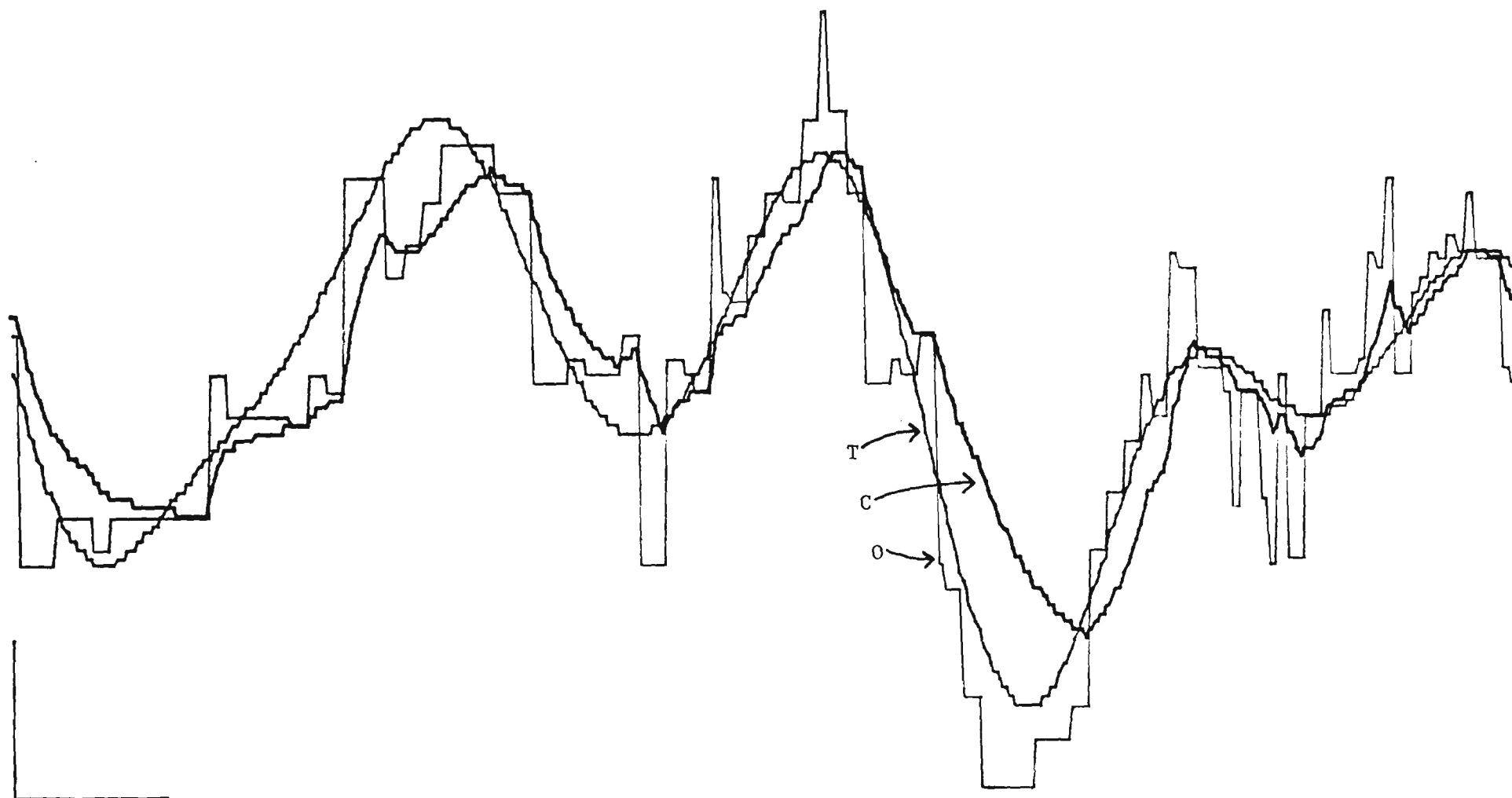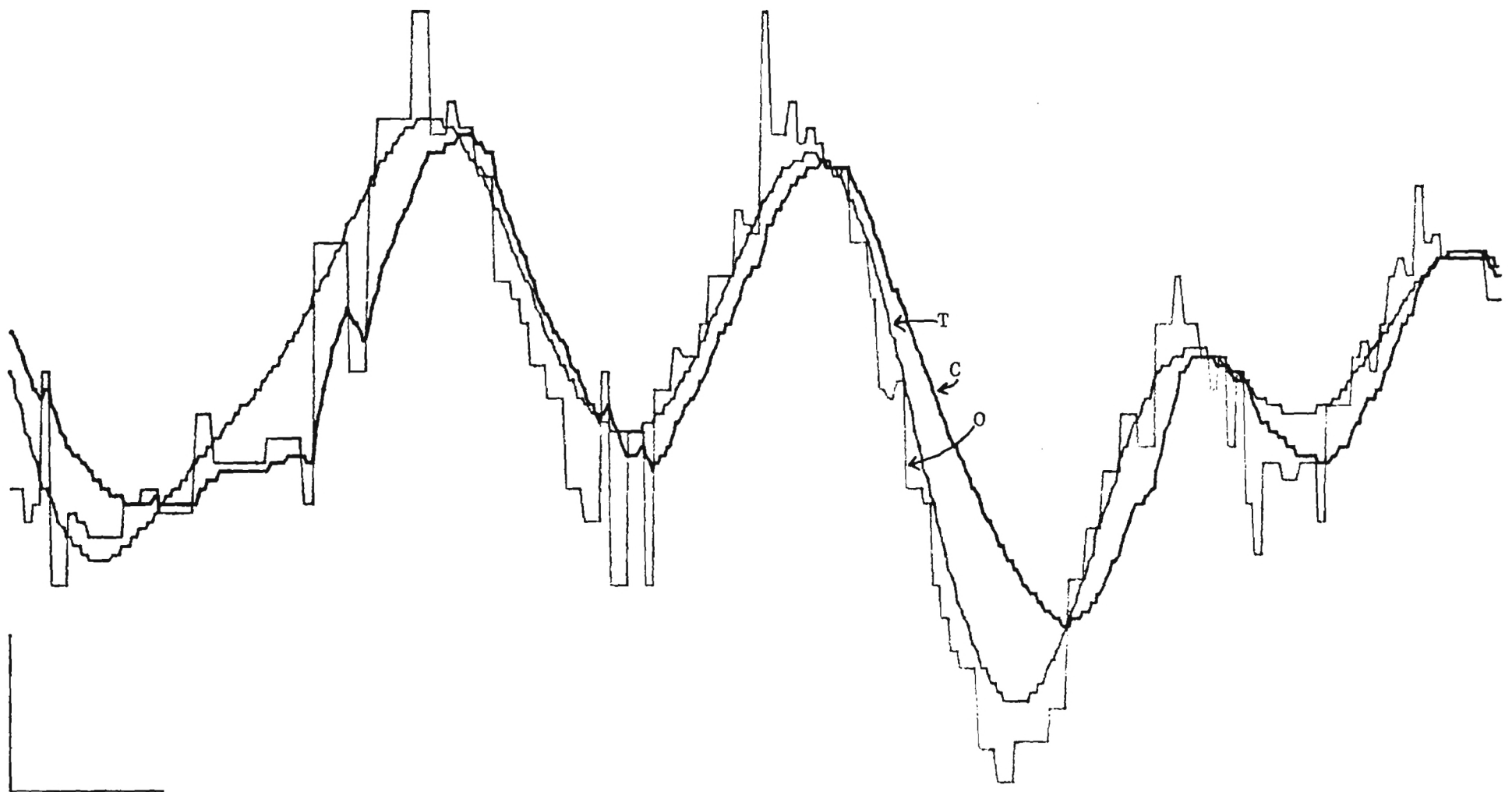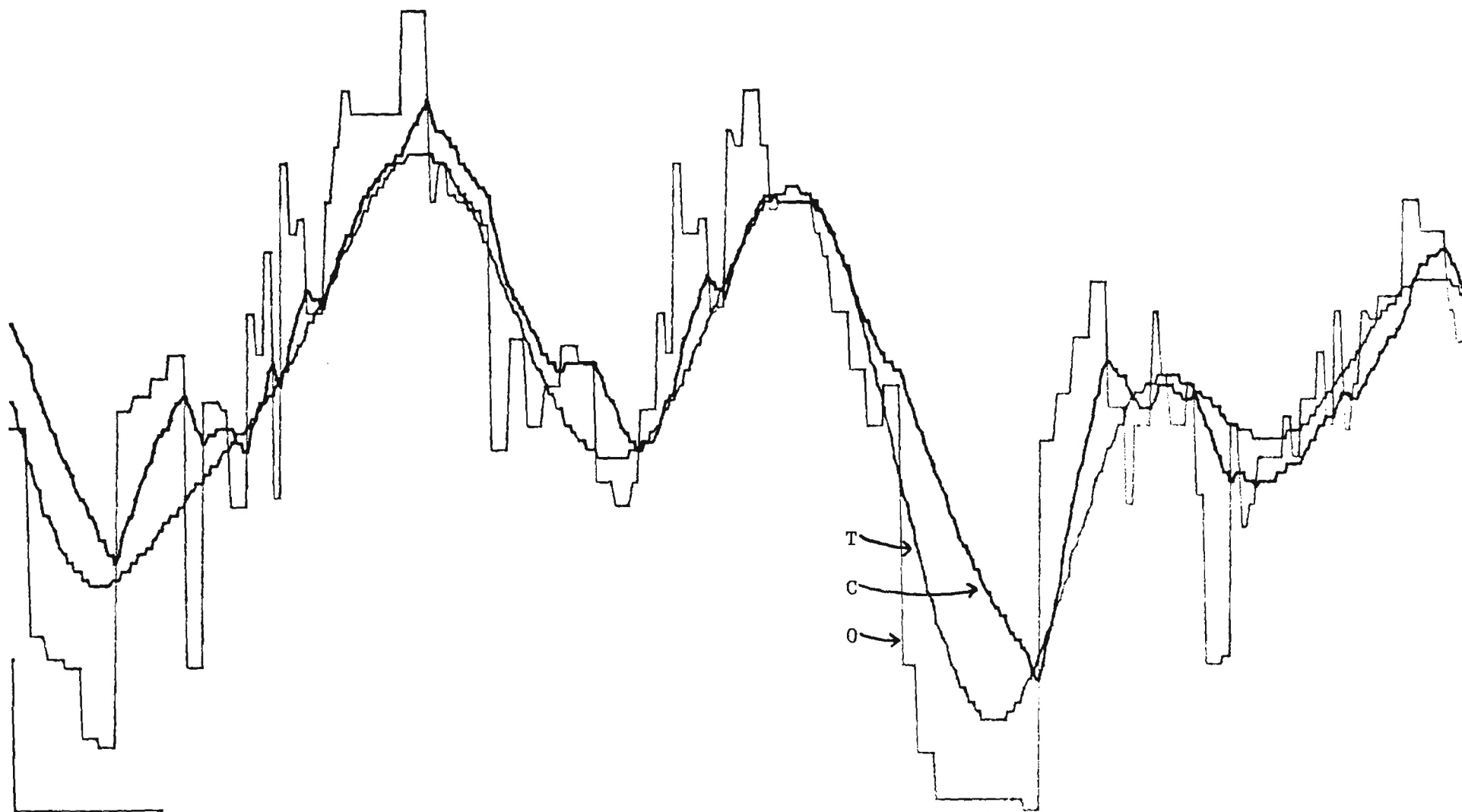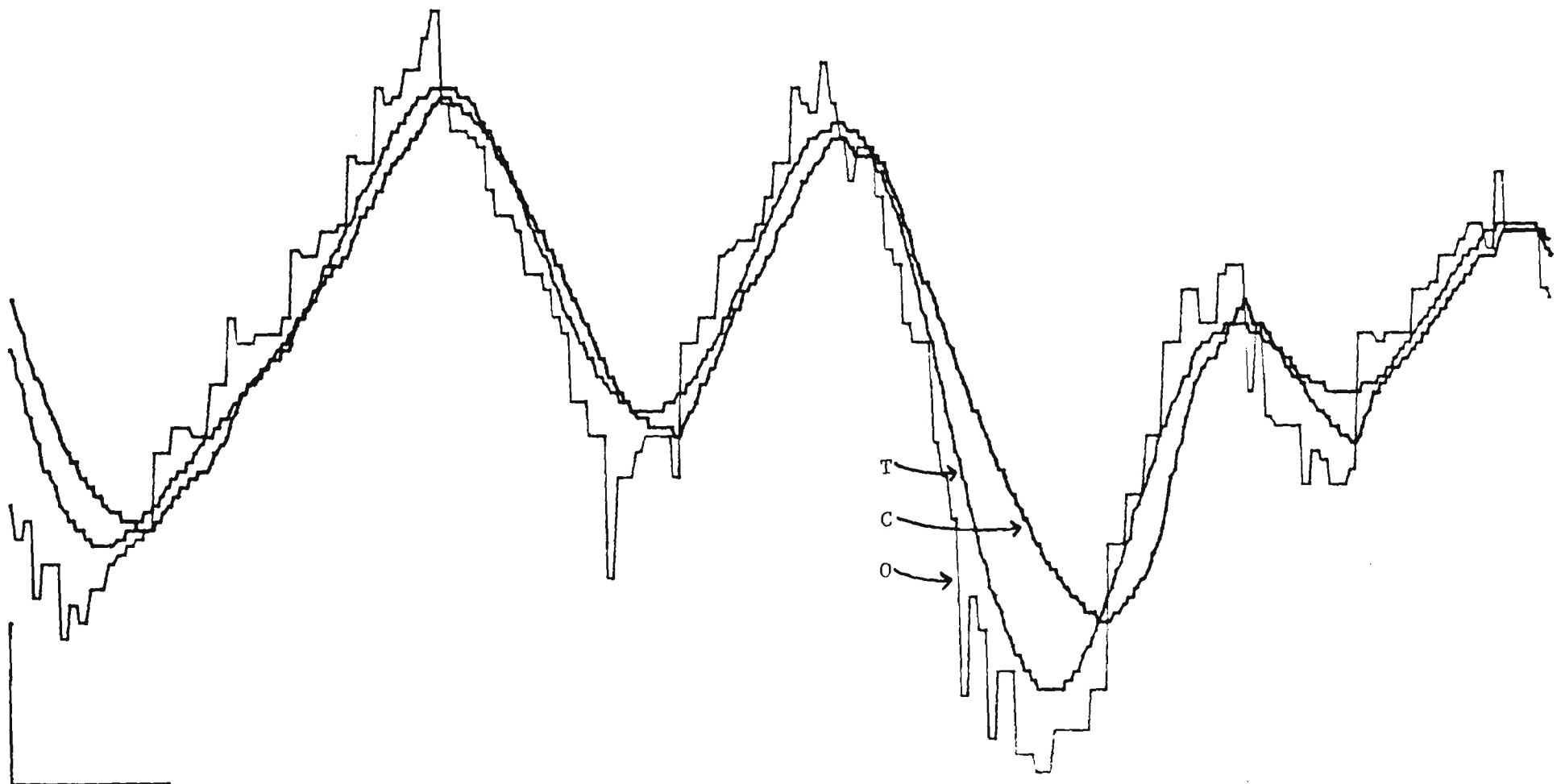
T = Track
C = Cursor
O = Operator Control

SAMPLE DIAGNOSTICS
OLD HOPE

```
        TRACK ID =   444
3       ERLIM =   16      ADJUST =   5
  ER     UGCOM    UCOM   UNNF    UNN   NERR  ASSN1  ASSN2
```

ER	UGCOM	UCOM	UNNF	UNN	NERR	ASSN1	ASSN2
7.21900	75	240	7	146	18	137	251
5.29200	122	268	0	141	5	116	301
4.90100	220	339	6	108	12	77	268
3.59300	234	322	0	86	2	56	214
3.60200	268	354	0	85	1	41	220
5.78100	196	305	12	95	15	54	244
2.99300	277	342	0	65	0	28	206
2.96800	321	359	0	38	0	21	174
3.82200	302	352	0	42	9	32	183
3.39200	338	378	0	37	4	29	180
3.07800	345	378	0	33	0	20	185
5.05700	236	332	0	86	11	46	254
2.92600	348	381	0	33	0	27	182
2.94400	312	335	0	23	0	6	160
3.68200	299	343	0	37	7	21	184
3.41300	353	384	0	29	2	22	174
3.32400	314	334	0	20	0	7	162
5.43900	289	360	0	60	11	30	216
3.04800	360	382	0	22	0	7	172
2.85100	321	334	0	13	0	8	161
3.74500	304	341	0	30	7	18	184
2.98400	306	333	0	27	0	15	166
3.31400	321	334	0	13	0	8	160
5.28700	288	343	0	53	3	28	208
2.87000	366	382	0	16	0	7	175
2.71400	324	334	0	10	0	5	161
3.44400	306	342	0	29	7	13	185
3.51900	311	333	0	22	0	14	163
3.35300	324	333	0	9	0	8	162
5.28300	305	348	0	42	1	20	189

SAMPLE DIAGNOSTICS
REFINED HOPE

DIAGOUT   DATE: 80/ 1/30 TIME: 12: 6:57   HOPE 7

MODEL =   41   TRACK ID =   444
COT =   3   ERLIM = 16   ADJUST = 5

COML	ER	UGCOM	UCOM	UNNF	UNN	NERR	ASSN1	ASSN2
6. 69000	2. 67000	98	246	67	147	0	211	324
26. 51700	2. 55300	200	321	18	121	0	81	280
55. 38901	3. 16300	252	346	15	90	4	76	234
72. 37199	2. 65000	203	291	7	89	0	59	227
94. 00200	2. 77800	323	381	9	58	0	35	204
69. 66000	4. 10000	219	307	29	87	0	52	233
117. 26700	2. 45000	325	365	1	40	0	22	182
138. 84599	2. 77900	322	349	0	26	0	17	158
124. 17900	3. 05700	300	336	1	37	0	24	179
125. 31000	2. 72700	285	324	0	39	0	21	177
140. 85001	3. 12400	325	342	0	17	0	14	157
103. 94099	4. 07700	279	334	5	55	0	40	207
133. 28400	2. 65500	360	383	0	23	0	12	180
142. 38000	2. 51300	315	334	0	19	0	4	159
130. 59900	3. 01500	303	333	1	30	0	10	180
128. 84700	2. 93800	296	331	0	35	0	16	173
146. 43300	3. 13300	322	336	0	14	0	12	161
106. 66200	4. 05100	281	334	4	53	0	30	205
137. 29500	2. 80200	366	383	0	17	0	8	174
142. 48801	2. 70900	315	334	0	19	0	7	160
124. 77901	3. 32500	302	336	3	30	4	8	178
139. 35899	3. 08000	310	333	0	23	0	12	164
147. 27600	3. 46000	322	333	0	11	0	9	161
113. 39700	4. 27800	287	333	2	46	0	23	193
140. 56200	2. 94500	372	383	0	11	0	8	172
145. 41600	2. 90400	320	334	0	14	0	5	160
127. 73100	3. 48500	309	339	2	28	2	7	183
138. 38699	3. 01900	309	332	0	23	0	11	164
149. 25600	3. 31000	326	334	0	8	0	4	158
121. 12801	4. 45200	293	333	5	40	0	21	181

III. CRITERIA USED TO ASSESS HOPE REFINEMENTS

A. Little or No Increase in HOPE Tracking Error

B. Reduced Variability in Control Stick Motion

C. Improved Trial One Matching

D. Equalization of RMS Differences Across Conditions

E. Less Drastic Shifts in Control Strategy Between Bins

IV. REFINEMENTS TESTED AND REJECTED

A. Column Search Only in Nearest Neighbor Search

B. Implementation of Internal Plant Dynamics

1. Limits

2. Delay

HOPE 3(AERPC=3, NNS#1)   Model 17
                          Points 2001-2500
                          1/2 Hz track, narrow

T = Track
C = Cursor
O = Operator control
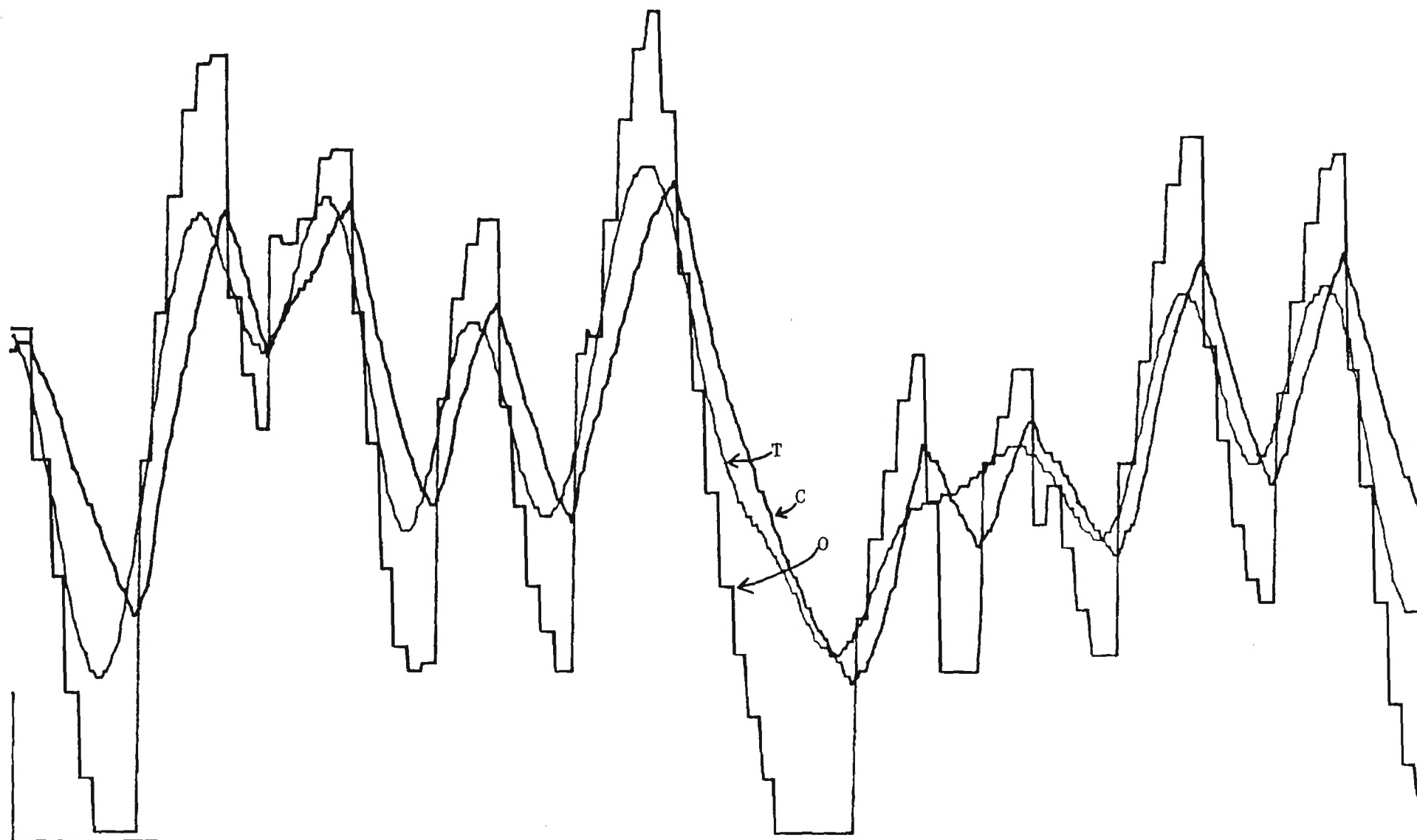
HOPE 4 (AERPC=3)   Model 17   T = Track
                          Points 2001-2500   C = Cursor
                          1/2 Hz track, narrow   O = Operator Control
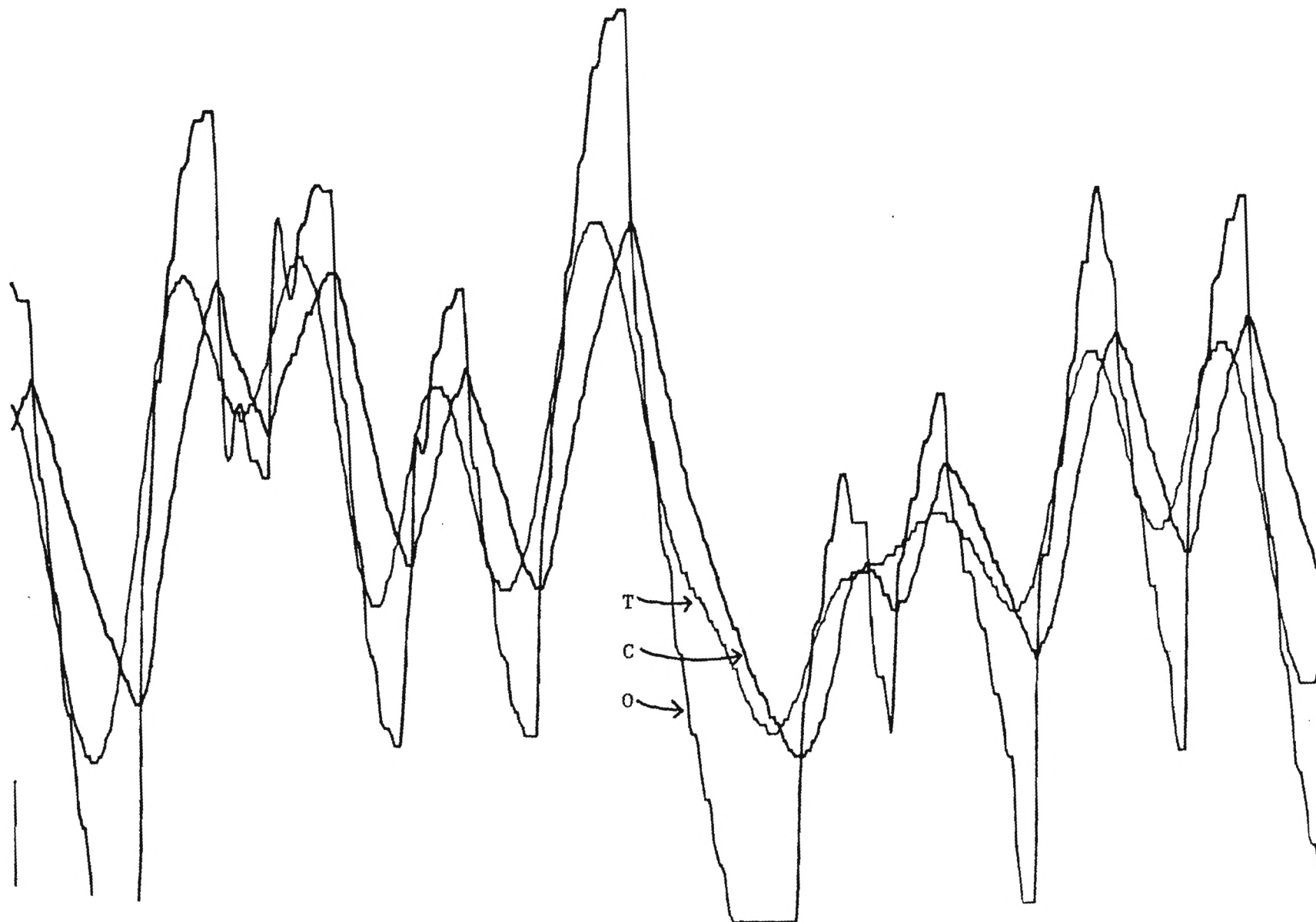
V. REFINEMENTS TESTED AND IMPLEMENTED

A. Perception

B. Command Generation

    1. Inhibition when EEP makes "best-guess"

    2. Ensure retention of correct variables in queue

C. "Flags" (Supervisory Processor)

    1. Flags determines when to re-enable inhibited processes--
        COMGEN or EEP

    2. Permits S-R-A to occur after EEP

D. Excessive Error Process (EEP)

    1. Criterion raised to 3 (120 msec)

    2. Command selected is a COT & EEP criterion away

    3. EEP can look for similar transitions to one needed

    4. ADJUST applied to east best guess

    5. EEP interrupts ongoing command

    6. Lead and Lag determined by error direction <u>and</u> future track
        direction

    7. Increment when (EEPN same type error), <u>except</u> when last command
        was out-of-bounds

    8. ADJUST sign determined by cursor now and a (COT + 2EEP criteria)
        away

    9. EEP waits to see effect of "best-guess" before further action
        planned; sets SRA flag at initiation of any EEP command

E. Nearest Neighbor Search

    1. When NNS starts, buffer is checked to be sure request is up-to-date;
        search variables can be updated if necessary

    2. Search is for transitions of same direction and extent

    3. If "best-guess" is used, it is ADJUSTed

VI. RESULTS

A. Excess Variability Reduced

B. RMS Differences with Humans Reduced

C. Improved Trial One Matching

D. Little Reduction in 1/2 Hz, 1/4 Hz Matching Differential

E. Continued Problems with RMS Measure

OLD HOPE
Best Match RMS = 13.33   Model 55   T = Track
                              Points 2001-2500   C = Cursor
                              1/4 Hz track, wide   O = Operator Control

NEW HOPE
Best Match RMS = 11.05

Model 25
Points 2001-2500
1/4 Hz track, wide

T = Track
C = Cursor
O = Operator Control

OLD HOPE
RMS = 14.22

Model 25
Points 2001-2500
1/4 Hz track, wide

T = Track
C = Cursor
O = Operator Control

Operator 1123
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control
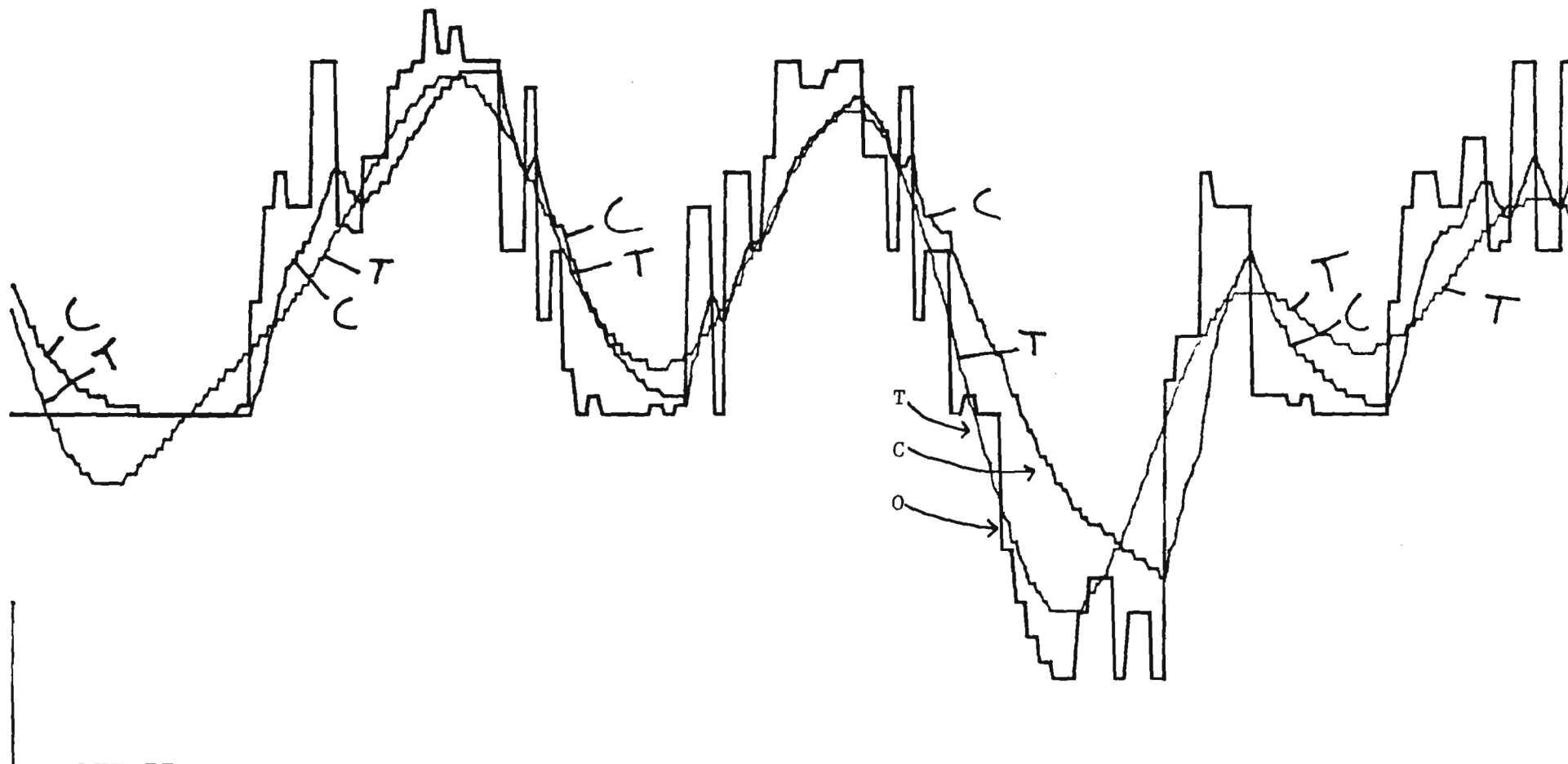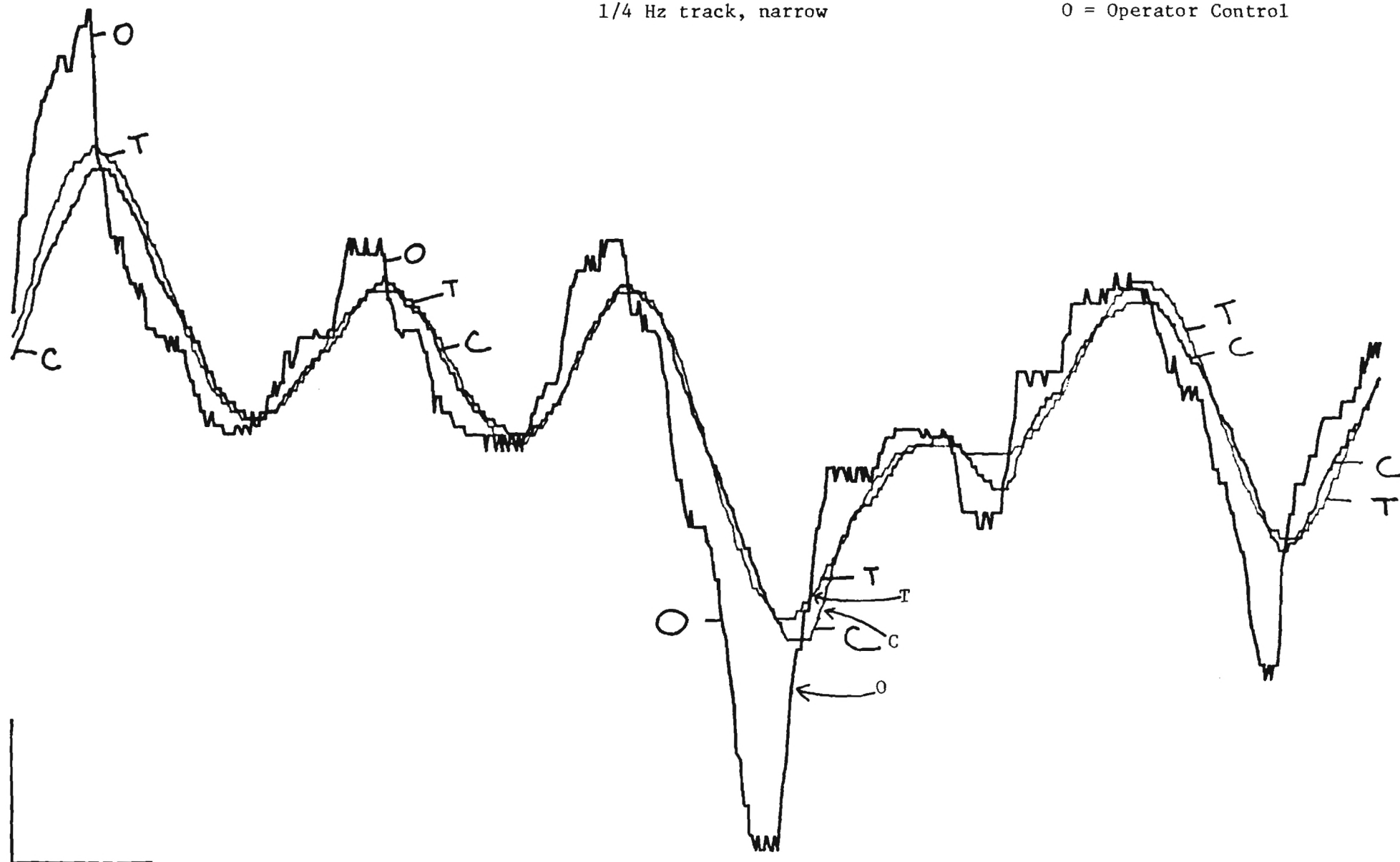
OLD HOPE
BM Op 1123
RMS = 7.03

Model 16
Points 2001-2500
1/4 Hz track, narrow

T = Track
C = Cursor
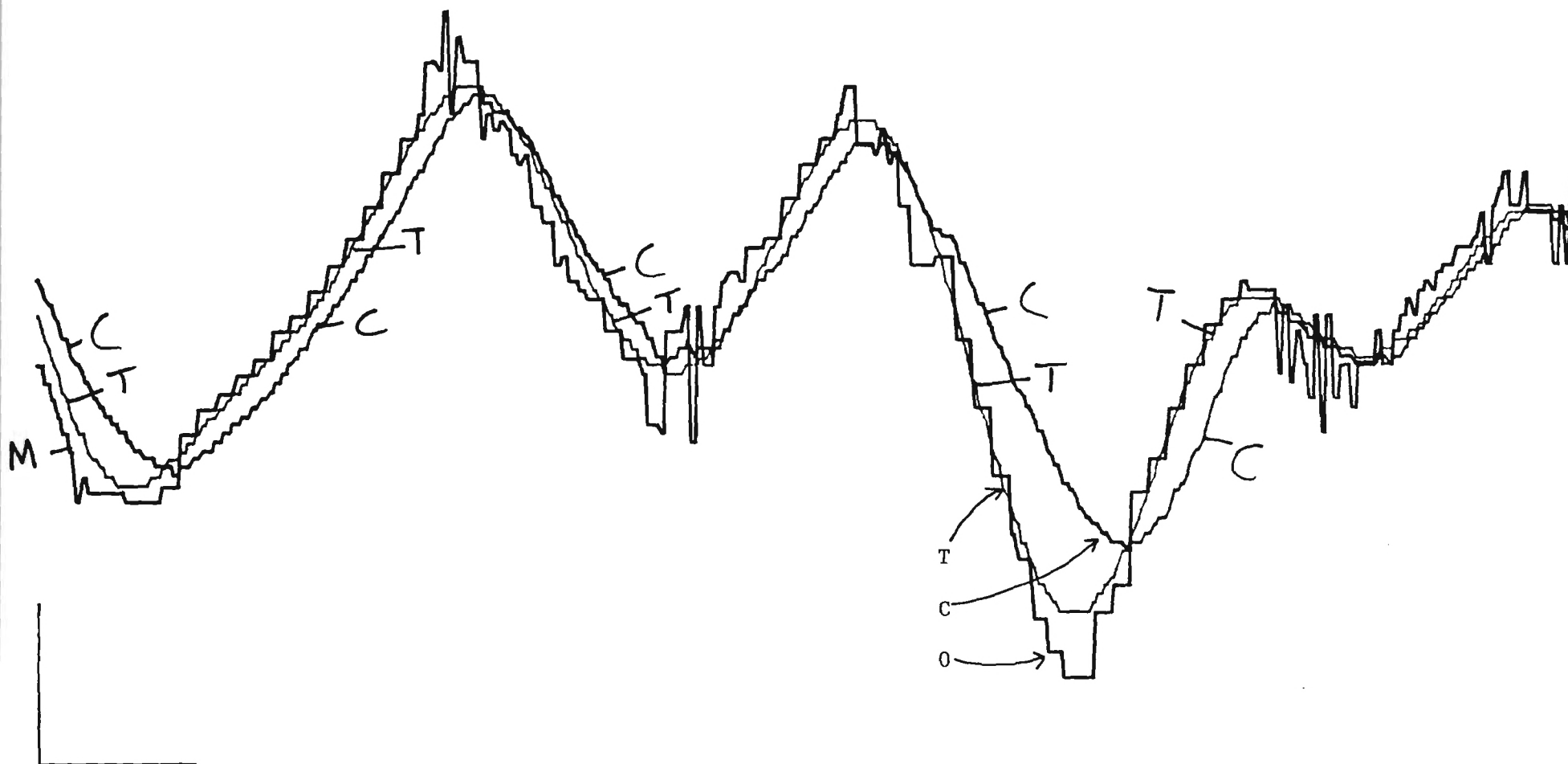O = Operator Control
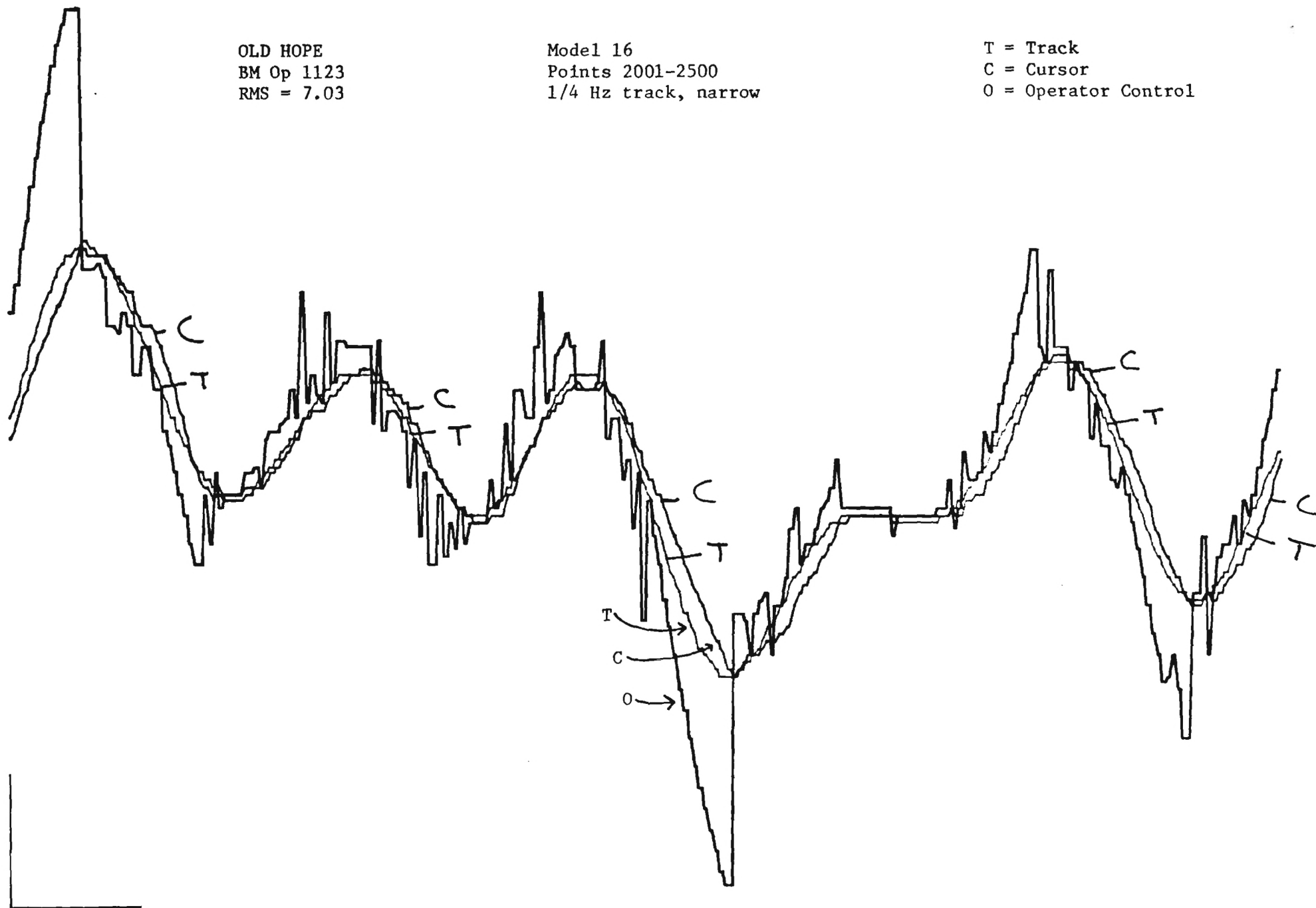
NEW HOPE
Best Match
RMS = 5.72

Model 23
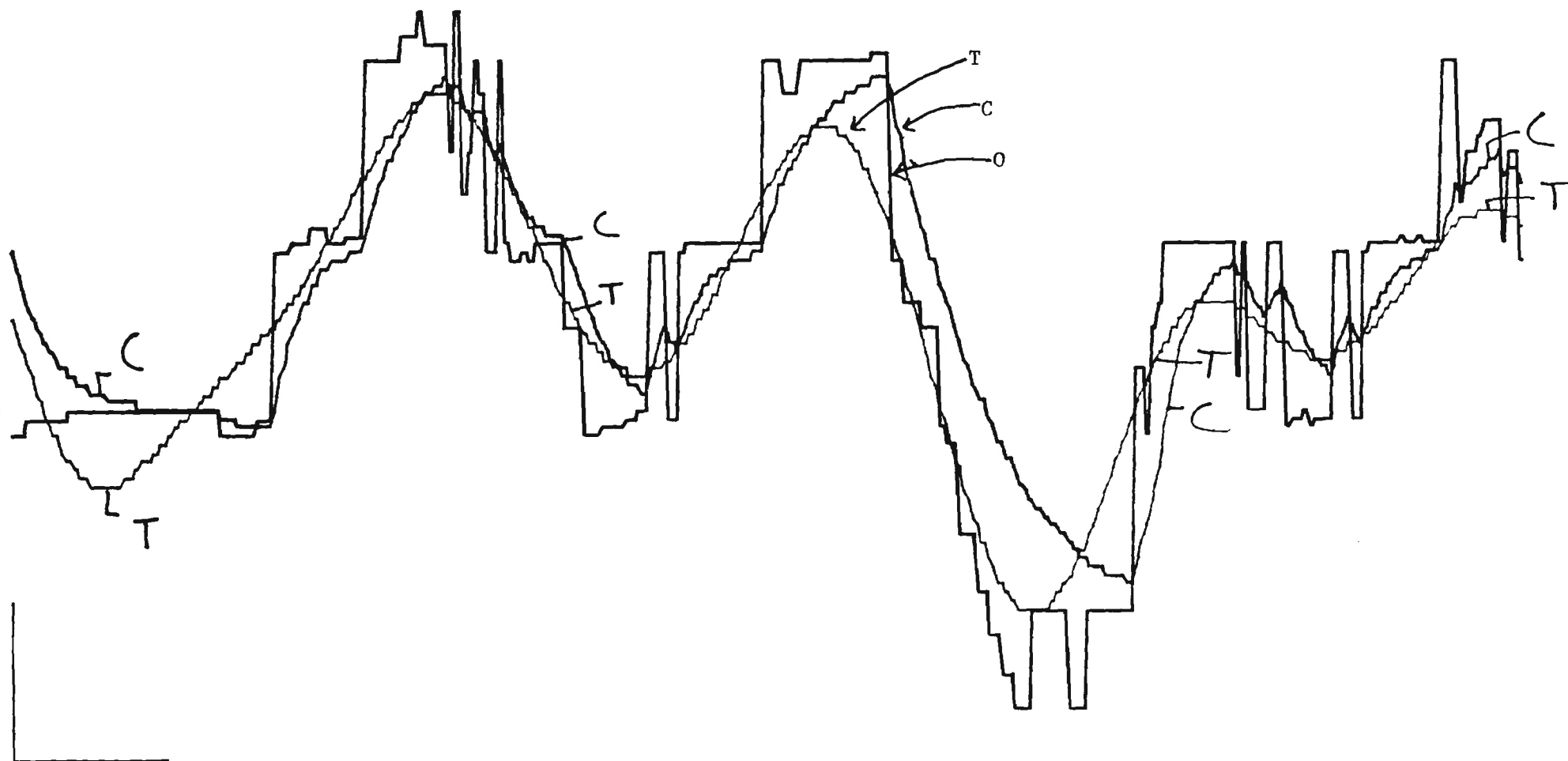Points 7001-7500
1/4 Hz track, narrow

T = Track
C = Cursor
O = Operator Control
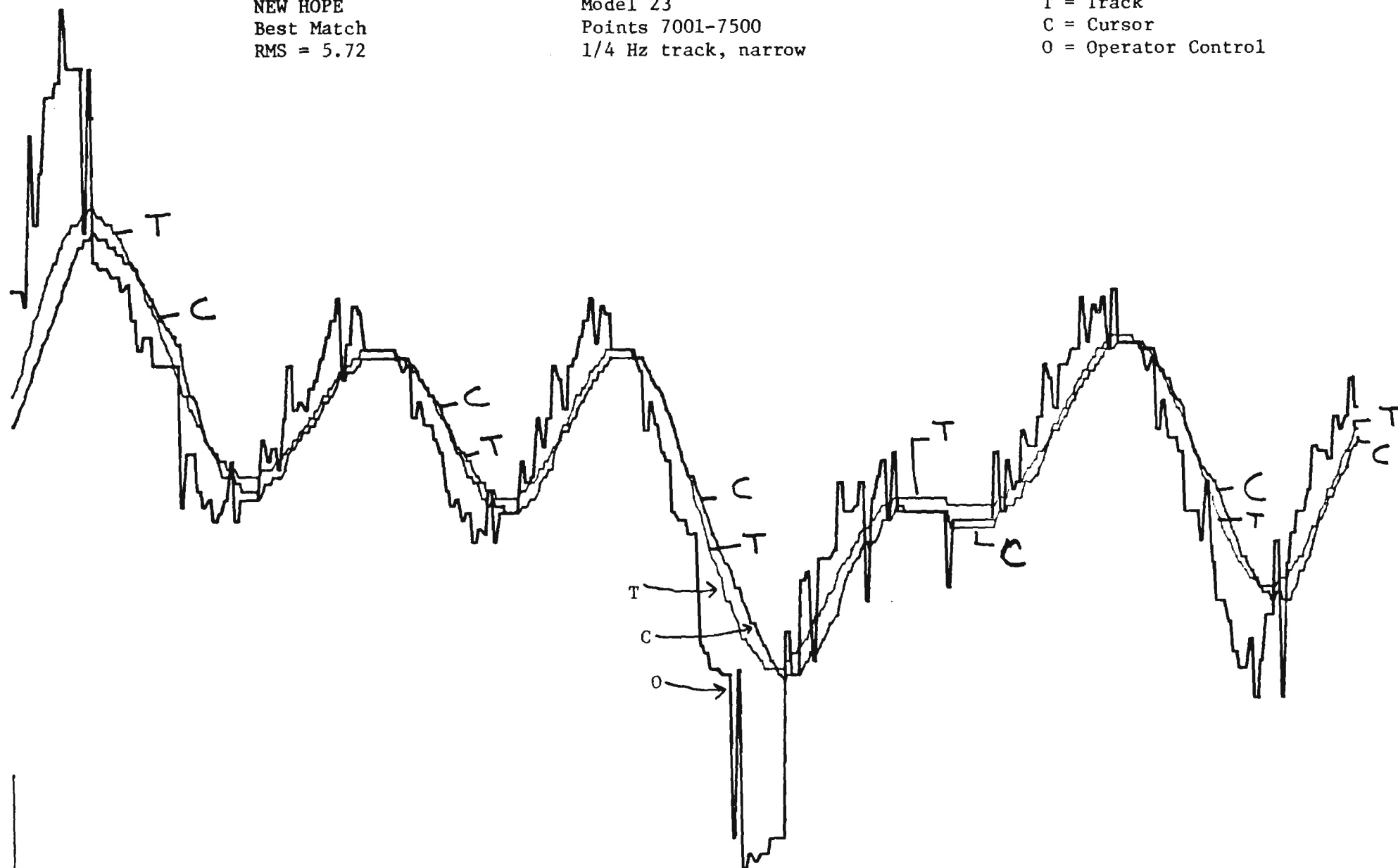
OLD HOPE
RMS = 7.95

Model 23
Points 7001-7500
1/4 Hz track, narrow
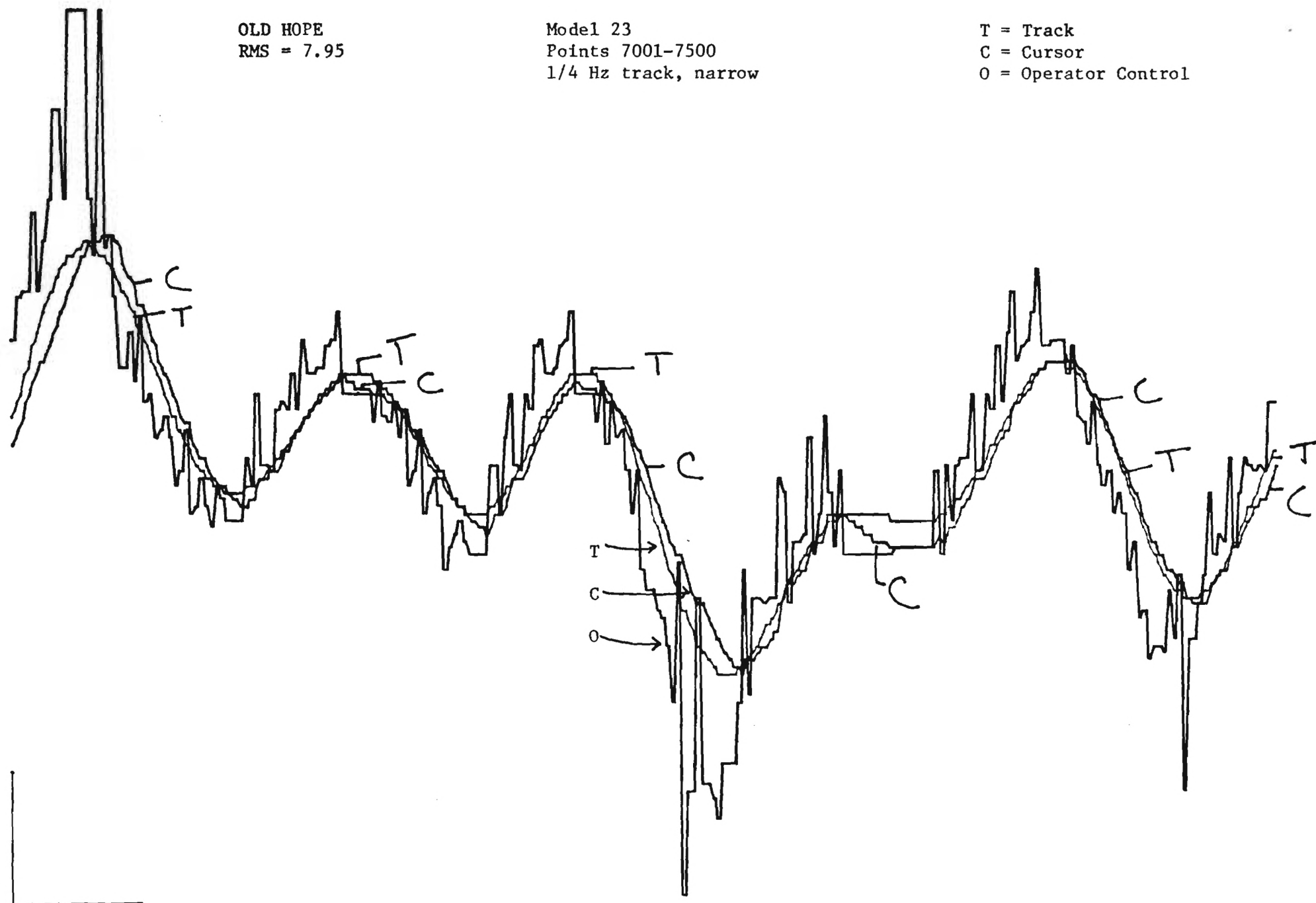
T = Track
C = Cursor
O = Operator Control

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS

AND BEST-FIT MODEL CONTROL STICK RECORDS

1/4 Hz Track, Narrow Guidelines

Refined HOPE

Number of bins (20 seconds) out of 59 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment

```
OP ID=1111 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.06  TR2 AVE= 2.56  TR3 AVE= 2.09  TR4 AVE= 2.02  TR5 AVE= 1.91    TOT AVE= 2.13
OP ID=1112 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.22  TR2 AVE= 2.08  TR3 AVE= 2.06  TR4 AVE= 2.25  TR5 AVE= 1.98    TOT AVE= 2.12
OP ID=1113 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.26  TR2 AVE= 2.17  TR3 AVE= 2.20  TR4 AVE= 1.94  TR5 AVE= 2.02    TOT AVE= 2.12
OP ID=1114 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.15  TR2 AVE= 2.32  TR3 AVE= 2.05  TR4 AVE= 2.13  TR5 AVE= 1.98    TOT AVE= 2.13
OP ID=1121 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 1.78  TR2 AVE= 1.79  TR3 AVE= 1.81  TR4 AVE= 1.87  TR5 AVE= 1.87    TOT AVE= 1.83
OP ID=1122 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.27  TR2 AVE= 2.09  TR3 AVE= 2.06  TR4 AVE= 2.11  TR5 AVE= 2.15    TOT AVE= 2.14
OP ID=1123 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.24  TR2 AVE= 2.03  TR3 AVE= 1.88  TR4 AVE= 2.46  TR5 AVE= 2.00    TOT AVE= 2.12
OP ID=1124 HAS 59 BINS WITH RMS <=  7.48    TR1 AVE= 2.20  TR2 AVE= 1.77  TR3 AVE= 1.88  TR4 AVE= 1.95  TR5 AVE= 1.98    TOT AVE= 1.96
```

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS
AND BEST-FIT MODEL CONTROL STICK RECORDS

1/4 Hz Track, Wide Guidelines
Refined HOPE

Number of bins (20 seconds) out of 50 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
OP ID=1211 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 1.71 TR2 AVE= 1.66 TR3 AVE= 1.64 TR4 AVE= 1.60 TR5 AVE= 1.49	TOT AVE= 1.62
OP ID=1212 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 2.18 TR2 AVE= 2.31 TR3 AVE= 2.10 TR4 AVE= 1.79 TR5 AVE= 2.04	TOT AVE= 2.08
OP ID=1213 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 1.91 TR2 AVE= 1.67 TR3 AVE= 1.76 TR4 AVE= 1.72 TR5 AVE= 1.65	TOT AVE= 1.74
OP ID=1214 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 2.06 TR2 AVE= 1.60 TR3 AVE= 1.53 TR4 AVE= 1.52 TR5 AVE= 1.47	TOT AVE= 1.64
OP ID=1221 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 1.85 TR2 AVE= 1.86 TR3 AVE= 1.73 TR4 AVE= 1.76 TR5 AVE= 1.69	TOT AVE= 1.78
OP ID=1222 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 2.06 TR2 AVE= 1.88 TR3 AVE= 1.71 TR4 AVE= 1.87 TR5 AVE= 1.70	TOT AVE= 1.84
OP ID=1223 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 1.69 TR2 AVE= 1.46 TR3 AVE= 1.60 TR4 AVE= 1.59 TR5 AVE= 1.61	TOT AVE= 1.59
OP ID=1224 HAS 60 BINS WITH RMS <= 7.48	TR1 AVE= 2.01 TR2 AVE= 1.86 TR3 AVE= 1.82 TR4 AVE= 1.65 TR5 AVE= 1.65	TOT AVE= 1.80

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS
AND BEST-FIT MODEL CONTROL STICK RECORDS

1/2 Hz Track, Narrow Guidelines
Refined HOPE

Number of bins (20 seconds) out of 59 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
_OP_ID=2111 HAS 24 BINS WITH RMS <= 7.48	TR1 AVE= 7.85 TR2 AVE= 7.28 TR3 AVE= 7.68 TR4 AVE= 7.46 TR5 AVE= 6.81	TOT AVE= 7.42
_OP_ID=2112 HAS 48 BINS WITH RMS <= 7.48	TR1 AVE= 5.38 TR2 AVE= 6.88 TR3 AVE= 5.85 TR4 AVE= 6.45 TR5 AVE= 5.93	TOT AVE= 5.98
_OP_ID=2113 HAS 56 BINS WITH RMS <= 7.48	TR1 AVE= 4.25 TR2 AVE= 4.62 TR3 AVE= 4.63 TR4 AVE= 4.77 TR5 AVE= 4.38	TOT AVE= 4.53
_OP_ID=2114 HAS 41 BINS WITH RMS <= 7.48	TR1 AVE= 7.42 TR2 AVE= 6.99 TR3 AVE= 7.48 TR4 AVE= 6.15 TR5 AVE= 6.36	TOT AVE= 6.86
_OP_ID=2121 HAS 58 BINS WITH RMS <= 7.48	TR1 AVE= 5.65 TR2 AVE= 4.90 TR3 AVE= 5.16 TR4 AVE= 5.85 TR5 AVE= 5.85	TOT AVE= 5.16
_OP_ID=2122 HAS 39 BINS WITH RMS <= 7.48	TR1 AVE= 6.41 TR2 AVE= 7.46 TR3 AVE= 5.98 TR4 AVE= 6.18 TR5 AVE= 6.76	TOT AVE= 6.56
_OP_ID=2123 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 4.11 TR2 AVE= 4.58 TR3 AVE= 4.69 TR4 AVE= 4.68 TR5 AVE= 4.95	TOT AVE= 4.57
_OP_ID=2124 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 4.26 TR2 AVE= 4.49 TR3 AVE= 4.74 TR4 AVE= 4.52 TR5 AVE= 4.42	TOT AVE= 4.49

RMS DIFFERENCES IN CENTIMETERS BETWEEN HUMAN SUBJECTS

AND BEST-FIT MODEL CONTROL STICK RECORDS

1/2 Hz Track, Wide Guidelines

Refined HOPE

Number of bins (20 seconds) out of 50 in which matching criterion was met	Trial by trial average differences	Averages for whole experiment
OP ID=2211 HAS 50 BINS WITH RMS <= 7.48	TR1 AVE= 5.83 TR2 AVE= 4.58 TR3 AVE= 4.54 TR4 AVE= 4.41 TR5 AVE= 4.34	TOT AVE= 4.74
OP ID=2212 HAS 54 BINS WITH RMS <= 7.48	TR1 AVE= 5.87 TR2 AVE= 5.92 TR3 AVE= 5.38 TR4 AVE= 5.28 TR5 AVE= 5.58	TOT AVE= 5.43
OP ID=2213 HAS 56 BINS WITH RMS <= 7.48	TR1 AVE= 3.62 TR2 AVE= 3.73 TR3 AVE= 4.18 TR4 AVE= 3.87 TR5 AVE= 5.08	TOT AVE= 4.06
OP ID=2214 HAS 58 BINS WITH RMS <= 7.48	TR1 AVE= 5.49 TR2 AVE= 5.28 TR3 AVE= 4.17 TR4 AVE= 4.38 TR5 AVE= 3.64	TOT AVE= 4.56
OP ID=2221 HAS 56 BINS WITH RMS <= 7.48	TR1 AVE= 4.63 TR2 AVE= 4.58 TR3 AVE= 5.19 TR4 AVE= 5.18 TR5 AVE= 4.25	TOT AVE= 4.75
OP ID=2222 HAS 59 BINS WITH RMS <= 7.48	TR1 AVE= 3.62 TR2 AVE= 3.01 TR3 AVE= 3.16 TR4 AVE= 3.46 TR5 AVE= 3.93	TOT AVE= 3.44
OP ID=2223 HAS 58 BINS WITH RMS <= 7.48	TR1 AVE= 4.25 TR2 AVE= 3.83 TR3 AVE= 3.71 TR4 AVE= 3.63 TR5 AVE= 3.74	TOT AVE= 3.83
OP ID=2224 HAS 55 BINS WITH RMS <= 7.48	TR1 AVE= 3.79 TR2 AVE= 4.94 TR3 AVE= 5.43 TR4 AVE= 5.66 TR5 AVE= 5.41	TOT AVE= 5.05

NEW HOPE
Best Match RMS = 9.64

Model 24
Points 4001-4500
1/2 Hz track, wide

T = Track
C = Cursor
O = Operator Control
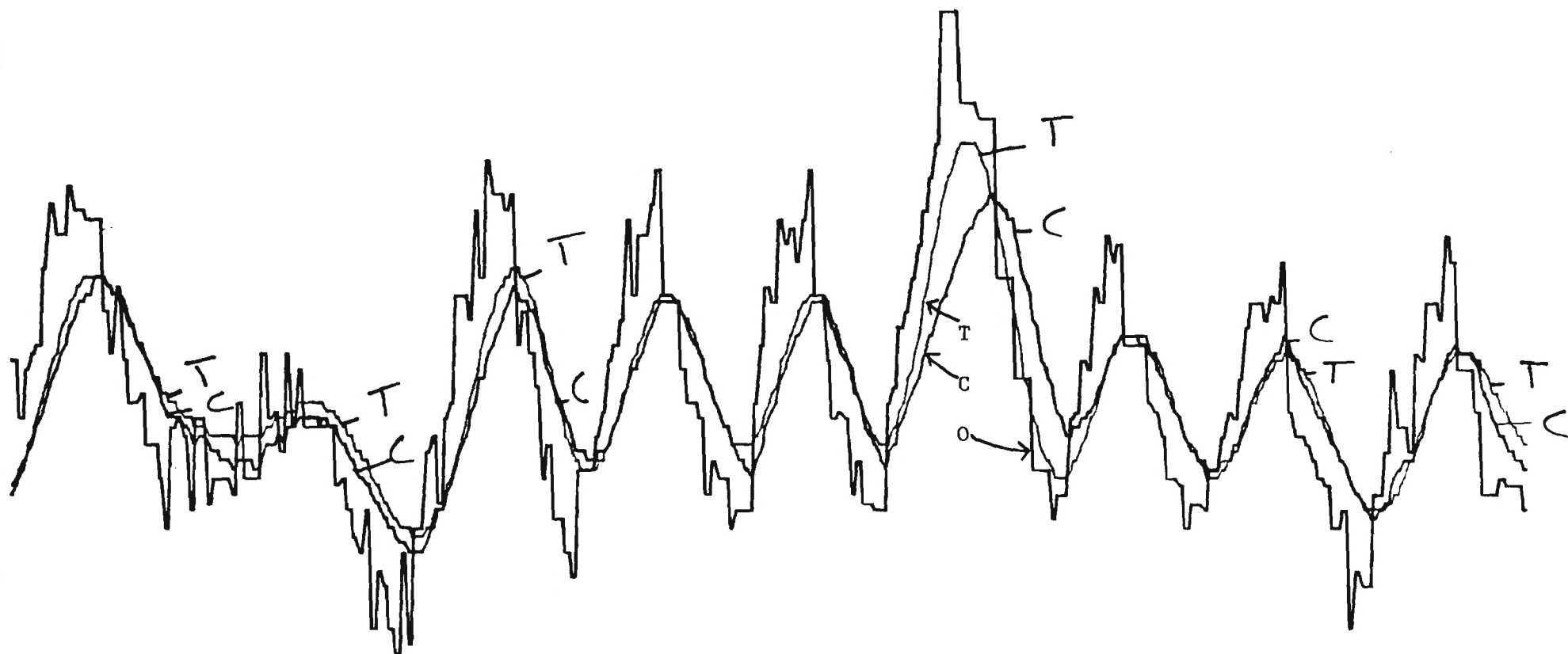
OLD HOPE

Model 29
Points 4001-4500
1/2 Hz track, wide

T = Track
C = Cursor
O = Operator Control
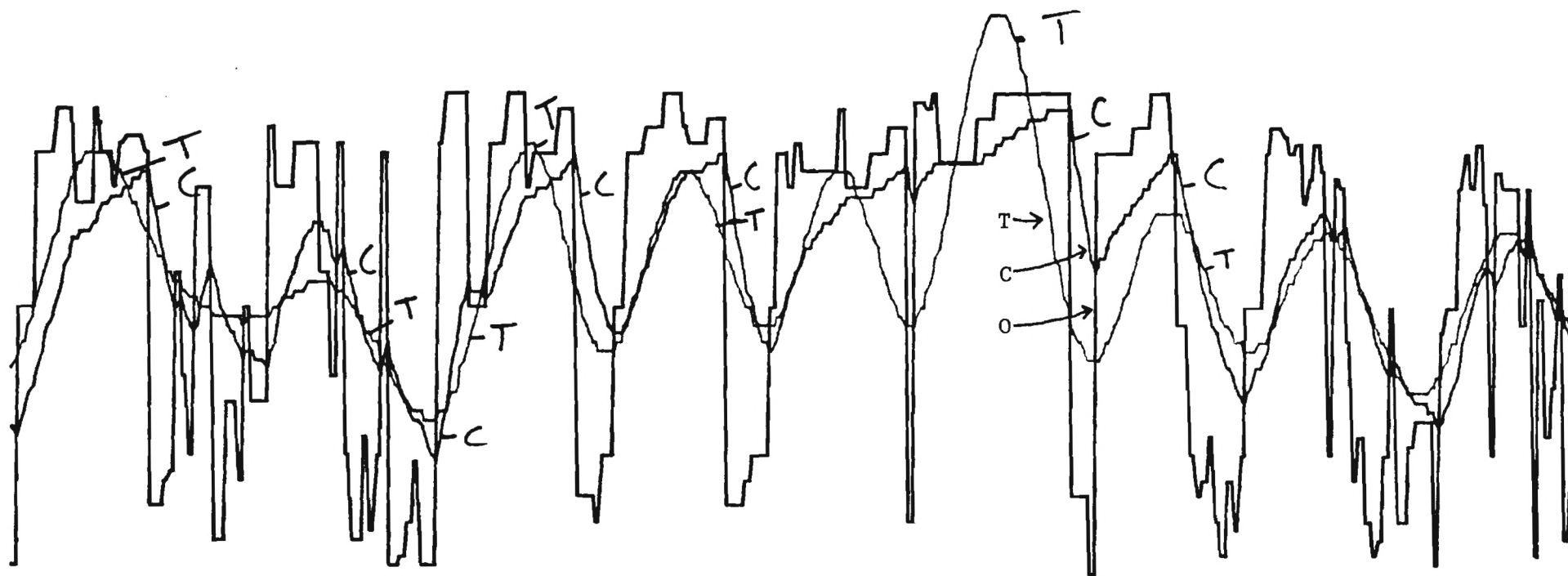
OLD HOPE
Best Match RMS = 11.86

Model 46
Points 4001-4500
1/2 Hz track, wide

T = Track
C = Cursor
O = Operator Control
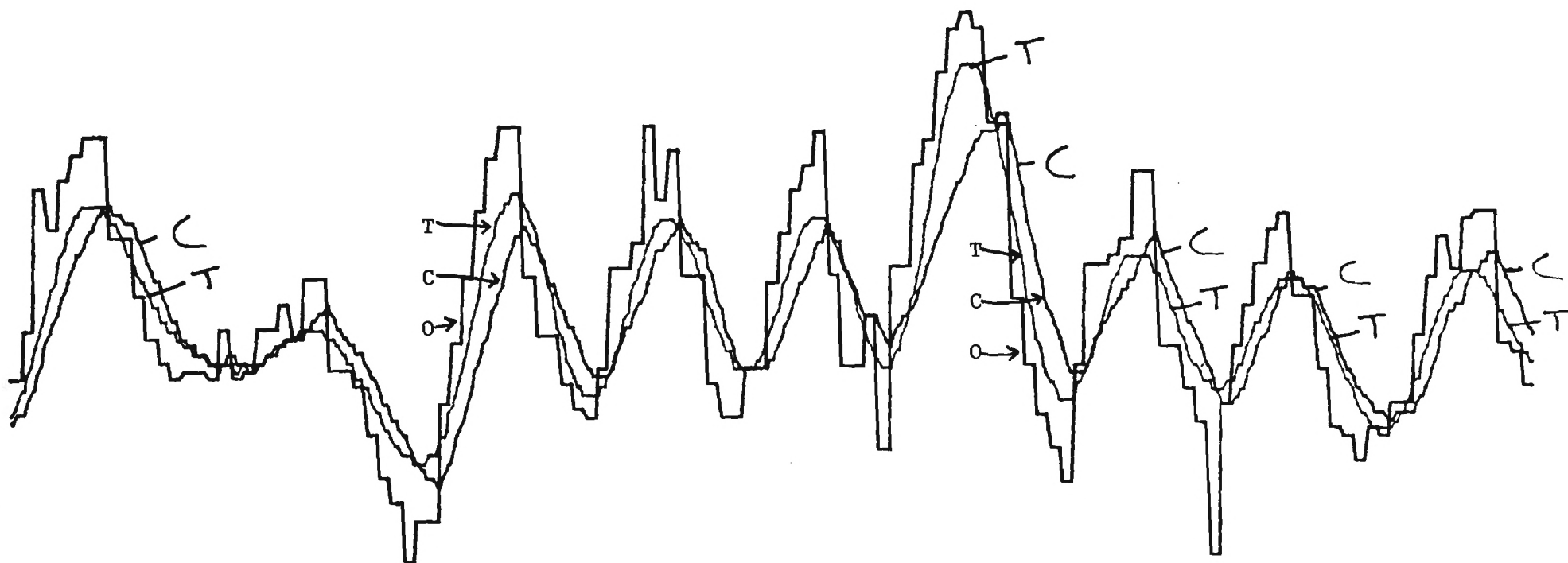
Operator 2224
1/2 Hz track, wide
Points 4001-4500

T = Track
C = Cursor
O = Operator Control
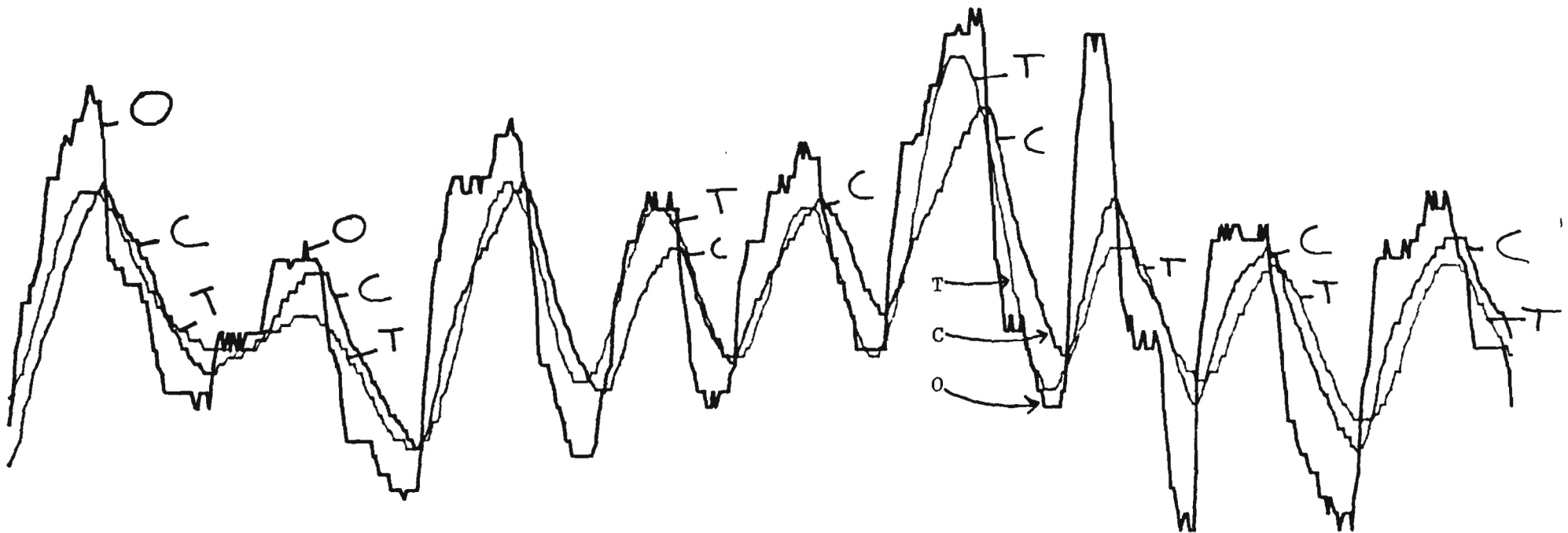
VII. RECOMMENDATIONS

A. Installation of Optional Additional Diagnostics and Graphics Display
    Capability in HOPE

B. Inclusion of Internal Plant Model in HOPE

C. Examination of RMS Measure

    1. Reduction of fitting interval

    2. Study of RMS response to various perterbations from exact signal

    3. Refinement of criterion for acceptable matching

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

April 28, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R & D Status Report No. 1
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator, the way it changes as a function of training and task variables, and the relationships between control strategy and cue utilization.

During the first period (April 1 through April 30), the following activities have been carried out: organizational meetings have been conducted with the project staff as a whole, and with key task leaders individually; milestone dates have been set (attached); technical discussions have been held at Wright-Patterson; a graduate research assistant has been selected from four candidates; and the review and summary of human performance characteristics has begun, based on the reference lists in the RFP and the proposal. Additional sources of information have been identified, with the help of the project engineer and the Georgia Tech project staff. Particularly promising seem to be the modelling approaches of J. A. Adams, E. C. Poulton, and Ward Edwards, although these remain to be reviewed in depth.

During the second period, approximately 60 articles will be reviewed and abstracted; at least three staff meetings will be held to review important findings, and telephone contact with the technical monitor will be maintained.

Respectfully submitted.

Esther Lee Burks
Project Director

HUMAN OPERATOR CONTROL STRATEGY MODEL

TASKS AND LEADERSHIP ASSIGNMENTS: COMPLETION DATES

Task I: Review/Summary of Human Performance
             Characteristics: Burks: June 30, 1977

Task II: Development of Operational Definition of Control Strategy and
             Specification of Theory: Ronan: August 13, 1977

Task III: Development of Model: Gagliano: September 30, 1977

Task IV: Test Design, Implementation and Data Collection:
             March 15, 1978

Task V: Analysis and Recommendations: Burks: April 30, 1978

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

May 30, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH   45433

<div align="right">

Subject: R & D Status Report No. X2
"Human Operator Control
Strategy Model:
GTRI Project A-1979

</div>

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator, the way it changes as a function of training and task variables, and the relationships between control strategy and cue utilization.

During the second period (May 1 through May 31), the following activities have been carried out: the review and summary of human performance characteristics has been continued. Approximately 30 items have been summarized for consideration by team members, and copies of these summaries are being mailed to you under separate cover. An in-depth discussion of promising theories relating to human perceputal-motor skill learning is being prepared.

During the next period, the review of performance characteristics will be continued, and a report on theories of skill learning will be completed and mailed to the sponsor. Telephone contact with the technical monitor will be maintained, and a mid-July date for a second set of technical discussions will be confirmed.

<div align="right">

Respectfully submitted,

Esther Lee Burks
Project Director

</div>

ELB/kf

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

July 5, 1977

Air Force Human Resources Laboratory
Attn: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH   45433

Subject: R&D Status Report No. 3
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Ms. Knoop:

The purpose of project A-1979 is to develop and perform preliminary
tests of a model of the control strategy (ies) developed and applied by a
human operator in the course of learning a manual control task. The main
purpose of the model shall be to characterize and predict the control
strategy used by a human operator, the way it changes as a function of
training and task variables, and the relationships between control strat-
egy and cue utilization.

During the third period (June 1 through June 30), the following
activities have been carried out: the major portion of the originally
planned literature review has been completed and an initial cut at a model
of the learning process has been created and presented to the project team
for discussion.

During the fourth period, the foregoing activities will be continued
and expanded upon; and some preliminary results will be presented to the
project engineer from AFHRL.

Randall Chambers, Task IV leader, has taken a one year leave of absence
from Georgia Tech, and will be unavailable to the project. His time on the
project will be replaced by Harold Engler and W.F. Sears, of the Systems
Engineering Division, EES.

Respectfully submitted.

Esther Lee Burks
Project Director

kf

GTEES ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 1, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH   45433

Subject: R & D Status Report No. 4
"Human Operator Control
Strategy Model:
GTRI Project A-1979

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator, the way it changes as a function of training and task variables, and the relationships between control strategy and cue utilization.

During the fourth period (July 1 through July 29), the following activities have been carried out: the level of effort in the literature search has been significantly reduced; a theory and model of human motor skill learning has been proposed and discussed; and initial control strategy definitions have been presented and discussed among the group.

Work on definition and operationalization of control strategy will be pursued during the coming month.

Respectfully submitted,

Esther Lee Burks
Project Director

kf

A-19L

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

September 1, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F 33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Subject: R&D Status Report No. 5 "Human Operator Control Strategy Model":
          GTRI Project A-1979

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary
tests of a model of the control strategy developed and applied by a human
operator in the course of learning a manual control task. The main pur-
pose of the model shall be to characterize and predict the control strategy
used by a human operator, the way it changes as a function of training
and task variables, and the relationships between control strategy and
cue utilization.

During the fifth period (August 1 through August 31), the following
activities have been carried out: the literature search has been completed
and a draft review written, further work on the programming aspects of
the Engler-Sears model has been carried out; and the project director has
submitted a proposed definition of control strategy to the project team
for written comment.

In the coming month, the following events are anticipated: the project
director will be away until September 15; computer records of learning
under varying task difficulties will be generated from the Engler-Sears
model; and work will continue on the refinement of the theory and model
being developed.

Respectfully submitted,

Esther Lee Burks
Project Director

ELB:ae

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 14, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F 33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Subject: R&D Status Report No. 6 "Human Operator Control Strategy
Model" GTRI Project A-1979

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary
tests of a model of the control strategy developed and applied by a human
operator in the course of learning a manual control task. The main pur-
pose of the model shall be to characterize and predict the control strategy
used by a human operator, the way it changes as a function of training
and task variables, and the relationships between control strategy and cue
utilization.

During the sixth period (September 1 through September 30) the following
activities have been carried out: preliminary testing of the implemented model
with respect to variation in task difficulty, development of effective ways to
plot the output from the model; discussion of a definition of control strategy
in terms of the relationship between human traits and learning performance.
This latter definition seems to be static in nature, and not suitable for a
dynamic simulation of human learning.

During the seventh period, the project team will plan a visit to Wright-
Patterson for the purpose of summarizing the results of the first three tasks
in the project.

Respectfully submitted,

Esther Lee Burks
Project Director

ELB:ae

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 14, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F 33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Subject: R&D Status Report No. 7   "Human Operator Control Strategy Model":
            GTRI Project A-1979

Dear Ms. Knoop:

The purpose of Project A-1979 is to develop and perform preliminary
tests of a model of the control strategy developed and applied by a human
operator in the course of learning a manual control task. The main purpose
of the model shall be to characterize and predict the control strategy used
by a human operator, the way it changes as a function of training and task
variables, and the relationships between control strategy and cue utilization.

During the seventh period (October 1 through October 31) the following
activities have been carried out: extensive project team discussions regarding
the appropriate behavioral and trait measures necessary for characterization of
the parameters in the learning model; further discussion of the contrasting ap-
proaches to defining control strategy proposed by various team members -- i.e.
a specified decision sequence, a trait-behavior correlation matrix, a pattern
recognition ability, or an ability to organize new algorithms; and a consider-
ation of the appropriate tracking task for implementation.

During November, it is anticipated that a selection of hypotheses to
be tested will be made with the assistance of the program manager, and a pre-
linimary testing plan will be presented.

Respectfully submitted,

Esther Lee Burks
Project Director

ELB:ae

A-1979

ENGINEERING EXPERIMENT STATION
Technology & Development Laboratory
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

December 15, 1977

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests
of a model of the control strategy (ies) developed and applied by a human
operator in the course of learning a manual control task. The main purpose
of the model shall be to characterize and predict the control strategy used
by a human operator, the way it changes as a function of training and task
variables, and the relationships between control strategy and cue utilization.

During the eighth period (November 1 through November 30), the following
activities have been carried out: Three team members visited Wright-
Patterson for the purpose of presentation and discussion of Tasks I, II, and
III. The meetings occupied most of two days. Follow-up work has included
a modification of the present version of the model to include the effect of
actual performance relative to a criterion on observing behavior. In
addition, the definition of control strategy has been expanded to include
the selection of a control pattern. The task for subsequent testing has
been defined as a one-dimensional preview tracking task, with a secondary
task presented at intervals on the same CRT as the track. Task difficulty
can be varied by controlling the rate of presentation, as well as the
complexity of the track. Different criterion functions can be implemented
through precise instructions to subjects.

Plans for December include refinement of test design in order to make a
specific proposal to AFHRL regarding equipment and analysis procedures in
January.

Respectfully submitted,

Esther Lee Burks
Project Director

hb
Enclosures

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

January 17, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator, the way it changes as a function of training and task variables, and the relationships between control strategy and cue utilization.

During the ninth period (December 1 through December 23), the following activities were carried out: Discussions of alternative means of model validation were held. A decision was made to propose an alternative means of identifying control strategy as it changes over time in the course of learning a one-dimensional tracking task. The validation of the identifiable control strategy concept and parameters remains the focus of the test design, although comparison of actual model output with output of the human operator is also of importance. The methodology proposed should allow both. Because of these discussions (and associated proposal-writing) and the short work month, only a low level of effort was charged to the project budget; and presentation of the test design to Wright-Patterson personnel was postponed until February.

January activities include preparation of the literature-theory briefing for February, and final experiment design.

Respectfully submitted,

Esther Lee Burks
Project Director

ae

ENCLOSURE

An Equal Employment/Education Opportunity Institution

GTEES ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

March 9, 1978

10th

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests
of a model of the control strategy (ies) developed and applied by a human
operator in the course of learning a manual control task. The main purpose
of the model shall be to characterize and predict the control strategy used
by a human operator, the way it changes as a function of training and task
variables, and the relationships between control strategy and cue utilization.

During the 10th period (January 1 through January 31), the following activities
were carried out:

> Preparation of a literature-theory briefing
> Selection of a set of hypotheses to be tested
> Selection of a transfer paradigm for testing of the hypotheses
> Review with Dr. Dar Hunt, as potential consultant on the project.

Weather problems in Ohio and Georgia caused delay of the briefing to February 15.
February activities center around final decisions on the test and implementation.

Respectfully submitted,

Esther Lee Burks
Project Director
Technology and Development Laboratory

ae

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

March 31, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report No. 11
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator as it changes as a function of training and task variables.

During the month of February, considerable technical progress was made on the project. The focus of the month, as you know, was on the technical discussions of 2/14/78 between AFHRL's Knoop and Reed, and the Georgia Tech team of Burks, Sears, Engler, and Hunt. During the course of that meeting, during preparations for it, and discussions in its after-math, decisions were made regarding the hypotheses to be tested in the experiment, on an innovative way to operationalize the difference between the model and human output (mean square state vector), on a way to classify differences as small (via an estimation of the natural variability of each individual subject), and on an experimental design using a transfer paradigm, in which an investigation will be made of the effects on control strategy of changing from one type of plant to another. Ideas regarding a means to measure individual differences in resolution were also discussed.

Respectfully submitted.

Esther Lee Burks
Project Director

ELB:ae

An Equal Employment/Education Opportunity Institution

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

March 31, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

<div align="right">

Subject: R&D Status Report No. 12
"Human Operator Control
Strategy Model"
GTRI Project A-1979
</div>

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator as it changes as a function of training and task variables.

During the month of March, 1978, the following activities were carried out. Equipment on which to run the proposed experiments was ordered, after a presentation to EES management on the importance of doing the testing here where the whole team can be present. A decision was made, with your approval, to run the tests here. Work was begun on video taping the model performance for presentation of the "1979 Review of Air Force Basic Research . . ." on April 18, 1978, and an abstract was prepared for the proceedings of that meeting. Considerable progress was made on the project in an operational sense, in that barriers to further progress were removed; but very little technical progress occurred, due primarily to the absence of three of the team members during much of this month. It is anticipated that the month of April will be devoted largely to concentrated effort on the technical aspects of this project.

Respectfully Submitted,

Esther Lee Burks
Project Director

ELB:ae

An Equal Employment/Education Opportunity Institution

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

May 4, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report No. 13
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary
tests of a model of the control strategy (ies) developed and applied by
a human operator in the course of learning a manual control task. The
main purpose of the model shall be to characterize and predict the control
strategy used by a human operator as it changes as a function of training
and task variables.

During the month of April, the following activities were carried out:

(1) The 20 minute presentation for the 1978 Review of Air Force-
Sponsored Basic Research in Flight and Technical Training was prepared.
A copy of this is attached.

(2) A proposed sequence of validation experiments was developed. A
copy of this is attached.

(3) The computer simulation was modified to improve its fidelity to
human cognitive processes.

The major modification is the conception of the human as a limited
capacity processer -- that is, even in a one-dimensional task, multiple
cognitive processes must be coordinated -- command generation, observation
of the task, command execution, learning or remembering. Each process
is assumed to take some (not necessarily equal) amount of time, and the
interchanges of information among the processes then become dependent on
the instantaneous state of these processes. We are assuming, for example,
that if a subject observes the task and notes that his error is unacceptably
large, but a command based on an earlier prediction is already in execution,
a certain amount of time must elapse before a correction to that error can
be dealt with. Assuming separate time constraints for the various processes
will result in occasional mistakes in storage of data, with resulting errors
in performance. The perception time may be 50 msec; the command operative

time 200 msec (depending on the task and on physiological limits). There
exists the possibility then, that an observation may occur before the full
effect of a command is attained, and the memory for the effects of a given
command will be subject to inaccuracy.

The modifications also include allowing the human to compare his achieved
results with his predictions. When this comparison shows inaccurate predictions,
the internal model of the process being controlled (the Predictive Response
Memory) is modified. When actual and desired position are 'close', a stored
command string may continue to build up. Thus a reserve capacity is accrued
with learning and a stable environment. These two comparisons are in accord
with theory and research on motor skills and divided attention, and their
implementation should result in more life-like performance on the part of
the model.

(4) The project team attended both the Review mentioned above, and the
Sixth Annual Symposium on Psychology in the D.O.D. Charges for time spent,
but not travel funds, were taken out of the project.

(5) Specifications for the CRT equipment were made final; and the equip-
ment was ordered for a delivery date of early July.

May activities include the further refinement of the model, finalization
of the experimental design and analysis procedures, and initial work on the
final report of the project.

Respectfully submitted,

Lee Burks
Project Director

ae

May 3, 1978

Technical Memorandum
TM-A-1979-000-8
TO: A-1979 File
FROM: Lee Burks
SUBJECT: 1978 Review Presentation
        Colorado Springs

This presentation stems from the initial phases of an ongoing contract
with Human Resources Lab at WPAFB.

The aspects of the research to be discussed here include a brief
description of the problem addressed, features of the approach taken, a
video tape of a simulation of human learning behavior, and our proposed
solution to one of the problems raised by our need to validate the approach.

In relatively specific terms, the goals of the research program are
the following: we want to devise a measurement system (to include defined
concepts, measures, methods of data acquisition) to provide researchers with
data characterizing the behavior of a human operator learning a tracking
task. The measurements taken should be able to differentiate within and among
individuals at differing skill levels, be sensitive to change in task or
environmental conditions, and provide a predictive ability with respect
to the behavior of individuals in transfer to different situations.

The approach to those demands that is taken in this research effort is to
simulate the process that produces tracking data: the human psycho-motor
learning process. Our first step toward this simulation was to create a paper
model, a theory of psycho-motor learning, based upon available psychological
data relating to learning of psycho-motor skills, and human tracking behavior.
It is also based on logical deduction and even on introspection.

We have attempted to create a content-valid model which uses processes be-
lieved to be those used by human beings --processes such as association, re-
sponsiveness to feedback, predictive capacity, development of 'schema', or
learned relationships among internal and external states and desired outcomes,
generalization of learned skills to novel situations, and goal orientation.

Controlling parameters in a computer program which correspond to
processes we term control strategies in the human, can easily be obtained
and manipulated.

Our measurement system is then based on the premise that when we identify the best fitting simulation models of the learning process for a given individual, the values of the controlling parameters for the model give us insight into the control strategies being used by the human operator.

Thus a plausible fiction has been created -- plausible because it is in large part data-based and fiction because it has yet to be empirically tested.

A simplified version of the theory has been realized as a computer program, and the culmination of the first phase of this research will be the experimental testing.of the validity of that simulation. The measures taken from the model will include not only output values, but also controlling parameter values that are identified with what we defined as 'control strategy'. Briefly put, control strategy is defined here as the criteria applied by the operator to evaluate his own actual and predicted performance, and the utilized pattern of perception and cue utilization. The parameters in the simulation that control these two aspects include values for the command string length necessary for leaving the task and the criterion utilized to evaluate the operator's actual and predicted performance. Measures of the parameters for the model that fits an individual are what we propose as sensitive measures of the progress being made by an individual learning a tracking task.

The simulations implemented in this year's work are of fixed control strategies, and a main output from the contract will be the experimental testing of first the existence of, and second the changes in, control strategies used by an individual, as they change as a function of both the course of learning itself and of changes in task variables. Our view is that control strategy is environmentally determined and therefore manipulable.

Our goals for the future include creation of a simulation of the h.o. in which not only an effector and task dynamics are learned, but also one in which control strategies themselves are learned interactively with the simulated environment, and in which prediction of performance in transfer situations may be attained.

In the next few minutes, you'll see a speeded portrayal of the control behavior of our simulated human operator, as he learns to control a plant -- a device - unlike any he has ever controlled before.

Specifically, the task set-up is this: the operator's job is to control the blip on a CRT in such a way as to stay within the bounds of an automatically paced psendo random sinusoidal track which he can see for 3 seconds ahead. So long as he stays within a criterion distance of the center of the track, he switches attention periodically away from the track to something else. The

criterion distance and the attention switching pattern constitute a fixed
pre-learned control strategy.

If he gets out of the criterion bounds, he senses that fact, and he returns
his attention to the tracking task. It always has priority, in this demonstration.
He updates his memories only when he is attending.

The effector is a position control with exponential delay -- in control theory
terms a first order plant with a time constant of two seconds. That is, it
takes the blip on the CRT two seconds to move 63% of the input magnitude.

The simulation of the operator's learning assumes no given mathematical
form for the ffector. He has to build his knowledge of the plant strictly from
data about the states of the plant before and after he executes a given
command, in comparison to the desired state -- the goal.

We've given him no pre learning of this plant, and in the absence of data,
he assumes a zero order plant with no delay.

In the first four frames of the tape you will see the effects of this as-
sumption. His performance is very poor, though fairly smooth, lagging the track
considerably. This is due, of course, to the delay in the effector, which
requires anticipation on his part, something he has not yet learned.

In this next section of the tape, taken from approximately midway through
the learning process, you note that his error is reduced, but his performance is
quite jerky. This seems to be the result of his switching back and forth from
his original habits of assuming a zero order, no delay, plant, and his using
the new information he is acquiring about the characteristics in this plant.

The next two frames are taken from toward the end of the run, and by now he
knows the plant pretty well. His internal representation or schema of that
plant is quite accurate. Here you will note that not only is his performance
again smooth, as it was very early in learning, but is now extremely accurate,
with little or no lag.

You will recall that earlier I described one of the goals of the project as the
identification of the control strategies being used by a human operator in the
course of learning a preview tracking task. In order to do that, we must choose
the simulation that matches human output most closely in each of several
intervals across the learning process. Thus, part of the validation process I
mentioned earlier is the confirmation, across a number of time intervals, of the
hypothesis that the difference between output from some version of model and
human control output is small. The control strategy parameter set that pro-
duces the smallest difference will constitute our estimate of the human's

control strategy for a given time interval. Of interest in this identification process is the difference between C_{HO} and C of each of the distinct models produced by changing the controlling parameter set.

Note that this phase is for the purpose of identifying the strategy being used by the subject, not for the purpose of identifying the optimal strategy for the task. Thus for each of a number of time intervals across the course of the learning process, we will select the control strategy parameter set which produces the smallest average difference between the human control output and the simulation output wave forms. However, within a given averaging interval, the choice among simulations as to which is best may be difficult. For example, the two red lines on the graph represent two distinct simulation outputs - two distinct control strategy parameter sets. Yet the average absolute position error across this interval - a commonly used measure - is the same for the two. An interval error statistic is needed which uses more information than position. The concept of waveform state is useful here. The wave form state at any instant of time is defined as the collection of values representing the absolute magnitude of the waveform's derivatives -- including the zero order derivative, or position.

With a set of these values computed at each time sample within an averaging interval, an average of these absolute values in the interval may be computed. The arithmetic sum of these averages constitutes a measure of the difference between h.o. output and simulation output which is sensitive to more of the available information than is the position error alone. In fact, if the components in the sum were weighted appropriately before summing, one may en- vision an automation of the famous Turing test, which requires subjective judg- ment to differentiate among waveforms, since a wave form can be completely approximated (characterized)by its time varying derivatives.

In summary then, we are approaching the problem of a sensitive measurement system for human psychomotor skill learning _via_ a simulation of that learning, characterized by internal processes assumed valid for the time being and by controlling strategy parameters which are assumed to vary in the course of learning. You've seen a tape of the learning performance of a model using a fixed control strategy, and I have described to you an error statistic that we intend to use to identify the particular control strategy being used by human subjects. Thank you for your attention.

4

Technical Memorandum

TM A-1979-000-7

TO: A-1979 File

FROM: Lee Burks

SUBJECT: Validation Experiment
           (Draft)

Validation Experiments (Draft)

1. <u>Hypothesis</u>: Control strategy model produces control outputs that match human output at better than chance level.

 <u>Test of Hypothesis</u>: Identify the best-fitting control strategy model for all T for 8 S's selected at random from the several experimental groups. The hypothesis will be confirmed if, for each subject, at least 51 percent of T intervals are such that the difference between at least one control strategy model output and the h.o. output is small, (MASE is within the bounds of the operator's own test-retest MASE).

Procedure

 <u>Subjects/Groups</u>. From the groups defined in the remainder of the validation experiments, (four) men and (four) women will be selected at random for this testing. At least one subject from each of the experimental groups will be selected.

2. <u>Hypothesis</u>. Control Strategy (the parameter values of the best-fit model, including the internal error limit, the amount of preview used) will be more stable for a fixed task than for a varied task.

 <u>Test of hypothesis</u>. The mean coefficient of variation (ratio of mean to standard deviation) will be larger in the varied task condition (defined below) than in either of the fixed task conditions.

Procedure

 <u>Subjects/Groups</u>. Male Subjects will be assigned at random to one of three groups of six subjects. Two of the groups will participate in a fixed task condition and one group in a varied task.

Task

 Subjects will perform a one-dimensional preview tracking task with 10 seconds of available preview. Variation in the task will consist of two

different top frequencies in the track -- one above and one below the 1/2 Hz frequency suggested by Magdaleno, Jex, and Johnson (1969) as the crossover point between two types of strategies in a pursuit-type task.

Group A will receive 20 minutes of experience on the low frequency track, with a first order plant.

Group B will receive 20 minutes of experience on the high frequency track, with the same plant.

Group C will receive 15 minutes on the low frequency track, followed by 10 minutes on the high frequency track.

Analysis

For each subject, control strategy parameter values will be computed for all intervals in the last five minutes of tracking for each condition. For each subject, an average of each parameter value, along with the standard deviation of that parameter, will be computed, and their ratio formed. This ratio will be averaged across parameters for each subject, and then across all subjects in each group, and Dunn's Multiple Comparison will be applied after a significant ANOVA to determine if the relationships are in the hypothesized directions. Specifically it is expected that $\mu_C > \mu_A = \mu_B$.

3.   <u>Hypothesis</u>: The criterion applied by the h.o. to his own actual or predicted performance depends upon the width of displayed bounds on the track.

    <u>Test of Hypothesis</u>: The average value of the parameter ERRLIM for identified C.S.'s for subjects with a wide track boundary will be wider than that for subjects presented at narrow track boundary, even with exactly the same verbal insturctions.

Procedure

<u>Subjects/Groups</u>. Half the subjects in each of the fixed groups in the first experiment will do the task described there with error bounds of size 1 displayed, half with error bounds of size 10.

Task

The task is of course the same as in hypothesis (1). Displayed error bounds are varied as described above.

Analysis

Several indirect measures of the internal criterion will be used. These include: the average size of the Erflim parameter in the best-fitting models for the last five minutes of tracking in the two fixed conditions, for each subject and averaged within groups; the mean absolute position error for each subject and averaged within groups; and the subjects' reported acceptable error limit, when asked after the test, averaged within groups. Non parametric methods can be used for the differences in average ERRLIM, parameteric methods for the modulus mean error and reported error. Task Groups will be compared separately.

4. **Hypothesis**: The length of the command string generated will depend upon the incentive scheme used.

    Test of Hypothesis: The average command string length estimated for last five minutes of tracking will be greater for a group operating under the incentive scheme 1, than under incentive scheme 2.

Procedure

Subjects/Groups. Six subjects - three male and three female - will be assigned at random to one of two conditions -- Incentive Scheme One provides a reward unit for each second of in-bounds tracking, only if the subject is not looking at the track. Subjects are not penalized for out-of-bounds performance, nor can they gain points for good performance while the track is on the screen. This incentive scheme is illustrated below:

In Tolerance	Out of Tolerance	
0	0	look at track
+1	0	don't look at track

Incentive Scheme One

If this scheme is changed as follows, we have:

	In tolerance	out of tolerance	
	0	-1	look at track
	+1	-1	don't look at track

Incentive Group Two

Task

A preview tracking task of a moderate level of difficulty will be used, approximately $\frac{1}{2} H_Z$. Subjects will be able to remove the track from the screen by pressing a button with the left hand. 10 seconds of preview will be available Scores will be available continuously to the subject when the track is on the screen.

Analysis.

The average command string length from the best fitting models in the T intervals for the last five minutes of tracking will be averaged across subjects within groups. An additional measure of the same construct will be the average length of time away from the task.

5. Hypothesis: Control strategies will be similar across different individuals.

   Test of Hypothesis: Control strategy parameter sets for randomly selected individuals for last five minutes of tracking will be compared within and across experimental conditions. Men and women within the same condition will be compared. Directions of changes across conditions will be compared for men and women and for individuals within the varied task condition of hypothesis 2.

Experimental Design, Note:

Sheridan and Ferrell (1974) point out that human operator nonlinearity shows up in responses to single steps and simple sine waves. Therefore people taking the describing function approach use random-appearing inputs, to which the human responds in an approximately linear fashion (pp 183-185). For this reason, a better test of the content validity of our model may be the use of step and simple sine wave inputs. This requires the use of an input predictor, however, and may be beyond the capabilities of the current effort.

Note 2:

The time-varying nature of control strategy is of interest as well. Therefore, for at least three individuals, identification of C.S. during the entire course of learning will be carried out. Examination of the changes during learning and comparisons across individuals will be carried out.

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

June 7, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, Ohio 45433

> Subject: R&D Status Report No. 14
> "Human Operator Control
> Strategy Model"
> GTRI Project A-1979

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy (ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator as it changes as a function of training and task variables.

May activities on the project have included a review of Larry Fogel's materials, creation of the second draft of the experimental design, writing of computer programs for the purpose of interfacing the Grinnell display we have ordered with existing computer hardware, beginning work on programming for the revised model, and discussion of directions for future research. With this letter you will receive a second draft of the design, incorporating changes we have discussed as well as others, and an up-to-date flow chart and list of parameters for the model, including a delineation of those we believe are associated with control strategy.

With respect to the programs necessary for the Grinnell display, you will be pleased to learn that Bud Sears has made substantial progress in this area, with the cooperation of personnel from another lab here at EES. He is convinced, as a result of this work, that the task of bringing the new equipment into operation in time for August testing of subjects is feasible, and that the work done in May is relatively easily adaptable to the computer system we will be using.

The recent discussion of directions for further work suggests a number of useful directions. We believe that an excellent course to follow would be to (1) analyze the mis-matches between the model and human output, (2) fine-tune the model, based on that analysis, (3) repeat the system identification process using the old data, (4) apply the results to a new sample of subjects in new experimental conditions, (5) determine the dependencies among control strategy parameters and among these parameters and task variables.

Another important area for investigation of model validity and potential applications is to examine multi-dimensional inputs and outputs. For example, we might examine a one-dimensional control which affects the vehicle in two dimensions -- a control result like the effect of an aileron input on the roll and heading of an aircraft.

An area of considerable potential application is the relationship of the established internal model of the controlled plant to the external environment -- what factors control the modification of the model? This is quite important in learning how operatio s adapt to new situations, and how failure detection occurs. Still another aspect of the control strategy that should certainly be investigated and modelled is in the input prediction portion. We envision this as much like the internal model for the controlled plant, but structured as a model of the goal states - the input task.

In June the goals are to begin to structure the final report, so that the analysis resulting from the experiments can be placed in the body of an existing document, and to complete a final version of the experiment design. Writing and de-bugging the program for the attached flow charts is scheduled, and is, in fact, now under way.

Respectfully submitted,

Lee Burks
Project Director

ae

Enclosures

A-1979

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

July 24, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report No. 15
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary
tests of a model of the control strategy(ies) developed and applied by
a human operator in the course of learning a manual control task. The
main purpose of the model shall be to characterize and predict the control
strategy used by a human operator as it changes as a function of training
and task variables.

June activities on this project included the development of a documented
program for the model HOPE, in a form which can be readily modified for in-
clusion in a final report. While we do not anticipate inclusion of the
program itself in the report, a complete narrative will be presented. One
copy of the listing and definition of all model parameters is enclosed. In
addition, verbal agreement was reached on the first set of validation experi-
ments, and the write-up of this was prepared.

The paperwork to permit delivery of the test equipment by approximately
August 4 was completed. A concept paper for continuation of this modelling
and validation was mailed and discussed.

July activities will consist of further work on the final report, mailing
of the proposed experimental design, and programming associated with the equip-
ment interface. In addition subjects for the August experimentation will be
identified from ROTC students on campus.

Sincerely,

Esther Lee Burks
Principal Investigator
Technology and Development Laboratory

Enclosure

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 18, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

> Subject: R&D Status Report No. 16
> "Human Operator Control
> Strategy Model"
> GTRI Project A-1979

Dear Miss Knoop:

The purpose of Project A-1979 is to develop and perform preliminary tests of a model of the control strategy(ies) developed and applied by a human operator in the course of learning a manual control task. The main purpose of the model shall be to characterize and predict the control strategy used by a human operator as it changes as a function of training and task variables.

July activities were at a relatively low level due to factors both internal and external to the project. The principal investigator was away for approximately 30 percent of the month for work in preparation for examinations preliminary to the Ph.D. degree; other team members were away on vacation. Delivery of the majority of equipment was expected on August 4; but one essential piece, coming from Interdata Corporation, was threatened with a September delivery date. Negotiations with the company resulted in an estimated delivery date of August 10.

ROTC units on campus were contacted about use of their students as subjects, and the local unit commanders agreed to notify their units of the opportunity to participate, and provide us with names of those who wished to participate.

Problems with the new implementation of the model were experienced; and about half of hours spent on the project were spent either in problems related to this programming or in the task of writing control programs for the experiment.

We anticipate that August activities will center around getting the programs for the experiment ready, improving the implementation of the theory, and assembling equipment and subjects.

> Respectfully submitted,
>
>
> Esther Lee Burks
> Principal Investigator

ELB/jcd

GT EES ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

October 2, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 4533

> Subject: R&D Status Report No. 17
> Human Operator Control
>   Strategy Model
> GTRI Project A-1979

Dear Miss Knoop:

Project activities during the month of August centered primarily on be-
ginning test and assembly of the experimental equipment, and on thinking
through the logical problems associated with the new implementation of the
model. The project team is aware that the amendment to the contract did not
include reworking of the model. However, consideration of the implications
of some of the processes involved in the older version of the model made
such reworking a necessity.

The basic change made in the model is toward a hierarchial organization,
analagous to the cerebellum/cerebrum distinction, in which routine activities
of command selection and execution are made at a "lower" level from decisions
about what to do in new situations or when to leave the primary task.

Status of the project at the end of August was on the positive side of
unsatisfactory. That is, the model shows a logical consistency that is quite
satisfying, but still has some 'bugs' in its program; the equipment is delivered,
but had some flaws which have delayed assembly.

September activities include preparation for the AFOSR Review Visual
Processes and Human Operator Control, continued work on the test equipment,and
limited sensitivity analyses on the (hopefully) working H.O.P.E.

> Respectfully submitted,

> Esther Lee Burks

ELB:wc

GT EES

October 4, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R & D Status Report No. 18
"Human Operator Control Strategy
Model"
GTRI Project A-1979

Dear Miss Knoop:

September activities on this project included solution to most of the
difficulties with new model, preparation of a paper for the AFOSR Review
Processes and Human Operator Control, continued work on configuration of
equipment, and construction of an outline for the final report on the pi

The paper and the outline are appended to this letter. You will n
the paper are tables which define the control strategy parameter set
HOPE. It would be of particular value to the project team if you con
tables, and the appended outline of the final report in order for us
later this month.

An examination of the tasks remaining in the project shows that
activities remain to be carried out:

- writing of the code for the data collection for the experi
  generation, plant dynamics, control outputs

- repair of software (probable) problem with the Grinnell

- writing of code for the system identification of each h

- scheduling of 15 male; 15 female subjects

- sensitivity analyses of model

- rehost model to interdata computer

- pilot runs of experiment

    - experiment

    - qualitative and quantitative analysis of experimental data

    - final report draft

The primary reasons for the current status of the project are the late delivery and subsequent assembly problems with the Grinnell display, and the additional time necessary to cast the model in its present form.

It seems clear from these facts that it is necessary to request a no-cost extension of about three months. While such an extension is not normal practice for our organization, the causes for the delay are of such a nature that the request seems reasonable rather than a reflection of our disinterest in the project. A request for the extension was made on 9/30/78.

The discussions with experienced control theorists and human factors people at the Review underscored the importance of the work we're doing, as well as its difficulty. The next few months are thus both promising and risky. It is essential that we not let failure in execution mar the concepts developed. I believe the schedule we discussed with you during the Dayton visit will permit the quality execution we all desire.

                    Respectfully submitted

                    Esther Lee Burks
                    Principal Investigator

ELB:wc

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

October 31, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

> Subject: R & D Status Report No. 19
> "Human Operator Control Strategy
> Model"
> GTRI Project A-1979

Dear Miss Knoop:

Activities in October were centered about detailed preparation for running the experiments, including work on programs, hardware, and writing the detailed experiment plan. Specifically, the following work has been accomplished:

- writing of the code for control of the experiment. This includes generation of a pseudo-random sequence of numbers, writing code for a filter to exclude excessive high frequency components, writing code for control of color and intensity in display, for plant dynamics, and codes to transmit these to the screen.

- repair of the problem with the display which caused it to disappear unexpectedly.

- construction of the electronics necessary to read the stick position, to control the cursor on the Grinnell display. A calibration program had to be written to linearize the output of the bat handle.

- construction of the operator console for experimentation.

- rehosting of the model to the Interdata computer.

- limited sensitivity analyses of the model.

- writing of codes for the system identification of each human operator. This is the MASE computation described in the Detailed Experiment Plan, along with the procedures necessary to transfer and store the data.

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Miss Pat Knoop
October 31, 1978
Page 2

- revision of the outline of the final report (attached).

- writing and revision of the Detailed Experiment Plan (final being mailed under separate cover.)

- writing of a portion of Part II of the final report.

While the accomplishments of the month have been considerable, there remains the following tasks to be accomplished in November.

- The display, console, and computer must be moved from their present location in the C&S building to their permanent location as the Human Operator Laboratory in the Electronics Research Building on campus. We anticipate this will take place about November 13.

- Code to output the MASE computations as described in the Detailed Experiment Plan (Analysis Plan, Item 3) must be written, along with the code to compute the performance measure for operators.

- Additional sensitivity analyses on the model.

- Based on these, the 3^K runs of the HOPE model must be made.

- Characteristics of the track will be examined, in order to be sure operators get as complete exposure as possible to the situation space within about 5 minutes.

- Pretesting and Pilot Runs of the experiment. In pretesting, we need to examine learning curves of a number of subjects to make sure the task is reasonable. In pilot runs, we will do complete rehearsal of the experiment in order to ensure all details are complete. These should be carried out the week of November 27.

- For the pretesting, code must be written to compute learning curves over time. Further, code to transmit stick position to a graphical display on the CRT will be written, in order to give subjects accurate feedback about their positioning skills before the experimental trials. (See Experiment Plan, p.4.)

- Scheduling of subjects for the first two weeks in December. This will be carried out during the week of November 13, with follow-up reminders by phone to each subject shortly before their scheduled trial.

- Writing of Section I, II of the Final Report. Drafts of these should be ready by November 29.

Respectfully submitted.

Esther Lee Burks
Principal Investigator

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

GT EES

December 20, 1978

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R & D Status Report No. 20
"Human Operator Control Strategy
Model"
GTRI Project A-1979

Dear Miss Knoop:

Activities in November were, like those in October, focussed on
detailed preparations for the validation experiment. Specifically, the
following work was accomplished in November.

- The diplay, control console, and computer were moved to a per[manent]
location as the Human Operator Laboratory in the Electronics
Research Building on the Georgia Tech Campus.

- Pre-testing of the experiment plan was carried out on a doz[en]
volunteer students. The purpose of this was to determine[the]
reaction of subjects to the proposed task; to the selected
and to the work-rest pattern in the experiment. Examina[tion]
various performance measures was scheduled in order to d[etermine]
degree of learning of the proposed experimental task th[at is]
expected to take place within the 20-minute proposed ti[me]

- A pool of potential subjects from the three ROTC unit[s was]
generated by using a poster and sign-up sheet at each[of the]
quarters. This was placed with the permission of th[e]
commanding officers. Approximately 115 students vo[lunteered for next]
week's period--20 of them female.

Fortran code to give flexibility in selecting task a[nd]
istics for the experiment was written. Also, programs +[to give]
feedback on two performance measures--mean absolute pos[ition]
error--were written. Both CRT graphical display and h[ard copy were]
generated by these programs. Code to record and outpu[t]
was also written. This latter data is, of course, th[e]
used to select the best-fit models. Fortran code to[]
and output (specified in the validation experiment [was]
in a fraction of completion.

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As you are, of course, aware, a working meeting between Dr. Larry Reed, yourself, and the project team was held during November. One of the primary results of this meeting was the decision to present subjects with some number of repeated trials on the same track segment, as opposed to a single presentation. An additional result of that meeting was a proposed new error measure—one which would tend to reduce the confounding of task difficulty and learning. Basically that measure would be created by averaging the absolute position error at identical time periods across all repetitions of the track, and using that average error as divisor for each of the individual errors. This should have the effect of allowing comparison of performance across repetitions, independent of mementary task difficulty.

Respectfully submitted,

Esther Lee Burks
Principal Investigator

ELB/nrf

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

January 3, 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

> Subject: R & D Status Report No. 21
> "Human Operator Control Strategy
> Model"
> GTRI Project A-1979

Dear Miss Knoop:

Project activities in the month of December were focussed primarily
on the carrying out of the preliminary validation testing. As was agreed
upon during the briefing at the end of November, the approved validation
test plan was modified to provide for taking data on repeated sections of
the same track. Pre-testing was carried out (5 subjects) and using mean peak
position error as a gauge, a set of five repetitions of a four-minute seg-
ment of track was selected as an acceptable procedure to use. The experi-
mental control program was modified to permit automatic presentation to the sub-
ject of the desired length segment for any desired number of repetitions.
Subjects tracked the four-minute segment, rested one minute, and then pressed
a button to start the next repetition. Asking subjects to time their own
breaks using a hand-held timer had the advantage of forcing subjects to look
away from the screen during their rest periods.

An additional change to the test procedure was made in that the aim of
determining the responsiveness of control strategy parameters to task varia-
tion is to be met by a between groups contrast (between a low and high frequency
input track) rather than by a within subjects comparison of earlier and later
portions of tracking. This change was necessitated by the very gradual learn-
ing displayed by subjects, resulting in the absence of asymptote. Further, if
we use the normalized error described above, the number of points in the
average becomes too small for utility. Finally, the number of repetitions
in each condition (in the varied task) would be too small. To summarize then,
there were four conditions in the experiment: Low corner frequency (1/4 Hz),
narrow (1 1/2 inch) guidelines; low corner frequency wide (3 inch) guidelines;
high corner frequency (1/2 Hz), narrow guidelines; high corner frequency, wide
guidelines.

The controlled element was a position control with a first order lag. The
lag was progressively greater at the edges of the bat handle range than at the
center. The change from was .4 second time constant at the center, to .8, to
1.2, to 1.6 seconds at the farthest extremes. Subjects reported enjoyment of
the experience, and were quite interested in the purpose of the research when
it was explained to them after the test. Sixteen men and 12 women ROTC
students were run. The remaining women will participate during the first week

of January upon their return to school.

The program to compute the normalized error was written, debugged, and tested on subject data. The measure seems more sensitive to practice on the task than any tried so far. The MASE analysis programs were completed, documented, and tested. Rehosting of the model to the Interdata was nearly complete.

Georgia Tech closes the week after Christmas and no project work occured during that week. A proposal for add-on work to the existing contract was, however, prepared during that week.

Respectfully submitted,

Esther Lee Burks
Principal Investigator

ELB/nrf

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

30 April 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001. Sequence No. 1-5
Wright Patterson AFB, OH   45433

Subject: R & D Status Report No. 22
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop,

Activities in January included writing of sections of the project technical report, completion of testing of human subjects, data analysis, and working at solutions to persistent problems in the particular Interdata machine utilized by the project.

Results of the preliminary tests appeared to support the idea that control strategy parameter values for best fit models of persons, could reveal interesting aspects of the learning process. For example, the ERRLIM parameter was larger,(resulting in an increased size of the acceptable performance area,)in conditions in which human beings were given wide, rather than narrow guidelines. Human performance, however, was slightly <u>better</u> in the wide guideline condition. Similarly, the $\frac{1}{4}$ Hz track condition was associated with wider ERRLIM in best-fit models than was the $\frac{1}{2}$ Hz condition. Human performance, on the other hand, was significantly better in the $\frac{1}{4}$ Hz condition, (associated with less stringent ERRLIM).

Two hypotheses of interest result from these observations. First, it appears that ERRLIM is sensitive to environmental cues. That is, the behaviors of people in wide guideline conditions are matched best by models which have less stringent criterion boundaries for good performance than models which match the behaviors of persons given narrower guidelines. It is of interest to consider whether other forms of criterion function (parabolic, triangular) would show similar patterns.

A second interesting idea raised by these results is that a more relaxed criterion may be associated with better, rather than poorer, performance. This hypothesis is, of course, dependent for its support upon the assumption that the model can provide insight into human learning behavior. This assumption is, of course, the purpose of the preliminary testing and must not be prematurely made. Nevertheless, the idea that a less stringent criterion may produce fewer errors than a stricter criterion is a perhaps useful insight. ERRLIM in best-fit models gets significantly smaller during the course of the five trials, as does error for subjects. Thus, a change toward more stringency in criterion in best-fit models is associated with a reduction of errors, while larger absolute values appear to be associated with lower error. Thus, the ERRLIM was smaller for later in learning, for narrow guidelines, and for ½ Hz tracks. Error was lower later in learning, but larger in narrow guidelines and ½ Hz track. Like the first hypothesis, this idea has interesting implications for training.

Finally, it should be noted that in January a problem arose which has not yet been resolved. This is the question with respect to the efficacy of the MASE statistic as means for choosing the best-fit model. Some models selected by the statistic appear visually to be very poor fit to some portions of human operator performance. Other models selected are excellent visual fits. There may be a need to modify this statistic or apply another one for this selection purpose. If so, the analyses made thus far on the control strategy parameters are suspect. Their very reasonable and interesting appearance gives us reason to believe, however, that the results we have obtained will be supported by a reapplication of the procedure with a different or modified selection procedure.

Analysis of the unexpected results mentioned above will continue, using both visual and analytic means. If these examinations indicate that the MASE statistic itself is inadequate, the analyses will be re-run, before publication of the final report. The primary goals of current work are finding the solution to the analysis problem and completion of the final report.

Respectfully submitted,

APPROVED:

Esther Lee Davenport
Research Engineer
Special Projects Office

R. P. Zimmer, Chief
Systems Engineering Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

19 July 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM   (Miss Knoop)
Contract No. F33615-77-C00042
Item No. 0001. Sequence No. 1-5
Wright Patterson AFB, OH   45433

Subject: R & D Status Report No. 23
          "Human Operator Control
          Strategy Model"
          GTRI Project A-1979

Dear Miss Knoop:

February activities on the project were primarily focussed on the reporting effort. The delays in the analyses experienced in January meant that the first draft of the technical report on the contract items 4.1 through 4.12 was delayed. Thus, insufficient time was allowed for the necessary synthesis of the results from the separate subtasks. The draft report was delivered in February, with the knowledge that a considerable rewrite effort would be necessary prior to its acceptance in final form.

Other activity during February included the development of programs to permit selective plotting of several types of data taken in the preliminary testing. Specifically, plots of HOPE model and human behavioral (control stick position) and performance (cursor position) over time are needed in order to carry out the parts of task 4.13.1, Analysis of Preliminary Testing. The visual examination of these outputs will be an important addition to the various statistical analyses planned.

The experiences during the performance of preliminary testing and analyses have underscored the importance of allowing ample time for de-bugging and documentation of software during basic research that depends on software. The HOPE model is software which embodies psychological constructs. The control strategy identification process is implemented in software, and the results from that process are used to make scientific inferences. When, as here, the actual code is written by individuals other than those who have developed the concepts, the opportunities for error multiply beyond even the normal opportunities for error in software development. Future work on this project will deal with this problem by implementation of much more complete documentation of programming efforts, by more extensive check-out procedures, and by greater involvement of all project personnel in the details of the software development process.

March activities planned included rewriting of the first draft report, further check-out of project software, and attendance at the AFOSR Symposium on Flight and Technical Training at the USAF Academy in Colorado Springs.

Respectfully submitted,

Esther Lee Davenport
Project Director

APPROVED:

_____
W. E. Sears, III, Chief
Special Projects Division

_____
R. P. Zimmer, Director
Systems Engineering Laboratory

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 July 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Knoop)
Contract No. 0001. Sequence No. 1-5
Wright Patterson AFB, OH 45433

Subject: R & D Status Report No. 24
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop,

March activities included preparation for and attendance at the
AFOSA Symposium on Flight and Technical Training, continued check-out
of the program software, and planning for better ways to present the
results of the work in tasks 4.0 through 4.12. In addition, a cognitive
psychologist, Dr. Joanne Green, was added to the Special Projects Division
staff, primarily for work on this project in tasks 4.13-4.15. She brings
a strong background to the project, because her areas of specialization
are in human learning, memory, and attention. Since the focus of the
tasks 4.13-4.15 continues to be on the cognitive aspects (esp. cue utilization)
of the learning and performance of manual control tasks, her areas of
specialization are particularly appropriate supplements to the design and
analysis skills of the present team. She is a graduate of Tufts and of the
University of Mass. and has worked at Cambridge (England) with Dr. Anne
Treisman. The work on rewriting of the draft technical report was materially
aided by the process of orienting Dr. Green to the project, in that her
questions and comments were representative of reactions of the intelligent
reader new to the ideas being conveyed.

April work planned included drafting a written commentary on the
AFOSR meeting, detailed examination of the processes and structures in the
HOPE Model with respect to their validity, examination of the preliminary
test data, and rewriting of the draft technical report.

Respectfully submitted. .

Esther Lee Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 July 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Knoop)
Contract No. 0001. Sequence No. 1-5
Wright Patterson AFB, OH   45433

Subject: R & D Status Report No. 25
"Human Operator Control
Strategy Model"
GTRI Project A-1979

Dear Miss Knoop,

April activities involved detailed check-out procedures on
the project software to try to determine the cause of several unexpected
results obtained in preliminary testing, consideration of HOPE process
and structures from a psychological standpoint, rewriting of the technical
report draft, and writing of a written response to Jack
for commentary on the AFOSR meeting. The first two of these contribute
specifically to task 4.13.1, while the others involve contribution to the
project as a whole.

The unexpected results obtained included the selection, as best
fits to human control stick outputs, of several HOPE models which appeared
to produce very poor matches to human behavior; the observation that MASE
values were nearly as low for these poor-appearing fits as they were for
much better-appearing fits; and the observation that MASE values were systema-
tically higher in 1/2 Hz conditions than in 1/4 Hz conditions. The problem
that such results present is the ambiguity as to their cause. That is, the
HOPE model may be faulty, the model identification programs may have an
undetected error, or the model identification statistic -- MASE -- may be
inadequate. The work in April established that some refinements to HOPE will
be necessary, that the model identification procedures were implemented
correctly, and that the MASE statistic may need further investigation.

Consideration of the structures and processes in HOPE resulted
in the conclusion that the assumptions embodied in HOPE about which mental
operations take attention seem to be appropriate, in the absence of explicit
data. Much work has been done (reviewed by Kerr, 1973), in determining
which mental operations take the most of human limited capacity, as demanded
by verbal or arithmetic tasks. Frequently tracking has been used as a

secondary task. The HOPE model assumes that performance monitoring, error
correction, association and storage in a long term memory, command development
in novel situations, and attention reallocation are processes that require
attention, and must be carried out serially. Activation of memory for
responses in familiar situations, storage of selected commands in short term
memory, and command execution do not require attention in the current HOPE
model. They are "automatic" in the sense that they are carried out in
parallel with the attention demanding processes. There is an absence of
experimental data on mental processes utilized by manual control tasks; and
whether these divisions of processing are the source of differences between
HOPE output and human output may only be decided by experimentation with
the simulation.

        May activities planned included further writing of the draft report
and an investigation of the properties of the MASE statistic, an activity
associated with task 4.13.1.

                                    Respectfully submitted.

                                    Esther Lee Davenport
                                    Project Director

APPROVED:

_____
W. E. Sears, III, Chief
Specials Projects Division

_____
R. P. Zimmer, Director
Systems Engineering Laboratory

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

26 June 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C0042
Item No. 0001. Sequence No. 1-5
Wright Patterson AFB, OH   45433

> Subject: R & D Status Report No. 26
> "Human Operator Control
> Strategy Model"
> GTRI Project A-1979

Dear Miss Knoop:

Activities in May included work on a rewrite of the first major technical report for the project and a study of the properties of MASE (mean absolute state error) as measure of goodness of fit between the HOPE simulation and human control stick output. Specifically MASE was compared to RMS (root mean squared) error. MASE, as you will recall, is a statistic composed of 3 types of components of the difference waveform between human and model control outputs. Those components are aspects of position, velocity, and acceleration, sampled every 40 ms. and summed over each 20 s. of tracking. (A four-step procedure was followed and is described in the attached technical memorandum.) The comparison was made as part of our activity on Contract item 4.13.1, Preliminary Test Analysis.

The analyses were quite preliminary, and it is not within the scope of this contract to pursue them further. For one subject output, and 44 model outputs, in one 20 s. time bin, MASE choices of best-fit model were no closer than RMS choices of best-fit model to human judgements (N=6) of best-fit models. Human judgements were themselves not consistent; but inview of the novelty of MASE, and of the fact that RMS has been used quite successfully in other applications, the decision was made to use RMS as criterion measure of goodness-of-fit. MASE deserves further testing because of its greater information content, compared to RMS.

In the month of June, work will continue on the technical report, and further work on preliminary test data analyses will be carried out. This

will include comparison of HOPE model "learning" trends with human learning
and examination of clustering of the parameter values in best-fit models.

Respectfully submitted,

Esther Lee Davenport
Research Engineer
Special Projects Office

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 October 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001 - Sequence No. 1-5
Wright Patterson AFB, OH   45433

Subject: R&D Status Report No. 27
"Human Operator Control
 Strategy Model"
GTRI Project No. A-1979

Dear Miss Knoop:

At the end of the month of June, 1979, the completely rewritten final technical report on contract items 4.0 to 4.12 was submitted. Further work on item 4.13.1, <u>Preliminary Test Analysis</u>, was carried out, and it is that work which is described in this report.

The purpose of 4.13.1 is to identify possible model deficiencies and the need for additional data collection to resolve uncertainties. Several types of data are appropriate for these purposes, including:

1. data comparing model and human control actions,

2. data comparing model and human performance,

3. analyses of both model and human learning trends,

4. determination of the most important discrepancies between expected and observed results

   a. in the variation of estimated control strategy parameters and

   b. in the results from the control strategy identification process.

Each of these types of data should be used to aid in the identification of model refinements that are needed.

During June, data from category (1) was obtained, in the form of plots
of human control stick position over time, together with control stick positions
of best-fit models. Visual examination of these plots revealed one primary
problem, the "spiky" nature of HOPE control stick records compared to humans.
(One individual human operator from each of the four experimental conditions
was selected at random for this visual examination.) The values of the
parameter ADJUST were suspected as a possible cause of this problem. As you
know, ADJUST is a parameter which controls the magnitude of control stick
response when the HOPE model perceives its cursor is outside the ERRLIM
criterion limit. Because ADJUST was viewed as a possible source of the
problem, detailed examination was made of the simulation's FORTRAN code,
especially in the operation of the ADJUST parameter. A subtle coding error
was discovered, which had the effect of occasionally, and unpredictably
exaggerating the size of the ADJUST parameters specified for a given model.
Because this effect was obtained in error, the decision was made to remedy
the error and rerun the entire control strategy identification process.
This was carried out, and the same plots described above were obtained again.
The result was that while the 'spike' problem was considerably reduced, it
still was evident. Indeed, this model deficiency remains the primary problem
to which model refinements will be addressed. The probable source of this
difference between model and human control stick output was not discovered
in June, and, indeed, did not become evident until September.

During June, data was also collected in category (3), model learning
trends. Several interesting results were noted. First, there appears to
be a nonlinear relationship between values of control strategy parameters and
model performance, as measured by mean absolute error. That is, some models
very close together in parameter space have widely different performance levels.
Second, there exist some parameter sets which cause HOPE to perform very well
(relative to other sets) in the ½ Hz track, which do not produce outstanding
performance in the ¼ Hz track, and vice versa. Both these results suggest
that the best control strategy may be task specific.

During June, analysis was made of the degree to which the best ten
models for a person in a particular time bin could be obviously said to
cluster. This analysis was done by hand, for a few bins for a few subjects,
although later, another type of cluster analysis was automated. The analysis
brought no good evidence of clustering -- a result which could stem from
several causes:

1. The parameter space is to grossly defined for clustering to emerge, or

2. The control strategy identification process is not refined enough, or

3. Multiple control strategies produce similar control stick position
    records.

Also in June, a revised (from the proposal) schedule of delivery dates on the contract data items for ELIN 7, "Detailed Research Plan," and for ELIN 9, "Presentation Material," was developed by the project team and discussed with you. A realistic estimate for mailing of the first part of ELIN 7, "Proposed Model Refinements, " appeared to be September 4.

The July work plan included continued activity on contract item 4.13.1, Preliminary Test Analysis, and the beginning of work on 4.13.2a, Model Refinement Proposals Development.

Respectfully submitted,

Esther Lee Davenport
Project Director
Special Projects Division

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 October 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Item No. 0001 - Sequence No. 1-5
Wright Patterson AFB, Ohio   45433

Subject: R&D Status Report No. 28
          "Human Operator Control
           Strategy Model"
          CTRI Project No. A-1979

Dear Miss Knoop:

July's activities were a continuation of activities on Task 4.13.1, Preliminary Test Analysis, and a beginning on the first activities in 4.13.2, Model Refinements.

Task 4.13.1 activities included not only the generation of certain data according to the categories described in R&D Status Report No. 27, but also refinements of data manipulation procedures. The volume of information generated in the validation of the simulation HOPE is such that great care must be taken that these procedures are done accurately and efficiently.

For example, there arose this month a problem in regenerating cursor error data directly from control stick position records. The problem lay in the fact that the absolute position error generated by running control stick positions through the plant equations and comparing the output to "road" positions did not exactly correspond to the error computed at the time. Correlations between the two were computed, for all operators; and these were quite high -- .95 or better -- but the difference was unsatisfactory. The details of the investigation carried out are beyond the scope of this letter report, but the results are important. They are: Future tests of the HOPE simulation will be conducted (within the one dimensional constraints imposed) in a numerical environment exactly like that experienced by humans. Small differences between the two were discovered in the course of identifying the source of the inconsistencies between regenerated and recorded error, and these have been remedied.

Model refinement proposal development (Task 4.13.2) includes checking the HOPE program code for psychological fidelity as well as identifying sources of differences in model and human behavior. As part of this effort we have examined not only the behavior of best-fit models, but also have examined the learning and performance behavior of the simulation HOPE in general. One additional suggestion for doing the latter is to give the HOPE certain test tasks, for which data on human behavior is available, in order to see what the differences may be. This activity will probably be a part of the method used for checking out the refinements in task 4.13.2, and has not been pursued during this month.

A July activity related to model refinements proposals was a test modification of the Nearest Neighbor Search Process. As implemented now, this process searches in a "box" shape in the Command Memory, when the exact situation has never been experienced before. That is, if the cursor is at 64, for instance, and the next position desired is 70, and the HOPE has no information about the correct control stick position to accomplish this, then the Nearest Neighbor Search Process checks for cells close by which do have information -- not only along columns of desired positions close to 70, but also along rows of present positions close to 64. A change was made in a test version of HOPE so that the Process searches only in the "columns" of desired positions close to 70. The result of this was a reduction in the undesireably "spiky" behavior of the models visually examined. If some conceptual support can be developed for the psychological validity of this change, it may be considered as one of the refinements recommended.

A consultation visit from Dr. Darwin P. Hunt was scheduled for August 20 and 21. The first day was to be devoted to discussion of the final technical report on items 4.0 - 4.12, and the second day devoted to proposed model refinements. Other activities in August would include continuation of work on tasks 4.13.1, and on 4. 13.2, in an effort to make detailed model refinement proposals by early September.

Respectfully submitted

Esther Lee Davenport
Project Director
Special Projects Division

APPROVED:

W. E. Sears, III, Chief
Special Projects Division
Systems Engineering Laboratory

R. P. Zimmer, Director
Systems Engineering Laboratory

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

4 October 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright Patterson AFB, Ohio 45433

> Subject: R&D Status Report No. 29
> "Human Operator Control
> Strategy Model:
> GTRI Project A-1979

Dear Miss Knoop:

August activities included work on Tasks 4.13.1 and 4.13.2. Both of these tasks culminate in refinements to the HOPE model to make it more valid, and therefore, more useful. In addition, two full days were spent by the project team in consultation with Dr. Darwin P. Hunt, of New Mexico State University. This R&D Status Report will summarize these activities.

The major advance during the month was the organization of data so as to make the task of prioritizing model refinements proposals possible. In other words, the project team began to: identify the results which are the strongest evidence for a need to change HOPE, to identify possible sources in HOPE or in the model identification process of the observed problems, and to sort through various possible refinements. Analysis of possible causes of observed problems in HOPE involved consideration of the controversial assumptions about human information processing that are embodied in HOPE.

The problems revealed by the analysis process so far included:

1. Many of the models don't show a learning curve, although many do. (This may be a confirmation of the idea that certain fixed control strategies are ineffective for learning.)

2. Many of the models show greater error than humans.

3. Certain models picked as best-fitting in successive time
   bins show very different control styles, even when the human
   being identified does not show such wide changes in control
   style.

4. Humans seem to develop a smoother control style than do models.

5. Undesirable "spikiness" shown in many models' control behaviors.

6. Model 'fits' seem better later in learning and for the easier
   $\frac{1}{4}$ Hz task.

   A preliminary analysis of actions that might be taken in order to
prioritize desired model refinements and to establish validity of model
identification process included the following:

Additional Data to be Collected (General)

1. Examine the medians of the control strategy parameters.

2. Correlate control strategy parameters with performance.

Data to be Collected to Check Out Model Identification Process

1. Examine plots of a bin of $\frac{1}{2}$ Hz tracking by all 75 models to see
   if there is a better fit (by human criteria) to one of the operators
   in that condition.

2. Check to see if the first choice models are, on the whole,
   significantly better than the next few choices.

3. Remove the A/D "jitter" present in human operator records and then
   rerun identification process.

4. Revise the range of the control strategy parameters to see if fits
   improve.

Data to be Collected to Find Problems in HOPE

1. Give HOPE a linear zero order position control and see if it
   looks more like humans.

2. Examine the contents of the Command Memory at various points in
   the task for both "smart" and "dumb" models.

3. Vary the control strategy within HOPE, according to the parameters
   specified by the model identification process for one individual,
   and see if the control stick record produced is more like the
   person than the original string from several fixed-strategy models.

4. Compare model behavior in later trials to comparable bins of human behavior in early trials.

5. Give one of the HOPE models some pre-memory for the task and examine "likeness" to humans.

Possible Refinements to HOPE

1. Round, rather than truncate in HOPE Preception Process.

2. Constrain the HOPE to choose a command for the next cursor position that will also permit a smooth transition to the positions desired after that.

3. Introduce some analog to associative strength in the HOPE memory.

4. Introduce a method to permit the HOPE to "generalize" in its Command Memory.

5. Consider making the priorities of Supervisory Processor Processes vary as part of control strategy.

An additional project-related event during the month was the receipt of an invitation to discuss our work at the workshop on "Human Factors in Military Systems" at the Annual Convention of the American Psychological Association in New York City, August 31. We made a presentation entitled, "Engineer-Psychologist Collaboration: Spare Parts into Systems."

September activities were scheduled almost entirely on Task 4.13.2, Model Refinements proposal development. The complexity of the issues raised during August's work indicated that the proposal for model refinements would be delayed by approximately one month from the original goal of September 4.

Respectfully submitted,

Esther Lee Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

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ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

9 October 1979

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Knoop)
Contract F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright Patterson AFB, OHIO   45433

> Subject: R&D Status Report No. 30
> "Human Operator Control
> Strategy Model"
> GTRI Project A-1979

Dear Miss Knoop:

September activities on the project were devoted primarily to the clarification and prioritization of the refinements that are needed by the model, the major part of Task 4.13.2. The secondary activity for the month of September was the beginning of activity on Task 4.13.4.3 "Approach to Model Demonstration."

The results of the work on Task 4.13.2 are contained in the separate report to be submitted as part of "Detailed Research Plan," on or about 12 October 1979, so only a sketch of that work will be presented here. Basically, the report recommends that a relatively straightforward change to the simulation HOPE be made first, followed by a parallel testing of three much more complex changes. The most effective of these latter three is to be fully implemented, followed by a decision on whether further refinements seem necessary. The idea is that the second refinement, once selected from the three candidates may remove the problems in the data that suggested the last group of changes, even though at this time the last set seem independent of the first sets.

The beginning of activity on Task 4.13.4.3 involved the definition of a computer search of several data bases on the topics of motion, flight simulators, flying training, proprioception, and related matters. A manual literature search was also begun, with the following aims:

- Define current important issues in these topics

- Relate important issues to our concept of control strategy

- Delineate the operational definitions of motion cues used in studies

- Delineate the engineering parameters related to motion in flight simulators

- Delineate what is known about human processing of motion cues

A list of articles reviewed so far for this task is attached to this report.

October activity will include further work on the above task, preparation of a paper for presentation at the Psychonomics Society in Phoenix November 9, and submission of the final technical report on items 4.0 to 4.12. As soon as your reaction to the proposals for model refinements is received, those activities can begin as well.

Respectfully submitted,

E. L. Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Project Division

R. P. Zimmer, Director
Systems Engineering Laboratory

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Attch.

ATTACHMENT 1

EFFECTS OF MOTION ON TRAINING FOR CONTROL TASKS IN FLIGHT SIMULATORS

1. Beck, L. J., The effects of spurious angular accelerations on tracking in dynamic simulation. Human Factors, 1974, 16, 423-431.

2. Bergerson, H. P., and Adams, J. A., Measured transfer function of pilots during two-axis tasks with motion. NASA-TN-D-2177, 1964.

3. Caro, P. W., The relationship between flight simulator motion and training requirements. Human Factors, 1979, 21 (4), 493-501.

4. Clark, B., and Stweart, J. D., Effects of angular acceleration on man: Choice reaction time using visual and rotary motion information. Perceptual and Motor Skills, 1974, 38, 735-743.

5. Cohen, E., Is motion needed in flight simulators used for training? Human Factors, 1970, 12 (1), 75-79.

6. Guercio, J. G., and Wall, R. L., Congruent and supurious motion in learning and performance of a compensatory tracking task. Human Factors, 1972, 14 (3), 259-269.

7. Gundry, A. J., Threshold to roll motion in a flight simulator. Journal of Aircraft, 1977, 14 (7), 624-631.

8. Koonce, J. M., Predictive validity of flight simulators as a function of simulator motion. Human Factors, 1979, 21 (2), 215-233.

9. Kron, G. J., Advanced simulation in undergraduate pilot training: G-seat development. Air Force Human Resources Laboratory, Brooks Air Force Base, Texas, AFHRL-TR-75-59 (III), October 1975.

10. Matheny, W. G., Dougherty, D. J., and Willis, J. M., Relative motion of elements in instrument displays. Aerospace Medicine, 1963, 34, 1041-1046.

11. Poulton, E. C., Arousing Environmental stresses can improve performance, whatever people say. Aviation, Space, and Environmental Medicine, 1976, 47, 1193-1204.

12. Sadoff, M., and Harper, C. W., Piloted flight-simulator research: A critical review. Aerospace Engineering, 1962, 21, 50-63.

13. Stewart, J. D., Human Perception of angular acceleration and implications in motion simulation. Journal of Aircraft, 1971, 8 (4), 248-253.

14. Williges, B. H., Roscoe, S. N., and Williges, R. C., Synthetic flight training revisited. Human Factors, 1973, 15 (6), 543-560.

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

3 January 1980

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright Patterson AFB, OH   45433

Subject: R&D Status Report No. 31
"Human Operator Control
Strategy Model": GTRI
Project A-1979

Dear Miss Knoop:

October activities on the project included completion of the written recommendations for refinements to the HOPE program, writing of the paper to be presented at the Psychonomics Society annual meeting, study of ways to expand the Command Memory in the HOPE program, and continuing study of the literature on the uses of motion cues in simulator training for pilots. These activities are related to Items 4.13.2 and 4.13.3.

The proposal for HOPE model refinements was mailed on October 18. The report included (a) recommendations for a change from truncation to rounding in the data collection and recording activities of HOPE, (b) a note that a certain amount of excess variability in HOPE program output may be due to the absence in HOPE of a representation of neuromuscular system dynamics, (c) a recommendation that an improved use of preview by HOPE may be necessary to reduce excess variability, (d) a recommendation that additional (other than COT and ADJUST parameters) criteria on control stick movement may also be helpful in reducing 'spiky' control behavior by HOPE, (e) a suggestion that the improved matches obtained when human behavior in early trials was matched with model behavior at comparable points in later trials may be due to a need to give HOPE some preliminary information about controlling lag-type plants. The overall strategy recommended is to implement the simplest changes first, test other alternatives in a limited way, and implement the option to give HOPE 'prior knowledge' (option e) only if the others fail to remedy the observed problems.

The preparation of the Psychonomics paper was timed so as to permit mailing of a draft to you in time for comments. The opportunity to present at this prestigious meeting is a valuable one in several ways. First, presentation to a critical audience forces further examination of the work for

weaknesses as well as strengths, thus contributing to improving the quality
of inquiry. Second, there exists the opportunity for exchange of ideas at
a meeting of this kind that is very valuable to the basic research being
conducted here.

In future work, it may be necessary to expand the number of environ-
mental cues to be taken into account by the HOPE models. If this is so,
or if a decision were made to store several commands at one location in
Command Memory rather than average in new experiences as is now done, the
present matrix representation of memory would be inefficient. An investi-
gation of capabilities in programming languages other than FORTRAN, such
as LISP and PASCAL, was begun. Also under consideration were other storage
and search algorithms that could be used to represent our theoretical ideas.

On October 31, the edited copy of the final technical report on Items
4.0 - 4.12 was received, along with the information that the final version
was due back within thirty days.

November activities planned included revisions on the technical report,
attendance at Psychonomics meeting, a two-day meeting with you to discuss
HOPE model refinements, preliminary testing of the approved refinements,
and continued work on task 4.13.3.

                                        Respectfully submitted,

                                        Esther Lee Davenport
                                        Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

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ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 January 1980

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Knoop)
Contract F33615-77-C-0042
Item No. 0001, Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report No. 32
"Human Operator Control
Strategy Model": GTRI
Project A-1979

Dear Miss Knoop:

November activities included writing of the final draft of the Psycho-
nomics Society paper (attached), attendance at the two and one-half day
meeting of that society, continued work toward implementation of refine-
ments to HOPE, rewriting of the TRACE and certain portions of the final
technical report on Items 4.0 - 4.12 of this work, and initial write-up
on motion cues and flight simulators.

Consideration of the relationship of this work to the topic of motion
cues resulted in the following conclusions:

1. Motion cues have never been explicitly considered in relation to
   what we have defined as control strategy.

2. We need to identify the motion cues most commonly used in flight
   simulators and determine deductively what effect these should
   have on control strategy.

3. The most valuable demonstration of the utility of HOPE as a measure-
   ment tool would be to demonstrate that measurement of control strat-
   egy using HOPE can reveal differences in subjects due to differences
   in motion cues presented in training--differences not measurable by
   conventional error measures.

4. Items 2 and 3 suggest a need to identify, in detail, the motion
   cues in Air Force simulators now in use, as well as all studies
   made using those simulators to study the learning effects of motion.
   Of particular interest would be those studies that show no sub-
   stantial effect of the use of motion cues in training.

An Equal Employment/Education Opportunity Institution

   Both the writing of the Psychonomics paper, and the rewriting of the theoretical sections of the final technical report have contributed substantially to the strength and testability of the theory and measurement approach being tested in this research.

   Such strengthening has been costly in time and effort. Indeed, the November 30 deadline for the final report was not met, primarily due to the additional questions raised by ever-increased attention to clarity and detail of theoretical statements. The project team should become increasingly realistic in estimation of the time needed for the quality of work desired by the team. Such realism should be reflected in future improvements in meeting of deadlines; certainly, every effort will be devoted to improving this aspect of project performance.

                                        Respectfully submitted,

                                        Esther Lee Davenport
                                        Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

slb

Attachment

A-1979

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 January 1980

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright Patterson AFB, OH 45433

Subject: R&D Status Report No. 33
"Human Operator Control
Strategy Model": GTRI
Project A-1979

Dear Miss Knoop:

December activities included extensive refinement of the theoretical
basis for the research. This work is reflected in the completely rewritten
Section III in the technical report. The reproducible copy and one bound
copy of the report "Human Operator Control Strategy Model--Development and
Initial Test" were mailed to you on December 21, along with the two review
copies of the draft. Other December activities included testing of HOPE
program refinements and organization of the literature reviewed for task
4.13.3, Approach to Model Demonstration.

The refinement of theoretical ideas and rewriting of Section III occu-
pied the majority of the project team's efforts during December. The re-
finements were undertaken so as to provide coherence to the ideas that
underlie the work--coherence sufficient so as to permit recommendations
regarding the design of cost-effective training for continuous control tasks.
The term refinement, rather than development, is used to indicate that no
new assumptions are made in the revised Section III, but rather that the
assumptions previously underlying the research were made as explicit as
possible through the refinement process. One very exciting result of this
thinking is the very clear implication that training for manual control
tasks should include two major thrusts. The first of these would be aimed
toward aiding the learner in building an 'external plant model'--a mental
representation of the input-output relationships in the system being con-
trolled. The other major thrust which should be a part of training is train-
ing for optimal control strategies--control strategies which are associated
with high performance quality and minimal attentional demands. This latter
thrust appears to be a novel idea, one deserving of considerable research
attention. The reason for the value of research related to defining, measur-
ing, and training for optimal control strategies is that such efforts should

make possible much more accurate prediction of future trainee performance
and of the degree of transfer from one task to another than is now possible.

The work carried out in December related to model refinements also
resulted in significant project events. Briefly put, the refinement acti-
vity resulted in increasing certainty that certain relatively simple changes
in HOPE would remedy the majority of the symptoms discussed in the October
1979 report "Proposals for HOPE Model Refinements." Specifically, the ex-
cess variability in HOPE control stick actions compared to humans may result
from the fact that humans appear (in control stick plots) to resist movements
opposite in direction from that of the track, while HOPE does not. HOPE
moves in a much more exaggerated manner than the human, even though both
accomplish the task effectively after learning. Three relatively minor
changes in the HOPE program may have major corrective effects. The first
is to include the neuromuscular system dynamics in HOPE. Data taken by
Stark (1968) suggests that a two pole filter, which would result in little
control stick movement beyond 5-6 Hz, and a moderately reduced amount beyond
1.1 Hz,is an accurate representation of neuromuscular dynamics. This filter
would be installed between the representation in HOPE of neural or brain
commands and the representation of control stick position. A second rela-
tively minor change which should, logically, result in reduced 'out-of-
synch' control stick motion by HOPE models is in the present Excessive
Error Process. As coded now, if a HOPE model observes that its cursor is
outside acceptable limits, it responds by first checking in its Command
Memory for a control stick movement. If no command is found, HOPE uses a
default command which is simply to move the stick to the position corres-
ponding to the desired cursor position. Additional commands are then gen-
erated, on the assumption that the default command was effective in achieving
the track center. At least one of these moves will be made, after the de-
fault move. It is clear that these moves, based on the erroneous assump-
tion that the default command achieved track center, could likely be in
directions opposite to the flow of the track. A simple change to HOPE which
would eliminate this undesireable effect is to use the default command twice,
long enough to permit generation of new commands based on the actual cursor
position rather than an erroneously assumed desired cursor position.

The final relatively simple change recommended for HOPE is to change
the code so as to ensure that the Stimulus-Response Association Process
occurs in conditions of excessive error, if it is time to carry out this pro-
cess. As the code is now written, there are conditions in which requests for
Stimulus Response Associations are ignored, resulting in a sort of 'retro-
active inhibition' on the part of HOPE.

The first two of these changes were given preliminary testing in Decem-
ber. The results of these tests, along with our November activities, indi-
cate that during the first half of January the following steps should be

taken, each in addition to those preceeding.

1. Change truncation to rounding.

2. Implement neuromuscular dynamics.

3. Modify Excessive Error Process default command use.

4. Prevent Stimulus-Response Association inhibition in excessive error
    conditions.

Each step should be followed by careful examination of several complete
sets of HOPE diagnostics and plots, to be sure implementation is correct.
After all four changes are implemented, the complete control strategy measure-
ment process, using all the old subject data and the refined HOPE models,
should be repeated.

Other January activities include preparation of abstracts for the AFOSR
and the 'Annual Manual' conferences, design of the second set of validation
tests, preparation of briefing material for February 1 visit to Wright-
Patterson, draft of the "Approach to Model Demonstration" report, and repair
of the cursor on the Grinnel/Conrac display system.

Repectfully submitted,

Esther Lee Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

slb

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY ● ATLANTA, GEORGIA 30332

February 15, 1980

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright Patterson AFB, Ohio 45433

<div align="right">

Subject: R&D Status Report #34
"Human Operator Control
Strategy Model:" GTRI
Project A-1979

</div>

Dear Miss Knoop:

January activities included work on Tasks 4.13.2 (Implementation and Results of Model Refinements), 4.13.2 (Validation Test Design), and 4.13.4.3 (Approach to Model Demonstration). Much of this work was reported to you in a visit by Lee Davenport on February 4.

A great deal of time was spent in implementing and examining the results of refinements aimed at improving the validity of HOPE and its ability to match human behavior. The procedure used was to implement the refinements in a serial fashion one at a time. After each refinement of HOPE was made, diagnostics from model operation and plots of model control stick behavior were examined to insure that the refinement had been implemented correctly, and had not changed HOPE's performance in an unexpected way. The main thrust of the refinements was to reduce model control stick position variability to a level more similar to that used by humans, and to make changes in HOPE processes so they would more closely resemble human mental processes. Some of the refinements that were implemented and tested are summarized below, and were reported by Lee Davenport.

1. In the Perception Process, variables representing cursor position are now integerized by rounding, instead of truncating their value. This makes percepton more analogous to what human perception is believed to be.

2. The time necessary for the Excessive Error Process has been increased to 120 msec to more closely approximate human processing time.

3. The processes by which the Excessive Error Process chooses commands have been refined. These processes now involve:

   a. search of Command Memory cell corresponding to current and desired state.

       b.   search of Command Memory cells corresponding to the same size of a state transition as that between the current and desired state. A command found will produce a transition of the desired size, though not between the current and desired state. The value of this command is used to infer the command necessary to move between the current and desired state.

       c.   use of an adjusted positional guess. All position guesses are now adjusted by at least one multiple of the control strategy parameter ADJUST, and the manner of adjustment makes use of information about whether the model is leading or lagging the track.

4.   When the Excessive Error Process selects a position guess as a command, the regular Command Generation Process (Comgen) begins selecting commands again only after the consequence of the position guess is available. This prevents Comgen from using often incorrect predictions of this consequence as a basis for beginning generation of a new string of commands.

5.   Before the Excessive Error Process dumps the Supervisory Processor request queue, the Stimulus-Response Association nearest the top of the queue is performed. This reduces the loss of learning due to interruption by the Excessive Error Process.

6.   The Stimulus-Response Association Process no longer re-enables the Excessive Error Process.

7.   The Satisfactory Command Search Process now chooses commands in a manner similar to that described for the Excessive Error Process (see Number 3, above). The only difference is that position guesses are always adjusted by only one multiple of ADJUST, and the adjustment does not consider lag or lead.

8.   The Command Execution Process can now be interrupted in conditions of excessive error. Also, it can signal the Satisfactory Command Search Process if the Command Buffer is empty.

These refinements have succeeded in alleviating some of the symptoms that have been of concern (see Proposal for HOPE Model Refinements, page 3). The variability of model control stick positions has been reduced, making model behavior appear smoother and more continuous. Models match human behavior somewhat better, as indicated by reduced root mean square (RMS) error values. RMS error values are especially reduced for early trials of human behavior, and for $\frac{1}{2}$ Hz track conditions.

The second major area of work in January was the development of the proposed validation test design to be used in further testing of HOPE in February and March (Task 4.13.4). The design that is proposed for Air Force approval is a transfer task paradigm in which most subjects will track in two different conditions in testing sessions on consecutive days. As in the preliminary validation tests, track frequency and guidelines will be varied. The design was selected because it allows use of HOPE to identify control strategy changes with learning and conditions, and to measure predictions about control strategy in a transfer task. The design includes modifications in instructions to subjects to emphasize the role of the guidelines as external standards for performance, and will allow further testing of the relation of the control strategy parameter ERRLIM to internal standards for performance. Finally, the fact that some subjects will be trained in the same testing conditions for both sessions (a total of ten trials) will allow us to examine changes in control strategy over longer periods of training.

The third major area of work in January involved planning the demonstration of the model's utility in assessing the effects of alternate cueing techniques. We are aiming toward the design of an experiment which will demonstrate the model's superiority to conventional performance measures in distinguishing between behavior based on visual cues alone as opposed to visual plus motion cues. Johanna Williams, a graduate research assistant, is completing an extensive literature review of motion cues and their effects on pilot training and performance. During January we have focused on examining data relevant to a number of important issues, including the following:

What are the relations between motion cues and the control strategy parameters in HOPE?
Which motion cues might be expected to affect which CSPs, and how?
Can a HOPE which perceives visual information only be expected to measure the effects of motion information?
What are the characteristics of motions cues which would seem necessary for them to effect behavior?
In what conditions will motion cues not affect behavior?
In studies not demonstrating effects of motion cues on training or performance, to what extent can the absence of such effects be attributed to insensitivity or subjectivity of performance measures?

Answers to these questions are being used to construct a theoretical framework describing the relation of motion cues to control strategy parameters. This framework can be used to select motion cues which are believed to affect control strategy but whose effects have not been detected through use of conventional performance measures.

        January work also included preparation of two abstracts--one submitted
for presentation at the Annual Conference on Manual Control in May,
and one for the Air Force Review of Flight and Technical Training in
March. We also organized a symposium on "Measurement and Training
of Continuous Control Behavior" that was submitted for the American
Psychological Association meeting in September. Other participants
will include William Levison, Jefferson Koonce, Beverly Willeges, Robert
Willeges, Darwin Hunt, and Christopher Wickens.

        Activities planned for February include continued work on the
approach to model demonstration (Task 4.13.4.3), and a pilot study
of the validation test design (Task 4.13.4.1). If possible, we would
like you or another Air Force representative to participate in the
pilot study. A written report at the end of February will summarize
the outcomes of the pilot study, and any resulting changes in the tests
or procedures for your approval.

                                Respectfully submitted,

                                Joanne Green
                                Associate Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

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ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

March 12, 1980

Air Force Human Resources Laboratory
ATTN: AFRHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report #35
"Human Operator Control
Strategy Model:" GTRI
Project A-1979

Dear Miss Knoop:

During the month of February, the following activities were carried out:

- briefing at Wright-Patterson on the results of the model refinement process and on the proposed validation test design;

- investigation of the matching procedure and related measurement issues; development of supporting software for this;

- pilot tests related to the proposed validation tests;

- correction of typographical errors on the final report for contract items 4.0 - 4.12;

- draft of final report chapter (4.13 - 4.15) on model refinements.

The discussions at Wright-Patterson on February 4 confirmed the need to improve the matching procedures in order to get the best estimates of control strategy possible. The procedure involves specifying a measure, an averaging interval for matching, a set of parameter values, and a criterion for goodness of fit. The procedure for the preliminary test analyses involved use of RMS differences, computed every 40 msec and averaged over 20s intervals, with no criterion for 75 sets of parameter values. During February, we examined the effects on control strategy estimates of variations in each of these factors.

The stimulus for an investigation of this procedure lies in the existence of several problems in the data. First of all, human control behaviors appeared to change pattern more often than every 20 seconds. Thus, control strategy may need to be estimated more often than every 20 seconds. Another problem was that some RMS-selected models looked

very dissimilar from humans. Further, values at the end of the range
allowed for the CSP's were moderately often selected. Matching was,
on the average, about twice as good in $\frac{1}{4}$ Hz as in $\frac{1}{2}$ Hz conditions.
We were aware, as well, that a great number of distinct wave forms
could produce the same RMS value. Finally, and perhaps most seriously,
estimates of control strategy using the refined model did not appear
to vary smoothly with time or distinctly with conditions unlike esti-
mates using the old, inferior HOPE.

     Investigation of each of the aspects of the matching procedure
was carried out, in hopes of reducing or removing the problems described
above. Investigation involved making changes in the procedures and
trying them out on a part of the original data. The first change tested
was to extend the range of the CSP values used and to use equal intervals
between the limits. Thus, COT was permitted to vary from 1 to 6 by
ones, ERRLIM from 4 to 32 by fours, and ADJUST from 2 to 14 by threes,
making 240 models. This change--a more than three-fold increase in
the number of models--made very little improvement (about 2-3%) in
average RMS differences by trials. The $\frac{1}{2}$ Hz - $\frac{1}{4}$ Hz differential remained,
as did the other problems. This test result suggested that fewer parameter
values could be used, when convenient.

     The next change made was to reduce the matching interval from
20s to 2s, the smallest interval to be considered. Trying the 2s interval
first permitted estimation of the greatest improvement possible from
this type change. Results, obtained using the expanded version of
the model, were rather dramatic. The average RMS values were reduced
by nearly half. Furthermore, the range of values of RMS was increased--
some very large as well as very small values were noted--suggesting
that use of a small matching interval per se was not the cause of the
lowered average. Because some intervals resulted in very large RMS
values, and because the averages were nontheless much improved, the
decision was made to estimate control strategy every 2s. Control strategy
estimates obtained did not, however, appear to show the variation with
time and condition that had been such a gratifying aspect of the original
data.

     The third change considered was in respect to the criterion for
goodness-of-fit. In preliminary testing, all estimates were accepted,
regardless of the quality of the match on which they were based. A
graphics display program was developed which permits detailed examination
of model and human data in any time period on any scale. Thus, we
were able to examine the visual meaning of an RMS value of 25, compared
to one of 12 or 7. The consensus of opinion was that matches larger
than 12 were unacceptable. The model control stick records looked
too different from human records to use such models to estimate control
strategy. A decision was made to impose a 10% goodness-of-fit criterion
on the estimation procedure. That is, if no model was found that could
match within   10% of the range of RMS, then no estimate of control
strategy would be obtained from that bin. The matching procedure was

repeated, accepting only 2s bins which met a 10% criterion. Values and standard deviations of estimated control strategy did not show much change; and the majority of bins met this criterion. A clear advantage of this is that control strategy estimate differences between conditions are not confounded with differences in the average goodness-of-fit. The consensus of the project team was for keeping this change.

The final aspect of the measurement procedure addressed was the matter of the measure itself. RMS fails to take into account velocity differences in the wave forms being compared, and such differences are very evident to the human eye. Several ways to include velocity differences were developed and given preliminary testing. Details of these will not be presented here because the testing given is not complete. Until time and funds permit the completion of the initial testing, RMS will be used as the measure. The tests did indicate that some combination of RMS and a velocity measure, each normalized to the same scale, would provide a useful measure. Two other trends observed in the four measures tested were a similarity in the control strategy values selected by all four measures and an agreement in the relative levels of the four measures across individual bins. That is, if a given bin achieved a very low RMS, then other measures tested were also likely to rate it low.

In summary, the mesurement procedure that the month's work has produced is:

(1) compute RMS differences between human and all models every 40 msec,

(2) add these RMS values over 50 points, to get a sum for 2 sec of tracking,

(3) select the model with lowest RMS as candidate control strategy representative,

(4) check the lowest RMS value against a 10% matching criterion (12.7),

(5) if value is less than the criterion, accept that model as estimate. Otherwise, do not include.

(6) Models are generated for all 100 possible combinations of COT, ERRLIM, and ADJUST in the following ranges:

COT   - 2, 3, 4, 5, 6
ERRLIM - 5, 10, 15, 20, 25
ADJUST - 4, 8, 12, 16

Pilot testing for the upcoming validation tests was carried out during February, according to the following design.

	S_1	S_2	S_3	S_4	S_5	S_6
Trial Group						
1						
2	½ Hz Sinusoid	½ Hz Sinusoid	½ Hz Random	½ Hz Random	½ Hz Random	½ Hz Sinusoid
3						
Overnight						
4						
5					¼ Hz Sinusoid	
6	¼ Hz Sinusoid	¼ Hz Sinusoid	¼ Hz Random	¼ Hz Random	_____	½ Hz Random
7						
Overnight	_____		_____		¼ Hz Random	_____
8						
9						

The design was particularly focused on finding out what effect various length breaks had on measured control strategy, on the stability of measured control strategy within various conditions, and on differences between control strategies measures in various conditions. Analysis programs were developed based on the procedures described in the preceding paragraphs.

March activities planned include analysis of pilot study data followed by proposed design revision, preparation of the written reports on the pilot testing and on the approach to model demonstration, data collection in the validation testing, and attendance at the three-day AFOSR Symposium on Basic Research in Flight and Technical Training.

Respectfully submitted,

Esther Lee Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

slb

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

April 10, 1980

Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Miss Pat Knoop)
Contract No. F33615-77-C-0042
Sequence No. 1-5
Wright-Patterson AFB, OH 45433

Subject: R&D Status Report #36
"Human Operator Control
Strategy Model:"
GTRI Project A-1979

Dear Miss Knoop:

The primary foci of work in March included the following:

a. pilot testing related to the validation tests of HOPE (Task 4.13.4.1)

b. analysis of pilot test data and application to the validation test design (Task 4.13.4.1)

c. testing and initial data analysis for the validation test (Task 4.13.4.2)

d. continued work on the approach to model demonstration (Task 4.13.4.3)

The initial experimental design for the validation tests was described in a visit to you by Lee Davenport on March 4-5. The design was selected to allow examination of control strategy changes as measured by HOPE as a function of training condition and practice, as well as control strategy transfer between different training conditions. The original proposal called for exposing subjects to two, 20-minute training sessions occurring on consecutive days. You suggested that in this design the training session might be too short relative to the break between sessions for there to be development of a stable control strategy and transfer of this between sessions. You also indicated interest in examination of control strategy changes over periods longer than the proposed 20-minute sessions. Pilot tests were, in part, designed in response to these concerns, and are described in the "Pilot Study Report" (Contract Item 4.13.4.1). The pilot tests examined performance of six subjects in conditions which varied in terms of length of training, condition of training and length of breaks between training sessions. Major findings relevant to the validation test included the following:

a. There was no evidence that increases in training duration
    contributed to changes in control strategy beyond those previous-
    ly observed in the 20-minute testing sessions. For this one-
    dimensional preview tracking task control strategy seems to
    stabilize within 20 minutes.

b. Although there were differences in control strategy between
    training conditions, there was no evidence of transfer of
    control strategy between different training conditions. When
    beginning a new training condition, subjects did not seem
    to perseverate with the control strategy used in a previous
    condition. Rather, they switched immediately to a control
    strategy specific to the new condition.

c. The length of the interval between test trials had no effect
    on the retention of a previously applied control strategy
    or on the extent (i.e., absence) of transfer of control strategy
    from one condition to another.

These results were considered in the final design for the validation
test. The design is an A-B-A transfer design in which subjects practice
in one condition, then switch to another condition, then switch back
to their initial condition. The two training conditions being examined
are the tracking of a ¼ Hz cut-off frequency random track, or of a
½ Hz cut-off frequency random track. Twelve subjects will begin with
the ¼ Hz track and twelve will begin with the ½ Hz track. Within each
condition each subject will be exposed to five trials, each lasting
1½ minutes. The experimental design is summarized in Table 1.

TABLE 1

SUMMARY OF A-B-A DESIGN USED IN VALIDATION TEST

| | Subject Assignment to Training Condition | | |
Subject Number	Condition A	Condition B	Condition A
1 through 12	¼ Hz track	½ Hz track	¼ Hz track
13 through 24	½ Hz track	¼ Hz track	½ Hz track

Given the pilot study results, there may not be transfer of control
strategy, although the data will be carefully examined for evidence

of this. A major advantage of the design is that it requires the testing of a greater number of subjects within specified training conditions for longer periods of time. This design will allow us to examine correlations between measures of control strategy at different points in training and between different conditions. The nature of these correlations has important implications for the possibility of predicting control strategy. The design will also allow us to accomplish the other purposes of the validation tests: to examine HOPE's ability to match human behavior, and to measure differences in control strategy that occur with learning and between training conditions.

Initial testing of subjects for the validation tests has begun. As of April 1, half of the total of 24 subjects has been tested. The preliminary analysis of their data suggests that HOPE is able to match well their behavior even after transfer between track conditions. Preliminary analysis tends to show little evidence of transfer of control strategy, although there appear to be differences in the control strategies measured for the two training conditions, and over the course of learning. Correlational analysis will begin when subject testing is completed around April 11.

Another project activity in March was the participation by Lee Davenport in the AFOSR Symposium on Flight and Technical Training in Colorado. Lee described the current status of the project and met with the future project monitor Dr. Tom Longridge and with Dr. Marty Rockway of AFHRL/OT, Williams AFB. We have sent Dr. Longridge information about the project and hope to brief him during May.

Work has also continued on the approach to model demonstration. Review of the literature concerning the relation between motion cues and control strategy has been completed. A difficult issue now being discussed is whether the current HOPE can measure important effects of motion cues described in the literature. The literature suggests effects on aspects of control strategy not currently represented in HOPE due to its application so far only to control strategy in a one-dimensional preview tracking task. For example, motion cues often guide the pattern of attention paid to different visual cues, and may direct the sudden switching of attention to a particular display. These aspects of control strategy are not represented in the current HOPE. Therefore, it is questionable whether HOPE can measure these effects of motion cues on behavior. We are currently focusing on developing a plan for further research leading to HOPE's ability to measure effects of motion cues.

April activities will include further development and completion
of this plan. The validation testing of subjects and data analyses
will also be completed.

<div align="right">
Respectfully submitted,
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Joanne Green
Associate Project Director

APPROVED:

W. E. Sears, III, Chief
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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

May 16, 1980

Air Force Human Resources Laboratory/OT
ATTN: Dr. Tom Tom Longridge
Contract No. F33615-77-C-0042
Sequence No. 1-5
Williams AFB, AZ 85284

Subject: R&D Status Report #37
"Human Operator
Control Strategy
Model:" GTRI
Project A-1979

Dear Dr. Longridge:

During the month of April, a variety of project activities were carried out, including the following:

- Paper for the Annual Conference on Manual Control was written and prepared for presentation. (This will be sent separately as one of the required Administrative Reports required by the CDRL.)

- Three technical memoranda were prepared on the subject of the Model Assessment phase (Item 4.15) of the current contract and on the subject of logical next steps for research.

- The last four subjects in the current validation test experiment were run.

- Initial analyses of the validation test data were compiled.

- A basic content analysis of the interviews with the pilot test subjects was completed.

The results of these project activities will be fully reported in the final technical report draft due June 30. In this letter only a brief summary of these will be provided.

    The Model Assessment plans were made on the basis of preliminary
results of the validation test data. These data seemed to show little
trend over the fifteen trials in the estimates of control strategy
parameters, but rather a wide variation of values selected within each
three-minute trial. The quality of model matches, on which the inferences
about control strategy were based, was very high. Indeed, 90 percent
of behavior was matched to within ten percent of the control stick
range of movement. Post-experiment interviews with subjects indicated
that the inferences about rapidly varying control strategy made by
the model-matching procedure were not unreasonable.

    Based on these preliminary results, a strategy for the Model Assess-
ment phase (Contract Item 4.15) was proposed. The strategy builds
on the initial analyses in the following way. Figure 1 summarizes
the decision flow that will result from an analysis of frequency distri-
butions of control strategy parameters within one-minute time segments.
This analysis will begin with a visual examination of the frequency
distributions of parameter estimates and a separation of these into
two categories depending on whether they appear clearly unimodal or
not. For each individual subject, these frequency distributions then
lead to several further analyses as indicated in Figure 1. An examina-
tion of the same data for each group of subjects will permit a final
determination of the suitability of the parameter range selected.

    One of the purposes for the examination of individual data will
be to create, where feasible, predictions of individual performance
late in learning, based on control strategy parameter estimates made
early in learning. Further, an assessment of the feasibility of creation
of a time-varying predictive model of individual control strategy can
be made using these analyses. These efforts are laboratory analogs
to one of the ultimate goals of this work--the ability to measure an
individual trainee's control strategy at the time s/he enters simulator
training, and then use those measures as basis for a simulation of
the effect of various training regimes on that individual. The simula-
tion would permit selection of the most cost-effective training methods
for individuals with different control strategies.

Goals for the month of May include completion of the Model Assessment phase of the work and development of a detailed Report Outline for June 1 submission.
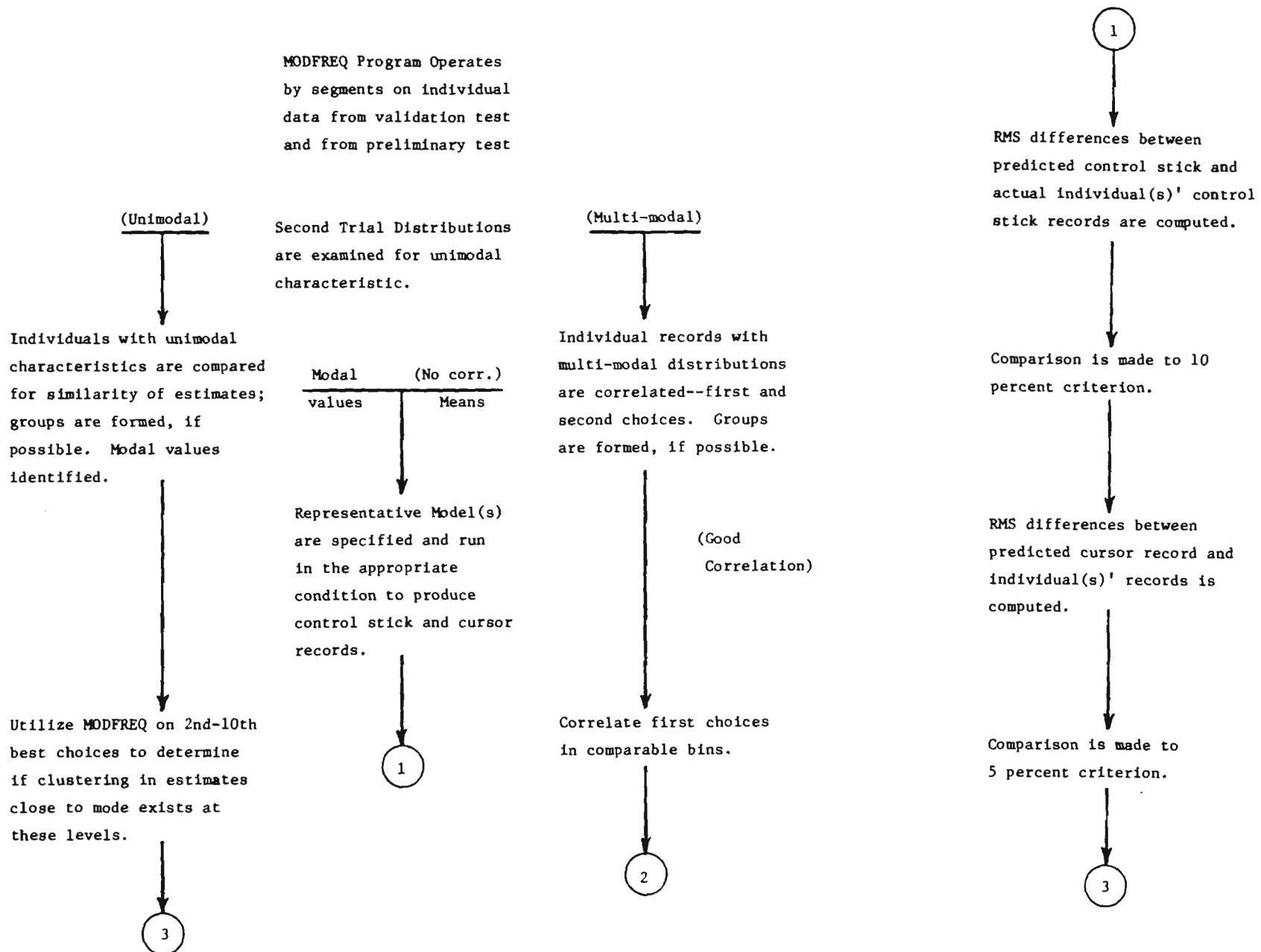
Respectfully submitted,
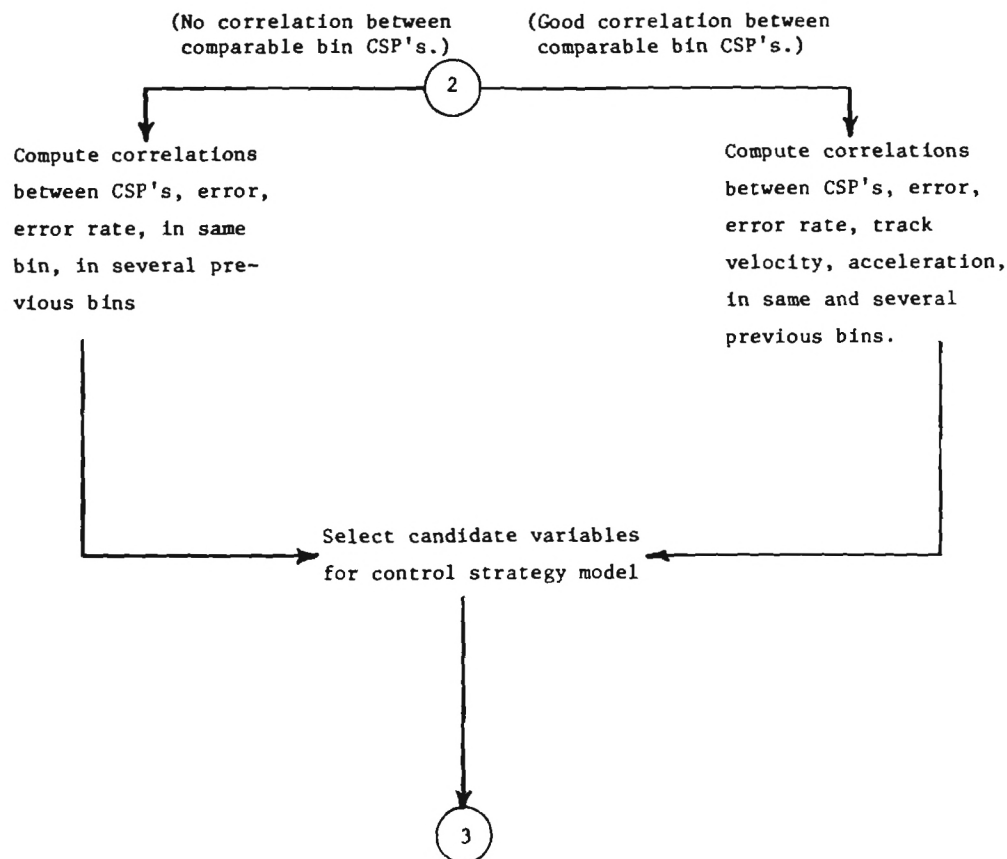
Esther Lee Davenport
Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

FIGURE 1.   PROPOSED MODEL ASSESSMENT PROCESS

MODFREQ Program Operates
by segments on individual
data from validation test
and from preliminary test

(Unimodal)

(Multi-modal)

Second Trial Distributions
are examined for unimodal
characteristic.

①

RMS differences between
predicted control stick and
actual individual(s)' control
stick records are computed.

Individuals with unimodal
characteristics are compared
for similarity of estimates;
groups are formed, if
possible. Modal values
identified.

Modal   (No corr.)
values   Means

Individual records with
multi-modal distributions
are correlated--first and
second choices. Groups
are formed, if possible.

Comparison is made to 10
percent criterion.

Representative Model(s)
are specified and run
in the appropriate
condition to produce
control stick and cursor
records.

(Good
    Correlation)

RMS differences between
predicted cursor record and
individual(s)' records is
computed.

Utilize MODFREQ on 2nd-10th
best choices to determine
if clustering in estimates
close to mode exists at
these levels.

①

Correlate first choices
in comparable bins.

Comparison is made to
5 percent criterion.

③

②

③

(No correlation between
comparable bin CSP's.)

(Good correlation between
comparable bin CSP's.)

(2)

Compute correlations
between CSP's, error,
error rate, in same
bin, in several pre-
vious bins

Compute correlations
between CSP's, error,
error rate, track
velocity, acceleration,
in same and several
previous bins.

Select candidate variables
for control strategy model

(3)

(3)

Utilize Outputs From:

MODFREQ on unimodal 2nd-10th best choices,
comparison of representative model(s) predictions
to criteria, and attempts at selecting candidate
variables for a control strategy time-varying model
to:

o re-evaluate theoretical basis of HOPE, and
   its representation of control strategy,

o critique functional aspects of HOPE,

o appraise parameter identification process

o recommend changes to theory, to the
   definition of control strategy, and/or to
   HOPE that would increase the potential
   utility of the model in simulation
   research,

o translate recommendations for changes into
   proposed work.

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

9 June 1980

Air Force Human Resources Laboratory/OT
ATTN: Dr. Tom Longridge
Williams AFB, AZ 45433

Subject: R&D Status Report No. 38
"Human Operator Control
Strategy Model:" GTRI
Project A-1979

Dear Dr. Longridge:

During the month of May, project activities included the following:

- Attendance of project team members E. Lee Davenport, Joanne Green and Bud Sears at the Annual Conference on Manual Control and presentation of a paper describing the project

- Analysis of the validation test data, including the development of several new analysis programs

- Development of a detailed outline of the final technical report

- Preparation of drafts of chapters for the final report describing model refinements and the pilot study preceding the validation test

- Preparation of a research plan for the option to the current contract.

The major part of this month's work focused on analysis of data collected in validation testing of HOPE. The questions of interest and the analyses performed during May are indicated below. Newly developed analysis programs are starred.

Question	Analysis
Does control strategy vary with changes in practice or conditions?	Computation of average control strategy parameters (CSPs) and absolute position error for each subject for each 30 sec trial segment and for each trial, and for all subjects in a testing condition.

Question	Analysis
Can HOPE match human behavior acceptably well?	Computation of RMS difference score between best-match models and human behavior in each time bin, and of average RMS difference score for each subject for each trial.
What is the relationship between the CSP values of best-match and second best-match models?	*1) Development of contingency tables indicating CSP values of second best-match HOPE models, given specified CSP values for best-match models.
	*2) Correlation of CSP values of best-match and second best-match models.
What is the relationship between CSP values early and later in training?	*1) Correlation of CSP values a time bin in a given trial with those for a comparable time bin in later trials.
	*2) Correlation of CSP values for a given time bin in a given trial with those for later bins in that trial.

The results of these analyses are currently being scrutinized with respect to the listed questions, and will be reported in the final technical report.

The outline of the final technical report is now complete and should be in your office within a week. Current plans are for seven chapters: Introduction; Refinements to HOPE; Refinement to Control Strategy Measurement Procedure; Application of Refined HOPE and Measurement Procedures to Preliminary Test Data; Validation Testing and Results; Research Assessment and Recommendations; Summary.

Project activities for June will include the following:

- Interpretation of completed data analyses

- Additional data analyses aimed especially at model assessment

- Analysis of subject protocols on perceptions of control strategy

- Completion of the first draft of the final technical report

- Writing of a project TRACE

- Briefing at Williams AFB of model assessment and of research proposals for the option to the current contract.

Respectfully submitted,

Joanne Green
Associate Project Director

APPROVED:

W. E. Sears, III, Chief
Special Projects Division

R. P. Zimmer, Director
Systems Engineering Laboratory

slb

Georgia Institute of Technology

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

28 January 1981

Air Force Human Resources Laboratory
ATTN: Dr. Tom Longridge
Williams AFB, AZ 85224

Reference: Request for Reports Due

Subject: R&D Status and Monthly Cost & Performance Reports
          for Period July - October 1980,
          "Human Operator Control Strategy Model,"
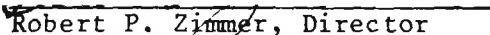   GTRI Project A-1979
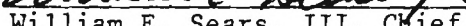
Dear Dr. Longridge:

All technical efforts during this period were devoted toward comple-
tion of the Final Technical Report. Attached is the Monthly Cost and
Performance Report for said period.

Respectfully submitted,

Joanne Green
Associate Project Director

APPROVED:

William E. Sears, III, Chief
Special Projects Division

Robert P. Zimmer, Director
Systems Engineering Laboratory

slb

Attachment

Monthly Cost & Performance Report
For Period June – September 1980
Contract No. F33615-77-C-0042

ATTN: Air Force Human Resources Laboratory
        Dr. Tom Longridge
   ··   Williams Air Force Base, AZ 85224

Costs:

	Expended This Period	Cumulative	Total Contract
Total Expended	$14,819.13	$225,702.36	$225,702.36
% Total Expended	6.6%	100%	
Man-Hours Spent	505	11,979.63	9348.0
% Total Man-Hours	4.2%	126.75%	

Performance:

	Status End of September 1980
Tasks 4.0 – 4.12	C
Task 4.13 (Model Refinement & Validation Test)	C
Task 4.14 (Demonstration Test, Optional)	I(NF)
Task 4.15 (Overall Model Assessment & Reporting)	C

_____

Status Codes: A = Active
               I = Inactive
              NF = Not Funded
               C = Complete

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period April 1, 1977 through April 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	2090.14*					2090.14
Cumulative Funds Spent to Date	2090.14					2090.14
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	25					3
Remaining Funds Sufficient to Complete Task?	Yes					Yes

* Includes $323.50 encumbered

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period April 1,   through April 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed This Period	20					3
Percent of Total Work Called For	33*					7*
Difference	(10)					(4)

*Assuming Linear Rate of Progress

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period April,1977   through April 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	140					140
Cumulative Total to Date	140					140
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	41					5
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes					Yes

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period May 1, 1977 through May 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	156					
Cumulative Total to Date	296					
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	86					
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes					

USAF/AFSC
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        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period May 1, 1977   through May 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	$3,081.35					
Cumulative Funds Spent to Date	$4,753.66					
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	57%					
Remaining Funds Sufficient to Complete Task?	Yes					

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period May 1, 1977 through May 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed This Period	66					
Percent of Total Work Called For	66					
Difference	0					

USAF/AFSC
Aeronautical Systems Division
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Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period June 1, 1977 through June 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	181	123	123			
Cumulative Total to Date	477	123	123			
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	53%	29%	29%			
Remaining Assigned Man Hours Sufficient to Complete the Task?	--	Yes	Yes			

*These are estimates, based on 8 hour work day $20,000

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period June 1, 1977 through June 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	1,728.75*	1,169.73	1,169.73			4,068.21
Cumulative Funds Spent to Date	6,482.41	1,169.73	1,169.73			8,821.87
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	21%	11%	11%			
Remaining Funds Sufficient to Complete Task?	1,891.59	9,151.27	9,151.27			54,956.13

*Includes $94.33 not reported in May.

USAF/AFSC
Aeronautical Systems Division
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period June 1, 1977 Through June 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed This Period	10	40	30			
Percent of Total Work Called For	100	66	0			
Difference	-25	-26	+30			

*These percentages are, of necessity, estimates, due to the nature of the work.

USAF/AFSC
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        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period July 1   through July 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed Through This Period	95	60	60			
Percent of Total Work Called For	100	100	33			
Difference	(5)	(40)	27			

USAF/AFSC
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Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period July 1   through July 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	46	206	220			
Cumulative Total to Date	523	328	343			1194
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	152	77	81			46
Remaining Assigned Man Hours Sufficient to Complete the Task?	---	Yes	Yes			Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period July 1   through   July 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	$860	3,799	4,059	---	---	8,719
Cumulative Funds Spent to Date	$7,342	4,968	5,229	---	---	17,539
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	98	48	51	---	---	29
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory —
ATTN: AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio   45433

Subject: Monthly Cost and Performance Report (a) Manhours
           Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

           For the Period Aug. 1, 1977 through Aug. 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	40	115	115			270
Cumulative Total to Date	563	443	458			1,474
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	163	104	108			56
Remaining Assigned Man Hours Sufficient to Complete the Task?	---	---	---			Yes

USAF/AFSC
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(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period Aug. 1, 1977   through Aug. 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	1000	2215	2220	---	---	5435
Cumulative Funds Spent to Date	$8,342	7,183	7,449	---	---	22,974
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	70	72	---	---	36
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
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      Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
         Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

         For the period Aug. 1, 1977 through Aug. 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed This Period	95	60	75			
Percent of Total Work Called For	100	100	66			
Difference	(5)	(40)	9			

USAF/AFSC
Aeronautical Systems Division
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period Sept. 1   through September 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	2	198	150	-0-	-0-	350
Cumulative Total to Date	565	641	608	-0-	-0-	1824
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143			69
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period Sept. 1   through September 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	.32	4112	2872	-0-	-0-	7026
Cumulative Funds Spent to Date	8374	11,305	10,321	-0-	-0-	30,000
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	109	100	-0-	-0-	47
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) <u>Work Completion</u>
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period Sept. 1   through Sept. 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Percent of Work Completed By end of This Period	90	90	90	0	0	
Percent of Total Work Called For	100	100	100	0	0	
Difference	(10)	(10)	(10)			

*Assuming Linear Rate of Progress

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period Oct. 1   through October 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	106	-0-	106
Cumulative Total to Date	565	641	608	106	-0-	1930
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	9	-0-	73
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period October 1   through October 31, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	0	500	500	1123	-0-	2123
Cumulative Funds Spent to Date	8374	11,805	10,821	1123	-0-	32,123
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	3	-0-	50
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
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(FY8993) Air Force Human Resources Laboratory
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        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period Oct. 1   through October 31, 1977

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed By End of This Period	95	95	95	33	0
Percent of Total Work Called For	100	100	100	33	0
Difference	(5)	(5)	(5)	0	0

*Assuming Linear Rate of Progress

Nov 77 8 #

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

        For the Period November 1   through November 30, 1977.

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	153	-0-	153
Cumulative Total to Date	565	641	608	274	-0-	2,083
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1,172	296	2,620
Percent Assigned Manhours Expended to Date	164	150	143	23	-0-	79
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
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     Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
         Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

         For the period November 1 through November 30, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	3,689	-0-	3,689
Cumulative Funds Spent to Date	8,374	11,805	10,821	4,812		35,812
Total Funds Assigned (From Management Plan and Budget)	8,374	10,321	10,321	28,530	5,932	63,778
Percent Assigned Funds Expended to Date	100	114	104	17	-0-	56%
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes

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Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period November 1 through November 30, 1977

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed by the end of This Period	95	95	95	66	-0-
Percent of Total Work Called For	100	100	100	66	-0-
Difference	(5)	(5)	(5)	-0-	-0-

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period December 1 through December 23, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	-35-	-0-	35
Cumulative Total to Date	565	641	608	309	-0-	2,118
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	26	-0-	80
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes	Yes	Yes	Yes	Yes	Yes

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Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period December 1, . through December 23, 1977

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	1930	-0-	
Cumulative Funds Spent to Date	8374	11,805	10,821	5619	-0-	37,742
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	20	-0-	59
Remaining Funds Sufficient to Complete Task?	YES	YES	YES	YES	YES	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period December 1 through December 23, 1977

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed This Period	95	95	95	66	-0-
Percent of Total Work Called For	100	100	150	100	-0-
Difference	(5)	(5)	(5)	(34)*	-0-

*This substantial difference is due to the impact of the proposed new approach
to model validation. Basic research does not commonly proceed at a linear rate;
but contractor anticipates no severe difficulty in meeting requirements of
this or an amended contract.

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period January 1   through January 31, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	-108-	-0-	-108-
Cumulative Total to Date	565	641	608	417	-0-	2226
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	36	-0-	85
Remaining Assigned Man Hours Sufficient to Complete the Task?	YES	YES	YES	YES	YES	YES

USAF/AFSC
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Wright Patterson AFB, Ohio 45433

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period January 1, · through January 31, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	2374	-0-	2,374
Cumulative Funds Spent to Date	8374	11,805	10,821	7993	-0-	39,816
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	25	-0-	63
Remaining Funds Sufficient to Complete Task?	YES	YES	YES	YES	YES	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

       For the period January 1, through January 31, 1978

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed This Period	100	100	100	70	-0-
Percent of Total Work Called For	100	100	100	100	-0-
Difference	-0-	-0-	-0-	(30)*	-0-

*This difference is due to the impact of the delay in funding of the proposed new approach to model validation.
Contractor anticipates no severe difficulty in meeting requirements.

       *Assuming Linear Rate of Progress

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
     Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
       Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

     For the Period February 1   through February 28, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	211	-0-	211
Cumulative Total to Date	565	641	608	628	-0-	2437
Total Manhours Assigned (From Mgt. Plan)	344	424	424	117	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	54	-0-	93
Remaining Assigned Man Hours Sufficient to Complete the Task?	Yes	Yes	Yes	Yes	Yes	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio   45433

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(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio   45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period February 1 through February 28, 1978

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed By End This Period	100	100	100	70	-0-
Percent of Total Work Called For	100	100	100	100	-0-
Difference	-0-	-0-	-0-	(30)*	-0-

   *This persisting difference is due to delays in getting equipment on which
    to run the proposed experimentation. Delivery is not anticipated until
    July; and experimentation cannot be completed until that time.

USAF/AFSC
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Wright Patterson AFB, Ohio 45433

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the period February 1   . through February 28, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	-4,211	-0-	4,211
Cumulative Funds Spent to Date	8374	11,805	10,821	12,204	-0-	44,027
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	43	-0-	69
Remaining Funds Sufficient to Complete Task?	Yes	Yes	Yes	Yes	Yes	Yes Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the Period March 1,1978 through March 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	256	-0-	256
Cumulative Total to Date	565	641	608	883	-0-	2692
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	75	-0-	103
Remaining Assigned Man Hours Sufficient to Complete the Task?	YES	YES	YES	YES	YES	YES

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period March 1, 1978 through March 31, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	5174	-0-	5,174
Cumulative Funds Spent to Date	8374	11,805	10,821	17,378	-0-	51,619
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	61	-0-	81
Remaining Funds Sufficient to Complete Task?	YES	YES	YES	YES	YES	Yes

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion *
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period March 1, 1978 through March 31, 1978

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed By end This Period	100	100	100	70	-0-
Percent of Total Work Called For	100	100	100	100	-0-
Difference	-0-	-0-	-0-	-30	-0-

*A revised schedule will be in effect upon signing of modification and extension
 to contract. Until that time, the old work schedule will appear in these reports.

          *Assuming Linear Rate of Progress

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the Period April 1, 1978 through April 30, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	200	-0-	200
Cumulative Total to Date	565	641	608	1083	-0-	2892
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	92	-0-	110
Remaining Assigned Man Hours Sufficient to Complete the Task?	YES	YES	YES	YES	YES	YES

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        Wright Patterson AFB, Ohio   45433

Subject: Monthly Cost and Performance Report (b) Funds
           Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

           For the period April 1, 1978 through April 30, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	4337		4337
Cumulative Funds Spent to Date	8374	11805	10821	21715	-0-	55956
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	76	-0-	88
Remaining Funds Sufficient to Complete Task?	YES	YES	YES	YES	YES	Yes

USAF/AFSC
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(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion*
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period April 1, through April 30, 1978

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed By End This Period	100	100	100	80	-0-
Percent of Total Work Called For	100	100	100	100	66
Difference	-0-	-0-	-0-	-20	-66

*A revised schedule will be in effect upon signing of modification and extension to contract. Until that time, the old work schedule will appear in these reports.

*Assuming Linear Rate of Progress

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period May 1,   through May 31, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	255	-0-	255
Cumulative Total to Date	565	641	608	1338	-0-	3147
Total Manhours Assigned (From Mgt. Plan)	344	424	424	1172	296	2620
Percent Assigned Manhours Expended to Date	164	150	143	114	-0-	120
Remaining Assigned Man Hours Sufficient to Complete the Task?	YES	YES	YES	*	*	*

*Work is proceeding according to the amended work plan, contract now under negotiation.

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period May 1,   . through May 31, 1978

	Task I	Task II	Task III	Task IV	Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	5537	-0-	5537
Cumulative Funds Spent to Date	8374	11,805	10,821	27,252	-0-	61,493
Total Funds Assigned (From Management Plan and Budget)	8374	10,321	10,321	28,530	5932	63,778
Percent Assigned Funds Expended to Date	100	114	104	96	-0-	96
Remaining Funds Sufficient to Complete Task?	YES	YES	YES	*	*	*

*Work is proceeding according to the amended work plan, contract now under negotiation.

USAF/AFSC
Aeronautical Systems Division
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(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period May 1,   through   May 31, 1978

	Task I	Task II	Task III	Task IV	Task V
Percent of Work Completed This Period	100	100	100	80	-0-
Percent of Total Work Called For *	100	100	100	100	100
Difference	-0-	-0-	-0-	-20	-100

*Assuming Linear Rate of Progress. Work is proceeding according to the amended
work plan, contract now under negotiation.

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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(FY8993) Air Force Human Resources Laboratory
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the Period   through

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	129	-0-	129
Cumulative Total to Date	565	641	608	1467	-0-	3276
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date	164	150	143	83	-0-	93
Remaining Assigned Man Hours Sufficient to Complete the Task?	YES	YES	YES	YES	YES	YES

* As amended June, 1978

USAF/AFSC
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        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
        Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

        For the period June 1   through   June 30, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	3604	-0-	3604
Cumulative Funds Spent to Date	8374	11,805	10,821	30,856	-0-	65,097
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	68	-0-	73
Remaining Funds Sufficient to Complete Task?						Yes

*As amended June, 1978

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period June 1   through June 30, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	60	-0-
Percent of Total Work Called For*	100	100	100	75	38
Difference	-0-	-0-	-0-	-15**	-38**

*As amended (June, 1978) assuming linear rate of progress.

  ** Delay here is due to necessity of ordering equipment. We anticipate being
     back on schedule by end of August.

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the Period July 1   through July 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	126	-0-	126
Cumulative Total to Date	565	641	608	1593	-0-	3646
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date	164	150	143	90	-0-	
Remaining Assigned Man Hours Sufficient to Complete the Task?						Yes

* As amended   June, 1978

USAF/AFSC
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          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period   July 1   through   July 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	3,242	-0-	3,242
Cumulative Funds Spent to Date	8374	11,805	10,821	34,098	0-0	68,339
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	75	-0-	77
Remaining Funds Sufficient to Complete Task?				Yes		Yes

*As amended   June, 1978

USAF/AFSC
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Wright Patterson AFB, Ohio 45433

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Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the period   July 1   through   July 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	60	-0-
Percent of Total Work Called For*	100	100	100	83	-50-
Difference	-0-	-0-	-0-	-23**	-50**

*As amended   June, 1978, assuming linear rate of progress.

** Delay due to equipment delivery problems. We anticipate a return to scheduled performance in September, since all equipment except one piece has arrived.

Monthly Cost & Performance Report No. 17

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the Period August 1 through August 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	129	-0-	129
Cumulative Total to Date	565	641	608	1722	-0-	3775
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date	164	150	143	97	-0-	
Remaining Assigned Man Hours Sufficient to Complete the Task?						Yes

* As amended June, 1978

Monthly Cost & Performance Report No. 17

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the period August 1   through   August 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	$3,384	-0-	$3,384
Cumulative Funds Spent to Date	$8374	$11,805	$10,821	$37,482	-0-	$71,713
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	82	-0-	80
Remaining Funds Sufficient to Complete Task?						Yes

*As amended   June, 1978

Monthly Cost & Performance Report. No. 17

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

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Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the period August 1 through August 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	60	-0-
Percent of Total Work Called For*	100	100	100	92	63
Difference	-0-	-0-	-0-	-32*	-63*

*As amended June, 1978, assuming linear rate of progress.

**Delay here is due to time necessary to configure the test equipment, which Georgia Tech has purchased at the request of the Air Force. No serious problems are anticipated, but more time than expected has been necessary for this installation.

Monthly Cost and Performance Report #18
Manhours

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the Period September 1 through September 30

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	105	-0-	105
Cumulative Total to Date	565	641	608	1827	-0-	3880
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date				Yes	Yes*	
Remaining Assigned Man Hours Sufficient to Complete the Task?						

 * As amended   June, 1978

*The manhours being expended are for
 programming assistance, and are charged
 at a lesser rate than the professional
 hours included in the

USAF/AFSC
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       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the period Sept. 1   through Sept. 30

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period				$5,120*	-0-	$5,120
Cumulative Funds Spent to Date	$8374	$11,805	$10,821	42,602	-0-	$76,833
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	94	-0-	86
Remaining Funds Sufficient to Complete Task?				Yes	Yes	Yes

*As amended   June, 1978

*This includes certain approved equi...

Monthly Cost and Performance Report #18
Work Completion

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
        AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

        For the period Sept. 1   through Sept. 30

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	70	-0-
Percent of Total Work Called For*	100	100	100	100	75
Difference	-0-	-0-	-0-	-30*	-75*

*As amended June, 1978, assuming linear rate of progress.

        *Delay is due to inanticipated time necessary to configure the test
        equipment, which Georgia Tech has purchased at the request of the
        Air Force. A 90-day no-cost extension has been requested, with the
        approved of the project engineer.

• October, 1978
Man hours

A-1979

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the Period Oct. 1   through Oct. 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period				146	146	292
Cumulative Total to Date	565	641	608	1973	146	4172
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date						
Remaining Assigned Man Hours Sufficient to Complete the Task?						

* As amended   June, 1978

.Monthly Cost and Performance Report #19
October, 1978
Funds

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
         Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period Oct. 1   through   Oct. 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period				$2,529	$2,529	$5,058
Cumulative Funds Spent to Date	$8374	$11,805	$10,821	$45,131	$2,529	$82,832
Total Funds Assigned (From Management Plan and Budget) *	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	99	18	92
Remaining Funds Sufficient to Complete Task?				Yes	Yes	Yes

*As amended   June, 1978

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) **Air Force Human Resources Laboratory**
        AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the period Oct. 1   through   Oct. 31, 1978

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	70	10
Percent of Total Work Called For*	100	100	100	100	100
Difference	0	0	0	-30	-90**

*As amended   June, 1978, assuming linear rate of progress.

**Due to delay caused by test facility configuration and equipment delivery
  problems, a 90 day no-cost extension has been requested.

A-1971

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
        Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the Period 11/1   through 11/30/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	130	18	148
Cumulative Total to Date	565	641	608	2,103	164	4320
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date	164	151	143	119	28	124
Remaining Assigned Man Hours Sufficient to Complete the Task?						

* As amended   June, 1978

November 1978
Funds

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio   45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period 11/1   through 11/30/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	2856	383	3149
Cumulative Funds Spent to Date	8374	11,805	10,821	47,897	2912	85,981
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	105	20	96
Remaining Funds Sufficient to Complete Task?						Yes

*As amended   June, 1978

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
         AFHRL/ASM (Ms. Pat Knoop)
         Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
          Contract No. F33615-77-C-0042   Item No. 0001 Sequence No. 1-5

          For the period 11/1   through 11/30/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	75	15
Percent of Total Work Called For*	100	100	100	100	100
Difference	-0-	-0-	-0-	-25	-85 **

*As amended   June, 1978, assuming linear rate of progress.

**A 90-day no-cost extension has been requested and approved, due to delay in test facility configuration.

Monthly Cost and Performance Report #21
December 1978

Man Hours

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (a) Manhours
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the Period 12/1   through 12/31/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Manhours Expended This Period	-0-	-0-	-0-	130	9	139
Cumulative Total to Date	565	641	608	2233	173	4459
Total Manhours Assigned (From Mgt. Plan) *	344	424	424	1772	596	3520
Percent Assigned Manhours Expended to Date	164	151	143	126	29	127
Remaining Assigned Man Hours Sufficient to Complete the Task?						

* As amended   June, 1978

December 1978
Funds

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
ATTN: AFHRL/ASM (Ms. Pat Knoop)
       Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (b) Funds
          Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

          For the period 12/1   through 12/31/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis and Reporting Task V	Total
Total Funds Expended This Period	-0-	-0-	-0-	2730	189	2919
Cumulative Funds Spent to Date	8374	11,805	10,821	50,753	3,101	88,900
Total Funds Assigned (From Management Plan and Budget)*	8374	10,321	10,321	45,504	14,419	89,240
Percent Assigned Funds Expended to Date	100	114	104	111	22	99.6
Remaining Funds Sufficient to Complete Task?						Yes

*As amended   June, 1978

December 1978
Work Completion

USAF/AFSC
Aeronautical Systems Division
Wright Patterson AFB, Ohio 45433

Buyer: CPT W. R. Swenson

(FY8993) Air Force Human Resources Laboratory
AFHRL/ASM (Ms. Pat Knoop)
Wright Patterson AFB, Ohio 45433

Subject: Monthly Cost and Performance Report (c) Work Completion
Contract No. F33615-77-C-0042 Item No. 0001 Sequence No. 1-5

For the period 12/1 through 12/30/78

	Literature Search Task I	Theory Development Task II	Model Development Task III	Validation Task IV	Analysis Task V
Percent of Work Completed by End Of This Period	100	100	100	95	20
Percent of Total Work Called For*	100	100	100	100	100
Difference				-5	-80**

*As amended June, 1978, assuming linear rate of progress.

**A 90-day no-cost extension has been requested and approved, due to delay in test facility configuration.

ILY COST AND PERFORMANCE REPORT # 22
RY   1979

AFSC
AUTICAL SYSTEMS DIVISION
T PATTERSON AFB, OHIO 45433

: CPT W. R. SWENSON

?3) AIR FORCE HUMAN RESOURCES LABORATORY
  AFHRL/ASM (MISS. PAT KNOOP)
  WRIGHT PATTERSON AFB, OHIO 45433

:T: MONTHLY COST AND PERFORMANCE REPORT (B) FUNDS
     CONTRACT NO. FY33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

     FOR THE PERIOD JANUARY   1, 1979 THROUGH JANUARY   31, 1979.

	LITERATURE SEARCH TASK I	THEORY DEVELOPMENT TASK II	MODEL DEVELOPMENT TASK III	VALIDATION TASK IV	ANALYSIS AND REPORTING TASK V	TOTAL
FUNDS EXPENDED PERIOD	0.00	0.00	0.00	0.00	1176.00	1176.00
IVE FUNDS TO DATE	8763.45	12386.43	11787.02	52026.76	4277.14	89240.80
UNDS ASSIGNED MANAGEMENT AND BUDGET)	8374.00	10321.00	10621.00	45504.00	14420.00	89240.00
ASSIGNED FUNDS DED TO DATE	104.65	120.01	110.98	114.33	29.66	100.00

NG FUNDS SUFFICIENT
NPLETE TASK?

AFSC
AUTICAL SYSTEMS DIVISION
T PATTERSON AFB, OHIO 45433

: CPT W. R. SWENSON

73) AIR FORCE HUMAN RESOURCES LABORATORY
   AFHRL/ASM (MISS. PAT KNOOP)
   WRIGHT PATTERSON AFB, OHIO 45433

T: MONTHLY COST AND PERFORMANCE REPORT (B) MANHOURS
   CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

   FOR THE PERIOD JANUARY   1, 1979 THROUGH JANUARY   31, 1979.

	LITERATURE SEARCH TASK I	THEORY DEVELOPMENT TASK II	MODEL DEVELOPMENT TASK III	VALIDATION TASK IV	ANALYSIS AND REPORTING TASK V	TOTAL
MANHOURS EXPENDED						
PERIOD	0	0	0	0	140	140
IVE						
TO DATE	565	642	608	2348	313	4476
MANHOURS ASSIGNED						
MANAGEMENT						
AND BUDGET)	344	424 —	424	1772	596	3560
ASSIGNED MANHOURS						
DED TO DATE	164.24	151.42	143.40	132.51	52.52	125.73
NG MANHOURS SUFFICIENT						
MPLETE TASK?	YES	YES	YES	YES	YES	YES

NTHLY COST AND PERFORMANCE REPORT NO. 23
R FEBRUARY ,1979

AF/AFSC
RONAUTICAL SYSTEMS DIVISION
IGHT PATTERSON AFB, OHIO 45433

8993) AIR FORCE HUMAN RESOUCES LABORATORY
N: AFHRLH/ASM (MS.PAT KNOOP)
     WRIGHT PATTERSON AFB, OHIO 45433

JECT: MONTHLY COST AND PERFORMANCE REPORT
        CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	3877.36	1292.45	0.00	0.00	5169.81
SPENT CUMULATIVE	93117.36	1292.45	0.00	0.00	94409.81
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	104.34	1.04	0.00	0.00	40.28
N-HOURS SPENT THIS MONTH	267.75	89.25	0.00	0.00	357.00
-HOURS SPENT CUMULATIVE	4743.75	89.25	0.00	0.00	4833.00
-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
JTAL MAN-HOURS EXPENDED	133.25	1.82	0.00	0.00	51.70
ANCE:					
AL STATUS END OF EBRUARY ,1979	A	A	I	I	N/A
NED STATUS END OF EBRUARY ,1979	A	I	I	I	N/A
ED STATUS END OF RCH ,1979	C	I	I	I	N/A

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HLY COST AND PERFORMANCE REPORT NO. 24
MARCH   ,1979

/AFSC
NAUTICAL SYSTEMS DIVISION
IT PATTERSON AFB, OHIO   45433

93) AIR FORCE HUMAN RESOUCES LABORATORY
    AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO   45433

CT: MONTHLY COST AND PERFORMANCE REPORT
     CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
PENT THIS MONTH	1556.86	4670.57	0.00	0.00	6227.43
PENT CUMULATIVE	94674.22	5963.02	0.00	0.00	100637.24
SSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
OTAL $ EXPENDED	106.09	4.78	0.00	0.00	42.94
-HOURS SPENT THIS MONTH	86.42	259.26	0.00	0.00	345.68
-HOURS SPENT CUMULATIVE	4830.17	348.51	0.00	0.00	5178.68
-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
TAL MAN-HOURS XPENDED	135.68	7.10	0.00	0.00	55.40
ANCE:					
L STATUS END OF RCH ,1979	A	A	I	I	N/A
IED STATUS END OF RCH ,1979	C	I	I	I	N/A
ED STATUS END OF RIL ,1979	C	A	I	I	N/A

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NTHLY COST AND PERFORMANCE REPORT NO. 25
R APRIL   ,1979

AF/AFSC
RONAUTICAL SYSTEMS DIVISION
IGHT PATTERSON AFB, OHIO 45433

'8993) AIR FORCE HUMAN RESOUCES LABORATORY
N: AFHRLM/ASM (MS.PAT KNOOP)
     WRIGHT PATTERSON AFB, OHIO 45433

UECT: MONTHLY COST AND PERFORMANCE REPORT
        CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	1325.03	3975.09	0.00	0.00	5300.12
SPENT CUMULATIVE	95999.25	9938.11	0.00	0.00	105937.36
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	107.57	7.96	0.00	0.00	45.20
N-HOURS SPENT THIS MONTH	62.32	186.94	0.00	0.00	249.26
N-HOURS SPENT CUMULATIVE	4892.49	535.45	0.00	0.00	5427.94
I-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
OTAL MAN-HOURS EXPENDED	137.43	10.91	0.00	0.00	58.07

IANCE:

IAL STATUS END OF PRIL ,1979	A	A	I	I	N/A
NED STATUS END OF PRIL ,1979	C	A	I	I	N/A
IED STATUS END OF IY ,1979	C	A	I	I	N/A

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THLY COST AND PERFORMANCE REPORT NO. 26
MAY   ,1979

F/AFSC
ONAUTICAL SYSTEMS DIVISION
GHT PATTERSON AFB, OHIO 45433

1993) AIR FORCE HUMAN RESOUCES LABORATORY
: AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO 45433

ECT: MONTHLY COST AND PERFORMANCE REPORT
     CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	1245.75	3737.26	0.00	0.00	4983.01
SPENT CUMULATIVE	97245.00	13675.37	0.00	0.00	110920.37
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	108.97	10.96	0.00	0.00	47.33
N-HOURS SPENT THIS MONTH	74.61	223.83	0.00	0.00	298.44
N-HOURS SPENT CUMULATIVE	4967.10	759.28	0.00	0.00	5726.38
!-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
OTAL MAN-HOURS EXPENDED	139.53	15.47	0.00	0.00	61.26

MANCE:

UAL STATUS END OF IAY ,1979	A	A	I	I	N/A
INED STATUS END OF IAY ,1979	C	A	I	I	N/A
NED STATUS END OF UNE ,1979	C	A	I	I	N/A

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THLY COST AND PERFORMANCE REPORT NO. 27
JUNE   ,1979

F/AFSC
ONAUTICAL SYSTEMS DIVISION
GHT PATTERSON AFB, OHIO 45433

3993) AIR FORCE HUMAN RESOUCES LABORATORY
I: AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO 45433

ECT: MONTHLY COST AND PERFORMANCE REPORT
     CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	1891.58	5674.75	0.00	0.00	7566.33
SPENT CUMULATIVE	99136.58	19350.12	0.00	0.00	118486.70
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	111.09	15.50	0.00	0.00	50.56
-HOURS SPENT THIS MONTH	112.70	338.08	0.00	0.00	450.78
-HOURS SPENT CUMULATIVE	5079.80	1097.36	0.00	0.00	6177.16
-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
TAL MAN-HOURS XPENDED	142.69	22.36	0.00	0.00	66.08

ANCE:

L STATUS END OF JNE ,1979	A	A	I	I	N/A
IED STATUS END OF NE ,1979	C	A	I	I	N/A
ED STATUS END OF LY ,1979	C	A	I	I	N/A

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HLY COST AND PERFORMANCE REPORT NO. 28
JULY   ,1979

/AFSC
NAUTICAL SYSTEMS DIVISION
HT PATTERSON AFB, OHIO 45433

993) AIR FORCE HUMAN RESOUCES LABORATORY
: AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO 45433

ECT: MONTHLY COST AND PERFORMANCE REPORT
      CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	0.00	7811.25	0.00	0.00	7811.25
SPENT CUMULATIVE	103990.83	27161.37	0.00	0.00	131152.20
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
OTAL $ EXPENDED	116.53	21.76	0.00	0.00	55.96
-HOURS SPENT THIS MONTH	0.00	498.01	0.00	0.00	498.01
-HOURS SPENT CUMULATIVE	5079.80	1595.37	0.00	0.00	6675.17
-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	860.00	9348.00
OTAL MAN-HOURS EXPENDED	142.69	32.51	0.00	0.00	71.41

ANCE:

AL STATUS END OF
ULY   ,1979   C   A   I   I   N/A

IED STATUS END OF
ULY   ,1979   C   A   I   I   N/A

IED STATUS END OF
GUST   ,1979   C   A   I   I   N/A

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MONTHLY COST AND PERFORMANCE REPORT NO. 29
FOR AUGUST   ,1979

SAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8993) AIR FORCE HUMAN RESOUCES LABORATORY
ATTN: AFHRLH/ASM (MS.PAT KNOOP)
       WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
          CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

COSTS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
$ SPENT THIS MONTH	0.00	8844.13	0.00	0.00	8844.13
$ SPENT CUMULATIVE	103990.83	36005.50	0.00	0.00	139996.33
$ ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
% TOTAL $ EXPENDED	116.53	28.85	0.00	0.00	59.74
MAN-HOURS SPENT THIS MONTH	0.00	529.01	0.00	0.00	529.01
MAN-HOURS SPENT CUMULATIVE	5079.80	2124.38	0.00	0.00	7204.18
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	142.69	43.28	0.00	0.00	77.07

PERFORMANCE:

ACTUAL STATUS END OF AUGUST ,1979	C	A	I	I	N/A
PLANNED STATUS END OF AUGUST ,1979	C	A	I	I	N/A
PLANNED STATUS END OF SEPTEMBER ,1979	C	A	I	I	N/A

STATUS CODES:
ACTIVE
INACTIVE
COMPLETE

MONTHLY COST AND PERFORMANCE REPORT NO. 30
FOR SEPTEMBER ,1979

USAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8793) AIR FORCE HUMAN RESOURCES LABORATORY
ATTN: AFHRLH/ASN (MS.PAT KNOOP)
      WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
         CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
COSTS:					
$ SPENT THIS MONTH	0.00	9202.69	0.00	0.00	9202.69
$ SPENT CUMULATIVE	103910.83	45208.19	0.00	0.00	149199.02
$ ASSIGNED (TOTAL)	89240.00	124002.00	59831.00	20317.00	234390.00
% TOTAL $ EXPENDED	116.53	36.22	0.00	0.00	63.66
MAN-HOURS SPENT THIS MONTH	0.00	426.57	0.00	0.00	426.57
MAN-HOURS SPENT CUMULATIVE	5079.80	2548.95	0.00	0.00	7628.75
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	142.69	51.93	0.00	0.00	81.61

PERFORMANCE:

ACTUAL STATUS END OF SEPTEMBER ,1979	I	A	I	I	N/A
PLANNED STATUS END OF SEPTEMBER ,1979	C	A	I	I	N/A
PLANNED STATUS END OF OCTOBER ,1979	C	A	I	I	N/A

STATUS CODES:
A ACTIVE
I INACTIVE
C COMPLETE

MONTHLY COST AND PERFORMANCE REPORT NO. 32
FOR NOVEMBER ,1979

USAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8993) AIR FORCE HUMAN RESOURCES LABORATORY
ATTN: AFHRLM/ASM (MS,PAT KNOOP)
       WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
         CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

COSTS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
$ SPENT THIS MONTH	2604.45	7813.36	0.00	0.00	10417.81
$ SPENT CUMULATIVE	106595.28	60925.21	0.00	0.00	167520.49
$ ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
% TOTAL $ EXPENDED	119.45	48.82	0.00	0.00	71.48
MAN-HOURS SPENT THIS MONTH	58.85	465.52	0.00	0.00	524.37
MAN-HOURS SPENT CUMULATIVE	5138.65	3460.55	0.00	0.00	8599.20
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	144.34	70.51	0.00	0.00	91.99

PERFORMANCE:

ACTUAL STATUS END OF NOVEMBER ,1979	A	A	I	I	N/A
PLANNED STATUS END OF NOVEMBER ,1979	C	A	I	I	N/A
PLANNED STATUS END OF DECEMBER ,1979	C	A	I	I	N/A

STATUS CODES:
A=ACTIVE
I=INACTIVE
C=COMPLETE

MONTHLY COST AND PERFORMANCE REPORT NO. 33
FOR DECEMBER ,1979

USAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8993) AIR FORCE HUMAN RESOUCES LABORATORY
ATTN: AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
    CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

COSTS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
$ SPENT THIS MONTH	3318.07	6059.52	0.00	0.00	9377.59
$ SPENT CUMULATIVE	109913.35	66984.73	0.00	0.00	176898.08
$ ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
% TOTAL $ EXPENDED	123.17	53.67	0.00	0.00	75.48
MAN-HOURS SPENT THIS MONTH	123.90	399.04	0.00	0.00	522.94
MAN-HOURS SPENT CUMULATIVE	5262.55	3859.59	0.00	0.00	9122.14
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	147.82	78.64	0.00	0.00	97.58
PERFORMANCE:					
ACTUAL STATUS END OF DECEMBER ,1979	C	A	I	I	N/A
PLANNED STATUS END OF DECEMBER ,1979	C	A	I	I	N/A
PLANNED STATUS END OF JANUARY ,1980	C	A	I	A	N/A

STATUS CODES:
A=ACTIVE
I=INACTIVE
C=COMPLETE

MONTHLY COST AND PERFORMANCE REPORT NO. 34
FOR JANUARY   ,1980

USAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8993) AIR FORCE HUMAN RESOUCES LABORATORY
ATTN: AFHRLM/ASM (MS.PAT KNOOP)
       WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
          CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

COSTS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
$ SPENT THIS MONTH	0.00	10969.35	0.00	0.00	10969.35
$ SPENT CUMULATIVE	109913.35	77954.08	0.00	0.00	187867.43
$ ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
% TOTAL $ EXPENDED	123.17	62.46	0.00	0.00	80.16
MAN-HOURS SPENT THIS MONTH	0.00	561.20	0.00	0.00	561.20
MAN-HOURS SPENT CUMULATIVE	5262.55	4420.79	0.00	0.00	9683.34
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	147.82	90.07	0.00	0.00	103.59

PERFORMANCE:

	TASKS 4.0-4.12	TASK 4.13	TASK 4.14	TASK 4.15	TOTAL CONTRACT
ACTUAL STATUS END OF JANUARY ,1980	C	A	I	I	N/A
PLANNED STATUS END OF JANUARY ,1980	C	A	I	I	N/A
PLANNED STATUS END OF FEBRUARY ,1980	C	A	I	I	N/A

STATUS CODES:
 A=ACTIVE
 I=INACTIVE
 C=COMPLETE

MONTHLY COST AND PERFORMANCE REPORT NO. 35
FOR FEBRUARY ,1980

USAF/AFSC
AERONAUTICAL SYSTEMS DIVISION
WRIGHT PATTERSON AFB, OHIO 45433

(FY8993) AIR FORCE HUMAN RESOUCES LABORATORY
ATTN: AFHRLM/ASM (MS.PAT KNOOP)
       WRIGHT PATTERSON AFB, OHIO 45433

SUBJECT: MONTHLY COST AND PERFORMANCE REPORT
          CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

COSTS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
$ SPENT THIS MONTH	0.00	9479.83	0.00	0.00	9479.83
$ SPENT CUMULATIVE	109913.35	87433.91	0.00	0.00	197347.26
$ ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
% TOTAL $ EXPENDED	123.17	70.06	0.00	0.00	84.21
MAN-HOURS SPENT THIS MONTH	0.00	541.18	0.00	0.00	541.18
MAN-HOURS SPENT CUMULATIVE	5262.55	4961.97	0.00	0.00	10224.52
MAN-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2320.00	880.00	9348.00
% TOTAL MAN-HOURS EXPENDED	147.82	101.10	0.00	0.00	109.38

PERFORMANCE:

	TASKS 4.0-4.12	TASK 4.13	TASK 4.14	TASK 4.15	TOTAL CONTRACT
ACTUAL STATUS END OF FEBRUARY ,1980	C	A	I	I	N/A
PLANNED STATUS END OF FEBRUARY ,1980	C	A	I	A	N/A
PLANNED STATUS END OF MARCH ,1980	C	C	I	A	N/A

STATUS CODES:
   A=ACTIVE
   I=INACTIVE
   C=COMPLETE

NTHLY COST AND PERFORMANCE REPORT NO. 36
R MARCH   ,1980

AF/AFSC
RONAUTICAL SYSTEMS DIVISION
IGHT PATTERSON AFB, OHIO 45433

(8993) AIR FORCE HUMAN RESOUCES LABORATORY
N: AFHRLM/ASM (MS.PAT KNOOP)
    WRIGHT PATTERSON AFB, OHIO 45433

JECT: MONTHLY COST AND PERFORMANCE REPORT
       CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

TS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	0.00	6704.72	0.00	0.00	6704.72
SPENT CUMULATIVE	109913.35	94138.63	0.00	0.00	204051.98
ASSIGNED (TOTAL)	89240.00	124902.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	123.17	75.43	0.00	0.00	87.07
AN-HOURS SPENT THIS MONTH	0.00	409.09	0.00	0.00	409.09
AN-HOURS SPENT CUMULATIVE	5262.55	5371.05	0.00	0.00	10633.60
N-HOURS ASSIGNED (TOTAL)	3560.00	4906.00	2328.00	800.00	9343.00
TOTAL MAN-HOURS EXPENDED	147.82	109.43	0.00	0.00	113.75

RMANCE:

UAL STATUS END OF MARCH ,1980	I	A	I	I	N/A
NNED STATUS END OF MARCH ,1980	C	C	A	I	N/A
NNED STATUS END OF APRIL ,1980	C	C	A	I	N/A

CODES:
CTIVE
NACTIVE
OMPLETE

RFORMANCE REPORT NO. 37
R APRIL   ,1980

AF/AFSC
RONAUTICAL SYSTEMS DIVISION
IGHT PATTERSON AFB, OHIO 45433

(8993) AIR FORCE HUMAN RESOUCES LABORATORY
TN: AFHRL/OT (Dr. Tom Longridge)
       Williams AFB, AZ 85224

JECT: MONTHLY COST AND PERFORMANCE REPORT
      CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

TS:	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
SPENT THIS MONTH	0.00	3864.00	0.00	3864.00	7728.00
SPENT CUMULATIVE	109913.35	98002.63	0.00	3864.00	211779.98
ASSIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
TOTAL $ EXPENDED	123.17	78.53	0.00	19.02	90.37
AN-HOURS SPENT THIS MONTH	0.00	214.10	0.00	214.10	428.20
AN-HOURS SPENT CUMULATIVE	5262.55	5585.15	0.00	214.10	11061.80
N-HOURS ASSIGNED (TOTAL)	3560.00	4908.00	2328.00	880.00	9348.00
TOTAL MAN-HOURS EXPENDED	147.82	113.80	0.00	24.33	118.33

RMANCE:

TUAL STATUS END OF APRIL ,1980	C	C	I	A	N/A
NNED STATUS END OF APRIL ,1980	C	A	I	I	N/A
NNED STATUS END OF MAY ,1980	C	C	I	A	N/A

 CODES:
CTIVE
NACTIVE
OMPLETE

ANCE REPORT NO. 38
Y   ,1980

FSC
UTICAL SYSTEMS DIVISION
PATTERSON AFB, OHIO 45433

3) AIR FORCE HUMAN RESOUCES LABORATORY
AFHRLN/ASM (MS.PAT KNOOP)
WRIGHT PATTERSON AFB, OHIO 45433

T: MONTHLY COST AND PERFORMANCE REPORT
CONTRACT NO. F33615-77-C-0042 ITEM NO. 0001 SEQUENCE NO. 1-5

	TASKS 4.0-4.12	TASK 4.13 MODEL REFINEMENT AND VALIDATION TEST	TASK 4.14 DEMONSTRATION TEST (OPTIONAL)	TASK 4.15 OVERALL MODEL ASSESSMENT AND REPORTING	TOTAL CONTRACT
ENT THIS MONTH	0.00	0.00	0.00	7760.02	7760.02
ENT CUMULATIVE	109913.35	98002.63	0.00	11624.02	219540.00
SIGNED (TOTAL)	89240.00	124802.00	59831.00	20317.00	234359.00
AL % EXPENDED	123.17	78.53	0.00	57.21	93.68
OURS SPENT IS MONTH	0.00	0.00	0.00	412.83	412.83
OURS SPENT NULATIVE	5262.55	5585.15	0.00	626.93	11474.63
URS ASSIGNED ITAL)	3560.00	4908.00	2328.00	880.00	9348.00
L MAN-HOURS ENDED	147.82	113.80	0.00	71.24	122.75

CE:

STATUS END OF ,1980	C	C	I	A	N/A
STATUS END OF ,1980	C	C	I	A	N/A
STATUS END OF ,1980	C	C	I	C	N/A

ES:
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PROPOSALS FOR HOPE MODEL REFINEMENTS

BY

E. L. Davenport, J. Green, H. F. Engler, W. E. Sears

October, 1979

Prepared for

Air Force Human Resources Laboratory
Wright-Patterson Air Force Base
Ohio

by

Systems Engineering Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

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I. INTRODUCTION

The Human Operator Performance Emulator is a psychologically-based computer simulation of human control learning and behavior. The "learning" processes and the control behaviors of the HOPE are modulated both by task demands and also by control strategy. Control strategy is determined in HOPE by the values of certain key parameters called control strategy parameters and the resulting simulated behaviors are matched against those recorded from human operators given a similar task. A complete description of HOPE and of initial validation procedures is given in the final technical report on contract items 4.0-4.12 of the current contract. The present report is descriptive of work undertaken on items 4.13.1 and 4.13.2 of that contract. Specifically, this report contains prioritized proposals for model refinements, descriptions of the observations made which suggest each refinement, the aspects of the HOPE which will be affected, and recommendations regarding check-out procedures for the several refinements. The remainder of the introduction consists of a description of the data examined, and a summary account of certain symptoms of the need for model refinement that emerged from analyses of the data.

A. Data Analyses

Data analyses involved statistical, visual, and conceptual analysis of data collected during the initial testing of HOPE, as well as of additional data generated to document the operation of HOPE. The following sets of data were examined.

1. Plots of control stick positions, both those used by selected humans and those generated by certain HOPE models.

2. Data listings of control stick positions from selected operators and models.

3. Plots of cursor positions produced by humans and by HOPE models.

4. Root mean square (RMS) difference values (computed between humans and their best-fitting models) averaged within and across trials for each person, and across conditions for the group as a whole.

5. Minimum RMS difference values for the first 12 time bins of tracking (trial one) for all operators, as selected by comparing first trial operator behaviors with model behaviors in comparable bins in all five trials.

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6. Clustering of the control strategy parameters (CSPs) of the ten top-ranked models, for selected individuals and bins.

7. Clustering of the CSP's of the best fitting models within and across trials for selected individuals, and for all subjects in each of the four conditions.

8. Changes in control strategy, as identified by the CSP's of best fitting models, as a function of conditions of testing and of practice.

9. The nature and value of commands valid for producing specified changes in cursor position, for the plant dynamics used in the test.

10. The value of commands stored in the HOPE Command Memory at various points in "training," for selected models.

11. Mean absolute position error of all human operators and their best fit models, within and across trials.

12. Diagnostics generated during model execution, such as command string length, calls to the Command Selection Process, calls to the Excessive Error Process, etc., for all models.

13. Mean absolute position error for all 75 models, averaged within and across trials, and across conditions.

These data were collected for the following types of analysis:

1. Analysis of the differences between model and human control outputs and performance.

2. Analysis of model and human learning trends.

3. Determination of the most important discrepancies between expected and observed results.

4. Analysis of control strategy variations within and between subjects and across the various task conditions.

5. Evaluation of the control strategy identification process.

The Appendix to this report is a graphical presentation of the entire system of programs and data files on which the work through contract item 4.13.1 is based.

B. Symptoms Suggesting Need for Refinements

Analyses of the data listed previously revealed a variety of symptoms which suggest that HOPE and, possibly, the procedures for best fit model identification, require further refinement. The symptoms are named and briefly described below:

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1. Excessive variation in model control stick position — The commands executed by best fit models are much more variable than those in the human behavior being matched. Human command behavior is much smoother, and more continuous than (best fit) model behavior.

2. Poor model matches for early trials — The quality of HOPE matches to human behavior increases as model and human become more experienced. Ideally, HOPE should be able to match human behavior equally well at all points in experience.

3. Improved model matching using "experienced" models — The behaviors of operators in the first trial of the task are better matched by models in trials four and five than by models in the first trial.

4. Problems in the best fit model identification process — There are reasons to believe that improvements are necessary in the measure currently used to judge model matching. In particular, the RMS difference measure currently being used by the model identification process seems to be somewhat insensitive to apparent model behavior differences caused by variation in Command Operative Time (COT).

5. Poor matching for $\frac{1}{2}$ hz conditions — HOPE models match human behavior in $\frac{1}{2}$ hz testing conditions less well than in $\frac{1}{4}$ hz testing conditions.

6. Relatively different control strategy parameters in neighboring bins — Best fit models in certain isolated bins have control strategy parameters (CSP's) which are inconsistent with the control strategy of that trial, as identified by the CSPs of most of the best fit models for that trial. Although control strategy is believed to vary with practice, changes every 20 seconds seem excessive, especially when human control behaviors do not appear to be changing so dramatically.

7. Clustering of CSPs at the edges of parameter space — In certain testing conditions, the CSP's of the best fit models have the maximum or minimum values currently implemented in HOPE models.

The following sections of the report provide more complete descriptions of each symptom and the data evidencing it. For each symptom, probable causes of the symptom are listed, as well as proposals for refining HOPE or the model identification procedures so as to eliminate the symptom. Procedures for evaluating the success of each proposed refinement are described. The recommended priority of the proposed refinements

is indicated by the order in which they are described. A summary table (Table 6) of all refinements discussed is found following Section V of the report.

II. SYMPTOM 1: EXCESSIVE VARIATION IN MODEL CONTROL STICK POSITION

A. Symptom Description

The major impetus for proposing this model refinement has been comparisons of plots of control stick position for selected bins of human behavior and the corresponding best fit models, as identified by the minimum root mean square difference. Figures 1 and 2 are samples of the plots which show control stick positions for a subject and for the corresponding best fit models in two 20 second intervals. The most impressive difference between human and model behavior shown here is that human behavior is relatively smooth and continuous, while model behavior is not. (Note that there exists in the human record a "jitter" which is caused by noise in the A/D conversion, and does not reflect human control behavior.) Model behavior differs from human behavior in at least two respects. First, model behavior is more "variable" - there is greater fluctuation of control stick position within a given limit of time. Secondly, model control behavior includes a considerable number of "spikes". These spikes are produced when there is execution of an "out of context" command, one quite different in value from the surrounding sequence of commands. The execution of an "out of context" command causes a relatively large shift in control stick. For example, if commands such as 58, 58, 60, 60, 62, 62, 40, 40, 63, 63 were executed, the execution of the "out of context" commands, 40, 40, would appear in the plots as a spike in an otherwise smooth movement of control stick to the right.

Spikes and variability are particularly apparent when the model is trying to reverse the direction of tracking. In contrast, when trying to reverse direction, human behavior is more constant. It seems the human chooses a command which is held over some interval of time.

B. Probable Causes

The implementation of the computer simulation involved several simplifying assumptions. One of these was the assumption that the time between initiation of a neural signal for a motor command and the execution of a command is negligible. This is, of course, not a true assumption, but was made to simplify the program execution during the initial test phases. The absence of this limitation which we know to be present in humans has certainly resulted in greater variability on the part of the model's

	Mean Absolute Position Error		Best Fit Models Control Strategy Parameters		
	Human	Model	COT	ERRLIM	ADJUST
Bin 55	2.056	2.000	5	5	2
Bin 56	2.578	2.348	5	5	2
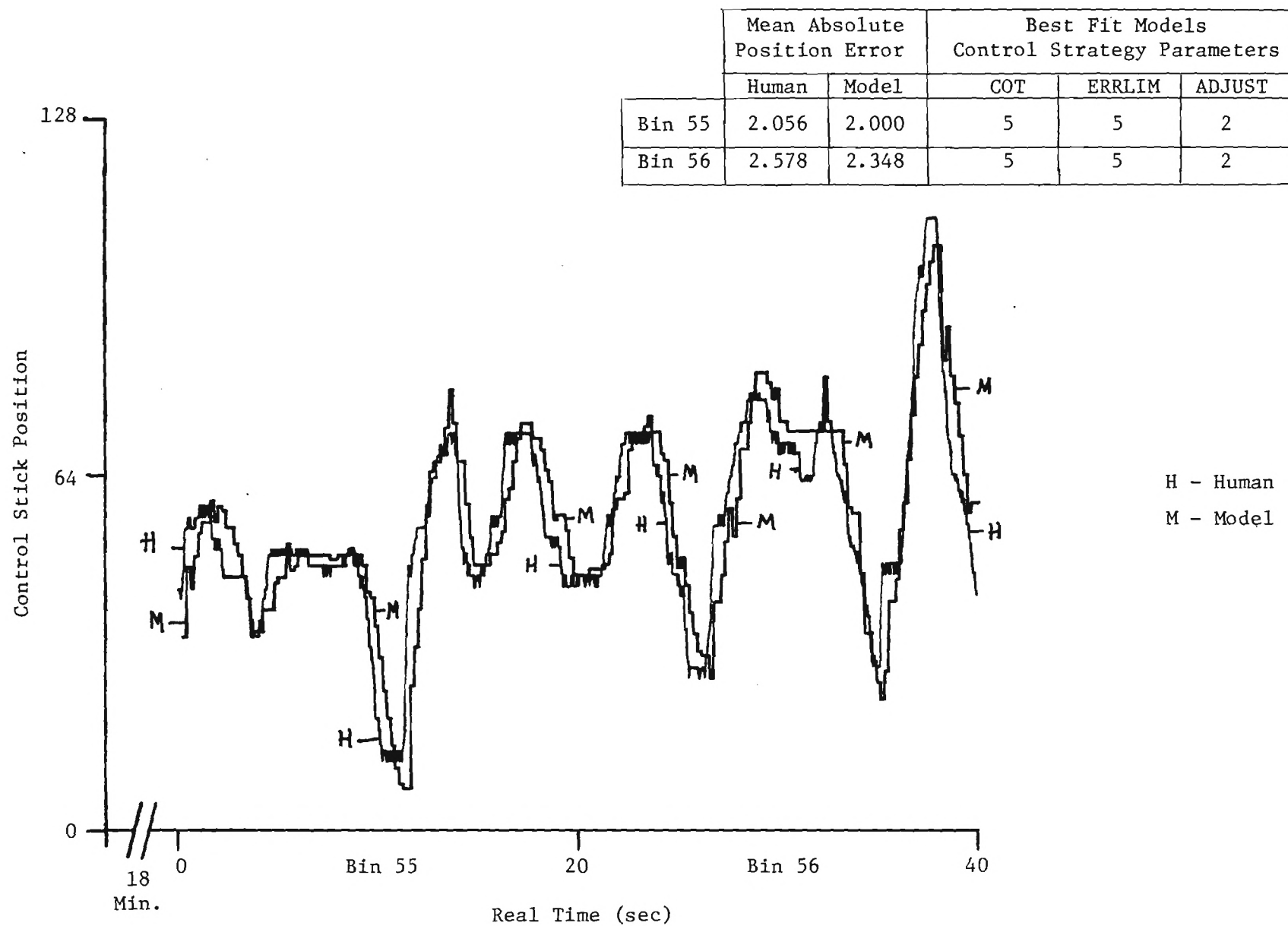
H – Human

M – Model

Figure 1.   Example of Control Stick Positions of Subject 1212 and Best-Fit Models
(Tracking 1/4 Hz Track; Non-linear First-order Plant).

	Mean Absolute Position Error		Best Fit Models Control Strategy Parameters		
	Human	Model	COT	ERRLIM	ADJUST
Bin 53	2.896	3.340	2	16	5
Bin 54	2.684	2.954	2	32	8

H – Human
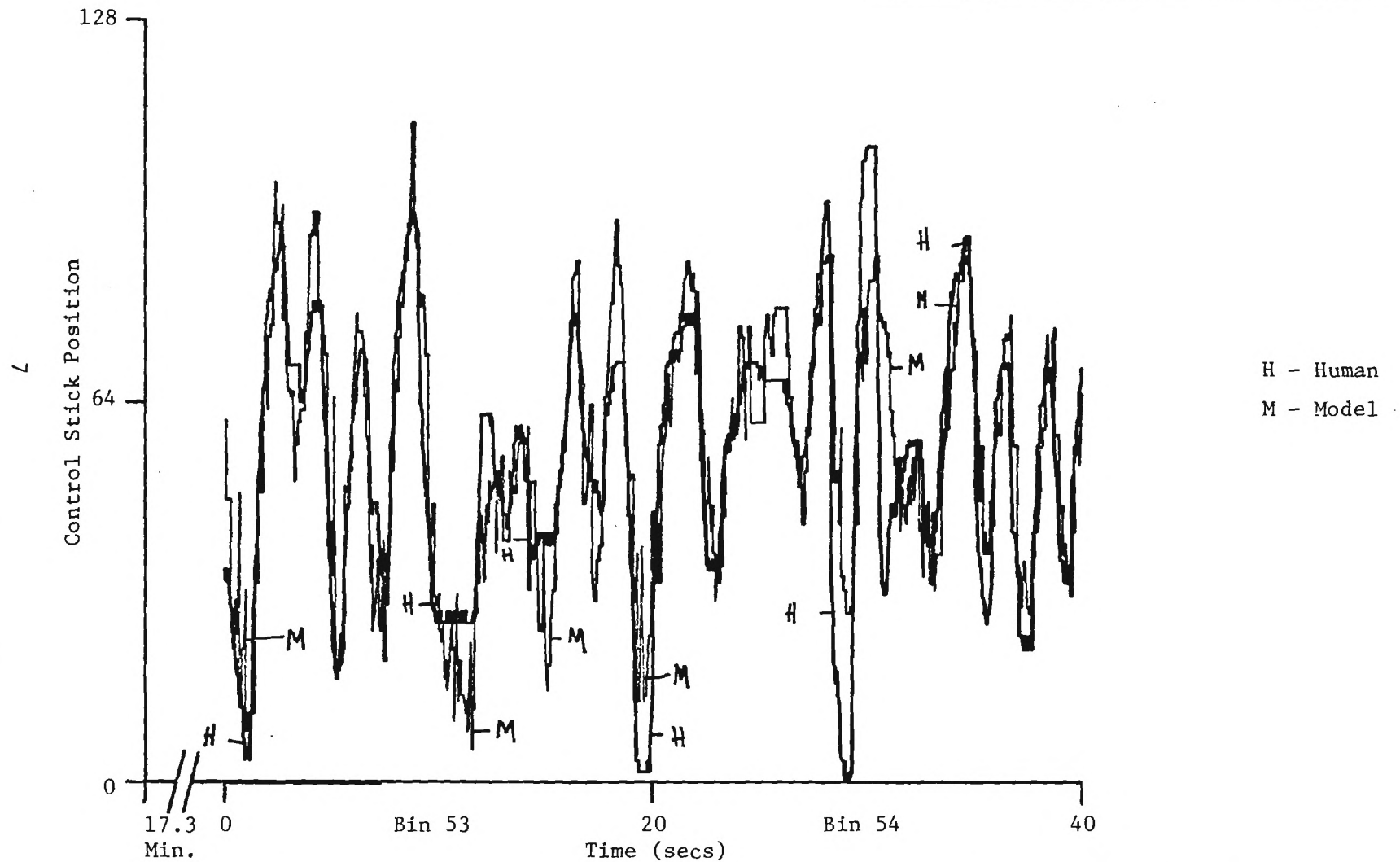
M – Model

Figure 2.   Example of Control Stick Positions of Subject 2222 and Best-Fit Models
(Tracking 1/2 Hz Track; Non-linear First-order Plant)

control stick, than if we has implemented this limitation. However, the majority of observed variability is believed to be associated with causes other than the absence of neuromuscular lag in the model.

These model behaviors could represent errors in the Command Memory; that is, they could be commands which are ineffective in moving the cursor from a current state to a desired state, but which were erroneously entered into the memory due to a fault in the model. However, examination of a variety of data reveals that this is definitely not the case. The execution of "out of context" commands, as well as of a varying sequence of commands, produces effective cursor manipulations. As shown by both model and human cursor plots and by absolute position error data, even though the model is executing "out of context" or highly variable commands, it is smoothly manipulating the cursor position, and sometimes shows even less position error than the human. Figures 3 and 4 show the human and model cursor plots, and the mean absolute position error corresponding to the time bins displayed in Figures 1 and 2.

These observations suggested that further examination of the Command Memory and its development was important. It will be recalled that each location in the Command Memory is addressed by current and desired cursor positions and contains an average of commands that have been used to accomplish this change in position.

Two strategies were used to examine the development of the Command Memory. First, an examination was made of all possible ways a "good" (e.g., effective) command memory could develop, given the particular plant dynamics implemented in this testing. The value of this examination lay in the idea that if the "best" Command Memory, or Memories, for a given COT, included "out of context" commands like those actually used by the models, then a probable source for model human differences would be identified -- e.g., either the model's Command Memory store should not contain out-of-context commands, or humans use a criterion to prevent "excessive" control stick variation, even when such variation is effective in doing the task.

Indeed, the generation of all possible commands which could effect a specified change in cursor position revealed that, for these nonlinear plant dynamics, many "good" Command Memories exist. That is, for most possible transitions in cursor position, there exists a range -- and sometimes a discontinuous range -- of control stick positions which accomplish that transition.
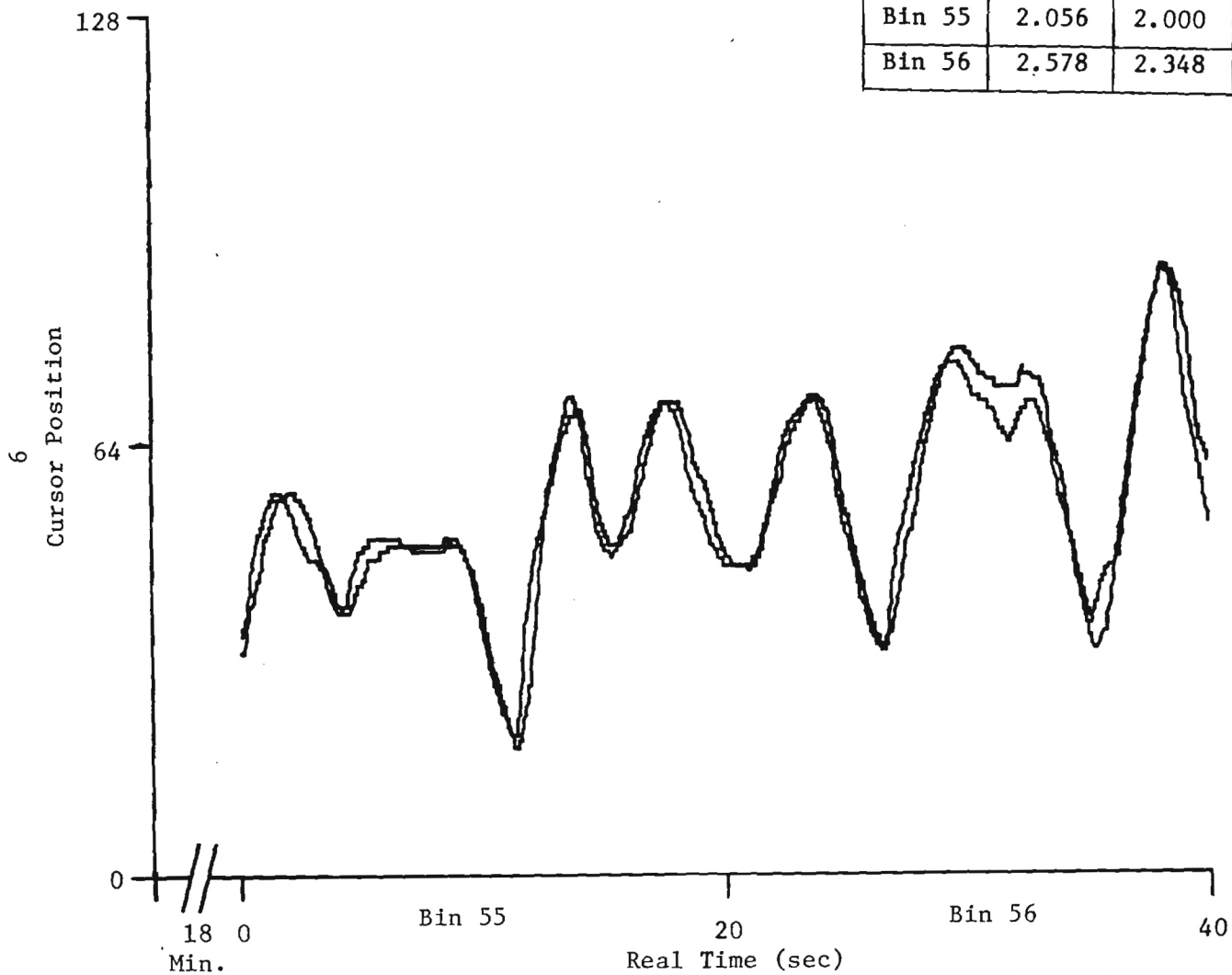
	Mean Absolute Position Error		Best Fit Models Control Strategy Parameters		
	Human	Model	COT	ERRLIM	ADJUST
Bin 55	2.056	2.000	5	5	2
Bin 56	2.578	2.348	5	5	2

Figure 3.   Example of Cursor Positions for Subject 1212 and Best-Fit Models
(Tracking 1/4 Hz Track; Non-linear First-order Plant).

	Mean Absolute Position Error		Best Fit Models Control Strategy Parameters		
	Human	Model	COT	ERRLIM	ADJUST
Bin 53	2.896	3.340	2	16	5
Bin 54	2.684	2.954	2	32	8
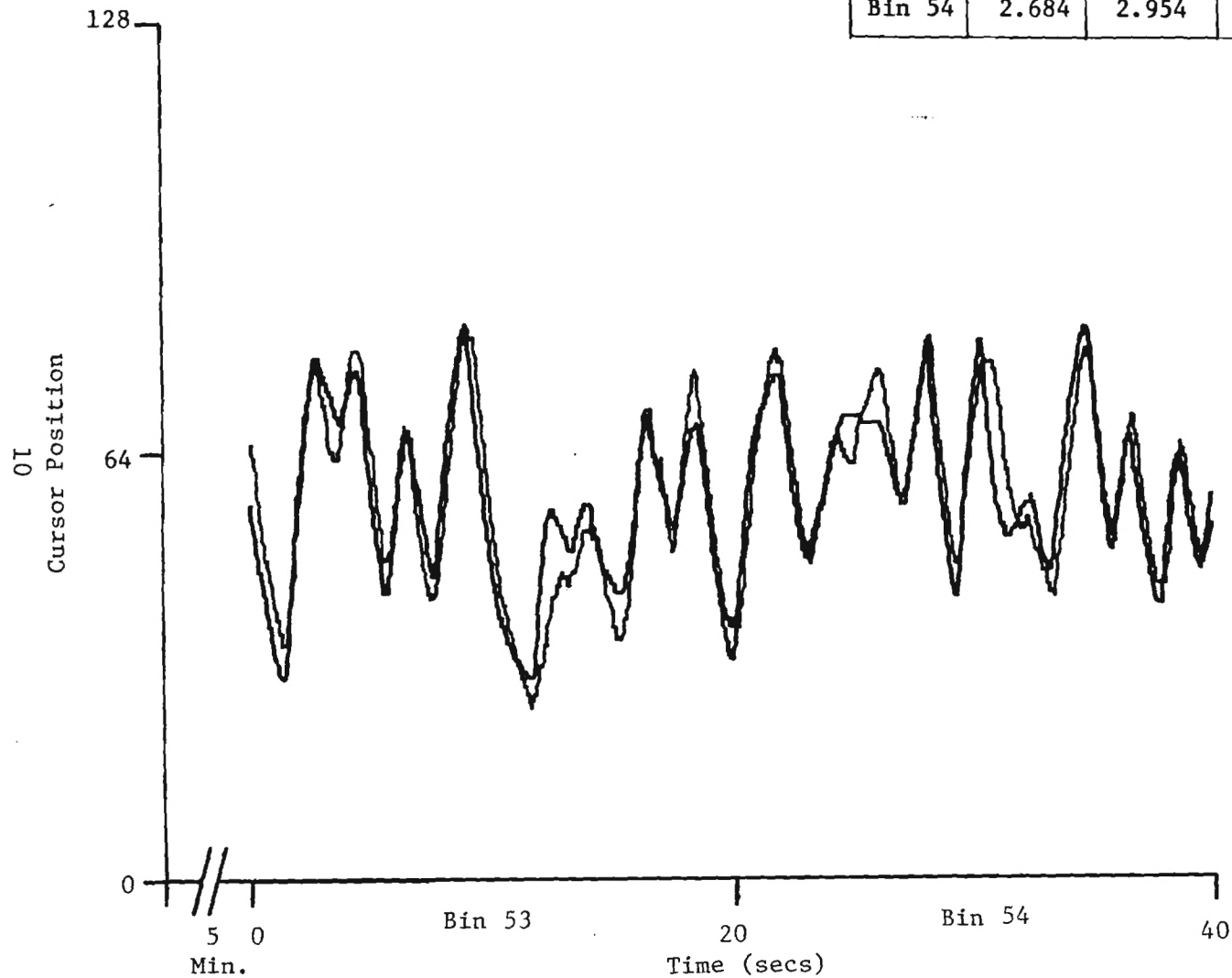
Figure 4. Examples of Cursor Positions for Subject 2222 and Best-Fit Models
(Tracking 1/2 Hz Track; Non-linear First-order Plant).

Further, the range of commands which can function to effect a given change in cursor position makes it possible for highly dissimilar commands to be associated with changes within a limited area of cursor movement. For example, consider the data in Table 1, showing a sequence of cursor movements, and the commands possible to effect these movements, given a COT of 2.

Table 1. Effective Commands for a Sample Cursor Movement

Cursor Position		Effective Commands
CP_i	CP_{i+1}	
1	5	38, 39
5	5	5 - 20
5	10	44-50, 115-126
10	11	25-30

In this sequence, the cursor would be moving in a relatively small area steadily to the right. Yet the ranges of commands valid for this non-linear plant make it possible for average commands in neighboring locations to be quite different, with the result that the model control stick would be moving both to the right and to the left on alternate commands.

The second strategy for examination of the HOPE Command Memory development was to resimulate the "learning" and performance in the task, using selected HOPE models, and to record at several stages in "learning," the current contents of the developing Command Memory. Examination of such records revealed that the experience and the averaging process which determine Command Memory contents had indeed resulted in the storage of "out-of-context" commands in several locations. Table 2 displays a section of the Command Memory developed by a $\frac{1}{4}$ hz model at the end of the fifth trial. Note that to move steadily to the right from cursor position 35 to 37, 37 to 38, and 38 to 40, the stored commands are 45, 36, 53.

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Table 2. Section of a HOPE Model Command Memory After Five Trials
of Experience with Nonlinear Plant

Cursor Positions (CPs) at t_i, t_{i+1}		Stored Command (Control Stick Position)
CP_i	CP_{i+1}	
35	37	45
37	38	36
38	39	47
38	40	53
39	40	41
40	40	30

The two analyses described above indicate that the variability and
spikiness in model behavior may be in large part due to "out-of-context,"
yet correct, commands stored in the HOPE model Command Memory, and then
utilized by the Command Selection Process.

It was fortuitous that a non-linear plant was chosen for the initial
validity testing of HOPE, because it provided more opportunity for
dissimilarities between HOPE and human behaviors to emerge than would a
linear plant. In other words, the potential for use of "out-of-context"
commands would have been much less if a linear plant had been used. It is
believed, however, that the model would have exhibited tendencies to
"overcontrol" (far more variability in control stick position than human)
even with a linear plant. To see this, consider the following argument.

The underlying description of the commands used by HOPE in con-
trolling the plant is that they are (or should be) the ones which result in
the cursor attaining the same position as the track at the end of the COT.
This aim does not take into account the amount of energy needed to manipu-
late the control stick in such a fashion, nor does it consider the merit of
toleration of some position error now for the sake of being able to achieve
smaller error in the near future. For example, a sharp turn is likely to
be executed by a human as shown in Figure 5.

Figure 5. Illustration of a Cursor Path Which Minimizes Control
Stick Manipulation at Expense of Position Error

This approach involves minimal manipulation of the control stick at the expense of some (although still acceptable) error. Note that the cursor is only in the center of the track in a few instances.

In order to see why the model would "overcontrol" even if controlling a linear plant, consider the response of a first order position type system (the type used in HOPE) to a step change in input. This is shown in Figure 6.
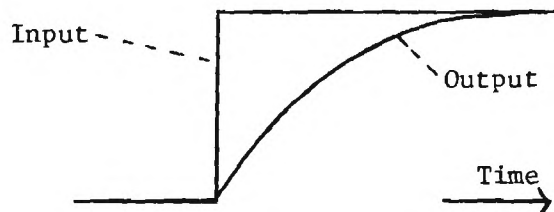
Figure 6. Response of a First Order System to a Step Change
in Input

The rate at which the response (cursor output) reaches asymptote (input position) is dependent upon the time constant of the system. Regardless of the magnitude of the step change in control stick input, the cursor output will never surpass it; there is always a lag. This means that if the plant dynamics are first order, then the optimum way to minimize cursor error is to attempt to minimize it on a step by step basis rather than over some extended time interval of several steps.

This is not a very leisurely method of control, however. For instance, consider a linear plant whose output is currently 50 and consider a track which moves back and forth between values of 50 and 51. The equation for such a plant is:

$$O_{i+1} = O_i + \frac{\Delta_t}{T_c} (CMD_i - O_i),$$

where

O_i = current cursor output

Δ_t = sampling time

T_c = time constant

CMD_i = current control stick position

Solving for CMD_i:

$$CMD_i = O_i + \frac{T_c}{\Delta_t} (O_{i+1} - O_i)$$

Table 3a shows the command needed to get from 50 to 51 with several values for the time constant and for t = 0.04, the value used in HOPE. Table 3b shows the command needed to go the other way: from 51 to 50.

Table 3. Variation in Commands as a Function of Time Constants

(a) Command for Cursor Movement from Position 50 to 51		(b) Command for Change from Position 51 to 50	
Command	Time Constant	Command	Time Constant
53	.1	48	.1
55	.2	46	.2
58	.3	43	.3
60	.4	41	.4

So, if the track is moving between 50 and 51 and back every 40 msec., then in order to eliminate all position error when the time constant is 0.4, the control stick must be alternately moved from 41 to 60 -- not a very leisurely behavior for eliminating such a small error. In contrast, if the control stick were just left at 50 and not moved, the average position error on this track would be only 0.5 instead of 0. Hence, by striving to stay on the track every COT, HOPE would be minimizing position

error at the expense of excessive control stick manipulation. Since the subjects' control stick motion does not appear this energetic, one possible explanation is that the subjects impose some criterion on control stick manipulation at the expense of somewhat larger cursor error. Another explanation is that humans selectively remember only "in context" commands. Note that these ideas also explains why some models actually have less position error than the subjects, while not being selected as good fits to humans.

Although these characteristics of HOPE can be viewed as a need for a criterion on control stick position, or as a need for Command Memory "smoothing", they could also be viewed, equivalently, as a need for additional utilization by HOPE of the available preview. The minimization of position error each COT without regard for later track characteristics is equivalent to pursuit tracking. Even though a preview of the track to come is available to HOPE, the considerations for selection of a particular command do not use this information. Better subject/model matches might perhaps have been obtained by giving the subjects no preview. Or, conversely, better subject/model matches should occur by refinement of the model to make better use of available preview.

There exists still another possible source for the smooth behaviors of human operators that is suggested by the above discussion. Humans may impose different criteria on cursor position than the point-to-point ERRLIM excessive error boundary utilized by HOPE. Perhaps HOPE should select commands good enough to attain a cursor position anywhere within ERRLIM of the track, for a sequence of points, in addition to evaluation of its point-by-point performance by this criterion. This type of change is only indirectly related to spiky control stick position, however. Thus, in the absence of strong evidence for a change in the operation of the existing cursor position criterion, this refinement is considered a less likely remedy than is an application of some form of criterion to control stick behavior sequences.

C. Proposals for Refinement

The objective of the following refinement is to reduce the variability in model behavior so that it more closely matches that of humans. Several alternative methods for accomplishing this are described below. Each of these alternatives represent methods which could be representative

of how the human is able to achieve smoothness in manipulating the control stick - that is, each has psychological validity. Before making any final changes in the model, the effects of implementing each of these alternatives will be tested and evaluated. Then the most effective method, or combinations of methods, for reducing model variability will be implemented in HOPE.

    1.   <u>Modification of Perception</u>.   In HOPE, there is a distinction between "perceived" cursor position and actual cursor position. The "perceived" cursor position is where the model "sees" the cursor to be. This is an integer number in the range 1 to 128 and is used to reference the Command Memory (present perceived cursor position, next desired cursor position). The actual cursor position is the internal number used by the cursor plant and includes a decimal portion. The two are currently related by:

$$\text{"Perceived" cursor} = \text{IFIX (actual cursor)} = \text{integer truncation of actual cursor.}$$

This means, for example, that any actual cursor position between 64.000 and 64.999 is recorded by the model as position 64. The proposed change is to make the two related by:

$$\text{Perceived cursor} = \text{IFIX (actual cursor + .5)} = \text{integer rounding of actual cursor.}$$

Thus, real cursors between 63.50 and 64.499 would be perceived as position 64.

    This is desirable for two reasons. First, it is more consistent with how the human sees the cursor move. The human operator is more likely to associate an actual cursor position of 64.87 with a perceived cursor of 65 than with 64. Also, rounding instead of truncating should result in "more reasonable" commands in the Command Memory. For example, suppose actual cursor position is 64.25 (perceived as 64 by the model both before and after the proposed change). Also suppose that the next desired cursor position is 65. In the current implementation, any command from 72 to 89 will result in a perceived cursor of 65 (in one time interval). With rounding, this range would be altered to 67 to 76 and 78 to 82 (the jump is due to a time constant boundary). This is a result that more truly reflects the true cursor dynamics. Thus, through the perception process, more accurate commands will be stored in Command Memory. This refinement

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should be the first made. It is very simple to do, and should aid, although not fully accomplish, the reduction of excessive control stick position variability.

2. Command Memory Smoothing. Another method with potential for reducing model variability is to induce memory continuity by changing the HOPE Command storage procedures that occur during the Stimulus-Response Association Process. Currently the command that is stored is an average of commands effective in producing a given cursor movement. Each of the experienced commands is weighted equally with the average that has already been developed. To induce a more continuous memory, a differential weighting of commands could be implemented. A command which contributed to the local continuity of the memory might receive a greater weight in determining the average than did a command which was inconsistent with the continuity. This method of reducing model variability is referred to as "memory smoothing." This refinement would affect the Command Memory and the Stimulus-Response Association Process.

3. Command Selection Criterion. Another method for reducing model variability would involve the imposition of a "command selection criterion." All experienced commands effective for a given cursor movement would be stored, and a criterion would be applied to determine which command was actually selected for execution at any given instance. In other words, rather than averaging the commands corresponding to a given cursor movement, the variety of commands associated with each cursor movement would be stored. All processes involved in the choice of commands would operate to select from the stored commands according to a criterion. This criterion would dictate the choice or generation of a command that fit into the context of just-selected control stick positions. For example, if just-selected commands included 40, 42, and 44, and the possible commands corresponding to the desired cursor movement included 20, 46, and 100, the command of 46 would be selected because it fits into the previous command context.

Implementation of a "command selection criterion" would involve changes in the structure of the Command Memory, to allow storage of multiple commands for each current-desired cursor position pair. In addition, the Command Selection Process, Satisfactory Command Search Process, and Excessive Error Process, all of which select commands for

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execution, would have to select among the stored commands through use of the criterion.

4. <u>Extended Utilization of Preview</u>. As discussed earlier, imposition of certain criteria on control stick position could also be described in terms of increasing the utilization of available preview. Thus, in addition to the method just described, it may also be useful to impose criteria on the control stick based on the future characteristics of the task. Currently, the command to be used at time t_i is determined entirely based on the cursor position (CP) at t_i and the desired cursor position at t_{i+1}; that is, the memory is addressed by CP_i and CP_{i+1}. One method to include consideration of desired cursor positions past t_{i+1} is to expand the address space of the memory such that the command to be used at t_i would be pointed to by CP_i, CP_{i+1}, CP_{i+2}, . . . CP_{i+N} where N indicates the amount of preview being used in determining the command for t_i.

This change would affect the Command Memory, expanding it by a multiplicative factor of N. However, current results indicate that only about 1/10 of the array allocated for the Command Memory is actually used. Similar reductions would be expected in this expanded memory, which might be implemented as a list rather than an array. This change would also effect any process which has use for the Command Memory; namely, the Command Selection Process, the Stimulus-Response Association Process, the Satisfactory Command Search Process, and the Excessive Error Process.

Another method for utilizing those previewed positions past t_{i+1} is to select from among the various commands available that are within ERRLIM of each of these previewed positions --under the constraint that a string of "in-context" commands must be selected.. This method of utilizing preview is directly linked to refinement 3, since it involves application of a smoothness criterion to selection from among available control stick position alternatives. It would affect the same processes as would refinement 3. It would not involve expansion of the address space of the Command Memory, but rather would, like Refinement 3, expand the storage capacity at a given address.

D. Evaluation of Refinements

The alternative refinements suggested above are all aimed at reducing model variability. One criterion for evaluating the success of each is the extent to which each accomplishes this. Comparisons of plots of model

control stick position before and after each refinement is implemented will be used to judge if this criterion is met.

It is conceivable that one of the proposed refinements could reduce model variability but in such a way that the quality of a model matching did not improve. Therefore, a second criterion is that the refinement reduce model variability such that model control stick positions better match human behavior. To judge this, the RMS difference values (or other measures of model matching) for best-fit models produced by implementing each refinement will be compared. A refinement procedure which reduced model variability, and also improved model matching will be incorporated in HOPE.

If several of the alternative refinements meet the above criteria, then the criterion of parsimony will be applied. That is, the refinement that makes the simplest assumptions about human information processing will be selected.

III. SYMPTOM 2: POOR MODEL MATCHES FOR EARLY TRIALS AND RELATED PROBLEMS

A. Symptom Description(s)

In the $\frac{1}{4}$ Hz condition, model matches are less good on early trials than on late trials. This is evidenced by the fact that the RMS difference values, which gauge the goodness of model fits, are larger in early trials than in later trials. Table 4 shows for each operator the RMS error values averaged over the 12 time bins in each trial. For subjects in the $\frac{1}{4}$ Hz condition, the decrease in RMS differences value over trials is quite consistent. In contrast, in the $\frac{1}{2}$ Hz condition, RMS difference does not consistently decrease for all subjects. This contrast may be due to the fact that the RMS difference of $\frac{1}{2}$ Hz models may be particularly inflated due to model control stick variability (Symptom 1). The greater the track frequency, the more variable the model becomes. After model control stick position variability has been reduced, it will be interesting to see if RMS differences more consistently decrease over trials for $\frac{1}{2}$ Hz models.

A second related symptom that leads to the recommended refinement discussed below is the following. An analysis was performed in which each bin of human control stick position in Trial 1 was matched against model behavior in comparable bins in Trials 1 through 5. For example, human bin 1 behavior was matched against model behavior in the first bin of Trial 1, 2, 3, 4, and 5. For each of the human Trial 1 bins, the best-fit model generated by HOPE during a comparable bin in Trials 1 to 5 was chosen, using the RMS difference value as the criterion. Table 5 shows the model number, trial of that model's operation, and RMS difference value for the best fit model for each bin of Trial 1 for a subject in the $\frac{1}{2}$ Hz condition and a subject in the $\frac{1}{4}$ Hz condition. There is clear evidence that Trial 1 human behavior is not best matched by Trial 1 model behavior. Trial 1 human behavior is best matched by models in later trials of training, and there is a tendency for operators in the $\frac{1}{2}$ Hz condition to be matched by models in later stages of learning than those matching operators in the $\frac{1}{4}$ Hz condition.

The third related symptom of concern is the fact that human position error on Trial 1 is consistently less than that of the best-fitting models for trial 1.

TABLE 4.   AVERAGE ROOT MEAN SQUARE DIFFERENCES BETWEEN SUBJECTS AND
            SAME-TRIAL BEST FIT MODEL CONTROL BEHAVIORS FOR ALL TRIALS
            AND SUBJECTS

a.   ¼ Hz Track, Narrow Guidelines

SUBJECT	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1111	8.52	9.19	7.30	6.87	6.49
1112	8.41	8.04	7.40	7.72	6.86
1113	8.72	8.15	7.64	6.95	6.95
1114	8.39	8.26	7.16	7.17	6.81
1121	7.49	6.54	6.26	6.44	6.30
1122	8.46	7.50	7.22	7.30	7.38
1123	8.44	7.38	6.58	8.16	6.61
1124	8.13	6.38	6.34	6.52	6.56

b.   ¼ Hz Track, Wide Guidelines

SUBJECT	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1211	6.88	6.08	5.70	5.40	5.25
1212	8.07	8.49	7.57	6.37	6.91
1213	7.60	6.12	6.33	6.00	5.78
1214	8.44	5.97	5.56	5.21	5.18
1221	7.74	6.73	6.02	6.12	5.99
1222	8.03	6.92	6.42	6.57	5.87
1223	6.68	5.56	5.66	5.48	5.40
1224	7.83	6.75	6.37	5.76	5.75

TABLE 4. (Continued)

c. ½ Hz Track, Narrow Guidelines

SUBJECT	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
2111	29.13	26.15	26.83	25.60	23.41
2112	20.78	21.89	20.89	22.34	20.85
2113	15.73	16.62	16.64	17.13	15.38
2114	27.31	24.60	25.57	21.16	21.97
2121	21.85	17.92	18.18	17.69	17.52
2122	23.80	26.90	21.09	21.30	23.16
2123	15.73	16.47	16.77	16.44	17.40
2124	16.03	16.48	17.14	16.07	15.75

d. ½ Hz Track, Wide Guidelines

SUBJECT	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
2211	21.94	16.88	16.08	15.79	15.05
2212	19.18	21.21	18.97	18.77	18.97
2213	13.72	13.27	14.56	13.43	16.89
2214	20.73	18.55	14.56	15.32	12.59
2221	17.23	16.51	18.36	18.45	14.87
2222	14.35	11.04	11.38	12.35	13.36
2223	16.48	14.56	13.35	13.35	13.02
2224	13.88	17.21	18.54	19.42	18.88

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TABLE 5.   BEST FIT MODELS FOR EXAMPLE SUBJECT FIRST TRIAL CONTROL BEHAVIORS, RMS DIFFERENCES, AND TRIAL NUMBER OF BEST-FIT MODELS

a.   ¼ Hz Subject

Time Bin	Lowest RMS Error	Model Number	Trial of Best Fitting Model
1	5.66	68	4
2	7.05	61	5
3	5.93	34	3
4	6.43	34	5
5	8.69	40	4
6	4.58	31	5
7	7.14	32	3
8	5.67	61	5
9	3.70	64	4
10	6.68	34	3
11	6.38	47	5
12	9.37	50	4

b.   ½ Hz Subject

Time Bin	Lowest RMS Error	Model Number	Trial of Best Fitting Model
1	11.41	19	5
2	15.23	30	4
3	19.49	30	5
4	15.94	27	4
5	16.88	26	5
6	19.56	29	4
7	25.07	26	5
8	27.07	44	3
9	21.95	26	5
10	20.91	25	5
11	17.82	54	5
12	23.20	6	5

B. Probable Cause

The probable cause of the poorer fits on early trials is a difference between model and human knowledge that is larger early in training. The model begins Trial 1 with a "blank" Command Memory that contains no commands for use. It begins with no knowledge of the plant dynamics. On the other hand, there are reasons to believe that the human operator begins Trial 1 with some useful knowledge. First, the human is able to begin to fill his memory at the beginning of Trial 1 when the track begins moving down the screen, but before tracking begins. During this period, the human operator is able to manipulate the control stick, observe changes in cursor position, and store the knowledge gained. This gives the human an advantage over the model, which begins storing commands only after the first road position is tracked.

Secondly, the human may begin Trial 1 with some useful knowledge of control dynamics based on past experience with other plants. Human operators probably begin with knowledge of a linear plant, at least. Since the plant used in validating HOPE has unusual, non-linear control dynamics, it is unlikely that past experience (with a linear plant) would supply commands that were very appropriate to this plant. However, knowledge of linear plant dynamics could provide human operators with some idea about possible commands, thus giving the human operator an advantage over HOPE. Indeed, human Trial 1 error is less than error of best-fitting models, as noted above.

Third, the fact that human behavior on Trial 1 is best matched by models already having some experience suggests that humans begin Trial 1 with some knowledge of the task. When some knowledge is accumulated by the model, it better matches human behavior.

C. Proposal for Refinement

The objective of the proposed refinement is to remedy the symptoms described above. The method proposed is to provide the model with some initial knowledge. Initiating the model with some knowledge at the beginning of Trial 1 will more closely approximate the human knowledge state at the beginning of Trial 1, thus producing closer matches of model behavior to human behavior on early trials.

A major decision in implementing the refinement is to choose the manner of providing the model with initial knowledge. To be psychologi-

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cally valid, the model should be provided with knowledge that is similar to that with which humans begin training. One way to determine the nature of initial human knowledge is to examine the commands issued by humans very early in training. The pattern of human control stick positions may indicate that they are applying knowledge of a plant experienced previously. For example, most humans have had experience controlling a linear plant. The human operators in the initial testing of HOPE may have tried to apply this knowledge to control the cursor. If so, the initial commands on Trial 1 (i.e., their control stick positions) should be appropriate for control of a linear plant. Comparison of the commands used by humans to those appropriate for control of a linear plant will determine if humans begin Trial 1 applying knowledge of a linear plant. Comparison of human commands on Trial 1 to commands appropriate for different types of plant control (e.g., linear with either zero or first order position control, non-linear with either zero or first order position control) will be used to determine the kind of knowledge with which HOPE models should begin Trial 1.

Implementation of this refinement will affect only the Command Memory with which HOPE begins training. Rather than beginning with a "blank" memory, HOPE will be initiated with a Command Memory containing commands representing the knowledge with which humans begin training.

D. Evaluation of Refinement

The success of the refinement will be evaluated by examining whether RMS difference values (or other measures of model matching) on early trials become more comparable to those of later trials. In addition, human behavior on early trials will again be matched against model behavior in comparable bins of later trials. The refinement's success can also be judged by whether human behavior on Trial 1 is best matched by model behavior on that trial. If the refinement is successful, there should be greater consistency between the trial of human behavior and the trial of the HOPE model picked as best fit.

IV. SYMPTOM 3: PROBLEMS IN THE BEST FIT MODEL IDENTIFICATION PROCESS

A. Symptom Description

One recurring issue in this research is how to select the best fit model. Although a variety of measures were examined, (see final technical report on items 4.0 through 4.12 (June, 1979)), it was decided to use root mean square (RMS) difference values to judge and rank model goodness of fit. However, a variety of patterns in the present data suggest this measure may be inappropriate for present purposes. RMS difference includes only information about position differences, not velocity or acceleration differences. It is for this reason fairly insensitive to changes in control stick style resulting from changes in Command Operative Time (COT). Since COT controls the frequency of command execution, varying COT can be thought of as varying the maximum velocity of control stick motion. Since the RMS difference does not consider velocity differences, it is necessarily insensitive to differences between models with different COT's.

The insensitivity of RMS difference to COT differences is evidenced by several patterns in the data. First of all, an analysis of the control strategy parameters (CSPs) of the ten top-ranked models of persons in several experimental conditions reveals that the COTs of these top-ranked models are dispersed, and do not cluster around a particular COT value. Yet all of these models have low, and similar RMS difference values.

Secondly, the COT of a best fit model is frequently fairly long, when in fact human behavior seems to be exhibiting use of much shorter COT. For example, the record of human control stick positions in moving to the right might be: 50, 51, 54, 56, 58, 60, 62, 64, 64, etc. This suggests the human is using a very short COT, perhaps 40 msec. The COT of the best fit model for such behavior frequently has a relatively long COT value of 160 or 200 msec, which results in a rather "steppy" pattern of control stick positions such as the following: 50, 50, 50, 50, 55, 55, 55, 55, 60, 60, 60, etc. Figure 1 illustrates such steppy behavior on the part of a best fit model for relatively less steppy human behavior. Since RMS difference does not consider velocity information, its use will not distinguish differences in goodness of match between models with different COTs.

Third, models selected as best fits by the RMS difference criterion in successive 20 second bins occasionally have very different COT's, and very

different (to the human eye) control stick records, even though the human control stick record does not show much change. Further, these occasional "odd" bins are usually inconsistent with the majority of COT's identified for the trial. Although strategy is believed to vary with practice, these very sudden changes in COT of the model identified as best-fit, when human behavior shows very little apparent change in character, are viewed as possible symptoms of problems in the model identification process.

B. Probable Cause

The calculation of RMS difference includes only information about position differences. For this reason, it is unable to distinguish between models whose COT (and hence, velocity) vary in goodness of match to human behavior. For this reason, models with inappropriate COT values are sometimes chosen as best fit models.

C. Proposal for Refinement

Earlier efforts at choosing a best fit model identification process examined use of new measure called mean absolute state error (MASE). This measure includes not only position difference information, but also velocity and acceleration difference information, derived from position data by differentiation. Although MASE is believed to be a more informative measure of model-human differences, and is sensitive to the effects of COT, difficulty in initially validating MASE resulted in use of the more conventional RMS error value.

It is recommended that further efforts be aimed at developing the use of MASE, particularly if reductions in model variability do not change the patterns of data described above. In particular, efforts will be aimed at determining appropriate weights for the various components of MASE-position, velocity and acceleration error. This recommendation is not for model refinement per se but will result in improvements in the identification of the best fit model by use of an improved MASE statistic.

D. Evaluation of Refinement

Procedures used previously for choosing between MASE and RMS difference will be repeated. That is, MASE and RMS difference rankings of the best-fitting models for selected time bins will be compared to human rankings. Agreement with human judgment will be one indicator of measure quality. Furthermore, the selection in successive bins of models with

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widely differing COT's, in the absence of evident changes in human control style, should be eliminated.

The sensitivity of MASE to model-human differences in COT will also be examined. If MASE is developed properly, it should be more sensitive to differences between models having different COTs. Models with short COTs should have the lowest MASE values in matching human behavior apparently exhibiting a short COT.

V. Summary of Specific Refinement Proposals

It should be evident from the discussions above that the work carried out to this date on contract items 4.13.1 and 4.13.2 has provided a type of "tree" structure for the refinement activity. That is, the implementation of the simple refinement of rounding rather than truncating in the Perception Process should be followed by the testing of several other refinements in HOPE's basic functioning, the best of which should be fully implemented. This implementation should be followed by a recheck on the symptoms which stimulated the discussion in Part II. If these persist, then refinements to remedy them should be implemented. Finally, steps to improve the model identification process should be undertaken after all model refinements are implemented, in order that they be based on the best model possible. Table 6 provides a summary of these ideas.

PROPOSED REFINEMENT	OBSERVATION SUGGESTING NEED	HOPE PARAMETERS, PROCESSES OR STRUCTURES AFFECTED	CHECK OUT PROCEDURES	RELATIVE SEVERITY OF WEAKNESS ADDRESSED	ESTIMATED PROBABILITY OF FAVORABLE IMPACT	COMPLEXITY OF IMPLEMENTATION AND TEST	COST
1. ROUND INSTEAD OF TRUNCATE IN PERCEPTION PROCESS (P. 16 - 17)*	LOGICAL CONSEQUENCES OF TRUNCATION (P. 16 - 17) EXCESS MODEL CONTROL VARIABILITY (P. 5)	PERCEPTION PROCESS	VISUAL EXAMINATION OF PLOTS OF CONTROL STICK MOVES; RERUN MODEL IDENTIFICATION PROCEDURES; PARSIMONY (P. 18 - 19)	MILD	HIGH	LOW	LOW
2A.[1] COMMAND MEMORY "SMOOTHING" (P. 17)	EXCESS MODEL CONTROL VARIABILITY (P. 5)	COMMAND MEMORY STIMULUS-RESPONSE ASSOCIATION PROCESS			HIGH	MODERATE	MODERATE
B. IMPOSE A COMMAND SELECTION CRITERION (P. 17 - 18)	DATA ITEMS 1, 2, 3, 9, 10 (P. 1-2) AND (P. 5-15)	COMMAND MEMORY COMMAND SELECTION PROCESS SATISFACTORY COMMAND SEARCH PROCESS EXCESSIVE ERROR PROCESS STIMULUS-RESPONSE ASSOCIATION PROCESS		SEVERE	HIGH	HIGH	HIGH
C. EXTEND MODEL UTILIZATION OF PREVIEW (P. 18)	LOGICAL ANALYSIS (P. 12 - 15)				HIGH	HIGH	HIGH
3. GIVE HOPE MODELS SOME INITIAL KNOWLEDGE OF PLANT DYNAMICS (P. 24 - 25)	DATA ITEMS 5, 11, 13 (P. 1-2) AND (P. 20-23)	COMMAND MEMORY	REPLICATE MODEL IDENTIFICATION PROCESS OF SAMPLE OF OPERATORS (P. 25)	MILD-MODERATE	MODERATE	MODERATE	MODERATE
4. REFINE MASE STATISTIC	DATA ITEMS 4, 6, 7, (P. 1-2) AND (P. 25) LOGICAL ANALYSIS (P. 26 - 27)	NA	REPLICATE MODEL IDENTIFICATION PROCESS (P. 27 - 28)	MODERATE-SEVERE	MODERATE HIGH	MODERATE	MODERATE

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*(P. ___) INDICATES PAGE NUMBERS WHERE MORE DISCUSSION BEGINS

1. REFINEMENTS 2A, B, AND C ARE CONSIDERED TO BE EQUAL
   ALTERNATIVES WHICH SHOULD BE IMPLEMENTED AND COMPARED

VI. OTHER SYMPTOMS OF CONCERN

This section describes a variety of other patterns in the data which are troublesome, and which may require additional model refinements. Detailed description of model refinements designed to eliminate these symptoms will not be presented at this time for the following reason. It is likely that most of these symptoms may be associated with difficulties in the best fit model identification process or with the excessive variability in model control behaviors. It may be the case that once model variability is reduced and the best fit model identification process reevaluated, there may be different choices of best fit models. Detailed consideration of the model refinements necessary to eliminate the symptoms listed below will be postponed until these improvements have been made and best fit models have been re-selected. The data will then be examined for the presence of these symptoms, and necessary model refinements will be proposed.

A. Poorer Model Matching for $\frac{1}{2}$ Hz Conditions

One area of concern is the fact that RMS error values for the best fit models are two to three times larger in the $\frac{1}{2}$ Hz condition than in the $\frac{1}{4}$ Hz condition. This means current HOPE models better match human tracking of the $\frac{1}{4}$ Hz track. The current HOPE model has no features that would predict better matching of $\frac{1}{4}$ Hz track performance. That is, HOPE should generate models that match equally well human performance on $\frac{1}{2}$ and $\frac{1}{4}$ Hz tracks.

The difference beteen RMS values for $\frac{1}{2}$ and $\frac{1}{4}$ Hz track conditions could be associated with model variability discussed above. The models generated by HOPE for the $\frac{1}{2}$ Hz condition show more control stick variability and spikiness than those generated for the $\frac{1}{4}$ Hz condition. This is in part due to the fact that $\frac{1}{2}$ Hz models must reverse direction more frequently than $\frac{1}{4}$ Hz models, and such reversals are particularly associated with variability on the part of the model. The greater variability and spikiness of $\frac{1}{2}$ Hz models could elevate their RMS difference values when they are compared to human behavior. Reducing model variability might reduce the RMS difference of the $\frac{1}{2}$ Hz models to values more equivalent to those computed for $\frac{1}{4}$ Hz models.

B. Different Control Strategy Parameters in Neighboring Time Bins

A second area of concern arises from the observation that the best fit models of neighboring bins sometimes have widely different control strategy parameters (CSPs). This is illustrated by the CSPs for bins 29 and 30 of an operator in the $\frac{1}{2}$ Hz condition shown in Figure 7. The best fit model for bin 31 has CSPs of COT=4, ERRLIM=2, ADJUST=2. Thus, the best fit model for bin 30 is rather different than those of surrounding bins. Although it is theorized that control strategy varies over trials, it is less comprehensible why control strategy, as represented by the CSPs of the best fit model, should vary dramatically between neighboring bins of a trial, especially when human control behavior does not vary so dramatically. The consistency of CSPs between neighboring bins will be examined once the refinements described previously have been implemented, to see if the dramatic differences disappear. It is likely that improvement in the model identification process will eliminate this symptom.

C. Clustering of Control Strategy Parameters at the Edge of the Parameter Space

A third area of concern is that in certain testing conditions the CSPs of the best fit models as currently identified may cluster at the edges of the CSP space. Table 7 presents a tabulation of the best fitting models for each testing condition for Trials 1 and 5 (for all subjects). For Trial 1, most best fit models have COT values of 4 or 5, which are at the upper range of possible COT values. (However, as discussed earlier, the high COT values are questionable since human control stick data seems to show use by humans of short COT's.) ADJUST values of best fit models frequently have the value of 2, which is the minimum ADJUST value. Best fit models, especially in the $\frac{1}{4}$ Hz condition, tend to have the minimum ERRLIM values of 2 or 4.

The clustering of CSP values will be re-examined once model variability has been reduced and the model identification process re-evaluated. If CSP clusters at the edge of the parameter space still exist, the identity of these clusters will be used to alter the ranges of CSP values implemented in HOPE models. HOPE models will then be rerun and matched against human behavior to see if there is improvement in the matching.

	Mean Absolute Position Error (Track Units)		Best Fit Models Control Strategy Parameters		
	Human	Model	COT	ERRLIM	ADJUST
Bin 29	4.954	6.412	5	2	2
Bin 30	3.882	4.856	1	8	2
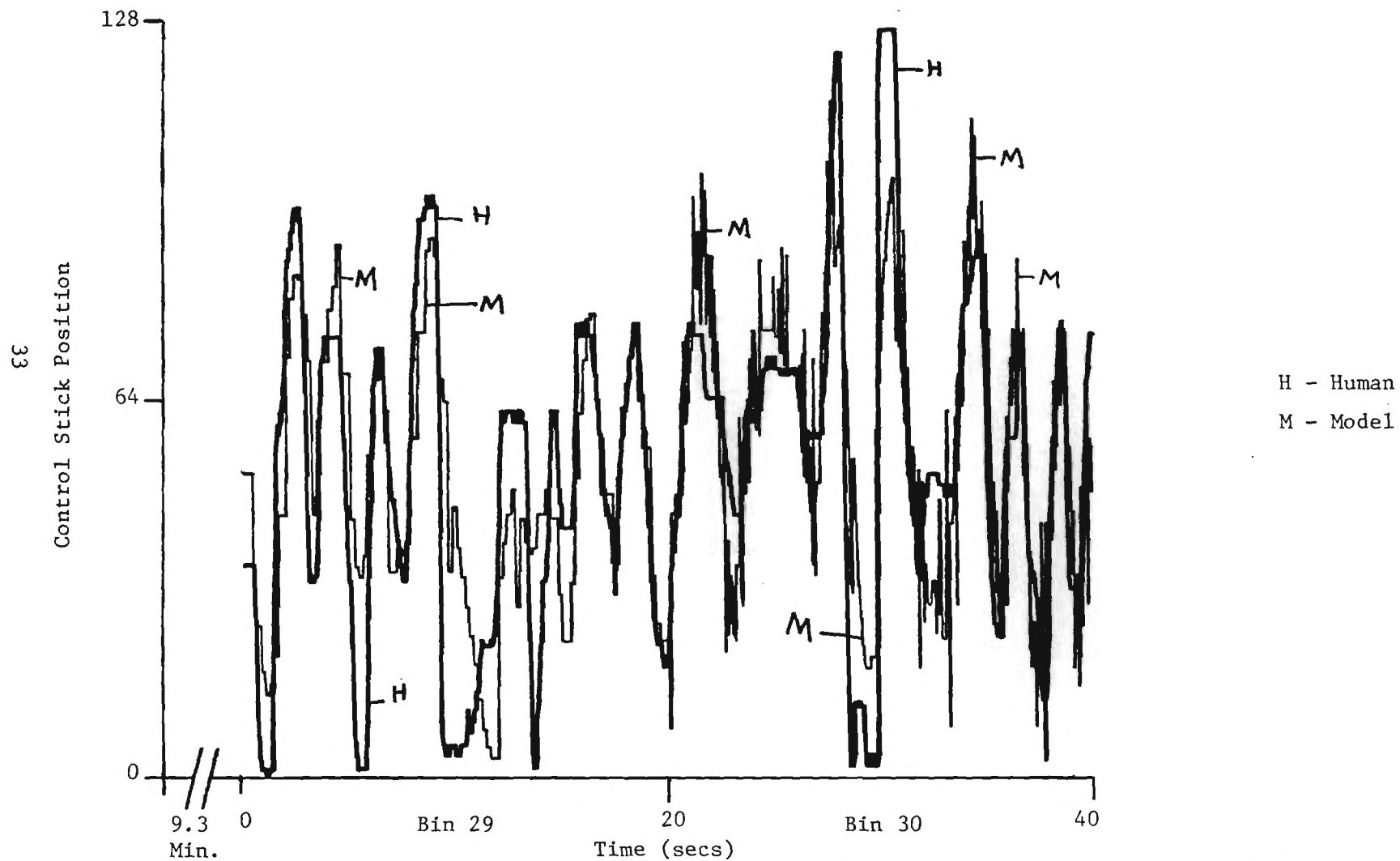
Figure 7. Example of Control Stick Positions of Subject 2122 and Best-Fit Models (Tracking 1/2 Hz Track; Non-linear First-order Plant)

BEST FIT HOPE MODELS FOR EACH CONDITION, TRIALS 1 AND 5

a. ¼ Hz Track, Narrow Guidelines

Trial 1

Control Strategy Parameter Values			Frequency of Combination
ADJUST	ERRLIM	COT	
2	2	4	33
2	2	5	26
2	4	4	1
2	4	5	1
2	8	2	2
2	8	5	2
5	2	4	2
5	2	5	5
5	4	4	10
5	4	5	4
8	4	4	1

Trial 5

Control Strategy Parameter Values			Frequency of Combination
ADJUST	ERRLIM	COT	
2	2	2	1
2	2	3	4
2	2	4	20
2	2	5	1
2	4	2	3
2	4	3	2
2	4	4	7
2	8	2	1
2	8	3	1
2	16	2	1
2	32	2	1
5	2	2	1
5	2	3	1
5	2	4	10
5	2	5	10
5	4	2	3
5	4	4	8
5	4	5	1
8	2	2	2
8	2	4	1
8	4	3	4
8	4	4	1

b. ¼ Hz Track, Wide Guidelines

Trial 1				Trial 5			
Control Strategy Parameters Values			Frequency Combination	Control Strategy Parameter Values			Frequency Combination
ADJUST	ERRLIM	COT		ADJUST	ERRLIM	COT	
2	2	1	1	2	2	3	20
2	2	2	3	2	2	4	15
2	2	3	2	2	2	5	11
2	2	4	18	2	4	2	4
2	2	5	36	2	4	3	2
2	4	2	3	2	4	4	7
2	4	4	9	2	8	2	5
2	4	5	2	2	8	2	1
2	8	3	1				
2	8	4	1	5	2	2	5
2	8	5	2	5	2	3	3
2	16	4	1	5	2	4	6
2	16	5	1	5	2	5	3
				5	8	5	2
5	2	4	2	5	16	2	1
5	2	5	2	5	32	2	1
5	4	2	1				
5	4	4	2	8	2	4	1
5	16	5	1	8	4	5	1

c. ½ Hz Track, Narrow Guidelines

Trial 1

Control Strategy Parameters Values			Frequency Combination
ADJUST	ERRLIM	COT	
2	2	4	26
2	2	5	25
2	4	4	6
2	4	5	8
2	8	4	6
2	16	5	2
2	32	5	2
5	2	4	1
5	2	5	1
5	8	2	1
5	16	4	2
5	32	3	3
8	2	2	1
8	2	3	1
8	2	4	2
8	32	5	1

Trial 5

Control Strategy Parameter Values			Frequency Combination
ADJUST	ERRLIM	COT	
2	2	4	3
2	2	5	2
2	4	3	1
2	8	2	1
2	16	2	5
2	32	2	32
5	2	3	1
5	4	4	1
5	8	2	3
5	16	2	13
5	32	2	4
8	2	4	5
8	2	5	2
8	4	2	2
8	4	4	2
8	4	5	1
8	8	2	1
8	16	2	9

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d. ½ Hz Track, Wide Guidelines

	Trial 1					Trial 5		
Control Strategy Parameter Values			Frequency Combination		Control Strategy Parameter Values			Frequency Combination
ADJUST	ERRLIM	COT			ADJUST	ERRLIM	COT	
2	2	4	16		2	2	5	1
2	2	5	24		2	4	4	1
2	4	2	1		2	8	2	10
2	4	4	6		2	16	2	11
2	4	5	12		2	32	2	1
2	8	4	1					
2	8	5	1		5	2	4	5
2	16	2	2		5	2	5	2
2	16	3	1		5	4	4	1
2	16	4	1		5	8	2	3
					5	16	2	23
5	2	4	6		5	32	2	3
5	4	4	1		5	32	3	3
5	4	5	1					
5	8	2	2		8	2	4	6
5	8	4	1		8	4	4	1
5	16	2	2		8	8	2	3
5	16	4	1		8	8	4	1
5	16	5	6		8	8	5	1
					8	16	2	2
8	2	1	1		8	32	2	10

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A P P E N D I X

HOPE PROGRAM AND
DATA FILES ORGANIZATION

Tasks 4,11 - 4.13.1

10 October 1979

HOPE PROGRAM AND
DATA FILES ORGANIZATION

TERMINAL
INPUT

DISK

TAPE

PROGRAM
(NORMALLY
ON DISK)

LINE
PRINTER

SYMBOL DESCRIPTION

HOPE PROGRAMS AND DATA FILES

FCOEFF   -   Data files (2) containing filter coefficients for the 1/4 Hz and 1/2 Hz roads.

MROADGEN   -   Program used to generate the 4 model roads, with points in the range 1 to 128.

OROADGEN   -   Program used to generate the 4 operator roads, with points in the range 0 to 511.

ROAD---   -   Data files (4) containing the model road coordinates, 6000 points per files.

OROAD---   -   Data files (4) containing the operator road coordinates, 6000 points per files.

```
  ┌──────────────┐        ╭──────────────╮        ┌──────────────┐
  │  ROAD WIDTH  │        │   FCOEFF—     │        │  ROAD WIDTH  │
  └──────┬───────┘        │  (4 − 1/4 Hz, │        └──────┬───────┘
         │                │   2 − 1/2 Hz) │               │
         │                ╰───────┬───────╯               │
         │                        │                       │
         ▼                        ▼                       ▼
  ┌──────────────┐        ┌──────────────┐
  │   MROADGEN   │        │   OROADGEN   │
  └──────┬───────┘        └──────┬───────┘
         │                       │
         ▼                       ▼
  ╭──────────────╮        ╭──────────────╮
  │   ROAD───     │        │   OROAD───    │
  │ (1-128 FOR    │        │ (0-511 FOR    │
  │  HOPE)        │        │  OPERATORS)   │
  ╰──────────────╯        ╰──────────────╯
```
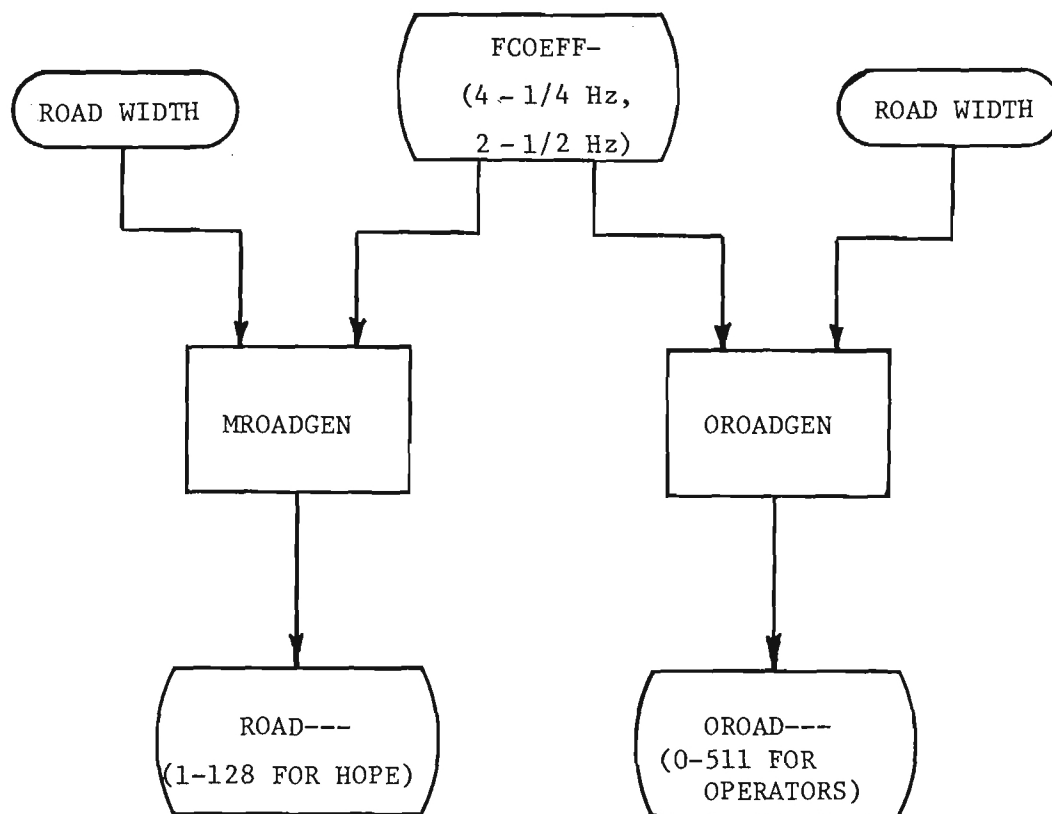
ROAD GENERATION

(Repeated for Each Road Condition)

HOPE PROGRAMS AND DATA FILES (Continued)

OCS----   – Data files (32) containing the operator's BHP values. There
             is one file for each operator, each containing 3000 values
             and the operator identification number.

OCSGEN   – Program used to create OCS tapes from OCS files that were
             loaded onto the disk from the backup tape.

OCS---   – Tapes (4) containing all off the OCS files for each of the
             4 road conditions.

```
        ╭───────╮
        │ BACKUP│          ⎧ CONTAINS
        │  TAPE │          ⎨ OCS
        ╰───────╯          ⎩ FILES
            │
            │
            ▼
      ╭─────────────╮
      │ OCS────     │       ⎧ 8 FILES:
      │OPERATOR BHP'S│      ⎨ ONE FILE PER EACH OPERATOR
      │  FOR ONE    │       ⎩ IN THIS ROAD CONDITION
      │ CONDITION   │
      ╰─────────────╯
            │
            ▼
      ┌─────────────┐
      │             │       ⎧ YIELDS ONE TAPE
      │   OCSGEN    │       ⎨ PER RUN
      │             │       ⎩
      └─────────────┘
            │
            │
            ▼
        ╭───────╮
        │       │          ⎧ EACH TAPE HAS ALL 8
        │OCS────│          ⎨ OPERATORS IN EACH CONDITION
        │       │          ⎩
        ╰───────╯
```
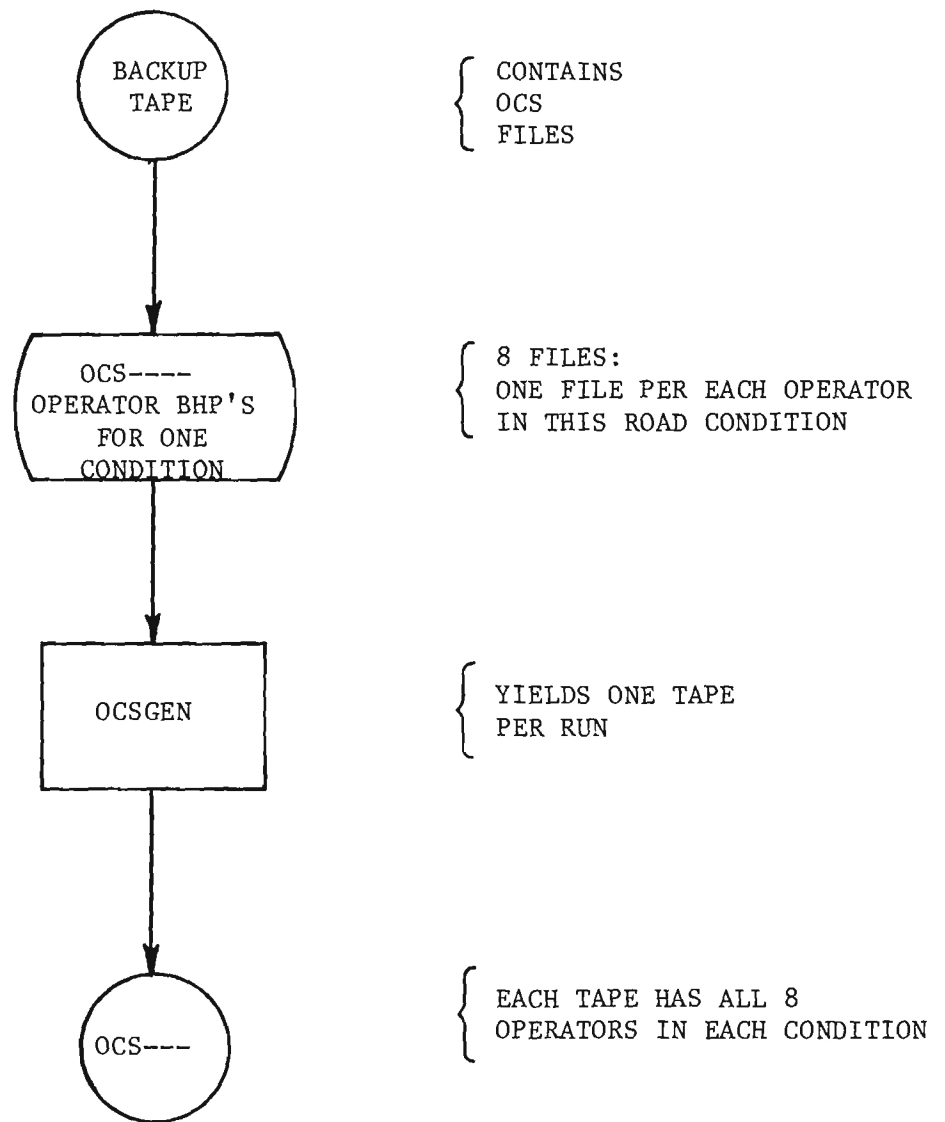
SUBJECT DATA PREPARATION

(Repeated For Each Road Condition)

HOPE PROGRAMS AND DATA FILES (Continued)

PARAMGEN – Program used to generate the parameters that will be used to run HOPE.

PARM--- – Data files (4) containing the parameters for one run of HOPE.

RDFORM – Program to generate a formatted file of 30000 points from the unformatted data in ROAD---.

ROAD---F – Data file (4) containing 30000 road points to be used as input to HOPE.

HOPE – Program to generate MCS tapes and diagnostic output files for the 75 models in each of the 4 road conditions.

DIAG--- – Data files (4) containing the diagnostic output of a HOPE run.

MCS--- – Tapes (4) containing the bat handle points for each model generated during a HOPE run.
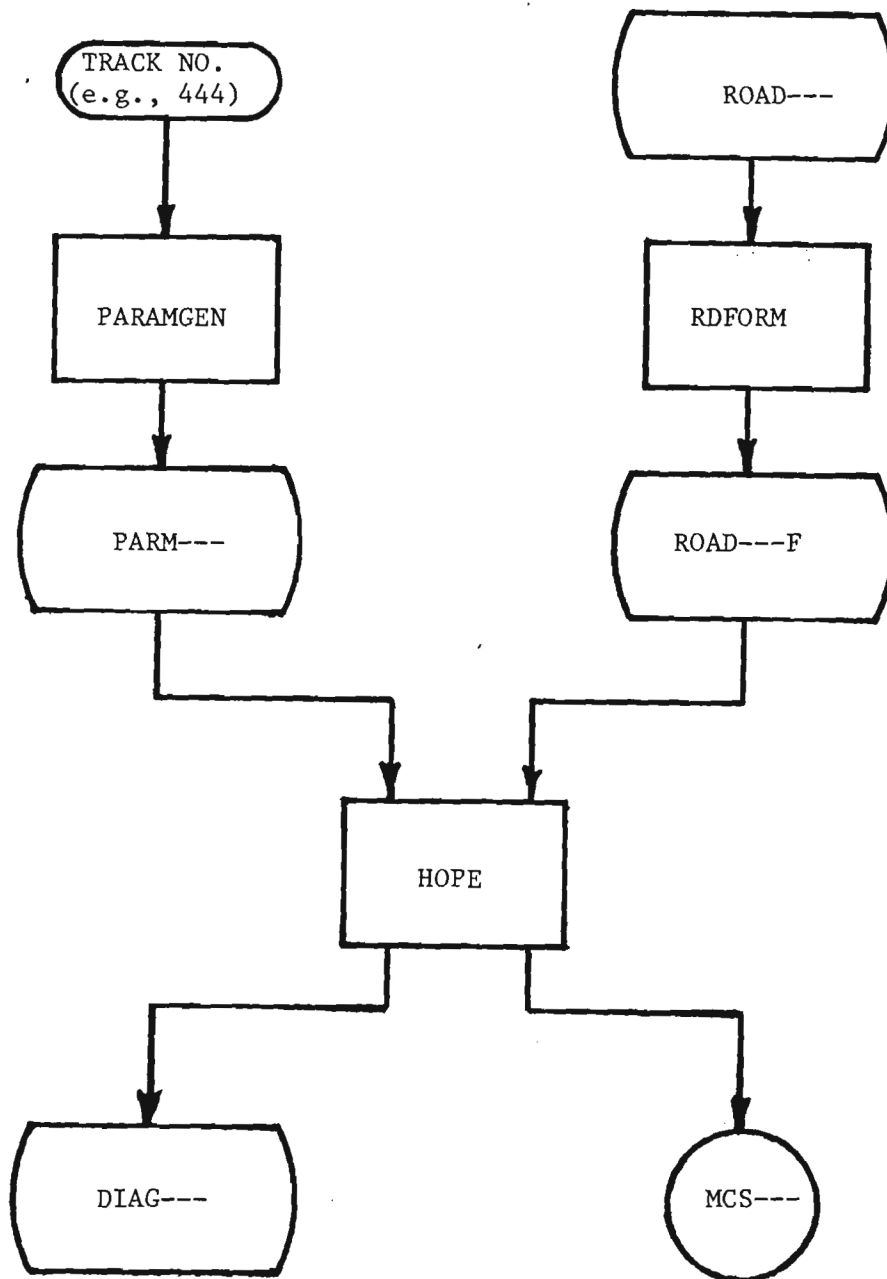
HOPE SYSTEM
(Repeated for Each Road Condition)

DIAGOUT   - Program to output the diagnostic data from HOPE.

DIAGAVG   - Program to average the diagnostic data over each parameter
             value.

HOPE SYSTEM (Continued)

RMS   –   Program to generate an RMS statistic for each bin for each model with each operator.

RMS---   –   Tapes (4) containing the RMS statistics for each bin for every model and operator that tracked this road.

QUASOR   –   Program to find the 10 best matches between each operator and the models based on the RMS statistic for each bin.

SRM---   –   Data files (4) containing the 10 best match RMS statistics for every bin of each operator that tracked this road.

SMD---   –   Data files (4) containing the 10 best match model numbers for every bin of each operator that tracked this road.

PARAT   –   Program to output the best match model numbers with the corresponding parameter values.
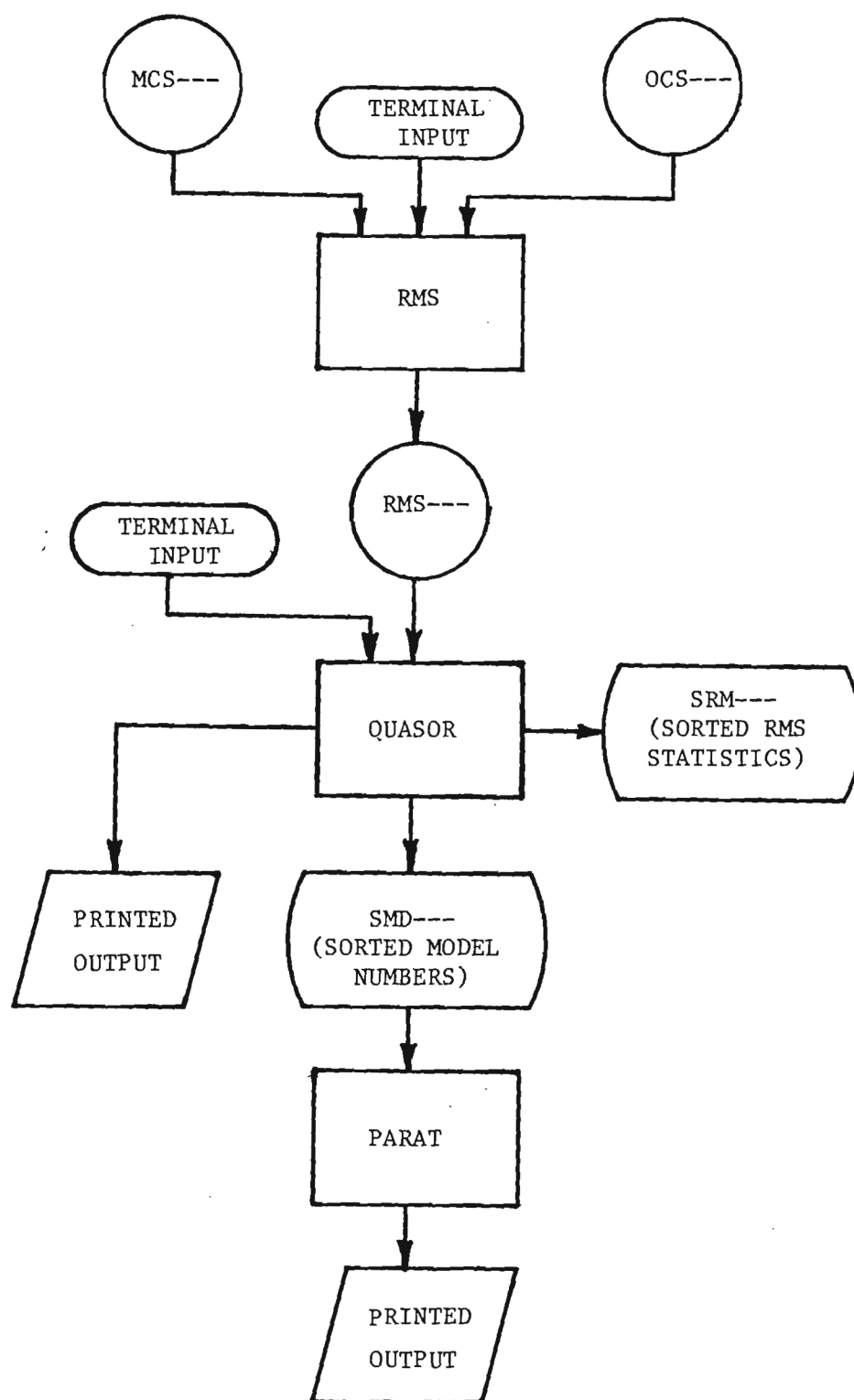
HOPE SYSTEM (Continued)

HOPE PROGRAMS AND DATA FILES (Continued)

OPEGEN   – Program to generate signed operator cursor position error
              for each operator in a given road condition.

OPE---   – Data files (4) containing the signed operator cursor position
              error for every track this road.

GLUSHGEN   – Program to generate the data tape containing the road coordi-
              nates and signed position error for each operator, to be sent
              to bill Glushko.

GLUSHOUT   – Program to make a partial listing of Bill Glushko's data tape
              to send as part of the documentation that was sent with the
              tape.

OCS---

OROAD---
(0-511 RANGE)

OPEGEN

OPE---
(4 FILES)

A

TERMINAL
INPUT

GLUSHGEN

ROAD---
(1-128 RANGE)

DATA
TAPE

GLUSHOUT

PRINTED
OUTPUT

Mailed to Arizona
State University
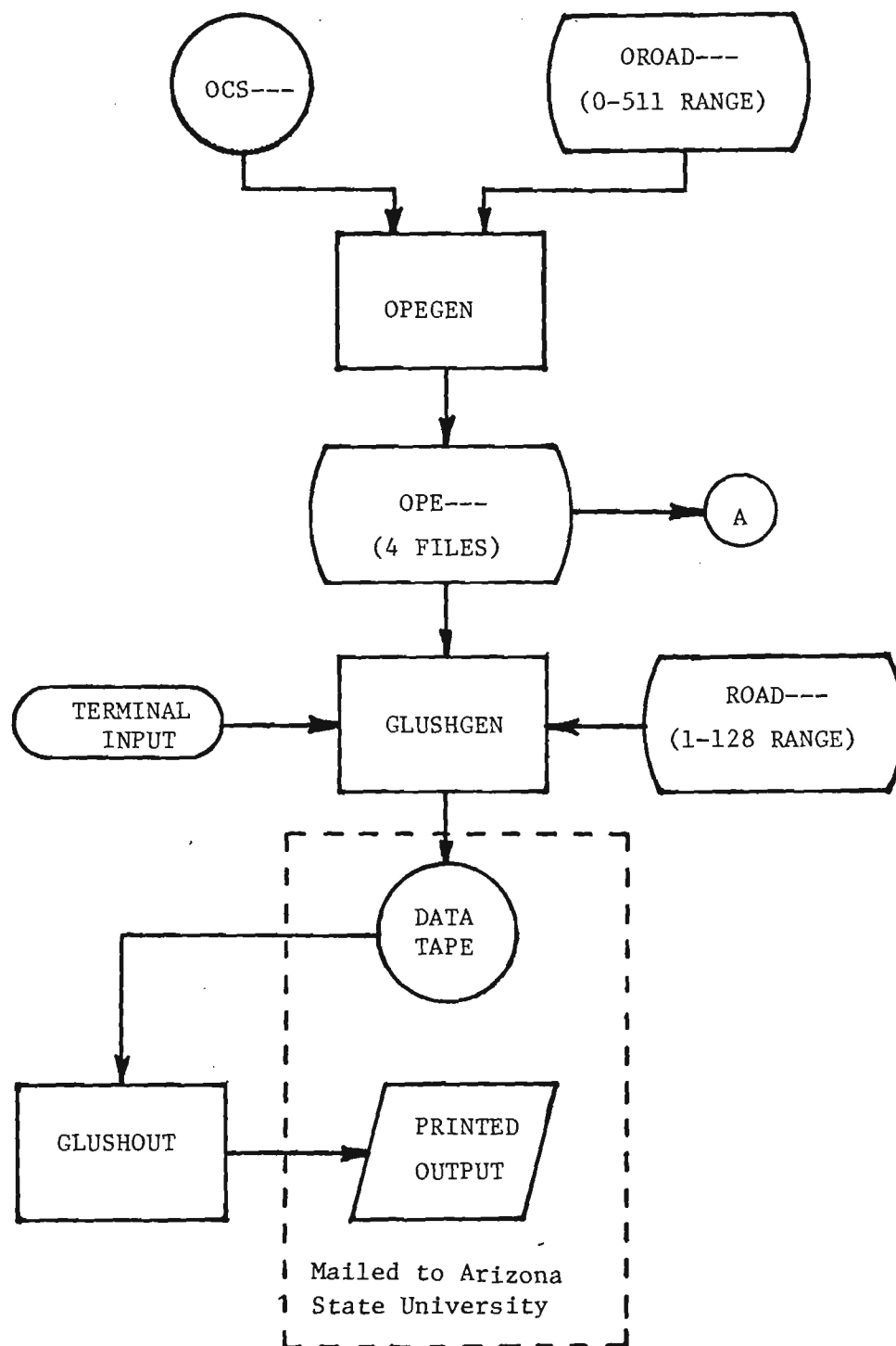
HOPE SUPPORT PROGRAMS

MDTGEN   — Program to generate the master data file.

MSTRDAT   — Master data file containing the parameter values, RMS statis-
             tics, and cursor position error for each bin of the 10 best
             match models of each operator.

```
                    ┌─────────────┐
                    │  TERMINAL   │
                    │   INPUT     │
                    └─────────────┘
                           │
  ┌──────────────┐         │         ┌──────────────┐
  │   SRM───     │         │         │   SMD───      │
  │  (4 FILES)   │         │         │  (4 FILES)    │
  └──────────────┘         │         └──────────────┘
         │                 │                │
         └───────────┐     │     ┌──────────┘
                     ▼     ▼     ▼
                  ┌─────────────────┐
        ┌───┐     │                 │
        │ A │────▶│    MDTGEN       │
        └───┘     │                 │
                  └─────────────────┘
                           │
                           ▼
                  ┌─────────────────┐
                  │    MSTRDAT      │
                  │  (32 OPERATORS  │
                  │   UNFORMATTED)  │
                  └─────────────────┘
```
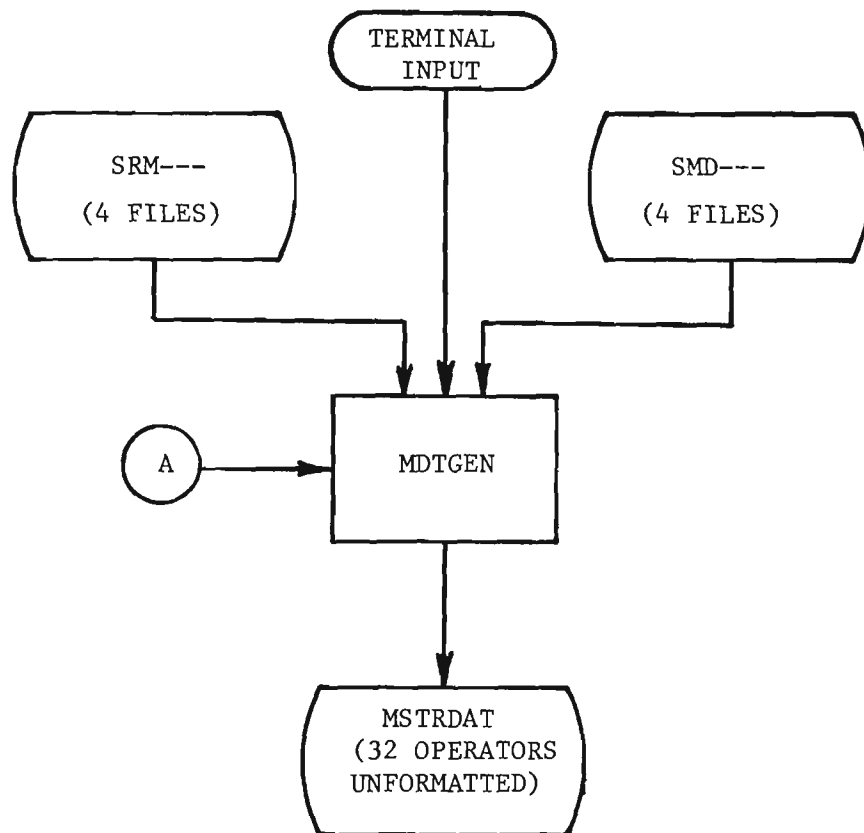
HOPE SUPPORT PROGRAMS (Continued)

MSTDEV   –   Program to calculate the mean and standard deviation of parameter values and position error for each trial for every operator and road condition.

MODFREQ   –   Program to compute the frequency of occurrence of models and parameter values for the specified trials and best match numbers.

```
        ┌─────────────┐                          ┌─────────────┐
        │  MSTRDAT    │                          │  MSTRDAT    │
        └──────┬──────┘                          └──────┬──────┘
               │                                        │
               ▼                                        ▼
        ┌─────────────┐          ┌──────────┐    ┌─────────────┐
        │   MSTDEV    │          │ TERMINAL │───▶│  MOD FREQ   │
        │             │          │  INPUT   │    │             │
        └──────┬──────┘          └──────────┘    └──────┬──────┘
               │                                        │
               ▼                                        ▼
        ┌─────────────┐                          ┌─────────────┐
        │  PRINTED    │                          │  PRINTED    │
        │  OUTPUT     │                          │  OUTPUT     │
        └─────────────┘                          └─────────────┘
```
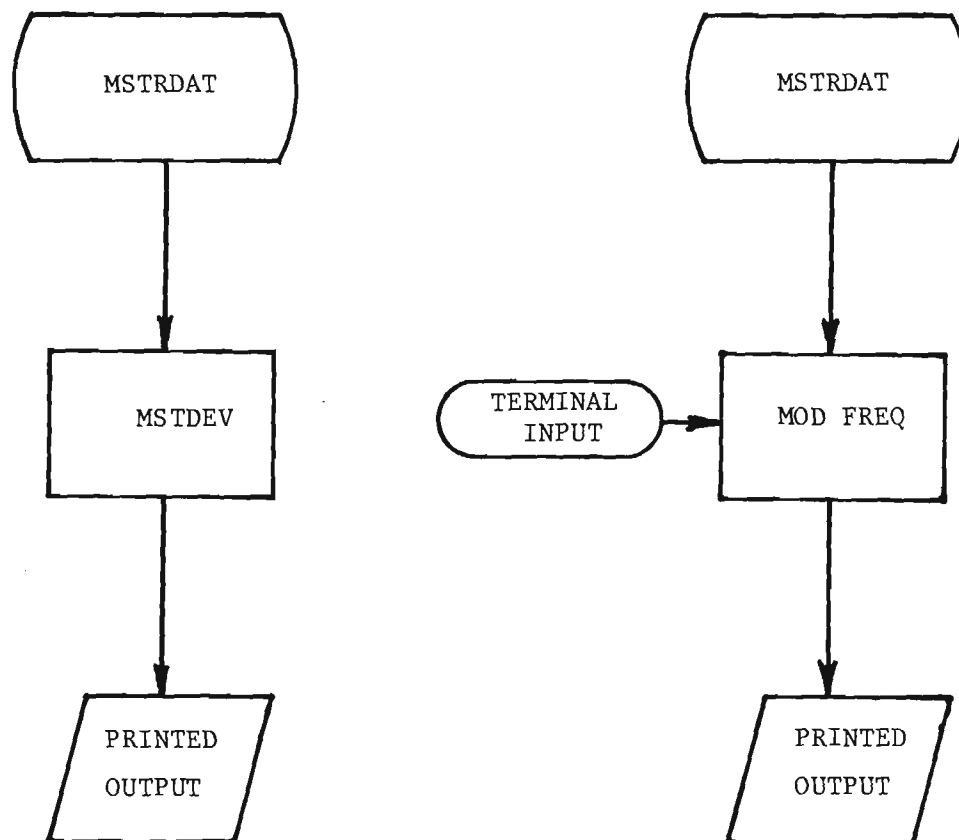
HOPE SUPPORT PROGRAMS (Continued)

MDFORM   — Program to format master data file on tape for transfer
            to CYBER.

MASTER   — Procedure file to read the Interdata master data file and
            write it to a CYBER file.

FIXDAT   — Program to remove the unwanted lines inserted in the master
            data file by master.

INFYL–   — Data files (2) containing input parameters for a single
            model.

RBHOPE   — Program to run HOPE for one model and output the non-zero
            segments of the command memory at the middle and end of
            each trial.

```
  ┌─────────────┐                                    ╭──────────╮
  │   MSTRDAT   │                                    │ TERMINAL │
  └─────────────┘                                    │  INPUT   │
         │                                           ╰──────────╯
  ┌─────────────┐         ┌─────────────┐                 │
  │   MDFORM    │         │ INFYL-(CYBER)│                │
  └─────────────┘         └─────────────┘                 │
         │                                                │
      ╭──────╮            ┌─────────────┐                 │
      │MSTRDAT│           │  ROAD---    │                 │
      │(FORMAT-│          │  (CYBER)    │                 │
      │ TED)  │           └─────────────┘                 │
      ╰──────╯                                            │
         │                        │         │             │
  ┌─────────────┐                 ▼         ▼             ▼
  │   MASTER    │              ┌─────────────┐
  │  (CYBER)    │              │   RBHOPE    │
  └─────────────┘              │  (CYBER)    │
         │                     └─────────────┘
  ┌─────────────┐                     │
  │   FIXDAT    │                     ▼
  │  (CYBER)    │              ╱─────────────╲
  └─────────────┘              │   PRINTED    │
         │                     │   OUTPUT     │
  ┌─────────────┐              ╲─────────────╱
  │   MSTRDAT   │
  │  (CYBER)    │
  └─────────────┘
```
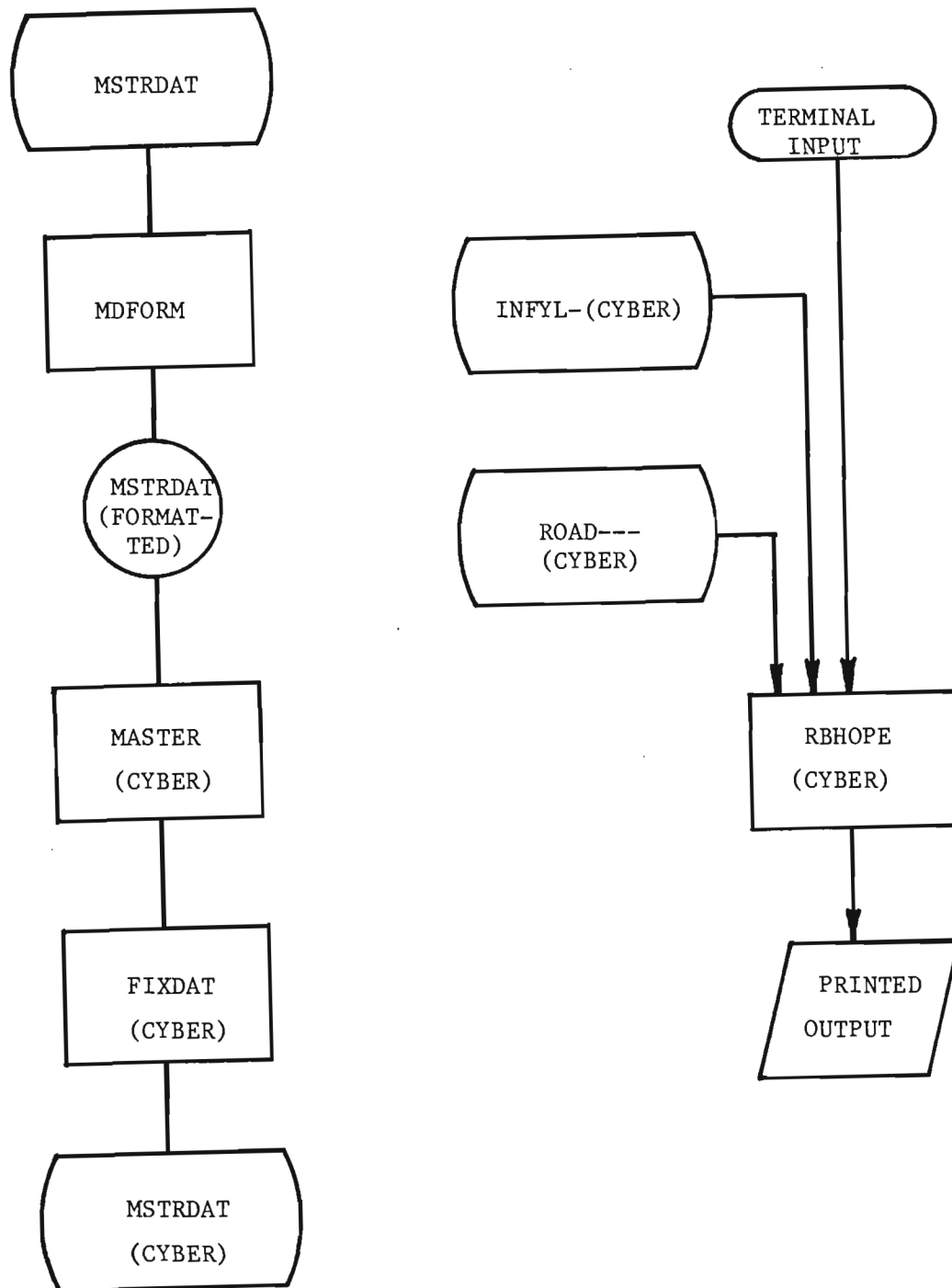
HOPE SUPPORT PROGRAMS (Continued)

REPDAT   — Data file containing money and man-hour limits and task time-
              table for each task of Project A-1979. It also contains the
              cummulative total of money and man-hours expended for each
              task in the previous month.

MONREP   — Program to store monthly report on expenditures and task
              status for Project A-1979.

ROADGEN   — CYBER program to generate the same road coordinates as
              MROADGEN does on the Interdata.

```
┌─────────────┐                          ╭─────────────╮
│   REPDAT    │                          │  TERMINAL   │
│   (CYBER)   │                          │   INPUT     │
└─────────────┘                          ╰─────────────╯
       │                                        │
       │                                        │
       │                                        ▼
┌─────────────┐                          ┌─────────────┐
│   MONREP    │                          │  ROADGEN    │
│   (CYBER)   │                          │   (CYBER)   │
└─────────────┘                          └─────────────┘
    │     │                                     │
    ▼     ▼                                     ▼
┌────────┐  ┌─────────────┐            ┌─────────────┐
│PRINTED │  │  UPDATED    │            │  ROAD---    │
│OUTPUT  │  │  MONREP     │            │  (CYBER)    │
└────────┘  │  (CYBER)    │            └─────────────┘
            └─────────────┘
```
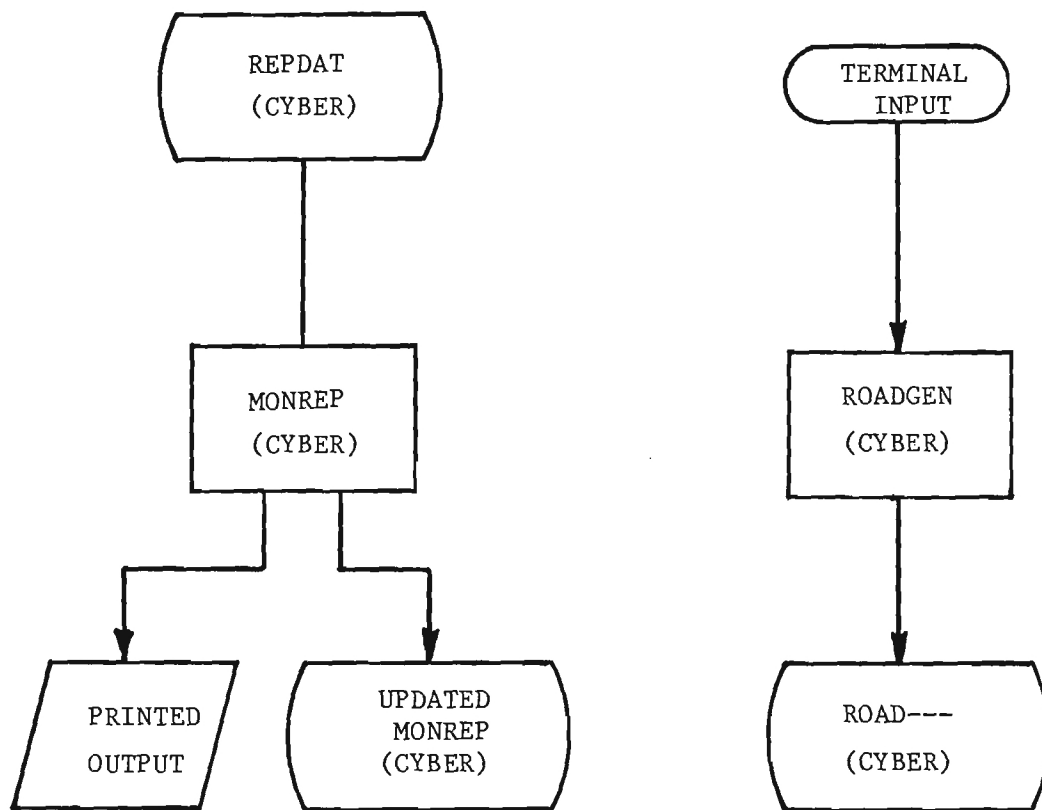
HOPE SUPPORT PROGRAMS (Continued)

SUPERPLT – Program to plot any combination of bat handle and cursor
positions versus time that the user desires.
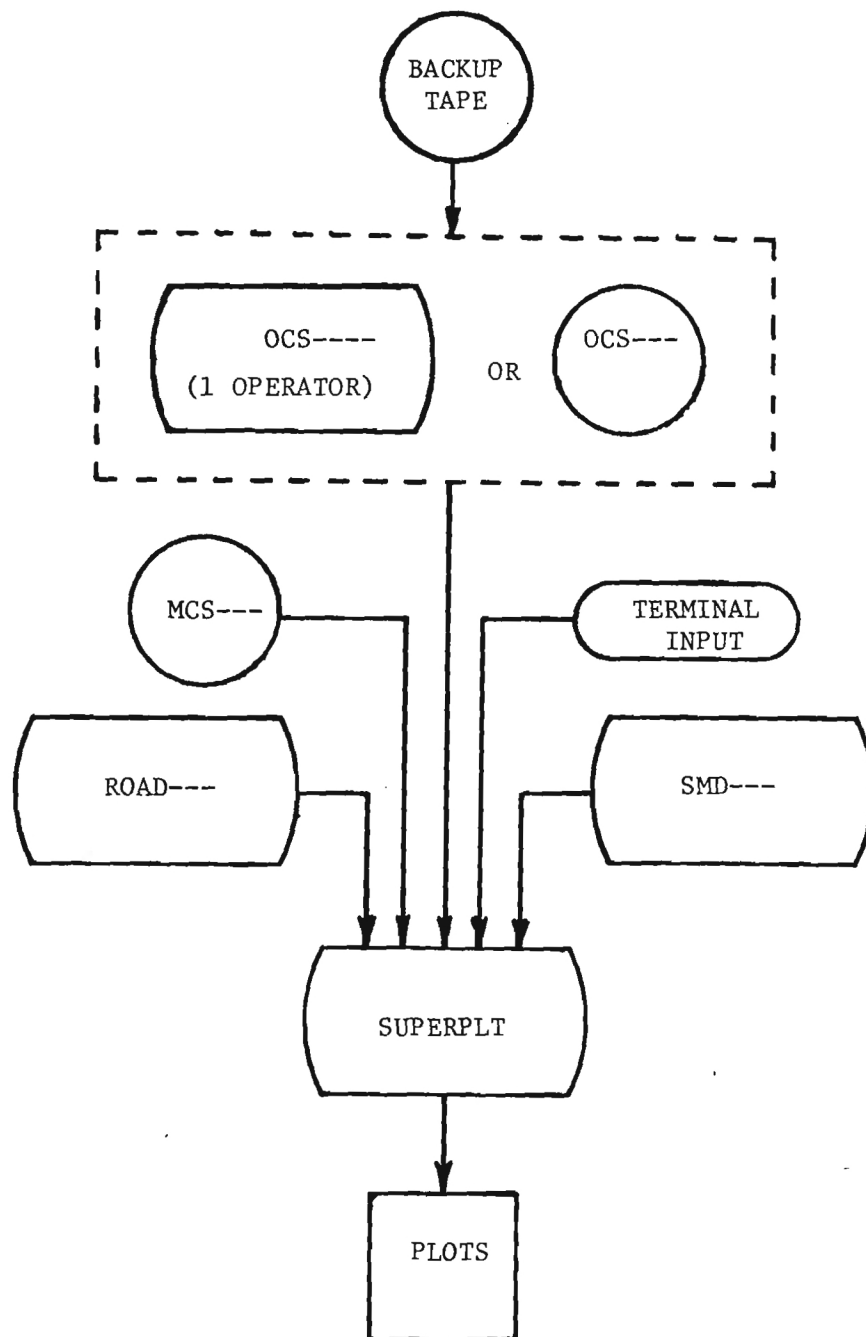
HOPE SUPPORT PROGRAMS (Continued)

MPEGEN   – Program to generate average absolute and signed cursor error for every bin for each model in all four road conditions.

MODERR   – Data file containing average absolute and signed cursor error for every bin for each model in all four road conditions.

MPELIST – Program to list the average absolute or signed cursor error for every bin and trial for the specified models.

BFMELIST – Program to list the average absolute or signed cursor error for every bin and trial for the specified operator and his best fit models.

```
    ┌─────────┐      ╭─────────────╮         ╭──────────────╮
   ╱   MCS    ╲     │  TERMINAL   │        │   ROAD───     │
  │   TAPES    │    │   INPUT     │        │  (4 FILES)    │
   ╲   (4)    ╱     ╰─────────────╯         ╰──────────────╯
    └────┬────┘            │                       │
         │                 │                       │
         └────────┐        │        ┌──────────────┘
                  ▼        ▼        ▼
              ┌─────────────────┐
              │    MPEGEN       │
              └─────────────────┘                ╭────────────────╮
                       │                         │    MSTRDAT      │
                       ▼                         ╰────────────────╯
              ┌─────────────────┐                         │
              │    MODERR        │                        ▼
              │ (ALL 300 MODELS) ├───────────▶┌────────────────┐      ╭─────────────╮
              └─────────────────┘              │   BFMELIST     │◀─────┤  TERMINAL   │
                       │                        └────────────────┘      │   INPUT     │
  ╭─────────────╮      │                                 │              ╰─────────────╯
  │  TERMINAL   │      │                                 ▼
  │   INPUT     │      ▼                          ╱──────────────╱
  ╰─────────────╯  ┌─────────────┐               ╱   PRINTED    ╱
         │         │   MPELIST   │              ╱   OUTPUT     ╱
         └────────▶│             │             ╱──────────────╱
                   └─────────────┘
                          │
                          ▼
                   ╱──────────────╱
                  ╱   PRINTED    ╱
                 ╱   OUTPUT     ╱
                ╱──────────────╱
```
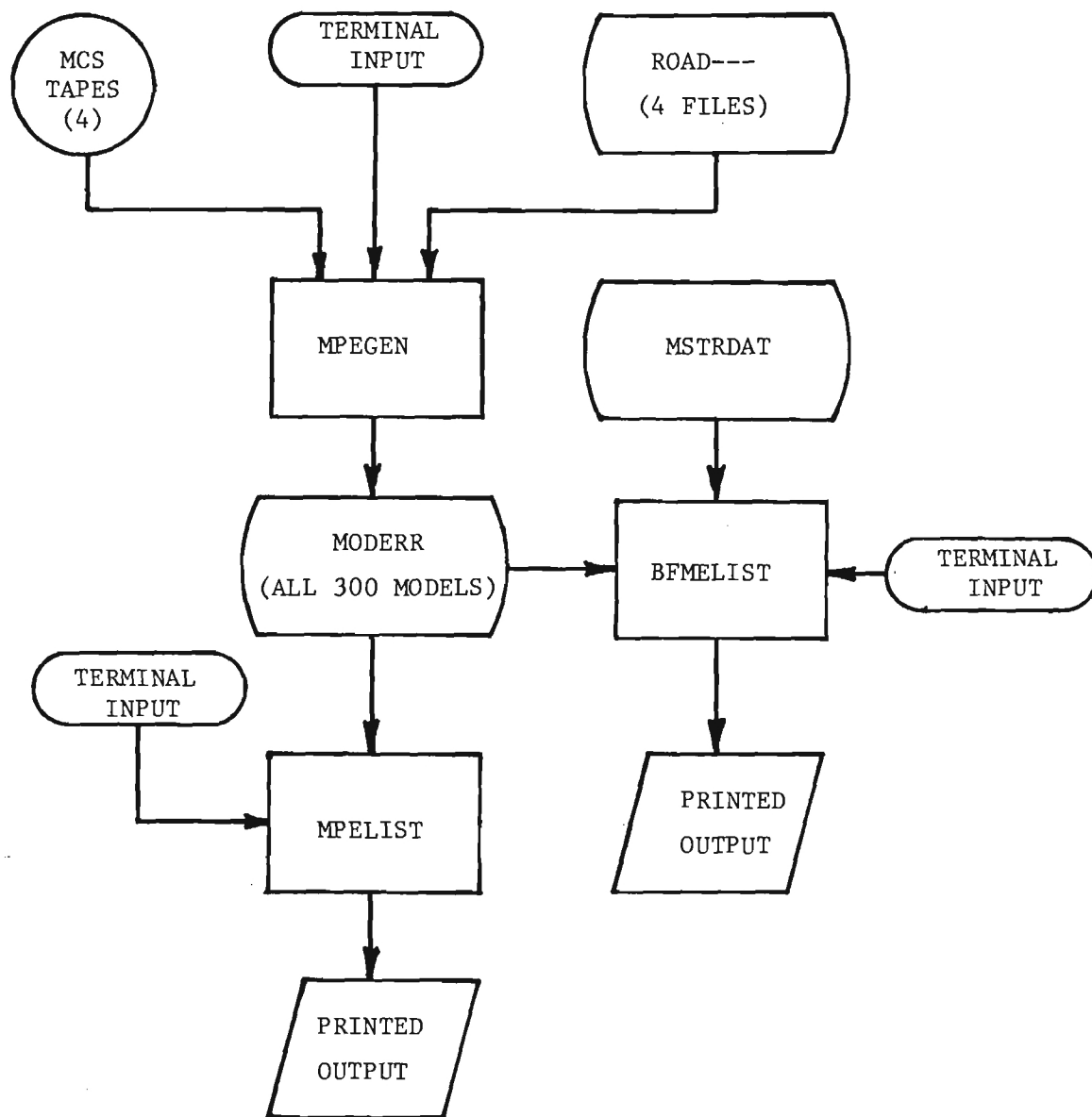
HOPE SUPPORT PROGRAMS (Continued)

RMSCHECK   —   Program to determine the number of bins that the RMS
statistic of the best fit model is below 25.60 for every
operator, and determine the average RMS statistic for
each trial for every operator.

PARVECT   —   Program to output the frequency counts of MODFREQ in a
vector format.

OPELIST   —   Program to list the average absolute signed cursor error
for each bin and trial for the specified operators.
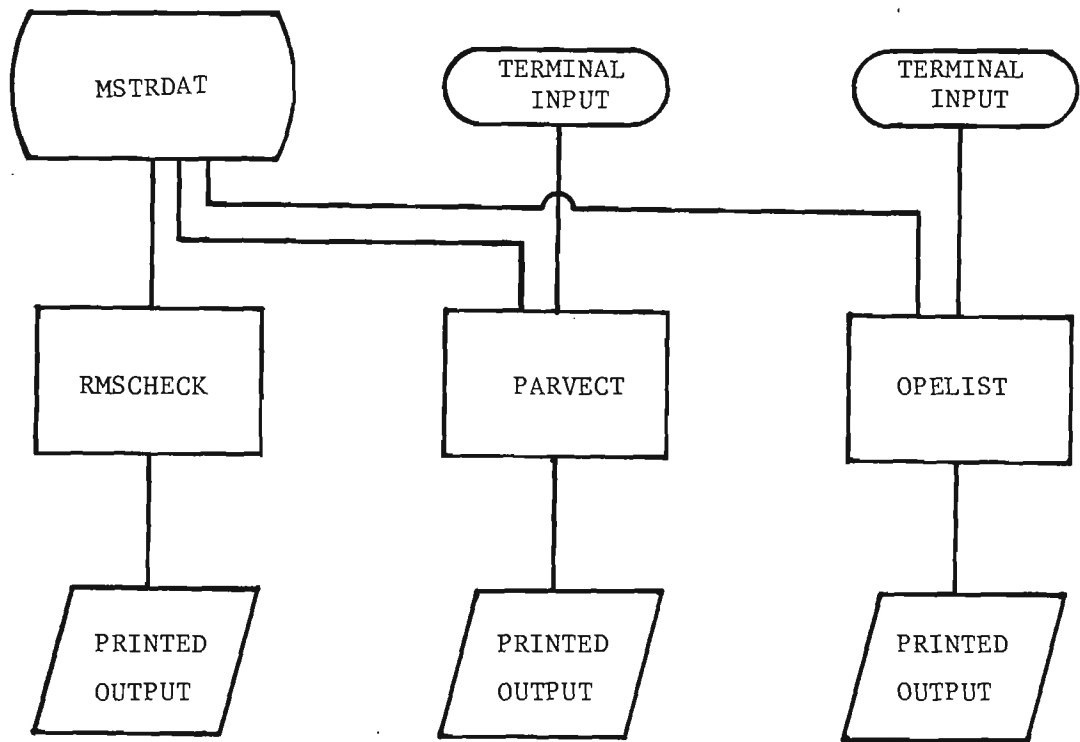
HOPE SUPPORT PROGRAMS (Continued)

CSMSIM   —   Program to list a complete command memory for the
              specified value of COT. In every case, the largest
              possible bat handle which will accomplish a given
              position transfer is listed.

BATRANG   —   Program to list all the bat handle positions which
              result in the same cursor output for the specified
              initial cursor position and COT value.

```
   ╭─────────────╮                        ╭─────────────╮
   │  TERMINAL   │                        │  TERMINAL   │
   │   INPUT     │                        │   INPUT     │
   ╰─────────────╯                        ╰─────────────╯
         │                                      │
         ▼                                      ▼
   ┌─────────────┐                        ┌─────────────┐
   │             │                        │             │
   │   CSMSIM    │                        │   BATRANG   │
   │             │                        │             │
   └─────────────┘                        └─────────────┘
         │                                      │
         ▼                                      ▼
    ╱─────────╲                           ╱─────────╲
   ╱  PRINTED  ╲                         ╱  PRINTED  ╲
  ╱   OUTPUT    ╲                       ╱   OUTPUT    ╲
  ╲─────────────╱                       ╲─────────────╱
```
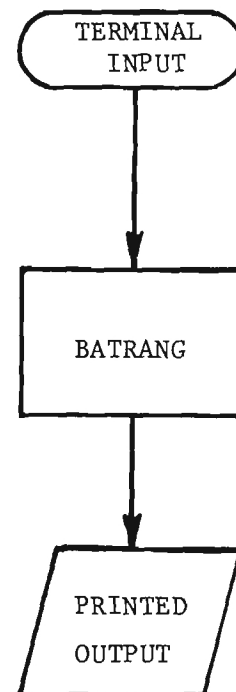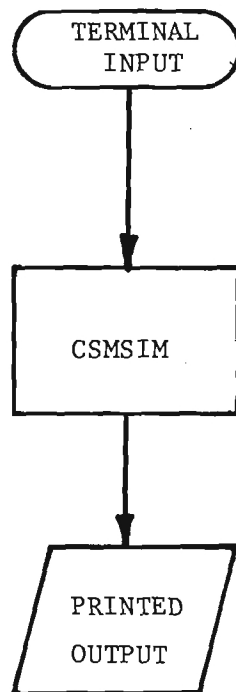
HOPE SUPPORT PROGRAMS (Continued)

HOPE PROGRAMS AND DATA FILES (Continued)

MEANCSP   –   Program to calculate the mean and median parameter values
and position error for each trial for every road condition.

CORCSP   –   Calculates the correlation between each of the control
strategy parameters and the position error.

```
     ┌─────────────┐              ┌─────────────┐
     │   MSTRDAT    │              │   MSTRDAT    │
     └──────┬──────┘              └──────┬──────┘
            │                             │
            ▼                             ▼
     ┌─────────────┐              ┌─────────────┐
     │             │              │             │
     │   MEANCSP   │              │   CORCSP    │
     │             │              │             │
     └──────┬──────┘              └──────┬──────┘
            │                             │
            ▼                             ▼
      ╱───────────╱                ╱───────────╱
     ╱  PRINTED  ╱                ╱  PRINTED  ╱
    ╱   OUTPUT  ╱                ╱   OUTPUT  ╱
   ╱───────────╱                ╱───────────╱
```
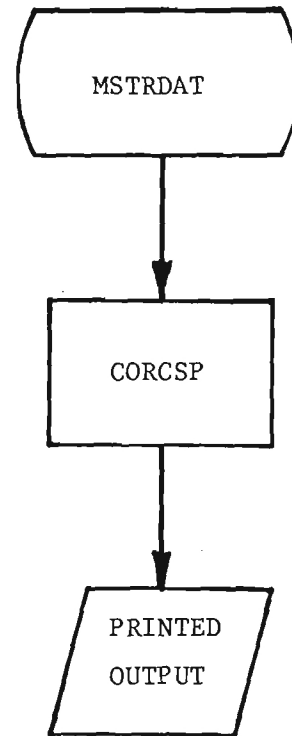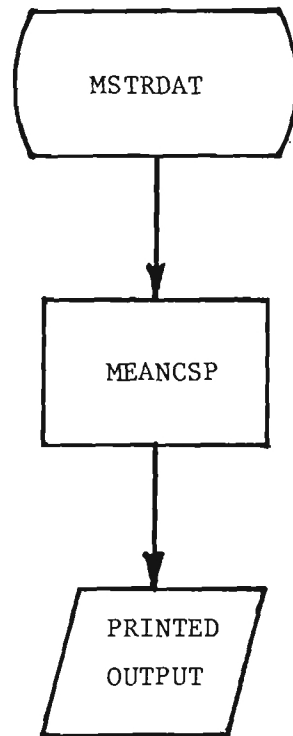
HOPE SUPPORT PROGRAMS (Continued)

LOWRMS   —   Program that generates the RMS statistic for every bin
for each model in one road condition compared with the
bins in one trial of every operator in the same road
condition. For the specified trial input, it picks
the lowest RMS value for each road.

```
                    ┌─────────────┐
                    │  TERMINAL   │
                    │   INPUT     │
                    └─────────────┘
                           │
      ╱────╲               │               ╱────╲
     │      │              │              │      │
     │ OCS──┤──────┐       │       ┌──────├──MCS │
     │      │      │       │       │      │      │
      ╲────╱       │       │       │       ╲────╱
                   │       │       │
                   ▼       ▼       ▼
                  ┌─────────────────┐
                  │                 │
                  │     LOWRMS      │
                  │                 │
                  └─────────────────┘
                           │
                           ▼
                   ╱──────────────╲
                  ╱    PRINTED      ╲
                 ╱     OUTPUT        ╲
                ╱────────────────────╱
```
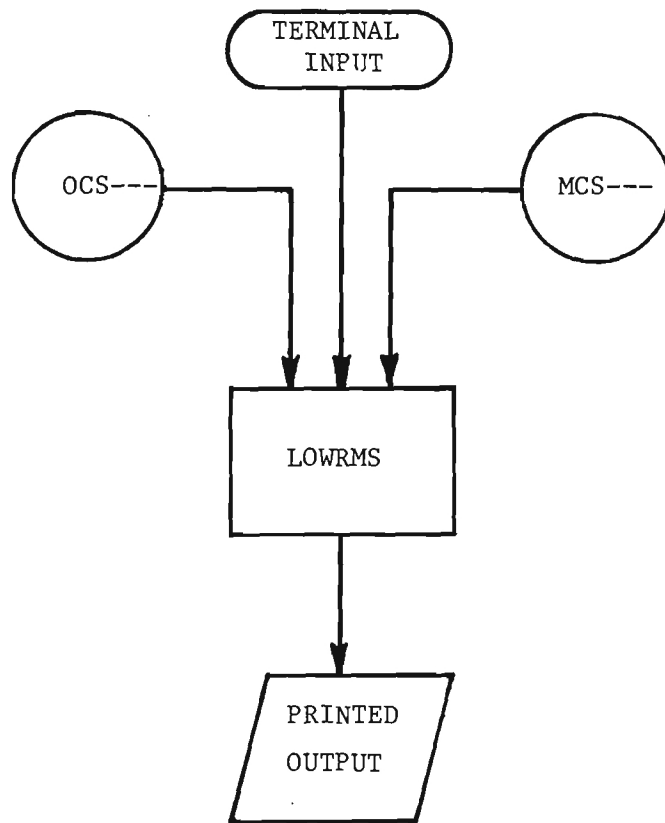
HOPE SUPPORT PROGRAMS (Continued)

HOPE PROGRAMS AND DATA FILES (Concluded)

OCSBHP   –   Program to print the BHP values for specified trials of specified operators.

BFMBHP   –   Program to print the BHP values for specified trials of best fit models of specified operators.

```
      ┌─────────────┐              ╭───────────╮
      │  TERMINAL   │              │    OCS--- │
      │   INPUT     │              ╰───────────╯
      └──────┬──────┘                    │
             │                           │
             └──────────┐   ┌────────────┘
                        ▼   ▼
                  ┌──────────────┐
                  │              │
                  │    OCSBHP    │
                  │              │
                  └──────┬───────┘
                         │
                         ▼
                   ╱──────────╲
                  ╱  PRINTED    ╲
                 ╱   OUTPUT      ╲
                ╱─────────────────╲
```

```
   ╭─────────╮      ┌─────────────┐        ╭─────────────╮
   │ MCS---  │      │  TERMINAL   │        │   SMD---     │
   ╰─────────╯      │   OUTPUT    │        ╰─────────────╯
        │           └──────┬──────┘               │
        └────────────┐     │     ┌────────────────┘
                     ▼     ▼     ▼
                  ┌──────────────┐
                  │              │
                  │    BFMBHP    │
                  │              │
                  └──────┬───────┘
                         │
                         ▼
                   ╱──────────╲
                  ╱  PRINTED    ╲
                 ╱   OUTPUT      ╲
                ╱─────────────────╲
```

HOPE SUPPORT PROGRAMS (Continued)