AN APPLICATION OF PREDICTOR DISPLAYS TO AIR TRAFFIC CONTROL PROBLEMS

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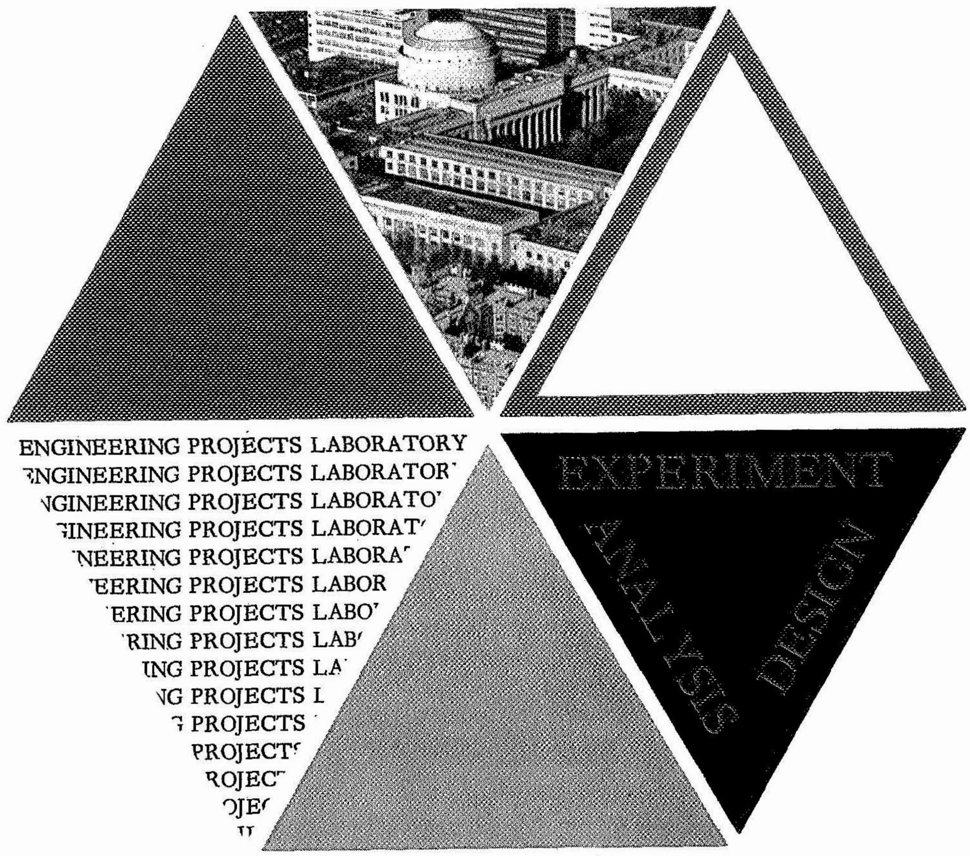

AN APPLICATION OF PREDICTOR DISPLAYS

TO

AIR TRAFFIC CONTROL PROBLEMS

by

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William B. Rouse

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This thesis is concerned with evaluating the feasibility of using a predictor display system to help solve terminal area air traffic control problems. A computer-based predictor display is proposed as an aid for the air traffic controller to use in guiding aircraft to the glidepath.

An air traffic control simulation was designed and constructed using two analog computers. One computer generated the aircraft while the other performed the prediction and display functions.

Two experiments were performed using this system. The first experiment consisted of guiding a single aircraft through its approach pattern. The second experiment consisted of guiding three aircraft through their approach patterns simultaneously.

The results of the subjects' performance of the experiments were used to study the learning process with and without the predictor display. An analysis of variance was performed. The predictor system was assessed considering such task components as error, error rate, task completion time, and length of prediction.

It was determined that learning, in most cases, was faster with the predictor display. However, the difference in performance with and without the predictor display decreased as learning proceeded. The predictor display helped to reduce errors, but not task completion time. A prediction which was too long and displayed more than the necessary amount of information increased task completion time. The prediction display significantly improved performance for the easier tasks while it did not significantly improve performance for the more difficult tasks.

Thesis Supervisor: Thomas B. Sheridan
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I. SUMMARY

This research was concerned with the use of a predictor display system, an example of a man-computer system, to aid in the guiding of aircraft during their approach to the glidepath of a runway. Such a system would enable an airport to handle a larger volume of aircraft.

An air traffic control simulation was constructed using two analog computers. One computer generated the aircraft while the other computer performed the prediction and display functions.

Two experiments were performed. The first experiment consisted of guiding a single aircraft through its approach pattern. Five subjects performed this task. For each subject there were ninety-six trials, i.e., all combinations of two initial conditions, three prediction lengths, and sixteen iterations. Performance was based on aircraft position error, error rate, and task completion time.

The second experiment consisted of guiding three aircraft through their approach patterns simultaneously. It was necessary to merge the aircraft into a specified sequence for the approach. Three subjects performed this task. For each subject there were one-hundred and sixty trials, i.e., all combinations of four initial conditions, two prediction lengths, and twenty iterations. Performance was based on aircraft position error, error rate, task completion time, and error in maintaining the proper spacing between aircraft.

The learning process with each display was studied by fitting three parameter exponential curves to the data. In most cases, the learning process with the predictor display was faster than that

with the conventional system. However, the difference in performance with and without the predictor display decreased as learning proceeded.

An analysis of variance was performed to study the differences between the predictor and conventional displays. It was determined that the predictor display helped to reduce errors, but not task completion time which has a lower limit dictated by the dynamics of the system. A prediction which is too long and which displays more than the necessary amount of information can increase task completion times.

The strategies that the subjects used were investigated. It was apparent that the subjects generated their own switch curves (decision time criteria) by which to give commands. Thus, the tasks could be related to optimal control problems.

Examination of the results showed that the predictor display significantly improved performance for the easier tasks while it did not significantly improve performance for the more difficult tasks. Using this result and the subjects's comment that the more difficult tasks often proved taxing, the idea was presented that an upper limit on the applicability of display aids exists. Very difficult tasks tax the operator to the point that he reverts to an intuitive level of performance and disregards the information presented by the display.

The feasibility of using a predictor display system to help solve air traffic control problems was assessed. It was suggested that a digital computer with some decision making capability might be necessary to make the predictor display generally applicable. This notion was not pursued in this thesis but rather proposed as basis for future research.

II. INTRODUCTION

As technology and the state-of-the-art advances, computers are gaining the capability to perform many tasks that man once considered solely his responsibility. Examples of such tasks include teaching and elementary decision making. However, many complex tasks still require the flexibility of the human decision maker. An example of this arises in the field of air traffic control. This example will be pursued in later chapters.

Although a human operator may be needed as part of a specific system, computer usage must not thereby be excluded from that system. In fact most complex tasks that require a man also have many facets of their operation that are better suited to computer control. Two questions arise from this situation. First, which tasks can man perform better than the computer and vice versa? Second and more important, which allotment of tasks produces the best overall system performance? The answer to these two questions may not be the same.

As an example, consider a task such that the summation of many subtasks produce a result upon which a human operator will base a decision. A computer may easily surpass the man in ablilty to perform most of the subtasks, but the result of summing the products of the subtasks may have little meaning to the human if he has not taken part in the intermediate steps of the process. Thus, performance of some of the subtasks may have to be delegated to the human in order that he can produce a proper decision based on the final result.

In view of the above, the problem can be simply stated as that of determining the proper man-computer combination for whatever task is under consideration. This problem will not be totally considered within the confines of this thesis. The concern here will be restricted to one type of computer aid with respect to one specific task.

When the human operator controls low frequency high order dynamic systems, he must base his present decisions on what he thinks will be the future state of the system. This situation occurs because the operator's present inputs are subject to the lag in the system so that most of the effects of his present actions are delayed. The length of time that he must think into the future depends upon the speed and dynamic order of the system. The accuracy of his mental predictions depends on his experience with the system and knowledge of the inputs that the system will receive.

Computers far surpass man in the ability to make rapid repetitive calculations. Given a model of a dynamic system and its inputs, the computer could predict future states of the system with much more accuracy and speed. The human could then base his control decisions on the computer's extrapolations. This idea is not new, it originated with Zeibolz and Paynter [(1)] and was extensively pursued by Kelley [(2)]. The realization of this idea Kelley has termed the "predictor instrument" or "predictor display."

The principles upon which a predictor display is constructed are straight forward. A dynamic model of the system to be controlled is fabricated. Using the present state variables of the actual system as initial conditions, the model is repeatedly operated at a much faster rate than the actual system. Thus, the model predicts future states of the system which can be displayed to the operator in various ways [(3)].

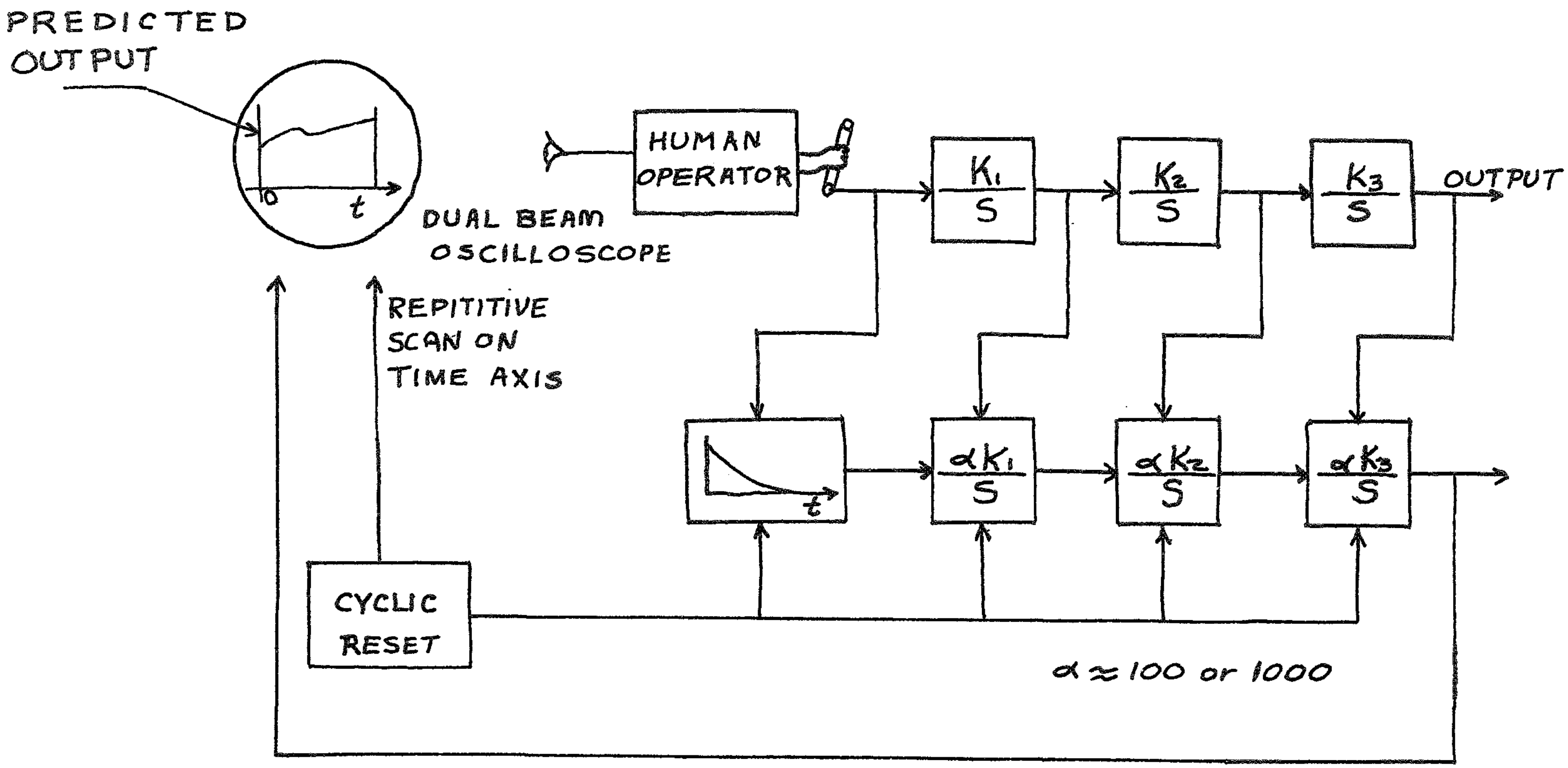
This concept may also be called "fast time simulation." The dynamic model of the system is thereby termed the "fast time model."
A predictor display system is illustrated in Figure 1. This system assumes that the operator returns his control to zero. This assumption will be discarded in later chapters.

Although the concepts of predictor displays are over fifteen years old, such displays have received little application. Adoption of predictor displays for use in aerospace control applications has been considered [3,5,6], but seldom implemented. This may be attributed to some questions that still exist about these displays [4].

1. How should two dimensional predictor displays be coded?
2. Is there an optimum prediction span, and if so what determines it?
3. How closely must the fast time model compare to the actual system?
4. How does the operator use such a system in effecting his response?

Recent research [7,8,9] has considered some of these points, but no general answers to all of these questions have been obtained. Answers to these questions will not be specifically pursued in this thesis. The main concern will focus on a different level. However, results of this research will be later discussed as it relates to these questions.

A predictor display can be viewed as an elementary computer aid. The computer performs calculations and the operator bases his decisions upon these results. At this level of computer aid, the computer performs none of the decision making. However, this



PREDICTOR DISPLAY SYSTEM [4]

FIGURE 1.

possibility should not be excluded and will later be discussed.

To investigate this level of man-computer interaction, a single complex task has been chosen. The concern will be with the air traffic control task of merging aircraft as they approach an airport into a safe and efficient line of traffic. Before continuing with a discussion of this task, some background on the workings of air traffic control is necessary.

III. THE AIR TRAFFIC CONTROL PROBLEM

It is common knowledge that the Air Traffic Control (ATC) system is having problems, but the specific details of the problems and their sources are poorly understood. A recent appraisal of the state of ATC [10] showed that the problems are of various types and sources. These problems extend from those associated purely with engineering to financial and political considerations.

The problem of concern in this thesis is that of determining the role of the controller. Some solutions now being proposed include automation of the ATC system to the point that the controller becomes a passive and parallel element in the system. Proponents of such a solution, however, are quick to add that a controller is needed to run the system when unusual circumstances occur. Such unusual occurences might include damaged aircraft (A/C) in the approach pattern, stalled A/C on the runway, and pilots new to an airport and unfamiliar with the control system.

It appears that the controller cannot be subjugated to a standby role in ATC. He could not be expected to respond quickly and efficiently to emergency situations if he is not an active part of the system.

The solution seems to be the combining of talents of controller and computer, but the question of what the computer should do and what the man should do remains to be answered.

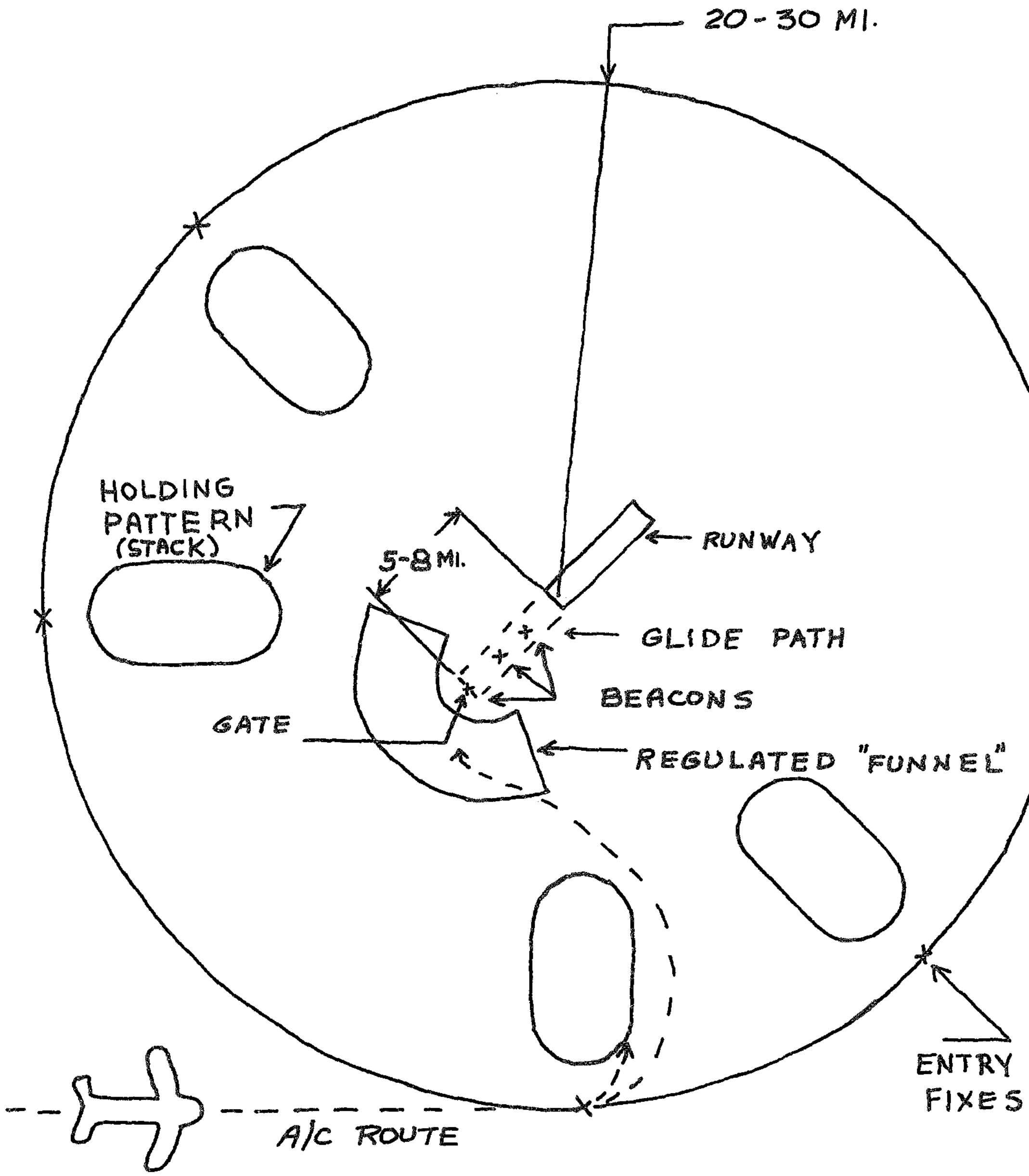
Before discussing a plan for considering this man-computer question, it is important to be aware of the controller's present role and the general operation of ATC system.

The national system of air routes and airports as it currently exists is fairly well organized. This organization of the air system was basically accomplished between 1919 (when ATC rules were first considered) and 1945. Minor changes have occurred in the past 20 years, but innovation has seriously lagged behind growth.

The air system consists of several hundred thousand miles of airway defined in the sky by VOR and VORTAC, which are VHF omni range beacons. Currently, enroute A/C use the radial beams emitted by these beacons and fly from beacon to beacon along these radial paths. A/C flying in opposite directions are separated by 1000 feet in altitude.

The U.S. is divided into many Air Route Traffic Control Centers (ARTCC). Each of these has control of a geographical area, e.g., New England. The ARTCC monitors all A/C in its area via radio and radar. When an A/C leaves one ARTCC and enters another, the controller of the area which the A/C is leaving "hands-off" the A/C to the controller of the next area via telephone. The A/C then communicates with the new ARTCC and receives such information as communication frequencies, etc. The above procedure applies to enroute A/C (those in transit and away from airport) only, which limits the ARTCC control to those A/C at altitudes over 18,000 feet.

As a subset of each ARTCC and around each airport are Terminal Areas (TMA) which have responsibility for A/C at all altitudes in an area that extends radially for 20-30 miles around the airport. Figure 2 is a sketch of a TMA. An A/C may enter the TMA through one of several entry fixes which are defined by radio beacons. At these points, the ARTCC controller hands-off the A/C to the TMA approach controller. The approach controller is aware that the A/C is due to arrive because he receives the flight plan of that A/C from its point



TERMINAL CONTROL AREA

FIGURE 2.

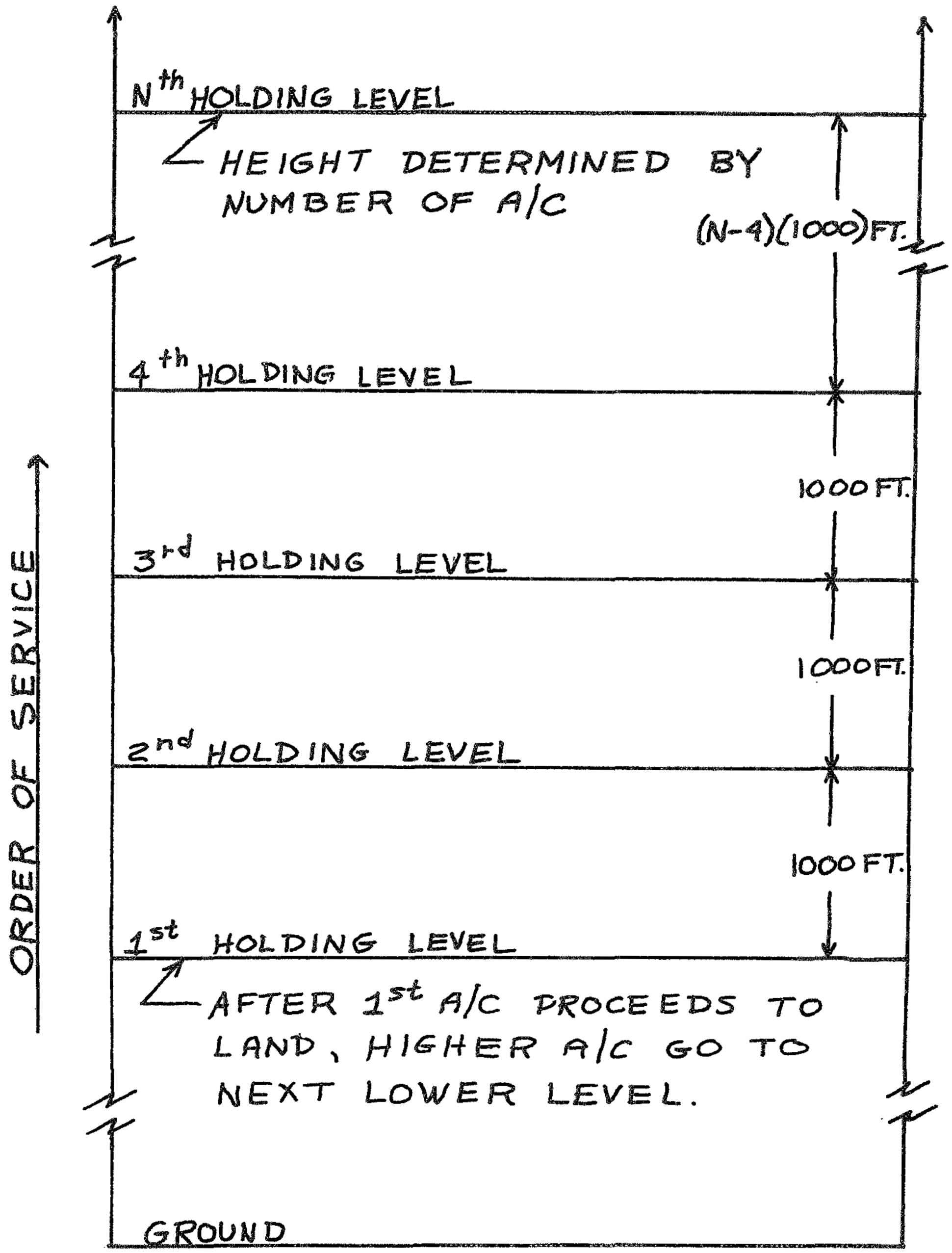
of departure. This flight plan contains such information as estimated time of arrival (ETA), cruising altitude, speed, etc. The flight plan is updated enroute if any great changes occur in data originally sent to the TMA. However, since the ETA is by definition only an estimate, the controller experiences random arrivals of A/C into the TMA.

Upon entering the TMA, the A/C can be instructed to do one of two things. Either the A/C can be advised to proceed to land, or can be instructed to join one of the holding stacks and wait to be cleared to land.

If he is told to proceed to land, he enters the regulated "funnel," enters the glide path and descends to the runway.

If he is ordered into a holding pattern, he joins the highest level of the appropriate stack, as shown in Figure 3, and cycles down the stack as the A/C in the lower levels leave the stack to land. When he reaches the lowest level of the stack, it then becomes his turn to land.

There are two basic situations in which an A/C will use an airport. Visual Flight Rules (VFR) are such that A/C fly on a "see and be seen" basis. Instrument Flight Rules (IFR) indicate that A/C are being guided onto the runway with use of various equipment. IRF requires a great deal more use of the ATC system since it must in effect control the A/C. In the past, IFR use was limited to weather conditions of poor visibility, but increased density in airspace has resulted in most commercial carriers using IFR all the time when using high density airports. This accelerated use of IFR is one of the biggest problems in ATC. Naturally, this does not mean that IFR use should be reduced, but that the system should be



HOLDING STACK

FIGURE 3.

developed so as to have the capability of handling an ever-increasing IFR use.

When using the TMA under IFR, several aids enable the controlling of traffic. Holding patterns are established using radio beacons. Upon proceeding to land, the A/C uses an Instrument Landing System (ILS) to guide itself to the runway. Radio transponders define the glide path so as to enable the A/C to determine its position.

When an A/C is departing form a TMA, he files a flight plan with departure control, as previously mentioned. Departure control clears the A/C to use a taxiway. When a runway is available, the A/C is cleared to depart. Departure control remains in charge of the A/C until it is handed-off to the next control area as it leaves the TMA.

There are many safety standards which complicate the above procedures. In the air, A/C are required to maintain a 3 mile horizontal and 1000 foot vertical separation from all other A/C. When A/C reach the runway, a minimum separation of 1.5 minutes is usually required to allow the runway to be cleared for the next landing. For enroute A/C the minimum spacing requirements are somewhat greater (5 miles) because the greater amount of airspace allows a larger margin of safety. Thus, all of these standards as administered by the FAA are for safety's sake.

There are also departure separation standards. If two A/C are planning to fly the same course, their departure must be separated by at least 3 minutes. If their courses will diverge after 5 minutes in the air, the standard is 2 minutes, and, if their courses are completely different, the separation is 1 minute.

A/C could physically be flown much closer than these standards require, but equipment that the ATC system uses has some inherent uncertainty. Radar is the main system used by ATC in controlling A/C. The accuracy possible with this equipment is ± .333 nautical miles for distance and ± 2° for bearing (11). Using this data and a little trigonometry yields the result that at 20 miles from the airport, the controller knows only that the A/C is somewhere in an area of space 1.40 miles by .77 miles. ATC knows the A/C altitude only by what the A/C tells them. Using these figures, the separation standards seem quite realistic for A/C traveling at a couple of hundred miles per hour.

Often the controllers are skillful in avoiding situations where separation standards hinder operation. An example might be a faster A/C following a slower A/C. Here it is impossible to maintain the minimum standard constantly. When arriving A/C are too close or appear to be heading for that situation, the controllers instruct them to take courses which will delay them for a certain length of time. In other words, the A/C flies some pattern off course for a period of time so that when it rejoins the normal pattern, it has lost a desired amount of time and/or distance and thus has not violated the separation standards. Simpson (11) explains these various delaying patterns and their effectiveness. Porter (12) has studied optimal strategies for these maneuvers. With respect to departures, the controllers usually sequence the departing A/C on the taxiway so that planes going in the same direction do not follow each other. This eliminates needless delay in meeting time separation standards.

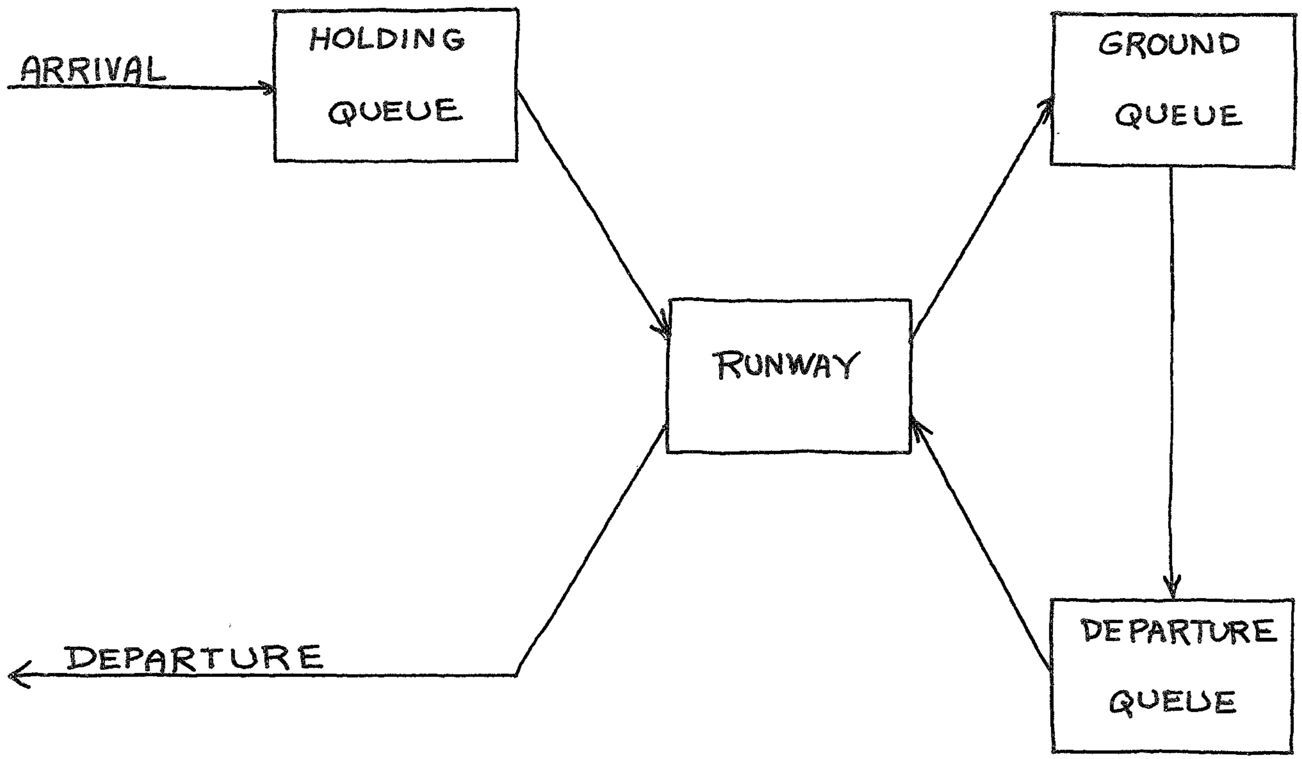
There are many other pieces of navigational equipment in use today that are not discussed here. Basically, they are simply variations of the equipment previously explained.

Communications between ATC and A/C is via radio. During IFR situations at peak times, the frequencies available become dangerously overloaded. As an example, on an average flight from Washington to New York with a flying time of 39 minutes, there are 55 separate two-way voice communications on 11 different frequencies [13]. Telephone and teletype are used to communicate between ARTCC's and TMA's. The teletype is used to process flight plans. These are sent on paper "flight strips" which the controller manually handles and arranges in order of expected arrival. As previously mentioned, the telephone is used during the hand-off procedure.

Operation of the system is based on a "first-come first-served" basis with landings given priority over departures. Landings have priority because of the increased costs for delays in the air as opposed to those on the ground, and also for safety reasons. In communications, ground transmissions have priority over A/C transmissions. When the system is extremely busy, A/C are reduced to simply being listeners since there are no channels available [11].

The system may be modeled as a series of queues [10]. The holding, ground and departure queues are displayed in Figure 4. In this context, 'ground' means all those activities which take place on the ground exclusive of landing and departing, such as loading and unloading passengers, fuel, and baggage and performance of any necessary maintenance.

Thus far the discussion has been limited to airports that have only one runway. With a few exceptions, all the rules and procedures are the same regardless of the number of runways available.



TERMINAL FACILITY QUEUES

FIGURE 4.

Many times multiple runways exist simply because of the variations in wind direction. If parallel runways are 5000 feet apart, then they can be used independently for departures and arrivals or for a mixture of both. Under IFR, the runway must have an ILS, but only a few of the busiest of the nation's airports have more than one. Therefore, capacity is lowered considerably when IFR is used in many airports that normally have multiple landing capability.

Thus, the ATC system is fairly complex and ladden with operating rules and restrictions. Many problems could be explored.

This study is concerned with the controllers effect on system performance. The importance of this investigation can be seen if one considers that the greatest cause of inefficiency in the ATC system is error resulting from equipment tolerances and inaccuracies in A/C spacing caused by the controller (14).

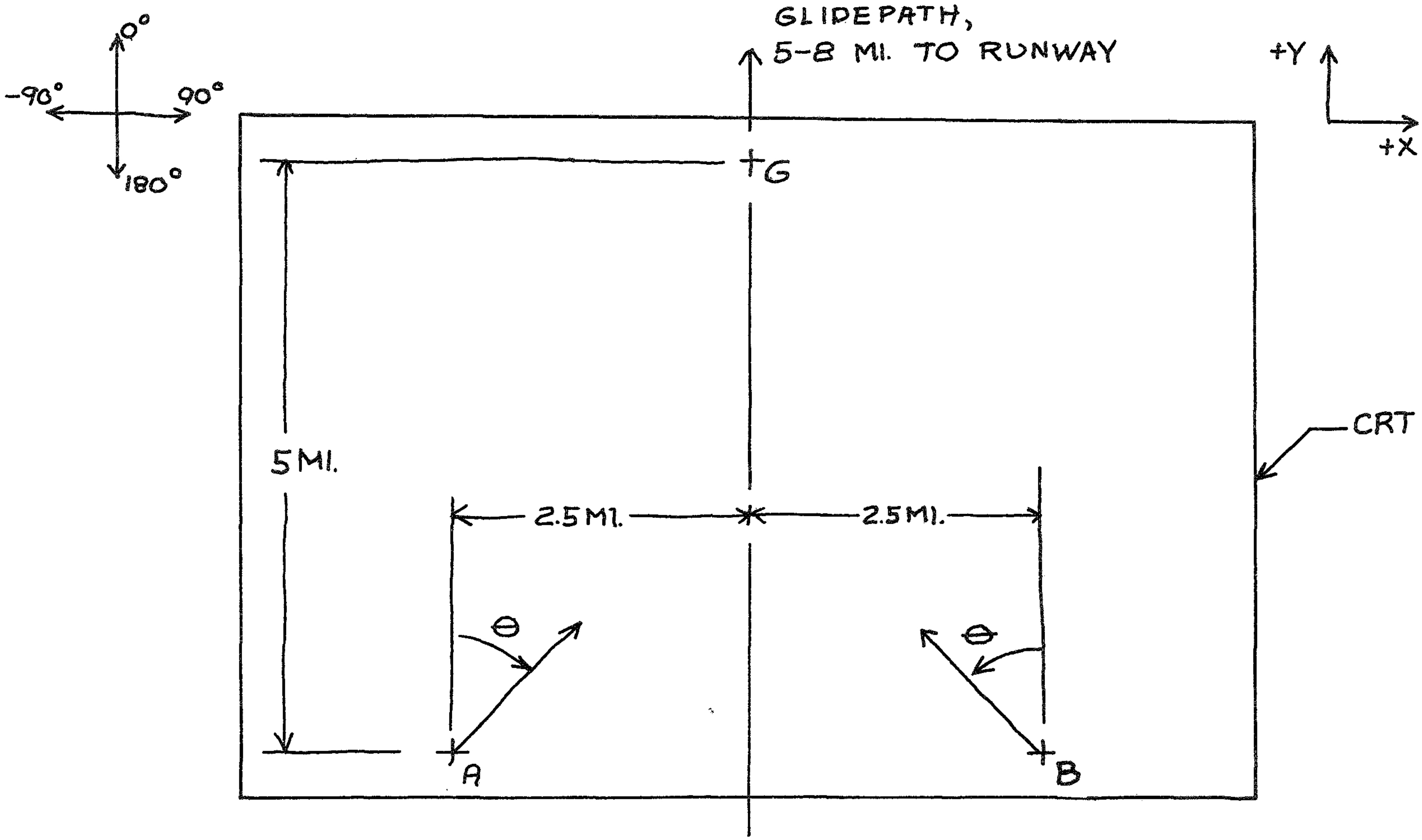
One of the main purposes of this work is to determine how well a human operator can perform under the restrictions that the ATC system imposes and if a computer aid such as a predictor system can improve the operator's performance.

IV. EXPERIMENTS

The experiments upon which this thesis is based were designed with two goals in mind. First, concern was focused on ATC problems and predictor displays as a possible solution. With respect to this goal, the effect of predictor displays on system performance and the feasibility of such aids were the main considerations. The second and more general goal concerned the question of how the operator uses this computer aid to help make his decisions. In other words, if the operator performs better (worse) with a predictor display, what causes the improvement (degradation)? Answers to this question may allow results obtained from a specific example (ATC) to be generalized to predict the outcome of applying such displays to other complex problems such as high speed merging of automobiles.

A. Experiment I

The first experiment performed consisted of guiding a single A/C through the vicinity of the regulated "funnel" to the gate of the glidepath. Beginning with only one A/C served two purposes. It enabled the five subjects to develop some proficiency with a simplified ATC task. Also, this initial experiment allowed study of the basic ATC task unencumbered by inter-aircraft constraints such as separation standards. Inter-aircraft constraints were studied via an experiment that will later be discussed. Figure 5 illustrates the display arrangement used for this first experiment. The single A/C being considered could have initial states A or B with initial headings of 45°, 90°, -90°, or -45° as based on the coordinate system shown in the figure. The initial velocity was always 180 mph. The subject's task was to guide the A/C to point G (the gate) subject to the constraints



DISPLAY FOR EXPERIMENT I

FIGURE 5.

that the A/C should cross G at 180 mph with a bearing of 0. degrees. If the velocity was below 150 mph or above 210 mph, the A/C was not permitted to continue its approach. It was assumed that once the A/C crossed G, it was guided the remainder of the distance to the runway by an ILS system.

The subject accomplished this task by giving bearing and speed commands to the pilot. The experimenter acted as the pilot in an A/C with a quasi-autopilot system. The pilot used commands given to him by the controller to set two dials for thrust and bearing respectively, which controlled the A/C. These inputs then operated upon the dynamics of the A/C and the commands were achieved. This type of system minimized the use of any strategy on the pilot's part. The reason for including a human operator as a pilot was based on the necessity of the controller being able to use voice commands as he would in any actual ATC system.

The predictor system displayed an X-Y trajectory on the screen. The Z coordinate (altitude) was not considered. For this experiment, predicted trajectories of 0.0, 20.0, and 40.0 seconds were used. A trajectory of length 0.0 seconds simply refers to a conventional system with no predictor. During each run of the experiment, the subject was told the length of predictor that he would use. In other words, he could not choose among them.

The time prediction gave information to the controller in two ways. The shape of the prediction indicated the path of the A/C to a future position. The contours of this path displayed the angular velocity of the A/C. The length of the path was relative to the speed of the A/C. Besides the information obtained from the shape and length of the prediction, the operatior also received feedback from the pilot as the commands were executed. This feedback consisted of acknowledgement of the command and verification when the maneuvers were completed, The pilot also answered any specific inquiries by the controller.

For this experiment as well as the next, measures of performance were developed that reflect the relative importance of various aspects of the situation under investigation. Thus, while task completion time was measured, the errors in arriving at the gate were also important. The performance index that the subject was to minimize for this experiment was

$$PI = t + |X_f| + |\dot{X}_f| + \frac{X_f \dot{X}_f}{X_f + \dot{X}_f} , \qquad (4\text{-}1)$$

where

t = task completion time

X_f = error at the gate

$\dot{X}_f$ = error rate at the gate

The error rate is a measure of the angle at which the A/C crosses the gate. Actually, the angle is,

$$\Theta_f = 1 - \tan^{-1} \frac{\dot{Y}_f}{\dot{X}_f} , \qquad (4\text{-}2)$$

but since $\dot{Y}_f$ was constrained to be in the neighborhood of 180 mph, $\dot{X}_f$ was a reasonable measure. The fourth term of the index is sensitive to the derivative of the error. If error is decreasing then the term subtracts from the score. This occured whenever X_f and $\dot{X}_f$ were of opposite signs which indicated that the A/C was heading towards the gate.

The units used for t were hundredths of minutes. X_f and $\dot{X}_f$ were measured in arbitrary error units on a linear scale of -100 to 100, where 100 equals 3.75 miles and 60°, respectively.

Scores were compiled on data sheets as shown in Figure 6. The t, X_f, and $\dot{X}_f$ numerics were given to the subject at the end of each run and

SUBJECT: ____________ DATE: ____________

1	2	3	4	5	6	7	8	9	10
POS.	θ_i	$PRED_L$	X_f	$\dot{X}_f$	$X_f\dot{X}_f$	t	|4| + |5|	6/8	PI=7+8+9
A	45	0.							
		20.							
		40.							
	90	40.							
		20.							
		0.							
B	-90	0.							
		20.							
		40.							
	-45	40.							
		20.							
		0.							
A	90	0.							
		20.							
		40.							
	45	40.							
		20.							
		0.							
B	-45	0.							
		20.							
		40.							
	-90	40.							
		20.							
		0.							

DATA SHEET FOR EXPERIMENT I (3/4 SIZE)

FIGURE 6.

he then calculated his own PI. In this way the subject was able to see the components of his score immediately after each run.

For this experiment, five subjects were used: three male undergraduates, one male graduate student, and one female secretary. Each worked four evenings and performed the task a total of 96 times. Each subject was allowed as many practice runs as he desired during the first evening. For the remainder of the sessions, only one practice run was permitted before the beginning of scored runs. They were paid $2.25 per evening. Thus, their hourly wage depended on how fast they could complete the evening's work. As an incentive, a $5.00 bonus was given to the subject with the lowest average score and the subjects were told that only the best subjects from the first experiment would be retained for the more lucrative second experiment.

The experimental set-up for this experiment was kept very simple. The subject did not sit in a darkened booth. Both he and the experimenter sat near each other in an open room and commands were simply voiced without the aid of any audio equipment. The above atmosphere was consonant with the purpose of this experiment.

The results of this experiment as well as illustrations of the simulation equipment used will be discussed in later chapters.

B. Experiment II

The second experiment was designed to investigate the interaction of A/C in the terminal area. The controller's task was to merge 3 A/C into a given sequence so that they traversed the funnel to the gate in a minimum time subject to the same speed and bearing constraints as used during experiment one and such that no A/C was ever within 3 miles of another A/C. Figure 7 illustrates the experimental display. A/C_1 always had an initial heading of 0°. A/C_2 had either a 45° or 90° initial heading. A/C_3 had either a -45° or -90° initial heading. The initial velocity for all A/C was always 180 mph. These initial conditions yield 4 combinations of initial states for the system.

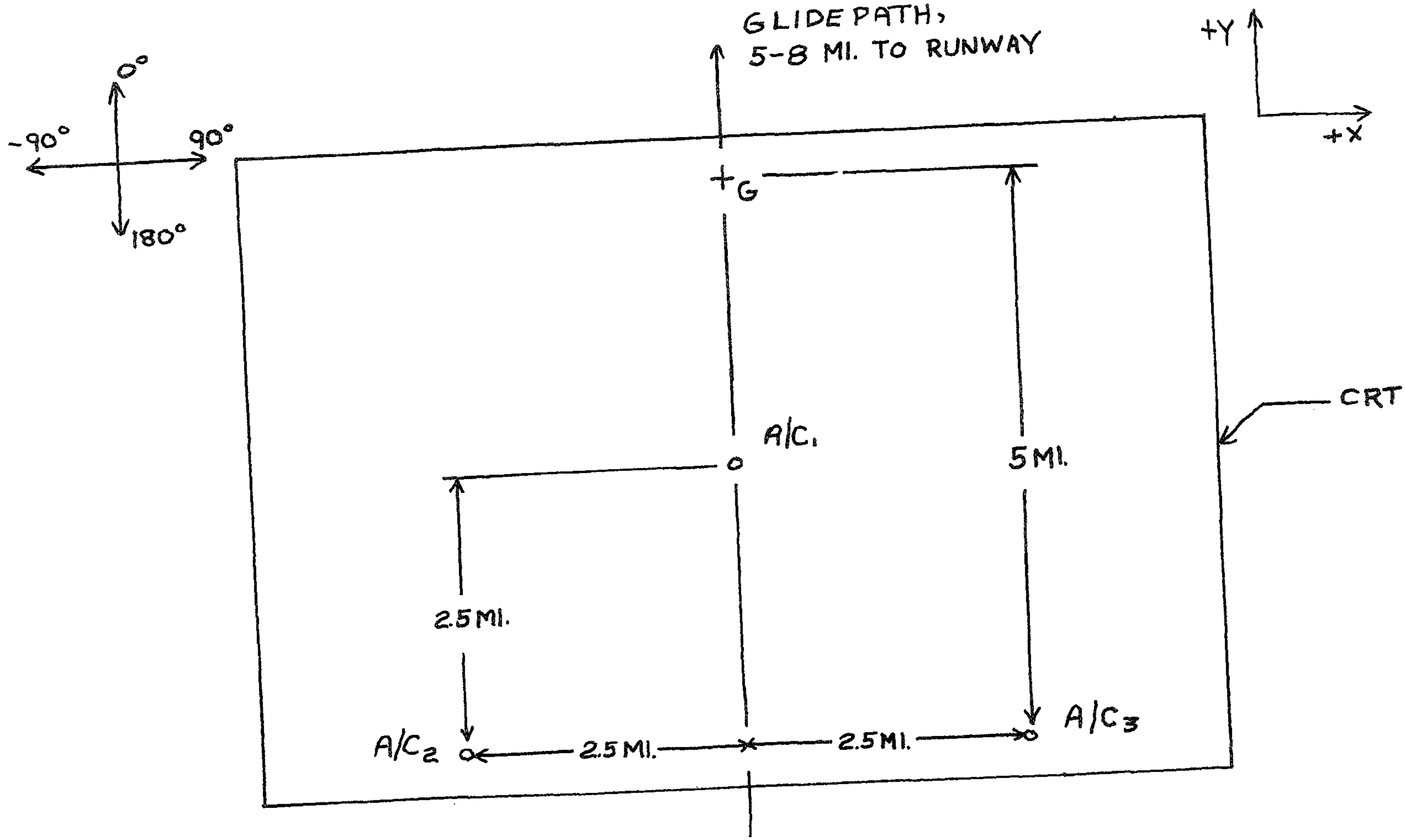
The subject was told to guide the A/C in such a way as they would cross the gate in the sequence A/C_1, A/C_2, A/C_3. The initial state had an effect on the difficulty of the task; especially the mandatory landing of A/C_2 before A/C_3. As will be seen later, it often would have been easier to land A/C_3 before A/C_2. However, task difficulty does not always dictate the priorities given to the landing of A/C.

The task could be accomplished with predictor trajectories of length 0. or 20. seconds. Combining the 2 possible predictor lengths (0.0 sec. and 20. sec) with the 4 possible initial states yields 8 variations of the experiment. Four different sequences of these variations were used as experimental treatments. They appear in Table I. The subjects performed 2 sequences per session.

The subject could give only speed commands to A/C_1, while he could give speed and bearing commands to A/C_2 and A/C_3. As during the first experiment, the A/C were piloted by the experimenter.

The performance index used for this experiment was

$$PI = t + |x_f|_2 + |\dot{x}_f|_2 + \frac{x_{f2}\,\dot{x}_{f2}}{|x_f|_2 + |\dot{x}_f|_2} + |x_f|_3 + |\dot{x}_f|_3 + \frac{x_{f3}\,\dot{x}_{f3}}{|x_f|_3 + |\dot{x}_f|_3} + .015\int_0^t \sum_{i,j} f\,(d_{ij})\,dt \tag{4-3}$$



DISPLAY FOR EXPERIMENT II

FIGURE 7.

SEQUENCE 1			SEQUENCE 2			SEQUENCE 3			SEQUENCE 4		
L	A/C_2	A/C_3	L	A/C_2	A/C_3	L	A/C_2	A/C_3	L	A/C_2	A/C_3
0.	90	-90	20.	45	-90	0.	45	-45	20.	90	-45
20.	90	-90	0.	45	-90	20.	45	-45	0.	90	-45
20.	45	-90	0.	45	-45	20.	90	-45	0.	90	-90
0.	45	-90	20.	45	-45	0.	90	-45	20.	90	-90
0.	90	-45	20.	90	-90	0.	45	-90	20.	45	-45
20.	90	-45	0.	90	-90	20.	45	-90	0.	45	-45
20.	45	-45	0.	90	-45	20.	90	-90	0.	45	-90
0.	45	-45	20.	90	-45	0.	90	-90	20.	45	-90

EXPERIMENTAL SEQUENCES

TABLE I

where,

$$f(d_{ij}) = \begin{cases} 3 - d_{ij} & d_{ij} \angle 3 \text{ miles} \\ 0 & \text{otherwise} \end{cases} \qquad (4\text{-}4)$$

and,

d_{ij} = the distance between the i^{th} and j^{th} A/C.

The use of the first 7 terms of the index was explained with the first experiment. The final state of A/C_1 was not included because it would have always been zero since bearing commands could not be given to this A/C. The last term of the index, henceforth called the integral term, penalized the subject whenever any A/C were closer than 3 miles. The .015 was used to scale this term to a reasonable proportion with the other terms. This scale was such that d_{ij}'s of much less than 3 miles penalized the subject to a great extent (because $f(d_{ij})$ was large and t was long), and d_{ij}'s slightly less than 3 miles only penalized the subject a small amount. The generation of this numeric will be discussed in the next chapter.

This index allowed the subject several trade-offs. If the A/C are brought in very close trgether, then t is small but $f(d_{ij})$ is high. If the A/C are spaced far apart for the approach, t is large and $f(d_{ij})$ = 0. Thus, the subject's task was to develop a strategy that compromised among all of the factors and gave him a low score.

An additional constraint was added to the above PI besides the speed constraints previously discussed. If any A/C crossed the gate with $|X_f| \geq 20$, the run was started over. The reasoning for this addition will be explained in a later chapter as it is contingent on some early results.

Three A/C were used for this experiment because that was the minimum number that retained all of the basic characteristics of the ATC task.

This task essentially amounts to the problem of keeping A/C_2 3 miles behind A/C_1 and 3 miles in front of A/C_3 and performing the whole operation in a minimum of time. More A/C would have certainly complicated the subject's task but they would not have added any new facets of the ATC problem to study.

Scores were compiled on data sheets as shown in Figure 8. The variables of the index were given to the subject and he performed the manipulations to obtain PI. Since this data sheet was fairly complicated, a template was made that was placed over the sheet and allowed much quicker calculation of the scores.

Three subjects were used for this experiment: two male undergraduates and one male graduate student. They each worked 10 evenings and performed 2 sequences each evening. Each subject was allowed as many practice runs as he desired during the first evening. For the remainder of the sessions, only one practice was permitted before the beginning of scored runs. Their pay for each evening equaled $6.00 minus their average score for the evening. Thus, their hourly wage was determined by how well they did and how fast they worked. As an additional incentive, a $10.00 bonus was given to the subject who most improved his performance over the first experiment.

The experimental atmosphere during this experiment was more formal than that of the first experiment. The subject sat in a darkened booth with the screen. He relayed his commands to the pilots with a microphone.

The results of this experiment as well as the other will be presented and discussed in a later chapter. The design of the simulation equipment will be presented in the next chapter.

SUBJECT: ______				SEQUENCE: ______									DATE: ______		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$PRED_L$	A/C_2	A/C_3	X_2	$\dot{X}_2$	$X_2\dot{X}_2$	$\|4\| + \|5\|$	6/7	X_3	$\dot{X}_3$	$X_3\dot{X}_3$	$\|9\| + \|10\|$	11/12	t	$\int_0^t d_{ij}$	PI=7+8+12+13+14+15

DATA SHEET FOR EXPERIMENT II (3/4 SIZE)

FIGURE 8.

V. EQUIPMENT DESIGN

Equipment was needed to perform three functions for this research. A/C had to be simulated and controlled. Trajectory predictions had to be computed and displayed. Also, the integral term of equ. 4-3 had to be generated.

A. Modeling A/C

To generate A/C, a simple second-order model was chosen Each direction (x and y) was generated separately and the governing equations were,

$$M\ddot{x} + (F_D)_x = (F_T)_x$$
$$M\ddot{y} + (F_D)_y = (F_T)_y \qquad (5\text{-}1)$$

where F_T = thrust

F_D = drag

M = mass.

Effects of wind were neglected and as can be seen from 5-1, the various control surfaces of an A/C were not considered. The model is a simple second-order, point-mass, viscously damped system.

To determine the parameters for equation 5-1, a Boeing 707 aircraft was assumed. From Taylor[15], the following characteristics were obtained:

w = weight = 247,000 lbf

F_T thrust = maximum of 18,000 lbf per engine (4 engines)

V_S = stall speed ≈ 121 mph

S = wing area ≈ 3,650 ft^2

$$M = \text{mass} = 7{,}680 \ \frac{\text{lbf sec}^2}{\text{ft.}}$$

$$0 \leq F_T(t) \leq 72{,}000 \text{ lbf} \qquad (5\text{-}2)$$

The drag was assumed to be linear. A least squares fit of a linear model was used. Using the drag-speed curves as they appear in Fischel (16) and assuming a recommended approach of 1.5 V_S (16), then for $\frac{W}{S} = 67.8$, the following linear model was determined,

$$F_D = 131 \ V \qquad (5\text{-}3)$$

where

V = velocity in the direction of interest.

The reason for using a least squares fit of Fischel's data is not obvious. A Taylor series linearization would be more accurate if an operating point could be defined. However, generating each dimension of the A/C separately does not allow the definition of an operating point. Since $\dot{X}$ and $\dot{Y}$ can range from 0. - 240. mph as a turn is being executed, any drag model that is used must allow for $(F_D)_x = 0$ when $\dot{X} = 0$ and similarly for the y direction. Dynamic drag curves are not defined below the stall speed and therefore an operating point below 121 mph could not be considered. If a point above 121 mph was used, then when one direction of the A/C was operating below 121 mph, it would move backwards. Thus, the least squares technique was used.

The remainder of the development of 5-1 will consider only the X direction since the Y direction equation will be exactly the same. Combining the above parameters with 5-1,

$$7680\ddot{X} + 131\dot{X} = F_x(t), \qquad (5\text{-}4)$$

where $\dot{X}$ was assumed to be the indicated airspeed of the A/C. This assumed that while Fischel used "calibrated" airspeed for his drag curves, that the use of indicated airspeed would at most be a translating factor and would not greatly effect the slope characteristics of the drag curves.

To scale 5-4 for simulation, redefine $F_x(t)$ so that,

$$0 \leq F_x(t) \leq 1.0. \quad (5\text{-}5)$$

This changes 5-4 to

$$7680 \ddot{X} + 131 \dot{X} = 72{,}000 F_x(t) \quad (5\text{-}6)$$

Dividing,

$$\ddot{X} + .0171 \dot{X} = 9.38 F_x(t). \quad (5\text{-}7)$$

Assuming,

$$\dot{X}_{max} = 220 \text{ mph} = 320 \frac{ft}{sec}$$

$$X_{max} = \pm 2.5 \text{ miles} = 13{,}200 \text{ ft.}$$

and using scale factors,

a_v = velocity scale factor = 320

a_p = position scale factor = 13,200

equation 5-7 becomes,

$$\ddot{X} + 5.46 \dot{X} = 9.38 F_x(t) \quad (5\text{-}8)$$

Equation 5-8 is scaled for simulation without amplifier saturation but the time constant of the system has been lowered considerably. Multiplying the two constants in 5-8 by 1/320 returns the time constant to the correct value without changing the scaling. Therefore,

$$\ddot{X} + .0171 \dot{X} = .0293 F_x(t) \quad (5\text{-}9)$$

The thrust for each direction of A/C operation, $F_x(t)$ and $F_y(t)$ (or $(F_D)_x$ and $(F_D)_y$ respectively), follow the equation,

$$F = (Fx^2(t) + Fy^2(t))^{1/2} \quad (5\text{-}10)$$

where

F= the magnitude of the total A/C thrust.

Thus, the directions of A/C motion are linked by the interaction of their individual thrust components. The control of each A/C was accomplished with a combination of a linear potentiometer and a sine/cosine potentiometer The linear potentiometer controlled the magnitude of the thrust. The sine/cosinge potentiometer controlled the angle of the thrust and therefore the bearing of the A/C. For example, if the linear potentiometer was set at .50 and the sine/cosine potentiometer was set at 60° (see coordinate system used on Figures 5 and 7), then $Fx(t) = .50 \cos 30°$ and $Fy(t) = .50 \sin 30°$ which satisfies 5-10.

To aid the pilot in flying the A/C , an airspeed indicator was used that read airspeed according to

$$V = (\dot{X}^2 + \dot{Y}^2)^{1/2} \tag{5-11}$$

where

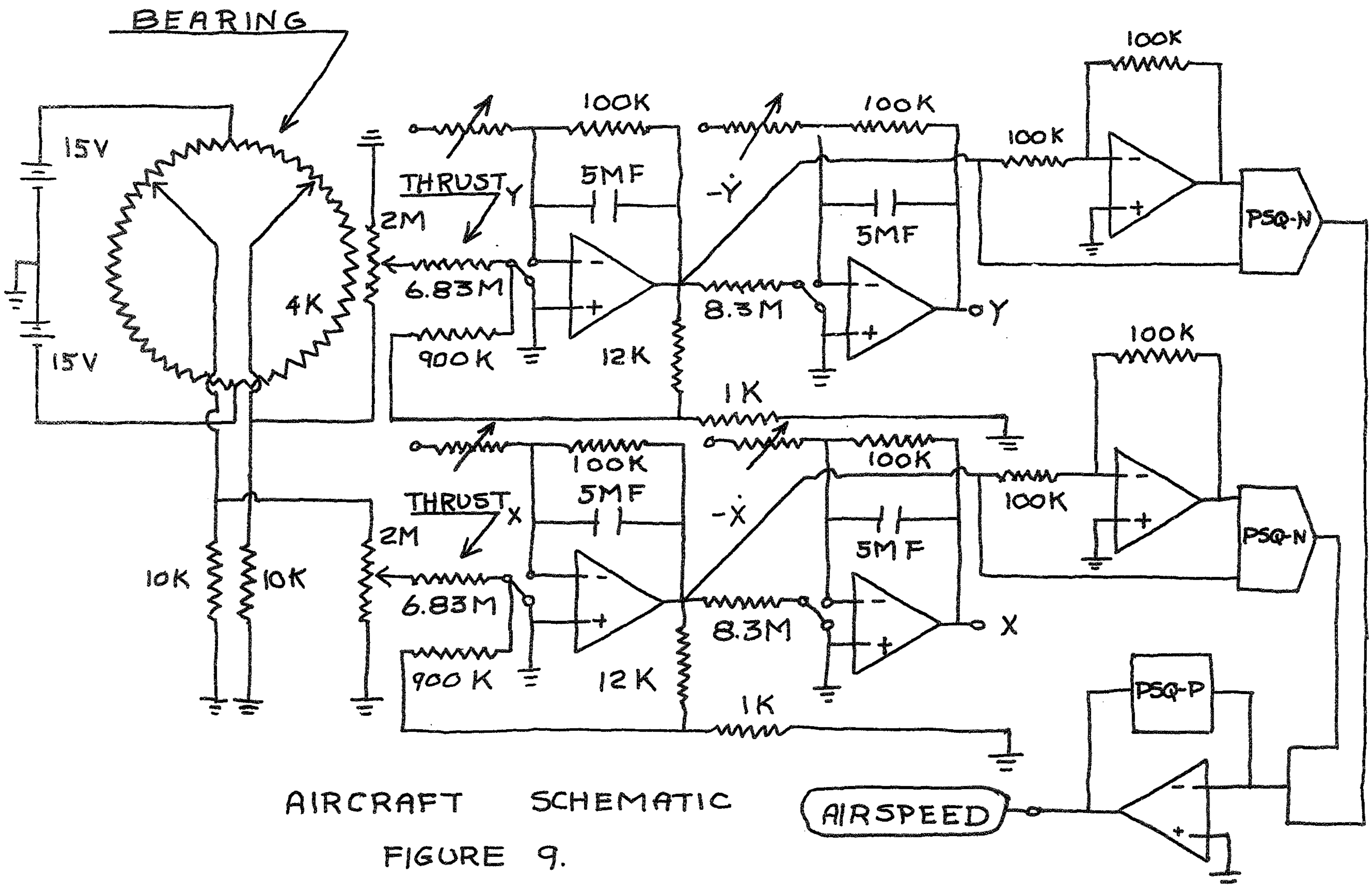
V = airspeed.

A complete schematic of an aircraft appears in Figure 9. Further discussion of some aspects of this circuitry can be found in the Philbrick manual[17].

An analog computer was constructed which contained three of the A/C described by Figure 9. Each of these could be operated independently. This constituted the A/C generation portion of the ATC simulation. Illustrations of this equipment will appear at the end of this chapter.

B. Prediction and Display

Prediction and display of A/C were accomplished with an EAI 680 analog computer. Three fast time A/C models were programmed on the 680. Each of the three were used to predict future trajectories of one of



AIRCRAFT SCHEMATIC

FIGURE 9.

of the real time A/C. As explained in chapter II, the present state of the real A/C was used as initial conditions upon which the fast time A/C based its predictions. The A/C generator and the 680 where connected by a shielded cable.

It is important to note that only one fast time A/C is needed if sufficient multiplexing capability is available to allow rapid switching of initial conditions of this single model. The need for only one fast time A/C is important if the prediction concept is to be feasible in a terminal area where there are many A/C.

Use of a ring shift register on the 680 allowed sequential display of the A/C on the 680. The shift register simply sequenced repetitively through the outputs of each A/C (a position) very rapidly.

The prediction and display program for the 680 appears in Figure 10. The potentiometer settings for inputs and feedback of the A/C were the same as those for the real time A/C since the 680 has an independent time scale control.

The difference between Figures 1 and 10 should be noted. The predictor of Figure 1 assumes that the operator returns his control to the equilibrium point (the exponential portion of the diagram). As previously discussed, there is no equilibrium point for the A/C system. Thus, this portion of a conventional predicter system was eliminated.

C. Measuring Performance

The generation of the integral term of 4-3 was accomplished on the 680. A combination of comparators and gates were used such that the two ranges of 4-4 were determined and $f(d_{ij})$ calculated and integrated. The program to accomplish this appears in Figure 11.

PREDICTION AND DISPLAY PROGRAM

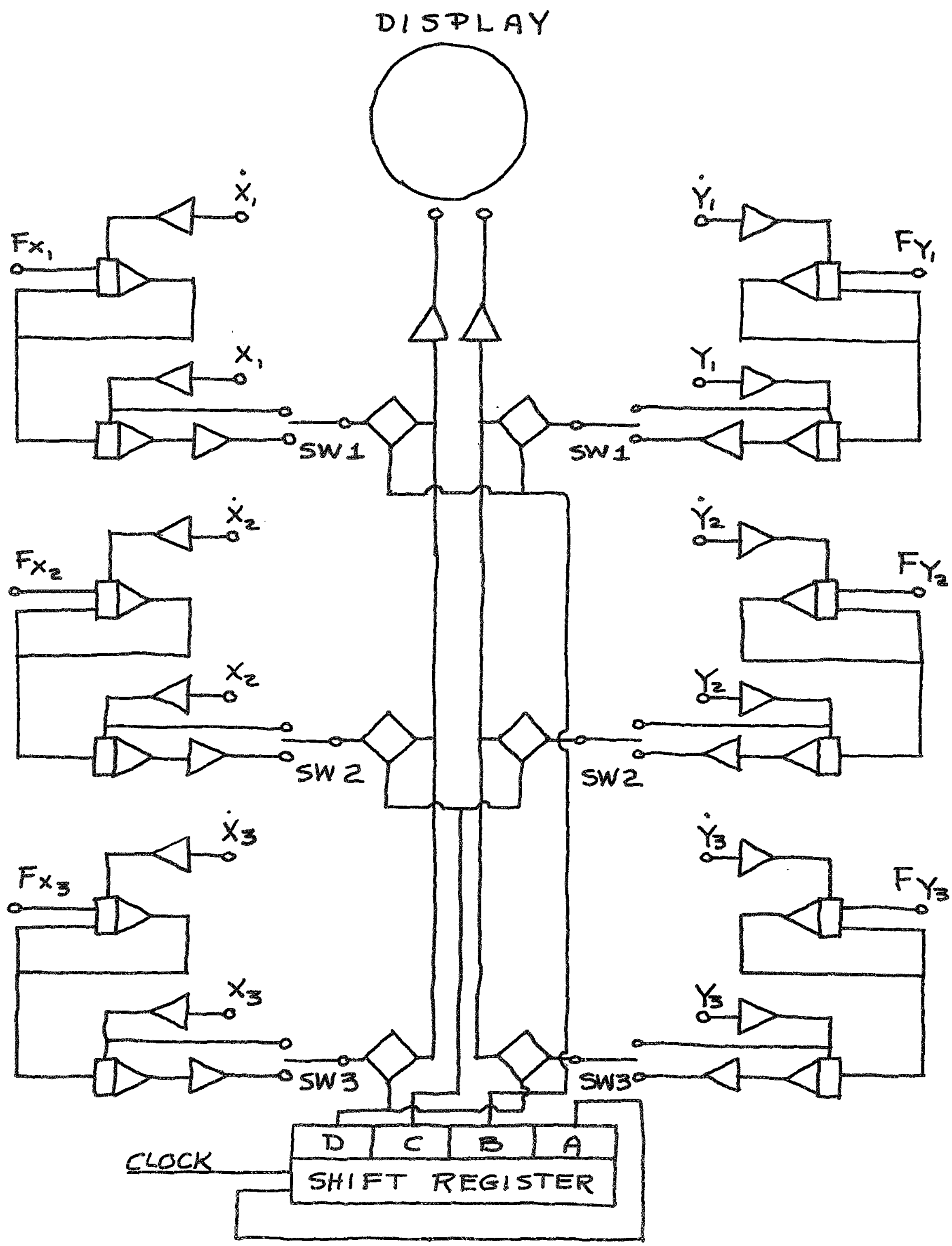
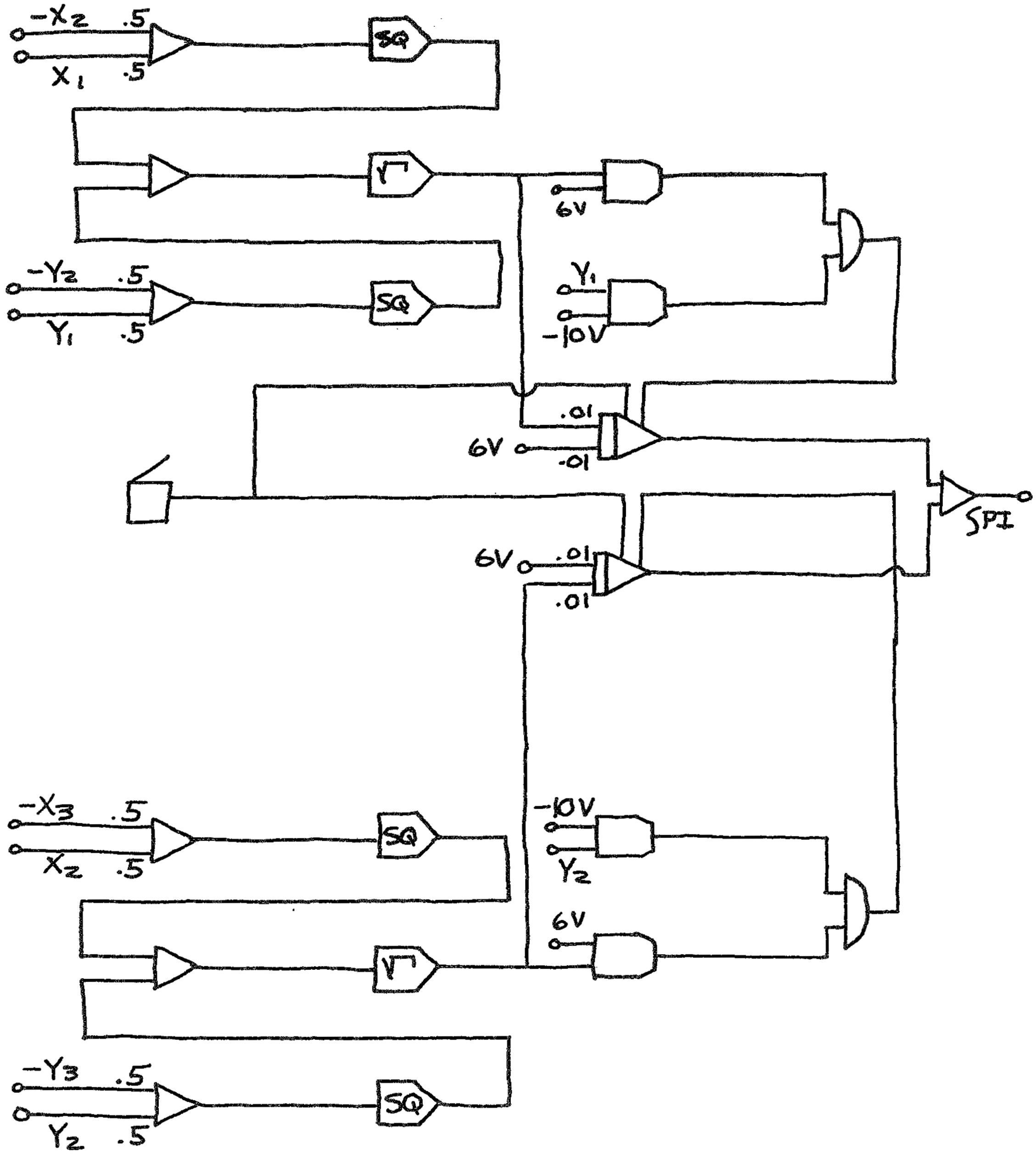


FIGURE 10.



PERFORMANCE CRITERIA PROGRAM

FIGURE 11.

D. Apparatus Configuration

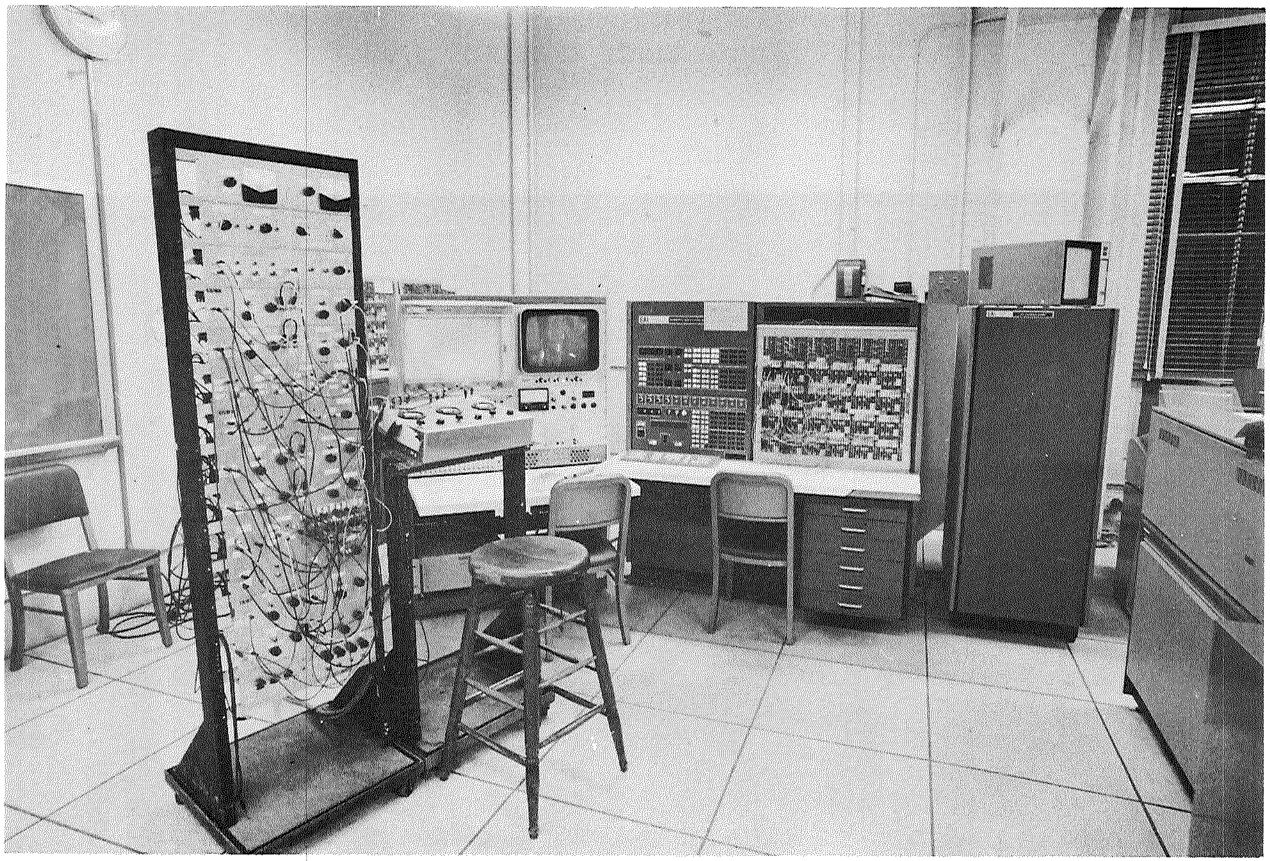
The following photographs illustrate the system and the resulting displays. Figure 12 pictures the entire simulation system. The equipment rack on the left is the A/C generator with the A/C controls to its right. The EAI 680 and the display can be seen in the background. During the second experiment the display portion of the system was surrounded by a darkened booth and the subject communicated with the pilot by a microphone.

Figure 13 is a close-up of the A/C control panel. Each A/C had independent thrust and bearing control. The thrust knob controlled the magnitude of the thrust and the bearing knob apportioned it to each A/C dimension. It is important to note that the bearing knob did not indicate the present heading of the A/C, but that bearing to which the A/C was proceeding. The pilot had no feedback concerning his present heading other than that supplied by the controller.

Figure 14 illustrates how the use of the predictor was controlled. The box was connected to the 680 with a shielded cable. The subject operated the box, but the settings were dictated by the experimenter. The length of the predictions were set on the 680.

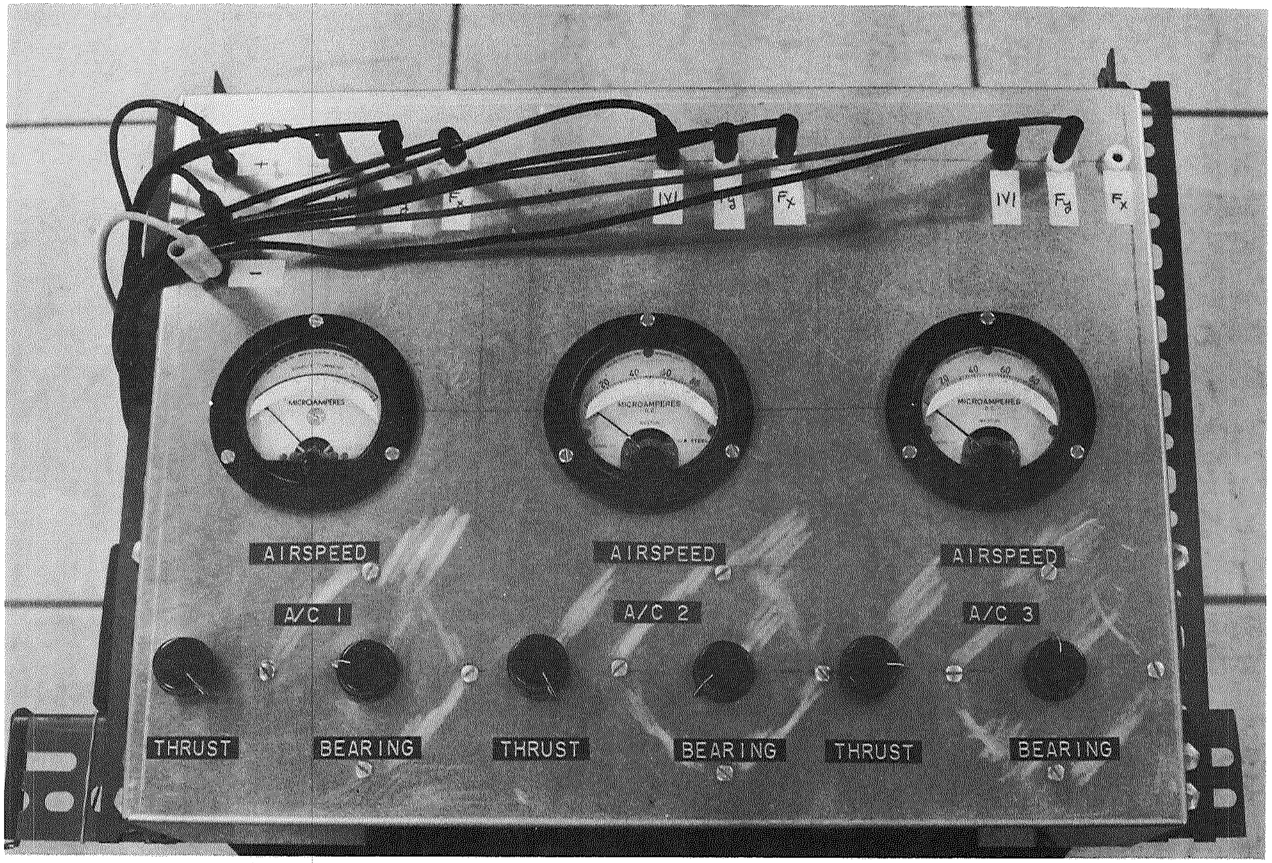
Figures 15, 16, and 17 are typical displays of length 0., 20, and 40 seconds respectively. The position of the real A/C is at the bottom of the prediction. The trajectories indicated what would happen to the A/C during the next 0., 20, or 40 seconds if its control was unchanged.

It now remains to discuss how the subjects performed with the equipment during the experiments.



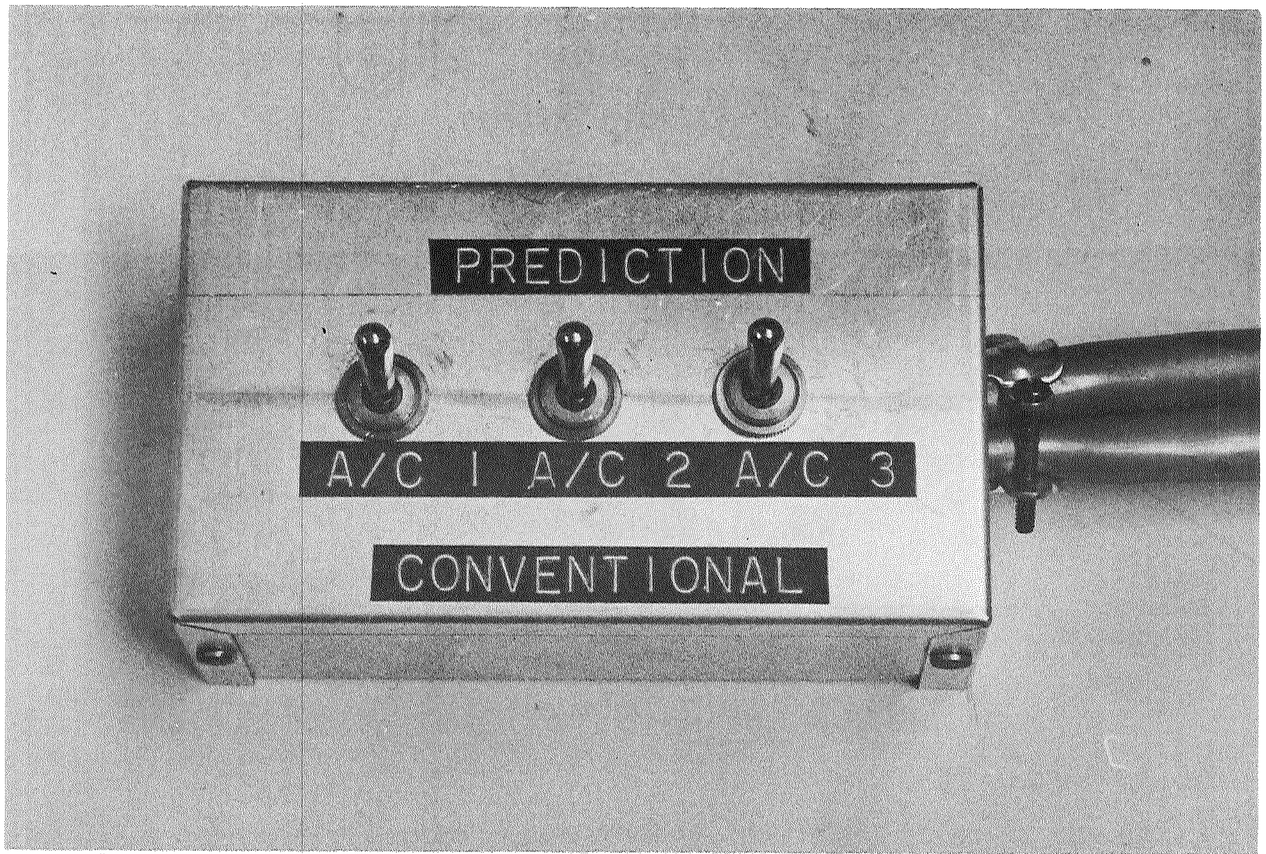
ATC SIMULATION

FIGURE 12.



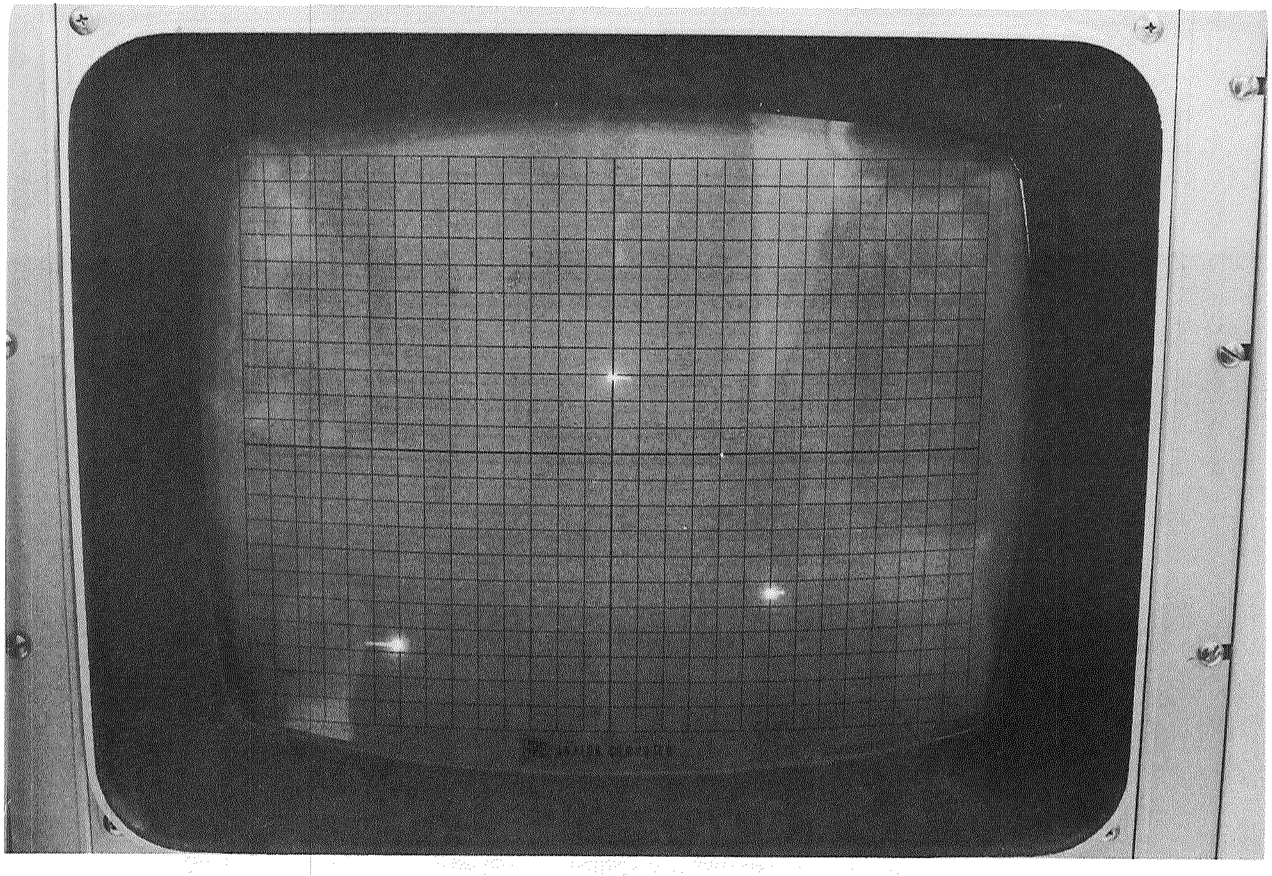
A/C CONTROL PANEL

FIGURE 13.



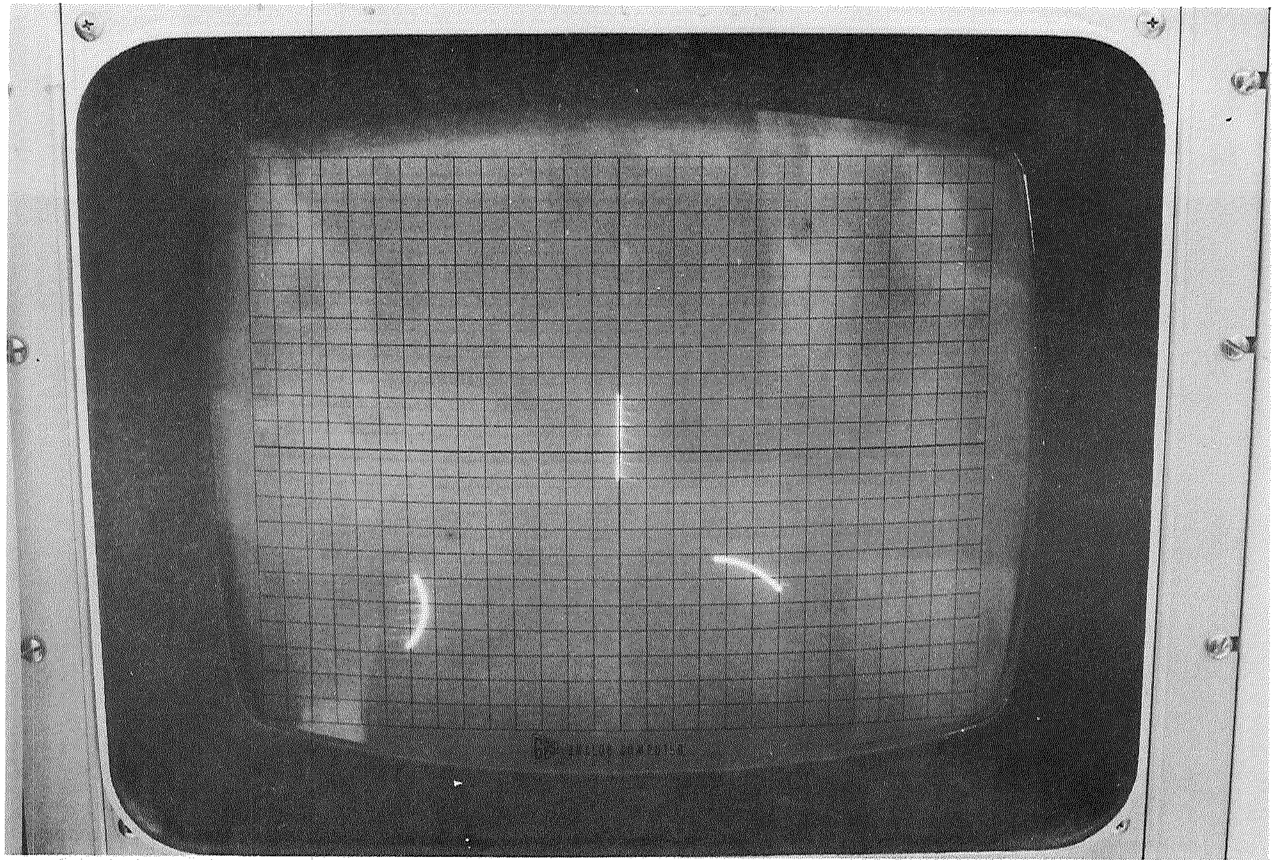
PREDICTION CONTROL

FIGURE 14.



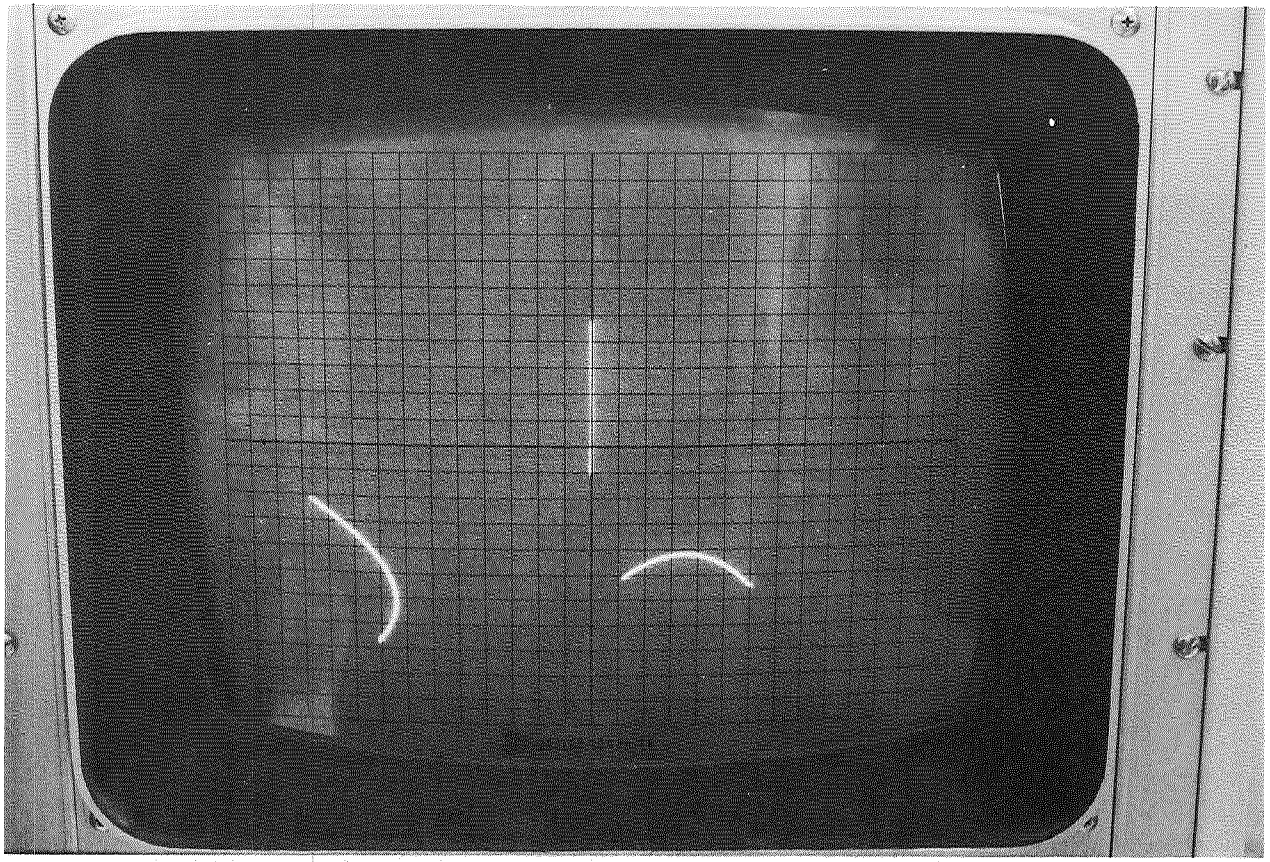
DISPLAY WITH L=0.0

FIGURE 15.



DISPLAY WITH L=20.0

FIGURE 16.



DISPLAY WITH L=40.0

FIGURE 17.

VI. RESULTS

This chapter presents the results of the analyses performed with the data gathered during the experiments. Discussion of these results and conclusions will follow in the next chapter.

A goal of these analyses was to determine whether a predictor display produces significantly better performance than a conventional display does. A more general goal was that of determining why a predictor display might be different from a conventional display.

With these goals in mind, data was collected by component scores and not as a single score. As discussed in Chapter IV, the subjects calculated their own total score from the components using equations 4-1 and 4-3 during experiments I and II respectively. While this enabled subjects to know how each component of the task affected his final score, it also allowed separate analyses to be performed on each of these components. This allowed a determination of the portions of the task which the predictor system was effecting. Task components studied included aircraft position error, position error rate, task completion time, and separation error.

Experiments I and II used two and four different initial conditions respectively. Thus, six different tasks were investigated. The differences between these tasks will later be discussed and they will be ranked in order of difficulty.

The procedure used for this analysis was analysis of variance. This type of analysis was designed to study experiments where several variables can influence the outcome. The total procedure will not be discussed here as several texts provide good presentations of this material[18, 19].

The hypothesis used is that two (or more) samples come from the same normally distributed population. By analyzing the components of variance of the data, we accept or reject this hypothesis. The components of variability for these experiments were:

1. Between displays
2. Between subjects
3. Interaction between displays and subjects
4. Within the groups of displays and subjects.

The hypothesis is tested using variance ratios (F-ratios) of the various components of variability as explained in the references. If the F-ratio is large[21], the hypothesis is rejected and it is assumed that the samples came from different normal populations. The magnitude of the F-ratio necessary for rejection depends on the risk of making a wrong decision that the analyst is willing to accept. One minus the probability of error is termed the significance level. Typical significance levels are .70, .90, and .95.

For this analysis, the rejection of the hypothesis meant that the performance with the various display systems was significantly different from what would occur by chance if the two displays were identical. If it was determined that one display was better than another, the difference between the arithmetic means of the scores with each display was used as a measure of this difference.

A basic assumption necessary to use the analysis of variance is that the data is normally distributed. However, data collected during these experiments included the learning process through which the subjects went. In fact. the nature of the ATC task was complicated to the point that the subjects' scores never reached an asymptote. Thus, the luxury of throwing away all data taken before the task was completely learned could not be afforded. This problem was solved by fitting an exponential learning curve to the data and then subtracting it from the data. This served two purposes. It removed the learning bias from what could then be assumed normally distributed data. Also, this process allowed a study of the learning process with each type of display.

A least-squares fit of an exponential curve was used. The exponential had three parameters,

$$y = A_1 + A_2 e^{A_3 T_i} , \qquad (6\text{-}1)$$

where,

A_1, A_2, A_3 = the parameters

T_i = the number of the consecutive trial

y_i = the data

A combination of two techniques was used to perform the curve fitting. Both were based on minimizing the least-square error given by

$$\text{RMS} = [(f(T_i) - y_i)^2]^{1/2} \qquad (6\text{-}2)$$

The first technique used produced a least-squares approximation [20] in closed form. The second technique produced an exact least-squares fit in an iterative manner[22]. This second technique required a first (non-zero) estimate of the parameters. The first approximate technique was used to produce these estimates. As with many iterative numerical techniques, convergence of the result is not guaranteed. This occurred during several of the sixty curve fits that were performed. When this occurred, the parameters produced by the approximate technique were used.

Such instances are indicated in the results. Several sample plots of data and the curves fit to this data appear in the Appendix.

The analyses that were performed with experiment I data included three comparisons of displays with different prediction lengths (L) for each initial condition:

1. L = 0. and L = 20.
2. L = 0. and L = 40.
3. L = 20. and L = 40.

For each of these analyses, a curve was fit to the combined data for both prediction lengths and then subtracted from the data. If the data for each prediction length was fitted and subtracted separately, the differences in the various displays would not have been preserved and the results of the analysis of variance would have been erroneous. Curves were fit to the data for each prediction length individually to use in studying the learning process, but these curves were not used with the analysis of variance.

Only two prediction lengths were used for experiment II. Thus, only one analysis was done for each initial condition. As with experiment I, the learning curves that were subtracted were those fit to the combined data for both prediction lengths.

Learning curves were fit to all of the components of the data except A/C position error and error rate. The scale upon which this data was taken prevented any such fitting. These two components could have values from -100. to 100., but the negative signs were only used to indicate direction and the performance indexes used the absolute value of the data. Error scores were reasonably normally distributed about the origin (0.0) if the signs were retained and therefore the actual data (with signs) were used for the analysis of variance. Because of the dual roles of this error data, it was not appropriate to fit learning curves to this data. Fortunately, as previously mentioned, the error data could be assumed to be normally distributed about the origin.

Two computer programs were written to perform the above analyses. These were based on the references cited with the above discussion. The first program, LCURV, performed the least-squares fitting of the data. The second program, ANVAR, performed the analysis of variance. Listings of these programs appear in the Appendix. A complete listing of all experimental data also appears in the Appendix.

The results for the two experiments appear in Tables II - VIII. Conclusions will be drawn from these results in the following chapter.

Initial Condition	L	A_1	A_2	A_3	RMS	MEAN
	0	132.96	35.57	-.436	2.28	137.02
	20*	-37.75	177.48	-.005	3.55	133.50
45	40*	11.09	135.89	-.011	3.75	136.81
	0,20	130.96	24.82	-.306	2.08	----
	0,40*	24.65	121.74	-.011	3.35	----
	20,40*	-9.30	152.64	-.007	3.19	----
	0*	-53.87	217.50	-.006	5.46	153.38
	20*	16.17	140.46	-.009	2.55	147.95
90	40	143.22	36.65	-.196	2.59	153.32
	0,20	139.24	26.38	-.114	3.00	----
	0,40*	-24.20	189.31	-.009	4.37	----
	20,40	141.03	29.55	-.164	1.95	----

*Approximate Fit

EXPERIMENT I

LEARNING PARAMETERS A_1, A_2, AND A_3, RMS FITTING ERROR, AND MEAN OF PERFORMANCE INDEX (PI)

(DATA FOR 16 TRIALS X 5 SUBJECTS PER INITIAL CONDITION)

TABLE II

Initial Condition	L	A_1	A_2	A_3	RMS	MEAN
45	0	126.10	19.71	-.353	1.45	129.00
	20*	-26.03	157.40	-.003	2.55	128.10
	40*	34.48	101.35	-.008	2.70	130.06
	0,20*	14.34	118.63	-.005	2.31	---
	0,40	126.57	20.49	-.359	.94	---
	20,40	126.46	16.19	-.326	1.21	---
90	0*	-2.43	155.46	-.007	3.72	145.60
	20	125.05	26.79	-.040	1.62	144.51
	40	143.57	31.94	-.301	2.16	149.21
	0,20	134.94	19.82	-.089	2.15	---
	0,40*	10.54	145.53	-.008	3.45	---
	20,40	141.32	21.99	-.215	1.57	---

*Approximate Fit

EXPERIMENT I

LEARNING PARAMETERS A_1 , A_2, AND A_3, RMS FITTING ERROR, AND MEAN OF TASK COMPLETION TIME (t)

(DATA FOR 16 TRIALS X 5 SUBJECTS PER INITIAL CONDITION)

TABLE III

Condition	Comparison	X	$\mathring{X}$	t	PI
45:0,20	Betw. Subj.	.41	.30	1.91[d]	4.32[a]
	Betw. Displ.	.87	.35	1.00	5.46[b]
	Interaction	.63	.10	.14	.36
45:0,40	Betw. Subj.	.36	.12	1.33[d]	1.55[d]
	Betw. Displ.	1.91[d]	.02	.65	.02
	Interaction	1.20	.33	.87	.44
45:20,40	Betw. Subj.	1.50[d]	.05	1.68[d]	2.05[c]
	Betw. Displ.	.86	.29	2.75[c]	3.89[b]
	Interaction	.40	.89	.75	.57
90:0,20	Betw. Subj.	.50	1.57[d]	3.40[b]	6.47[b]
	Betw. Displ.	.13	1.00	.52	8.22[b]
	Interaction	.46	.32	1.04	1.46[d]
90:0,40	Betw. Subj.	1.33[d]	.86	2.79[d]	3.97[d]
	Betw. Displ.	.07	.38	2.79[d]	.01
	Interaction	.08	1.33[d]	2.11[c]	1.81[d]
90:20,40	Betw. Subj.	1.00	1.17	3.54[a]	3.54[a]
	Betw. Displ.	.00	.39	5.73[b]	5.77[b]
	Interaction	.50	1.67[d]	1.14	.94

a = 99%, b = 95%, c = 90%, d = 70%

EXPERIMENT I

ANALYSIS OF VARIANCE RESULTS

(DATA FOR 16 TRIALS X 5 SUBJECTS PER INITIAL CONDITION)

TABLE IV

Initial Condition	L	A_1	A_2	A_3	RMS	MEAN
	0	248.18	285.66	-.362	20.57	280.86
90,-90	20	231.91	191.38	-.240	17.13	266.91
	0,20	240.27	233.13	-.297	17.76	---
	0	209.67	148.78	-.145	20.66	254.75
45,-90	20	215.88	129.84	-.258	8.68	237.81
	0,20	214.02	135.12	-.186	12.29	---
	0	242.89	113.35	-.129	10.41	281.01
90,-45	20	242.52	113.87	-.159	13.01	274.25
	0,20	242.39	113.17	-.141	9.20	---
	0	227.92	159.13	-.219	8.43	259.98
45,-45	20	219.66	129.28	-.189	10.24	250.05
	0,20	224.07	144.15	-.206	7.09	---

EXPERIMENT II

LEARNING PARAMETERS A_1, A_2, AND A_3, RMS FITTING ERROR, AND MEAN OF PERFORMANCE INDEX (PI)

(DATA FOR 20 TRIALS X 3 SUBJECTS PER INITIAL CONDITION)

TABLE V

Initial Condition	L	A_1	A_2	A_3	RMS	MEAN
	0	14.64	751.97	-1.463	16.19	25.96
90,-90	20	10.36	375.10	-1.330	9.12	17.11
	0,20	12.49	557.45	-1.406	12.03	---
	0	2.09	91.47	-.239	13.39	18.86
45,-90	20	2.31	30.58	-.222	4.70	8.38
	0,20	2.22	61.03	-.235	7.31	---
	0	-5.19	42.28	-.060	7.45	18.75
90,-45	20	9.47	62.30	-.279	8.80	19.13
	0,20	7.60	44.41	-.174	7.06	---
	0	5.10	92.45	-.401	6.97	14.48
45,-45	20	-7.73	49.03	-.099	4.69	12.50
	0,20	1.15	59.01	-.212	5.16	---

EXPERIMENT II

LEARNING PARAMETERS A_1, A_2, AND A_3, RMS FITTING ERROR, AND MEAN OF SEPARATION ERROR (INTEGRAL)

(DATA FOR 20 TRIALS X 3 SUBJECTS PER INITIAL CONDITION)

TABLE VI

Initial Condition	L	A_1	A_2	A_3	RMS	MEAN
	0	218.78	62.36	-.143	8.52	237.93
90,-90	20	222.63	76.69	-.248	5.52	236.15
	0,20	221.43	67.71	-.193	5.93	---
	0	209.18	50.82	-.182	9.16	221.56
45,-90	20	206.70	70.89	-.261	10.28	218.50
	0,20	208.40	59.93	-.221	8.23	---
	0	231.03	64.94	-.193	10.90	245.93
90,-45	20	232.81	56.49	-.247	7.92	242.81
	0,20	231.70	59.89	-.209	6.66	---
	0	215.97	75.39	-.251	8.00	229.11
45,-45	20	217.11	67.71	-.293	10.09	227.01
	0,20	216.49	71.09	-.267	7.09	---

EXPERIMENT II

LEARNING PARAMETERS A_1, A_2, AND A_3, RMS FITTING ERROR,

AND MEAN OF TASK COMPLETION TIME (t) (DATA FOR 20 TRIALS X 3 SUBJECTS PER INITIAL CONDITION)

TABLE VII

Condition	Comparison	X_2	$\dot{X}_2$	X_3	$\dot{X}_3$	t	$\int dt$	PI
	BETW. SUBJ.	.72	1.83[d]	1.25[d]	21.25[a]	.19	1.31[d]	3.48[b]
90,-90	BETW. DISPL.	.88	.11	.03	.15	.13	.89	1.52[d]
	INTERACTION	.39	.43	.03	.07	.30	.29	.01
	BETW. SUBJ.	1.35[d]	4.67[b]	1.56[d]	3.96[b]	1.41[d]	1.23	1.93[d]
45,-90	BETW. DISPL.	.79	.00	.45	.91	.29	2.17[d]	3.99[b]
	INTERACTION	1.00	.27	.13	.40	.48	1.84[d]	.22
	BETW. SUBJ.	1.85[d]	7.41[a]	.37	4.71[b]	.09	8.15[d]	2.15[d]
90,-45	BETW. DISPL.	.10	.00	.11	.67	.23	.01	1.01
	INTERACTION	.43	.23	.90	.83	2.59[c]	1.38[d]	.05
	BETW. SUBJ.	3.76[b]	7.20[d]	4.40[d]	1.59	1.94	.99	.13
45,-45	BETW. DISPL.	.10	.22	.27	.96	.08	.17	1.02
	INTERACTION	.32	1.26[d]	1.83[d]	5.50[a]	3.06[c]	.44	.64

a = 99%, b = 95%, c = 90%, d = 70%

EXPERIMENT II

ANALYSIS OF VARIANCE RESULTS

(DATA FOR 20 TRIALS X 3 SUBJECTS PER INITIAL CONDITION)

TABLE VIII

VII. DISCUSSION AND CONCLUSIONS

The conclusions that can be drawn from the previous analyses will be presented in several sections. A concise statement of these conclusions appeared in Chapter I.

A. Learning

The learning process for the ATC tasks was modeled with a three parameter exponential curve given by equation 6-1. The parameters are A_1 the asymptote, A_2 the initial condition, and A_3 the rate.

During the experiments, each subject performed with all of the various displays. Thus, it is difficult to separate the learning achieved with the predictor display from that achieved with the conventional display. For this reason, any differences between the learning processes with and without the predictor display may not appear as great as they actually are.

By comparing the parameters A_3 and $A = A_1 + A_2$, the differences between the processes with the various displays can be studied. The most important characteristic of the learning curves can be seen by noting that two curves with large A and A_3 and low A and A_3 respectively will approach each other as T increases. Whether or not they ever meet depends on the magnitudes of A and A_3. However, regardless of the magnitudes of these parameters, curves of this type will exhibit less and less difference as T increases.

For the most part, these are the types of curves that are found in the tables of Chapter VI. A and A_3 for the predictor display are smaller than the comparable parameters for the conventional display. Consequently, the predictor usually yields a lower mean score, but the usefulness of the predictor decreases as the subject's intuitive feeling for the A/C dynamics increase. The possibility of the predictor becoming completely useless once the learning process is complete will vary with the difficulty of the task and for many instances the learning curves will never converge.

The above conclusions agree with those found by Bernotat for a somewhat different task[5]. He also found that using the same subjects on both displays will not show as wide a difference in learning curves as would be shown by segregating the subjects into separate groups for each display.

In most cases, it appears that the learning process with the predictor display is faster than that with the conventional system and that the difference in performance with and without the predictor display decreases as learning proceeds.

B. Analysis of variance

In this section, conclusions will be drawn from Tables IV and VII.

Table IV presents the results of the analysis of variance of experiment I. The performance index for experiment I is given by equation 4-1. Reference to this equation shows that PI is affected by X, $\dot{X}$, t, and a composite $X - \dot{X}$ term. Any significant differences that are found between the PI of different displays was necessarily caused by some combination of the above four terms.

Considering the L = 0. and L = 20. comparison, the analysis indicates that there is a significant difference between the scores

(PI) obtained with each display. Referring to Table IV, it is seen that the difference must be attributable to the $X - \dot{X}$ term.

The comparison between L = 0. and L = 40. indicates no significant difference between scores. Two of the score components indicate a 70% significant difference, but since the final scores indicate no differences, these results are considered meaningless.

The L = 20. and L = 40. comparison shows that the reason the 40. does not improve performance while the 20. does is that task completion times with 40. are significantly higher. Looking at the means of Table III substantiates this. The conclusion is that the 40. second prediction extrapolates the A/C movement much farther into time than the subject needs. As the subject attempts to use this extra information, he wastes time in making corrections that do not affect his error score. Thus, he compensates for errors that would never be realized if he ignored them.

Table VIII presents the results of the analysis of variance of experiment II. There is only one initial condition that shows a significant difference between displays. The score component causing this difference was the separation error. Some of the composite $X - \dot{X}$ terms of 4-3 may also have had an effect.

In general, the predictor display helps to reduce errors, but does not reduce task completion time which has a lower limit dictated by the dynamics of the system. A predictor which displays more than the necessary amount of information can increase task completion time.

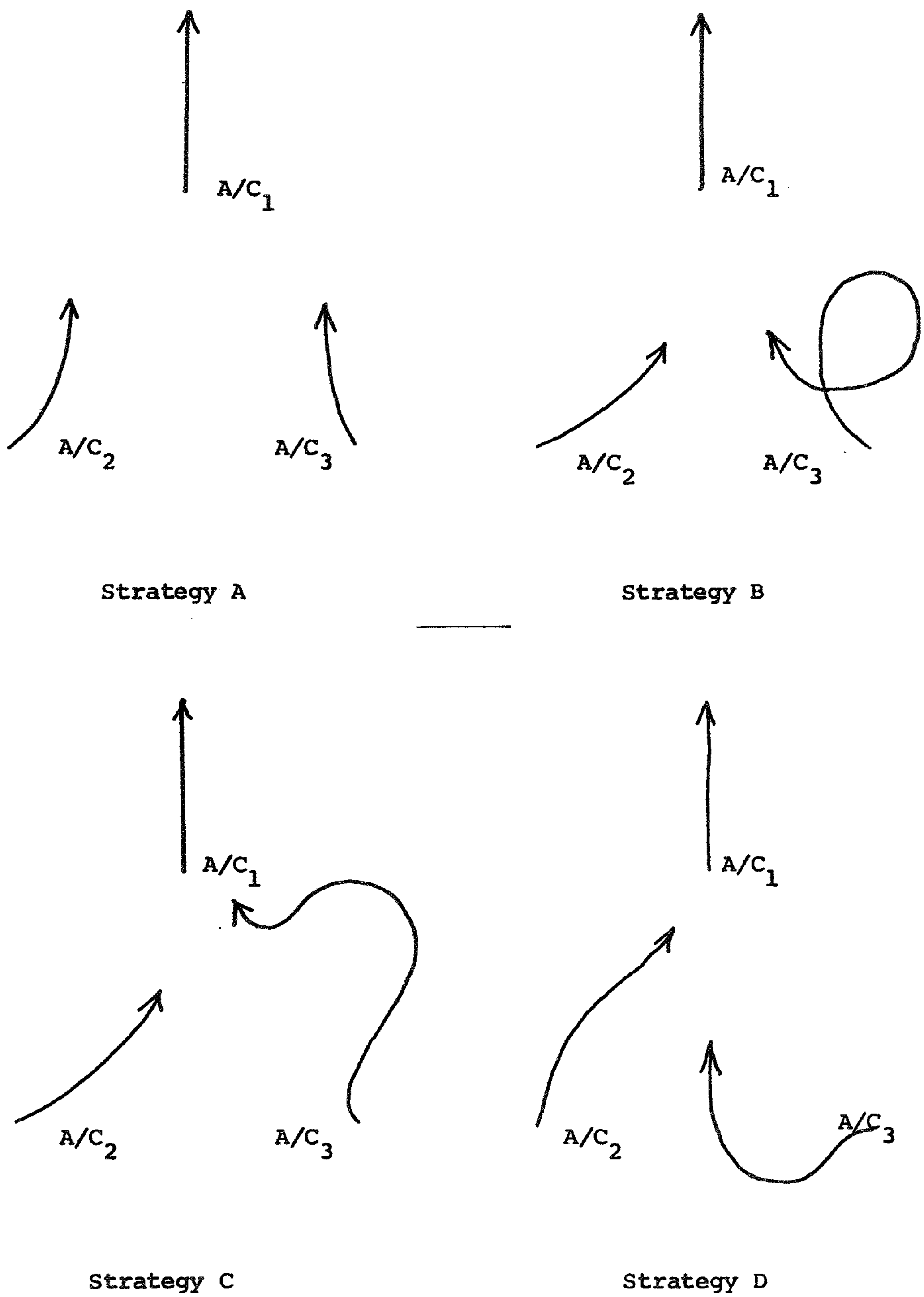
Before discussing the results of all of the analyses for both experiments, a brief discussion of some particular aspects of the experiments will be presented.

C. Strategies

The strategy that subjects used for experiment I was straightforward. They simply tried to guide the single A/C to the gate as quickly as possible. The trade-off between error and time was consistent among the subjects. However, the strategies that were used during experiment II were varied and changed during the course of the experiment.

The task for experiment II was basically one of guiding three A/C in a specified order to the gate. The subjects were faced with with the problem of delaying A/C_3 in some manner so as to bring A/C_2 across the funnel first and avoid separation errors between A/C_2 and A/C_3. Figure 18 illustrates some possible strategies.

The subjects used all of these strategies except A. This strategy illustrates why the $|X| \leq 20$ criteria was added to equation 4-3. To avoid separation error and have low task completion times, strategy A might be plausible. Bringing A/C_2 and A/C_3 along the opposite sides of the screen keeps them well away from the separation standard of 3 miles and also low task completion times can be obtained if they both cross the top of the screen in the same small time interval. However, large errors of the order of 3 miles result which would be entirely unacceptable in an actual ATC situation. Thus, to keep the PI realistic the extra criterion was added for experiment II.



EXPERIMENT II STRATEGIES

FIGURE 18.

Strategies B and C allow the A/C to cross the gate having accumulated zero separation error, but the task completion time is high for B and the error rates are high for C. All of the subjects eventually settled on using D. Those who found this strategy first obtained the lowest overall score for the experiment.

To use strategy D, the subject had to allow A/C_3 to leave the screen. When this happened, the prediction was lost and the subject had to learn through intuition where the A/C would reappear.

The perfection of the strategies used for experiments I and II was influenced by the presence of a grid on the CRT. Subjects used the cartesian coordinate system on the display (it was not numbered or lettered) to remember where to give commands. This closely resembles the use of switch curves in an optimal control task. Miller [(9)] has investigated this and found human subjects to be capable of reproducing optimal solutions once they are learned.

The subjects during this experiment made various errors in attempting to find a good strategy for guiding the A/C. These errors were strictly of an unintentional nature. Once they had settled on strategy D, they began to try and find a lower limit. Errors resulted from this testing process, but they were of a more intentional nature. They would not have occurred if the subjects were aware of the actual optimal solution.

D. Subjects' comments

Although the comments of subjects are only qualitative, they can be used as substantiating evidence.

When the experiments first began, the subjects were fairly impressed with the predictor system and felt that it made a great difference. Study of the earlier portions of the learning curves shows that the difference between the predictor and conventional displays was greatest then. As the experiments progressed, the subjects gained more confidence in their intuitive abilities and their praise of the predictor decreased. By the end of the experiments the subjects felt that the guiding process was easier with the predictor but they weren't sure that it made any difference in their performance.

Their overall final opinion was that the predictor helped them to learn the dynamics of the process. Once the process is learned, the predictor is good as a check during the execution of commands but isn't necessary. In most cases, the subjects' opinions agree with the results of the data analysis. However, some of the conclusions reached here were not mentioned by the subjects.

Considering task complexity, the subjects often commented that they had difficulty keeping track of all of the A/C during the more complex tasks, The frequency of these comments decreased as the experiment proceded, but occasional gross errors on the part of the subjects indicated that the problem of feeling overloaded never completely disappeared.

E. A conjecture

Two tasks were performed during experiment I and four tasks were performed during experiment II. Ranking these tasks according to the mean score obtained, it is noted that for the three tasks with the lowest mean scores the predictor display yielded significantly better performance while for the three tasks with highest mean scores the predictor did not significantly improve performance.

Order of difficulty can be related to mean score. Tasks which yielded higher scores were those during which the subjects accumulated high error and integral scores. The subjects found the more difficult tasks very taxing. This is evidenced by their comments as well as the numerical results.

The above allows the conclusion that when the subject was highly taxed, his responses were reduced to a very intuitive level. Although the predictor aid was available, the subject apparently lid not use the information that was presented. On the easier tasks which he did not find troublesome, he was able to use the information from the prediction. This conclusion is evidenced by the results of the analyses.

It appears that there is an upper and lower limit on the complexity of tasks that can be benifited by computer aids such as predictor displays. These limits might be quantified in terms of information transmitted. Tasks with very low information content do not need computer aids. Tasks with high information content tax a subject to the point that he will respond on an intuitive level regardless of the presence of an aid.

This particular conclusion is presented in the form of a conjecture because of the lack of supporting evidence available. Many different tasks would have to be investigated before this conjecture could be verified.

F. Air traffic control

The results of this research indicate that the applicability of the predictor display system presented in this thesis depends on the nature of the ATC tasks. Tasks similar to those of experiment I and the easier of experiment II would benefit from a predictor display. Tasks similar to the harder tasks of experiment II would not benefit.

The predictor concept might be made generally applicable if a digital computer was included in the system. Some decision making responsibility could be delegated to the digital computer. A hybrid system of this type could be used to govern the complexity of the tasks that the operator performs. If a task became difficult the computer would take some of the responsibility. In this way the upper limit on task complexity would never be exceeded and the operator's aids would remain useful to him. A man-computer combination of this type would keep the man and his flexibility as a vital link in the system but would allow the system to handle tasks of much more complexity than the man could handle himself.

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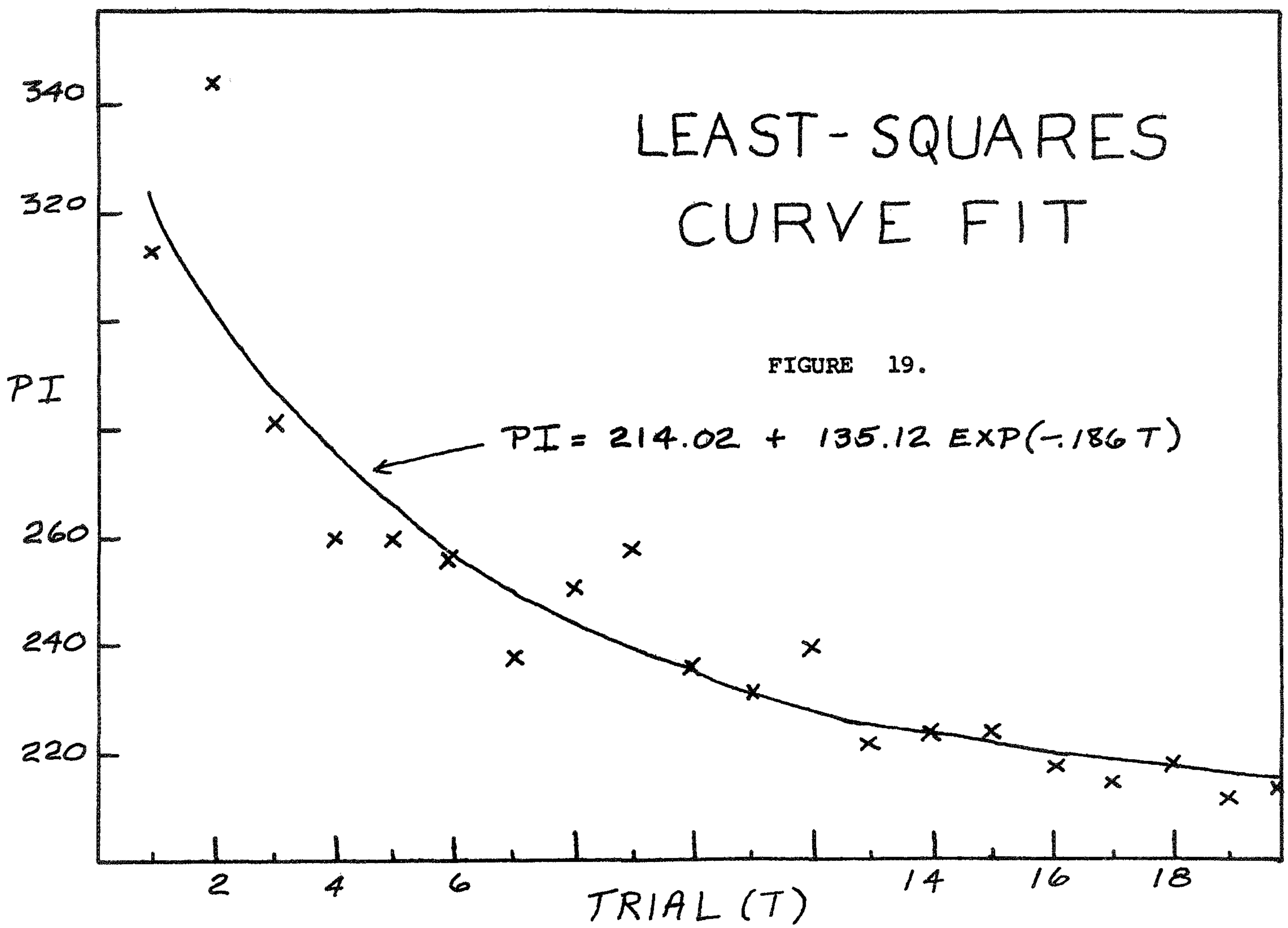
APPENDIX A. SAMPLE LEARNING CURVES

The fitting of three parameter exponential learning curves to the data was discussed in Chapter VI. Although many curves were produced (60), only two example curves will be presented. These will represent a least-squares fit and an approximate fit respectively. The computer program used to generate all of the learning curves appears in Appendix B.



LEARNING CURVE

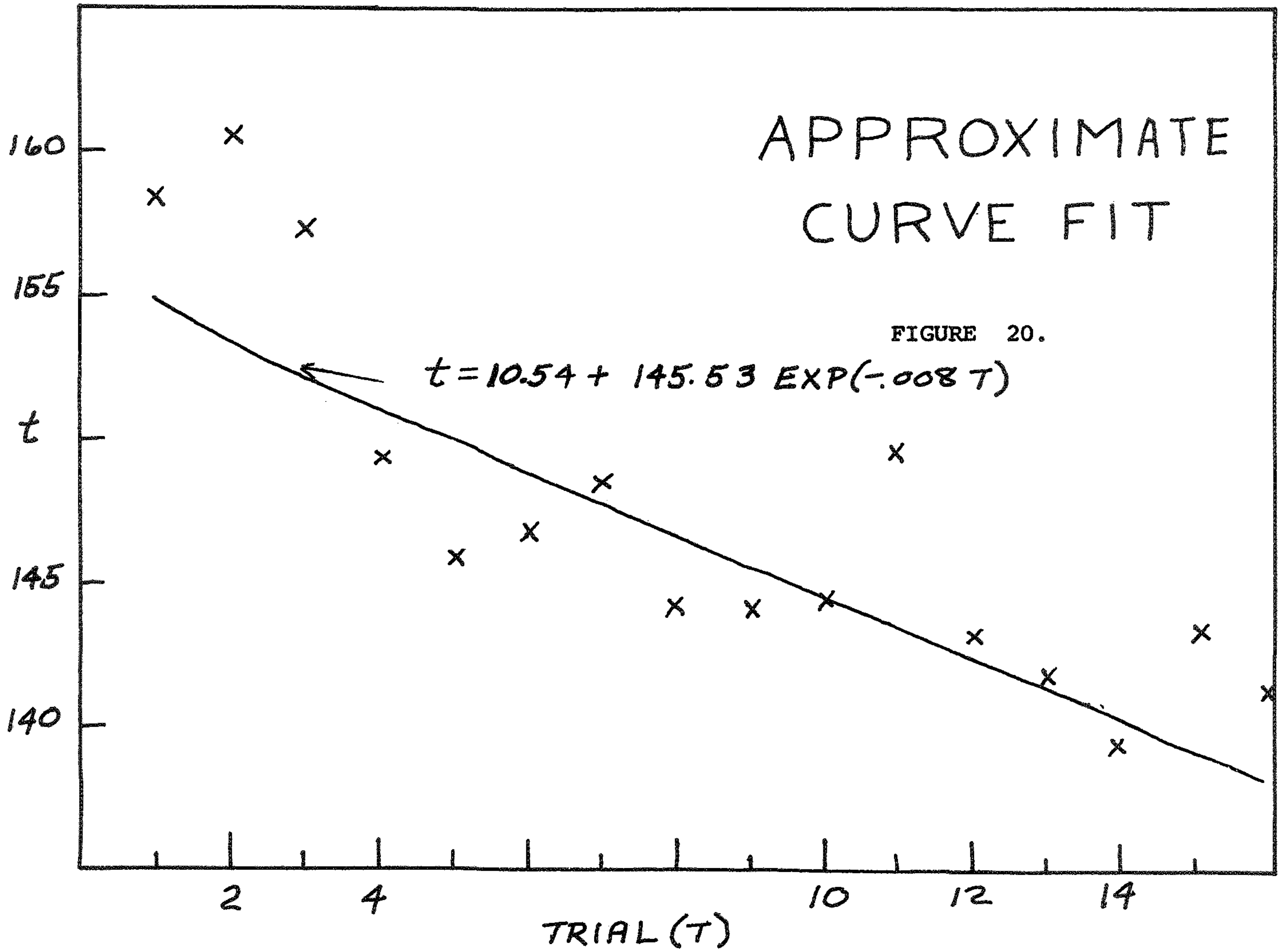


FIGURE 20.

LEARNING CURVE

APPENDIX B. COMPUTER PROGRAMS

The following two computer programs were used to perform the analysis described in Chapter VI. The first program, LCURV, performed the exponential curve fitting. The second program, ANVAR, performed the analysis of variance.

```
C      LCURV
C      LEAST-SQUARES FITTING OF AN EXPONENTIAL
C      LEARNING CURVE TO DATA
       DIMENSION ITRL(2,5,20),IX2(2,5,20),IX2D(2,5,20),
      1IX3(2,5,20),IX3D(2,5,20),ITI(2,5,20),
      1II(2,5,20),IPI(2,5,20),IX(2,5,20),FXA(20),
      1A(3,20)
C      DATA MUST BE IN INTEGER FORM
C      N1 TREATMENTS - MAX 2
C      N2 SUBJECTS - MAX 5
C      N3 TRIALS - MAX 20
C      N4 DATA COMPONENTS - MAX 10
       N1=2
       N2=5
       N3=16
       N4=4
C      DATA INPUT
C      THIS SECTION WILL CHANGE WITH THE TYPE OF DATA
       DO 20 I=1,N1
       DO 20 J=1,N2
       DO 20 K=1,N3
       READ(2,10)ITRL(I,J,K),IX2(I,J,K),IX2D(I,J,K),
      1IX3(I,J,K),IX3D(I,J,K),ITI(I,J,K),II(I,J,K),
      1IPI(I,J,K)
    10 FORMAT(8I9)
    20 CONTINUE
C      SELECTION OF PERFORMANCE COMPONENT TO BE ANALYZED
C      WILL CHANGE WITH THE NUMBER OF DATA ITEMS
       IC=3
    30 IC=IC+1
       DO 60 I=1,N1
       DO 60 J=1,N2
       DO 58 K=1,N3
       GO TO (40,42,44,46,48,50,52),IC
    40 IX(I,J,K)=IX2(I,J,K)
       GO TO 58
    42 IX(I,J,K)=IX2D(I,J,K)
       GO TO 58
    44 IX(I,J,K)=IX3(I,J,K)
       GO TO 58
    46 IX(I,J,K)=IX3D(I,J,K)
       GO TO 58
    48 IX(I,J,K)=ITI(I,J,K)
       GO TO 58
    50 IX(I,J,K)=II(I,J,K)
       GO TO 58
    52 IX(I,J,K)=IPI(I,J,K)
    58 CONTINUE
    60 CONTINUE
```

```
C       AVERAGES
        NS1=1
        NS2=1
     90 DO 300 K=1,N3
        IXA(K)=0
        DO 200 I=NS1,NS2
        DO 100 J=1,N2
    100 IXA(K)=IXA(K)+IABS(IX(I,J,K))
    200 CONTINUE
        NP=NS2-NS1+1
        DD=FLOAT(IXA(K))
        DN=FLOAT(NP*N2)
        FXA(K)=DD/DN
    300 CONTINUE
C       CURVE FITTING
C       FIRST APPROXIMATIONS
        N=N3
        N3P=N3-1
C       ALPHA
        SUMA=0.
        SUMB=0.
        DO 320 I=1,N3P
    320 SUMA=SUMA+FXA(I)*FXA(I+1)
        DO 330 I=1,N3P
    330 SUMB=SUMB+FXA(I)**2
        AAPHA=SUMA/SUMB
        ALPHA=ABS(AAPHA)
        A3=ALOG(ALPHA)
C       LINEAR PORTION
        T1=0.
        T2=0.
        T3=0.
        T4=0.
        DO 340 I=1,N3
        ADD=ALPHA**(I-1)
        T1=T1+ADD
        T2=T2+ADD**2
        T3=T3+FXA(I)
    340 T4=T4+ADD*FXA(I)
        DEN=N*T2-(T1**2)
        A1=(T2*T3-T1*T4)/DEN
        A2=(N*T4-T1*T3)/DEN
```

```
C      ITERATIVE FIT
  345 V1=0.
      V2=0.
      V3=0.
      V4=0.
      V5=0.
      V6=0.
      V7=0.
      V8=0.
      DO 350 I=1,N
      TA1=EXP(A3*I)
      TA2=A2*I*EXP(A3*I)
      TA3=-A1-A2*EXP(A3*I)+FXA(I)
      V1=V1+TA1
      V2=V2+TA2
      V3=V3+TA1**2
      V4=V4+TA1*TA2
      V5=V5+TA2**2
      V6=V6+TA3
      V7=V7+TA1*TA3
  350 V8=V8+TA2*TA3
      W1=V3*V5-V4**2
      W2=V2*V4-V1*V5
      W3=V1*V4-V2*V3
      W4=N*V5-V2**2
      W5=V1*V2-N*V4
      W6=N*V3-V1**2
      DEN=N*W1+V1*W2+V2*W3
      Z=(W1*V6+W2*V7+W3*V8)/DEN
      B=(W2*V6+W4*V7+W5*V8)/DEN
      C=(W3*V6+W5*V7+W6*V8)/DEN
      D1=Z**2+B**2+C**2
      D2=A1**2+A2**2+A3**2
      D=D1/(D1+D2)
      A1=A1+Z
      A2=A2+B
      A3=A3+C
      IF(D.LT.1.E-8) GO TO 360
C     DATSW    14,2=PAPER  1=SCOPE   15,1=STOP ITERATING
      CALL DATSW(15,J)
      GO TO (360,345),J
  360 CONTINUE
```

```
C       ERROR
        ESUM=0.
        DO 600 K=1,N
        D=A1+A2*EXP(A3*K)
        E=D-FXA(K)
  600   ESUM=ESUM+E**2
        RMS=SQRT(ESUM/FLOAT(N3))
C       PRINTOUT
        WRITE(3,700)IC,NS1,A2,A3,A1,RMS
  700   FORMAT(1X,'COMPONENT',I2,2X,'TREATMENT',I2,2X,
       1'HEIGHT',F10.2,2X,'RATE',F10.6,2X,'ASYMP',F10.2,
       12X,'RMS ERROR',F10.2)
C       PLOTTING
        I=1
        DO 710 J=1,N3
  710   A(I,J)=FXA(J)
        I=2
        DO 720 J=1,N3
  720   A(I,J)=A1+A2*EXP(A3*J)
        I=3
        DO 730 J=1,N3
  730   A(I,J)=J
        IA=3
        XLAB=0.
        XSCL=0.
        NVARS=3
        NPTS=N3
        NX=3
        MOVE=1
        LABEL=1
        ISCL=1
        FTIME=0.
        CALL DATSW(14,J)
        LOOK=J-2
        CALL PICTR(A,IA,XLAB,XSCL,NVARS,NPTS,NX,MOVE,LABEL,
       1ISCL,FTIME,LOOK)
        IF(NS1.GT.1) GO TO 800
        IF(NS2.EQ.2) GO TO 900
        NS1=2
        NS2=2
        GO TO 90
  800   NS1=1
        GO TO 90
  900   CONTINUE
        IF(IC.LT.N4) GO TO 30
        END
```

```
C     ANVAR
C     TWO DIMENSIONAL ANALYSIS OF VARIANCE PROGRAM
      DIMENSION IX2(2,5,20),IX2D(2,5,20),IX3(2,5,20),
     1IX3D(2,5,20),ITI(2,5,20),II(2,5,20),IPI(2,5,20),
     1IX(2,5,20),IT(2,5),ITR(5),ITC(2),F(2),ITRL(2,5,20),
     1A1(10),A2(10),A3(10)
C     DATA MUST BE IN INTEGER FORM
C     N1 TREATMENTS - MAX 2
C     N2 SUBJECTS - MAX 5
C     N3 TRIALS - MAX 20
C     N4 DATA COMPONENTS - MAX 10
      N1=2
      N2=3
      N3=20
      N4=7
C     DATA INPUT
C     THIS SECTION WILL CHANGE WITH THE TYPE OF DATA
C     TO AVOID SUBTRACTING LEARNING FROM
C     A COMPONENT, USE A1=2000.
      READ(2,5)A1(1),A1(2),A1(3),A1(4),A1(5),A1(6),A1(7)
      READ(2,5)A2(1),A2(2),A2(3),A2(4),A2(5),A2(6),A2(7)
      READ(2,5)A3(1),A3(2),A3(3),A3(4),A3(5),A3(6),A3(7)
    5 FORMAT(7F10.5)
      DO 20 I=1,N1
      DO 20 J=1,N2
      DO 20 K=1,N3
      READ(2,10)ITRL(I,J,K),IX2(I,J,K),IX2D(I,J,K),
     1IX3(I,J,K),IX3D(I,J,K),ITI(I,J,K),II(I,J,K),
     1IPI(I,J,K)
   10 FORMAT(8I9)
   20 CONTINUE
C     SELECTION OF PERFORMANCE COMPONENT TO BE ANALYZED
C     WILL CHANGE WITH THE NUMBER OF DATA ITEMS
      IC=0
   30 IC=IC+1
      DO 60 I=1,N1
      DO 60 J=1,N2
      DO 58 K=1,N3
      GO TO (40,42,44,46,48,50,52),IC
   40 IX(I,J,K)=IX2(I,J,K)
      GO TO 58
   42 IX(I,J,K)=IX2D(I,J,K)
      GO TO 58
   44 IX(I,J,K)=IX3(I,J,K)
      GO TO 58
   46 IX(I,J,K)=IX3D(I,J,K)
      GO TO 58
   48 IX(I,J,K)=ITI(I,J,K)
```

```
      GO TO 58
   50 IX(I,J,K)=II(I,J,K)
      GO TO 58
   52 IX(I,J,K)=IPI(I,J,K)
   58 CONTINUE
   60 CONTINUE
      GO TO 1950
   65 CONTINUE
C     SUBTRACTING THE LEARNING CURVE
C     SUBTRACTS A1 + A2EXP(-A3T) FROM DATA
C     WHERE A1,A2, AND A3 ARE CONSTANTS
C     SUPPLIED BY USER AND T IS THE
C     CONSECUTIVE NUMBER OF THE TRIAL
      IF(A1(IC).GT.1000.) GO TO 90
      DO 80 I=1,N1
      DO 80 J=1,N2
      DO 70 K=1,N3
      A=FLOAT(N3)
      B=A1(IC)+A2(IC)*EXP(-A3(IC)*A)
   70 IX(I,J,K)=IX(I,J,K)-IFIX(B)
   80 CONTINUE
   90 CONTINUE
C     SUBTOTALS
      DO 200 I=1,N1
      DO 100 J=1,N2
  100 IT(I,J)=0
  200 CONTINUE
      DO 400 I=1,N1
      DO 400 J=1,N2
      DO 300 K=1,N3
  300 IT(I,J)=IT(I,J)+IX(I,J,K)
  400 CONTINUE
C     ROW TOTALS
      DO 600 I=1,N2
  600 ITR(I)=0
      DO 800 J=1,N2
      DO 700 I=1,N1
  700 ITR(J)=ITR(J)+IT(I,J)
  800 CONTINUE
C     COLUMN TOTALS
      DO 900 I=1,N1
  900 ITC(I)=0
      DO 1100 I=1,N1
      DO 1000 J=1,N2
 1000 ITC(I)=ITC(I)+IT(I,J)
 1100 CONTINUE
```

```
C       TOTAL SUM OF SQUARES
        ITSUM=0
        FSQ=0.
        DO 1300 I=1,N1
        DO 1300 J=1,N2
        DO 1200 K=1,N3
        ITSUM=ITSUM+IX(I,J,K)
  1200  FSQ=FSQ+(FLOAT(IX(I,J,K)))**2
  1300  CONTINUE
        T=((FLOAT(ITSUM))**2)/(FLOAT(N1*N2*N3))
        WRITE(3,1400)T
  1400  FORMAT(1X,F15.2)
        V1=FSQ-T
C       SUM OF SQUARES FOR ROWS
        V2=0.0
        DO 1500 I=1,N2
  1500  V2=V2+((FLOAT(ITR(I)))**2)/(FLOAT(N1*N3))
        V2=V2-T
C       SUM OF SQUARES FOR COLUMNS
        V3=0.0
        DO 1600 I=1,N1
  1600  V3=V3+((FLOAT(ITC(I)))**2)/(FLOAT(N2*N3))
        V3=V3-T
C       SUM OF SQUARES FOR SUBTOTALS
        V4=0.0
        DO 1800 I=1,N1
        DO 1700 J=1,N2
  1700  V4=V4+((FLOAT(IT(I,J)))**2)/(FLOAT(N3))
  1800  CONTINUE
        V4=V4-T
C       PRINTOUT
        WRITE(3,1900)IC,V1,V2,V3,V4
  1900  FORMAT(1X,'COMPONENT',I2,2X,'TOTAL',F15.2,2X,
       1'ROW',F15.2,2X,'COLUMN',F15.2,2X,'SUBTOTAL',F15.2)
        GO TO 2300
C       CALC OF MEANS
  1950  CONTINUE
        DO 2200 I=1,N1
        IMS=0
        DO 2100 J=1,N2
        DO 2000 K=1,N3
  2000  IMS=IMS+IX(I,J,K)
  2100  CONTINUE
        F(I)=(FLOAT(IMS))/(FLOAT(N2*N3))
        WRITE(3,2150)I,F(I)
  2150  FORMAT(1X,'MEAN',I2,5X,F10.2)
  2200  CONTINUE
        GO TO 65
  2300  IF(IC.LT.N4) GO TO 30
        END
```

APPENDIX C. DATA

The following pages present the data collected during experiments I and II. For experiment I, initial conditions 1 and 2 refer to 45 and 90, respectively. For experiment II, initial conditions 1, 2, 3, and 4 refer to 90,-90; 45,-90; 90,-45; and, 45,-45, respectively.

EXPERIMENT 1 INITIAL COND 1 SUBJ 1 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	0	-4	145	149
2	2	10	138	152
3	1	4	128	134
4	-2	-12	132	148
5	-1	6	123	129
6	1	-1	124	126
7	4	1	130	136
8	1	-2	125	127
9	0	-4	126	130
10	0	-3	126	129
11	0	1	124	125
12	0	-10	121	131
13	1	8	124	134
14	0	-9	123	132
15	2	5	125	133
16	0	-5	124	129

EXPERIMENT 1 INITIAL COND 1 SUBJ 2 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	14	6	134	158
2	4	-8	152	162
3	2	-2	140	143
4	-1	2	140	142
5	7	-3	133	141
6	2	0	123	125
7	-4	5	130	137
8	2	-8	124	132
9	1	1	127	130
10	3	0	132	135
11	1	-1	126	128
12	0	-1	128	129
13	-2	4	123	128
14	0	1	125	126
15	1	4	127	133
16	-5	-14	126	149

EXPERIMENT 1 INITIAL COND 1 SUBJ 3 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	-4	12	139	152
2	2	-6	130	137
3	-1	-6	128	136
4	-1	0	130	131
5	-5	-12	136	156
6	0	4	126	130
7	0	4	124	128
8	0	0	126	126
9	0	-6	129	135
10	0	-4	144	148
11	0	-6	128	134
12	1	-1	137	139
13	0	0	127	127
14	0	0	127	127
15	0	0	128	128
16	0	0	129	129

EXPERIMENT 1 INITIAL COND 1 SUBJ 4 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	12	4	137	156
2	0	-10	129	139
3	7	0	135	142
4	0	2	127	129
5	-4	-12	131	144
6	0	1	126	127
7	5	-1	128	132
8	0	6	129	135
9	-8	-3	125	138
10	-2	-1	124	128
11	4	1	129	135
12	4	0	127	131
13	-7	4	124	132
14	-1	-12	126	140
15	0	8	125	133
16	1	-8	124	132

EXPERIMENT 1 INITIAL COND 1 SUBJ 5 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	12	-20	143	167
2	-8	6	134	151
3	4	5	132	143
4	-6	-8	127	144
5	8	4	130	145
6	-4	-14	130	151
7	0	8	126	134
8	-7	-14	127	153
9	5	13	126	148
10	-2	-5	127	135
11	7	11	129	151
12	-3	-4	127	136
13	6	0	128	134
14	8	-7	121	132
15	-1	3	126	129
16	5	-2	125	131

EXPERIMENT 1 INITIAL COND 1 SUBJ 1 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	0	0	130	130
2	0	8	151	159
3	2	3	130	136
4	-2	-6	119	129
5	0	5	129	134
6	0	-3	122	125
7	1	0	129	130
8	0	-2	126	128
9	1	1	125	128
10	0	0	126	126
11	0	0	124	124
12	0	-1	124	125
13	0	0	125	125
14	0	0	124	124
15	0	1	124	125
16	0	0	124	124

EXPERIMENT 1 INITIAL COND 1 SUBJ 2 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	1	2	137	141
2	-12	1	138	150
3	1	4	132	138
4	-2	-2	139	144
5	1	4	133	139
6	0	-6	128	134
7	0	4	125	129
8	0	-1	124	125
9	1	2	127	131
10	0	0	126	126
11	0	-3	129	132
12	0	0	125	125
13	0	0	125	125
14	0	0	124	124
15	0	0	125	125
16	0	-1	127	128

EXPERIMENT 1 INITIAL COND 1 SUBJ 3 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	0	1	131	132
2	-2	-2	132	137
3	0	-2	133	135
4	-1	0	129	130
5	0	0	130	130
6	0	0	125	125
7	0	0	126	126
8	0	2	126	128
9	0	-2	128	130
10	1	4	127	133
11	0	-3	128	131
12	0	-2	138	140
13	0	0	130	130
14	0	-2	127	129
15	0	-2	133	135
16	0	-2	129	131

EXPERIMENT 1 INITIAL COND 1 SUBJ 4 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	4	12	130	149
2	-1	-12	129	143
3	6	0	133	139
4	-1	-4	129	135
5	0	16	122	138
6	-2	-4	125	132
7	0	4	125	129
8	-2	-10	127	141
9	0	-8	123	131
10	-1	-4	125	131
11	2	2	129	134
12	4	-6	123	131
13	0	6	124	130
14	0	-7	126	133
15	0	7	127	134
16	0	-8	125	133

EXPERIMENT 1 INITIAL COND 1 SUBJ 5 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	4	6	127	139
2	-4	-10	141	158
3	-3	9	133	143
4	-4	-12	125	144
5	2	6	132	142
6	0	-8	127	135
7	0	7	126	133
8	-4	-9	124	140
9	4	6	130	142
10	0	-4	127	131
11	6	4	130	141
12	0	-10	126	136
13	12	0	133	145
14	-3	-8	125	138
15	0	0	127	127
16	0	-8	125	133

EXPERIMENT 1 INITIAL COND 1 SUBJ 1 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	0	-10	165	175
2	-2	-4	147	154
3	2	6	141	151
4	-2	-10	128	142
5	0	0	128	128
6	0	-1	125	126
7	1	0	128	129
8	0	-2	124	126
9	0	1	128	129
10	0	0	131	131
11	0	0	128	128
12	0	0	128	128
13	0	1	125	126
14	0	-8	123	131
15	0	0	124	124
16	0	-4	124	128

EXPERIMENT 1 INITIAL COND 1 SUBJ 2 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	-2	10	131	141
2	-4	-10	140	157
3	-5	-8	143	159
4	-2	-8	138	150
5	-1	1	131	133
6	0	-12	135	147
7	-1	2	128	130
8	-1	-2	127	131
9	0	1	125	126
10	0	-3	126	129
11	0	0	127	127
12	0	-6	125	131
13	-1	0	126	127
14	0	-4	127	131
15	0	0	129	129
16	0	-3	128	131

EXPERIMENT I INITIAL COND 1 SUBJ 3 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	-1	0	143	144
2	-2	-10	136	150
3	0	-4	139	143
4	-4	-4	131	141
5	0	-4	129	133
6	0	4	144	148
7	-1	-4	136	142
8	0	3	134	137
9	0	-4	128	132
10	0	0	129	129
11	0	-4	129	133
12	0	1	138	139
13	0	0	129	129
14	-1	-1	127	130
15	0	0	128	128
16	0	0	128	128

EXPERIMENT 1 INITIAL COND 1 SUBJ 4 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	1	9	130	141
2	4	-13	127	141
3	0	12	130	142
4	0	-15	128	143
5	4	9	124	140
6	-1	-9	126	137
7	3	12	125	142
8	0	-4	128	132
9	4	8	125	140
10	-2	-5	127	135
11	4	5	128	139
12	0	-7	125	132
13	0	4	127	131
14	-2	-8	125	137
15	-3	8	127	136
16	2	-4	124	129

EXPERIMENT 1 INITIAL COND 1 SUBJ 5 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	2	6	139	149
2	-2	-12	134	150
3	-6	12	131	145
4	-2	-12	131	147
5	-1	8	126	134
6	0	-12	127	139
7	-1	7	125	132
8	0	-9	126	135
9	2	8	129	141
10	0	-5	129	134
11	2	7	126	137
12	0	-10	129	139
13	1	6	131	139
14	-2	-8	128	140
15	0	8	126	134
16	-1	0	131	132

EXPERIMENT 1 INITIAL COND 2 SUBJ 1 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	0	-2	156	158
2	-3	4	161	166
3	0	-6	157	163
4	-2	-4	144	152
5	-2	-6	147	157
6	0	-4	141	145
7	-1	-3	154	159
8	0	0	142	142
9	3	0	142	145
10	0	0	140	140
11	2	1	141	145
12	0	-5	136	141
13	1	0	138	139
14	0	-3	137	140
15	0	0	137	137
16	1	-7	136	143

EXPERIMENT 1 INITIAL COND 2 SUBJ 2 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	7	-12	149	164
2	0	-16	148	164
3	-4	-20	162	190
4	-6	-6	139	154
5	0	0	146	146
6	0	3	160	163
7	1	2	145	149
8	0	-4	152	156
9	-1	-2	155	159
10	2	-1	147	149
11	0	-4	155	159
12	-1	3	140	143
13	-2	-2	142	147
14	-4	-2	137	143
15	0	-7	148	155
16	3	-4	140	145

EXPERIMENT 1 INITIAL COND 2 SUBJ 3 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	-1	-5	150	157
2	1	-4	144	148
3	2	8	140	152
4	-4	-6	139	151
5	0	-1	138	139
6	1	0	138	139
7	0	-4	140	144
8	0	0	136	136
9	0	-8	138	146
10	2	-7	135	142
11	0	-4	145	149
12	1	-1	137	139
13	0	0	135	135
14	0	-6	135	141
15	-2	-4	136	141
16	0	-1	138	139

EXPERIMENT 1 INITIAL COND 2 SUBJ 4 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	-3	-8	163	172
2	-4	29	187	216
3	0	-4	167	171
4	-1	-1	161	164
5	5	6	144	158
6	8	-12	146	161
7	-5	7	144	153
8	7	3	137	149
9	-3	-8	143	156
10	8	4	143	158
11	11	-15	165	180
12	0	4	135	139
13	-2	-1	137	141
14	0	-2	136	138
15	6	0	142	148
16	0	15	143	158

EXPERIMENT 1 INITIAL COND 2 SUBJ 5 PRED LENGTH 0

TRIAL	X	XDOT	TIME	PI
1	0	1	143	144
2	-12	-1	142	156
3	1	-20	157	177
4	-10	20	150	173
5	4	1	149	155
6	6	16	152	170
7	8	-12	151	166
8	-6	-6	141	156
9	0	-1	143	144
10	0	-1	144	145
11	4	-16	152	169
12	-2	15	153	168
13	12	-7	146	161
14	-7	-5	143	158
15	9	-6	152	163
16	-9	0	139	148

EXPERIMENT 1 INITIAL COND 2 SUBJ 1 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	0	0	163	163
2	-1	-1	158	161
3	1	-4	151	155
4	0	-6	147	153
5	0	-2	143	145
6	-1	-2	145	149
7	0	0	147	147
8	1	0	146	147
9	0	0	136	136
10	0	-1	136	137
11	0	0	144	144
12	0	1	151	152
13	0	1	139	140
14	0	0	138	138
15	0	0	137	137
16	0	-4	136	140

EXPERIMENT 1 INITIAL COND 2 SUBJ 2 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	-1	0	152	153
2	-2	-12	149	165
3	0	-6	157	163
4	-4	-2	144	150
5	0	-3	154	157
6	1	-1	158	160
7	0	-2	146	148
8	0	0	147	147
9	0	-1	149	150
10	0	0	147	147
11	0	-1	152	153
12	0	0	142	142
13	-1	-3	152	157
14	0	0	140	140
15	0	0	148	148
16	0	0	138	138

EXPERIMENT 1 INITIAL COND 2 SUBJ 3 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	-1	-3	146	151
2	0	-12	143	155
3	0	1	142	143
4	0	-2	141	143
5	0	0	146	146
6	0	0	144	144
7	0	0	137	137
8	0	-4	142	146
9	1	1	138	141
10	0	-2	135	137
11	0	0	138	138
12	0	-2	138	140
13	0	0	137	137
14	0	-3	135	138
15	-1	0	137	138
16	0	0	138	138

EXPERIMENT 1 INITIAL COND 2 SUBJ 4 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	4	7	152	166
2	-2	0	158	160
3	4	4	151	161
4	-4	2	148	153
5	0	7	142	149
6	-1	-4	142	148
7	1	-4	148	152
8	-1	0	145	146
9	2	1	140	144
10	-2	0	144	146
11	4	1	146	150
12	-4	-3	140	148
13	1	0	138	139
14	1	-4	136	140
15	0	0	140	140
16	0	0	139	139

EXPERIMENT 1 INITIAL COND 2 SUBJ 5 PRED LENGTH 20

TRIAL	X	XDOT	TIME	PI
1	4	4	147	157
2	-4	-8	143	158
3	0	4	142	146
4	-6	-2	145	155
5	5	-1	146	151
6	-2	8	153	161
7	2	0	148	150
8	-3	-4	145	153
9	3	-3	148	152
10	0	2	148	150
11	4	2	141	148
12	0	6	150	156
13	5	-4	145	152
14	0	-4	139	143
15	3	-1	144	147
16	-3	0	139	142

EXPERIMENT 1 INITIAL COND 2 SUBJ 1 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	0	-4	189	193
2	0	-2	196	198
3	0	-4	165	169
4	-1	-2	161	165
5	-2	-12	157	173
6	-1	-3	152	157
7	0	-1	158	159
8	0	0	142	142
9	1	0	146	147
10	0	-1	146	147
11	0	0	147	147
12	0	0	145	145
13	0	0	138	138
14	0	-4	136	140
15	0	0	139	139
16	0	0	141	141

EXPERIMENT 1 INITIAL COND 2 SUBJ 2 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	0	-1	167	168
2	-4	-10	169	186
3	-4	4	187	193
4	-4	-8	150	165
5	-1	-2	143	147
6	-1	0	153	154
7	0	-7	152	159
8	0	-4	160	164
9	1	0	146	147
10	0	1	148	149
11	0	-5	145	150
12	1	3	149	154
13	0	0	151	151
14	0	0	143	143
15	0	-1	152	153
16	0	0	147	147

EXPERIMENT 1 INITIAL COND 2 SUBJ 3 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	0	-2	148	150
2	-3	-3	154	162
3	0	4	141	145
4	-4	-8	143	158
5	0	-1	146	147
6	0	0	143	143
7	0	0	139	139
8	0	1	146	147
9	1	0	141	142
10	0	-1	137	138
11	0	0	138	138
12	0	1	138	139
13	0	0	138	138
14	0	-1	137	138
15	0	0	138	138
16	0	0	138	138

EXPERIMENT 1 INITIAL COND 2 SUBJ 4 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	6	-3	159	166
2	-5	-5	154	164
3	4	-10	153	164
4	-3	0	154	157
5	8	-2	143	155
6	0	-12	139	151
7	7	-7	154	164
8	-4	0	147	151
9	8	-4	143	152
10	-7	4	147	155
11	6	0	147	153
12	0	-3	138	141
13	0	4	137	141
14	0	0	137	137
15	0	1	139	140
16	0	0	137	137

EXPERIMENT 1 INITIAL COND 2 SUBJ 5 PRED LENGTH 40

TRIAL	X	XDOT	TIME	PI
1	3	-6	162	169
2	-6	-3	153	164
3	0	4	143	147
4	-6	4	151	159
5	4	1	147	153
6	-4	0	144	148
7	2	2	148	143
8	0	-7	140	147
9	2	4	145	152
10	0	5	157	162
11	4	0	161	165
12	-2	1	158	160
13	9	-2	157	166
14	-4	1	154	158
15	4	-1	151	157
16	-1	5	153	158

EXPERIMENT 2 INITIAL COND 1 SUBJ 1 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	2	8	-48	232	375	658
2	0	-27	0	-12	305	45	389
3	-1	16	-2	-26	256	15	317
4	-6	0	-4	-26	224	0	263
5	2	15	-2	1	230	23	274
6	-9	-16	1	-10	235	78	354
7	8	10	-1	0	234	90	347
8	-2	12	-1	-5	241	0	260
9	0	22	0	-36	265	36	359
10	-6	20	0	-22	246	4	292
11	6	-5	-5	-20	255	24	316
12	-5	12	1	-40	250	27	330
13	3	2	0	-3	223	0	232
14	-2	-7	-1	0	225	0	236
15	0	12	0	-2	234	0	248
16	-1	10	0	2	217	0	229
17	0	4	0	-2	222	0	228
18	2	4	1	-1	228	0	237
19	2	20	1	0	217	2	243
20	-1	5	-5	0	215	8	231

EXPERIMENT 2 INITIAL COND 1 SUBJ 2 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	-4	0	4	263	150	421
2	1	-1	-1	0	249	90	341
3	-3	0	0	6	222	45	276
4	1	0	1	3	249	45	300
5	0	5	1	5	247	47	306
6	13	7	1	8	252	71	357
7	-2	3	-2	-1	227	50	284
8	0	8	1	2	230	60	302
9	-2	8	0	-7	265	0	280
10	-1	0	0	1	244	0	246
11	2	14	0	2	235	0	255
12	0	4	-2	-3	228	0	238
13	1	1	0	-1	238	0	242
14	0	7	0	6	224	0	237
15	1	7	0	-4	225	0	238
16	0	-10	-2	0	219	0	231
17	0	0	0	-3	215	12	230
18	2	10	0	-4	224	0	242
19	2	0	1	0	216	23	242
20	2	2	-1	1	240	8	252

EXPERIMENT 2 INITIAL COND 1 SUBJ 3 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	6	12	1	-4	294	45	365
2	0	-3	0	0	280	0	287
3	3	2	1	1	324	60	393
4	-8	-16	4	0	306	30	369
5	3	8	-1	-1	243	6	265
6	0	1	0	-1	231	0	233
7	-2	2	-1	4	210	42	259
8	-1	0	1	12	214	11	239
9	-1	1	-1	0	233	0	235
10	1	8	-2	-10	233	0	257
11	2	3	2	-1	229	0	237
12	2	7	1	2	217	0	231
13	1	6	1	0	213	0	222
14	-5	1	-1	0	231	24	261
15	0	4	0	-2	233	12	251
16	3	14	1	-5	238	0	263
17	2	10	2	0	220	0	236
18	-1	2	0	-2	224	0	228
19	0	0	-2	-3	219	0	225
20	-1	4	-2	-7	218	0	233

EXPERIMENT 2 INITIAL COND 1 SUBJ 1 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	0	0	-36	277	210	523
2	0	4	0	4	304	0	312
3	-3	8	-7	-20	242	0	283
4	-5	4	-4	-38	250	0	302
5	-2	38	-1	-50	221	8	319
6	-6	15	7	-40	236	3	297
7	2	14	-6	-7	238	24	296
8	-4	3	-4	-16	241	30	299
9	0	-4	1	-2	248	30	284
10	-8	10	1	-16	228	11	269
11	0	20	-1	-12	238	15	287
12	0	12	-5	-24	258	27	322
13	0	0	0	0	227	15	242
14	0	-2	0	0	237	6	245
15	1	8	2	2	231	0	246
16	7	-16	1	-10	241	0	269
17	0	2	0	-1	224	0	227
18	1	1	2	0	221	0	226
19	1	10	1	-1	214	5	232
20	0	0	1	2	217	12	233

EXPERIMENT 2 INITIAL COND 1 SUBJ 2 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	22	-3	-2	264	60	352
2	0	-13	-3	-2	268	60	347
3	-1	3	-1	-1	241	45	292
4	4	4	-1	-1	252	30	295
5	-2	5	0	0	250	48	304
6	0	0	0	-1	245	90	346
7	-1	8	0	0	229	48	285
8	-4	2	-1	-1	236	44	287
9	0	8	2	-1	216	0	226
10	-1	-1	1	-2	234	0	239
11	-1	-1	0	0	220	0	223
12	-2	-3	0	0	230	0	236
13	-1	3	0	-2	223	0	228
14	0	1	1	0	225	0	227
15	-1	-3	0	1	242	0	248
16	0	2	0	-1	218	0	221
17	0	-1	2	0	223	0	226
18	0	0	0	-2	218	0	220
19	0	2	0	0	234	0	236
20	1	3	1	1	221	0	228

EXPERIMENT 2 INITIAL COND 1 SUBJ 3 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	2	6	0	-6	295	60	371
2	0	0	0	0	269	45	314
3	-6	-4	-1	-2	281	0	297
4	-2	-12	0	-1	241	30	288
5	1	6	1	-1	254	0	263
6	-1	0	3	7	254	0	267
7	0	3	0	0	215	0	218
8	1	5	0	-1	228	0	236
9	0	6	0	-1	231	2	240
10	-1	-2	0	-1	226	0	231
11	6	10	0	-2	228	36	286
12	1	3	-1	-1	223	24	254
13	0	0	0	0	209	0	209
14	-1	-4	-1	-2	220	3	233
15	0	2	0	0	224	0	226
16	0	0	0	-2	230	6	238
17	-1	0	0	0	211	0	212
18	0	1	1	0	213	0	215
19	0	0	0	-1	218	0	219
20	0	0	0	-2	217	0	219

EXPERIMENT 2 INITIAL COND 2 SUBJ 1 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	0	0	-2	204	150	356
2	0	-2	6	-24	235	240	502
3	4	-5	4	-4	240	90	343
4	-6	12	0	-5	237	15	271
5	-5	32	0	-56	198	12	299
6	1	22	3	-9	212	0	246
7	-16	36	-2	-1	190	6	241
8	2	4	-1	0	220	0	228
9	3	6	0	8	245	78	352
10	-16	15	8	-24	179	39	268
11	-2	12	0	2	230	0	244
12	1	-12	2	1	240	15	271
13	0	1	0	5	218	0	224
14	0	-1	1	1	230	3	237
15	2	4	0	-5	219	0	231
16	-1	1	1	2	214	0	219
17	0	2	0	-2	216	0	220
18	0	-1	0	-2	206	0	209
19	1	9	0	-3	199	0	213
20	0	-6	-2	-12	205	0	227

EXPERIMENT 2 INITIAL COND 2 SUBJ 2 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	-5	-2	-2	241	15	266
2	8	-16	0	-4	246	30	298
3	4	3	2	-1	238	0	249
4	-3	-2	1	-7	221	15	249
5	-2	-1	0	-4	200	78	286
6	0	8	0	8	226	30	272
7	2	8	-2	-2	211	35	261
8	-1	0	1	-1	215	54	271
9	0	3	0	-4	215	26	248
10	2	10	0	-6	215	0	235
11	4	10	0	0	205	21	243
12	-1	8	-1	-4	221	18	253
13	1	4	1	-6	207	17	235
14	1	5	1	5	212	12	238
15	1	10	-1	0	215	0	228
16	2	6	-2	-2	206	0	220
17	0	0	1	-1	212	0	213
18	2	1	0	-1	211	0	216
19	-1	-1	1	0	229	0	233
20	0	2	2	3	216	0	224

EXPERIMENT 2 INITIAL COND 2 SUBJ 3 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	8	7	2	-2	266	15	303
2	4	12	0	6	307	30	362
3	0	-16	-1	1	266	15	298
4	-9	-7	0	1	249	0	270
5	0	-10	0	1	266	6	283
6	1	2	1	1	232	9	247
7	0	1	-2	-4	214	8	230
8	2	7	-1	2	233	20	265
9	3	4	-1	-4	234	2	240
10	-1	-5	2	7	221	0	238
11	3	4	1	-5	214	3	231
12	1	-1	-2	-7	229	5	246
13	1	6	0	1	208	0	217
14	1	1	-1	-1	214	0	219
15	1	6	2	0	216	0	226
16	1	2	1	0	208	0	213
17	1	0	0	0	202	8	211
18	3	-2	2	4	202	9	222
19	2	0	0	0	210	0	212
20	2	1	0	-2	204	3	213

EXPERIMENT 2 INITIAL COND 2 SUBJ 1 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	4	-18	-5	-28	244	60	360
2	-2	-4	0	-2	245	0	254
3	2	16	0	-3	248	0	271
4	-2	26	0	0	250	0	276
5	0	24	0	-20	167	14	225
6	5	8	1	2	225	12	257
7	-1	24	-1	-2	214	0	242
8	1	14	0	1	225	30	272
9	1	-4	-1	-1	240	2	249
10	-16	-4	-2	0	186	33	244
11	-1	4	0	-1	220	0	225
12	-18	26	14	-32	187	8	265
13	1	3	0	-2	215	2	223
14	0	1	0	-2	211	0	214
15	1	2	1	-1	228	0	233
16	0	2	0	-2	228	0	232
17	0	1	2	2	217	0	223
18	1	2	1	2	225	2	234
19	0	-1	1	0	195	5	202
20	2	8	0	-5	202	0	219

EXPERIMENT 2 INITIAL COND 2 SUBJ 2 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	-4	26	-4	-1	271	0	303
2	2	22	-2	-4	248	30	307
3	-1	4	1	-1	215	30	251
4	1	4	0	0	220	15	241
5	-1	4	1	0	203	8	216
6	-2	-4	-1	-2	220	36	267
7	-2	5	0	-1	207	27	241
8	-2	4	-1	-1	211	17	235
9	0	3	0	-2	227	8	240
10	-1	2	0	-1	212	0	215
11	-1	4	0	0	195	3	202
12	0	-2	-1	0	202	6	211
13	-2	1	0	0	222	0	224
14	1	5	0	-1	225	3	236
15	-1	1	0	0	211	0	212
16	-3	-4	0	0	202	2	212
17	0	2	1	-1	209	0	212
18	2	3	1	0	199	9	214
19	0	-1	1	0	203	5	210
20	0	0	1	1	199	0	202

EXPERIMENT 2 INITIAL COND 2 SUBJ 3 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	-2	-4	0	-4	246	30	287
2	0	4	-1	-3	315	30	354
3	-3	-16	-1	-3	217	30	273
4	-2	-4	0	-1	247	0	255
5	0	1	0	-1	245	3	250
6	0	-4	0	0	249	0	253
7	0	0	0	-1	213	0	214
8	0	1	0	0	225	6	232
9	-1	1	1	1	222	0	226
10	-1	-2	0	-1	205	6	216
11	2	5	0	-1	232	5	246
12	0	2	0	-1	197	0	200
13	-1	-7	0	-2	200	0	211
14	1	1	0	-2	200	0	204
15	0	-2	0	-1	212	0	215
16	0	2	0	0	210	0	212
17	2	1	2	0	201	5	211
18	3	4	1	0	192	21	223
19	0	0	0	-2	203	0	205
20	-2	-1	0	-1	206	0	211

EXPERIMENT 2 INITIAL COND 3 SUBJ 1 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	0	-4	2	228	15	248
2	0	-7	-16	8	322	0	348
3	-6	6	9	-38	256	15	320
4	-7	4	-3	30	240	0	284
5	4	0	-7	-24	257	45	342
6	0	0	1	-18	294	5	310
7	-16	22	16	-48	198	5	284
8	3	12	4	-12	229	42	301
9	-4	8	12	-26	221	3	263
10	0	10	8	-16	238	66	333
11	-8	12	8	-24	216	5	262
12	-7	14	-1	-20	217	9	264
13	0	4	-2	-3	243	0	253
14	0	5	-1	-5	223	26	260
15	4	20	1	1	248	0	278
16	0	10	1	-12	243	3	268
17	1	-3	1	10	236	15	266
18	2	10	1	1	244	18	278
19	0	20	0	-2	239	0	261
20	0	8	0	0	230	0	238

EXPERIMENT 2 INITIAL COND 3 SUBJ 2 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	-6	20	-4	6	263	90	404
2	0	-4	-2	-2	287	75	371
3	0	10	0	-8	292	30	340
4	2	16	1	0	279	15	315
5	0	10	0	6	289	39	344
6	10	-18	0	-5	251	72	352
7	0	10	-1	-1	231	18	262
8	-1	6	-1	0	245	4	256
9	4	5	0	1	250	16	278
10	1	-1	2	0	225	33	261
11	1	8	0	-3	234	21	268
12	-1	5	0	3	229	26	261
13	1	4	0	-2	243	15	266
14	-2	7	0	-5	231	27	270
15	-1	2	0	2	238	8	250
16	-1	1	-1	2	231	8	242
17	0	-2	0	-3	229	6	240
18	0	0	0	4	235	17	256
19	1	3	1	0	252	14	271
20	0	-2	0	-2	240	8	252

EXPERIMENT 2 INITIAL COND 3 SUBJ 3 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	0	-1	-4	298	30	334
2	0	-14	0	0	287	15	316
3	-2	8	0	-5	271	30	318
4	1	-4	0	-2	249	30	285
5	0	-3	1	-3	265	9	280
6	1	1	1	0	252	15	271
7	-2	0	-3	-1	253	21	281
8	2	0	0	1	243	15	261
9	1	-4	0	1	243	15	263
10	-1	-2	0	2	240	14	259
11	1	1	2	0	238	14	254
12	4	4	0	-1	248	11	270
13	2	9	0	-1	242	12	268
14	-3	-1	-1	-4	231	18	260
15	-1	6	0	0	241	24	271
16	1	6	0	-2	230	18	258
17	3	8	0	-2	233	11	259
18	1	5	1	0	228	9	245
19	4	10	0	0	235	0	252
20	0	1	0	-2	233	0	236

EXPERIMENT 2 INITIAL COND 3 SUBJ 1 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	0	-2	-10	296	0	310
2	0	-4	-1	-3	317	0	326
3	0	10	0	-6	275	0	291
4	-1	0	0	-4	262	0	267
5	-1	28	2	-16	251	0	295
6	-2	2	1	-16	218	42	279
7	-12	20	-3	9	264	0	298
8	-9	20	0	-14	244	5	286
9	-13	14	0	-20	230	5	275
10	3	32	-8	12	303	6	362
11	1	8	-1	-20	236	2	269
12	-2	16	6	-16	232	11	278
13	0	-1	0	-1	230	44	276
14	3	-12	0	-1	239	0	253
15	-1	3	1	-2	244	0	250
16	0	-3	0	-2	231	0	236
17	6	8	1	-1	230	0	248
18	0	22	2	1	238	0	264
19	2	26	1	-5	240	6	281
20	3	-10	0	0	232	0	242

EXPERIMENT 2 INITIAL COND 3 SUBJ 2 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	2	-3	-2	267	120	395
2	2	14	-2	-2	252	75	350
3	-4	-2	1	-2	244	60	314
4	-10	20	0	7	257	15	302
5	0	10	1	0	210	42	263
6	12	8	0	-1	240	78	344
7	-1	8	0	1	221	47	277
8	-3	10	-1	-1	230	18	261
9	1	0	1	0	255	30	287
10	0	1	1	0	220	38	260
11	-1	-1	0	-1	237	36	277
12	0	-3	-1	-2	253	41	300
13	-2	10	0	0	224	8	242
14	-1	2	0	-2	213	42	259
15	-2	4	0	0	246	5	255
16	0	2	0	-1	227	0	230
17	-1	0	2	-2	214	18	236
18	0	0	2	-2	228	5	236
19	0	0	1	0	252	9	262
20	-1	-2	1	-1	234	5	244

EXPERIMENT 2 INITIAL COND 3 SUBJ 3 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	-2	-4	0	-3	253	60	323
2	10	0	0	-2	270	75	357
3	-3	-8	0	-3	252	30	298
4	-1	-4	0	-1	247	30	284
5	1	2	1	0	253	6	264
6	-1	6	0	-2	252	12	272
7	2	-3	-1	0	262	8	274
8	1	5	0	-1	238	6	252
9	-1	2	0	0	244	3	249
10	-2	0	0	-1	241	15	259
11	1	1	0	-1	237	20	260
12	1	0	0	-1	249	8	259
13	0	0	0	-2	233	12	247
14	0	0	-1	-2	219	21	244
15	0	2	0	-2	225	8	237
16	-2	0	-1	-1	232	0	237
17	1	1	1	0	224	6	234
18	1	2	0	-1	226	5	235
19	0	1	0	-1	239	5	246
20	-1	1	0	-1	237	5	244

EXPERIMENT 2 INITIAL COND 4 SUBJ 1 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	1	1	-1	-1	269	0	274
2	0	-2	6	-20	254	60	337
3	-6	27	-2	0	259	60	349
4	-4	10	-5	1	226	0	242
5	-10	36	15	-5	179	32	265
6	-2	32	1	-36	201	23	292
7	-2	10	0	0	234	57	301
8	-8	8	10	-40	183	42	279
9	-14	10	9	-12	182	6	222
10	-14	2	14	-40	175	24	257
11	0	-2	0	-3	214	8	227
12	1	8	3	-2	215	8	237
13	-2	5	0	1	219	0	226
14	0	0	0	-6	220	6	232
15	4	8	0	-3	211	23	251
16	1	8	1	-2	227	2	241
17	0	10	0	-2	212	0	224
18	1	4	1	0	221	0	228
19	-1	8	2	4	204	0	225
20	-2	-4	1	5	208	0	222

EXPERIMENT 2 INITIAL COND 4 SUBJ 2 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	16	-4	-7	16	246	180	460
2	5	-13	-2	0	290	45	351
3	-8	8	0	3	262	15	292
4	2	8	0	0	239	0	251
5	-1	-8	-1	0	266	24	301
6	1	8	-1	-10	219	18	259
7	2	10	-1	-3	212	12	242
8	-1	4	-2	0	234	14	254
9	3	10	2	6	223	0	248
10	-1	8	0	0	221	3	232
11	-2	0	0	0	225	9	236
12	-2	-1	-1	-1	211	33	250
13	-1	2	-1	0	227	0	230
14	2	12	-2	9	222	2	249
15	-1	9	-1	4	211	3	227
16	3	9	-2	0	220	0	236
17	-1	3	1	-1	218	0	223
18	1	3	2	-2	213	17	237
19	0	5	0	-4	214	0	223
20	-1	7	0	-3	213	0	223

EXPERIMENT 2 INITIAL COND 4 SUBJ 3 PRED LENGTH 0

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	2	12	0	0	286	30	332
2	-5	-12	0	-1	231	30	283
3	-7	-15	2	-2	300	30	362
4	-12	-8	0	4	289	15	333
5	1	3	1	2	253	3	264
6	1	3	1	1	254	9	270
7	1	4	-5	-3	232	8	255
8	0	3	0	4	248	5	260
9	0	6	0	0	237	0	243
10	-2	-8	1	-1	230	5	248
11	0	-3	0	1	252	0	256
12	7	5	0	2	228	0	245
13	0	4	0	0	233	3	240
14	0	6	0	-3	229	2	240
15	-1	4	0	0	234	0	238
16	0	-6	0	-2	230	0	238
17	0	9	2	3	221	3	242
18	0	2	0	0	215	0	217
19	2	3	-1	-8	230	0	246
20	1	8	-2	-3	216	0	232

EXPERIMENT 2 INITIAL COND 4 SUBJ 1 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	0	-2	-1	-2	290	45	341
2	0	0	0	8	303	15	326
3	2	-1	-4	-2	296	45	351
4	4	-2	2	0	227	0	234
5	-11	8	6	-28	196	12	251
6	-2	4	0	-2	222	48	277
7	-7	20	0	-1	221	8	252
8	-20	6	11	-18	174	5	222
9	-1	8	-2	-1	257	18	287
10	-10	2	8	-20	179	27	239
11	0	2	-3	-18	230	2	257
12	-2	2	1	-1	232	0	236
13	1	4	0	-1	242	5	253
14	0	0	0	0	229	0	229
15	0	0	0	-2	200	23	225
16	2	18	2	2	230	0	257
17	-2	-1	0	-1	211	0	216
18	2	5	0	0	216	0	224
19	0	0	1	0	213	0	214
20	0	-4	0	-1	202	0	207

EXPERIMENT 2 INITIAL COND 4 SUBJ 2 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	38	11	-4	5	247	45	356
2	0	12	-4	-3	214	30	264
3	-1	-1	0	0	219	30	252
4	-2	6	0	-2	225	15	248
5	2	1	0	0	216	30	250
6	-2	1	-1	-2	223	26	265
7	0	10	0	0	221	27	258
8	-1	-2	0	-2	203	42	251
9	2	0	1	-2	237	0	241
10	0	-1	1	0	208	6	216
11	0	2	0	0	218	24	244
12	-2	-2	-1	-1	212	9	229
13	1	4	-1	-2	218	2	229
14	0	1	0	0	214	2	217
15	1	8	1	0	222	0	233
16	1	4	0	0	207	0	213
17	0	0	1	-1	209	0	210
18	2	6	1	0	207	0	218
19	0	9	1	-1	223	0	233
20	0	0	1	0	213	0	214

EXPERIMENT 2 INITIAL COND 4 SUBJ 3 PRED LENGTH 20

TRIAL	X2	X2D	X3	X3D	TIME	ITGL	PI
1	1	0	0	-2	244	30	277
2	-20	-31	0	1	285	30	379
3	-1	-6	0	-2	241	30	282
4	-1	-6	0	0	236	45	289
5	0	2	0	0	255	9	266
6	-4	-10	0	-1	255	12	285
7	0	0	-1	0	243	9	253
8	-1	1	0	0	236	24	261
9	-2	-4	0	-1	248	0	256
10	0	2	0	0	224	3	229
11	1	3	0	0	234	2	240
12	2	8	1	-1	220	2	235
13	-1	-2	-1	-2	222	3	232
14	0	0	0	-1	214	0	215
15	1	1	0	1	235	0	239
16	-1	0	0	-1	220	0	222
17	0	1	0	0	224	6	233
18	0	0	0	0	219	2	221
19	0	-3	0	-1	230	0	234
20	-1	-2	0	-2	210	0	216