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THE EFFECT OF COMMUNICATIONS AND TRAFFIC SITUATION DISPLAYS ON PILOTS AWARENESS OF TRAFFIC IN THE TERMINAL AREA

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ABSTRACT

The Air Traffic Control (ATC) system is evolving under a general plan specified by the Federal Aviation Administration. Among the developments being considered is the Discrete Address Beacon System (DABS). The use of this system, although relieving congestion on the communications frequencies, would eliminate informatyion about other aircraft because the "party line" communications now in use would be lost. One alternative to restore this lost information is an Airborne Traffic Situation Display (TSD). Having been requested to evaluate the "assurance" that this display gives the pilot, we defined assurance to be equivalent to awareness, which is true for the majority of pilots. Experienced airline and military pilots participated in a factorial design to evaluate two types of communication (discrete address, party line) and two types of displays (TSD, no TSD). A stop-action quiz was used to evaluate their knowledge of other aircrafts' position, altitude, speed, heading, rate of climb, identity, and landing sequence number. Significant differences between conditions were detected, primarily in the position variables. Workload, as measured by a spare capacity side-task, showed a main effect of displays and a significant interaction between displays and communications. The data are summarized by plotting each display/communication condition configuration in the plane defined by information and workload index. A limited number of blunders by other aircraft were included in the simulations with a significant, but not entirely satisfactory, improvement in blunder detection attributed to the TSD.

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I. INTRODUCTION

Background

The basic idea of presenting an onboard pictorial display of traffic information is not new. This was introduced as early as 1946 by RCA in their TELERAN program (RCA, 1946). In 1963, the FAA conducted simulations using a cockpit display (Sluka, 1963), and more recently in 1966, an effort to provide televised radar pictures for pilots was tested in the Boston area under the direction of the FAA (FAA, 1966). A priori investigations declare that definite advantages for the air traffic control (ATC) system could be derived from such information, but that the attention span required to derive enough information from a rather poor quality of display was too high. What these initial efforts lacked was the ability to provide the essential elements of information about traffic in an easily discernable format for quick interpretation by the pilot. The advent of computerized radar tracking systems in the terminal area and computer-generated displays now overcomes this previous drawback with symbolic and alpha-numeric presentation of traffic information in an appropriate format.

One approach to the presentation of this information is presented by Bush et al (1970) where it is assumed that a Traffic Situation Display (TSD) could be devised that would make portions of the NAS/ARTS (National Airspace System/Automated Radar Terminal System) computerized data base available to the air crew by an omnidirectional broadcast of traffic information throughout the terminal area. This information would be received by all aircraft equipped with a TSD and onboard processing would be performed to present a symolic representation with either a north-up or heading-up display format.

Three academic research labs at M.I.T. participated in the design and construction of a fixed-based simulator to evaluate the concept of a Traffic Situation Display with flexible format under pilot control. A basic evaluation of the concept with the new display techniques has been completed (Imrich, 1971) with initial indications that several aspects of air traffic control can be improved through implementation of such a cockpit display. Furthermore, it was found that these improvements can reduce radar controller workloads significantly by increasing air crew participation in ATC functions. Other studies (Anderson, 1971) examined the effect of different display formats on pilot's scan workload and ability to follow other aircraft in trail.

Because a pictorial traffic situation display has the capability of presenting both navigation information and traffic situation information at a glance it became of interest to determine whether or not such a display would increase the overall flow rate of traffic within the terminal area under Instrument Meteorological Conditions (IMC) as compared to Visual Meteorological Conditions (VMC). Aircraft separations of about 2 or 3 miles are maintained during VMC by direct sightings; during IMC, the air traffic controller is responsible for maintaining separations and these are on the order of 5 miles. Thus the TSD has the potential for giving the pilots information nearly equivalent to VMC under IMC, with the attendant potential for increasing landing rate by reducing separations.

Scope of the Present Work

Whether or not the pilots can maintain separations with a TSD depends largely on the type and quality of information that the pilots have about their position relative to the ground and other aircraft. To evaluate the information transfer, we have undertaken a set of simulation studies to determine the type of information that the pilot has with respect to his navigation and traffic situation within the terminal area. The information the pilot has about his own aircraft and those surrounding him seems to be of general interest, and to our knowledge, this is the first time that a quantitative study has been undertaken. We evaluated the information transfer under four major treatment conditions resulting from the factorial combination of with and without TSD and with shared communications channel and discrete address commands. No display, shared communications corresponds to the present day air traffic control system and provides a convenient base line for comparison purposes. No TSD, discrete address commands corresponds to the case where the pilot receives only the commands directed towards his aircraft as will be the situation under the Discrete Address Beacon System. TSD, discrete address commands corresponds to the situation where a display is added to the DABS, whereas, TSD, shared communications corresponds to the information situation that would exist if the TSD were added to the present day ATC system.

The original request og the sponsoring agency was the evaluation of the TSD as an "assurance" device. To do this, we have here equated assurance with awareness. We have defined, for the purpose of this investigation, awareness to consist of the following elements:

1. The pilot's knowledge of his current position with respect to the air route structure
2. The pilot's knowledge of the position of other aircraft around him
3. The pilot's ability to predict the evolution of the traffic situation in the short term (especially the evolution of abnormal situations)
4. The pilot's ability to choose appropriate escape routes should an emergency occur.

The simulations, then, were designed to evaluate these facets of awareness under the four display/communications conditions described above.

II. SIMULATION FACILITIES

Cockpit

The basic component of the simulation facility is a fixed-base cockpit simulator that uses three cathode ray tubes to produce the primary flight instruments and a TSD. The basic cockpit was built from an SST prototype donated by the Boeing Company, and the interior panels, assorted switches, and instrumentation facsimiles are representative of a Boeing 707-123B aircraft. An ADAGE AGT-30 digital computer with 16K core memory and a two microsecond cycle time was used to simulate the aircraft dynamics and perform calculations for the displays.

The aircraft dynamics are representative of a Boeing 707 aircraft; the flight instrument package is patterned after a Collins FD-109 integrated flight system but does not have the flight director. The flight control system simulates control wheel steering (an attitude rate command system) as is available on the newer wide-body jets. This not only provides a uniform flying workload for either maintaining or changing altitudes, but in addition, it is felt that the attitude control task with control wheel steering in a fixed base simulator (no motion cues) is comparable to that with conventional controls in a moving base simulator.

The experiment was conducted by the simulated air traffic controller in an adjacent room. Communications between the pilot-subject and the controller were accomplished through the use of standard head sets and intercom lines. Responses from other aircraft in the traffic scenarios were stored sequentially on a tape recorder and played back in response to the controller commands. The cockpit,controller,display, computer and associated hardware are shown in block diagram form in figure 3.

Traffic Situation Display

The TSD was presented in the simulator by a cathode ray tube masked to a 7" square size. The CRT was mounted to the instrument panel where the weather radar is normally located in a Boeing 707. The display presentation was a heading-up own-ship centered format with a four second display information update rate (Figure 4). Traffic elements were shown as small circles with points at the centers. Each element was trailed by three dots that marked the past position of that aircraft (12, 24 and 36 seconds previously). Associated with each traffic element was the NAS/ARTS data block showing aircraft identification, altitude in hundreds of feet, and ground speed in knots; the own-ship data tag had only ground speed readout. Also displayed on the CRT were navigation stations, route structure, and ground features, providing the pilot with a pictorial display of his geographic position.

The display controls were mounted to the left of the CRT and allowed the pilot to select the amount of traffic and map information by adjusting the volume of displayed airspace and limiting the amount of alpha-numeric readouts for each aircraft. The major controls were an altitude layer above and below the subject aircraft within which traffic would be displayed and ranges of 4, 8, 16, 32, 64, and 128 nautical miles. A typical group of settings used during ascent and approach phase was 15 nautical miles range, and a display of other aircraft within 1000 feet above and 5000 feet below the subject aircraft.

The presence of the alpha-numeric readout was controlled by four toggle switches, which could selectively eliminate identification, ground speed, altitude, and the tracer dot feature of the other aircraft. These combinations would allow the pilot to minimize clutter and to have high resolution in the area of special interest to him.

III. METHODS

Subjects

The participants who flew the simulator for the data runs were all professional pilots. Most were licensed air carrier pilots; others were military personnel and/or general aviation pilots with instrument ratings. All subjects participated on a voluntary basis. Of the twenty subjects used in the data runs, the minimum flight time was 1800 hours, all but three had over 4000 flight hours, and eleven had over 10,000 flight hours.

All participants were given a nominal three hour training session prior to performing in the data runs. In the training run, the subject was required to fly landing approaches to Logan Airport, while establishing and maintaining proper sequencing and precise spacing intervals on the preceding aircraft. A subject was considered adequately trained when he demonstrated proficiency in maintaining a specified spacing interval of 0.1 nautical miles and when he agreed that he could at least maintain this proficiency through the subsequent evaluation series at a later date. Those candidates who felt that they needed more than one training session to gain this proficiency were given that opportunity, and three of the subjects took advantage of this opportunity.

Experimental Conditions

As was described in the introduction, there are four experimental conditions resulting from a 2 x 2 matrix of display/communications possibilities: with and without TSD and simultaneously discrete or shared communications. Henceforth, a display/communications condition will be denoted by X-Y, where X is either T or $\overline{T}$ corresponding to TSD or no TSD and Y is D or S corresponding to discrete and shared communications, respectively.

Except for a subset of experiments with four subjects which were arranged in a Latin Square configuration, the D/C conditions were not arranged in a balanced experimental design. This resulted from the fact that our interest was primarily in determining the amount and type of information that the pilots had about the other aircraft and their ability to detect and resolve blunders, and the $\overline{T}$-D congiguration resulted in no information to the pilot about other traffic. Thus we concentrated our effort on those D/C approaches in which information was available.

Seven approach simulations were developed providing different dynamic preprogrammed traffic situations at Logan Airport. Four featured merging streams of traffic to a single runway and three featured independent approaches to parallel runways spaced only 2600 feet apart. For each of the single runway simulations four different communication dialogues were prepared corresponding to the four D/C combinations. Thus any D/C combination could be used with any of these single runway simulations. For the parallel runway set of traffic situations, only two communication dialogues were prepared to represent the conditions of T-S and T-D. Simultaneous independent approaches to runways separated by less than 5000 feet are illegal under today's ATC regulations. An effort was made to evaluate the possibility that the TSD would contribute to the pilot's acceptance of closely-spaced parallel runways. Thus the dialogues without the TSD were not of primary interest for these simulations.

Scenario Development

In each of the seven basic traffic simulations, all the aircraft conformed to the Standard Terminal Arrival Route (STAR) chart constructed for this work. The transition routes appeared on the TSD along with the three fixes and the two ILS (Instrument Landing System) courses for runways 04 left and 04 right. Prior to each data run, the subject was briefed on his position, responsibilities, and tasks, and the D/C system being simulated. Responsibilities and tasks were of two general types:

Without TSD - subject to fly from holding fix to localizer in accordance with step-by-step commands from the radar controller.

With TSD - subject to fly from holding fix to localizer on designated STAR, achieving and maintaining spacing from preceding aircraft as initially specified by the radar controller.

The primary difference, and one that we feel has an influence on the results of the experiment, is that the subject must acquire and maintain a desiganted spacing from another aircraft, whereas this task is not required in those runs made without the TSD. To verify this, data from a follow-up study (Melanson, in preparation) taken under the T-D format but without the spacing task is included.

To distinguish between these two groups, the notation T-D(SP) and T-D($\overline{SP}$) is used to differentiate the T-D treatments with and without the spacing task, respectively.

Each data run began with a formal clearance which included a weather summary read by the air traffic controller. The simulation was begun once the correct response was given. The controller then, if the treatment warranted it, read a series of commands intermittently directing the pre-programmed targets and the subject in the simulator. The commands were timed to fit the pre-programmed trajectories, and were sequenced by referring to a stop-watch. Responses from the program targets were played back from a tape recorder, while the dialogue with the subject was, of course, live.

Stop-Action Quiz

One of the primary goals of this investigation was to determine the type of information that the pilot had about other traffic within the terminal area. A stop-action quiz was used to evaluate this type of information. When the situation had developed to the extent that a reasonable amount of information had been presented to the pilot and the traffic density was approaching maximum, the simulation was halted without warning. A given situation was always halted at the same point for all subjects. Presentations on the CRTs were blanked. The pilot was then required to complete the quiz on a map shown in Figure 5. The pilot was asked to supply the following information about each aircraft in the traffic situation: position, identification, landing sequence number, heading, ground speed, altitude, and 'attitude', i.e. climbing, descending, or maintaining altitude. These maps were the primary source of quantitative information in the results described below.

The stop action quiz responses were graded for accuracy and completeness. Errors in subject estimates of information components were recorded. Those components which could be graded on a right or wrong basis (i.e. identification, landing sequence number, and attitude) were scored on a point system. Correct responses received a positive point score, while incorrect responses received a negative point score. Position error was defined as the pilot's estimate of the position of aircraft including his own, with respect to the route structure. For all other information components a component error was computed by subtracting the estimated value form the true value of the particular component. Thus both positive and negative errors were possible. Those cases where it was obvious that the subject's estimate for a given aircraft had it originating from the wrong holding fix, were scored as gross errors. Missing entries were recorded as null responses.

Spacing error was measured to determine the pilot's accuracy in estimating the other aircraft positions with respect to his own craft. It was computed in the same manner as the other information components.

Blunder Detection

Four of the seven traffic situations culminated with intrusions by other aircraft in the subject's airspace. Each intrusion was due to some abnormal event, and evidence of those events was provided to the pilot through each of the D/C conditions prior to the pause for the stop-action quiz. The subjects were required to specify on the quiz whether or not the traffic situation was normal. If the blunder intrusion had not been detected before the quiz when the subject was using the TSD, the simulation was continued until either the controller was notified of an intruder, or until the point of closes approach had been reached. If the blunder had not been detected before the quiz and if the TSD was not being used, there was little likelihood that the intrusion could be detected subsequent to the quiz and the simulations were not continued. Two of the conflict scenarios occurred during single runway approach situations, while the other two occurred during independent operations on closely spaced parallel runways.

One of the single runway approach conflicts was the misinterpretation of a heading change instruction from the approach controller. This resulted in a potential collision abeam of the subject's own aircraft which at the time was flying on the ILS. This blunder could be monitored in all the treatment conditions except $\bar{T}$-D since the erring pilot read back the wrong heading.

The second single runway conflict consisted of a radio failure and subsequent failure to turn to a new heading, thus bringing the intruding aircraft into a head-on collision course with the subject's aircraft.

The parallel runway conflicts were both essentially ILS crossover blunders. The first conflict had the intruding aircraft overshooting his ILS and acquiring the subject's ILS. The second blunder had the intruding aircraft veering sharply from his ILS towards the subject aircraft after both craft had passed the outer marker.

Workload Measurements

Four of the subjects participated in a standard Latin Square counterbalanced for order effects. These subjects participated in four runs, one for each of the possible D/C combinations. A low intensity light was placed at a point which subtended equal visual angles from the center of the primary flight instruments and the TSD. An auxilliary self-paced task was presented to the subjects by having them extinguish the light whenever they noticed that it was on. The light would come on at random intervals (mean of 10 seconds after it was last extinguished) and the sub- would respond by tripping a switch on the control wheel. The measure of workload was taken as the response latency in extinguishing the light when compared with the mean "unloaded" response latency obtained when the subject fixated on the center of the primary flight instruments and was performing no other tasks.

IV. RESULTS

Information Components

This section summarizes the results of the stop-action quiz (SAQ) for the various information components, thus addressing the first two points of the presented definition of pilot awareness (and consequently, pilot assurance). The data is presented in such a way as to show general trends in the pilot's ability to estimate aircraft information components as a function of relative landing sequence (RLS), which is defined as follows: All aircraft in the landing sequence are indexed with respect to the subject's aircraft which is "0". The aircraft just ahead of the subject in the sequence is designated as "+1", while the aircraft just behind is designated "-1". The aircraft two slots ahead and behind in the sequence are indexed "+2" and "-2", respectively, and so forth. Generally, there were four or five aircraft including the subject in the landing sequence ranging from -1 to +3; however only the -1 through +2 aircraft will be considered here.

The manner in which the data is summarized reflects the assumptions that were made during analysis. These assumptions were:

1) The four scenarios used during the experiment were representative of the entire ensemble of possible scenarios.
2) All subject-pilots were representative of a homogeneous group of equal abilities and motivation.

It is realized that this data summary format obscures some of the more subtle aspects of information component estimation; however it does provide a means by which the treatment conditions can be compared.

Data summary tables consisting of the mean error, standard deviation and percent null responses as a function of relative landing sequence have been prepared for the position, spacing, altitude, ground speed and heading information components (see tables 1-9). In addition, composite graphs for the comparison of mean error responses as a function of RLS for these information components have been generated. Similar composite graphs have been developed for null responses and gross errors (Figures 7-13).

To determine statistical significance, a simple analysis of variance was performed between aircraft (RLS) for a given treatment condition and between treatment conditions for a given aircraft. The results of this analysis are summarized in Tables 6 and 7. Statistical variation was judged as either not significant (n.s.), significant at the five percent level (5%), or significant at the one percent level (1%) using standard F ratio tables. The data for the identification, landing sequence and altitude are not summarized here but are discussed later.

Blunder Detection

The blunder detection results for the single runway approach scenarios and the parallel runway approach scenarios are collected in Tables 8 and 9. Contingency tables indicating the statistical significance between treatment conditions with and without the TSD and with and without the spacing task are shown in Tables 10 and 11.

The $\overline{T}$-S, T-D(SP) and T-D($\overline{SP}$) treatment conditions were tested in the first blunder case while the T-S and T-D($\overline{SP}$) were used in the second.

For the single runway case the table indicates how many subject-pilots detected the conflict before or at the stop-action quiz (SAQ) as well as before or at the closest point of approach (CPA).

For the parallel runway case, the number of detections at or before the uncorrected CPA for each treatment condition tested (T-D(SP) and T-D($\overline{SP}$)) is recorded. The uncorrected CPA is taken to be the closest point of approach of the intruding aircraft had the subject not performed an avoidance manuever.

Workload Measurement

The statistics for the perceptual sidetask response latencies are presented in Figure 14 for each of the treatment conditions tested ($\overline{T}$-D, $\overline{T}$-S, T-S, T-D(SP)) plus the unloaded (UNL) condition. A logarithmic transformation was done on each response delay in order to normalize the reaction time distribution. The mean log response times and standard errors were then transformed back to a linear scale.

A workload index (WI) was defined as

$$WI = 1 - M_{UL}/M_L$$

where M_{UL} was defined as the mean unloaded response time for the particular treatment condition in question and M_L was defined as the mean loaded response time. A higher value of WI indicates a higher workload level.

A graph of WI versus information (INF) is plotted in Figure 15. Here information is defined as

$$INF = 1/\bar{e}^2$$

where $\bar{e}^2$ is the mean squared spacing error taken over all aircraft. The units of INF are therefore (nautical miles)$^{-2}$.

V. DISCUSSION

Information Components

The quality of information component responses is highly dependent upon the accuracy and completeness of the pilot's internal model of the air route structure and traffic environment and the information sources available to him. The shared communications channel allows the pilot to monitor air traffic control (ATC) radio transmissions. These transmissions give the pilot specific indications of the information components of the surrounding aircraft. A communication concerning any given information component of any given aircraft occurs rather infrequently. In fact such a transmission occurs only when a change in that component is desired by the approach controller. The lack of visual presentation of information requires that the pilot use his memory for the storage of the information components. Moreover, if the pilot has no other means of monitoring traffic motion, he must assume that each aircraft is following instructions. This assumption is not always justified, especially in the case of blunders.

The TSD on the other hand, provides the pilot with a nearly continuous source of information, but by its nature requires that the pilot specifically seek out a desired information component. In addition, the display acts as an auxiliary memory, thus eliminating the necessity of memorizing information components.

The addition of the shared communication channel information source to the TSD presentation augments information transfer by providing a periodic readout of commanded information component values, i.e. changes in these values. The pilot can then compare these commanded values with the actual values and can therefore confirm that the other aircraft are behaving correctly. In addition, verbal cues such as a heading readback error or a failure to reply to a transmission, can be used to draw his attention to an abnormal situation.

Requiring the pilot to performaa spacing task with respect to the +1 aircraft has a tendency to focus most of the pilot's attention on that aircraft. This fact is most evident in the T-D (SP) treatment as indicated in the composite graph for the mean position error and the position null responses (Figures 7 and 8). When the spacing task is removed, as is the case for the T-D($\overline{SP}$) treatment, position estimation accuracy becomes a monotonically decreasing function of landing sequence. The null response curve retains the same basic form, but the number of null responses for the -1 and +2 aircraft decrease while those for the -1 aircraft increase slightly.

The mean position response plot tor the T-S treatment which also has a spacing task does not follow the same trend as the T-D(SP) treatment, however a comparable null response pattern occurs. It is believed that communication transmissions concerning the -1 and +2 aircraft which occur prior to the stop-action quiz and which place these aircraft leaving a holding fix (-1 aircraft) and acquiring the ILS (+2 aircraft) aid the pilot in estimating the positions of these craft.

As a consequence of the air route structure used in the simulations, the other information components (altitude, ground speed, and heading) change rather infrequently and in a generally predictable way (except of course for abnormalities). When these components change to their new values, however, they usually change fairly rapidly, thus requiring a high sampling rate on the part of the pilot in order to effectively monitor these changes. The increased sampling rate is clearly impossible under the $\overline{T}$-S treatment, but is possible when the TSD is employed.

It happens that at the time of the SAQ, some information parameters of some aircraft are in transition, while others are relatively stable. The errors in the responses for these components reflect this fact (see Figures 7-13). At the time of the SAQ, the -1 aircraft was always descending at a rate of about 2000 fpm, while the +1 aircraft was usually flying straight and level or descending at a slower rate of about 500 fpm. The +2 aircraft was almost always flying straight and level on the ILS but not yet on the glideslope. These facts seem to account for the trends observed in the altitude data.

In the case of ground speed at the SAQ, the -1 aircraft was generally reducing to 1.0 knots. At this point, the +2 aircraft was usually reducing to 160 knots. At the quiz point during some scenarios, the -1 and +1 aircraft had just turned to a new heading while the +2 craft was established on the ILS (thus making its heading that of the ILS).

Responses to aircraft identification were comparable and quite good for all treatment conditions. This is not surprising since there were only a small number of aircraft in each scenario.

The munber of correct responses to the landing sequence component were comparable and quite high for those cases with the TSD, but were quite poor when the TSD was not employed. This fact strongly indicates the superiority of the visual display in allowing the pilot to extrapolate the evolution of the traffic situation and conversely, the difficulty in doing this on the basis of aural information alone.

The attitude responses showed no discernable trend and the very high number of null responses indicated hhat the pilots did not take this component into consideration or at least thought that it was implied in the other information components.

Blunder Detection

The culprit in the heading command readback error was the -1 aircraft. The $\overline{T}$-S treatment required that the pilots pick up the transmission cue (i.e. the readback error) in order to detect the blunder. If they missed this cue thay would have no other opportunity to detect the conflict. The T-D(SP) and T-D($\overline{SP}$) conditions did not have the communications cue, but they did allow the pilot to monitor the development of the abnormal situation that was a consequence of the readback error.

In the radio failure-track deviation conflict simulation, the intruding aircraft was the +1 aircraft. The T-S treatment provided a communication cue as well as the TSD presentation. The T-D($\overline{SP}$) treatment group did not have the transmission cue.

To the extent that these blunder scenarios are in some way representative, some conclusions can be drawn concerning the pilots conflict detection capabilities under the different treatment conditions. At least during instrument meteorological conditions it seems evident that the TSD provides the pilot with a more effective means of detecting potential conflicts than is currently available to him (see Tables 8 and 10). The addition of the spacing task seems to focus the pilot's attention on the -1 aircraft and therefore detracts from his ability to detect abnormalities associated with the other aircraft.

The only two treatments compared during the parallel runway simulations were T-D (SP) and T-D ($\overline{SP}$). This effectively compared pilot performance both with and without the spacing task. It would seem apparent (see Tables 9 and 11) that the inclusion of the spacing task detracts from the pilot's ability to monitor the adjacent aircraft effectively by drawing most of his attention from the conflict detection task to the spacing task.

It is recognized that conflict detection in itself is insufficient because enough lead time must be provided in order that the pilot be given an adequate opportunity to execute an avoidance manuever. This important problem is not discussed here, but is reported elsewhere (Howell 1972; Melanson, in preparation).

Workload Measurement

The perceptual workload versus information plot (Figure 15) indicates comparative values of workload and information for the four treatment conditions. Subjects in the $\overline{T}$-D condition had zero information (infinite variance) about aircraft other than their own. Since they did not have to monitor the TSD, their perceptual workload was relatively small.

In the $\overline{T}$-S condition, the subjects had an aural source of information input. As a result, their knowledge of surrounding traffic was improved over that of the subjects in the $\overline{T}$-D condition. Although the $\overline{T}$-S pilots did not have to monitor the TSD, the fact that they were receiving auditory distractions resulted in an increased workload index level.

In the T-D(SP) treatment, subjects had visual but no aural information about other aircraft. In fact, monitoring the TSD for spacing and sequencing tasks was a primary pilot responsibility in this condition. It can be seen that although the pilot's information about his surroundings was susbstantially improved, this improvement was gained at the cost of a significantly higher workload.

During simulations run under the T-S treatment conditions the pilots had both a visual and an aural information source. As a result, the measured information for this treatment was higher than all other treatments and the workload index is high (but lower than the T-D(SP) treatment). The increased information and decreased workload can be attributed, we think, to the addition of redunt aural information leading to less reliance on the visual modality, which was, of course, the same modality as the side task. In an analysis of variance of the response times, the D-C interaction was significatn ($p < .01$), i.e. going from discrete to shared communications without the TSD increases the workload index while going from discrete to shared communications with the TSD decreases the workload index.

VI. SUMMARY AND CONCLUSIONS

We have evaluated the transfer of traffic and navigation information to a pilot in a fixed-base simulation. The experimental conditions were derived from the combinations of with/without TSD and shared/discrete address communications. Dependent variables were the information components of other traffic (position, attitude,etc) scanning workload, and the detection of blunders.

Analysis of variance showed most of the information components to be sensitive to the display-communications configuration and the landing sequence number relative to the subject aircraft for the scenarios and the time of the stop action quiz.

The workload index shows a significant main effect for displays and a significant display-communication interaction (adding shared communications without a display increases workload, but decreases workload when the display is present.)

The ability to detect intruders in the subject's airspace was found to depend significantly on the display condition (with or without). The ability of a pilot to detect a blunder while performing a spacing task is significantly worse than when the spacing task is not required.

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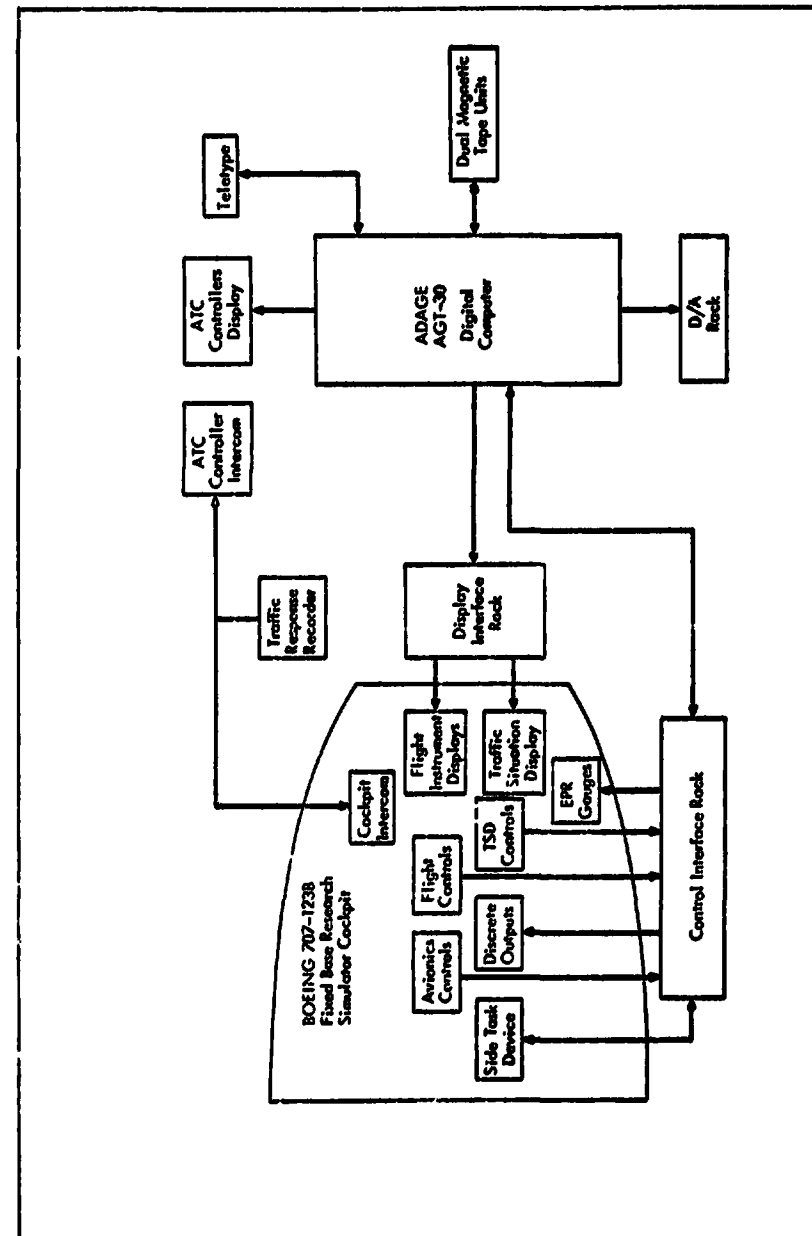

Figure 3 Simulation Facility Block Diagram 8

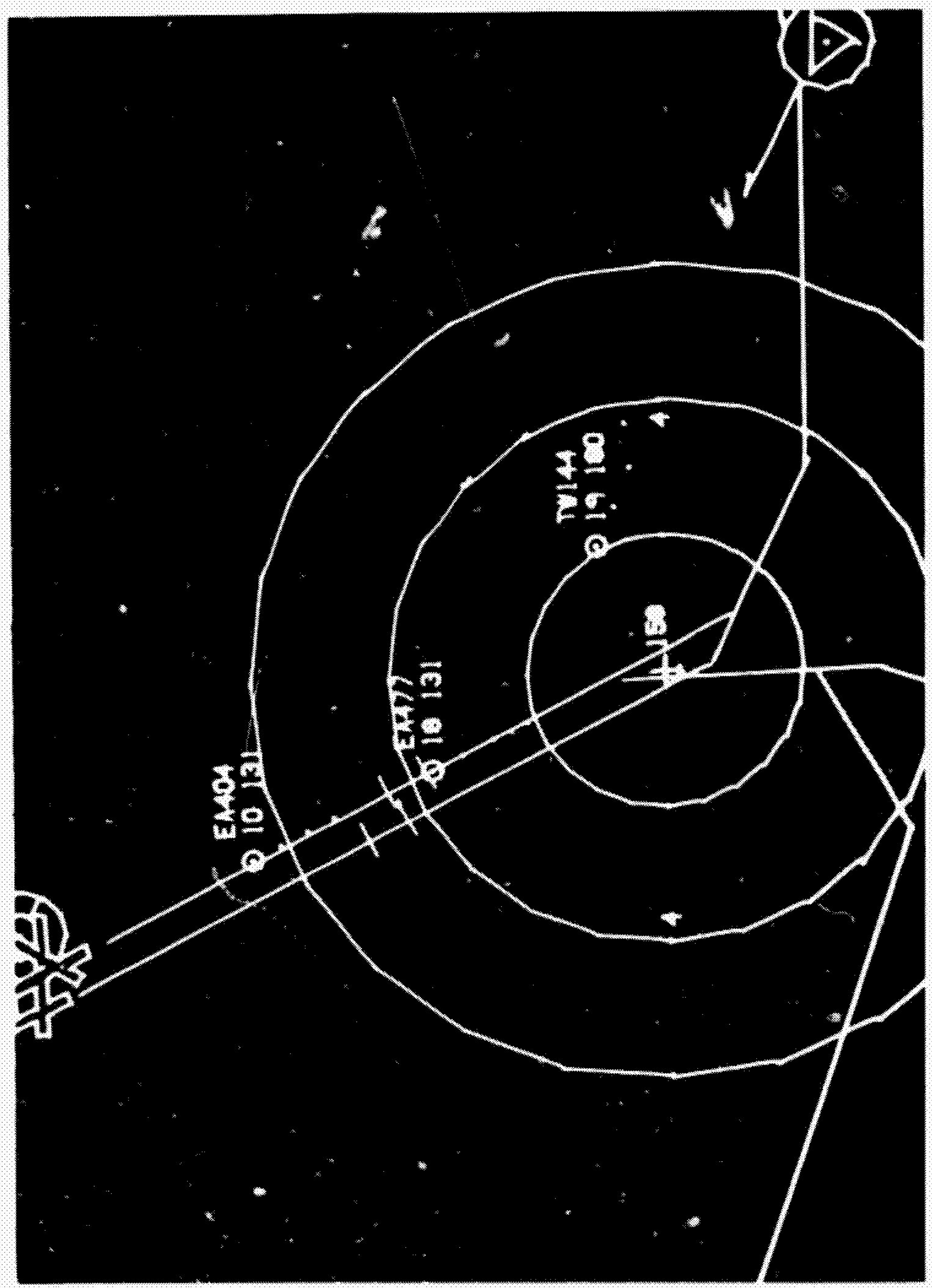

FIGURE 4. Sample Display

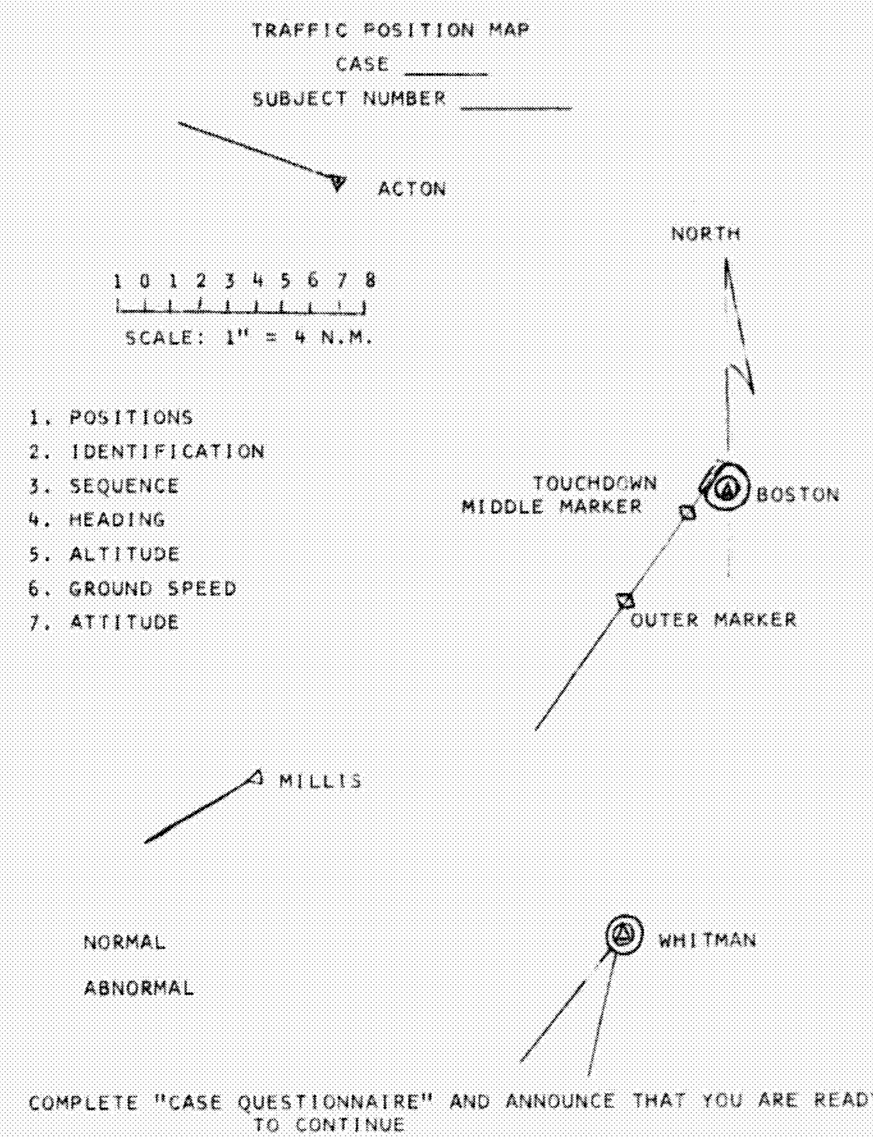

FIGURE 6. STOP-ACTION QUIZ MAP

TABLE I. POSITION ERROR (Nautical Miles)

TREATMENT CONDITIONS	RELATIVE LANDING SEQUENCE -1			0			+1			+2		
	M	S.D.	%N	M	S.D.	%N	M	S.D.	%N	M	S.D.	%N
$\bar{T}$-S	3.8	2.8	14	3.6	2.6	0	3.9	3.1	3	2.4	2.6	0
T-S	3.4	1.9	25	1.8	1.5	0	2.3	1.5	4	1.0	0.6	18
T-D (SP)	4.0	1.1	37	2.0	1.4	0	1.6	1.4	0	1.7	1.5	26
T-D (S$\bar{P}$)	3.3	2.4	13	2.6	1.6	0	2.1	1.2	5	1.7	1.0	7

TABLE 2. SPACING ERROR (Nautical Miles)

TREATMENT CONDITIONS	RELATIVE LANDING SEQUENCE -1		+1		+2	
	M	S.D.	M	S.D.	M	S.D.
$\bar{T}$-S	-2.4	4.2	-5.1	5.0	-2.5	4.3
T-S	-1.2	2.9	-0.3	1.9	-0.4	1.6
T-D (SP)	1.8	3.9	-1.3	2.1	-1.2	2.1
T-D (S$\bar{P}$)	0.0	3.8	0.6	2.0	0.5	2.1

TABLE 3. HEADING ERROR (Degrees)

TREATMENT CONDITIONS	RELATIVE LANDING SEQUENCE -1			+1			+2		
	M	S.D.	%N	M	S.D.	%N	M	S.D.	%N
$\bar{T}$-S	-5	54	32	-1	25	18	14	28	14
T-S	-5	10	39	12	30	14	0	0	21
T-D (SP)	14	60	58	-2	18	10	1	7	16
T-D (S$\bar{P}$)	29	74	40	10	38	33	-1	3	35

TABLE 4. GROUNDSPEED ERROR (knots)

TREATMENT CONDITIONS	RELATIVE LANDING SEQUENCE -1			+1			+2		
	M	S.D.	%N	M	S.D.	%N	M	S.D.	%N
$\bar{T}$-S	-5	54	32	-1	25	18	14	28	14
T-S	-5	10	39	12	30	14	0	0	21
T-D (SP)	14	60	58	-2	18	10	1	7	16
T-D (S$\bar{P}$)	29	74	40	10	38	33	-1	3	35

TABLE 5. ALTITUDE ERROR (Feet)

TREATMENT CONDITIONS	RELATIVE LANDING SEQUENCE -1			+1			+2		
	M	S.D.	%N	M	S.D.	%N	M	S.D.	%N
$\bar{T}$-S	375	619	27	-1079	1550	36	8	519	41
T-S	-520	1121	64	-315	983	26	43	253	50
T-D (SP)	725	1517	79	-288	574	16	-54	238	42
T-D (S$\bar{P}$)	57	913	25	-147	564	10	-117	292	25

TABLE 6. RESULTS OF ANALYSIS OF VARIANCE BETWEEN TREATMENT CONDITIONS FOR A GIVEN AIRCRAFT

	RELATIVE LANDING SEQUENCE			
	-1	0	+1	+2
POSITION	n.s.	1%	1%	1%
ALTITUDE	1%		1%	n.s.
GROUNDSPEED	5%		1%	n.s.
HEADING	n.s.		n.s.	1%

n.s. Not Significant 1% Significant at 1% level

5% Significant at 5% level

TABLE 7. RESULTS OF ANALYSIS OF VARIANCE BETWEEN AIRCRAFT FOR A GIVEN TREATMENT CONDITION

	TREATMENT CONDITIONS			
	$\overline{TS}$	TS	TD(SP)	TD($\overline{SP}$)
POSITION	n.s.	1%	1%	1%
ALTITUDE	1%	n.s.	1%	n.s.
GROUNDSPEED	1%	1%	5%	n.s.
HEADING	n.s.	n.s	n.s	n.s.

TABLE 8. CONFLICT DETECTION DURING SINGLE RUNWAY SIMULATIONS

CONFLICT DESCRIPTION	TREATMENT CONDITIONS	DETECTION		
		NO. OF TRIALS	BEFORE OR AT SAQ	BEFORE OR AT CPA
HEADING COMMAND READBACK ERROR (COLLISION ABEAM)	$\overline{TS}$	10	1	1
	TD(SP)	8	1	5
	TD($\overline{SP}$)	6	3	6
RADIO FAILURE-TRACK DEVIATION (COLLISION HEAD-ON)	TS	10	4	10
	TD($\overline{SP}$)	6	2	6

$\overline{TS}$ = Shared communications, no display

TS = Shared communications, with display

TD(SP) = Discrete communications, display, and spacing task

TD($\overline{SP}$) = Discrete communications, display, and spacing task

SAQ = Stop action quiz

CPA = Closest point of approach

TABLE 9. CONFLICT DETECTION DURING INDEPENDENT OPERATIONS ON CLOSELY SPACED PARALLEL RUNWAYS

CONFLICT DESCRIPTION	TREATMENT CONDITIONS	DETECTION	
		NO. OF TRIALS	BEFORE OR AT CPA
ACQUISITION OF WRONG ILS	TD(SP)	7	7
	TD($\overline{SP}$)	11	11
SUDDEN ILS CROSSOVER MANUEVER	TD(SP)	7	4
	TD($\overline{SP}$)	8	8

TABLE 10.

	WITH TSD	WITHOUT TSD
DETECTED	57	1
UNDETECTED	3	9

$\chi^2 = 42.1$ ($p < .001$)
d.f. = 1

TABLE 11.

	TSD WITH SPACING TASK	TSD WITHOUT SPACING TASK
DETECTED	16	31
UNDETECTED	6	0

$\chi^2 = 4.07$ ($p < .01$)
d.f. = 1

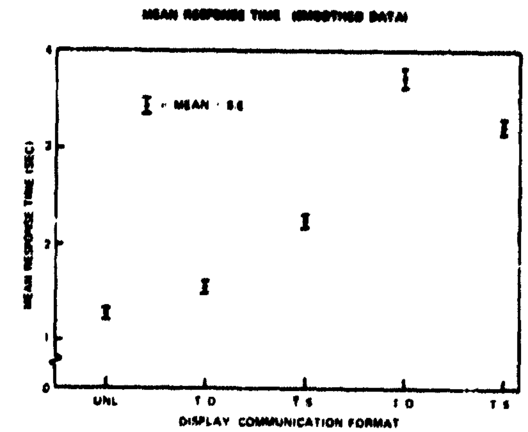

FIGURE 14

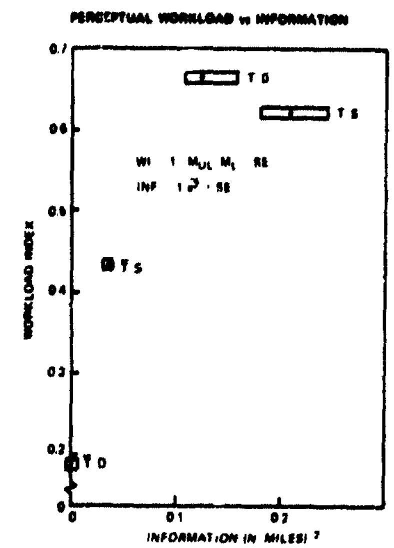

FIGURE 15