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TOWER CONTROLLER SURVEILLANCE SYSTEM PARAMETERS

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16. Abstract A brief study of airport ground traffic control surveillance parameters has been conducted. The study addressed the following questions by means of a set of simple experiments: (1) Can vehicle ID be displayed in a suitable format; (2) What size display is required by ground controllers and by local controllers if their surveillance requirements are to be met; (3) What effect does viewing distance have on the size of the display required; and (4) What is the effect of update rate on the ability of controllers to extract velocity information.

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PREFACE

The work described in this report was performed at the Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts in support of the Airport Ground Traffic Control Program. This program is sponsored by the Federal Aviation Agency's Systems Research and Development Service.

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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Today, airport surface traffic surveillance by controllers is accomplished predominately by visual observation. However, eight airports in the United States have ground surveillance radar (Airport Surface Detection Equipment-ASDE II), a skin-track radar manufactured by the Airborne Instruments Laboratory. This radar is used by both local and ground controllers during poor weather and night operations. The general lowering of runway operating minimums and increasing traffic levels are increasing the number of additional airports having a requirement for an electronic surveillance system. The ASDE II, however, was designed twenty years ago, is no longer in production, and no longer represents the best system that technology can provide in terms of performance, reliability, or cost. Therefore, the Transportation Systems Center (TSC) has been given the responsibility to develop an airport surface surveillance system to replace the ASDE II.

In generating the system specifications, TSC's Airport Ground Traffic Control (AGTC) Project Office conducted a preliminary AGTC surveillance system requirements analysis.[1] This analysis established what surveillance information is required by tower controllers and to what extent a display can provide this information.

This study directly supports this requirements analysis and is centered around experiments designed to provide performance data to answer the following questions quantitatively:

a. What size surveillance display is required by ground and local controllers?

b. What effect does viewing distance have on the display size required?

c. What effect does update rate have on the controller's ability to extract velocity information?

1.2 TOWER CONTROLLER SURVEILLANCE DISPLAY SIMULATION

This study was based on a set of simple experiments conducted on the in-house Tower Controller Surveillance Display Simulation.[2] The simulation facility consisted of a PDP-10 digital computer which interfaced through a Honeywell 516 digital computer to a Sanders ADDS-900 display. This is a direct view, 21-inch display that uses a P-31 phosphor. The simulation program generated an outline map of Logan International Airport and permitted aircraft symbols to be generated and routed through the ramp/taxiway/runway system either manually by teletype or automatically by a scenario file. The size of the background map and of the displayed aircraft symbols could be varied as well as the update rate of the display.

1.3 LIMITATIONS

The limited time available to conduct the experiments led to the following general experimental limitations:

a. The two engineers who designed the experiments served as the operators and tested one another;

b. Only a small amount of performance data was collected for each experiment;

c. The experimental display was a direct view type, and no attempt was made to determine the effect that a raster display would have on the results;

d. No attempt was made to duplicate the ambient lighting conditions found in the tower CAB or the display brightness that a *bright* surveillance display would operate at in the tower.

Although the operators were not naive, they made every attempt to make honest responses. Whenever a particular test was remembered by an operator, that test was passed over and no data was collected. Although the experiments generated less data than was desired, they were straightforward and the statistics sought were of a gross nature meant only to give an indication of performance. The experiments were conducted in a room lighted by indirect fluorescent lighting. The ambient lighting at the face of the display was 30 ft. candles. The display brightness level was adjusted to each operator's convenience. It was estimated that the display's brightness level was in excess of 50 ft. lamberts during the experiments.

1.4 SUMMARY

Three display parameters were examined - display size, viewing distance, and update rate. A set of three experiments were conducted determining the effects of target heading, position, and identification discrimination on display size and viewing distance. Two operators served in the experiments. A fourth experiment was conducted determining update rate effects on velocity extraction. Three operators served in this experiment. The results, briefly and in general, were as follows:

1.4.1 Display Size and Viewing Distance

Under the experimental conditions, it was found that an operator could discern target heading, identification, and position to the extent required by the ground and local controller positions, when the operator was within three feet of a 12-inch display at airports of 12000-foot diameter (average) or of a 16-inch display at airports of 18000-foot diameter (large). Extending the viewing distance to four feet required the size of the displays to be increased to 16-inches at 12000-foot diameter airports and to 21-inches at 18000-foot diameter airports.

1.4.2 Update Rate

It was hypothesized that as update rate goes from displaying continuous aircraft movement to increasingly discrete movements, controllers would find it increasingly more difficult to extract velocity information from a display. This, in turn, would affect the controller's ability to use a display for monitoring potential conflicts[1], such as assessing the situation in which two aircraft are coverging on the same intersection. An experiment examining how update rate affects an operator's ability to extract velocity information from a display was conducted. This experiment required the operator to extract the relative velocity of two converging targets and then make a judgment as whether or not the two targets were in conflict for possession of the intersection. The operator was permitted a five-second decision period, and performance data was taken for update rates of .2, .5, 1 and 4 seconds. The experiment's results indicated that (to a surprising degree) the ability to do this task was independent of update rate. The performance was approximately the same for the .2, 1 and 4 second update rates. An exception to this relatively flat performance curve occurred at the .5 second update rate, where the performance of each of the operators was sharply lower. A conclusive explanation for this dip in performance has not been found.

2.0 PARAMETER STUDIES

2.1 DISPLAY SIZE AND VIEWING DISTANCE

2.1.1 Introduction

To establish the surveillance display size required (by tower controllers), it was first necessary to determine the display scale range for such a system. Display scale is the ratio of display size to surveillance area. There are three standard display tube sizes available - 12-inches, 16-inches, and 21-inches in diameter. This display size range goes from the smallest that could provide the surveillance information required to the largest that could fit into the limited space provided in the control tower. Surveillance areas vary with the airport size and controller type. Table 1 presents the maximum dimension across the taxiway/runway system of the nation's larger airports. 18,000 ft. was taken as representative of large airports. Boston's Logan International Airport was taken as a medium airport example and has a dimension of 12,000 ft. Since the surveillance area for the ground controller is the taxiway/runway system, it has the diameter range of 12,000 to 18,000 ft. The local controller's concern with runway clearance expands his surveillance area to include the final 4,000 ft. of the approach path to the active runway.[1] If this

TABLE 1. THE SIZE OF VARIOUS LARGE AIRPORTS

Airport	Maximum Dimension Across The Taxiway/Runway System
Los Angeles International	18,500 ft.
Greater Pittsburgh	18,000 ft.
Kennedy International	17,000 ft.
O'Hare International	16,000 ft.

length is added directly to the airport's diameter, then the local controller requires a surveillance area ranging from 16,000 ft. at medium sized airports, to 22,000 ft. at large airports. The display scales examined involved the possible use of all three tube sizes by the ground and local controllers at medium and large airports for a total of twelve conditions.

Next, it was necessary to establish the possible distances the controllers would view the display. Ideally, the controller would be within three feet of the display. This may not always be possible due to the limited space available in the tower. It was expected, however, that the controller would be within six feet of the display and certainly within twelve feet. These three viewing distances were examined.

Next, it was necessary to establish display scale and viewing distance combinations that would satisfactorily provide the surveillance information required. This study's purpose was to determine this relationship for the surveillance system requirements - target heading discrimination, target position resolution, and target identification discrimination.[1]

2.1.2 Target Heading Discrimination Experiment

2.1.2.1 Purpose - Maintaining traffic flow and monitoring potential conflicts are the most critical tasks for which ground controllers require course information.[1] One method of displaying course directly is to use a directional aircraft symbol. This experiment's purpose was to examine the effects of display scale and viewing distance on an operator's ability to discern the aircraft symbol's heading shown in Figure 1. Two TSC engineers served as operators.

2.1.2.2 Display Details - The experiment was set up on the Tower Controller Surveillance Display Simulation described in Section 1.0. The experiment consisted of 22 surveillance situations. Each situation consisted of three stationary aircraft located at various points on the airport's surface. The symbols were stationary to prevent the operator from using symbol course information to establish heading. The three aircraft symbols had either a north, south, east or west orientation. Twenty-two surveillance situations were made by combining 15 possible situations. No situation occurred more than twice during the experiment.

Figure 1. Aircraft Symbol Used in Experiments

There were twelve possible display condition combinations (four display scales and three viewing distances).

The display scales examined were for an aircraft symbol 100 ft. in length in a:

a. 16-inch display for a ground controller at a medium sized airport;

b. 21-inch display for a ground controller at a large airport;

c. 16-inch display for a ground controller at a large airport;

d. 12-inch display for a ground controller at a large airport.

Assigning a lower bound on the symbol's size that was expected to provide heading information, it was assumed that any vehicle under 100 ft. in length could satisfactorily be represented by a 100-ft. symbol. If this proves invalid, then these smaller vehicle's will not be readily detectable by the controller. The viewing distances examined were 3, 6, and 12 ft.

2.1.2.3 Operators - The operators were the two TSC engineers who designed the experiments. These operators served for the remaining experiments in this study. Both operators had 20/15 vision.

2.1.2.4 Procedure - There were 12 problems, each one having one display scale and one viewing distance. Two surveillance situations were run during each problem. Both operators saw the same sequence of situations. The problems were presented from the largest display scale to the smallest; first at a viewing distance of 3 ft., then at 6 ft., and finally at 12 ft.

Each operator was instructed to look away from the display until the next surveillance situation was displayed. This procedure prevented the operator from obtaining target location and orientation information by their movements from former positions to new positions. For each surveillance situation, the operator stated the target's location and orientation.

Due to the task's simplicity the operators were not given any training before performance data was collected. The experiment was run for both operators in one evening. The only break taken was at the experiment's completion by the first operator. Each operator was in his operating position before a problem started, and remained so for the entire problem.

2.1.2.5 Data Collection - Manually collected data were:

a. The operator's identifying the displayed aircraft symbol's location and heading;

b. The operator's comments concerning his degree of confidence in correctly discerning the aircraft symbol's heading for that particular problem.

The confidence scale was:

- absolute confidence - the chances of error are remote
- high confidence - errors could occur on occasion

- low confidence - frequent errors are to be expected

2.1.2.6 Results - The results of the Heading Discrimination Experiment are presented in Figure 2. Each problem is defined by a particular viewing distance and display scale combination. The various display scale values noted by the triangles represent a 100-ft. aircraft symbol on the three display sizes available for a ground controller display at medium sized and large airports. For each problem that data was collected, the results are shown as the percentage of correctly identified headings and the operator's identification confidence factor.

The critical parameter that characterizes the operator's performance and identification heading confidence is the angle subtended by the aircraft symbol at the observer's eye. The task's difficulty remains unchanged as the operator moves away from the display if the display scale changes such that the apparent size of the aircraft symbol remains unchanged to the observer's eye (i.e., the angle subtended by the symbol remains constant). This parameter is the right hand scale in Figure 2 and it unites the problem's results and permits these results to be projected for other combinations, such as the 21-inch Logan ground controller display and for viewing distances other than 3, 6, and 12 ft.

The 6 arc/min. target seems to represent the break point in the operator's confidence to discern heading. For larger targets, the operators had absolute confidence and made few errors. For smaller targets, the operators' confidence rapidly declined. For targets only slightly smaller than 6 arc-min., the errors were still few although confidence was low. With the 4 arc-min. target, the operators made a substantial number of errors.

2.1.2.7 Limitations - The limitations of this experiment are similar to those described in Section 1.0.

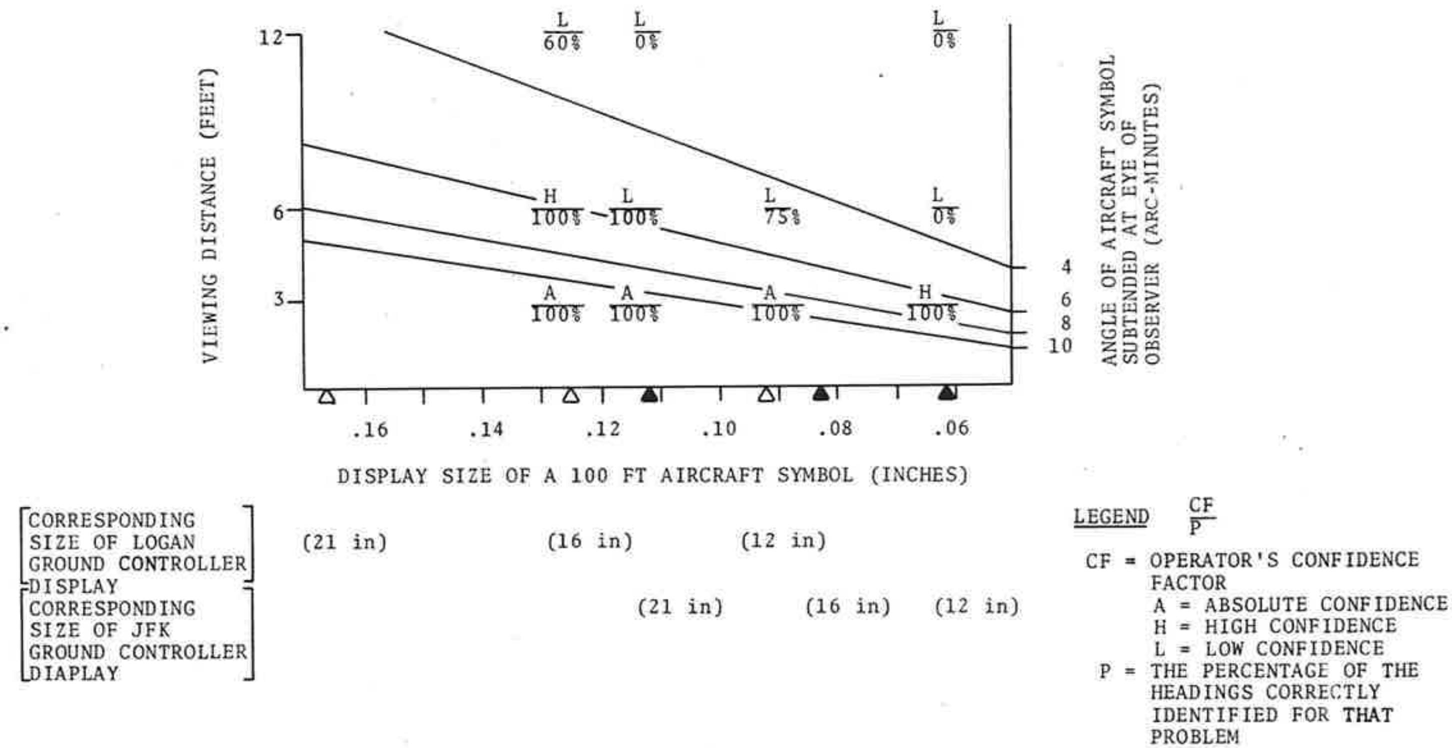


Figure 2. Results of the Target Heading Discrimination Experiment

2.1.2.8 Conclusions - Under the experimental conditions, an operator can readily discern heading of an 8 arc-min. aircraft symbol (i.e., an eighth inch symbol seen from 4.5 ft.) This is somewhat conservative because it is 30% larger than the 6 arc-min. target below which operator confidence deteriorates. The relationship between display size and viewing distance for an 8 arc-min. target, is presented in Table 2.

TABLE 2. RELATIONSHIP OF MAXIMUM VIEWING DISTANCE TO DISPLAY SCALE FOR HEADING DISCRIMINATION OF A SCALED 100 FT. AIRCRAFT SYMBOL

Display Scale	Maximum Viewing Distance
Ground Controller at	
Medium Sized Airport with	
21-inch display	6.0 ft.
16-inch display	4.5 ft.
12-inch display	3.0 ft.
Large Sized Airport with	
21-inch display	4.0 ft.
16-inch display	3.0 ft
12-inch display	2.0 ft
Local Controller at	
Medium Sized Airport with	
21-inch display	4.5 ft.
16-inch display	3.5 ft.
12-inch display	2.5 ft.
Large Sized Airport with	
21-inch display	3.0 ft.
16-inch display	2.5 ft.
12-inch display	1.5 ft.

2.1.2.9 Recommendations for Further Study - This experiment's results are preliminary because there were only two operators, these operators were the two engineers who designed the experiment, and the experiment's results pertain only to the experimental environment. In addition, future experiments should investigate other symbol formats from which heading may be more easily distinguished.

2.1.3 Position Resolution Experiment

2.1.3.1 Purpose - If ground and local controllers are to detect when an aircraft is blocking an intersecting taxiway or runway, high positional accuracy is required.[1] If high positional accuracy is required, Reference 1 calls for a display resolution that a 20 ft. separation between the nose of a holding aircraft and a reference line is detectable. This experiment's purpose was to examine an operator's ability to detect this 20 ft. gap as a function of display scale and viewing distance. Two TSC engineers served as operators.

2.1.3.2 Display Details - The experiment was set up on the Tower Controller Surveillance Display Simulation (Section 1.0). The experiment consisted of 40 situations. Each situation consisted of a stationary aircraft with its nose located either 20, 40, or 60 ft. in front of or over the leading edge of a reference line.

The problems examined were for the local controller at a large airport with a:

1. 16-inch display and a viewing distance of 3 ft.
2. 16-inch display and a viewing distance of 6 ft.
3. 21-inch display and a viewing distance of 12 ft.

Due to the limited time available for the experiment, only the local controller display scale was examined.

2.1.3.3 Procedure - Twelve situations were run for three problems. The sequence of situations were different for each of the three problems and operators. The problems were presented in a sequence that progressed from a viewing distance of 3 ft., 6 ft. and 12 ft.

As in the previous experiment, each operator was instructed to look away from the display whenever a new surveillance situation was to be input. After a couple of seconds of observation, the operator stated that the aircraft symbol was either *clear* of the reference line or over the reference line thereby *not clear* of the runway.

The operators were given a number of trial situations before performance data was collected. The experiment for both operators was conducted in one afternoon. The only break taken came at the completion of the experiment by the first operator. Each operator was in his operating position before a problem started, and remained there for the entire problem.

2.1.3.4 Data Collection - The operator's assessment of each situation was manually recorded.

2.1.3.5 Results - The results of the Position Resolution Experiment are presented in Figure 3. The general format for presenting the results is similar to that described in the Target Heading Discrimination Experiment. The results are shown as the percentage of runway hold situations, involving a 20 ft. separation between the nose of the aircraft symbol and the reference line, correctly called by both operators.

Figure 3 shows that a 20 ft. gap on the airport's surface was readily detectable if it appeared as a .75 arc-min. gap on the display.

2.1.3.6 Limitations - The experiment's limitations are similar to the general limitations discussed in Section 1.0.

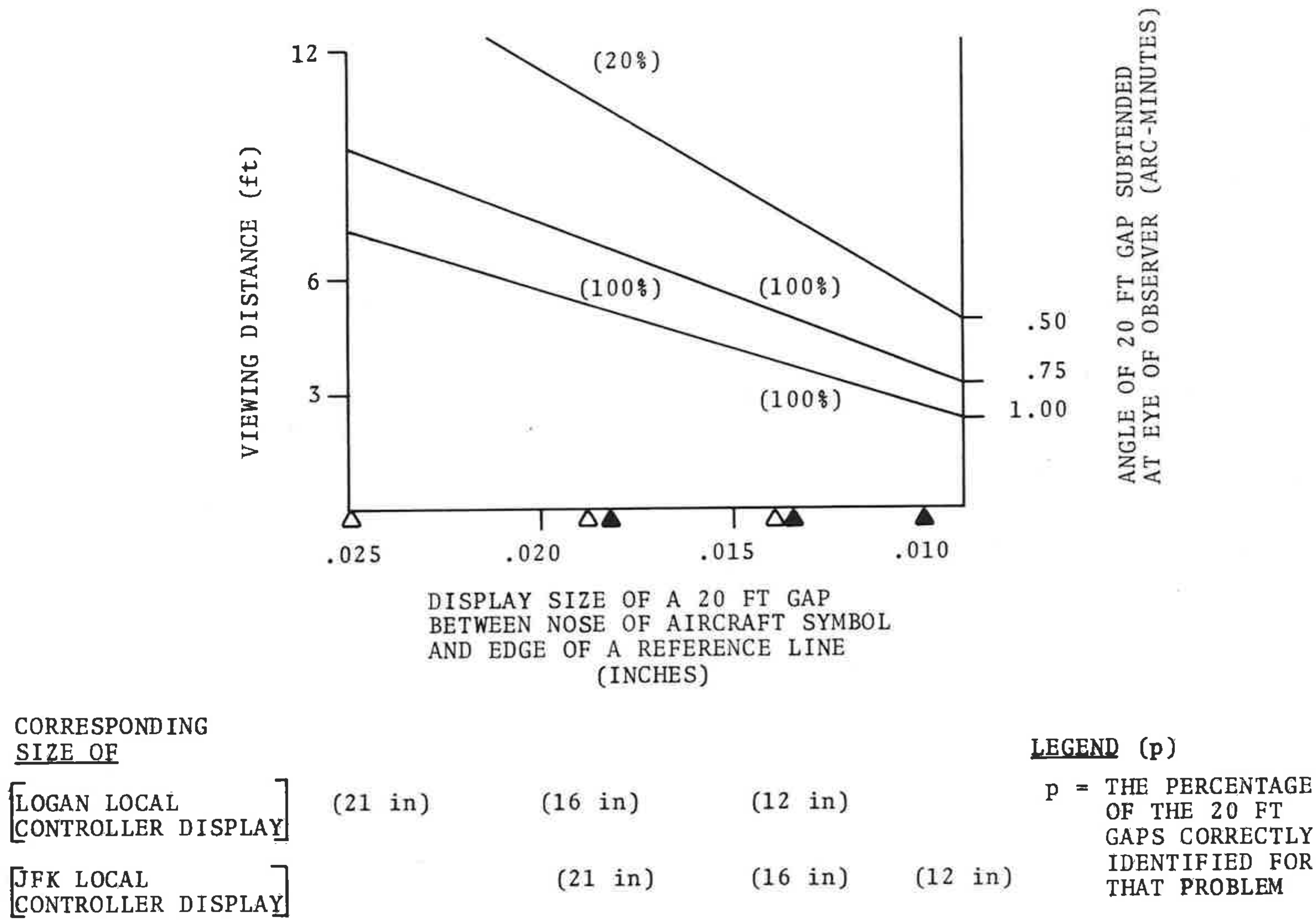


Figure 3. Results of the Position Resolution Experiment

2.1.3.7 Conclusions - Under the experimental conditions, an operator can readily detect a 20 ft. gap when it is represented by a 1 arc-min. gap on the display. For a 1 arc-min. gap, the relationship between display size and viewing distance is presented in Table 3.

TABLE 3. RELATIONSHIP OF MAXIMUM VIEWING DISTANCE TO DISPLAY SCALE FOR TARGET RESOLUTION OF 20 FT.

Display Scale	Maximum Viewing Distance
Ground Controller at	
Medium Sized Airport with	
21-inch display	9.5 ft.
16-inch display	7.0 ft.
12-inch display	5.0 ft.
Large Sized Airport with	
21-inch display	6.5 ft.
16-inch display	5.0 ft.
12-inch display	3.5 ft.
Local Controller at	
Medium Sized Airport with	
21-inch display	7.0 ft.
16-inch display	5.5 ft.
12-inch display	4.0 ft.
Large Sized Airport with	
21-inch display	5.0 ft.
16-inch display	4.0 ft.
12-inch display	3.0 ft.

2.1.3.8 Recommendations for Further Study - The recommendations for further study are similar to those discussed in the Target Heading Discrimination Experiment.

2.1.4 Target Identification Discrimination Experiment

2.1.4.1 Purpose - Positive target identification on a surveillance display would make traffic control easier by correlating the controller's visual and voice contacts with the vehicles under his control.[1] This experiment examined display scale and viewing distance effects on an operator's ability to discern target ID. Two identification schemes were considered. Two TSC engineers served as operators.

2.1.4.2 Discussion - An obvious basis for a target identification scheme is the one used in the ARTS display. An ID tag moves along with the target and is associated with it through a leader. A possible version of an airport surface display is shown in Figure 4 and shall be referred to as the Off-Symbol ID format. Relative to terminal airspace with which the ARTS surveillance system is concerned, the traffic density on an airport's surface will be higher.

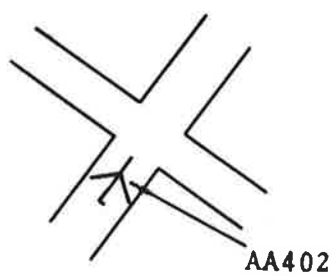


Figure 4. Off Symbol ID Format

These higher traffic densities may cause difficulties in the use of an ARTS-like identification tag, for example: (1) the tags obscuring one another, (2) the tags obscuring nearby vehicles, and (3) tag leaders crossing and confusing the target ID association. Another possible display clutter source may be the airport's extensive background map which may obscure and be obscured by the ID tags.

A possible alternative is shown in Figure 5 and is referred to as the On-Symbol ID format. This scheme minimizes clutter associated with the Off-Symbol ID format by replacing the simple aircraft symbol by an identity symbol consisting of two alphanumerics and a pointer that circles about the ID tag to indicate course.

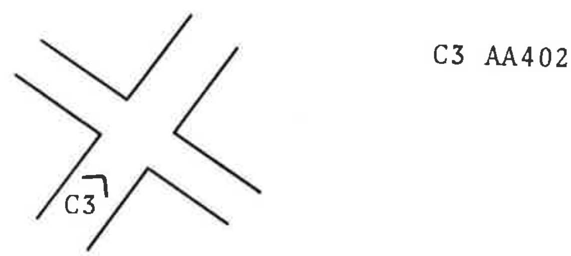


Figure 5. On Symbol ID Format

Correlating target ID with the actual aircraft ID can either be made manually by the controller with a grease pencil on the appropriate flight strip or electronically on the side of the display. This format, however, severely constrains the size of the alphanumerics that could be used. If the controller is expected to use the target symbol to carry out tasks requiring high accuracy position information, such as using the display to determine when a holding vehicle is blocking an intersecting taxiway or runway, then the symbol's scaled size must closely approximate that of the vehicle it represents.[1] To establish a reasonable lower bound on the alphanumeric's size that the controller will use with this format, it was assumed that all vehicles under 100 ft. in length could satisfactorily be represented by 100-ft. target symbols.

If this proves invalid, then these smaller vehicles will not be identified, at least by this format. Consequently, the smallest target symbol using this format will have its course indicator (the pointer) describe a circle 100 ft. in diameter. This corresponds to a scaled 50-ft. alphanumeric height. To permit somewhat large alphanumerics to be used, a second case was examined in which the width of the ID tag itself, excluding the pointer, was permitted to be 100 ft. This corresponds to a scaled 67-ft. alphanumeric height. The actual implementation of this second case may require some additional logic to eliminate the symbol pointer in those situations that prove confusing.

The suitability of both these formats was in question. Concerning the Off-Symbol ID format, the alphanumeric's size in the ID tag was unknown but was believed to relate to the amount of clutter that would be caused by these tags. The larger the display area each tag covered, the more the tags masked other vehicles and themselves. The On-Symbol ID format reduced the clutter problem but alphanumeric's size was severely constrained and was quite small. This study attempted to assess these two format's suitability by the means at hand, observation and a simple experiment.

2.1.4.3 Off-Symbol ID Format - This format simulation was not available in-house and time did not permit the necessary software modifications to be made. A version of this format existed in a simulation very similar to the one described in Section 1.0 at the Bolt, Beranek and Newman (BB&N) facilities in Cambridge. These facilities were made available to TSC engineers to observe the BB&N version in operation.

The 13- by 14-inch BB&N display was filled by a non-scaled map of Logan. The map was less bright than the targets, ID tags, and leaders. The ID tags were located approximately 1/2 inch from the associated target and consisted of five alphanumerics 3/16 inch high. The leaders stopped approximately 1/32 inch from the target. A tag could be located in any one of four positions relative to its associated target - at 45, 135, 225, and 315 degrees. The actual position of each tag was controlled by a logic designed to reduce the occurrances of over-lapping tags. The logic tested to determine which, if any, tags were over-lapping; and if the test was positive, the logic would position one of the interfering tags into another quadrant about its target.

The following observations of the BB&N Off-Symbol ID format were made. The reduced brightness of the airport layout is a recommended feature that permits the tags to overlay the background without being obscured. Associating the tag with the target by means of a leader appears to represent no serious problem. Over-lapping tags obscured both tags but the quadrant logic designed to prevent this seems adequate. Whenever a tag masked a target, both were obscured. Perhaps the quadrant logic could be extended to prevent this situation. A queue of ten targets was observed and looked manageable. The observers concluded that the Off-Symbol ID format shows definite promise and it is possible that ID tags in this format may use alphanumerics of up to 3/16 inch high for 16-inch ground controller display at medium sized airports.

2.1.4.4 Letter Discrimination Experiment - To determine display size and viewing distance effects on the basic readability of electronically generated upper case letters, a simple experiment was conducted in which the operators attempted to identify various size letters. There were twelve possible display combinations used (6 letter sizes and 2 viewing distances). The letter sizes examined approximated those required by the On-Symbol ID format - .083, .074, .060, .054, .042, .031 inches. The viewing distances examined were 3 and 6 ft. Each combination was called a problem.

The procedure consisted of each operator identifying a sequence of upper case letters presented, one at a time, on the display described in Section 1.0. Ten letters were presented during each problem. The letters varied from problem to problem and a sequence of letters was never repeated. Both operators went through the problems in the same order, proceeding from the largest to the smallest letter size first at a viewing distance of 3 ft., then 6 ft. Each operator was in his operating position before a problem started, and remained there for the entire problem. The operators were the two TSC engineers that were used in each of the other experiments.

The results are presented in Figure 6. For each problem the results are shown as the percentage of letters correctly identified. The bound on reliable performance occurs near letter sizes of 6 arc-minutes.

2.1.4.5 Conclusions - The relationship between display scale and viewing distance for the two ID formats is presented in Table 4. This relationship is: based on the experimental result that two operators, under the experimental conditions, readily identified single upper case letters 8 arc-min. high; based on the assumption that the smallest targets using the On-Symbol ID format will be 100 ft. in length, corresponding to scaled alphanumeric heights of 50 ft. and 67 ft.; and based on the observation that 3/16 inch alphanumerics may prove satisfactory for use by the Off-Symbol ID format in the case of the 16-inch ground controller display at medium sized airports, which scales to an alphanumeric height of 150 ft. The Off-Symbol ID format is preferable because it permits alphanumerics two to three times the size permitted by the On-Symbol ID format. Table 4 does not consider the possible clutter effects due to the formats themselves or due to the formats being used in a display containing a background airport map, targets, or other tags, on the basic readibility of these two ID formats.

2.1.5 Summary

This study has examined the effects of target heading, position, and identification detection on the size of the surveillance display required and the distance at which the display can be viewed. The limited time available for this examination required that the substantiating experiments were neither extensive, exhaustive, nor conducted under conditions similar to those in a control tower. The experiments indicated that an observer can readily detect the separation of an aircraft symbol from a reference line when that separation is greater than 1 arc-min. and can readily

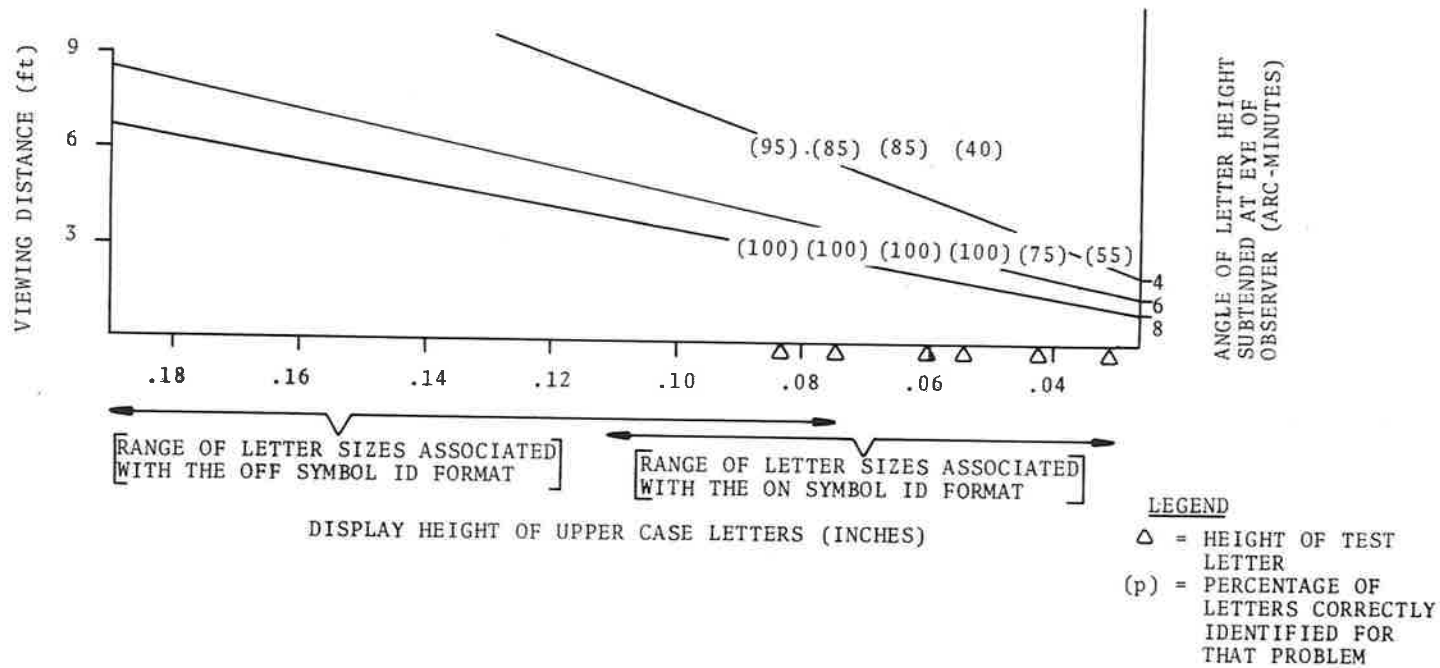


Figure 6. Results of the Letter Discrimination Experiment

TABLE 4. RELATIONSHIP OF MAXIMUM VIEWING DISTANCE TO DISPLAY SCALE FOR TWO TARGET IDENTIFICATION FORMATS

Display Scale	Scaled Alphanumeric Height 150 ft.	67 ft.	50 ft.
Ground Controller at			
Medium Sized Airport (Logan) with			
21-inch display	9.0 ft.	4.0 ft.	3.0 ft.
16-inch display	6.5	3.0	2.0
12-inch display	4.5	2.0	1.5
Large Sized Airport (JFK) with			
21-inch display	6.0	2.5	2.0
16-inch display	4.5	2.0	1.5
12-inch display	3.0	1.5	1.0
Local Contoller at			
Medium Sized Airport (Logan) with			
21-inch display	6.5	3.0	2.0
16-inch display	5.0	2.0	1.5
12-inch display	3.5	1.5	1.0
Large Sized Airport (JFK) with			
21-inch display	4.5	2.0	1.5
16-inch display	3.5	1.5	1.0
12-inch display	2.5	1.0	0.5
Corresponding Identification Formats	Off Symbol	On-Symbol	

identify symbols, such as the heading of an aircraft symbol and alphanumerics, when they subtend an angle of 8 arc-min. or more at the eye of the observer.

The implications of these findings for the ground controller are shown in Figure 7. The figure shows that target identification detection using the On-Symbol ID format is the surveillance parameter that most severely limits viewing distance. This is followed in order by: (1) the detection of heading of 100 ft. aircraft symbols, (2) the detection of target identification using the Off-Symbol ID format and (3) 20 ft. position resolution. If target identification is by means of the Off-Symbol ID format, the limiting factor becomes heading detection. In this case, Figure 7 shows that an operator, under the experimental conditions, can readily discern target heading, identification, and position with a 12-inch diameter display for medium sized airports and with a 16-inch diameter display for large airports if the operater is within 3 ft. of the display. Increasing the display size to 16 inches and 21 inches respectively will extend the viewing distance to 4 ft.

The ability to detect target heading is not required by the local controller[1], leaving target identification by means of the Off-Symbol ID format as the limiting parameter on viewing distance. In this case, Figure 8 shows that an operator, under the experimental conditions, can readily detect target identification and position with a 12-inch diameter display at medium sized airports and with a 16-inch diameter display at large airports if the operator is within 3 ft. of the display. Once again the viewing distance can be extended to 4 ft. if the size of the displays are increased to 16 inches and 21 inches respectively. If the requirement for target identification is dropped, leaving position resolution as the critical parameter, the relationship of viewing distance to display size remains essentially unchanged.

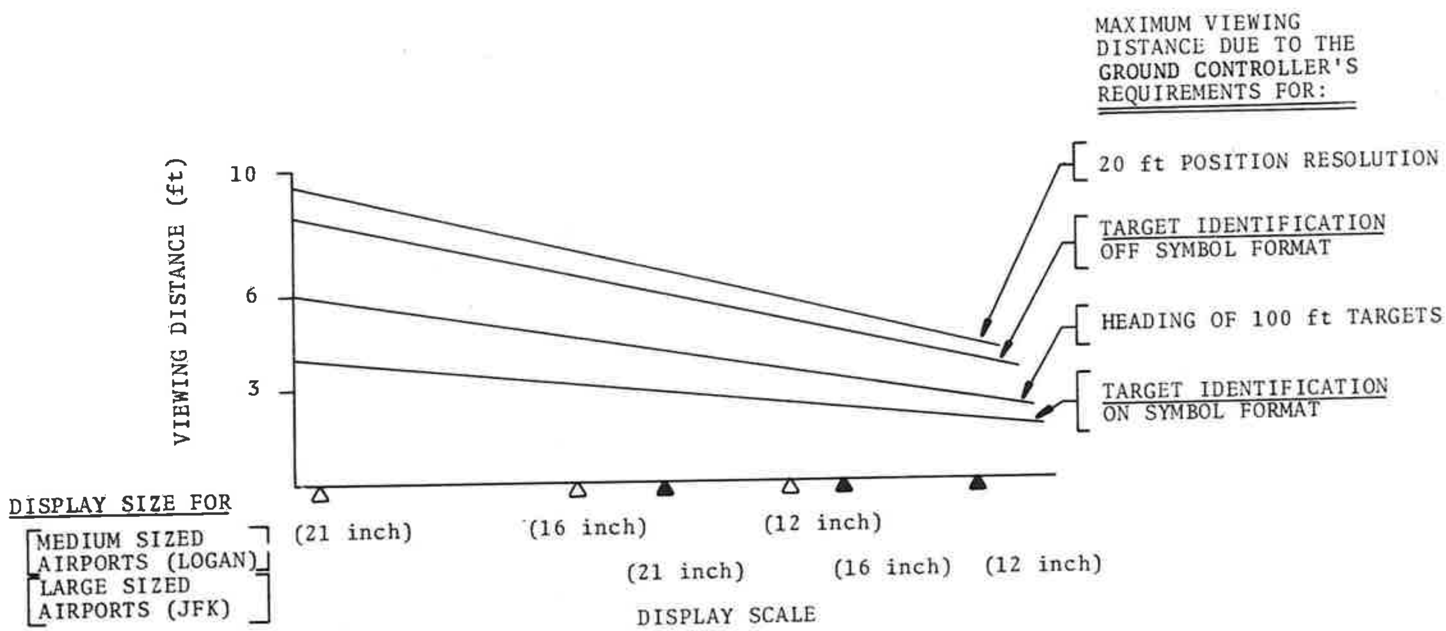


Figure 7. Maximum Viewing Distance to Display Scale Relationship for the Ground Controller Surveillance Display

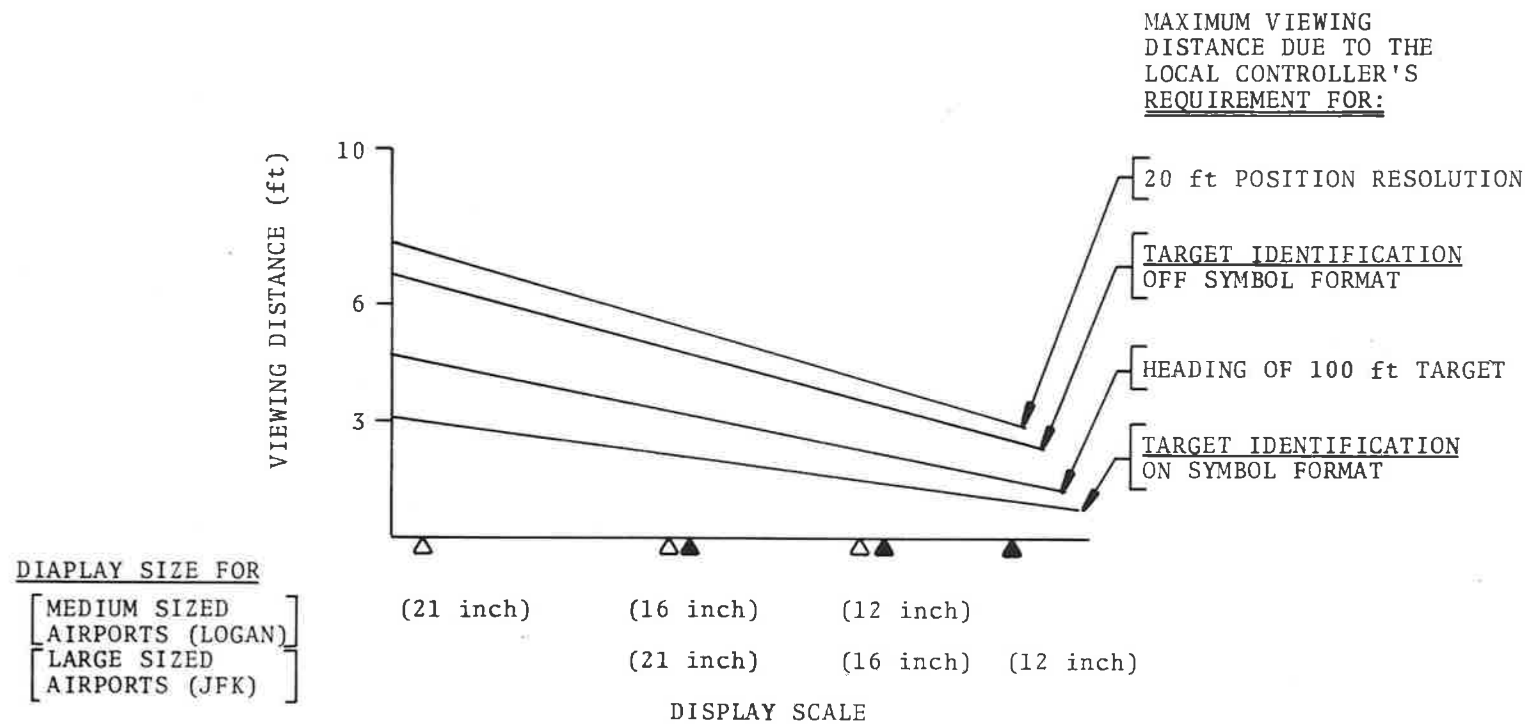


Figure 8. Maximum Viewing Distance to Display Scale Relationship for the Local Controller Surveillance Display

2.2 UPDATE RATE

2.2.1 Velocity Extraction Experiment

2.2.1.1 Purpose - It was hypothesized that as update rate goes from displaying continuous aircraft movement to displaying increasingly discrete movements, controllers would find it increasingly more difficult to extract velocity information from a display. This, in turn, would affect the controller's ability to monitor for potential conflicts, such as assessing the situation in which two aircraft are approaching the same intersection on converging taxiways.[1] This experiment examined the extent update rate affects an operator's ability to extract velocity information from a display. The experiment was built around the intersection conflict detection task. Three TSC engineers served as operators.

2.2.1.2 Discussion - Monitoring intersection conflicts, the controller has to determine whether an approaching aircraft will clear the intersection with a sufficient time margin to ensure safety. Time margin is defined as the time between the first aircraft clearing the intersection and the second aircraft entering the intersection. At a minimum, the controller will base his assessment of the potential conflict on the two aircraft's position relative to the intersection. In this case, the controller can make his decision quickly by simply assuming an arbitrary strategy, such as the aircraft closest to the intersection has the right of way, and then issuing a "give way" command to the other aircraft unless it is so far back relative to the first aircraft that it has little chance of overtaking it in the intersection. If the controller wants to reduce the number of aircraft that must be controlled at intersections, velocity information is required. Using both velocity and position, the controller can more readily predict the possibility of an unsafe condition and therefore can permit aircraft to freely operate in the intersections on smaller time margins. Reducing the number of times a controller must actively control traffic unnecessarily in an intersection, reduces the load on the VHF communication channel, reduces pilot workload, and contributes to smoother traffic flow.

To estimate the sensitivity of the number of intersection conflicts perceived by a controller to the time margin which he operates an intersection, a brief analysis was made and is presented in Appendix A. The analysis indicates that if a 10-second time margin is required to confidently control traffic in an intersection, the controller will react 10 times as often as required. This sensitivity makes the availability of adequate velocity information on a surveillance display highly desirable.

2.2.1.3 Display Details - The experiment was set up on the Tower Controller Surveillance Display Simulation described in Section 1.0. The experiment consisted of ninety computer runs. Each computer run consisted of two aircraft symbols on converging taxiways moving towards the same intersection and represented a possible conflict situation. The geometry of the displayed conflict situation is shown in Figure 9. To reduce the operator's skill required in this experiment, both targets' velocities were kept constant for

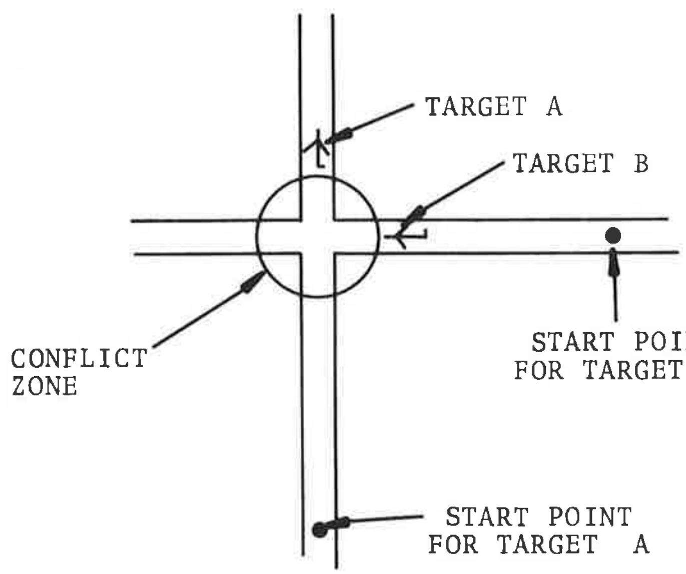


Figure 9. Display Geometry Used in the Velocity Extraction Experiment

each computer run and the velocity of Target A remained fixed for the entire experiment at 19 Kts. This is representative of the mean velocity of an aircraft taxiing along a straightaway.[3] The velocity of Target B varied from run to run and ranged from 8.5 Kts, which is representative of the mean velocity for an aircraft under tow[3], to 19 Kts. The point at which the two targets started each run was 630 ft. from the common intersection's center and remained fixed for the entire experiment. This distance was obtained by looking at the case in which a controller finds it necessary to issue a "hold short of the intersection" command to an aircraft taxiing at 19 Kts. To be considered clear of the intersection operationally, the aircraft must come to a full stop 125 ft. from the center of the intersection. The assumptions that the aircraft would decelerate at 5 ft/sec^2 and that it would take on the order of eight seconds to issue the command brought this distance to 475 ft. To this, it was assumed that a busy controller could not afford to spend any more than five seconds assessing the potential conflict situation, which brought the final distance to 630 ft.

For this experiment the term, *conflict zone*, was defined as the area within a 125 ft. radius from the center of the intersection. An intersection conflict was said to have occurred if some portion of both targets were in the conflict zone at the same time. The conflict zone was not marked on the display. If the nose of Target B was to enter the conflict zone an instant before or after the tail section of Target A cleared the zone, it was impossible to predict the outcome other than by chance regardless of the update rate. The basic difficulty in predicting whether or not a conflict was about to occur, therefore, depended on the amount of time by which the tail of Target A would or would not clear before the nose of Target B entered the zone, which is the definition of the time margin discussed previously. The time margin associated with each conflict situation examined was controlled by selecting the appropriate velocity for Target B.

There were twelve possible combinations of conditions (4 update rates and 3 time margins). The update rates examined spanned the range of rates used by existing and experimental airport ATC and airport surface radars, .2, .5, 1. and 4. seconds. The time margins examined were 2, 5 and 10 seconds. The viewing distance remained fixed at 3 ft. as did the display scale set for the 21-inch display for ground controllers at large airports. Any one combination was called a problem.

2.2.1.4 Operators - The operators were three TSC engineers - the two engineers that designed the experiment and a naive subject.

2.2.1.5 Procedure - The experiment consisted of a varied sequence of eighteen conflict situations, six for each time margin, presented first at an update rate of .5 sec, then of 1 sec, .2 sec, 4 sec, and finished with a repetition of the .5 sec value. The repetition of the .5 sec case was used to estimate if any learning took place during the performance runs. The sequence of eighteen conflict situations had no particular order, and the order varied with each update rate. The total sequence was repeated for each operator.

Each operator was given a stop watch. When a conflict situation started, the observer started the stop watch, assessed the situation, and stopped the watch when he was ready to call the game. He would then state whether or not a conflict was about to occur and the time taken for his assessment. If the time was over 5 sec, the response time was considered unrealistic and that response was not included in the performance data.

Due to the skill required in extracting relative velocity information and using it to judge if a conflict situation existed in the general case:

1. This experiment was designed to minimize the skill needed and yet provide an indication of the impact of update rate on the task;
2. The operators went through a fifteen minute training period before performance data was collected;

3. The first test sequence was repeated at the end of the experiment to provide a measure of the learning that took place during the data runs.

The experiment was run for two operators in one evening and for the third operator during an afternoon. The operators were permitted to take a break whenever they desired. Each operator was in his operating position before a computer run started and remained so for the entire run.

2.2.1.6 Data Collection - Manually collected data were:

a. the operator's call as to whether a conflict situation existed or not

b. the operator's time in making his assessment

2.2.1.7 Results - The Velocity Extraction Experiment results are presented in Figure 10. The three curves show the time margin effect on operator performance. As the time margin decreases, the observer's performance deteriorates for all update rates. This was expected; however, there are two surprising features concerning

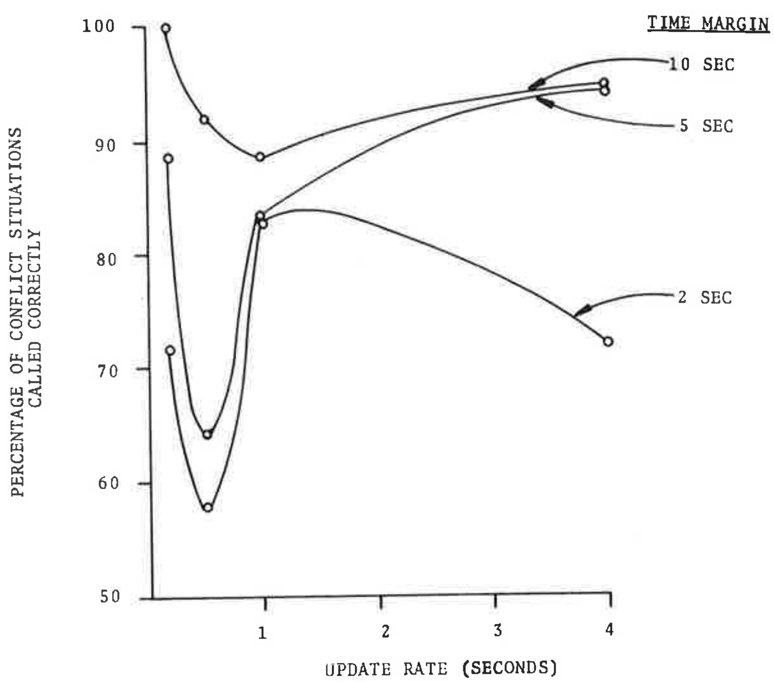


Figure 10. Results of the Velocity Extraction Experiment

these curves. Performance does not decrease monitonically with increasing update rate, and there is a distinct dip in performance that becomes increasingly associated with the .5 second update rate as the time margin decreases.

In Figure 11, these three performance curves are combined. The resulting curve reinforces the observation that performance is not strongly related to update rate with the exception of the update rates in the vicinity of .5 seconds. Each of the three operators expressed a preference for the 1 second update rate.

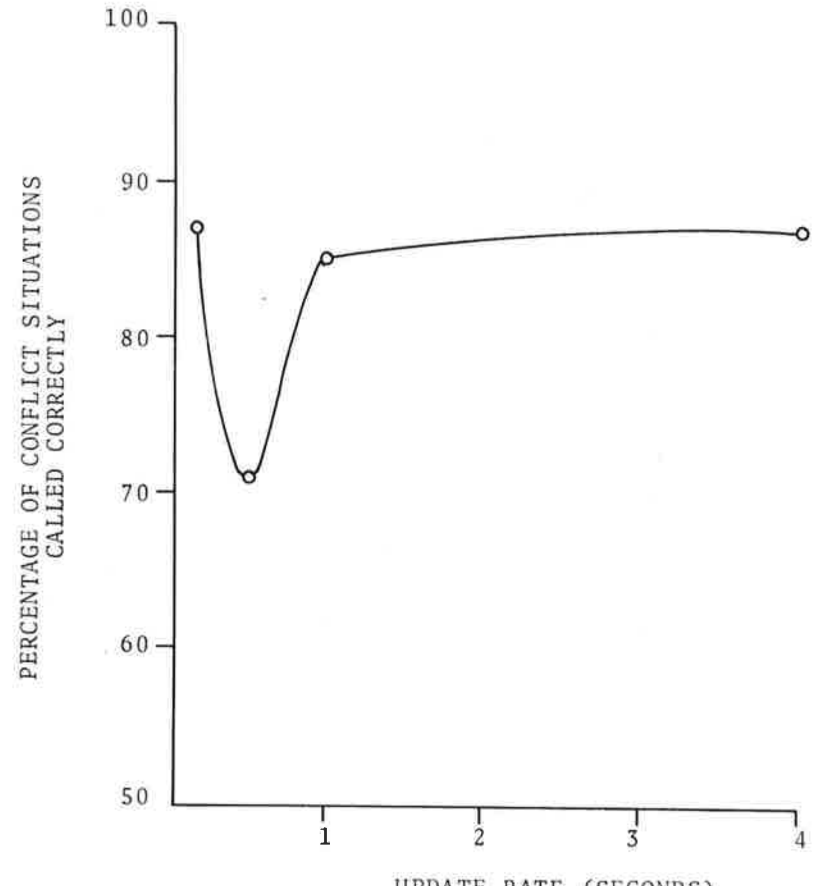


Figure 11. Composite Results of the Velocity Extraction Experiment

The operators' skill did not improve during the experiment. Each operator's performance during the second run through the .5 sec update rate sequence at the end of the experiment was the same or somewhat lower than the operator's performance for the same sequence run at the beginning of the experiment.

The time for each operator to make his assessment varied from two to five seconds and averaged about four seconds.

2.2.1.8 Limitations - In addition to the general limitations discussed in Section 1.0 this experiment severely restricted the range of intersection conflict situations examined. The targets started each computer run from the same two points; the velocity of Target A was fixed for the entire experiment; Target B was restricted to a set of six velocities; and acceleration was not permitted.

2.2.1.9 Conclusions - Under the experimental conditions, the ability of an operator to extract relative velocity is about the same for update rates of .2, 1., and 4. seconds. This ability is significantly reduced for update rates in the vicinity of .5 seconds. There is no conclusive explanation as to why this dip in performance occurs. One possible explanation however, is that with high update rates an operator processes velocity information as if it were continuous while with low update rates an operator processes it as if it were discrete; and for this experiment, the range of update rates around .5 sec marks the transition between these two modes.

REFERENCES

1. Rempfer, P. S., Preliminary Airport Ground Traffic Control Surveillance System Requirements Analysis, 3 March 1972.

2. Airport Ground Traffic Control Version of the Route Oriented Simulation System (ROSS) Technical and User Manual, written by Bolt, Beranek, and Newman Corp. for DOT/TSC, March 1972.

3. Belcher and Savage: A Summary of the Results Obtained from a Study of the Ground Movement System of Heathrow Airport, Summer 1969.

APPENDIX A

INTERSECTION ANALYSIS

APPENDIX A

INTRODUCTION

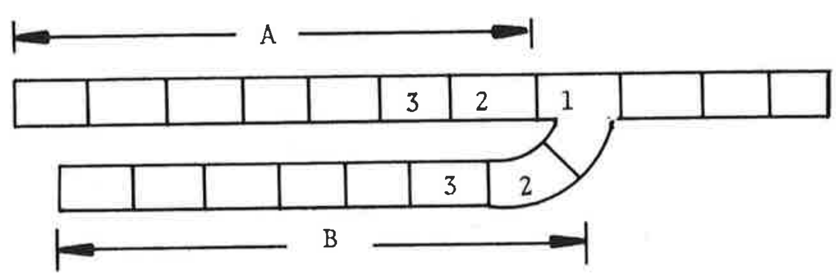
While monitoring intersection conflicts, a controller will instruct one of the two aircraft converging on the intersection if:

a. The two aircraft will pass one another at an unsafe distance in the intersection, or

b. The two aircraft will safely pass by one another, but the controller is unsure of this due to his limited sensing and predicting capabilities.

This results in the controller reacting to more aircraft than is actually required. To assure safety, the controller handles traffic through each intersection as if the conflict zone is suffuciently expanded so that he is confident that the actual restricted area will not be violated. The purpose of this analysis was to estimate the sensitivity of the number of conflicts perceived by the controller to the size of the expanded intersection conflict zone with which he handles traffic.

ANALYSIS



F_A = Flow on A in operations/hour
F_B = Flow on B in operations/hour
V_A = Mean speed on A in ft/sec
V_B = Mean speed on B in ft/sec
L_A = Length of A in ft.
L_B = Length of B in ft.
ΔX = Block length in ft.

Derivation of the probability that a particular block in A is occupied

then

$$\overline{N}_A = \overline{N}_B = 4000/200 = 20 \text{ blocks}$$

$$T_A = T_B = 4000/40 = 100 \text{ sec}$$

$$N_A = \frac{(60)\ (100)}{3600} = 1.7$$

$$N_B = \frac{(20)\ (100)}{3600} = .56$$

$$P_A = 1.7/20 = .085$$

$$P_B = .56/20 = .028$$

Case 1 - An actual conflict will occur in the intersection (Equation 1)

$$\text{Probability of a Conflict} = P_A P_B = (.085)(.028) = .0024$$

Case 2 - Conflict zone expanded to two blocks (Equation 2)

$$\text{Probability of a Conflict} = \left[P_A^2 + 2P_A(1-P_A)\right] \left[P_B^2 + 2P_B(1-P_B)\right] = .0089$$

The probability of a conflict is four times greater than in Case 1.

Case 3 - Conflict zone expanded to three blocks (Equation 3)

$$\text{Probability of a Conflict} = \left[1-(1-P_A)^3\right] \left[1-(1-P_B)^3\right] = .0215$$

The probability of a conflict is nine times greater than in Case 1.

In Case 1, the one 200 ft. block represents the actual conflict zone, and the probability is of an actual conflict occurring. In this example it takes each vehicle five seconds to pass over each 200 ft. block traveling at the mean speed of 40 ft/sec. Each block represents, on the average, an additional five second increment to the time margin with which the controller operates the intersection. With a time margin of five seconds, Case 2, the controller will perceive four times the number of conflicts that actually occur. A 10 second time margin, Case 3, finds the controller reacting nine times more often than required.

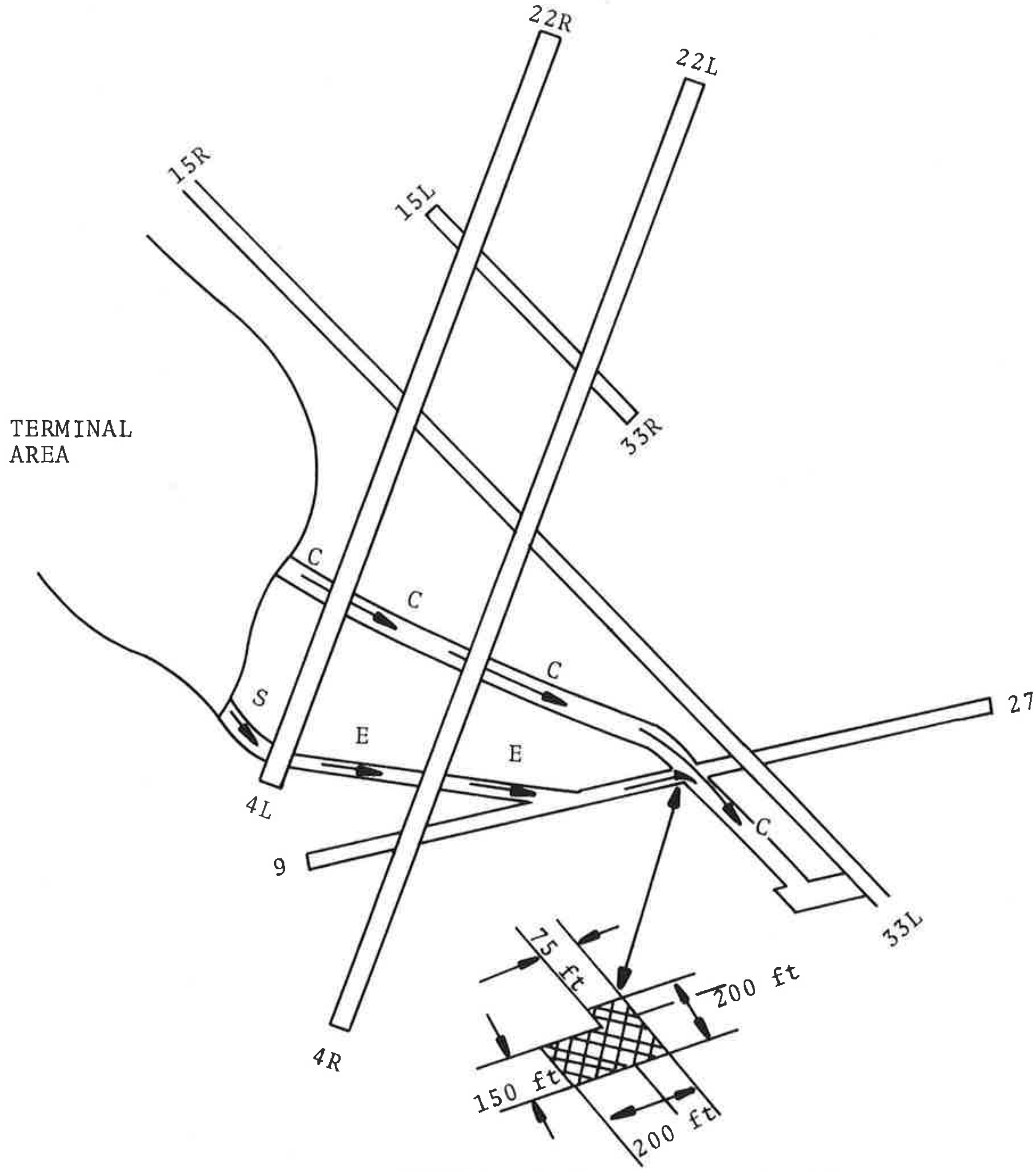


Figure A-1. Map of Logan Airport Showing the Routes Taken by the Traffic Proceeding to Runway 33L