Report No. FAA-RD-72-46

A SUMMARY ON ALTITUDE DISPLAYS WITH AN ANNOTATED BIBLIOGRAPHY

Jack J. Shrager
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

MAY 1972

FINAL REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington D. C., 20591

FSS 000164 R

The contents of this report reflect the views of the National Aviation Facilities Experimental Center, Atlantic City, New Jersey, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification or regulation.

The Federal Aviation Administration is responsible for the promotion, regulation and safety of civil aviation and for the development and operation of a common system of air navigation and air traffic control facilities which provides for the safe and efficient use of airspace by both civil and military aircraft.

The National Aviation Facilities Experimental Center maintains laboratories, facilities, skills and services to support FAA research, development and implementation programs through analysis, experimentation and evaluation of aviation concepts, procedures, systems and equipment.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-72-46	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SUMMARY ON ALTITUDE DISPLAYS WITH AN ANNOTATED BIBLIOGRAPHY		5. Report Date May 1972
		6. Performing Organization Code
7. Author(s) Jack J. Shrager		8. Performing Organization Report No. FAA-NA-72-6
9. Performing Organization Name and Address National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405		10. Work Unit No.
		11. Contract or Grant No. Project No. 076-311-01X
12. Sponsoring Agency Name and Address FEDERAL AVIATION ADMINISTRATION Systems Research and Development Service Washington, D. C. 20591		13. Type of Report and Period Covered Final Report November 1971-February 1971
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A review of all literature published since 1960 relating to aircraft height or altitude display was made. This review was supplemented by a series of conferences with experimentalists currently working in this field. The results of the literature review and series of conferences are evaluated and summarized, and this is further supplemented by an annotated bibliography of the documents included in the literature review.

17. Key Words Altimeter Flight Instrument Displays Human Factors	18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	81	$3.00 PC .95 MF

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

INTRODUCTION

Purpose

The objectives of this literature review and analysis were:

1. Review and summarize general altimeter display reasearch for the post 1960 period.

2. Identify areas for further Research and Development (R&D) work based on the results and conclusions of the previous work identified through "1" above.

Background

Under the direction of the Systems Research and Development Service (SRDS), of the Federal Aviation Administration (FAA), a study was instituted by the MITRE Corporation to provide guidance to FAA for future R&D in altimetry. The basis for this guidance would encompass:

1. A review of National Transporation Safety Board (NTSB) reports for altimeter-related accidents.

2. A literature review and analysis of height information display research since 1960.

3. Examination of existing altimeter installations and evaluation of generated retrofit costs for improved displays.

4. Consultation with the several experts in the aviation community and government agencies on the subjects of altimetry and altitude display.

Item 1 was undertaken by the Flight Safety Foundation (FSF), Item 2 by the National Aviation Facilities Experimental Center (NAFEC), and Item 3 by the MITRE Corporation. Item 4 would be a cooperative effort of the several investigators and the complete undertaking would be coordinated by MITRE.

DISCUSSION

General

The considerations which influence altitude display were delineated in a U.S. Air Force technical report titled "Altimeter Display Study" (Index No. 10). The report places emphasis on the relationship of "what information man needs rather than an interest in the overall amount of information which must be processed for control of the system." This raises the question of the priority of altitude information.

Another approach to flight information display is discussed analytically in "A Manual Control-Display Theory Applied..." (Index No. 71). Here, the pilot is considered as part of a complex servo system which includes the aircraft's stability characteristics and utilizes the display and the pilot's control input as part of the feedback loop and system control. Here, too, the question of the priority of displayed information is raised.

There are some modes of aircraft operations in which the absolute value of pressure altitude, flight level, or absolute altitude are of primary interest. Included in this area are assigned altitude in positively controlled airspace and minimum descent altitude (MDA) in instrument approaches other than Category III. The former example is one in which altitude control is about a constant reference altitude. The second example is one in which not only the absolute numerical value of altitude is important, but so is the rate at which a reference altitude is being approached. The first is an example of what information man needs, the second, an example of the pilot as part of the servo system.

Another mode of aircraft operations places the presentation of the numerical value of height into a secondary role. Included in this area are level flight utilizing some form of automatic altitude hold, Category III automatic landings, flight director system which includes vertical situation information and manual instrument approaches which utilize glide slopes. The altimeter is subservient to some other flight instrument (e.g., glide slope indicator) in all the examples noted.

Bibliography

The sources for the publications contained herein were in part:

1. Aeronautical Engineering Index

2. International Aerospace Abstracts

3. NACA Index of NACA Technical Publications

4. NASA Scientific and Technical Aerospace Reports

5. NASA Technical Publications Announcements

6. Technical Abstract Bulletin, ASTIA, 1960-1963

7. Technical Abstract Bulletin, DDC, 1964-1971

8. Termatrex Index of Reports in the FAA Library, Washington, D.C.

9. U.S. Government Research and Development Reports, 1965-1971

10. DDC Bibliography ARB 021131, "Barometric Altimetry," August 14, 1969, 66 sheets

11. DDC Bibliography ARB 041655, "Display Systems," October 28, 1965

The documents contained in the bibliography, which are listed in alphabetical order by title, were reviewed in detail. A critical abstract or summary has been included in most cases along with the author, date of publication, and cognizant organization.

As a further aid to the reader, an authors' index is also provided with the index number reference also included.

Literature Review

A detailed review of the publications contained in the bibliography was accomplished. Specific efforts were directed toward extracting those test results which could be incorporated in this report which would contribute toward accomplishing the above noted objectives. All test results incorporated are not necessarily presented in the exact manner in which they appeared in their respective publications. In some cases, the analysis or presentation of the results have been supplemented by the author for clarity or emphasis. The publication from which they were extracted is identified by its appropriate index number.

The analytical technique used and conclusions reached by the author are paraphrased for brevity or clarity, unless specifically set off in quotations. The source of these abstracts are also identified by their corresponding index number.

Consultations

Formal and informal conferences were held or attended with experimentalists in the field of aircraft flight instruments and instrument display. Included were:

1. Air Carriers

    a. American Airlines
    b. Eastern Airlines
    c. Ozark Airlines
    d. Ransome Airlines
    e. TransWorld Airlines
    f. United Airlines

2. Airframe Manufacturers

    a. Beech Aircraft
    b. Boeing Airplane
    c. Cessna Aircraft

d. Douglas Aircraft
e. Hughes Aircraft
f. Piper Aircraft

3. Airplane Owners and Pilots Association (AOPA).

4. Air Transport Association (ATA).

5. Government Laboratories

   a. Aberdeen Proving Grounds (APG)
   b. Aeronautical Systems Division (ASD)
   c. National Transportation Safety Board (NTSB)
   d. Naval Air Development Center (NADC)
   e. Naval Air Systems Command (NASC)
   f. Naval Air Test Center (NATC)
   g. Transportation Systems Center (TSC)

6. Institutes and Research Organizations

   a. Massachusetts Institute of Technology (MIT)
   b. Systems Technology Incorporated (STI)
   c. University of Illinois

7. Flight Instrument Manufacturers

   a. Aerosonics
   b. Bendix
   c. Karman Autodyne
   d. Kollsman Instruments
   e. Ryan Aeronautics
   f. Smith Instruments
   g. Spar Aerospace
   h. Sperry

The discussions were directed toward supplementing their respective published technical documents in the display field, reviewing current experimental efforts, and projecting anticipated programs or system applications specifically in the height display area.

Displays

The types of displays are categorized as:

1. Pointer (1P, 2P, and 3P)

2. Drum-Pointer (DP)

3. Counter-Pointer (CP)

4. Counter-Drum Pointer (CDP)

5. Counter (C)

6. Vertical Tape (VT)

7. Miscellaneous

A broader form of categorization of the various altitude displays which is sometimes used is:

1. Analog - Any display which employs a moving indicator with respect to a fixed numerical or symbolic scale.

2. Digital - Any display which uses a changing numerical presentation as part of the display.

Using this broader categorization, the displays shown in Figures 1, 2, 3, and 15a would be grouped as analog and all the other displays shown in Figures 4 through 15 would be considered digital. A more descriptive and definitive general grouping would be to separate those displays which use a combination of numerical and analog from those using numerical only.

The pointer-type altimeter is the one most frequently found in general aviation aircraft and is still being used in many military and some commercial aircraft. The various types of pointer altimeter displays are shown in Figures 1 through 3, inclusive. The pointer type usually encountered is the 3P which has a large pointer for indicating hundreds of feet, and an intermediate size pointer for indicating thousands of feet, and finally a small third pointer which indicates ten thousands of feet. These pointers are mechanically driven through a gear and lever system by an aneroid-type pressure transducer.

The various types of DP displays are shown in Figures 4 to 6. This type of display utilizes a large pointer for indicating hundreds of feet, and a single vertically rotating drum which indicates thousands and ten thousands of feet. The drum-pointer type of altimeter is usually a mechanical type, similar in construction to the pointer type. However, there are some altimeters using this type of display which are electrical servos that are being driven from a central air data system (CADS).

The several CP types of displays are shown in Figure 7. This display also utilizes the single pointer for indicating hundreds of feet and an independent vertically or horizontally rotating drum or other type of gear driven numerical display to indicate thousands and tens of thousands of feet. This type of display may be driven mechanically, electrically, or by a combination of both. One version of the CP display, not shown in any of the above noted figures, utilizes light-emitting diodes to generate the numerical display.

Shown in Figures 8 to 12 are the CDP types of altitude display. This type used the pointer for indicating hundreds of feet and may be supplemented by a vertically rotating drum or other display presenting the numerical display of this quantity in 20 or 50 foot increments and independent counters or drums representing thousands and tens of thousands of feet. The military version of this type (AAU-19) of instrument is a servo instrument with a pneumatically-operated mechanical backup. Most air carrier versions of this type of display utilize the electrical servo version.

The vertical tape-type of altitude are shown in Figures 13 and 14. This type of display presents altitude on a single, vertically moving, servo-driven tape which indicates discrete altitude.

Other types of experimental displays are shown in Figure 15. These displays are experimental only, and are discussed in detail in the particular document identified by the index number shown in the brackets under the particular figure.

TEST RESULTS AND ANALYSIS

Displays

Multiple-Pointer: Several techniques have been employed to enhance the multiple-pointer displays. The techniques included:

(1) Cross-hatched window which indicates when the instrument is presenting an altitude below 10,000 feet (Figure 1a);

(2) Cross-bar on the 10,000 foot indicating pointer, (Figure 1d);

(3) Design of the 10,000 pointer to give the illusion of perimeter indexing (Figure 1c);

(4) Masking of pointers not in use (not shown).

The investigations relating to these techniques predates the period covered by this report. However, the experimental work covered in the literature review, reflects several different versions of pointer enhancement.

Drum-Pointer: Various techniques for improving the display characteristics of the DP altimeter have been utilized. These include:

(1) Numerical display of barometric setting, (Figure 4a versus 4b);

(2) Reduction in dial clutter through use of 50 foot scale increments (Figure 4a versus 4c);

(3) Minimizing ambiguity at zero altitude (Figure 4d versus 4a);

(4) Blockage of the drum indication by the pointer (Figure 4d versus 4b);

(5) Minimizing ambiguity in 1,000 foot indication by partial masking (Figure 5c);

(6) Metric and english system indication of the barometric setting (Figure 5d);

(7) Decimal increment for numerical metric barometric setting (Figure 6a);

(8) Horizontal versus vertical drum display (Figure 6c versus 6b).

The experimental evaluation of these several techniques are not covered in the time period of this report (1960 to 1971, inclusive), and in some cases, has not been specifically evaluated.

Counter-Pointer: The techniques which have been incorporated into the CP altimeter to improve readability or reduce errors include:

(1) Reduction in dial clutter by use of the 50 foot scale increments (Figure 7a versus 7b).

(2) Numerical display of barometric setting (Figure 7d versus 7a).

(3) Size of numerical display characters (Figure 7b versus 7a).

(4) Inside dial versus outside dial location of counter (Figure 7b versus 7a).

Evaluation of these techniques are not covered in the literature covered in this report.

Counter-Drum-Pointer: The methods employed in the display design of CDP type altimeters include:

(1) Number of counters (Figure 8d versus 8a).

(2) Number of digits on the drum (Figure 8c versus 8a)

(3) Position of numerical display in the inside dial presentation (Figure 8a versus 8b versus 8d).

(4) Character color and background (Figure 8c versus 8d)

(5) Variation of character size (Figure 8d versus 8c).

(6) Variation in drum scaling (Figure 10a versus 8c).

(7) Location of dual barometric indicators (Figure 10d versus 8d).

(8) Transition of the counter segment (Figure 9a versus 9d)

(9) Color contrast between counters and/or drum (Figure 12a).

(10) Dial scaling (Figure 12b versus 12a).

(11) Barometric setting units (Figure 11c versus 11b).

(12) Dial character size (Figure 11d versus 11c).

The variations in the displays, which have been identified above, are not discussed nor have they been evaluated in the literature contained in the bibliography.

Literature Review

The Naval Research Laboratory (NRL) report of December 1964, Index No. 54, covers the evaluation of the 3P, DP, CP, and CDP altimeter displays by both pilots and nonpilots. Shown in Figures 1c, 4a, and 11d are the displays of the 3P, DP, and CDP instruments covered in the NRL document. The CP display was that shown in Figure 7a with the exception that the barometric setting indication was similar to that shown in Figure 7c. The total number of errors by each subject group and the mean number of errors for each display, as reflected in the report, are shown in Figure 16. These results indicate that the 3P-type display was the most error-prone and took the longest time to interpret. Using pilot subjects, the results indicated that the best display was the CP, however, the nonpilot subjects were less error prone with the CDP display. The total mean error shown in the upper table are approximately equal for both the CD and CDP displays, less than half of that for the DP display, and 10 percent of the total mean error of the 3P display. This report noted that the CDP display induced a 1,000-foot high leveling error during descent. This was apparently due to the dual presentation of the counter and dial as one approaches a given thousand-foot increment. The fact that the 1,000-foot leveling error was more common than a 100-foot leveling error, suggests that the pointer was used cooperatively, as opposed to independently, with the counter by the subjects to establish the 100-foot value.

The test results of the NRL Report of April 1964, Index No. 27, are shown in Figure 17. The altimeter displays employed in this program are shown in Figures 7a (CP), 10b (CDP), 4c (DP), and 1c (3P). The subjects used in this program were five Navy enlisted personnel without previous knowledge of altimeter displays. The results also indicate that more errors were experienced with the 3P display than those experienced with all other types tested. This is shown in tabular form in Figure 17 for both the 200 trials and the 400 trials. The test results also show that the CP display produced the best results, both in decision time and resultant errors, closely followed by the CDP. The tracking error performances of both the CP and CDP displays are similar and better than the DP and 3P displays. The 1,000-foot error problem associated with the CDP displays is clearly shown in the lower table of Figure 17.

A flight test evaluation was conducted by the NATC using 23 military pilots. The displays used in these test are shown in Figures 1c (3P), 4c (DP), 7a (CP), and 10b (CDP). Ninety-two flights of approximately 1.5 hours each were flown during this program. The test results reported, Index No. 60, based on a preferential questionnaire, are shown in Figure 18. The least desirable in every category shown was the 3P display. The preferred display was the CDP with the CP a poor second. It should be noted that this preference reflects a transposition of the test results obtained by NRL regarding the CP and CDP displays. This may, in part, be due to the fact that the U.S. military's display experience is greater with the CDP than with the CP display and could be biasing the results.

The U.S. Air Force results relating to these tests, Index No. 110, show the pilot preference noted in Figure 19. The displays used in this experiment were the same as that used in the NATC tests above. These results are consistent with the NATC report noted above. Here again, next to the 3P, the U.S. Air Force's greatest experience at the time of these tests was with the AAU-19 type CDP altimeter display. The marked preference, of the display by the subjects was probably due to this experience.

The Aeronautical Research Laboratories (ARL) of the Commonwealth of Australia ran an evaluation of three production-type altimeter displays using six pilot subjects. Results shown in Index No. 53 for the single task experiment are, in part, shown in Figure 20. The total number of readings made by each subject was 40, and the definition of gross error was one whose magnitude was greater than 100 feet, though the subject was to read to the nearest 50 feet. These results again indicate the relatively poor showing of the 3P display, and indicate that the CDP display does not necessarily produce the best test results. However, the reported preferential ranking of the subjects showed a preference for the CDP display over the DP and the least, by far, was the 3P. There is a strong possibility that the pilot subjects may have had significant experience with the CDP display used. Therefore, the marked preference reflected in the report for the CDP display may have been influenced by such experience.

The RCAF Institute of Aviation Medicine (IAM) report of December 1962, Index No. 23, reflects the simulation test results obtained with six pilot and six nonpilot subjects with three different types of altimeter displays. These results are shown in Figure 21. The altimeter classified as a counter-analog (CA) is a modified version of the CDP display. The difference between the experimental CA (Figure 12b), and CDP (Figure 11c), displays is that the former used a single pointer and scale arrangement in which one revolution represented the full range of the altimeter. The test results indicate that the 3P (Figure 2c) produced more errors than either of the other displays for both types of subjects. The results show that the 1,000-foot error for the 3P is equal to or greater than the other displays. The influence of pilot familiarity and experience is the probable cause for the reduction in the 1,000-foot reading error with the 3P display. The fact that the CA display produced the least errors is not believed to be in conflict with previously noted results for a CDP display due to the difference in pointer and scale characteristics. Most of the 1,000-foot leveling errors by the pilot subjects were in the descent mode regardless of the display.

The level-off error was also reported by C. Gainer, (Index No. 98). His results which used the CDP (Figure 9a), CP (Figure 7b), and DP (Figure 4a), displays are shown, in part, in Figure 22. These results also reflect that the displays which used counters are more sensitive to misinterpretation during changes in altitude.

A simulation program to evaluate five digital-type altimeter displays was conducted by Douglas Aircraft, Index No. 97. The displays shown in Figure 23 were evaluated by 10 experienced pilot subjects. The results shown in Figure 24 reflect the ranking of each altimeter display; thus, the lower the numerical value, the higher the display preference. It was noted that the performance of the "A" display was biased by a jitter in the display and that of "C" by a partial malfunction in the hold feature at 80 and 00. Their conclusions indicate that this could eliminate performance difference between altimeters A, B, and C. Test results indicate that displays D and E (CP-type) resulted in the largest number of 1,000-foot errors. The transposition of the CDP and CP in the 1,000-foot error area may be influenced by the fact that displays D and E were modified CDP displays. Further, both analog CDP displays resulted in more 1,000-foot errors than the snap-action display. The average tracking error was poorest with the snap-action display. This indicates that there could be deficiencies in such a display.

A RAF IAM report of August 1964, Index No. 30, notes the results of a CP (Figure 15c), pointer-only, same as Figure 15c with the counter masked, or counter-only (Figure 15d) display under limited dynamic conditions. The randomized altitude changes were between -275 to +300 feet. The test results of 12 subjects are shown in Figure 25. Although the summary results indicate better performance by the ranking of the pointer-only display, there are indications of noticeable improvement between test 1 (T1) and test 2 (T2) for the CP. Both displays, CP and P, which provide rate information through pointer motion, indicate improved performance under simulated dynamic conditions.

A tracking experiment was conducted by IAM in March 1966, Index No. 43. This experiment reflected the results obtained using a CP (Figure 15c), and counter-only (Figure 15d) display in which the random variation of altitude was -800 to +600 feet from an assigned altitude. The subjects were eight airmen from IAM's staff. These results, showing a tracking-only and a tracking-with a secondary task, are shown in Figure 26. There is a noticeable degrading in tracking performance with the counter-only display. The tracking performance deteriorates even further with a simple secondary task. An additional experiment was conducted by IAM (Index No. 106), in which the assigned altitude that was to be tracked was varied during the tests. The displays to be evaluated were again just the CP and counter-only. The test results are shown in Figure 27. These results indicate that, while the pilot subject is able to compensate for random deviations in a tracking problem with the CP display, his performance sharply deteriorates when given a secondary task. These results reflect the sensitivity of vertical tracking performance to even small increases in workload when changes in altitude are part of the problem.

One of the studies of pilot eye scanning behavior during the approach and landing phase of flight operations was reported by Systems Technology Inc. in August 1970, Index No. 72. The percentage of time spent on each instrument and the eye-scanning pattern between instruments are shown in Figure 28. These results indicate that during the approach phases noted, the Altimeter (PALT) occupies less than 10 percent of the pilot's attention. This suggests that the altimeter may be in a secondary role for vertical guidance.

Conferences

The ASD, U.S. Air Force, is currently engaged in a jointly sponsored program, which includes the FAA, on the evaluation of six altitude displays. Included in the evaluation is the vertical tape display. The program is using the simulation of a large transport category aircraft and both military and ATR rated civilian pilots. Among those characteristics being evaluated are 20-foot versus 50-foot scale increments.

Three of the flight instrument manufacturers are currently engaged in a development program to improve both the altimeter system and its display. These efforts include the development of low cost, snap-action CDP altimeters, CP altimeter displays using light-emitting diodes, and cathode ray tube (CRT) EADI, displays which incorporate digital presentation of altitude, and also advanced vertical situation indicators (VSI) with digital altitude presentation. Examples of some of these displays are shown in Figure 29 through 31.

The air carriers are introducing or have introduced the CDP altimeter into their respective fleets to replace the 3P. In many instances, this action of replacing the 3P-type altimeter was an adjunct to providing an altitude reporting capability in their fleet of aircraft. In the process of accomplishing the conversion to CDP displays, the same type of aircraft within a given carrier's fleet may have different altimeter displays. Further, in some cases, only the captain's altimeter is being changed, thus resulting in different altimeter displays for the captains' and first officers' flight panel. The type of CDP display used varies from one carrier to another and includes the broad spectrum available from American manufacturers of altimeters. Several of the carriers retain a 3P altimeter as a third altimeter in the cockpit which has been located toward the lower center of the flight instrument panel as a backup. The other types of displays such as the DP and CP, which are adaptable to meet the altitude reporting and altitude altering requirements, are still in use. It was the collective opinion of those in attendance at the FAA sponsored RNAV conference, held at Washington, D.C. in March 1972, that the next major change which was anticipated would be related to the broad application of 3-dimensional area navigation (3D RNAV), the next generation of aircraft with the CRT display or both. These forecasts were based on the cost benefit which would direct such a decision.

The several groups which are associated with the manufacture, sale, or operation of the general aviation aircraft indicated that the principal display in use is the 3P. Due to the requirement for redundancy in the event of power failure, and hence the increased cost, low cost new aircraft are usually equipped with pointer-type pneumatically driven altimeters.

Efforts to establish those critical design criteria for the optimization of CDP displays or programs to develop acceptable CDP displays for general aviation use were not evidenced by either the literature review or during the conferences held or attended.

CONCLUSIONS

The following conclusions may be drawn from the information gleaned during the literature review and series of conferences:

1. Tests indicate that numerical presentation (C, CP, CDP) of altitude is less prone to misinterpretation than the analog type (circular or vertical displacement index or pointer).

2. When the altimeter is used as a primary height instrument, both quantitative height and qualitative rate information is used.

3. Comparative laboratory, simulator, and flight tests of 3P, DP, CP, and CDP altimeter displays indicate that the least preferred was the 3P and the most desirable was the CDP by subject opinion. This order of ranking is most pronounced when the subjects used were pilots as opposed to nonpilots. The subjective display preference was further accentuated when random dynamic changes in altitude and secondary tasks were introduced into the experiment.

4. The 3P display required the longest time to interpret and produced the largest number of errors among all the production-type displays evaluated. The misreading errors included both those of 1,000- and 10,000-foot altitudes. The experimental test results have been supported by significant actual flight experiences on the part of both the military and commercial aviation.

5. A majority of the air carriers and the military have or are converting to displays other than the 3P. The principal display selected has been the CDP.

6. The most prevalent type of altimeter display in general aviation is the 3P. The 10,000-foot error of the 3P display has not been supported by significant actual flight experience by general aviation. However, the 1,000-foot error is a problem in the 3P display.

7. There are electrical type CDP displays with built-in pneumatic redundancy. Due to the limited energy available in the pneumatic mode, this type is prone to 1,000-foot ambiguity.

8. Laboratory and simulator tests have indicated that the CDP display can be misread by 1,000 feet during climbing or descending flight. This type of problem has been encountered by both the military and air carriers.

9. The electrically driven CDP displays with snap-action motion supplemented by a ±20-foot hold feature at the 100- or 1,000-foot switching point did minimize the leveling problem experienced with the analog CDP display.

10. Reading errors due to pointer screening of the counter or drum were encountered with CDP displays. Various counter positions and display formats, which have been evaluated to date, did not significantly alter the problem.

11. Test results of CDP displays with the counters above and outside the pointers and the circular scale against the counters inside the scale did not produce significant results upon which design criteria could be based. Subjective opinions by pilots were equally inconclusive.

12. The vertical tape display resulted in improved pilot performance over any of the circular motion pointer displays when evaluated under steady-state altitude conditions or tracking to maintain a constant altitude. This display also resulted in improved performance when used in relation to furnishing command guidance.

13. The vertical tape presentation was not as desirable as the circular motion displays where both indicated altitude and rate of change of altitude information were required, such as approach and landing.

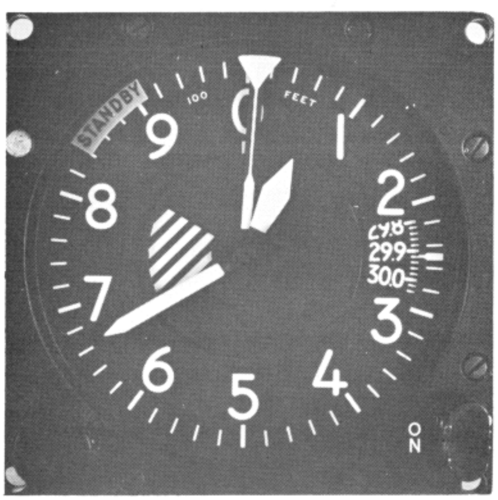
14. Counter-only displays were superior to all other displays where maintaining a constant, preselected altitude was the only requirement. This type of display was unacceptable when random dynamic changes of altitude were introduced into the experiment.

15. Counter-only displays used to supplement command or flight director guidance displays are currently being considered by experimentalists. Preliminary results suggest that with the altimeter presentation in a secondary role, the counter-only altitude display many not be objectionable.

16. The air carriers indicated that they were interested in the digital presentation of altitude coupled with such system components as the CRT presentations. Such a system does meet the requirement of an altitude altering requirement; would be compatible and adapatable to 3D RNAV; and the counter display could further serve as an independent altitude-monitoring role with the primary vertical guidance presented on the CRT.

a

b

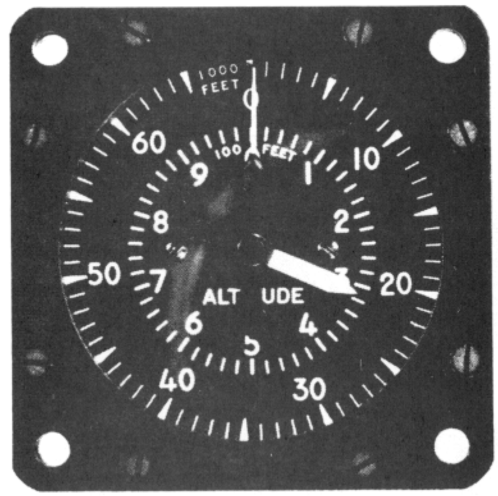


c

d

FIGURE 1   POINTER-ONLY-TYPE ALTIMETER DISPLAYS

a

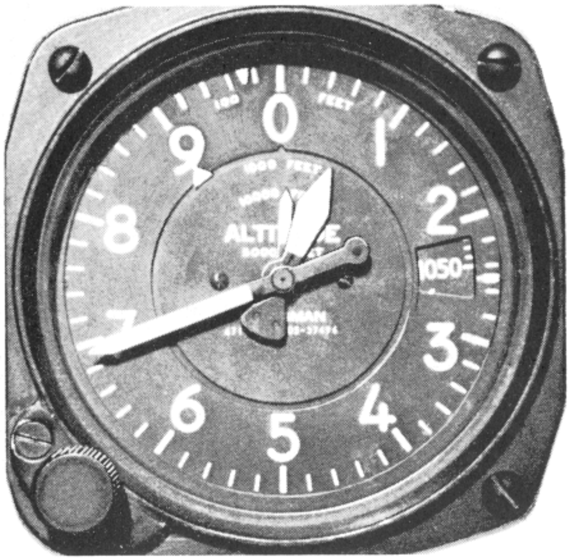


b

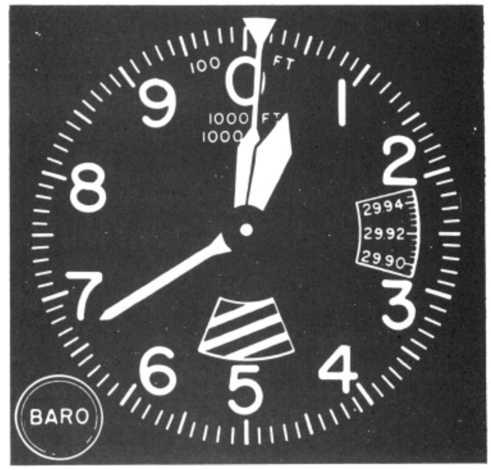
c

d

FIGURE 2 POINTER-ONLY-TYPE ALTIMETER DISPLAYS



a



b

FIGURE 3 POINTER-ONLY-TYPE ALTIMETER DISPLAYS

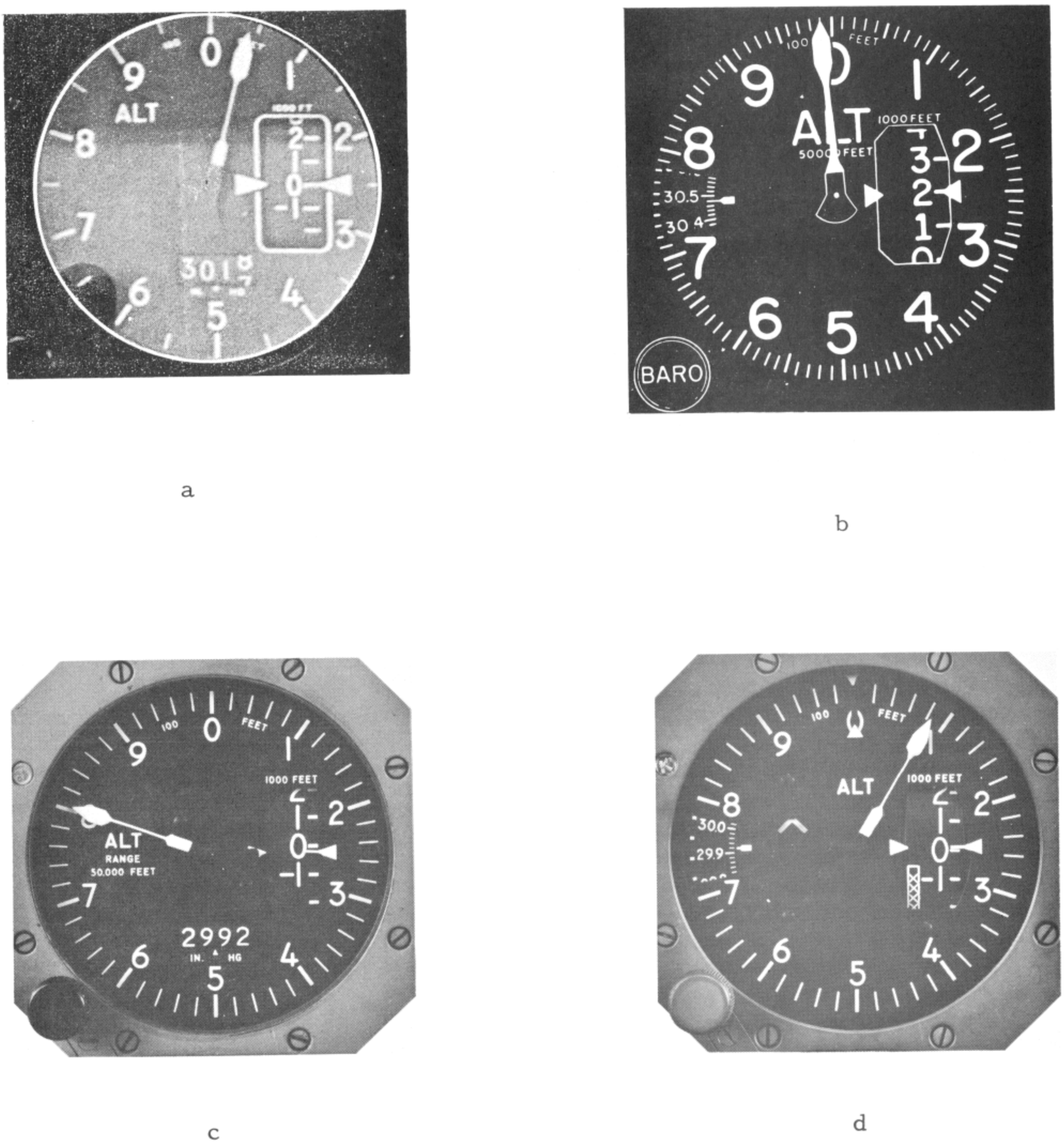
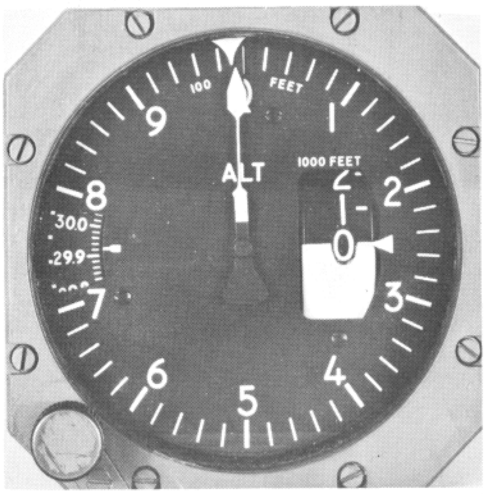
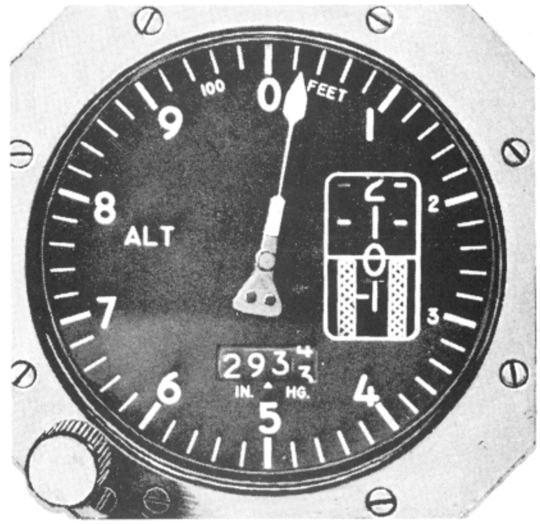


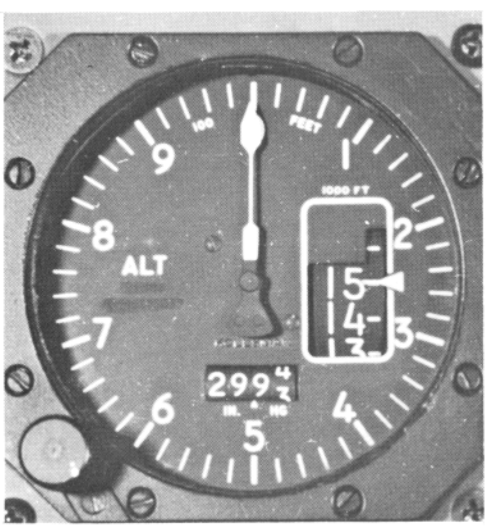
FIGURE 4 DRUM-POINTER-TYPE ALTIMETER DISPLAYS



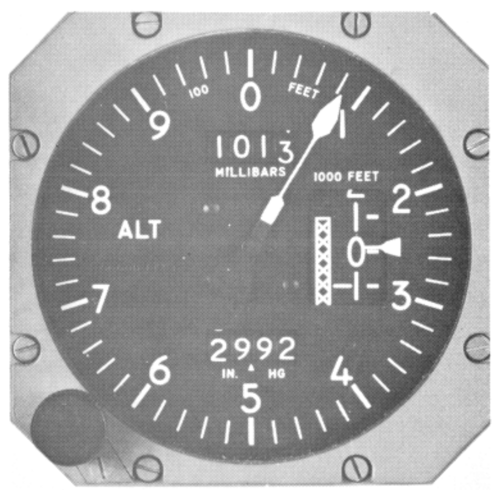
a



b

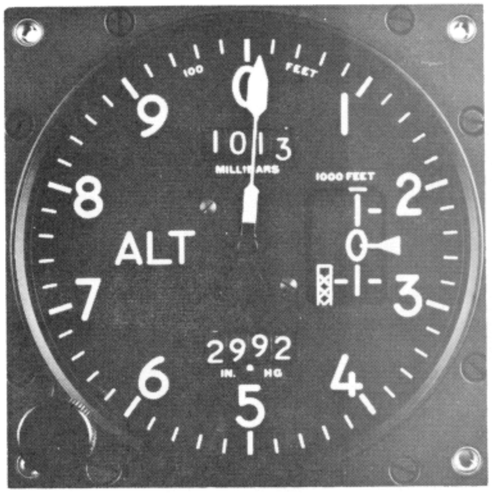


c



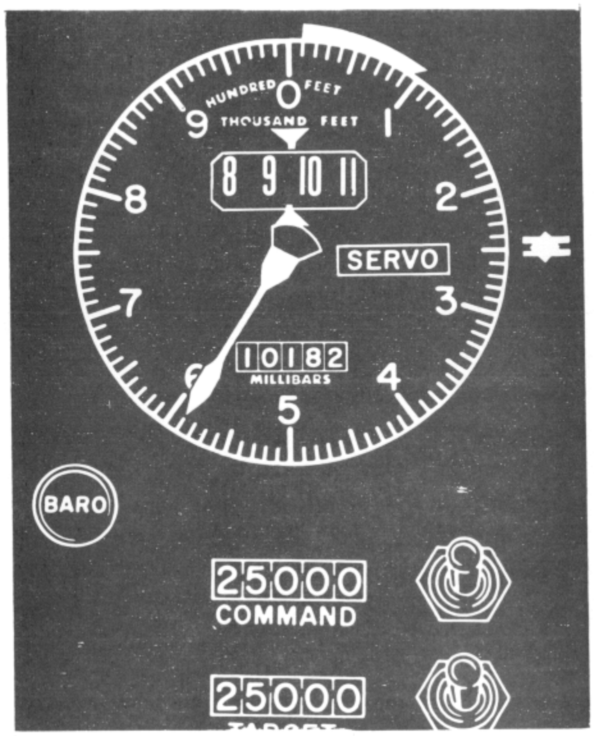
d

FIGURE 5 DRUM-POINTER-TYPE ALTIMETER DISPLAYS



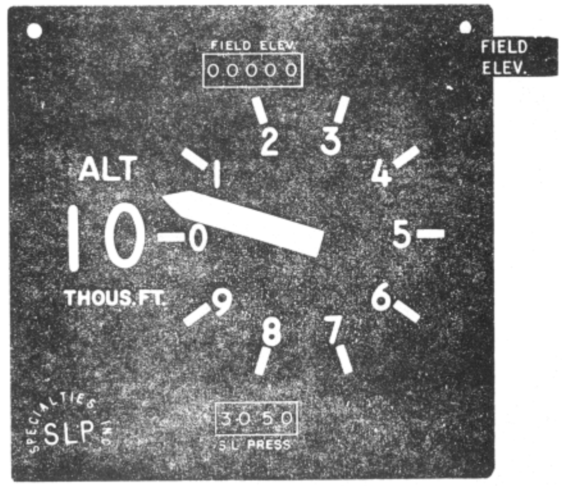
a

b



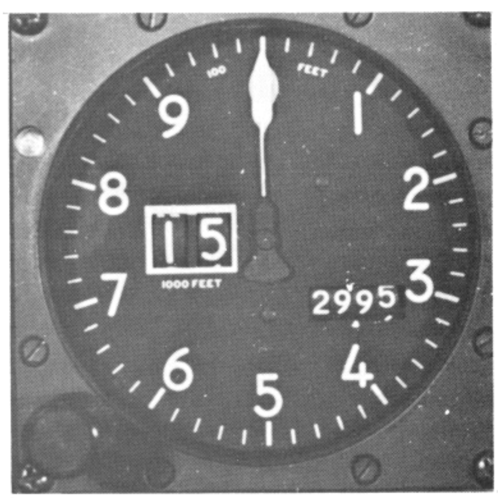
c

FIGURE 6 DRUM-POINTER-TYPE ALTIMETER DISPLAYS



b

a



c

d

FIGURE 7 COUNTER-POINTER-TYPE ALTIMETER DISPLAYS

a b

c d

FIGURE 8 COUNTER-DRUM-POINTER-TYPE ALTIMETER DISPLAYS

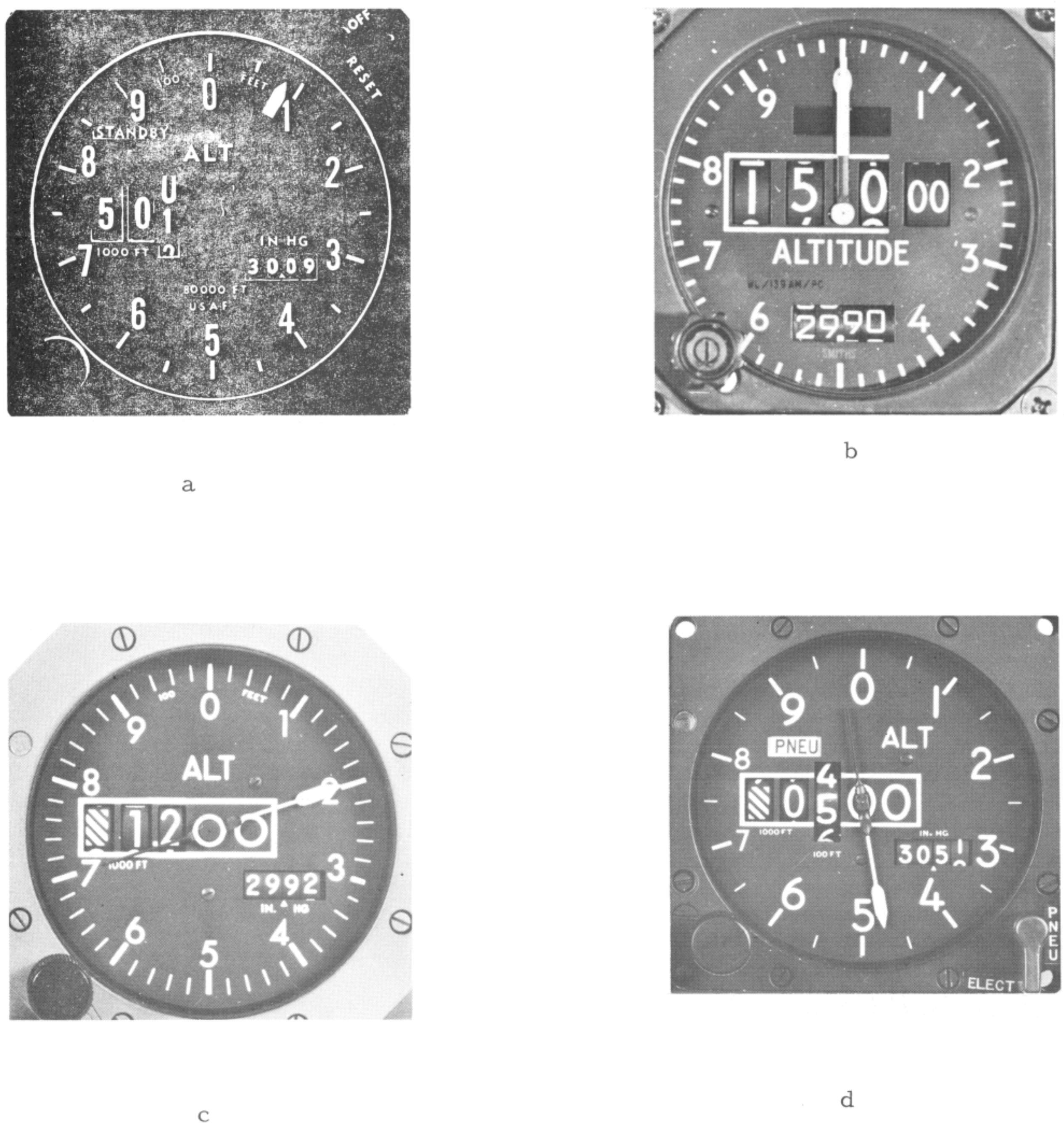
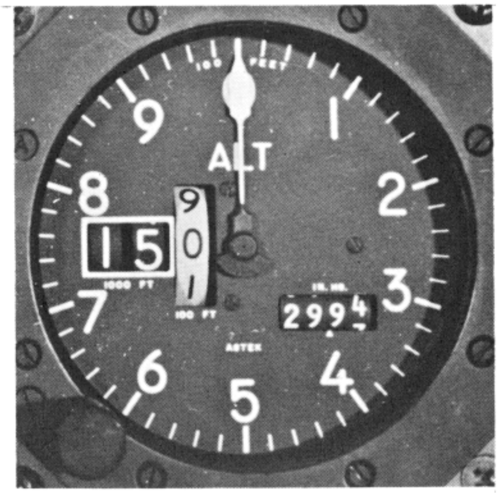
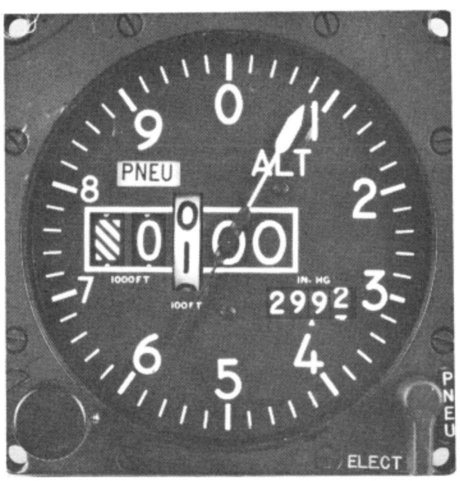


FIGURE 9 COUNTER-DRUM-POINTER-TYPE ALTIMETER DISPLAYS

a



b



c

d

FIGURE 10 COUNTER-DRUM-POINTER-TYPE ALTIMETER DISPLAYS

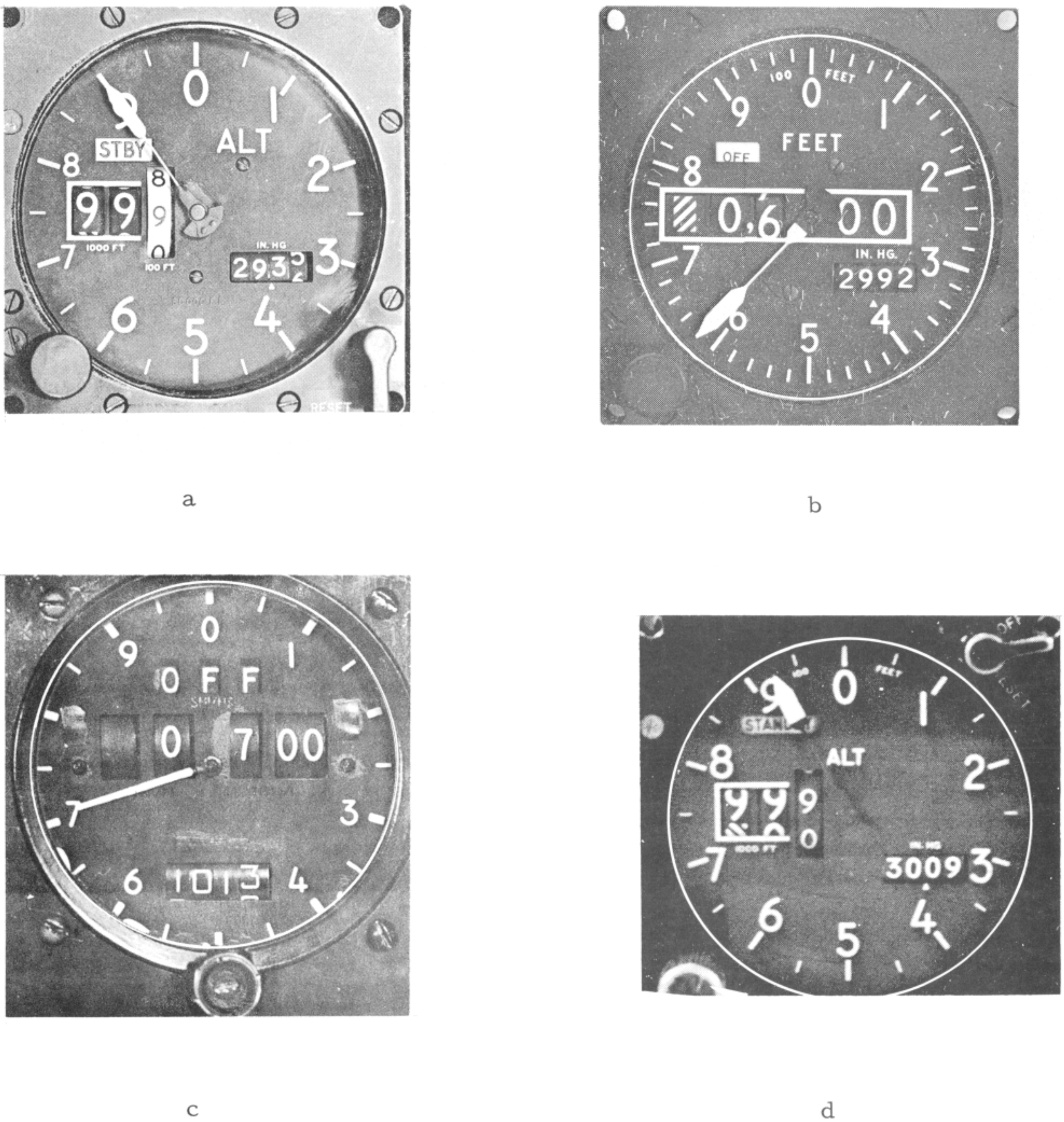
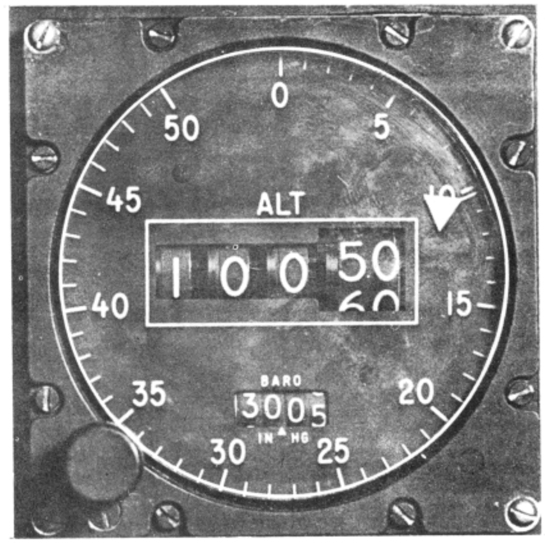


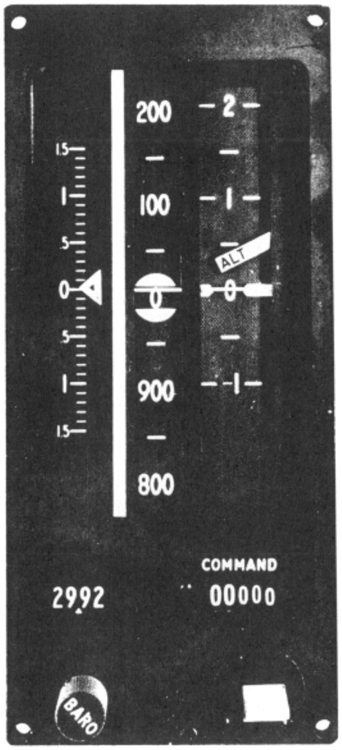
FIGURE 11 COUNTER-DRUM-POINTER-TYPE ALTIMETER DISPLAYS

a

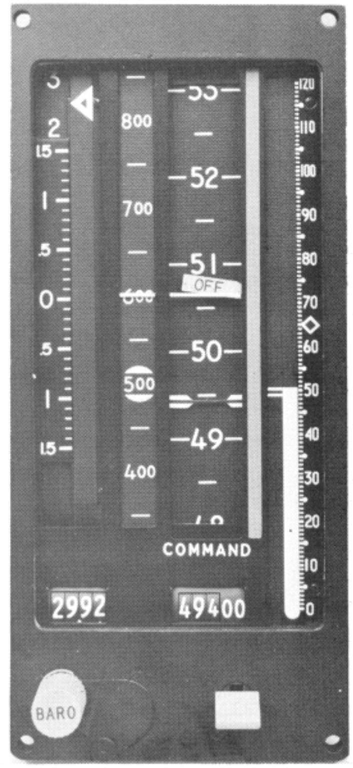


b

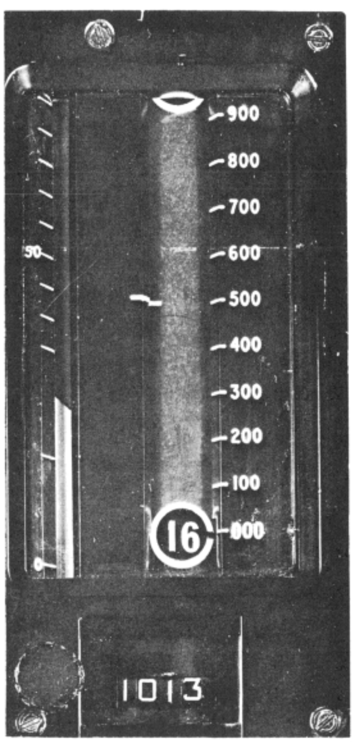
FIGURE 12 COUNTER-DRUM-POINTER-TYPE ALTIMETER DISPLAYS



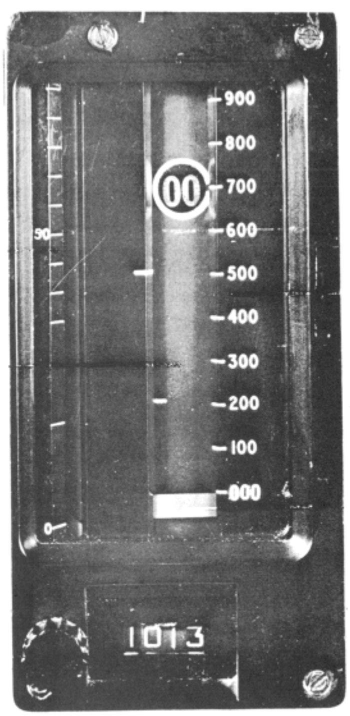
a



b

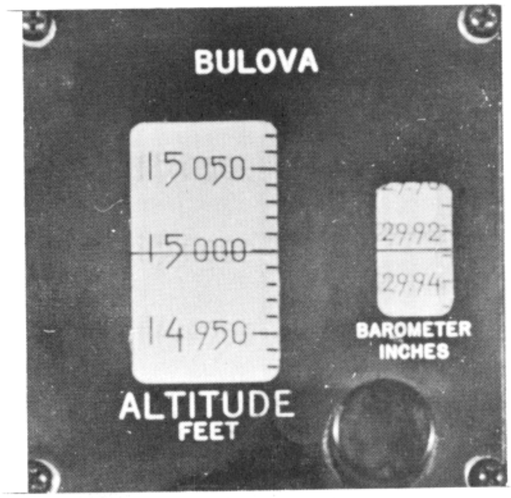


c

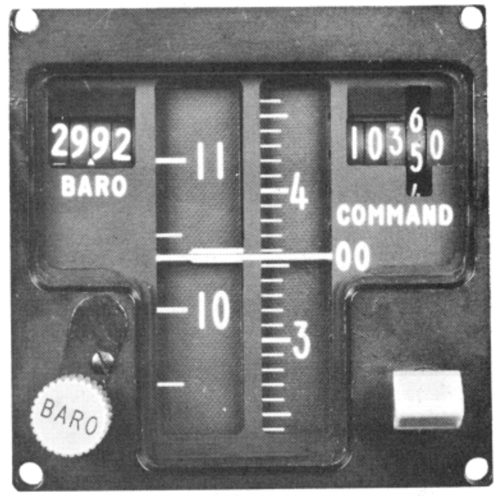


d

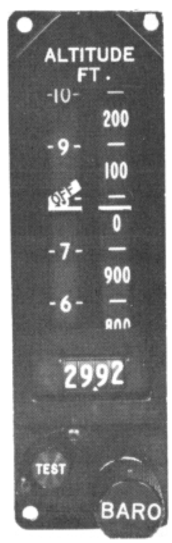
FIGURE 13 VERTICAL TAPE-TYPE ALTIMETER DISPLAYS



a

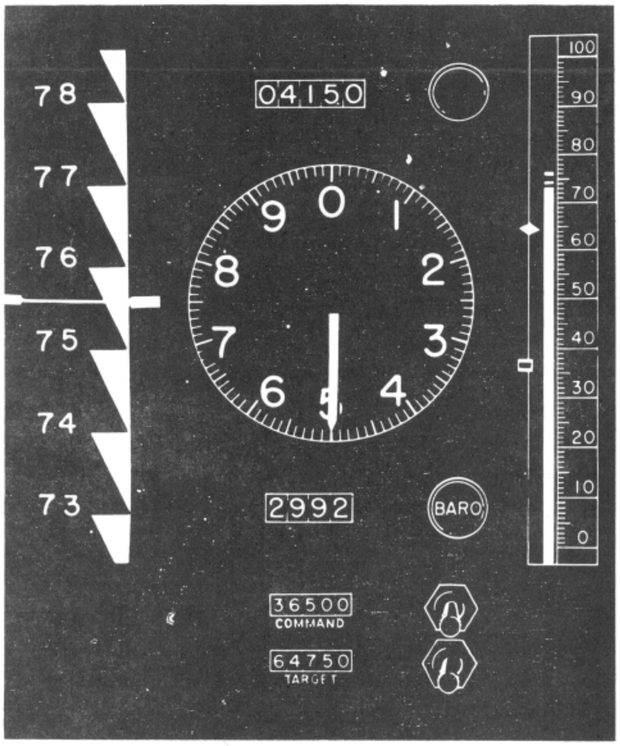


b

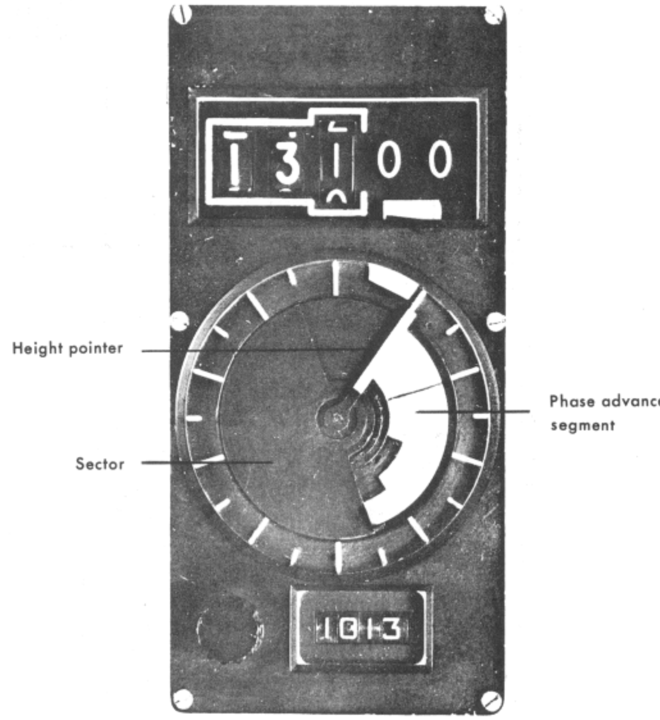


c

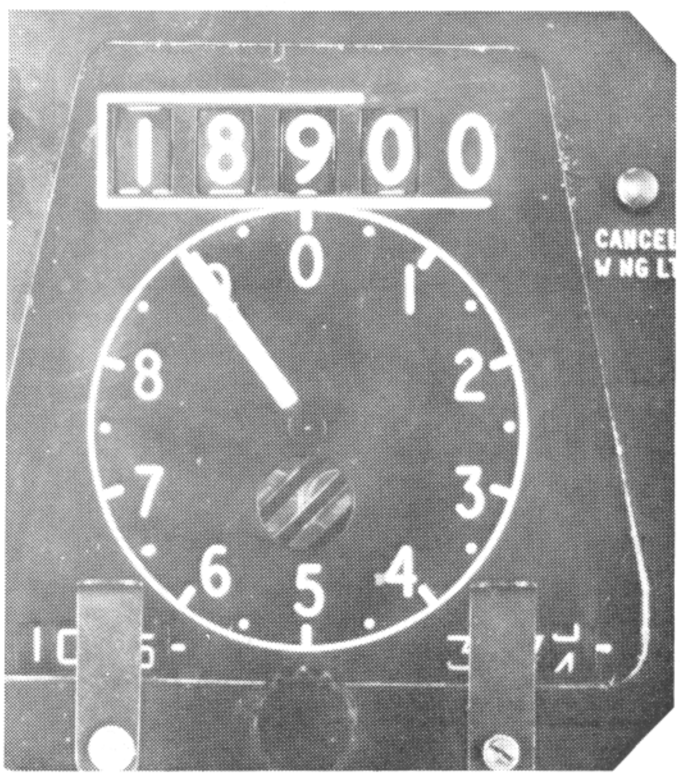
FIGURE 14 VERTICAL TAPE-TYPE ALTIMETER DISPLAYS



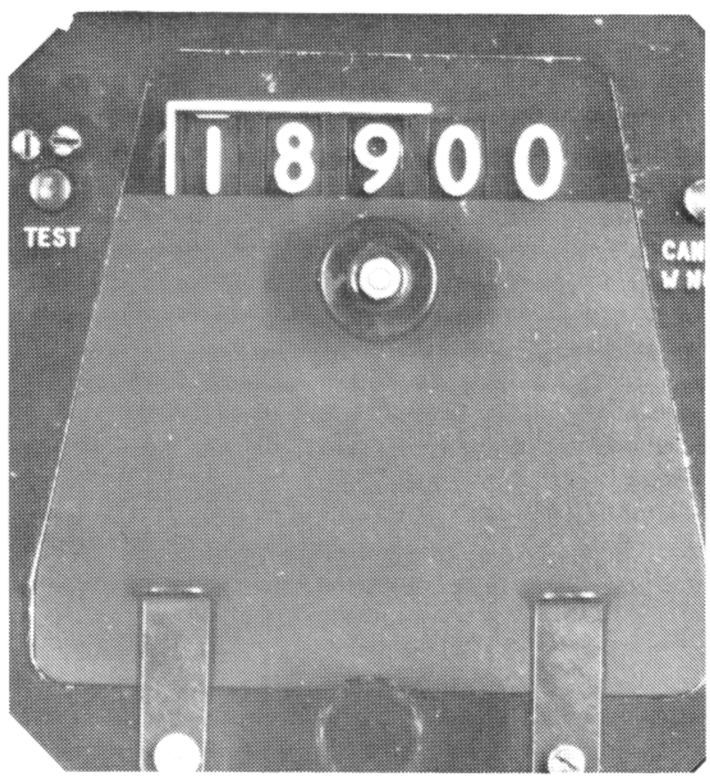
Vertical Scale Pointer



CDP Phase Advance

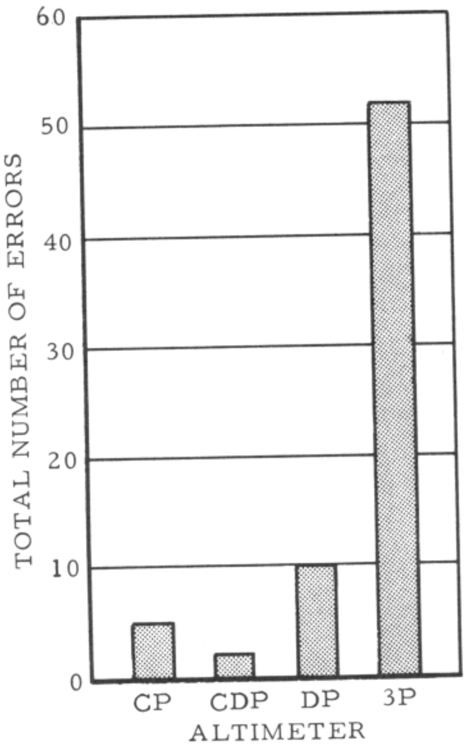


CDP Counter Outside



Counter Only

FIGURE 15 MISCELLANEOUS TYPES OF ALTIMETER DISPLAYS



TOTAL NUMBER OF ERRORS MADE BY THE SEVEN ENLISTED MEN SUBJECTS ON EACH OF THE FOUR ALTIMETERS

MEAN NUMBER OF ERRORS MADE ON EACH ALTIMETER

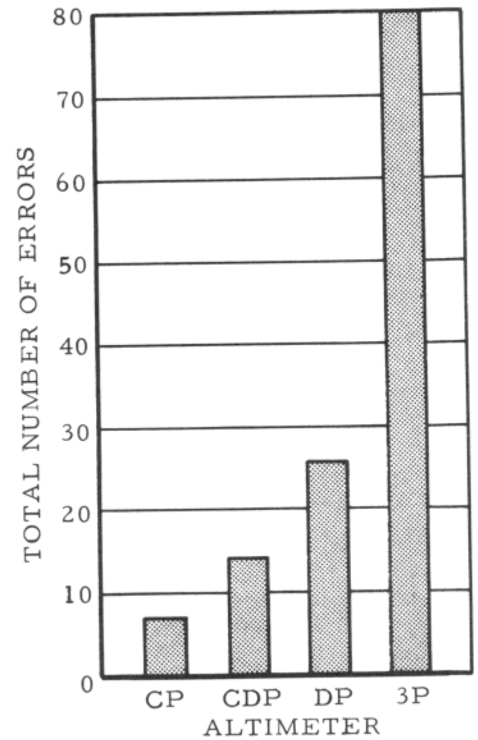
SUBJECTS	ALTIMETER			
	CP	CDP	DP	3P
PILOTS (18)	0.39	0.78	1.44	4.44
ENLISTED MEN (7)	0.71	0.29	1.43	7.43

MEAN EXPOSURE TIME AND NUMBER OF ERRORS FOR ENLISTED MEN ON EACH ALTIMETER (420 TRIALS)

MEASURE	ALTIMETER			
	CP	CDP	DP	3P
EXPOSURE TIME (SEC)	0.85	0.86	1.50	2.93
ERRORS (NUMBER)	5	2	10	52

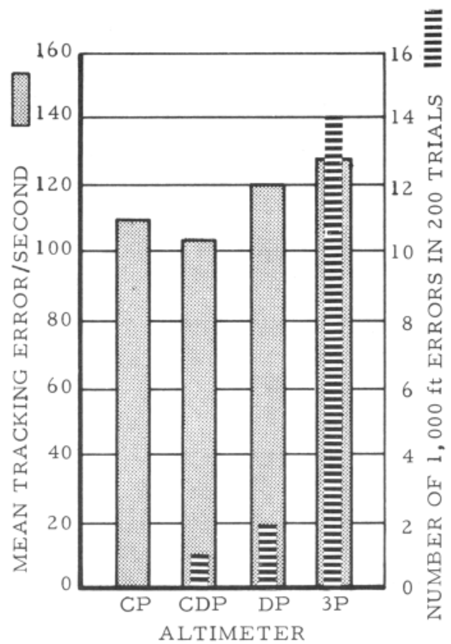
MEAN EXPOSURE TIME AND NUMBER OF ERRORS FOR PILOTS ON EACH ALTIMETER (1080 TRIALS)

MEASURE	ALTIMETER			
	CP	CDP	DP	3P
EXPOSURE TIME (SEC)	0.80	0.84	1.38	2.28
ERRORS (NUMBER)	7	14	·26	80



TOTAL NUMBER OF ERRORS MADE BY THE 18 PILOT SUBJECTS ON EACH OF THE FOUR ALTIMETERS

FIGURE 16 NRL ALTIMETER DISPLAY TEST RESULT USING PILOT AND NON-PILOT SUBJECTS (INDEX NO. 54)



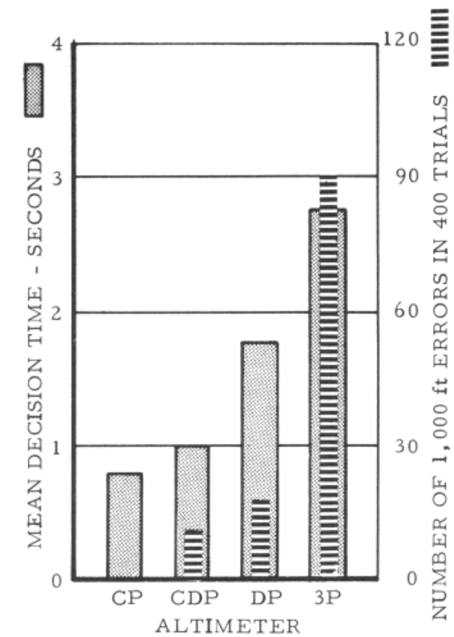
MEAN TRACKING ERROR/SECOND AND NUMBER OF 1,000 ft ERRORS FOR EACH OF THE FOUR ALTIMETERS

MEAN TRACKING ERROR/SECOND AND NUMBER OF 1,000 ft LEVEL-OFF ERRORS FOR EACH ALTIMETER (200 TRIALS)

	ALTIMETER			
	CP	CDP	DP	3P
TRACKING ERROR/SECOND	109	105	120	128
LEVEL-OFF ERRORS	0	1	2	14

MEAN DECISION TIME AND NUMBER OF 1,000 ft ERRORS FOR EACH ALTIMETER (400 TRIALS)

	ALTIMETER			
	CP	CDP	DP	3P
DECISION TIME (SECONDS)	0.77	1.02	1.77	2.77
1,000 FOOT ERRORS	0	11	21	90



MEAN DECISION TIME AND NUMBER OF 1,000 ft ERRORS FOR EACH OF THE FOUR ALTIMETERS

FIGURE 17 NRL ALTIMETER DISPLAY TEST RESULTS USING NON-PILOT SUBJECTS (INDEX NO. 27)

GRAPHIC RESULTS OF ALTIMETER PRESENTATION PREFERENCE QUESTIONNAIRE

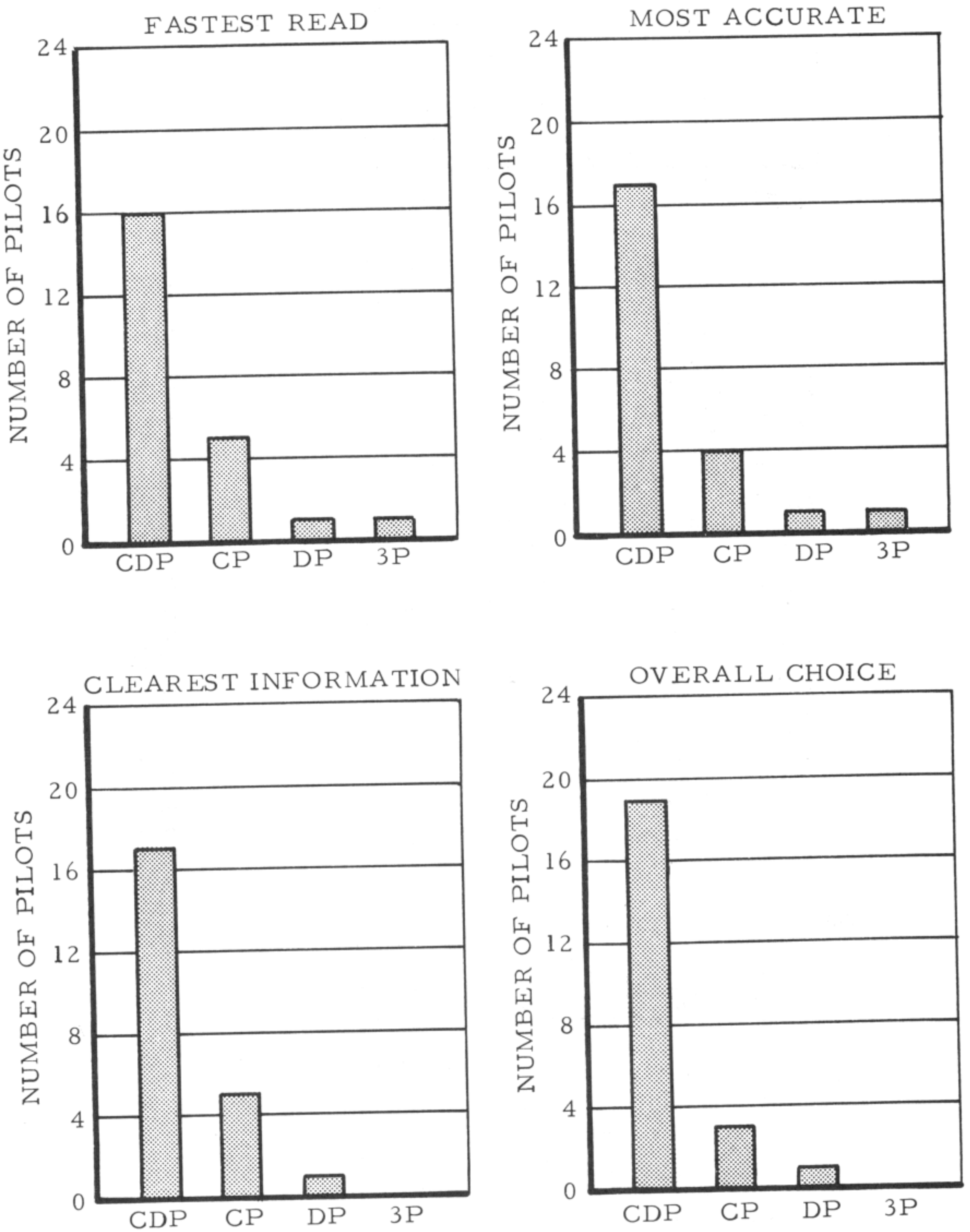


FIGURE 18 NATC ALTIMETER DISPLAY PREFERENCIAL RESULTS USING PILOT SUBJECTS (INDEX NO. 60)

GRAPHIC RESULTS OF ALTIMETER PRESENTATION PREFERENCE QUESTIONNAIRE

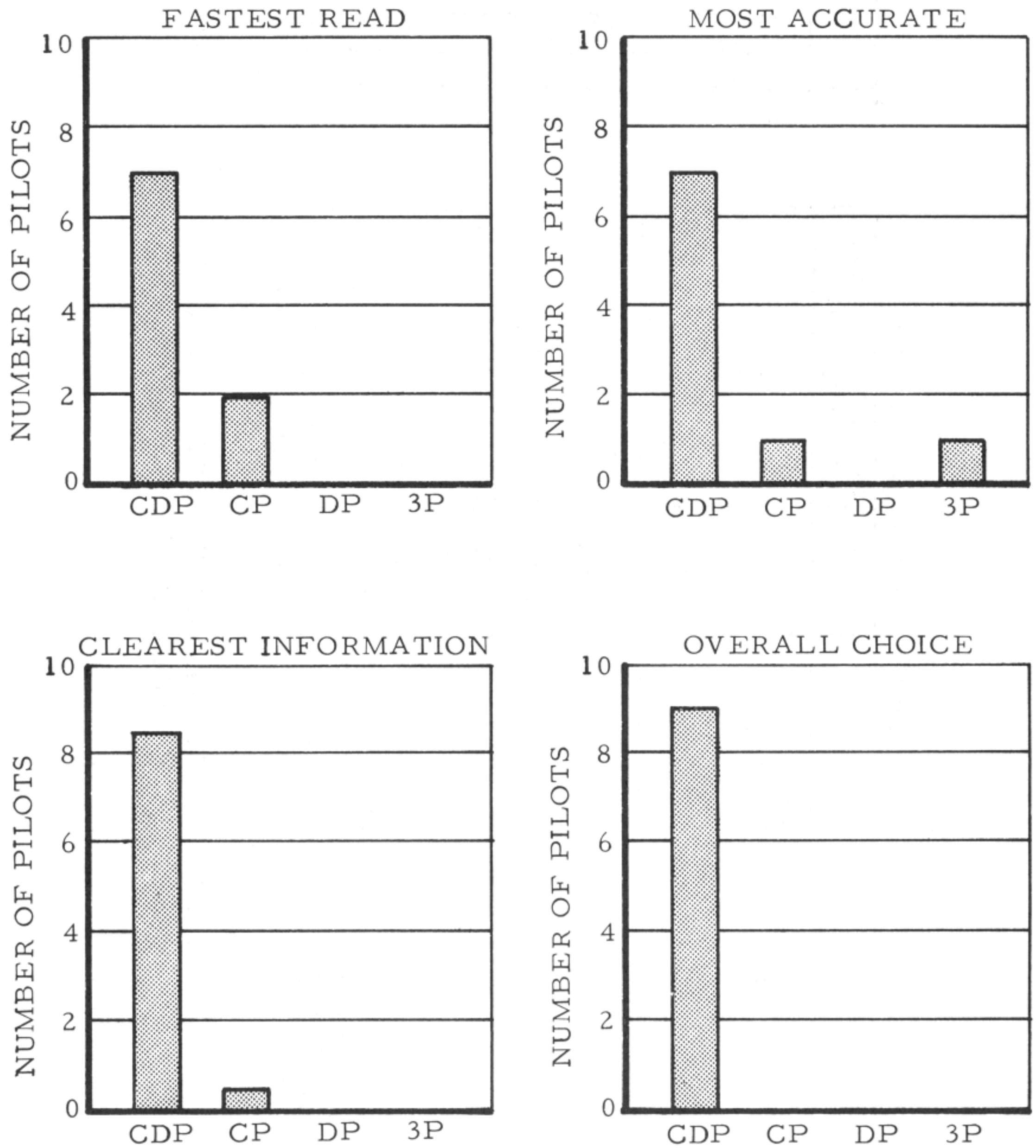
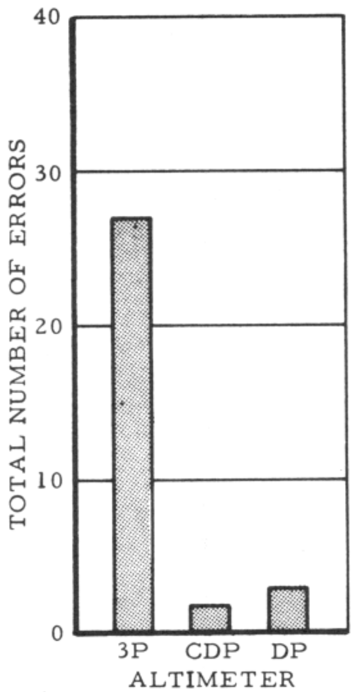


FIGURE 19 ALTIMETER DISPLAY PREFERENCIAL RESULTS USING U.S. AIR FORCE PILOT SUBJECTS ONLY (INDEX NO. 110)



NUMBER OF ALL GROSS ERRORS

	YELLOW LINE	SMITH'S COUNTER	KOLLSMAN DRUM
SUBJECT 1	1	0	0
SUBJECT 2	8	0	0
SUBJECT 3	5	1	1
SUBJECT 4	4	1	0
SUBJECT 5	1	0	0
SUBJECT 6	8	0	2
	3P	CDP	DP

SUBJECT AVERAGE READING TIMES OVER FINAL TWO BLOCKS

	YELLOW LINE	SMITH'S COUNTER	KOLLSMAN DRUM
SUBJECT 1	3.75	2.80	1.72
SUBJECT 2	4.51	1.50	1.39
SUBJECT 3	3.56	1.19	1.45
SUBJECT 4	3.49	1.18	1.22
SUBJECT 5	2.63	0.87	1.43
SUBJECT 6	3.18	0.81	0.95
	3P	CDP	DP

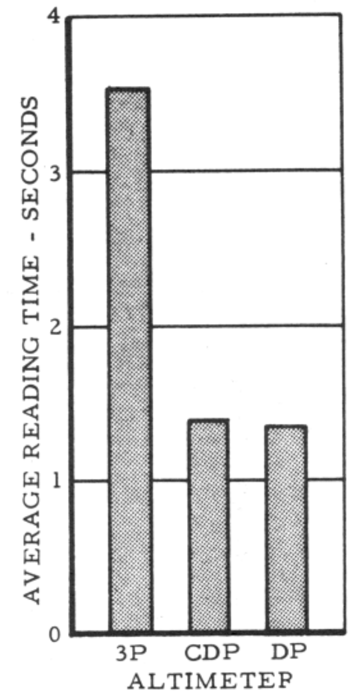
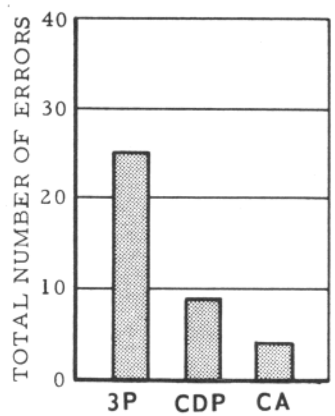


FIGURE 20 ARL ALTIMETER DISPLAY TEST RESULTS USING PILOT SUBJECTS (INDEX NO. 53)



	MA-I			COUNTER-DRUM POINTER			COUNTER-ANALOG		
	1,000' ERRORS	10,000' ERRORS	ALL OTHERS	1,000' ERRORS	10,000' ERRORS	ALL OTHERS	1,000' ERRORS	10,000' ERRORS	ALL OTHERS
EXPERIENCED									
ASCENT	0	0	2	1	0	0	0	0	0
DESCENT	2	0	1	3	0	0	2	0	0
TOTAL	2	0	3	4	0	0	2	0	0
INEXPERIENCED									
ASCENT	4	2	5	0	0	0	1	0	0
DESCENT	3	1	5	5	0	0	1	0	0
TOTAL	7	3	10	5	0	0	2	0	0
GRAND TOTAL	9	3	13	9	0	0	4	0	0

FIGURE 21 RCAF, IAM ALTIMETER DISPLAY SIMULATOR TEST RESULTS USING PILOT AND NON-PILOT SUBJECTS (INDEX NO. 23)

NUMBER OF LEVEL-OFF ERRORS

	COUNTER-DRUM POINTER	COUNTER-POINTER	DRUM-POINTER
LEVEL-OFF 40,000	0	0	0
LEVEL-OFF 20,000	6	11	1
LEVEL-OFF 4,000	5	4	1
LEVEL-OFF 18,000	1	1	0
TOTAL	13	16	2

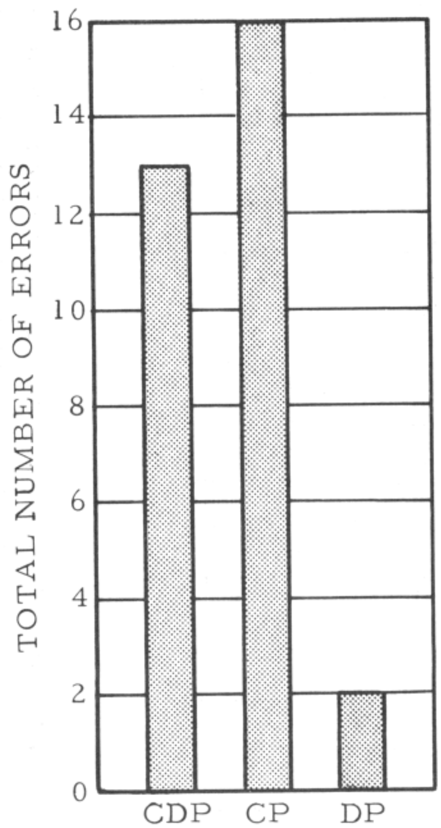


FIGURE 22 MARTIN COMPANY ALTIMETER DISPLAY SIMULATOR TEST RESULTS USING PILOT SUBJECTS (INDEX NO. 98)

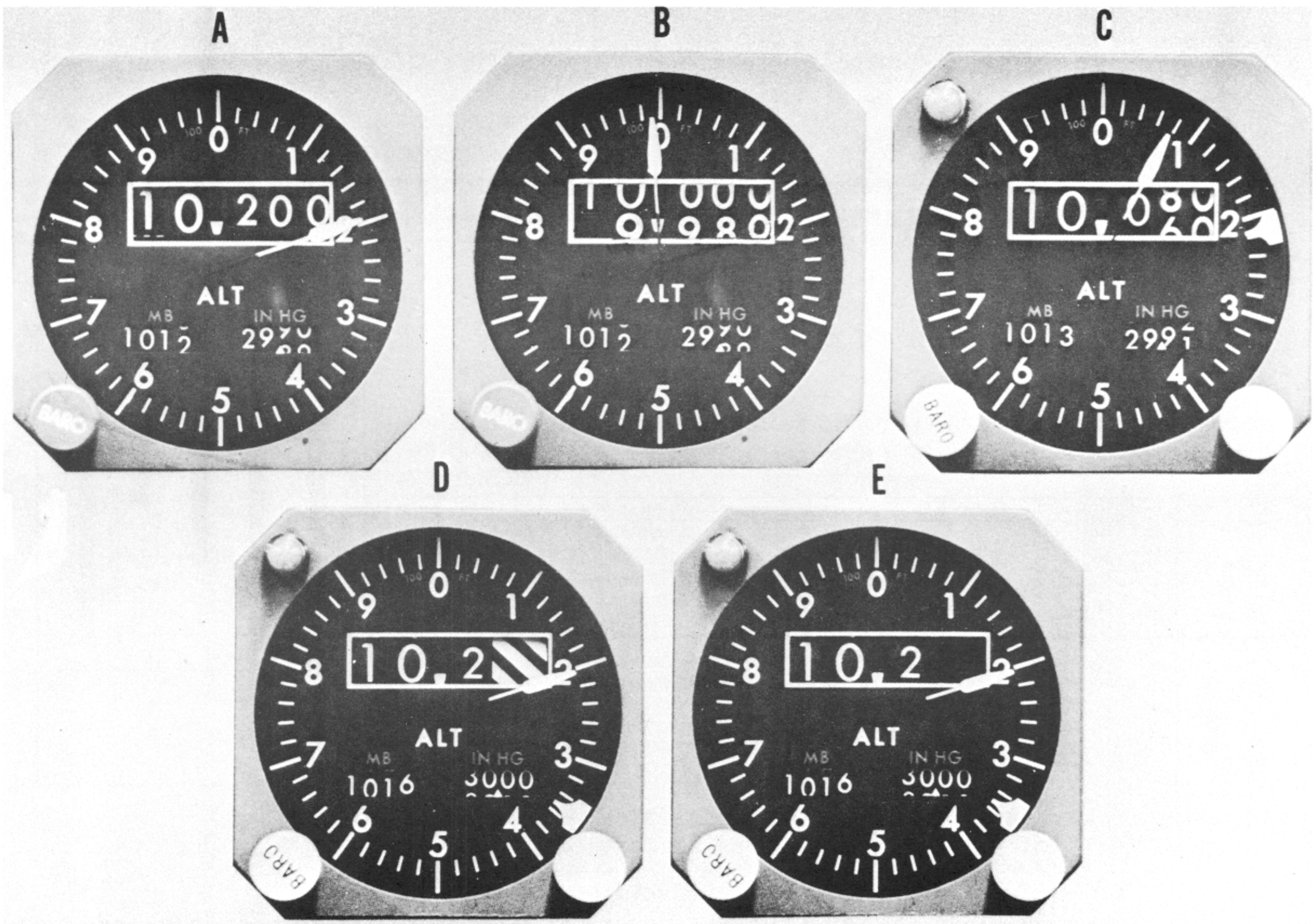
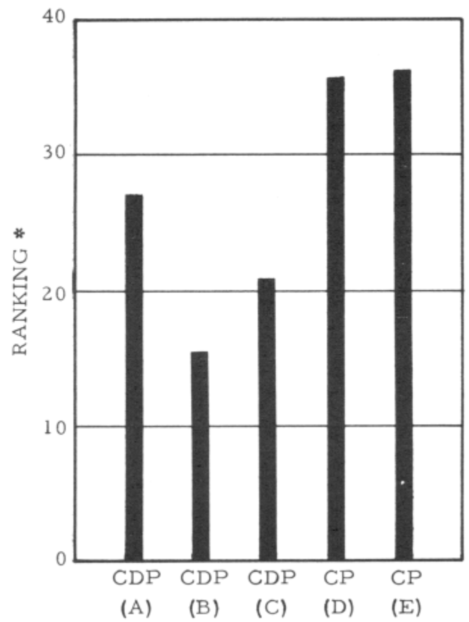


FIGURE 23 DIGITAL DISPLAYS EVALUATED BY DOUGLAS AIRCRAFT
(INDEX NO. 97)



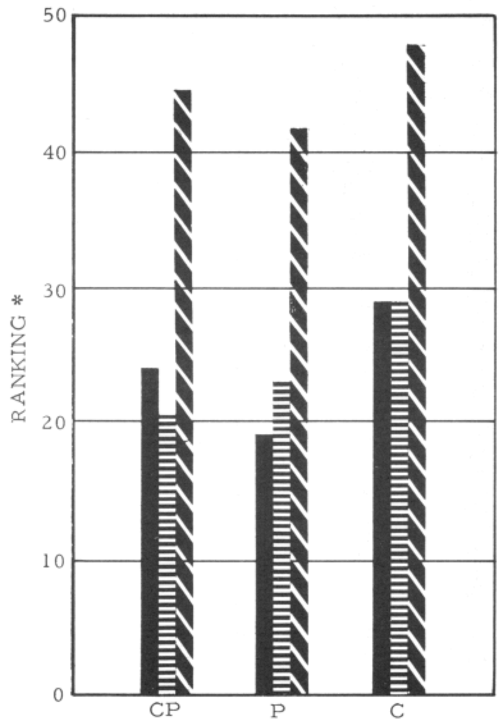
RANK OF EACH ALTIMETER ON EACH OF NINE DEPENDENT MEASURES

DATA SOURCE	A CDP	B CDP	C CDP	D CP	E CP
PERFORMANCE DATA					
TOTAL READING ERRORS	1	2	4	3	5
READING ERRORS GREATER THAN 1,000 ft	1	3	2	4	5
CORRECTED READING ERRORS	5	2	1	3	4
READING TIME	2.5+	1	2.5	4.5++	4.5
INTEGRATED TRACKING ERROR	3	1	4	2	5
AVERAGE TRACKING ERROR	5	3	1	4	2
QUESTIONNAIRE DATA					
NUMBER OF TIMES RANKED FIRST	4	1	2.5	5	2.5
OVERALL RANKING	2.5	1	2.5	5	4
PAIRED COMPARISON RANKING	3	1.5	1.5	5	4
SUM OF RANKS	27.0	15.5	21.0	35.5	36.0

\+ RANK OF 2.5 INDICATES THAT TWO ALTIMETERS WERE TIED FOR SECOND AND THIRD PLACE
++ RANK OF 4.5 INDICATES THAT TWO ALTIMETERS WERE TIED FOR FOURTH AND FIFTH PLACE

* RANKING:
A = 5 DIGIT SNAP ACTION
B = 5 DIGIT ANALOG ACTION
C = 3 DIGIT SNAP ACTION - 2 DIGIT ANALOG
D & E = 3 DIGIT SNAP ACTION (MODIFIED CP)

FIGURE 24 DOUGLAS AIRCRAFT COMPANY ALTIMETER DISPLAY DC-10 SIMULATOR TEST RESULTS USING PILOT SUBJECTS (INDEX NO. 97)



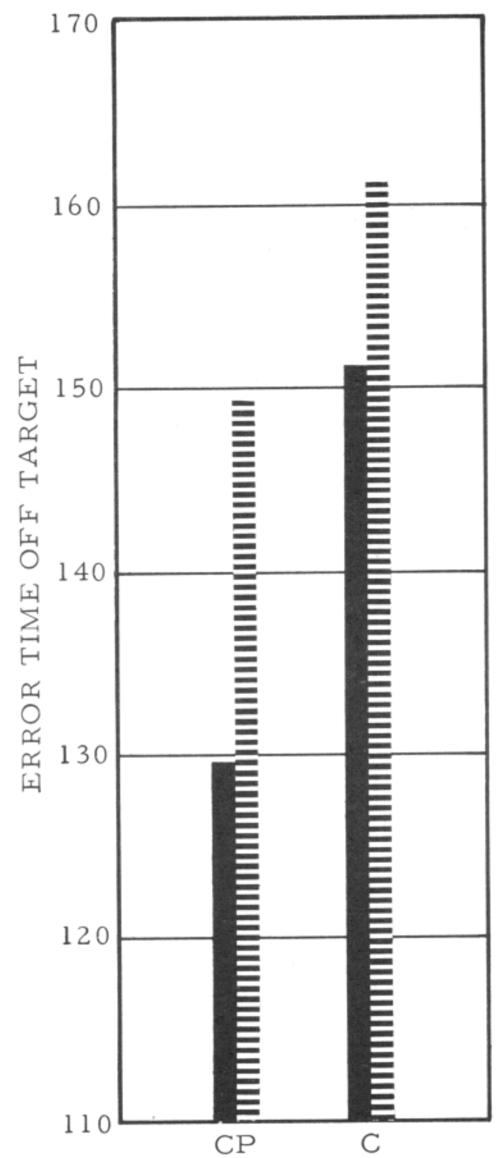
TIME ON TARGET IN MINUTES OUT OF TOTAL TRIAL TIME OF 3 MINUTES FOR EACH TWO TRIALS

SUBJECT	COUNTER POINTER			POINTER			COUNTER		
	T_1	T_2	TOTAL	T_1	T_2	TOTAL	T_1	T_2	TOTAL
1	1.94	1.91	3.85	1.76	1.78	3.54	1.69	2.15	3.84
2	1.57	2.13	3.70	1.63	1.99	3.62	1.73	1.63	3.36
3	1.51	1.88	3.39	1.69	1.79	3.48	1.66	1.83	3.49
4	1.76	2.11	3.87	1.88	1.88	3.76	1.53	2.22	3.75
5	1.97	2.18	4.15	1.81	2.19	4.00	1.79	2.08	3.87
6	1.83	1.46	3.29	2.16	1.71	3.87	1.68	1.21	2.89
7	1.51	1.42	2.93	2.06	1.58	3.64	1.48	1.30	2.78
8	1.68	1.51	3.19	1.75	1.51	3.26	1.56	1.91	3.47
9	1.58	1.74	3.32	1.64	1.71	3.35	1.60	1.56	3.16
10	1.55	1.58	3.13	1.69	1.74	3.43	1.71	1.55	3.26
11	1.76	2.13	3.89	1.26	1.75	3.01	1.63	1.71	3.34
12 .	1.42	1.14	2.56	1.33	1.71	3.04	1.16	1.13	2.29
TOTAL	20.08	21.19	41.27	20.66	21.34	42.00	19.22	20.28	39.50

LEGEND

* RANKING:
1 = LONGEST TIME ON TARGET
2 = SECOND LONGEST TIME ON TARGET
3 = SHORTEST TIME ON TARGET

FIGURE 25 RAF, IAM ALTIMETER DISPLAY DYNAMIC TEST RESULTS USING 12 SUBJECTS (INDEX NO. 30)



MEAN TIME OFF TARGET IN SECONDS (PER 4 MINUTES) DURING WHICH ERROR WAS MORE THAN ±50 FEET

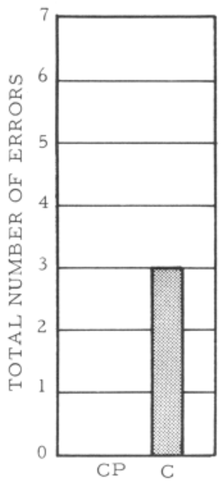
	TRACKING ONLY	TRACKING + TASK
COUNTER-POINTER	129.9	149.3
COUNTER	151.3	161.8

LEGEND

TRACKING ONLY

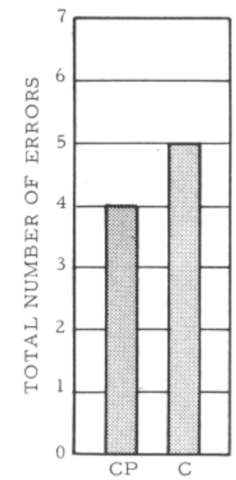
TRACKING + TASK

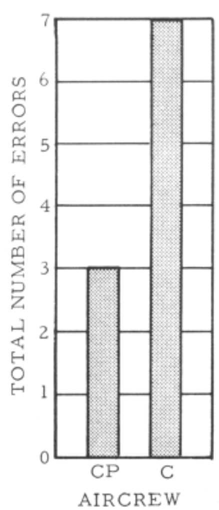
FIGURE 26 RAF, IAM ALTIMETER DISPLAY DYNAMIC TEST RESULTS USING EIGHT AIRMEN SUBJECTS (INDEX NO. 43)



ANALYSIS OF AIRCREW GROUPS SETTING ERRORS

	SETTING TASK ALONE				SETTING TASK WITH SUBSIDIARY TASK			
	COUNTER-POINTER		COUNTER ONLY		COUNTER-POINTER		COUNTER ONLY	
CATEGORY OF ERROR	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING
OVERSHOOT	0	0	1	1	2	0	5	2
LEVELLING EARLY	0	0	0	0	0	1	0	0
LEVELLING LATE	0	0	0	0	0	0	0	0
CONTROL REVERSAL	0	0	1	0	0	0	0	0
	0	0	2	1	2	1	5	2
TOTAL ERRORS	0		3		3		7	





ANALYSIS OF NON-AIRCREW GROUPS SETTING ERRORS

	SETTING TASK ALONE				SETTING TASK WITH SUBSIDIARY TASK			
	COUNTER-POINTER		COUNTER ONLY		COUNTER-POINTER		COUNTER ONLY	
CATEGORY OF ERROR	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING	ASCEND-ING	DESCEND-ING
OVERSHOOT	0	0	2	0	2	3	5	2
LEVELLING EARLY	1	3	1	1	4	4	0	1
LEVELLING LATE	0	0	0	0	0	0	0	2
CONTROL REVERSAL	0	0	1	0	0	1	0	1
	1	3	4	1	6	8	5	6
TOTAL ERRORS	4		5		14		11	

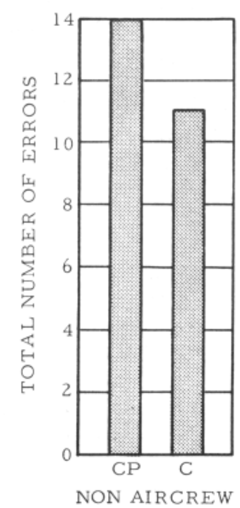
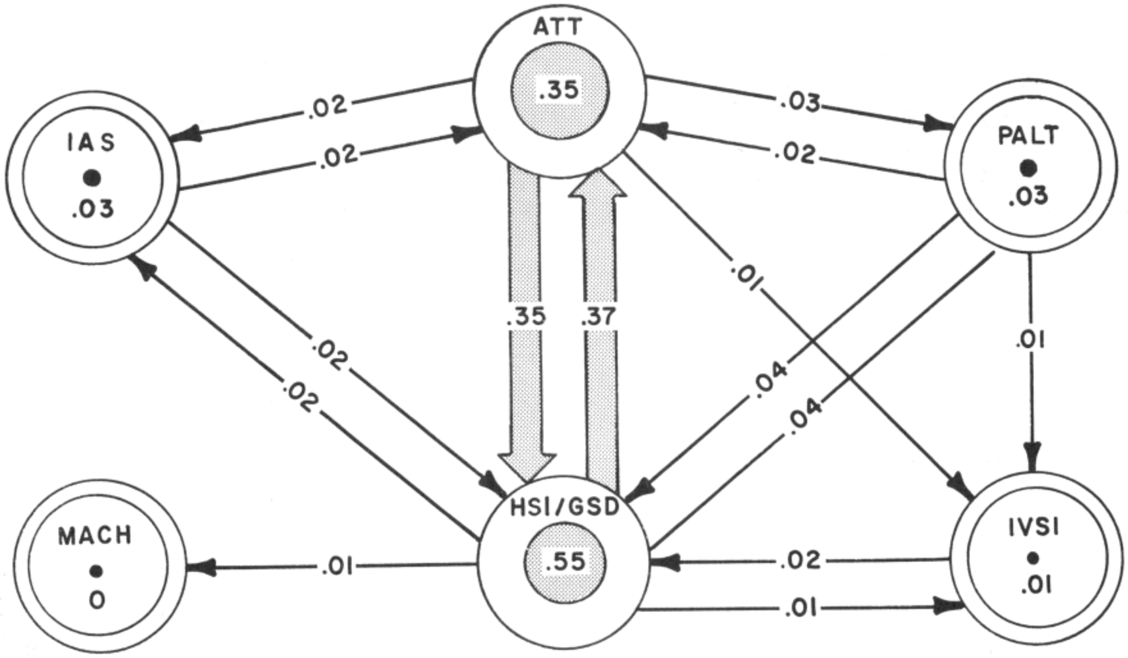
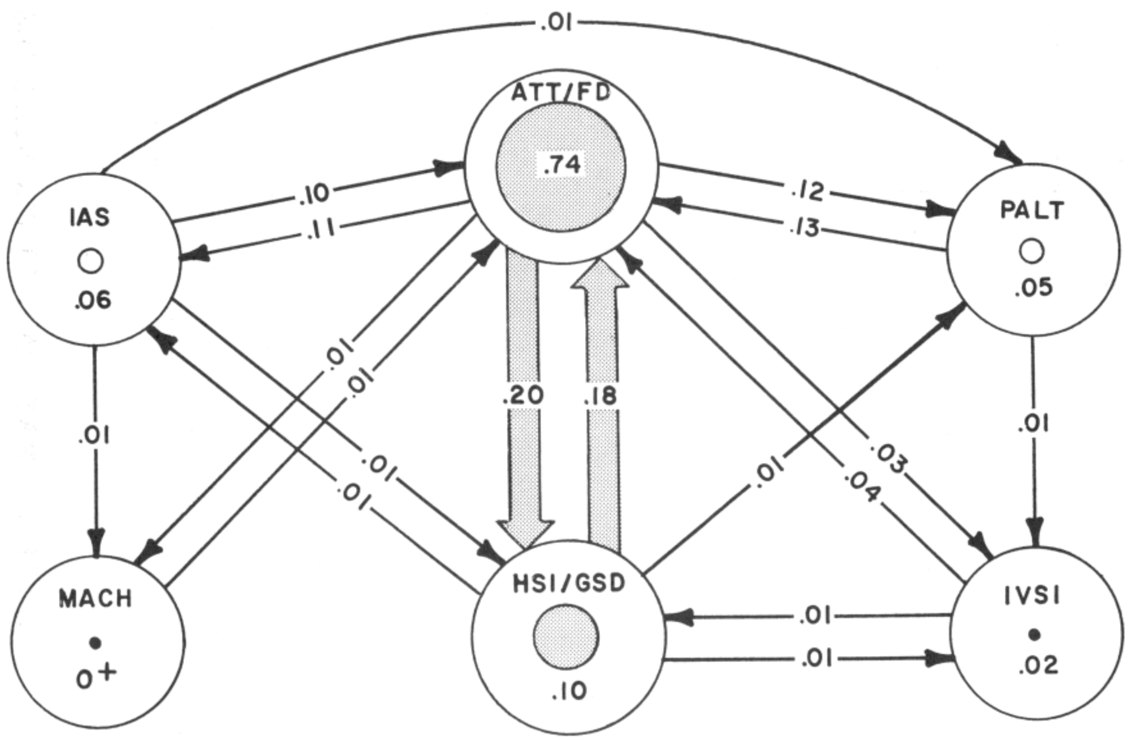


FIGURE 27 RAF, IAM ALTIMETER DISPLAY DYNAMIC TEST RESULTS USING AIRCREW AND NON-AIRCREW SUBJECTS (INDEX NO. 106)



(a) MANUAL ILS CONFIGURATION, CL



(b) FLIGHT DIRECTOR CONFIGURATION, EL

FIGURE 28 STI FLIGHT PANEL SCANNING TEST RESULTS DURING SIMULATED INSTRUMENT APPROACHES (INDEX NO. 72)

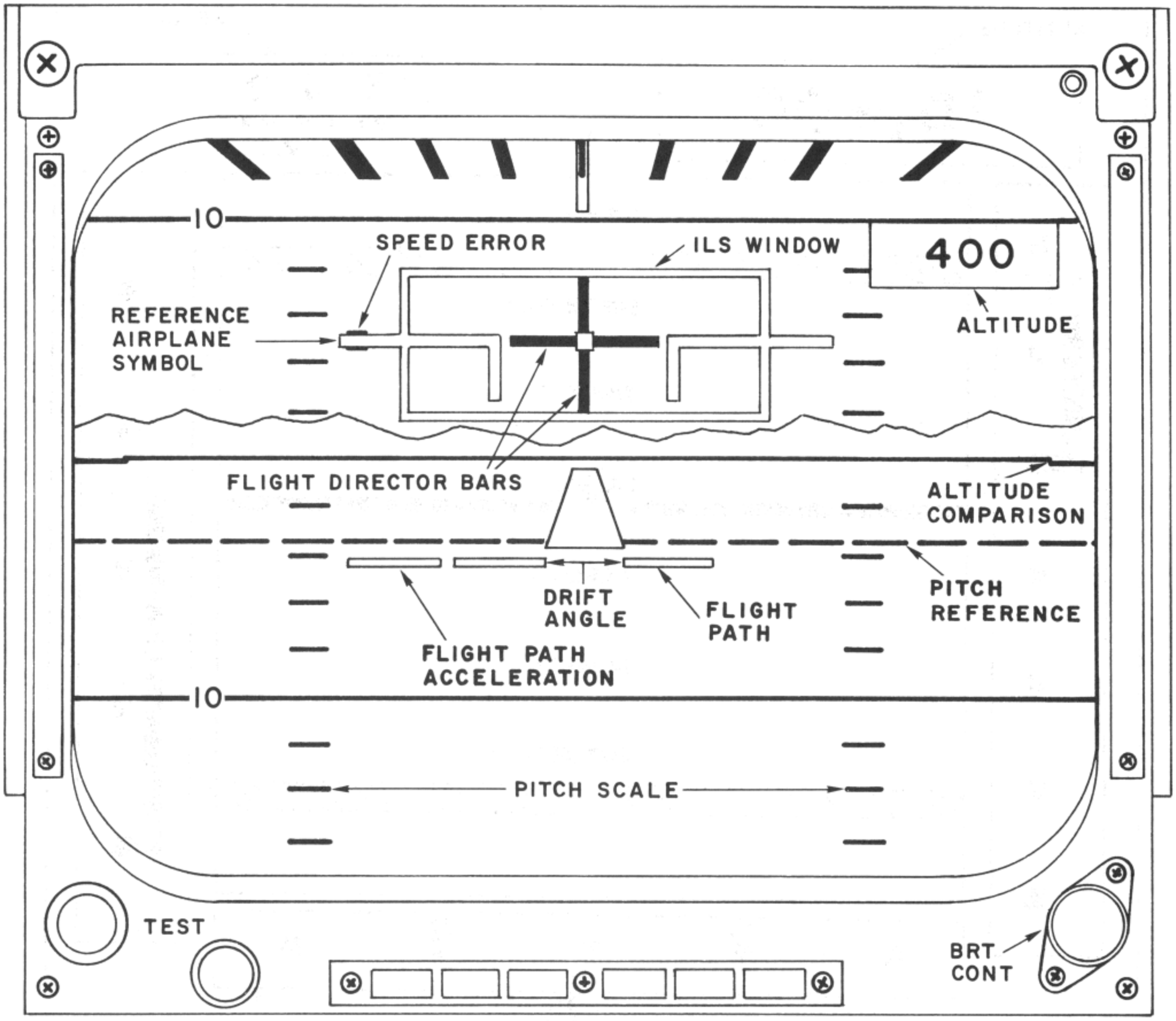


FIGURE 29 PROPOSED EADI WITH SYNTHESIZED VIDEO DISPLAY AND DIGITAL ALTITUDE READOUT

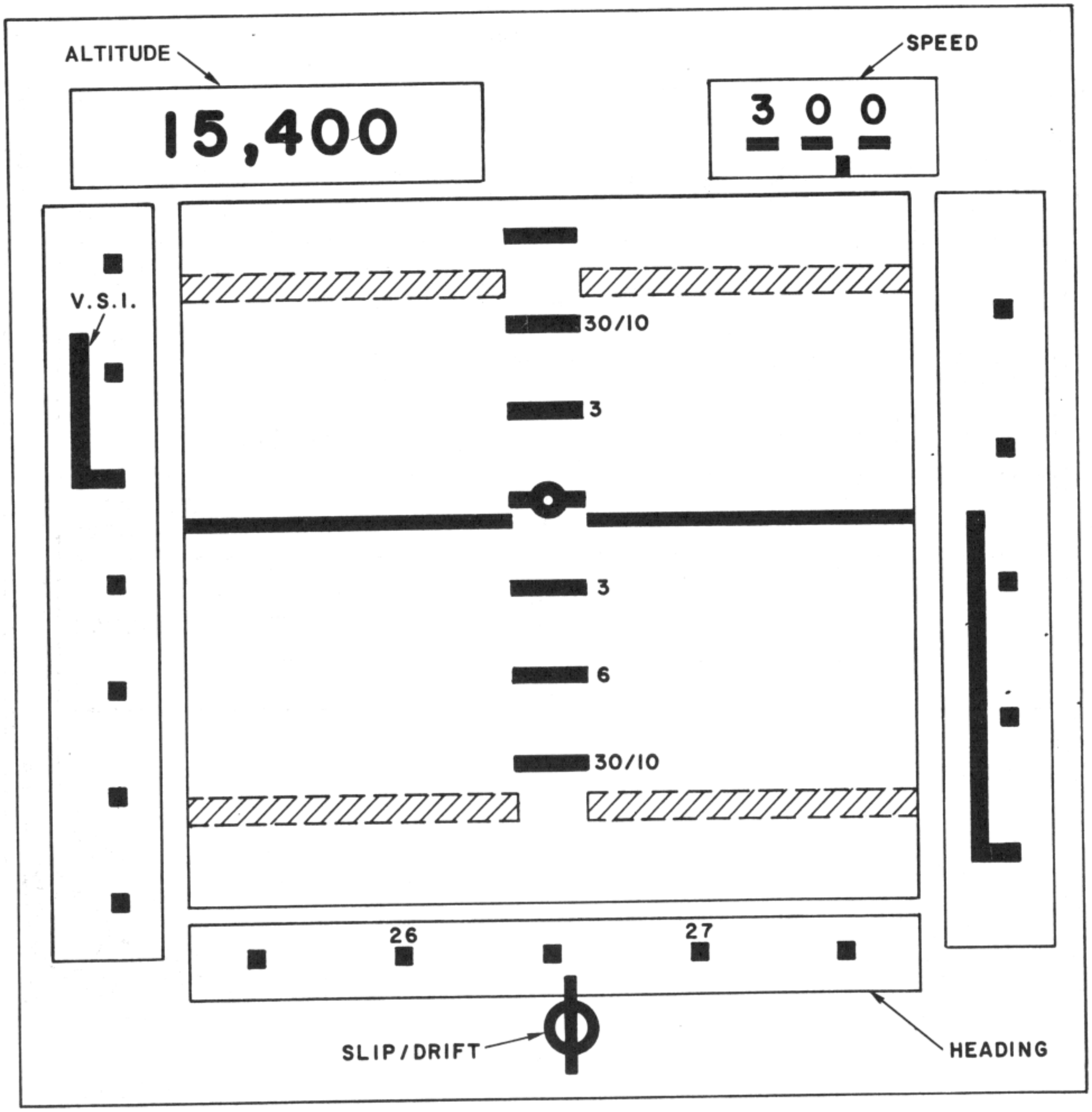


FIGURE 30 PROPOSED EADI WITH DIGITAL ALTITUDE READOUT

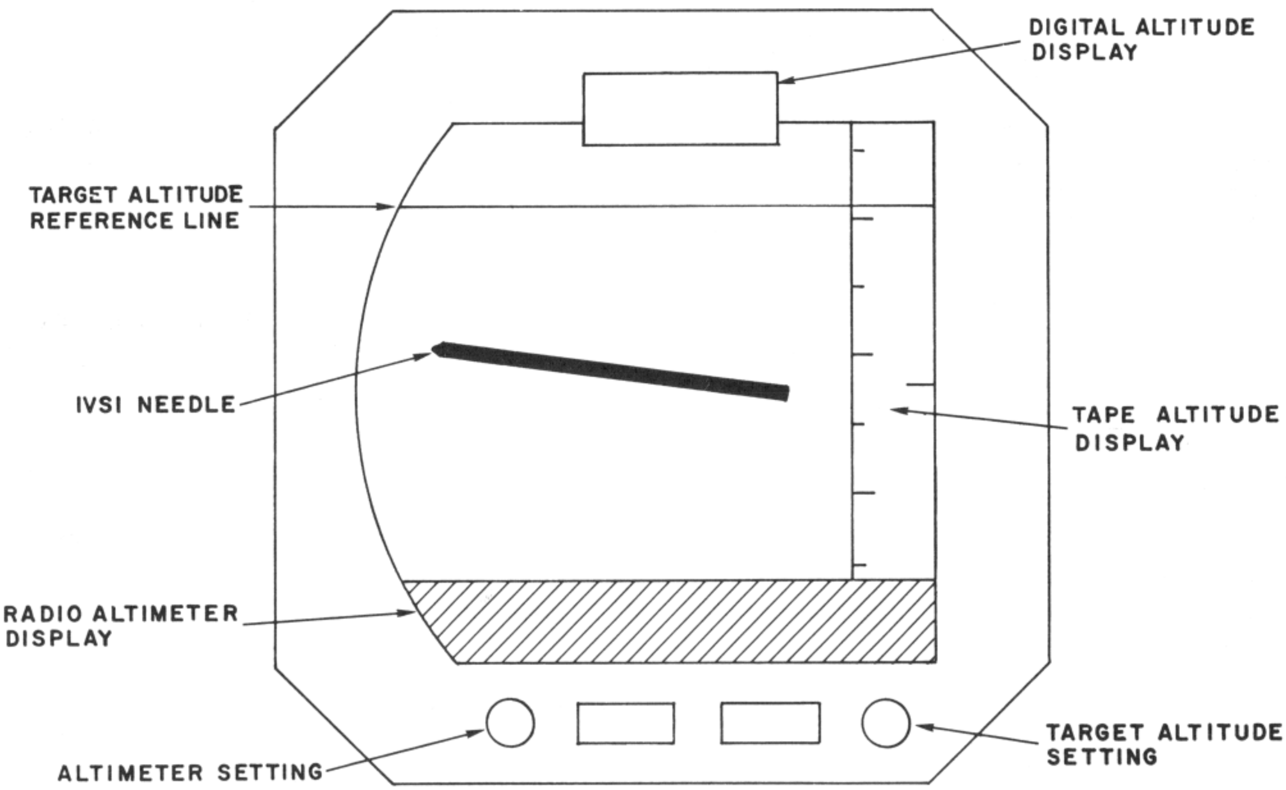


FIGURE 31 PROPOSED VSI WITH DIGITAL ALTITUDE READOUT

BIBLIOGRAPHY

1. ACQUISITION OF RATE INFORMATION FROM A FIVE-DIGIT COUNTER, Moir, G. D. and Innes, L. G., Institute of Aviation Medicine, Toronto, Canada, Report No. 63-RD-3 August 1, 1963

The purpose of this study was to determine ability to estimate rate information from the speed of increase and decrease of five-digit counter readings. The subjects in Group A received a total of 54 minutes of exposure to the five-digit counter presentation and the subjects in Group B received 71 minutes of exposure. Group A made 23 errors out of 60 readings in the final test session, and Group B made 14 errors out of 60 readings in their final test session. The first test session, after 25 and 34 minutes training, respectively, showed 22 errors for Group A and 21 errors for Group B. The results suggest that these subjects were learning to identify rates from the five-digit counter presentation.

2. ADVANCED ARMY AIRCRAFT INSTRUMENTATION SYSTEM Quarterly Progress REPORT NO. 1, Cahon, J. N., Douglas Aircraft Co. El Segundo, California, June 30, 1962, AD 282 750

3. AIRBORNE DISPLAYS FOR FLIGHT AND NAVIGATION, Roscoe, Stanley, N. Hughes Aircraft Company, Culver City, California, Human Factors 10 (4) pp.321-332, August 1968

Certain airborne displays which are used in navigation of aircraft are discussed. The nature of the crew's flight task to certain principles of flight display and experimental evidence bearing on display principles are considered.

4. AIR FORCE FLIGHT CONTROL AND FLIGHT DISPLAY INTEGRATION PROGRAM, Final summary report. The Martin Company, Baltimore, Maryland, ER12905, Contract AF33 657-8600 February 1963

The Martin Company provided human engineering support to a number of Air Force programs being conducted under Project 6190. The subject matter of these tasks, in part, consisted of controller studies, display evaluations, display development, performance and opinion measurement, and program planning.

5. AN AIRLINE FLIGHT ASSESSMENT OF A SERVO ALTIMETER PRESENTATION, Cameron, C., Austrailian Defense Scientific Service, Aeronautical Research Laboratories, Human Engineering Note No. 11, January 1962

6. ALTIMETER DISPLAY EVALUATION, Hill, J. H., Chernikoff, R. Naval Research Laboratory, Washington, D. C., NRL-6242, January 26, 1965, AD 610 664

A series of investigations were completed to determine the relative effectiveness of various altimeter displays. These investigations were in support of a program concerned with the replacement of current altimeters in most military aircraft with a servo-pneumatic-type instrument.

7. ALTIMETER DISPLAY AND HARDWARE DEVELOPMENT, 1903-1960, Schum, David A., Robertson, John R., Matheny, W. Guy, (Bell Helicopter Company, Fort Worth, Texas), ASD-TDR-63-288, May 1963

This report is a review of the literature on altimeter display and hardware development. It places major emphasis upon human engineering aspects of altmeter display development and upon methods and mode of altimeter mechanization and sensing. The evolution of altimeter displays is explored in a historical survey of display development. Particular emphasis is placed upon the present functional altimeters in use and those which are being experimentally tested.

8. ALTIMETER DISPLAY RESEARCH, SUMMARY OF THE EVALUATION PROGRAMME, Rolfe, J. M., Flying Personnel Research Committee, London, England, November 1963, AD 439 367

The United Kingdom Altimeter Committee was formed to advise on the best means of displaying altitude information. After the field of possible displays had been narrowed, an evaluation program was devised. The results of this program showed that (1) both forms of counter-pointer display are superior to conventional multi-pointer displays, and (2) when leveling from a descent there is a tendency for pilots to level out 950 feet too high.

9. ALTIMETER DISPLAY STUDY, Matheny, W. G., Bell Helicopter Company, Fort Worth, Texas, January 1962

A treatise on the broad area of display information based on the work reported in 31 references noted in its bibliography.

10. ALTIMETER DISPLAY STUDY - PART I. SUMMARY AND REVIEW OF DATA REQUIREMENTS, Matheny, W. G., (Bell Helicopter Company, Fort Worth, Texas,), ASD-TDR-63-621, May 1964

This report presents a brief overview of a number of reports dealing with the subject of flight control information requirements. The author singles out certain points which seem worthy of note. One of these is the distinction between system data requirements (as the totality of data to be processed by the human operator).

11. ALTIMETER DISPLAY STUDY - PART II. HANDBOOK FOR STATIC TESTING OF ALTIMETERS, Elam, C. B., Matheny, W. G., and Schum, D. A.(Bell Helicopter Company, Fort Worth, Texas) ASD-TDR-63-622, May 1964

12. ALTIMETER DISPLAY STUDY - PART III. SUMMARY OF EXPERIMENTAL TESTING, Elam, C. B., Matheny, W. G, and Schum, D. A.(Bell Helicopter Company, Fort Worth, Texas) ASD-TDR-63-623, May 1964, AD 601 903

Results of five altimeter display studies (four by static presentation and one by cinematic presentation) are described. The five altimeter display designs evaluated were: The Three-Pointer MA-1, The Horizontal Drum-Pointer, The Single Tape-Pointer, The Vertical Drum-Pointer MD-1, and The Dual Tape Instruments. Methods of evaluation were varied extensively. Measurements of errors and response time were taken for all studies.

13. ALTIMETRY - A LITERATURE REVIEW AND BIBLIOGRAPHY, Shrager, Jack J., Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey, Project No. 560-103-05X, Final Report (Phase I), FAA-RD-70-52 (FAA-NA-70-19), September 1970

The Federal Aviation Administration is interested in disseminating information which could be used by the aviation community to promote safety and economy. This document has been prepared to assist both government and the aviation industry in the design, maintainability and reliability of altimeter systems.

14. ALTITUDE AWARENESS, Illston, Fred, Director - Flying Operations American Airlines, Flight Safety Foundation, Inc, 15th Corporate Aircraft Safety Seminar, San Antonio, Texas, May 11-13, 1970

15. ALTITUDE DISPLAYS PARTS I AND II, Anon, August 26, 1971, NASA, College Park, Maryland

Literature search for pertinent references to the subject of altitude displays.

16. ALTITUDE...OR PRESSURE?, Carroll, John J., (Chief Accident Prevention Branch, Bureau of Aviation Safety, NTSB) Flight Safety Foundation, Inc., 15th Corporate Aircraft Safety Seminar, May 13, 1970

17. ANALYSIS OF DISPLAY-PILOT-VEHICLE DYNAMICS FOR ILS APPROACH OF A LARGE JET AIRCRAFT, Clement, W. F., Best, J. J., and Stapleford, R. L., Systems Technology, Inc., Hawthorne, California, (Contract N00014-66-C-0072) TM-163-C; AD-661855, May 27, 1967

The theory for manual control displays is applied to the instrument landing approach of a large subsonic jet transport and a methodical display design procedure is presented. Analytically derived performance and pilot workload measures are compared with allowable norms.

18. ANALYSIS OF HUMAN FACTORS DATA FOR ELECTRONIC FLIGHT DISPLAY SYSTEMS, Semple, Clarence A., Jr., Heapy, Raymond, J., and Conway, Ernest J., Jr., Air Force Flight Dynamic Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, AFFDL-TR-70-174, April 1971

This report presents the results of a review of 1178 technical documents dealing with human factors considerations in electronic flight display systems. Design-oriented human factors data are presented for the following families of design considerations: display size, information coding, alphanumerics, scale legibility, visual acuity, display system resolution, flicker, contrast ratio requirements, and environmental variables including ambient illumination, vibration and acceleration. Quantitative, design-oriented functional relationships are emphasized. Research recommendations are made where existing data were found inadequate for design use. A model is presented for organizing the variables impacting upon human performance as a function of electronic flight display system design.

19. AN APPRAISAL OF DIGITAL DISPLAYS WITH PARTICULAR REFERENCE TO ALTIMETER DESIGN, Rolfe, J. M. (Royal Air Force, Institute of Aviation Medicine, Farnborough, England) Ergonomics, Vol. 8, No. 4, pp. 425-434, October 1965

The paper examines critically the experimental evidence currently available which relates to the display of height information using digital indicators. The conclusion drawn is a need for more research into information transmission characteristics of digital display.

20. AVIONICS DISPLAYS: WITH PARTICULAR REFERENCE TO AREA NAVIGATION SYSTEMS, Giles, P. M., Computing Devices Co., Ltd. 1971

This paper describes the trends in avionic displays leading up to the Combined Display which is still in the development phase. The paper briefly reviews the developments leading up to and the Combined Display itself. The significant benefits to be obtained from this display are: (1) Direct Pictorial Interpretation of Navigation, (2) Correlation of Navigation with a Threat and Navigation with Detection, (3) Ability to Employ Color Discrimination, (4) Display of Processed Information with Raw Data, and (5) Efficient Transfer of Information from Several Sensors Through One (Small) Instrument Panel Space.

21. BIBLIOGRAPHY ON ALTIMETER DISPLAYS, Anderson, O. E. E., (San Francisco International Airport, San Francisco, California), United Airlines Report F-1267, March 7, 1968

22. COCKPIT CONTROL-DISPLAY SUBSYSTEM ENGINEERING, Kearns, John H., and Ritchie, Malcolm L., Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, ASD TR 61-545, October 1961

23. COMPARATIVE EVALUATION OF A KOLLSMAN THREE-POINTER, A SMITH's COUNTER-POINTER, AND A BENDIX COUNTER-ANALOG ALTIMETER PRESENTATION, Innes, L. G., Beldam, E. H., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Canada, Report No. 62-RD-7, December 1962, AD 298 233

A comparative evaluation of the Kollsman MA-1 three-pointer Smith's five-digit counter-pointer, and Bendix counter-analog altimeters was carried out. The three-pointer and counter-pointer instruments each produced errors of 1,000 feet while the counter-analog produced only four.

24. COMPARATIVE READABILITY OF THREE SIZES OF A FIVE-DIGIT COUNTER, Innes, L. G., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Canada, Report No. 62-RD-4, 1962

25. A COMPARISON BETWEEN AN AREA SCALE ALTIMETER AND A COUNTER-POINTER ALTIMETER, Chernikoff, R., and Ziegler, P. N., U.S. Naval Research Laboratory, Washngton, D. C. NRL 1641 September 1965

An experimental Area Scale Altimeter was compared with a Counter-Pointer Altimeter for speed of reading and accuracy using six nonpilot subjects in a simulation study. The Counter-Pointer was far superior in all aspects tested.

26. A COMPARISON OF FOUR ALTIMETER PRESENTATIONS OF THREE-POINTER INSTRUMENT TYPE, Triggs, T. J., Aeronautical Research Laboratories, Melbourne, Australia, ARL/H.E.10 December 1961

A comparative evaluation of four different three-pointer altimeter displays was made using 32 pilots as subjects. The test program included both static presentation tests and dynamic link trainer simulation tests. All modified three-pointer altimeters were superior to the standard three-pointer instrument.

27. A COMPARISON OF FOUR TYPES OF ALTIMETERS, Reilly, R. E., Ziegler, P. N., Hill, J. H., and Chernikoff, R., U.S. Naval Research Laboratory, Washington, D. C., NRL Memorandum Report 1522, April 1964

The results of evaluating four altimeter displays; counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P) by nonpilot subjects indicates that the CP and CDP displays are superior in tracking performance and reading accuracy.

28. COMPARISON OF A LINEAR AND A NON-LINEAR SCALE AS A GROSS ANALOGUE INDICATION OF ALTITUDE, Innes, L. G., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Canada, Report No. 62-RD-6, November 1962, AD 294 708

This study was concerned with the type of scale used as a gross analogue indication of altitude to be used in conjunction with a five-digit counter. A comparison was made between a linear scale and a non-linear scale in terms of accuracy of giving distance and direction to command altitude.

29. A COMPARISON OF SIX VERTICAL SPEED INDICATOR PRESENTATIONS, Moir, G. D., Innes, L. G., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Canada, Report No. 63-RD-5, December 1963

The currently employed vertical speed dial is used as a standard in comparison with five other designs produced by the Human Engineering staff. No consideration was given to compatability with existing or possible drive mechanisms.

30. COMPENSATORY TRACKING PERFORMANCE ON A DIGITAL DISPLAY, Rolfe, J. M., and Clifford, A. C., Royal Air Force Institute of Medicine, Farnborough, England, IAM Report No. 293, August 1964

An experiment was undertaken which compared performance on a digital display with displays using scale and pointer indication. No significant difference in performance scores could be shown between the two forms of display.

31. THE COMPUTATION OF EFFECTIVE DISPLAY SENSITIVITY IN AIRCRAFT LANDING, Perry, Barbour Lee, Naval Research Laboratory, Washington, D. C., Applications Research Division, Report No. NRL-6055, January 1964, AD 430 516

In analyzing the altitude control loop in carrier landing, it is necessary to examine the geometry involved in the calculation of effective display sensitivity. This report describes the method of determining this gain for a deck-mounted display of glide path error. Of particular utility in comparing existing systems with one another or with proposed new systems is the ratio of the effective display sensitivity of one display to that of another.

32. CONTACT ANALOG SIMULATOR EVALUATIONS: ALTITUDE AND GROUNDSPEED JUDGMENTS, Abbott, Billie A., and Dougherty, Dora J., Bell Helicopter Company, Fort Worth, Texas, References, Project Janair D228-421-015; March 1964, AD 467 203

This report summarizes work which was accomplished during the first phase of evaluation of the JANAIR vertical display. The purpose of this study was to determine the accuracy with which altitude and groundspeed could be interpreted from the existing display. The display presentation was "open loop" i.e., no control task was required of the experimented subjects. Pertinent applied maneuver variables were presented. These included heading, groundspeed and altitude. The influence of the test variables are discussed. Recommendations are made for use and redesign of this type of display.

33. CURRENT RESEARCH ON ADVANCED COCKPIT DISPLAY SYSTEMS, Winblade, Roger L., North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, AGARD Report 491, 1965

Current cockpit display philosophy is discussed in terms of the pilot's informational requirements. Pilot's scan patterns obtained through the use of an eye-position camera and a ground-based simulator are depicted for both a conventional display system and two advanced concepts. Preliminary results of some flight-test and ground-simulation evaluations of advanced concepts, such as totally integrated displays and indirect pilot viewing systems, are discussed.

34. THE DESIGN AND FLIGHT EVALUATION OF EXPERIMENTAL DISPLAYS OF HEIGHT, RATE OF CLIMB AND AIRSPEED, Karavis, A., Frampton, R. A., and Buckle, J. W., Royal Aircraft Establishment, Ministry of Technology, Farnborough, England, Report No. TR-69 217, October 1969

The design of four prototype instruments is described and a brief design philosophy given. The airborne assessment of the instrument displays, based on pilots' written reports is described in detail. The instruments were a Tape Altimeter, a Tape Vertical Speed Indicator, a Phase Advanced Altimeter, and a Variable Scale Airspeed Indicator.

35. DESIGNING EASY-TO-READ SCALES, ANON, Instrument Control Engineering, p. 20-23, June 1963

36. DEVELOPMENT OF AN OPTIMUM ALTIMETER DIAL, Innes, L. G., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Canada, Final Summary Report 64-RD-1, January 1964

This report summarizes the work done at the RCAF Institute of Aviation Medicine between 1955 and 1963 on the design of an improved display of altitude information for an interim period and as a retrofit for existing aircraft. Work done in this area by other agencies is referred to only if it is applicable to the program as it was conducted at the IAM.

37. DIGITAL DISPLAYS - AN APPRAISAL, Rolfe, J. M., Royal Air Force, Institute of Aviation Medicine, Scientific Memo No. 57, 1964

38. DISPLAY AND CONTROL REQUIREMENTS FOR MANNED SPACE FLIGHT, Hopkins, Charles O., Bauerschmidt, Donald K., and Anderson, M. J., WADD Technical Report 60-197, April 1960

39. DISPLAY OF INFORMATION IN THE AIRCRAFT COCKPIT, Rolfe, J. M. and Chappelow, J. W., Royal Air Force, Institute of Aviation Medicine, Farnborough, England, 1971

40. DISPLAY REQUIREMENTS AND TECHNIQUES FOR SPACE NAVIGATION, Quarterly Report for the Period April 1 to June 30, 1962, Technical Report No. 61.55-3, July 2, 1962

Information quantities and techniques are related to each of the critical mission phases to determine what specific information quantities man must utilize in performing the required navigation functions, and the form for display of the required information as well as techniques applicable for the display. An examination of the information quantities man must use is made for the following: trajectory, orbital elements and flight path error; velocity; position, position fix and coordinate systems; distance, altitude, range and range rate; direction; attitude; time elapsed, event and operation; propulsion, thrust and fuel; life support, water, oxygen and safety. Both single parameter and integrated display techniques are considered.

41. DISPLAY RESEARCH AND ITS APPLICATION TO CIVIL AIRCRAFT, Naish, J. M. Royal Aircraft Establishment, Farnborough, England, Journal of the Royal Aeronautical Society, Vol. 69, No. 658, pp. 662-669 (1965)

Based on recent work accomplished to date, primarily in the field of Head-up Display, a proposal for an advanced cockpit layout is suggested.

42. DISPLAY SYSTEMS FOR VERTICAL TAKE-OFF TRANSPORT AIRCRAFT, Francis, Barry C., Control Systems Limited, 1971

43 DYNAMIC DIGITAL DISPLAYS: A STUDY OF COMPENSATORY TRACKING WITH AN ACCELERATION ORDER CONTROL, Allnutt, M. F., Clifford, A. C., and Rolfe, J. M., RAF Institute of Aviation Medicine, Farnborough, England, IAM Report No. 374, March 1966

Eight subjects undertook a compensatory tracking task using an acceleration order control. A purely digital display was compared with a scale and pointer one, performance being measured by the time-off target, and reaction time on a non-central light acknowledging task. Performance using a pure digital display was significantly worse than when using a scale and pointer display. In addition, it was found that the intensity of the non-central visual stimuli influenced performance on both tasks.

44. EFFECTS OF BRIEF EXPERIENCE VERSUS PRINTED COMMUNICATION ON ALTIMETER PREFERENCE, Matheny, W. G., Berger, Philip K., Life Sciences Inc., Fort Worth, Texas, October 1964

The report covers those factors which may influence subject performance based on prior experience or attitude based on two types of altimeter displays and a printed questionnaire.

45. EFFECTS OF DISPLAY FORMAT ON PILOT DESCRIBING FUNCTION AND REMNANT, Jex, Henry R., Allen, R. Wade, and Magdaleno, R. E., Systems Technology, Inc., Hawthorne, California, Paper No. 111, June 1971

As a part of a program to develop a comprehensive theory of manual control displays, six display formats were used by three instrument-rated pilots to regulate against random disturbance with a controlled element of $Yc=K/s(s+2)$ (which requires mild lead equalization), under both foveal and 10° parafoveal viewing conditions. The six display formats were: CRT Line, CRT Thermonmeter Bar, 14-Bar Quantized on a CRT, a Rotary Dial and Pointer (meter movement), and two variations of a Moving Scale Tape-Drive (C-141 VSI). All were scaled to equivalent movement and apparent brightness. Measures included overall performance, describing functions, error remnant power spectra, "critical instability" scores, and subjective display ratings. Other controlled elements and parafoveal angles were partially investigated. The results show that the main effect of display format is on the loop closure properties. Less desirable displays induce lower bandwidth closures with consequent effects on the closed-loop remnant and performance. The normalized injected error remnant remains roughly similar for all cases except quantized formats. The quantized display induces larger pilot lags and observation remnant. The moving tape display (off-reference case) could not be tracked parafoveally. Parafoveal viewing affected each display differently. The second-order critical instability task seems to provide a sensitive and convenient test for overall display format problems. Simple analytical models are presented which show good agreement with the preliminary-test data, and a tentative set of rules for estimating format effects of the display/pilot/vehicle system are given.

46. EVALUATION OF AIMS ALTIMETERY, Madero, Major Ralph P., Hartwig, Major James A. Project Officers, Randolph Air Force Base Air Force Instrument Pilot Instructor School, IPIS TR 70-2, December 1970

This report is the summation of an (IPIS) project, TE 70-3, Evaluation of AIMS Altimetry. The evalution began on May 1970 at the request of Mr. David Stockman (ASD/ENFI) and was completed in December 1970.

47. EVALUATION OF THE ASTEK ALTIMETER-ENCODER TYPE A AU-22/A INTEGRALLY LIGHTED, THREE-POINTER DISPLAY RANGE 1,000 TO 25,000 FEET. FINAL REPORT, Kakatucka, S., Naval Air Development Center, Johnsville, Pa. (Aeromechanics Dept.), NADC-AM-6918, June 20, 1969

Developmental model of altimeter with optical shaft encoder for use in automatic altitude reporting systems.

48. AN EVALUATION OF CERTAIN DESIGN FEATURES OF A FIVE-DIGIT COUNTER PRESENTATION, Innes, L. G., Royal Canadian Air Force Institute of Aviation Medicine, Toronto, Ontario, Canada, Report No. 62-RD-1, 1962

49. THE EVALUATION OF A COUNTER-POINTER ALTIMETER DISPLAY FOR THE UNITED KINGDOM ALTIMETER COMMITTEE, Rolfe, J. M., Royal Air Force Institute of Aviation Medicine, Farnborough, England, IAM Report No. 253, December 1963

The United Kingdom Altimeter Committee was formed to advise on the best means of displaying altitude information. The results showed: (a) both forms of the counter-pointer display are superior to conventional multipointer displays, (b) when levelling from a descent there is a tendency for pilots to level out 950 feet too high. This error is the only one that seems associated with counter-pointer displays and rapidly disappears with experience, (c) Future research should consider the possibilities of combining altitude and vertical speed information, and the use of all digital indication (e.g., counters), (d) Any evaluation program should possess both operational and methodological validity, e.i., the right questions should be asked and the relevant methods used to obtain answers. This comprehensive program indicated the advantages and disadvantages of the various methods used in each phase.

50. EVALUATION OF THE INTERIM INTEGRATED AIRCRAFT INSTRUMENTATION AND LETDOWN SYSTEM, Van Aredel, John H., U.S. Army Electronic Proving Ground, Fort Huachuca, Arizona, December 1961

51. EVOLUTION OF THE MODERN ALTIMETER, du Feu, A. N., Technical Air, Volume 25, pp. 12-16, February 1969

Review of the past and present status of modern altimeters with indication of the likely lines of future developments. Attention is given to the advantages and disadvantages of radio and radar altimeters. The introduction of the servo altimeter, with its 5-digit counter/pointer presentation made misreading virtually impossible, and this promises to be the preferred standard for many years to come. Aspects of accuracy are examined. A current development of greater importance, the Central Air Data Computer (CADC), is described. For the immediate future, increasing use of servo altimeters is anticipated. Other possibliities are briefly outlined.

52. EXPERIMENTAL DESIGN FOR QUANTITATIVE MEASUREMENT AND EVALUATION OF PILOT PERFORMANCE ON COCKPIT DISPLAYS, Bradley, W. A., Naval Air Development Center, Johnsville, Pennsylvania, NADC-A-6146, June 9, 1961

The evaluations of instruments and displays have been subjectively flight evaluated. Such evaluations, are no longer completely adequate in view of the sophistication and sometimes dramatic changes in the new instruments and displays. The purpose of this experimental design is to set up a method of quantitatively measure pilot performance on cockpit displays in order to permit objective evaluations of new instruments and displays and to isolate display requirements.

53. AN EXPERIMENTAL EVALUATION OF DIGITAL ALTIMETERS, Triggs, T. J., Aeronautical Research Laboratories, Melbourne, Australia, ARL/HE-21, August 1966, NASA N68-30381

Three advanced displays and an improved three-pointer display were evaluated in a comparative experiment. Six airline pilots were used as subjects in this study. Static presentations were first read using subject-controlled exposure time and display exposure time were recorded during this action. Then, with a continuous extra task, the subject was called on to make altimeter readings at random times. Tracking performance was recorded in this section, in addition to reading times and accuracy.

54. AN EXPERIMENMTAL EVALUATION OF FOUR TYPES OF ALTIMETERS USING BOTH PILOT AND ENLISTED MEN SUBJECTS, Chernikoff, R., Ziegler, P. N., Naval Research Laboratory, Washington, D.C., NRL-6232, December 18, 1964, AD 610 665

Eighteen pilots and seven Navy enlisted men participated in an evaluation of the four altimeters: counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P). The experimental situation required the subjects to track a dot in a CRT while reading altimeter settings suddenly presented by the opening of a shutter. Subjects operated a hand-switch to close the shutter after reading the altitude presented. Measures were taken of the length of the exposure time and the accuracy of the reported altitude. The results indicated that for both pilots and enlisted men, the CP and CDP altimeters yielded nearly identical exposure time.

55. AN EXPERIMENTAL INVESTIGATION OF COMPENSATORY AND PURSUIT TRACKING DISPLAYS WITH RATE AND ACCELERATION CONTROL DYNAMICS AND A DISTURBANCE INPUT, Allen, R. W.,Jex, H. R., Systems Technology Inc., Hawthorne, California, NASA CR-1082, June 1968

Four instrument-rated pilots were trained and tested with a series of different tracking displays envolving rate and deceleration inputs. Error performance is related to display criteria.

56. F-106A/B CATEGORY II VERTICAL FLIGHT INSTRUMENT PRESENTATION TESTS, Add I, Gordon, Captain H., and Schwedes, 1/Lt., J., USAF, AFFTC-TR-59-26, 96 pages, February 1960

The F-106 Vertical Flight Instrument Presentation Test was conducted by the Air Force Flight Test Center at Air Force Plant 42, Palmdale, California. The purpose of this program was to evaluate the vertical instrument equipped aircraft for safety of flight deficiencies and instrument system accuracy, reliability, and maintainability. One F-106A was flown on 52 test missions for 70:15 hours and one F-106B was flown on 30 missions for 40:05 hours. The F-106 Vertical Flight Instrument Presentation, when operating malfunction-free, provides an improved overall operational capability. However, the flight safety and operational suitability of the integrated presentation are degraded by inadequate failure warning annunciations, the lack of adequate published technical information, and pilot operating instructions, and the poor overall functional reliability.

57. FLIGHT DECK DISPLAY FOR FUTURE AIRCRAFT PROJECTS, Brown, Milton (Bendix Corp.) Aircraft Engineering, pp.18-22, February 1966

Article relates the relationship of display to control input. The advantages of vertical scale instrument display are discussed from the viewpoint of a United States manufacturer.

58. FLIGHT DECK DISPLAYS: PSYCHOLOGICAL AND PHYSIOLOGICAL ASPECTS, Corkindale, K. G., Rolfe, J. M, Royal Air Force Institute of Aviation Medicine, Farnborough, England, S 90, January 1968

The paper summarizes the psychological and physiological aspects of flight instrument displays and outlines the program of IAM in flight instrument display.

59. FLIGHT EVALUATION OF THE MODIFIED COUNTER-DRUM-POINTER SERVO-ALTIMETER DISPLAYS FOR THE AIR TRAFFIC CONTROL RADAR BEACON SYSTEM/IFF/MARK 12/SYSTEM (AIMS) PROGRAM, Lee, R. P., Naval Air Test Center, Patuxent River, Maryland, Final Report ST 32-22R-65, February 26, 1965

Evaluation of CDP Servo-Altimeter for AIMS Program usage. Several encountered deficiencies are noted.

60. FLIGHT EVALUATION OF SERVO-ALTIMETER DISPLAYS FOR THE AIR TRAFFIC CONTROL RADAR BEACON SYSTEM/IFF/MARK 12/SYSTEM (AIMS) PROGRAM, Lee, R. P., Naval Air Test Center, Patuxent River, Maryland, Report ST 32-92R-64, November 23, 1964

The Counter-Drum-Pointer, Counter-Pointer, Drum-Pointer, and Three-Pointer altimeter presentations were evaluated by 23 pilots to select the best altimeter display for use in airplanes operating above 18,000 feet. The Counter-Drum-Pointer (CDP) was the first choice of 80 percent of the pilots.

61. FLIGHT NAVIGATION INSTRUMENTS: INSTRUMENT FLYING. (THE PILOTING OF A PLANE BY INSTRUMENTS), Denisov, V.G., and Lopatin, R. N., Wright-Patterson AFB: Air Force Systems Command, Foreign Technology Division, Translation (from Russian) FTD-TT-63-636 102, 1963, AD-429

62. HEAD-UP DISPLAY SYSTEMS IN MODERN AIRCRAFT, Sones, J. H., Smith's Industries Ltd. Aviation Division, Cheltenham, England, 1971

63. HUMAN ENGINEERING PROBLEMS OF LOW-ALTIUTDE, HIGH-SPEED FLIGHT, Mille, James W., 8 Preferences Presented at AGARD Specialists Meeting on Low-Altitude, High-Speed Flight, Paris, October 20-23, 1964 AD 460 918

Pilot task loading, function allocation, specific displays, and pilots selection are discussed in reference to the human engineering aspects of low-altitude flight. In a man-machine system, man is capable of functioning as a servo-mechanism, a controller, and a computer. However, this "black box" concept of him must take into account his physiological limitations, individual differences, motivation, non-linearity, and adaptation. Pilot task loading is increasing and the margin of tolerable error is becoming narrower. In a low-level flight, a pilot must now perform functions in less time than previously afforded him in a low-level-system instrument design.

64. HUMAN ENGINEERING SUPPORT TO AIR FORCE FLIGHT CONTROL AND FLIGHT DISPLAY INTEGRATION PROGRAM, Rabideau, G. F., Semple, Clarence A.(The Bunker-Ramo Corp.) AFFDL-TR-66-157, October 1966

65. HUMAN FACTORS AND THE DISPLAY OF HEIGHT INFORMATION, Rolfe, J. M.(Principal Psychologist, Head of Flight Skills Research Section, Royal Air Force Institute of Aviation Medicine, Farnborough, England) Applied Ergonomics, pp. 16-24, December, 1969

This article summarizes the course of events leading up to the situation where some ergonomic interest and intervention was necessary; to describe the research which has been undertaken in the United Kingdom in relation to the display of height information; and to consider the more general lessons to be learned from this area of applied investigation.

66. AN INVESTIGATION INTO PILOT AWARENESS OF HEIGHT LOCK OSCILLATION, Waller, P., B.E.A. Project and Development Branch Engineering Department, Technical Note No. A307, January 1963

67. JANAIR VERTICAL CONTACT ANALOG DISPLAY EVALUATION PROGRAM: ACCURACY OF ALTITUDE, ROLL ANGLE, AND PITCH ANGLE JUDGEMENTS AS A FUNCTION OF SIZE OF VERTICAL CONTACT ANALOG DISPLAYS, Cross, K. D., and Bittner, A. Naval Missile Center, Point Mugu, California, TM-69-2; JANAIR-680713, January 31, 1969, AD 683 302

The purpose of the document is to report the first results from a series of experiments establishing and optimizing the utility of the Vertical Contact Analog Display (VCAD). The VCAD concept is that of a computer-generated pictorial display which provides the observer with visual cues as to aircraft orientation. The objectives were: (1) to establish the relationship between size of VCAD display and judgement accuracy for altitude, pitch, and roll estimates, and (2) to obtain estimates of the accuracy with which these quantities may be judged. The analytic procedure consisted of the fitting of response surface models and the graphical representation of the accuracy for each of the three-flight quantities, but the nature of the effect depended on both the type of judgement task (maintenance versus recalled standard) and the magnitude of the standard being judged. Generally, the effect was more pronounced for the maintenance experiments.

68. LINK TRAINER TESTS ON SIMPLE MODIFICATIONS TO THE THREE POINTER ALTIMETER, Baines, D. J., Baxter, J. R., Aeronautical Research Laboratories, Melbourne, Australia, ARL/H.E.6, April 1960

69. LITERATURE SURVEY ON HUMAN FACTORS IN VISUAL DISPLAYS, Sampson, Philip B., and Wade, Edward A., (The Institute for Psychological Research, Tufts University), Rome Air Development Center, New York, RADC TR 61-95, June 1961

The ability of the human operator to assimulate, process, and use information presented visually, is an important factor in the design of visual displays. This report, which takes the form of an annotated bibliography, was prepared to access the current state of knowledge on this topic. The annotations are organized under four major headings which are: (1) Information Load and Speed, (2) Display Format and Content, (3) Display Integration, and (4) Human Complex Processes as Related to Displays. Under these headings, reports dealing with a variety of subtopics such as search and detection of visual targets, recognition and interpretation of display elements, human information processing and channel capacity, signal presentation rate, coding, S-R compatibility, and decision making are to be found. Each of the four parts contains introductory text which analyzes and evaluates the annotations contained in the part.

70. MAN AND HIS ALTIMETER, Rolfe, J. M, Flight International, pp. 819-821, May 14, 1970

A summarization of the steps taken which led to the development and evaluation of the counter-pointer type altimeter through a human factors analysis, laboratory experiments, flight simulation, and flight test program.

71. A MANUAL CONTROL-DISPLAY THEORY APPLIED TO INSTRUMENT LANDINGS OF JET TRANSPORT, Clement, Warren F., Jex, Henry R., Graham, Dunstan, (Systems Technology, Inc., Princeton, New Jersey), IEEE Trans. Man-Machine System Vol. MMS-9, No. 4, pp.93-109, December 1968

A presentation of the theoretical relationship of display theory and manual control in a multiloop dynamic systems.

72. MEASUREMENT AND ANALYSIS OF PILOT SCANNING BEHAVIOR DURING SIMULATED INSTRUMENT APPROACHES, Weir, D. H., and Klein, R. H., (Systems Technology, Inc., Hawthorne, California) AIAA Paper No. 70-999, August 17-19

Experimental measurements of pilot scanning and control response in a simulated instrument approach are reported. Airline pilot subjects flew ILS approaches in a 6° of freedom fixed-base DC-8 simulator at the NASA Ames Research Center. Pilot eye fixations and scan traffic on the panel were measured using a recently developed eye-point-of-regard (EPR) system. Flight director (zero reader) approaches as well as standard localizer/glide slope (manual) approaches were made. The scanning results showed the attitude and glide slope/localizer instrument to be primary in a manual ILS approach, sharing 70 to 80 percent of the pilots attention. The glide slope/localizer instrument required shorter dwell times with a fixed instrument sensitivity.

73. NEW COCKPIT CONTROL AND DISPLAY TECHNIQUE - WHAT CAN THEY DO FOR THE PILOT, Hattendorf, E. R., Fenwick, C. A., and Schweighofer, H. M., (Collins Radio Co.), SAE 680292, Society of Automotive Engineers, May 1968

Advances in avionics technology have made possible a number of new airborne equipments which can provide improved operating capabilities desired by the airlines. The individual control and display requirements of such equipments could, however, increase the total pilot workload. New techniques, including digital processing and control, must be applied to the control/display problem in the proper manner to assure that these added devices are truly pilot aids.

74. NEW VERTICAL SCALE INSTRUMENTS WILL EASE PILOTS' TASK, ANON - Electron Weekly, p.14, October 16, 1963

75. NUMERICAL DISPLAY PROBLEMS, Rolfe, J. M., (RAF Institute of Aviation Medicine, Farnborough, Hants, England), Applied Ergonomics pp. 7-11, 1971

After reviewing current knowledge about the presentation of dynamic information using numerical displays, this paper describes a series of experiments to assess their effectiveness in a tracking task. It is concluded that a numerical display can provide sufficient dynamic information to allow the performance of a variety of tasks, but appears to demand more of the operator's attention than other types. A number of other problems about numerical displays are noted to need investigation.

76. OPERATIONAL TEST AND EVALUATION OF THE B-70 VERTICAL FLIGHT INSTRUMENT DISPLAY, Final project, Richard N. Goodall, Instrument Pilot Instructor School, Randolph AFB, Texas, IPIS RAFB 63-12, May 1963

The B-70 vertical flight instruments are an improvement over the F-105/106 instrument. The change that was accepted most universally is the vernier altitude scale. This scale eliminated the previous complaints that altitude was too difficult to maintain due to the altitude scale movement. A fluctuating indication will be much more eyecatching, especially during periods of high-task load, The self-test feature proved to be beneficial during this evaluation. The altitude readout feature proved to be of no value. It is felt that the addition of the vernier scale eliminated the need for the readout position.

77. PILOT OPINION SURVEY: THREE-POINTER ALTIMETER, Green, M. R., Mengelkoch, R. F., The Martin Company, Human Engineering Support Group, Baltimore, Maryland, Conference Memo #161, Contract AF 33(616)5472, January 22, 1960

78. A PILOT-VEHICLE SYSTEMS APPROACH TO LONGITUDINAL FLIGHT DIRECTOR DESIGN, McRuer, D. T., Weir, D. H., and Klein R. H., (Systems Technology, Inc., Hawthorne, California), AIAA Paper No. 70-1001, August 17-19, 1970

Recent developments in the theory of manual control displays make feasible the statement of principles for analytical design of flight directors, given the dynamics of the (augmented) vehicle and its manual control system. The principal result from the theory is that there are effective director/vehicle controlled element dynamics which are preferred from the standpoint of pilot response and system performance. This paper summarizes the requirements and illustrates the analytical process for longitudinal control of transport-type aircraft during landing approach.

79. PITOT STATIC SYSTEMS, Sevart, J. A., (Manager, Service Engineering, Swearingen Aircraft), Flight Safety Foundation, Inc., 15th Corporate Aircraft Safety Seminar, San Antonio, May 13, 1970

80. PRE-EXPERIMENTAL RESULTS: COCKPIT DISPLAY FOR ALL-WEATHER LANDINGS, Gainer, C. A., and Welde, W. L., The Martin Company, Baltimore, Maryland, Memorandum Report 62-4, January 31, 1962

81. PREFERRED ALTIMETER DISPLAYS, Anderson, O. E. E., United Air Lines, San Francisco, California, Report No. F-1295, May 29, 1968

82. PRELIMINARY FLIGHT EVALUATION OF THE F-11B PRIMARY FLIGHT DISPLAYS, Blose, L. E., and Hubner, J., Naval Air Test Center, Patuxent River, Maryland, T-46R-66, June 22, 1966

Flight evaluation of F-11B primary flight displays.

83. PRELIMINARY STUDIES OF COCKPIT INFORMATION CONTENT AND EQUIVALENCY OF INFORMATION IN COCKPIT STANDBY INSTRUCTION, Lear, Inc., Advance Engineering Division and Ritchie and Associates, Inc., Grand Rapids, Michigan, Lear Advance Engineering Report No. 32, November 1960

84. PRELIMINARY V/STOL CONTROL-DISPLAY SUBSYSTEM REQUIREMENTS STUDY, Fellinger, J. G., (Lear Siegler Inc., Grand Rapids, Michigan), Air Force Flight Dynamics Lab, Wright-Patterson Air Force Base, Ohio, FDL-TDR-64-85, June 1964

As a result of project analysis and static evaluation conducted during the program, display requirements have been established for angle of attack, indicated airspeed mach, absolute and barometric altitude, altitude, terminal guidance, and engine data. Areas requiring intensive control-display analysis to fully utilize the unique V/STOL capabilities include: lift engine instrumentation, low airspeed sensing and display, angle of attack during transition phases, and terminal guidance requirements.

85. THE PRESENTATION OF HEIGHT INFORMATION, Honick, K. R., Journal of Institute of Navigation, Vol. XIV, No. 3, July 1961

86. PRESENTATION OF HEIGHT INFORMATION, Jackson, K. F., International Air Transport Association, Lucerne, Switzerland, Technical Conference Report No. 13, WP-39, May 1960

87. PRESSURE INSTRUMENTS--THEIR USE AND MISUSE, Angus, James W., (Kollsman Instrument Corporation), Flight Safety Foundation, Inc., 15th Corporate Aircraft Safety Seminar, San Antonio, Texas, May 13, 1970

88. A PSYCHOLOGIST'S POINT-OF-VIEW, Corkindale, K. G., (Institute of Aviation Medicine, RAF, England, Journal of the Aeronautical Society, Vol. 69, No. 658, pp. 651-659, October 1965

The contributions of psychology to the design of flight instrument displays has been in advising on details of design. Three areas in which useful contributions may be made are:

(1) Defining the basic characteristics of the human operator.

(2) Relating the enviornmental conditions to performance.

(3) Determine the information requirements as related to man's role in the system.

89. A PSYCHOPHYSIOLOGICAL STUDY OF COMPENSATORY TRACKING ON A DIGITAL DISPLAY, Benson, Alan J., Huddleston, Jo H. F., and Rolfe, John M., (RAF Institute of Aviation Medicine, England), Human Factors, pp. 457-472, October 1965

Comparable performance on a compensatory tracking task was achieved with a purely digital altimeter display and with a combined digital and scale-and-pointer display. Performance of a subsidiary, light responding, task was degraded significantly when the digital task was employed. In the presence of the subsidiary task a larger change was recorded in a number of physiological variables (heart rate, muscle activity, skin resistance and respiration) with the digital than with the counter-pointer display. Thus, both performance and physiological measures indicated that parity of performance on the primary task was achieved by increased "effort" when using the digital display.

90. QUANTITATIVE READING RESPONSE TIMES TO A FIVE-DIGIT COUNTER, Innes, L. G., RCAF Institute of Aviation Medicine, Toronto, Canada, Report No. 62-RD-5, 1962

91. RECENT DEVELOPMENTS IN THE UNITED KINGDOM IN FLIGHT INSTRUMENTS, Honick, K. R., Advisory Group for Aeronautical Research and Development, Rue De Varenne, Paris, AGARD Report 405, July 1962

92. RELATIVE MOTION OF ELEMENTS IN INSTRUMENT DISPLAYS, Matheny, W. G., Dougherty, D. J. and Willis, J. M., Aerospace Medicine 34(11), pp. 1041-1046, 1963

93. RESEARCH ON DISPLAY SCANNING, SAMPLING AND RECONSTRUCTION USING SEPARATE MAIN AND SECONDARY TRACKING TASKS, Allen, R. W., Clement, W. F., and Jex, H. R., Systems Technology, Inc., Hawthorne, California, Technical Report No. 170-2

Theoretical models and corroborative experimental data are presented on the human operator's scanning behavior and tracking performance while simultaneously controlling two closed-loop tasks using separate displays. A novel experimental technique is used to force the subjects (skilled instrument-rated pilots) to scan two displays in a manner that is done via a "subcritical" side task (stabilizing a slightly unstable first-order plant),

such that the time-away-from-the-side-task (i.e., available for the main task) is limited by the time-constant of the divergence. A new "scan frequency parameter," S, is derived to correlate the combined effects of sampling frequency and finite dwell time. A theoretical model for the sampling remnant is given, which has the form of first-order-filtered noise; it depends on the displayed signal variance, sampling frequency, fixation dwell time and sampling frequency variations. The experimental remnant data fit this model well, and thereby provide good correlations between theoretical and experimental tracking performance measures.

94. RESULTS OF SPECIALITIES ALTIMETER PILOT OPINION SURVEY, Martin Human Engineering, C. M. 171, 1960

95. SAAMA TASK VII FOR CADC REPLACEMENT PROGRAM, Garrett, L. Y., Systems Divisions, Aerospace Group, Hughes Aircraft Co., Canoga Park, California, Report No. MA-1-AIP-71-73TTF, October 1971

96. SCALING OF ALTITUDE INFORMATION. AN ANALYTICAL STUDY, Gainer, C. A., Annex "A" to MAS(AIR) (61) 65NATO 1961

97. SIMULATOR EVALUATION OF FIVE COUNTER-POINTER ALTIMETERS, Zamarin, D. M., Blom, D. I., McDonnell-Douglas Corporation, Long Beach, California, Report No. MDC-J0909, October 1970

Ten airline pilots served as subjects. An experimental comparison of five counter-pointer altimeters was conducted in the DC-10 cockpit simulator. The altimeters were: (A) 5 digits, snap-action counter turnover; (B) 5 digits, analog counter turnover; (C) 5 digits, snap action for the hundreds counter and higher, analog for less than a hundred values. A hold 80, hold 00 feature (during ascent and descent, respectively) was added to eliminate display ambiguity; (D) 3 digits, snap-action turnover with barber pole striping in the 4th and 5th digits locations, to aid trend and rate determination; and (E) 3 digits, snap-action turnover.

98. SIMULATOR TEST OF KOLLSMAN DRUM-POINTER ALTIMETER, COUNTER-POINTER ALTIMETER, AND SPECIALTIES ALTIMETER, Gainer, C. A., Brown, J. E., The Martin Company, Baltimore, Maryland, Engineering Report 11, 787, June 1961

Twenty-four pilots flew a simulator over a standardized profile using the drum-pointer altimeter, the Kollsman counter-drum-pointer altimeter, and the Specialties Altimeter. An analysis was made of performance in terms of root-mean-square and average error as a function of altimeter, maneuvers, altitude ranges, and order of altimeter presentation. The results indicate that the drum-pointer altimeter was superior to those altimeters tested in conjunction with it.

99. SIX ALTIMETER DISPLAYS COMPARED, Anderson, O. E. E., United Air Lines, San Francisco, California, Report F-1204, July 28, 1967

The report covers the description and subjectives evaluation, including advantages and disadvantages of six different altimeter displays.

100. SOME DEVELOPMENTS IN FLIGHT-DECK DISPLAY, Penny, N. W., (Smiths' Industries Ltd.), Flight International, pp. 993-994, December 25, 1969

Two types of counter-pointer altimeters and their desirable features are described in brief.

101. SOME INVESTIGATIONS INTO THE EFFECTIVENESS OF NUMERICAL DISPLAYS FOR THE PRESENTATION OF DYNAMIC INFORMATION, Rolfe, J. M., Royal Air Force Institute of Aviation Medicine, Farnborough, England, Report R470, May 1969

The paper reviews recent published information on numerical display and its relationship and possible limitations for providing dynamic information. The potential areas which may require evaluation are discussed.

102. SPIRAL WINDOW ALTIMETER, Aircraft (Australia), Vol. 42, p. 27, May 1963

Brief description of the main features of a spiral window altimeter devised to meet the requirements for a simple instrument. The new presentation is said to offer the pilot ease and accuracy in reading the digital display, without the servo-mechanisms required in other digital types. Cut away drawings of the instrument are included.

103. STUDY OF ATTITUDE CHANGE TOWARD EQUIPMENT DESIGN, EFFECTS OF BRIEF EXPERIENCE VERSUS PRINTED COMMUNICATION OF ALTIMETER PREFERENCE, Matheny, W. G., Berger, Philip K., Life Sciences, Fort Worth, Texas, Report No. TR-1, October 1964, AD 614 655

The study was undertaken in an effort to gain a better understanding of the problem of resistance to change and how such resistance may be counteracted. The report discusses and illustrates some of the problems surrounding the methodology for investigating equipment preferences and reports the results of a preliminary investigation into procedures for producing changes in preference for new equipment. The selection of the altimeter as an instrument for use in the study was based upon the fact that suitable data was available as to the relative adequacy of the two instruments chosen and that the altimeter is an instrument around which controversy still revolves.

104. STUDY OF ATTITUDE CHANGE TOWARD EQUIPMENT DESIGN, THE MEASUREMENT OF ALTIMETER DISPLAY PREFERENCE AND AN INVESTIGATION OF PREFERENCE CORRELATES, Berger, Philip K., Life Sciences, Inc., Fort Worth, Texas, Report No. TR-2, August 1965

The purpose of this study was to evaluate the test-retest reliability of two single item measures of altimeter preference and to investigate some correlates of display prefference. One altimeter display has been operational for many years (MA-1 Three Pointer) while the second display is a development design (Moving Tape Single Pointer). Adequate reliability for the two preference measures was demonstrated.

105. A STUDY TO DETERMINE AN OPTIMUM ALTIMETER PRESENTATION, Beldam, E. M., RCAF Institute of Aviation Medicine, Toronto, Ontario, Canada, IAM 59/2, 1960

106. A STUDY OF SETTING PERFORMANCE ON A DIGITAL DISPLAY, Rolfe, J. M., RAF Institute of Aviation Medicine, Farnborough, England, January 1966

Two groups of subjects performed a series of setting operations using two forms of digital display. A subsidiary task was also present. The results obtained showed differences in the performance of the groups indicating a differential effect of both task and display. The presence of the subsidiary task resulted in a deterioration in performance on the setting task.

107. A STUDY OF THE EFFECT OF REWARD ON THE PERFORMANCE OF A TRACKING TASK EMPLOYING A DIGITAL DISPLAY, Dynamic Digital Displays, Rolfe, J. M., RAF Institute of Aviation Medicine, Farnborough, England, IAM Report No. 395, June 1967

Two groups of subjects performed a series of com-pensatory tracking and setting tasks using a digital display. A secondary visual light acknowledging task was also present. One group of subjects was offered financial reward for good primary task performance.

The presence of reward had an effect on performance in both primary task conditions. However, it could not prevent primary task performance being degraded by the presence of the secondary task in the compensatory tracking condition.

108. A SYSTEM MODEL FOR LOW LEVEL APPROACH, Johnson, W. A., and McRuer, D. T., Systems Technology, Inc., Hawthorne, California, AIAA Paper No. 70-1034, August 17-19, 1970

This paper describes a system model for analyzing Category II approaches and presents examples of its application. Although the model considers both the longitudinal and lateral situations, only the longitudinal will be discussed in any detail here.

109. SYSTEMATIC MANUAL CONTROL DISPLAY DESIGN, Clement, W. F., McRuer, D. T., and Klein, R. H., Systems Technology Inc., Hawthorne, California, Conference Preprint No. 96 on Guidance and Control Displays

A theory of displays, together with validated techniques for analyzing closed-looped pilot-vehicle dynamic performance provides a systematic procedure for improving the guidance and control display design process.

110. A SYSTEMATIC METHOD FOR DETERMINING THE BEST ALTIMETER DISPLAY FOR HIGH PERFORMANCE AIRCRAFT, Master's Thesis, Heininger, Howard G. Jr., School of Engineering and Applied Sciences, George Washington University, Washington, D.C., February 22, 1966, AD 638 318

The methodology was implemented by conducting static and dynmamic laboratory testing. The results of the testing were thoroughly analyzed and presented to the Air Force and the Navy. As a result, the Air Force and the Navy standardized upon the counter-pointer altimeter display. The display should also reduce the number of aircraft accidents caused by altimeter reading errors. The methodology was further refined and extended so that it can be utilized in future flight display developments and evaluations.

111. A SYSTEMS ANALYSIS OF MANUAL CONTROL TECHNIQUES AND DISPLAY ARRANGEMENTS FOR INSTRUMENT LANDING APPROACHES IN HELICOPTERS, Clement, Warren F., and Hofmann, Lee Gregor, Systems Technology, Inc., Hawthorne, California JANAIR Report 690718, July 1969

A comprehensive theory for displays used in manual control systems is applied to the instrument-landing approach problem for helicopters. A single-articulated-rotor transport and a compound rigid-rotor attack helicopter serve as examples. A comparative analysis of manual control techniques for speed and height regulation in the approach is given. Suitable display arrangements and task performance are predicted for the better control techniques. The applications of the theory incorporate recent revisions for predicting eye-scanning patterns, workload measures and preferred arrangements for combined displays as well as separated instruments. Results show how display combinations which enhance the usefulness of parafoveal perception can reduce scanning workload. Other immediate applications of the theory and areas for future research are suggested.

112. A SYSTEMS ANALYSIS THEORY FOR DISPLAYS IN MANUAL CONTROL, McRuer, Duane, Jex, Henry R., Clement, Warren F., and Graham, Dustan, Systems Technology, Inc., Hawthorne, California, STI Technical Report No. 163-1, October 1967, Revised June 1968

A comprehensive theory for displays used in manual control systems is developed in servo analytic terms, and the process is illustrated by a tutorial example. The display-pilot-control-vehicle combination is treated as a multi-loop feedback control system, using the notion that display system synthesis is fundamemtally a guidance and control problem which involves human psychomotor activity. A detailed analysis of the manually controlled blind-landing of a jet transport using conventional ILS instruments is given and preferred instrument panel arrangements are predicted. The results agree well with airline experience. A number of immediate applications for the theory and areas for future research are suggested.

113. A SYSTEMS ANALYSIS THEORY OF MANUAL CONTROL DISPLAYS, McRuer, D. T. and Jex, H. R., (Systems Tech. Inc., Hawthorne, California), NASA SP-144, Proceedings of Third Annual NASA-University Conference on Manual Control, Los Angeles, March 1967

This paper summarizes basic elements of a unified theory for the development of displays for pilots of manually controlled vehicles. The theory combines several recent manual control developments in its structure.

114. THEORY OF MANUAL VEHICULAR CONTROL, McRuer, D. and Weir, D. H., (Systems Technology, Inc., Hawthorne, California). Ergonomics, No. 4, Volume 12, pp. 599-639, 1969

The analytical basis of manual vehicular control theory is a combination of feedback systems analysis and mathematical models for human operators engaged in control tasks. Simplified representations for the operator-system combination are provided by the 'crossover model' which is described in detail. The system dynamics and average performance of the crossover model system are developed. Two aircraft control examples illustrate the use of the theory and its empirical correlates to estimate operator dynamic characteristics, system performance, pilot ratings, automobile example is presented to illustrate the use of the theory in structuring the key guidance and control features of the driver's visual field. A comprehensive bibliography of operator-vehicle system analysis applications is also provided.

115. TRUST YOUR ALTIMETER?, Hemingway, James L., (Federal Aviation Administration) Flight Safety Foundation, Inc., 15th Corporate Aircraft Safety Seminar San Antonio, Texas, May 13, 1970

116. VERTICAL INSTRUMENTS, Kearns, J. H., Warren, E., North Atlantic Treaty Organization, Advisory Group for Aeronautics Research and Development, Paris, France, AGARD Report 404, 1962

This report is a discussion of vertical scale instruments covering the historical facts which lead to their design through to their application. The point is made that vertical instruments represent the foundation of a new approach to the creation, design, and development of displays. This was our first attempt to deliberately design displays so that they would be suited to the total system job.

117. VISUAL ASPECTS OF COCKPIT MANAGEMENT, Ormanroyd, F., (British European Airways), Journal of the Aeronautical Society, Vol. 69, No. 658, pp. 651-659, October 1965

An account of some of the practical display problems experienced by an airline pilot.

118. WHOLE PANEL CONTROL-DISPLAY STUDY, Lear, Inc., Grand Rapids, Michigan, Advance Engineering Division, Progress Report 10, Contract NO. USAF 33(616)-5901, February 1960

AUTHORS' INDEX