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NRL Report 6242

Altimeter Display Evaluation

Final Report

J. H. HILL AND R. CHERNIKOFF

Engineering Psychology Branch
Applications Research Division

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ABSTRACT

A series of investigations has recently been completed to determine the relative effectiveness of various altimeter displays. These investigations, consisting of laboratory research at NRL and flight tests at NATC Patuxent River, were in support of a DOD program concerned with the replacement of current altimeters in most military aircraft with a servo-pneumatic type instrument. Four types of altimeter presentations, namely the counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P), were compared in a series of laboratory experiments measuring reading time and accuracy with both pilots and nonflying enlisted men. The same instruments were also compared by NATC in flight, using the questionnaire technique to elicit pilot judgments.

The results of the various phases of laboratory research showed that CP and CDP altimeter presentations ranked highest, followed by the DP, with the 3P consistently lowest. Pilot preference in the flight tests was overwhelmingly in favor of the CDP.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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ALTIMETER DISPLAY EVALUATION

FINAL REPORT

THE ALTIMETER PRESENTATION EVALUATION PROBLEM

Approximately 20 years of research and critical flight incidents have demonstrated inadequacies in the readability of the standard three-pointer altimeter (1). Despite these inadequacies, replacement of the three-pointer instrument in military aircraft has not received serious consideration because of two principal factors:

1. The multi-million-dollar cost of replacing existing altimeters in military aircraft.

2. Lack of clear evidence that a superior replacement instrument actually exists. Findings in research and flight tests directed toward determining the relative effectiveness of various presentations have been ambiguous and inconsistent.

The economic obstacle to a change of presentation has for the immediate present largely disappeared, however, because replacement of the altimeters in most DOD aircraft is currently required for reasons independent of display presentation. This requirement stems from recently imposed air-traffic-control rules which specify the installation of automatic height-reporting devices on most military aircraft as well as on commercial airliners and certain general aviation craft.

In order to arrange for equipping military aircraft to fulfill the requirements imposed by these rules, the Department of Defense has set up the AIMS program*, with interservice responsibilities. Since altimetery has an important bearing upon AIMS efforts, the Special Project Office of AIMS has expended considerable effort in attempts to establish a single replacement altimeter type for all DOD aircraft. Interservice agreement has been reached to employ servo-pneumatic altimeters as replacement for the existing standard barometric altimeters in high-performance aircraft. Servo-pneumatic instruments are capable of providing the required electrical signals to the height-reporting equipment. Excepted from replacement are existing altimeters which are already electrically driven, such as tape altimeters. Since a requirement for the changeover from barometric to servo-pneumatic instruments has been established, the present time is fortuitous to consider a change in altimeter presentation as well.

It still remains to determine with reasonable certainty that there is a display available which is, indeed, superior to the three-pointer. It is to this problem that the altimeter display evaluation, reported here, is directed.

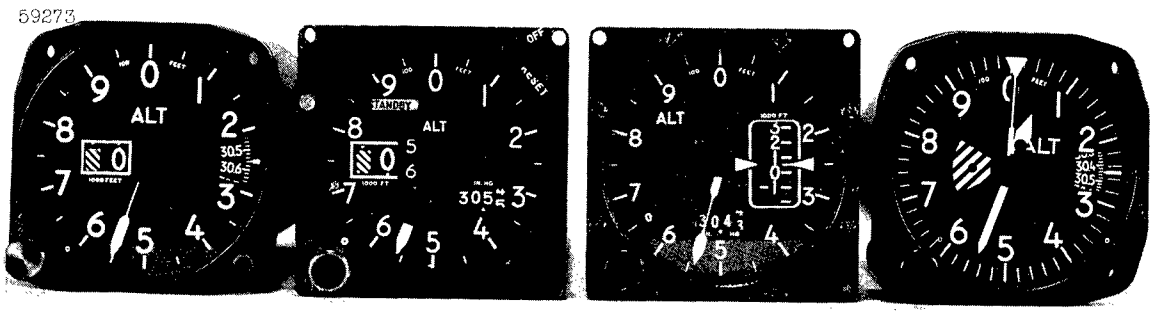
CRITERIA FOR SELECTING A REPLACEMENT ALTIMETER

Since the chosen instrument must serve as the replacement for altimeters now installed aboard large numbers of existing aircraft, consideration must be limited to instruments which will fit the space provided for the previously installed altimeter. Also, an instrument must be selected which is solely an altimeter, and not part of an integrated instrument system in a common case with other indicators.

*AIMS is an acronym for Air Traffic Control Radar Beacon System IFF/MK12/System. This title refers to the combination of equipments which will be used by DOD to communicate aircraft identity and height information to the air traffic control system.

Since the instrument must be of the servo-pneumatic type to conform to the inter-service agreement mentioned above, consideration must be given to the problem of servo deactivation in the case of power failure. The presentation selected should therefore be capable of adequate operation in a standby mode under direct drive from barometric pressure. The use of a separate standby instrument is not regarded as an acceptable solution.

The time schedule for the current replacement program limits consideration to those altimeters which are already developed to the point where they can be shortly put into production.



COUNTER-POINTER COUNTER-DRUM-POINTER DRUM-POINTER THREE-POINTER

Fig. 1 - The four types of altimeter presentations compared

There are available four basic types of altimeters (Fig. 1) which conform to the above requirements:

1. Counter-pointer (CP)
2. Drum-pointer (DP)
3. Counter-drum-pointer (CDP)
4. Three-pointer (3P).

Accordingly, the comparative evaluation reported here was limited to these four types.

NEED FOR EVALUATION PROGRAM

In order to make a selection of an altimeter presentation, a program of studies is required. Choice cannot be based on the data from previous investigations, since no comprehensive study has ever been made of the above four types of altimeter presentations under both laboratory and flight conditions.

The human-factors evaluation of altimeter displays has a history of numerous investigations, commencing with studies such as that of Fitts and Jones, 1947 (2), and Grether, 1948 (3). These earliest studies provided scientific data on the large and relatively frequent reading errors associated with the standard 3P altimeter, and suggested that a display incorporating a counter would result in fewer errors. Since that time, numerous studies on altimeter presentations have been carried out which employed various laboratory experiments, flight simulations, and flight tests. A comprehensive review of this work (1) indicates that the studies have, in the aggregate, been inconclusive. The reasons for this include the following:

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1. Differing effectiveness of a given instrument in the static as opposed to the dynamic situation. A presentation which permits fast and accurate readout of an unchanging value may prove inadequate when the reading is continually changing in response to a dynamic environment.

2. Differing aspects tested in the various studies. Previous studies have generally investigated only one aspect of altimeter use. In flight, an altimeter is used under diverse conditions, as indicated in the situations enumerated below.

a. The pilot has a reasonably accurate knowledge of the likely value even before reading the altimeter.

b. The pilot has no good estimate of what altitude reading to expect, as after recovery from an unusual attitude.

c. The pilot uses the altimeter to maintain or change altitude, and is thus continually referring to it.

3. Inadequate test procedures and data. This shortcoming is particularly true of flight tests, largely because of the high cost of performing extensive testing in the air and the difficulty of obtaining objective measures.

The currently required selection of an altimeter presentation therefore necessitates a program of studies which will:

- Test the various aspects of altimeter use
- Compare all four potential replacement presentations under appropriate experimental conditions
- Provide data which are as objective as possible.

THE PROGRAM

With the above goals in view, a program was formulated incorporating the following studies.

1. The first part of the program consisted of laboratory tests of the four types of presentations, aimed at measuring readability and tracking performance.

2. The second part of the program consisted of flight tests. These tests were characterized by the following aspects intended to improve objectivity.

a. A standardized profile was used for all flights.

b. There was a relatively large number of pilots and flights.

c. The flight-test schedule was designed so that the various altimeter types were tested in different orders for different pilots. This precaution served to prevent systematic biases which would be expected if the same order were used for all pilots.

d. The pilots' questionnaires were written to elicit pilot observations rather than simply opinions.

e. A second pilot, in the forward cockpit, observed the accuracy of flight performance and recorded pilots' comments and observations. This observer also served

as safety pilot, since all flights were performed either at night or with simulated blind-flying conditions (under the hood).

f. Approximately half of each flight was performed with the instrument gyro caged, so as to increase the pilot's work load and the stress he experienced. Thus, each altimeter test flight was, in part, appreciably more severe than a normal flight.

3. The third part of the program consisted of additional laboratory experimentation employing 18 of the same pilots who participated in the flight tests as well as seven Navy enlisted men who were inexperienced on altimeters. This experimentation provided (a) comparison between flight tests and laboratory tests, using the same subjects in both tests, and (b) comparison between the performance of pilots and nonpilots (enlisted men).

Flight-simulator tests of the altimeters were not part of this program. It was felt that the contribution of such tests to the already broad program would not be sufficient to justify the added cost, time, and effort that would be entailed.

INITIAL LABORATORY TESTS OF TRACKING AND READING

This first series of tests (4) consisted of both a tracking and a reading phase. In the tracking phase, the subject was required to set an altimeter to a commanded altitude by operating, with one hand, the valve controlling the vacuum which actuated the instrument, while simultaneously performing a two-coordinate compensatory tracking task using a joystick operated with the other hand. Data in this phase consisted of altitude errors and tracking errors. In the reading phase, the subjects were required to read a series of altitudes from each type of presentation. Records were made of reading time and errors. Five Navy enlisted men served as subjects.

The results were as follows. (a) Tracking performance was best for the CP and CDP, with no statistically significant difference between them; the DP gave significantly poorer results than the two leading altimeters, and the 3P ranked poorest. (b) The same ranking was found for reading time. The differences between the CP and the CDP were also not statistically significant, in the reading tests, while the DP was significantly inferior to the two best instruments; the 3P was significantly inferior to them all. (c) The reading-error data showed the same rank order; statistical significance was not tested for the error data.

FLIGHT TESTS

Flight tests of all four altimeters were performed by the U.S. Naval Air Test Center, Patuxent River (5). Ninety-two test flights were flown, using 23 pilots, each pilot making four flights, one with each altimeter. Level-off accuracy, as observed by the safety pilot, did not differentiate between altimeters. With every pilot, an improvement in control accuracy was reported by the safety pilot as the tests progressed, regardless of the order in which the various types of altimeter presentations were flown. In other words, control accuracy, as observed in these flight tests, was apparently related to practice with the aircraft and with the flight profile rather than to the type of altimeter used. The principal findings differentiating among altimeter types are to be seen in the questionnaire data rather than in observations of performance. Questionnaires were administered after each flight and at the end of the flight series.

The most meaningful finding was the relative overall pilot preference among altimeter types. Most pilots (19 out of 23) selected the CDP as first choice. The CP came next as the first choice of three pilots; the DP was next, with one first choice. The 3P was never accorded a first choice. The CDP was the overwhelming first choice of the pilots for

reading speed, reading accuracy, and clarity of information. The smoothest operating altimeters in standby mode were judged to be the 3P and DP. Aside from general preferences, the questionnaire data also brought forth comments on design factors.

ADDITIONAL LABORATORY TESTS

Following the flight tests, 18 of the pilots who participated, as well as seven Navy enlisted men, served as subjects in a combined tracking-readout task at NRL (6). While tracking, the subject was, from time to time, shown an altimeter which the experimenter had set to an altitude value according to a predetermined schedule. The subject would then read the altimeter, close a shutter which obscured the instrument and verbally report the altitude read. Measures were taken of the length of time the altimeter was exposed and reading errors.

The data for both time and accuracy indicated a rank order of CP, CDP, DP and 3P. The difference between CP and CDP altimeters was not statistically significant; all other comparisons were significant.

FINDINGS FROM ALL STUDIES

As indicated in the introduction, the present program was set up to sample a broad spectrum of conditions under which altimeter presentations are employed; the program included tasks of complexity varying from simple readout to actual use in flight. The data from the laboratory and flight tests discussed above consistently show the CP and CDP altimeter presentations to rank highest in all comparisons, followed by the DP, with the 3P ranking lowest. Accordingly, the review in terms of human-engineering factors, as given below, will be confined to the CDP and CP types.

HUMAN-ENGINEERING FACTORS IN THE CDP AND CP ALTIMETERS

In addition to the studies discussed above, the CP and CDP presentations were subjected to an examination of their design details from a human-factors point of view. None of the design aspects were found to be serious enough to imply an alteration of the order of choice indicated by the test data, although certain features are susceptible to improvement through minor redesign. To the extent of feasibility, these improvements should be accomplished in the design of the presentation selected prior to commencement of production.

COMMENTS ON THE CP ALTIMETER

Although the CP instrument has been demonstrated to be superior to the 3P in tests extending back to 1947, the mechanization of this design has always been limited by unfavorable response characteristics whenever the instrument is made to operate without a servo. This response is due to the friction imposed by the Geneva movement, which is used to achieve a rapid change of counter digits. A fuller discussion of the mechanization is contained in Ref. 7. In terms of effect on the display, the friction causes the pointer and counter to stop upon reaching a region where the Geneva movement commences to engage; when sufficient differential pressure is built up to overcome the friction the pointer whips, overshooting the true reading. The effect, which destroys the smoothness of rate indication, is particularly noticeable during slow rates of climb or descent. It has proven unacceptable to pilots in flight tests and could be contributory to 1000-ft reading errors.

Considerable development effort has been put forth to minimize the friction; as a result, the CP instrument is much improved over early models, yielding reasonably smooth performance when a vibrator is installed to reduce the effect of friction. Consequently, the CP instrument can be depended upon for smooth operation, even when power failure causes servo stoppage, provided that vibrator action is maintained. This action would be maintained if the vibrator were connected to the emergency power buss. The problem of pointer hang-up and whip becomes negligible when the altimeter's servo mechanism is active, as would be true almost all of the time.

COMMENTS ON THE CDP ALTIMETER

The CDP instrument is subject to the same hang-up and pointer-whip problems which affect the CP instrument. The above comments on these problems in the CP instrument also hold for the CDP.

The CDP instrument presents the problem that the pilot may misinterpret the hundreds digit, on the drum, as a thousands digit. As an example, with the ten-thousands digit being zero, the thousands digit 1, and the hundreds digit 3, the actual reading would be 1300 ft; if the confusion under consideration were to occur, the indication would be interpreted as 13,000 ft. The possibility of such confusion was voiced by some of the pilots participating in the flight tests.

A possible solution for the second problem resides in reversing the figure-ground contrast on the hundreds drum from that of the thousands and tens of thousands counters. For instance, if the thousands counter has white numerals on a black background, then the hundreds drum would have black numerals on a white background. It is felt that this reversed-contrast coding would prevent confusion of hundreds and thousands digits; it follows the precedent of automobile odometers, on which contrast is reversed between the miles counters and tenths-of-mile drum. Such an arrangement would present no problem under daylight illumination. Neither is it a problem under nighttime illumination, provided that this is not the backlighting type, which shows only through the digit outlines. The latter lighting scheme would obviate the value of figure-ground contrast coding, since all digits would be seen as illuminated figures against a dark field.

Although no objective evidence was obtained favoring the CDP over the CP, the CDP is acceptable provided that no detrimental factors can be charged against it. The main potential detriment, the possible confusion of a hundreds digit for a thousands digit, can probably be eliminated by the expedient of reversing contrast, as indicated previously.

SUMMARY OF PROGRAM FINDINGS AND INTERPRETATION

The following conclusions can be drawn from the data in the three studies.

1. In all objective measurements taken, the 3P altimeter ranked the poorest among the instruments tested. The finding that the 3P was poorest proved to be statistically reliable in every study in which tests of statistical significance were applied.

2. The DP ranked consistently below the CP and CDP in all tests. Its differences from the CP and CDP were found to be statistically significant in two aspects of the initial laboratory tests, and in the reading-time aspect and most of the error comparisons of the second laboratory series. The laboratory tests provided not a single item of evidence that the DP was superior to the CP and CDP.

3. The CP ranked ahead of the CDP in most of the laboratory tests, but the differences were usually small and were not statistically significant in all comparisons where

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statistical tests were applied. It is therefore reasonable to conclude that performance of CP and CDP is equivalent. Lacking clear-cut, objective evidence of superiority of one of these instruments over the other, one would be justified in selecting either. Under the circumstances, pilot preference would be a good basis for selection between them. Such a preference was strongly indicated on the flight-test questionnaire, in which 19 of the 23 pilots favored the CDP instrument.

There is no evidence available, from the performance data of this program, that the CDP instrument would compromise plane-pilot performance. Neither is there evidence, from the human-factors consideration of the instrument design, that it contains inherent, unalterable characteristics which predispose it to misreading or other difficulties in use.

In summary, then, the objective evidence of this program indicates the 3P instrument to be least desirable, while the CDP and the CP are tied for first place. The DP, although sometimes close to the leading contenders, ranks consistently below them in all laboratory tests. With the choice, then, being between the CDP and the CP, the former is suggested on grounds of overwhelming pilot preference. To select the CP would go against this preference, an action which could not be justified on the basis of the objective evidence gathered in this program.

ACKNOWLEDGMENTS

This program was originated as a Navy effort by Mr. J. Wolin and Cdr. H. Heininger of the Instrumentation Branch, Bureau of Naval Weapons. Subsequently, the work was incorporated into a DOD-wide program, largely through the efforts of Mr. Walter Melnick of the Special Project Office, AIMS Program. They have all extended themselves in assisting and encouraging these investigations, for which the writers are indebted.

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A series of investigations has recently been completed to determine the relative effectiveness of various altimeter displays. These investigations, consisting of laboratory research at NRL and flight tests at NATC Patuxent River, were in support of a DOD program concerned with the replacement of current altimeters in most military aircraft with a servo-pneumatic type instrument. Four types of altimeter presentations, namely the counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P), were compared in a series of laboratory experiments measuring reading time and accuracy with both pilots and nonflying enlisted men. The same instruments were also compared by NATC in flight, using the questionnaire technique to elicit pilot judgments.

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