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HUMAN FACTORS EXPERIMENTS FOR DATA LINK

Edwin H. Hilborn

Transportation Systems Center

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16. Abstract

This report discusses three experiments aimed at providing information pertinent to the Data Link Operational Experiments Program. Section 1. describes the evaluation of the WIDCOM, a visual display, and a voice synthesizer for providing ATC information to pilots in a GAT-1 simulator. Section 2. is concerned with the evaluation of the intelligibility of the individual words in the vocabulary of the voice synthesizer. Section 3. describes an experiment to provide information as to possible coding formats for short message ATC commands and advisories.

The three sections of the report are independent in content, having as a common denominator their applicability to the Data Link Program.

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PREFACE

In the development of the Data Link Operational Experiments Program which has an eventual goal of evaluating airborne I/O devices, it has become increasingly evident that laboratory and simulator testing of devices and concepts can provide useful information which should make possible a reduction in the number of devices and techniques requiring eventual flight testing. The present report discusses three studies aimed at providing information of this sort.

The first section describes evaluation of a visual display, the WIDCOM, and of a speech synthesizer as means for providing ATC commands to experimental subjects in a GAT-1 simulator. The second provides data on intelligibility measurements of the voice synthesizer. The final section describes a laboratory study to determine reaction time differences when information coded in various ways is presented to experimental subjects.

The author wishes to acknowledge the contributions of numerous TSC personnel in equipment design, experimental assistance and for their helpful suggestions in clarifying the content of this report:

Mr. Joseph Vrable for design of the keyboard interface for the voice synthesizer.

Mr. Bela Nagy for design of the WIDCOM visual display.

Messrs. Rudy Nags and John Gakis for the fabrication and packaging of displays and interfaces.

Mr. Bernard Patten, Jr. for modifications to the GAT-1 simulator and for assistance in conducting the tests on the simulator.

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1. SIMULATOR TESTS

1.1 INTRODUCTION

Study and planning for the DOT/TSC Data Link program has brought to light the wealth of display technologies and coding techniques which appear to be suitable for presenting digitally transmitted data. This section reports on one of a series of simulator studies aimed at screening candidate devices so that only a limited number of the most suitable will require subsequent flight testing.

The present tests evaluated two devices: a voice synthesizer and a visual display, the WIDCOM. The objectives of the studies were to determine:

a. Could synthetic speech be generated with a sufficient approximation to real time to permit accurate control of a flight path?

b. Was the intelligibility of commands generated by synthetic speech acceptable?

c. Could a visual display of heading, altitude and speech commands replace the present use of voice?

d. Were there advantages in presenting commands both visually and aurally?

The voice synthesizer used in the experiment has been described previously.[1] It provides solid state storage of a vocabulary of one-hundred and twenty-eight words, stored as complete words as opposed to phoneme storage. In its previous use on the simulator, real time message generation was not possible, so that it was necessary to present messages on a prerecorded audio tape generated from synthetic speech. The inability to adjust timing or to change

[1] Hilborn, E.H., "Preliminary Evaluation of Synthetic Speech," Report FAA-RD-72-109, August 1972.

heading, altitude or speed commands with this tape made accurate control of desired aircraft position difficult. During the present series of runs, a keyboard interface was used which made possible the generation of commands in real time.

The keyboard interface was based upon the TSC concept[2] of a ten-key layout with letters arranged so that successive striking of the first two letters of the words in the phonetic alphabet uniquely defined the desired letter, even though multiple letters appear on the key faces. For the voice synthesizer, two additional keys were present, one denoted as "." and the other as "#". This made possible one-hundred and forty-four combinations and a call-out of any of the one-hundred and twenty-eight words in the synthesizer by two keystrokes, a majority of which were mnemonically coded. The keyboard interface also contained a real time printer and a buffer storage so that messages could be proofread prior to the activation of the voice synthesizer. The voice synthesizer is depicted in Figure 1.1, the keyboard interface in Figure 1.2 and the code used for vocabulary callup is specified in Table 1.1. The output from the voice synthesizer was piped into a GAT-1 simulator where it could be heard on a loudspeaker or via headphones.

The WIDCOM, depicted in Figure 1.3, uses seven-segment numerics to give continuous information on heading, altitude and speed commands. Flashing legend lights adjacent to the numeric readouts alert the pilot to new commands; at the same time a buzzer provides an audible alert. Pushing the flashing legend returns the light to steady state and silences the buzzer. The WIDCOM was installed on the upper left corner of the GAT-1 instrument panel, as depicted in Figure 1.4. The control box for the WIDCOM, depicted in Figure 1.5, was installed next to the GAT-1 X-Y plotting board and the keyboard interface for the voice synthesizer.

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[2] Hilborn, E.H., "Keyboard and Message Evaluation for Cockpit Input Data Link." Report DOT/TSC-FAA-71-21, Nov. 1971.

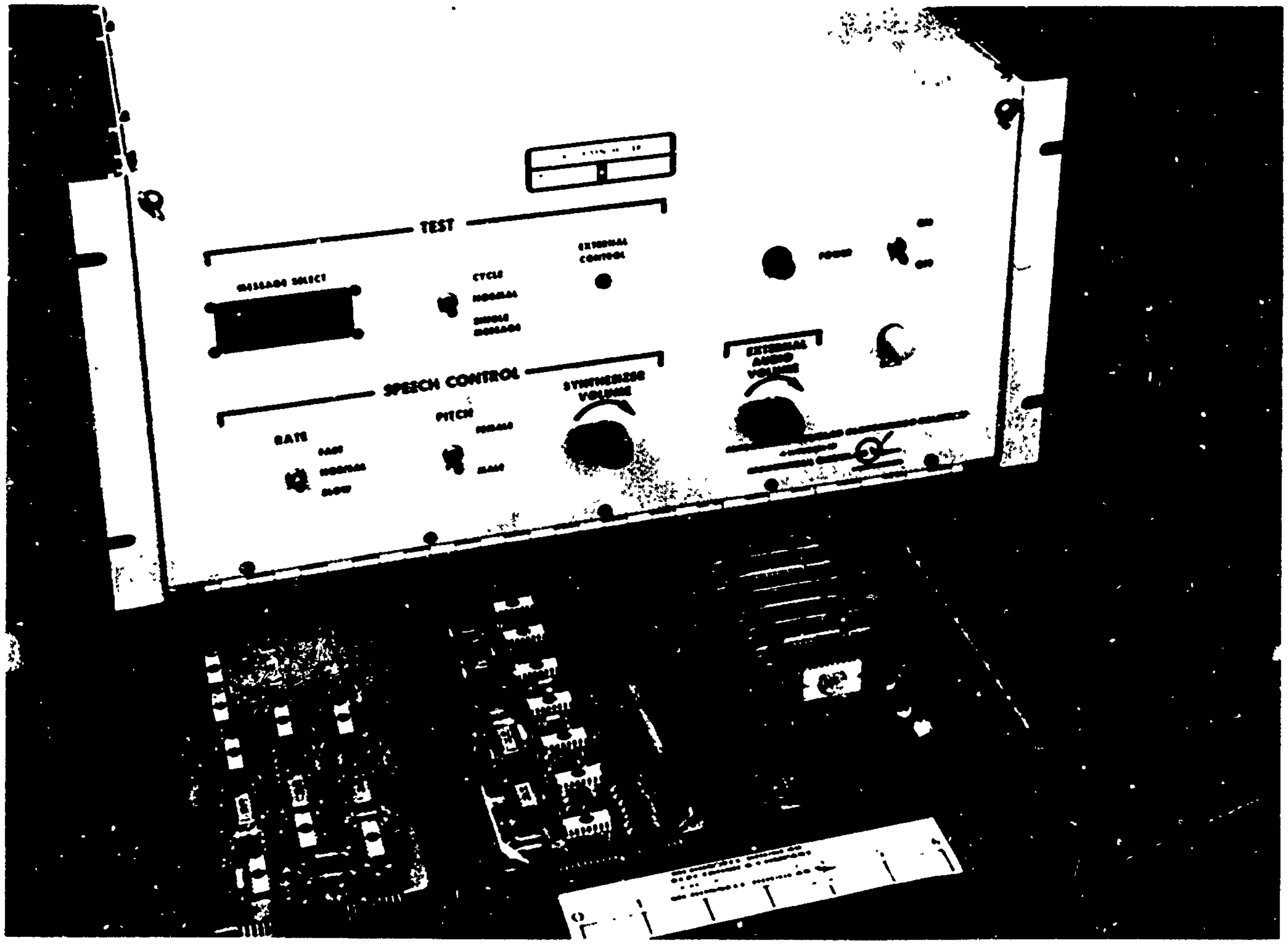

Figure 1.1 The McDonnell-Douglas Voice Synthesizer

Figure 1.2 Keyboard Interface for the Voice Synthesizer

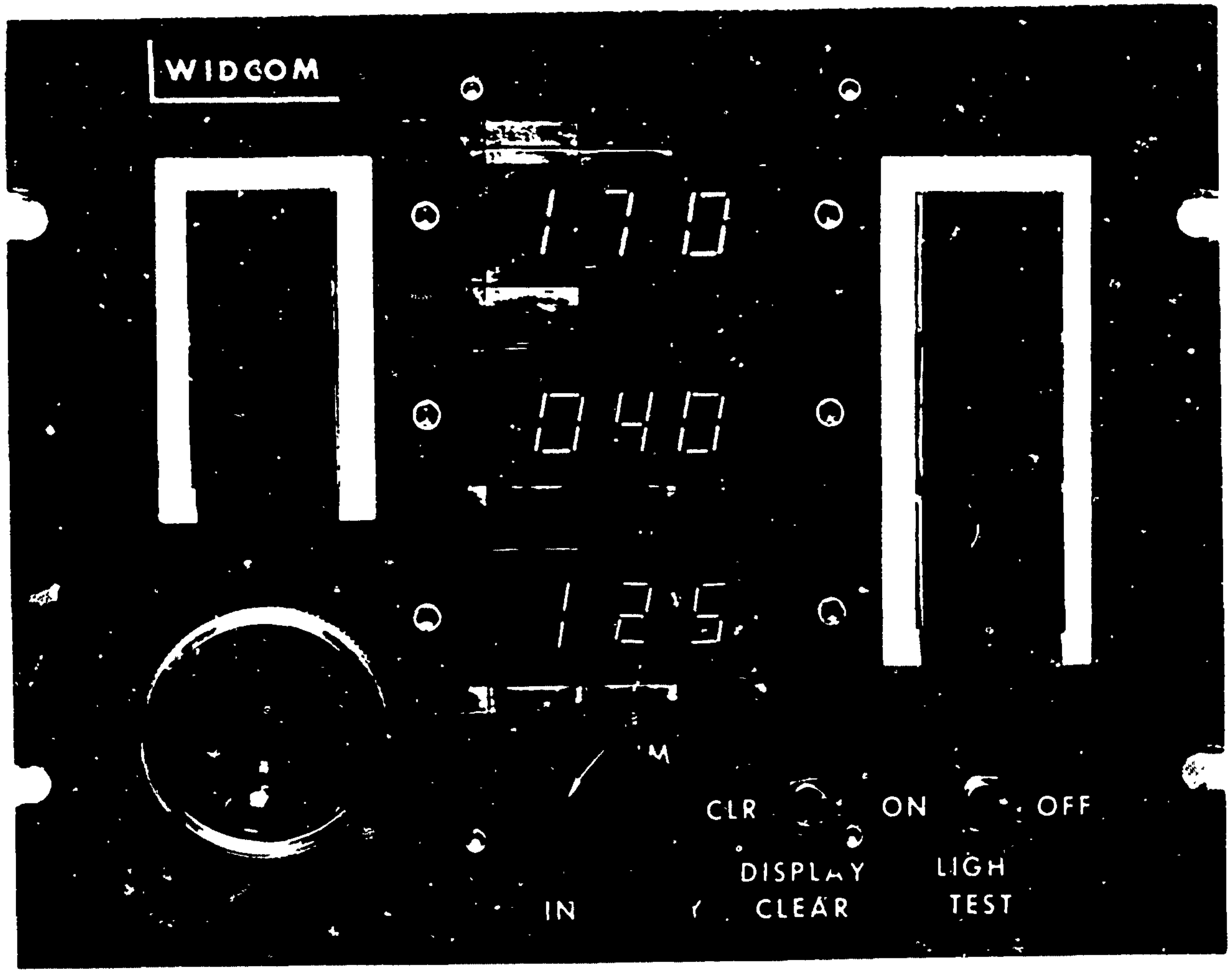

Figure 1.3 The WIDCOM Visual Display

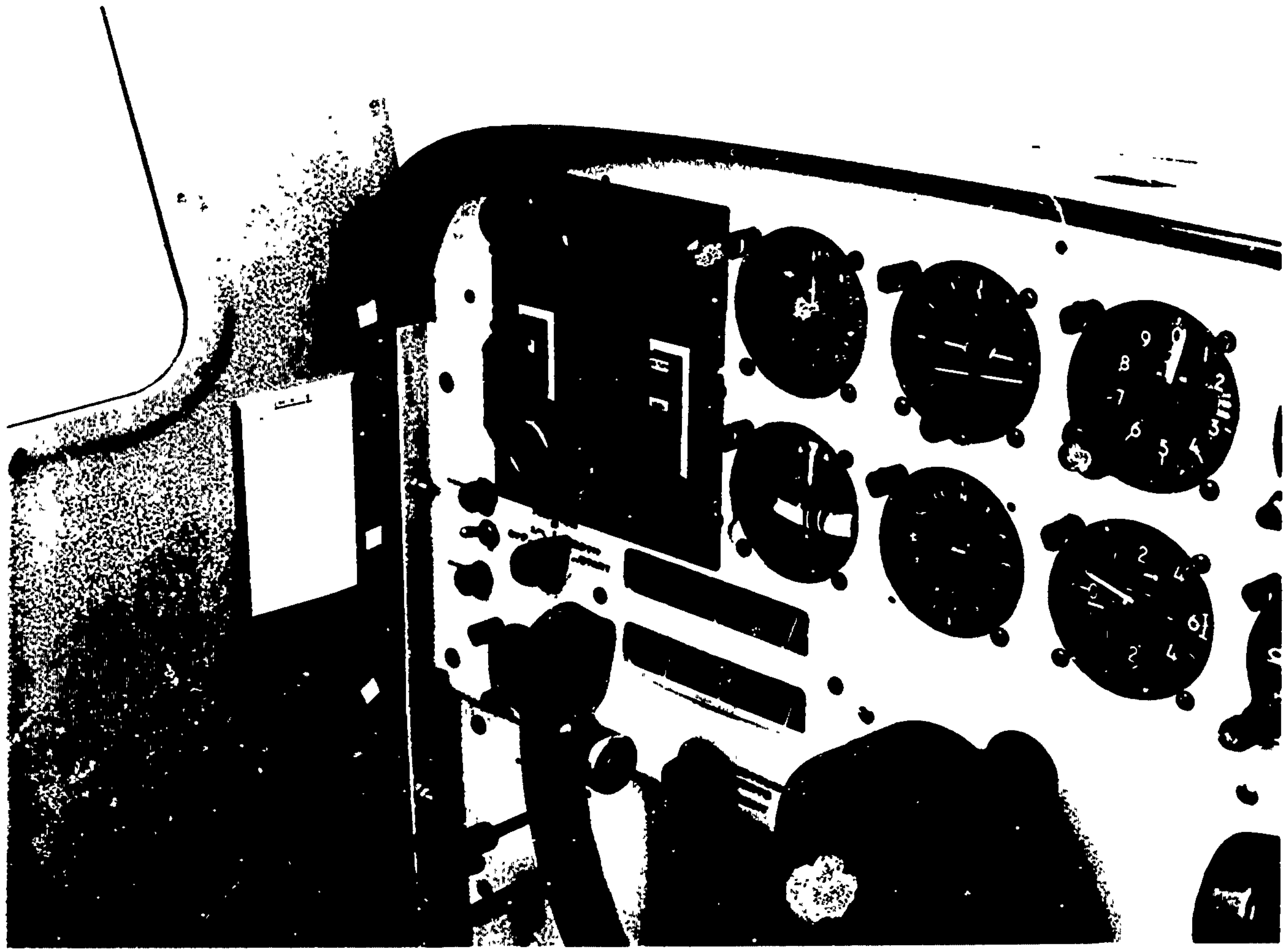

Figure 1.4 The WIDCOM as Installed in the GAT-1 Simulator

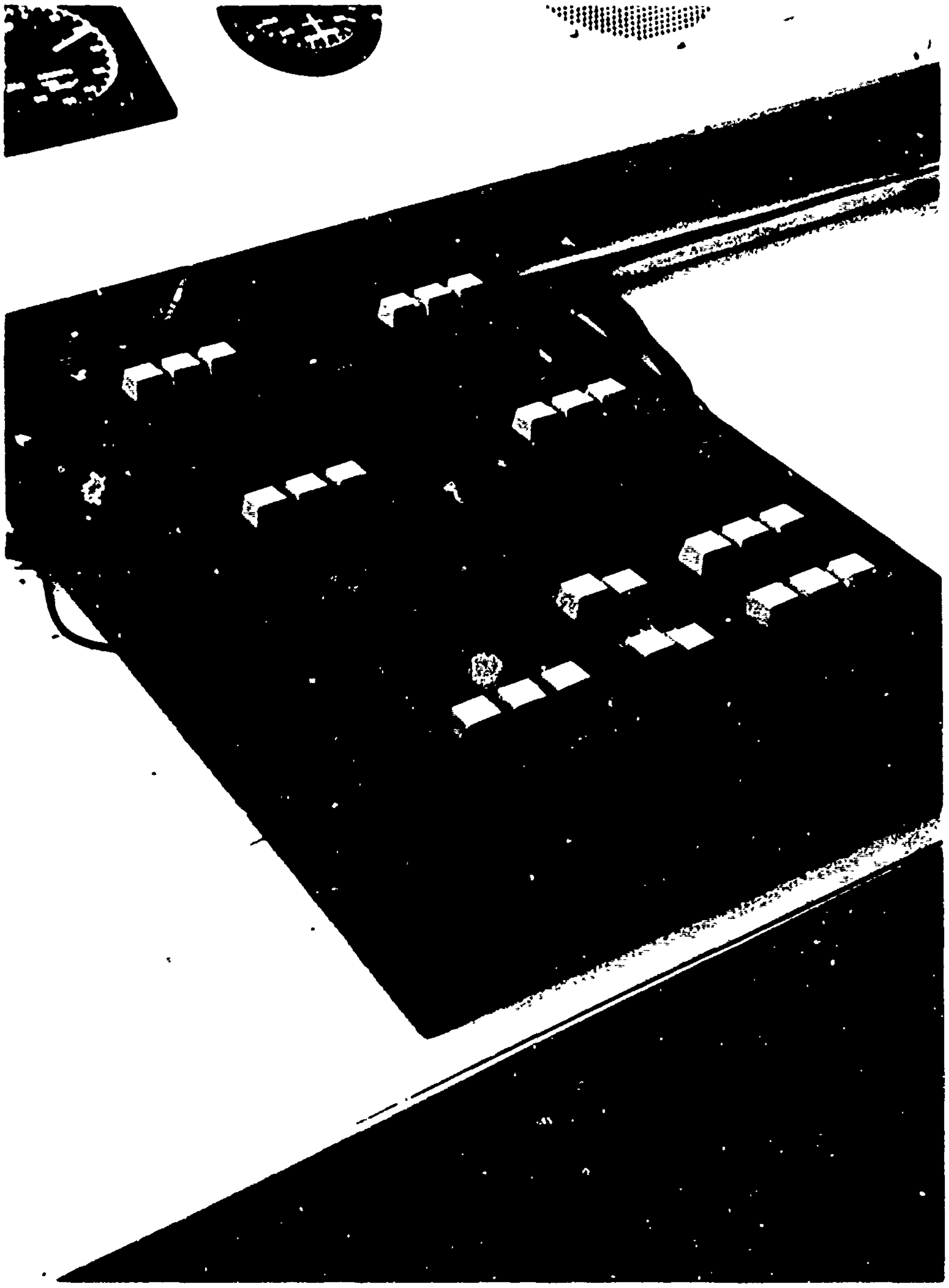

Figure 1.5 The WIDCOM Control Box

TABLE 1.1 KEYSTROKE CODING REQUIRED FOR ACCESS TO THE VOCABULARY OF THE SPEECH SYNTHESIZER

ABOVE	G.	EMERGENCY	EY	MARKER	MZ	SLOW	SL
ACKNOWLEDGE	##	FEET	FH	MIKE	MI	SNOW	.G
AFFIRMATIVE	Y.	FIVE	#5	MILES	ML	SOUTH	S#
AHEAD	HA	FOG	GF	MINIMUM	MH	SPEED	AI
ALFA	AL	FOLLOW	FI	MINUTES	MT	SQUAWK	.K
ALTIMETER	A#	FOUR (FOR)	#4	NEGATIVE	NG	STOP	S.
ALTITUDE	HI	FOXTROT	FO	NINE	#9	TAKEOFF	T.
AND	GH	FREQUENCY	FR	NORTH	N#	TANGO	TA
APPROACH	A.	GOLF	GO	NOVEMBER	NO	TAXI	TG
ASCEND	GG	GROUND	GR	O'CLOCK	O.	TEN	TE
AT	AT	GUSTY	GU	ON	.N	THANKS	HS
BELOW	BW	HEADING	HE	ONE	#1	THOUSAND	TH
BOUND	H.	HEAVY	HY	OSCAR	OS	THREE	#3
BRAVO	BR	HOLD	HL	OUTER	OE	TO (TWO)	#2
CANCEL	CA	HOTEL	HO	PAPA	PA	TOWER	.W
CEILING	CG	HUNDRED	HU	QUEBEC	QU	TRAFFIC	TR
CENTER	CE	IF ABLE	IA	QUESTION	.U	TURBULENCE	T#
CHARLIE	CH	IFR	IF	RADAR	.D	TURN	TU
CLEARED	LR	INCREASE	I.	RAIN	.A	TWELVE	TL
CONTACT	CO	INDIA	IN	REACH	RH	UNIFORM	UN
CONTINUE	GI	-ING	IG	REPEAT	.P	USE	UZ
CONTROL	GL	INTERMITTENT	IH	REPORT	RE	VFR	G#
DEGREES	DG	JULIET	JU	REQUEST	L#	VICTOR	VI
DELAY	D.	KILO	KI	RESTRICTION	RG	VISIBILITY	.L
DELTA	DE	KNOTS	KS	RIGHT	RR	WEATHER	WE
DEPARTURE	GA	LEAVE	LE	ROMEO	RO	WEST	W#
DESCEND	ZZ	LEFT	LL	RUNWAY	RW	WHISKEY	WH
DON'T	DT	LIGHT	LT	RVR	H#	WIND	WI
EAST	E#	LIMA	LI	SEVEN	#7	X-RAY	XR
ECHO	EC	LOCATED	LO	SIERRA	SI	YANKEE	YA
EIGHT	#8	LOWEST	LW	SIX	#6	ZERO	#0
ELEVEN	EL	MAINTAIN	MA	SLIPPERY	LG	ZULU	ZU

The location of beacons and ILS beams on the GAT-1 simulator were adjusted to correspond with the area surrounding Boston's Logan International Airport, with ILS landings on runways 4R and 33L.

It should be pointed out that while the WIDCOM and voice synthesizer were evaluated both separately and concurrently during this series of simulator runs, this should not be considered a comparative evaluation of the merits or deficiencies of either device since they possess very different total capabilities.

1.2 EXPERIMENTAL PROCEDURE

In order to develop four flight plan scenarios equated for difficulty, a piece of bent wire was placed on the plotting board map with its end lined up with Logan's runway 4R, and its outline traced. The wire was then rotated 180° and the outline again traced to produce a mirror image of the first flight path. The same procedure was followed with the same wire lined up with runway 33L. Altitude and speed command changes were then interspersed, again inverting sequences. The four scenarios then developed as:

```
Scenario "J"  Initial Altitude, 060, Airspeed 110, Heading 240
              Descend to 050
              Airspeed 115
              Right turn, heading 330
              Descend to 040
              Maintain airspeed 115
              Left turn, heading 260
              Descend to 030
              Airspeed 120
              Right turn, heading 350
              Descend to 020
              Airspeed 130
              Right turn, heading 070
              Descend to 015
              Airspeed 120
              Left turn, heading 020
              Cleared, runway 4 right
```

Scenario "L" Initial Altitude 020, Airspeed 115, Heading 175
Climb to 030
Airspeed 120
Right turn, heading 265
Climb to 040
Airspeed 115
Left turn, heading 195
Descend to 030
Maintain airspeed 115
Right turn, heading 285
Descend to 020
Airspeed 120
Right turn, heading 005
Descend to 015
Slow to 110
Left turn, heading 315
Cleared, runway 33 left

Scenario "K" Initial Altitude 060, Airspeed 110, Heading 095
Descend to 050
Airspeed 115
Left turn, heading 005
Descend to 040
Maintain airspeed 115
Right turn, heading 075
Descend to 030
Airspeed 120
Left turn, heading 345
Descend to 020
Airspeed 130
Left turn, heading 265
Descend to 015
Airspeed 120
Right turn, heading 315
Cleared, runway 33 left

Scenario "I" Initial Altitude 020, Airspeed 115, Heading 160
Climb to 030
Airspeed 120
Left turn, heading 070
Climb to 040
Airspeed 115
Right turn, heading 140
Descend to 030
Maintain airspeed 115
Left turn, heading 050
Descend to 020
Airspeed 120
Left turn, heading 330
Descend to 015
Slow to 110
Right turn, heading 020
Cleared, runway 4 right

The flight paths generated by these commands are depicted in Figure 1-6. At the scale used, commands occurred approximately every 90 seconds. The limitations of the WIDCOM required that the final clearance to a specific runway be delivered by voice. With the voice synthesizer, the commands were expanded from the above Scenarios, in that headings included the word "degrees", altitudes added "feet" and speeds, "knots" for additional clarification.

Eight licensed non-professional pilots, five of them TSC personnel, were used as experimental subjects. Each was given time to familiarize himself with the GAT-1 simulator prior to the experimental trials. At the start of the experiment they were given the following written instructions:

"You are about to take part in an evaluation of new visual and auditory displays for Air Traffic Control. The visual display presents continuous commands of heading, speed and altitude; the auditory display uses synthetic speech which can be transmitted digitally. The displays will be used separately or combined in four different scenarios, each of which will present a series of heading, speed and altitude commands leading to an eventual ILS approach to runway 4 right or 33 left at Logan airport.

"Before starting the formal experimental runs, you may take as much time as you need to familiarize yourself with the simulated aircraft. You will also be given a chance to listen to the simulated speech and to familiarize yourself with the visual display.

"During the runs, altitude changes should be made at 500' per minute, and turns at 3° per second. Please ignore any ILS indications until you have been given clearance to land. To save time after landing clearance, you may be given a waveoff so that you can start the next run as soon as possible. Each run will take about 25 minutes.

IT IS IMPORTANT THAT YOU ACKNOWLEDGE ALL COMMANDS, since this will be used as a performance measure. Additionally, in the case of the auditory-only display, you may request a repeat of a command and may use a scratch-pad if you are accustomed to do so. With the auditory commands, your aircraft ID will be 28 Bravo. Do you have any questions?"

Each experimental subject made four simulator runs under the following conditions:

E: WIDCOM without auditory alarm.
F: WIDCOM with buzzer to alert to new information.
G: WIDCOM plus Voice Synthesizer

H. Voice Synthesizer alone.

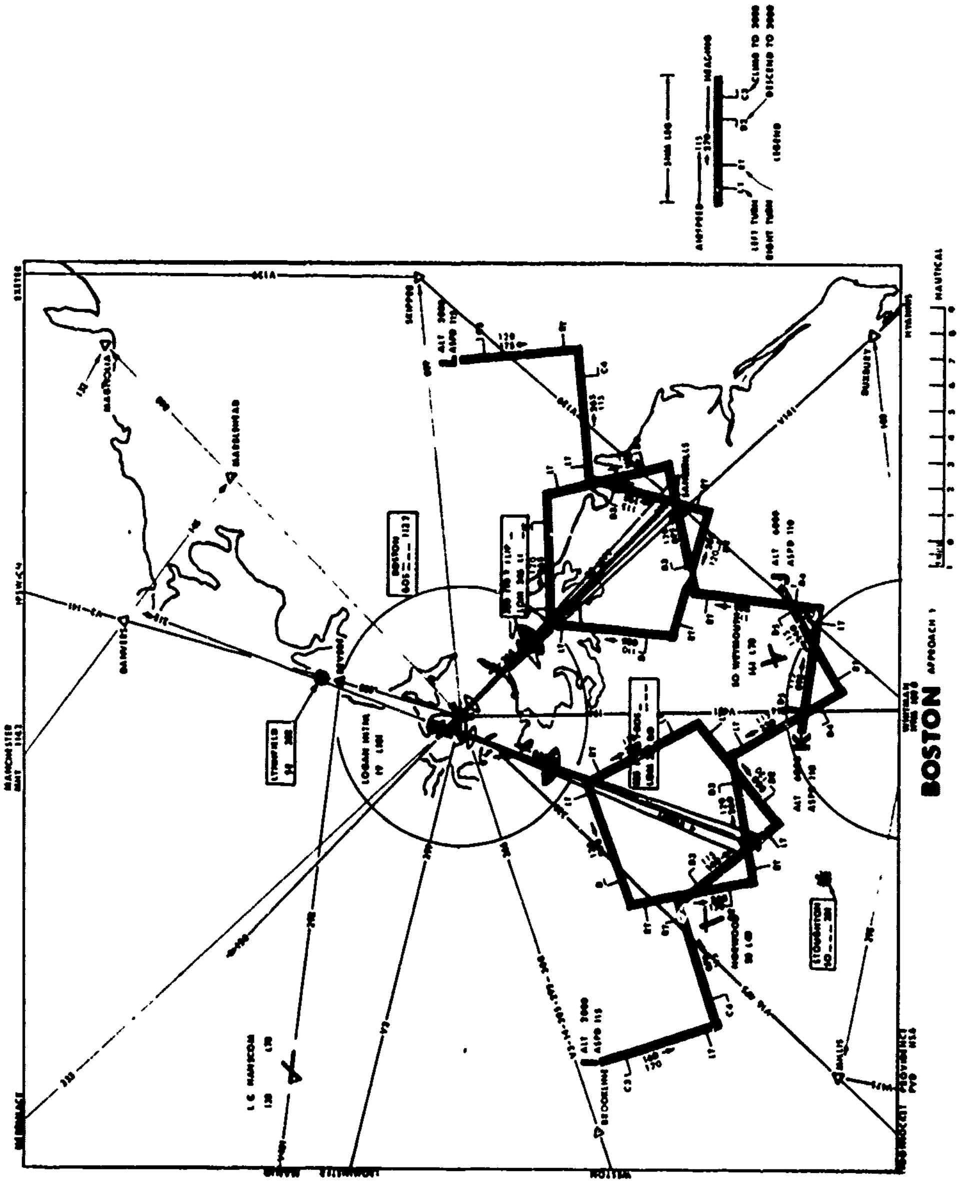

Figure 1.6 Flight-Path Model

To counterbalance for practice effects, the four experimental conditions (E, F, G, H) and the four scenarios (I, J, K, L) were presented to the individual subjects using a Latin square design:

		SUBJECTS			
		1 and 5	2 and 6	3 and 7	4 and 8
Order	1	EI	FL	GK	HJ
of	2	HK	GJ	FI	EL
Presentation	3	FJ	EK	HL	GI
	4	GL	HI	EJ	FK

At the completion of the experimental runs, the subjects were asked to complete a short written questionnaire. All runs were made under IFR conditions with the cockpit of the simulator hooded. The time to acknowledge commands was measured with a stopwatch. In the case of the voice synthesizer, timing was from the completion of the verbal command to the start of the reply. With the WIDCOM, timing was from transmission of the message to the light up of the "Acknowledged" light on the WIDCOM control box. Subjects normally made two experimental runs in rapid succession with the third and fourth runs made at least a day later.

1.3 EXPERIMENTAL RESULTS

The necessary differences in timing standards for responses to the WIDCOM and voice synthesizer, as explained earlier, makes precise comparisons impossible. Ninety-six percent of the total of four-hundred eighty responses occurred within two to four seconds. Rather than attempt to tabulate mean and standard deviations for such data and set a fixed value for direct comparison with the other sets of measurements, it seems more fruitful to examine the number of times that responses were delayed by more than five seconds. This approach was determined since these are the sort of delays which could interfere seriously with overall air traffic control operations. Data for these delayed responses are presented in Table 1.2; only one of these delays extended beyond 10 seconds.

TABLE 1.2 NUMBER OF RESPONSE TIMES GREATER THAN FIVE SECONDS

Subject	Voice Alone	Voice+ WIDCOM	WIDCOM+ Buzzer	WIDCOM NoBuzz	Total
1	3	0	3	0	6
2	0	0	0	0	0
3	0	3	1	2	6
4	0	0	1	0	1
5	0	4	0	0	4
6	0	1	0	1	2
7	0	0	0	1	1
8	0	0	0	0	0
Total	3	8	5	4	20

It is dangerous to generate firm conclusions based upon such a small number of data points. However, it would appear that (1) subjects can respond promptly to the majority of ATC commands regardless of whether they are visual or auditory, and that (b) certain subjects do not believe their ears (or eyes) and double check both modalities when possible before responding. It is important that this be checked with further simulator tests prior to flight testing of data link hardware.

In Table 1.2, it should also be noted that only one subject delayed his responses to the "voice alone" commands. Since the visual display persisted until a new command for that particular flight parameter was issued, there was no need for subjects to request a repeat of a command. When commands were issued by synthetic speech alone, four subjects did not request any repeats. However, two asked for a single repeat and two asked for three repeats.* One of the subjects who asked for three repeated commands later volunteered the information that he was presently undergoing some difficulties in hearing. It thus appears that the quality of the synthetic speech, while possibly marginal, is usable by a majority of subjects. As a result of the intelligibility testing reported in Section 2. of this report, certain of

*It should be noted that in actual data link operation, repeats by the controller would not be necessary, since the message would be stored temporarily aboard the aircraft.

the vocabulary words are being reprogrammed to improve their clarity. This should increase the acceptability of the synthetic speech.

The results of the questionnaire administered to the subjects at the completion of their experimental runs can be found in Appendix D. All the subjects agreed on the clarity and desirability of the WIDCOM, and the WIDCOM in conjunction with the voice synthesizer. However, half the subjects found the intelligibility of the synthesizer alone to be inadequate, although they all agreed that the intelligibility improved with practice. The subjects' suggestions for improvement on this system are also listed in Appendix D.

1.4 DISCUSSION

Although this series of tests indicated that simulation can provide a valuable tool for display evaluation, it also pointed out the need for more strict control of the choice of hardware components if meaningful evaluations are to be made. A simulator may be used to obtain information concerning the deficiencies or merits of a given device, or under the proper circumstances, it can provide comparative information as to the relative merits of two or more displays. In this latter instance, we should be careful to do comparative evaluations of displays having similar characteristics and/or capabilities.

The experiment reported herein provides a cogent example of lack of such experimental wisdom, brought about by the lack of a variety of display devices, such that no valid cross-comparisons could or should be made. The visual display which was evaluated was strictly limited as to the types of information which it could present. Despite the fact that the auditory display could handle a much larger proportion of normal ATC commands and advisories, it could not be exercised to this full capability because of the limitations of a flight scenario containing only the heading, speed and altitude commands which could be presented on the visual display. Furthermore, in order to provide a reasonable workload in such a scenario, changes of these parameters were required so frequently that no pilot subject could hope to remember the continually changing commands, and thus any display which retained the current information on all three of these parameters would almost by definition, be found to be useful and desirable.

On a more positive note, the experiment demonstrated that accurate control of a flight path is possible using a visual display, and that the information retention feature of such a visual display yields a favorable reaction from pilots. The comparative evaluation of the WIDCOM with other visual display devices is now in order, so as to determine the comparative value of the information requirements which can be satisfied by a given display device as opposed to its requirements for panel space, particularly in prime panel areas. Additional tests of such visual displays in non-prime panel areas are also in order, so as to determine what other positions are allowable and/or acceptable, since a device such as the WIDCOM could certainly not justify its positioning in the panel of a commercial aircraft as optimally as was possible in the GAT-1 simulator.

The voice synthesizer, since it requires nothing in the way of panel space, should remain a candidate for eventual comparative evaluation against the best of the visual displays. At the moment, the intelligibility of certain words in its vocabulary is marginal. Section 2. of this report provides such intelligibility data. Reprogramming of these presently marginal words should result in a more acceptable device.

The inclusion of an out-the-window task on future simulator experiments should not be overlooked, since this can provide additional information concerning the acceptability of purely visual ATC displays which require time-sharing of a single sensory modality.

1.5 SUMMARY AND CONCLUSIONS

Eight pilot subjects each made four experimental runs in a GAT-1 simulator to evaluate synthetic speech and a prototype visual display as means for conveying ATC command information. The experiment indicated (a) that synthetic speech could be generated with a sufficient speed to permit accurate control of a flight path,

(b) that the intelligibility of the synthetic speech was marginal for certain subjects, (c) that the visual display was highly acceptable to pilots, and (d) that responses by pilots may be delayed when information is presented both visually and aurally.

2. INTELLIGIBILITY TESTING OF VOICE SYNTHESIZER

2.1 INTRODUCTION

Report FAA-RD-72-109* discussed methods for synthesis of speech, and preliminary testing of a voice synthesizer with a 75-word vocabulary purchased from McDonnell-Douglas Electronics. At about the same time that these earlier tests were being conducted, additional funds became available which permitted the purchase of an additional 53 words of vocabulary, a total of 128 words. This section of the present report discusses intelligibility testing of the new vocabulary words, along with additional testing of the marginal words in the original vocabulary and of those words in the original vocabulary which appeared acceptable on the original tests but which might be confused with words in the new vocabulary.

2.2 EXPERIMENTAL PROCEDURE

The output from the voice synthesizer was recorded on magnetic tape using professional quality tape recording equipment. This was done to avoid the possibility of any keying errors which could result in the presentation of the wrong word during the experimental session, and secondly, to permit "playing" the experiment in a laboratory where the subjects sat in individual cubicles containing earphones connected to a central tape player. Since the output of the voice synthesizer has a frequency response of telephone quality, it was not felt that recording of such output on good quality magnetic tape could yield a measurable difference in intelligibility. Even though no stereo was present in the voice synthesizer output, the recording was made using both channels of stereo equipment in order to maintain a high signal-to-noise ratio.

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*See Footnote #1. (page 1)

The magnetic tape also contained instructions to the subjects, starting with:

> "This is a test of the intelligibility of 62 words in the vocabulary of a solid-state voice synthesizer. The words are some of those used in air traffic control. In order to give you some familiarity with the way they are pronounced, we will first present each word three times in alphabetical order while you follow along with the printed sheets which have been supplied to you."

At the completion of the vocabulary presentation, the tape then contained this announcement:

> "At this time the experimenter will stop the tape while the printed sheets are collected and the scoring sheets are passed out. - - - During the scoring trials, each word will be pronounced twice. Please write your name at the top of your scoring booklet, and we will begin. Are you ready?"

The tape then contained five presentations of the entire vocabulary, each time in a different random sequence, with announcements interpolated to direct the subjects to start the next scoring sheet at the appropriate time.

Twenty female undergraduates from Regis College were used as experimental subjects. All had passed complete audiometer tests and a majority had participated in similar experiments previously.

The procedure described above differed somewhat from that employed during the earlier tests of the original 75-word vocabulary, in that subjects were now required to write down the word rather than to check it off from among multiple possiblities. This was done to permit precise identification of the difference between sound-alikes such as "Mike", "right" and "light," since on the earlier test each of these words had appeared only once on a given check-off sheet, and the remaining possibilities could be checked off by a process of elimination.

2.3 EXPERIMENTAL RESULTS

The specification for the voice synthesizer as purchased included a requirement for 95% recognition accuracy for each vocabulary. The tape prepared for testing this contained three randomized presentations of the 62 words to be tested on one side and the final two on the other side of the tape, such that with twenty subjects, 100 responses would be obtained for each word. However, it was found that when playing the four-track stereo recorded tape on the monophonic equipment at Regis College, there was some cross talk between opposite sides of the tape. Fortunately, this occurred during portions of only two out of the five presentations since it was only at the middle of the length of the tape that material was recorded on both sides. All data concerning presentations two and five were accordingly disregarded, and the data presented below is based upon trials one, two and four only, with a perfect score being 60 correct responses.

Words which had 57 or more correct responses, meeting the 95% recognition accuracy criterion included:

WORD	TIMES CORRECT	WORD	TIMES CORRECT
ahead	60	minimum	59
ascend	58	minutes	60
below	60	north	59
cancel	60	outer	60
continue	58	rain	57
degrees	60	request	60
delay	60	restriction	60
departure	60	RVR	60
east	60	slippery	60
emergency	60	slow	58
feet	59	snow	58
follow	60	south	57
frequency	60	stop	60
heavy	59	takeoff	60
if able	60	taxi	60
IFR 60	60	thanks	60
increase	60	turbulence	60
intermittent	58	VFR	59
knots	57	weather	60
light	59	west	60
lowest	60		

Words deemed completely unacceptable include:

WORD	TIMES CORRECT	COMMON WRONG ANSWERS
Bravo	38	goggle, throttle, follow
fog	34	phone, home, foam, fall
heading	27	heavy
hundred	46	upward, corporate
-ing	42	meet, need
leave	19	home, plane, blaze, laid, late please, lane, lose
Mike	21	might, light
repeat	46	brigade, return
Tango	51	to go, thank you, can do.

Twelve words remain in a "questionable" category and require individual consideration, weighing possible lack of the subject's training on the vocabulary against the consequences of failure in recognition by pilots completely familiar with the vocabulary, the way that a word is pronounced by the voice synthesizer and taking into account the difficulty of recognizing isolated words out of context. These words are:

a. "above." 53 correct responses, 5 blanks, heard as "upon" twice. Since its antonym, "below" received 60 correct responses, there seems no danger in accepting this word.

b. "acknowledge". 55 correct responses, 5 blanks. Not a critical command word and therefore should be acceptable.

c. "and" 52 correct responses, 3 blanks, also heard as "ahead" and "end." Should be acceptable in its present form.

d. "bound" 51 correct responses, but also heard as "found." Credit this to lack of experience on the part of the subjects and accept it.

e. "control" 53 correct responses, 5 blanks, also heard as "to go." There is no serious hazard in accepting this word, since in context it would be used regularly with "approach" or "departure", etc.

f.	"descend"	55 correct responses, but also heard as "ascend". This word should definitely be reprogrammed, even though it is anticipated that "ascend" will be replaced by "climb" in a revised vocabulary.
g.	"don't"	55 correct responses; also heard as "built". Should be accepted.
h.	"ground"	52 correct responses, 3 blanks, also heard as "round" and "land". Decision: acdept.
i.	"gusty"	56 correct responses; also heard as "testing." Accept.
j.	"question"	54 correct responses, 4 blanks. Also heard as "less good". Decision: accept.
k.	"reach"	56 correct responses; also heard as "range". Accept.
l.	"right"	52 correct responses; also heard as "ride." Accept.

We are thus left with a requirement for reprogramming a total of 10 words in the existing vocabulary.

During the period since the original order was placed for the voice synthesizer, there has been a continuing effort at TSC to analyze the content of air traffic control messages and to select the precise words most useful in a limited vocabulary. As a result of this analysis, certain changes in the present vocabulary are anticipated. Table 2.1 presents the anticipated vocabulary for Data Link Flight Tests as it appears in the recently issued specification.[3] New words, not yet programmed for the voice synthesizer are identified by the prefix "N"; old words requiring reprogramming are identified by "R".

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[3] Data Link Airborne System Specification, PGGs213-3.0. July 1972, Pages 51-52.

TABLE 2.1 VOICE SYNTHESIZER VOCABULARY CODES: REVISED

(Words requiring reprogramming indicated by "R"; new words indicated by "N.")

EXTERNAL ADDRESS		WORD	EXTERNAL ADDRESS		WORD
0 100 011		ABOVE	1 000 110		FOXTROT
0 100 100		ACKNOWLEDGE	1 000 111		GOLF
0 000 000		AFFIRMATIVE	1 011 110		GROUND
0 100 101		AHEAD	1 011 111		GUSTY
1 000 001		ALFA	0 001 011	R	HEADING
0 000 001		ALTIMETER	1 100 000		HEAVY
0 000 010		ALTITUDE	0 001 100		HOLD
0 100 110		AND	1 001 000		HOTEL
0 000 011		APPROACH	1 100 001	R	HUNDRED
0 101 111	N	Airline*	1 100 010		IF ABLE
0 000 101		AT	1 100 011		IFR
1 011 101	N	BACKCOURSE	1 100 111	N	ILS
0 100 111		BELOW	1 100 100		INCREASE
0 101 000		BOUND	1 001 001		INDIA
1 000 010	R	BRAVO	1 100 110		INTERMITTENT
0 101 001		CANCEL	1 001 010		JULIET
1 111 011	N	CAN YOU	1 001 011		KILO
0 000 110		CEILING	0 001 101		KNOTS
0 000 111		CENTER	1 110 000	N	LANDING
1 000 011		CHARLIE	0 001 110		LEFT
0 001 000		CLEARED	1 101 000		LIGHT
0 000 100	N	CLIMB	1 001 100		LIMA
0 001 001		CONTACT	0 001 111		LOCATED
0 101 010		CONTINUE	1 101 001		LOWEST
0 101 011		CONTROL	0 010 000		MAINTAIN
0 101 100		DEGREES	0 010 001		MARKER
0 101 101		DELAY	1 001 101	R	MIKE
1 000 100		DELTA	0 010 010		MILES
0 101 110		DEPARTURE	1 101 010		MINIMUM
0 001 010	R	DESCEND	1 101 011		MINUTES
0 111 110		EAST	0 010 011		NEGATIVE
1 000 101		ECHO	0 111 001		NINE
0 111 000		EIGHT	1 101 100		NORTH
0 111 011		ELEVEN	1 001 110		NOVEMBER
0 111 111		EMERGENCY	0 010 100		O'CLOCK
1 100 101	N	ESTIMATED	0 010 101		ON
1 000 000		FEET	0 110 001		ONE
0 110 101		FIVE	1 001 110		OSCAR
1 011 011	R	FOG	1 101 101		OUTER
1 011 100		FOLLOW	1 010 000		PAPA
0 110 100		FOUR (FOR)	1 010 001		QUEBEC

*This word to be programmed for a specific airline or aircraft.
(Continued on following page).

TABLE 2.1 (CONTINUED)

EXTERNAL ADDRESS		WORD	EXTERNAL ADDRESS		WORD
1 101 110		QUESTION	1 111 010		TAXI
0 010 110		RADAR	0 111 010		TEN
1 101 111		RAIN	0 111 101		THOUSAND
1 111 000	N	REDUCE	0 110 011		THREE
1 110 001	R	REPEAT	0 011 101		TOWER
0 010 111		REPORT	0 011 110		TRAFFIC
1 110 011		REQUEST	1 111 100		TURBULENCE
1 110 010		RESTRICTION	0 011 111		TURN
0 011 000		RIGHT	0 111 100		TWELVE
1 010 010		ROMEO	0 110 010		TWO (TO)
0 011 001		RUNWAY	1 010 101		UNIFORM
1 110 100		RVR	1 111 101		VFR
0 110 111		SEVEN	0 100 000	N	VIA
1 010 011		SIERRA	1 010 110		VICTOR
0 110 110		SIX	0 110 001		VISIBILITY
1 110 101		SLIPPERY	1 111 110		WEATHER
0 011 010		SLOW	1 111 111		WEST
1 110 110		SNOW	1 010 111		WHISKEY
1 110 111		SOUTH	0 100 010		WIND
0 011 011		SPEED	1 011 000		X-RAY
0 011 100		SQUAWK	1 011 001		YANKEE
1 111 001		TAKEOFF	0 110 000		ZERO
1 010 100	R	TANGO	1 011 010		ZULU

In this revised vocabulary, the words ascend, don't, frequency, -ing, leave, reach, stop, thanks and use have been replaced by climb, backcourse, estimated, ILS, landing, reduce, can you, via and a blank which may be used by a specific airline for its own name.

2.4 SUMMARY AND CONCLUSIONS

Intelligibility tests were run on each of the 128 words in the vocabulary of a solid state speech synthesizer, as part of the acceptance tests of the synthesizer. Nine words were found to be completely unacceptable, twelve were marginal and the balance acceptable. Individual consideration was given to the marginal words on the basis of possible lack of training of the experimental subjects, the possible hazards inherent in incorrect interpretation and the difficulty of recognizing individual words out of context. On this basis, only one of the twelve marginal words requires reprogramming.

3. COMPARISON OF MESSAGE FORMATS

3.1 INTRODUCTION

Information may be encoded and presented in many forms. The device for displaying such information may, in turn, impose certain restrictions on how the message is encoded. For example, a device capable of displaying only a limited number of characters imposes requirements for abbreviation not needed with larger displays. Other display devices may permit information to be presented as an extended line of text while others require that the same information be presented on several short lines. The ability for an observer to assimilate such information rapidly may vary as a function of such display format and enforced coding limitations. This section of this report deals specifically with preliminary experiments to assess the effects of some of these variables.

The development of specifications for the airborne portions of the Data Link Program within the time constraints allowed made it necessary to make certain somewhat arbitrary decisions as to the types of display devices which would be tested.and the precise manner in which information would be encoded and presented to pilots. Rather than to rely on such arbitrary decisions as a basis for flight tests of hardware, it appeared that some information could be obtained by relatively basic laboratory experiments, and the first of such experiments is the subject of this section of this report.

3.2 OBJECTIVES

This experiment attempted to obtain information on such display variables as:

a. Type font. Are there differences in speed or accuracy or reaction when ATC information is presented as dot matrix characters, stencil type characters or as portions of 16-segment arrays?

b. Differences in readability between an extended linear display and the same information presented on three short lines.

c. Arrows versus words. Are arrows denoting "climb", "descend", "right", and "left" recognized more rapidly than the words or their abbreviations?

d. Differences in reaction time and error rate between the presentation of purely qualitative information and of information providing quantitative values of parameters.

e. Differences between presenting a new command by itself and presenting the new command while maintaining a "scratchpad" of the old values of other parameters.

f. When both new and old material is presented in a complex message, is it necessary to present the new material at the beginning of the message, or can material be presented in a fixed sequence of parameters, with means for delineating which is the new information?

These and other parameters were explored in the following experiment.

3.3 EXPERIMENTAL CONDITIONS

Eight formats for commands were generated under each of the six broad categories "climb", "descend", "turn right", "turn left", "tune your transceiver" and "this is a message requiring acknowledgement."* Artwork was prepared for each of these 48 messages using three type fonts; a 5 x 7 dot matrix, characters simulating those from a 16-segment array, and characters simulating stencils such as might appear on the face of a Charactron CRT. The artwork was then photographed to provide a total of 144 double frame 35 mm. high-contrast negative slides (white characters on a black background).

The slides were then mounted in 2" by 2" slide carriers, randomized in order and distributed evenly between two slide trays.

*The precise formats for each of the 144 slides are reproduced along with the raw data in Appendix A.

Each slide additionally contained a clear spot in the upper right hand corner to permit the activation of a photocell when the slide was presented on a screen.

Equipment for the experiment, other than the slides, consisted of a 35 mm. slide projector, a projection screen with affixed photocell, a response box for subjects, with six pushbuttons to permit the subjects to indicate their interpretation of the message in terms of the appropriate response, a series of numbered lights to permit the experimenter to ascertain the correctness of the subjects' response, and an interval timer calibrated in hundredths of a second which automatically measured the time from the appearance of the slide to the subjects' responses.

Ten engineers and scientists from TSC were used as experimental subjects. While four of these were members of the Data Link team, none had any precise knowledge concerning the variables which were being explored.

All subjects were handed a typewritten sheet containing the instructions:

> "IT IS IMPORTANT THAT YOU READ THESE INSTRUCTIONS CAREFULLY, TAKING ALL OF THE TIME THAT YOU WISH, SINCE YOUR PERFORMANCE ON THIS TEST WILL DEPEND TO A LARGE EXTENT ON HOW WELL YOU HAVE ABSORBED THE INFORMATION ON CODING AND ABBREVIATIONS.
>
> This is a study to determine how best to present some of the commands which will be issued to pilots via Digital Data Link during forthcoming flight tests. In this experiment, slides will be presented on a screen and you will be asked to respond as rapidly and accurately as possible to the various types of command.
>
> Your control box has six buttons. The four central buttons, arranged in a diamond-shaped pattern, represent your aircraft controls for up, down, right and left. The button on the extreme left represents your control of the frequency of your radio transceiver. The button on the extreme right is used to acknowledge all other commands or advisories. You are thus required to interpret the message before making a response. You will be scored both for the accuracy and speed of your response, although accuracy is the preferred criterion.

Various types of abbreviations will be used at the start of messages:

A = ALT = ALTITUDE, modified by up, down, climb, descend or appropriate arrows.
C = CONTACT. This indicates a command to change radio frequency.
H = HDG = HEADING, modified by R, Right, L, Left or appropriate a rows.
S = SPD = Speed
T = TURN, modified by R, RIGHT, L, LEFT or appropriate arrows.

When single-letter abbreviations are used, the ones listed above always appear first, but may be followed in the case of a radio frequency command by a second single-letter abbreviation to indicate a specific controller with the following specific interpretations:

CT = CONTACT TOWER
CA = CONTACT APPROACH CONTROL (Note that the "A" in second position stands for "Approach", not "Altitude".
CG = CONTACT GROUND CONTROL

On some slides, you may see multiple categories of information. In this case, the new information to which you should respond is set off by astericks, e.g., HDG 230 *ALT↑160* SPD 220. In the example listed, the appropriate response is, of course, to press the "climb" button.

Examples of commands which require the use of the "Acknowledge" button are:

MAINTAIN ALTITUDE
HOLD SPEED
SQUAWK (This supplies a setting for your transponder).
RADAR CONTACT
CLEARED FOR TAKEOFF
TRAFFIC 12 O'CLOCK 2 MILES

You will have only one chance to respond to each slide. Do you have any questions?"

As further training, the subjects were then handed the response box layout depicted in Figure 3.1, demonstrating the possible coding for each of the six numbered control buttons, and were urged to check out possible finger placement on the actual control box to facilitate their responses.

Subjects were run individually, and the average total time per subject was approximately 25 minutes. In order to counterbalance the effect of practice, slide tray 2 was presented first to the last five subjects.

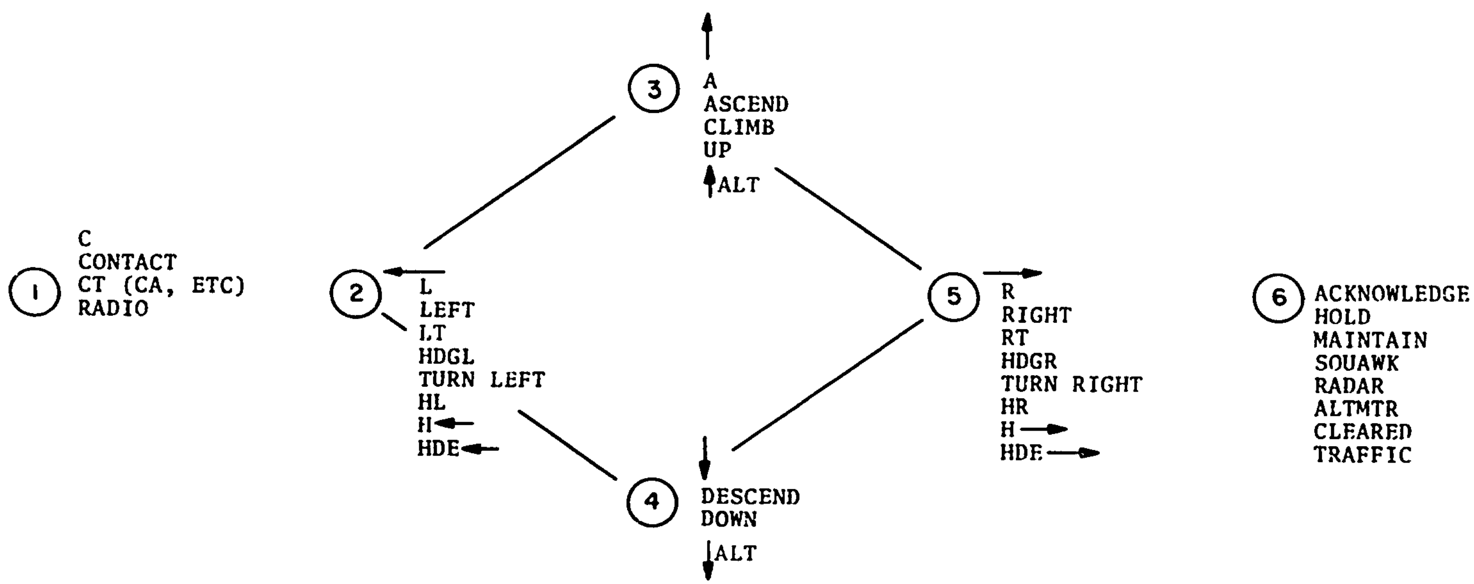


Figure 3.1 Response Box Layout

Since this was a test of the recognizability of the information and not of visual acuity, the characters of the messages were projected at a height of approximately 1/2" on the screen, and the subjects viewed them from a distance of approximately 30".

During the experiment, the subjects usually volunteered the information that they were aware when they had made an error in their response. When this information was not volunteered, the conductor of the experiment pointed out the error to facilitate performance on the remaining slides. The raw data from the experiment, organized by subject and slide categories are presented in Appendix A. The actual sequence in which the slides were presented to the subjects is indicated in Appendix B.

3.4 EXPERIMENTAL RESULTS

Experimental design must always represent a compromise between limitations on the number of variables to be explored and the time needed to obtain the required number of data points to permit meaningful comparisons. Where a completely balanced experimental design is possible, analysis of variance* provides a powerful tool for determining relationships among variables, but with an increase in the number of required data points if all combinations of all conditions are to be tested. Thus an increase is required in the number of experimental man-hours. Conversely, simple t-tests of differences among multiple mean values are prone to misinterpretation unless a requirement for a high level of statistical significance is enforced.

A reasonable alternative is to use analysis of variance of those data blocks which are complete to generate an error term suitable for use with multiple t-tests, and this technique has been applied in the reduction of the present data.

*A brief summary of statistical terminology is included in Appendix C.

From the tabulated raw data reproduced in Appendix A, the means of non-overlapping variables have been selected and are reproduced in Table 3.1*

TABLE 3.1 MEANS FOR NON-OVERLAPPING VARIABLES

Disjunctive reaction time in seconds.

MESSAGE TYPE	CHARACTER FONT		
	DM	ST	SEG
SINGLE WORD	0.96	0.84	0.99
ARROWS ONLY	0.81	0.76	0.79
WORDS + NUMBERS	1.06	1.00	1.11
ARROW + NUMBERS	0.96	1.08	0.95
3-LINE: WORDS	0.96	1.10	1.02
3-LINE: ARROWS	0.96	0.83	1.03
1-LINE: WORDS	1.52	1.66	1.80
1-LINE: ARROWS	1.51	1.74	1.70

*In generating the tables for this subsection, data points were eliminated in those few cases where a single subject recorded a response time for a particular slide which was more than twice the response time for any other subject, since such data points would probably indicate momentary inattention by that subject. Also, in these tables, means for subjects for any particular slide were deleted when there were fewer than six measurable responses for the ten subjects. The numbers in the tables accordingly represent means for at least six subjects for the selected slides and conditions to be compared, with times recorded in seconds and hundredths of a second. In the majority of these cases, three such numbers appear for a given message, these representing the response times for the same message when presented respectively with dot matrix (DM), stencil (ST) and 16-segment (SEG) fonts.

†Disjunctive reaction time is the time required for a response to a stimulus which requires selection of the appropriate action from multiple possible choices.

Analysis of variance for these data was calculated, and is summarized in Table 3.2.

TABLE 3.2 ANALYSIS OF VARIANCE FOR THE DATA OF TABLE 3.1

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F-RATIO
Message Type	233.73	7	33.39	35.9
Font	2.67	2.	1.34	1.44
Interaction	13.03	14	0.93	
Total	246.76	23		

Using the error term thus calculated and the values of the t-distribution for 14 degrees of freedom, the required differences between means for various levels of significance may be calculated using the formula:

$$M_D = \left(\sqrt{\frac{2s^2}{N}}\right)(t)$$

where M_D is the mean difference between measures being compared, s^2 is the variance, N is the number of data points being compared and t is the value obtained from tables of the t-distribution. The results of such calculations for various levels of statistical significance are presented in Table 3.3.

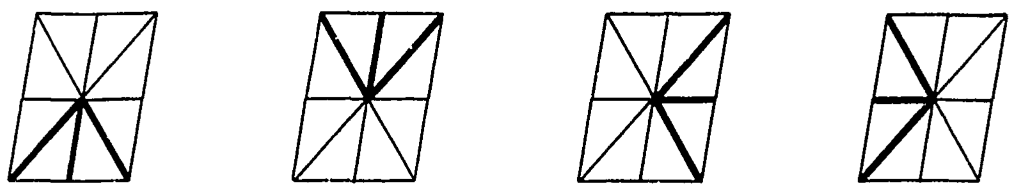
TABLE 3.3 MEAN DIFFERENCES REQUIRED FOR MESSAGE TYPE/FONTS FOR VARIOUS SIGNIFICANCE LEVELS

Required differences in seconds

SIGNIFICANCE LEVEL		0.1	0.5	0.02	0.01	0.001
t-distribution for df = 14		1.761	2.145	2.624	2.977	4.140
MEAN DIFFERENCE MD	MESSAGE TYPE	0.085	0.103	0.127	0.147	0.200
	FONTS	0.139	0.170	0.207	0.234	0.326

A prime consideration in this experiment was to determine the differences, if any, between responses to the type fonts, since ruling out of significant differences here could greatly simplify the preparation of artwork for any subsequent experiments. The analysis of variance of Table 3.2 indicated lack of significance of fonts as an experimental variable. This is substantiated by the data of Table 3.4, where response times to the several types of commands are compared for the three types fonts used.

However, this generalization is not valid when directional arrows are included within textual material. With a 16-segment array, it is possible only to generate arrows half the size of other characters, as indicated below. Locating and interpreting these half-size arrows within textual material increases reaction time appreciably over that for the same message displayed in dot matrix or stencil type characters.



Data for "buried" arrows are presented in Table 3.5 The differences here would probably be greater if better quality arrows had been used in the stencil type font. To facilitate the artwork preparation, the arrows were made by adding a line to the letter "V" and placing the letter in the appropriate orientation. It thus was less noticable in alphanumeric material than would be an arrow such as ⟶ or ➔ . The differences between 16-segment and dot matrix fonts were significant at the 0.01 level.

Arrows by themselves are better than single words for IPC-type commands as indicated in Table 3.6. Differences are significant at the 0.02 level.

TABLE 3.4 COMPARISON OF TYPE FONTS

Message type means represent means for a maximum of 80 measurements. Disjunctive reaction times in seconds.

MESSAGE TYPE	TYPE FONT DM	ST	SEG
RADIO	1.53	1.49	1.63
LEFT TURNS	1.21	1.08	1.18
CLIMB COMMANDS	1.06	1.05	1.19
DESCEND COMMANDS	0.99	1.12	1.15
RIGHT TURNS	1.29	1.14	1.12
ACKNOWLEDGMENTS	1.38	1.37	1.56
MEAN	1.24	1.21	1.31

TABLE 3.5 TYPE FONT COMPARISON FOR "BURIED" ARROWS

Disjunctive reaction time in seconds.

DOT MATRIX		STENCIL		SEGMENTED	
Slide	Time	Slide	Time	Slide	Time
10	0.96	58	0.98	106	1.23
13	1.16	61	1.25	109	1.35
19	1.22	67	1.71	115	2.30
21	1.56	69	1.14	117	1.52
27	1.20	75	1.87	123	1.67
29	1.28	77	1.52	125	1.32
34	0.93	82	1.01	130	0.99
37	1.58	85	0.97	133	1.41
MEAN	1.24		1.31		1.47

TABLE 3.6 SINGLE WORDS VERSUS ARROWS

Disjunctive reaction time in seconds.

	SINGLE WORD COMMANDS		ARROWS ONLY	
LEFT	DM	1.09	←←DM	0.84
	ST	0.82	ST	0.76
	SEG	1.04	SEG	0.71
CLIMB	DM	0.86	↑↑DM	0.74
	ST	0.78	ST	0.71
	SEG	1.00	SEG	0.83
DESCEND	DM	0.83	↓↓DM	0.79
	ST	0.95	ST	0.73
	SEG	0.93	SEG	0.90
RIGHT	DM	1.05	→→DM	0.87
	ST	0.81	ST	0.82
	SEG	0.97	SEG	0.72
MEANS		0.93		0.79

On the other hand, the differences between means between words and arrows when numerical values are added to the display, as depicted in Table 3.7 are non-significant. Arrows again show non-significant differences from words in 3-line messages indicating a single command, as indicated in Table 3.8.

The comparison between the use of arrows alone (an IPC command) and arrows along with numerical values, depicted in Table 3.9 again indicates the superiority of the simple IPC command. Since the differences here are significant at the 0.02 level, consideration should accordingly be given to the use of arrows alone for emergency maneuvers, with numerical data added only after the maneuver has begun.

The differences between text alone versus text with numerical values for simple commands such as "climb" are less striking, as indicated in Table 3.10, but are significant at the 0.05 level.

TABLE 3.7 WORDS VERSUS ARROWS WITH NUMERICAL VALUES ADDED

Disjunctive reaction time in seconds.

MESSAGE	TIME	MESSAGE	TIME
CLMB210	DM 1.11	A↑120	DM 1.00
	ST 1.10		ST 1.02
	SEG 1.23		SEG 0.88
DOWN 120	DM 1.01	A↓120	DM 0.91
	ST 0.99		ST 1.14
	SEG 0.99		SEG 1.02
MEAN	1.06		1.00

TABLE 3.8 3-LINE MESSAGES: WORDS VERSUS ARROWS

Disjunctive reaction time in seconds

MESSAGE	TIME	MESSAGE	TIME
TURN	DM 0.83	TURN	DM 0.94
LEFT	ST 0.97	←←	ST ---
180	SEG 0.89	290	SEG 1.13
TURN	DM 1.08	TURN	DM 0.98
RIGHT	ST 1.22	→→	ST 0.83
090	SEG 1.15	110	SEG 0.92
MEAN	0.79		0.96

TABLE 3.9 ARROWS ALONE VERSUS ARROWS WITH NUMERICAL VALUES ADDED

Disjunctive reaction time in seconds.

ARROWS ALONE Slide No.	Time	ARROWS + NUMBERS Slide No.	Time
15	0.84	16	0.94
63	0.76	64	1.40
111	0.71	112	1.13
23	0.74	20	0.87
71	0.71	68	0.95
119	0.83	116	0.94
31	0.79	28	0.93
79	0.73	76	1.00
127	0.90	124	1.23
39	0.87	40	0.98
87	0.82	88	0.83
135	0.72	136	0.92
MEAN	0.79		0.92

TABLE 3.10 COMPARISON OF MESSAGES HAVING TEXT WITH AND WITHOUT NUMERICAL VALUES

Disjunctive reaction time in seconds

	TEXT: NO NUMBERS		TEXT WITH NUMBERS	
	Slide	Time	Slide	Time
	14	1.09	12	0.83
	62	0.82	60	0.97
	110	1.04	108	0.89
	22	0.86	18	1.11
	70	0.78	66	1.10
	118	1.00	114	1.23
	30	0.83	26	1.01
	78	0.95	74	0.90
	126	0.92	122	0.99
	38	1.05	36	1.08
	86	0.81	84	1.22
	134	0.97	132	1.15
MEAN		0.93		1.04

In quite a different vein, Table 3.11 depicts the differences between the use of a single long line and of three short lines for presenting three parameters of data. The single line format is typical of the Burroughs Self Scan Display, whereas the 3-line format would typically involve the use of individual Light Emitting Diode (LED) characters. The differences in favor of the 3-line display are significant at the 0.001 level.

We have also been concerned with needs for putting new information on a parameter first or at the top when a scratchpad is maintained on values of other parameters. The data of Tables 3.12 and 3.13 indicate that reaction time is appreciably shorter when the new information is in front or on top, both significant at the 0.05 level. Whether or not these differences are sufficiently great as to justify the extra computer programming required to place new information at the front or top and displace older information remains a question to be resolved.

TABLE 3.11 LINEAR VERSUS THREE-LINE PRESENTATION OF THREE PARAMETERS

LINEAR		THREE-LINE	
Slide	Time	Slide	Time
11	1.93	13	1.16
59	----	61	1.25
107	1.35	109	1.35
19	1.22	21	1.56
67	1.71	69	1.19
115	2.30	117	1.52
27	1.21	29	1.28
75	1.87	77	----
123	1.67	125	1.32
35	1.67	37	1.58
83	1.65	85	0.97
131	1.49	133	1.41
MEAN	1.64		1.33

TABLE 3.12 COMPARISON OF POSITION OF NEW INFORMATION WITH SINGLE-LINE FORMAT

Disjunctive reaction time in seconds.

NEW INFORMATION "BURIED"		NEW INFORMATION IN FRONT	
Slide	Time	Slide	Time
4	1.57	7	1.61
52	2.10	55	1.97
100	1.96	103	1.28
19	1.22	11	1.93
67	1.71	59	----
115	2.30	101	1.35
27	1.21	35	1.67
75	1.87	83	1.65
123	1.67	131	1.49
MEAN	1.73		1.62

TABLE 3.13 COMPARISON OF POSITION OF NEW INFORMATION WITH THREE-LINE FORMAT

Disjunctive reaction time in seconds

NEW INFORMATION "BURIED"		NEW INFORMATION ON TOP	
Slide	Time	Slide	Time
21	1.56	13	1.16
69	1.19	61	1.25
117	1.52	109	1.35
29	1.28	37	1.58
77	1.52	85	0.97
125	1.32	133	1.41
MEAN	1.40		1.29

Table 3.14 depicts the most striking difference found in all of the data, involving an unfortunate choice of symbology to fill a 7-window display. Specifically, the symbology HDGLXXX and HDGR, where X represents a digit, should be avoided, whereas HDG←XXX and HDG→XXX are reacted to rapidly and accurately.

TABLE 3.14 ARROW VERSUS "BURIED" "L" OR "R".

MESSAGE		TIME	MESSAGE		TIME
HDGL210	DM	1.96	HDG←230	DM	0.96
	ST	1.05		ST	0.98
	SEG	1.74		SEG	1.23
HDGR110	DM	2.19	HDG→120	DM	0.93
	ST	1.77		ST	1.01
	SEG	1.32		SEG	0.99
MEAN		1.67			1.02

Throughout the experiment, the subjects maintained a high degree of accuracy in their choice of the correct pushbutton for a particular response, with a mean error rate of approximately 2.5 percent. Error data are presented in Table 3.15, but the total number of errors is too small to permit drawing conclusions.

The final table, Table 3.16, presents data for the individual subjects in terms of mean reaction times for the six message categories. The distribution of reaction times appears normal. Differences in reaction time among messages categories should be ignored since we have no means of determining the time differences required for finger movement to the appropriate response button for a particular slide.

Finally, there appears to be no correlation between the response time data and the number of errors made by individual subjects, as presented in Tables 3.15 and 3.16

TABLE 3.15 THE NUMBER OF ERRORS TO ONE-HUNDRED FORTY-FOUR VISUAL AIRCRAFT COMMAND MESSAGES FOR A SAMPLE OF TEN SUBJECTS AND SIX CONTROL COMMANDS

BUTTON	CONTACT RADIO 1			TURN LEFT 2			CLIMB 3			DESCEND 4			TURN RIGHT 5			ACKNOW-LEDGE 6			TOTAL PER SUBJECT		
SUBJECT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1		1	1			1														1	2
S2															1						1
S3			1														1			1	1
S4	1	2	2			1													1	2	3
S5	1		1	1	1														2	1	1
S6						1		1								1			1	1	1
S7	1	1				1													1	1	1
S8				1		1					1			1				1	1	2	2
S9			1			1					1			1			1	1		3	3
S10						1									1		1			1	2
TOTAL PER BUTTON	3	4	6	2	1	7	0	1	0	0	2	0	0	2	2	1	3	2	6	13	17

TABLE 3.16 MEAN RESPONSE TO ONE-HUNDRED FORTY-FOUR VISUAL AIRCRAFT COMMAND MESSAGES FOR A SAMPLE OF TEN SUBJECTS AND SIX CONTROL COMMANDS VERSUS RESPONSE TIME IN SECONDS

BUTTON / SUBJECT	CONTACT RADIO 1	TURN LEFT 2	CLIMB 3	DESCEND 4	TURN RIGHT 5	ACKNOW-LEDGE 6	MEAN PER SUBJECT
S1	1.19	0.86	0.72	0.85	0.81	0.95	0.90
S2	1.56	1.20	1.15	1.14	1.22	1.54	1.30
S3	1.64	1.17	1.06	1.13	1.11	1.44	1.26
S4	1.62	1.14	1.06	1.04	1.17	1.24	1.21
S5	1.41	1.25	1.23	1.17	1.36	1.33	1.29
S6	1.58	1.20	1.21	1.13	1.44	1.32	1.31
S7	1.56	1.13	1.22	1.09	1.18	1.70	1.31
S8	1.43	1.09	1.17	1.15	1.09	1.47	1.23
S9	1.72	1.14	1.05	1.08	1.22	1.50	1.30
S10	1.93	1.19	1.05	1.05	1.33	1.77	1.39
MEAN PER BUTTON	1.56	1.14	1.09	1.08	1.19	1.43	1.25

3.5 SUMMARY AND CONCLUSIONS

A series of one hundred and forty-four slides was prepared representing ATC messages in six general categories, with variations in message format, coding and type fonts. The slides were presented individually to ten subjects and disjunctive reaction times measured. The results of the experiment indicate that:

a. There are no differences in reaction time resulting from the use of different type fonts except when arrows as symbology are "buried" within the text. Here, the use of 16-segment font should be avoided.

b. Arrows are better than words or abbreviations for simple IPC commands or for short messages containing numerical values of a parameter.

c. For an emergency situation, only arrows should be presented, followed later, if necessary, by a numerical value.

d. Multiple commands are preferably presented on three short lines rather than one extended line.

e. "New" information should preferably be presented at the top or left of a display which maintains a scratchpad of the previous values of other parameters.

f. The command HDGLXXX or HDGRXXX, where "X" represents a digit, should be avoided and arrows substituted for the "L" or "R".

APPENDIX A

MESSAGE FORMATS AND RAW DATA

All reaction times in seconds

An "E" indicates a response error, and reaction times for these errors were not recorded

DM = Dot Matrix Characters; ST = Stencil Type Font; SEG = 16-Segment Characters

A blank in these data indicates failure of a slide to drop into the projector properly or a failure of the timer to reset.

TABLE A-1. COMMANDS CONCERNING RADIO FREQUENCY MANAGEMENT

MES-SAGE	CONTACT GROUND CONTRC. ON 1237			CONTACT TOWER 1191			CT 1172			H260A040 S170 *CONTACT TWR 1245*		
SLIDE	1	49	97	2	50	98	3	51	99	4	52	100
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	-	1.13	0.85	1.00	0.83	0.49	1.06	0.99	1.02	1.09	1.05	1.77
S2	1.53	1.42	2.86	1.23	0.89	0.88	1.27	1.09	1.36	1.36	2.13	1.74
S3	1.63	1.34	2.01	1.98	-	E	1.43	2.29	1.28	1.86	1.92	2.19
S4	1.19	1.15	1.12	1.16	0.96	0.81	0.90	E	1.52	1.59	3.75	2.95
S5	1.19	1.42	0.81	1.26	1.02	0.96	1.31	1.33	1.27	1.28	1.83	2.77
S6	1.79	1.58	1.96	1.48	1.00	1.11	1.34	1.96	1.65	1.62	2.21	1.79
S7	1.50	1.26	2.00	1.38	0.94	1.21	0.96	1.65	0.81	1.70	1.89	1.22
S8	1.70	1.15	1.69	1.37	0.92	1.17	1.21	1.81	1.19	1.40	1.50	1.23
S9	1.55	1.59	2.32	-	1.43	1.09	1.39	2.19	1.31	1.60	2.26	1.92
S10	2.21	1.18	2.12	3.11	1.08	1.49	1.46	2.88	1.49	2.18	2.42	1.97
MEAN	1.59	1.33	1.77	1.55	0.99	1.02	1.23	1.79	1.29	1.57	2.09	1.92
	1.56			1.18			1.43			1.86		

MES-SAGE	CA 1205			RADIO 1213			*CONTACT TWR 1234* H120 A200 S200			*CG1184!* HDG 070 ALT 110		
SLIDE	5	53	101	6	54	102	7	55	103	8	56	104
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	1.29	1.25	2.03	1.45	0.88	E	1.11	1.44	0.94	1.72	E	1.25
S2	1.21	1.28	3.02	2.14	0.82	1.05	1.73	1.65	1.16	2.18	1.75	1.64
S3	1.34	1.03	2.17	1.19	1.52	1.33	1.50	1.48	1.33	2.19	1.58	1.42
S4	1.21	0.82	E	2.17	E	E	1.35	2.15	0.96	E	2.50	2.35
S5	E	1.70	E	1.66	0.77	1.34	0.85	1.40	1.09	3.19	1.37	1.49
S6	1.22	1.50	2.11	1.37	0.94	1.04	1.49	1.99	1.30	1.32	1.41	2.57
S7	1.02	1.00	1.72	E6	F6	1.12	2.27	2.46	1.68	1.32	1.10	3.61
S8	1.23	1.02	1.66	1.06	1.04	1.21	1.53	2.11	1.48	1.54	1.32	2.72
S9	1.06	1.07	3.64	1.26	1.56	1.15	2.24	2.05	1.51	2.17	1.32	E6
S10	1.27	1.11	1.63	1.85	0.93	0.97	1.99	2.99	1.32	3.07	1.50	3.99
MEAN	1.20	1.13	2.25	1.57	1.03	1.15	1.41	1.97	1.28	1.87	1.39	2.34
	1.53			1.25			1.55			1.87		

TABLE A-2. COMMANDS REQUIRING LEFT TURN

MESSAGE	HDGL210			HDG←230			*HDG←070* ALT 191 SPD 210			TURN LEFT 180		
SLIDE	9	57	105	10	58	106	11	59	107	12	60	108
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	2.44	0.88	E	0.61	0.75	0.86	0.91	-	1.23	0.65	0.68	0.63
S2	3.01	1.38	1.57	[illegible]	0.99	0.81	1.34	-	1.55	1.05	0.92	1.09
S3	2.47	1.37	1.35	0.93	1.25	1.04	1.51	-	1.54	1.00	0.99	1.12
S4	1.89	1.13	E	1.04	1.14	1.23	2.12	-	1.23	0.84	-	0.86
S5	E	1.11	2.01	0.87	E	0.91	1.58	-	1.56	0.71	0.78	0.84
S6	1.30	1.88	E6	1.18	0.99	1.69	2.29	-	1.45	0.72	1.15	0.70
S7	0.92	1.43	E6	1.15	0.75	2.16	2.77	-	1.10	0.76	1.13	0.72
S8	E6	1.40	E6	1.12	0.93	1.19	1.38	-	1.44	1.02	1.13	0.96
S9	1.53	1.57	E6	0.76	1.11	1.18	2.72	-	1.12	0.78	1.02	0.85
S10	2.15	1.38	E6	1.12	0.94	1.24	2.71	-	1.25	0.75	0.96	1.15
MEAN	2.64	1.35	1.74	0.96	0.86	1.23	1.93	-	1.35	0.83	0.91	0.92
	1.79			1.02			1.64			0.89		

MESSAGE	*HDG←260* ALT 080 SPD 175			LEFT			←			TURN ← 290		
SLIDE	13	61	109	14	62	110	15	63	111	16	64	112
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	0.90	0.66	0.88	1.05	0.69	0.79	[illegible]	0.62	0.45	0.73	1.04	0.68
S2	[illegible]	1.48	1.41	1.54	0.85	1.37	0.84	0.74	0.50	0.83	-	0.99
S3	-	1.24	1.29	1.07	0.82	1.09	0.80	0.79	0.72	0.99	-	1.14
S4	1.23	1.58	1.14	1.08	0.84	0.92	0.79	0.77	-	0.77	1.19	0.76
S5	1.28	2.71	1.90	1.52	1.33	1.37	0.75	0.99	0.59	0.84	2.05	0.80
S6	1.22	0.97	1.57	1.01	0.64	0.94	1.14	0.74	0.81	1.14	1.31	1.24
S7	1.18	0.87	1.31	0.87	0.68	0.75	0.87	0.64	0.70	1.03	-	1.59
S8	1.09	0.93	1.43	0.98	0.77	1.06	0.88	0.92	0.86	1.15	-	0.98
S9	1.18	1.16	1.25	0.73	0.76	1.06	0.78	0.75	0.88	0.93	-	1.58
S10	1.13	0.88	1.35	1.05	0.78	-	0.93	0.65	0.84	0.96	-	1.55
MEAN	1.05	1.37	1.35	1.09	0.82	1.11	0.84	0.76	0.71	0.94	1.40	1.13
	1.26			1.01			0.77			1.10		

TABLE A-3. COMMANDS REQUIRING ASCENT

MESSAGE	A*120			CLMB210			HDG 160 *ALT*140* SPD 240			↑↑ ALT 150		
SLIDE	17	65	113	18	66	114	19	67	115	20	68	116
FONT	DM	ST	SFG	DM	ST	SFG	DM	ST	SFG	DM	ST	SFG
S1	0.60	0.64	0.72	0.79	0.61	0.66	0.75	1.13	-	0.51	0.48	0.60
S2	0.83	0.79	1.06	1.11	1.01	7.70	0.94	1.24	-	0.80	0.97	0.80
S3	1.10	0.93	1.06	1.00	1.15	1.02	1.34	1.31	-	1.09	0.81	0.91
S4	0.90	1.40	0.82	0.96	0.72	0.90	0.91	1.63	3.93	0.67	0.60	0.97
S5	0.94	1.24	0.96	1.57	0.88	1.25	0.97	1.62	3.53	0.70	0.68	0.76
S6	1.36	1.09	0.84	1.12	1.74	1.20	1.70	2.44	2.17	0.90	0.94	0.93
S7	1.24	-	0.81	0.96	1.17	1.04	1.49	2.19	1.56	1.37	1.14	1.17
S8	1.19	1.15	0.83	1.08	1.12	1.27	1.39	2.31	1.74	0.90	1.06	1.34
S9	1.07	0.91	0.92	0.88	1.40	1.34	1.27	1.90	1.50	0.90	0.93	0.89
S10	0.73	1.01	0.77	1.59	1.18	0.96	1.40	1.35	1.66	0.84	0.91	1.00
MEAN	1.00	1.02	0.88	1.11	1.10	1.76	1.23	1.71	2.30	0.87	0.85	0.94
	0.97			1.32			1.70			0.89		

MESSAGE	HDG 190 *ALT*110* SPD 165			CLIMB			↑↑↑			UP 130		
SLIDE	21	69	117	22	70	118	23	71	119	24	72	120
FONT	DM	ST	SFG	DM	ST	SFG	DM	ST	SFG	DM	ST	SFG
S1	1.17	0.88	0.82	0.77	0.83	0.78	0.61	0.40	0.71	0.63	0.86	0.55
S2	2.72	1.67	1.39	0.85	0.78	0.77	0.95	0.69	1.10	1.06	1.33	0.79
S3	1.44	1.45	1.29	0.84		0.98	0.81	0.71	0.93	0.90	1.12	0.96
S4	2.03	1.03	1.22	0.81	0.77	0.82	0.73	0.65	0.73	0.76	0.97	0.69
S5	2.30	1.25	1.40	1.11	0.80	0.77	0.84	0.61	1.04	0.86	1.40	0.54
S6	1.54	1.10	1.81	0.98	0.85	1.34	0.60	0.65	0.68	1.14	F2	0.91
S7	1.19	1.05	2.60	0.78	0.74	1.35	0.74	0.88	0.73	1.88	0.78	0.99
S8	1.25	1.43	1.45	0.95	0.80	1.00	0.74	0.93	0.82	1.24	1.00	1.14
S9	1.13	1.10	1.57	0.72	0.67	1.05	0.64	0.75	0.75	1.07	0.79	0.89
S10	0.83	0.95	1.68	0.81	0.74	1.11	0.73	0.79	-	1.24	0.78	1.00
MEAN	1.56	1.19	1.52	0.84	0.77	1.00	0.74	0.71	0.83	1.08	1.00	0.85
	1.42			0.87			0.76			0.98		

TABLE A-4. COMMANDS REQUIRING DESCENT

MES-SAGE	A↓120			DOWN120			HDG 260 *ALT↓060* SPD 210			↓↓ ALT 130		
SLIDE	25	73	121	26	74	122	27	75	123	28	76	124
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	0.80	0.74	0.86	0.76	0.59	0.73	0.87	1.24	1.82	0.66	0.73	1.10
S2	0.77	1.27	1.11	1.08	0.97	1.25	1.36	1.82	2.13	1.07	0.94	1.39
S3	0.89	1.11	1.02	1.02	1.05	1.01	1.48	1.69	1.37	1.11	0.96	1.54
S4	0.87	1.56	0.91	0.76	0.83	1.03	1.58	1.68	1.77	0.95	0.65	1.48
S5	0.88	1.34	0.88	0.84	1.28	1.12	1.88	1.61	1.82	-	0.96	-
S6	0.93	1.16	1.24	1.08	1.27	0.74	1.12	-	1.58	1.10	1.23	1.21
S7	1.12	0.82	0.84	0.93	0.59	0.83	0.86	2.67	1.40	1.03	1.73	0.91
S8	1.00	1.17	1.23	1.44	0.81	1.09	1.04	E3	2.01	-	1.07	1.01
S9	0.93	1.09	1.07	1.09	0.81	1.35	1.12	E3	1.43	0.81	0.95	1.29
S10	0.86	-	1.04	1.14	0.82	0.79	0.75	2.41	1.39	0.73	0.76	1.11
MEAN	0.91	1.14	1.02	1.01	0.90	0.99	1.20	1.87	1.67	0.93	1.00	1.23
	1.02			0.97			1.58			1.09		

MES-SAGE	HDG 040 *ALT↓100* SPD 180			DESCEND			↓↓↓			DESCEND 120		
SLIDE	29	77	125	30	78	126	31	79	127	32	80	128
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	0.85	1.19	1.13	0.61	0.91	0.69	0.65	0.60	0.50	-	0.82	0.79
S2	1.11	1.30	1.57	0.81	-	1.09	0.75	0.74	0.78	1.03	1.08	1.00
S3	1.31	1.52	1.29	0.87	1.01	1.20	0.91	0.97	0.71	0.94	0.96	1.17
S4	0.97	1.32	1.45	0.70	0.87	0.67	0.77	0.86	0.79	0.75	0.69	0.90
S5	1.25	1.58	1.67	0.88	1.49	0.79	0.93	0.82	0.79	0.88	0.76	1.11
S6	1.54	1.51	1.27	0.92	0.92	0.95	0.96	0.69	1.13	0.99	1.05	1.38
S7	1.62	2.07	0.93	0.87	0.80	0.99	0.63	0.52	1.12	0.98	0.80	1.11
S8	1.49	1.58	1.40	0.93	0.51	1.09	0.75	0.79	1.03	1.19	0.93	1.11
S9	1.49	1.50	1.15	0.85	0.87	0.90	0.76	0.65	1.18	1.03	-	1.29
S10	1.20	1.58	-	0.86	0.74	0.84	0.76	0.70	0.99	0.99	0.75	1.94
MEAN	1.28	1.52	1.32	0.83	0.95	0.92	0.78	0.73	0.90	0.88	0.87	1.18
	1.37			0.90			0.76			0.98		

TABLE A-5. COMMANDS REQUIRING RIGHT TURN

MES-SAGE	HDCR110			HDG+120			*HDG+160* ALT070 SPD 230			TURN RIGHT 090		
SLIDE	33	81	129	34	82	130	35	83	131	36	84	132
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	1.14	1.18	0.76	0.79	0.70	0.86	1.01	0.93	0.98	0.88	0.69	0.67
S2	1.29	1.30	0.86	1.08	0.94	1.08	1.27	0.90	1.54	1.44	1.46	E
S3	1.49	1.21	1.10	0.95	0.98	1.18	1.74	1.29	1.82	1.12	1.04	1.13
S4	1.84	2.22	1.21	1.00	0.84	0.97	1.78	1.27	1.25	1.08	0.81	0.95
S5	3.39	1.81	1.30	0.96	1.63	0.79	1.66	2.15	2.05	1.45	1.35	1.00
S6	2.04	1.80	1.66	0.88	1.19	1.03	2.61	2.57	1.71	1.12	1.54	1.84
S7	2.23	2.02	1.45	0.82	0.87	0.95	2.08	1.94	1.23	0.88	1.20	1.18
S8	1.64	1.23	1.41	0.98	0.91	0.99	1.28	1.50	1.27	1.02	1.22	1.15
S9	2.72	E6	1.77	0.86	0.99	1.12	1.96	2.11	1.27	0.95	1.35	1.31
S10	4.07	3.12	1.70	0.98	1.01	0.30	1.30	1.82	1.78	0.83	1.46	E6
MEAN	2.19	1.76	1.32	0.93	1.01	0.99	1.67	1.65	1.49	1.08	1.22	1.15
	1.75			0.98			1.60			1.15		

MES-SAGE	*HDG+190* ALT 090 SPD 165			RIGHT			++			TURN ++ 110		
SLIDE	37	85	133	38	86	134	39	87	135	40	88	136
FONT	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG	DM	ST	SEG
S1	1.11	0.73	0.79	0.63	0.59	0.90	0.68	0.70	0.60	0.99	0.52	0.60
S2	2.55	1.13	1.25	0.87	0.65	0.96	0.82	0.89	0.74	1.07	0.60	1.17
S3	1.45	0.95	1.07	0.88	0.85	0.97	0.91	0.84	0.82	1.00	0.86	0.93
S4	3.19	0.77	0.94	0.85	0.61	1.05	1.11	0.79	0.67	1.20	0.73	0.93
S5	-	1.16	1.62	0.93	0.73	1.34	0.97	1.18	0.73	1.52	0.61	1.16
S6	1.22	0.92	3.16	1.32	1.29	1.32	0.90	0.87	0.65	0.67	1.09	0.98
S7	1.41	0.81	1.45	1.78	0.83	0.77	0.77	0.76	0.61	0.73	0.84	0.80
S8	1.04	E6	1.31	1.10	0.78	0.79	0.90	0.83	0.87	0.97	1.08	0.88
S9	1.18	1.10	1.26	1.02	0.92	0.80	0.75	0.79	0.75	0.82	1.07	0.88
S10	1.11	1.12	1.24	1.09	0.80	0.84	0.87	0.59	-	0.86	0.92	0.84
MEAN	1.58	0.97	1.41	1.05	1.01	0.99	0.87	0.82	0.78	0.98	0.83	0.92
	1.32			1.02			0.82			0.91		

TABLE A-6. COMMANDS REQUIRING ACKNOWLEDGEMENT

MES-SAGE	HOLD ALT 060			MNTAIN SPEED 165			SQUAWK 1300			NORADAR		
SLIDE / FONT	41 / DM	89 / ST	137 / SEG	42 / DM	90 / ST	138 / SEG	43 / DM	91 / ST	139 / SEG	44 / DM	92 / ST	140 / SEG
S1	1.04	0.69	0.80	0.87	0.85	0.79	1.05	1.53	1.02	0.72	1.28	0.86
S2	1.91	1.17	1.62	1.79	1.96	1.33	1.72	-	1.13	1.19	1.09	2.16
S3	-	1.24	1.30	1.38	1.30	1.41	1.72	-	2.10	1.04	1.51	1.59
S4	1.34	1.06	1.20	0.84	0.94	0.78	3.62	1.13	1.02	0.58	2.40	1.55
S5	1.17	0.92	1.04	1.17	0.88	0.87	1.34	1.54	0.93	1.19	1.74	2.02
S6	1.31	1.13	1.76	1.12	0.75	0.96	E1	1.37	3.30	0.83	0.91	1.22
S7	1.36	2.00	3.07	1.37	0.82	2.69	0.84	0.84	2.20	0.82	1.30	1.63
S8	1.85	0.97	2.75	1.25	0.94	1.28	1.41	1.56	E1	0.93	1.12	1.0[illegible]
S9	1.55	1.78	2.20	1.44	1.01	1.20	1.11	2.15	E1	1.17	1.27	1.01
S10	1.30	1.50	3.22	1.31	1.04	1.91	1.02	-	1.75	1.83	1.76	1.42
MEAN	1.42	1.25	1.90	1.25	1.05	1.32	1.34	1.45	1.68	1.03	1.44	1.45
	1.52			1.21			1.56			1.31		

MES-SAGE	NO RADAR CONTACT			ALTMTR 2973			CLEARED FOR TAKEOFF RUNWAY 22R			TRAFFIC 12 O'CLK 2 MLS		
SLIDE / FONT	45 / DM	93 / ST	141 / SEG	46 / DM	94 / ST	142 / SEG	47 / DM	95 / ST	143 / SEG	48 / DM	96 / ST	144 / SEG
S1	0.75	0.93	-	1.15	0.95	-	0.81	1.1[illegible]	0.8[illegible]	0.88	0.86	1.07
S2	1.50	1.30	-	1.74	-	1.27	1.37	1.47	1.9[illegible]	1.31	1.41	2.02
S3	1.05	1.28	-	2.07	E	1.17	1.31	1.47	1.37	1.41	1.44	1.63
S4	0.69	0.95	-	1.08	1.27	0.92	1.00	1.35	1.38	1.12	1.08	1.24
S5	1.56	1.07	-	1.87	1.60	0.99	1.12	1.6[illegible]	[illegible]61	1.08	1.47	1.71
S6	0.98	1.37	-	1.99	1.23	1.37	0.97	1.[illegible]	1.45	1.19	1.32	1.06
S7	0.29	2.08	-	3.07	2.99	1.51	2.0[illegible]	[illegible].5[illegible]	[illegible]94	1.51	0.91	1.24
S8	0.97	1.72	-	1.50	1.80	1.37	1.66	[illegible].9[illegible]	2.00	1.55	1.04	1.52
S9	0.96	1.62	0.99	2.09	E5	3.43	1.50	[illegible]90	[illegible]16	1.44	1.04	1.28
S10	2.01	E6	-	2.32	2.29	1.05	2.86	-	[illegible]57	1.54	0.91	1.48
MEAN	1.15	1.37	-	1.89	1.73	1.45	1.40	[illegible]	[illegible]72	1.30	1.15	1.42
	1.26			1.69			1.5[illegible]			1.29		

APPENDIX B

SLIDE-PROJECTION SEQUENCE

APPENDIX B-1

SLIDE PROJECTION SEQUENCE

Slide Tray 1

Seq.	Slide	Seq.	Slide	Seq.	Slide
1	14	25	82	49	61
2	92	26	144	50	99
3	115	27	31	51	122
4	72	28	53	52	79
5	134	29	18	53	141
6	21	30	96	54	28
7	43	31	119	55	50
8	6	32	74	56	13
9	37	33	136	57	91
10	59	34	23	58	114
11	64	35	45	59	70
12	101	36	9	60	108
13	124	37	40	61	131
14	87	38	110	62	41
15	5	39	73	63	12
16	36	40	135	64	90
17	58	41	22	65	113
18	62	42	44	66	69
19	100	43	8	67	107
20	123	44	39	68	130
21	78	45	109	69	85
22	140	46	63	70	3
23	27	47	102	71	34
24	49	48	125	72	56

Slide Tray #1 presented first to subjects 1 through 5.
Slide Tray #2 presented first to subjects 6 through 10.

APPENDIX B-2

SLIDE PROJECTION SEQUENCE

Slide Tray 2

Seq.	Slide	Seq.	Slide	Seq.	Slide
1	75	25	7	49	68
2	137	26	38	50	106
3	24	27	60	51	129
4	46	28	65	52	86
5	11	29	103	53	4
6	89	30	126	54	35
7	112	31	81	55	57
8	67	32	143	56	20
9	105	33	30	57	98
10	128	34	52	58	121
11	84	35	16	59	77
12	2	36	94	60	137
13	33	37	17	61	26
14	55	38	80	62	48
15	66	39	142	63	19
16	104	40	29	64	97
17	127	41	51	65	120
18	83	42	15	66	76
19	1	43	93	67	138
20	32	44	116	68	25
21	54	45	71	69	47
22	117	46	133	70	10
23	95	47	132	71	88
24	118	48	42	72	111

Slide Tray #1 presented first to subjects 1 through 5.
Slide Tray #2 presented first to subjects 6 through 10.

APPENDIX C

STATISTICAL TERMINOLOGY

The following brief appendix is provided for the reader who may be unfamiliar with or requires review of statistical methods and terminology.

Statistically, it is never possible to prove that one set of measurements is different from those obtained in measurement of a different parameter or variable; that is, the numerical comparison of two populations. Statistics, instead provide means for determining how often differences measured for two or more parameters would occur by chance; this is the probability value. Thus a probability of .01 indicates that by chance the determined differences in measurements would occur only one time in a hundred, and for a probability of .001, only one time in a thousand.

Calculations of such probabilities utilize the properties inherent in the variability of measurements of data points. Three data points have values of 2, 2 and 2 have a mean (average) value of 2; similarly, three data points having values of 1, 2 and 3 also have a mean value of 2, but here the values vary around this mean. "Variance" is the measure of such dispersion of values, and is based upon the square of the differences between the individual measurements and the mean value.

When two such sets of measurements having different means values are available, a t-test permits computation of the probability that these differences might occur by chance. Tables of required values of t for different levels of statistical significance are available in any standard text on Statistics.

The technique of analysis of variance extends the concept to permit the simultaneous comparison of variables in multidimensional arrays. Here, because of the different computational procedure, different numerical values are required to establish various levels of confidence. Appropriate values here are found in tables of F-ratio, again available in any standard text on Statistics.

As the number of measurements of any discrete parameter is increased, we obtain increased confidence that the mean of the measurements becomes increasingly closer to the true value of that parameter, and lower values are required in tables of t and F for a given level of statistical significance. "Degrees of freedom" is the term used to indicate the number of measurements, and is defined as one less than the total number of measurements being evaluated. Similarly, in computing F-ratios, the concept of degrees of freedom is used to indicate the number of levels in each dimension of the experimental design. The difference between the sum of the degrees of freedom taken up by these levels and the total degrees of freedom available represents the degrees of freedom attributable to interaction among or between the variables. The variances associated with these degrees of freedom for interaction are defined as the "error term", and this is utilized in portions of the computation of the F-ratio.

APPENDIX D

BREAKDOWN OF RESPONSES TO QUESTIONNAIRE

The questionnaire administered to the subjects at the completion of their experimental runs elicited the following information:

Question 1: "Did the buzzer on the WIDCOM provide sufficient information that a new command had appeared?"
Answers: 8 Yes, 0 No.

Question 2: "Did you have any difficulty in identifying what the new information was?"

Question 3: "Did you consider the synthetic speech to be sufficiently intelligible?"
Answers: 4 Yes, 4 No.

Question 4: "Did the intelligibility improve with practice?"
Answers: 0 No, 8 Yes; 2 qualified with "slightly".

Question 5: "Did you consider the combination of the two better than either WIDCOM or synthetic speech alone?"
Answers: 6 Yes, 1 No, 1 Blank

Question 6: "If only one device were available, which would you prefer?"
Answers: 6 WIDCOM, 1 Blank, 1 Question Mark.

Question 7a: "In an emergency, do you feel that you would react faster to one device than to the other?"
Answers: 6 Yes, 1 No, 1 Question Mark.

Question 7b: "If so, which?"
Answers: 7 WIDCOM, 1 Synthetic Speech.

Question 8: "Do you have any suggestions as to how either device might be improved, or what improvements are required?"
Answers:

S1: "Synthesizer intelligibility. Add frequency selection to WIDCOM. I feel WIDCOM with buzzer was very good."

S2: "The two used together would be fine."

S3: No comments.

S4: "WIDCOM display could be higher (slightly). WIDCOM buttons pop out if pushed and released rapidly. Synthetic speech and headset combination could be reason for not hearing synthetic speech clearly. WIDCOM lost display twice."

S5: "Voice Synthesizer: (1) intelligibility, (2)vocabulary, c.f., "climb to" instead of "ascend to." WIDCOM: flash information and only have one response. Buzzer terminal areas, pilots like to maintain a mental situation plot, therefore the V/S could be used much more easily to inform all required A/C of situation changes, particularly holding information."

S6: "Voice synthesizer could be more intelligible in some cases. Also a little slow. Both devices were quite helpful. The WIDCOM was particularly useful by providing a constant display of the last issued commands. Trying to maintain speed to 5 knots is quite difficult, at least with relatively little experience. The GAT simulator is extremely sensitive to all controls. This is somewhat difficult to adjust to. The voice synthesizer was generally easy to follow, but it might be more difficult when multiple aircraft are being controlled."

S7: "Emergency commands are unusual and unexpected and therefore hard to recognize on the synthesizer. Some key that an unusual and important command is being transmitted is needed."

S8: "Fewer errors in WIDCOM (difficulty in clearing and obtaining some displays seen inherent in this particular system). *Add to WIDCOM or voice more aid in capturing ILS signals. Manual flying is difficult in low visability

*Note: Electrical interference during the runs caused occasional erratic behavior of the WIDCOM).

so any additional info, such as small vectoring to intercept ILS oould be very valuable. This is vastly better than monitoring all ATC traffic."