FAA-73-6

REPORT NO. FAA-RD-73-55

HUMAN FACTORS EXPERIMENTS FOR DATA LINK
Interim Report No. 2

Edwin H. Hilborn
Leonard R. Devanna

APRIL 1973
INTERIM REPORT

Prepared for:
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research and Development Service
Washington, DC 20591

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-73-55		

4. Title and Subtitle	5. Report Date
HUMAN FACTORS EXPERIMENTS FOR DATA LINK Interim Report No. 2	April 1973
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Edwin H. Hilborn Leonard R. Devanna	DOT-TSC-FAA-73-6

9. Performing Organization Name and Address	10. Work Unit No.
Department of Transportation Transportation Systems Center Kendall Square Cambridge, MA 02142	R-3130
	11. Contract or Grant No. FA313
	13. Type of Report and Period Covered Interim Report August 1972 - January 1973
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Two experiments involving the coding of Air Traffic Control messages for Digital Data Link transmission are reported. Reaction times and error rates to slide presentations were recorded for both experiments as a means for assessing the relative meaningfulness of messages.

Experiment I studied the differences between long and short abbreviations with and without spaces. The need for the use of spaces was demonstrated. The experiment also indicated that with proper spacing, short and somewhat cryptic abbreviations were as useful as the longer and seemingly more meaningful abbreviations, even with only brief training of the experimental subjects.

Experiment II provided a procedural variation using the same stimulus material as that reported in Section III of Report FAA-RD-72-150, with generally comparable results. It was again determined that for short ATC messages differences in type font were not significant, that arrows were generally better than words for altitude and heading commands, that a format of three short lines was better than one extended line, and that "L" and "R" as heading commands in messages such as "HDGL230" were extremely difficult to comprehend.

17. Key Words	18. Distribution Statement
Air Traffic Control Data Link Message Coding	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	46	

Form DOT F 1700.7 (8-69)

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1.1 INTRODUCTION

Throughout the history of the ARINC Data Link Subcommittee and the gradual and ongoing development of ARINC Characteristic 586, the emphasis has been on transmission standards. Thus, while standards are presently reasonably well established for bit rate, modulation scheme to be employed and polling methods, much less thought has been given to the means for displaying information to flight crews. On an apparently intuitive basis, it has been suggested that a seven-window display be used for short messages, supplemented by a printer for messages not amenable to display in the seven-character format, along with means for sequentially presenting two seven-character messages or two seven-character portions of slightly longer messages.

While a seven-window display is entirely adequate for the display of heading, altitude or speed commands, alternation of two portions of a message is required for radio frequency assignments if the location of the facility (three characters), the type of facility* (one or three characters), and the frequency (four or five digits) are to be presented. For such messages, there appears to be no hazard in providing the information by such an alternating means, since the information on each portion of the command is incomplete. For certain other commands or advisories, however, the lack of hazard is less well defined should a busy pilot happen to see only one portion of such an alternated message. It therefore appears that some effort should be expended on the exploration of coding schemes for a variety of messages having varying lengths in order to determine the response characteristics and errors of interpretation associated with such messages. The eventual goal of such a program should be the specification of the minimum number of characters required for the display of a high proportion of the normal ATC commands and advisories in an unambiguous manner.

*e.g., tower, approach, departure, etc.

Ruled out from consideration in this, of course, are ATIS reports and extended clearances, since these should be more properly provided as hard copy readout.

This document complements the research embodied in the preceding report FAA-RD-72-150.* Experiment I, described in the present section, studied the effects of length of abbreviation and the use of spaces for a variety of ATC messages which in their shortest form varied from four to eleven characters.

1.2 EXPERIMENTAL CONDITIONS

Twenty-five typical ATC messages were selected, and each typed on individual file cards in four different forms:

(a) using the shortest possible abbreviation and without spaces

(b) using the same short abbreviations but separated by spaces

(c) using longer abbreviations without spaces

(d) using the same longer abbreviations with spaces.

High contrast negative slides (clear characters on a black background) were prepared using a 2-inch by 2-inch format. The slides had a clear spot at one corner to permit the activation of a photocell which started a timer when a slide was projected on a screen. The slides were randomized in sequence and placed in alternate positions in slide trays, separated by blank slides so that a response by subjects would remove the stimulus material from the screen. In order to randomize the presentation sequence further, the slides were divided equally between two slide trays and the order in which the two trays were presented to experimental subjects was alternated.

*E. H. Hilborn, "Human Factors Experiments for Data Link," Interim Report FAA-RD-72-150 (November 1972).

Twelve engineers from TSC, all having some knowledge of air traffic control commands, were used as experimental subjects. The subjects were seated approximately 30 inches from a projection screen. Since this was a test of message meaning and not of visual acuity, characters were projected at a height of approximately 1/2 inch on the screen. Subjects were, of course, run individually. At the start of the experimental session, each subject was given a typewritten sheet of instructions whose content is reproduced in Appendix A-1.

1.3 EXPERIMENTAL RESULTS

The raw data from the experiment, organized by subject and slide categories, are presented in Appendix B. Mean response times for each of the slides and the number of errors, along with the precise formats displayed on the slide are presented in Table 1-1. Errors were recorded either when the subject failed to verbalize the message correctly or when his response time was greater than 8 seconds. Even prior to any further processing of the data, it should be noted that the use of spaces reduced errors by approximately 50 percent and reduced response times by approximately one-half second.

In the shortest form presented (slides 1 through 25), message lengths varied from four to eleven characters. Mean response times as a function of message length for these 25 slides, along with the equivalent messages in longer versions (using spaces and/or longer abbreviations) are presented in Figure 1-1. As might be anticipated, the messages having larger numbers of characters produced longer response times.

Even though a sharp increase in response time occurred as message length increased from eight to nine characters, it was decided to divide the messages into short (four to six characters) and long (seven to eleven characters) in order to provide a more nearly even distribution of data points. This permitted a three-dimensional analysis of variance* using the variables; short

*A brief discussion of statistical terminology is provided in Appendix D, reproduced verbatim from FAA-RD-72-150.

TABLE 1-1 MESSAGE FORMATS, MEAN REACTION TIMES AND ERRORS

A	MESSAGE	B	C	A	MESSAGE	B	C	A	MESSAGE	B	C	A	MESSAGE	B	C
1	HLDOFFRY33R	2.45	0	26	HLD OFF RY 33R	2.62	0	51	HLDOFFRNY33R	2.93	1	76	HLD OFF RNY 33R	1.58	1
2	HLDONTXB	2.07	1	27	HLD ON TX B	1.38	0	52	HLDONTXYB	2.94	2	77	HLD ON TXY B	1.37	0
3	RESS	1.54	0	28	RES S	1.32	0	53	RESSPD	1.39	1	78	RES SPD	1.01	0
4	BOST1234	1.52	0	29	BOS T 1234	1.81	2	54	BOSTWR1234	1.85	0	79	BOS TWR 1234	1.31	0
5	RQPOS	1.93	0	30	RQ POS	1.74	0	55	REQPOS	1.00	0	80	REQ POS	1.10	0
6	REPPOS	2.07	0	31	REP POS	1.06	0	56	REPTPOS	1.26	0	81	REPT POS	1.33	0
7	FPCNO	2.28	2	32	FPS NO	1.85	0	57	FPCNEG	2.01	0	82	FPC NEG	2.03	0
8	TXOFFRY	1.95	1	33	TX OFF RY	1.47	0	58	TXIOFFRNY	1.65	0	83	TXI OFF RNY	2.39	1
9	CLTKOFRY33L	2.24	3	34	CL TKOF RY 33L	1.77	0	59	CLRTKOFRNY33L	3.61	1	84	CLR TKOF RNY 33L	1.37	0
10	PHLA1234	2.27	0	35	PHL A 1234	1.47	1	60	PHLAPP1234	1.73	1	85	PHL APP 1234	1.85	2
11	SQLO	2.74	1	36	SQ LO	1.47	0	61	SOKLOW	1.16	0	86	SOK LOW	1.37	0
12	PHLD1196	2.29	1	37	PHL D 1196	1.41	1	62	PHLDEP1196	2.05	0	87	PHL DEP 1196	1.55	1
13	CLLDGRY33R	3.06	0	38	CL LDG RY 33R	2.18	0	63	CLRLDGRNY33R	3.27	1	88	CLR LDG RNY 33R	1.60	0
14	REPA	1.65	0	39	REP A	1.15	0	64	REPTALT	1.65	0	89	REPT ALT	0.96	0
15	REPS	1.46	0	40	REP S	1.39	1	65	REPTSPD	1.47	1	90	REPT SPD	1.30	0
16	CLHIAPP	2.13	0	41	CL HI APP	2.29	1	66	CLRHIAPP	3.00	0	91	CLR HI APP	1.85	0
17	V2MLS	1.74	3	42	V 2 MLS	1.21	0	67	VIS2MLS	2.04	0	92	VIS 2 MLS	1.21	0
18	W220@05	1.79	0	43	W 220 @ 05	1.59	0	68	WND220@05	1.96	0	93	WND 220 @ 05	1.97	0
19	RESS	1.27	1	44	RES S	1.23	0	69	RESSPD	1.51	1	94	RES SPD	1.17	0
20	CLRY	1.17	0	45	CL RY	1.14	0	70	CLRRNY	1.14	0	95	CLR RNY	1.20	0
21	CT@OM	2.39	0	46	CT @ OM	2.13	0	71	CTCTWR@OUM	2.98	4	96	CTC TWR @ OUM	2.46	2
22	XBOSA120	2.09	1	47	X BOS A 120	1.91	0	72	XBOSALT120	2.90	1	97	X BOS ALT 120	1.92	0
23	SLOS130	2.98	1	48	SLO S 130	1.41	0	73	SLOSPD130	2.46	3	98	SLO SPD 130	1.92	1
24	CBOSD1320	2.98	4	49	C BOS D 1320	2.06	3	74	CTCBOSDEP1320	3.27	4	99	CTC BOS DEP 1320	2.66	5
25	CLINT	2.14	0	50	CL INT	1.37	0	75	CLRINT	1.98	1	100	CLR INT	1.08	0
MEAN TIMES AND TOTAL ERRORS		2.08	19			1.61	9			2.20	22			1.58	13

Note: A columns indicate slide numbers, B columns the mean reaction time in seconds, and C columns the errors. The raw data from which this table was derived are reproduced in Appendix B.

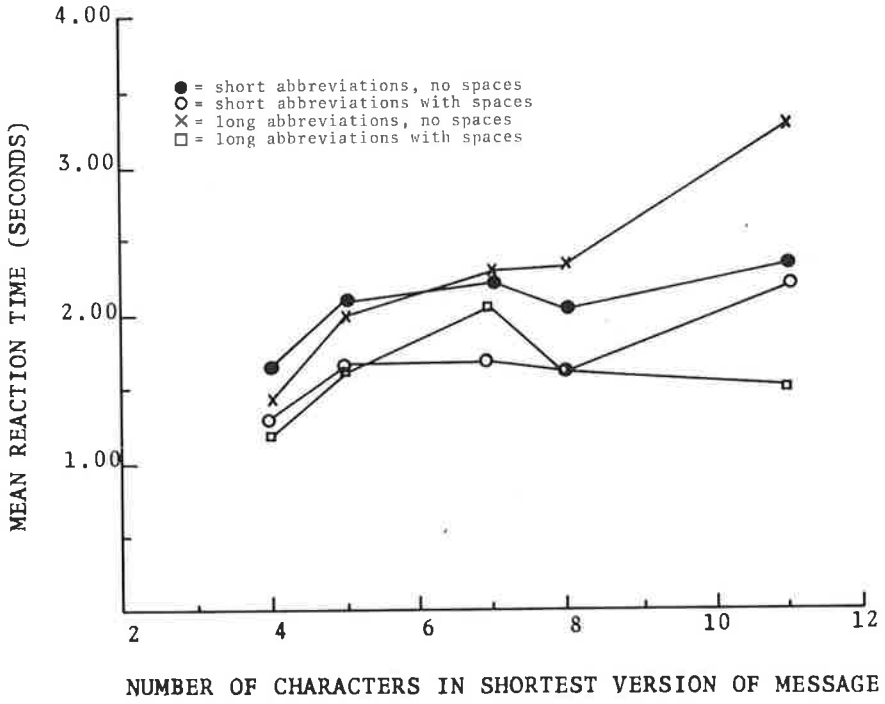

Figure 1-1 Mean Reaction Time in Seconds as Function of Message Length

versus long messages, short versus long abbreviations and spaced versus non-spaced messages, as well as the examination of any possible interaction terms. The analysis of variance is presented in Table 1-2. Here, as might be anticipated from the examination of the raw data in Table 1-1, reaction times to long messages are greater (significant at the .001 level), differences in reaction time as a function of the use of long versus short abbreviations are non-significant, and the differences between spaced and non-spaced messages are significant at the .001 level, with a major reduction in reaction time resulting from the use of spaces in messages. There were no significant interactions.

Further analysis of the data is made somewhat difficult by the long reaction time and high error rate which occurred for unknown reasons for all versions of the message, "Contact Boston Departure Control on 1320." More than 25 percent of the total errors which were recorded during the running of the experiment resulted from this message. Accordingly, in Figure 1-1, where reaction time is

TABLE 1-2 ANALYSIS OF VARIANCE OF THE THREE VARIABLES

SOURCE	df	SS	ms	F RATIO
A (Spaces)	1	756.04	756.04	33.04
B (Abbrev)	1	.05	.05	0.00
C (Length)	1	651.77	651.77	28.49
AB	1	56.36	56.36	2.46
AC	1	50.92	50.92	2.23
BC	1	3.52	3.52	0.15
ABC	1	32.45	32.45	1.42
Within cells	92	2105.69	22.88	
TOTAL	99	3656.80		

Note:

A indicates presence or absence of spaces
B indicates short versus long abbreviations
C indicates short versus long messages

plotted as a function of message length, the data from this message have been omitted. Figure 1-1 indicates the importance of the use of spaces, particularly as long abbreviations are used in the longer messages. Here, it becomes increasingly difficult to determine how many characters constitute a given abbreviation and where the next abbreviation begins. The curves here contrast sharply with the data of Figure 1-2 where mean error rate is plotted as a function of message length with the data of the "Contact Boston Departure Control on 1320" message included. Without the inclusion of this message, error rate appears to be independent of message length.

For both of these figures, and for the two which follow, the four versions of the message are plotted as the number of characters used in the shortest version in order to make possible the direct comparison of the four formats.

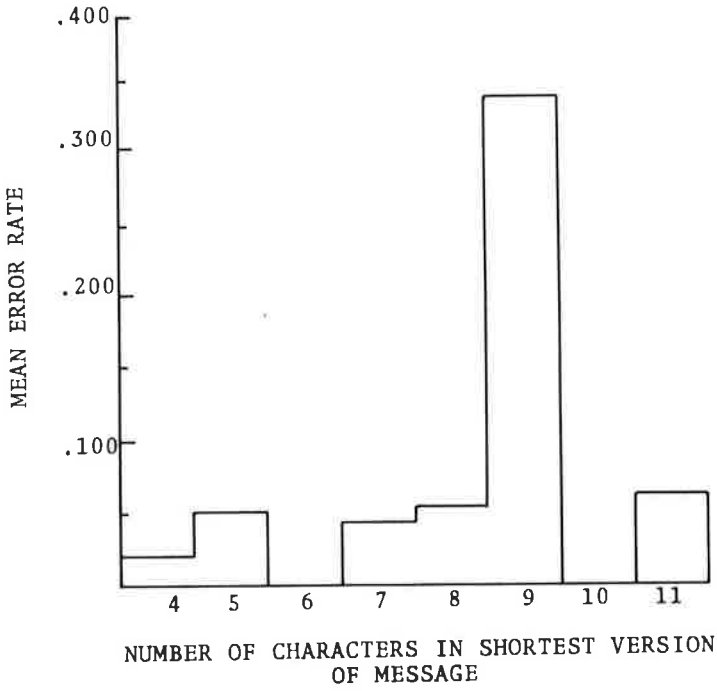

Figure 1-2 Mean Error Rate for All Messages as Function of Message Length

Since all abbreviations were not equally short or long, it further seems desirable to plot the data as a function of the number of information units in the message. "Information Units" in this context is defined simply as a word or a group of digits. Figure 1-3 indicates the mean reaction time in seconds as a function of the number of such information units in the messages. Here again, it can be noted that the slope of the curve for the messages with long abbreviations and no spaces is much greater.

Figure 1-4 presents mean error rate as a function of number of units of information in the message. Unlike Figure 1-2, which indicated that error rate was relatively constant regardless of the number of characters in messages, Figure 1-4 indicates that error rate increases sharply as the amount of information presented is increased. To obtain maximum confidence that information is transmitted to the pilot and interpreted correctly, messages should be as short as possible.

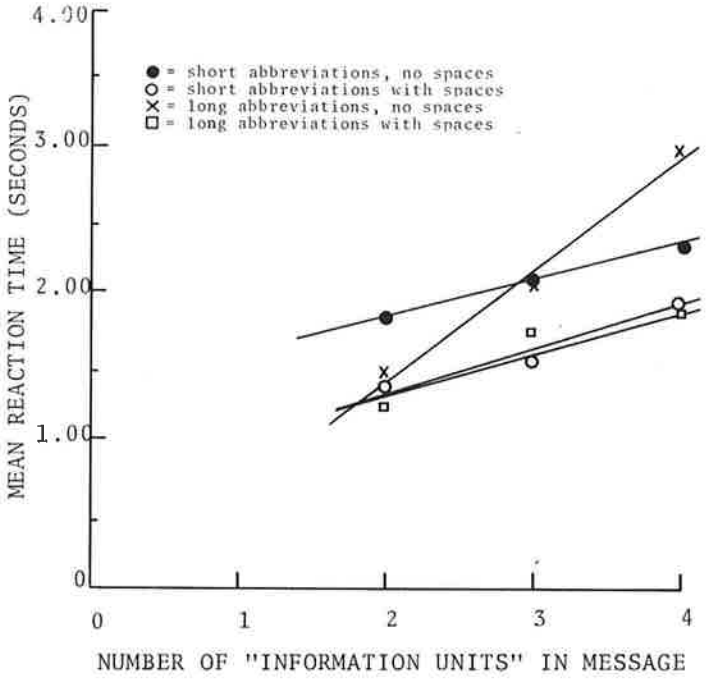

Figure 1-3 Mean Reaction Time as Function of Number of Information Units in Message

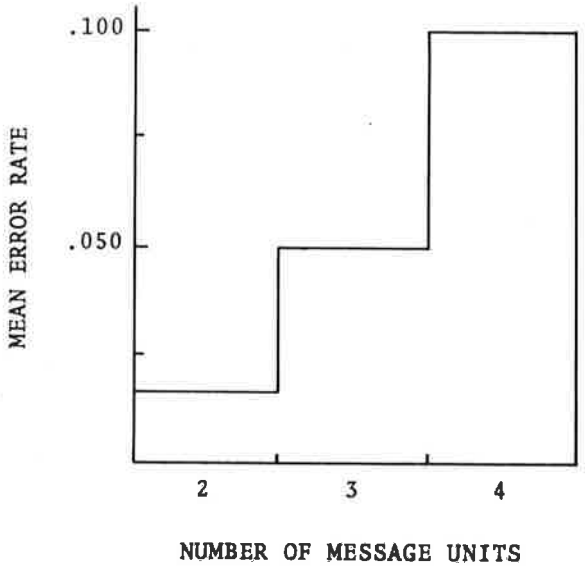

Figure 1-4 Mean Error Rate as Function of Number of Message Units

1.4 SUMMARY AND CONCLUSIONS

Twenty-five typical short Air Traffic Control messages were generated in each of four different forms involving the use of short and long abbreviations with and without spaces. These were presented as slides to twelve experimental subjects, and reaction time and error rate in message interpretation were measured. The experiment indicated that the shortest possible abbreviation was meaningful to the experimental subjects after only brief training, but that spaces between abbreviations were necessary if rapid and error-free interpretation was to be achieved.

2. FURTHER COMPARISON OF MESSAGE FORMATS

2.1 INTRODUCTION

Section III of FAA-RD-72-150 described an experiment wherein subjects were required to select an appropriate response from among multiple possibilities as slides were presented containing ATC commands and advisories coded in several ways and having several formats. This section of the present report describes a procedural variation of the original experiment, using the same stimulus material. The original experiment was limited to the measurement of disjunctive reaction times*. It seemed probable that under these conditions, subjects looked only for the portion of the message which determined the required response, while overlooking the overall message content. For the present experiment, when the subject responded, the slide was automatically removed from the screen, and he was then asked to verbalize the message.

2.2 OBJECTIVES

In addition to the determination of performance differences resulting from the procedural variation described above, the objectives of Experiment II were:

(a) The determination of any response-time differences or error rates resulting from the use of three different type fonts: dot matrix, stencil, and 16-segment characters.

(b) The determination of any differences resulting from the use of an extended linear display as opposed to the presentation of the same information on three short lines.

(c) The measurement of differences resulting from the use of arrows versus words for simple altitude and heading commands.

(d) The comparison of reaction time and error rate for purely qualitative information versus information providing quantitative values of parameters.

*Disjunctive reaction time involves the selection of a correct choice from among multiple possibilities.

(e) The comparison of differences between the presentation of a new command by itself versus the presentation of the new command while maintaining a "scratchpad" of the previous values of other flight parameters.

(f) The determination of requirements for presenting new information at the left or top of the display versus maintaining a fixed sequence for heading, altitude and speed commands.

(g) The determination of practice effects resulting from subject's previous exposure to the stimulus material.

These and other parameters were explored in the following experiment.

2.3 EXPERIMENTAL CONDITIONS

The slides used in this and the original experiment described in FAA-RD-72-150 contained eight formats for commands in each of the six broad categories: "climb," "descend," "turn right," "turn left," "tune your transceiver," and "this is a message requiring acknowledgment."* Artwork for each of the 48 such messages was generated in three different type fonts: a 5 x 7 dot matrix, characters simulating those from a 16-segment array, and characters simulating stencil such as might appear on the face of a Charactron CRT. The artwork was photographed to provide a total of 144 double-frame 35 mm high-contrast negative slides (white characters on a black background.

The slides were mounted in 2 inch by 2 inch slide carriers, randomized in order and distributed evenly among three slide trays. The slides were alternated with pieces of blank cardboard in the slide trays to permit blanking of the screen as soon as a subject responded to the presentation of each slide.

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

Each slide also contained a clear spot in the upper right corner to permit the activation of a photocell which started a timer when the slide was presented on the 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' responses, and an interval timer calibrated in hundredths of a second which automatically measured the time elapsed from the appearance of the slide to the response of the subject.

Ten engineers and scientists from TSC were used as experimental subjects. Six had participated in the earlier experiment; the remaining four were new subjects so as to permit the determination of the effects of the brief training which the original six subjects had had approximately one month previously.

All subjects were handed a typewritten sheet containing the instructions reproduced in Appendix A-2.

As further training, the subjects were then handed the response box layout depicted in Figure 2-1, 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. The sequence in which the slide trays were presented to subjects was randomized to counterbalance for practice effects.

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 inch on the screen, and the subjects viewed them from a distance of approximately 30 inches.

During the running of the experiment, the subjects usually volunteered the information that they were aware when they had

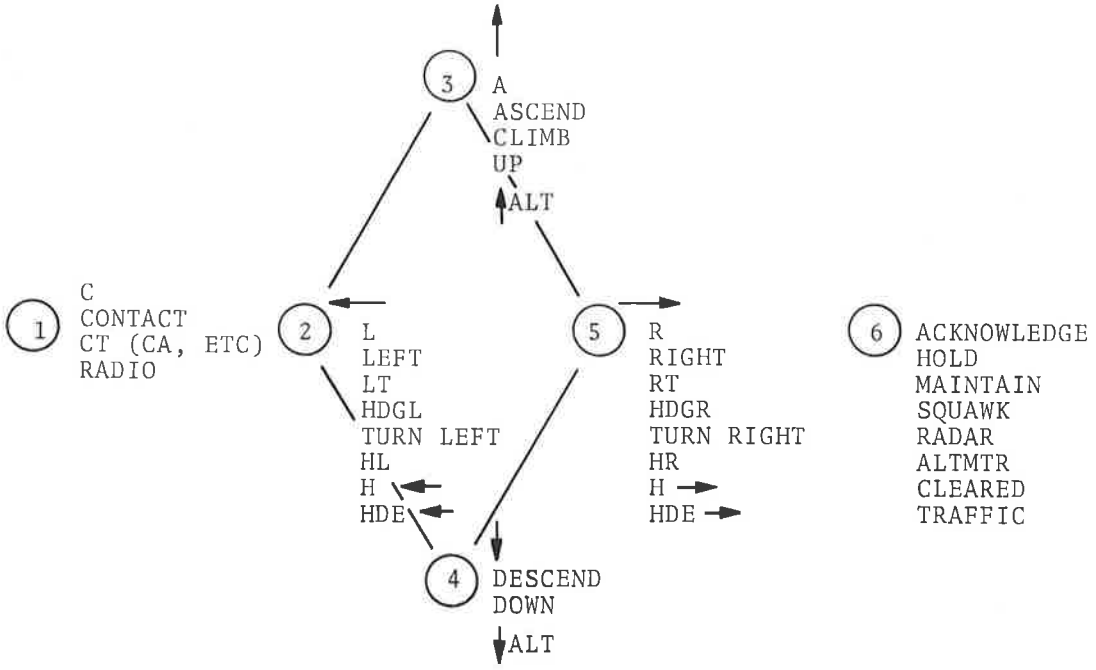

Figure 2-1 Response Box Layout

made an error in their response. When this information was not volunteered, the experimenter 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 C. A blank in these data indicates failure of a slide to drop into the projector properly or a failure of the timer to reset. "0" represents an error in response, and reaction times for these errors were not recorded. Additionally, in generating the tables for the next subsection of this report, 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 the tables of the following subsection, 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 of the following subsection 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 time for the same message when presented respectively with dot matrix (DM), stencil (ST) and 16-segment (SEG) fonts.

2.4 RESULTS OF EXPERIMENT

As explained in the report on the earlier experiment (FAA-RD-72-150), the experimental design used would not have permitted data reduction by an analysis of variance without a major increase in the number of slides requiring presentation. For this repeat experiment, the technique of the previous report has again been used; namely, that of using analysis of variance of complete data blocks to generate an error term suitable for use with multiple t-tests.

From the tabulated raw data which are reproduced in the Appendix, the means of non-overlapping variables have been selected and are presented in Table 2-1. Analysis of variance for these data was calculated and is summarized in Table 2-2.

TABLE 2-1 MEANS FOR NON-OVERLAPPING VARIABLES

Disjunctive reaction time in seconds

MESSAGE TYPE	CHARACTER FONT		
	DOT Martix	Stencil	Seg-mented
Single Word	0.86	1.03	1.08
Arrows Only	0.80	0.82	0.88
Words + Numbers	1.27	1.00	1.29
Arrows + Numbers	1.06	1.14	1.15
3-Line Words	1.68	1.68	1.38
3-Line Arrows	1.88	1.36	1.51
1-Line Arrows	1.56	1.55	1.74
1-Line Words	1.59	1.69	1.94

TABLE 2-2 ANALYSIS OF VARIANCE FOR DATA OF TABLE 2-1

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F-RATIO
Message Types	241.58	7	34.51	13.91
Font (Rows)	3.11	2	1.56	0.63
Interaction	34.74	14	2.48	
TOTAL	279.43	23		

Using the error terms 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 2-3.

TABLE 2-3 MEAN DIFFERENCES REQUIRED FOR MESSAGE TYPE/FONTS FOR VARIOUS SIGNIFICANCE LEVELS

Required differences in seconds

SIGNIFICANCE LEVEL		0.1	0.05	0.02	0.01	0.001
t-distribution of df = 14		1.761	2.145	2.624	2.977	4.140
MEAN DIFFERENCE M_D	MESSAGE TYPE	.098	.119	.146	.166	.231
	FONTS	.160	.195	.239	.271	.376

A primary consideration in the earlier experiment using the same stimulus material was the determination of any differences in reaction time or error rate attributable to the use of the different type fonts, since lack of significance of this variable would greatly simplify the preparation of art work for future experiments. No significant differences among type fonts were found in the original experiment and the data of Table 2-4 further substantiate this conclusion.

TABLE 2-4 COMPARISON OF TYPE FONTS FOR DIFFERENT MESSAGE CATEGORIES

Disjunctive reaction time in seconds

MESSAGE TYPE	TYPE FONT		
	DOT Matrix	Stencil	16-Seg.
Radio Frequency	1.76	1.73	1.77
Left Turns	1.47	1.11	1.40
Climb Commands	1.06	1.14	1.27
Descend Commands	1.12	1.24	1.26
Right Turns	1.26	1.14	1.25
Acknowledgements	1.33	1.31	1.32
MEANS	1.33	1.27	1.38

This generalization is, however, not strictly true when arrows are "buried" within messages. With stencil type characters, bold face arrows are possible and this resulted in appreciably shorter reaction times, as indicated in Table 2-5. Arrows are better than words for IPC-type commands, as indicated in Table 2-6. The differences here are significant at the .05 level.

This difference between the use of word and arrow commands becomes non-significant when numerical values of parameters are added, as indicated in Table 2-7. Similarly, the differences between the use of words and arrows in three-line messages become non-significant, as shown in Table 2-8.

TABLE 2-5 COMPARISON OF TYPE FONTS FOR MESSAGES CONTAINING "BURIED" ARROWS

Disjunctive reaction time in seconds

DOT MATRIX		STENCIL		16-SEGMENT	
Slide No.	Time	Slide No.	Time	Slide No.	Time
10	1.16	58	1.20	106	1.26
13	2.60	61	1.42	109	1.55
19	1.48	67	1.55	115	2.01
21	1.46	69	1.70	117	1.49
27	1.31	75	2.05	123	2.03
29	1.63	77	1.42	125	1.42
34	0.99	82	0.98	130	1.12
37	1.85	85	0.92	133	1.51
MEAN	1.56		1.41		1.55

TABLE 2-6 COMPARISON OF SINGLE WORDS VS. ARROWS

Disjunctive reaction time in seconds. DM = dot matrix; Sten. = stencil; Seg. = 16-segment characters

SINGLE WORD COMMANDS			ARROWS ONLY		
Left	DM	0.99	← ←	DM	0.82
	Sten.	0.87		Sten.	0.73
	Seg.	----		Seg.	1.23
Climb	DM	0.76	↑ ↑	DM	0.73
	Sten.	0.85		Sten.	0.73
	Seg.	0.99		Seg.	0.76
Descend	DM	0.83	↓ ↓	DM	0.84
	Sten.	0.95		Sten.	0.85
	Seg.	1.07		Seg.	0.79
Right	DM	0.89	→ →	DM	0.82
	Sten.	1.18		Sten.	0.97
	Seg.	1.15		Seg.	0.76
MEAN		0.96			0.84

TABLE 2-7 COMPARISON OF WORDS VS. ARROWS WITH NUMERICAL VALUES ADDED

Disjunctive reaction time in seconds. DM = dot matrix; Sten. = stencil; Seg. = 16-segment characters

MESSAGE	TIME		MESSAGE	TIME	
CLIMB210	DM	1.18	A↑120	DM	1.09
	Sten.	0.98		Sten.	1.20
	Seg.	1.67		Seg.	1.15
DOWN120	DM	1.19	A↓120	DM	1.03
	Sten.	1.00		Sten.	1.46
	Seg.	1.11		Seg.	1.04
MEAN		1.19			1.16

TABLE 2-8 COMPARISON OF WORDS VS. ARROWS IN THREE-LINE MESSAGES

Disjunctive reaction time in seconds. DM = dot matrix; Sten. = Stencil; Seg. = 16-segment characters

MESSAGE	TIME		MESSAGE	TIME	
TURN LEFT 180	DM	1.06	TURN ← 290	DM	1.15
	Sten.	1.43		Sten.	1.22
	Seg.	1.35		Seg.	1.03
TURN RIGHT 090	DM	1.14	TURN → 110	DM	1.07
	Sten.	1.11		Sten.	0.91
	Seg.	1.22		Seg.	1.05
MEAN		1.15			1.07

When rapid reaction is required, arrows alone should be used, followed later by the addition of numerical values if they are required. The data of Table 2-9 indicate the differences in reaction time for use of arrows alone versus arrows with numerical values added. These differences are significant at the .001 level.

TABLE 2-9 COMPARISON OF ARROWS ALONE VS. ARROWS WITH NUMERICAL VALUES ADDED

Disjunctive reaction time in seconds

ARROWS ALONE		ARROWS + NUMBERS	
Slide No.	Time	Slide No.	Time
15	0.82	16	1.15
63	0.73	64	1.22
111	1.23	112	1.03
23	0.73	20	0.81
71	0.73	68	0.94
119	0.76	116	1.12
31	0.84	28	1.20
79	0.85	76	1.33
127	0.79	124	1.45
39	0.82	40	1.07
87	0.97	88	0.91
135	0.76	136	1.05
MEAN	0.84		1.11

The addition of numbers also increases reaction time when such numerical values are added to textual commands such as "climb" or "descend" as indicated in Table 2-10. The differences here are significant at the .01 level.

A comparison between messages using an extended single-line format and the same information presented on three short lines indicates a shorter reaction time for the three-line format as can be noted in Table 2-11. The difference here is again significant at the .01 level.

As long as the portions of such multiple messages which contain new information are indicated in some manner, such as by the use of preceding and following asterisks, it does not seem necessary to locate the new information at the top or left side of the compound message. Tables 2-12 and 2-13 indicate this respectively for one-line and three-line message formats. The differences in both of these messages are not statistically significant.

TABLE 2-10 COMPARISON OF MESSAGES HAVING TEXT WITH AND WITHOUT NUMERICAL VALUES

Disjunctive reaction time in seconds

TEXT WITHOUT NUMBERS		TEXT WITH NUMBERS	
Slide No.	TIME	Slide No.	Time
14	0.99	12	1.06
62	0.87	60	1.03
110	----	108	1.35
22	0.76	18	1.18
70	0.85	66	0.98
118	0.99	114	1.67
30	0.83	26	1.19
78	0.95	74	1.00
126	1.07	122	1.11
38	0.89	36	1.14
86	1.18	84	1.11
134	1.15	132	1.22
MEAN	0.96		1.17

TABLE 2-11 COMPARISON OF LINEAR VS. THREE-LINE PRESENTATION OF THREE PARAMETERS (SUCH AS HEADING, SPEED AND ALTITUDE COMMANDS)

Disjunctive reaction time in seconds

LINEAR MESSAGE		THREE-LINE MESSAGE	
Slide No.	Time	Slide No.	Time
11	1.87	13	2.60
59	----	61	1.42
107	1.72	109	1.55
19	1.48	21	1.46
67	1.55	69	1.70
115	2.01	117	1.49
27	1.31	29	1.63
75	2.05	77	1.42
123	2.03	125	1.42
35	1.72	37	1.85
83	1.48	85	0.92
131	2.01	133	1.51
MEAN	1.75		1.58

TABLE 2-12 COMPARISON OF POSITION OF NEW INFORMATION WITH SINGLE-LINE FORMAT

Disjunctive reaction time in seconds

NEW INFO "BURIED"		NEW INFO IN FRONT	
Slide No.	Time	Slide No.	Time
4	1.65	7	2.01
52	2.03	55	1.68
100	2.16	103	1.58
19	1.48	11	1.87
67	1.55	59	----
115	2.01	101	1.72
27	1.31	35	1.72
75	2.05	83	1.48
123	2.03	131	2.01
MEAN	1.81		1.76

TABLE 2-13 COMPARISON OF POSITION OF NEW INFORMATION WITH THREE-LINE FORMAT

Disjunctive reaction time in seconds

NEW INFO "BURIED"		NEW INFO ON TOP	
Slide No.	Time	Slide No.	Time
21	1.46	13	----
69	1.70	61	1.42
117	1.49	109	1.55
29	1.63	37	1.85
77	1.42	85	0.92
125	1.42	133	1.51
MEAN	1.52		1.45

In the earlier experiment reported in FAA-RD-72-150, the most striking difference found in the data was for the use of arrows versus a buried "L" or "R" in messages such as HDGL210. For this repeat experiment, a similar difference was noted, as can be seen in Table 2-14. Again, the differences are at the .001 level of significance.

TABLE 2-14 ARROWS VS. "BURIED" "L" OR "R"

Disjunctive reaction time in seconds. DM = dot matrix, Sten. = stencil, Seg. = 16-segment characters

MESSAGE	TIME		MESSAGE	TIME	
HDGL210	DM	2.08	HDG←230	DM	1.16
	Sten.	1.32		Sten.	1.20
	Seg.	1.65		Seg.	1.26
HDGR110	DM	1.57	HDG→120	DM	0.99
	Sten.	1.53		Sten.	0.98
	Seg.	1.21		Seg.	1.12

The procedural change introduced in this experiment, which required subjects to verbalize the content of slides after they no longer appeared on the screen produced remarkably little change in the experimental results, these changes being limited to slight differences in the level of statistical significance obtained. Table 2-15 tabulates the significance levels for parameters compared in the original and present experiments.

Earlier, it was mentioned that six of the subjects in the present experiment had participated in the earlier experiment. As such, they had had approximately 45 minutes of experience some four to six weeks prior to the present experiment. The mean reaction time for the six experienced subjects was 1.22 seconds, and 1.46 seconds for the new subjects. While the mean reaction time for

TABLE 2-15 COMPARISON OF STATISTICAL DIFFERENCES FOUND IN ORIGINAL AND PRESENT EXPERIMENTS

n.s = no statistically significant differences

PARAMETER	ORIGINAL EXPERIMENT	PRESENT EXPERIMENT
Type font differences	n.s	n.s
Buried arrows in type fonts	.001	.02
Single words versus arrows	.02	.05
Words versus arrows with numbers	n.s	n.s.
3-line messages: words vs. arrows	n.s.	n.s.
Arrows alone versus arrows + numbers	.02	.001
Text with and without numbers	.05	.01
Linear versus 3-line messages	.001	.01
Position of information in 1-line format	.05	n.s.
Position of information in 3-line format	.05	n.s.
Arrows versus "buried" "L" or "R"	.001	.001

the "experienced" subjects was somewhat shorter than for the new subjects, it is difficult to assess how much of this difference is a result of the practice which they had had, and how much resulted from differences in the subject's familiarity with air traffic control terminology since on the earlier experiment the subjects most familiar with such terminology were selected.

2.5 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. Disjunctive reaction time was measured; additionally, when the subjects reacted, the information was automatically removed from the screen and the subjects were required to verbalize the content of the message. The results of the experiment indicated that:

(a) There were no differences in reaction time resulting from the use of different type fonts except when arrows as symbology were "buried" in the text. Here, the bold-face arrows possible with the stencil-type characters produced shorter reaction times.

(b) Arrows were 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 and if necessary by numerical values.

(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. However, reaction time differences here are so small that it may be difficult to justify this if additional computer programming is required to accomplish it.

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

APPENDIX A

INSTRUCTIONS TO EXPERIMENTAL SUBJECTS

A-1 INSTRUCTIONS GIVEN IN EXPERIMENT I

This is an experiment to determine how cryptic the coding of Data Link messages may be and still provide meaningful information which can be interpreted accurately and rapidly by the pilot. With brief coding, we can use a smaller display and have a higher probability that the display can be located in a prime viewing area on the panel, but this must be weighted against the training requirements for the pilot and the possibility of effors in message interpretation. We will accordingly give you a maximum of 15 minutes to memorize the abbreviations below; you may take less time if you feel confident that you have them memorized. We will then test you on your ability to interpret short air traffic control messages accurately and rapidly using these abbreviations in combination.

Heading, altitude and speed commands are always followed by 3-digit numbers and radio frequency settings by 4 or 5-digit numbers; this in the shorter abbreviations serves to differentiate between the use of "A" for "altitude" and for "approach," since the latter represents the radio frequency setting for the approach controller position. Runways are designated by one or two-digit numbers and taxiways by 1 or 2 letters. Airports and fixes are 3-letter combinations. This experiment will limit these to Boston (BOS) and Philadelphia (PHL). The other abbreviations to be used are:

ALTITUDE	A,ALT	HOLD	HLD
APPROACH	A,APP	INTERSECTION	INT
CLEAR (or) CLEARED	CL, CLR	LANDING	LDG
CONTACT	C, CTC	LEFT	L
CROSS	X	LOW	LO,LOW
DEPARTURE	D, DEP	MILES	MLS
FLIGHT PLAN CHANGE	FPC	NEGATIVE	NO, NEG
HIGH	HI	OUTER MARKED	OM,OUM

POSITION	POS	SQUAWK	SQ,SQK
REPORT	REP,REPT	TAKEOFF	TKOF
REQUEST	RQ, REQ	TAXI	TX
RESUME	RES	TAXIWAY	TX, TXY
RIGHT	R	TOWER	T, TWR
RUNWAY	RY,RNY	TRAFFIC	TFC, TRAF
SLOW	SL	VISIBILITY	V,VIS
SPEED	S, SPD	WIND	W,WND

Certain distinctions should be made from the context of a message. Thus, you might be asked to clear a runway, moving off to allow an emergency landing by another aircraft, or you may be cleared for takeoff on a specific runway. Similarly, you may be asked to hold on a taxiway or to taxi to a position.

During the experiment, each time a slide is presented, press the response button as soon as you have interpreted the message. The slide will then blank, and you will be asked to verbalize the message to demonstrate that you know its meaning and that you are not merely repeating the symbols which you have seen on the screen.

Are there any questions?

A-2 INSTRUCTIONS GIVEN IN EXPERIMENT II

IT IS IMPORTANT THAT YOU READ THESE INSTRUCTIONS CAREFULLY TAKING ALL 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 ex-

treme 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. When you do make a response, the screen will go blank and you will then be asked to verbalize the message. 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 arrows.

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. Thus:

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 asterisks, 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 right hand (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?

APPENDIX B

MESSAGE FORMATS AND RAW DATA FOR EXPERIMENT I

All reaction times in seconds.

An "0" indicates a response error, and reaction times for these errors were not recorded.

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

	1. HLDOFFRY33R 26. HLD OFF RY 33R 51. HLDOFFRYN33R 76. HLD OFF RNY 33R				2. HILDONTXB 27. HLD ON TX B 52. HLDONTXYB 77. HLD ON TXYB				3. RESS 28. RES S 53. RESSPD 78. RES SPD				4. BOST1234 29. BOS T 1234 54. BOSTWR1234 79. BOS TWR 1234				5. RQPOS 30. RQ POS 55. REQPOS 80. REQ POS			
SLIDE	1.	26.	51.	76.	2.	27.	52.	77.	3.	28.	53.	78.	4.	29.	54.	79.	5.	30.	55.	80.
S1	1.71	1.64	1.84	1.27	2.03	2.01	1.58	1.26	1.73	.72	.94	.83	1.96	2.59	1.25	1.09	1.48	.98	.97	1.03
S2	1.43	2.50	5.21	1.43	1.92	1.92	3.20	1.00	1.06	1.43	1.45	.92	1.12	1.41	1.68	1.81	1.25	1.56	.80	.89
S3	2.87	2.85	0	1.28	1.89	1.41	5.27	1.71	.80	.88	.86	.73	1.81	1.00	1.75	1.12	1.12	1.22	.69	.70
S4	2.81	4.97	2.67	1.31	1.37	1.38	0	1.31	2.34	.65	3.45	.82	1.15	1.85	3.90	1.38	1.15	1.29	1.01	.98
S5	2.76	1.75	0	2.93	3.61	1.48	2.94	1.39	.97	1.55	1.38	1.10	1.69	2.44	1.50	1.07	1.70	1.74	1.42	1.45
S6	1.83	1.44	1.55	0	1.60	1.15	1.42	1.37	1.13	1.22	1.32	1.05	.88	1.42	1.31	1.17	1.13	1.53	1.38	1.17
S7	.96	1.19	.99	1.01	.95	1.16	4.60	0	1.60	.88	.77	.72	1.36	2.17	1.53	.99	1.69	1.76	.83	1.02
S8	1.00	6.24	1.12	0	3.09	.97	2.38	.90	.82	1.06	1.25	.75	1.11	.82	1.32	.77	1.31	1.36	.77	.58
S9	1.50	0	2.82	1.11	1.61	1.07	1.05	.74	.98	.97	.94	1.06	1.18	0	1.15	.91	1.10	1.23	.89	.84
S10	7.63	1.68	0	1.28	0	.90	0	1.20	2.46	1.87	1.41	.97	1.25	1.94	2.17	1.43	2.65	2.00	.90	.93
S11	1.85	2.07	1.90	1.34	1.90	1.20	0	1.86	2.18	2.26	0	1.35	3.68	2.54	1.41	2.32	5.12	2.77	1.10	2.36
S12	3.10	2.56	2.85	2.84	2.85	1.42	4.07	2.41	2.49	2.35	1.61	1.88	1.06	0	3.31	1.77	3.55	3.46	1.29	1.28
MEAN	2.45	2.62	2.98	1.58	2.07	1.33	2.94	1.37	1.54	1.32	1.39	1.01	1.52	1.81	1.85	1.31	1.93	1.74	1.00	1.10

	6. REPPOS 31. REP POS 56. REPTPOS 81. REPT POS				7. FPCNO 32. FPC NO 57. FPCNEG 82. FPC NEG				8. TXOFFRY 33. TX OFF RY 58. TXIOFFRNY 83. TXI OFF RNY				9. CLTKOFRY33L 34. CL TKOF RY 33L 59. CLRTKOFRNY33L 84. CLR TKOF RNY 33L				10. PHLA1234 35. PHL A 1234 60. PHLAPP1234 85. PHL APP 1234			
SLIDE	6.	31.	56.	81.	7.	32.	57.	82.	8.	33.	58.	83.	9.	34.	59.	84.	10.	35.	60.	85.
S1	1.57	1.85	1.42	1.21	1.53	1.03	0	1.43	1.85	.96	1.00	1.31	2.31	2.06	2.21	1.52	1.70	1.82	0	0
S2	.97	.77	1.39	1.32	2.37	1.16	1.58	2.82	4.38	1.31	1.18	1.49	2.32	2.56	4.83	1.08	1.39	1.19	1.86	1.66
S3	1.33	.73	1.87	2.65	0	1.60	1.60	3.52	0	1.63	2.31	5.27	2.12	1.41	4.50	1.21	1.80	1.17	1.96	1.67
S4	5.17	1.18	1.27	.96	2.15	3.48	2.43	1.31	1.57	.97	4.24	0	1.60	1.59	2.71	1.61	1.24	1.70	1.18	2.28
S5	1.40	1.45	1.72	1.65	1.87	1.68	1.71	1.76	1.92	2.57	1.61	1.23	2.77	2.01	4.28	1.74	3.01	1.55	1.56	2.06
S6	1.23	.92	1.24	1.27	1.62	1.31	1.57	2.52	1.11	1.27	1.20	1.35	1.51	1.64	1.86	1.22	1.73	1.27	1.76	1.02
S7	4.97	.97	.65	.77	1.80	2.51	2.02	1.09	1.71	.53	.86	3.69	4.40	1.71	1.86	1.55	1.30	1.39	1.26	0
S8	1.00	.71	.98	.91	0	1.32	1.32	2.08	.99	1.72	.90	1.00	.88	.85	3.74	.83	2.22	.81	.93	1.21
S9	1.06	.84	1.13	.90	1.24	.89	1.19	1.40	1.56	.91	1.90	1.10	0	1.28	2.10	1.07	2.02	1.16	1.38	.99
S10	1.72	.92	.94	1.26	2.08	1.49	2.51	1.45	1.76	.79	.85	1.54	0	1.49	0	1.15	4.87	0	1.56	1.59
S11	1.88	1.26	1.19	1.30	6.00	1.82	2.82	0	1.34	1.04	1.54	2.27	2.27	2.24	5.25	1.90	2.65	2.00	2.22	1.24
S12	2.60	1.20	1.38	2.45	2.17	4.02	3.44	3.00	3.33	3.98	2.26	6.12	0	2.50	6.37	1.56	3.38	2.19	3.36	4.85
MEAN	2.07	1.06	1.26	1.33	2.28	1.85	2.01	2.03	1.95	1.47	1.65	2.39	2.24	1.77	3.61	1.37	2.27	1.47	1.73	1.85

	11. SQLO 36. SQ LO 61. SQKLOW 86. SQK LOW				12. PHLD1196 37. PHL D 1196 62. PHLDEP1196 87. PHL DEP 1196				13. CLLDGRY33R 38. CL LDG RY 33R 63. CLRLDGRNY33R 88. CLR LDG RNY 33R				14. REPA 39. REP A 64. REPTALT 89. REPT ALT				15. REPS 40. REP S 65. REPTSPD 90. REPT SPD			
SLIDE	11.	36.	61.	86.	12.	37.	62.	87.	13.	38.	63.	88.	14.	39.	64.	89.	15.	40.	65.	90.
S1	.85	.76	.85	1.05	2.62	1.50	2.22	1.63	1.70	2.26	2.33	1.40	1.46	.79	1.42	1.00	1.01	1.00	0	.84
S2	1.06	2.68	.87	.98	6.39	1.48	3.05	1.32	5.33	1.85	5.53	2.15	.90	.88	1.26	.93	.95	0	2.00	1.15
S3	1.10	1.56	1.30	1.04	0	2.04	3.00	1.49	2.66	1.48	.0	1.49	1.18	1.25	0	.88	1.01	.68	1.95	.90
S4	4.23	1.27	.77	1.38	1.67	.94	1.80	1.65	3.86	3.55	3.73	1.51	1.92	.92	3.21	1.13	.88	1.17	1.47	.77
S5	1.49	1.51	2.22	1.79	3.18	2.71	2.15	1.21	3.30	1.60	4.00	2.34	1.61	1.56	1.49	1.51	1.77	1.10	1.42	2.02
S6	2.34	1.07	1.22	1.18	1.25	1.13	1.47	1.54	1.62	1.73	3.57	1.48	1.89	1.08	1.15	1.06	1.29	1.24	1.31	1.03
S7	0	1.10	0	1.35	.75	.68	1.23	1.78	2.10	2.07	1.45	1.32	1.51	.40	1.44	.59	.95	0	0	1.13
S8	1.80	1.12	.92	1.08	1.19	1.40	1.87	0	1.49	1.29	3.05	1.03	.94	.99	1.17	.70	2.20	.70	1.40	.78
S9	.98	1.34	.87	1.04	1.99	1.09	1.78	1.06	1.27	1.01	2.48	.85	1.10	1.17	1.38	.82	1.11	.96	1.24	1.28
S10	2.52	1.52	.73	1.05	1.92	.90	1.38	2.03	2.42	1.52	2.35	1.49	2.24	1.08	1.76	.85	2.18	0	.94	1.80
S11	7.19	1.18	.95	2.75	2.16	0	2.51	1.56	4.42	2.46	3.11	1.77	2.03	2.14	1.70	1.02	1.85	2.17	1.67	1.59
S12	6.66	2.58	2.13	1.76	2.17	1.66	2.19	1.82	6.61	5.37	4.43	2.40	3.05	1.58	2.18	1.10	2.38	3.51	1.31	2.36
MEAN	2.74	1.47	1.16	1.37	2.29	1.41	2.05	1.55	3.06	2.18	3.27	1.60	1.65	1.15	1.65	.96	1.46	1.39	1.47	1.30

	16. CLHIAPP 41. CL HI APP 66. CLRHIAPP 91. CLR HI APP				17. V2MLS 42. V 2 MLS 67. VIS2MLS 92. VIS 2 MLS				18. W220@05 43. W 220 @ 05 68. WND220@05 93. WND 220 @ 05				19. RESS 44. RES S 69. RESSPD 94. RES SPD				20. CLRY 45. CL RY 70. CLRRNY 95. CLR RNY			
SLIDE	16.	41.	66.	91.	17.	42.	67.	92.	18.	43.	68.	93.	19.	44.	69.	94.	20.	45.	70.	95.
S1	.86	1.13	1.57	1.59	0	1.04	2.02	.97	1.35	1.66	3.24	1.85	.84	1.12	2.15	1.02	.67	.97	.98	1.12
S2	1.63	1.35	2.33	2.49	0	1.47	1.28	2.17	1.96	2.95	4.51	1.49	1.62	1.52	1.90	.81	1.40	.77	1.01	.81
S3	1.74	1.16	4.25	2.68	0	1.11	2.44	1.01	1.67	1.55	0	1.79	1.16	1.16	0	.71	2.01	1.18	1.05	.87
S4	2.61	4.41	0	1.76	.93	.88	1.88	.74	3.01	1.25	1.40	1.47	1.31	.83	1.13	1.75	1.12	.86	1.07	1.08
S5	1.71	1.75	0	1.73	3.24	1.54	2.42	1.49	1.42	2.57	1.62	2.01	1.25	1.35	1.78	.86	1.43	1.42	1.28	1.53
S6	1.55	1.31	1.96	1.32	1.74	1.22	3.24	1.73	2.11	1.72	1.42	1.93	1.04	.95	1.06	.89	1.12	1.22	1.23	1.37
S7	3.16	0	2.45	1.22	.90	1.05	1.24	.79	1.13	.97	1.58	2.00	.86	.63	.80	1.16	.70	1.46	1.14	1.02
S8	2.11	1.46	0	1.30	3.14	1.34	1.08	.70	1.30	1.21	1.61	1.28	0	2.12	0	.86	.92	.71	.88	.92
S9	2.03	.96	1.48	1.33	1.76	.83	1.43	.88	1.29	1.27	1.60	.85	1.13	1.11	1.65	1.08	1.00	.75	.87	.80
S10	1.60	6.06	3.09	1.70	1.16	.74	1.23	.77	.97	.80	.87	1.93	1.27	1.12	1.04	1.47	.70	1.02	1.03	.80
S11	2.81	3.38	3.25	2.33	1.59	1.76	2.31	1.72	3.07	1.29	1.78	3.50	2.15	2.07	1.52	1.82	1.53	1.79	1.91	2.13
S12	3.76	0	6.68	2.78	1.22	1.61	4.01	1.56	2.20	1.95	1.92	3.57	1.43	.83	2.14	1.72	1.49	1.62	1.34	2.00
MEAN	2.13	2.29	3.00	1.85	1.74	1.21	2.04	1.21	1.79	1.59	1.96	1.97	1.27	1.23	1.51	1.17	1.17	1.14	1.14	1.20

	21. CT@OM 46. CT @ OM 71. CTCTWR@OUM 96. CTC TWR @ OUM				22. XBOSA120 47. X BOS A 120 72. XBOSALT120 97. X BOS ALT 120				23. SLOS130 48. SLO S 130 73. SLOSPD130 98. SLO SPD 130				24. CBOSD1320 49. C BOS D 1320 74. CTCBOSDEP1320 99. CTC BOS DEP 1320				25. CLINT 50. CL INT 75. CLRINT 100. CLR INT			
SLIDE	21.	46.	71.	96.	22.	47.	72.	97.	23.	48.	73.	98.	24.	49.	74.	99.	25.	50.	75.	100.
S1	1.38	2.13	3.58	2.43	2.29	2.89	1.81	1.70	1.28	1.88	2.65	1.09	2.51	1.83	2.55	4.81	1.41	.93	1.87	.94
S2	2.96	1.38	0	2.80	1.96	4.00	3.41	3.79	0	1.15	0	1.02	0	1.42	3.65	2.80	1.05	1.42	1.60	1.09
S3	1.35	1.76	0	2.34	2.11	0	4.76	2.03	3.00	1.44	0	1.03	0	1.45	0	0	1.57	.68	2.54	1.32
S4	1.42	1.59	0	0	2.10	1.80	5.45	2.65	3.19	.77	2.10	0	2.14	1.37	8.25	1.41	1.68	1.67	0	1.01
S5	2.22	3.31	1.78	1.98	1.61	2.28	1.96	1.54	0	2.24	0	1.26	2.71	3.83	4.04	1.42	2.77	1.23	1.40	1.07
S6	1.85	2.49	2.96	0	2.01	1.88	2.39	1.96	1.69	1.30	1.47	1.54	1.80	0	0	0	2.00	1.39	1.19	1.16
S7	2.77	1.35	0	4.00	0	1.26	0	1.76	0	1.31	1.63	2.37	2.46	0	0	0	1.38	1.93	1.55	1.09
S8	2.28	1.49	3.69	2.07	1.28	1.43	2.07	1.42	6.91	1.36	.80	.88	0	.75	1.56	0	1.25	2.56	1.80	.95
S9	1.59	1.77	1.90	1.45	.90	1.12	1.44	1.17	1.73	1.13	1.04	.77	1.91	1.08	1.81	1.36	1.13	.73	1.12	.86
S10	2.43	3.59	4.00	2.91	2.02	1.28	2.20	1.80	2.57	1.18	1.36	1.49	0	2.21	1.73	2.66	2.65	1.11	1.91	1.16
S11	5.11	2.62	0	2.49	2.65	1.21	2.53	1.26	3.40	0	0	1.39	0	4.61	0	0	2.82	.94	3.83	1.23
S12	3.36	0	0	2.10	4.07	1.77	3.91	1.98	3.05	1.83	2.02	2.07	7.39	0	2.60	4.16	6.08	1.85	3.06	1.17
MEAN	2.39	2.13	2.98	2.46	2.09	1.90	2.90	1.92	2.98	1.41	2.46	1.92	2.98	2.06	3.27	2.66	2.14	1.37	1.98	1.08

APPENDIX C

MESSAGE FORMATS AND RAW DATA FOR EXPERIMENT II

All reaction times in seconds.

An "0" 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 a failure of a slide to drop into the projector properly or a failure of the timer to reset.

MES-SAGE	CONTACT GROUND CONTROL ON 1237			CONTACT TOWER 1191			CT 1172			H260A040 S170 *CONTACT TWR 1245*		
SLIDE FONT	1 DM	49 ST	97 SEG	2 DM	50 ST	98 SEG	3 DM	51 ST	99 SEG	4 DM	52 ST	100 SEG
S1	1.95	2.15	2.16	1.51	0	1.43	2.03	2.62	.46	2.07	0	3.70
S2	.94	1.34	0	1.16	0	1.15	1.33	1.18	1.21	.92	1.19	1.16
S3	1.16	1.19	0	.92	.91	.67	1.18	.90	0	.87	2.23	1.78
S4	0	.86	1.50	1.11	1.04	.86	2.12	1.22	1.92	1.27	1.89	.99
S5	1.42	1.32	1.08	2.17	1.15	1.23	1.12	1.76	3.33	.92	2.46	2.77
S6	2.85	1.61	2.64	1.53	1.51	1.29	0	1.76	1.94	2.20	2.34	0
S7	1.53	1.55	2.35	0	1.67	1.08	2.02	1.78	1.73	3.56	1.32	0
S8	1.18	2.49	3.16	1.27	1.20	1.48	1.46	4.42	3.47	1.90	2.44	2.96
S9	1.74	0	2.47	0	3.41	1.01	1.48	1.57	1.52	1.49	2.19	1.74
S10	1.73	1.07	1.42	1.57	1.93	1.14	1.57	2.35	0	1.32	2.27	2.21
MEAN	1.61	1.50	2.19	1.40	1.60	1.13	1.59	1.95	1.94	1.65	2.03	2.16
MEAN		1.77			1.38			1.83			1.95	

MES-SAGE	CA 1205			RADIO 1213			*CONTACT TWR 1234* H120 A200 S200			*CG11845* HDG 070 ALT 110		
SLIDE FONT	5 DM	53 ST	101 SEG	6 DM	54 ST	102 SEG	7 DM	55 ST	103 SEG	8 DM	56 ST	104 SEG
S1	2.81	2.09	0	2.05	0	2.06	2.66	2.32	1.68	3.23	2.41	2.04
S2	1.26	.89	1.14	1.07	.72	0	1.68	1.26	1.02	0	1.63	1.29
S3	.89	1.31	1.35	1.02	.69	.88	1.28	0	1.15	1.41	0	1.67
S4	1.21	.65	1.45	1.30	.85	.86	1.10	1.68	1.15	1.30	0	1.37
S5	0	1.17	1.39	.92	0	1.91	2.48	1.04	2.31	2.52	3.88	1.46
S6	1.44	1.42	3.06	1.39	0	1.42	3.89	1.73	1.53	2.03	4.24	2.23
S7	0	0	2.51	0	1.21	2.28	1.89	1.82	1.59	0	2.27	1.70
S8	2.36	2.14	2.47	1.56	.99	2.09	1.87	1.17	2.14	4.66	1.73	1.45
S9	1.40	1.40	0	1.64	1.44	1.31	1.48	1.52	1.48	2.94	1.79	1.85
S10	3.29	1.55	0	0	2.09	1.05	1.86	2.65	1.79	3.23	0	0
MEAN	1.83	1.40	1.91	1.36	1.14	1.54	2.01	1.68	1.58	2.66	2.56	1.67
MEAN		1.71			1.35			1.76			2.30	

MES-SAGE	HDGL210			HDG←230			*HDG←070* ALT 191 SPD 210			TURN LEFT 180		
SLIDE FONT	9 DM	57 ST	105 SEG	10 DM	58 ST	106 SEG	11 DM	59 ST	107 SEG	12 DM	60 ST	108 SEG
S1	2.24	1.45	1.52	1.27	1.21	1.47	1.66	-	2.05	1.07	1.10	1.59
S2	1.28	1.13	1.17	.73	.65	.98	1.86	-	1.81	0	.88	1.02
S3	1.90	1.09	1.80	.85	.84	.88	0	-	1.39	1.04	.90	.81
S4	.92	1.14	1.90	1.12	.96	1.15	2.12	-	2.04	.99	1.04	1.12
S5	1.64	1.13	1.25	1.36	2.18	1.79	2.54	-	0	0	1.14	2.09
S6	1.40	0	1.22	1.23	1.15	1.32	1.57	-	1.51	1.15	1.09	1.06
S7	0	1.47	2.17	1.24	1.12	1.30	1.34	-	1.87	1.11	1.07	1.22
S8	4.02	1.76	1.52	1.31	1.61	1.36	1.72	-	.75	1.03	1.03	1.54
S9	2.06	1.34	2.31	1.26	1.42	1.11	1.82	-	1.40	1.05	.98	1.18
S10	3.31	1.45	0	1.25	.95	1.24	2.26	-	2.69	0	1.16	1.90
MEAN	2.08	1.32	1.65	1.16	1.20	1.26	1.87	-	1.72	1.06	1.03	1.35
MEAN		1.68			1.21			1.80			1.15	

MES-SAGE	*HDG←260* ALT 080 SPD 175			LEFT			←←			TURN ←← 290		
SLIDE FONT	13 DM	61 ST	109 SEG	14 DM	62 ST	110 SEG	15 DM	63 ST	111 SEG	16 DM	64 ST	112 SEG
S1	0	0	2.11	1.08	.76	-	.73	.78	0	1.32	0	1.13
S2	0	.82	1.08	.87	0	-	.69	.58	.47	.82	0	.83
S3	0	0	1.16	0	1.09	-	.59	.62	.51	.75	0	.76
S4	0	1.88	.87	0	.69	-	.90	.55	.74	.96	0	.98
S5	2.26	0	2.62	.83	.83	-	.62	.82	0	1.40	.85	.92
S6	2.34	1.32	1.25	.94	0	-	1.07	.71	.87	1.58	0	1.15
S7	2.15	1.44	0	.98	.87	-	.69	.70	.73	.99	0	1.16
S8	0	0	1.99	0	.93	-	.99	.88	3.46	1.18	0	1.27
S9	0	1.68	1.41	1.32	1.04	-	.86	.99	.84	1.03	1.57	1.09
S10	3.65	0	1.52	.92	.76	-	1.10	.72	2.27	1.54	1.24	0
MEAN	2.60	1.42	1.55	.99	.87	-	.82	.73	1.23	1.15	1.22	1.03
MEAN		1.86			.93			.93			1.13	

MES-SAGE	HDGR110			HDG→120			*HDG→160* ALT070 SPD 230			TURN RIGHT 090		
SLIDE FONT	33 DM	81 ST	129 SEG	34 DM	82 ST	130 SEG	35 DM	83 ST	131 SEG	36 DM	84 ST	132 SEG
S1	1.06	1.60	1.23	1.00	1.07	0	2.02	1.53	1.89	.66	.98	1.17
S2	1.15	1.11	1.01	.73	.82	.78	1.80	1.51	1.21	.98	.95	.95
S3	2.07	1.59	1.03	.82	.77	.80	1.44	1.96	2.42	.82	1.20	1.18
S4	1.51	1.14	1.11	1.03	.79	.91	1.82	1.39	1.80	1.14	1.36	1.21
S5	1.27	2.01	0	.92	1.07	1.05	1.54	1.66	2.32	1.03	.83	1.30
S6	1.24	1.39	1.30	1.25	.95	1.04	1.47	1.31	1.36	1.31	.92	1.20
S7	1.30	1.03	1.34	.92	0	1.00	1.58	1.14	2.02	1.26	.85	1.21
S8	1.46	2.14	1.32	1.11	1.24	1.37	2.22	1.29	1.99	1.57	1.11	1.52
S9	1.73	1.22	1.25	1.13	1.24	1.26	1.71	1.42	1.61	1.45	0	1.27
S10	2.95	2.12	1.38	0	.87	1.88	1.64	1.68	3.56	1.21	1.79	1.27
MEAN	1.57	1.53	1.21	.99	.98	1.12	1.72	1.48	2.01	1.14	1.11	1.22
MEAN	1.44			1.03			1.74			1.16		

MES-SAGE	*HDG→190* ALT 090 SPD 165			RIGHT			→→			TURN →→ 110		
SLIDE FONT	37 DM	85 ST	133 SEG	38 DM	86 ST	134 SEG	39 DM	87 ST	135 SEG	40 DM	88 ST	136 SEG
S1	1.83	1.27	1.49	.83	.79	.88	.98	.91	.80	1.14	.93	1.38
S2	1.26	1.82	1.24	.87	.84	.85	.99	1.03	.70	1.03	.72	.80
S3	1.33	1.01	1.66	.73	.57	.94	.65	.76	.54	.82	.67	1.07
S4	1.04	.95	1.21	.87	.80	1.04	.58	0	.61	.68	.84	.71
S5	2.26	1.00	0	0	1.10	2.99	.83	0	.78	.90	.88	.89
S6	1.10	1.08	1.59	1.16	1.82	.82	.76	.84	.71	.89	1.30	1.00
S7	2.09	1.07	1.59	.74	.77	.79	.77	.72	.73	1.56	.80	1.24
S8	1.83	.87	1.93	.89	.84	1.11	.87	1.30	.93	1.20	1.15	1.58
S9	2.83	1.18	1.28	.79	.83	1.00	1.03	1.29	.98	1.05	1.13	1.13
S10	2.96	1.60	1.63	1.16	.88	0	.74	.91	.82	1.43	.73	.79
MEAN	1.85	.92	1.51	.89	1.18	1.15	.82	.97	.76	1.07	.91	1.05
MEAN	1.43			1.07			.85			1.01		

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	1.86	0	1.82	2.25	1.40	1.80	1.44	1.15	1.62	1.49	1.69	1.23
S2	1.86	.98	1.09	1.80	1.37	.88	0	.98	1.16	.63	1.10	.92
S3	1.03	.98	1.42	.99	0	.75	1.13	0	.83	.70	2.19	1.58
S4	2.99	.94	1.04	.93	.97	.87	1.09	1.23	1.06	.64	.79	.69
S5	1.73	.97	1.40	1.21	1.00	1.11	.82	.75	.88	.85	.81	1.35
S6	1.71	1.20	2.00	1.88	1.18	1.78	1.03	1.44	2.21	.89	1.21	1.08
S7	2.33	1.12	1.22	1.14	1.15	1.28	1.02	0	1.18	0	1.41	0
S8	2.05	2.94	1.17	1.61	0	1.20	1.24	1.05	1.35	.93	1.63	1.52
S9	1.55	1.03	0	1.17	1.21	0	1.18	.98	0	.82	1.17	.92
S10	1.78	1.02	1.61	1.06	1.65	1.10	1.97	1.19	1.04	.85	1.27	1.00
MEAN	1.88	1.24	1.41	1.40	1.24	1.19	1.21	1.09	1.25	.86	1.32	1.14
MEAN		1.51			1.27			1.18			1.10	

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	114 SEG
S1	1.19	.94	1.17	1.35	2.16	0	2.35	1.97	3.43	2.01	0	2.03
S2	.88	.74	0.00	1.12	1.59	1.73	1.14	1.37	1.22	1.00	1.05	1.18
S3	.94	.91	0	0	1.55	1.06	.98	1.33	1.10	1.20	1.11	0
S4	.64	.89	1.24	1.69	1.16	1.11	.80	1.03	1.00	.88	.67	.77
S5	.95	.57	.91	1.18	2.54	1.04	0	1.28	0	.75	1.07	1.22
S6	1.25	2.21	1.59	1.48	0	0	2.20	1.83	0	1.54	1.20	1.43
S7	0	.87	1.03	2.24	1.36	.94	1.62	2.10	1.09	1.22	0	2.08
S8	1.28	.94	1.18	1.37	2.42	0	1.66	1.99	1.88	1.71	2.95	2.42
S9	.98	1.06	1.03	1.40	1.32	1.55	2.23	1.10	0	1.18	1.54	1.42
S10	.78	1.21	0	1.17	1.25	1.49	1.33	1.28	1.71	1.36	1.06	1.26
MEAN	.98	1.03	1.16	1.44	1.70	1.27	1.59	1.52	1.63	1.28	1.33	1.53
MEAN		1.06			1.47			1.58			1.38	

APPENDIX D

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 multi-dimensional arrays. Here, because of the different computational procedure, different numerical values are required to establish

*This discussion appeared previously in the Report FAA-RD-72-150

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.