

# THE CHANGING FACE OF THE ALTIMETER

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## ABSTRACT

Experimental psychologists and instrument designers have during the past three decades or more, made several attempts to improve the design of the altimeter dial display. These efforts have in fact been necessitated by the many problems of dial interpretation peculiar to the altimeter. This paper describes some of the designs which have been developed during the recent years and discusses also the main trends of future design.

### The Design of Multirevolution Dials

The earliest design of the altimeter is of the multirevolution type. In this type of dial, the pilot has to combine the readings of two or more pointers in order to get the information he wants. Dial designs of this type are used because one revolution of the pointer on a circular dial does not give enough scale length to provide as much accuracy as is needed. Thus, it was thought that the altitude range in which conventional aircraft operate cannot possibly be covered accurately in one revolution of a pointer on a dial of ordinary size. The early designs of the altimeter had two or three pointers, indicating hundreds, thousands, and ten thousands of feet. In 1929, James Doolittle in the U. S. A. used a two pointer altimeter with a range of 20,000 feet for his famous blind flying experiments. This is illustrated in Fig. 1. The three pointer altimeter with a range of 35,000 feet did not come into use till 1933. Tens of thousands was displayed separately on the dial face by a tiny pointer, as shown in Fig. 2, rotating round a small circle at the bottom of the dial. In a subsequent design, all three pointers moved on the same dial and a red reference pointer was added on. With the red reference pointer, set, the pilot could compare the white indicator with the red reference. One dial, three pointers and a range of 50,000 feet characterised the U. S. Army model altimeter, which came into use in 1941, during World War II. This design of the altimeter, illustrated in Fig. 3, is used in most of the aircraft of the Indian Air Force today.

### Drawbacks of the Conventional Design

*"Pilot Error" Experiences.* In 1947, two United States Air Force psychologists, P. M. Fitts and R. E. Jones, analyzed 270 "pilot error" experiences and they found that a considerable number of errors occurred in reading the altimeter. In fact, the three pointer altimeter was found to be about the most difficult instrument to read correctly. By far the most common error in reading altitude was one of exactly 1,000 feet. Experiences in which this particular type of error occurred were described by thirty six out of 187 men who reported incidents. The following account of the pilot of a B-29 practising night landings is typical:

"The traffic pattern was to be 2,500 feet. The field elevation was 1,000 feet. The pilot misread the altimeter, and was actually 1,000 feet lower on his traffic pattern than he thought he was. He went through his landing procedure, had his wheels down, flaps 30° and was on his final approach. Before he realised what had happened, he flew into the ground, about  $1\frac{1}{2}$  miles short of the runway. Luckily, he hit an open field, bounced and managed to maintain flying speed".

*Frequent Causes of Error*—Some of the basic sources of error may be considered in this connection. First of all, there is the type of error in which the pointer is read to the nearest numeral rather than the lowest adjacent number. Such an error frequently occurs in reading the thousand-foot pointer of the conventional design of the altimeter. In a recent study, carried out on I.A.F. pilots, it was found that the frequency of errors of this type varied between 10 to 12 per cent of the test readings of all pilots. A good example of an altimeter setting which is frequently misread by a thousand feet in excess of the correct height is given in Fig. 3. This setting was read as 14,960, instead of as 13,960 feet. Secondly, there is the type of error which results from the "eclipsing" of one pointer by one of the other two. A good example of this is the setting shown in Fig. 5. In this case, the little pointer is eclipsed by one of the other two pointers. If it is under the medium pointer, the reading would be 11,300 feet. If it is under the long pointer, the reading would be 31,300 feet. Under actual flying conditions, a pilot will be able to tell what the correct height is, since he checks on his height from time to time. Nevertheless, it is desirable that such instrument conditions should be avoided by having a display in which all the three pointers are visible, wherever they happen to be. It has been found that such conditions as this have resulted in the misinterpretation of altitude readings by 1000 and 10,000 feet, sometimes bringing forth dire results.

### Recent Modifications in Altimeter Design

*Extended Pointer indicating 10,000 Feet*—In 1954, the Wright Air Development Centre in the United States developed a modified design of the altimeter, in which the 10,000 feet pointer was extended out of the cover of the other hands. They also incorporated on the dial face a striped warning area, visible only between 0 and 17,000 feet. When it is obscured, the altitude is above 17,000 feet. This design is shown in Fig. 4.

*British Modification*—Quite recently, the R.A.F. adopted a modification of the altimeter pointers which is illustrated in Fig. 6. The small, 10,000 foot pointer is replaced by an arrow shaped pointer. The medium, 1,000 foot pointer is reshaped with a circular central feature, permitting visibility of the small pointer when the two overlap. The long pointer remains unaltered in the modified design.

During the autumn months of 1955, a large scale study was undertaken by two scientists of the Defence Science Organisation, on a varied sample of pilots from the Indian Air Force. Photographs of altimeter settings of the conventional and modified designs were presented to each pilot, and their responses recorded. The time taken for each reading was also measured. It was found that speed in reading the modified design improved by about 30 per cent. A decrease in reading error of approximately the same order was evident in the case of the

modified design. The British modification has now been accepted by the Indian Air Force. It is in use by the Royal Australian Air Force as well.

It was noticed, however, that the most serious type of reading error, namely, misreading the altimeter by a thousand feet was not reduced in the modified design. This will be evident from the following table showing the error rates of I.A.F. pilots during the test readings of the two designs.

Type of Pilot	Conventional Design	Modified Design
Fighter Pilots .. ..	11.2%	11.0%
Bomber Pilots .. ..	11.6%	12.0%
Transport Pilots .. ..	9.3%	10.7%
Flying Instructors .. ..	4.8%	8.3%
Flight Cadets .. ..	10.0%	10.3%

This makes it look as if the modification serves only one useful purpose namely, to render clear visibility of all the three pointers in any setting; but it does not lower the chances of error in reading the altimeter by 1,000 feet in excess of the correct height.

*The 'Veeder' Counter Type of Altimeter*—In a study carried out on U. S. pilots, the Aviation Psychologist, Dr. W.F. Grether, found that the combination of a sensitive pointer and a 'veeder' counter was by far the most satisfactory arrangement. With the conventional design of the three pointer altimeter, he found that interpretation time worked out to 7.1 seconds on the average, and the percentage of errors in reading was 11.7. With the single pointer-counter type of altimeter, on the other hand, interpretation time was 1.7 seconds on the average, and reading error rate was 0.7%. Dr. Grether came to the following conclusion as a result of his experiment with United States Air Force pilots: "Bearing in mind the reading requirements of an altimeter for use by the pilot the combination of a sensitive pointer and counter offers the most promise. Such an indicator should, however, have the counter displaced approximately 90° from the zero position on the scale to prevent its being obscured by the pointer in its most common position". The Kollsmann design, constructed in conformity with the requirements laid down by Dr. Grether, was developed in 1955. A reproduction of this altimeter display is shown in Fig. 7.

*Vertical Scale Presentation*—A recent type of altimeter display, developed by the Hughes Aircraft Company in the U. S. A., is a 'slide rule' or vertical scale presentation of altitude information. In such an arrangement, a visual comparison of altitude is directly given without any need to read numbers. The indicator is an aircraft silhouette, superimposed on a vertical graduated scale, with a terrain clearance line or shaded area at the bottom. A digit counter records the actual altitude of the aircraft at all times.

## Laboratory Experiments with Non-Linear Scales of the Logarithmic Type

*Foley's Work in Canada*—Since most errors in altimeter reading arise out of the complex task of having to interpret three pointers, attempts have been made during recent years to evolve a dial design in which information regarding height could be shown on one dial with one pointer. Working under the Defence Research Board of the Canadian Department of National Defence, P. J. Foley carried out a series of experiments on the application of non linear scales of the logarithmic type to altimeter design. The type of dial design which has been developed by this investigator is shown in Fig. 8. It has a range from 10 to 60,000 feet. In order that more accuracy can be given where it is needed, the cycle lengths increase with altitude. The first cycle, indicating heights from 10 to 100 feet, is 1 inch in length. The second, which indicates heights between 100 and 1,000 feet, is  $1\frac{1}{2}$  inches long. The third, displaying heights from 1,000 to 10,000 feet has a length of 2 inches. The fourth, which covers the range from 10,000 to 60,000 feet is  $3\frac{1}{2}$  inches in length. The dial has a circumference of 8 inches, the normal altimeter dial size.

*Method of Evaluation*—The display was evaluated in terms of interpretation error with controlled exposure time, and interpretation error and interpretation time with uncontrolled exposure. For the purpose of laboratory experiment, horizontal logarithmic scale were drawn on white cards and mounted on a board such that the tip of a pointer under the control of the experimenter was  $\frac{1}{8}$  inch from the bottom line of the scale. Immediately in front of the card was a shutter, which when opened by the experimenter, automatically started a timer measuring in hundredths of a second. The subject's response closed the shutter and stopped the clock. All the subjects in these experiments were employees of the Defence Research Medical Laboratories in Toronto. The general procedure was that, with the shutter closed, the experimenter set the pointer at a particular spot on the scale, the subject was given a ready signal, the shutter opened, the subject responded, the shutter closed, and the experimenter recorded the time and the response.

*Results*—It was found that the interpretation time was of the order of 1.9 seconds, and the interpretation error varied with altitude. For the 10—100 feet cycle, the standard deviation of reading error was  $\pm 0.97$  feet. For the 100—1,000 feet cycle, it was  $\pm 6.03$  feet. For the 1,000—10,000 feet cycle, it was  $\pm 107.88$  feet; and for the 10,000—60,000 feet cycle, it was  $\pm 251.74$  feet. These errors are considered to be insignificant.

*Experiments with Dial Display*—Further experiments carried out with a dial display, similar to what is shown in Fig. 8, confirmed the results of the initial experiments. With the exposure time fixed at  $1\frac{1}{2}$  seconds, the average reading error was found to be proportional to the cycle, and was roughly equivalent for the first three cycles. In another experiment, the subjects were allowed to read dial indications at their own pace. The mean reading time for the first cycle was 1.57 seconds. For the second it was 1.53 seconds. It was 1.88 for the third cycle and 2.74 seconds for the fourth cycle. The mean reading time for the whole display was 1.93 seconds. The development of an altimeter displaying a non linear scale on its dial face is now in progress, and it will not be long before an altimeter of this design is available for use.

## Conclusion

The altimeter on an aircraft does in fact serve two different functions. Most of the time, the pilot merely wants to know in general whether he is, say around 20,000 feet. Occasionally, however, he has got to know exactly how high he is. When he comes in for a landing, for example, he must know that he is exactly so many feet above the ground, so that he can make a proper approach to the airfield. It is therefore vitally important to resolve all possible complications in altimeter design which make interpretation difficult or render the dial face capable of being misread. The use of a counter with one sensitive pointer solves many problems of altimeter reading. Even better than this appears to be the non linear, logarithmic type of scale, which when available for use, will simplify the design considerably. This, at any rate, appears to be the verdict of laboratory experiments.

## DEVELOPMENT OF THE ALTIMETER DIAL

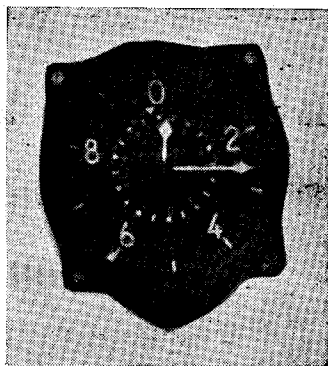


FIG. 1: The sensitive two pointer altimeter used in 1929 in blind flying experiments.

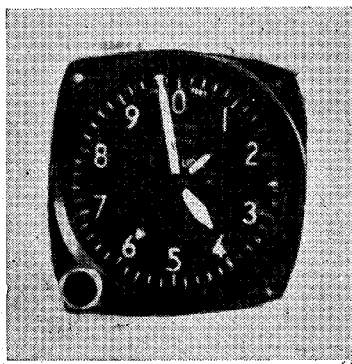


FIG. 3: U. S. Army model altimeter with range of 50,000 ft., developed in 1941, and used during World War.

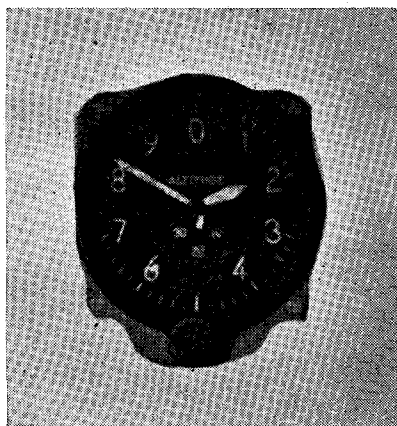


FIG. 2: Altimeter developed in 1933. Large pointer reads 100s. Small one reads 1000s. Tiny pointer on separate dial marks the 10,000 level.

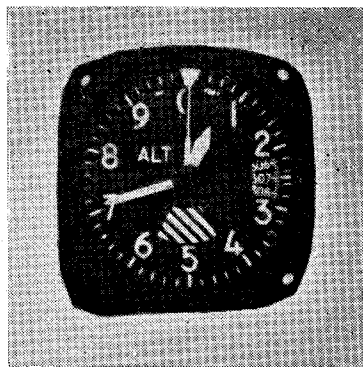


FIG. 4: Altimeter developed in 1954. Small pointer extended out of cover of other hands.

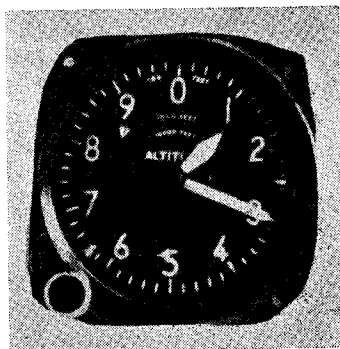
DEVELOPMENT OF THE ALTIMETER DIAL—*contd.*

FIG. 5 : A case of 'eclipsing'. The small pointer is covered by one of the other two.

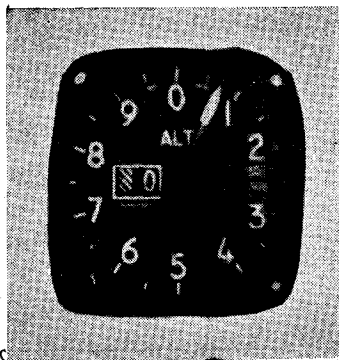


FIG. 7 : The 'veeder' counter single pointer altimeter, Kolsmann design developed in 1955.

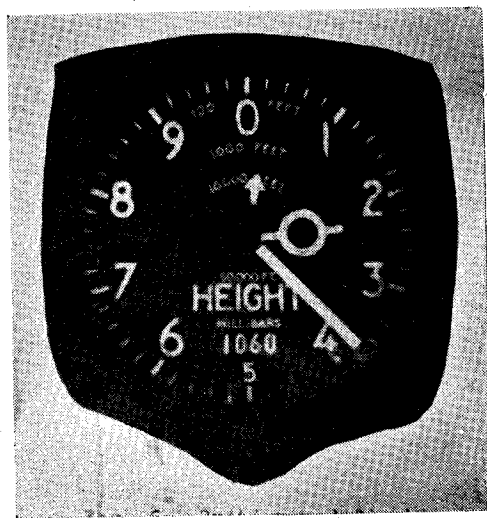


FIG. 6 : British modification adopted by RAF and RAAF. Trials on IAF pilots indicated 30% improvement in reading efficiency.

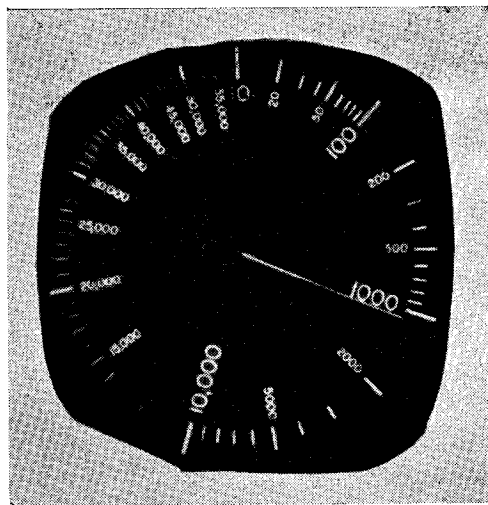


FIG. 8 : Non linear scale for altimeter dial, developed by Canadian Defence Research Medical Laboratory. March 1956.