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AIR TRAFFIC CONTROL BY DISTRIBUTED MANAGEMENT IN A MLS ENVIRONMENT

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ABSTRACT

The mic wave landing system (MLS) is a technically feasible means for increasing runway capacity since it could support curved approaches to a short final. The shorter the final segment of the approach, the wider the va iety of speed mixes possible so that theoretically, capacity would ultimately be limited by runway occupance time only.

The dense traffic environment resulting from efficient use of the MLS necessarily reduces the permissible response times and tolerances in the ATC system thus emphasizing the tactical aspects of traffic control.

An experiment using the multi-man ATC facility of the Man-Vehicle Systems Research Division at NASA-ARC contrasted air traffic control in a MLS environment under a ntralized form of management and under distributed management which was supp ed by a traffic situation display in each of the 3 piloted simulators.

Objective flight data, verbal communication and subjective responses were recorded on 18 trial runs lasting about 20 minutes each. The results were in general agreement with previous distributed management research. In particular, distributed management permitted a smaller spread of intercrossing times and both pilots and controllers perceived distributed management as the more "ideal" system in this task.

It is concluded from this and previous research that distributed management offers a viable alternative to centralized management with definite potential for dealing with dense traffic in a safe, orderly and expeditious manner.

INTRODUCTION

In previous papers [1-6] we have discussed some of the advantages and disadvantages that seem to be inherent in operating air traffic control in the terminal area by distributed management as opposed to a centralized ground based ("vectoring") management. These discussions were based on results obtained over a period of 5 years from manned simulation experiments at NASA-ARC in the Man-Vehicle Systems Research Division using the multi-man ATC simulation facility developed there. This facility was designed to capture the absolutely vital pilot-pilot and pilot-controller interactions that are lacking in smaller or totally computerized studies.

The results of each experiment have consistently indicated that distributed management, made possible by the appropriate display of traffic information in the cockpit, exhibited highly desirable characteristics such as a smaller interarrival time variance than did the ground based management alternative as well as dramatically reducing controller verbal workload[3,6]. Thus distributed management has a definite potential for coping with present and projected increases in traffic densities and rising costs in a natural, safe, orderly and expeditious manner without increasing system workloads.

The experiments leading to the above statements are by no means exhaustive. Other possible traffic procedures could be devised to deal with increasing traffic densities even without the concept of distributed management and the natural question arises as to whether or not such procedures could themselves be accommodated under a distributed management regime.

Microwave Landing System.

The microwave landing system (MLS) has been proposed as a technical advance which could support an increase in airport capacity and safety.[7,8,9] The anticipated precision and coverage of the MLS could define precise curved descending approaches thus increasing capacity in existing airport space through two mechanisms. The precision together with curved approaches could permit independent operations to closely spaced runways and closer spacing effectively increasing airport capacity. Together with or independently of multiple runways, the precise curved approaches could also be used to shorten the long common final all A/C must share on present ILS approaches. A long common final,low position precision and wake turbulence necessitates considerable interaircraft spacing between aircraft of different speed and weight characteristics. Reducing the common final approach length also increases runway capacity.

Although considerable technical work is taking place in MLS design for civil aviation, no experimental results have been found investigating the impact of the MLS on air traffic management incorporating the capability for multiple curved approaches as a means for increasing runway capacity.

EXPERIMENTAL OBJECTIVES AND PURPOSES

This experiment had two primary objectives:

A) determine the feasibility of distributed management in a MLS environment of multiple curved descending approaches

B) study the impact of multiple curved descending approaches on air traffic management.

The purposes for each objective were respectively:

A-1) increase the range of understanding of the distributed management concept

A-2) accrue evidence as to its situational robustness

B-1) provide basic information pertinent to air traffic management in the MLS environment

B-2) obtain pilot-controller reactions to MLS capabilities

B-3) provide basic information useful in the design of a MLS terminal traffic area utilizing multiple curved approaches.

Both objectives were accomplished under the same experiment. However, this paper will address objective A only. A second paper[10] addresses objective B.

METHODOLOGY

The methodology used to accomplish the stated objectives was essentially similar to that employed in prior experiments.[1-6] Limited descriptions of common features will be given here. Items peculiar to this experiment will be described in more detail. Reference 10 may also be consulted for further descriptions.

FACILITIES

The basic simulation facility comprises:

- three fixed-base simulators with throttle, aileron and elevator control and CRT flight information and status displays
- a two-man controller station with a CRT displayed terminal traffic and an alphanumeric graphic I/0 terminal
- a programmable intercommunication system linking all participants
- an SEL 840 computer with a E&S line drawing system.

All flight dynamics etc., for each simulator as well as complete experimental control are performed by the SEL 840. All CRT graphics displays are supported by the SEL 840 and the E&S graphics system.

This facility is being expanded and upgraded as described in another paper[11] but the basic interactive nature of the simulation facility is retained.

TASK

1. Route Structure

The basic task was structured around multiple curved approaches to two closely spaced STOL runways as shown in Figures 1 and 2.

The problem begins about 5 1/2 nm along each approach from threshold. All routes merge at the Final Approach Fix (FAF) 1 nm from threshold. The routes have different turn radii with the Mercury Approach (18L) being most severe. This differs from the technique in Benner, et al [8] in which the approaches tangentially intersected a common curved path but at different "merge" points. Table 1 shows the turn radii and required bank angle at 70 kts for each approach used in this experiment.

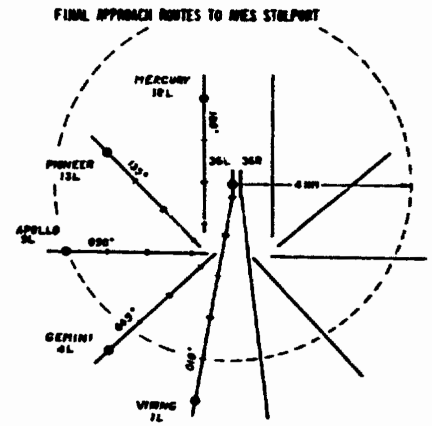


FIGURE 1 FINAL CURVED STOL APPROACH ROUTES TO AMES STOLPORT. SIMULATORS AND COMPUTER CRAFT FLEW APPROACHES TO RUNWAY 36 LEFT. GROUND PROJECTIONS ARE SHOWN.

TABLE 1 - CURVED APPROACH PATHS

Approach	Radius (ft)	Bank Angle (70 kts) deg.	Curved Segment (ft)
MERCURY (18L)	1616	15	4795
PIONEER (13L)	2424	10	5288
APOLLO (9L)	3232	8	4512
GEMINI (4L)	4040	6	2468
VIKING (1L)	-	-	-

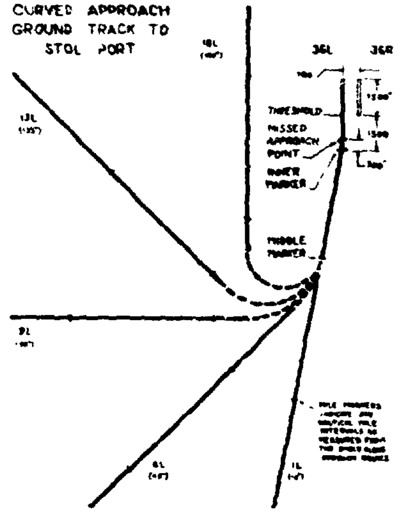


FIGURE 2 DETAILS OF THE CURVED APPROACHES.

Radius and bank angle are monotone functions of the approach route but PIONEER (13L) had the longest curved segment. *The range of bank angles is similar to that studied in Benner, et al.*[8]

The MERCURY approach (18L) *was only used for go arounds. No simulator or computer craft was introduced on 18L.*

The curved segments of the ground projection were omitted on the CRT displays because *of their considerable drawing overhead.* Previous experiments[12] had indicated that path predictors allowed pilots to fly omitted curved segments using their path predictor as a "fairing" device. It was hoped that this effect could be advantageously used in this experiment.

All approaches had the same required altitude profile beginning at 2000 ft, intersecting a 6° glide slope at three miles from the threshold along the approach and descending to 100 ft at the missed approach point (MAP) 1000 ft from threshold. Figure 3 details this profile for reference.

A wind shear of 25 kts at 2000 ft linearly decreasing to 15 kts at ground level blew constantly from the North. No turbulence was presen

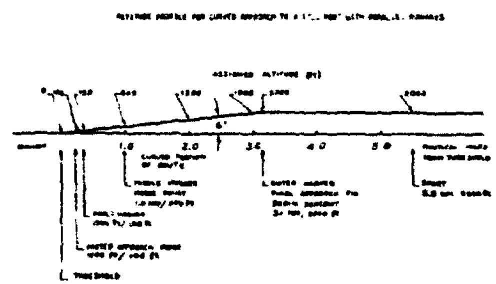


FIGURE 3 ALTITUDE PROFILE FOR EACH OF THE CURVED APPROACHES TO THE SIMULATED AMES STOL PORT.

2. Pilot Equipment

Pilot displays were CRT generated[1,5] with a Vertical Situation Information (VSI) display and a Horizontal Situation Information (HSI) display. The HSI displayed *a moving map of ground tracks, A/C symbols and 60 sec. path predictor on own ship only.* Previous experiments[2] *had determined that path predictors on other A/C were not necessarily an advantage and therefore were eliminated.* This also helped *reduce drawing requirements.* Figure 4 shows a typical pilot CRT display in which *other traffic is also visible.*

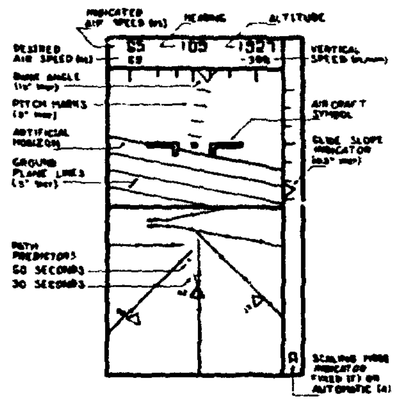


FIGURE 4 TYPICAL CRT COCKPIT DISPLAY. LOWER DISPLAY SHOWS OWN SHIP CENTRALLY LOCATED AND WITH A 60 SEC. PATH PREDICTOR.

A moving pointer glide slope indicator was displayed on the right of the VSI. Horizontal deviations were detected from the HSI which was autoscaled by altitude as an option. Obviously, better indicators should be devised.

Pilots had a switch selectable choice of a translating North up map with a centered rotating A/C symbol or of a heading up centered A/C symbol and rotating translating map.

A second option allowed selection of either a map scale fixed (F) to a constant altitude of 2000 feet encompassing a half width of 12 nm or an automatic scaling (A) option which monotonically decreased the half width with descending altitude to approximately 0.8 nm at 100 ft. The scaling algorithm requires decreasing sensitivity with altitude otherwise vertigo sensations and loss of perspective can easily result as altitude decreases and fluctuates. Automated map scaling requires considerable design thought and experimentation.

Pilots had full use of aileron, elevator and throttle control. Desired Air Speed corresponded to the Indicated Air Speed in straight and level flight which would be achieved at the present throttle setting.

Approach plates for each of the 5 approaches were available in the cockpits.

3. Controller Equipment

The controller station was remotely located from any of the simulators. Two controllers manned the station with one positioned before a CRT showing the Approach ground tracks and the A/C. The second controller sat before a Hazeltine CRT (text display) I/O Terminal which displayed flight number, A/C type, speed, altitude and heading for each A/C. A/C were listed with the most recent flight at the top. Note that the traffic display showed only the A/C flight number. The symbol itself displayed heading information. Altitude and speed information, however, had to be obtained from the text display CRT.

Separating the text from the traffic display A/C symbols was an expedient decision to reduce the amount of graphic display from the E & S unit which, because of the alphanumerics would have been prohibitive.

The controller at the text display could enter selected information via the keyboard. For example, he was responsible for entering A/C speed commands (under the traffic controller's request) to computer generated A/C which were otherwise preprogrammed to fly the approaches along the specified altitude and speed profiles. In this capacity, the text display controller was designated the "super pilot" This role will be discussed in more detail later.

4. Aircraft Types

Both simulators and computer craft were programmed to have simple STOL speed characteristics. The Simulator dynamics were modified NAVION dynamics.(12) Two types of STOL craft were simulated as shown in Table 2.

TABLE 2 - SIMULATED STOL TYPES

Aircraft Type	Speeds (kts) Maximum	Terminal	Approach & Landing	Stall
DHC-7	240	120	65	50
YC-15	425	150	80	60

Computer craft had preprogrammed speed profiles from terminal to approach speed. The super pilot controller could type in commanded speed changes which were accepted (with reasonable inertial response) as long as the resultant speed fell between stall and terminal speeds. Otherwise an error message was immediately shown on the CRT. All computer craft followed their approach route exactly and no path stretching, go around or alternate routes were permissible.

The 3 simulators were only restricted between maximum and stall speeds. The IAS display indicated STALL if such were the case.

An approximately 50-50 mix of the two types of A/C was implemented

5. Task Descriptions

The A/C were required to fly the curved approaches to the 100 ft wide runways spaced 750 ft apart on centerlines. Simulators made approaches to runway 36L only along with other computer craft. Only computer craft made approach to 36R The MERCURY approach (18L) was reserved for any simulator go arounds.

The basic task required all A/C to cross the 1000 ft missed approach point at 60 sec. intervals on a 6 degree glide slope and at the proper landing speed for the A/C type (65 or 80 kts).

Aircraft were continuously introduced into the problem at 5.5 nm out on an approach at approximately 1 minute intervals. The approach was randomly selected from those not just used on the previous introduction. Any simulator which completed a successful approach was placed into the queue awaiting reintroduction. Thus each simulator could fly several new approaches during the single run of about 20 minutes.

After passing the 1000' marker, a simulator was automatically landed if the glide slope, heading and lateral deviation were within a narrow performance window. If these window requirements were not met, the pilot's CRT flashed GO AROUND and he executed a missed approach to 18L. Controllers could also request a pilot to execute a go around.

Computer craft made perfect approaches and landings (except possibly for speed). No go arounds or missed approaches could be executed with them. This caused considerable problems which will be discussed later and which will be rectified in future experiments.

6. Experimental Conditions: Distributed-vs-Centralized ATC

Two traffic management conditions were studied; A distributed management concept (Sequencing) and a ground centralized procedure (Vectoring) both used in previous experiments. In sequencing pilots had full traffic information displayed on the CRT HSI, that is they had a Traffic Situation Display. In vectoring, pilots saw only their own A/C symbol.

In sequencing, controllers issued sequence information only to each simulator as it made its approach and refrained from any other statements interpretable as a request or command except for status information. Pilots navigated as needed on their approach to establish their given sequence and satisfy the basic task requirements.

In vectoring, pilots followed controller requests. The super pilot controller in both cases executed the appropriate speed inputs for the computer craft as requested by the traffic controller. The super pilot also provided the traffic controller with flight information if requested from the CRT text display which was also visible to the traffic controller.

In both management condtions, the problem was solved in a man-intensive rather than computer-intensive fashion. Special purpose automated sequencing, spacing and metering algorithms could perhaps have been devised for this particular experiment. However, the history of efforts on that approach suggests that a universally viable procedure should make intensive use of the intrinsic human capabilities already present in the system.

Data were obtained from 3 groups of three professional pilots and two professional controllers per group. Each group made three experimental runs of 20 minutes under each of the management conditions. The number of approaches varied somewhat among groups. Table 3 outlines the experimental design for this study.

TABLE 3 - EXPERIMENTAL DESIGN FOR CURVED APPROACH AND DISTRIBUTED MANAGEMENT STUDY.

		GROUPS. 3 COMMERCIAL AIRLINE PILOTS 2 AIR TRAFFIC CONTROLLERS		
		GROUP 1	GROUP 2	GROUP 3
TRAFFIC MANAGEMENT SYSTEM	CENTRALIZED AUTHORITY	2 PRACTICE RUNS 3 EXP. RUNS 54 APPROACHES	2 PRACTICE RUNS 3 EXP. RUNS 71 APPROACHES	2 PRACTICE RUNS 3 EXP RUNS 57 APPROACHES
	DISTRIBUTED AUTHORITY	2 PRACTICE RUNS 3 EXP. RUNS 53 APPROACHES	2 PRACTICE RUNS 3 EXP. RUNS 61 APPROACHES	2 PRACTICE RUNS 3 EXP. RUNS 54 APPROACHES

Each group completed its sessions in one day. The morning was spent in familiarization with the equipment, procedures and task while the experimental session with 3 data runs and a practice run on each management conditions occupied the afternoon.

Subjects were first briefed and given a set of instructions completely describing the experiment. Any questions were answered and discussed as necessary.

Open microphones in the cockpits and push to talk microphones at the controller station connected all 5 participants in a common network. Thus all participants overheard every communication. This is a sensitive condition which requires further study.

It should be pointed out that each A/C symbol on each CRT display carried a simple identifying tag as to its flight number. All simulation were labeled A, B or C followed by a numeral indicating its (re)introduction number. Thus a simulator could be tagged as B1, B2, B3--- etc. If a simulator made a go-around its tag and ID did not change. All computer craft had ID's from D . . also followed by their (re)introduction number.

Altitude and speed information on each A/C could be exchanged among pilots through direct address or via the controller.

The mix of A/C types was randomly determined at the beginning of each run with the provision that only two simulators could be of the same type. Each simulator and computer craft then retained its type throughout the run. As a new computer craft was introduced, its type was randomly assigned. It was possible to have upwards of 7 and more A/C making approaches to 36L. All A/C making approaches to 36R were computer craft and proceeded without intervention on the controllers part. It was originally planned to require speed control by the controller of A/C on 36R with the spacing results at the inner marker to be used as a secondary task measure. The problem on 36L proved sufficiently difficult to drop the 36R concern in this experiment. The two runways were thus operated independently.

All pilots including the super pilot (for computer craft) announced their arrival over each approach and from that point proceeded according to the problem development. Simulators could be held at any point but were restricted from holding once on their descent (3 nm from threshold). Computer craft could not be held once past the 5 nm approach marker.

7. Data Recorded

As in our previous experiments, selected flight information from each simulator was recorded at 1 second intervals ("objective" data). All verbal communications were tape recorded. In addition, pilots filled out questionnaires after each successful approach and all subjects filled out other questionnaires after each run. All subjects also completed a final questionnaire after completing the total experiment. Thus objective, subjective and verbal data were available for analysis.

The ground track position of each simulator and computer craft were recorded as part of the objective data and later pla· 1 back. These reconstructions were videa taped in real time and in a speed up (10:1) version for visual analysis.

The objective data provide indications of pilot manual workload as well as spacing information throughout the flights and intercrossing times at the missed approach point and final approach fix (the merge point for the curved approaches).

Verbal data were recorded for analysis of verbal workload in the syst . nc content analysis of th· messages.

Subjective data were obtained to study the uniquely human perceptions, suggestions, comments, preferences, etc., necessary for a full evaluation of such complex eperiments.

The intercrossing time data and some of the subjective response data will be presented in this paper

RESULTS

A complete presentation of results will be available in later reports. This paper will discuss intercrossing time (ICT) to contrast (1) distributed-vs-centralized management and (2) differences obtained from piloted simulators-vs-computerized A/C. Limited analysis of subjective data will also be presented. Other results are available elsewhere.[10]

OBJECTIVE DATA ANALYSIS

1. Intercrossing times

The intercrossing times between aircraft at the missed approach point are somewhat complicated by the lack of any control other than speed on the computer craft so that simulator and compu r craft results must be treated separately. Accordingly, the four combinations of A/C c ssings-simulator precedes simulator (SS), computer precedes simulatro (CS), computer precedes computer (CC) and simulator precedes computer (SC), are analyzed independently. The first tw pairings (SS, CS) can be taken as representative of simulator only involvements since the following craft · more likely to make all adjustments relative to the preceding craft. The second two pairings (CC, SC) represent computer craft involvement, by the same reasoning. Certainly SS and CC are most clearly representative of a simulator only study and a computer only study. Besides permitting study of management conditions and curved approaches, the mix of simulators and computer craft also provides insight into vital differences between computer A/C studies an' "live" studies will be seen.

Figure 5 shows the cumulative distributions of intercrossing times (ICT) under the sequencing and vectoring conditions without distinction as to the four pairings.

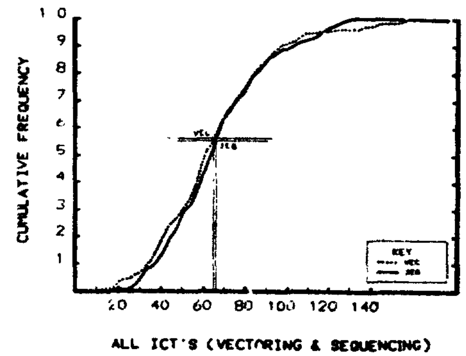


FIGURE 5 INTERCROSSING TIMES FOR THE SEQUENCING AND VECTORING MANAGEMENT CONDITIONS NO DISTINCTIONS ARE MADE AMONG SIMULATORS AND COMPUTER A/C.

The high degree of similarity under the two management conditions is actually somewhat misleading since results are heavily weighted by computer craft in the sequencing condition where half of the approaches were computer craft handled from the ground as in the vectoring condtion.

Figure 6 shows the ICT distributions for the four pairings under the two management conditions. The differences due to simulator and computer craft behavior are evident here. Note in particular that the smallest ICT values are obtained with computer craft in the vectoring condition which probably represents an inherent lack of responsive control further aggravated by the management condition.

Figure 7 shows the means and standard deviations for the four pairings under sequencing and vectoring management conditions. These are the indicated values from Figure 6. The distinctions between management conditions and computer craft-vs-simulators are easiest to draw from the SS and CC pairings. The mean ICT values are essentially the same at 72 and 70 sec for SS and 61 sec for CC in sequencing and vectoring. Thus there was no appreciable difference in mean ICT between management conditions. The all computer craft crossings (CC), however, show a ICT closer to the specified 60 sec. interval than do the more realistic SS piloted simulators.

However, the standard deviation for SS was about half as large in sequencing (17.7 sec.) as in vectoring (32.1 sec.) while CC again showed negligible differences (23 and 22 sec.).

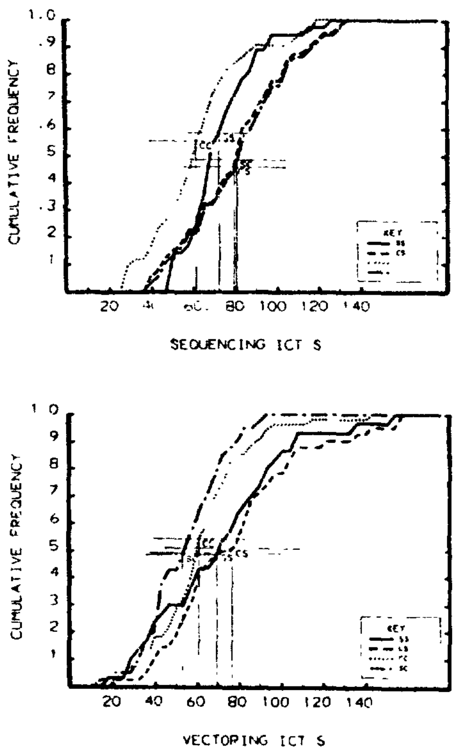


FIGURE 6 SEPARATE ANALYSES OF SIMULATOR AND COMPUTER CRAFT INTERCROSSING TIMES FOR SEQUENCING AND VECTORING MANAGEMENT.

The similarity of means and standard deviations for CC under both sequencing and vectoring is reasonable since the computer craft was always under the super pilot's control and apparently the management condition made no control difference. However, where the pilots could exercise some management, (sequencing) the reduced spread of ICT values demonstrates better system control about the average arrival time.

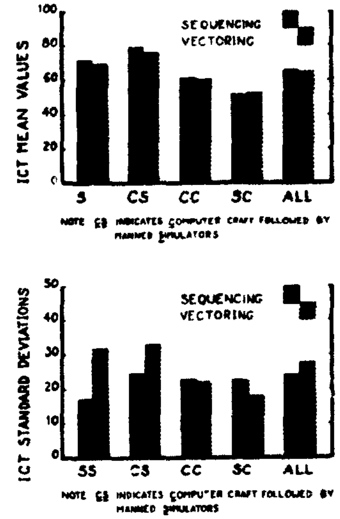


FIGURE 7 DIFFERENCES IN INTERCROSSING TIMES BY MANAGEMENT CONDITIONS AND AIRCRAFT PAIRINGS.

Very similar distinctions can be drawn from the CS and SC pairings in which the standard deviations for CS are about 25 percent smaller for sequencing (24.8 sec.) than for vectoring (32.75 sec.) while SC shows a somewhat smaller spread in vectoring than in sequencing.

Combining the SS with CS crossings and CC with SC crossings provides a broader distinction between simulator active (SS + CS) and computer active (CC + SC) results. Nonparometric statistical analysis showed a *nonsignificant difference in* mean ICT values for sequencing and vectoring (76 and 74 sec.) but a highly significant *difference* (p .002) in spreads (22 and 32.5 sec.) between sequencing and vectoring confirming that the pilots in an active role were able to exercise better system control of their ICT than the ground.

The computer active crossings (CC + SC) displayed no significant differences in either mean ICT (57 and 58 sec.) or spreads (23 and 21 sec.) for sequencing or vectoring respectively. Thi is again a reasonable result since the computer craft lacking individual pilots was always directed by the super pilot under the traffic controller's direction.

2. Statistical Analyses

Prior to any statistical analysis an elementary treatment of the data was performed. Because full experimental control was not always available, several non-representative intercrossing times occurred due either to lack of sufficiently responsive control of the computer craft, start up transients, or lulls due to the aircraft introduction statistics. These outliers were removed to arrive at the final number of approaches used in the analysis as shown in Table 4.

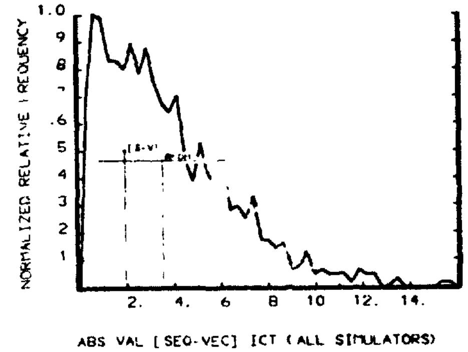
TABLE 4 - LIST OF OUTLIER INTERCROSSING TIMES REMOVED FROM ORIGINAL NUMBER OF APPROACHES.

AIRCRAFT PAIRINGS	OUTLIERS REMOVED 20 sec. ICT 175 sec. Sequencing	Vectoring	CORRECTED NUMBER OF APPROACHES Sequencing	Vectoring
SS	-	-	36	30
CS	192	190	40	42
CC	3, 10, 15	2, 4, 8, 9, 16	43	55
SC	-	11, 12, 13, 14	36	40
TOTALS	4	10	155	167

Some elementary instructive observations can be made at this point. More than twice as many outliers (10) had to be removed under the vectoring condition than under sequencing (4) while the number of approaches was about the same in each case. More outliers had to be removed in the computer craft active pairings (CC + SC = 12) than in the simulator active (SS + SC = 2). Most outliers were removed from the strictly computer active crossings (CC = 8), fewer from a computer craft following a simulator (SC = 4), fewest from a simulator following a computer craft (CS = 2) and none at all from the totally simulator active crossings (SS = 0). This is strictly in accordance with the flexibility of system control due both to distributed management and to live-vs-computer simulation.

Initial x^2 tests of the ICT data did not support a normality assumption for the data in every pairing and management condition as might be supposed by inspection of Figure 6. The normality assumption was rejected for the CC pairing alone in vectoring and for all but CS in sequencing. Rather than depend on robustness arguments or comparison specific tests, a single nonparametric test philosophy[13] was used for all the ICT comparisons.

Essentially, the nonparametric test hypothesizes for each comparison n- tuple that the groups in question are simply randomly selected from the pooled comparison data according to each group sample size; this hypothesis is exercised by computer until stable estimates are obtained for each group distribution and then confidence limits are set. The significance of the obtained statistic (e.g. mean or standard deviation) is then accepted or rejected accordingly. Comparisons between mean values were based on the unsigned difference statistic while *standard deviation were compared by the familiar ratio statistic.* ***Figure 8 shows*** **the computer generated hypothetical "no difference" statistics for a mean and a standard deviation comparison. The actual test comparisons are also shown.**



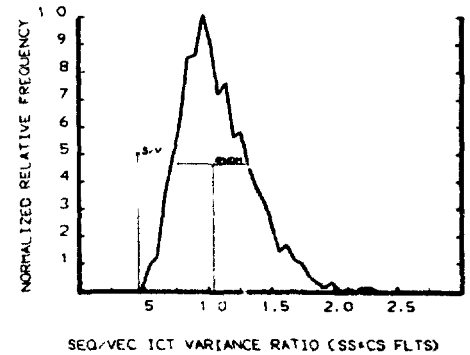


FIGURE 8. COMPUTER GENERATED TEST STATISTICS FOR A MEAN VALUE DIFFERENCES AND A STANDARD DEVIATION RATIO. ACTUAL TEST VALUES ALSO SHOWN.

The significance levels of ICT means and stand deviations are graphed in Figure 9. All the two way comparisons are made between the 4 aircraft pairings.

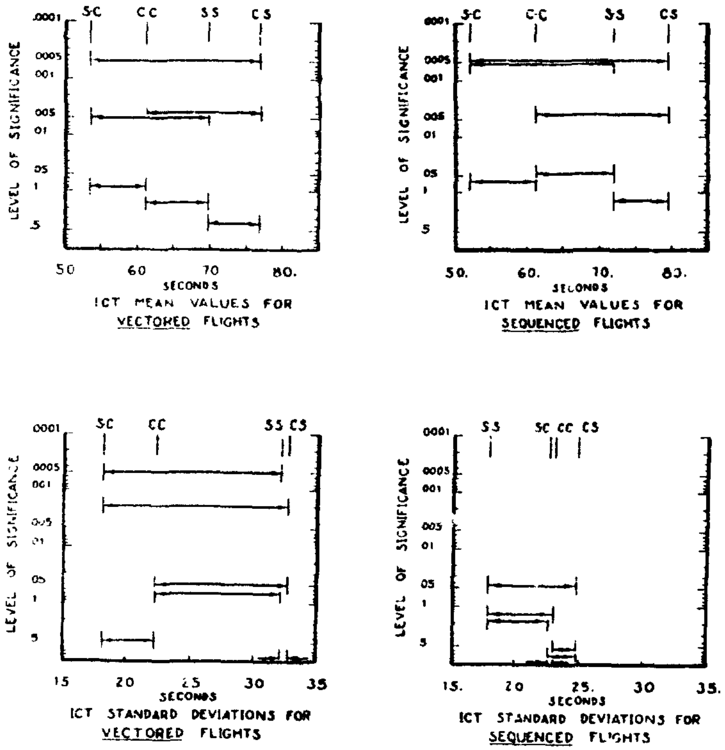


FIGURE 9 PAIRWISE COMPARISONS OF ICT MEANS AND STANDARD DEVIATIONS FOR THE FOUR A/C PAIRINGS. DIFFERENCES BETWEEN THE TWO MANAGEMENT CONDITIONS CAN BE INFERRED.

3. Simulator - Compute. A/C Differences

The analysis of effects due to mixing simulators with computer generated A/C is examined in this section.

a. Vectoring

i) Mean ICT

Within the vectoring condition SS and CC produced mean ICT values not significantly different from the grand average of 64.8 sec. although CS and SC with means of 77.0 and 53.3 sec. were significantly different from the grand average at the 0.002 level or better. As Figure 9 shows, there was no significant difference between the all simulator and the all computer pairings (SS-CC) nor between the two simulator active pairings (SS-CS). The two computer pairings (CC-SC) are marginally significant. However, where the comparisons involve simulator-vs-computer active (or vice versa) pairs, the differences are highly significant.

These tests *suggest* that *mixing* computer and *simulator craft* in the same vectoring type experiment can produce very different mean value results due to sequential effects (SC or CS) whereas the homogeneous pairings (SS-CS), (CC-SC) produce more consistent mean values. The smallest ICT (53.3 sec.) was obtained with a computer following a simulator (SC) while a simulator following a computer (CS) produced the longest ICT (77.0 sec.).

ii) Standard Deviations of ICT

The SS ICT spread is significantly larger than those of CC and SC (the computer active cases) in vectoring. Paralleling the results for the mean values, the spread of ICT values is *significantly* smaller for SC than for CS. No other comparisons showed any *significant* differences.

These results suggest that vectoring simulators as opposed to computer craft results in greater standard deviations which is in keeping with the mean ICT values.

b. Sequencing

i) Mean ICT

Within the sequencing management condition, the CC crossings had a ICT mean value significantly lower than the SS crossings (61.0 vs 72.0 sec.). In fact, the only nonsignificant differences (at the 0.05 level) were between the pairs SS and CS (both simulator active) and CC and SC (both computer active). This indicates that the pilots received no differential advantage to following another simulator or a computer craft (ground controlled). The ground likewise received no clear advantage to scheduling a computer craft after either another computer craft or a simulator.

ii) Standard Deviations of ICT

The only standard deviations which appear to be significantly different are those of SS and CS, the two simulator active pairings in which the all simulator case has about half the spread of the mixed case (17.7-vs-24.8 sec.). The SS ICT spread is the only one significantly smaller than the other three.

Combining these observations in the sequencing case suggests that in fact the mean ICT value is closer to the desired value of 60 sec. for the strictly computer A/C (controller managed) than for the strictly simulator A/C (pilot managed) and that the consistency (spread) of ICT values is the same in both cases. There is some indication that the presence of computer craft made things harder for the pilots since the SS spread is smaller than for CS and the mean ICT is better for SS than for CS although this is marginally significant.

In the vectoring case (controller managed all A/C), the mean value is again closer to the 60 sec. value for CC than for SS although the spread was considerably greater when managing the "real" A/C (32.1-vs-22.3 sec.). For some reason it appeared easier to schedule a computer craft to follow a simulator than vice versa and rather than to follow a computer craft or another simulator.

These observations suggest that results based on computer studies not using simulators or using computer-simulator mixes must be cautiously analyzed and interpreted for extrapolation to all simulator behavior. The problem obviously is that nothing substitutes for the inherent human characteristics which, however, subtle they may be, have a profound effect.

4. Management Conditions

Differences due to management conditions (sequence or vector) are examined in this section as reflected in intercrossing times (ICT). Figures 8 and 9 may be reexamined with the results given in Table 5.

The all simulator pairing (SS) may be taken to be the most representative of the results which would arise from an all simulator environment. There was a nonsignificant difference (2.27 sec.) in mean ICT values between sequencing and vectoring producing an average ICT of about 70 sec. However, the standard deviation of ICT in sequencing (17.7 sec.) is nearly 100% smaller than that for vectoring which is highly significant (p = .001) both practically and statistically.

Nearly the same observations can be made for the CS pairing in which a simulator followed a computer craft in. There was no significant difference in mean

TABLE 5. COMPARISON OF MANAGEMENT CONDITIONS BY ICT SIGNIFICANCE LEVELS GIVEN.

MANAGEMENT	SIMULATOR ACTIVE PAIRS						COMPUTER ACTIVE PAIRS		
	SS		CS		SS & CS		CC & SC		
	MEAN		VALUE		COMPARISONS				
	$\bar{X}$	P	$\bar{X}$	P	$\bar{X}$	P	$\bar{X}$	P	$\bar{X}$ = MEAN (SEC)
SEQUENCING	71.97	NS	7940	NS	75.88	NS	56.48	NS	P = LEVEL OF
VECTORING	69.70	NS	76.98	NS	73.94	NS	57.83	NS	SIGNIFICANCE
SEQ-VEC	2.27	NS	2.42	NS	1.94	NS	1.36	NS	
	STANDARD		DEVIATION		COMPARISONS				
	S	P	S	P	S	P	S	P	S = STD. DEV.
SEQUENCING	17.67	.004	24.83	.086	21.92	.001	23.20	NS	(SEC)
VECTORING	32 13	.004	32.75	.056	3246	.001	20.87	NS	P = LEVEL OF
SEQ/VEC	.550	.001	.758	.080	.675	.0005	1.11	NS	SIGNIFICANCE

ICT between sequencing and vectoring but (marginally) significant difference in standard deviations with sequencing producing a spread of ICT values about 50 % smaller than that from vectoring. The reduction in the relative magnitudes of spreads for CS compared with SS must be due to the reduced control flexibility of a computer craft-simulator pair. In the SS pairing the lead A/C can also actively participate in maintaining spacing from the following A/C in sequencing. Removing this opportunity (CS) decreases the control consistency. Notice that in vectoring the spreads of SS and CS were the same showing that the pairing had no effect on the spread.

Combining the simulator active pairs (SS + CS) also produces nonsignificant mean differences between sequencing and vectoring and a highly significant ratio of standard deviations reflecting the previous statements for SS and CS.

The results for the computer active pairings (CC + SC) are included for comparison. Note that the two management conditions do not produce significantly different means nor standard deviations for the computer active pairs. As remarked before the "super pilot" controller handled these A/C the same way ("vectored") in both conditions.

It is obvious that inferences drawn from the CC or (CC + SC) pairings would be very misleading compared to the more realistic SS pairings.

Some of the more important findings based on intercrossing times are summarized.

1. *Distributed-vs-Centralized Management.*

   . No significant differences in mean ICT(71 sec.).

   . Spread of ICT twice as large in centralized management as in distributed management.

- Shortest ICT (15 sec.) was produced under centralized management. Shortest ICT for distributed management was 47 sec.

These statements are based on simulator-simulator pairings.

2. Piloted Simulator-vs-computerized A/C.

- Simulator mean ICT was greater than for computer A/C in distributed management and nonsignificantly greater in centralized management.
- Simulator ICT spread was nonsignificantly smaller than for computer A/C in distributed management and significantly greater in centralized management.
- Mean ICT was significantly greater for a simulator following a computer A/C than vice versa for both management conditions.
- ICT spread was significantly greater for a simulator following a computer A/C than vice versa in centralized management and nonsignificantly greater in distributed management.
- Largest Mean ICT and ICT spread occurred for simulators following computer A/C. Smallest mean ICT occurred with computer A/C following simulators. Smallest ICT spreads in distributed management occurred for simulators followed by simulators Smallest ICT spread in centralized management occurred for computer A/C following simulators.

SUBJECTIVE RESPONSES

At the end of the experiment, all subjects were requested to rate the two management conditions on 8 scaled lines reflecting their own feelings. On a scale such as "visual workload", the subject placed a labelled mark somewhere between the LOW and HIGH end. The mark was labeled either vectoring or sequencing. The data were analyzed both for absolute strength of each rating (0-10) and for simple rank order (dominance) of the two conditions. The results are shown in Figure 10.

The pilots felt safety to be somewhat higher in vectoring than in sequencing where as the controllers were fairly unanimous and determined that sequencing was safer than vectoring. This also applies to expeditiousness and orderliness.

Workload particularly visual workload, was judged better in vectoring by both pilots and controllers. Pilots were unanimous in their agreement that vectoring produced a somewhat lower visual workload and total workload than sequencing.

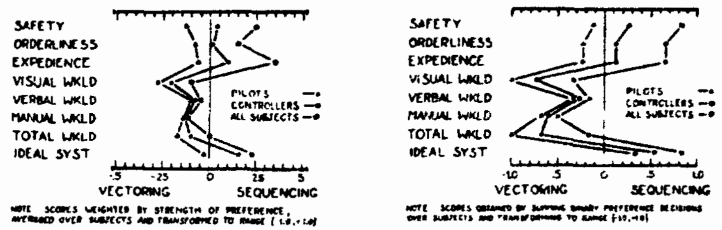


FIGURE 10 SUBJECTIVE RESPONSES BY PILOTS AND CONTROLLERS TO THE DISTRIBUTED AND CENTRALIZED MANAGEMENT CONDITIONS. ABSOLUTE DIFFERENCES ARE SHOWN ON THE LEFT WHILE STRICT DOMINANCE IS SHOWN ON THE RIGHT.

On the average, both controllers and pilots ranked sequencing over vectoring as being closer to their notion of an ideal ATC System for this task. Individually, some pilots dissented from this view vigorously enough to make the average preference strength slightly favor vectoring.

Subjective responses in this experiment presented several anomalies compared to those obtained in previous experiments.[2,5] Previously, controllers felt vectoring to produce greater safety, orderliness and expeditiousness while pilots favored sequencing on these attributes. The present reversals of this stance suggest that the MLS curved approach environment is an entirely new and different task in which neither the pilot or controller group felt itself to have produced the best performance. This may change as the curved approach regime becomes more familiar and/or much higher levels of proficiencies are developed for this task.

Pilots and controllers both felt vectoring to have a lower verbal workload than sequencing which again is a reversal of past results. The verbal analysis presently under way will shed definitive light on this.

However, in spite of the pilots stance favoring vectoring on the first three attributes and its perceived favorable workload measures from both pilots and controllers, the group consensus indicated that distributed management is closer to the notion of an ideal system than centralized management. This apparent contradiction suggests that there are important attributes not included in the ones listed which favor distributed management. It could also be that the "ideal system" concept expresses the pilots' desire to participate more in their own local traffic management (as in previous experiments) and the controllers' desire in this task to assume less responsibility (unlike previous experiments), in favor of the improved performance which occurred under distributed management.

CONCLUSIONS

The following conclusions are drawn from the results obtained in this and previous experiments.

- Distributed management which allows pilots to exercise some tactical control will reduce the standard deviation of interarrival times significantly compared to centralized management.
- Mean intercrossing time will be about the same for distributed or centralized management.
- Studies using directed computer A/C instead of more realistic piloted simulators may provide highly misleading results.
- Distributed management produces system performance at least as good or better then centralized management.
- Distributed management is a task robust concept.
- Pilots favor distributed management. Controllers may favor it depending on the task.
- Traffic management of multiple curved approaches is a complex problem requiring specialized techniques and aids.

In general, distributed management in which controllers assign a sequence to each A/C and allow the individual pilots the freedom to accomplish it is a natural mode of control and produces safe, accurate and consistent results in an orderly and expeditious manner.

REFERENCES

1. Kreifeldt, J.G., Wempe, T., "Future Terminal Air Traffic Management Concepts". Proc. 10th Annual Conference on Manual Control, WPAFB, April 9-11, 1974.

2. Kreifeldt, J.G., Wempe, T., "Human Decision Making in Future ATC Systems. Comparative Studies in Distributed Traffic Management". Proc. 1974 International Conference on Systems, Man and Cybernetics. IEEE-SMC 74 CHO-4SMC Oct. 2-4, 1974.

3. Kreifeldt, J.G., Pardo, B., Wempe, T., Huff, E., "Verbal Workload in Distributed Air Traffic Management". Proc. 11th Annual Conference on Manual Control, NASA ARC, TMX-62, 46.4, May 21-23, 1975.

4. Kreifeldt, J.G., Parkin, L., "Subjective Evaluation with FAA Criteria - A Multidimensional Scaling Approach". Proc. 11th Annual Conference on Manual Control. NASA-ARC. TMX-62,464, May 21-23, 1975.

5. Kreifeldt, J.G., Wempe, T., "Implications of a Mixture of Aircraft With and Without Traffic Situation Displays for Air Traffic Management". Proc. 12th Annual Conference on Manual Control, Urbana-Champaign, Ill. NASA TMX-73, 170, May 25-27, 1976.

6. Pardo, B., Effects on Verbal Communication and Task Variables of Different Air Traffic Control Configurations. Unpublished M.S. Thesis. San Jose State University, August 1975.

7. Cherry, G.W., DeWolf, B., MacKinnon, D., "Increasing Airport Capacity and Terminal Area Safety by Means of the Scanning Beam Instrument Landing System". AIAA Guidance, Control and Flight Mechanics Conference, AIAA No. 70-1033, August 17-19, 1970.

8. Benner, M.S., Sawyer, R.H., McLaughlin, M.D., "A Fixed-Base Simulation Study of Two Stol Aircraft Flying Curved, Descending Instrument Approach Paths", NASA TND-7298, Oct. 1973.

9. Brady, F.B., "Landing Guidance Systems" in A Survey of Modern Air Traffic Control, Vol. II. AGARD-AG-209-Vol. II, 1975.

10. Hart, S., McPherson, D., Kreifeldt, J., "Multiple Curved Descending Approaches and the Air Traffic Control Problem", paper presented at the 13th Annual Conference on Manual Control, MIT, June 15-17, 1977.

11. Kreifeldt, J.G., "Design Outline for a New Multiman ATC Simulation Facility at NASA-ARC", paper presented at the 13th Annual Conference on Manual Control, MIT, June 15-17, 1977.

12. Kreifeldt, J.G., Wempe, T., "Pilot Performance During a Simulated Instrument Procedure Turn With and Without a Prediction Display", NASA TMX-62,201, Jan. 1973.

13. Bock, R. D., Multivariate Statistical Methods in Behavioral Research. McGraw-Hill, 1975.

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