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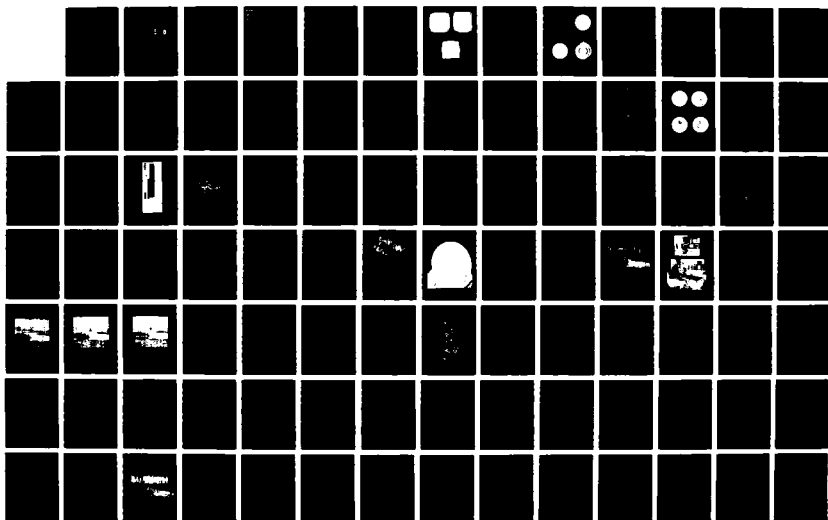
AN EVALUATION OF THREE LINEAR SCALE RADAR ALTIMETER
DISPLAYS(U) AERONAUTICAL SYSTEMS DIV WRIGHT-PATTERSON
AFB OH L A CARR JAN 88 ASD-TR-87-5005

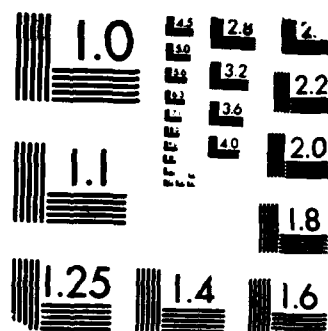
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ASD-TR-87-5005

AN EVALUATION OF THREE LINEAR SCALE RADAR ALTIMETER DISPLAYS

Larry A. Carr, Lt Col, USAF

Crew Station Design Facility
ASD/ENECH

Wright-Patterson AFB OH 45433-6503

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January 1988

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Twelve fighter pilots were used as subjects to fly six low altitude missions in a full mission F-16 simulator with a visual system projected on a head-up display. The subjects were required to accomplish three descents to one of two altitudes (300' or 1000') on each of the missions and to maintain that altitude before then climbing back to a cruising altitude. The time to descent to low altitude, the partial time to descend from 1000' above the desired altitude, the RMS altitude deviation from desired altitude and the time to climb back to cruising altitude were used as measures of performance. A Modified Cooper Harper scale was used to assess workload and a questionnaire was also used to ascertain subjective opinion concerning each scale. The original scale was compared with two alternative scales that both had an expanded lower portion and one of the two had an expanded upper altitude range. The results indicated that none of the performance measures were significant with respect to the scales being used. Accuracy for reading and plotting altitudes was better using the original scale apparently due to its larger number of scale				
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Block 19 Abstract (continued)

markings. Workload ratings showed lower workload associated with the expanded upper scale in transitioning into and out of low altitude. Questionnaire data was not significant, but did result in key comments that showed distinct preference for the two alternative scales with the expanded low altitude regions. A separate alternative scale was recommended for further testing.



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than they actually were. Thus, the requirement to increase altimeter sensitivity and range led to the development of multi-revolution instruments resulting in severe misreading errors by pilots.

DISPLAY REFINEMENTS

Fitts and Jones (1947) recommended several methods of presentation including the following: different dials, tapes viewed through windows, tape counters, logarithmic scales, scales with variable limits, pointer counters, and others (Schum et al., 1963). Grether (1948) evaluated eight altimeter design alternatives against the standard three-pointer altimeter in use at the time. He used speed and accuracy of reading to compare these designs in a static legibility test using college students and Air Force pilots as subjects. The designs are shown in Figure 3 and briefly described below (Grether 1947; Schum et al., 1963):

1. Standard three-pointer (Fig. 3A)- longest pointer gives hundreds of feet, the broad pointer indicates thousands, and the small pointer indicates tens of thousands.
2. Three-pointer with separate 10000 foot scale (Fig. 3B)-a slight variant to standard three-pointer with the 10000-foot pointer offset and read on a separate scale.



Figure 2A. Pioneer Two-Pointer Altimeter



Figure 2B. Pioneer Three-Pointer Altimeter

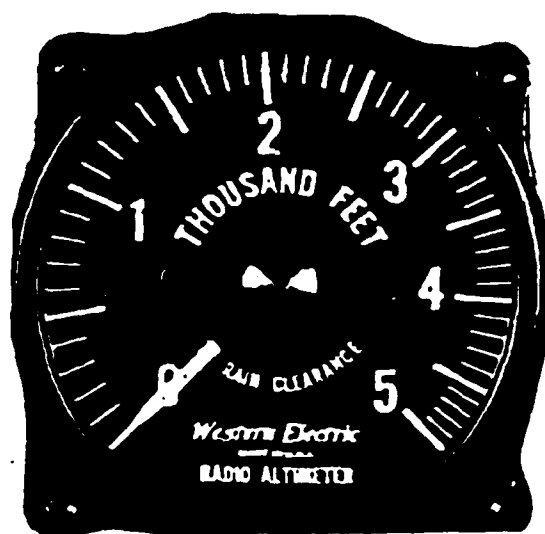


Figure 2C. Western Electric Altimeter

EARLY ALTERNATIVE ALTIMETER DISPLAYS

FIGURE 2

clockwise pointer movements for altitude increases; windows to display pressure settings; and a knob to adjust pressure settings (Schum et al., 1963). This gave the two-pointer altimeter a range of 10,000 feet and the three-pointer display a 10,000-foot range. These designs dominated until the mid 1950's and were common in most aircraft as late as the 1960's for the display of barometric altitude. Requirements for precise altitude measurement for precision navigation and bombing in World War II led to increased emphasis on absolute or terrain clearance altimeters. The display was initially by fixed circular scales (see Fig. 2C), that used a reference mark at the zero point and an absolute altitude mark which was read at its counter-clockwise edge. This scale and others like it were superimposed on CRT displays and used radar to generate the reference and altitude measurement marks (Schum et al., 1963). Various techniques were used to generate scale values which varied from mentally keeping track of the number of revolutions the marks transversed to manually switching scale factors.

DISPLAY PROBLEMS

Fitts (1947) conducted a study of errors in reading and interpreting aircraft instruments. He found the three-pointer altimeter to be the most error prone of all aircraft instruments. Grether (1948) reaffirmed these findings and showed the errors included: reading to the nearest numeral instead of to lower adjacent numeral; reading to lower adjacent numeral when the nearest is correct; displacement of a digit in the number series; misreading scale or pointer; pointer exchange; and repetition of reading of one pointer. Often these errors resulted in loss of aircraft and lives. The severity of the errors was increased by the fact that in most cases the pilots thought they were higher

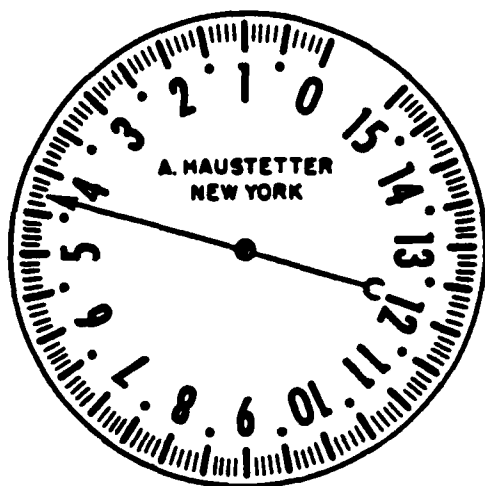


Figure 1A. Haustetter
Dashboard Barometer

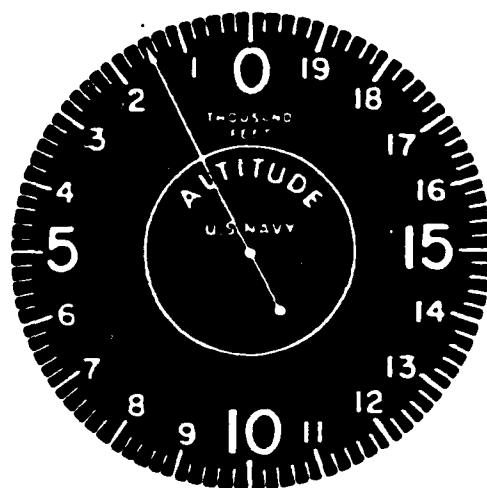


Figure 1B. Tycos Altimeter

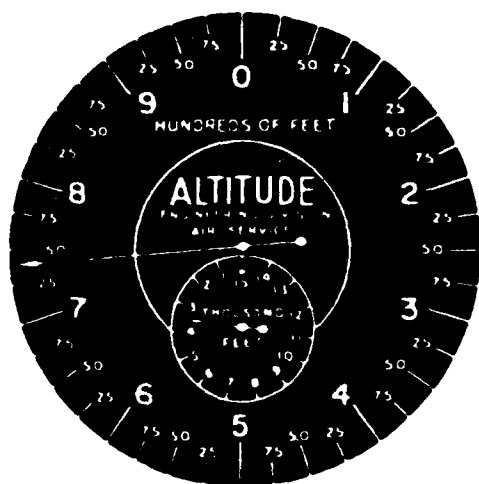


Figure 1C. Engineering Division
of Air Service Altimeter



Figure 1D. Aneroid Barometer

EARLY ALTIMETER DISPLAYS

FIGURE 1

ranges of 7000, 12000 and 15000 feet; could be supplied with luminous dials for night flying; and was read in a counter-clockwise direction. The Tycos altimeter (Fig. 1B) had 200-foot graduations; equal scale divisions; a single pointer; a maximum range of 20000 feet; and a counter-clockwise rotation. Variations of these two altimeter types were produced, but they all basically relied on the single pointer concept with a counter-clockwise rotation for an increase in altitude. The altimeter developed by the Engineering Division of the Air Service (Fig. 1C) introduced the multiple scale concept. Two scales were used with different major and minor increments that displayed two different altitude ranges. It also introduced a setting knob to account for large temperature induced errors. All early design efforts were exploratory yet conservative in their approach. The primary focus of these efforts appeared to center on providing a very sensitive altimeter. The need for this sensitivity was generated by the the historic efforts of Jimmy Doolittle in successfully demonstrating "fog" or instrument flying in 1929 (Nicklas, 1958).

Between World War I and World War II, aircraft underwent radical design changes with the installation of instruments and communications equipment that permitted the pilot to fly at night and in clouds. As the complexity of aircraft increased, so did its operational speed and altitude capability (Jarvi et al., 1982). The greater speed and altitude capability increased the need for greater sensitivity and range-of-altitude coverage for aircraft altimeters. By 1940, the most common altimeters in use were the single pointer type which used one complete pointer revolution for every 5000, 10000, or 20000 feet of altitude (Nicklas, 1958). Subsequently two- and three-pointer altimeters (Figs. 2A and 2B) were developed which had different minor, intermediate and major scale graduations; different pointers to record 1000, 10000 and multiples of 10000-foot altitude regions;

EARLY DISPLAY DEVELOPMENTS

Early aviation enthusiasts, aircraft designers, and aviators were concerned primarily with achieving and maintaining flight rather than developing any particular component or set of components to assist this task (Nicklas, 1958). Early aviators oriented themselves by visual observation of the earth. During World War I, if aviators encountered poor weather, they turned back or, if caught in the clouds, intentionally would spin the aircraft with the intention of recovering the spin beneath the clouds (Raleigh, 1922). During the WWI period, the Army developed certain requirements for the altimeters or barometers in use at that time. These requirements were that the altitude display must be sensitive, have an open scale, and must have equal scale divisions (Schum et al., 1963). From this early period in aviation, a great amount of research has taken place, but as Muckler (1959) relates:

"...the basic techniques for the display of altitude information was established early in the history of manned aircraft and dominated the design of altitude instruments throughout the first fifty years of manned aircraft instrument development. Four basic display principles predominated; altitude instruments were (1) circular, (2) open scale, (3) with equal scale divisions, and (4) until the 1940's had a single pointer."

Three of the early displays are shown in Figure 1 (Schum et al., 1963). The Haustetter dashboard barometer (Fig. 1A) has equal scale divisions; a single pointer; ranges of 7000, 12000 and 15000 feet; could be supplied with luminous dials for night flying; and was read in a counter-clockwise direction. The Tycos altimeter (Fig. 1B) had

instrument approaches, landings, and in descending through clouds to where flight may be continued visually. Over areas of uneven terrain, where exact elevations are not always known or where flight profiles change too quickly to predict the altitude with this technique, pilots must rely on some other technique for safe flight above the ground. Typically they have picked a Minimum Enroute Altitude (MEA) which, when considering all normal altimeter errors, would guarantee the aircraft flight path would safely be above all terrain. This technique satisfies the operational requirements of most aircraft, but precise terrain clearance (absolute) altitude information became a military requirement beginning with the precision bombing missions during World War II (Nicklas, 1958).

Absolute or terrain clearance altimeters were developed in the 1920's (Nicklas, 1958). They use radio or radar waves to directly measure the altitude beneath the aircraft. Military aircraft use this type of altimeter to provide the precise altitude measurement necessary for weapons delivery and low-altitude, high-speed flight. Typically, the radar altimeter is integrated with other sensors and provides a real-time measurement with which to crosscheck the precise altitude during low-altitude flight to the target area.

Both the barometric and radar altimeters have become standard instruments. Each has its own display requirement.

II. LITERATURE REVIEW

The development of altimeter displays followed an evolutionary pattern similar to the evolution of the aircraft itself. Both progressed from a cautious, exploratory phase into a conservative, evolutionary phase and thence into a period of continual experimentation and refinement, followed by a period of lethargy and finally, a revolutionary jump into the technology-intensive period of today. The literature review is broken down into the following sections: early display developments, display problems, display refinements, movements toward a vertical scale, current developments, LANTIRN design work, and future efforts. A brief discussion of altimetry is provided first.

ALTIMETRY

Altimetry is the science of altitude measurement. Classically, it has used the barometer to measure changes in atmospheric pressure during ascents and descents. The usefulness of altitude measurement has been recognized from the beginning of early manned balloon flights in 1783 (Schum et al., 1963). The mercurial barometer was replaced by the aneroid barometer still in use today. Various calibration schemes were used until 1934 and the advent of communicating altimeter settings from the ground to air (Schum et al., 1963). Pilots could update the calibration to account for changing atmospheric pressure. The major drawback was that mental calculations were required to determine the actual height of the aircraft above the ground. The pilot had to mentally calculate the difference between the altimeter reading and the actual height of the terrain above sea level to ascertain his height above the terrain. If operating in an area with precisely known elevations and a well defined position, the technique is used by pilots to execute

achieve. This study is an attempt to design a universally acceptable altitude display for the LANTIRN system to be displayed on the F-16 HUD.

airspeed and altitude on the gunsight. These displays have been simple vertical scales with limited display ranges. The introduction of advanced graphic displays allows the display of a far wider range of information on the evolving family of HUDs.

The focus of this study is the display of radar altitude on the new HUD for the F-16 fighter aircraft equipped with the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) system. The LANTIRN system projects an imaging infrared scene on a wide field-of-view HUD with imbedded cues to allow the pilot to fly the aircraft while looking almost exclusively at the HUD. Included in the cues is a vertical scale altimeter which provides the pilot with a choice of pressure or radar altitude. The radar altimeter data are used to crosscheck the performance of the terrain-following system of the aircraft as the pilot flies at tree-top level whether it be day or night. While cockpit altimeters and other flight instruments have evolved from simple devices in the early 1900's with the help of numerous studies and evaluations, little research has been conducted on the radar altimeter for the HUD. The initial design for the radar altimeter HUD display attempts to optimize and integrate the altimeter display for the LANTIRN mission.

Previous altimeter design evaluations have seldom attempted to use a simulator to obtain an objective measure of pilot performance (Schum et al., 1963). The present study uses a full mission capable simulator to evaluate the current altimeter design against two alternate designs that have been proposed as the result of design simulations and limited flight testing. Pilot performance on transitions into and out of the low-altitude environment and on maintenance of a precise altitude were used in conjunction with subjective ratings to develop a new display for future flight testing and subsequent system development. DuFeu (1975) suggested that the advent of advanced Cathode Ray Tube (CRT) displays would provide the opportunity for presentation of optimum altitude displays for each phase of flight that a pilot could encounter, but that a single universally acceptable display may be impossible to

separation from other aircraft or to comply with published takeoff, landing, or cruising flight procedures. Radar altitude, on the other hand, is used to accurately position the aircraft for precision bombing, weapons aiming or to crosscheck the performance of other sensors such as radars, terrain-following systems, or instrument flight systems.

Many studies and evaluations have been conducted on the present altitude displays. Initial work in altimeter displays focused on including the altimeter as an additional instrument component. Nicklas (1958) points out that during and just after World War I a set of techniques evolved for the display of altitude. These techniques formed the basis for the first generation of round-dial altimeter designs. Grether (1948) compared existing altimeter displays with several candidate displays with respect to speed and accuracy of display reading. Several other studies laid the framework for vertical scale instruments (Grether 1949; Simon 1956; and Mengelkoch and Houston 1958), but their results did not support such a radical departure from the standard round-dial pattern that had evolved. Necessity forced vertical altimeter displays into the cockpits of military and civilian aircraft in the 1960's because cockpits had become overcrowded with knobs, dials, instruments, and gauges. Cockpit designers introduced vertical displays to conserve space as well as to provide more altitude information than was possible with round-dial altimeters. These initial vertical altimeter displays formed the basis for altitude information included in the head-up gunsights of modern fighter aircraft and the now evolving HUDs for present and future aircraft. Early optical gun sights were merely reflecting lenses that displayed aiming cues for precise weapons delivery. In order to deliver the weapons accurately, key aircraft parameters must be attained in addition to the positioning of the aiming symbols over the target. Airspeed, flight path angle, and altitude must be precisely controlled. To facilitate this parameter crosscheck and minimize the time spent looking away from the gunsight, designers included the key parameters of

I. INTRODUCTION

As a result of significant advances in aircraft sensors, avionics, and displays, more and more information is being presented to the pilot in new and different formats and locations. One such location is the Head-Up Display (HUD) which is being pursued as a new situational awareness device. It will allow integration of numerous display formats from several sensors in front of the pilot's eyes to allow him to fly while looking at the surrounding world (real or projected) through the display. Aircraft altitude is receiving increased attention as an item to be displayed on the HUD.

Pilots rely on an altimeter for height information with respect to some datum plane. In instrument flight, this datum may be a standard value or a localized pressure setting, both of which allow the pilot to operate the aircraft at a specified height with respect to this plane. This type of altitude is often referred to as "pressure", "barometric", or "MSL" altitude. To successfully determine one's height above the ground with this type of altitude measurement, the local barometric pressure (in inches of Mercury) is set and the elevation of the ground beneath the aircraft subtracted from the altimeter reading. Radar altimeters, on the other hand, provide a direct measurement of the height above the ground by aiming a radar beam directly beneath the aircraft. This altitude is referred to as "absolute", "above ground level (AGL)", or "radar" altitude. Both of these altitude measures are important to the pilot for different reasons. Pressure altitude is used for instrument flight and allows the pilot to precisely position the aircraft at preassigned altitudes for

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3. Two-pointer with separate 1000-foot scale

(Fig. 3C) - range of only 20000 feet with long pointer for hundreds of feet and the inner pointer for thousands.

4. Counter pointer (Fig. 3D)- combination of a single pointer for hundreds of feet and a dual-digit Veeder counter for thousands.

5. Scale (drum) pointer (Fig. 3E)- combination of a single pointer for hundreds of feet and a drum that rotated with a continuous motion to show thousands of feet.

6. Range pointer (Fig. 3F)- a single pointer with selectable ranges. One revolution of the pointer covers the whole range. The meaning of the numerals was determined by the range selected. Ranges included: 0-1000 feet, 0-10000 feet and 0-100000 feet. The precision of the display necessarily changed with the range.

7. Counter, moving tape (Fig. 3G)- endless tape or drum used for hundreds and smaller units and a Veeder counter for thousands. The scale moved under the

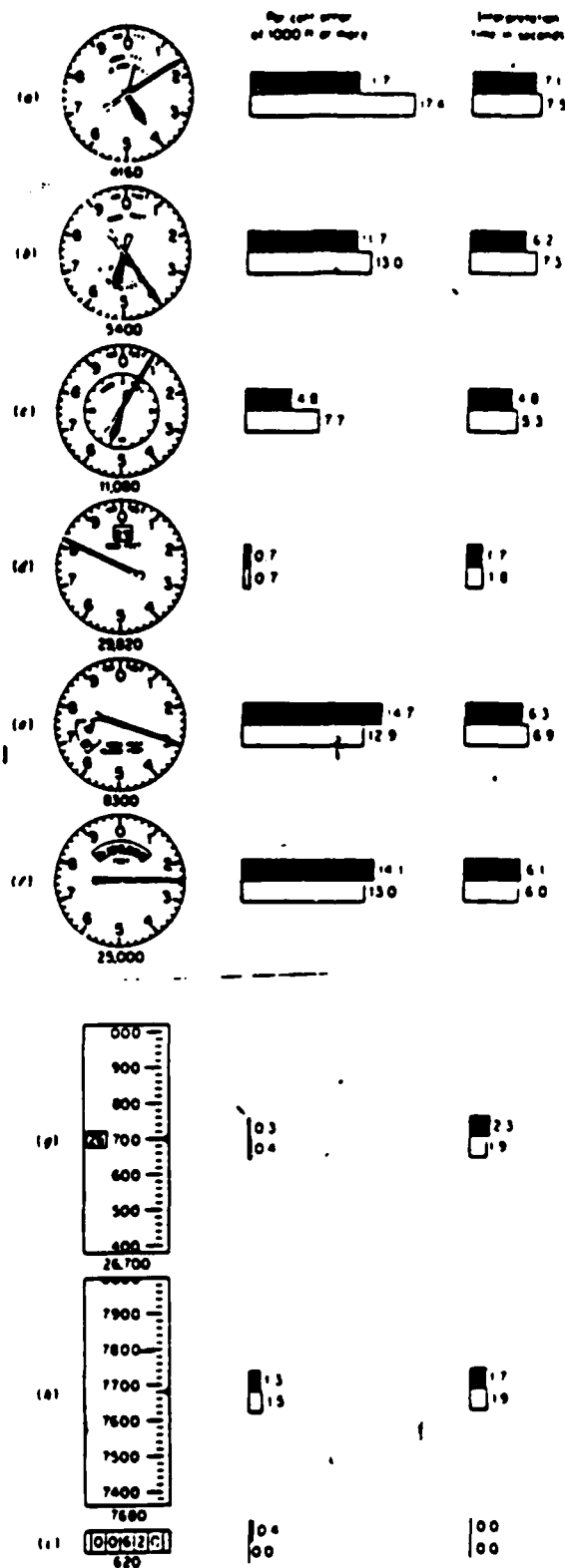
pointer.

8. Fixed-Pointer Moving Scale (Fig. 3H)-long tape
with a scale covering the whole altitude range.

9. Digital Readout (Fig. 3I)- Veeder counter
without a pointer or scale.

Grether's results showed that the counter pointer, both vertical tapes, and the direct digital readout altimeters were all superior to the three-pointer altimeter for speed and accuracy of reading. The digital readout did not provide adequate dynamic information and the vertical tapes were thought to be too difficult to read quickly unless more distinctive markings were provided on the scales. As a result, Grether recommended the counter-pointer-type instrument for future development. The results of his experiment are included in Figure 3 (Schum et al., (1963)).

Brown (1954) conducted an extensive flight test to evaluate various alternatives to the standard three-pointer altimeter and recommended a modified three-pointer with coded hands and a crosshatched warning area (Fig. 4A). Several alternative three-pointer displays tested during this period are shown in Figure 4. Navy studies and several subsequent studies by Simon (1956) and Stone (1960), led to displays shown in Figure 5 and Figure 6, several of which were evaluated flown. The pointer often obscured the counter on the counter pointer displays (Crumley, 1954). The drum-pointer display presented



GRETHER'S SCALES

FIGURE 3



Figure 4A. Three-Pointer
Two-Dial Altimeter.

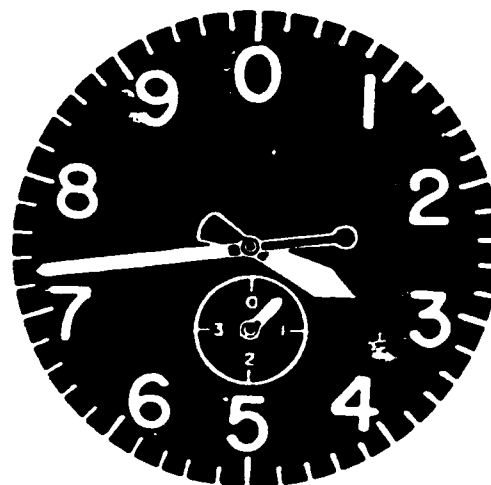


Figure 4B. Three-Pointer,
Two Dials.

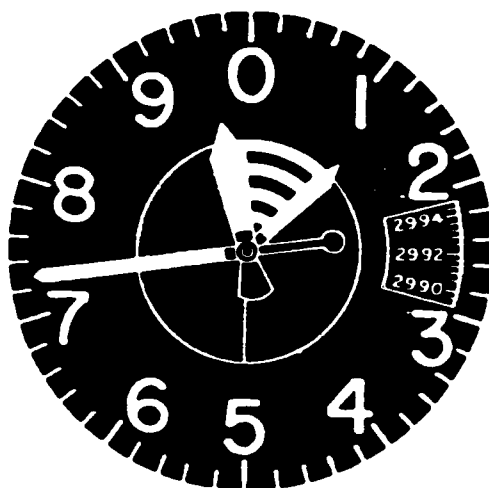


Figure 4C. Three-Pointer,
Shaded Warning Area.

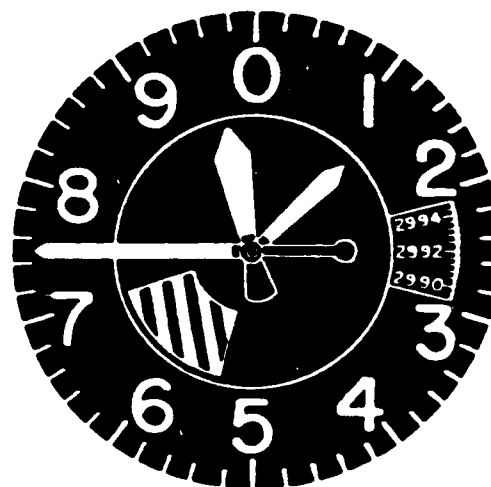


Figure 4D. Standard
Three-Pointer.

ALTERNATIVE 3-POINTER DISPLAYS

FIGURE 4

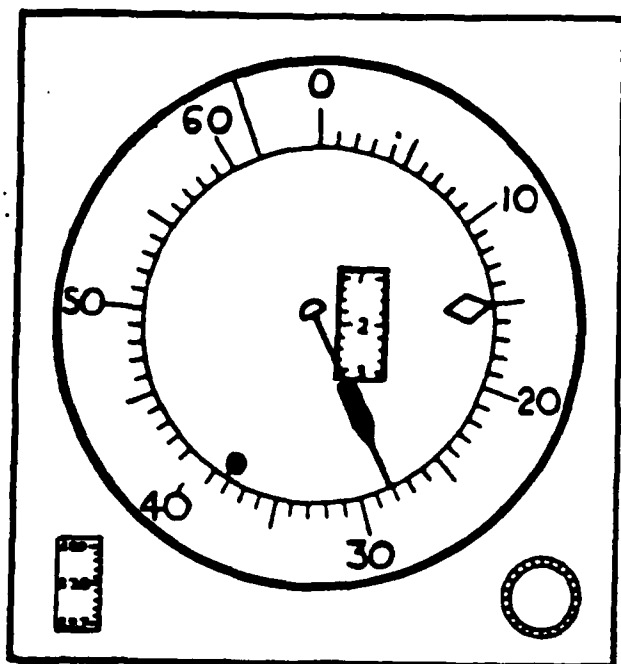


FIGURE 5A. Integrated Circular Scale Display (Simon).

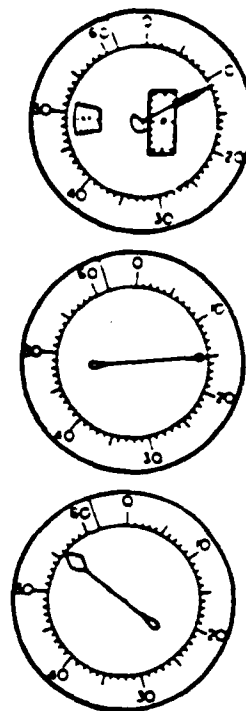


Figure 5B. Separated Circular Scale Display (Simon).

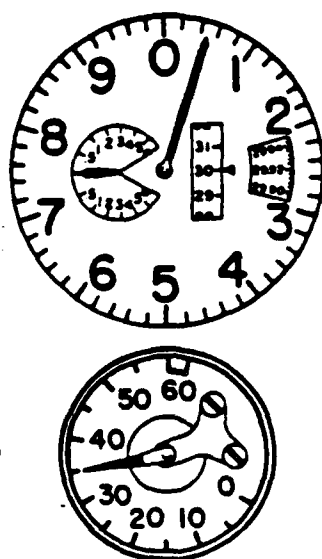


Figure 5C. Tape Pointer With Vertical Speed Insert (Simon)

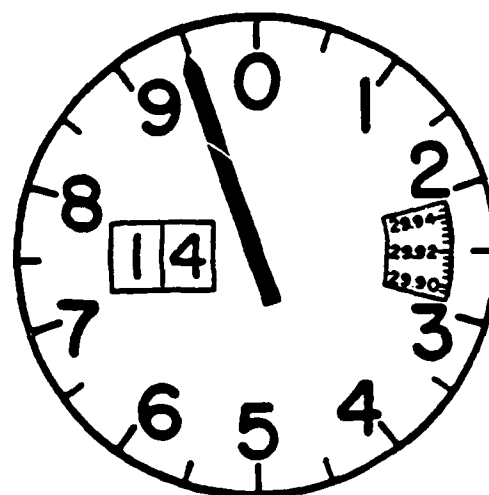


Figure 5D. Counter Pointer Display (Simon).

OTHER ROUND-DIAL ALTERNATIVE DISPLAYS

FIGURE 5

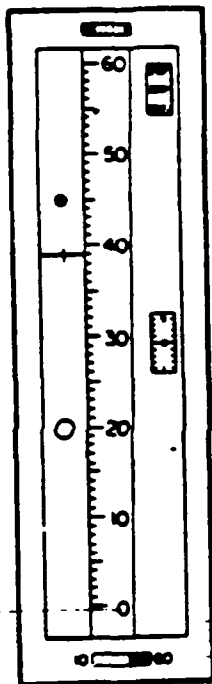


Figure 6A. Changeable Vertical Scale.

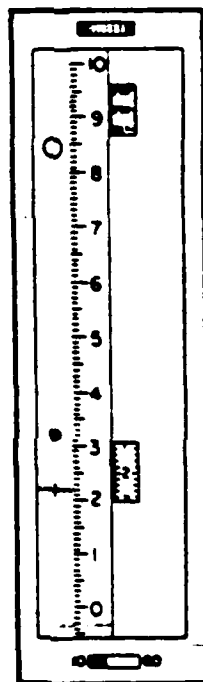


Figure 6B. Alternate Vertical Scale.

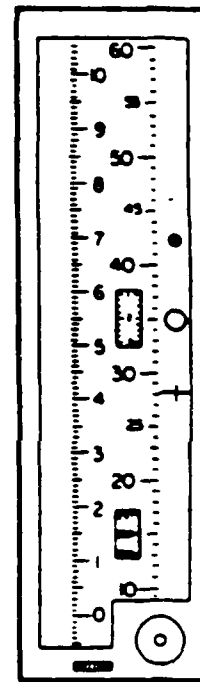


Figure 6C. Dual Vertical Scale.

NEW VERTICAL DISPLAYS (SIMON)

FIGURE 6

problems with numeral size, counter/pointer interference, pointer sensitivity, and color schemes (Amon, 1955).

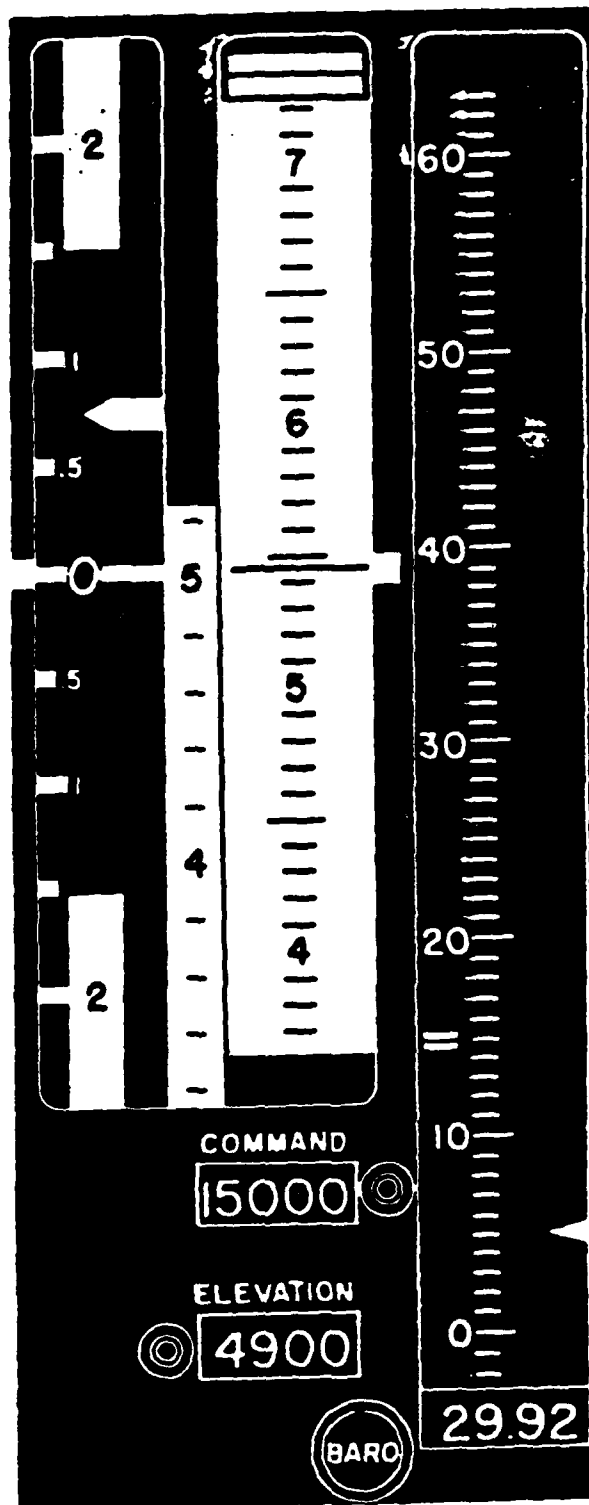
MOVEMENT TOWARD A VERTICAL SCALE

By a process of elimination, vertical displays were seen as the only available practical means of integrating command and performance information (Schum et al., 1963). Grether's earlier experiments had indicated the potential usefulness of these displays and provided the foundation for subsequent work by Simon (1956), Wright (1956), Mengelkoch and Houston (1958) and Stone (1960).

Simon (1956) studied three different vertical altitude displays with three commonly used altimeter scales of the time (Fig. 6). The changeable, alternate and dual vertical scales displayed altitude on a fixed tape, moving-pointer type scale with one of two ranges. The small aircraft tail pointer indicated present altitude while the solid dot indicated predicted altitude in one minute based on the rate of climb. A small sliding "hundreds" window was appended to the scale as was the altimeter barometric setting window. In these studies he used a paper and pencil analysis to compare the speed and accuracy with which decisions could be made with respect to vertical flight path using these various displays. Altitude information from the displays had to be combined with other information to determine the aircraft's vertical flight path. In addition, the subjects were asked to determine the required rate of climb to reach a specified altitude which was commanded by the display. All three vertical displays were superior to the circular displays in both speed and accuracy of performance ($p < .01$). Additionally, the alternate display (a single vertical display as opposed to a dual or combined display) was favored most consistently. In a subsequent study, Simon (1956) found that the vertical displays provide an undistorted analogue presentation of altitude (up is up, down is down)

while the circular displays do not. The control display relationships are better, and not as confusing as the clockwise and counterclockwise rotations of dials. Simon also pointed out that these scales provide trend information which cannot be extracted from the tape/counter pointer displays.

Mengelkoch and Houston (1958) used a C-8 Link Trainer (manned simulator) to evaluate vertical displays of altitude information. In a series of three studies they first evaluated a moving tape altimeter against a standard three-pointer altimeter, then the effects of practice on the use of the altimeters, and lastly, the effects of expanding the vertical scale. In the first study, the three-pointer altimeter was marginally better than the vertical tape. In the second study, the three-pointer altimeter retained this advantage even after subjects were practiced on the use of the vertical display. In the third study, however, when the altimeter scales were expanded on the vertical display, the advantage disappeared and the vertical display became more competitive. It is important to note several points concerning these studies. This was the first simulation evaluation of vertical displays and it appears that the major significance of the study lies mainly in the demonstration of the simulation as an acceptable means of evaluation. The scale gradients of the vertical scale were 1.50 inches per 1000 feet of altitude, while on the three-pointer altimeter the gradient was 10 inches per 1000 feet. When the scale gradient of the vertical display was increased to 2.375 inches per 1000 feet, the advantage of the three-pointer display vanished. The simulations relied on precision of control as a measured variable. This variable would intuitively favor the larger scale, which would permit more precise adjustments within the same altitude range as on the vertical scale. In spite of the fact that the three-pointer altimeter had undergone a long history of evolution and refinement, the new and unrefined vertical display fared quite well.



VERTICAL ABSOLUTE SCALE

FIGURE 7



Simon's studies (1956) would have predicted that the vertical displays would be easier to interpret, but the dynamic evaluations in the C-8 trainer produced quite different results. In fairness to Simon, he went much further in the design of the vertical displays for evaluation than did Mengelkoch and Houston. Mengelkoch and Houston were successful in demonstrating the need for more than paper and pencil studies and the utility of simulators for evaluating altitude displays.

Wright (1956) developed several vertical altitude displays, including the first one to display absolute, radar derived, altitude (Fig. 7). Stone (1960) followed with several other designs which followed very closely the same layout as Wright's. Eventually vertical displays were integrated into the cockpits of the Air Force's C-141, F-105 and F-111 aircraft. The F-111 cockpit layout is shown in Figure 8. It shows not only a vertical altimeter, but also a vertical display for airspeed, mach and vertical velocity. These displays are very similar to those used in the early experiments of Grether and Simon.

Numerous other aircraft of the same generation continued to use the standard altimeters of the 1950's and 1960's and the aerospace industry still relies on these instruments. Until cockpit space becomes so precious as to force a move away from these gauges, it is most likely they will continue in use.

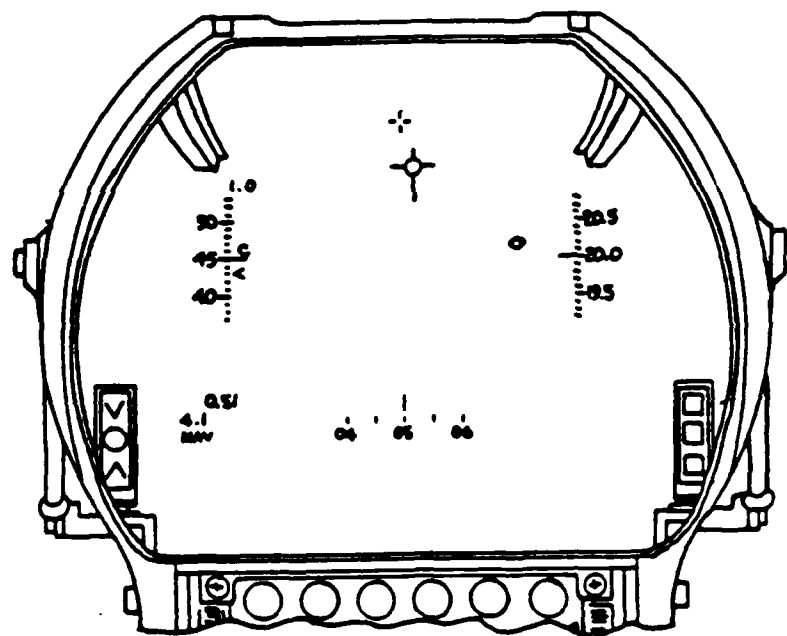
CURRENT DEVELOPMENTS

The advent of the computer coupled with the microchip and the CRT have opened a whole new approach to cockpit design. In the past, designers were forced to dedicate one instrument to one or two functions. Today's multi-function displays and digital electronics allow the designer much more flexibility. They likewise allow the opportunity

to present more information to the pilot. In the rush to get all this new information into the cockpit, new instruments and displays are finding their way into the cockpit. One such device is the Head Up Display (HUD).

A HUD is a display used to present information to the pilot while keeping his head in an upright position and looking outside the aircraft. Its forerunner was the simple gunsight which was used by the pilot to aim his guns for aerial combat and air to ground gunnery. It was meant to be observed while maneuvering the aircraft using outside references. It has evolved to very sophisticated optical sighting elements and CRTs. The displayed cues have remained dedicated to gunnery but they are now beginning to include other information. Airspeed and altitude information were two of the early inclusions to these sights and were presented as vertical tape indicators similar to the vertical displays used by Grether and Simon. The symbols were collimated at optical infinity and located towards the periphery of the display to preclude cluttering the central field of view which is to be used for aiming. Figure 9 shows a typical display of this type. These displays did not take the place of the primary altitude display in the cockpit, but rather are to be used at very specific times for the purpose of crosschecking key aircraft parameters (altitude, airspeed, dive angle, etc.) during weapons delivery. Current HUDs offer the opportunity to display much more information, and efforts are under way to optimize the HUD as a primary flight instrument to replace such instruments as altimeters, airspeed indicators and vertical velocity indicators to make room for more advanced sensors that are being developed. Simulations have been undertaken and flight tests performed which use increasingly complex HUD symbol sets for aircraft control and monitoring. Altimeters, basic flight instruments and cockpit displays evolved with the aircraft with which they were intended to be used. HUDs are relatively new and design

HEAD-UP DISPLAY



TYPICAL GUNSIGHT SCALES

FIGURE 9

guidelines have not kept pace with the technology. McCormick (1964), Van Cott and Kinkade (1972), and Military Standard 1472C provide guidelines for the general design of a display, its location, and interface to the operator, but they do not address the symbol designs necessary to emulate the numerous analogue instruments these displays are to replace.

Subsequently, the Air Force published MIL-STD 1787 (1984) for aircraft display symbology. This standard relies on the previous HUD work and formulates a baseline for future designs. Although the F-16, F-18, F-15, A-7, and A-10 aircraft HUDs were developed independently, they all have altitude displayed on the right side of the HUD by a moving tape, fixed pointer. Likewise, they display barometric altitude primarily for use in crosschecking aircraft parameters for weapons delivery and retain the cockpit altimeter for primary use in instrument flight, although in some cases they have been reduced from a standard 5 inch to a 3 inch display. Some opinions would relegate these cockpit displays to a backup role and rely on the HUD as the primary flight display.

Commercial aviation has been quick to realize some of the benefits of digital avionics. Flight Dynamics Inc. has undertaken to certify a holographic HUD for full instrument landing operations in commercial airliners (Merrifield, 1985). Flight Dynamics has successfully demonstrated the ability to safely land and takeoff using only the HUD as a reference, and they have in fact done it in instrument flight conditions to as low as 50 feet before visually acquiring the field. This achievement relies upon an accurate and easily interpretable altitude display for crosschecking the flight path of the aircraft. Current airliners are capable of doing the same thing without a HUD and the eventual inclusion of this capability seems to hinge on a cost benefit analysis.

In past years, the 2-seat fighter aircraft accomplished the difficult night, all weather attack mission. The single-seat fighter pilot has been used to fight the

air-to-air battles and the daylight/good weather attack missions. The roles were dictated by the sophistication of the systems required to do the missions and the workload required to crosscheck and operate these systems. In recent years the Air Force has invested very heavily in single-seat fighter aircraft and its 2-seat fighters are nearing obsolescence. Until a new fighter can be developed, it will be necessary to rely on existing single-seat aircraft to accomplish portions of the night attack mission. The A-10, F-15 and F-16 aircraft have all been identified as candidates to perform this mission. In order to develop a night attack capability for these aircraft, significant enhancements are planned. One is the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) system. This system incorporates a Terrain-Following Radar (TFR), a wide field of view HUD, two Forward-Looking Infrared Receivers (FLIRs), and several target tracking devices. Using LANTIRN, the pilot will fly the aircraft while looking at an imaging FLIR scene presented on a 30x20-degree HUD. This concept of head-up flying while looking at a television-type picture was supported by several simulations preceding the formal implementation of the LANTIRN program. The F-16 Night Attack Simulation Study (1979) and the Martin Marietta A-10A Precision Attack Enhancement Studies (1979) demonstrated the feasibility of the concept.

The LANTIRN system, along with other systems, sensors and avionics are competing with each other for prime cockpit locations. Unfortunately, these single-seat cockpits are already filled to overflowing. One very critical component that is competing for this space is the newly developed Combined Altitude Radar Altimeter (CARA). With LANTIRN, the radar altimeter becomes an even more critical component for these aircraft since the mission has been expanded to the dangerous low-altitude night arena. It will be the sole source of altitude information to crosscheck the performance of the TFR and the FLIRs that will be used to control the flight path of the aircraft. It is nearly impossible to provide a dedicated radar altimeter display in these aircraft, as has been done in

previous two-seat aircraft, because of space limitations. While the designer could replace an existing display with a radar altimeter, he realistically only has two alternatives: 1) integrate a radar altimeter on an existing heads down display or 2) integrate the display into a HUD. Since pilots would prefer to operate in a "heads up" posture as much as possible (Caughlin 1981), this latter integration alternative is the one currently being pursued by the Air Force for the LANTIRN system.

LANTIRN DESIGN WORK

The first attempt with this integration was made for the A-10 and F-16 aircraft. A survey of operational fighter pilots, several flight tests and an executive Air Force steering group were used to pinpoint the operational requirements for the radar altimeter (Jarvi et al., 1982). The Night Adverse Weather A-10 (Gartland and Shimer, 1980), the Single Seat Night Attack A-10 (Kreuzer, 1983) and the Quick Look (Fain et al., 1981) flight tests provided some key insights into some of the essential requirements for the radar altimeter to be used for the single-seat night attack mission. Specific requirements that were identified are:

1. The radar altitude display must be easily read and understood at a glance.
2. The radar altimeter scale should be easily discernible from the currently available barometric scales.
3. A non-linear scale is preferred with the larger scale gradients at the very low altitudes to allow

precise altitude control with ever smaller gradients at the upper end of the scale.

4. Two separate scales are preferred. One for maneuvering out of the very low altitude environment for conventional weapons delivery and one for low altitude flight.

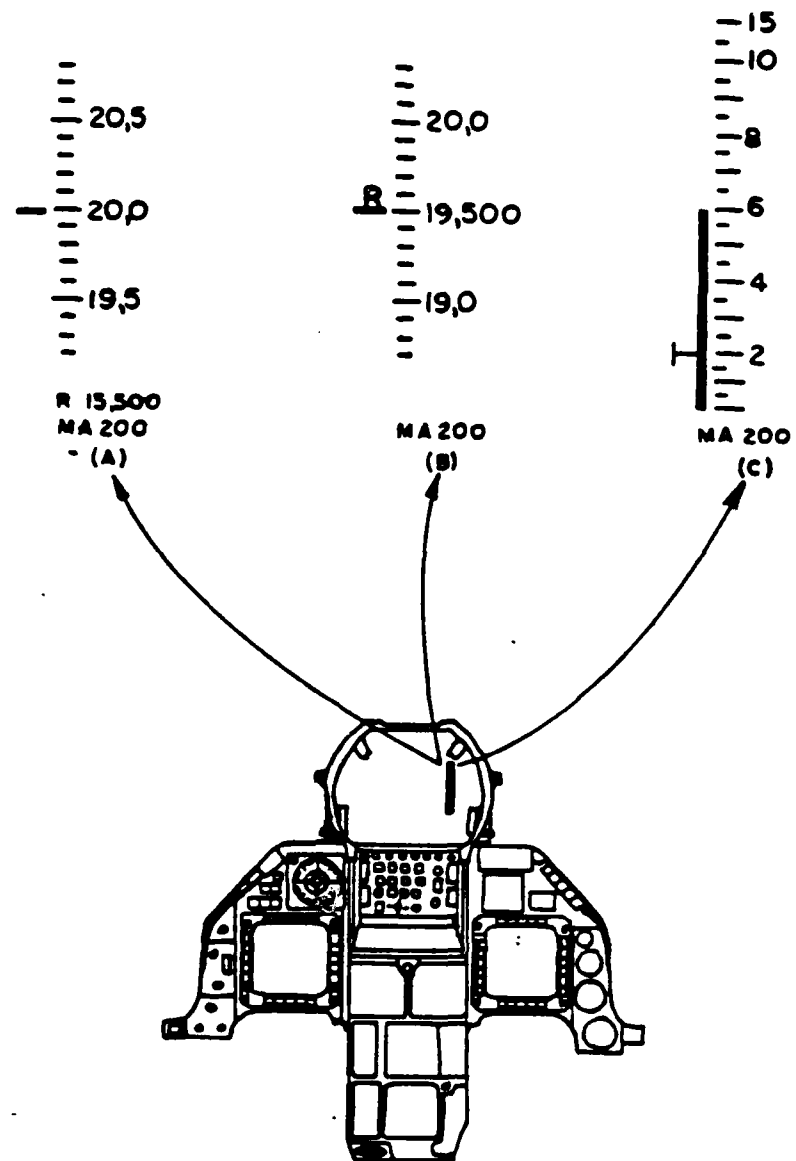
5. Digital and analogue display options should be provided with an optional thermometer type scale.

6. An automatic switchover feature should be provided to prevent the pilot from forgetting to select radar altitude display when descending into the low altitude arena.

7. A distinct warning should occur when the aircraft altitude falls below a manually selected low altitude setting on the radar altimeter. The altitude warning should be present if the system fails or if the aircraft descends below the set altitude.

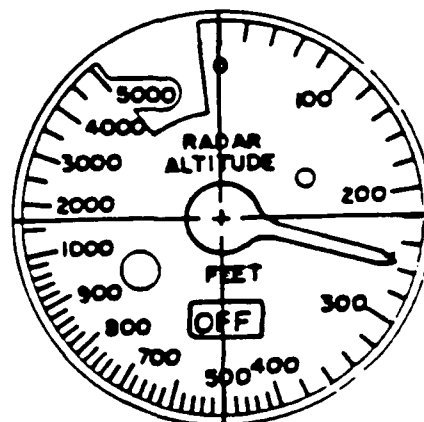
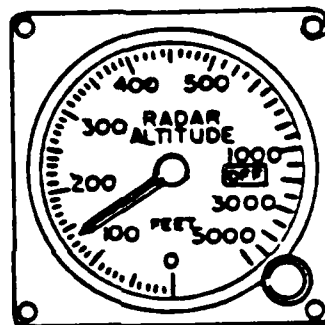
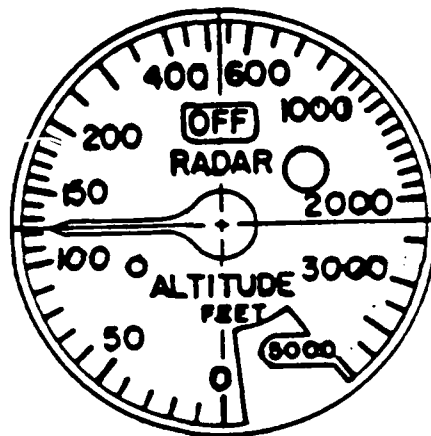
These recommendations were used together with the limited design guidance available in MIL-STD 1472C to develop a radar altimeter design for the LANTIRN HUD in 1981. The F-16 design (Figure 10) entered flight test in July 1983. Prior to flight test, pilots

from both the flight test and the operational communities participated in simulations to refine the design and provide the baseline for flight testing (Geiselhart, 1982; and Lovering, 1981). The scales shown here in Figure 10 are provided for reference and future discussion. Scale A is the normal barometric altimeter scale used in all F-16s. It is available anytime that radar altitude is not selected for display. Scale B is a radar altitude display presented on the same linear scale as in Scale A. It is used to display radar altitude above 1500 feet and is pilot selectable with a switch on the HUD control panel. Scale C is a unique non-linear (actually piecewise linear) scale that is used to display radar altitude below 1500 feet. This scale is automatically switched on when the aircraft descends below 1200 feet and automatically reverts to Scale A when climbing through 1500 feet. It can only be selected by selecting an AUTO position on the HUD control panel. This feature is provided as a safety feature to prevent the pilot from flying with barometric altitude on the HUD when in the low altitude arena. The TEE BAR () shown on the thermometer scale is the manually selected minimum altitude warning that is also presented digitally beneath the scale as MA200 to indicate that in Figure 10 the pilot has set 200 feet as the warning altitude. Flight below this altitude will result in an aural and visual warning to the pilot that he has descended too low. The uniqueness of Scale C and the large R on Scale B are cues to the pilot that he is in fact displaying radar altitude on the scales. This design attempted to consider all previously identified requirements and Scale C is a graphic representation of most of these. It is not unusual to find that this scale actually encompasses most of the features of a standard radar altimeter of the 1960s. Figure 11 shows a common radar altimeter instrument currently in use in other aircraft. It is piecewise linear with larger gradients at low altitudes and a set index for low altitude warning. The LANTIRN F-16 design appears to have emulated this type of instrument on the HUD.



F-16 LANTIRN RADAR ALTIMETER

FIGURE 10



COMMON RADAR ALTIMETERS

FIGURE 11

SUMMARY

The display of altitude information had its early beginnings coincident with manned flight. Early efforts following World War I set the trend for the next 50 years. Numerous efforts, including Grether's work in 1949, were attempts to develop better displays, but with minor exceptions pointer and counter-pointer displays became the norm. Vertical displays were investigated in several studies and appeared to be promising for altitude display. These type displays found their way into selected cockpits as a result of new avionics advancements and were favorably received. They form the basis for the new graphic vertical displays that are being included on the HUDS in developmental aircraft. The altimeter display literature is found in aerospace development technical reports up through the late 1960s. Recently, simulation has played an important role in testing equipment before flight test. Mengelkoch and Houston (1958) demonstrated the first simulation of altimeters and found results that paper and pencil analyses would not have predicted. The new LANTIRN system, along with other systems, requires the creation of symbology sets to replace existing instruments that have been in use for almost 50 years.

III. THE PROBLEM

Man-in-the-loop simulations were conducted in the Crew Station Design Facility (CSDF) at Wright Patterson AFB, OH. to evaluate the LANTIRN system concept and to optimize the controls and displays that were to proceed to flight test. Several of these simulations resulted in specific comments regarding the utility and acceptability of the initial F-16 radar altimeter. Unfortunately, the simulation program was begun too late to change the hardware and software and several key problems have been identified by simulations and flight test.

An F-16 simulation (Carr, 1983) recommended widening the thermometer line for better readability and separation of the thermometer line from the scale for clearer definition; a proposal that was accepted. A recommendation that was not tested was to widen the range between altimeter switch on at 1200' and switch off at 1500'. Subsequent simulations including the LANTIRN Workload Simulation (Hale, 1984) provided the following inputs to the design:

1. The scale appeared to be too compressed at the very low altitudes (0-500') and as such did not provide fine enough resolution for precise altitude control at critical low altitudes.
2. Operation at altitudes near the top portion of the scale (1000-1500') resulted in frequent scale switchings from the thermometer scale to the barometric scale when operating over anything but level to very mildly rolling terrain. This proved to be very distracting.

Consistent with the findings in simulation, subsequent flight tests showed that "the scale lacks sufficient definition at the lower altitudes for operation at very low altitude (Engel, 1984)". Test pilots have recommended a simulation to investigate a revised radar altimeter display offering a more expanded scale than the one currently being used. The flight test program did not identify the switching problem and the associated distractions seen in the simulation testing. This is thought to be because of the relatively benign terrain over which the tests have been conducted in conjunction with the extremely low altitudes (500 feet and below) used.

IV. PURPOSE

The purpose of this experiment is first to evaluate, by simulation, two alternative candidate radar altimeter displays and the existing LANTIRN display, and then to select a display for further flight test evaluation. As seen from previous literature, very little simulation has been accomplished to support altimeter developments. In the past where simulation was used, the results differed considerably from those found in actual flight tests. In the present study, the results from the initial LANTIRN design simulations and the first stage of developmental flight testing are complementary. This presents a key opportunity to refine the design. The present experiment took advantage of a full mission F-16 simulator to conduct a relatively inexpensive evaluation that would otherwise be extremely costly and inefficient to conduct in flight test.

Static reading, altitude tracking, subjective assessments and post trial altitude scale marking were used to assess scale utility, performance capability, readability and scale preferences. Two alternative designs were chosen, one from simulation and one from flight test recommendations. This experiment was designed to evaluate the capability of pilots to use each of the altimeters in transitioning in and out of the LANTIRN operational environment and in tracking a desired altitude while in that environment.

Two altitudes were selected to vary the difficulty of the tracking task and also to check performance at each end of the scale. Six representative LANTIRN missions were developed for the simulation. The following hypotheses were evaluated:

1. Pilot performance in tracking and maintaining low altitudes will significantly increase with an expanded scale in the low altitude portions of the scale. This should allow the pilot to more precisely interpret the need for aircraft control inputs and then more precisely make these changes.

2. Pilot performance in transitioning in and out of the low-altitude environment should significantly increase with an expanded switchover range from radar to barometric altimeters. This would allow greater anticipation of level-off requirements.

3. Pilot preference would favor the scale which not only expands the low-altitude portion of the scale, but also minimizes switchover distractions while operating at the upper end of the scale.

4. Pilot workload, while trying to track and maintain a low altitude, would be less with an expanded scale than the existing scale.

5. Pilot workload while transitioning in and out of the low-altitude environment would be less with a wider switchover range for radar to barometric altitude.

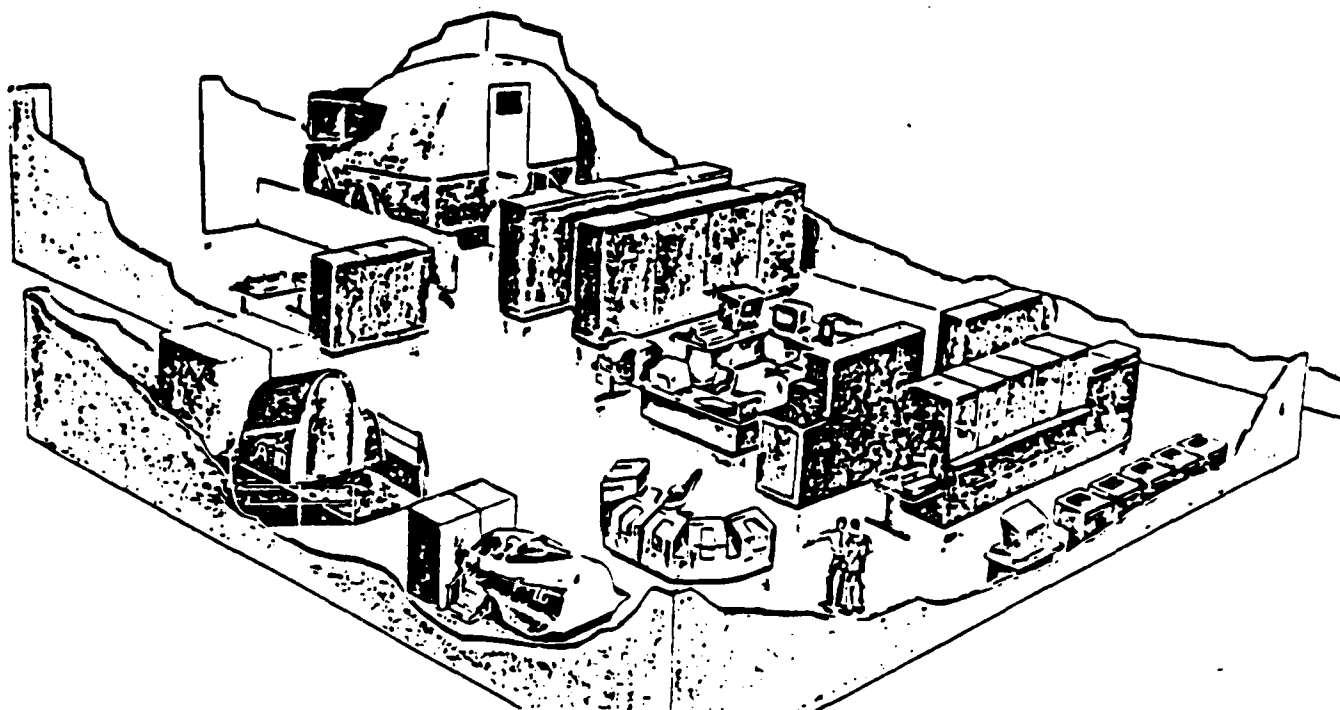
Following the evaluation, a recommendation is made to the LANTIRN development program office for changing and refining the existing design based on the overall performance of each of the altimeters during this simulation.

V. METHOD

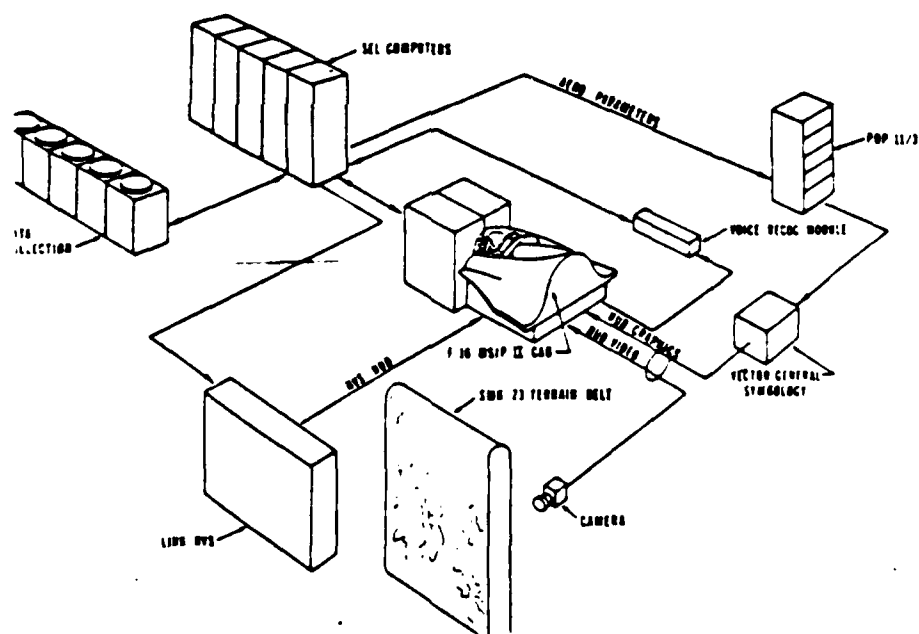
APPARATUS:

Experimental Facility. This research and simulation was conducted at the Crew Station Design Facility (CSDF) located at the Aeronautical Systems Division, Wright Patterson AFB, OH. The facility is shown in Figure 12. The key elements of the facility which pertain to this study are described below.

Simulator Cab. A salvaged single-seat F-16 cockpit was used as the main platform to create this simulator. It was configured to the advanced F-16 Multi-National Staged Improvement Program (MSIP) design shown in Figure 13. This is an all digital design which includes two 4 x 4-inch Multi-Function Displays (MFDs), a Wide Field of View (WFOV) raster video Head Up Display (HUD), an Integrated Control Panel (ICP), a Data Entry Display (DED), Hands on Stick and Throttle (HOSAT) controls, centralized flight instruments, and the LANTIRN avionics suite (terrain following, radar altimeter, FLIR, etc.). The stick, throttle and flight instruments were all actual F-16 components, but all other instruments, controls and displays were emulated by using locally available equipment. Coupled with software emulation, F-16 components were simulated to produce a high fidelity replication of the MSIP design. Controls and displays were fully operational and were integrated with a full visual system and aircraft aerodynamic model.



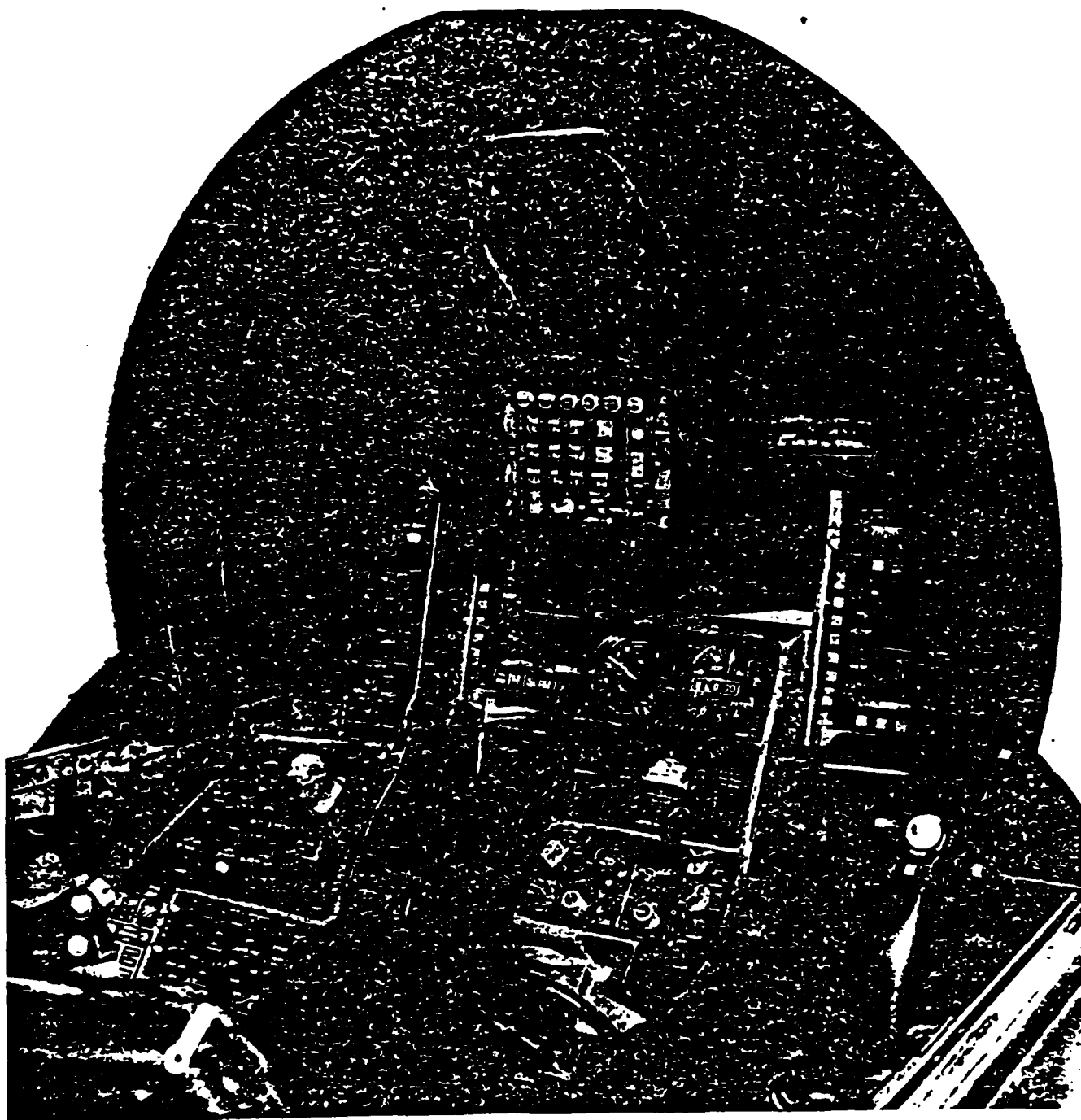
Artist's Conception (Kirk 82)



Configuration Diagram

SIMULATION FACILITY

FIGURE 12



F-16 MSIP COCKPIT DESIGN

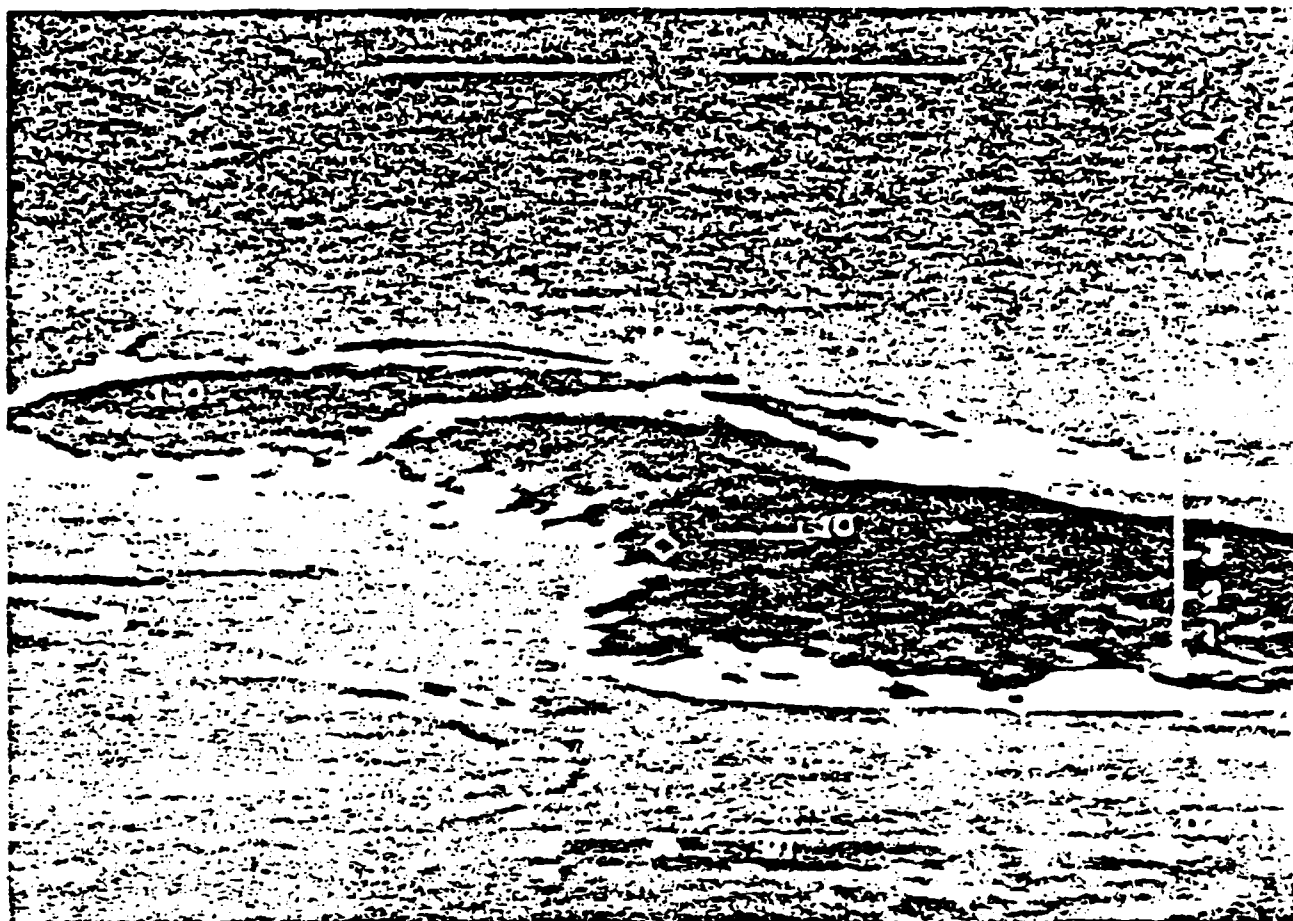
FIGURE 13

This aerodynamic model was the same one used for aircrew training and had been extensively evaluated in previous simulations. The stick and throttles were integrated to provide precise control of the simulator and incorporated the planned switches for the MSIP design. For the purpose of this study, the visual system, HUD and primary flight controls were the only components used to fly the simulator and evaluate the radar altimeter.

Visual System. A scaled moving terrain model belt (1 foot = 1 nautical mile) was used to create a night FLIR visual scene. The belt replicated a 23x15 nautical mile section of western Pennsylvania digitized data base that was selected because it provided a good representation of a wide variety of terrain types found worldwide. This same data base had been used extensively in past computer simulations of terrain following systems. A high resolution COHU TV camera, which was built for this type of simulation in the 1960's, is flown across the terrain belt and provides a visual scene which the pilot uses to fly the aircraft. The belt moves in the north/south direction to provide movement in that axis, while the camera moves in the up/down and east/west directions and is fully gimballed to provide 360 degrees of pitch and roll. The visual scene was modified by providing only black and white video and then selectively tuning and focusing portions of the picture to create a FLIR image of the terrain. This simulated FLIR image is then projected in standard 525 line raster video format on a Wide-Angle Collimating (WAC) window which consists of a beam splitter and a parabolic collimating lens. The visual scene is then focused at optical infinity and the field of view restricted to replicate the 30x20-degree scene provided by the LANTIRN system. This simulated FLIR imagery was evaluated against recorded FLIR imagery from a LANTIRN flight test and both the terrain model and the camera focusing modified to produce a high fidelity visual simulation.

Head Up Display. The LANTIRN HUD was replicated by using the actual HUD model that was used to verify the production design. This model was incorporated into the simulator to require the pilot to not only look in exactly the same place as in the aircraft, but also within the same area and around the same obstructions. The control panel was built and interfaced through software programming to provide full control of the HUD symbology. This graphic stroke symbology was produced by a Vector General symbol generator and its position mapped and controlled by a PDP 11/34 computer. The PDP computer received flight parameters (e.g., heading, altitude, airspeed, and attitude) from a SEL 32/77 computer and in turn positioned this symbology within the raster video scene to allow the pilot to control the simulator by looking at the HUD scene and the imbedded symbology. A representation of the HUD and background scene are contained in Figure 14. Comparisons with actual LANTIRN video and HUD displays have shown the simulation to be representative of the actual system.

Experimenter's Console. The experimenter's console was located approximately 10 feet to the side of the simulator. It included a complete intercom system for four experimenter/observer stations as well as for communication with the pilot inside the simulator. It also included full repeater displays of the pilot's HUD, MFDs, and DED for observing and crosschecking the pilot's performance and to make pertinent notes concerning abnormal situations that might be encountered during the course of the mission (e.g., large variations in altitude, deviations from navigation course, simulator malfunctions, impending crashes, etc.). To control the simulation, the console included stop, start, and system reset switches. To provide data collection, a computer terminal was used to access the SEL 32/77 and input the mission number, subject number, trial number and then start and stop the data collection. The console is pictured in Figure 15.



HUD SCENE

FIGURE 14



SIMULATOR CONSOLE



SIMULATOR CONSOLE WITH OPERATOR

FIGURE 15

SUBJECTS:

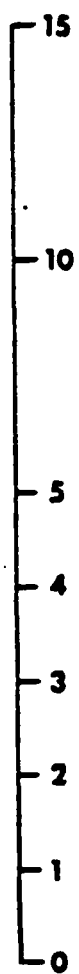
Subjects were 12 experienced fighter pilots drawn from the LANTIRN test force at Edwards AFB, Ca, and from the WPAFB area. They were unpaid volunteers who had an average tactical experience of 1760 flight hours in various aircraft including: A-7, AT-38, F-86, F-100, F-4, F-15, F-16 and F-111 aircraft. All but two of the subjects had prior experience with vertical scale instruments and also with HUDs, and their data were indistinguishable from those of other subjects. All of the subjects had either previously flown the F-16 or the CSDF simulator, however, none of the subjects had flown the simulator in this test configuration.

EXPERIMENTAL DESIGN:

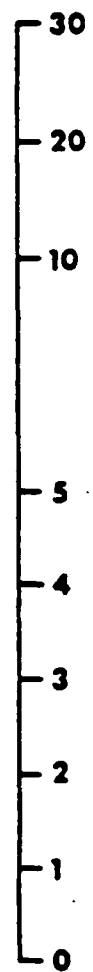
A repeated measures 3x2 factorial design was used in this evaluation. The particular altimeter being used and the altitude being flown constituted the two independent variables in the analysis. The three altimeters were discussed earlier, but for convenience they are shown side by side in Figure 16. The existing altimeter is labelled altimeter A, it has a switch-on value of 1200' and switches off at 1500'. The 0-1500' alternative is labelled altimeter B and is identical to the original altimeter except for the expanded low altitude region. The 0-3000' alternative is labelled altimeter C. It has an expanded low altitude region exactly like altimeter B, but also an expanded upper end with switch-on at 2000' and switch off at 2500'. The two altitudes selected for use were 300 and 1000'. These two altitudes were chosen for three reasons: 1) they are two of the specific operating altitudes for the proposed LANTIRN system, 2) they are located in opposed regions of concern on the altimeter scales, and 3) they represent considerably



SCALE A



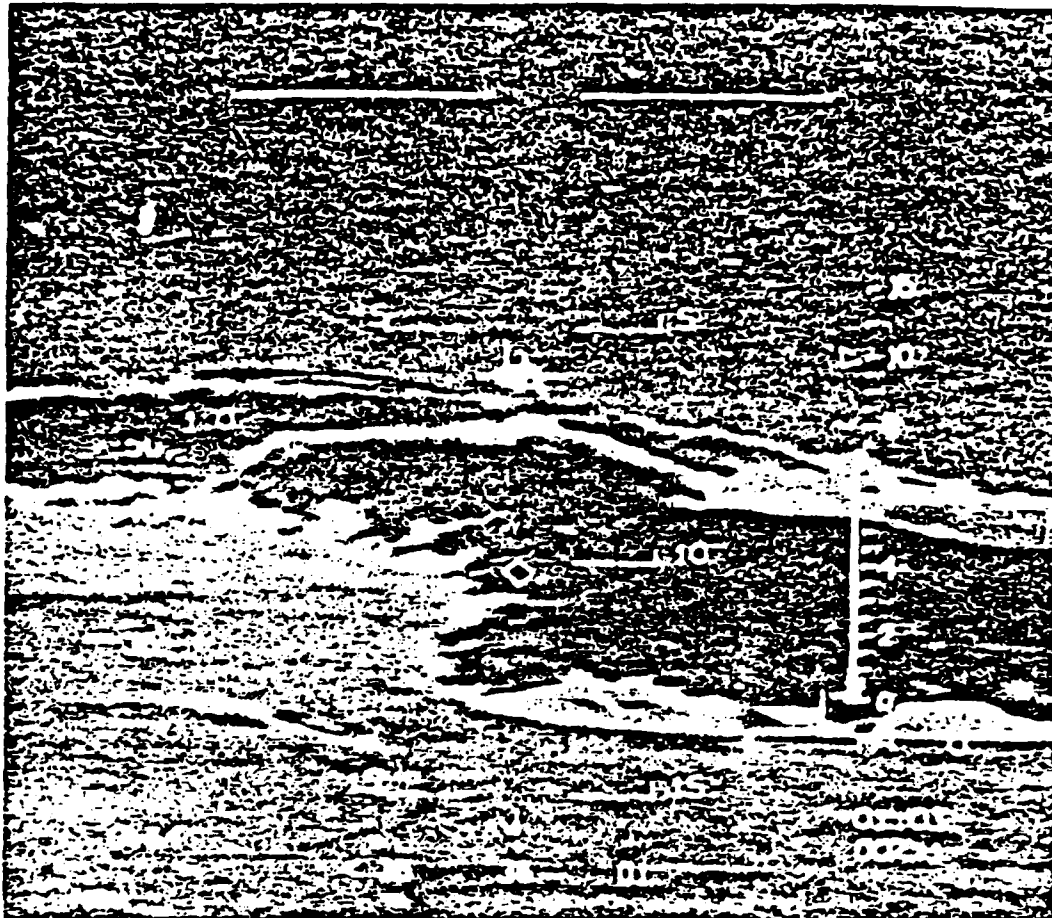
SCALE B



SCALE C

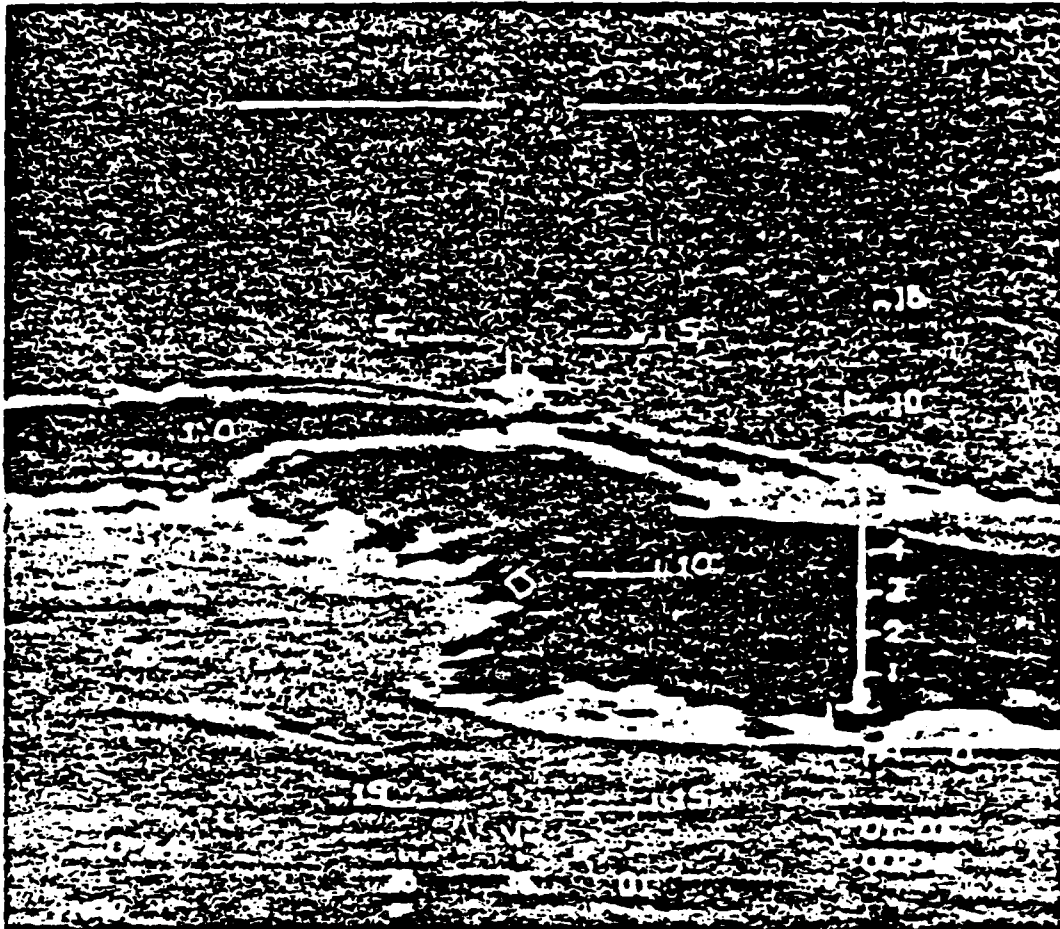
EVALUATION SCALES

FIGURE 16



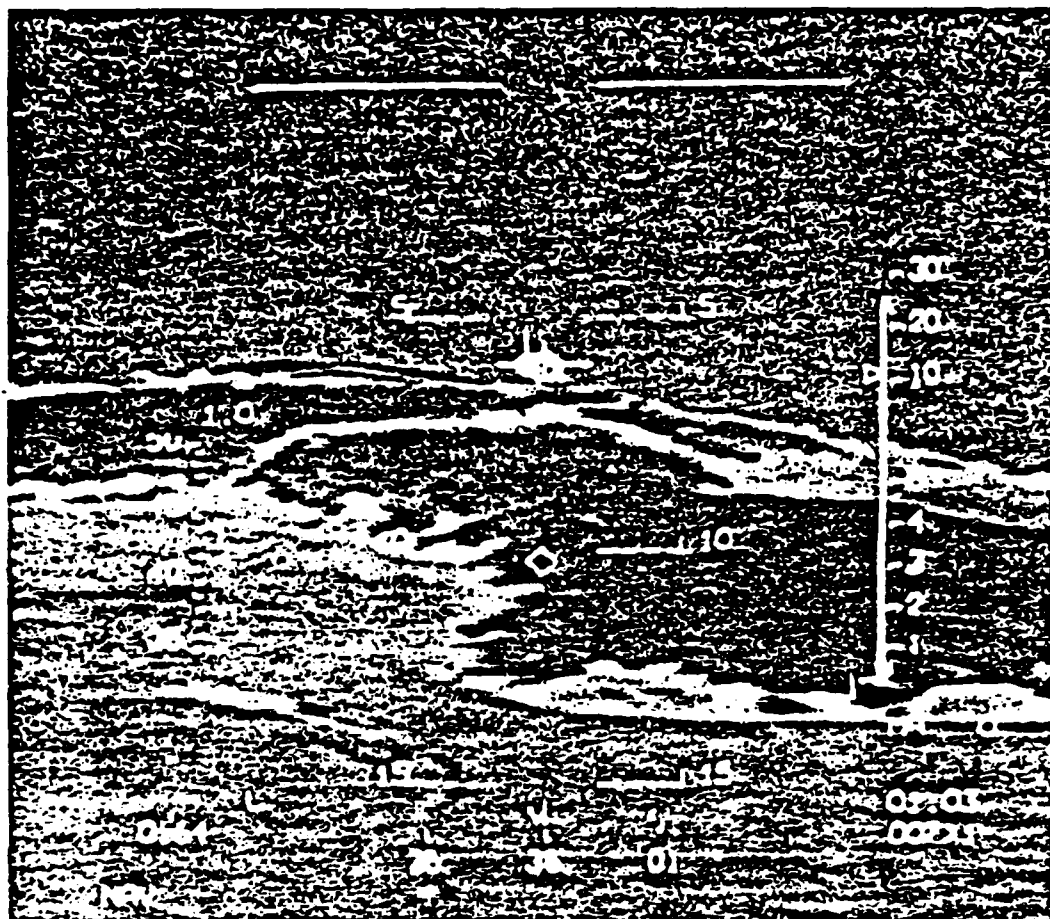
EVALUATION SCALE A (Current Scale)

FIGURE 16A



EVALUATION SCALE B (Flight Test Proposal)

FIGURE 16B



EVALUATION SCALE C (Simulation Proposal)

FIGURE 16C

different levels of pilot workload during low altitude flight (higher workload occurring at the lower altitude). The evaluation then focused on three key areas of concern: 1) the pilots' ability to transition from high to low altitude, 2) the ability to track and maintain a desired altitude while at low altitude, and 3) the ability to transition back from low altitude to the high altitude arena. The transitions were investigated to test the switchover features of the scales, and the altitude tracking was designed to test the precision available with the various scales. This analysis was conducted using test missions designed to replicate the flight environment envisioned for use with the LANIRN system.

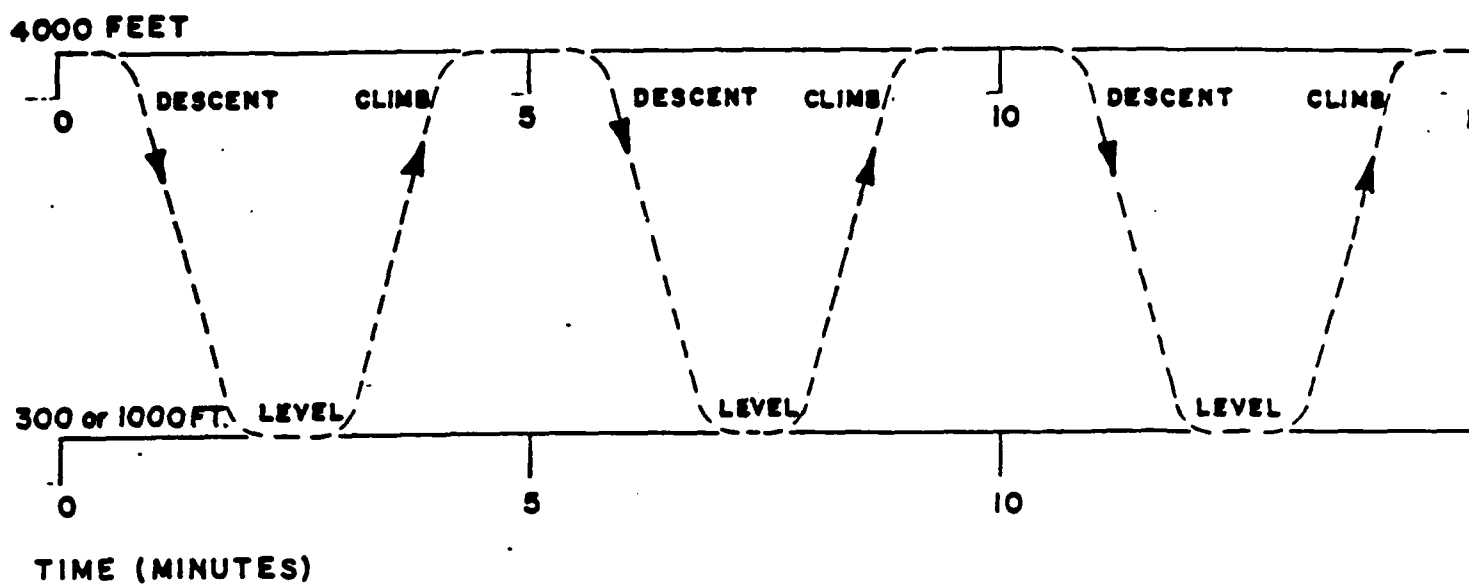
Missions. Eight low-altitude, terrain-following missions were designed for this analysis. The first two were for training. The remaining six missions were used for the evaluation. All eight missions were 15-20 minutes long with three separate transitions in and out of the low-altitude environment with stabilized flight at one of the two altitudes between these transitions. The missions were designed such that an elliptical flight path around the terrain belt was flown to prevent retracing the flight path. This has very obvious advantages over the typical terrain model boards which have to be reset every 5 minutes or so. A graphic time line presentation of a mission is shown in Figure 17. Each mission was also designed such that the type of terrain to be flown over and the average vertical maneuvering was consistent from mission to mission. Levels of difficulty were therefore constant except for the difficulty and workload associated with the two different altitudes to be flown and the scales to be used. The missions were computer-loaded into the simulator just as they will be in the actual aircraft and steering to each of the navigation points along each mission was provided on the HUD for the pilots use. Navigation along each mission was to be maintained by centering a

steering cue. This was done, not to impose a dual task or to increase difficulty, but to insure that each pilot flew over the same terrain and essentially flew the same mission profile. One of the pilot mission maps is shown in Figure 18.

Test Procedure.

Briefing. Each subject received a detailed orientation briefing on the intent of the simulation, simulator configuration and operations, and specific mission instructions. The briefing took approximately 30 minutes and an equally long question and answer session was provided. In addition, a written set of instructions were provided for each participant to review before the evaluation (see Appendix A).

Training. Each pilot was given a short hands-on familiarization with the simulator, after which they were allowed to fly the simulator for 15-20 minutes. Following this period, each pilot participated in a short test of their ability to read and interpret each of the altimeter scales. During this test, 10 separate altitudes were displayed on each of the three altimeter scales. The pilots were asked to read and report the displayed altitude to the nearest 10 feet as quickly as possible. In order to pass this training stage, each pilot had to report all of the altitudes to within 25 feet of the actual value. The evaluator recorded all values and, where necessary, repeated readings to insure that each pilot was familiar with each scale and able to accurately read the displayed altitude. After meeting this criteria, each pilot flew the two training missions during which all six test conditions of altimeter and altitude were used. These proceeded from a least to most-difficult condition with 1000' being flown first and then 300'. The order of training was the same for all pilots. As a training



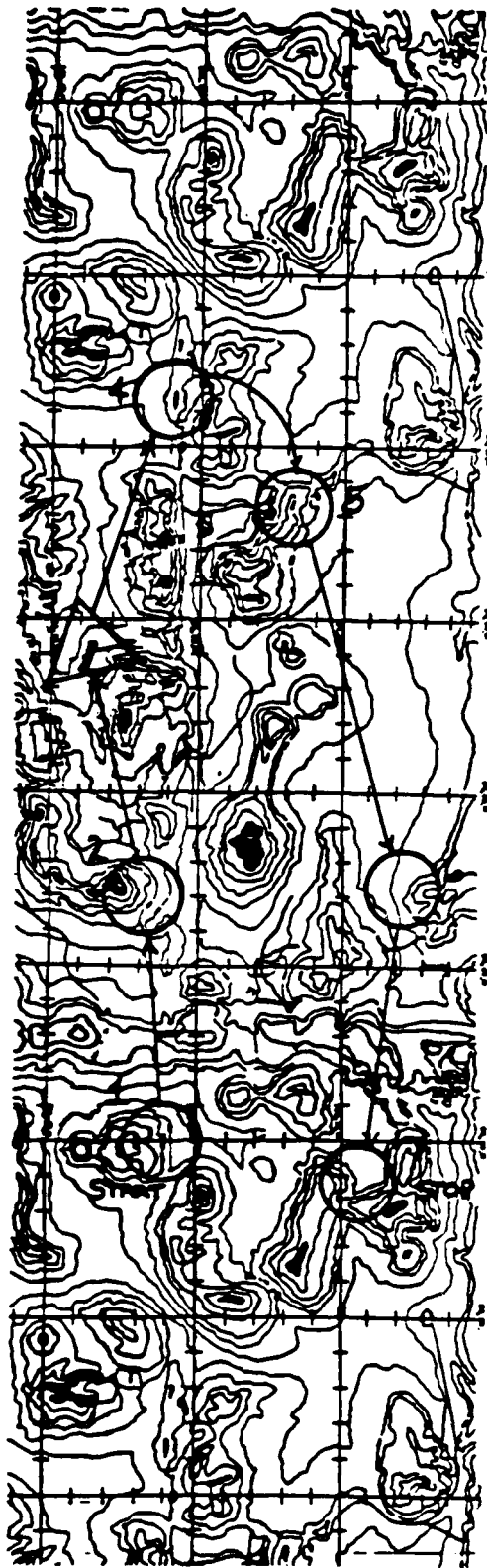
MISSION TIMELINE

FIGURE 17

criteria, each pilot was required to successfully complete the descent to low altitude within 45 seconds and maintain the desired altitude within 25% of that desired for 45 seconds. This criteria was required to be met on the last training mission for the pilot to proceed to the actual experiment. If the criteria were not met, then the training was to be repeated until it was met, or the subject rejected.

Dynamic Evaluation. Each pilot flew the six evaluation missions in a logical order, with each pilot experiencing the same test conditions as the other pilots during this repeated measures design. The balanced design is shown in Figure 19. Prior to each mission, the pilots reviewed the mission for correlating the route of flight, number of turn points, and direction of turns. During each mission they were then instructed to descend to the test altitude three times and maintain that altitude as well as they possibly could. Following each stabilized track, they were instructed to climb back to the starting altitude. To maintain consistency, they were instructed to use 10 degrees of climb and dive during the transitions. This is a value which is normally used in night transitions and is operationally safe and practical. Following each mission, the simulator was reset to the starting point for the next mission and the pilots were then asked to complete a Modified Cooper-Harper workload scale for the mission just flown. The console operator collected the scale and then prepared the simulator for the next mission and data collection.

Data Collection and Measurements. The console operator entered each pilot's identification on the written materials and also into the SEL computer for data recording. This included subject number, evaluation type (static reading or dynamic), and mission number. During the static scale reading test, the operator selected the scale to



MISSION MAP

FIGURE 18

be used and then recorded the pilot's responses as he cycled through each of the ten readings. After completing all three scales, the operator assessed the need to repeat any of the scales and did so if required to meet the established criteria. During the dynamic flying portion of the experiment, the operator positioned the simulator at the predetermined starting location for the mission, entered the identification data and then, when the subject was ready, released the simulator to begin the mission. During the mission the operator monitored the mission performance and prompted the beginning of each of the three data recording segments of the mission. To do this, the operator depressed an initiate switch and informed the pilot to begin a descent to the altitude required by that mission. The SEL computers monitored the aircraft performance and recorded the aircraft altitude and timing for the mission at a 30-Hz sampling. Following the initiate switch actuation, the descent stage was triggered by a pitch change of two degrees. This was established as a value large enough to avoid spurious pitch changes affecting the timing and biasing the data (normal aircraft pitch changes during level flight are restricted to approximately one degree). The completion of the descent segment was determined when the pilot entered a zone within 25% of the desired altitude and stayed there for five seconds. This value was selected as a reasonably achievable criterion that was both operationally acceptable and also capable of being interpreted on each of the three scales. In order to be able to compare the descent times to the two different altitudes, it was decided to measure not only the total descent time, but also the time from descent from 1000' above the level off altitude to level off. The low-altitude tracking segment was begun simultaneously with the completion of the descent phase. It was completed at a specific predetermined point when the operator actuated the initiation switch a second time and cued the pilot to begin a climb to the starting altitude of 4000'. The timing of this climb segment was recorded beginning when the pilot increased

the aircraft pitch by two degrees. It was completed when the aircraft entered within 200' of the level off and stayed there for five seconds (this value is the accepted tolerance of cruising altitudes during pilot proficiency evaluations). This procedure was repeated three times during the course of each mission. The dependent variables were defined as : TOTALDOWN for the total time to descend in seconds, PARTIALDOWN for the time to descend from 1000 feet above level off in seconds, RMS DEV for the RMS deviation in feet from the desired low altitude value, and TIMEUP for the time to climb back to 4000 feet in seconds. The console operator observed the mission on the repeater monitor to note any large deviations from the route or desired altitude performance and any unusual situations that might occur (e.g., simulator malfunctions, crashes, pilot difficulties, etc.). A tape recorder was used to record both pilot and operator voices during each mission to preserve the mission and resolve any questions that might arise after the simulation.

In addition to the performance measures taken, a MCH evaluation scale and a questionnaire were used to gather the pilots' subjective assessments of the scales. The MCH scale was used at the completion of each subject's flying to assess the difficulty the pilots experienced in using each scale during the missions on two separate tasks, the transitions in and out of the low altitude environment, and the maintenance of the low altitude settings. This questionnaire was administered following the simulation and the operator was available to clarify the questionnaire and provide further information. A questionnaire is provided in Appendix B. In the questionnaire, the pilots were encouraged to provide comments to help further refine the altimeter design and to also comment on the utility of the simulation for this evaluation. In the questionnaire each pilot was asked to complete a series of six altitude plots for each of the scales. These were included to help refamiliarize the pilots with the scales while they were answering the questionnaire and to further evaluate the accuracy of reading and interpreting each of the scales.

SCALES = A,B,C
 ALTITUDES = 300', 1000'
 MISSIONS = 1-6 (LOGIC ORDER)
 SUBJECTS = 1-12 (LOGIC ORDER)

<u>CONDITIONS (SCALE X ALTITUDE)</u>						<u>TEST ORDER</u>	
1	A X 1000	B X 1000	C X 1000	A X 300	B X 300	C X 300	7
2	A X 1000	C X 1000	B X 1000	A X 300	C X 300	B X 300	11
3	B X 1000	A X 1000	C X 1000	B X 300	A X 300	C X 300	1
4	B X 1000	C X 1000	A X 1000	B X 300	C X 300	A X 300	4
5	C X 1000	A X 1000	B X 1000	C X 300	A X 300	B X 300	9
6	C X 1000	B X 1000	A X 1000	C X 300	B X 300	A X 300	8
7	A X 300	B X 300	C X 300	A X 1000	B X 1000	C X 1000	3
8	A X 300	C X 300	B X 300	A X 1000	C X 1000	B X 1000	6
9	B X 300	A X 300	C X 300	B X 1000	A X 1000	C X 1000	10
10	B X 300	C X 300	A X 300	B X 1000	C X 1000	A X 1000	5
11	C X 300	A X 300	B X 300	C X 1000	A X 1000	B X 1000	12
12	C X 300	B X 300	A X 300	C X 1000	B X 1000	A X 1000	2
1	2	3	4	5	6		
MISSIONS (1-6)							

EXPERIMENTAL DESIGN

FIGURE 19

VI. RESULTS

DATA TREATMENT FOR ANALYSES:

The flying performance data were analyzed using a 2 x 3 repeated-measures ANOVA with scale and altitude (300, 1000) as factors. Due to the low degrees of freedom in the error terms, a single pooled error term, subject by treatment, was used to test all effects (see Table 1). The MCH and questionnaire data were also evaluated using a repeated-measures ANOVA with scale as the only factor. Only the scale factor was available because the MCH data and the questionnaire data were collected for each of the scales only after the completion of all of the flying tests. The Student-Newman-Keuls test was used as a post-hoc statistic to evaluate significant effects in the ANOVA. Performance data are presented first, broken down into three sections: transitions into and out of the low-altitude environment, maintaining low altitude, and static performance in altitude reading and plotting. Secondly, the MCH data are presented in two sections: the difficulty in transitioning into and out of the low-altitude environment and maintaining low altitude. Thirdly, the questionnaire data are presented. Lastly, the results of other analyses are presented.

PERFORMANCE DATA

Transitioning into and out of the low altitude environment. The mean TOTAL DOWN time data are presented in Table 2A and the mean PARTIAL DOWN time data are presented in Table 2B. In this study, neither the total time from beginning the descent to the level off, $F(2,55) < 1.0$, nor the time to descend from 1000 feet above the

TABLE 1. Analysis of Variance for Performance Data

ANALYSIS

3 X 2 ANOVA (Scale x Altitude)

<u>SOURCE</u>	<u>DEGREES OF FREEDOM</u>
SCALE	2
ALTITUDE	1
SCALE X ALTITUDE	2
SUBJECTS	11

POOLED ERROR TERM

Scale x Subject	22	
Altitude x Subject	11	
Scale x Alt. x Subject	<u>22</u>	
	55	55
TOTAL		71

desired altitude to the leveling off altitude, $F(2,55) < 1.0$, were dependent on the scales used. Likewise, the scale by altitude interactions for both the total and partial descent times were not significant, $F(2,55) < 1.0$. The main effect of altitude, however, was significant, $F(1,55) = 6.80$, $P < 0.01$, for the total time to descend. As Table 2A shows, total time to descend to 1000 feet was 35.78 seconds, but the time increased to 40.89 seconds for a descent to 300 feet. This increase was to be expected because the time to descend should be dependent on the distance to be traversed. The sensitivity of TOTAL DOWN time to altitude shows that the simulation design was sensitive to important experimental manipulations.

Similar results were obtained when the time to climb from the low altitude environment back to cruising altitude was analyzed. Neither the scale, $F(2,55) < 1.0$, nor the scale by altitude interaction, $F(2,55) < 1.0$, were statistically significant. Once again, however, the time to climb was dependent on the altitude required to climb, $F(1,55) = 53.97$, $P < 0.01$. As Table 2C shows, the time to return to cruising altitude (TIMEUP) was 28.43 seconds from 1000 feet and 33.18 seconds from 300 feet. This 4.75 second difference is approximately the same as the 5.11 second difference that was found for the total time to descend (see Table 2A). (Hypothesis #2 was not supported by the data).

Maintaining low altitude. The pilots' abilities to track and maintain a low altitude did not depend on the altimeter being used at either of the two altitudes that were tested. Table 2D presents the root mean squared (RMS) deviation from the target altitude. The main effects of scale, $F(2,55) < 1.0$, altitude, $F(1,55) < 1.0$, or the scale by altitude interaction, $F(2,55) < 1.0$, were not statistically significant. As Table 2D shows, the mean RMS error was approximately 225 feet for all experimental conditions.

TABLE 2. Effects of Scale and Altitude on the Performance Measures.

TABLE 2A. TOTAL DOWN Time (sec).

SCALE	<u>ALTITUDE</u>		X
	1000	300	
1	33.53	42.06	37.80
2	38.54	41.81	40.18
<u>3</u>	<u>35.28</u>	<u>38.81</u>	37.05
X	35.78	40.89	38.34

TABLE 2B. PARTIAL DOWN Time (sec).

SCALE	<u>ALTITUDE</u>		X
	1000	300	
1	21.50	25.14	23.32
2	26.40	24.76	25.58
<u>3</u>	<u>23.00</u>	<u>21.51</u>	22.26
X	23.63	23.80	23.72

TABLE 2 (Continued).

TABLE 2C. TIMEUP (sec)

SCALE	<u>ALTITUDE</u>		X
	1000	300	
1	27.86	32.77	30.32
2	28.33	33.90	31.12
3	29.09	32.87	30.98
X	28.43	33.18	30.81

TABLE 2D. RMS Altitude Deviation (feet)

SCALE	<u>ALTITUDE</u>		X
	1000	300	
1	218.12	222.33	220.23
2	200.37	232.58	216.48
3	239.06	237.79	238.43
X	219.18	230.90	225.05

Thus, hypothesis #1 was not supported by the data.

Static reading and altitude-plotting performance. In the pre-mission phase, each pilot was tested to determine the accuracy of reading a static display of each scale. For each scale, a mean absolute error score in feet was obtained by computing the mean for unsigned deviations from the altitude presented. This static reading was statistically significant for the main effect of scale, $F(2,22) = 7.83$, $P < 0.01$. The mean absolute error was only 10.71 feet for Scale A as compared to 14.75 feet for Scale B and 17.96 feet for Scale C. A Student Newman Keuls test supported this description. Scale A was significantly different from Scale B and C, but Scale B and C were not significantly different from each other.

In a similar fashion, each of the pilots was tested on his ability to accurately plot a series of six altitudes on scaled prints of each of the three altimeters. This was done after the mission simulation and just prior to completing the final questionnaires. The mean absolute errors were once again computed. The main effect of scale was again significant, $F(2,22) = 7.99$, $P < 0.01$. The mean absolute error was only 4.56 feet for Scale A as compared to 12.04 feet and 13.28 feet for Scale B and C respectively. The Student Newman Keuls test again supported this interpretation with Scale A significantly different than the other two, but the other two not significantly different from each other.

SUBJECTIVE DATA

MCH ratings for transitioning into and out of low altitude. Mental workload estimates were obtained using the MCH ratings. The main effect of scale was

significant, $F(2,22) = 6.06$, $P < 0.01$. Scale C received a mean rating of 3.25 compared to 4.58 and 4.08 for Scales A and B respectively. The Student Newman Keuls test supported this interpretation. Scale C was significantly easier to use in making transitions into and out of the low altitude environment. This was the scale proposed by previous simulation. (Hypothesis #5 was supported by the data).

MCH ratings for maintaining a low altitude. Pilots were asked to rate the mental workload required to use each scale to maintain aircraft altitude. The workload data gathered using the MCH ratings was consistent with the performance data. No significant differences were observed between the scales in the workload required to maintain a low altitude, $F(2,22) = 1.76$, $P > 0.05$. The mean ratings were 3.58, 3.08, and 3.00 for Scales A, B, and C respectively. (Hypothesis # 4 was not supported by the data).

Questionnaire data.

The responses to the questionnaire were summed for each subject and analyzed with scale as the only factor. The responses were scaled so that 1 represents the easiest or best performance and 5 the most difficult or worst performance. The questionnaire responses were not significant for either transitioning into and out of the low altitude environment or for tracking and maintaining low altitude, $F(2,22) = 2.03$, $P > 0.05$. The unstructured comments did, however, provide some insight into why the simulation proposed scale (Scale C) required less difficulty to use in transitioning into and out of low altitude. Additionally, the subjects' responses provided some useful information for future testing of the scales and for redesign of the scale for better pilot useability. These will be addressed in the discussion section. (Hypothesis # 3 was not supported by the data).

OTHER ANALYSES

Subsequent analyses on each of the four performance measures were performed using mission as a factor to determine if there were any significant differences between missions. The results indicated that there was no significant main effect of mission in any of the ANOVAs.

To further analyze the experiment, subsequent 3 x 2 x 3 ANOVAs (Table 3) using segment as a factor (Scale x Altitude x Segment) were conducted to explore segment effects for each of the four performance measures. To conduct the analyses, pooled error terms were used in the ANOVAs to increase the degrees of freedom. In this case, the error terms were pooled separately by main effects, two way interactions and three way interactions. These error terms are shown in Table 3. The results of these ANOVAs were identical to those already reported in that those significant findings remained significant and no others dealing with factors already analyzed became significant. However, the main effect of segment was significant for the RMS altitude deviation measure, $F(2,55) = 9.25$, $P < 0.01$. Also, there was a significant scale by segment interaction in the TIME UP measure, $F(4,88) = 2.57$, $P < 0.05$. The mean values are presented in Table 4 and show that pilots maintained altitude significantly better in the middle segment of each mission (Segment 2). Segment and segment by scale were not statistically significant for any of the other performance measures. Table 4 shows the scale by segment interaction. The pattern of results is not easy to interpret. No scale was consistently better or worse than the others.

As a final analysis, each of the ANOVAs previously performed, including the analysis of segment were conducted without pooling error terms. The pattern of results reported above did not change when error terms were not pooled.

**TABLE 3 Analysis of Variance for Performance Data with
Segment Included**

ANALYSIS

3 X 2 X 3 ANOVA (Scale x Altitude x Segment)

<u>SOURCE</u>	<u>DEGREES OF FREEDOM</u>	
SCALE	2	
ALTITUDE	1	
SCALE X ALTITUDE	2	
SEGMENT	2	
SCALE X SEGMENT	4	
ALTITUDE X SEGMENT	2	
SCALE X ALTITUDE X SEGMENT	4	
SUBJECTS	11	
<u>POOLED ERROR TERMS</u>		
Scale x Subject	22	
Altitude x Subject	11	
Segment x Subject	<u>22</u>	
	55	55
Scale x Altitude x Subject	22	
Scale x Segment x Subject	44	
Altitude x Segment x Subject	<u>22</u>	
	88	88
Scale x Altitude x Segment x Subject	<u>44</u>	
	44	<u>44</u>
<u>TOTAL</u>		208

TABLE 4. Effects of Scale and Segment on the Performance Measures.

TABLE 4A. TIME UP (sec).

SCALE	<u>SEGMENT</u>			X
	<u>1</u>	<u>2</u>	<u>3</u>	
1	29.94	29.16	31.86	30.32
2	30.33	31.02	32.00	31.12
3	33.11	29.94	29.89	30.98
X	31.13	30.04	31.25	30.81

TABLE 4B. RMS Altitude Deviation.

SCALE	<u>SEGMENT</u>			X
	<u>1</u>	<u>2</u>	<u>3</u>	
1	240.35	183.37	236.99	220.23
2	271.83	152.07	221.76	215.23
3	269.50	190.42	259.09	239.68
X	260.56	175.29	239.14	225.05

VII. DISCUSSION

LOW-ALTITUDE PERFORMANCE

One of the most important findings of this study was that none of the three scales evaluated appeared to be better in facilitating pilot performance in maintaining low altitude or in transitioning in and out of the low-altitude environment. The effect of widening the low altitude portion of the scale on the two alternatives did not appear in the performance of the pilots in maintaining low altitude nor did it appear to affect the workload involved in maintaining low altitude. The static reading and plotting data provide some insight into this. The original scale, although compressed, offers more scale increments and allows the pilot to more precisely read an altitude. While the wider scale in both alternatives may be more comfortable to use, it does not offer the precision originally thought because of the interpretation required. This is particularly important when considering the time dedication to task at the low altitudes to be flown. When analyzing the questionnaire data, particularly the comments, it became obvious that the desired scale would be a combination of the original scale and the proposed alternatives. The pilots unanimously recommended that the low-altitude portion below 1000 feet should be expanded as proposed, but that additional increments should also be provided to allow for quicker and more precise reading. Some expressed that the large number of increments in the original scale were a cause of clutter, but it appears that widening the low-altitude portion below 500 feet would permit inclusion of 50-foot increments between each of the 100 foot altitudes without causing that same distraction.

ALTITUDE TRANSITIONS

In assessing the ability to transition into and out of the low-altitude environment, widening the switchover range in scale #3 did not affect the pilot's performance. The workload associated with that performance was, however, significantly lower on the modified scale. The questionnaire responses indicated that all of the pilots favored the higher switchover due to the lead time that it provided in anticipating the leveloff at 1000 feet. The other two scales caused a higher workload in precisely leveling off in the descent. The two shifts in linearity on scale #3 were not as distracting as one might anticipate. This is supported by previous data (by Cohen and Sanders, 1958). The double non-linearity did cause a few unfavorable comments and it appears that a single shift in linearity would be a better alternative as in the #2 scale. This appears to be easily tolerated. The modified scale had an upper end of 3000 feet to allow transition back into the medium altitude environment. This was thought by all pilots to be too high when traded against the requirement to widen the low altitude portion of the scale. They suggested that 2000 feet would be high enough to provide adequate warning of level off and also allow a smooth transition back to the intermediate altitudes where barometric pressure settings are required. Additionally, they provided an operational input that further suggests 2000 feet as a key switchover altitude. It seems that 2000 feet above the target elevation is very close to the altitude used for pop-up attacks to determine when to begin to dive toward the target. Several pilots recommended that 2000 feet would be the highest useful altitude to display, but that by switching the scale at 2000 feet this would provide a useful cue to assist them in target attacks as well as transitioning into and out of the low-altitude environment.

SIMULATION

The results of this simulation compare very favorably with those found in the initial LANTIRN developmental flight test. The pilots were all able to use the existing scale. In addition, they were also able to use the other two scales, and they retained a preference for expanding the area of the scale below 500 feet. Additionally, they reaffirmed the need for additional scale markings such as used in the original design which evolved from flight test data. This in itself speaks favorably for the realism of the simulation. Of particular note is the fact that this appears to be the only real dynamic simulation used to investigate altimeter development. Static readings and scale marking tests are a good starting point, but should be taken further into actual dynamic simulation before finalization of a design and costly flight testing of that design. In designing such a simulation, it is important to not only create a valid experimental design, with collectable and analyzable data, but also to create an environment that is acceptable to the subjects and is non-intrusive. In the case of highly qualified and specialized subjects, such as fighter pilots, the experimenter should either be completely versed in the subjects' language and familiar with the operational procedures, or employ an expert consultant who is in order to gain the confidence and acceptance of the subjects.

It is unfortunate that this effort was not undertaken prior to flight test, as it could easily have saved in excess of one million dollars. It is hoped that this experiment will contribute to the finalization of a better altimeter design that will achieve acceptable results in flight testing.

ALTIMETER DESIGN

Grether's work (1948) still stands as the cornerstone in altimeter design and evolution, however, others provided very useful contributions. Simon (1956) generated a movement toward a vertical display and Mengelkoch and Houston (1958) took altimeter evaluation into the simulation environment and demonstrated the feasibility of this type of evaluation. Numerous other pioneers worked to refine altimeters and their designs, but throughout aviation history, it appears that altimeters have relied on the initial design efforts of over fifty years ago until only very recently when emerging CRT technology has forced the designer to graphically and symbolically display instruments. Design guidance is only just now evolving to support numerous designs already in work and the key design guidance that is necessary is in the area of human engineering design. As Defeu (1975) so aptly pointed out, the CRT would provide the optimum display for altitude presentation. The very recently published MIL-STD 1787 (1984) "Design Guidance for Aircraft Display Symbology" was produced by the applied human factors branch at the Aeronautical Systems Division at Wright Patterson AFB. They are also working to publish several other cornerstone design standards. These are lagging the technological revolution in aerospace design that has arisen with the advent of CRT technology. This simulation is only one of many that should be undertaken to support the evolution of new designs. Human performance must be factored into the design and should be done well before the design reaches a relatively mature state in which change will be resisted because of time, money and personnel investments. They most certainly should be evaluated before they move to flight test. The altimeter design evaluated in this study was the result of trial and error design by several aviators. The proposed alternatives were arrived at by evaluating test data and interfacing human performance requirements. The end result is a design that should be very successful in flight test and more importantly be

exceptionally useful in providing the pilot with the information he needs and can use.

RECOMMENDATIONS FOR FUTURE STUDIES

In simulation, the experimenter must balance the design with a proper mix of experimental control and realism to ensure a reasonable chance for discriminating between variables and also to preserve the confidence of the subjects and ensure that the experiment will replicate what will transpire in the real operational setting. In this simulation, the author erred in favor of operational realism and consequently many of the differences in performance across the dependent variables may have been masked by this realism. This may actually happen in the operational environment, but in the early stages of development, particularly in simulation, one must introduce more rigid control if one wishes to rely upon performance measures to identify differences in alternative designs. The amount of realism must necessarily increase as one moves closer to final design and finally flight testing. The experimenter must learn how to balance the two. Even with proper experimental control, the experimenter would be wise to retain a measurement battery that includes such things as performance measures, subjective measures, physiological measures, interviews, and questionnaires. These should allow the experimenter to make useful conclusions and recommendations even in the absence of significant performance measurement data. This was especially true in this experiment. In order to improve upon this experiment, the following recommendations should be considered in evaluating a new set of alternative altimeter displays:

1. Consider using a simple counter-top visual display to evaluate static reading performance using a large sample of subjects (not just pilots).

2. Conduct dynamic reading performance tests while the subjects are involved with a simultaneous tracking task.

3. Conduct initial simulation testing over flat terrain to evaluate precision of control at the commanded altitudes with no other tasks.

4. Conduct subsequent testing over flat terrain with a lateral tracking task included.

5. Conduct final testing using rolling terrain and lateral tracking in conjunction with altitude tracking.

6. Consider using a different variable to measure performance during altitude transitions, such as number and magnitude of transits through the desired altitude or total number of reversals about the altitude. In the present experiment it is quite possible that the subjects were using different strategies to descend using the three different displays. This could have masked performance differences.

7. Collect MCH ratings after each run in order to evaluate workload across missions and altitude as well as scale.

VIII. CONCLUSIONS

The purpose of this study is to evaluate an existing altimeter display and two alternatives for use in low altitude flying, and to select a scale that would optimize both the low altitude performance and the ability to transition in and out of the low altitude arena. The conclusions that resulted from this study are as follows:

1. In analyzing the performance, workload, and questionnaire data, it was apparent that none of the three altimeter designs would satisfy the two fold criteria for low altitude and transition performance. All of the pilots expressed a preference for a scale that met both of the criteria. The scale that is proposed is shown in Figure 20. This scale is recommended for further evaluation in simulation and flight tests. It is piecewise linear from 0-500 feet with 50 foot increments and the 100 foot increments labeled and also from 500-2000 feet with 250 foot increments and the 500 foot increments labeled. The scale should switch from radar to barometric at 2000 feet climbing and from barometric to radar altitude at 1500 feet descending. This will provide a wide enough margin for stable readings over rough terrain and it provides an operationally sound region of performance. Additionally, it expands the critical low altitude region of the scale and centers the 500 foot index.

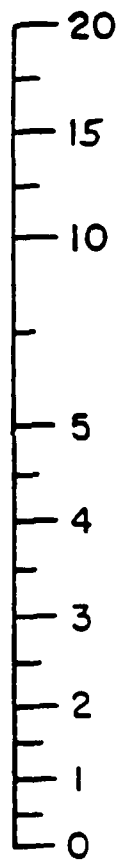
2. The vertical tape indicator should be widened to at least twice its current width to provide easily discernible altitude cueing.

3. The generic issue of using a head-up display for a primary flight instrument should be closely investigated for other potential display problems. The radar

altimeter is a very simple issue when compared with other more important issues such as attitude control, trajectory control and cueing, flight path monitoring, unusual attitude recovery, weapons cueing and firing, symbology declutter, and many others.

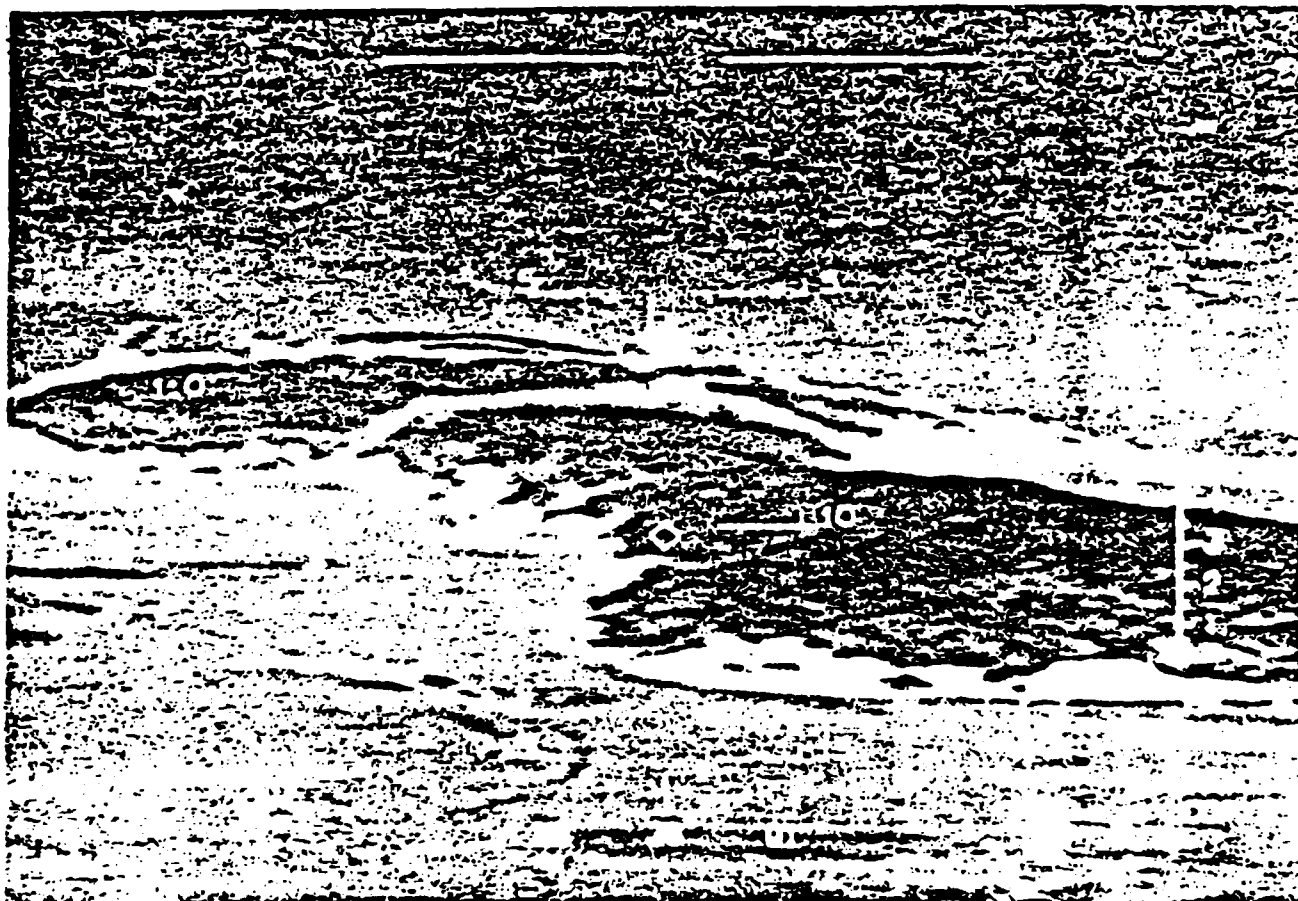
4. Simulation is a very useful tool in symbology evaluation. In this study it did not discriminate among any of the variables, but it did provide key answers that otherwise could only be answered through flight testing. The results of this study will be used to make a change to the flight test software. Each change will cost an estimated \$3 million. As a result, each change that can be designed as a result of simulation instead of flight testing will save the flight testing that would have been required to design the change. In addition, several changes may be recommended at the same time and save an entire change process.

5. The basic literature concerning altimeters and their development is still valid today. For the future, however, new design guidance is necessary to utilize the precepts that were evolved by Grether and his fellow pioneers.



PROPOSED SCALE

FIGURE 28



HUD SCENE WITH PROPOSED SCALE

FIGURE 21

APPENDIX A

RADAR ALTIMETER SIMULATION INSTRUCTIONS FOR PILOTS

During this study, each of you will be asked to fly several simulated low-level missions in the F-16 simulator. During these missions, you will be asked to make descents from 4000' MSL to either 300 or 1000' AGL. You will then be expected to maintain this altitude until instructed to begin a climb back to 4000' MSL. These climbs, descents, and low-altitude flight segments will be accomplished by referencing the simulated Head Up Display. On the display you will be given pitch, attitude, velocity, navigation steering and altitude information. In addition, the velocity vector of the aircraft will be depicted to allow you to control the flight path of the aircraft while crosschecking the other information. Your primary crosscheck will be the altimeter which will be your sole reference for determining the altitude performance of the aircraft. You are to attain an initial 10 degree climb or dive to begin the transitions in and out of the low-altitude environment and then to gradually decrease this attitude to achieve level flight as accurately yet as quickly as you can. Once stabilized at the low altitude, you will be asked to maintain the set altitude as accurately as you possibly can while not hitting the ground. You will be using two different types of altitude: barometric and radar. The same scale will be used for all barometric altitude, but three separate and distinct radar altitude scales will be used in the evaluation. The evaluation will focus on your ability to read, interpret and use these scales to transition in and out of the low altitude environment and also to accurately maintain a set low altitude. To ensure that each pilot sees the same routes and conditions, we will instruct you when to begin your descents and climbouts, and we will expect you to maintain course as commanded by the lateral steering cue. The console operator will remind you if you stray too far from

course. We are not asking that you fly a constant airspeed, but rather, we will expect you to set 83% power and leave it set there for the entire mission. This will allow you to operate at reasonable low-altitude speeds, yet also allow us to control the parameters so as to eliminate some variability across the participating pilots.

Prior to beginning the evaluation, you will be given a briefing on the F-16 simulator and its operation. This will be followed by a training period in which you will become familiar with the Simulator and be given the opportunity to practice flying. You will also be asked to practice reading each of the three altimeters to become familiar with them and to ensure that you understand the scaling of each. Two practice missions will be flown just prior to beginning the evaluation and you will be expected to demonstrate a reasonable level of competence in performing the desired test maneuvers prior to beginning the evaluation. If at any time you have any questions, please feel free to ask them. Following the evaluation we will ask you to fill out a questionnaire to accompany the data we will be gathering. Your subjective opinions will be relied upon very heavily for assessing these altimeters and making key recommendations for adopting one of these displays for subsequent flight test. Please do your best.

APPENDIX B

RADAR ALTIMETER QUESTIONNAIRE

This questionnaire will be used to gather pertinent information concerning the three radar altimeters you have just used. The personal data will be used to summarize the qualifications of the participants in this study and to make comparisons in analyzing the data. You do not have to include your name if you do not desire to do so.

PERSONAL DATA

NAME: _____ AERONAUTICAL RATING: _____

ORGANIZATION: _____ PHONE NO. _____

AIRCRAFT FLOWN: (Type/hours)

_____/_____/_____

Have You ever used scale instruments before? Yes__ No__

(if so in what aircraft?) _____ Where were they located and what were they used for?

ALTIMETER QUESTIONS

Please refer to the attached figure at the back of this questionnaire (detach if necessary) for the scale designations and to refresh your memory about their individual features. For each of the following questions, please use the five point rating scale provided to rate each altimeter by placing a number in the spaces provided for each designated altimeter.

1. Rate each of the altimeters on the ability to read the altitudes.

very easy	easy	okay	difficult	very difficult
1	2	3	4	5

ALTIMETER #1____ ALTIMETER #2____ ALTIMETER #3____

Comments: _____

2. Rate each altimeter on the ability to interpret control input requirements for deviations from desired altitude.

very easy	easy	okay	difficult	very difficult
1	2	3	4	5

ALTIMETER #1____ **ALTIMETER #2**____ **ALTIMETER #3**____

Comments: _____

3. Rate each altimeter on the ability to use it to transition into and out of the low altitude segments of the missions you flew.

very easy	easy	okay	difficult	very difficult
1	2	3	4	5

ALTIMETER #1____ **ALTIMETER #2**____ **ALTIMETER #3**____

Comments: _____

4. Rate the ease of crosschecking each of the scales while using other information on the HUD.

excellent	good	satisfactory	poor	unacceptable
1	2	3	4	5

ALTIMETER #1____ **ALTIMETER #2**____ **ALTIMETER #3**____

Comments: _____

5. Rate the ability to maintain 300' altitude using each of the altimeters.

excellent	good	satisfactory	poor	unacceptable
1	2	3	4	5

ALTIMETER #1____ **ALTIMETER #2**____ **ALTIMETER #3**____

Comments: _____

6. Rate the ability to maintain 1000' altitude using each of the altimeters.

excellent	good	satisfactory	poor	unacceptable
1	2	3	4	5

ALTIMETER #1____ **ALTIMETER #2**____ **ALTIMETER #3**____

Comments: _____

7. Rate the overall mechanization of each of the altimeters (switchover values, scale range, numbering, warning cues, etc.).

excellent	good	satisfactory	poor	unacceptable
1	2	3	4	5

ALTIMETER #1____ ALTIMETER #2____ ALTIMETER #3____

Comments: _____

8. Rate the overall quality and utility of each display and its integration into the HUD symbology of the F-16.

-

excellent	good	satisfactory	poor	unacceptable
1	2	3	4	5

ALTIMETER #1____ ALTIMETER #2____ ALTIMETER #3____

Comments: _____

9. Using the attached figure at the back of this to refresh your memory, did you have any difficulty in using the scales that may have been caused by the non-linearity of the scale units. If so, what were they and what impact to you think it had on your performance? Please address your answer to each of the separate altimeters.

ALTIMETER #1 _____

ALTIMETER #2 _____

ALTIMETER #3 _____

Thank you for your participation. If you have any comments or recommendations that may be used to improve the presentation of radar altimeter information on the HUD, please provide them in the space below.

ADDITIONAL COMMENTS:

Please rate the usefulness and overall effectiveness of this simulation as a design technique for improving the integration of our future aircraft and avionics.

Excellent	Good	Uncertain	Fair	Poor
1	2	3	4	5

What would you do to improve this evaluation or others like it?

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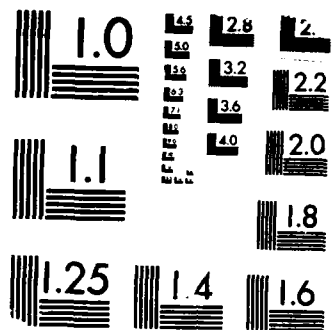
AN EVALUATION OF THREE LINEAR SCALE RADAR ALTIMETER
DISPLAYS(U) AERONAUTICAL SYSTEMS DIV WRIGHT-PATTERSON
AFB OH L A CARR JAN 88 ASD-TR-87-5005

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APPENDIX C

ALTIMETER-READING-PRACTICE VALUES

ALTIMETER #1

<u>Actual Value</u>	<u>Acceptable Reading</u>	<u>Actual Reading</u>
380	340-420	
730	660-800	
450	400-500	
1000	900-1100	
240	215-265	
550	500-600	
1300	1170-1430	
625	560-690	
165	145-185	
900	810-990	

ALTIMETER #2

<u>Actual Value</u>	<u>Acceptable Reading</u>	<u>Actual Reading</u>
1400	1260-1540	
700	630-770	
175	155-195	
950	855-1045	
200	180-220	
750	675-825	
1200	1080-1320	
350	315-385	
500	450-550	
1300	1170-1430	

APPENDIX D

CONSOLE OPERATOR'S INSTRUCTIONS (RADAR ALTIMETER STUDY)

1. Ensure that each pilot has read and understands the instructions.
2. Allow each pilot to fly the simulator for 10-15 minutes while instructing him on the use of the HUD symbology. Ensure that he practices a few climbs, descents and turns.
3. Have each pilot practice reading each of the preset 10 altitudes for each of the scales sequentially with #1 through #3. Record each response by marking a check by each correct response (correct = actual within 10%) or record the actual value when in error. Repeat each test until all 10 values are read correctly for each scale.
4. Load the first practice mission (#) and coach the pilot through it at 1000'. Use a different scale for each transition.
5. Load the second practice mission (#) and this time record the descent and climb times using a stop watch and also ensure that the pilot is able to maintain 300' for 45 seconds (within 100') on the last segment.
6. Give the pilot a break if he so desires.
7. Begin the evaluation and for each mission do the following:
 - a. Load the computer data.

b. Start the mission and verify that data collection is on.

c. Push the event start button on prior to every transition command.

d. Turn the event button off if the computer does not do so.

e. Remind the pilot of anticipated turns and of excessive deviations in steering control.

f. Reset the simulator after the end of each mission.

g. Annotate the data collection journal of any problems.

h. Reload the next mission and verify heading north.

8. Complete all the missions and then have the pilot annotate the altitudes on the blank altimeter handout.

9. Have each pilot fill out the questionnaire.

REFERENCES

Aircraft display symbology. MIL STD 1787. Aeronautical
Systems Division. Wright Patterson AFB, Ohio.
December 1984.

Amon, Final report on the operational suitability test
of the pointer-drum altimeter, Project #APG /SAT/
893-A, Air Proving Ground Command. Eglin AFB,
Florida. December 1955. (DTIC FILE)

Antenucci, A.J. State-of-the-art review of altitude
displays, US Army Human Engineering Laboratory.
Technical Report. Aberdeen Proving Grounds, Maryland.
1974. (DTIC FILE)

Bailey, R.W. Human performance engineering: A guide for
systems designers. Bell Laboratories Inc., 1982.

Brown, S.L. Jr. Comparative evaluation of ten altimeter
presentations. Technical Note (WCT 54-37),
Directorate of flight and all weather test, Wright
Patterson AFB, Ohio., April 1954. (DTIC FILE)

Carr, L.A., Nagle A. and Kinzig, J. F-16 MSIP
simulation: Switchology evaluation. Test report
(TIS 3). Aeronautical Systems Division. Wright
Patterson AFB, Ohio. April 1983.

Cohen, J., and Sanders, V.L., The effects of absolute
and conditional probability on instrument reading,
a comparison of a linear scale and two scales with
expanded central portions, WADC Report #57-65,
Antioch College, March 1958. (DTIC # AD-118019)

Crumley, L.M. Human engineering investigations of cockpit
visual displays: Evaluation of the display of
counter pointer altimeter. Technical Report (NAMC REP
TED-NAM-AE-7047. XG-T-215.), Naval Air Experimental
Center, Philadelphia, Pennsylvania, 1954. (DTIC FILE)

Defeu, A.N. Altimeters-the way ahead. Aircraft Engineer-
ing. July 1975 Vol. 47, no.7. pp12-21.

Engel, R.L. Flight test request to remechanize LANTIRN
TFR modes, Flight Test Request, Edwards AFB,
California, April 1984.

Fitts, P.M. and Jones, R.E. Psychological aspects of instrument display: Analysis of 270 pilot error experiences in reading and interpreting aircraft instruments. Technical Report (TSEAA-694-12A). Aero-Med Lab, Wright Patterson AFB, Ohio., October 1947. (DTIC FILE)

Gartland, T.C. and Shimer, S.E. A-10 Night Evaluator, Preliminary assessment of avionics and human factors. Technical report (AFFTC-TR-17). Edwards AFB, California, July 1980. (DTIC FILE)

Geiselhart, R. and Ivey, L. LANTIRN Simulation: A-10 Snap Look, Look Into Turn and symbology evaluation. Test Report. Wright Patterson AFB, Ohio. June 1982.

General Dynamics. (1979) F-16 night attack simulation study. Ft. Worth, Texas.

Grether, W.F. Analysis of the types of errors in the reading of the three pointer altimeter. Report # TSEAA 694-14A. Aero-Med Lab. Wright Patterson AFB, Ohio. March 1948. (DTIC FILE)

Grether, W.F. Instrument reading: The design of long scale indicators for speed and accuracy of quantitative and qualitative reading, Journal of Applied Psychology. 1949, Vol. 33, pp 363-372.

Hale, C.R. and Obrien, K.M. LANTIRN simulation data analysis. Simulation report. The BDM Corporation. Kirtland AFB, New Mexico. July 1984.

Human engineering design criteria for military systems, equipment and facilities. MIL STD 1472C. Aeronautical Systems Division. Wright Patterson AFB, Ohio, December 1984.

Jarvi, D.W., Carr, L.A., Curtice, W.L., Joyce, D.A., and Martin, W.L. Night attack workload steering group report, Technical report. ASD-TR-5002 Vol.I. Wright Patterson AFB, Ohio, June 1982. (DTIC # AD-8063 599)

Lovering, P.B. F-16 LANTIRN HUD Configuration and symbology assesment, Simulation report, Wright Patterson AFB, Ohio, July 1981.

McCormick, E.J. Human factors engineering. McGraw-Hill
Inc. 1964. Part Three, Chapt. 6.

Mengelcoch, R.F. and Houston, R.C. Investigation of
vertical displays of altitude information: A
comparison of a moving-tape and standard altimeter
on a simulated flight task. Technical report
(57-384). Wright Air Development Center. Dayton, Ohio.
March 1958. (DTIC # AD-130828)

Mengelcoch, R.F. and Houston, R.C. Investigations of
vertical displays of altitude information: The effect
of practice on performance of a simulated flight task
using a moving-tape altimeter. Technical report
(57-385). Wright Air Development Center. Dayton, Ohio.
March 1958. (DTIC # AD-130829)

Mengelcoch, R.F. and Houston, R.C. Investigations of
vertical displays of altitude information: The effect
of an expanded scale on performance of a simulated
flight task using a moving-tape altimeter. Technical
report (57-549). Wright Air Development Center. Dayton,
Ohio. March 1958. (DTIC # AD-142042)

Merrifield, J.T. Flight Dynamics to certify holographic
HUD for 737-200. Aviation Week and Space Technology.
September 30, 1985. McGraw-Hill.

Nicklas, D.R. A history of aircraft cockpit instrumentation, 1903-1946. Technical report (57-301). Wright Air Development Center. Dayton, Ohio. April 1958. (DTIC # AD-118299)

Quick look flight test report Technical Report (AFFTC TR-81-32), Edwards AFB, California. 1981. (DTIC FILE)

Schum, D.A., Robertson, J.R. and Matheny W.G. Altimeter and hardware development 1903-1960. Technical Report (ASD-TDR-63-288). Flight Control Laboratory. Aeronautical Systems Command. Wright Patterson AFB, Ohio. May 1963. (DTIC # AD-408989)

Simon, C.W., Slocum, G.K., Hopkins, C.O. and Roscoe, S.N. Altimetry studies: An experimental comparison of three pictorial and three symbolic displays of altitude, vertical speed, and altitude commands. Technical memorandum (245). Hughes Aircraft Company. Culver City, California. January 1956. (DTIC FILE)

Simon, C.W. and Roscoe, S.N. Altimetry studies: A comparison of integrated versus separated, linear versus circular, and spatial versus numerical displays. Technical memorandum (435). Hughes Aircraft Company. Culver City, California. May 1956. (DTIC FILE)

Spady, A.A. Jr. and Harris, Randall L. Sr. How a pilot looks at altitude. Langley Research Center, NASA, 1981. (NTIS # N81-22697/9)

Single seat night attack A-10 flight test program. Air Force Flight Test Center. Edwards AFB, California. 1983.

Stone, J.T. Review of WADD research and development efforts on altimetry. Flight Controls Laboratory. Wright Patterson AFB, Ohio. April 1960. (DTIC FILE)

Sundstrand Corporation, (1983). Fighter/attack mission ground proximity warning system (LAWS) program. Wright Patterson AFB, Ohio.

Sviminoff, C. Air Force integrated flight instrument panel. Technical report (58-431). Wright Air Development Center. Dayton, Ohio. October 1958. (DTIC FILE)

Van Cott, H.P. and Kinkade, R.G. Human engineering guide to equipment design. Revised Edition. American Institutes for Research. Washington, D.C., 1972.

Wright, L.C. The Air Force program for improved flight instrumentation. Technical report (56-582). Wright Air Development Center. Dayton, Ohio. November 1956. (DTIC FILE)

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