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PILOT RESPONSE IN COMBINED CONTROL TASKS

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Presented at the Human Factors Society Eleventh Annual Meeting

Boston, Massachusetts
September 25-28, 1967

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ABSTRACT

Pilot response in a multi-task simulation, which consisted of a primary control task combined with one or two secondary or side control tasks, was investigated. A general description of the response characteristics of each of these tasks was obtained and this information was used to determine the workload requirements of the tasks. Two different control tasks were used as the primary control task, either a fixed-base simulation of a lunar letdown or a simplified multi-loop tracking task which was similar to the end portion of the lunar letdown. The simplified tracking task was used in lieu of the more complicated lunar letdown because it could be represented and reproduced analytically. The secondary or side tasks consisted of a system failures task and a motor response task. The system failures task was incorporated from those systems present in a vehicle known as the Mercury Procedures Trainer. The motor response task was similar to that presented by the late Dr. Fitts of the University of Michigan. The task consisted of using a pencil-like device to make impacts on two separated, restricted columns.

An evaluation of the pilot's capability in controlling the multi-task simulation and a determination of the inter-task correlation was made. It was shown that either of the two side tasks produced similar effects on the primary task. Quality measurements were made of all three tasks in all possible combinations. The degradation of each, when in the combined task tests, was then correlated to the other task(s) of the same test. A simple relationship was

found by which one could predict the time required of a human operator to perform the particular task(s) in question. This relationship could be used to determine the workloading qualities of the tasks when performed either alone or combined. An analytical representation for the degraded pilot response in the multi-loop tracking task was also obtained.

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INTRODUCTION

This paper presents the results of an exploratory study investigating human control in a multi-task simulation. The study was an attempt to identify and define the control characteristics of three types of unrelated tasks and to determine their inter-task relationship when performed together. It will be shown that simple descriptions can be used to define control tasks that normally are difficult to represent, and how these descriptions can then be used to obtain a rough estimate of workload requirements of the tasks in a multi-task simulation.

TASKS

The three types of tasks considered were: (1) a closed-loop trajectory control task, (2) a systems failure task integral to a typical space vehicle, and (3) a simple, but well-defined, motor response task.

Trajectory Control Task

The simulation was divided into two phases. The different phases represented two different trajectory control tasks used in the study. In the first phase the trajectory control task was a fixed base simulation of a lunar letdown. In the second phase a simple multi-loop control problem was used in lieu of the lunar letdown.

The lunar letdown trajectory was a descent maneuver, initiated from a circular orbit and resulting in near-zero horizontal and vertical velocities at a

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predefined hover altitude (fig. 1(a)). The final translation and hover phase of the letdown trajectory, that portion which was later found to be most affected by the addition of the side tasks, can be closely approximated by a more restricted, but simple, multi-loop control problem. This simpler control problem is representative of a vehicle supported by a thrust vector alined along the vertical body axis (fig. 1(b)). Translation is obtained by changing the attitude of the vehicle to obtain the desired horizontal thrust. This system is restricted to only horizontal translation. However, it can be reproduced analytically, thereby allowing a more detailed analysis to be made of the control characteristics of the trajectory control task.

Figures 2(a) and 2(b) show the corresponding outputs of both trajectory tasks when each was performed alone. It should be noted that the end portion of the altitude trace of the lunar letdown resembles the end portion of translation trace of the multi-loop task. Also when a second or side task is added to the trajectory tasks the degradation in control of the two tasks is quite similar. Figures 2(c) and 2(d) illustrate this similarity. In the latter two runs the second task was the system failures task which will be explained in more detail later in this paper.

Inasmuch as the multi-loop task also could be represented analytically (previous work by the author, 1965, and Adams, 1966), it was decided to use the multi-loop task in the second phase of the study. Figure 3 is a block diagram of the multi-loop simulation and its corresponding analytical representation. Figure 4 compares the output of the multi-loop task with no side task and the output of the corresponding analytical representation. In this study the analytical representation has been further expanded to produce results similar to that observed in the multi-loop task when a side task is also included (fig. 2(d)). This was accomplished by switching the lead time constant of the outer-loop human transfer function on and off. This switching was done as a function of the translation being within a selected error band. When the translation was within the desired value for the length of time required for three control motion peaks the model lead would be switched off for a selected length of time. At the end of the time, the translation would again be tested, and the switch on the lead again cycled. The results are shown in figure 5. (Note: figs. 2(d) and 5(a) are from the same run.) The "off" time for this run was 11 seconds. This represents an "off" time for the lead time constant of about 60 percent during the end portion of the run. These times can then be related to the information processing rate of the task. The above switching logic was the one which showed the most promise, both in reproduction of the desired output and in interpretation of control logic as applied to the manually controlled runs.

A similar logic was used on the two large outputs of the inner loop. In this logic it was the inner-loop static gain which was switched in and out. Figure 6 compares the results of this method to the piloted runs.

Vehicle System Failures Task

The vehicle was a modified Mercury procedures trainer (see fig. 7), and the system failures were those obtained from failing several of the life support and electrical systems integral to the trainer. The subject was required to then make appropriate corrective responses to a random failure sequence. A measure of performance of this task was obtained by comparing the correction times for the failures. A physical response time, constant for all trials, was subtracted from the measured correction times to obtain refined correction times. These refined times were then considered to be an inverse function of the processing rate for the task.

Motor Response Task

This task consisted of alternately impacting two separated, restricted areas with a hand-held stylus. A theory has been hypothesized by the late Dr. Fitts of the University of Michigan for this task such that one can determine the workload or performance index of the task in bits/sec. Fitts (1954) defines this to be: $I_p \triangleq -\frac{1}{t_a} \log_2 \frac{W}{2A}$ bits/sec. Where $I_p \triangleq$ performance index, $t_a \triangleq$ average time in seconds per movement, $W \triangleq$ width of two columns, and $A \triangleq$ center-line distance between the two columns.

INTER-TASK RELATIONSHIP

To be able to determine the inter-task workload characteristics it was necessary to obtain a general quantitative representation that could be related to all three tasks. It was felt that a simple description would be more useful than a more exact but complicated representation. Therefore it was decided to use one task as an index for obtaining the workload of all other tasks. The motor response task, because of its ability to be used as a fill-in task, was chosen for this index. Also it was assumed that the workloads of all tasks were linearly additive.

The average performance of the motor response task, calculated by the technique described earlier, was found to be 8.7 bits/sec when this task was performed alone with the subject using his left hand. By using the 8.7 bits/sec as the maximum performance criterion, it was determined that when the trajectory and motor response tasks were combined and if no degradation was observed in the trajectory task, the performance rate of the motor response task was 3 to 4 bits/sec. The exact value decided upon was 3.7 bits/sec. Considering our previous assumption of linearly additive performance indices, this would imply that the performance of the trajectory task was 5 bits/sec when this task was performed alone. Several other experimental points were obtained in which the performance of the trajectory task was degraded by an increasing emphasis, from run to run, being placed on the motor response task. Figure 8 is an example of one of these runs. In this run the motor response task was performed at 5.2 bits/sec, implying that the trajectory task was performed at 3.5 bits/sec. From the above data the workload averages of the trajectory task, in rows F, G, H, and J of Table I, were determined.

The systems failure task was also performed in conjunction with the motor response task to relate the performance index of the motor response task to the inverse of the refined correction times mentioned earlier. For example, when the motor response task was performed at 4 bits/sec the average refined correction time of the system failures task was 2.54 sec. Therefore 1/2.54 equals 0.394 sec^{-1} which directly corresponds to the 4.7 bits/sec calculated and shown in row E of Table I. Once this correlation was obtained the correction times were then used to obtain the workload averages of the system failures task in rows C, F, G, H, and J of Table I.

It can be seen in Table I that the linear addition of the calculated workload averages were slightly under the expected 8.7 bits/sec; however, the results are considered consistent enough to be used in many present-day workload studies.

CONCLUSION

Quantitative measurements were made to determine the characteristics and workload relationship of several tasks both when performed alone and when combined. Relative values were obtained for the workload requirements of three separate tasks: a trajectory control task, a systems failure task, and a motor response task. The workload relationship of one to another was determined when performed together. It is believed that the fairly simple techniques of calibrating complex tasks by performing them in conjunction with a standard task such as the motor response task can produce data which are accurate enough to be used in many present-day workload studies.

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2. Bergeron, Hugh P.; Kincaid, Joseph K.; and Adams, James J.: Measured Human Transfer Functions in Simulated Single-Degree-of-Freedom Nonlinear Control Systems. NASA TN D-2569, 1965.
3. Fitts, Paul M.: The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement. J. Exper. Psych., vol. 47, pp. 381-391, 1954.

TABLE 1

TASK	EMPHASIS	MOTOR RESPONSE	TRAJECTORY	FAILURE SEQUENCE		TOTAL
		I_p	I_p	**	I_p	I_p
A MOTOR RESPONSE ONLY		8.7				8.7
B TRAJECTORY ONLY			5.0			□ 5.0
C FAILURES ONLY				2.1	5.7	□ 5.7
D MOTOR RESPONSE AND TRAJECTORY	TRAJECTORY	4.8	△ 3.9			8.7
E MOTOR RESPONSE AND FAILURES	FAILURES	4.0		2.54	△ 4.7	8.7
F TRAJECTORY AND FAILURES	FAILURES		3.2	2.33	5.1	*8.3
G TRAJECTORY AND FAILURES	TRAJECTORY		4.2	4.26	2.8	*7.0
H MOTOR RESPONSE, TRAJECTORY, AND FAILURES	MOTOR RESPONSE	5.4	1.2	6.28	1.9	*8.5
J MOTOR RESPONSE, TRAJECTORY, AND FAILURES	TRAJECTORY	2.7	3.2	5.43	2.2	*8.1

□ OBTAINED FROM EXTRAPOLATION OF TASK FROM KNOWN VALUES

△ OBTAINED FROM COMPARING TO MOTOR RESPONSE ~~MAKING~~ TASK

*OBTAINED FROM SUMMATION OF INDIVIDUAL TASK VALUES

**AVERAGE TIME IN SECONDS REQUIRED TO CORRECT THE FAILURES

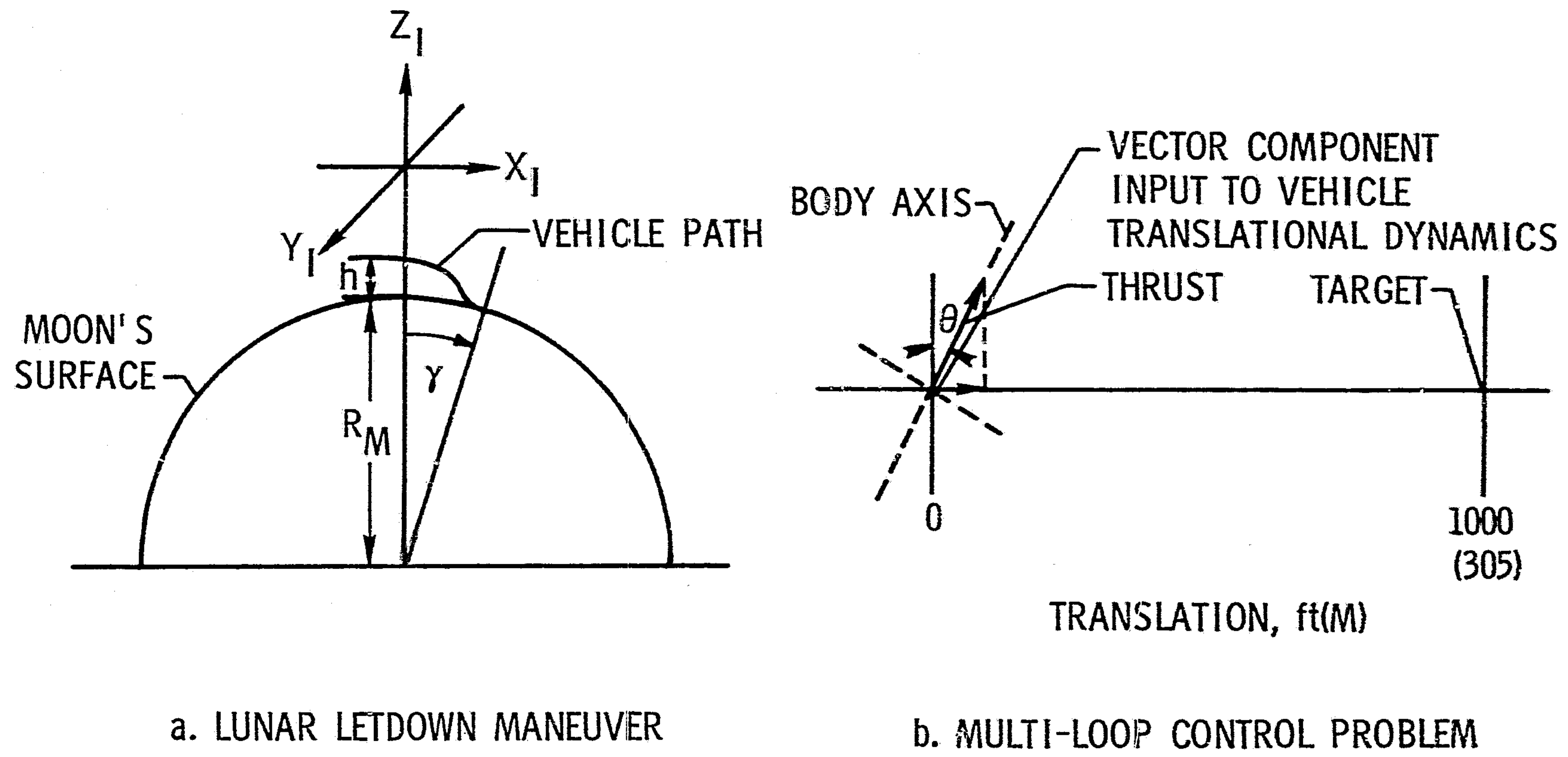

Figure 1.- Diagram depicting both trajectory control tasks.

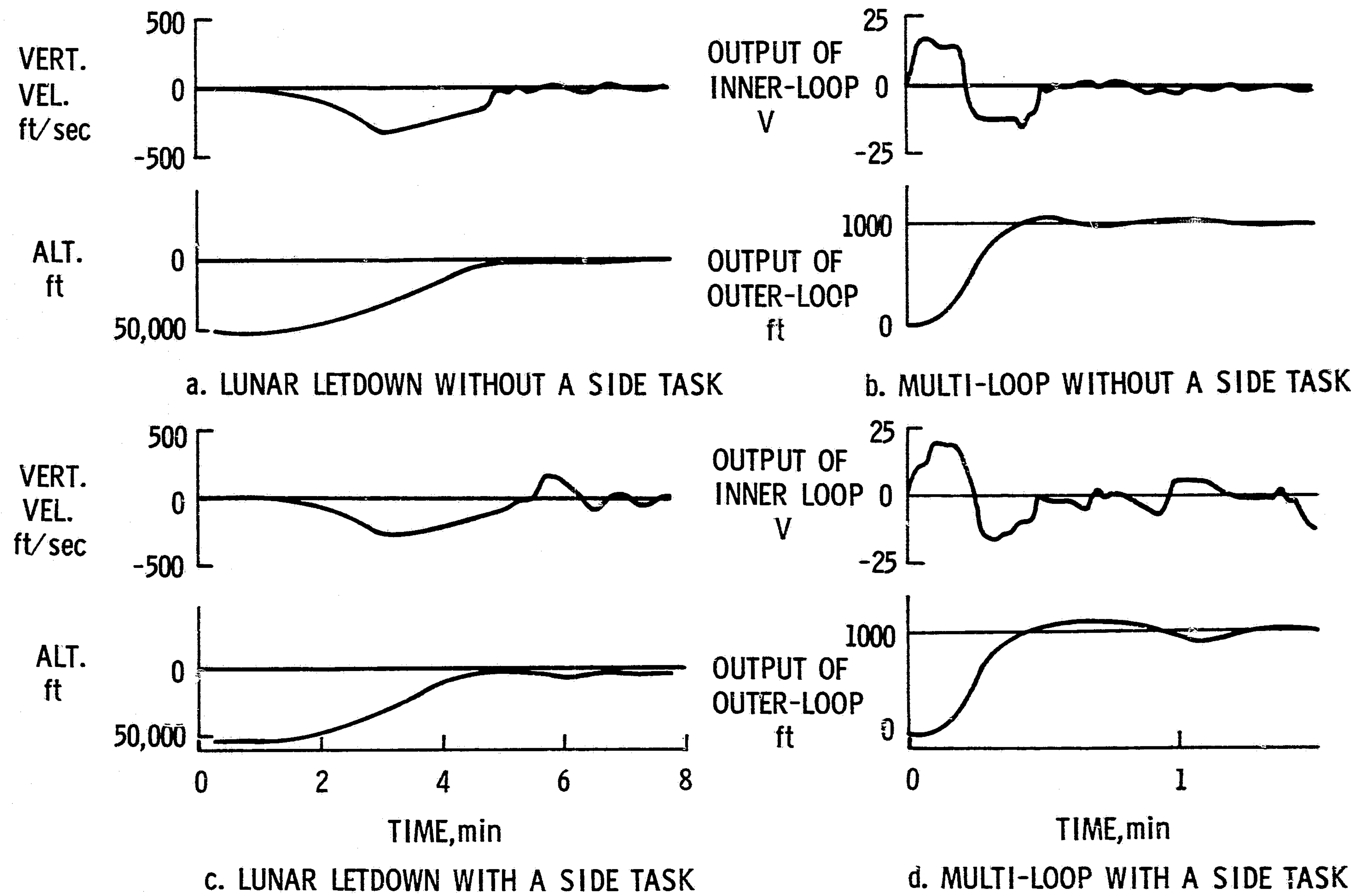

Figure 2.- Outputs of both trajectory control tasks.

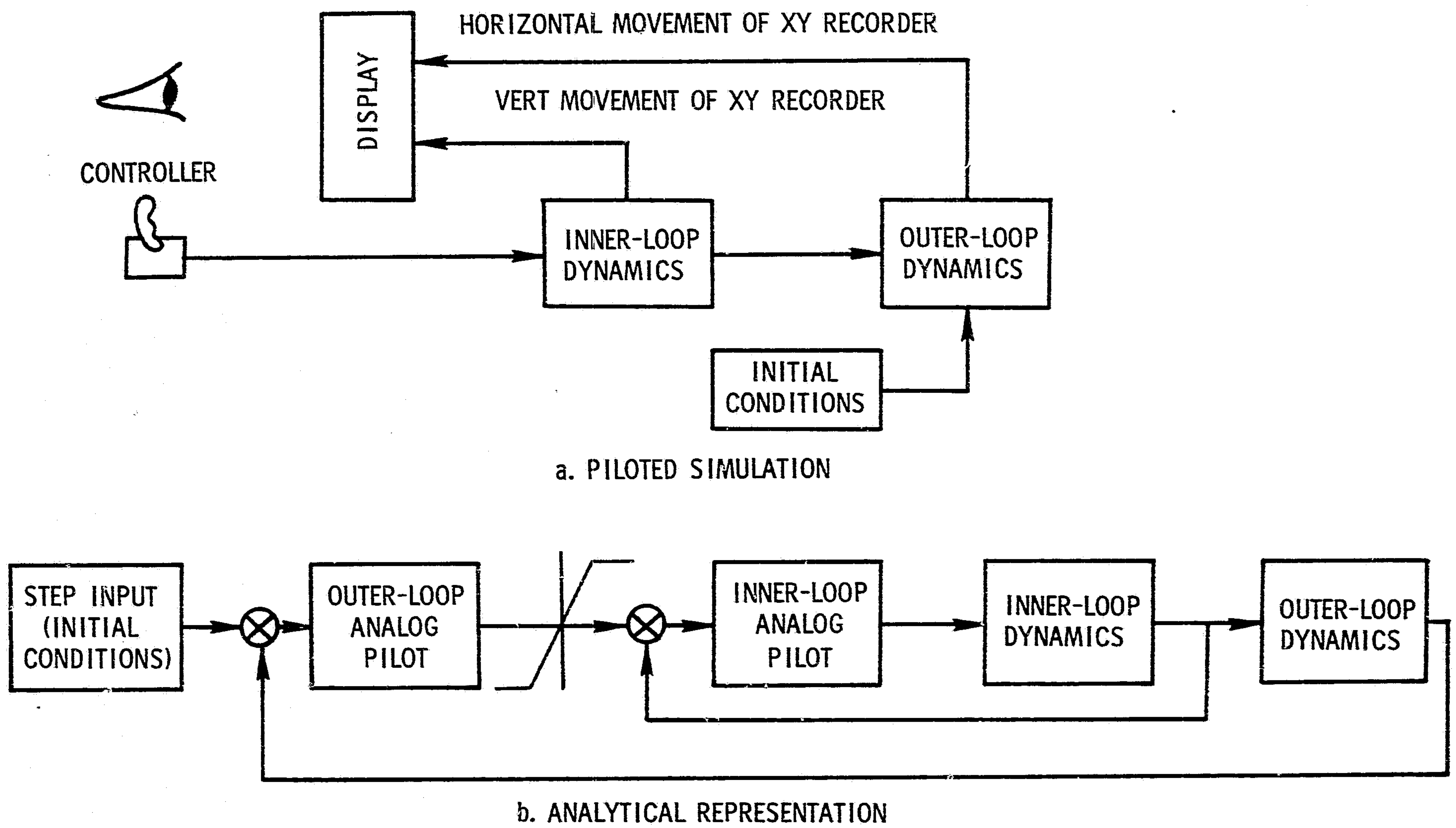

Figure 3.- Block diagrams of the multi-loop simulation.

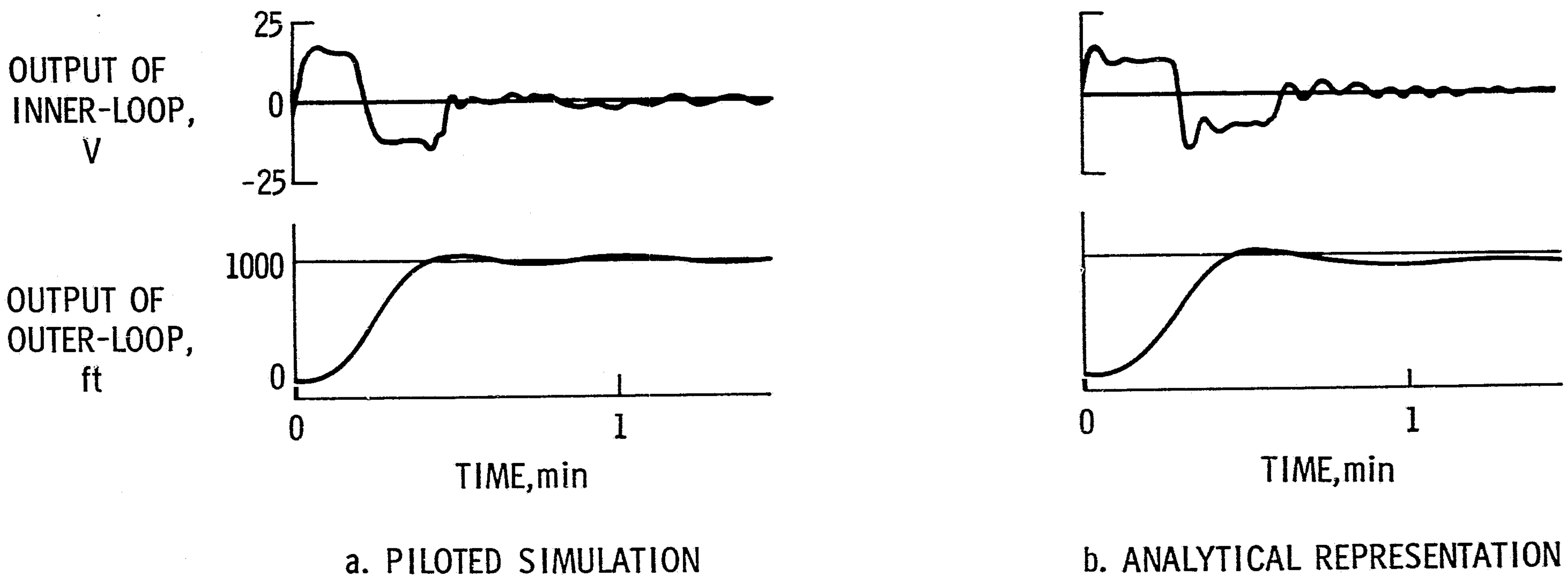

Figure 4.- Outputs of multi-loop simulation without a side task.

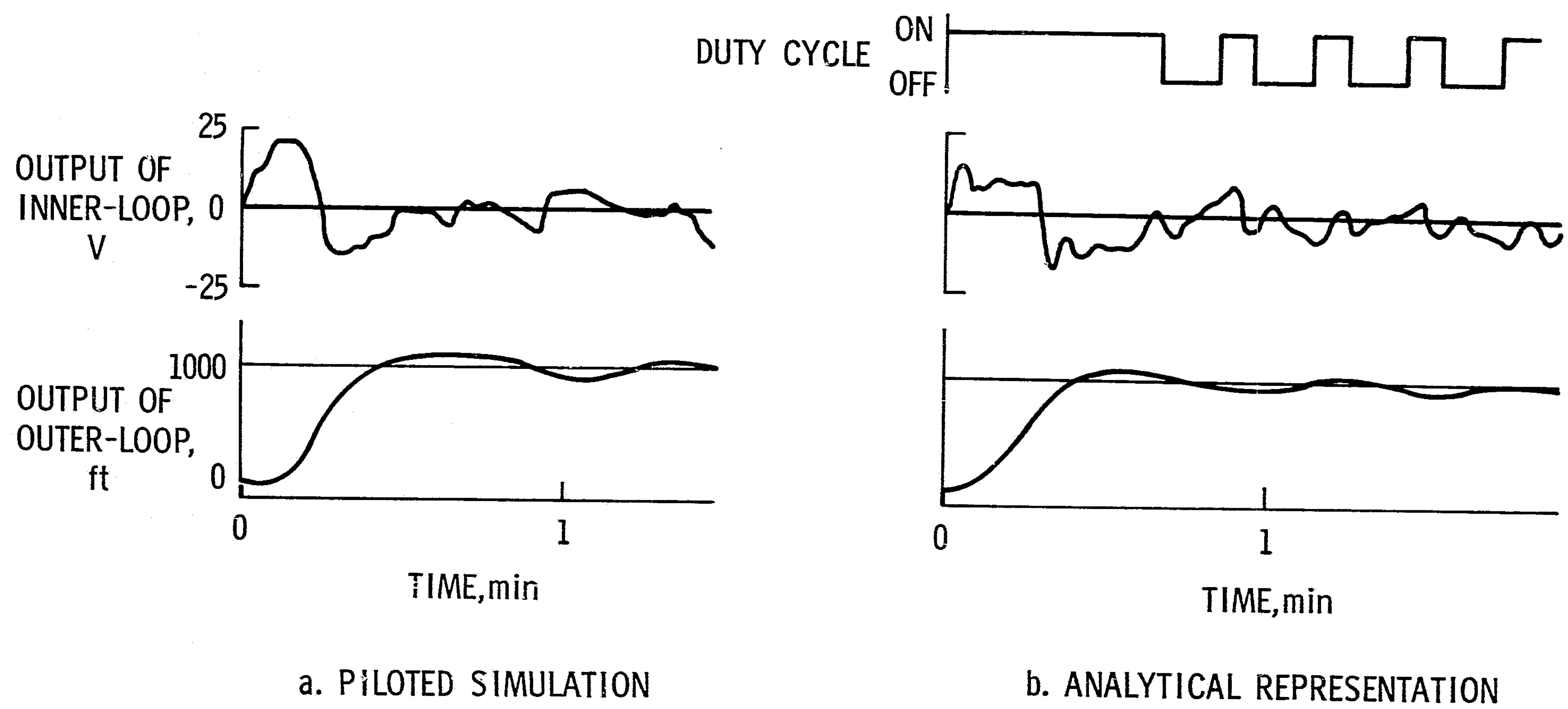

Figure 5.- Outputs of multi-loop simulation with a side task.

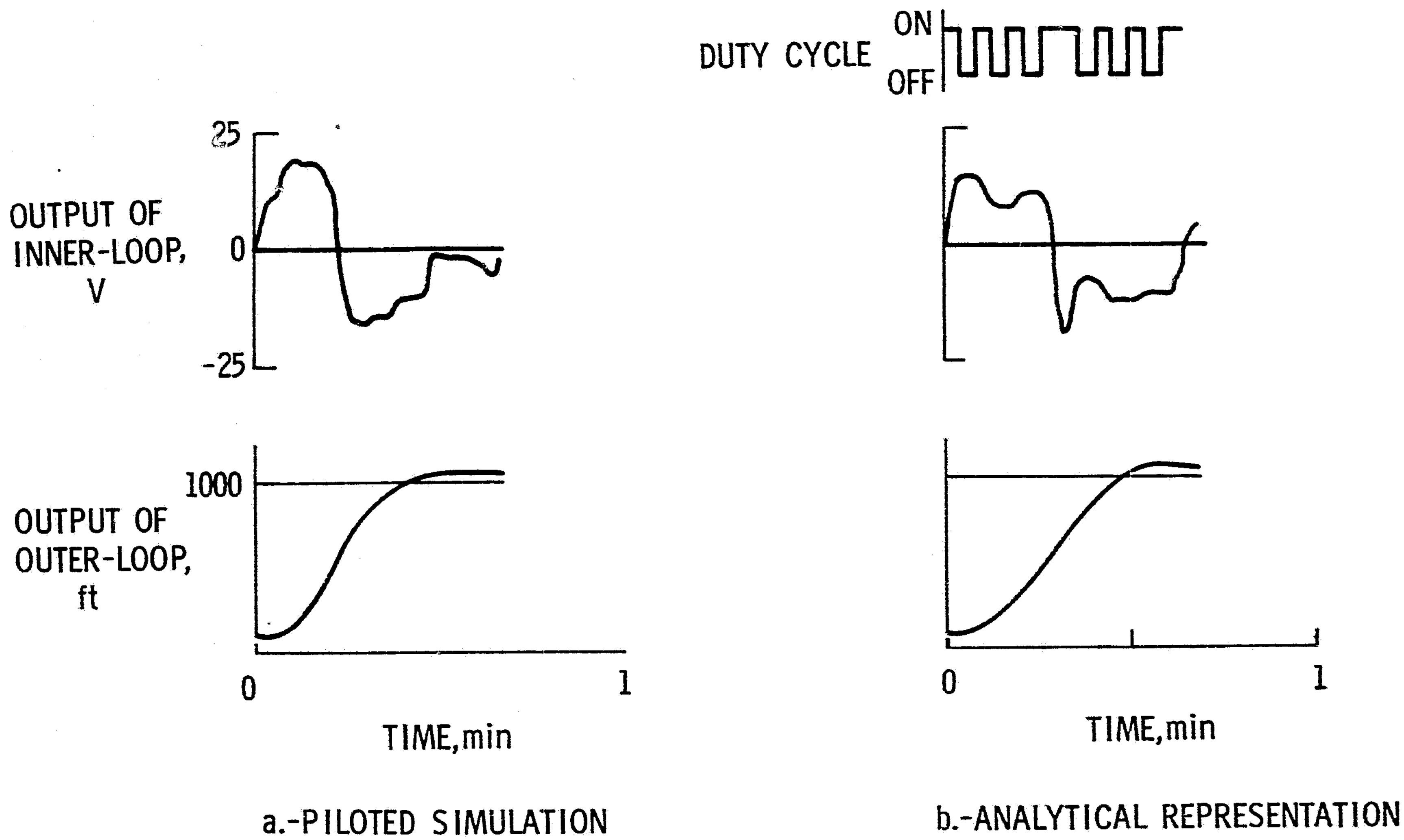

Figure 6.- Outputs of first part of the multi-loop simulation with a side task.

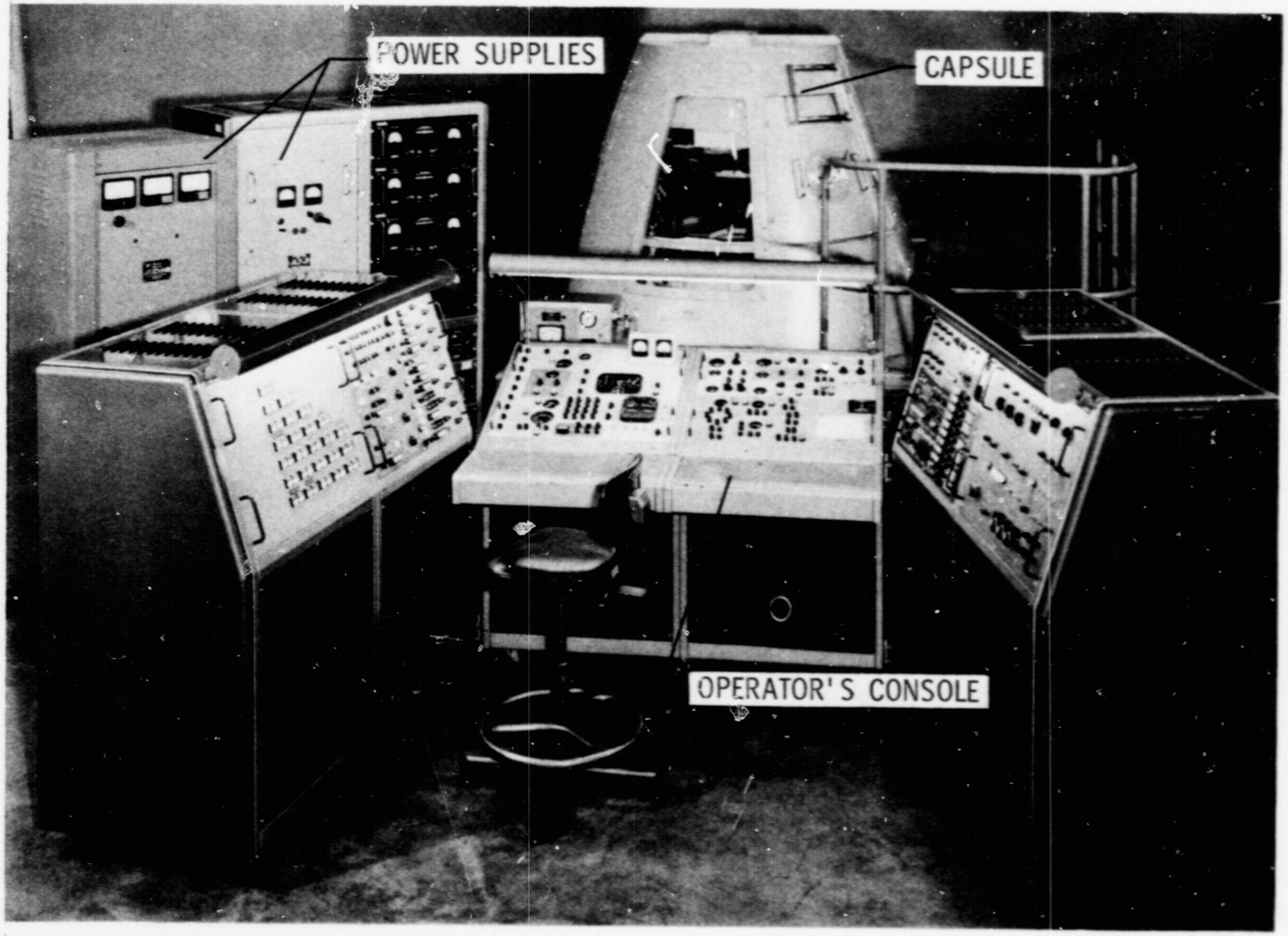

Figure 7.- Mercury Procedures Trainer and its associated equipment.

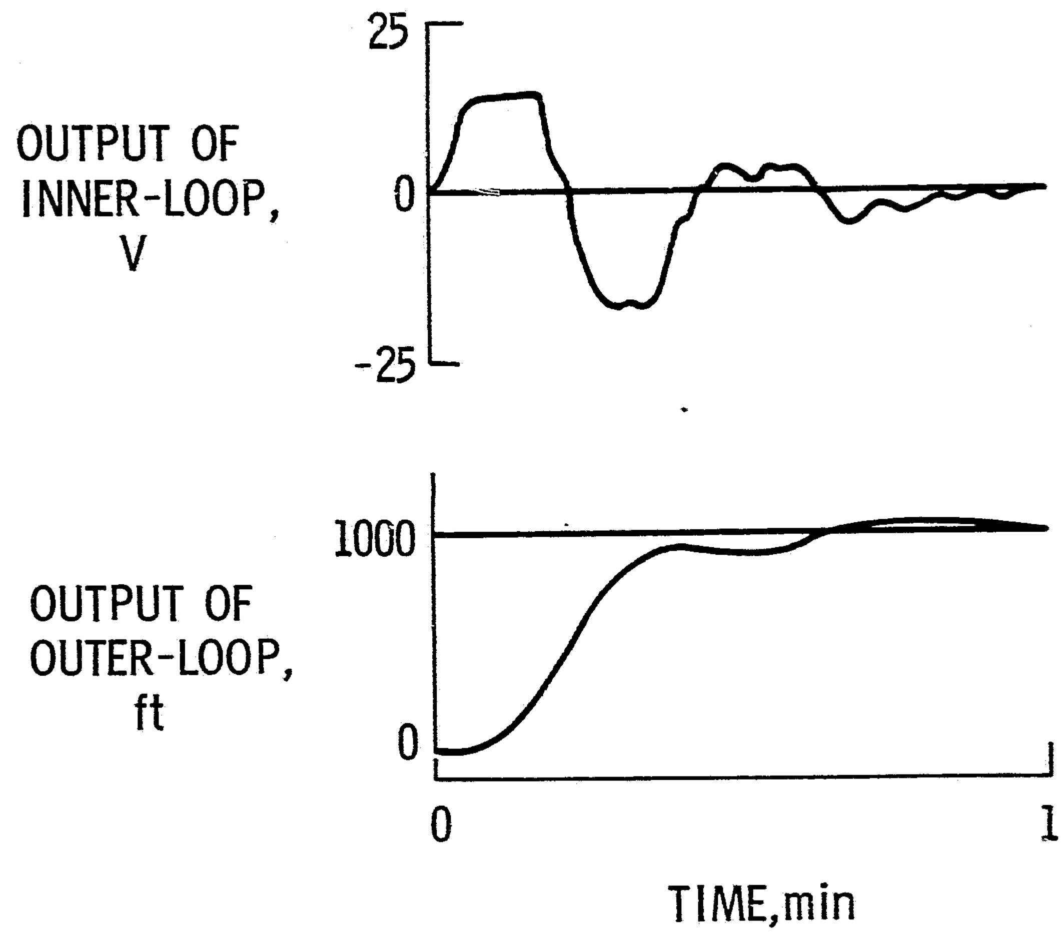

Figure 8.- Piloted multi-loop control problem with the side task (motor response task) performed at 5.2 bits/sec.

NASA-Langley, 1967