EFFECT OF CHANGES IN POINTER SHAPES ON SPEED AND ACCURACY IN ALTIMETER READING

DR. W.T.V. ADISESHIAH AND M. S. PRAKASH RAO,

Defence Science Organisation

It has been found in earlier studies abroad, that the conventional three pointer altimeter is liable to be misread more frequently than any other instrument in the aircraft cockpit. In an analysis of 270 "pilot error" experiences in reading and interpreting aircraft instruments, Fitts and Jones (1) found that as many as 40 were errors in misreading the altimeter by 1,000 feet. A more intensive study carried out by Grether (2) on a sample of pilots and college students revealed that the chances of a 1,000 foot error in reading an altimeter are well above the 10% level.

It is widely felt that the reason for this lies in the altimeter dial face itself. There are three pointers in the conventional altimeter (Fig 1). The smallest one, lowest on the dial face, indicates tens of thousand feet. The medium pointer indicates thousands of feet. The longest of the three pointers indicates hundreds of feet. Thus, the altitude shown in the setting on Figure 1 ought to read as 34,640 feet. Three pointers are considered necessary for the altimeter, because the altitude ranges over which modern aircraft operate cannot possibly be covered in a single revolution of one or even two pointers on a dial of ordinary size.

Two main types of reading error have been noticed to occur in connection with the reading of the three pointer altimeter. The first type of error is illustrated in figure 2. This particular setting has been so frequently misread, that the error has become well nigh classical. A very large number of people have read this as 14,960 feet, whereas the correct reading is a thousand feet less. One may well imagine what the repercussions of such a reading error might be, if it were to be committed by a pilot as he was descending over mountainous terrain at night or in cloud.

Fig. 1.

Fig. 2.

The second type of error results from the relative positions of the pointers especially when one of them is eclipsed by another above it on the axis of the dial face. This type of error is illustrated by the altimeter setting shown in figure 3. In this case, only two pointers are visible: the medium and the long ones. The short pointer is concealed under either the long or the medium pointer.

A considerable amount of research has gone into the question of producing an easily readable dial design which can be interpreted by pilots with the least chances of error. Recently, the Royal Air Force accepted a modified altimeter design in which pointer visibility was considerably improved. An adaptation of this design is shown in figure 4. The main features of this modified design are:

Fig. 3.

Fig. 4.

1. An arrow shaped pointer of the same length replaced the small 10,000 foot pointer.
2. In place of the medium sized pointer, a pointer of the same length, but with a circular central feature was used. When this overlaps the small pointer the small one will still be visible through the circular central feature.
3. The rear elongation of the long pointer was altered into a fan shaped feature, so as to prevent eclipsing of the small pointers.
4. Inner marks were inserted below each of the numerals of the dial face to serve as reference marks in the reading of the small and medium pointer.

The purpose of this paper is to assess efficiency in reading the new type of altimeter as against the conventional one, on the criteria of speed and efficiency.

METHODOLOGY

Personnel Tested: Pilots and Navigators, including Flying Instructors and Flight Cadets, numbering 150 in all, of ages ranging between 20 and 45 years, and with varying levels and types of flying experience participated in this experiment.

Kinds of Measurements: Three kinds of measurements were recorded in the course of the investigation:

1. **Reading of Altimeter Settings:** This was recorded by giving everyone the Dial Reading Test (No. AP 8) which was in two parts. In Part I, 20 photographs of different settings of the conventional altimeter mounted on a white background had to be interpreted one by one. Part II consisted of 20 corresponding settings of the modified design, presented similarly. The tests were administered to pilots and navigators individually and the altimeter readings called out by them were entered on a data sheet specially designed for the purpose.

2. **Interpretation Time:** The time taken to call out each reading was measured on a stop watch and entered in the proper place on the data sheet. Interpretation time represents the time taken to look at the setting and decide the reading indicated by it. It does not include the time taken to call out the reading. The mean time per reading for each of the two designs was worked out by averaging the times for the 20 readings of each type of design.

3. **Tachistoscope Tests:** Photographs of altimeter settings, mounted on cards, were exposed for duration varying between 0.1 and 5 seconds to a sample of Jet fighter pilots. The purpose of this test arrangement was to find out whether error rates in altimeter reading increased by time stress.

Errors: Two types of calculations were made with regard to errors committed by pilots and navigators in the reading of the test material;—

1. **Error Rates:** The readings called out by pilots and navigators were checked by the use of a key, and percentages of reading error for each type of design were worked out.
2. **Kinds of Error:** Each error was classified on a four point basis in order to find out which type of error occured most frequently.

ANALYSIS OF RESULTS

Interpretation Time: The mean time taken to read an altimeter setting under the conditions of this investigation worked out as follows:

Conventional Design	6.6 seconds
Modified Design	4.7 seconds

There is a saving of approximately 30% in time as a result of the modification. In a similar experiment on USAF pilots and college students, Grether (3) found that pilots took on the average 7.1 seconds and college students took about 7.5 seconds to read settings similar to those of the conventional design presented in our experiment.

Reading under Time Stress: A group of Jet fighter pilots who were made to read altimeter settings presented for short durations on a tachistoscope were able to call out correct readings even when the duration of the exposure was stepped down to 1.5 seconds. One pilot maintained accuracy in reading at an exposure duration of 0.3 seconds. In a study of eye movements of air pilots of the USAF, Fitts, Jones and Milton (4) have found that the mean duration of the eye fixation cycle of the altimeter is 0.38 second during instrument landing approaches, and 0.41 second during ground control approaches. A fixation cycle includes the time required to move the eyes to an instrument plus the total time spent on looking at the instrument. This being so, it would appear that the greater part of the interpretation time is spent on mental elaboration of the visual clues presented in the display.

Error Rates: Mean percentages of error in reading photographic reproductions of the two designs of the altimeter are as follows:—

Conventional Design	30.7%
Modified Design	22.6%

There is a saving of approximately 20% in the error rate as a result of the change in the design.

Ground and Flight Conditions: The flying personnel tested in this investigation were mostly assembled in crew rooms or near the hangars, before or after sorties. It is quite conceivable that interpretation time and error rates will be very different under flight conditions, although the saving in time and error by the use of the modified design may not be. Under flight conditions the time taken to read the altimeter would be considerably less, depending on the nature of the conditions and the phase of flight. Further, since the pilot will be much more alert while in the cockpit than he is on the ground, it may be expected that his error rate would also be far less. It has been found that the mere fact that one is being subjected to a psychological test is capable of being a potential source of increased error.

Interpretation Time		Error Rate	
Con Des	Mod Des	Con Des	Mod Des
5.2	3.8	30.0	23.5
6.0	4.1	33.8	27.3
6.5	4.3	34.8	24.3
7.6	6.4	24.0	19.0
9.1	6.3	29.8	17.8
6.6	4.7	30.7	22.6

Table I: Altimeter Efficiency.

Flying Experience: The saving in time and error rates in the case of pilots with different amounts of flying experience is indicated in the curves in Figure 4.

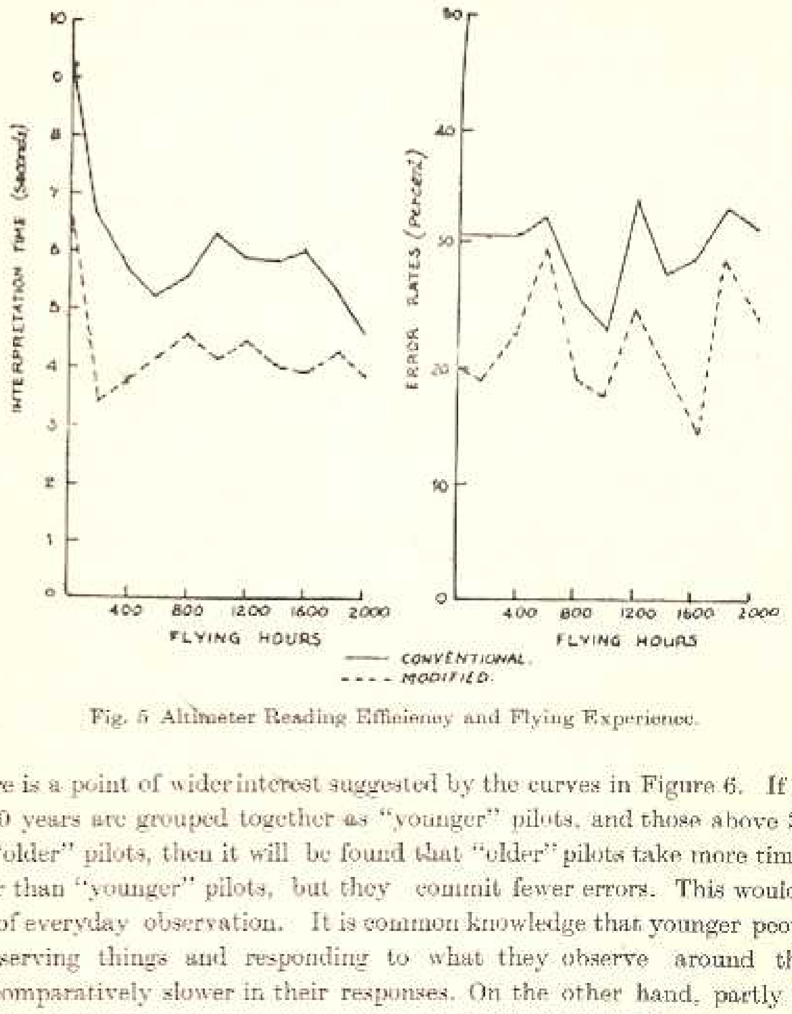

Fig. 5 Altimeter Reading Efficiency and Flying Experience.

There is a point of wider interest suggested by the curves in Figure 6. If pilots below the age of 30 years are grouped together as "younger" pilots, and those above 30 years are grouped as "older" pilots, then it will be found that "older" pilots take more time in reading the altimeter than "younger" pilots, but they commit fewer errors. This would be supported by facts of everyday observation. It is common knowledge that younger people are more quick in observing things and responding to what they observe around them. Older people are comparatively slower in their responses. On the other hand, partly as a result of insufficient experience and also on account of their relatively immature observational powers, younger people tend to go wrong more frequently than older persons. Experience and maturity of mental powers are aids to relatively greater accuracy in the case of older people.

At all the various levels of flying experience there is a distinct saving of time and reduction of error which is attributable to the modified design. The periodicity of the error curves in Figure 1 is rather striking. Error rates tend to rise at the 600, 1200 and 1800 flying hour stages. An interesting parallel to this is afforded by the findings of a study of accidents carried out by a Statistical Officer of the RAF. He found that the accident rates tended to rise sharply at the 500, 1500, 2000 and 2500 flying hour stages.

Age Levels: Speed and accuracy in the reading of the two designs of the altimeter are shown against age levels in Figure 6 .

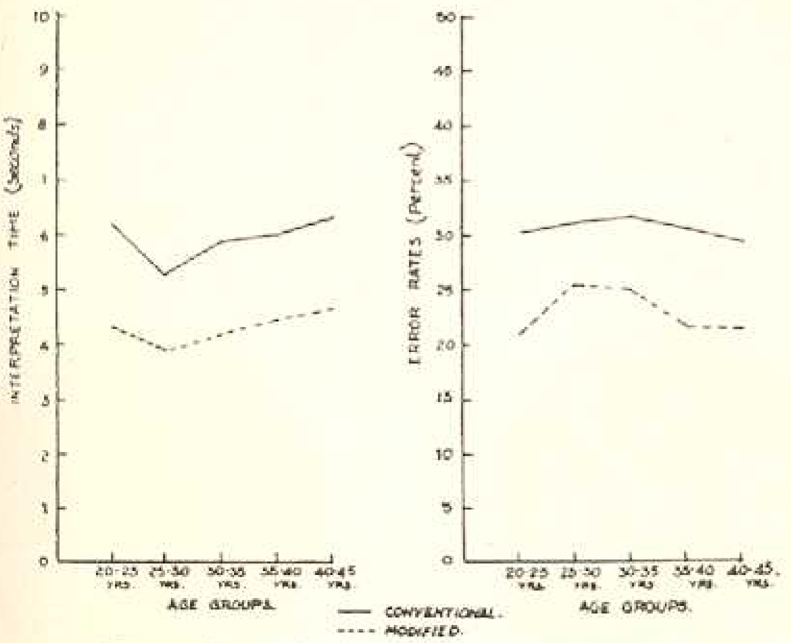

Fig. 6. Altimeter Reading Efficiency and Age Levels.

ERROR ANALYSIS

Types of Reading Error: Efficiency in any type of skilled performance is usually assessed in terms of two criteria: speed and accuracy. As between these two, it is fair to say that accuracy counts for more than speed. This is all the more so when it is realized that in flying, small errors of an apparently trivial nature are capable of leading to menacing situations. Following the classification adopted by Grether (2) in his study of USAF pilots, the various reading errors noted in this investigation were classified into four types:

1. **Reading to the nearest Numeral instead of to the lower adjacent Numeral:** For example, the altimeter setting in Figure 7 was read as 16,940 instead of as 15,940 feet. This error was committed because the medium pointer appeared so close to the numeral 6 that the reader failed to notice that 6 had not yet been reached.

Fig. 7

Fig. 8

2. **Misreading the Pointer Setting:** For example, the setting shown in Figure 8 was read as 24,400 instead of as 25,430 feet. This error has been explained by attributing it to the preception of "dominant" detail. It is argued that the long pointer is so dominant on the dial face that it influences the reading of the medium pointer.

3. **Omission of One Pointer:** For example, the setting in Figure 9 was read as 1,100 instead of as 11, 100 feet. In this setting the small pointer is eclipsed by the other two pointers. Hence it fails to be noticed.

Fig. 9

Fig. 10

4. **Pointer Exchange:** For example, the setting in Figure 10 was read as 12,300 instead of as 21,300 feet. It can be argued that the close proximity of the three pointers to each other is at the bottom of the confusion. At the same time, it is true that each pointer is distinctly visible. Hence the origin of the confusion must lie chiefly in the mind of the reader rather than in the design of the instrument.

Frequency of Reading Error: Errors of reading the nearest numeral were most frequent. Misreading the altimeter setting by ten thousand feet were not, however, so frequent as misreading by a thousand feet. The latter were of the order of 9.4% on the conventional, and 10.5% on the modified design. Misreading the altimeter setting occured in about 4% of the cases on the conventional design and was reduced to a negligibly small figure on the modified design. On the conventional type of altimeter, pointer omission, particularly of the small pointer was about 5% of the cases. It was reduced to nearly 1% with the modified design. A similar reduction of the 2.5% error due to pointer exchange was found to occur in the case of the modified design.

EVALUATION

Persistent Error Trends: Although there has been an overall reduction in reading error as a result of the change in pointer design, it is not an all round reduction. Errors of misreading the setting by a thousand feet are certainly not less, as Table 11 will show.

Role of Pilot	Percentage of Error	
	Conv Des	Mod Des
Fighter	11.2	11.0
Bomber	11.6	12.0
Transport	9.3	10.7
Instructor	4.8	8.3
Cadet	10.0	10.3

Table II Frequency of Error in Reading nearest Number.

Psychological Influences: When the typical error of misreading the altimeter by a thousand feet is studied, it will be found that an important psycholgical factor underlies the error. The reader notices the numeral ahead of the spot actually reached by the pointer instead of noting the lower adjacent one. His process of anticipatory interpretation impels him to run ahead of the pointer. It was thought that the insertion of interior markings would have the effect of restraining this tendency, but apparently this has not turned out to be so, judging from the Figures in Table II. If this kind of anticipatory tendency is to be effectively controlled, it will be necessary to have a display pattern in which the next numeral is not visible to the reader until the lower adjacent value has been entirely superceded. In other words, he should not be able to see 6 until 5 has passed completely.

Alternative Dial Designs: Apart from the fact that the anticipatory tendency predisposes the reader to misread altimeter setting by a thousand feet, the fact that there are three pointers in the modified setting of the altimeter, retains the same complexity as is found in the conventional setting. An alternative design which has come into use recently is the type of altimeter in which hundreds of feet are indicated by one pointer, while thousands and tens of thousands are shown on a counter device situated at the left centre of the dial. The Kollsman design of the ltimeter (5) appears in Figure 11. Since the natural slant of the eye is believed to be towards the left, the placing of the counter on the left side of the dial face is appropriate. Further, the only pointer on the dial has been made slender at the middle, so as to reduce eclipsing of the counter to the minimum. This design thus conforms to standard human engineering requirements.

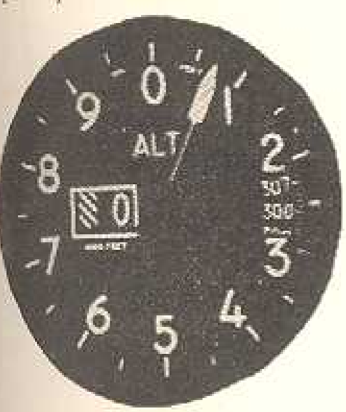

Fig. 11

All things considered, it would be fair to say that while the change in the design of the pointers of the altimeter does increase efficiency in altimeter reading, it does not forestall the reader's predisposition to misreading settings by a thousand feet. Since errors of this type are of the utmost consequence in critical flying situations, it is desirable in the interests of the pilot's efficiency and of flying safety to equip the aircraft, especially high speed aircraft, with the single pointer counter type of altimeter, in place of the present three pointer imeter. In his experiments with USAF pilots, Grether found that using altimeters with such counter devices, displaying thousands and tens of thousand feet and only one pointer to indicate changes in hundreds of feet, the error rates of USAF pilots dropped to the level of 0.7% from a level of 11.7% on the conventional design. Interpretation time was likewise reduced to 1.7 seconds, as against 7.1 seconds for the older type of altimeter.

Conclusion

The clearly distinguishable overall improvement in altimeter reading efficiency is attributable to the change in the shape of the altimeter pointers. Speed is increased by about 30%, and error is reduced by about 20%. Although there is an overall increase in efficiency it is by no means an all round improvement. Errors of misreading the altimeter by thousand feet are not reduced by the change of design. These errors are due to the influence of anticipatory interpretation during reading. Error rates in altimeter reading tend to rise to high levels at the 600, 1200 and 1800 flying hour stages. Older pilots tend to take relatively longer time on altimeter reading than younger pilots. Younger pilots on the other hand commit more mistakes than older pilots. Numerous studies carried out on altimeter design in other countries have shown that the single pointer counter type of altimeter is the best design from the point of view of pilot efficiency in the cockpit.

Acknowledgments

The authors of this paper are deeply grateful to the various pilots and navigators of the Indian Air Force, who volunteered as subjects for the experiment.

References

1. Fitts, P.M. and Jones R.E.: Psychological Aspects of Instrument Displays. Air Material Command (USA) Report No. TSEAA-694-12A (1947).
2. Grether, W.F.: Air Material Command (USA) Report No. MCREXD-694-14A (1948)
3. Grether, W.F.: Air Material Command Report No. TSEAA-694-14 (1947)
4. Fitts, P.M. Jones, R.E. and Milton, J.L.: Eye Movements of Aircraft Pilots during Instrument Landing Approaches. Preprint 213. Institute of Aeronautical Sciences New York (1949).
5. Anon: Altimeter History -26 years. Aviation Week, 62 : 24, 96 (1955).