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AN EXPERIMENTAL COMPARISON OF THE READABILITY OF TWO DIGITAL AL--ETC(U)

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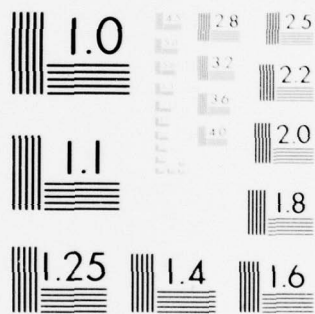
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MELBOURNE, VICTORIA

SYSTEMS NOTE 60

AN EXPERIMENTAL COMPARISON OF THE
READABILITY OF TWO DIGITAL ALTIMETERS

by

G. R. WHITE



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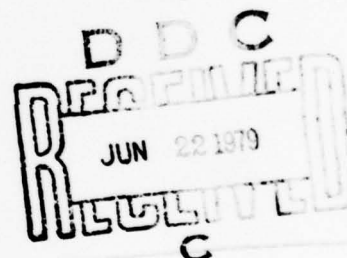
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SUMMARY

Twelve male volunteer subjects with flying experience were required to read one of two digital altimeters while performing a two dimensional tracking task. It was found that the Smiths Type 3B servo altimeter was read in a significantly shorter time than was the Aero Mechanism Type 8047/20A capsule altimeter. Furthermore, an ergonomic appraisal of the latter instrument and a subjective evaluation by the subjects indicates that the probability of misreading this altimeter is high.

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1. INTRODUCTION

Following a proposal to fit the Aero Mechanism Type 8047/20A capsule altimeter to RAAF Mirages as a back-up instrument, it was considered necessary to investigate its readability. The Aircraft Research and Development Unit (ARDU) accordingly requested ARL to undertake the investigation. The initial impressions of an ARDU test pilot who had used the instrument in flight were that the chances of misreading the digital part of the display were high. On the other hand, the main advantage of using a capsule altimeter is that it operates independently of the aircraft electrical power system. Furthermore, it could be argued that the readability of a back-up instrument need not be as good as the primary instrument. However engineering constraints appeared likely to result in the back-up instrument being mounted in a position on the panel where it would be particularly easy to see, namely, close to the airspeed indicator or radar so that pilots might use it in preference to the main display.

Accuracy and speed of reading cannot be assessed adequately in absolute terms in laboratory trials in which the levels of arousal, workload and general comfort of the user would be vastly different from those applying under operational conditions. However such trials can provide data on the *relative* readability of different instruments under the same conditions—the assumption being that the change in environment from the laboratory to the aircraft cockpit will not differentially affect their readability to a significant degree.

The Smiths Type 3B servo altimeter has a large easily readable display which was regarded by the ARDU test pilots as satisfactory. Consequently it was decided to use this as a reference or control condition in the laboratory trials.

Thus the evaluation of the Aero Mechanism altimeter for use in the Mirage aircraft consisted of two main parts: the laboratory evaluation in which the performance of subjects using it under carefully controlled conditions was compared with that when the Smiths Type 3B servo altimeter was used; and flight trials in which the readability of the Aero Mechanism altimeter was assessed under operational conditions.

This report describes the outcome of the laboratory part of the evaluation. The other part of the evaluation has been published by ARDU¹.

2. DESCRIPTION OF THE ALTIMETERS

Both altimeters have a digital read-out of tens of thousands and thousands of feet. Smaller increments of altitude are displayed by the pointer and circular scale which is marked off in hundred and twenty feet intervals in both instruments. The counter on the Smiths Type 3B has five segments. The first (extreme left) displays black and white cross hatching between altitudes of zero and 10 000 feet. As the pointer moves through 50 feet from 950 to 1000, the 'thousands' figure changes from one digit to the next. Similarly the 'hundreds' digits change within 5 feet increments. However the final two digits change in steps of 50 feet and are both on the same drum which rotates continuously with changes in altitude. A comma separating the thousands from the hundreds column improves the readability of the display although the use of a comma is becoming deprecated in modern usage. Readability of this instrument is also enhanced by the relatively large display (which is approximately 81 mm wide) and by two redundant sources of information—hundreds and fifty feet increments can be read from the counter as well as from the dial.

The counter of the Aero Mechanism Type 8047/20A altimeter comprises two windows behind which the tens of thousands and the thousands drums rotate. Three zeros are painted

1. Royal Australian Air Force, Mirage Aircraft-Evaluation of Counter Pointer Altimeters (Main and Standby) and Vertical Accelerometer Mirage Modification 833. Aircraft Research and Development Unit, Laverton, Oct. 1975.

horizontally across on the dial next to the thousands drum and because the drive to this drum is continuous, the digits on the drum move continuously as the altitude changes. This means that for most of the time two digits are displayed within the thousands window which is lengthened in the vertical direction so that both can be seen simultaneously. The tens of thousands drum changes its reading during the preceding thousand feet interval. The width of the dial of this instrument is 56 mm. The displays of both altimeters are shown full size in Figure 1.

3. OUTLINE OF THE EXPERIMENT

During each of the two main experiment runs the subject was required to read as quickly as possible each of five successive readings on one of the two altimeters. To provide an additional source of workload the subjects were also required to control the point of intersection of two mutually perpendicular lines on an oscilloscope screen by means of a small finger-operated control stick mounted on the arm of the subject's chair. Three indices of performance were measured during each trial: the time taken to read the altimeter; the number of reading errors for each instrument; and the integrated absolute error on the tracking task. Details of the experiment are given below.

3.1 Subjects

Twelve male volunteer subjects who had experience either as pilots or navigators participated in the experiment. Five of the subjects were RAAF personnel and the other seven were from the technical staff of ARL. Answers to a post-experiment questionnaire indicated that none of the subjects had used either of the instruments previously in their flying experience.

3.2 Equipment

General views of the equipment are shown in Figures 2 and 3. A Negretti and Zambra precision pressure regulator (-82.5 to 445.0 kPa) interposed in the air line between a vacuum pump and the altimeter enabled the experimenter to make both coarse and fine adjustments to the readings of the altimeters. The altimeters were mounted one at a time behind a circular aperture which had been cut into a small panel. A small servo motor opened a shutter when a hand-held push button switch was operated by the experimenter. This also started an electronic timer which measured the exposure duration. Another hand-held switch, which was operated by the subject, caused the shutter to close and the timer to stop. A circuit diagram of this is given in Figure 4.

The compensatory tracking task involved, amongst other things, a display on a Type 556 Dual Beam Tektronix Oscilloscope. The oscilloscope was mounted on the bench directly in front of the subject beside the altimeter aperture which was angled slightly to give the subject a direct 90° view of this display also. This is shown in Figure 2. Movement of the horizontal and vertical lines on the oscilloscope occurred in response to signals from an analogue computer and the subject's task was to try to keep the intersection of the lines within a small black reference circle which had been placed on the centre of the oscilloscope screen. Displacement of the vertical line to the right indicated an increase in the angle of bank to the right of a simulated delta wing fighter aircraft, and displacement of the horizontal line upwards from the circle indicated an increase in pitch angle. Consequently, controlling the position of the intersection of the lines amounted to controlling the attitude of the simulated aircraft. The aerodynamic coefficients which were chosen for this simulation were those which would be applicable to the aircraft configured for a landing approach.

Signals from a random noise generator were used to produce perturbations of the two lines—the amplitudes of the perturbations being those that could be expected when flying through moderately turbulent air. One of the random signals (± 5 V binary noise) was fed into the longitudinal dynamics to perturb the second derivative of pitch angle while a delayed version of this signal with an amplitude of ± 2 V was introduced into the lateral dynamics causing a perturbation in the first derivative of bank angle. The delay was such that the disturbing signals seemed uncorrelated to the subject. These amplitudes were chosen in a preliminary run during which a test pilot subjectively judged whether or not the size of the perturbations was realistic.



Aero mechanism capsule altimeter Type 8047/20A



Smiths Type 3B servo altimeter

FIG. 1. A FULL SIZE VIEW OF THE DIALS OF BOTH ALTIMETERS SET TO INDICATE AN ALTITUDE OF 1500 FEET.

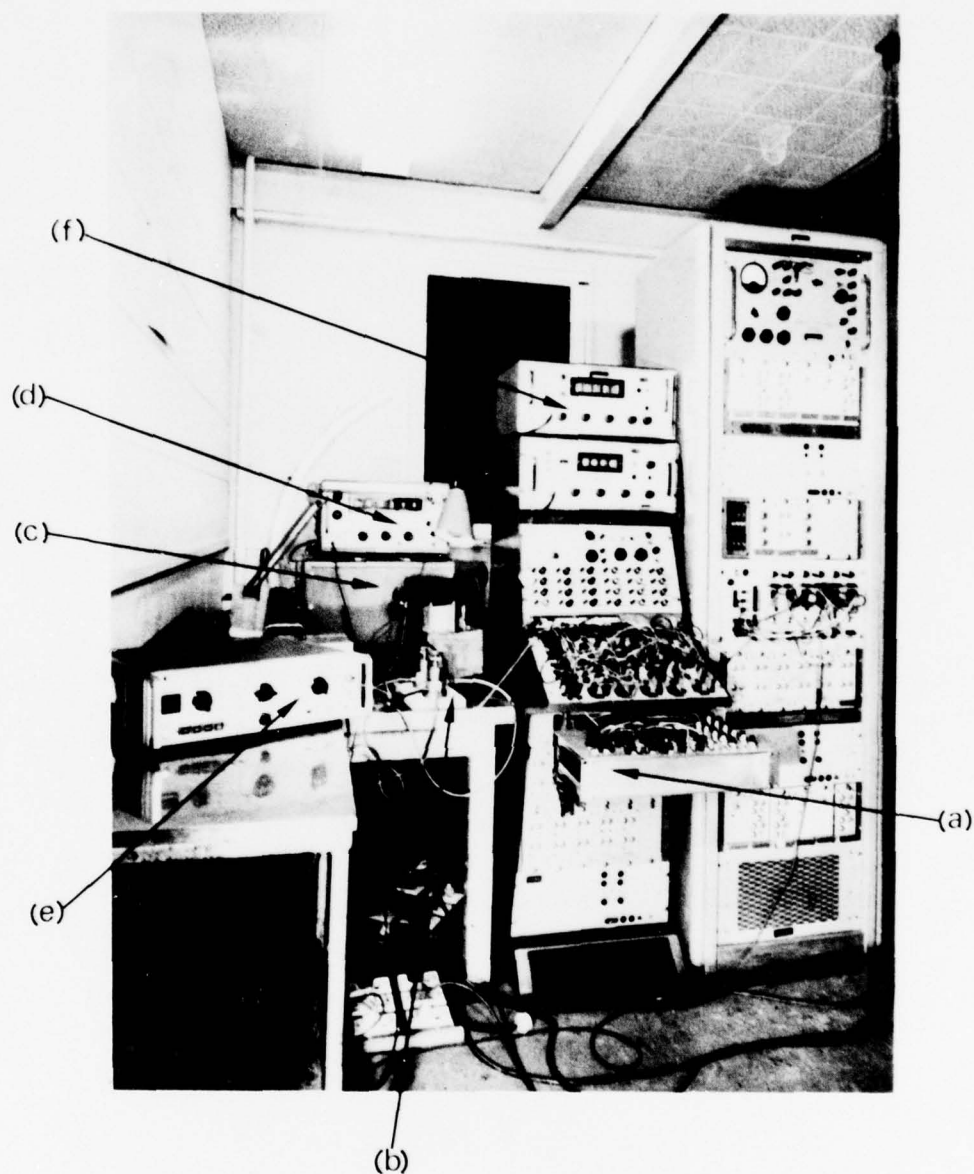


FIG. 2. A GENERAL VIEW OF THE LAYOUT OF THE EXPERIMENTAL EQUIPMENT
SHOWING:
(a) the analogue computer, (b) the needle valve, (c) the altimeter behind the aperture,
(d) the timer, (e) the noise generator and (f) the display of integrated absolute error.

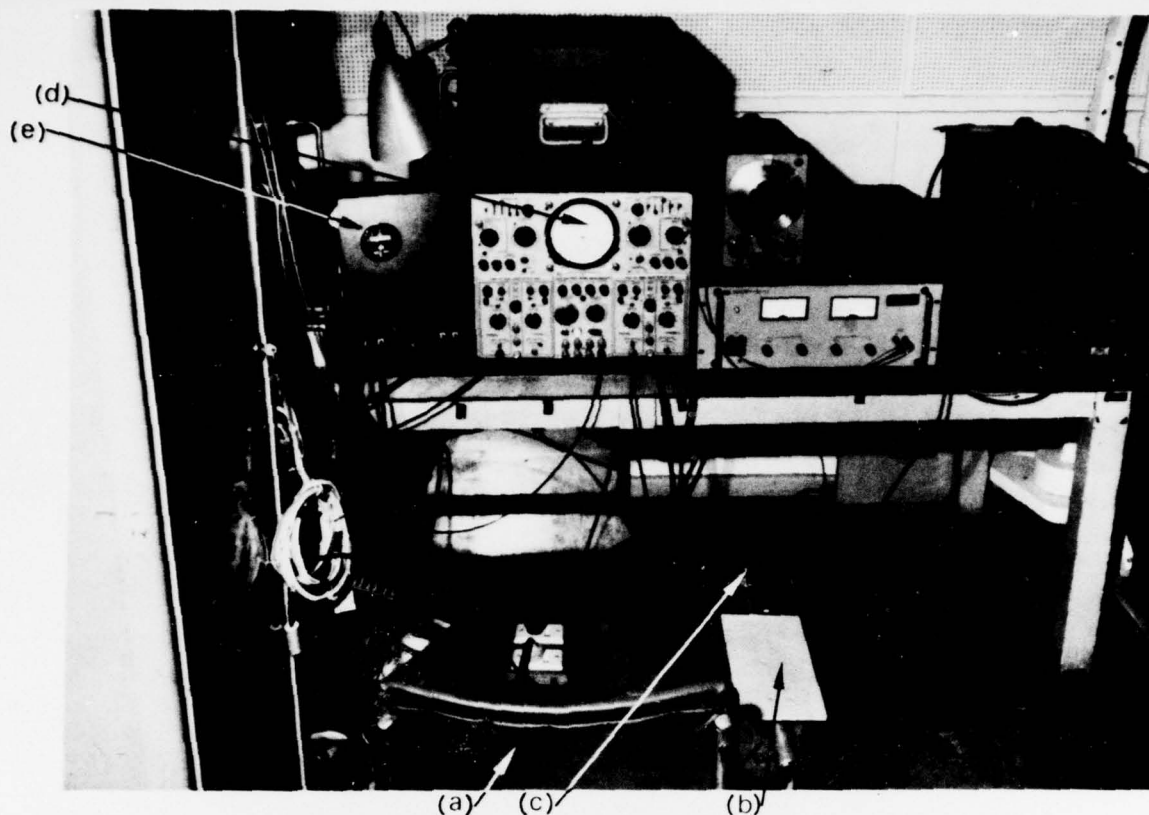


FIG. 3. A VIEW OF THE EQUIPMENT SHOWING, IN PARTICULAR:
 (a) the subject's chair, (b) the forearm rest, (c) the control stick, (d) the tracking task display, and (e) the altimeter display.

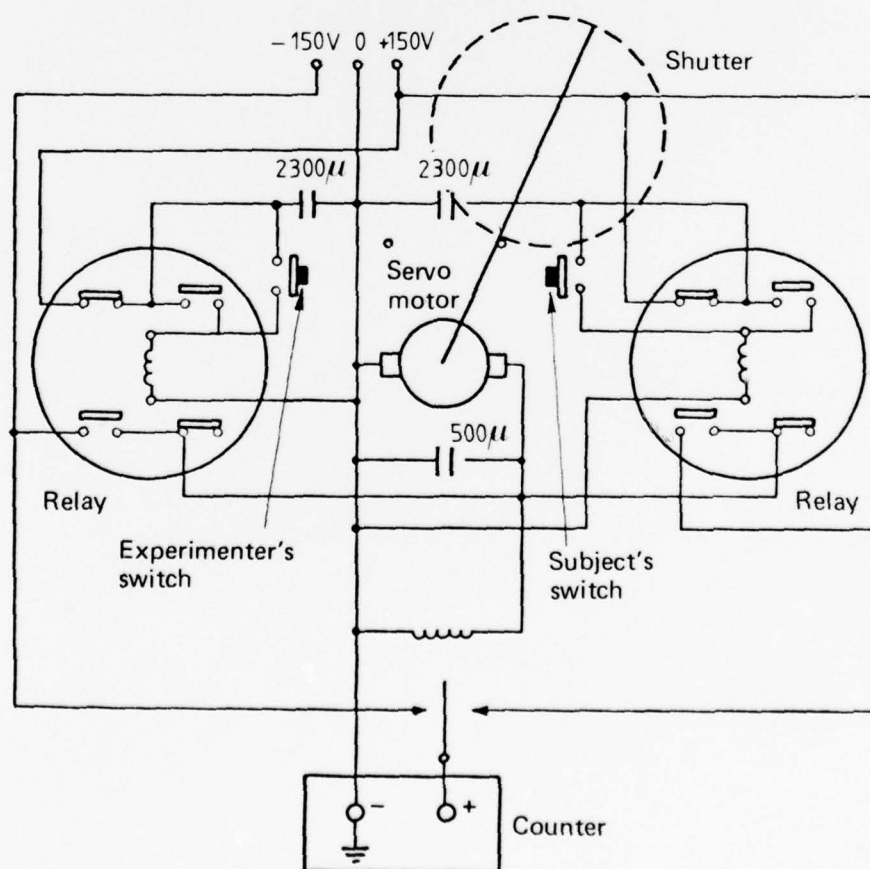


FIG. 4. THE CIRCUIT FOR THE MECHANISM WHICH OPENED AND CLOSED THE SHUTTER.

During each experimental run, the absolute values of the two errors, that is, angle of bank error and pitch angle error, were integrated continuously on an equal-weighting basis. Details of the realization of the lateral and longitudinal dynamics, and the characteristics of the noise signal are provided in Appendix 1.

Mounted on the right hand side of the chair was a flat metal plate to provide the subject with a forearm rest and in front of this was a small control box (see Figure 2). By moving the control stick left and right the subject could cause the vertical line on the CRO screen to move to the left and to the right of the reference circle. Similarly, movement of the stick forwards and backwards caused the horizontal line to move downwards and upwards. The distance between the subject's eyes and altimeter dial was approximately 1.14 m.

3.3 Procedure

Each subject was given a preliminary briefing during which the general purpose of the experiment was explained. It was also stressed that the experiment should not be viewed as a competition between subjects since the correspondence between each subject and his results would remain confidential. Subjects were asked to keep in mind any noteworthy aspect of the experiment such as unclear instructions or insufficient practice, in preparation for answering a post-experiment questionnaire. After this initial briefing the subject was taken into the laboratory where more instructions explaining the significance of the CRO display were read. Next the computer was switched on and for two minutes he was given practice on the tracking task. The aperture was then opened and the subject was asked to watch while the reading on the altimeter was changed from 1500 feet to 2500 feet. This was to show the direction in which the counter drums rotated and also the way in which the altitude information was presented. Following this, more instructions were read during which the procedure to be followed in making the response was explained. The subject was then given practice at reading ten settings on this altimeter under the same conditions which were to occur in the main experiment. The sequence was as follows: The experimenter said 'GO' and at the same time switched on the analogue computer which caused the lines on the screen to begin moving. Integration of the modulus of the tracking error was also started at this moment and continued until the end of the trial. While the subject tracked the lines, the experimenter adjusted the altimeter to give the first of ten previously selected altimeter readings. The shutter was then opened and the timer began timing the exposure. The opening of the shutter was a cue to the subject to read the altimeter and then close the aperture by operating the switch held in his left hand. This also stopped the timer and as the subject returned to the tracking task he verbalized the altimeter reading. The experimenter noted the response and the exposure duration. After each practice the subject was told the correct reading and if a large error had been made such as misreading the thousands drum, the aperture was reopened so that he could see the actual setting again. The experimenter then reset the timer and set the altimeter for the next reading.

After the ten practice readings the subject was told that the main experiment was about to begin and that he was to imagine that the aircraft being simulated was to descend from a height of 10 000 feet at a rate of 940 ft/min, that is, that the altimeter readings would be in descending order and would correspond to the time that had elapsed since the commencement of the trial. The main trial was then begun by the experimenter saying 'GO' as he switched on the computer and started a stop watch. The rest of the procedure for the five readings corresponded to that of the practice with the exceptions that the timing of the opening of the aperture was controlled in accordance with the simulated descent and that the subject was not given knowledge of results. After ten minutes the trial was ended and the absolute tracking error was recorded. The subject then had a break of about five minutes while the experimenter disconnected the altimeter and replaced it with the other altimeter. The same procedure was then followed for another group of ten practice readings and five main experiment readings for each subject. The complete text of the instructions is in Appendix 3.

3.4 Experimental Design

As each subject was used as his own control it was necessary to counterbalance the order of presentation of the altimeter readings. Six of the subjects responded first to the Aero Mechanism

altimeter. For the practice trials two sets of ten altimeter readings were chosen from tables of normally distributed random numbers¹. The two sets were: (a) 2420, 680, 1880, 1020, 2450, 2270, 3000, 2510, 1240, 3080; and (b) 1340, 1250, 890, 1150, 3030, 530, 2230, 2360, 1460, 3030.

In a similar way two sets of five altitudes were chosen for the main experiment but with the constraint that they had to lie in the ranges: 10 000 to 9000, 8000 to 7000, 6000 to 5000, 4000 to 3000, 2000 to 1000. The intervening thousand foot intervals were required to give the experimenter time to change the altimeter reading between successive exposures.

The two sets of readings which were used in the main experiment are given by the first numbers in the following bracketed pairs:

(a) (9470, 34); (7190, 179); (5150, 310); (3940, 386); (1230, 560); and

(b) (9550, 29); (7850, 137); (5950, 258); (3860, 392); (1030, 572).

The second number in each pair is the time in seconds after the beginning of the trial at which that reading was given.

Each of the two sets of practice readings and main experiment readings were taken with each of the two altimeters six times.

The main purpose in providing the tracking task was to place the subject under a higher workload when reading the altimeters. It has been found that comparative tests of altimeter readability are made more sensitive if a moderately difficult additional task is performed concurrently. Furthermore the provision of such a task brings the context of the readings chosen closer to that occurring in real life. But the frequency of reading errors and the measured exposure durations are not indicative in absolute terms of those to be expected in practice. They can only form the basis of a comparative evaluation between the two instruments. However some indication of the accuracy with which each instrument may be read in practice can be deduced from the subjective impressions of the subjects and also from a consideration of the ergonomic factors relevant to the two altimeter designs.

It was anticipated by the experimenter that owing to the differences in the design of the two altimeters the Aero Mechanism instrument would take longer to read and would be misread more frequently than the Smiths altimeter. But this expectancy was not allowed to introduce any bias into the design or execution of the experiment.

Reading an altimeter as quickly as possible can be considered to be an example of a choice reaction time task. Each subject's performance on the task would be a function of the accuracy and the time required for the response. The instructions did not give a specific weighting to these. Subjects were simply told to respond as quickly and as accurately as possible. In another choice RT experiment reported by Fitts², subjects who were instructed similarly were found to adjust their speed and error rate to produce the maximum information transmission rate. In the trials reported here however, it could not be expected that subjects would necessarily do the same. All of them had flying experience and it could be argued that they would place a greater emphasis on accuracy as the consequences of misreading the altimeter during flying are more potentially disastrous than taking a little longer over the reading. Consequently if the subjects use the same criterion of accuracy for both instruments, differences in readability would be reflected as differences in response times. If the subjects varied the weighting given to speed and accuracy from trial to trial this could introduce large random variations into the reaction times and verbal response data when analysed separately. Consequently it would be desirable to combine both measures into some overall index of performance. Unfortunately however, there does not appear to be any way of determining suitable magnitudes for the weighting factors and for this reason the two analyses were carried out independently.

4. RESULTS

The mean times taken to read the Smiths and the Aero Mechanism altimeters were respectively 2.96 and 3.88 seconds. As the direction of this difference was expected from *a priori* evidence it was appropriate to carry out a one-tailed test of significance. A Randomization Test for Matched-Pairs showed this difference to be significant ($p < 0.01$).

1. Dixon, W. J., Massey Jr. F. L., *Introduction to Statistical Analysis* 2nd Ed. McGraw-Hill: New York, 1957, p. 452.
2. Fitts, P. M.: Cognitive aspects of information processing: III Set for speed vs accuracy. *Journal of Experimental Psychology*, 71, 1966, 849-857.

Few errors were made in reading the altimeters. If only the responses which lay outside ± 50 feet of the correct reading are counted as errors, two errors were made in reading the Smiths and nine were made in response to the Aero Mechanism altimeter. A one-tailed Wilcoxon Matched-Pairs Signed-Ranks Test showed this not to be a significant difference. However of the nine errors in reading the Aero Mechanism altimeter seven were mistakes in reading the thousands or tens of thousands drum whereas no errors of this kind were made in response to the Smiths altimeter.

Table I list these errors and Figure 5 shows schematically the dial of the Aero Mechanism altimeter as it appeared when each of seven errors were made in reading the thousands drum. In six cases subjects thought that the reading was one thousand feet higher than it actually was—a potential hazard when flying at low levels.

The scores of integrated absolute tracking error were almost identical for both of the altimeters and consequently it was not necessary to carry out a statistical test of significance on these data.

TABLE 1
Reading Errors

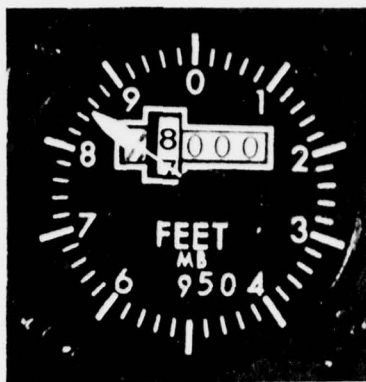
Subject	Aero Mechanism (B)		Smiths (A)	
	Display	Response	Display	Response
2	9550	9750		
2	5950	6000		
5			1030	1240
6	9550	10560	9470	9550
7	7850	8860		
7	5950	6950		
7	3860	4880		
10	9470	10480		
10	3940	4940		
12	9470	0490		

Appendix 2 lists the questions which appeared on the post-experiment questionnaire and provides the subjects' responses to some of them. The following is a summary of these answers. Subjects generally found that the tracking task was easier to control when using small stick movements. Some tried to control directly the point defined by the intersection of the two lines whereas the others controlled the two lines independently.

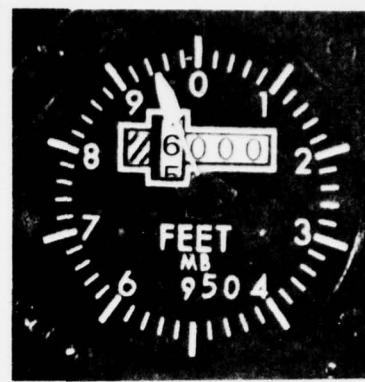
The responses of nine subjects indicated a clear preference for the Smiths altimeter, one indicated a preference for the Aero Mechanism altimeter and another two were critical of both altimeters. Criticisms of the Smiths altimeter were minor. For example, some subjects said that the last two digits (50 and 00) were redundant and could be confusing. Eight subjects stated explicitly that they had encountered trouble reading the thousands window of the Aero Mechanism altimeter. It appeared from their comments that the correct interpretation of this instrument required additional information compared with that displayed on the dial of the Smiths altimeter. This difficulty stemmed from being able to see two digits simultaneously in the enlarged thousands window. For example, at a height of 3500 feet, a three occupies the lower window area and a four is displayed just above it but at the same distance from the window centre. Furthermore, at say 950 feet, the numeral '1' is almost centred in the window to give a reading which could very easily be mistaken for 1950 feet. One subject described how he coped with this problem as follows: "I tried to pick the number that appeared through or mostly below the imaginary centre line through the figure slot". Another design defect is that when the pointer is at the 850 feet position its head completely obscures the 10 000's window. This added complexity was probably a factor contributing to the longer time which was needed to read this instrument. Since none of the subjects had used either altimeter previously in their flying experience it is unlikely that the subjects were expressing any prior prejudices about these altimeters when answering the questionnaire.



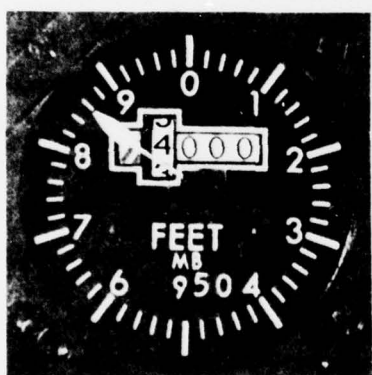
9550 read as
10560



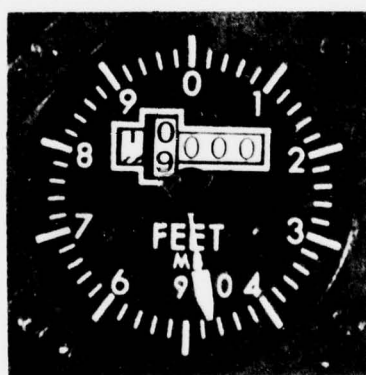
7850 read as
8860



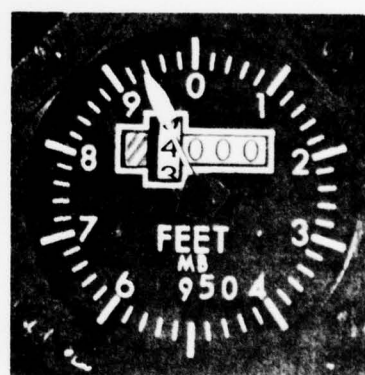
5950 read as
6950



3860 read as
4880



9470 read as
10480 and 0490



3940 read as
4940

FIG. 5. DIALS OF THE AERO MECHANISM ALTIMETER SHOWING THE SETTINGS FOR WHICH SEVEN ERRORS WERE MADE IN READING THE THOUSANDS DRUM.

5. CONCLUSIONS

Although the integrated absolute tracking error turned out to be an insensitive measure, there is sufficient evidence from the difference in exposure durations and from the subjects' comments to indicate that of the two altimeters the Aero Mechanism type is the more difficult to read. Furthermore, almost all of the reading errors were mistakes in reading the thousands scale of the Aero Mechanism altimeter. This can be rationalized ergonomically by considering the way in which the counter of this instrument has been designed. Another poor feature of this presentation is the shape of the pointer. When the pointer is in the 850 feet position, its widened end completely obscures the tens of thousands digit.

In contrast the Smiths altimeter has large digits which are easy to read and which change over quickly just before the pointer reaches the zero position. Although it has been found that the inclusion of redundant information in such a display often enhances the readability, some subjects found this characteristic of the altimeter display potentially confusing.

In practice, while the aircraft is actually changing height, the drums of the Aero Mechanism altimeter would move continuously. This would provide an extra cue to simplify the task of reading the counter. Yet from the results of the experiment, and from an ergonomic appraisal of the design of the display, it would appear that the possibility for making erroneous readings of the thousands and tens of thousands drums of the Aero Mechanism altimeter is significant. Consequently, use of this instrument in an aircraft could be hazardous.

APPENDIX 1

The lateral and longitudinal dynamics¹ of the aircraft were simulated by using uncoupled sets of linearized equations. Consequently this validity is limited to situations involving only small perturbations. Other aspects of the simulation can be deduced from the values of the coefficients given below. In this case the short period oscillation had a period of approximately 3 seconds and the period of the phugoid mode was approximately 42 seconds. Where the coefficients vary with α the values quoted correspond to when α is equal to ten degrees.

Approach Conditions

H	(m)	Sea Level	I_z (kg.m ²)	60 900
V	(m/s)	90	J_{xz} (kg.m ²)	0
M		0.2646	C.G. % c chord	49
W	(kg)	7 500	$\bar{c}$ chord c (m)	8.05
q	(kg.m ²)	502	M.A.C. c (m)	5.25
I_x	(kg.m ²)	9 100	b span (m)	8.22
I_y	(kg.m ²)	56 300	C_L	0.435
C_D		0.0945	$C_{L\beta}$	0.0859
C_L	(r ⁻¹)	2.63	$C_{L\delta a}$	(r ⁻¹) -0.146
C_L	(r ⁻¹)	1.15	$C_{L\delta r}$	(r ⁻¹) 0.0115
C_D	(r ⁻¹)	0.5*	C_{Lr}	(r ⁻¹) 0.2
C_m	(r ⁻¹)	-0.258	C_{Lp}	(r ⁻¹) -0.2
$C_{m\delta r}$	(r ⁻¹)	-0.499	C_n	(r ⁻¹) 0.36
Cmq	(r ⁻¹ .s ⁻¹)	-1.35	$C_{n\delta a}$	(r ⁻¹) 0.0349
$\bar{c}/2V Cmq$		-0.041	$C_{n\delta r}$	(r ⁻¹) -0.0412
$C_{y\beta}$	(r ⁻¹)	-0.573	C_{n_p}	(r ⁻¹) 0.0556
$C_{y\delta r}$	(r ⁻¹)	0.0963	C_{n_r}	(r ⁻¹) -0.2
$C_{y\delta a}$	(r ⁻¹)	-0.117	S	wing area (m ²) 34

* C_D should actually be 0.966 but this makes the task uncontrollable.

The two noise signals were from a Hewlett Packard HO-1-3722A noise generator with the following settings:

Delay code 259 —
Sequences length infinite
Clock period 3.33 ms
Binary Output ± 10 V

The circuit diagrams for the lateral and longitudinal dynamics show that the two binary noise signals were fed into the system at the input to integrators. Consequently the noise-induced changes in position of the display lines were continuous rather than binary in nature.

1. Blakelock, J. H. *Automatic Control of Aircraft and Missiles*. John Wiley and Sons Inc., New York: 1965.

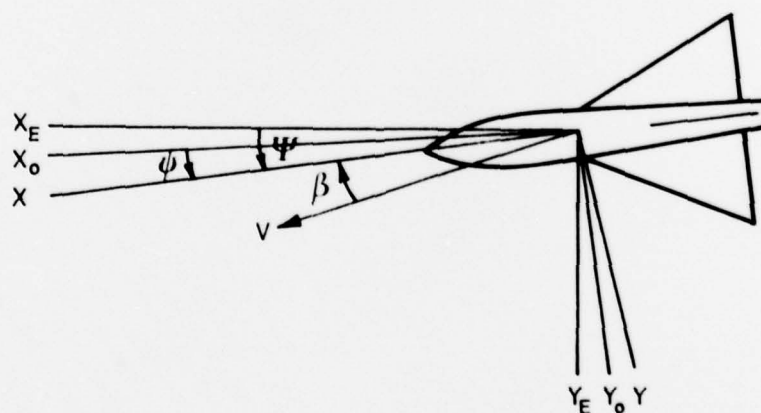
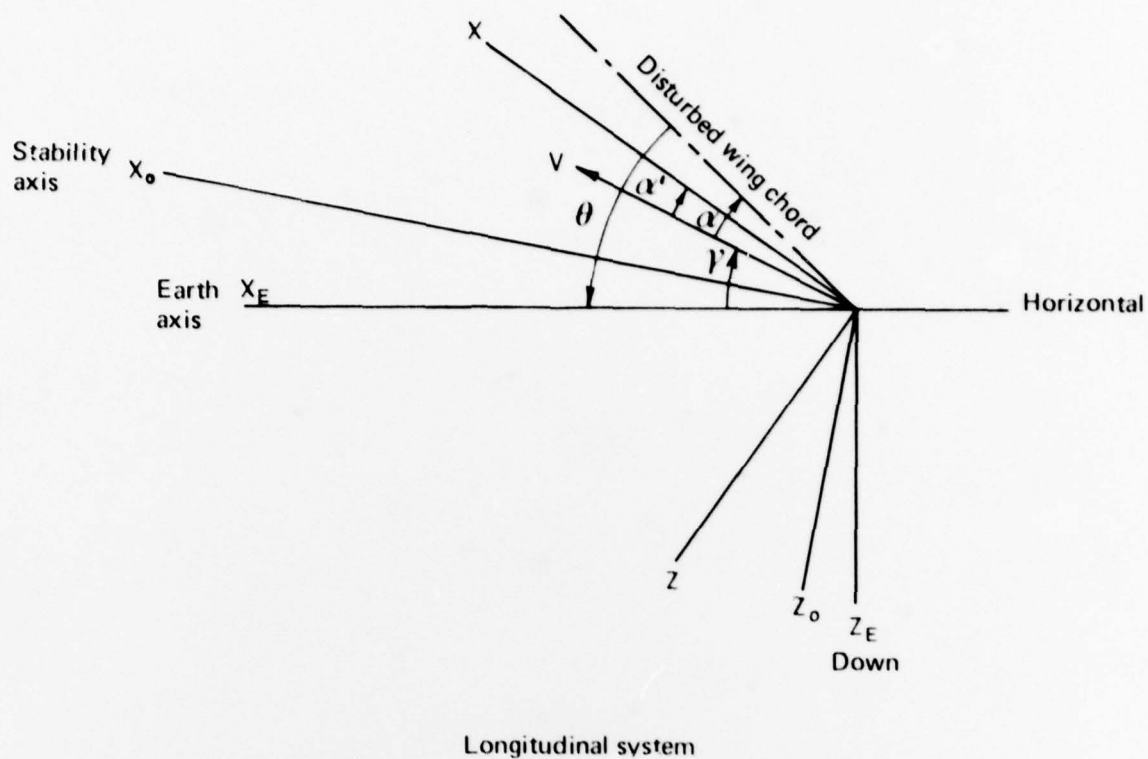


FIG. 6. DIAGRAM SHOWING THE AXIS SYSTEMS USED IN THE SIMULATION OF THE LATERAL AND LONGITUDINAL DYNAMICS.
 Note: The perturbations are considered with respect to the stability axes X_0 , Y_0 , Z_0 . These axes are considered to be fixed with respect to the aircraft once they are aligned with the X axis into the relative wind.

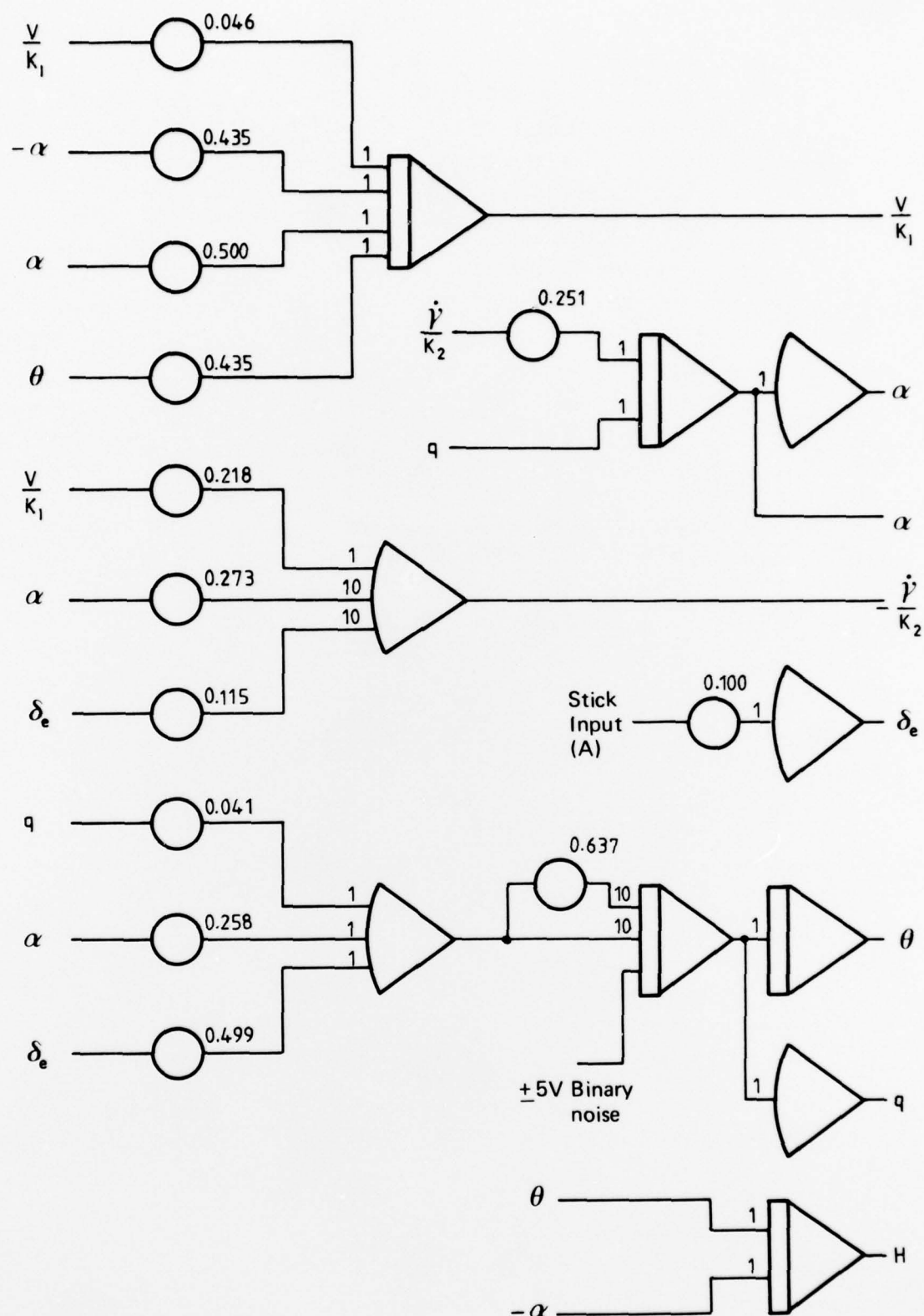


FIG. 7. ANALOGUE COMPUTER REALIZATION OF THE LONGITUDINAL DYNAMICS.

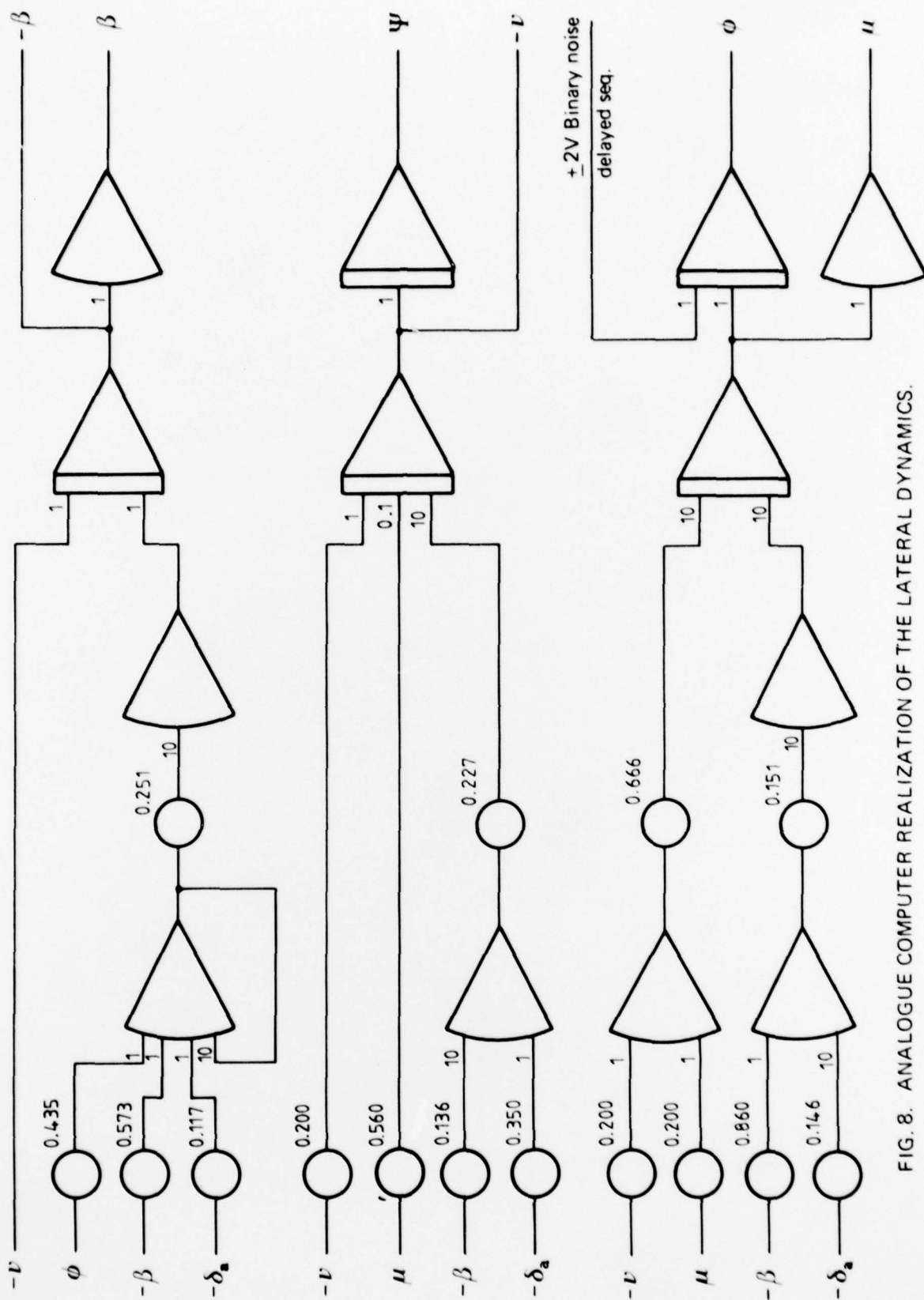


FIG. 8. ANALOGUE COMPUTER REALIZATION OF THE LATERAL DYNAMICS.

APPENDIX 2

Post Experiment Questionnaire

What line of approach if any did you use to optimise your performance on the tracking task?

What line of approach if any did you use to enable you to read altimeter A (larger of the two) quickly and accurately?

What line of approach if any did you use to enable you to read altimeter B quickly and accurately?

Did you adopt any particular strategy to enable you to optimise your performance on the task as a whole? If so describe it briefly.

What are your views on the adequacy with which altimeter A displays altitude information?

What are your views on the adequacy with which altimeter B displays altitude information?

In your previous flying experience, have you had occasion to use either type of instrument?

Altimeter A ☐ YES

☐ NO

Altimeter B ☐ YES

☐ NO

Place a tick in the appropriate box.

Did you notice any deficiencies in any aspect of this experiment? For example, you may have needed more practice or some aspect of the instructions may not have been clear. Write down these impressions and if possible suggest ways in which the experiment could be improved.

APPENDIX 3

Pre-experiment Briefing

Although this was not actually read to all of the subjects in this form the points which it covers were mentioned in each case.

"Thank you for agreeing to take part in this experiment. The aim of the experiment is to compare the readability of two altimeter displays and since the tasks are particularly relevant to flight crew it is important that people with your particular background of flying experience should participate as the subjects. All of the results of the experiment will remain confidential. That is, because of the method to be used in reporting the results it will not be possible to identify a particular subject with his particular score. Consequently there is no element of competition between subjects. It is the altimeters that are being evaluated—not the subjects. Nevertheless you are asked to do your best in each part of the experiment.

After the trials you will be given a questionnaire to answer. To do this you will need to try and remember the way in which you made your responses during the trials and also any deficiencies in the design of the experiment. So in preparation for answering the questionnaire try to remember any of these points that become apparent to you during the running of the experiment.

It is important that as far as possible each subject should participate in the experiment under identical conditions. Consequently I would appreciate it if you would refrain from discussing the experiment with others that may be taking part."

With the subject seated in front of the CRO screen he was given the following instructions and practice.

"On the screen in front of you are two intersecting straight lines. These move in response to signals from the computer and can be controlled by moving the sidearm controller stick located on the right side of the chair. During the trials you are to move the stick so as to maintain the intersection of the lines within the black circle.

The signals from the computer actually represent the deviations in attitude which would occur to a delta wing fighter aircraft flying through turbulent air on a landing approach. Displacement of the vertical line to the right indicates that the aircraft is banked to the right. Displacement of the horizontal line below the circle indicates a nose-down attitude. By moving the stick left, the vertical line can be moved to the centre of the screen. This indicates that the lateral axis of the aircraft is horizontal. If the stick is drawn backwards the horizontal line can be moved upwards until it intersects the circle. This occurs when the aircraft is flying along a horizontal path.

Are there any questions?

I will now switch on the computer for two minutes to give you practice at controlling the attitude of the simulated aircraft.

Now I want you to watch the altimeter as I change the reading from 1500 ft to 2500 ft. For the purpose of the experiment this instrument will be termed altimeter (A/B).

Next I want you to practice reading the altimeter at certain times while carrying out the tracking task. During the main experiment the procedure will be as follows. When I say "GO" begin tracking the lines and do this as accurately as possible. Tracking errors during the trial will be accumulated continuously and will be used as an index of performance.

While you are performing this task the aperture will open and when this occurs you are to read the altimeter as quickly and as accurately as possible then close the shutter by pressing the hand held push button switch. When you have done this tell me what the reading was and return to the tracking task. It is important to close the shutter before verbalizing the response because the exposure duration is also being recorded and used as an index of performance. During these practice trials I will tell you what the correct answers are.

Remember the procedure is:

- (a) to begin the tracking task when I say "GO",
- (b) read the altimeter as quickly and as accurately as possible when the aperture opens,
- (c) close the aperture by pressing the button, and
- (d) verbalize the altimeter reading and return to the tracking task.

Are there any questions?

You will be required to read the altimeter 10 times during this trial. Remember that it is important to try and minimise your errors on the tracking task during the entire trial.

The practice will now begin.

We are now ready to begin the main experiment. You are to imagine that the aircraft is descending from a height of 10 000 feet at a rate of approximately 940 ft/min. Consequently the trial will take ten minutes to run."

RESULTS FROM POST EXPERIMENT QUESTIONNAIRE

What line of approach if any did you use to optimise your performance on the tracking task?

- Subject 1 (a) Avoid tenseness in the hand.
(b) Found it possible to anticipate lateral oscillations.
(c) Used gentle corrections for small deviations and comparatively larger on-off inputs for longer deviations.

- Subject 2 Tried to keep the cross lines in the general circle area rather than on centre. Tried to relax eyes as often as possible to avoid fatigue i.e. focus a little away from circle for a few seconds here and there.

- Subject 3 **ALTITUDE READING**
(a) Select nearest 1000 ft and ascertain position of 100's pointer.
(b) Check A/C attitude.
(c) Select 100's of feet.
(d) Check attitude and at the same time calculate altitude.
(e) Check altimeter to confirm.
(f) Cancel altimeter and call.

TRACKING AIRCRAFT

Fly as for normal ILS procedure:

- (a) Small control movements.
(b) Stop error—change attitude to return aircraft to centreline smoothly without overcontrol.
(c) Relax pressure on control column periodically or if over control is evident.
- Subject 4 Tried to minimise stick movements and drive the intersection as a single variable.
- Subject 5 I attempted to centralize one axis first, then chased the second whilst holding the first near the centre. Once both were near centre I used small adjustment on both to attempt accurate centralizing. A system of "change-check-hold-adjust" technique used in instrument flying attitudes. I cannot recall what error there was after reading the altitude but instinctively chose one axis, then the next.
- Subject 6 Only watch the screen for short periods at a time because in an actual aircraft there would be other instruments to watch also. Continuous vision on such a screen is difficult but broken vision is more effective.
- Subject 7 No conscious line of approach other than to 'fly' it as a real aircraft with a rather strange roll attitude display, (the pitch display also being 'back to front').
- Subject 8 First action was to use elevators to keep attitude and airspeed right as one would in piston engined prop. driven aircraft as airspeed fairly important on approach particularly closer to the ground. Secondly to use the lateral effects of the control as one would to keep the aircraft on course and wings level I found myself chasing the thing around and overcorrecting. This might have caused misleading results as most aircraft have inbuilt lateral stability and tend to right themselves anyway. It might be that jet aircraft such as Mirage are flown differently with engine thrust affecting speed more and attitude, rate of descent.
- Subject 9 Initially just correction.
Finally anticipated for overcorrection.
- Subject 10 I did not use any conscious line of approach.

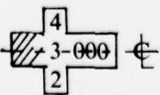
- Subject 11 Use as little control input as possible, practice looking at where altimeter (position) appears.
- Subject 12 Not having any feel for the control rate, I seemed to be overcontrolling markedly during the initial part of both experiments. The task seemed to become easier with time but may have been due to smaller perturbations. Smaller control movements seemed to be adequate towards the end of the experiment.

What line of approach if any did you use to enable you to read altimeter A (larger of the two) quickly and accurately?

- Subject 1 Read drums first then checked pointer.
- Subject 2 Difficult to answer. I simply read the first two digits from the drum and then the last two—to the nearest 20 ft. from the needle. I found this one easy on the eyes.
- Subject 3 Pick approximate height on digital display and check 100's pointer accurately using procedures as in altitude reading above (see the response of subject 3 to the first question).
- Subject 4 Read the numbers first (say 2950) then the pointer (930) for accuracy.
- Subject 5 I ignored the last two digits (i.e. 00, 50) and read the hundreds (e.g. 3900, etc.) then checked the "9" on the pointer and read the pointer to the nearest 20 ft.
- Subject 6 Forget last two digits.
- Subject 7 Read the numerical display first, then gained fine resolution with the pointer.
- Subject 8 Firstly digit indicating 1000's of feet. Secondly digit indicating 100's of feet. Thirdly read 100's and 20's off clockwise scale. Ignored digits indicating 00 and 50's.
- Subject 9 Read digits (tendency to ignore fifty foot reading) Estimate 20's of feet from pointer.
- Subject 10 First the digital display, then the pointer. The display to give thousands then hundreds and the pointer for tens.
- Subject 11 Read the thousands off digital scale then read hundreds and tens of feet off outside scale. Memorize position of needle and work out reading after altimeter disappears.
- Subject 12 (a) Quickly look at digital display.
(b) Modify the "tens" by referring to the needle.
(c) Check that the hundreds are of the right order.

What line of approach if any did you use to enable you to read altimeter B quickly and accurately?

- Subject 1 (a) Checked for lowest 1000 ft. figure.
(b) Read remainder of figures.
(c) Checked pointer.
- Subject 2 Much more concentration—more time required to read the first digit especially when it was ± 100 ft. from a new 1000 ft. step. Once the idea of reading up i.e. 3/2 used this made it a bit easier.
- Subject 3 Same as for A except the digital display required longer to check.
- Subject 4 Thousands and trend off the counters, then hundreds and tens from the pointer.

- Subject 5  centreline

I tried to pick the number that appeared thru' or mostly below the imaginary

centre line thru' the figure slot. That gave me the thousands and I read the remainder off the needle. The major problems occurred with figures, near the full thousand where there wasn't a bias below the centreline.

- Subject 6 None.
- Subject 7 Interpolate thousands of feet on the numerals, then hundreds and tens on the pointer.
- Subject 8 Quick look at 1000s, then looked at the 100s and 20s on circular scale. Then sometimes a second look at 1000s to ascertain that the 1 digit hadn't fully registered as it would if the reading was say around 950 ft. I might have had a second look at 1000s digit on 1st Alt but can't remember doing this.
- Subject 9 Read digits (say between 2 & 3 thousand).
Read hundreds.
Estimate 20s of feet pointer.
- Subject 10 The same method as with "A" however I found this type more difficult to read.
- Subject 11 There is no real way of reading this meter quickly. Time had to be taken to get the correct reading off the thousands digit. The needle had to be used as well to determine which digit was nearest for the thousands. Again I memorized the position of the needle and worked out the hundreds and tens of feet after the altimeter had disappeared.
- Subject 12 (a) Read the digital number.
(b) Decide whether it was above the "datum".
(c) Read needle for "hundreds".
(d) Close shutter and rely on memory for tens.

What are your views on the adequacy with which altimeter A displays altitude information?

- Subject 1 Very good presentation.
- Subject 2 Excellent.
- Subject 3 Generally adequate. However there are positions in which the 100s pointer obscures the digital display. Readability otherwise O.K.
- Subject 4 Good—gives "ball-park" figure immediately on reading.
- Subject 5 "A" gives too much info. on the drums.
- Subject 6 It would be better without the last two digits 00 and 50.
- Subject 7 I found the duplication of information confusing. That is, the display of digits less significant than one thousand on the numerals. It seems more natural to display only thousands numerically. This opinion is probably coloured by the type of altimeter I have used most.
- Subject 8 If flying along at constant altitude would tend to ignore the clockwork scale and just read the digital one. When changing altitude the fact that the 100s and 50s are displayed twice could lead to some confusion until one got used to it.
- Subject 9 Less distracting to obtain reading than B enabling more concentration for task.
- Subject 10 Very good. I found this type easy to read quickly.
- Subject 11 On using this altimeter I would tend to use only the digital reading unless I needed greater accuracy in which case the last two numbers on the digital display would be a nuisance.
- Subject 12 (a) Digital display figures were bold and easy to read.
(b) The "tens" figures were disconcerting at first, seeming to be redundant.
(c) Upon reflection however, it would enable very quick ball park estimation to be made, especially in a heavily tasked situation.

What are your views on the adequacy with which altimeter B displays altitude information?

- Subject 1 Possibility of misreading Alt. B seems very high, especially if
(a) only a quick glance is taken,
(b) no other altitude cues are available.
- Subject 2 Difficult to read, as explained earlier the first digit. Would much prefer to read altimeter A.
- Subject 3 *Too small*. Digital display difficult to absorb unless excessive attention is devoted to it as only one number moves.
- Subject 4 Confusing at first, better with practice.
- Subject 5 B gives all that I find necessary, that is, full thousands and the needle gives the next satisfactorily.
- Subject 6 The drum on which the "thousands" digits were painted needed to be larger so that the last number coming up could be read.
- Subject 7 As mentioned above, I found this design to be intrinsically better under most circumstances with one glaring exception. The readability of the numeral display was poor at the 9000-10 000 ft. transition. Better spacing of the numerals on the digital part of the display would have improved readability.
- Subject 8 The fact that the 1000 ft. digit changes as the hand of the clock scale turns could lead to confusion as to whether reading is 7900 ft. or 8900 feet. Could be a serious fault at altitudes in the vicinity of terrain alt. under I.F.R. conditions.
- Subject 9 Requires more concentration than "A". Thousand digits can be obscured by pointer needle.
Worst case partial blanking when two digits are displayed, wrong digit may be read as it is the only one seen, giving an order of error in reading. (Easily done when task is suffering due to temporary neglect.)
- Subject 10 More concentration had to be used to read this type. Possibly because less information is available at the first glance, the pointer having to be used to determine hundreds then tens.
Once or twice after reading the pointer I found I had forgotten the display reading.
- Subject 11 This meter is hard to read particularly with reference to thousands of feet as more than one number can be seen at any one time.
- Subject 12 (a) Decision making on the position of the digital display could lead to prolonged visual dwelling on this area.
(b) For an instrument panel seen during instrument flying this could break up the eye pattern.
(c) The smaller instrument dial seemed quite adequate and upon reflection may have made the task easier.

DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers		2. Security Classification	
(a) AR Number: AR-001-325		(a) Complete document: Unclassified	
(b) Document Series and Number: Systems Note 60		(b) Title in isolation: Unclassified	
(c) Report Number: ARL-Sys-Note-60		(c) Summary in isolation: Unclassified	
3. Title: AN EXPERIMENTAL COMPARISON OF THE READABILITY OF TWO DIGITAL ALTIMETERS			
4. Personal Author(s): G. R. White		5. Document Date: DECEMBER, 1978	
		6. Type of Report and Period Covered: Note	
7. Corporate Author(s): Aeronautical Research Laboratories		8. Reference Numbers	
		(a) Task:	
		(b) Sponsoring Agency:	
9. Cost Code: 73 6640			
10. Imprint Aeronautical Research Laboratories		11. Computer Program(s) (Title(s) and language(s)):	
12. Release Limitations (of the document) Approved for public release			
12-0. Overseas:	No.	P.R.	1 A B C D E
13. Announcement Limitations (of the information on this page): No Limitation			
14. Descriptors:		15. Cosati Codes:	
Digital altimeters	Aircraft instruments	0104	
Digital display systems	Flight instruments	0505	
Human factors engineering tests	Reaction time		
	Psychological effects		

16.

ABSTRACT

Twelve male volunteer subjects with flying experience were required to read one of two digital altimeters while performing a two dimensional tracking task. It was found that the Smiths Type 3B servo altimeter was read in a significantly shorter time than was the Aero Mechanism Type 8047/20A capsule altimeter. Furthermore, an ergonomic appraisal of the latter instrument and a subjective evaluation by the subjects indicates that the probability of misreading this altimeter is high.

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