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PERCEPTUAL FACTORS INVOLVED IN PERFORMANCE OF AIR TRAFFIC
CONTROLLERS USING A MICROWAVE LANDING SYSTEMGary Gershzojn*
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SUMMARY

This study investigated performance of air traffic controllers using a Microwave Landing System (MLS). Eight professional radar air traffic controllers acted as subjects and performed their normal duties within the constraints of the experimental design and simulation. The task involved the control of two simulated aircraft targets per trial, in a 37.0-km (20-n. mi.) radius terminal area, by means of conventional radar vectoring and/or speed control. The goal was to insure that the two targets crossed the Missed Approach Point (MAP) at the runway threshold exactly 60 sec apart. The effects on controller performance of the MLS configuration under wind and no-wind conditions were examined.

The data for mean separation time between targets at the MAP and the range about that mean were analyzed by appropriate analyses of variance. Significant effects were found for mean separation times as a result of the configuration of the MLS and for interaction between the configuration and wind conditions. The analysis of variance for range indicated significantly poorer performance under the wind condition. These findings are believed to be a result of certain perceptual factors involved in radar air traffic control (ATC) using the MLS with separation of targets in time.

INTRODUCTION

This study was designed to investigate some of the perceptual factors which affect performance of air traffic controllers using an MLS to control the landing of aircraft. The MLS is a new type of landing guidance aid and is still in an experimental phase. When fully operational its primary purpose will be to facilitate the safe and expeditious flow of a new generation of aircraft into airports with an efficiency that cannot be duplicated today. The implementation of the MLS will require an alteration of the physical structure of airways and the ATC system.

A radar scope was simulated on a cathode-ray tube (CRT) and displayed

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a terminal area with the MLS. The controllers were presented with several air traffic situations and were required to separate targets. The experimental goal was to identify some of the perceptual factors involved in and the performance of controllers using the MLS.

Although the MLS is one of the most recent developments in ATC, and as such has not been the subject of lengthy investigation, research in aeronautics has placed considerable emphasis on developments in human factors aspects of ATC. The literature contains numerous reports on topics such as mental processes of controllers (1), workload (11), and the role of automation (10). The general picture of the evolution of ATC responsibilities and required performance has also been outlined (8, 9). By and large, data on basic human perceptual processes specifically involved in ATC has received only scant attention. Therefore, this study, in part, examined pertinent psychological literature on visual motion perception in order to analyze performance of controllers using the MLS.

METHOD

The geometric arrangement of the MLS as viewed on the radar scope is significantly different from conventional Instrument Landing Systems. Whereas current Instrument Landing Systems employ a single, straight course to the runway, the complex MLS in this experiment was composed of five courses, both straight and curved. In order to evaluate the effects of this particular configuration on controller perception and performance, a specific task was developed.

Subjects

Eight professional air traffic controllers served as paid participants. All had extensive experience in radar ATC either with the military or FAA at high traffic density locations.

Apparatus

A 25.4- by 25.4-cm (10- by 10-in.) CRT display was generated by an Evans & Sutherland Line Drawing System interfaced with a Digital Equipment Corporation PDP 11/40 computer. Figure 1 illustrates the simulation that represented the ATC scope with the MLS. The scale of 2.9 km/cm (4 n. mi./in.) was close to standard usage.

Aircraft targets were represented by triangles measuring .45 cm (.18 in.) on each side. Each symbol was labeled by a single alphanumeric tag for use by the controller in identifying and tracking targets. The targets appeared to move in a manner not unlike those on conventional radar ATC scopes. Simulated aircraft had several basic movement capabilities: (a) entry along an MLS route at the periphery and complete tracking to the MAP, (b) automatic landing and exit from the display at the MAP, (c) heading change at a rate of 30/sec, and (d) acceleration at a rate of 3.7 km/hr

(2 knots)/sec (equivalent to $.0003 \text{ cm/sec}^2$ on the CRT). Altitude information was not required for this experiment.

The computer generated movement of targets was controlled by the subject. His verbal commands were transmitted by a standard microphone. Receiving and acknowledging these ATC instructions was the experimenter in the role of pilot of the simulated aircraft. Communication between the controller and experimenter reflected standard ATC operations and phraseology. Upon receipt of the controller's commands, the experimenter input the information to the PDP 11/40 computer via a high speed interface device which then altered the flight dynamics of the simulated aircraft accordingly.

Procedure

The task required that the controller control two targets per trial in order to achieve the desired goal of 60-sec separation between targets at the MAP. At the beginning of each trial one target appeared at the start of the VIKING route at the 37.0-km (20-n. mi.) hash mark at an airspeed of 464 km/hr (250 knots). It was followed approximately 60 sec later by a second target at the same airspeed which entered either along the VIKING route or one of the other four MLS routes. Since the second target traversed one of the five routes in following the first target, there were five different perceptual relationships between the two targets. These will be called path combinations of target movement. For example, a target entering on the VIKING route followed by a target on the GEMINI route would be called the VIKING-GEMINI (V-G) path combination.

The controller was instructed to adjust the movement of one or both targets by use of speed and/or directional control in order to insure that the two targets crossed the MAP exactly 60 sec apart. Each target automatically reduced its airspeed to 167 km/hr (90 knots) by the time it reached the 9.3-km (5-n. mi.) fix; this was in keeping with normal aircraft operating limitations. The airspeed of 167 km/hr (90 knots) was then maintained to the MAP. As the controller perceived the continuing relationship between the targets, he had to make a decision to issue or not to issue ATC instructions to change the relative movement or position of one or both in order to reach the goal of 60-sec separation. The airspeed and heading of either target could be changed only during the time that target was between the 37.0-km (20-n. mi.) fix and 9.3-km (5-n. mi.) fix; the controller had received instructions that no control was to be applied to a target after it had passed the 9.3-km (5-n. mi.) fix. When the second target reached the MAP the trial was at an end. The actual separation in seconds was recorded by the computer and used as the raw data for that trial. In order to measure performance in several situations, trials were conducted under wind (360° at 46 km/hr (25 knots)) and no-wind conditions.

An introductory session familiarized the controller with the general nature of the experimental purposes and MLS. Written instructions were supplied. Three practice trials with no-wind and three with wind before the respective experimental trials were used for the purpose of acquainting the controller with the appearance of the MLS and movement dynamics of targets. At the conclusion of each practice trial, the controller was told exactly how much separation in time existed between the two targets as they successively

crossed the MAP. This gave the controller an indication of the spatial and temporal relationships between targets under his control. This feedback, however, was not given during experimental trials.

Experimental Design

Two dependent variables were studied: (a) the mean separation time between targets at the MAP, and (b) the average range about that mean. A 5 X 2 X 2 factorial design for repeated measures was used to analyze the data. The five path combinations served as five levels of one independent variable. Two wind conditions constituted conditions of a second independent variable and the order of presentation of wind conditions was the third independent variable. The wind treatment condition was presented first to one half of the controllers and the reverse order was administered to the other half. There were 15 experimental trials under the no-wind condition and another 15 under wind. The same path combination was administered to each controller three times.

RESULTS AND DISCUSSION

The mean of the three separation times for each controller was calculated and constituted the data on which the analysis of variance was performed. For the purpose of noting the variability of controller performance, a second analysis of variance was performed on the range of the separation times per subject. Results of the analysis of variance for means are shown in Table 1 and for range in Table 2. A summary of the means and average ranges for each condition is presented in Table 3 and Table 4, respectively.

The effect of the order of presentation of wind conditions was not statistically significant. Therefore, for the purpose of analysis of other results, these data were combined.

The analysis of variance for means showed a significant difference between path combinations ($F = 3.84$; $df = 1, 10$; $p < .05$). This indicated that controller performance in attaining 60-sec separation between targets was affected by the different path combinations. The analysis of variance for range did not indicate any significant effects ($F = .98$; $df = 4, 24$; $p > .05$) due to different path combinations (fig. 2).

The mean separation times between targets under the no-wind condition (60.6 sec) and under the wind condition (57.0 sec) were close to the 60-sec target value, yet the magnitude of the average range of times about these means was quite large (fig. 2 and 3). Under the no-wind condition, the average range was 19.6 sec, and under wind, 43.2 sec. The analysis of variance for range showed a statistically significant difference in controller performance as a function of wind condition ($F = 12.42$; $df = 1, 6$; $p < .05$). The analysis of variance for means revealed no significant results ($F = .48$; $df = 1, 6$; $p > .05$). While the overall mean separation time between targets under the no-wind and wind condition were not significantly different, the average ranges about these means were. Both the no-wind and wind mean times indicated a high degree of accuracy on the average in attaining the 60-sec

target value. But the 19.6 and 43.2 sec ranges showed the accuracy reflected in the mean times to be a result of the high separation times between targets cancelling out the low separation times, especially under the wind condition.

These results will be discussed from three points of view: (a) the perceptual factors involved in performance of controllers using the MLS, (b) controller performance using time as a relevant separation criterion rather than distance, and (c) the implications of the findings for future development of the ATC system with the MLS.

The controller's perception of the ATC situation constitutes an important factor in understanding the results. Three primary perceptual factors are considered to be of importance in the controller's task in this experiment: (a) spatial separation of targets, (b) figure-ground (map overlay) effects, and (c) the perception of wind-generated accelerated motion. The latter point appeared to be most significant in evaluating the data and requires special consideration.

The mean separation time under the no-wind condition was closer to the 60-sec target value than under the wind condition. This was due primarily to the controller's difficulty in taking into account the differential effects of wind on ground speed as the target changed heading. The difficulty in perceiving the onset of accelerated motion had several consequences for controller performance. First, the reduction of the ground speed of a target, either in the automatic speed reduction phase of the approach or as a result of the wind, altered the separation between it and the other target. Should the velocity change have gone undetected, the result would have been a new amount of separation between targets of which the controller was completely unaware. Obviously, a continuous series of such changes by one or both targets would lead to inaccurate and erratic performance such as was evident under the wind condition. Second, the perception of acceleration of one or both targets required an evaluation by the controller of the actions necessary to maintain or change the relationship between the targets. This necessitated the ability to make an accurate prediction of the future progress of the target undergoing acceleration. It has been shown by Gottsdanker (4-6) and Gibson (3) that future target position during constant velocity motion can be predicted with considerable accuracy. However, predicting target position during accelerated motion was found to be generally inaccurate and appeared to be based on the last perceived velocity rather than on acceleration (2, 7). The apparent inability of the controller to successfully predict the accelerated motion of targets, and hence future positions in time, was associated with high variability in performance. Third, the changes in ground speed of a target traversing that part of the MLS course that curved toward the airport were difficult to assess. The controllers reported that the point in time when the ground speed began to slow was not immediately apparent nor was it possible to accurately predict the future motion of targets: The large magnitude of the change in ground speed in those MLS courses with long curved segments made accurate perceptions difficult and inaccurate performance most evident in the results. The accelerations that occurred within the curving courses were most significant under the wind condition and posed a situation which the controllers were unable to gauge precisely.

On the basis of discussions with the controllers after the experiment, it would appear that the controllers' attempt to separate the two targets by

60 sec at the MAP was not accomplished merely by estimating time. Rather, they used a time-distance conversion (distance = airspeed x time). This was not surprising since controllers perform their normal ATC duties using mileage not time as the separation criterion, and consequently they were faced with a novel and difficult task.

Two factors involving time and distance conversions were involved. The first concerned a principle that specific separation in time between two targets will remain constant if the ground speeds of the two targets remain unchanged. Secondly, separation in time will remain constant when ground speeds change if, and only if, the place and rate of change of ground speed of one target is identical to that of the other. The realization of these phenomena led to another point. Since time separation was held constant between the targets during the automatic speed reduction (under conditions heretofore described), the establishment of 60-sec separation between targets prior to the commencement of the speed reduction (which entailed accelerated motion) was seen as desirable. Once the automatic speed reduction began, the controller had no means of adjusting the airspeed of a target. This required action to be taken earlier in order to have control capability of a useful and realistic magnitude and to set up a relationship between the two targets when they proceeded at a constant velocity. Since the judgment of constant velocities is more accurate than accelerated velocities, the controller was able to judge the separation in time more precisely when targets moved at constant rates.

The results of the present experiment indicate that the control of aircraft using an MLS with curved courses and temporal separation may be subject to a number of limiting factors. The different path combinations had an effect on both the mean separation between targets and the variability of the controller's performance under the wind condition. Under the no-wind condition, there was little difference in performance by path combination. The controllers' comments indicated that they attributed this to their careful and precise attention to the position of the targets with reference to hash marks and the calculation of time-distance equations. The wind condition posed more serious difficulty since the use of hash marks and the time-distance equation did not provide information which could be used to compensate for the perceptual factors associated with the wind.

In consideration of the perceptual factors involved in controller performance, it seems unlikely that the addition of any appreciable workload (in the form of more targets) would permit positive and accurate control. One of the most important influences on performance is workload. It may be measured by the number of targets a controller has to deal with at one time. By current standards in the current ATC system, with complicating intersecting and converging routes, a light workload might be five targets; a heavy workload might reach as high as 15 targets. In this experiment, which employed only two targets at one time, the workload was minimal yet the variability in performance with wind was high. This was true in spite of the fact that the controller had enough time to calculate time-distance relationships for the two targets. With more than two targets, it is not likely that the controller would be able to maintain the mental strategies of control found in this experiment. Furthermore, an increase in workload that would reflect a busy terminal area would make accurate and successful separation between aircraft, with time as the separation criterion, a most unlikely occurrence.

Yet, innovations in ATC systems, cockpit displays, and possible alterations of the MLS configuration may alleviate some of the problems that faced controllers in this simulation. Such improvements may allow conventional radar ATC using the MLS with a real world workload.

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TABLE 1

Analysis of Variance for Mean Separation
Time Between Aircraft Targets at the
MAP

Source	df	MS	Error Term	F
Order of presentation of wind condition (A)	1	18.15	D	.03
Path combination (B)	4	589.68	B X D	3.83 ^a
Wind condition (C)	1	258.13	C X D	.48
Subjects (D)	6	655.18		
A X B	4	46.23	B X D	.31
A X C	1	200.66	C X D	.37
B X C	4	532.82	B X C X D	6.48 ^b
B X D	24	163.66		
C X D	6	542.16		
A X B X C	4	63.02	B X C X D	.77
B X C X D	24	82.19		

^a $p < .05$

^b $p < .01$

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TABLE 2

Analysis of Variance of Range About
Mean Separation Times between Aircraft
Targets at the MAP

Source	df	MS	Error Term	F
Order of presentation of wind condition (A)	1	68.45	D	.07
Path combination (B)	4	556.32	B X D	.98
Wind condition (C)	1	11,092.05	C X D	12.42 ^a
Subjects (D)	6	929.25		
A X B	4	451.45	B X D	.80
A X C	1	344.45	C X D	.39
B X C	4	551.98	B X C X D	1.03
B X D	24	565.02		
C X D	6	892.91		
A X B X C	4	178.89	B X C X D	.33
B X C X D	24	536.10		

^a $p < .05$

TABLE 3

Summary of Mean Separation Times (in seconds)
 between Aircraft Targets at the MAP by
 Path Combination and Wind Condition

Path combination	Wind condition		
	no-wind	wind	across no-wind/wind
V-V	62.6	71.5	67.1
V-G	58.1	56.2	57.1
V-A	59.1	41.4	50.2
V-P	65.4	52.4	58.9
V-M	57.7	63.4	60.6
Across all path combinations	60.6	57.0	58.8

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TABLE 4

Summary of Average Ranges (in seconds) about Mean
Separation Times between Aircraft Targets at
the MAP by Path Combination and Wind
Condition

Path combination	Wind condition		
	no-wind	wind	across no-wind/wind
V-V	19.1	24.8	21.9
V-G	20.9	54.5	37.7
V-A	20.1	42.9	31.5
V-P	24.0	45.1	34.6
V-M	14.1	48.8	31.4
Across all path combinations	19.6	43.2	31.4

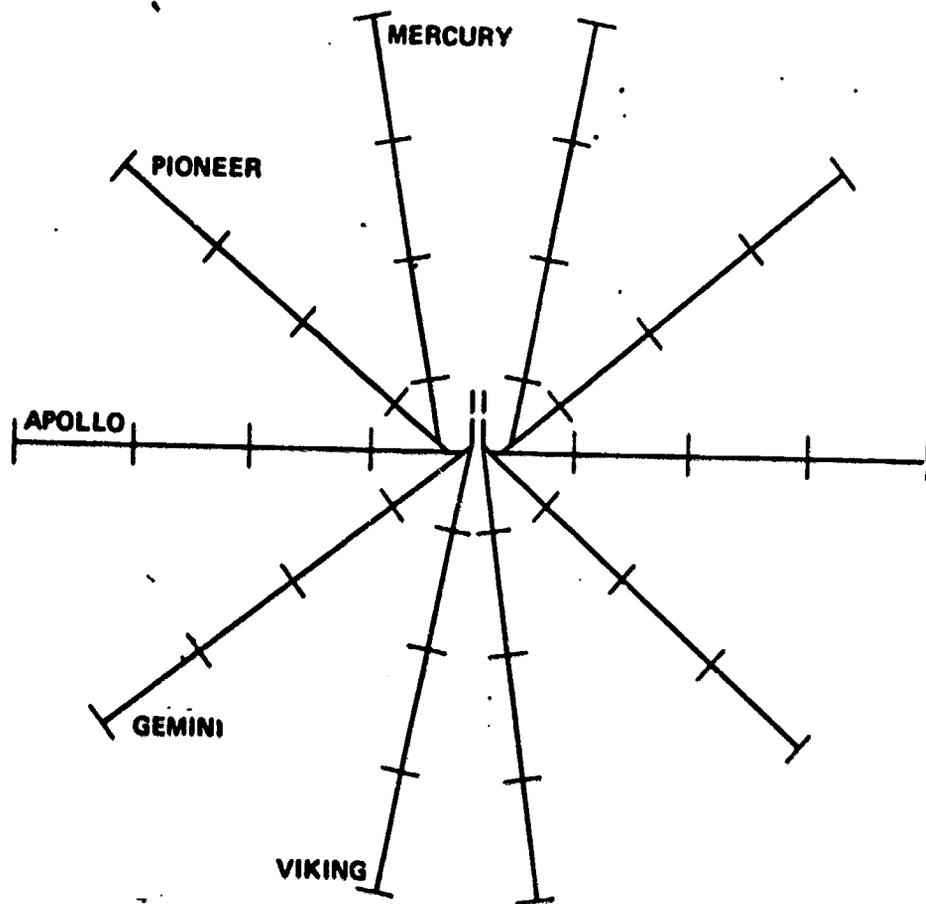


Figure 1.- MLS route configuration as seen on controller's display.

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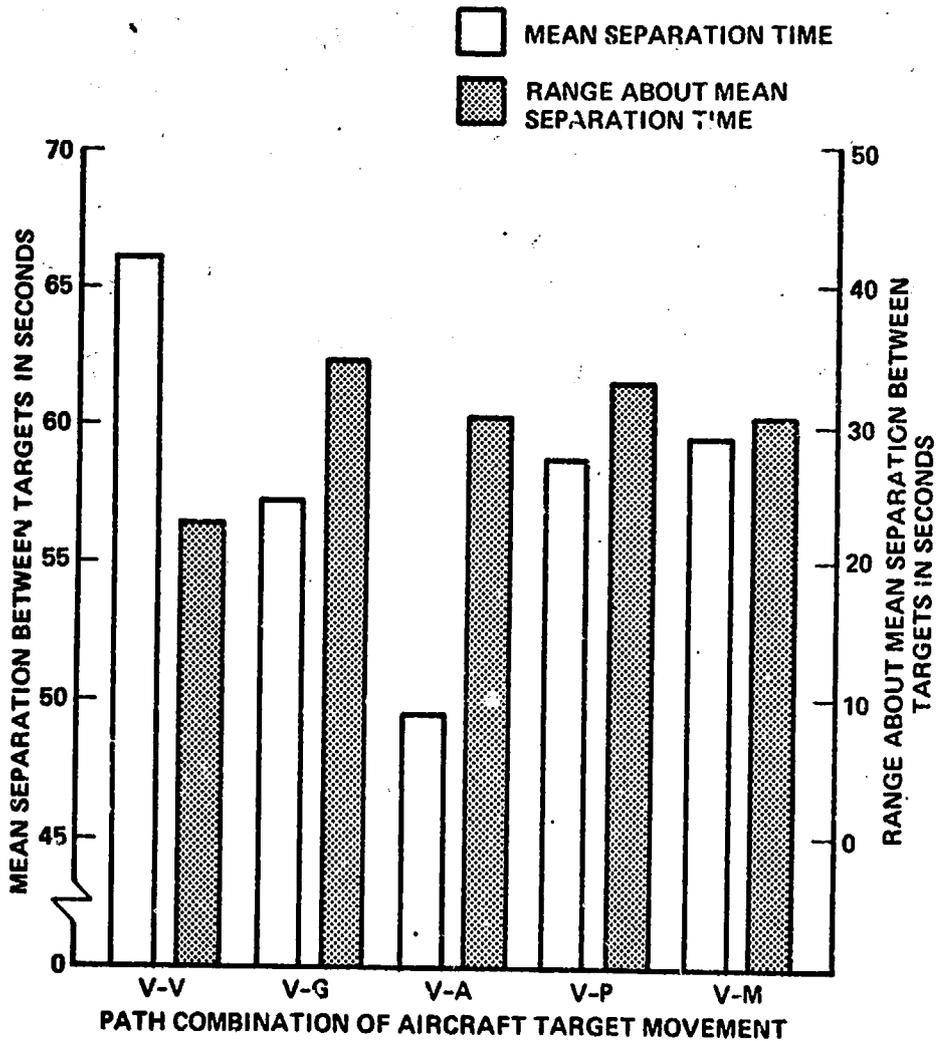


Figure 2.- Mean separation time and range about mean separation time between aircraft targets at the MAP by path combination.

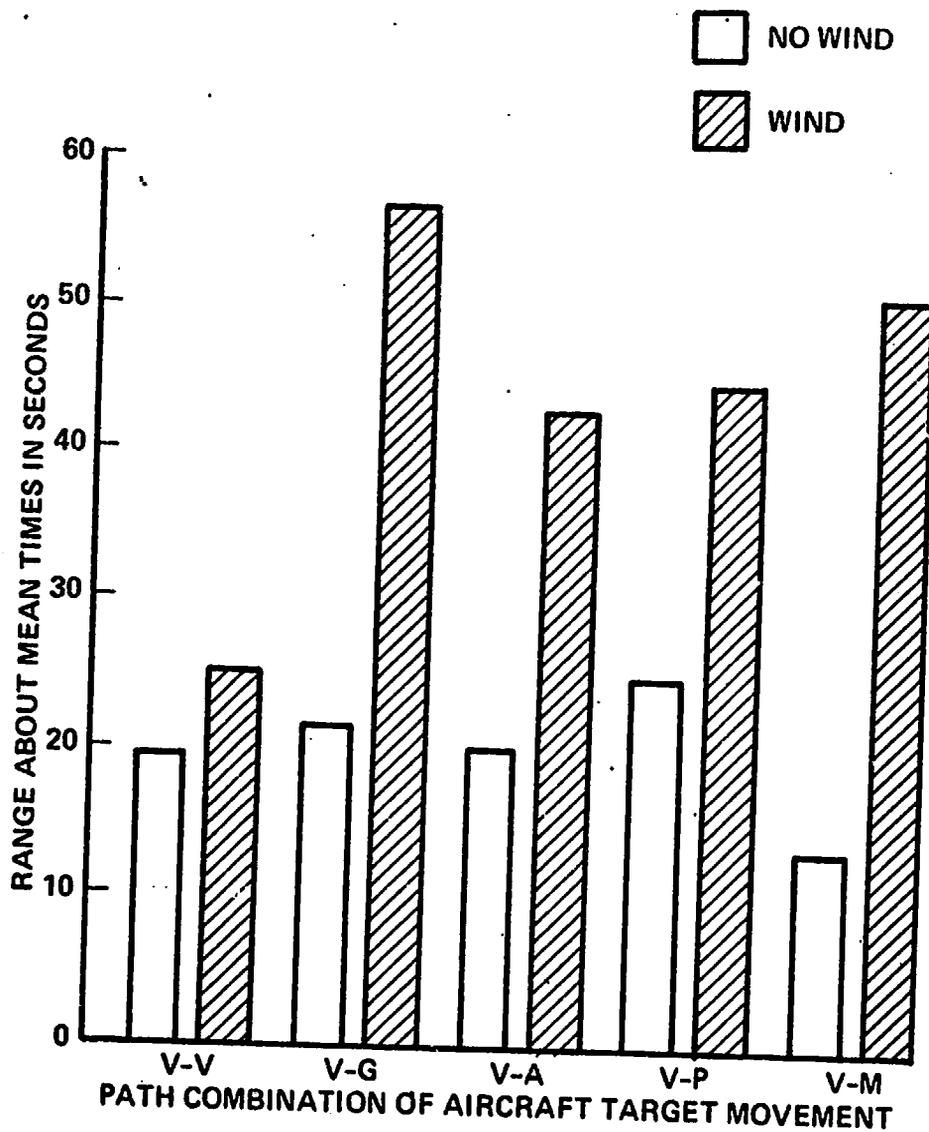


Figure 3.- Average range about mean separation time between aircraft targets at the MAP by path combination and wind condition.