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FLIGHT INFORMATION SCALE TEST FOR HEADS-UP AND PANEL MOUNTED DISPLAYS

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Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

October 1973

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The only statistically significant comparison occurred between best and worst display formats. On a moving thermometer tape display, the pilot performance was significantly lower. This difference was the result of scaling requirements rather than scale type.

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ABSTRACT

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PREFACE

The author wishes to thank the many people who gave of their time and ideas to this effort; particularly Messrs. Murray Foster, Clarence Fry and Harry Stowell for their invaluable aviation experience and assistance in this experiment and Dr. William Wokoun for his excellent critical review.

Thanks are also given to the pilots who are continually being solicited as subjects in our experiments.

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FLIGHT INFORMATION SCALE TEST FOR HEADS-UP AND PANEL MOUNTED DISPLAYS

INTRODUCTION

This study is the first in a series of three progressive investigations to assess airspeed and altitude flight status scale design for an Army helicopter heads-up display (HUD) and/or panel mounted display. The current symbology used by the Air Force and Navy has been developed based on the needs of fixed-wing, high-speed flight. Literature on symbology has not as yet addressed the current needs of helicopter flight.

One question for this investigation to resolve was the conflicting flight symbology scales contained in Military Standard MIL-STD-884B and Military Specification MIL-D-81641 (AS) and the apparently pre-conceived notion that a fixed-lubber, moving-scale presentation portrays information better than a moving-lubber, fixed-scale presentation.

The military standard for electro-optical generated symbology (MIL-STD-884B) and the military specification for HUD symbology (MIL-D-81641 (AS) used by the Navy specify conflicting altitude-scale presentations. Both use a moving scale with a fixed lubber. However, in the Navy specification, the bottom of the scale represents higher altitudes; to portray increasing altitudes, the scale moves upward. The military standard requires just the reverse, with higher altitudes at the top of the scale; to represent increasing altitudes, the scale moves downward.

To correct for increasing altitude, the pilot should move his cyclic control forward. Hence, the two kinds of displays should give different response times, since one moves compatibly with this control operations, while the other display moves opposite to it. Response times may also be affected by the differences between fixed-scale, moving-lubber presentations and moving-scale, fixed-lubber presentations.

In general, the moving scale afford the display an expanded range of values in a limited space. Combinations of such scales can be designed for rapid scale cross checking by presenting the fixed lubbers in line. However, one shortcoming is that only the error value is evident, since the zero or base value is not generally visible. A fixed scale with the base value visible presents both the total scale range and error values. The fixed scale may have to be compressed due to physical constraints and small differences not easily discernible. Also, scale value cross checking is more complex since the individual scale value indices are not aligned.

The objectives of this initial investigation are (1) to test a set of flight display formats (Figs. 1, 2, 3) which are composed of representative scale designs for altitude, airspeed, and heading, and (2) to rank-order the flight display formats based on control reaction time and frequency of control error. If results showed significant differences between the formats, the formats yielding the significantly poorest results would then be considered for deletion from further testing.

The hypothesis is that current rotary wing pilots will show control response differences, either in response time or error, when reacting to the different flight display formats.

METHOD

Six display formats (Figs. 1, 2, 3) were designed to blend unobtrusive but conspicuous scales and symbology with a clear central field of view. These display formats contained various altitude and airspeed scales combined with a heading scale, fixed aircraft symbol, horizon and pitch lines.

Representative scale deviations (Table 1) were selected as being typical for helicopter flight and were randomly assigned to slots in each of five change sequences (Table 2).

The six formats and five change sequences were arranged in a matrix, designed to counterbalance training transfer, daily variations and queueing by a single change sequence. Formats and scale change deviations were not randomly assigned to the matrix cells.

Informational Displays Inc. input/output hardware and software and a Varian 620i Computer (Fig. 4) were used to generate the formats and for orderly control of the testing. The logic diagram for test control is contained in Appendix C.

Rotary-wing qualified pilots stationed at Aberdeen Proving Ground and Edgewood Arsenal, Md, were asked to participate in the test. As the first twelve subjects became available, they were interviewed and assigned to a row in the matrix. Table 3 lists each subject's age, total flight time and total instrument time.

Subjects were not selected or grouped by any pretest basis; the only restrictions were that they be currently on flying status and have the time to participate.

All subjects stated that they had corrected 20/20 vision acuity. Subject (N) stated that he had a left eye condition of 20/400 and a right eye condition of 20/20 before correction. The relatively low instrument time for most of the subjects reflects the new Army program to qualify its pilots with an instrument rating. Subject (O) is an instrument instructor currently providing instruction.

A written set of instructions (Appendix A) was given to each subject before testing. Two or three subjects were run in sequence; each one was tested on two to four formats in a morning and/or afternoon session. During rest periods between format presentations, subjects were interviewed about their opinion of the format.

Subjects were seated at a twenty-eight-inch viewing distance and manipulated a single four-inch displacement control stick with their right hand. The experimental task was to provide the correct cyclic-control motion to maintain the base set of scale values of 80 knots, 100 feet and 70 degrees heading. Scale value indications were changed based on the change sequence. However, once a control input was made, the task was considered completed and the scales returned to their base values. The subjects did not control the dynamics of the altitude and airspeed scales, but control stick was directly coupled to the horizon and heading scale. Deviations in alignment between the aircraft symbol and horizon and the 70-degree heading provided the feedback for centering the control stick.

If the stick was not centered at the time a scale value change was about to initiate, a "center stick" message would appear on the screen.

For training purposes, subjects were given 26 individual unscored scale changes, or trials, on each format. Then a change sequence was given three times for the format, for a total of 39 individual scale changes that were scored. Within the total group of subjects, each change sequence was used on each format.

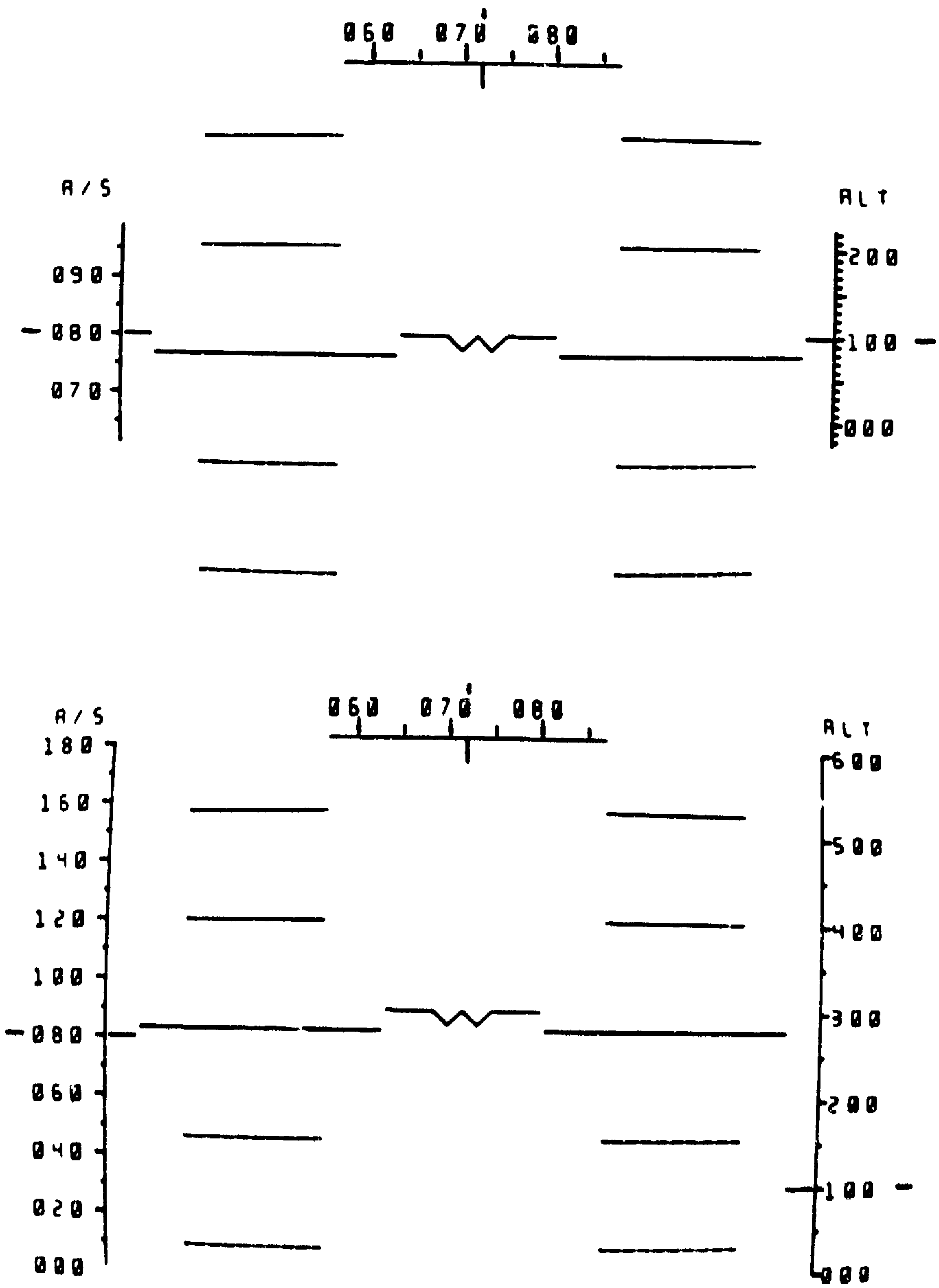


Fig. 1. Flight displays formats 1 and 2

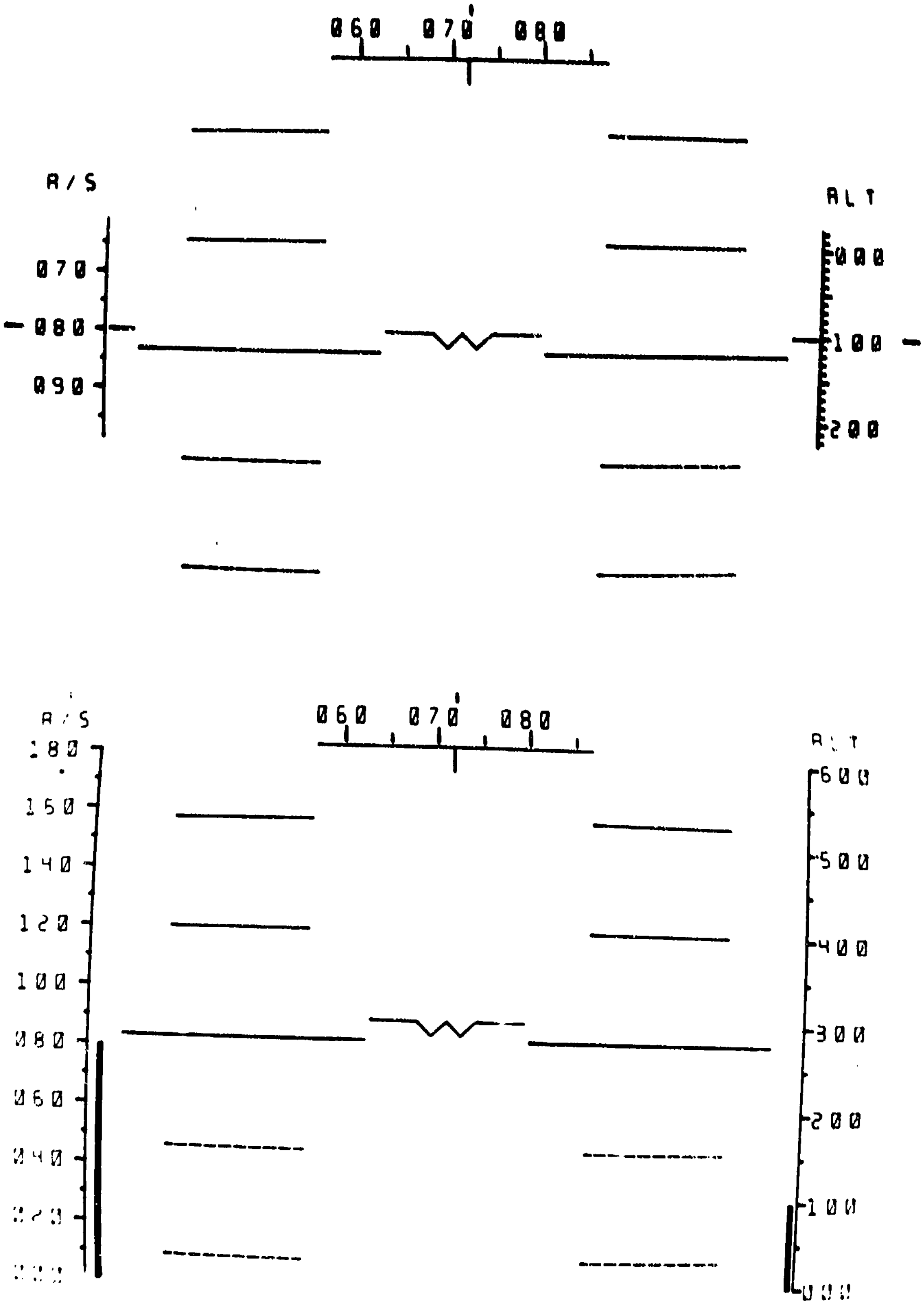


Fig. 2. Flight display formats 3 and 4

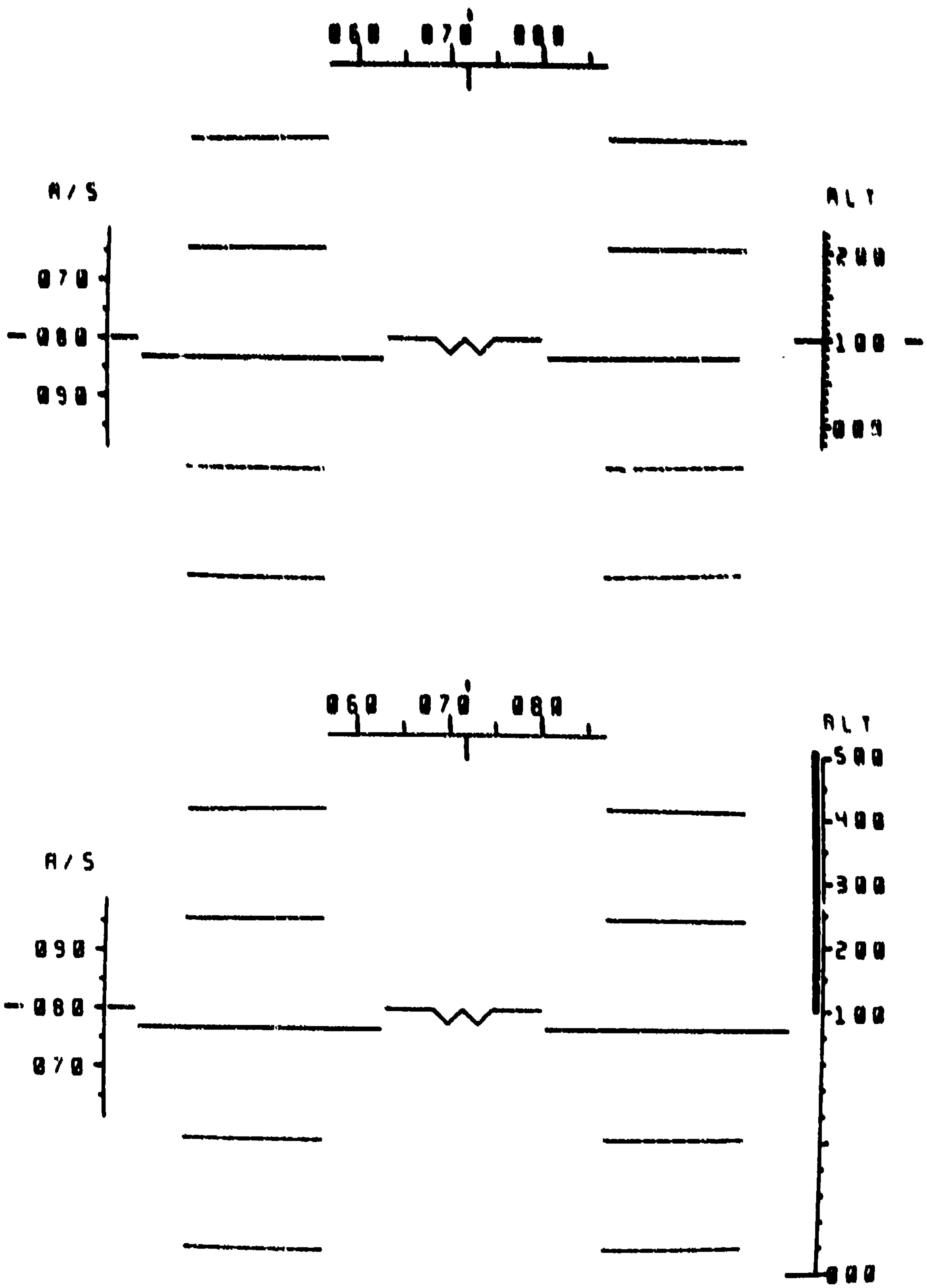


Fig. 3. Flight display formats 5 and 6

TABLE 1

Scale Change Deviations

No.	Scale	Rate of Change or Indication
1	Altitude	Positive 1000 feet per minute
2	"	Positive 500 feet per minute
3	"	Negative 500 feet per minute
4	"	Negative 2000 feet per minute
5	"	Positive 100 foot step
6	"	Positive 200 foot step
7	"	Negative 50 foot step
8	Airspeed	Positive 7 knots per second
9	"	Positive 2 knots per second
10	"	Negative 2 knots per second
11	"	Negative 7 knots per second
12	Heading	Positive 6 degrees per second
13	"	Negative 6 degrees per second

TABLE 2

Change Sequence and Order of Presentation

Order	Change Sequences I	II	III	IV	V
1	1*	10	13	3	11
2	8	13	5	10	9
3	2	3	10	4	7
4	12	6	2	11	5
5	3	9	7	5	3
6	9	12	12	12	1
7	4	2	4	6	12
8	5	5	9	13	10
9	10	8	1	7	8
10	13	11	6	1	6
11	6	1	11	8	4
12	11	4	3	2	2
13	7	7	8	9	13

* Scale change deviations from table 1

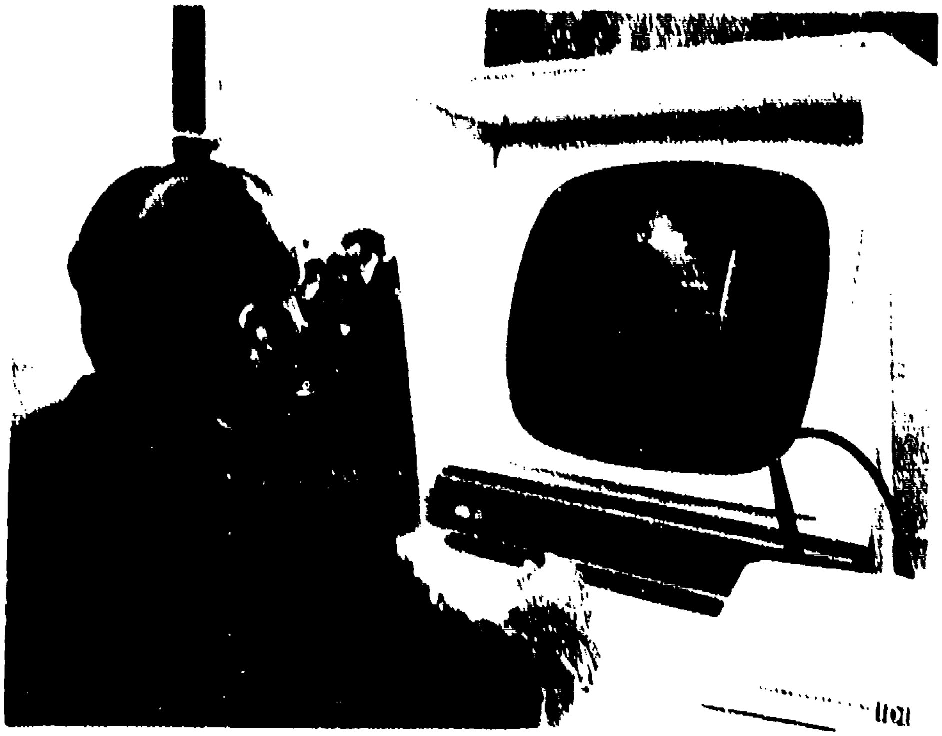


Fig. 4a. Display console.

Fig. 4b. Display control.

TABLE 3

Subject Data

Subject	Age	Total Flight Time (Hours)	Instrument Time (Hours)
E	43	1900	75
F	24	650	70
G	24	2600	200
H	35	1900	110
I	26	600	none
J	25	1200	150
K	23	1000	30
L	32	3000	125
M	26	700	40
N	27	1150	50
O	42	4200	1000
P	35	2300	100

DATA ANALYSIS

Analyses were accomplished to answer the original objective and to investigate ways of defining response time and control reversals as dependent variables. A multivariate analysis of variance using reaction times and incorrect control responses was used to evaluate whether display design affected pilot performance significantly. The same data were used in a second multivariate analysis of variance to rank the display formats.

Univariate analyses of variance were planned using a multi-level factorial design with repeated measures (Fig. 5). The 0.05 level of significance was the criterion for evaluating effects: the 0.05 significance level divided by the number of treatments[1] was used in the analysis of simple main effects; the Newman-Keuls test at the 0.05 level was used for multiple comparisons.

The multi-level stratification of data used here was intended to provide information which would allow simplifying future experiments on flight symbology. By testing a comparatively large range of stimulus variations, this experiment makes it possible to determine which stimulus conditions are not effective variables. Further attention can then be concentrated on the variables that have the most effect on pilot performance.

RESULTS (Data tables are contained in Appendix B)

1. Pilot performance with display format 4 was significantly poorer than with display format 6. These were the only formats which differed significantly when both response time and incorrect control responses were tested in a multivariate analysis of variance (Table 1B).

2. The same data values were used to rank the display formats for relative effectiveness. A similar analysis showed that display format 6 ranked significantly higher than display formats 2, 3 and 4. Also, display format 1 ranked significantly above display format 4 (Table 2B).

3. Pilots responded equally well to heading changes on all display formats. Heading performance was not significantly affected by display formats or by the direction of heading change (Table 3B, Fig. 6). This means that the subject's performance in maintaining heading was essentially the same under all of the experimental conditions.

4. The airspeed scales rate of movement interacted significantly with the display formats (Table 4B, Fig. 7). That is, the rate of movement that gives best performance depends on the specific display format. The numbers by the individual data points on Figure 8 show the number of comparisons that were significant (Newman-Kuels test, with 0.05 probability level).

5. A 500-feet-per-minute rate of descent is detected significantly sooner on display format 6 than on any of the other display formats. A 1000-feet-per-minute rate of ascent is detected significantly sooner on format 5 than on display formats 2, 4 or 6. None of the other differences were significant. However, there was significant interaction between scale-change rate and display format (Tables 5B & 6B, Figs. 8 & 9).

6. Response times and incorrect control responses are positively correlated except for display format 3 and subject G (Tables 1B & 2B). Thus later responses were more apt to be errors.

[1] Kirk, R. E. Experimental design, procedures for the behavioral sciences. Brook/Cole, 1968.

E	1											2	
D	1							2				3	
C	1				2			3				4	
B	1	2	3	4	5	6	7	8	9	10	11	12	13
F1													
F2													
F3													
F4													
F5													
F6													

B = Input to display from Table 1
C_1 = Dynamic altitude change
C_2 = Step altitude change
C_3 = Dynamic airspeed change
C_4 = Dynamic heading change
D_1 = Altitude changes
D_2 = Airspeed changes
D_3 = Heading changes
E_1 = Vertical indications
E_2 = Horizontal indications
F_i = Display formats 1-6
N = 12

Fig. 5. Experimental plan for stratifying data.

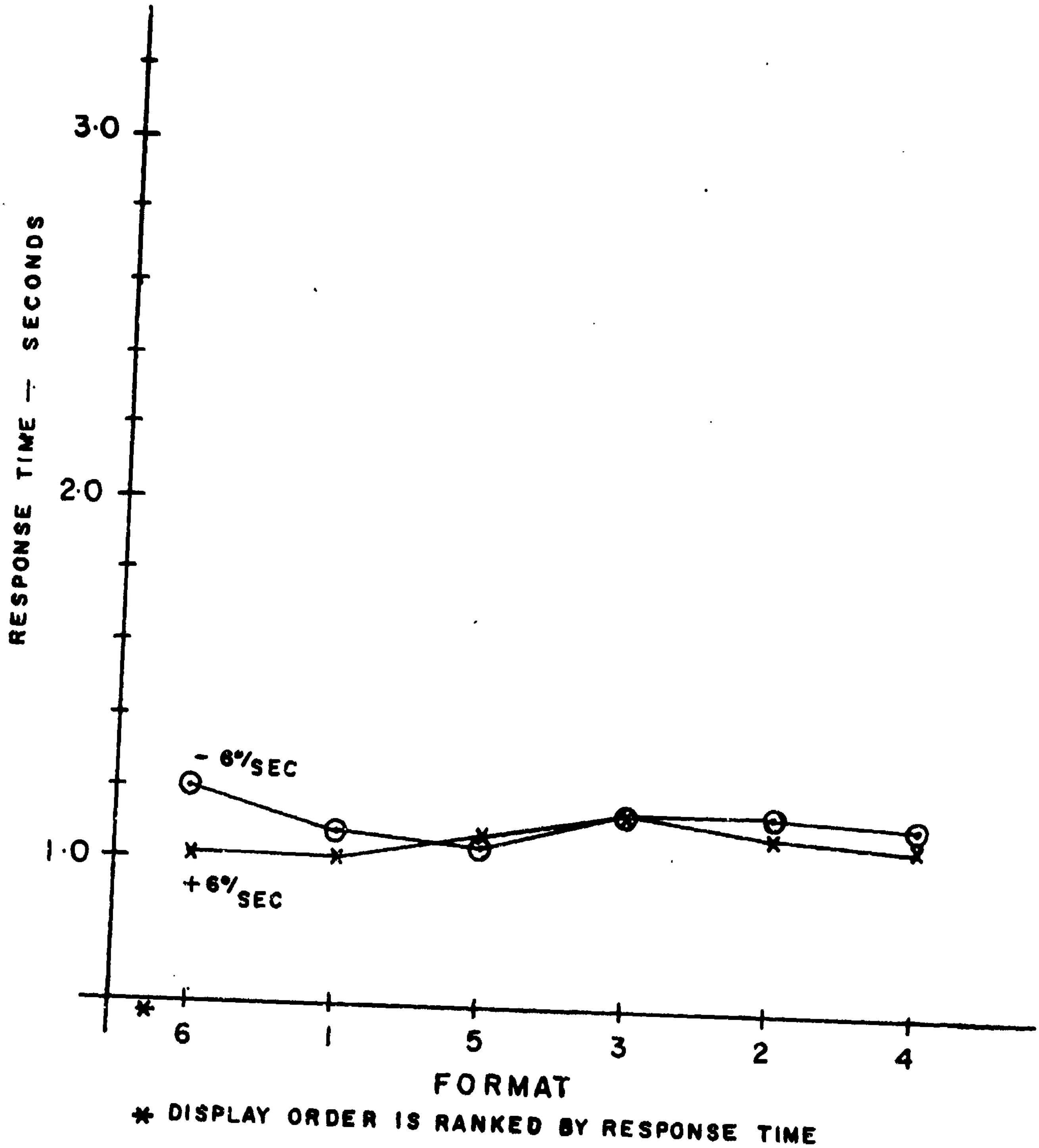


Fig. 6. Heading scale.

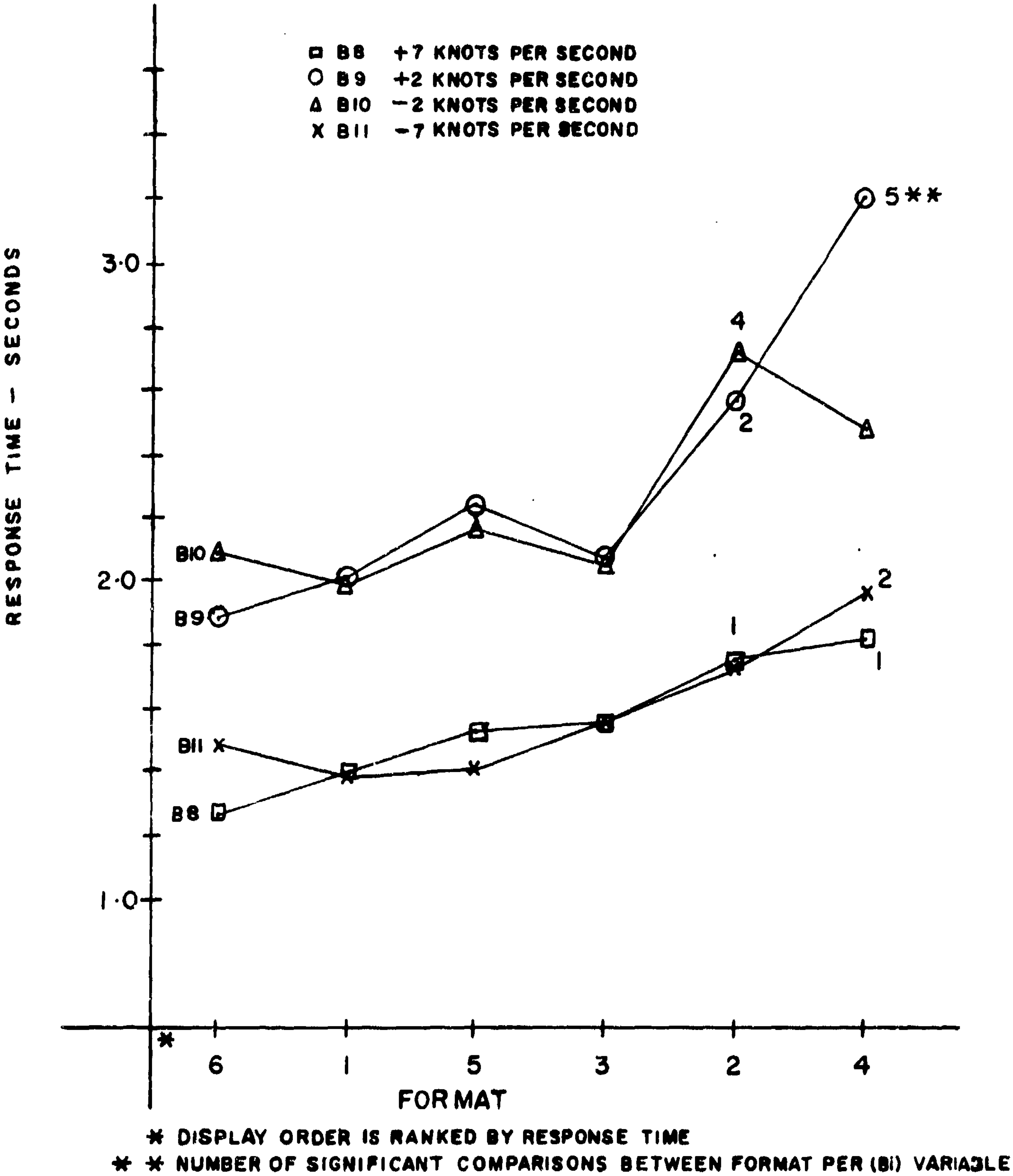
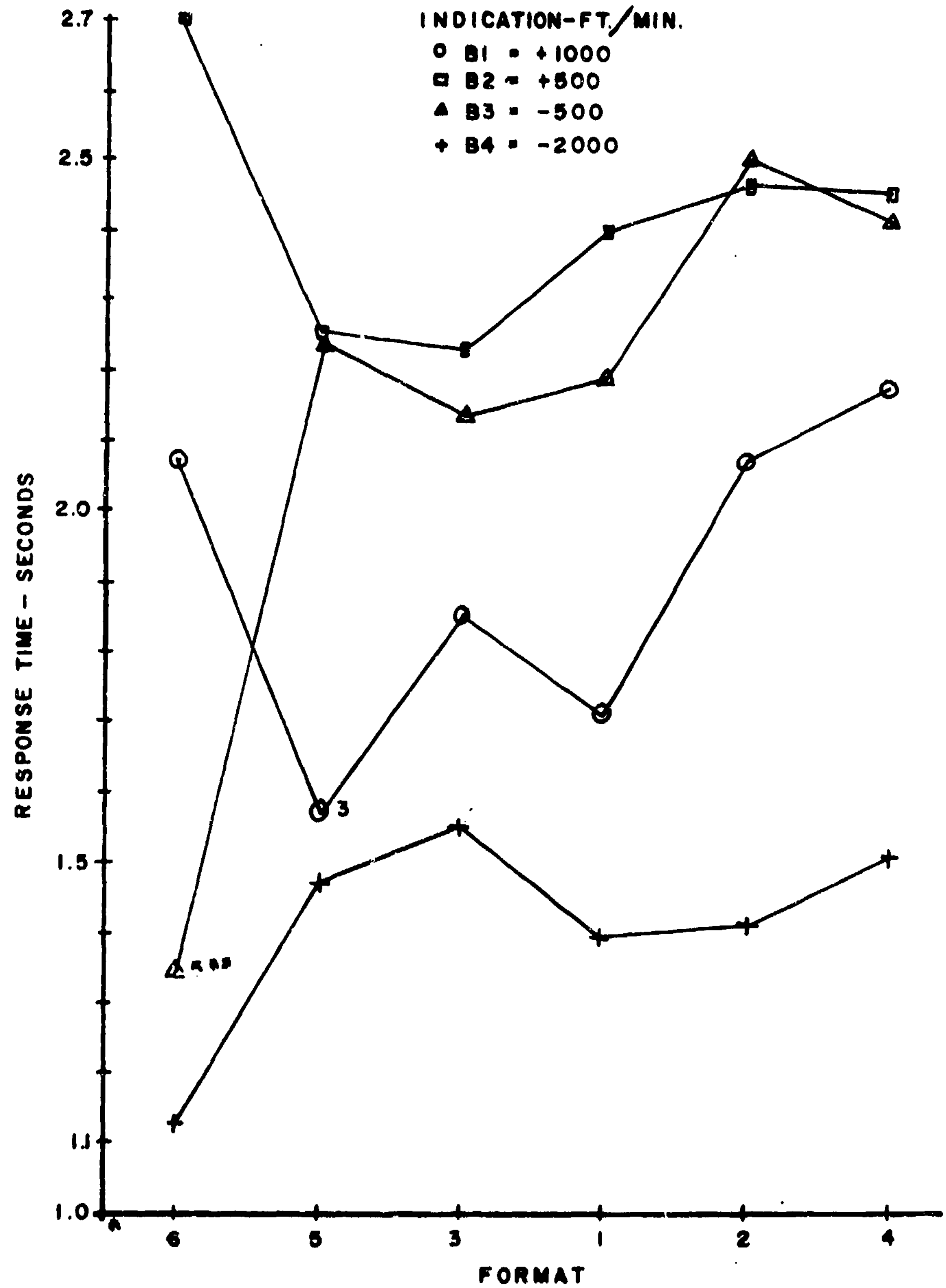


Fig. 7. Airspeed scale.



*Display order is ranked by response time
**Number of significant comparisons between format per (BI) variable

Fig. 8. Altitude scale.

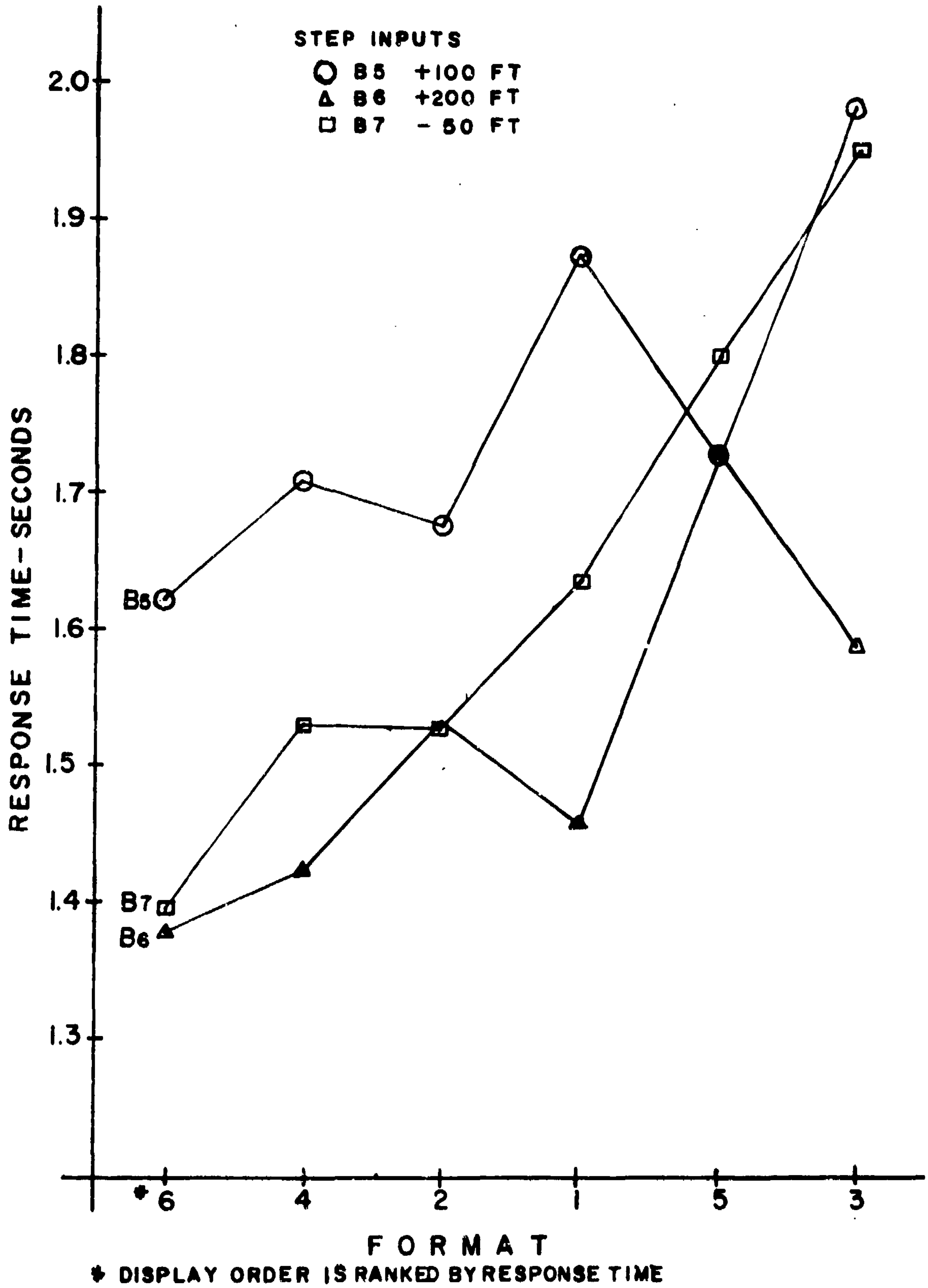


Fig. 9. Altitude scale.

7. Response time and rate of indication on the display screen are negatively correlated for both forward and aft correcting stick motion (Fig. 10). Subjects took longer to detect slow display changes.

8. A univariate analysis of control reversals revealed there were no significant differences either between display formats or between display scales (Tables 7B& 8B).

9. Pilot subjects were interviewed after using each display format. Comments were grouped as "favorable", "minor problems or no problems" and "negative".

Format 1	Seven pilots responded; two responded favorably and two responded negatively.
Format 2	Seven pilots responded; one responded favorably and four responded negatively.
Format 3	Eleven pilots responded; two responded favorably and four responded negatively.
Format 4	Ten pilots proved comments; two responded favorably and three responded negatively.
Format 5	Eight pilots provided comments; three responded favorably and two gave negative comments.
Format 6	Nine pilots provided comments; four responded favorably and three responded negatively.

DISCUSSION

Six display formats were configured to provide a relatively clear center field or view, with altitude, airspeed and heading scales at the edges of the display field. Character-size and display-brightness values were selected to avoid problems in conspicuity. A repeated-measure-factorial experiment was designed to use response time and control error as dependent variables, and display formats and scale indication as independent variables. Subjects were pilots, tested when they became available. Both multivariate and univariate analyses were done.

It had been hypothesized that display formats with markedly differing scale types would strongly affect the pilot's response times and errors. However, the results did not verify this hypothesis. There were some pronounced differences, but only between individual scale indications.

The single significant difference between format 4 and format 6 apparently arose from differing scale factors, rather than from the types of scales. The term "scale factor" means the relative distance between scale values. With larger distances between values, the scales move faster. 'Scale factor' appears to be important because it has a high correlation with response time.

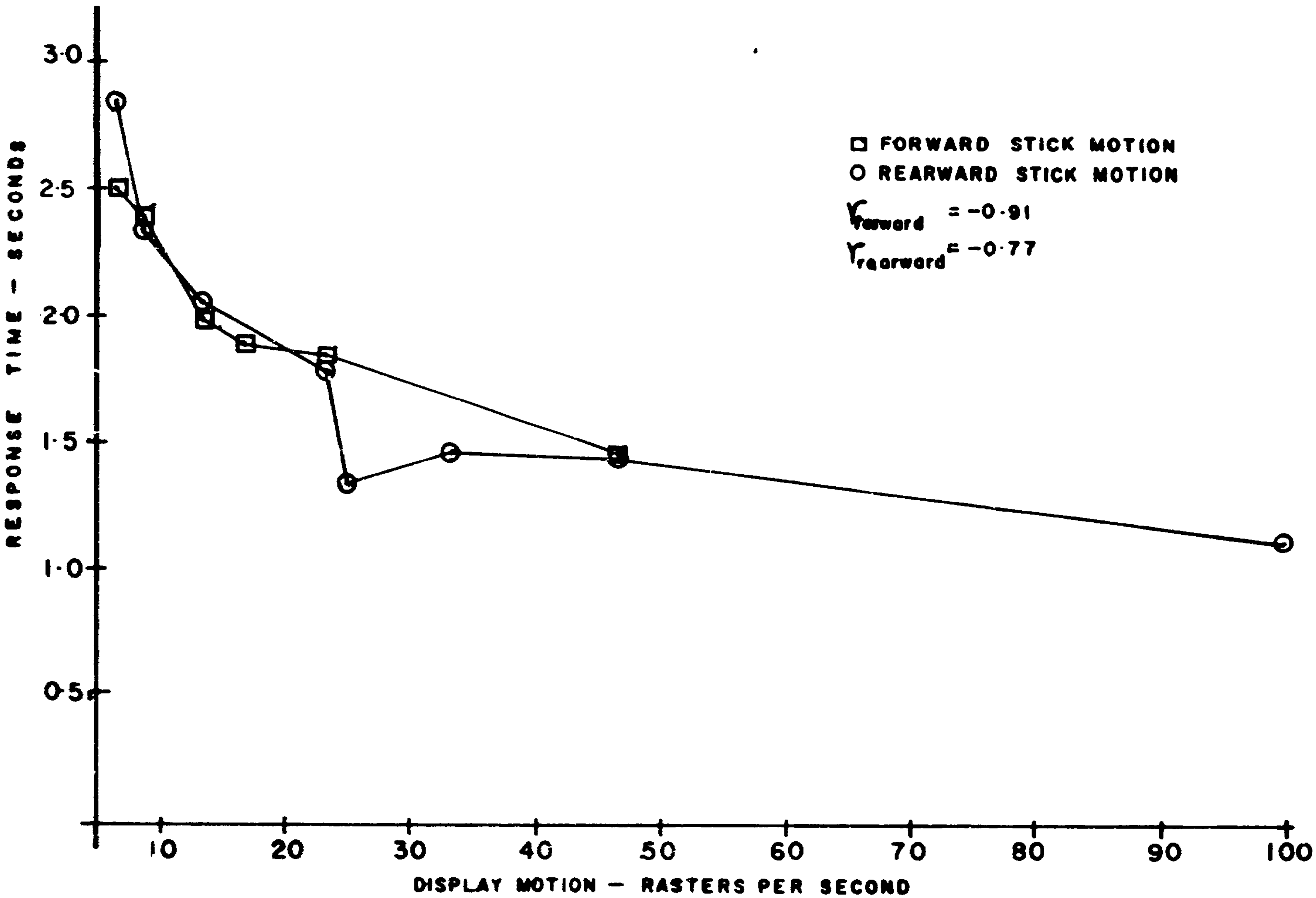


Fig. 10. Response time versus indication velocity.

The analysis of variance using reaction time was stratified into four analyses that separated the scale indications into moving altitude, step altitude, moving airspeed and moving heading indications. This was necessary because a test of the homogeneity of variance and the disproportionately high F ratios, indicated that it was not appropriate to include all the data in one grand factorial analysis. The results of this analysis are contained in Tables 9B through 12B, and they agree with the stratified analyses as reported in the results section.

CONCLUSIONS

Display format 4, as designed, yielded significantly poorer results than format 6. In its present form, at least, it should be deleted from further tests.

Considerably leeway in scale design seems permissible. The pilot subjects performed equally well on all display formats, even though they may have preferred one format design over another. Specific to our objective, however, it seems evident that once pilots have learned to fly with either MIL-STD-884B or MIL-D-8164 (AS) scale symbology, their performance will be equal.

Reaction time is highly correlated to the rate of scale motion on the display face. This finding indicates that displays can be improved by expanding the scales and consequently speeding response times.

Pilots tend to make more control errors as they take longer to respond. This result appears to show that both response times and errors are estimates of the same basic variable, rather than of two different aspects of performance. While neither time nor errors showed significant variation between formats in this experiment, it appears probable that time and errors will prove useful in evaluating formats under heavier task loads in future experiments.

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APPENDIX A

SUBJECT'S INSTRUCTION SHEET

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FLIGHT INFORMATION DISPLAY TEST
SUBJECT INSTRUCTIONS

You are about to participate in a test to measure your reaction time and control response to certain symbology. The symbology which results from these and other tests will probably be used in future Army helicopters.

The objective for you is to maintain these flight conditions:

HEADING ----- 070°

ALTITUDE ---- 100 ft

AIRSPEED ----- 80 K

Only one symbol (heading, altitude or airspeed) will vary from the flight condition at a time. Your task will be to observe which symbol moves from the steady state position and correct it with a control motion.

Control Motions:

Forward Stick -- Airspeed Increases or Altitude Decreases

Aft Stick -- Airspeed Decreases or Aktitude Increases

Right Stick -- Right Turn

Left Stick -- Left Turn

We will measure the time it takes for you to observe a symbol error and record whether your stick motion is in the correct direction to correct the error. These two factors are important -- recognizing the symbol change and error-free correction. Once the stick is moved out of the center position the test is complete for particular symbol under test at that time.

Various methods of portraying altitude and airspeed will be portrayed. The test is intended to indicate which form of the presentation will yield the best reaction times and the fewest control errors. The symbols will displace in both a gradual manner and in an instantaneous manner. A careful cross check will be required to insure picking up the error from the display. After each test, the command "centerstick" will appear on the screen. Follow this command and be prepared for the next symbol deviation.

In the event you commit an error, and "X" will appear on the screen. Center the stick and be ready for the next symbol variation.

APPENDIX B

DATA TABLES

CODE TO TABLES

The [B]variable is the thirteen scale indications; the [C]variable is generated by combining [B] variable into four values of moving altitude, step altitude, moving airspeed and moving heading indications. The [D]variable combines altitude indications and can be interpreted as altitude, airspeed and heading scales. The [E]variable combines altitude and airspeed scales and can be interpreted as vertical scales and horizontal scale. The [F]variable is the six display formats.

TABLE IB

Multivariate Analysis of Variance

Format Comparison	Variate Vector	Hotelling's Statistic	F Value
1, 6	$\begin{bmatrix}+103\\+.17\end{bmatrix}$	0.91	0.45
1, 5	$\begin{bmatrix}-15\\+0\end{bmatrix}$	.007	0
1, 4	$\begin{bmatrix}-222\\-.25\end{bmatrix}$	4.45	2.19
1, 3	$\begin{bmatrix}-79\\-.17\end{bmatrix}$	0.75	0.37
1, 2	$\begin{bmatrix}+163\\+.83\end{bmatrix}$	3.74	1.84
2, 6	$\begin{bmatrix}+266\\-.66\end{bmatrix}$	2.93	1.44
2, 5	$\begin{bmatrix}+148\\-.83\end{bmatrix}$	3.75	1.85
2, 4	$\begin{bmatrix}+59\\-1.08\end{bmatrix}$	0.002	0
2, 3	$\begin{bmatrix}+84\\-.66\end{bmatrix}$	1.51	0.75
3, 6	$\begin{bmatrix}+182\\+0\end{bmatrix}$	3.27	1.61
3, 5	$\begin{bmatrix}+64\\-.17\end{bmatrix}$	0.52	0.26
3, 4	$\begin{bmatrix}-143\\-.42\end{bmatrix}$	1.66	0.82
4, 6	$\begin{bmatrix}+325\\-.42\end{bmatrix}$	11.70	5.76*
4, 5	$\begin{bmatrix}+207\\+.25\end{bmatrix}$	3.85	1.89
5, 6	$\begin{bmatrix}-118\\+.17\end{bmatrix}$	1.56	0.77

*Significant at the 1% level.

TABLE 2B

Multivariate Analysis of Variance
(Ranked Data)

Format Comparison	Variate Vector	Hotelling's Statistic	F Value
1, 6	$\begin{bmatrix} +0.66 \\ +0.50 \end{bmatrix}$	1.25	0.62
1, 5	$\begin{bmatrix} -0.59 \\ +0.40 \end{bmatrix}$	1.98	0.97
1, 4	$\begin{bmatrix} -2.00 \\ -0.46 \end{bmatrix}$	10.36	5.10**
1, 3	$\begin{bmatrix} -0.92 \\ -0.25 \end{bmatrix}$	2.11	1.04
1, 2	$\begin{bmatrix} +1.17 \\ +0.83 \end{bmatrix}$	3.76	1.85
2, 6	$\begin{bmatrix} +1.83 \\ -0.33 \end{bmatrix}$	11.62	5.72**
2, 5	$\begin{bmatrix} +5.83 \\ -0.79 \end{bmatrix}$	3.76	1.85
2, 4	$\begin{bmatrix} -0.83 \\ -1.29 \end{bmatrix}$	4.29	2.11
2, 3	$\begin{bmatrix} +0.25 \\ -1.08 \end{bmatrix}$	4.04	1.99
3, 6	$\begin{bmatrix} +1.58 \\ +0.75 \end{bmatrix}$	6.29	3.10*
3, 5	$\begin{bmatrix} +0.33 \\ +0.29 \end{bmatrix}$	0.34	0.17
3, 4	$\begin{bmatrix} -1.08 \\ -0.21 \end{bmatrix}$	3.08	1.52
4, 6	$\begin{bmatrix} +2.67 \\ -2.87 \end{bmatrix}$	61.29	30.18**
4, 5	$\begin{bmatrix} +1.42 \\ +0.52 \end{bmatrix}$	5.06	2.49
5, 6	$\begin{bmatrix} +1.26 \\ +0.46 \end{bmatrix}$	3.92	1.93

*Significant at the 5% level.
**Significant at the 1% level.

TABLE 3B

Analysis of Variance (Heading Scale)

Source	SS	df	*df	MS	F
Blocks	4.789535	11		.318466	
B	.126025	1		.126025	3.89
F	.190201	5		.038040	1.22
FB	.161250	5		.032250	1.00
Within Cell	8.572804	132	(128)	.06945	
Residual	3.783269	121	(117)	.032336	
Total	9.050280	143			

*Corrected for fitted data.

TABLE 4B

Analysis of Variance
Airspeed Scale

Source	SS	df	df′	MS	F
Treatments	5.739524	23	23	.249545	
Blocks	13.594463	11	11	1.235860	
Residual	33.700586	253	245	.137553	
Within Cell	47.2950488	264	256	.184746	
FB	6.064645	15	15	.404310	2.94**
F	17.587672	5	5	.351753	2.56*
B	33.742923	3	3	11.247641	81.77**
Total	104.690288	287	279		

*Significant at the 5% level.
**Significant at the 1% level.
′ Corrected for fitted data.

TABLE 5B

Analysis of Variance
Using Dynamic Altitude Inputs

Source	SS	df	df*	MS	F
Treatments	57.841960	23	23	2.514868	
Blocks	16.977124	11	11	1.543375	
Residual	45.666121	253	245	.186392	
Within Cell	62.643245	264	256	.244700	
FB	13.090375	15	15	.872692	4.68**
F	3.918741	5	5	.783748	4.20**
B	40.832844	3	3	13.610948	73.02**
Total	120.485205	287	279		

**Significant at the 1% level.
* Corrected for fitted data.

TABLE 6B

Analysis of Variance
Using Step Inputs

Source	SS	df	df′	MS	F
Treatments	0.6745390	18		.0374744	
Blocks	2.8301441	11		.2572858	
Residual	6.1432784	187	(180)	.0341293	
Within Cell	8.9734225	198	(191)	.0409813	
FB	0.1150796	10		.0115080	0.34
F	0.3410081	5		.0682136	2.00
B	0.2183913	2		.1091957	3.20*
Total	9.6541948	215	(208)		

*Significant at the 5% level.
′Corrected for fitted data.

TABLE 7B

Error Rate Summary Table

Format	N=12 D1(1)	D2(2)	D3(3)
F1	0.905	0.750	0.833
F2	0.429	0.500	1.000
F3	0.286	0.833	2.000
F4	0.857	1.250	0.333
F5	0.857	0.917	0.667
F6	1.000	0.500	0.667

(1) Altitude scale - Total error/21 for 12 subjects.
(2) Air speed scale - Total error/12 for 12 subjects.
(3) Heading scale - Total error/6 for 12 subjects.

TABLE 8B

Error Rate Analysis of Variance Tables

Source	SS	df	MS
Blocks	0.5339	11	.049
Treatments	0.2047	17	.013
Display Formats (F)	0.5143	5	.004
Scales (D)	0.0095	2	.005
(FD)	0.1908	10	.019
Residual	2.3899	187	.013
Total	3.1285	215	

TABLE 9B

Analysis of Variance
At (B) Level

Source	SS	df	MS	F
Blocks	41.3674	11	3.7607	19.07
Treatments	208.5856	77		
F	11.0630	5	2.2126	11.22**
B	163.0154	12	13.5846	68.89**
FB	34.5074	60	.5751	2.91**
Residual	167.0098	847	.1972	
Total	416.9628	857		
Simple Main Effects				
Col 1	3.3435	5	.6687	3.39**
Col 2	1.3576	5	.2715	1.38
Col 3	10.9017	5	2.1803	11.06**
Col 4	1.4062	5	.2812	1.43
Col 5	1.1151	5	.2230	1.13
Col 6	.9723	5	.1945	.99
Col 7	2.4767	5	.4953	2.51*
Col 8	2.6078	5	.5216	2.65*
Col 9	13.9001	5	2.7800	14.10*
Col 10	4.1159	5	.8232	4.20**
Col 11	3.0061	5	3.0061	3.05*
Col 12	.1735	5	.0347	0.18
Col 13	.1736	5	.0347	0.18
Row 1	28.3674	12	2.3640	11.99**
Row 2	40.1600	12	3.3467	16.97**
Row 3	19.5337	12	1.6278	8.26**
Row 4	53.0951	12	4.4246	22.44**
Row 5	23.4833	12	1.9569	9.92**
Row 6	32.8831	12	2.7403	13.90**

*Significant at the 5% level.
**Significant at the 1% level.

TABLE 10B

Analysis of Variance At (C) Level

Source	SS	df	MS	F
Blocks	11.6654	11	1.0605	
Treatments	41.0695	23		
F	2.3727	5	.4745	6.00**
C	34.4640	3	11.4880	145.31**
FC	4.2328	15	.2822	3.57**
Residual	20.0018	253	.0791	
Total	72.7367	263		
Simple Main Effects				
Col 1 (Altitude Scale Motion)	.9797	5	.1959	2.48*
Col 2 (Altitude Scale Step)	1.1378	5	.2276	2.88*
Col 3 (Air Speed Scale Motion)	4.3956	5	.8791	11.12**
Col 4 (Heading Scale Motion)	.0923	5	.0185	.23
Row 1 (Display Format (1))	5.4927	3	1.8309	23.16**
Row 2 (Display Format (2))	8.5303	3	2.8434	35.97**
Row 3 (Display Format (3))	4.7813	3	1.5938	20.16**
Row 4 (Display Format (4))	11.4887	3	3.8296	48.44**
Row 5 (Display Format (5))	5.0528	3	1.6843	21.30**
Row 6 (Display Format (6))	3.3551	3	1.1170	14.13**

*Significant at 5% level. **Significant at 1% level.

TABLE 11B

Analysis of Variance
At (D) Level

Source	SS	df	MS	F
Blocks	6.9256	11	.6296	
Treatments	33.7580	17		
F	2.3365	5	.4673	7.68**
D	28.7692	2	14.3846	236.31**
FD	2.6523	10	.2652	4.36**
Residual	11.3829	187	.0609	
Total	52.0664	197		
Simple Main Effects				
Col 1 (Altitude Scale)	.5008	5	.1002	1.65
Col 2 (Air Speed Scale)	4.3956	5	.8792	14.44**
Col 3 (Heading Scale)	.0923	5	.0185	.30
Row 1 (Format (1))	4.2680	2	2.1340	35.06**
Row 2 (Format (2))	6.7655	2	3.3827	55.57**
Row 3 (Format (3))	4.0321	2	2.0161	33.12**
Row 4 (Format (4))	9.4524	2	4.7262	77.64**
Row 5 (Format (5))	4.3983	2	2.1992	36.12**
Row 6 (Format (6))	2.5051	2	1.2525	20.58**

**Significant at the 1% level.

TABLE 12B

Analysis of Variance
At (E) Level

Source	SS	df	MS	F
Blocks	4.1270	11	.3752	
Treatments	22.0693	11		
F	.7125	5	.1425	3.10*
E	20.8242	1	20.8242	452.56**
FE	.5326	5	.1065	2.32*
Residual	5.5676	121	0.0460	
Total	31.7640	131		
Simple Main Effects				
Col 1 (Vertical Scales)	1.1528	5	.2306	5.01**
Col 2 (Horizontal Scales)	.0923	5	.0185	.40
Row 1 (Format (1))	3.2802	1	3.2802	71.28**
Row 2 (Format (2))	4.3702	1	4.3702	95.11**
Row 3 (Format (3))	3.0966	1	3.0966	67.30**
Row 4 (Format (4))	5.4107	1	5.4107	117.59**
Row 5 (Format (5))	3.3383	1	3.338	72.55**
Row 6 (Format (6))	1.8547	1	1.8547	40.31**

*Significant at 5% level.
**Significant at 1% level.

APPENDIX C

EXPERIMENTAL DESIGN

TABLE 1C

Scale Change Values and Presentation Order

SCALE	INDICATION	TYPE	CHANGE SEQUENCES* TRAINING	TESTING I	II	III	IV	V
ALTITUDE	+ 1000 FEET/MIN.	1*	1*	1	10	13	3	11
	+ 500 FEET/MIN.	2	8	8	13	5	10	9
	− 500 FEET/MIN.	3	12	2	3	10	4	7
	− 2000 FEET/MIN.	4	4	12	6	2	11	5
	+ 100 FEET	5	11	3	9	7	5	3
	+ 200 FEET	6	13	9	12	12	12	1
	− 50 FEET	7	12	4	2	4	6	12
AIRSPEED	+ 7 KNOTS/SEC.	8	11	5	5	9	13	10
	+ 2 KNOTS/SEC.	9	1	10	8	1	7	8
	− 2 KNOTS/SEC.	10	4	13	11	6	1	6
	− 7 KNOTS/SEC.	11	8	6	1	11	8	4
HEADING	+ 6 DEGREES/SEC.	12	13	11	4	3	2	2
	− 6 DEGREES/SEC.	13	1	7	7	8	9	13

* CHANGE SEQUENCES ARE COMPOSED OF SCALE INDICATION TYPES WHICH ARE PRESENTED TO EACH SUBJECT BY COLUMN THREE TIMES PER TEST RUN

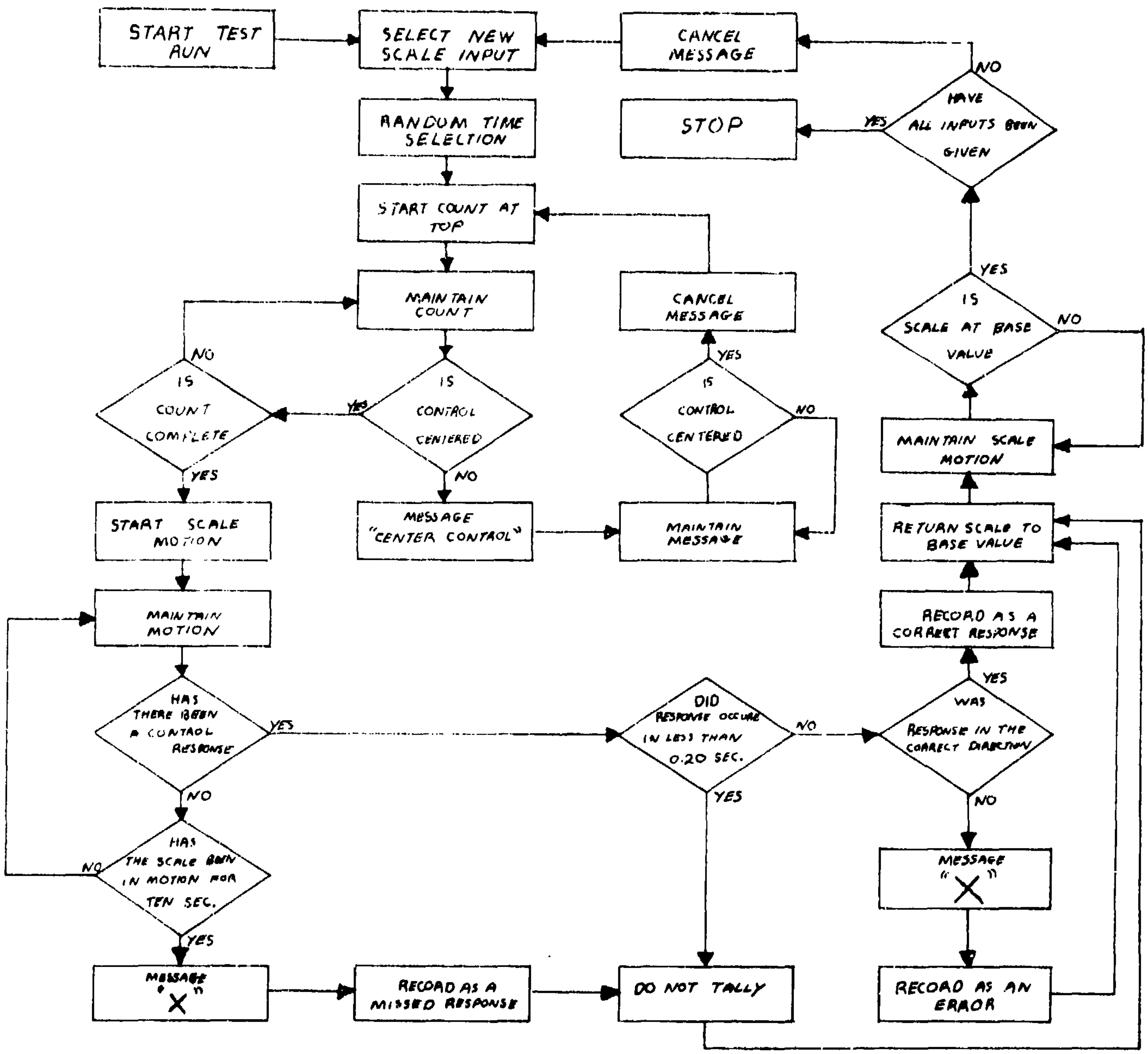

Fig. 2C. Program diagram.