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Date 12 August 1990

SUITABILITY OF THE A-7E CORSAIR II FOR "ALL WEATHER" ATTACK INGRESS AND TARGETING TRANSITION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Linda C. Shaffer-Vanaria

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DISCLAIMER

This thesis contains technical data collected during a study of the suitability of the A-7E CORSAIR II for "All Weather" attack ingress and targeting transition. All opinions and recommendations are the sole opinion of the author, and do not reflect the official position of the Naval Air Test Center, Naval Air Systems Command, the United States Navy, LTV (Ling-Tempco-Vought) Aerospace now called Vought Aerospace, or any other contractor mentioned throughout this text.

ABSTRACT

Since the Reagan Presidency, the emphasis on budget cuts, and in particular on defense spending, is forcing the Navy to reevaluate the mission capability of their aircraft with the mind set of extending their service life and tactical effectiveness through the turn of the century. The A-7E is a single seat light attack aircraft which has historically been utilized predominantly as a day visual bomber. Within the past decade, tactical aggressions on the part on third world countries has enhanced interest in utilizing attack aircraft for night and instrument ingress. Thus, it is the purpose of this thesis to determine the modification requirements for the A-7E in order to make the aircraft suitable for "All Weather" ingress and target transition.

The suitability study commenced with defining a generic ingress profile, defining "All Weather" mission scope and reviewing the pilot workload psychology considerations applicable to successful completion of a single seat "All Weather" ingress and targeting transition. The suitability study consisted of both ground and flight tests as well as extensive field research to include numerous personal interviews with experts in both the military and industry.

The A-7E would require extensive modification to make it suitable to perform "All Weather" ingress and targeting transition. The navigation system needs to undergo major upgrades in order to provide accuracy to within a few tens of meters. Terrain referencing navigation in combination

with a Ring Laser Gyro and Global Positioning System could provide the pilot the accuracy and confidence desired. Pilot cueing of flight path critical terrain features needs to be upgraded in order to ensure obstacle avoidance. Extensive modifications to the Forward Looking Radar, Forward Looking Infrared, Projected Moving Map Display, and HUD along with cockpit switchology and instrument layout are required.

In the past decade significant emphasis has been placed on interfacing cockpits for use with night vision devices. The A-7E can and should be modified for night vision device compatibility.

Undoubtedly low level ingress and targeting transition is best performed in a dual seat aircraft; however, modern system designs to include tactical system and aircraft automation open "All Weather" attack to single seat aircraft in some mission significant scenarios. Modernization programs similar in scope to the one described herein for the A-7E could be employed on other fleet aircraft in order to allow continued mission significant operation.

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1 INTRODUCTION

1.1 BACKGROUND

With the on-going trend of defense budget expenditure cuts the U.S. government is pursuing service life extension on current fleet and training airframes allowing for systems development and redesign in lieu of an entire full scale procurement and development cycle. The A-7E Corsair II was originally intended to be replaced fleet wide by the F/A-18 in the mid to late 1980's; however, fleet introduction has slowed and several squadrons of A-7E aircraft are currently still deploying on the east and west coasts. Completed F/A-18 fleet introduction is now not anticipated until the mid 1990's with further delays not anticipated at this time.

In consideration of the limited defense assets and lengthy procurement cycles of up to ten years, it would be desirable to consider an A-7E upgrade which incorporates recent technological advances expanding the current aircraft mission to "All Weather" attack. Not only would this assist current fleet needs but also could provide the naval reserves with improved assets as the A-7E is phased out of the active duty fleet. The Air National Guard has already upgraded the A-7D/K for enhanced "All Weather" capability (reference 1). It would be worthwhile to review the A-7D/K upgrades as well as other current fleet assets and technologies in determining the best recommendations for the A-7E.

1.2 PURPOSE

The purpose of this thesis is to determine the modification requirements for A-7E aircraft in order to make the aircraft suitable for "All Weather" ingress and target transition.

1.3 DESCRIPTION OF THE A-7E AIRCRAFT

The Vought A-7E CORSAIR II is a single seat, multiple sensor, light attack airplane. Airplane dimensions are presented in appendix A, figure 1. The airplane is powered by a single Pratt and Whitney TF41-A-402D turbofan engine rated at 15,000 pounds static thrust, uninstalled, under sea level, standard day conditions. The airplane structure includes a shoulder mounted wing with 35 degrees of leading edge sweep and 5 degrees of geometric anhedral, and an all-moving unit horizontal tail (stabilator). The airplane primary flight control system is fully hydraulic powered and irreversible. Primary flight controls consist of a unit horizontal tail, ailerons with interconnected spoilers, and rudder. The longitudinal control system incorporates feel springs, bobweights and viscous dampers designed to provide feel spring forces proportional to stick position, rate of stick movement and normal load factor. The right rudder pedal is equipped with a rudder shaker designed to warn of approaching stall conditions. An Automatic Flight Control System (AFCS) is incorporated to provides yaw stabilization, control augmentation, altitude hold, heading hold, an Automatic Carrier Landing System (ACLS), and ground controlled bombing. The yaw stabilization feature provides directional damping, aileron-rudder interconnect and rudder trim. Roll and pitch trim is provided by single channel actuators which change the neutral reference of the feel springs. Secondary flight controls consist of a single fuselage-mounted speedbrake, four leading edge flaps and two trailing edge single slotted flaps. An Automatic Maneuvering Flap (AMF) system controls both leading and trailing edge flap extension and retraction as a function of angle-of-attack (AOA). The external stores carriage capability consists of six wing stations capable of carrying a variety of conventional and special weapons and two fuselage stations fitted for AIM-9 sidewinder missiles. The airplane has an internally mounted 20-mm gun. Additional airplane features include a clam shell canopy, fully retractable tricycle landing gear with nosewheel steering and an anti-skid brake system, a retractable arresting hook and an ESCAPAC ejection seat. The operating weight of the airplane is approximately 21,000 lb and maximum takeoff weight is 42,000 lb.

The integrated navigation and weapons systems utilized during ingress navigation and targeting transition include the Inertial Measurement Set (IMS), Tactical Computer Set (TCS), Air Data Computer (ADC), Forward Looking Radar (FLR), Forward Looking Infrared (FLIR), Doppler Radar System, Communication, Navigation and Identification (CNI) equipment, along with various sensors, controls and displays. The FLR incorporates Terrain Following (TF) and Terrain Avoidance (TA) among other modes. The CNI equipment includes, in part, a radar altimeter and Projected Moving Map Display (PMDS). The principle display utilized is the Head-Up Display (HUD). The weapons system is designed for control of external stores release as well as the firing of the 20-mm gun. The weapons system additionally includes an

Electronic Countermeasures System (ECS), Armament Station Control Unit (ASCU) and various sensors, controls and displays for target tracking. A basic diagram of the weapons system is provided in appendix A, figure 2. The A-7E aircraft is described in detail in reference 2. External views of the aircraft are presented in appendix A, figures 3, 4 and 5.

1.4 DEFINITION OF "ALL WEATHER"

Tactical aircraft design criteria must ensure successful mission completion under the most marginal weather conditions possible. "All Weather" includes operations under a broad scope of environmental conditions. This definition includes day and night environmental lighting levels under weather ranging from clear to total cloud cover in precipitation. There have been no complete global climatology studies performed to date (personal interview 1); however, the following generalities may be made (personal interview 1 and reference 3, pp. 2, 5):

A. FLIR ranges increase with increasing latitude since humidity near the equator strongly attenuates infrared (IR) signals.

B. There is little seasonal variability in FLIR ranges at and near the equator.

C FLIR ranges decrease from winter to summer due to increases in humidity during the summer. Reference 3 provides global predicted FLIR ranges.

D. FLIR temporal transmisivity is diurnaly dependent. Minimum dependency occurs in the morning. Reference 4 provides global transmisivity data for Europe, Korea, the Middle East, the tropics and the United States.

With respect to night vision devices (NVD), night illuminance is dependent on lunar altitude, lunar phase, solar altitude, cloud cover, precipitation and artificial light sources (personal interview 1 and reference 5, p. 4). Minimal acceptable climatic requirements for NVD mission performance are as follows (reference 6, p. 1):

Astronomical:	Lunar altitude	greater than 20 degrees
	Lunar Illumination	greater than 20 percent
Climatic:	Near IR visibility	greater than 3 miles
	Cloud cover	less than overcast

NVD effectiveness envelopes for several areas in the United States are depicted in reference 6. A general rule utilized by the fleet for mission planning is that approximately 60% of night hours have no moon available and approximately 50% of the time when the moon is available will be overcast, leaving approximately 20% of night hours optimal for NVD use. Up to 30% of night hours may be suitable for NVD use with degraded NVD performance anticipated (personal interview 2). As a result of increased interest in NVD applications, the Naval Environmental Prediction Research Facility, the USAF Environmental Technical Application Center (USAFTAC) and the Department of Geophysics are periodically tasked with conducting "All Weather" research; however, defense spending cutbacks will most likely inhibit progress of such work in the near future.

1.5 ATTACK MISSION PROFILES

Four unclassified methods of conventional weapons delivery are available to the A-7E pilot. These methods include:

A. Level Lay-down Delivery

B. Offset Pop-up Maneuver

C. Reversal Pop-up Maneuver

D. Dive Delivery

These four methods are illustrated in appendix A, figures 6 through 9. Of the delivery methods enumerated above, the level lay-down is the most likely method to be utilized for night attack and, in particular, during Instrument Meteorological Conditions (IMC). Pop-up deliveries might possibly be considered for night Visual Meteorological Condition (VMC) deliveries with NVD (personal interviews 3 and 4).

1.6 PILOT WORKLOAD PSYCHOLOGY CONSIDERATIONS

In relation to piloting an aircraft, workload can be defined quantitatively as the ratio between time required and time available to complete a specified task (personal interview 5). However, reliable and valid quantification of this seemingly simple ratio is difficult because of the variation between actual and simulated scenarios. Workload may be most accurately determined during operation of equipment in actual mission scenarios. Mission scenario (or mission relation) is the key in determining workload requirements in that what might be considered an acceptable workload level for completion of one task may not be considered acceptable for completion of another. Aircraft designers are faced with the problem of designing aircraft systems for which workload is acceptable for the performance of required mission tasks. In elucidating this problem, it is apparent that it is not desirable to incorporate a system with the complexity necessary for the successful completion of the mission if it is not simple enough for the pilot to manage under the high stress of combat. Major concerns relating to design requirements for combat workload include pilot fatigue, night vs day, VMC vs IMC, and pilot sensory perception (personal interview 5).

With the onset of fatigue, workload problems exacerbate with perceptual and cognitive abilities becoming less efficient as fatigue increases. For the single-seat A-7E pilot, fatigue will come from the hurried pace of round the clock cyclic operations as well as the fast conduct and tempo of the individual flights themselves. The checklist approach and keeping procedures as simple as possible are the primary design concepts utilized to stave-off this type of fatigue (personal interview 5).

When transitioning from day to night operations as well as from VMC to IMC operations, pilot stress increases drastically. The primary reason for this increase in stress is that humans are primarily visual creatures. With respect to object motion, visual information occurs in two forms (personal interview 5):

A. Primary; directly observable information, for example information which instantaneously provides object velocity changes to the operator. This would relate to a VMC pilot scan.

B. Secondary; derived information, for example that information which must be interpreted via instrumentation and processed to provide object velocity changes to the operator. This would relate to an instrument scan. Information provided to the pilot must be ecological; meaning that it is critical to provide only essential mission information to the pilot. Humans become very nervous with restricted visual rate cues as is the case with secondary visual information (personal interview 5). In order to minimize stress levels, the current trend in cockpit display design is to mimic primary visual information on displays. The F-14 HUD, for example, utilizes dark trapezoids ("Muffins") on a lighter ground texture pattern in order to enhance the relationship between sky and ground. An F-14 "Muffins" display is presented as appendix A, figure 10. The ground texture patterns are designed to emanate from the horizon and move toward the pilot in order to simulate motion (personal interview 5 and reference 7, pp. 44-45). The PENETRATE Terrain Referencing Navigation (TRN) system utilizes what is known as "Highway in the Sky" shown in appendix A, figure 11 (reference 8). The "Highway in the Sky" is more technologically advanced than the "Muffins" in providing visual motion cues to the pilot in that the displays provide more seemingly realistic primary cues. Work is currently being done on laser horizon projectors which mount in the cockpit and project an image of the horizon onto the windscreen enhancing pilot spatial awareness and, as such, staving-off vertigo onset. Even though the above mentioned cues are animated and are therefore by definition secondary cues, they provide pilots security in that they act in the manner of primary cues (personal interview 5).

The two primary means of a pilot acquiring information are visual and auditory. In the high stress of combat, the information provided to the pilot needs to be primarily visual except for special auditory signals (personal interview 5). General design criteria for the combat environment are to visually provide information utilized for Management by Objectives (MBO) and to aurally provide information utilized for Management by Exception (MBE). In the combat arena it is desirable to use non-synchronized multi-coding (both visual and auditory cueing) when critical to ensure pilot information reception. During target ingress, the pilot is very "where" intensive (where is my target?, where is my next waypoint?, where is the enemy?). When the pilot proceeds from the ingress to performing the target transition, he becomes even more "where" intensive, channelizing attention to minimizing spatial differences between where he is and where he should be. When the pilot commences targeting, he transitions from "where" intensive to "what" intensive (what to do next?). During the critical transitions just mentioned, the pilot becomes vulnerable to fixation and overload errors which could ultimately result in loss of aircraft and pilot. This demonstrates that aircraft display design is critical and must provide the pilot the right information at the right time. Experimentation has shown that information should be communicated visually to the pilot if spatial analysis and/or a motor skill response is required. Likewise, information should be communicated to the pilot in an auditory manner when logic (experience relation) analysis and/or a speech response is required. Although these means of communication can be interchanged, steps and time to problem resolution will be added. In a high stress environment like combat it is undesirable to interchange communication means for sequential task requirements; however, interchanging communication means can be beneficial or even necessary for tasks which need to be performed simultaneously (personal interview 5).

1.7 MISSION UTILITY

In order to perform a suitability study of the A-7E for "All Weather" ingress and targeting transition, a representative ingress and targeting transition profile must first be defined. Based on current events, a typical ingress and targeting transition profile would require the following (personal interview 3):

A. Launch from carrier with subsequent 200 nm over water transit prior to ingress over land. Transit conducted below 200 ft AGL.

B. Up to 200 nm over land ingress over flat and mountainous terrain. Ingress altitudes will vary from below 200 ft AGL over flat terrain to between 500 and 1000 ft AGL in mountainous regions, elevation increasing as terrain becomes rougher. Typical terrain will be devoid of readily identifiable landmarks inhibiting navigation system updates.

The systems and equipment required for the performance of ingress and targeting transition vary with the ambient weather and lighting conditions. Experience has shown that day VMC ingress and targeting can be performed with limited systems augmentation. With deteriorating daylight, systems and equipment are necessary to effectively make the transition to a night VMC attack profile (personal interview 3). Experience over the last decade has shown a combination of FLIR and NVD to be successful in making this transition. One problem with NVD is the requirement for compatible cockpit lighting (personal interview 2). Cockpit mounted laser trackers have also proved helpful in assisting with target acquisition and tracking. With weather deterioration to IMC conditions it is necessary to provide the pilot reliable cues of aircraft, obstacle and target location. It is critical that the accuracy and reliability of the system be sufficient to provide the pilot the confidence to fly at low level in order to remain covert (personal interview 3). Experience has shown radar to be most suitable for this environment since FLIR and NVD are not effective in IMC (personal interviews 2 and 3). It is necessary to have a "tight" (accurate alignment with minimal drift) navigation system along with a mission suitable radar to ensure obstacle clearance and timely target acquisition during IMC. With the high workload of IMC, particularly at night, it is desirable to provide the pilot a TF capability which can be coupled to the AFCS (personal interview 3). The major emphasis on evaluating suitability for "All Weather" ingress and targeting transition needs to be the "complementary" nature of all systems and equipment provided to the pilot in order to conduct the mission (personal interview 2). Systems need to operate in a "complementary" manner and not to the exclusion of each other. This implies that it must be easy and natural for the pilot to obtain information from all the sources provided to him and also to transition between the sources with the ease necessary to perform mission tasks (personal interviews 2 and 3).

1.8 SCOPE OF TEST

This suitability study of the A-7E aircraft for "All Weather" ingress and target transition consisted of both ground and flight tests as well as personal interviews. The TA-7C aircraft was utilized for several tests. The TA-7C forward cockpit and mission systems are representative of those of the A-7E. Personal interviews as well as previous Naval Air Test Center (NATC) flight test results were utilized for data augmentation where available. The IMS, TCS, FLR ground mapping modes, doppler radar, PMDS, HUD, NVG compatibility, and weapons systems switchology were tested in flight. Flight tests were conducted within the envelope constraints of the applicable Naval Air Systems Command (NAVSYSCOM) manuals (references 2, 9, and 10). The FLIR, FLR Terrain Following (TF), Terrain Avoidance (TA), and Ground Collision Avoidance System (GCAS) were either not installed or not operational in the test aircraft. Data were additionally obtained from personal interviews with test pilots with A-7E expertise, fleet experienced test naval flight officers with "All Weather" attack expertise and appropriately experienced members of industry. Definitions of "All Weather" and workload psychology considerations were derived from data collected during personal interviews (personal interviews 1 and 5) and thesis research. The attack mission profile was defined from personal interview data (personal interviews 2 and 3) as well as Tactical Manual and fleet training publications (references 2, 9, and 10). Although conclusions and recommendations weigh heavily on results of government sponsored tests, this thesis is a personal work and carries no legal implications.

1.9 METHOD OF TEST

In general, aircraft systems were qualitatively evaluated with respect to successful mission profile completion. Where applicable, quantitative data were taken utilizing standard systems testing procedures (reference 11) in order to substantiate qualitative findings. Normal and emergency checklists were utilized to aid in the evaluation of switch location. Ergonomic data was primarily qualitative and not only considered individual systems, but also overall system integration. Night Vision Goggle (NVG) data were obtained utilizing various jet and rotary wing aircraft including the F-18, AV-8B, TA-7C, TH-57A, and CH-46E as study platforms. Both AN/AVS-6 and "Cats Eyes" NVD were studied. Applicable systems including aircraft lighting and NVD were flight tested at altitudes mimicking those required for actual low level ingress.

1.10 WORK CHRONOLOGY

The flight and ground testing for this thesis was conducted in part from June through July 1988 as part of a Phase IIA Developmental Testing Evaluation of the TA-7C Aircraft for a United States Naval Test Pilot School final project for graduation. Testing was augmented from October through July 1990 for the purposes of gathering further data. The suitability study of the A-7E for this thesis was completed during the fall semester of 1989 and spring and summer semesters of 1990.

2 A-7E INGRESS AND TARGETING TRANSITIONS

2.1 INERTIAL MEASUREMENT SYSTEM

2.1.1 Description

The Inertial Measurement Set (IMS) controls are located on the mid right console as shown in appendix A, figure 12. The IMS is the primary heading, attitude and velocity reference. The IMS consists of an Inertial Measuring Unit (IMU), an IMU adjustable mount, an adapter with power supply and a control panel. The IMS has a self-contained battery incorporated which is designed to provide continuous operation for up to 30 seconds in the event of a power failure (reference 12, pp. 73-74).

The IMU is a four-gimbal, all-attitude unit consisting of gyroscopes, accelerometers, and associated equipment. The four gimbal structure is incorporated to allow for proper orientation of accelerometers throughout the aircraft maneuvering envelope. The adapter with power supply is designed to provide regulated power to the IMU and attitude information to appropriate flight instruments (reference 12, pp. 73-74).

The IMS is designed to provide outputs including fail signals, as appropriate, to the TCS, Attitude and Direction Indicator (ADI), Horizontal Situation Indicator (HSI), Tactical Air Navigation (TACAN), AFCS, FLR and Doppler Radar. The IMS is designed to provide the Tactical Computer Set (TCS) incremental velocity signals along the east-west, north-south and vertical axes, as well as readouts of the platform gimbal angles representing aircraft pitch, roll and heading and an IMS fault signal. The spatial orientation of the IMS platform and the accelerometers are controlled by gyros under control of the TCS. The TCS uses the heading and incremental velocity signals to compute present position, distance to destination and bearing to destination (reference 12, pp. 73-74).

The IMS is designed to provide the ADI pitch, roll and magnetic heading signals as well as IMS fail signals. The IMS fail signal causes the OFF flag to appear on the ADI and additionally illuminates the PLATFORM caution light (reference 12, pp. 73-74).

The IMS is designed to provide magnetic heading to the Horizontal Situation Indicator (HSI) and TACAN. The IMS is designed to provide the AFCS pitch and roll acceleration signals, a heading reference and an IMS fail signal. The IMS fail signal to the AFCS cycles the control augmentation mode OFF and illuminates the PLATFORM caution light (reference 12, pp. 73-74).

The IMS is designed to provide the FLR and Doppler Radar with pitch and roll acceleration signals for antenna stabilization and an IMS fail signal. Should an IMS failure occur in the Terrain Following (TF) mode, the IMS is designed to signal the ADI off flag along with a flight directed climb command on the HUD (reference 12, pp. 73-74).

The IMS performs both coarse and fine alignments and contains Built-in-Test (BIT) equipment. The IMS modes provided to the pilot include Ground Align, Normal, Magnetic Slave, and Inertial (reference 12, p. 74).

2.1.2 Alignment

Alignment of the IMS means that the platform is oriented so that the three accelerometers are pointed east, north and vertically up respectively in order to provide respective east, north, and vertical incremental velocities. Alignment therefore results in gimbal axes coincidental to the coordinate system of the earth (north, east and local vertical) (reference 2. pp. 8-70 - 8-71).

There are four types of TCS controlled alignments. The two primary alignments utilized are the ground alignment when shore-based and the Ship Inertial Navigation System (SINS) alignment when carrier-based. Corrections for carrier motion are designed to be entered into the TCS via a SINS alignment cable. An airborne alignment capability is provided, designed to allow alignment utilizing doppler groundspeed as a velocity reference. The IMS allows for pilot updates utilizing HUD, radar, flyover, Projected Moving Map Display Set (PMDS), or TACAN. The IMS platform alignment is maintained by the TCS once the alignment cycle is complete (reference 12, p. 77).

IMS alignment duration was quantitatively evaluated for alignment duration and qualitatively evaluated for mission utility during four launch cycles. IMS alignment times are shown in appendix B, table I. The average alignment time exceeding 10 min was considered long; however, not so long as to require upgrade since alignment can be commenced with external electrical power prior to pilot preflight (reference 13, pp. 61-62).

2.1.3 Airborne Modes

The IMS is designed to work in two primary modes which include Normal Doppler Inertial Gyrocompassing (DIG) and Inertial (reference 12, p. 75). The Inertial mode is the preferred mode utilized in the fleet. The TCS is designed to compensate for IMS platform parameters and aircraft motion. Gyro and accelerometer bias errors gradually accumulate resulting in IMS drift (reference 2, pp. 8-152).

In the NORMAL mode (DIG), the Doppler groundspeed interface with the IMS is designed to detect platform misalignments and apply the necessary torquing corrections for gyro drift, earth rotation and earth relative rate at latitudes below 70 deg. Additionally, the TCS compares Doppler and IMS velocities and provides torquing signals for airborne gyrocompassing in order to maintain IMS azimuth alignment. Aircraft velocity and present position are computed from the IMS horizontal velocities coupled to Doppler groundspeed and IMS vertical velocity. IMS velocities are utilized in combination with the ADC for computation of wind velocity. Wind velocity information is designed to be fed to the weapons delivery systems (reference 2, p. 8-152).

The pure INERTIAL mode (no Doppler) utilizes inertial velocities from the IMS to maintain IMS alignment. IMS groundspeed, Doppler groundspeed, IMS drift angle, Doppler drift angle and several other diagnostics can be monitored one at a time in flight using TCS inputs in order to access system drift and accuracy (reference 2, p. 8-152).

IMS accuracy is crucial for successful low level ingress and target acquisition at night and in IMC conditions. If accuracy is questionable, the attack pilot will be required to increase altitude, significantly increasing the threat of discovery and enemy countermeasures. Ingress is normally performed over nondeveloped terrain in an actual threat environment to minimize discovery. It is critical that IMS accuracy be sufficient to covertly navigate terrain during a 1 1/2 hr mission. Although IMS updates are desired they should not routinely be required in order to maintain the accurate navigation required for target discovery and collision avoidance (personal interview 2).

The closeout IMS error in position was evaluated after three flights by recording initial and closeout position. Closeout errors in position are presented in appendix B, table II and north-south (N-S) versus west-east (W-E) position errors are presented in appendix A, figure 13. Data were reduced utilizing navigation computer programs as developed for standard use at the U.S. Naval Test Pilot School. All flights were 1.5 hr duration. On only one flight was error in position less than 3 nm (reference 13, pp. 62-63). Errors in position of 3 nm over a standard mission period of 1.5 hr are not acceptable for an "All Weather" ingress to targeting transition. At best, a 3 nm error in position would likely result in off-target weapons release, delayed weapons delivery or missed target. However; a 3 nm error in position could potentially result in obstacle impact, particularly in unknown terrain as would be typical of combat (personal interviews 2 and 3). Errors greater than 1 nm per a 1.5 hr mission are considered unacceptable for night VMC low level flight (personal interviews 2 and 3). In order to perform a low level ingress and targeting transition in IMC, precise navigation with no more than an approximate 200 ft error in position is desirable with little more tolerable for a high workload single seat environment (personal interviews 2 and 3). Without confidence in his navigation system, a pilot could not possibly be expected to fly at altitudes low enough to ensure remaining covert for fear of ground obstacle impact (personal interviews 2, 3, and 4).

Under the current system, IMS updates are performed manually. Present position coordinates are designed to be updated by the HUD, FLR, PMDS, flyover, or TACAN with procedures as enumerated in reference 2, pp. 8-180 to 8-181. Accomplishing IMS update procedures could best be described as high workload and cumbersome with resultant inertial system update accuracies unsuitable for "All Weather" attack. In the high stress, workload intensive environment of "All Weather" attack, simplified human factors are a necessity (personal interview 5). Presently, in performing navigation updates, pilot attention is diverted from flying the airplane, maintaining mission parameters and avoiding threats. A modern technology remedy for the navigational system will next be discussed.

In order to successfully navigate the "All Weather" mission described in paragraph 1.7 which entails both over water and over land flight, a combination of a Ring Laser Gyro (RLG), Global Positioning System (GPS) and Terrain Referencing Navigation (TRN) systems would be ideal to ensure redundancy and in such provide confidence to the pilot (personal interviews 3, 6, and 7).

A RLG is a standard stock item for the U.S. Air Force. As a rule the RLG accuracy is to within approximately 1/4 nm for the first hour and up to 1/2 nm during a 3 hr mission (personal interviews 6 and 7). The Air National Guard is consequently interested in integrating the RLG into the A-7D/K, with airframe integration and evaluation pending. The RLG incorporation would be enhancing and quick since the RLG is a stock item (no lengthy procurement required), with known accuracy, far exceeding the already incorporated IMS (personal interview 6). A RLG works on the principal of light propagating as travelling waves in a closed optical cavity with three or more mirrors. The RLG detects and measures angular rates by measuring the frequency differences between two counterrotating laser beams. The two laser beams circulate within the optical cavity simultaneously. With no rotation of the ring the clockwise and counterclockwise beams will travel the same distance and have the same frequency. If the ring is rotated, the beam in the direction of rotation will have had to travel further than if it had not been rotating. The arriving beam is out-of-phase with the originating beam. RLGs are subject to certain problems. One problem called "lock-in" is due to the output dropping abruptly to zero at a critical input rate and rising again only when the angular rate again exceeds the critical value. Another RLG problem is that a small proportion of the beam energy striking the mirror is randomly scattered rather than reflecting in the normal way. Therefore, two critical design requirements for RLG include a very high mirror reflectivity in order to reduce energy losses within the cavity and a very low scatter to reduce the "lock-in" effect (reference 14, pp. 165-168). Honeywell Avionics Division and other companies are performing on-going research to improve the accuracy of RLGs and reduce component size (reference 15, p. 22).

GPS is a satellite navigation system which provides the user three dimensional position and velocity data. With GPS, position is determined by passive ranging and velocity is determined by measuring the Doppler shift between received signals. Each satellite transmits satellite ephemeris, time of day, signal propagation information, satellite operational status, acquisition information of other satellites and special messages in a 1500 bit word, at a 50 bit per second rate. The satellite ephemeris provides the position of the satellite to the user. The GPS system consists of 18 satellites in order to provide worldwide coverage. For airborne applications, a GPS can be utilized to update an inertial navigation system or other dead reckoning system (reference 16, pp. 2.93, 2.99 and 2.100). GPS can determine position to within 16 meters in 3 dimensions (reference 16, p. 3). A GPS provides passive, jam-resistant, accurate, continuous "real time" 3-dimensional velocity and position information with controlled access. The characteristics just mentioned make GPS suitable for navigation updates during tactical enroute navigation and weapons delivery (reference 16, pp. 2.93, 2.99 and 2.100). During a war scenario, it is conceivable that the satellites could become targets. Therefore, GPS can be used as a secondary system for enhanced navigation accuracy but should not be counted on as a primary system component (personal interview 3). GPS receivers are being produced in small packages of reasonable size, for tactical aircraft integration, by Rockwell International (personal interviews 6 and 8). A GPS would definitely be advantageous in maintaining and crosschecking navigation system accuracy for tightness. It should be emphasized that GPS is a passive system which allows the aircraft to remain covert (personal interviews 3 and 6).

TRN is designed to provide the pilot navigational accuracy to within a few tens of meters. TRN works by subtracting radar height from barometric height (derived from the inertial system), as shown in appendix A, figure 14.

This calculation is continuously performed in a TRN system in order to determine the profile of the terrain under the flight path. The profile obtained is then compared with profiles generated from the stored Digital Terrain Elevation Data (DTED) to determine terrain match and in such aircraft position. By design, optimum system performance occurs in rugged terrain, but even over relatively flat terrain, errors in position are designed to remain within a few tens of meters (reference 15, p. 8). TRN is not designed for over water use or to be used at heights above the radar altimeter limit (5000 ft AGL) (reference 15, p. 8). On reaching land after crossing water, TRN is designed to quickly refine inertial position and thereafter track basic inertial system drift (reference 15, p. 8). Continuous high accuracy navigation is essential on a low level ingress in order for computer generated skeletal perspective images (such as obstruction cues, ridge lines and lattice images) to accurately depict actual terrain and obstructions (reference 8, pp. 8-9). TRN is a technology currently coming into fruition with prototypes being tested in U.S. military aircraft. Pilots and engineers who have been exposed to this technology are largely impressed with the design features and feel that it should be evaluated for possible implementation in future designs and retrofits (personal interviews 3 and 6). U.S. testing of TRN is planned for the near future. The maps available from the defense mapping agency for use with TRN are not certified and currently are geographically limited (personal interviews 3 and 6). Should this technology realize its potential during upcoming tests, it would be likely that government funding would be appropriated for establishing the mapping data base necessary to integrate TRN into fleet aircraft.

The systems elaborated upon in the previous paragraphs to include RLG, GPS and TRN are in and of themselves insufficient in order to conduct all aspects of the mission described in paragraph 1.7. However; when installed in a "complementary" nature, these systems could provide the navigational accuracy required to dependably ingress to a targeting transition. The author's proposal would be to employ the systems as follows:

A. Launch off the carrier using RLG for navigational information (TRN not designed for over water use). Utilize GPS for RLG system crosscheck and updates.

B. Upon crossing the shoreline and throughout ingress to target, TRN becomes the primary navigational updating source for the inertial system. Utilize GPS and RLG for TRN system crosscheck.

It is further recommended that the navigation system composite be automated for the routine proposed above, but should allow the pilot to manually select any of the systems if desired (refer to paragraph 2.3). Additionally, the pilot should be provided a single digit confidence factor on the HUD. The confidence factor scale would range from zero to five (0 - 5), with zero representing no confidence in navigational system accuracy and five representing an accurate mission capable system. Mid range numbers would be determined by human factors psychology and follow on testing. The number scale described above was selected since it is large enough to show navigational system degradation yet not so large as to require excessive pilot interpretation. Degradations in confidence level would be calculated by primary system crosschecks with ranges of single digit values being determined by flight test results. The confidence level display should be designed to communicate a warning to the pilot when it goes below a certain level established by flight test results. The warning should be both auditory and visual which would follow the fundamental design principal of MBE (refer to paragraph 1.6), ensuring pilot response during combat duress. The proposed system would provide pilots the confidence necessary not only to perform low level flight over rugged terrain but also the wherewithal to know when it is unsafe to do so.

In order to incorporate the system changes proposed above, the following individual components would be added to the aircraft: a RLG, a GPS control box and associated antenna, a TRN box, and a mass data store (contains DTED). The Rockwell GPS miniature 3M receiver proposed can be procured with an ARN-153 miniature TACAN (personal interview 8). This equipment combination is the same approximate size as and will fit into the space occupied by the currently installed ARN-118 TACAN (personal interview 8). This particular GPS-TACAN combination is currently being procured by the U. S. Air Force Space Division with navy participation and is advertised to meet the requirements of applicable Military Specifications (personal interview 8). Space for the additional units (RLG, TRN box and a mass data store) would be provided in the Engine Monitoring System (EMS) and camera compartments located on the starboard side of the aircraft as shown in appendix A, figure 15 and 16, and additionally in the port avionics bay as shown in appendix A, figure 17. The compartments incorporate the structural members necessary to support the weight of a shelf with the above equipment. It is desirable to additionally incorporate isolation mounts, small cooling fans or ram air hoses which would facilitate maintenance and further promote system longevity.

Installation would require routing new wiring and only minor drilling of holes in order to incorporate a shelf and isolation mounts. Utilizing the EMS compartment would require removal of the EMS box; however, the EMS could be temporarily reinstalled for any post maintenance checkflight in order to ensure continued engine health. GPS antenna installation would be required somewhere on the top of aircraft, with exact location to be determined via flight test antenna patterns. Cockpit control would be provided through incorporation of an Up-Front Control (UFC) (refer to paragraph 2.3).

2.2 TACTICAL COMPUTER SET

The Tactical Computer Set (TCS) is a preprogrammed digital computer designed to provide the pilot an interface for entry and display of data. An Operational Flight Program (OFP) must be programmed into the computer by ground personnel prior to operational use. The TCS with the installed OFP is designed to provide both automatic navigation information and computed weapons delivery when used in conjunction with the aircraft installed subsystems to include: IMS, Air Data Computer (ADC), Doppler Radar, and FLR. The TCS is designed to perform enroute navigation functions without ground based navigational aids. By design, the TCS includes a navigation capability in polar regions. Present position, ground track, range and bearing to selected destination, and lateral steering are by design continuously computed and presented as follows (reference 2, p. 8-51):

A. Present position: displayed on TCS control panel and on the PMDS.

B. Ground track, range, and bearing to selected destination: displayed on the HSI when Heading Mode switch is in AUTO NAV and also on the PMDS.

C Steering to selected destination: displayed on ADI when Heading Mode switch is in AUTO NAV and also on the HUD.

The TCS automatically switches from standard inertial navigation to polar grid navigation at latitudes greater than 72 deg with current fleet software (NWC-5). The TCS is designed to store different sets of destination coordinates and pilot marked coordinates. The AN/ASN-91(V) TCS will store nine sets of each type coordinates, while the AN/ASN-91A(V) TCS will store 18 sets of each type coordinates (reference 2, p. 8-51 and 56). The TCS control panel is used to access DATA parameters provided by the OFP program. There are three types of data parameters for pilot access which include: subsystem parameters used to control the TCS via the IMU, parameters used to permit the pilot to control functions in the OFP, and parameters which provide diagnostic readouts allowing the pilot to determine system status so as to troubleshoot systems. The TCS control panel provides the last computed wind velocity and direction data (reference 2, p. 8-67).

The TCS is located on the right-hand console as shown in appendix A, figure 18. Inflight use of the TCS panel to include the primary mission tasks of coordinate entry and selection of destination require the pilot to break scan and look down and right approx 90 deg from the primary Field-of-View (FOV) while switching hands from right to left on the control stick in order to free the right hand to input data into the TCS. This requirement to switch hands on the control stick and divert pilot attention away from the primary FOV in order to accomplish primary mission tasks is unsuitable for the already workload intensive environment of "All Weather" ingress and targeting transition. Therefore, ergonomic modification of the cockpit controls for pilot-computer interface is required for suitability of the "All Weather" mission (refer to paragraph 2.3).

2.3 UP-FRONT CONTROL

Most current tactical aircraft employ an Up-Front Control (UFC). A UFC, as installed in the F-18 is shown in appendix A, figure 19. A UFC is a panel located below the HUD which is within the primary FOV. A UFC incorporates a standard numerical keyboard along with function select switches which when depressed provide menus. In general, UFC menus mirror the functions which would be provided by the control panels for the individual systems (reference 17, p. 27). Although the TCS incorporates many of the features of the UFC, its large size and limited capability make it unsuitable for use as a UFC. The A-7 LANA incorporates its own UFC as shown in appendix A, figure 20. This UFC is not found in the A-7E. Neither the F-18 nor A-7 LANA UFCs are suitable to incorporate all of the proposed changes recommended herein. Yet, features of both could be utilized in a redesign for the A-7E. Required functions would include:

A. A means of selecting and updating destinations (DEST) and MARKs.

B. A means of inputting coordinates (either latitude and longitude or grid). Coordinates should remain illuminated for approximately 5 sec after entry so that the pilot can verify entry.

C. A means of accessing all navigation functions with a growth capability for new follow on navigation systems.

D. A means of performing enroute navigation updates.

E. A means of selecting all communications systems.

F. A means with which to access DATA functions. The data will be displayed for 10 sec unless the enter (ENT) key is depressed, at which time the data will remain displayed until clear (CLR) key is depressed.

G. A means of adjusting HUD brightness, reticle depression, selecting HUD on-off and selection of day-night display lightings.

H. A means of adjusting FLIR scene controls to include background level, raster brightness, contrast, on-off selection and polarity.

I. A means with which to remove unnecessary data from the display (DECLUTTER).

The HUD window will be utilized for display of information (refer to paragraph 2.7.2). Space with which to incorporate the newly proposed UFC would be created through the deletion of the existing HUD control panel. Development costs of the new UFC are justifiable in that incorporation would allow the A-7E to perform the "All Weather" attack mission.

2.4 FORWARD LOOKING INFRARED

2.4.1 Description

The Forward Looking Infrared (FLIR) is designed to provide the pilot the capability to conduct visual navigation and attack operations at night. The A-7E FLIR system utilizes an external wing-mounted pod on wing station number six along with the AN/ASN-91B(V) Navigation and Weapons Delivery Computer (NWDC), a modified Head-Up Display (HUD) as well as FLIR cockpit control and advisory lights. When the FLIR is operating the IR imagery and HUD symbology are designed to be combined and displayed on the HUD (reference 10, p. 3A-27).

The FLIR system provides two FOV modes (a wide FOV and a narrow FOV) selectable by a FLIR FOV switch located on the throttle grip. The wide FOV (WFOV) is designed to provide the maximum area detail considered necessary for TF, cloud avoidance and enroute search. The WFOV consists of a 12 deg circular view displayed on the 20 deg FOV HUD which results in a FLIR scene of 1.67 times magnification. The narrow FOV (NFOV) is designed for maximum range target acquisition with maximum target detail. The NFOV displays a 3 deg circular view on the 20 deg FOV HUD which results in a FLIR scene of 6.67 times magnification. With the FLIR WFOV selected, a corner bracket presentation is displayed on the HUD marking the approximate area of the FLIR NFOV display, if selected. The 1.67 magnification of the WFOV in combination with the depression angle in WFOV of only 6 deg in the FLIR-ON TF mode have been found to distort pilot perception of obstacle clearance in that obstacles will appear closer than actual with the perception of passing an obstacle seconds prior to actual passage. For example, at 360 kt ground speed and 500 ft Above Ground Level (AGL) a mountain peak disappears from sight 6 to 8 sec prior to passage in FLIR-ON TF (reference 10, pp. 3A-29 and 3A-34).

With aircraft weight off landing gear, the FLIR scene can be rejected and reselected by momentarily depressing the NWS switch. The SCENE REJ switch on the HUD control panel is designed to have priority over the NWS switch. Therefore, if the HUD SCENE REJ switch is out of the reject position when the FLIR is operating, the FLIR scene will not be rejected by depressing the NWS switch (reference 10, p. 3A-29).

The FLIR system is designed to place the aircraft boresight reference line (BRL) in parallel alignment with the FLIR boresight. The FLIR line-of-sight (LOS) is indicated by the FLIR crosshairs or the HUD aiming symbol (AS) both depicted in appendix A, figure 21. The FLIR crosshair position is aligned with the HUD raster display by a slew and designate sequence. The NWDC calculates the error in terms of azimuth and elevation angles. The pointing limits from the FLIR zero reference line are +/- 20 deg in azimuth and + 5 deg to - 35 deg in elevation. The LOS pointing errors are calculated by the NWDC after the slew and designate. Azimuth and elevation errors are addressable on the TCS control panel using. The displayed numbers are positive or negative in direction to the reference BRL. In the example of appendix A, figure 21, the FLIR would be slewed to the left and down to overlie the crosshair on top of the IR image of the boresight target. The signs of both slews would be negative. The alignment errors of the HUD AS and the IR image of the boresight target are observable and correctable by pilot realignment in the

HUD display. Three boresight alignment methods are available to include the long range FLIR boresight (LRFB), short range FLIR boresight (SRFB), and Narcissus Effect FLIR Boresight (NEFB) methods. The LRFB method uses a visual and IR significant target located several thousand feet in front of the aircraft located on azimuth with the aircraft standby reticle. The SRFB method uses a visual and IR significant target between 50 and 1,024 ft. The NEFB method is the most accurate using the reflected IR image from the FLIR detector array as the boresight target. The NEFB method requires a boresight fixture to be attached to the aircraft. The LRFB method can be performed on deck. The error introduced by this method is approximately 0.5 mil in each axis (reference 10, pp. 3A-30 and 3A-31).

There are four sub-modes of the FLIR-ON enroute navigation mode including Flightpath Marker (FPM) Stabilized, Snowplow, Ground Stabilized and FLIR Self-Contained (Back-up) Pointing. In the FPM Stabilized Mode, the FLIR LOS is positioned to point parallel to the aircraft velocity vector (FPM). The crosshairs are the LOS indicator. In the Snowplow mode, the FLIR crosshairs are slewed to the desired pointing angle. At the gimbal limits (5 deg travel both horizontally and vertically away from the FLIR LOS) the crosshairs disappear from the HUD as a visual cue. The FLIR gimbal depression angle is displayed in degrees on the HUD Vertical Velocity Indicator (0 deg to -40 deg from top to bottom). The ground stabilized mode is initiated by depressing the designate switch and the HUD AS will become coincident with LOS. The Back-up Pointing is mechanized in the FLIR hardware to position the FLIR LOS to 0 deg azimuth and -7 deg elevation in the event of a data channel failure. To enter the FLIR-ON navigation mode, the FLIR must be operational with navigation and weapons updates not selected. At the point of mode entry, the FLIR crosshairs appear on the HUD FPM stabilized with the slew and designate functions active. Navigational position updates can be performed with the FLIR operational using the HUD, radar, PMDS, TACAN, and flyover update options (reference 10, pp. 3A-30 and 3A-31).

The FLIR system includes a Terrain Following (TF) mode which was designed to provide the pilot the information necessary for performance of night low level target ingress and egress while minimizing the probability of early detection by enemy forces. The FLIR-ON TF system provides an IR HUD presentation to the pilot and otherwise utilizes the same equipment as the NON-FLIR TF system. FLIR-ON TF is to be utilized in WFOV and the FPM Stabilized mode so that the visual presentation minimizes magnification. The presentation of the FPM above the obstacle is designed to indicate safe aircraft clearance above an obstacle (reference 10, pp. 3A-34 and 3A-35).

2.4.2 FLIR Operation

The pilot should use AFCS to the maximum extent possible to aid in aircraft control during FLIR utilization. Altitude hold and NAV AFCS modes are stated to be extremely useful during target and attack phases (reference 10, p. 3A-36).

An A-7E fleet experienced aviator and test pilot (personal interview 4) stated that the current A-7E FLIR system is not conducive for successful operation during night ingress. His experiences elaborated the following issues as key areas of concern:

A. The FLIR pod is large and heavy requiring a parent weapons station. This reduces range and weapons loading.

B. Installation alignment must be performed at a shore facility. No alignment procedure was designed for carrier interface with the currently utilized pod. Consequently if a pod is removed on the carrier, the pod and the aircraft cannot be utilized for FLIR until alignment at a suitable shore facility is performed. Tight cruise schedules and limited facilities would probably result in negative FLIR installation for the pod and aircraft in question for the remainder of the cruise.

C Boresighting methods are not accurate on aircraft carriers. Reference 10 states that a pilot needs an easy, reliable and accurate boresighting method. Poor boresighting results in slow or negative acquisition of FLIR image checkpoint or target acquisition due to inappropriately displaced images from actual FOV. Since utilizing FLIR is like "looking at a target through a straw", it is imperative that the targets be close to where anticipated. A "tight" (accurate) INS can significantly assist here in FLIR checkpoint and target identification.

D. Reliability and maintainability of systems utilized at sea were poor. Older systems were definitively less reliable than newer systems. The Airborne Refrigeration Units (ARU) were noted to fail routinely.

E. The current FLIR installation is not good as a primary navigation and target identification system. At best, a ship combatant could be identified at 7 to 10 nm with actual ship determination not usually possible until approximately 3 nm.

F. The current FLIR installation is a "human factors nightmare" for combined switchology and system mechanization. Controls are somewhat dispersed and the system complicated. Numerous actuations of NWS had to be performed in order to achieve the desired FLIR mode, distracting the pilot from the primary task at hand, which for such low level flight is to fly the aircraft and maintain situational awareness. FOV selection as well as FLIR selection on the radar CRT required that the pilot divert scan from the primary FOV and in the latter case switch hands on the control stick.

G. WFOV magnification of the FLIR scene on the HUD was not 1:1 but 1:1.67. This WFOV magnification was noted to be not only vertigo inducing but also confusing to the pilot with respect to actual checkpoint and target location. It is not felt that any image magnification greater than 1:1 should be displayed on the HUD (personal interviews 2 and 4).

The A-7 Low Altitude Night Attack (LANA) aircraft utilizes a modified version of the current A-7E FLIR system. The A-7 LANA aircraft currently utilizes FLIR but does not utilize NVG in the performance of the "All Weather" attack mission over land. These modifications have been tested and are considered to be successful, with a high confidence level, for the shorebased "All Weather" attack mission (personal interviews 6 and 7). No concerns were expressed over shorebased boresighting as was cited for sea-based mission integration (personal interviews 6 and 7). It is recommended that the A-7E FLIR be modified as the LANA FLIR Pod to incorporate 1:1 magnification for the HUD WFOV FLIR scene (reference 18, pp. 6 and 11). Additionally, the A-7 LANA FLIR system utilizes only two modes; FIXED and SLAVED selectable by momentary actuation of the NWS switch. This is a more simplified approach to the four mode actuation of the A-7E FLIR and is recommended for integration into the A-7E (reference 18, p. 9). The A-7 LANA slew controller was modified by elevating it for improved access and installing a FOV pushbutton switch on the forward side. By continuously depressing the FOV switch the pilot commands the NFOV and SLAVED pointing. Releasing the switch returns the FOV to the previously commanded WFOV FLIR scene. A steady lock can be commanded on the NFOV scene by double actuation of the switch within 0.6 sec. Actuation of the switch once again returns the FOV to the previously selected WFOV FLIR scene (reference 18, p. 12-13). Although it is not optimal for the pilot to have to remove his hand from the throttle and reach for another control device in order to slew the FLIR and RADAR, the pilot-machine interface was not noted to be significantly jeopardized in the A-7 LANA aircraft. Since NVG were not tested utilizing this configuration, further study is required. Newer designs of single-seat night attack aircraft than the A-7E (such as the F-18 and AV-8) incorporate a Target Designator Controller (TDC) Hands on Throttle and Stick (HOTAS) system.

Target acquisition utilizing FLIR without use of a radar requires accurate target coordinates, good inertial navigation, and an accurate navigation update as close to the target as possible (references 14 and 15). The use of a close Offset Approach Point (OAP) to the target assists in accurate FLIR cueing to the target. Procedures for this type of attack include (reference 10, p. 3A-36):

A. Update Navigation

B. Select Navigation Steering to OAP

C Select (Bomb on Coordinates) BOC Offset

D. Immediately transfer to NORM ATTACK OFFSET

E. Designate OAP for FLIR acquisition of OAP

Performance of the FLIR target acquisition procedures above requires that the pilot perform five significant tasks, the first of which requires numerous subtasks for completion. Additionally, completion of the remaining tasks requires the pilot to access controls which are remotely located from each other and also requires more than one step for task completion. The result is a process which remains cumbersome (even after practice) with performance required when pilot workload is already extremely high (personal interview 2 and reference 12). Consequently, target acquisition needs to be by another means with FLIR only as a back-up for confidence level (personal interview 4).

The problems associated with sea based FLIR alignment following installation, coupled with difficult maintenance, poor reliability and inaccurate boresighting negate FLIR from being a primary means of navigation (personal interview 4). FLIR is desirable as a back-up mode; specifically for the identification of point targets and additionally for other features which might not be incorporated on maps. Since the A-7 LANA FLIR system is less complex yet as capable as the A-7E FLIR installation, the A-7 LANA system modifications including the slew controller FOV switch should be incorporated into the A-7E. Ideally, the attack pilot should be provided a three dimensional depiction of the terrain for obstacle avoidance (personal interview 5), with a superimposed FLIR display for point target thermal signature acquisition. The Ferranti International PENETRATE TRN (refer to paragraph 2.3) provides HUD options which are designed to be utilized as a primary means of navigation. Figures 22 through 25 illustrate these various terrain enhancement options. The PENETRATE TRN system is currently undergoing Navy evaluation. A study should be made in order to determine the feasibility of superimposing FLIR on the TRN displays for point target thermal signature acquisition. System control would be via the UFC (refer to paragraph 2.3), the designate switch on the flight control stick and the slew controller. With the implementation of a TDC, the FLIR FOV switch should be incorporated into the throttle. Although major work would be required for system integration (refer to paragraph 2.1.3), the systems should be implemented following successful test completion.

2.5 RADAR

2.5.1 General Description

The A-7E incorporates the AN/APQ-126(V) radar set, a J-band pulsed radar engineered with elevation and monopulse capabilities. The radar set is designed to operate in eleven modes to include:

A. Beacon (BCN)

B. Terrain Avoidance (TA)

C. Ground Map Pencil (GMP)

D. Ground Map Spoiled (GMS)

E. Air-to-Ground Ranging (AGR)

F. Air-to-Air Ranging (A/A)

G. Combined Terrain Following and Ground Mapping (CSGMP)

H. Combined Terrain Following and Terrain Avoidance (CSTA)

I. Terrain Following (TF)

J. Shrike Improved Display (SIDS)

K. Television Display (TV)

The radar set components include an antenna scan power supply-programmer, radar transmitter, antenna-receiver, air navigation computer, radar set, sweep generator, radar set fault indicator, air navigation multiple indicator, terrain clearance and range control set, electric equipment shock mount base and a centrifugal fan. The integrated components were designed so as to permit detection of targets at altitudes equal or above aircraft altitude as well as to provide accurate range information of clutter type targets (reference 12, pp. 62-63). Displays for the various modes are designed to appear in a digital scan presentation on the radar scope located on the main instrument panel as shown in appendix A, figure 26. Descriptions of the modes of operation applicable to ingress will follow. Detailed descriptions of other modes not discussed herein are provided in references 2 and 10.

The TA mode is entered by selecting TA on the radar control panel. In TA, the radar scans +/- 45 deg to each side of the ground track and displays all terrain at or above the aircraft altitude. In TA, climb and dive commands by design are not presented on the ADI or HUD. The TA mode was designed for 5 and 10 nm selectable ranges only (reference 2, p. 8-120). In TA, the preset receiver gain is designed to prevent inadvertent missing of terrain returns due to reduced manual gain. The antenna is designed to be stabilized in pitch, roll and drift. By design, nose-up attitudes should not cause the target to disappear until the aircraft is above the terrain. The FAIL light on the radar scope shown in appendix A, figure 26 is designed to come on in the event of a radar component malfunction. The TA mode display and operating characteristics are shown in appendix A, figure 27 (reference 2, pp. 8-116 and 8-120).

The ground map spoiled (GMS) mode is entered by selecting GMS on the radar control panel except when TF, NORM ATTACK, or NORM ATTACK-OFFSET are selected on the master function selector. (reference 2, p. 8-120) The GMS mode was designed for use at higher altitudes for the performance of medium range mapping. GMS was also designed for use in situations where target resolutions are not critical, such as locating land-water contrast or other prominent geographical features. The GMS mode is designed using horizontal polarization which enhances mapping performance of horizontally oriented targets more than vertically oriented targets. The GMS mode utilizes a cosecant squared shaped beam pattern displayed +/- 45 deg of ground track. The radiated pattern was designed for ground mapping optimization at a 35 nm range at 40,000 ft MSL. For all settings of the antenna tilt control, the antenna is designed to be depressed 7 deg lower than the corresponding position for the Ground Map Pencil (GMP) mode in order to maximize the energy point in the shaped beam. If a target can be identified in GMS mode, the GMS mode is preferable to GMP since less adjustments are required for antenna tilt. A HOLD function is available in the GMS mode. HOLD is designed to stop the display from updating in order to allow the pilot to study the target to cursor relationship as well as identify specific targets. When switching to NORM from HOLD, the display is designed to erase with current video and cursor information displayed on the next antenna scan. The GMS mode display and operating characteristics are shown in appendix A, figure 28 (reference 2, p. 8-120).

The Ground Map Pencil (GMP) mode is entered by selecting GMP on the radar control panel as shown in appendix A, figure 29. GMP is designed to be used for long range mapping or for improved resolution of point targets at low altitudes within the limits of antenna tilt. The GMP mode utilizes a narrow pencil beam displayed +/- 45 deg of aircraft ground track. The narrow pencil beam is designed to provide good resolution of point targets. The antenna tilt (+ 5 deg to -15 deg) shown in appendix A, figure 26 should be utilized to raise or lower the beam for obtaining an optimum display of the terrain. The HOLD function available in GMS is also available in GMP (reference 2, p. 8-121).

The combined Terrain Following (TF) and TA mode is referred to as the Cross Scan Terrain Avoidance (CSTA) mode. CSTA is entered by selecting the TF master function selector and the TA mode on the radar control panel. The combined utilization of TF and TA in the APQ-126(V) radar is designed to provide the necessary information for flight within rough protruding terrain at preselected terrain clearance altitudes. The radar presentation in TA is designed to display terrain obstacles at or above the aircraft altitude within +/- 20 deg of ground track. TF information is designed to be simultaneously presented on the ADI and HUD. Designed range selection is 5 or 10 nm. Manual antenna tilt is not available in this mode. The CSTA mode display and operating characteristics are shown in appendix A, figure 30 (reference 2, p. 8-121).

The combined TF and ground mapping mode is referred to as the Cross Scan Ground Map, Pencil (CSGMP) mode. CSGMP is entered by selecting the TF master function selector and GMP on the radar control panel (reference 2,

p. 8-121). CSGMP is designed to provide TF with a GMP presentation. As with CSTA the azimuth scan is likewise reduced in CSGMP to +/- 20 deg of ground track in order to allow sufficient time for TF cross scan. The TF information is designed to be displayed on the ADI and HUD. Antenna tilt utilization is designed to be provided in this mode for spotlighting ground mapping areas of interest. The HOLD feature is also available for use with this mode. The CSGMP mode display and operating characteristics are shown in appendix A, figure 31 (reference 2, pp. 8-121 and 8-122).

The TF mode is entered by selecting the TF master function selector and any radar operating mode except TA or GMP. In the TF mode, terrain following information is designed to be provided on the horizontal pointer of the ADI, on the HUD and on the radarscope. The TF presentation is designed to provide the pilot sufficient information to readily enable him to maintain the preset altitude above the terrain. The desired clearance altitude is set with the Terrain Clearance thumbwheel on the main instrument panel as shown in appendix A, figure 26. The TF set clearance tolerances are -50 to + 75 ft at 200 ft AGL with a minimum peak clearance of 135 ft AGL (reference 2, p. 8-123). In the TF mode, the radar antenna is designed to alternately scan vertically and horizontally in order to provide the required azimuth coverage. The TF mode display and operating characteristics are shown in appendix A, figure 32 (reference 2, p. 8-122).

2.5.2 Operation

2.5.2.1 Maximum Detection Range

Reference 12, p. 17 includes a recent maximum detection range evaluation of the APQ-126(V) radar. The evaluation was performed in the GMP mode during flight over land from 500 ft AGL to 10,000 ft MSL at 360 KIAS. The evaluation demonstrated a maximum detection range of 2 nm at 500 ft AGL for small point targets (tank and a transport aircraft on deck). The small maximum detection range of 2 nm would only allow approximately 10 sec for the pilot to identify and designate the target (reference 12, p. 17). To ensure sufficient time for target identification, designation and accurate weapons delivery, the pilot should be provided significant target information by 10 nm from the target (personal interviews 3 and 4). The severely limited maximum detection range of the APQ-126(V) radar is widely recognized. The A-7 LANA has incorporated some modifications to the APQ-126(V) for improved ground mapping (reference 18, p.15). The modification was to the APQ-126(V) antenna-receiver for the purpose of increasing the dynamic range and likewise the signal strength to the Digital Scan Converter (DSC). The radar modifications provided adequate results (personal interview 7); however, the Navy would need to test the radar modification to determine suitability. Upon successful testing, it is recommended that the LANA APQ-126(V) modifications be incorporated into the A-7E APQ-126(V) radar system. Testing would have to be comprehensive including both descript and nondescript terrains and various manmade obstacles like towers, power lines, phone wires, etcetera (personal interviews 2 and 4). The PENETRATE TRN system incorporates a Digital Map Generator (DMG) module. The DMG module provides two dimensional overlays for navigation and threat avoidance and three dimensional overlays which use elevation data computations for terrain masking depiction (reference 8, p. 9). The TRN digital map displays are advertised to provided visual cueing and warning to pilots of small, difficult to discern obstacles such as power lines and towers (reference 8, p. 9). (refer to paragraph 2.6.2 for more detailed information on the DMG) Utilizing the radar in a "complementary" manner to crosscheck map position on a periodic basis would serve to improve pilot confidence factor. "Complementary" interface between all provided cockpit indicators and displays is required so that the pilot can maintain the desired tactical situational awareness necessary for successful and safe mission completion (personal interview 2).

2.5.2.2 Narrow Scan Angle

Reference 12, p. 17 includes a recent narrow scan angle evaluation of the APQ-126(V) radar. The evaluation was performed in the CSTA mode during terrain following flight at 200 ft AGL and 360 KIAS. The narrow scan angle was determined to be +/- 20 deg of aircraft centerline. While performing low level terrain following flight during these tests, the limited narrow scan angle inhibited identification of obstacles in the turn (reference 12, p. 17). The A-7 LANA APQ-126(V) radar has increased antenna turn lead to allow a 1.5 deg/sec turn rate in the TF mode. Additionally, the turn rate forced fly-up command was disabled and replaced by a computer controlled HUD window "TURN LIM" display. A turn limit advisory light was also incorporated. Both indicators appear with the A-7 LANA radar if the turn rate exceeds 1.6 deg/sec continuously for a period of approximately 3 sec (reference 18, p. 19). The A-7 LANA TF antenna turn lead is shown in appendix A, figure 33. Confidence with using the A-7 LANA radar in low level instrument conditions has been expressed (personal interview 7). It is recommended that the Navy test the A-7 LANA radar modifications in the A-7E and upon a successful evaluation, incorporate these modifications into the fleet. Having a system which was "smart" on the terrain local to the aircraft is ideal (personal interview 3). The TRN system is designed to incorporate such a picture of the aircraft local flying environment. Unlike TF radars, the TRN system is designed to know what exists behind the upcoming hills and terrain. Since the TRN system would be "smart" on local terrain, turn rate by design need not be limited as required with current radars. Such terrain knowledge would provide the pilot maximum opportunity to take advantage of terrain masking while ensuring obstacle avoidance. TRN systems are available for installation and testing. It is recommended that the Navy test the TRN system and incorporate TRN into the A-7E upon successful testing (reference 8, p. 9), (refer to paragraph 2.1.3).

2.5.2.3 Wide Scan Angle

Reference 12, p.17 includes a recent wide scan angle evaluation of the APQ-126(V) radar. The evaluation was performed in the Ground Map Pencil (GMP) mode during low level flight at 200 ft AGL and 360 KIAS. The wide scan angle of the APQ-126(V) was determined to be +/- 40 deg of aircraft centerline.

During the evaluation, the limited scan angle delayed verification of the correct IMS cursor placement for IMS updates. Similar delays could be experienced during weapons delivery while attempting to designate offset aimpoints (OAPs) (reference 12, p.17). A proposed solution is discussed in paragraph 2.5.2.4.

2.5.2.4 Slew Controller

Reference 12, p. 17 includes a recent slew controller evaluation of the APQ-126(V) radar. The slew controller was evaluated for functional utility during both ground and flight phases of testing. The radar slew controller is shown in appendix A, figure 34. The slew controller was a two axis positioning device, designed to enable radar cursor placement. Forward movement of the slew controller decreased cursor range and aft movement of the slew controller increased radar range. During the evaluation, the operator noted the cursor displacement to be 180 deg opposite to that desired resulting in inadvertent displacements of the radar cursor from the desired target, delaying target designation (reference 12, p. 15). Operation of controls in the combat environment needs to be natural and as procedurally simple as possible (personal interview 5). Reference 19, p. 877 states that "people expect that when they move a vehicle control to the right or clockwise, the vehicle will move in that direction." In the situation above the vehicle by definition is the cursor. The apparent reverse sensing of the slew controller should be changed so that forward motion of the slew controller results in the cursor moving forward and aft movement of the slew controller results in the cursor moving aft. Correction would require minor rewriting of software.

The slew controller was located approximately one foot forward of the throttle on the left-hand console. The location of the slew controller required that the pilot remove his left hand from the throttle and reach forward to grasp the slew controller. This action required approximately 1 sec. Reference 19, p. 586 states that "to reduce operator fatigue and/or to improve control operation performance, locate the most frequently used or continous-operation controls where they are most convenient for the operator." A Target Designator Controller (TDC) on the throttle optimizes radar slewing since it provides the pilot an immediate access to slew cursors without displacement of hands from the primary stick and throttle controls. (reference 28) TDCs are widely used on modern tactical aircraft. The throttle incorporated TDCs utilized in the AV-8 Night Attack airplane and the F-18 are presented in appendix A, figures 35 and 36. It is recommended that a similar TDC arrangement be incorporated into the A-7E. This would require a new throttle incorporating the TDC and associated wiring to interface with navigation and weapons systems. The A-7 LANA has modified the slew controller by elevating it 2.1 in above the console in order to improve accessibility and eliminate interference with adjacent controls (reference 18 p. 12). It is recommended that the A-7 LANA slew controller improvement be evaluated by the Navy and incorporated as an interim improvement in the A-7E until a TDC can be designed and incorporated.

2.5.2.5 Radar Displays

It is unquestionable that provision of the maximum amount of primary visual information to the pilot is optimal (personal interview 5). The PENETRATE TRN system incorporates a series of display choices designed to simulate primary visual information. Several of the displays provide the pilot significant terrain perspective information heads-up on the HUD. Other displays require a heads-down presentation (reference 8, pp.13-19). Appendix A, figure 26 shows a detailed picture of the radar display and switchology interface in the A-7E. Note that the A-7E currently incorporates no Digital Display Indicator (DDI). DDIs are installed for radar presentation and switchology ease of use on nearly all tactical aircraft designs since the A-7E. DDIs provide a clean, organized pilot interface with the radar display. Pictures of AV-8 Night Attack airplane and F-18A DDIs are shown in appendix A, figures 37 and 38. It would be desirable to incorporate a similar display box in the A-7E. The Ferranti International PENETRATE TRN system utilizes a DDI as shown in appendix A, figure 39. Any of the DDIs mentioned would be of acceptable size for incorporation into the A-7E and would require only minor panel modifications using the present cockpit layout configuration. Major rewiring would be required to interface all navigation, radar, computer and display units. Switching hands on the control stick from right to left at low level in order to operate a radar scope or other equipment on a tactical low level ingress is not desirable, placing the aircrew in a nonadvantageous environment for ground collision avoidance (personal interview 4). DDI installation in the AV-8 night attack aircraft required analog instrumentation position shifts in order to allow operation using the left hand, allowing the pilot to normally fly the aircraft with his right hand. Such a change of instrumentation would require an instrument panel redesign and a major wiring change. The currently installed A-7E instrumentation could essentially be shifted from the left side of the panel to the right side of the panel. Map and radar displays could be shifted from the current right side of the panel to the left side of the panel. It is a reasonable assumption that an A-7E design could be developed and incorporated.

2.5.2.6 Terrain Following

Reference 12, p. 22 included a recent evaluation of the manual TF mode using the APQ-126(V) radar. Nominal 100 ft hills were detected at an average of 10 nm. Radio towers and power lines were detected at a maximum of 1 nm. During the above evaluation, detection of radio and power lines occurred less than 50% of the time. The limited detection capability of the APQ-126(V) radar in the TF mode could result in the aircraft impacting radio and power lines during TF flight without back-up visual cues. As previously stated, the TRN system is designed to know what is behind the next hill, providing the pilot improved information for increased pilot confidence. TRN is designed to enhance pilot capability in following contours in rough terrain (reference 8, p. 9). Automatic TF can be incorporated by coupling the TRN flight director to the flight control system. Precise navigation to within a few tenths of meters is required to safely perform "All Weather" ingress (personal interview 3 and reference 8, p. 8). TRN is designed to provide this capability while remaining covert. It is recommended that the Navy test TRN in an A-7E prototype for possible incorporation into A-7E fleet aircraft. Space exists in the A-7E aircraft for the required TRN modules in the EMS and camera compartments (refer to paragraph 2.1.3) (personal interview 7). TRN is being considered for future integration into the A-7 LANA (personal interview 7).

The A-7 LANA has modified the current radar and flight control systems and interface to accommodate Automatic Terrain Following (ATF) similar to the F-111 (personal interview 7 and reference 18, p. 15). In order to engage the LANA ATF system, the FLR TF and either AFCS control augmentation or attitude must be selected. The A-7 LANA has modified cowl switches to accommodate ATF as shown in appendix A, figure 40. By pressing the ATF cowl switch, the ATF mode is engaged and the upper segment of the ATF switch illuminates to advise the pilot that the system is selected. The FLR TF computer provides the TF climb and dive g command inputs. The system incorporates a safety feature by synthesizing a redundant TF command within the ATF coupler using raw FLR TF climb-dive data. The duplicate command is summed with normal acceleration and a roll attitude term. The duplicate command output is continually compared to the ATF command by a monitoring circuit. Should a disagreement is commands occur, the ATF is designed to disconnect and climb (reference 18, pp. 21-23). The LANA ATF integration has been successful and is considered to be reliable for "All Weather" ingress (personal interview 7). It is recommended that the Navy incorporate the A-7 LANA ATF modification for testing. Upon successful testing, TF should be integrated into the A-7E as a interim primary system and back-up system to TRN. The A-7 LANA ATF modification is not covert and is still restricted to the limits of the FLR. It is recommended that the Navy integrate and test the TRN ATF with the flight control coupling mentioned above into a prototype. Space exists for TRN modules as previously specified (refer to paragraph 2.1.3). The AFCS aircraft modifications should be transferrable within the current space allocate. Upon successful testing ATF should be incorporated into fleet A-7E aircraft.

2.6 PROJECTED MAP DISPLAY

2.6.1 Description

The AN/ASN-99 Projected Map Display Set (PMDS) consists of a display unit located on the right side of the main instrument panel as shown in appendix A, figure 41. The PMDS displays continuous visually depicted aircraft position information on a full color projection using white light of standard aeronautical charts to include scales 1:500,000 and 1:2,000,000 which are 25 nm and 100 nm diameter pictures respectively. The PMDS is dependent on the TCS and IMS for aircraft position information. The aircraft ground track is shown by the grid lubber line and read from the peripheral compass rose. A map decenter feature is selectable by a push button on the display border. Two map display orientations are selectable on the PMDS mode selector to include the aircraft track (NORM) or north upward (N UP). The PMDS adjustment controls are located about the perimeter of the the scope as shown in appendix A, figure 41 (reference 2, p. 8-146).

2.6.2 Utility

The PMDS utility was evaluated qualitatively for information provided and ease of use. The PMDS continuously displayed airplane position on the full color projection of the standard Defense Mapping Agency charts. The decentering feature for relocation of aircraft position from the center to the bottom of the display was a helpful aid in correlating radar display data. Range to destination was continuously displayed (reference 13). Since white lighting is not compatible with NVG the PMDS currently installed in the A-7E would have to be secured in order to utilize NVG (personal interview 2). Other than when NVG were worn, the PMDS displays were easily visible and provided the pilot with easily accessible position information (personal interviews 2 and 13).

The PENETRATE TRN system incorporates a Digital Map Generator (DMG) module. The DMG module provides two dimensional overlays for navigation and threat avoidance and three dimensional overlays which use elevation data computations for terrain masking depiction as shown in appendix A, figures 42 and 43 (reference 8, p. 9). The TRN digital map incorporates the features of conventional maps with the enhanced capability of highlighting particular features by changing the color. This capability is designed to aid in discrimination between similar shaped features such as power lines and railways and to declutter the map picture (reference 8, p. 9). The terrain elevation colors are designed to be modified according to aircraft tactical altitude to provide the pilot immediate information on ground collision avoidance (reference 20, p. 3-6). The DMG is also designed to provide the pilot the option of displaying the map located at remote points allowing inspection of waypoints enroute (reference 20, pp. 3-6). The single seat pilot needs the maximum amount of information in primary cues provided in the simplest manner possible (personal interview 5). The DMG maps better provide primary visual information on terrain collision avoidance and threats local to the aircraft. The Navy should incorporate the TRN in a prototype A-7E for testing. Space exists for incorporation of the required TRN modules as specified in paragraph 2.1.3. Upon successful testing, integration into fleet A-7E aircraft is recommended.

The F-18 incorporates a Digital Map System (DMS) which is NVG compatible (reference 21, p. 7-8). Although the map does not provide the color contrasts and terrain enhancement features of the TRN, it would be a desirable aid for night attack using NVG. Implementation of the DMS would require software modification and a hardware exchange with the current PMDS hardware. Since the F-18 DMS has already been tested and incorporated into fleet aircraft, incorporation of a similar device would minimize design costs and testing requirements. The author recommends incorporation of a DMS similar to the F-18 into a prototype A-7E. Upon successful testing, follow-on integration into fleet aircraft is recommended.

2.7 HUD

2.7.1 Description

The A-7E currently incorporates the AN/AVQ-7(V) Head-Up Display (HUD) as shown in appendix A, figures 44 and 45. The AN/AVQ-7(Q) HUD is an optical-electronic device designed to project attack and flight information onto a combining glass within the pilot FOV. The combining glass used in the A-7E has two positions referred to as fore and aft. The forward position was designed for utilization during enroute navigation while the aft position was designed for utilization during attack and landing. The HUD symbols are formed on a Cathode Ray Tube (CRT) and focused on the combiner glass via a series of collimating lenses. A standby reticle is incorporated for use in the event of a HUD failure. The designed total HUD FOV is 20 deg as shown in appendix A, figure 46. HUD symbology is designed to be mixed with FLIR video for a composite display on the combiner glass (reference 2, p. 8-137).

2.7.2 Utility

A 20 deg HUD FOV is considered to be insufficient for the "All Weather" attack mission (personal interviews 2 and 4). A 30 deg total HUD FOV is considered to be an acceptable design standard with more FOV desirable pending progression in HUD technology (personal interviews 2 and 4). The F-16 Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) incorporates a 30 deg total FOV, wide angle, conventional optics HUD system as shown in appendix A, figure 47 (reference 22, p. 3-19). The F-16 LANTIRN HUD navigation symbology is shown in appendix A, figure 48 (reference 22, p. 4-202). The A-7 LANA HUD is a conventional optics HUD system consisting of a Display Unit (DU) and an Interface Unit (IU) as shown in appendix A, figure 49. The A-7 LANA HUD FOV is shown in appendix A, figure 50. The DU is designed to interface with the IU, converting electrical signals from the IU into visual symbols and video. The IU is designed to provide symbol generation, computation processing and synchronization. The video outputs of the IU are designed to continually be mixed with display symbology (reference 18, p. 31). The A-7 LANA HUD window utilization is shown in appendix A, figure 51. The A-7 LANA HUD navigation symbology is presented in appendix A, figure 52. The A-7 LANA HUD FLIR symbols are presented in appendix A, figure 53. The A-7 LANA HUD TF command symbols are presented in appendix A, figure 54. The A-7 LANA HUD TF warnings are presented in appendix A, figure 55 (reference 18, pp. 35-40). The F-16 LANTIRN HUD is considered the most state of the art HUD in active tactical aviation (personal interview 3). Incorporation of the F-16 LANTIRN HUD is recommended since it accommodates the minimum FOV considered acceptable by fleet pilots (personal interviews 2 and 4). The A-7 LANA HUD displays have received favorable comments from pilots (personal interview 7) and are recommended for integration into the A-7E. Since the A-7 LANA and A-7E are similar airframes, integration should be without consequence switching the previous HUD component boxes for the new HUD component boxes. It is recommended that the Navy acquire the F-16 LANTIRN HUD and A-7 LANA HUD flight test results from the Air Force and perform some additional tests to ensure adaptability to low level ingress from the carrier. Upon successful flight testing, integration into the A-7E fleet is recommended.

2.8 NIGHT VISION GOGGLE COMPATIBILITY

2.8.1 General

One of the most significant break throughs within the past decade in the area of "All Weather" attack suitability was the advent of Night Vision Goggles (NVG). NVGs are designed to provide the pilot a VMC type flight capability in near total darkness through amplification of ambient light in the red and near infrared wavelengths (reference 23, p. 2-1). Light which is enhanced to produce a picture of the outside world falls within the range 600 to 900 nanometers (reference 24, p. III-24). Incandescent lamps or any other light emitters above approximately 525 nanometers (green light output) are a major problem and will cause "blooming" as shown in appendix A, figure 56 (reference 24, p. III-24). Excessive light from "blooming" or other sources causes the NVG to execute a protective shutdown (reference 24, III-24). As with all pre-NVG designed aircraft, the A-7E has a cockpit NVG compatibility problem. This problem and proposed solutions will be discussed in paragraph 2.8.2. Another problem is selection of the optimal NVG for the mission and cockpit interface. Several NVG devices currently exist and will be discussed further in paragraph 2.8.3.

2.8.2 NVG Cockpit Interface

Lighting is the primary consideration of a successful NVG cockpit interface (reference 25, p.1-1). In order to use NVD, "the interior aircraft lighting must be turned off, taped over or modified with various techniques to provide degrees of compatibility, while simultaneously providing the aircrew member the capability to see the instruments with the unaided eye" (reference 25, p.1-1). Two possible solutions used to provide NVG compatibility are either to provide light that is goggle compatible or to filter light so that it becomes goggle compatible (reference 24, III-25). The A-7E currently incorporates the traditional red integral-flood lighting with white flood lighting optional. An example of unfiltered red light "blooming" is shown in appendix A, figure 57. The PMDS display as mentioned previously (paragraph 2.1.6.1) utilizes a white lighting background. An NATC TH-57A specially modified for NVG compatibility through the use of blue and blue-green filters was evaluated in flight. No NVG compatible integral lighting was incorporated. Flood lights were noted to cause excessive glare off the windscreen, unnecessarily limiting visual acuity. Flood lights additionally were noted to cause shadows on instrumentation in the cockpit, making numerous essential guages difficult to read and on occasion totally unreadable. Filters were successful in masking most non-NVG compatible lighting; however, "blooming" was still a problem permitting excessive light in the cockpit and blurring frequencies and other numbers so that they were unreadable. In contrast, an NATC CH-46E specially modified with integral NVG blue-green and ANVIS yellow lighting was ground evaluated at night. The integral lighting permitted very low light levels in the cockpit, maximizing visual acuity. With integral lighting, all guages were as easily readable from the pilot position in the cockpit as during daylight conditions. Ideally, the solution to NVG compatibility in the A-7E would be to redo the cockpit in all integral NVG compatibility lights. A total NVG compatible light integration is quite impractical in that it would require procurement of new cockpit instrumentation as cockpit instruments currently incorporate integral red lighting. The most practical and cost effective solution is to modify the instruments with an add-on NVG compatible bezel. The Control Products Corporation advertises "LUMICON-PLUS" for this purpose. They advertise compliance of "LUMICON-PLUS" with NVG military specifications. A lumicon is a patented internal lighting system which utilizes a unique approach to distributing light across the full face of each instrument. The lumicon principal of operation is based on Newton's Rings Theory, determining a focal point and establishing a theoretical section of a cone. It is this principal which allows light to be distributed in equal intensity across the full face of the instrument regardless of size, configuration or voltage utilized (reference 26). Appendix A, figures 58 through 60 show a successful lumicon integration.

2.8.3 NVG Devices

An NVG is an Image Intensifier (I^2); an electronic device that amplifies light. The light enters the I^2 device where it is focused by the objective lens onto a photocathode that is receptive to visible and near infrared radiation. The photons emitted from the light striking the photocathode are designed to cause a release of electrons proportional to the amount of light projected through the lens. The power source for the I^2 is used to produce an electric field to accelerate the electrons away from the photocathode surface. The light produced by the I^2 photocathode tube is proportional to the number and velocity of the electrons that strike the incorporated phosphor screen. Voltage is applied between the photocathode and the phosphor screen in order to enhance electron acceleration and brighten the projected scene (reference 27, p. 2-2).

Object acquisition and identification during ingress and targeting transition is related to ambient light levels, visibility, and contrast between the object and its background (reference 36, p. 2-15). Some of the major variables which affect the ability of the pilot to see with NVG devices include: (reference 27, p. 2-15)

A. Type of NVG device.

B. Condition of aircraft windscreen.

C Age and condition of device components.

D. Moisture content in the air (humidity).

E. Individual pilot proficiency and capabilities.

F. Proper care and maintenance of the NVG device.

G. Capabilities of infrared band-pass filter used.

H. Visibility (haze, fog, rain, low clouds, dust, smoke).

I. Cockpit lighting color and installation.

NVG device selection will be discussed below.

AN/AVS-6 devices are "straight through" viewing devices. AN/AVS-6 are generally used by helicopter pilots (reference 25, p. 2-2). The author is shown wearing AN/AVS-6 devices in appendix A, figure 61. Under ideal conditions, AN/AVS-6 devices improve visual acuity from approximately 20/200 to 20/40 (reference 27, p. 2-7). Since modern tactical jet aircraft are equipped with both head-up and head-down displays, NVG called "Cats Eyes" have been developed. "Cats Eyes" incorporate a clear glass combiner eyepiece in front of each eye allowing the pilot to view the electro-optic image from the I^2 tubes and view as desired the cockpit displays. Appendix A, figure 62 shows an abstract drawing of a pilot wearing "Cats Eyes" and appendix A, figure 63 shows the "Cats Eyes" concept of direct view goggles (reference 25, p. 2-2). "Cats Eyes" designs are generally optimized for the ground attack mission (reference 25, p. 2-2). The GEC Avionics study on "Cats Eyes" itemized the following advantages to "Cats Eyes" utilization: (reference 25, p. 2-7).

A. Cockpit monitoring is much easier since pilot cockpit scan remains natural, either looking around or through the combiner glasses.

B. "Cats Eyes" are designed to be fully compatible with all types of HUDs, including holographic HUDs. The pilot should see HUD imagery directly with no loss of resolution.

C "Cats Eyes" are compatible with all types of head-down displays, including color cathode ray tubes (CRTs).

D. "Cats Eyes" are compatible with spectacles and Nuclear Biological Chemical (NBC) respirators, and can be used with a modified visor.

E. Pilot orientation is improved with "Cats Eyes" over other NVG devices because of the unique direct and peripheral vision capability of the devices.

Utilization of the "Cats Eyes" NVG device for the A-7E "All Weather" attack mission is recommended. The recommendation for use is limited to night VMC as it would not be helpful in an IMC environment and unnecessarily contribute to pilot fatigue. Additionally, "Cats Eyes" pose a problem since they are not ejection compatible, requiring removal prior to ejection (reference 25, p. 5-27). "Cats Eyes" are recommended for this reason only as an interim solution to the night VMC problem. The integrated helmet night vision system (INVIS) referred to as INVIS is in the design and testing phase. INVIS should eventually replace the present NVG design. INVIS will not only provide enhanced visual acuity with the helmet mounted display (HMD) but also ejection compatibility since the intensifier tubes and combiner elements will be housed directly in the helmet as shown in appendix A, figure 64 (reference 25, p. 5-28). The most significant gain by pilot utilization of a HMD is off-boresight acquisition and target updates allowing the pilot to fly an offset for a navigation update. The INVIS HMD will eliminate the need for not only NVG devices but also HUDs. Expanding the HUD FOV optimizes current technology; however, HUD systems still limit the pilot to approximately 2 percent of the outside viewing area. With an incorporated INVIS capability, the pilot would be provided the HMD wherever he looked "dramatically increasing ACM effectiveness and surface attack situational awareness (SA)" (reference 28, p. 91). The INVIS type helmet is considered to be the best tactical system integration to pursue at this time, giving the "biggest payback in mission effectiveness for the costs involved" (reference 28, p. 91). When operational, INVIS integration into the A-7E should be studied.

3 SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND IMPLICATIONS

3.1 SUMMARY

Due to lengthy procurement times and budget cuts, fleet aircraft service lives are being significantly extended. The A-4, for example, will be extending its service into the year 2000 for a service life of approximately 50 years. In order for the A-7E to successfully perform its mission into the next decade, the A-7E must be transformed into an "All Weather" attack airplane.

The A-7E is not acceptable in its current configuration for "All Weather" attack ingress and targeting transition. The A-7E can be successfully modified for this mission; however, major systems modifications to the inertial system, FLIR, FLR, PMDS, HUD and associated cockpit human factors are required. A summary of the recommended modifications are as follows:

A. A "complementary" integration and utilization of RLG, GPS, and TRN with a confidence factor display to replace the current IMS is recommended.

B. It is recommended that a UFC be designed and incorporated with the specifications described herein.

C. It is recommended that the A-7 LANA FLIR modifications be incorporated and that the possibility of FLIR overlay on TRN displays for point target acquisition be researched.

D. It is recommended that TRN be tested for covert "All Weather" navigation with radar crosscheck.

E. It is recommended that the A-7 LANA radar modifications for enhanced detection range and scan angle during turns be incorporated and tested.

F. It is recommended that a TDC be incorporated.

G. It is recommended that the F-16 LANTIRN 30 deg FOV HUD with A-7 LANA symbology formats be incorporated and tested.

H. It is recommended that current A-7E cockpit lighting be retrofitted with lumicon retrofit lighting.

I. It is recommended that "Cats Eyes" be utilized and INVIS HMD be integrated and tested when available.

The above modifications, although lengthy, would be far less expensive than procuring new aircraft for the naval fleet and reserves and are therefore justifiable and warranted. It should be noted that performing low level ingress and targeting transition is best performed in dual seat aircraft. It should be additionally noted that modern system designs allow "All Weather" attack performance in single seat aircraft like the A-7E for some mission significant scenarios. Similar modernization programs as described herein could be performed on other fleet assets and should be considered as the budget constraints become an increasingly serious consideration.

3.2 CONCLUSIONS

3.2.1 Pilot Workload Psychology Considerations

A. Workload may be most accurately determined during operation of equipment in actual mission scenarios. (refer to paragraph 1.6)

B. It is not desirable to incorporate a system with the complexity necessary for successful mission completion if it is not simple enough for the pilot to manage under the high stress of combat. refer to paragraph 1.6)

C When transitioning from day to night operations as well as VMC to IMC operations, pilot stress increases drastically. (refer to paragraph 1.6)

D. Humans are visual creatures. (refer to paragraph 1.6)

E Humans become very nervous with restricted visual rate cues as is the case with secondary visual. (refer to paragraph 1.6)

F. The "Highway in the Sky" is more technologically advanced than the F-14 "Muffins" in providing visual motion cues to the pilot in that the displays provide more seemingly realistic primary cues. (refer to paragraph 1.6)

G. Aircraft display design is critical and must provide the pilot the right information at the right time. (refer to paragraph 1.6)

H. Crossing communication lines can be beneficial for tasks which need to be performed simultaneously. (refer to paragraph 1.6)

3.2.2 Mission Utility

A. With deteriorating daylight special systems and equipment are necessary to effectively make the transition to a night VMC attack profile. (refer to paragraph 1.7)

B. It is necessary to have a "tight" navigation system along with a mission suitable radar to ensure obstacle clearance and timely target acquisition during IMC. (refer to paragraph 1.7)

3.2.3 Inertial Measurement Set

A. The average A-7E alignment time exceeding 10 min was considered long; however, not so long as to require upgrade since alignment can be commenced with external electrical power prior to pilot preflight. (refer to paragraph 2.1.2)

B. IMS accuracy is crucial for successful low level ingress and target acquisition at night and in IMC conditions. (refer to paragraph 2.1.3)

C. Errors in position of 3 nm over a standard mission period of 1.5 hr are not acceptable for an "All Weather" ingress to targeting transition. (refer to paragraph 2.1.3)

D. At best, a 3 nm error in position would likely result in off-target weapons release, delayed weapons delivery or missed target. (refer to paragraph 2.1.3)

E. A 3 nm error in position could potentially result in obstacle impact particularly in unknown terrain. (refer to paragraph 2.1.3)

F. Errors in position greater than 1 nm per a 1.5 hr mission are considered unacceptable for night VMC low level flight. (refer to paragraph 2.1.3)

G. Without confidence in his navigation system, a pilot could not possibly be expected to fly at altitudes low enough to ensure remaining covert. (refer to paragraph 2.1.3)

H. Accomplishing the IMS update procedures in the A-7E could best be described as high workload and cumbersome.with the resultant inertial system update accuracies being unsuitable for "All Weather" attack. (refer to paragraph 2.1.3)

I. For airborne applications, a GPS can be utilized to update an inertial navigation system or other dead reckoning system. (refer to paragraph 2.1.3)

J. GPS is suitable for navigation updates during tactical enroute navigation and weapons delivery. (refer to paragraph 2.1.3)

K. A GPS would definitely be advantageous in maintaining and crosschecking navigation system accuracy for tightness. (refer to paragraph 2.1.3)

L. Continuous high accuracy navigation is essential on a low level ingress in order for computer generated skeletal perspective images (such as obstruction cues, ridge lines and lattice images) to accurately depict actual terrain and obstructions. (refer to paragraph 2.1.3)

M. Should TRN realize its potential during upcoming tests, it would be likely that government funding would be appropriated for establishing the mapping data base necessary to integrate TRN into fleet aircraft. (refer to paragraph 2.1.3)

N. The proposed system in paragraph 2.1.3 would provide pilots the confidence necessary not only to perform low level flight over rugged terrain but also the wherewithal to know when it is unsafe to do so. (refer to paragraph 2.1.3)

O. IMS updates should not routinely be required in order to maintain accurate navigation required for target discovery and collision avoidance. (refer to paragraph 2.1.3)

P. In the high stress, workload intensive environment of "All Weather" attack, simplified human factors are a necessity. (refer to paragraph 2.1.3)

3.2.4 Tactical Computer Set

A. The requirement to switch hands on the control stick and divert pilot attention away from the primary FOV in order to accomplish primary mission tasks is unsuitable for the already workload intensive environment of "All Weather" ingress and target transition. (refer to paragraph 2.2)

B. Ergonomic modification of the cockpit controls for pilot-computer interface is required for suitability of the "All Weather" mission. (refer to paragraph 2.2)

3.2.5 Up-Front Control

A. Although the TCS incorporates many of the features of the UFC, its size and limited capability make it unsuitable for use as a UFC. (refer to paragraph 2.3)

B. Neither the F-18 or A-7 LANA UFCs are suitable to incorporate all of the proposed changes recommended herein. (refer to paragraph 2.3)

C. Development costs of a new UFC for the A-7E are justifiable in that incorporation would allow the A-7E to perform the "All Weather" attack mission. (refer to paragraph 2.3)

3.2.6 Forward Looking Infrared

A. The A-7E FLIR pod is large and heavy requiring a parent weapons station. This reduces range and weapons loading. (refer to paragraph 2.4.2)

B. If an A-7E FLIR pod is downloaded on the carrier, the pod and the aircraft cannot be utilized for FLIR until alignment at a suitable shore facility is performed. (refer to paragraph 2.4.2)

C. The A-7E FLIR boresighting methods are not accurate for carrier aviation. (refer to paragraph 2.4.2)

D. The reliability and maintainability of A-7E FLIR systems utilized at sea were poor. (refer to paragraph 2.4.2)

E. The current A-7E FLIR installation is not good as a primary navigation and target identification system. (refer to paragraph 2.4.2)

F. The current A-7E FLIR installation is a "human factors nightmare" for combined switchology and system mechanization. (refer to paragraph 2.4.2)

G. The A-7E FLIR WFOV magnification was noted to be not only vertigo inducing but also confusing to the pilot with respect to actual checkpoint and target location. (refer to paragraph 2.4.2)

H. The A-7E pilot-machine interface was not noted to be significantly jeopardized in the A-7 LANA aircraft. (refer to paragraph 2.4.2)

I. Since NVG were not tested utilizing the A-7 LANA modified FLIR configuration, further study is required. (refer to paragraph 2.4.2)

J. Target acquisition utilizing FLIR without use of a radar requires accurate target coordinates, good inertial navigation, and an accurate navigation update as close to the target as possible. (refer to paragraph 2.4.2)

K. The problems associated with the A-7E sea based FLIR alignment following installation, coupled with difficult maintenance, poor reliability and inaccurate boresighting negate FLIR from being a primary means of navigation. (refer to paragraph 2.4.2)

3.2.7 Radar

A. The small A-7E radar maximum detection range of 2 nm would allow approximately 10 sec for the pilot to identify and designate the target. (refer to paragraph 2.5.2.1)

B. The Navy would need to test the A-7 LANA radar modification to determine suitability of A-7E installation. (refer to paragraph 2.5.2.1)

C. Utilizing radar in a "complementary" manner to crosscheck map position on a periodic basis would serve to improve pilot confidence factor. (refer to paragraph 2.5.2.1)

D. Since the TRN system would be "smart" on local terrain, turn rate by design should not be limited as required with current radars. (refer to paragraph 2.5.2.2)

E. The A-7 E slew controller actuated cursor displacement was 180 deg opposite to that desired resulting in inadvertent displacements of the radar cursor from the desired target, delaying target designation. (refer to paragraph 2.5.2.4)

F. A Target Designator Controller (TDC) on the throttle optimizes radar slewing since it provides the pilot an immediate access to slew cursors without displacement of hands from the primary stick and throttle controls. (refer to paragraph 2.5.2.4)

G. It would be desirable to incorporate a similar DDI display box to the AV-8 Night Attack airplane or the F-18 in the A-7E. (refer to paragraph 2.5.2.5)

H. An A-7E instrument panel design to incorporate DDIs on the left-hand side could be developed and incorporated. (refer to paragraph 2.5.2.5)

I. The limited detection capability of the A-7E APQ-126(V) radar in the TF mode could result in the aircraft impacting radio and power lines during TF flight without back-up visual cues. (refer to paragraph 2.5.2.6)

J. Precise navigation to within a few tenths of meters is required to safely perform "All Weather" ingress. (refer to paragraph 2.5.2.6)

K. "Complementary" interface between all provided cockpit indicators and displays is required so that the pilot can maintain the desired tactical situational awareness necessary for successful and safe mission completion. (refer to paragraph 2.5.2.1)

3.2.8 PMDS

A. The PMDS decentering feature for relocation of aircraft position from the center to the bottom of the display was a helpful aid in correlating radar display data. (refer to paragraph 2.6.2)

B. Since white lighting is not compatible with NVG the PMDS currently installed in the A-7E would have to be secured in order to utilize NVG. (refer to paragraph 2.6.2)

C For utilization of the PMDS, the single seat pilot needs the maximum amount of information in primary cues provided in the simplest manner possible. (refer to paragraph 2.6.2)

3.2.9 HUD

A. A 20 deg HUD FOV is considered to be insufficient for the "All Weather" attack mission. (refer to paragraph 2.7.2)

B. A 30 deg total HUD FOV is considered to be an acceptable design standard with more FOV desirable pending progression in HUD technology. (refer to paragraph 2.7.2)

C. Since the A-7 LANA and A-7E are similar airframes, integration of the A-7 LANA should be without consequence switching the previous HUD component boxes for the new HUD component boxes. (refer to paragraph 2.7.2)

3.2.10 NVG Compatibility

A. Ideally, the solution to NVG compatibility in the A-7E would be to redo the cockpit in all integral NVG compatibility lights. (refer to paragraph 2.8.2)

B. A total NVG compatible light integration into the A-7E is quite impractical in that it would require procurement of new cockpit instrumentation as cockpit instruments currently incorporate integral red lighting. (refer to paragraph 2.8.2)

C. Pilot orientation is improved with "Cats Eyes" over other NVG devices because of the unique direct and peripheral vision capability of the devices. (refer to paragraph 2.8.3)

D. "Cats Eyes" pose a problem since they are not ejection compatible, requiring removal prior to ejection. (refer to paragraph 2.8.3)

E. INVIS should eventually replace the present NVG design. (refer to paragraph 2.8.3)

F. The most significant gain by pilot utilization of a HMD is off-boresight acquisition and target updates allowing the pilot to fly an offset for a navigation update. (refer to paragraph 2.8.3)

G. The INVIS HMD will eliminate the need for not only NVG devices but also HUDs. (refer to paragraph 2.8.3)

H. Expanding the HUD FOV optimizes current technology; however, HUD systems still limit the pilot to approximately 2 percent of the outside viewing area. (refer to paragraph 2.8.3)

I. The INVIS type helmet is considered to be the best tactical system integration to pursue at this time, giving the "biggest payback in mission effectiveness for the costs involved." (refer to paragraph 2.8.3)

3.3 RECOMMENDATIONS

3.3.1 Pilot Workload Considerations

A. In the high stress of combat, the information provided to the pilot should be primarily visual since auditory cues are more easily ignored. (refer to paragraph 1.6)

B. In a high stress environment like combat, communication lines for sequential task requirements should not be crossed. (refer to paragraph 1.6)

3.3.2 Mission Utility

A. With the high workload of IMC, particularly at night, the pilot should be provided a TF capability which can be coupled to the Automatic Flight Control System (AFCS). (refer to paragraph 1.7)

B. Systems should operate in a complementary manner and not to the exclusion of each other. (refer to paragraph 1.7)

3.3.3 Inertial Measurement Set

A. In order to successfully navigate the "All Weather" mission described in paragraph 1.7 which entails both over water and over land flight, a combination of a ring laser gyro (RLG), global positioning system (GPS) and terrain referencing navigation (TRN) systems would be ideal to ensure redundancy and in such provide confidence to the pilot. (refer to paragraph 2.1.3)

B. The RLG should be incorporated since it is a stock item. (refer to paragraph 2.1.3)

C. GPS should be used as a secondary system for enhanced navigational accuracy but should not be counted on as a primary system component. (refer to paragraph 2.1.3)

D. TRN should be evaluated for possible implementation in future designs and retrofits. (refer to paragraph 2.1.3)

E. The author's proposal for implementation of navigational systems is as follows:

1. Launch off the carrier using RLG for navigational information (TRN not designed for over water use). Utilize GPS for RLG system crosscheck and updates.

2. Upon crossing the shoreline and throughout ingress to target, TRN becomes the primary navigational updating source for the inertial

system. Utilize GPS and RLG for TRN system crosscheck. (refer to paragraph 2.1.3)

F. The navigation system composite should be automated for the routine proposed above, but should allow the pilot to manually select any of the systems if desired. (refer to paragraph 2.1.1.3)

G. The pilot should be provided a single digit confidence factor of the navigational system accuracy on the HUD. (refer to paragraph 2.1.3)

H. The confidence level display should be designed to communicate a warning to the pilot when it goes below a certain level established by flight test results. (refer to paragraph 2.1.3)

I. The warning of reduced confidence level should be both auditory and visual which would follow the fundamental design principle of MBE. (refer to paragraph 2.1.3)

3.3.4 Up-Front Control

Required functions of an UFC would include: (refer to paragraph 2.2)

A. A means of selecting and updating destinations (DEST) and MARKs.

B. A means of inputting coordinates (either latitude and longitude or grid). Coordinates should remain illuminated for approximately 5 sec after entry so that the pilot can verify entry.

C A means of accessing all navigation functions with a growth capability for new follow on navigation systems.

D. A means of performing enroute navigation updates.

E. A means of selecting all communications systems.

F. A means with which to access DATA functions. The data will be displayed for 10 sec unless the enter (ENT) key is depressed, at which time the data will remain displayed until clear (CLR) key is depressed.

G. A means of adjusting HUD brightness, reticle depression, selecting HUD on-off and selection of day-night display lightings.

H. A means of adjusting FLIR scene controls to include background level, raster brightness, contrast, on-off selection and polarity.

I. A means with which to remove unnecessary data from the display (DECLUTTER).

3.3.5 Forward Looking Infrared

A. The pilot should use the AFCS to the maximum extent possible to aid in aircraft control during FLIR utilization. (refer to paragraph 2.4.2)

B. The A-7E FLIR should be modified as the A-7 LANA FLIR Pod to incorporate 1:1 magnification for the HUD WFOV FLIR scene. (refer to paragraph 2.4.2)

C. Target acquisition should be by another means than FLIR, with a FLIR only mode option as a back-up for confidence level. (refer to paragraph 2.4.2)

D. FLIR should be used as a back-up mode; specifically for the identification of point targets and additionally for other features which might not be incorporated on maps. (refer to paragraph 2.4.2)

E. The A-7 LANA system modifications including the slew controller FOV switch should be incorporated into the A-7E. (refer to paragraph 2.4.2)

F. Provide a three dimensional depiction of the terrain for obstacle avoidance (reference 11), with a superimposed FLIR display for point target thermal signature acquisition. (refer to paragraph 2.4.2)

G. Perform a study to determine the feasibility of superimposing FLIR on the TRN displays for point target thermal signature acquisition. (refer to paragraph 2.4.2)

H. With the implementation of a TDC incorporate the FLIR FOV switch into the throttle. (refer to paragraph 2.4.2)

I. The A-7 LANA and TRN PENETRATE systems should be implemented following successful test completion although major work would be required for system integration. (refer to paragraph 2.4.2)

3.3.6 Radar

A. The pilot should be provided significant target information by 10 nm from the target to ensure sufficient time for target identification, designation and accurate weapons delivery. (refer to paragraph 2.5.2.1)

B. Upon successful testing of the A-7 LANA radar for maximum detection range, the LANA APQ-126(V) modifications should be incorporated into the A-7E APQ-126(V) radar system. (refer to paragraph 2.5.2.1)

C. The testing for the A-7 LANA radar modifications should be comprehensive including both descript and nondescript terrains and various manmade obstacles like towers, power lines, phone wires, etcetera. (refer to paragraph 2.5.2.1)

D. The Navy should test the LANA radar modifications in the A-7E for narrow scan angle and upon a successful evaluation, incorporate these modifications into the fleet. (refer to paragraph 2.5.2.2)

E. The Navy should test the TRN system and incorporate TRN into the A-7E upon successful testing for narrow scan angle. (refer to paragraphs 2.1.3 and 2.6.2)

F. The limited AN/ARR-65 wide scan angle delayed verification of the correct IMS cursor placement for IMS updates. (refer to paragraph 2.5.2.3)

G. The A-7E pilot should be provided radar control operation which is as natural procedurally simple as possible. (refer to paragraph 2.5.2.4)

H. The apparent reverse sensing of the slew controller should be changed so that forward motion of the slew controller results in the cursor moving forward and aft movement of the slew controller results in the cursor moving aft. (refer to paragraph 2.5.2.4)

I. A similar TDC arrangement to the AV-8 Night Attack airplane or the F-18 should be incorporated into the A-7E. (refer to paragraph 2.5.2.4)

J. The A-7 LANA slew controller improvement should be evaluated by the Navy and incorporated as an interim improvement in the A-7E until a TDC can be designed and incorporated. (refer to paragraph 2.5.2.4)

K. The currently installed instrumentation in the A-7E should be shifted from the left side of the panel to the right side of the panel. (refer to paragraph 2.5.2.5)

L. Map and radar displays should be shifted from the current right side of the panel to the left side of the panel. (refer to paragraph 2.5.2.5)

M. The Navy should test TRN in an A-7E prototype for possible incorporation into A-7E fleet aircraft. (refer to paragraphs 2.5.2.6 and 2.6.2)

N. The Navy should incorporate the A-7 LANA ATF modification for testing. (refer to paragraph 2.5.2.6)

O. Upon successful testing of the A-7 LANA TF modifications, TF should be integrated into the A-7E as a interim primary system and back-up system to TRN. (refer to paragraph 2.5.2.6)

P. The Navy should integrate and test the TRN ATF with the flight control coupling mentioned in paragraph 2.5.2.6 into a prototype. (refer to paragraph 2.5.2.6)

3.3.7 HUD

A. The F-16 LANTIRN HUD should be incorporated in the A-7E since it accommodates the minimum FOV considered acceptable by fleet pilots. (refer to paragraph 2.7.2)

B. The A-7 LANA HUD displays have received favorable comments from pilots and should be integrated into the A-7E. (refer to paragraph 2.7.2)

C. The Navy should acquire F-16 LANTIRN HUD flight test results from the Air Force and perform some additional tests to ensure A-7E adaptability to low level ingress from the carrier. (refer to paragraph 2.7.2)

D. The F-16 LANTIRN HUD should be integrated into the A-7E fleet following successful flight testing. (refer to paragraph 2.7.2)

3.3.8 NVG Compatibility

A. Add-on an NVG compatible bezel since it is the most practical and cost effective NVG compatibility solution for modification of the A-7E. (refer to paragraph 2.8.2)

B. "Cats Eyes" should be utilized as the NVG device for the A-7E "All Weather" attack mission. (refer to paragraph 2.8.3)

C. NVG should only be utilized in the A-7E for night VMC as it would not be helpful in an IMC environment and unnecessarily contribute to pilot fatigue. (refer to paragraph 2.8.3)

D. "Cats Eyes" should be utilized only as an interim solution to the night VMC problem. (refer to paragraph 2.8.3)

E. When operational, INVIS should be integrated into the A-7E and studied. (refer to paragraph 2.8.3)

3.4 IMPLICATIONS

The systems upgrades described herein will enable an A-7E aircraft designed in the 1960's to perform a tactically significant mission into the turn of the century. Undoubtedly, performing low level ingress and targeting transition is best performed in a dual seat aircraft. Modern systems designs to include tactical system and aircraft automation; however, open "All Weather" attack to single seat aircraft in some mission significant scenarios. Modernization programs similar in scope to the one described herein for the

A-7E could be employed on other fleet aircraft in order to allow continued operation.

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PERSONAL INTERVIEWS

PERSONAL INTERVIEWS

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2. Interview with LCDR Jeff Ashby, F-18 Program Manager, Fleet Experienced A-7 Pilot and Test Pilot, Naval Air Test Center, Patuxent River, Maryland, 21 November 1989.

3. Interview with LT Rich Harned, A-6 Combat Experienced Naval Flight Officer, Naval Air Test Center, Patuxent River, Maryland, 16 November 1989.

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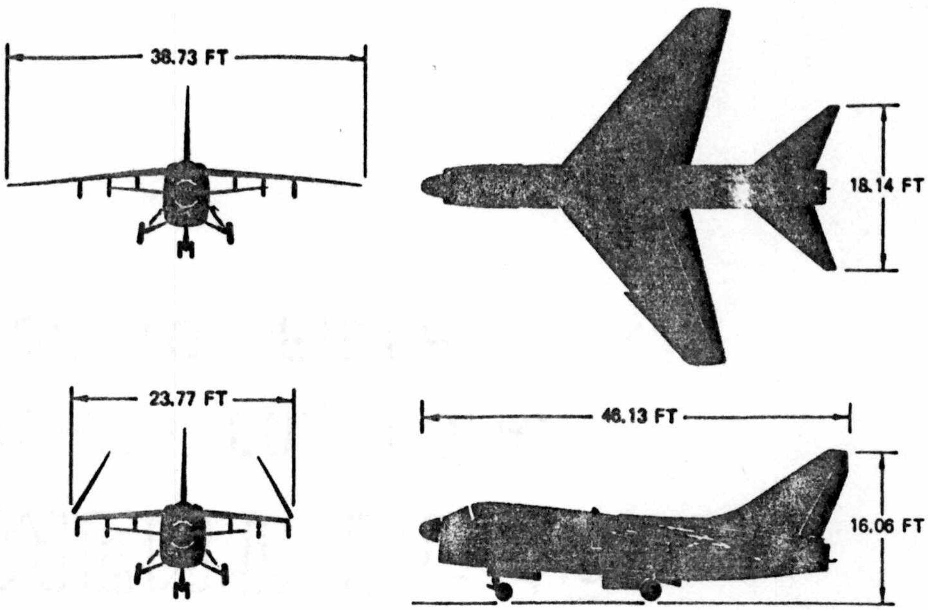
APPENDICES

APPENDIX A

FIGURES



OTHER DIMENSIONS

WING		HORIZONTAL STABILIZER		VERTICAL STABILIZER	
Area	375.00 sq ft	Area	93.75 sq ft	Area	115.20 sq ft
Aspect ratio	4	Sweep 1/4 chord	45°	Sweep	44°28 min
Incidence (root and tip)	−1°	Dihedral	5° 25 min		
Sweep 1/4 chord	35°				
Dihedral	−5°				

Figure 1
A-7E Aircraft Dimensions

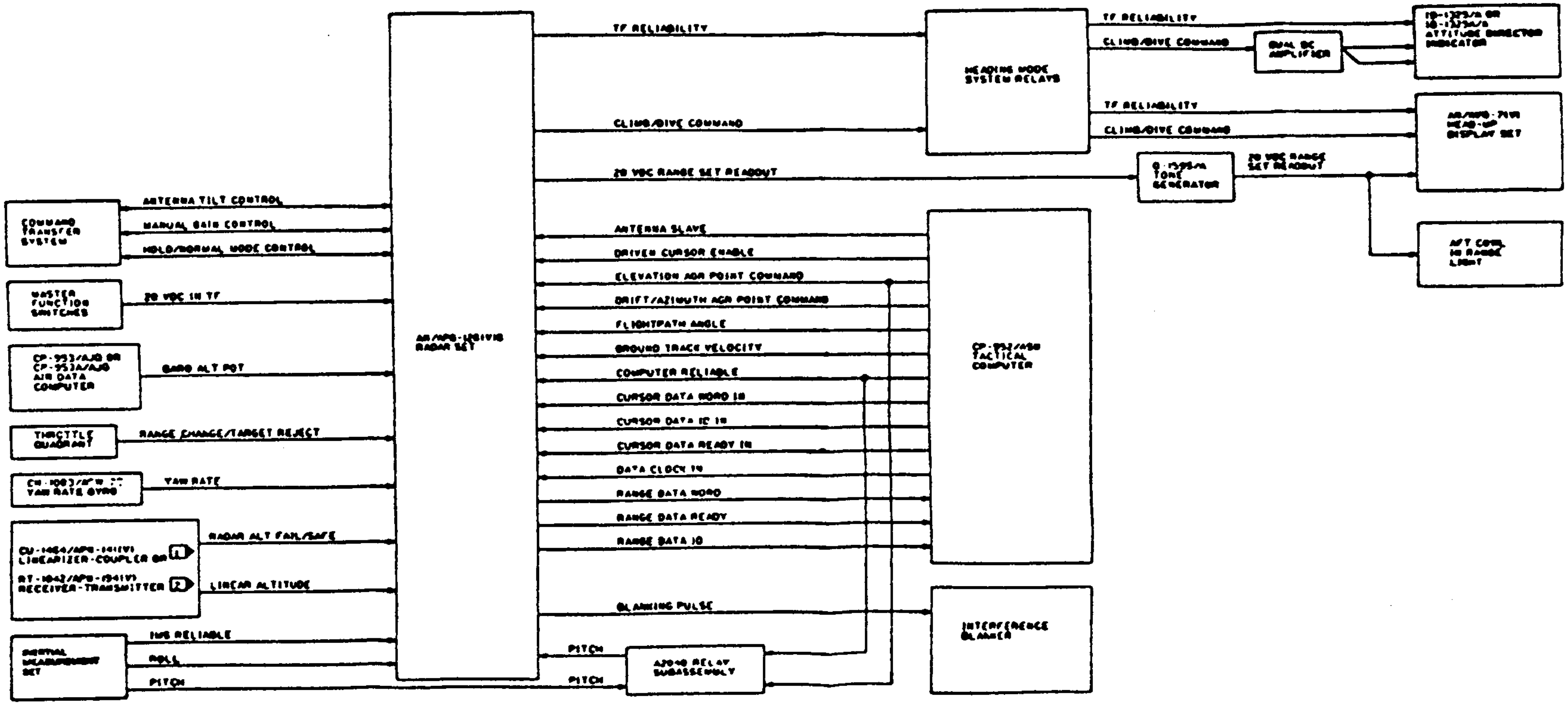


Figure 2
A-7E Basic Weapons System Diagram

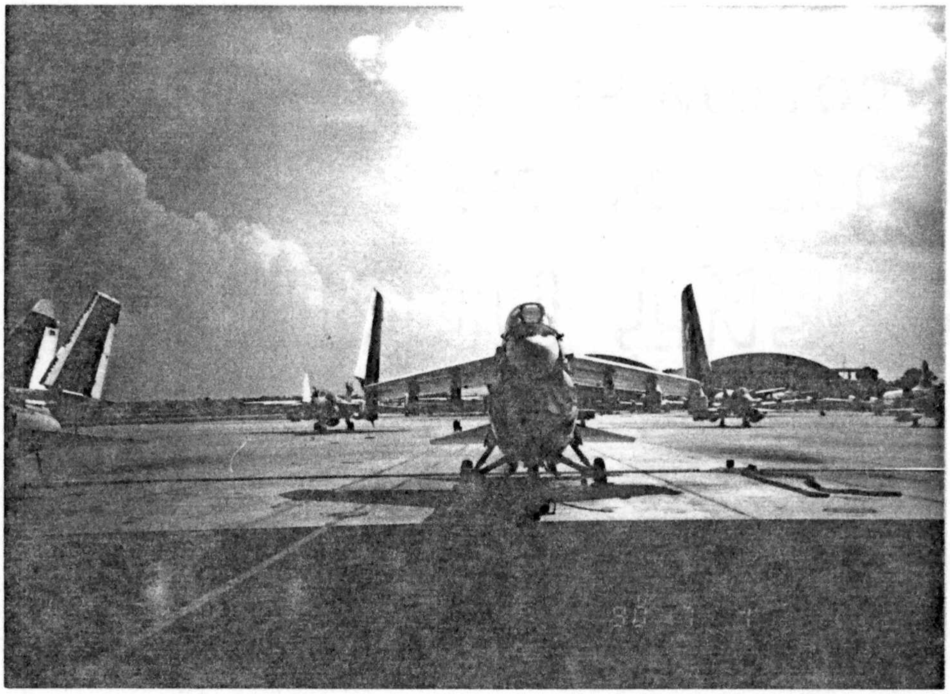


Figure 3
A-7E Head-On View

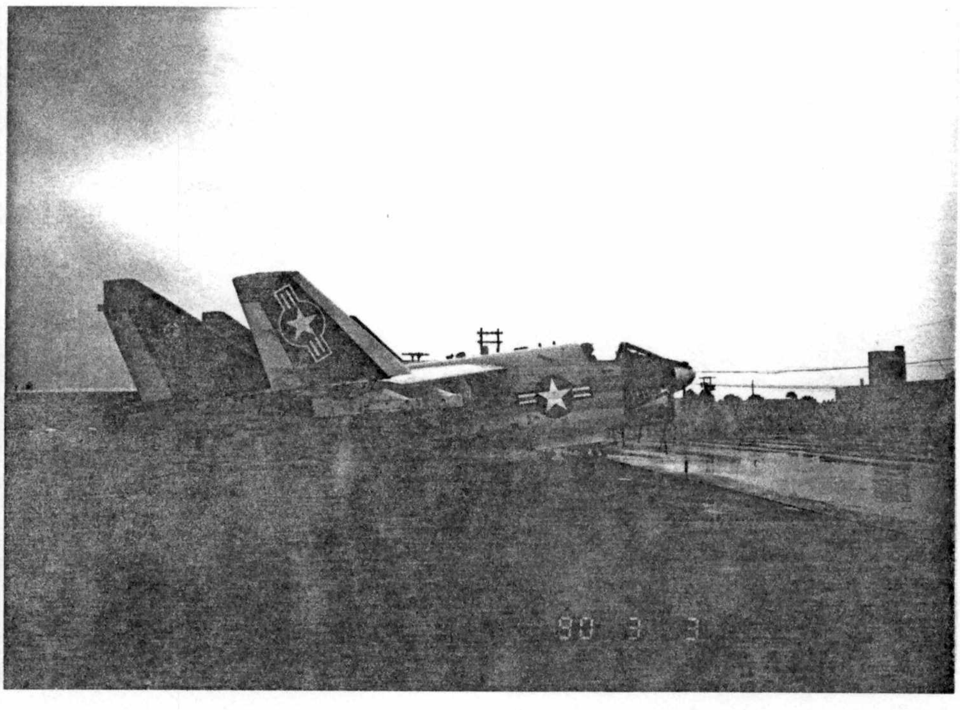


Figure 4
A-7E Starboard View

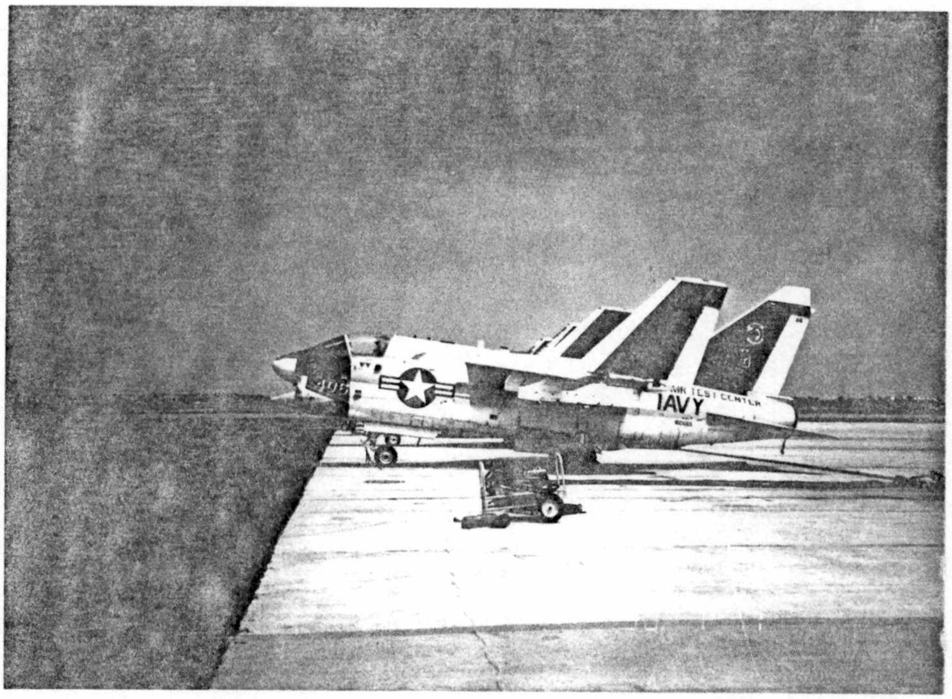


Figure 5
A-7E Port View

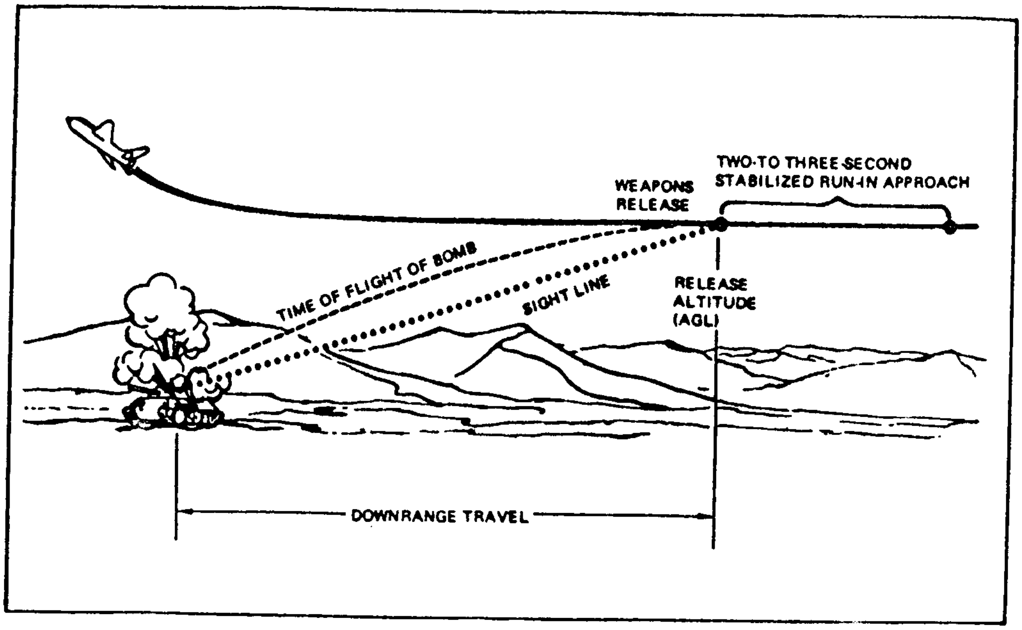


Figure 6
Level Lay-Down Delivery

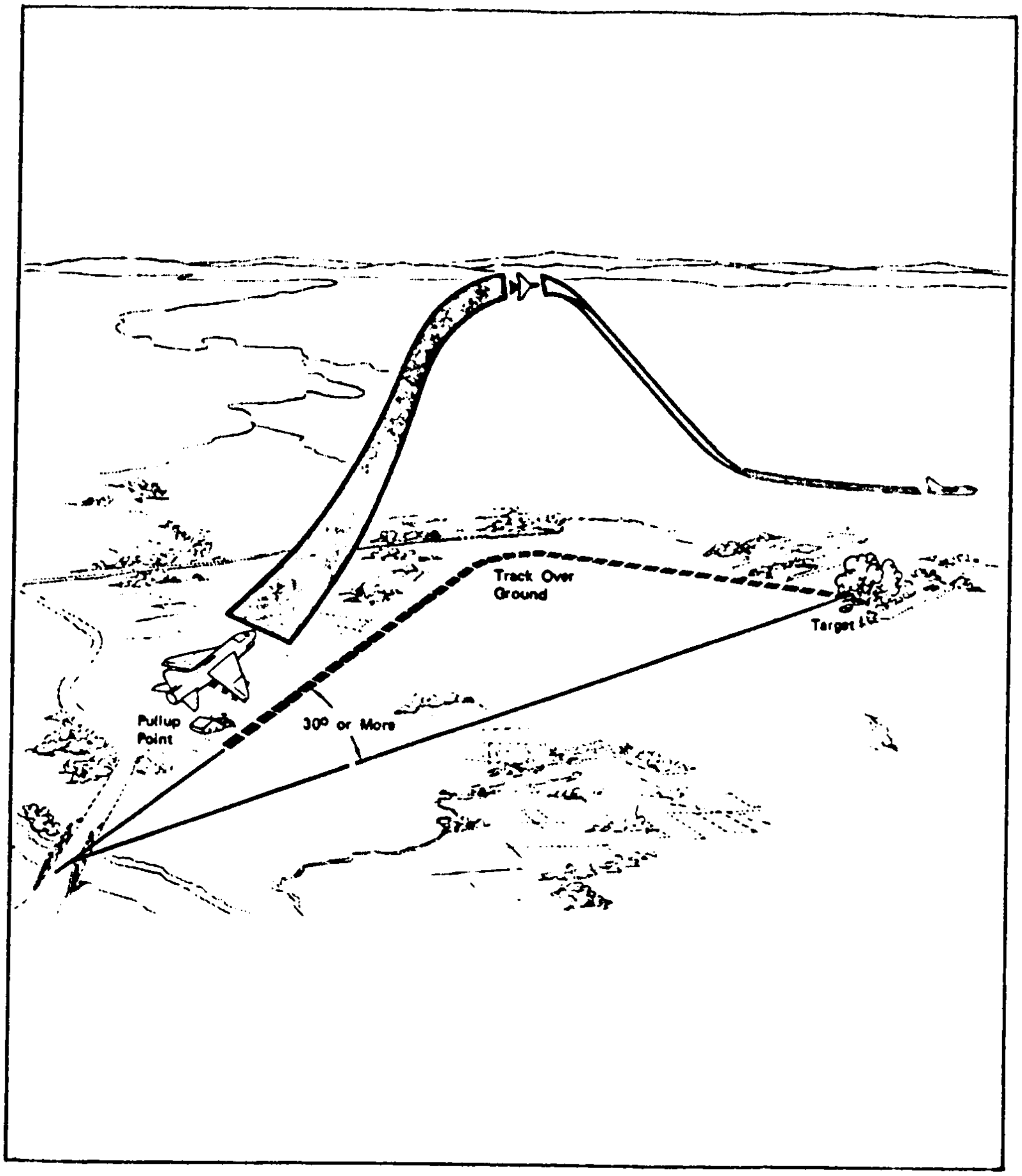


Figure 7
Offset Pop-Up Maneuvering Delivery

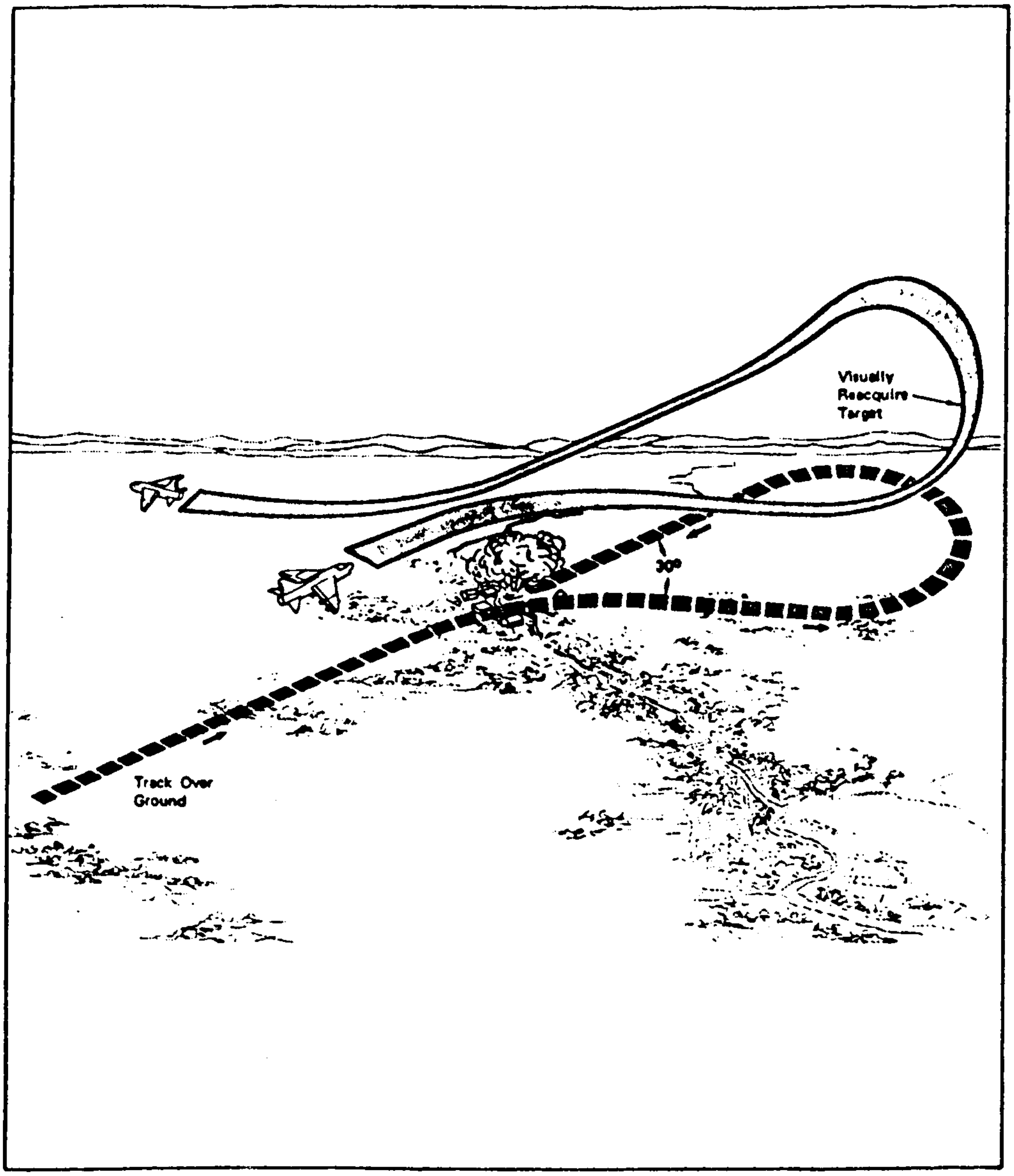


Figure 8
Reversal Pop-Up Maneuvering Delivery

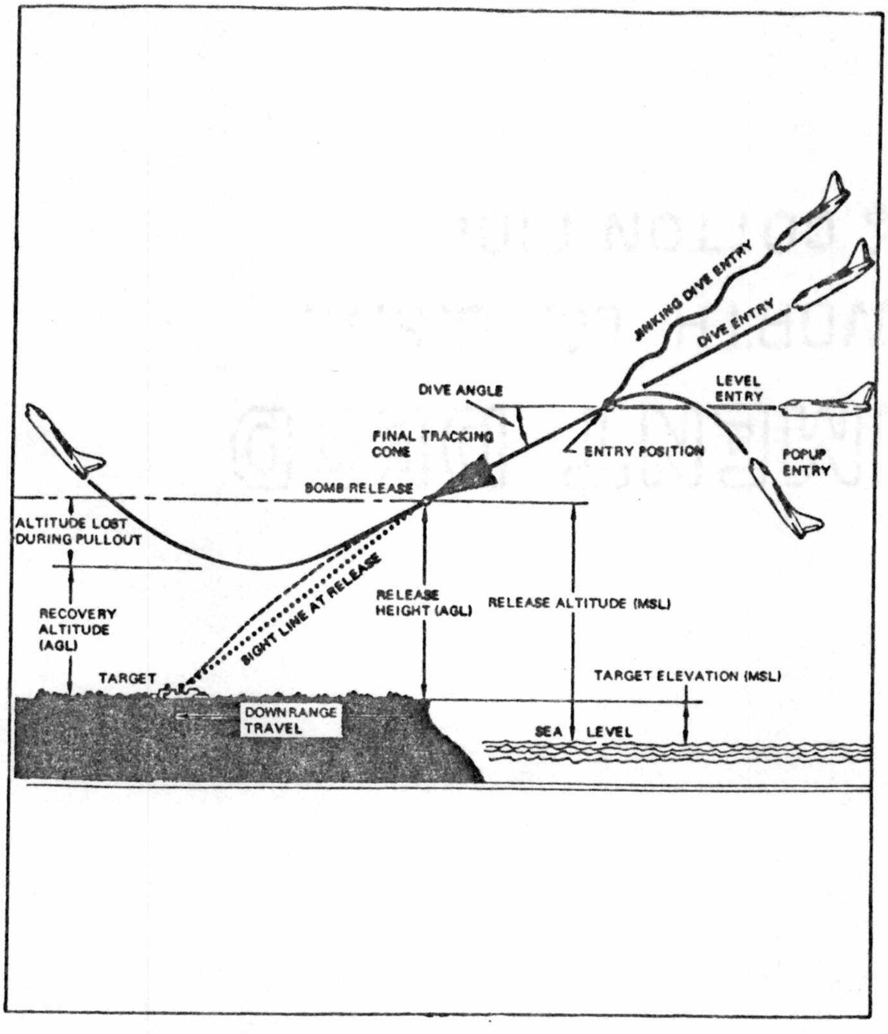


Figure 9
Dive Delivery

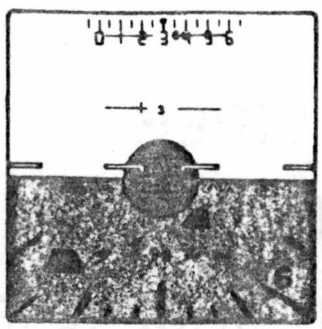


Figure 10
F-14 HUD "Muffins" Display

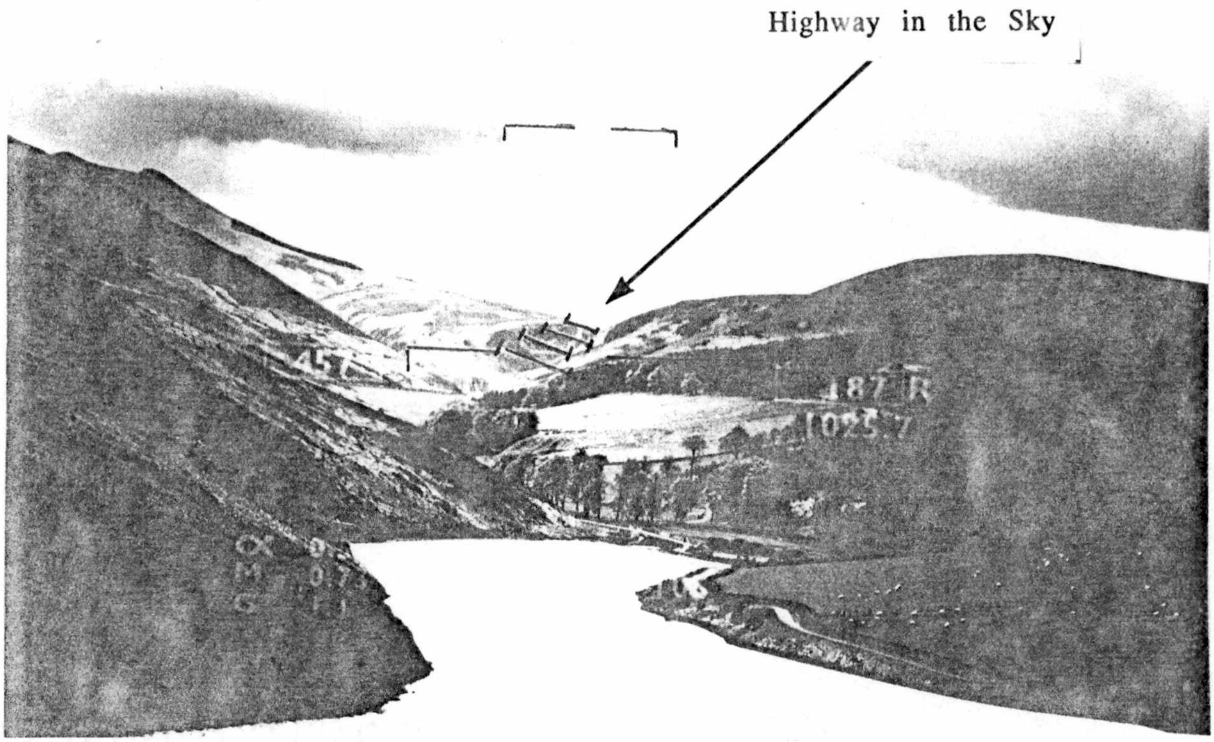


Figure 11
Ferranti International PENETRATE
"Highway In The Sky"

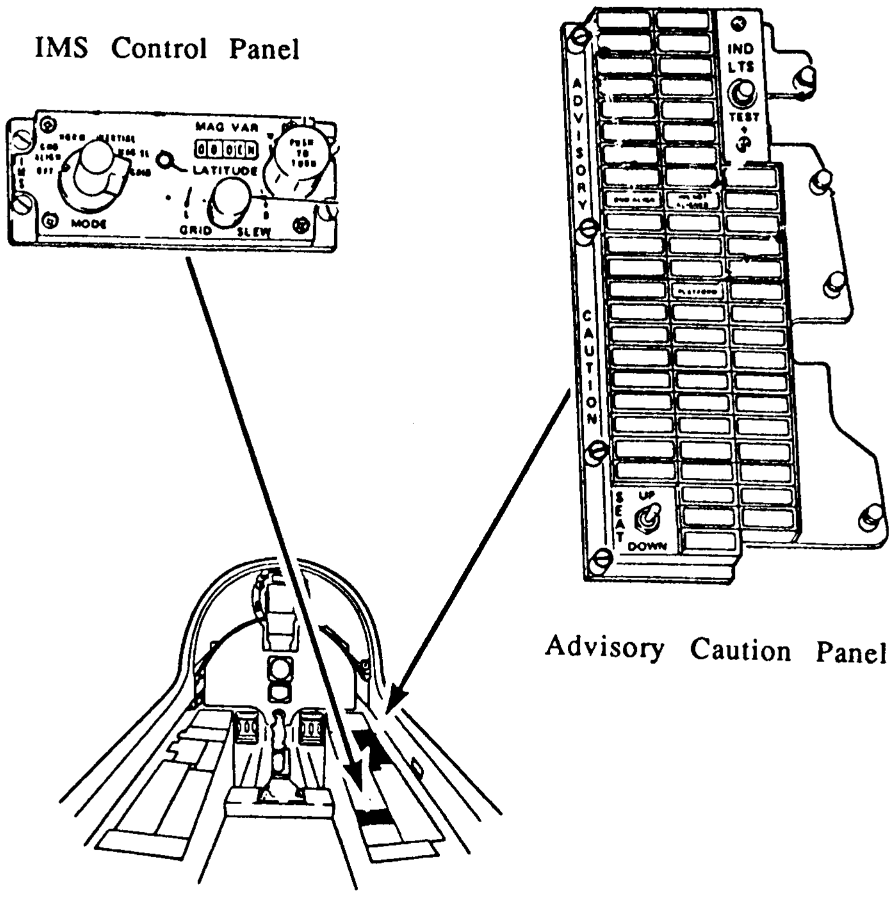


Figure 12
A-7E IMS Controls

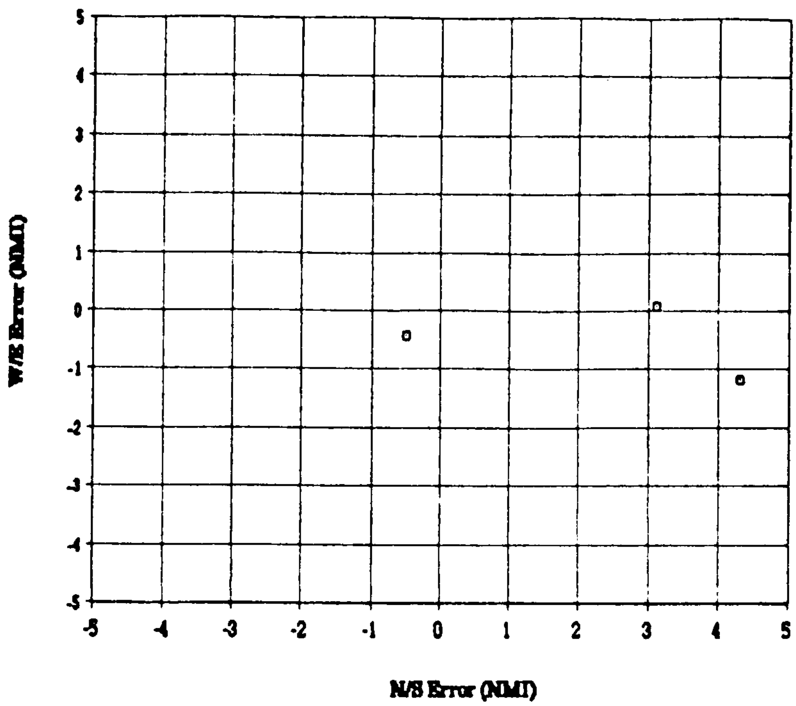


Figure 13
TA-7C IMS Closeout Errors In Position

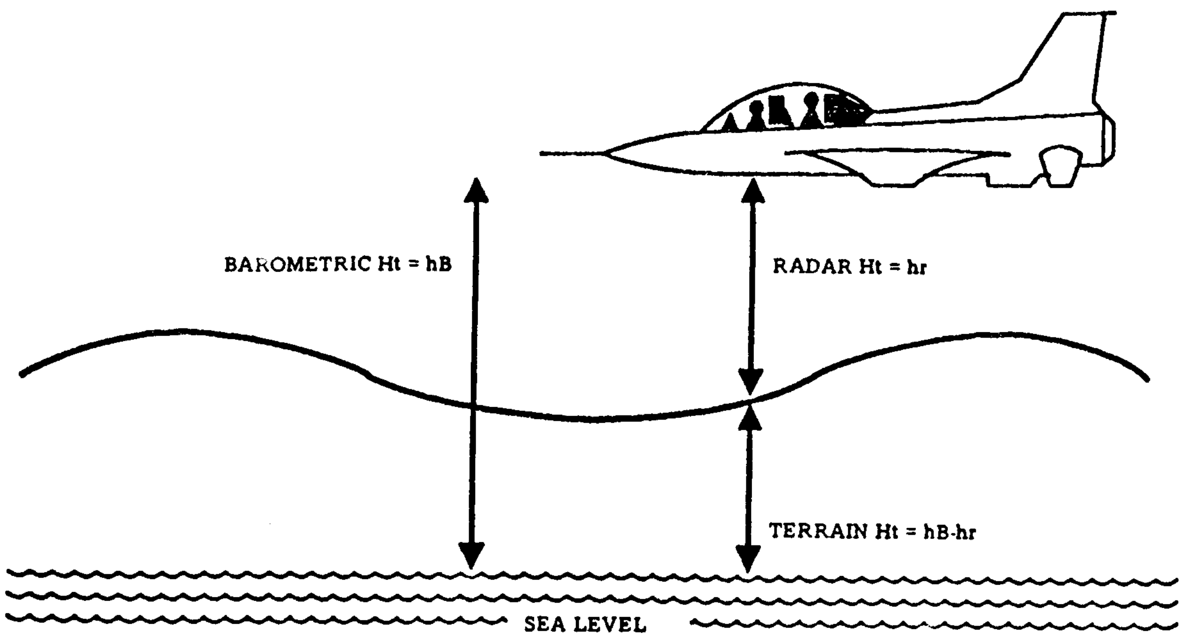


Figure 14
TRN Calculation of Terrain Height

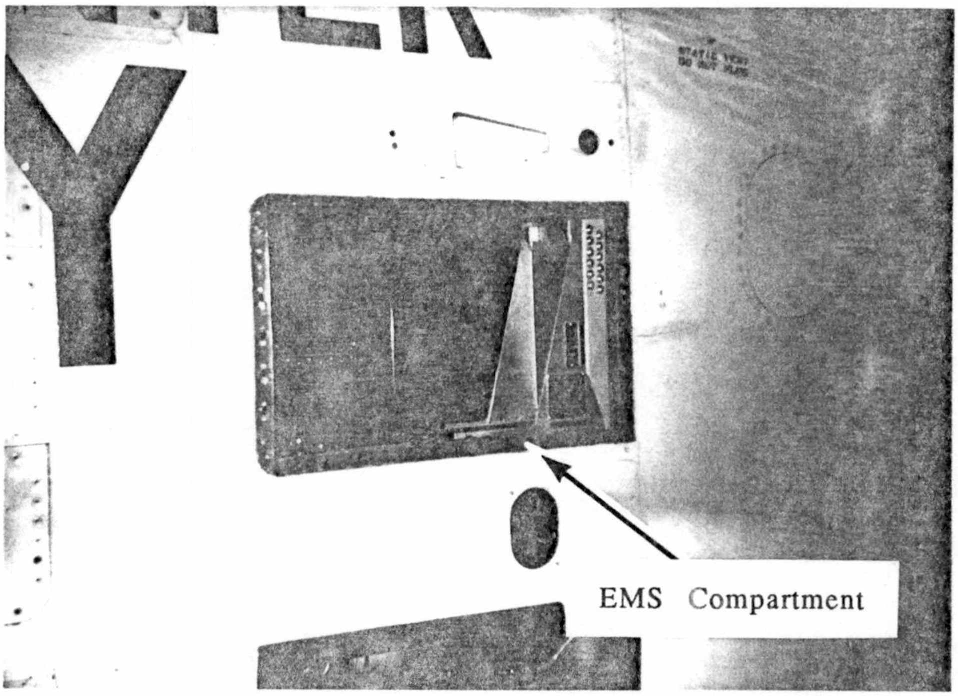


Figure 15
A-7E EMS Compartment

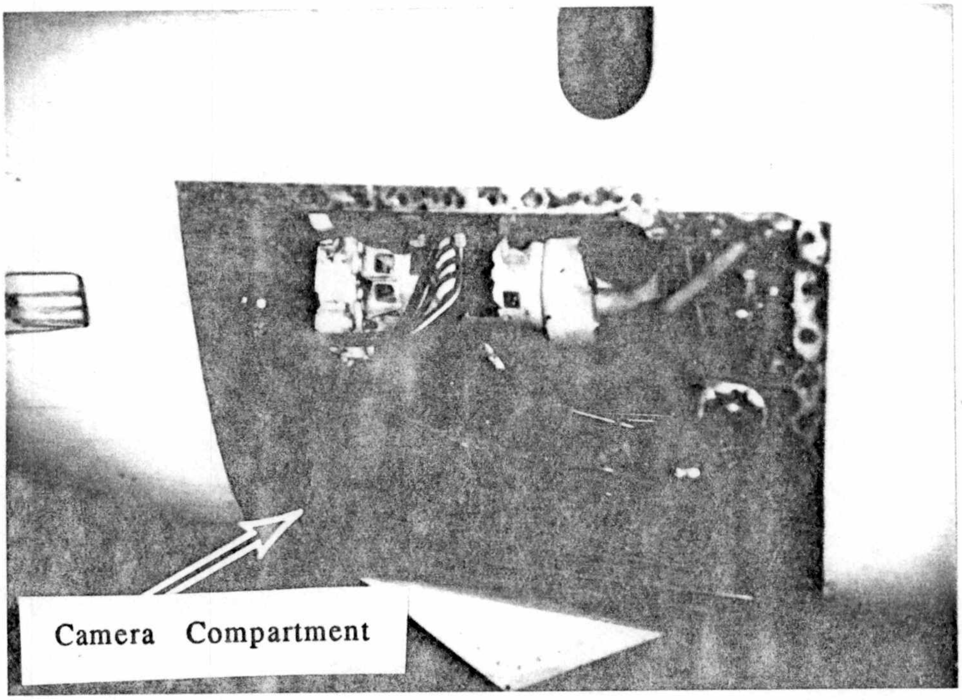


Figure 16
A-7E Camera Compartment

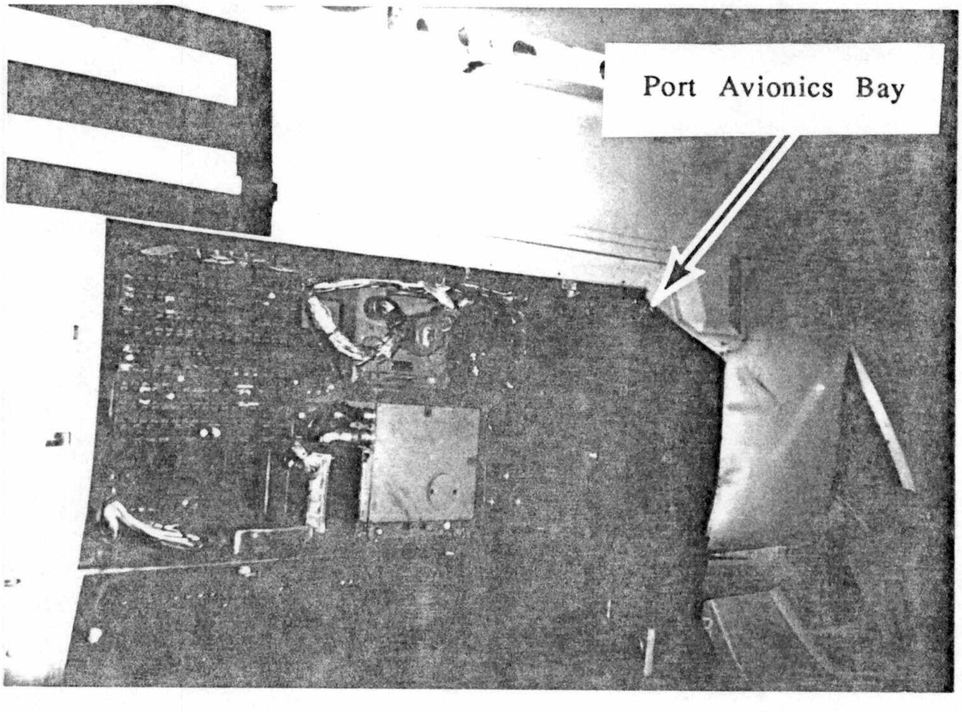
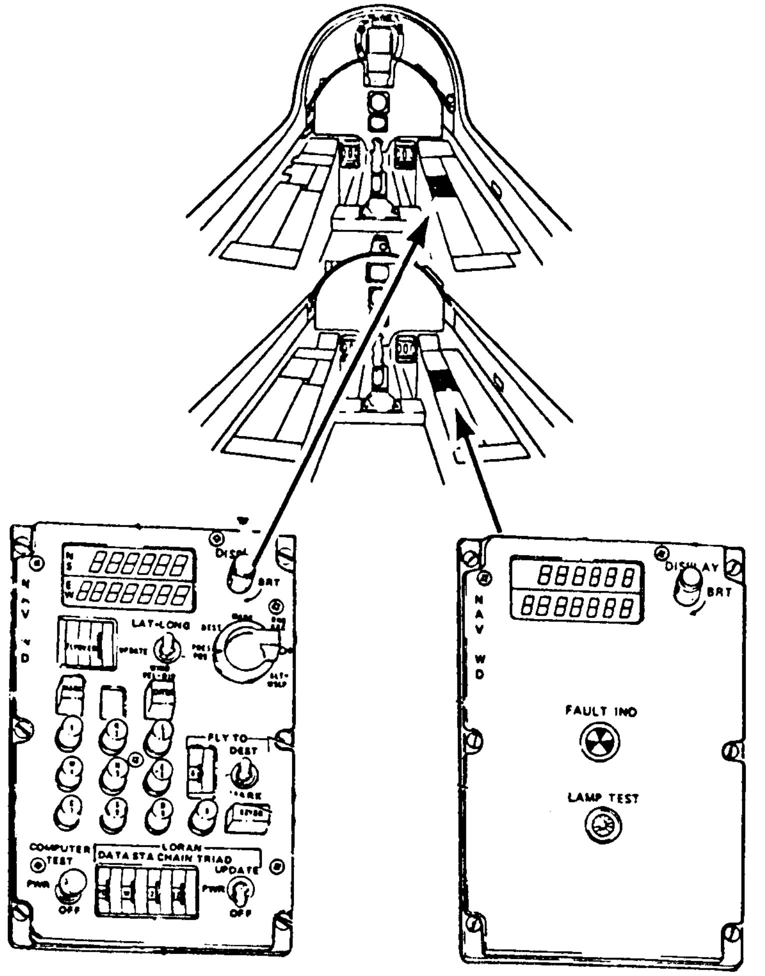


Figure 17
A-7E Port Avionics Bay



TCS Control Panel NAV Fault Indication

Figure 18
A-7E TCS Controls and Displays

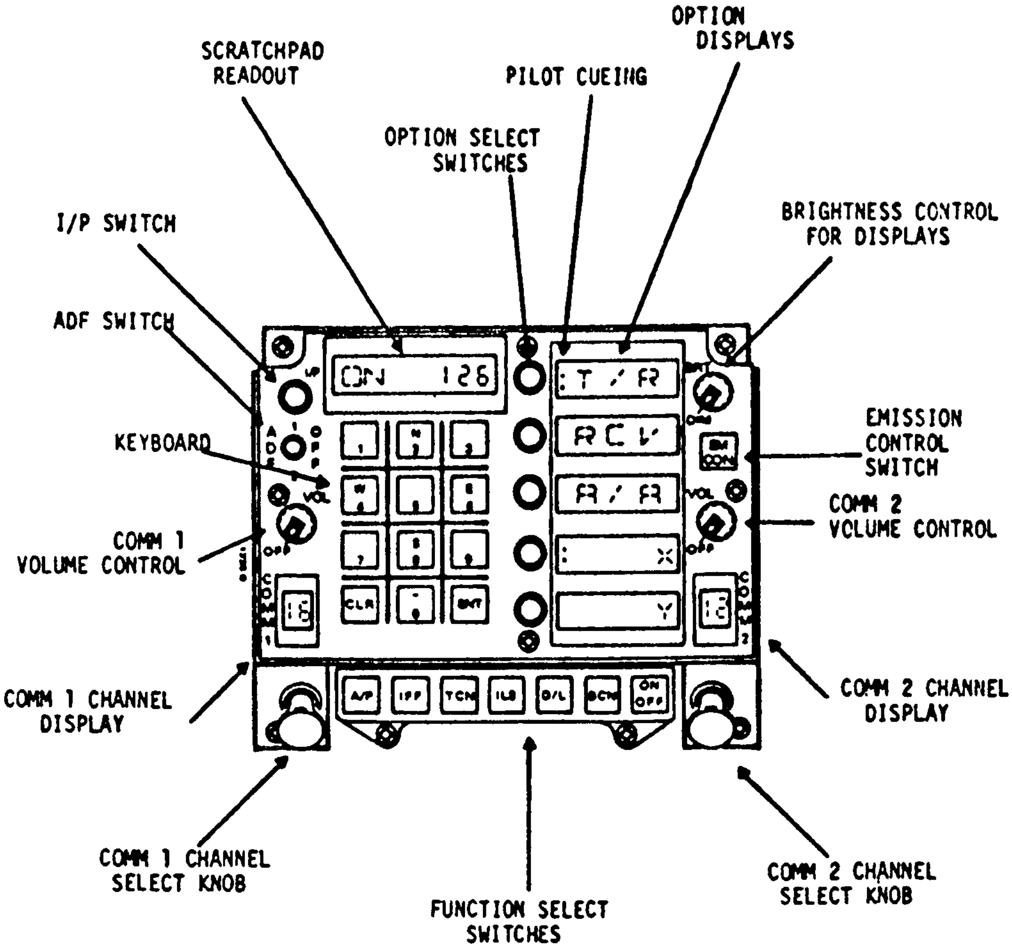


Figure 19
F-18 UFC

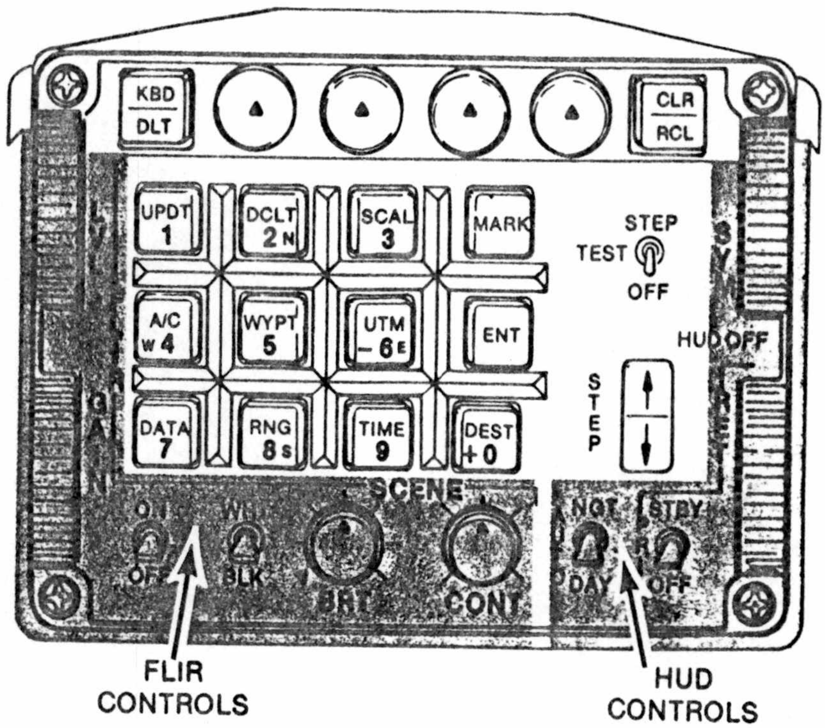


Figure 20
A-7 LANA UFC

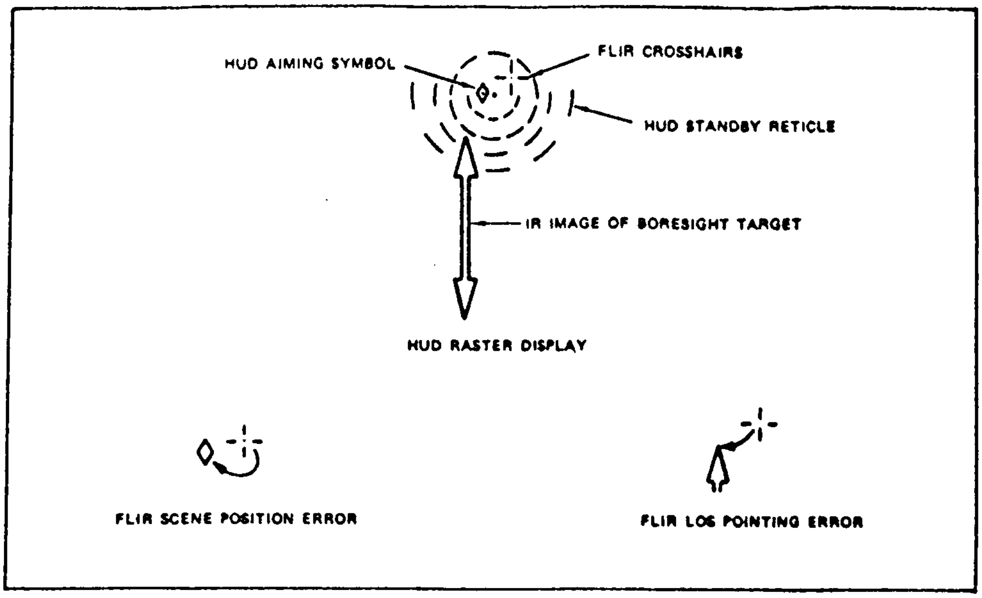


Figure 21
A-7E FLIR System Boresight

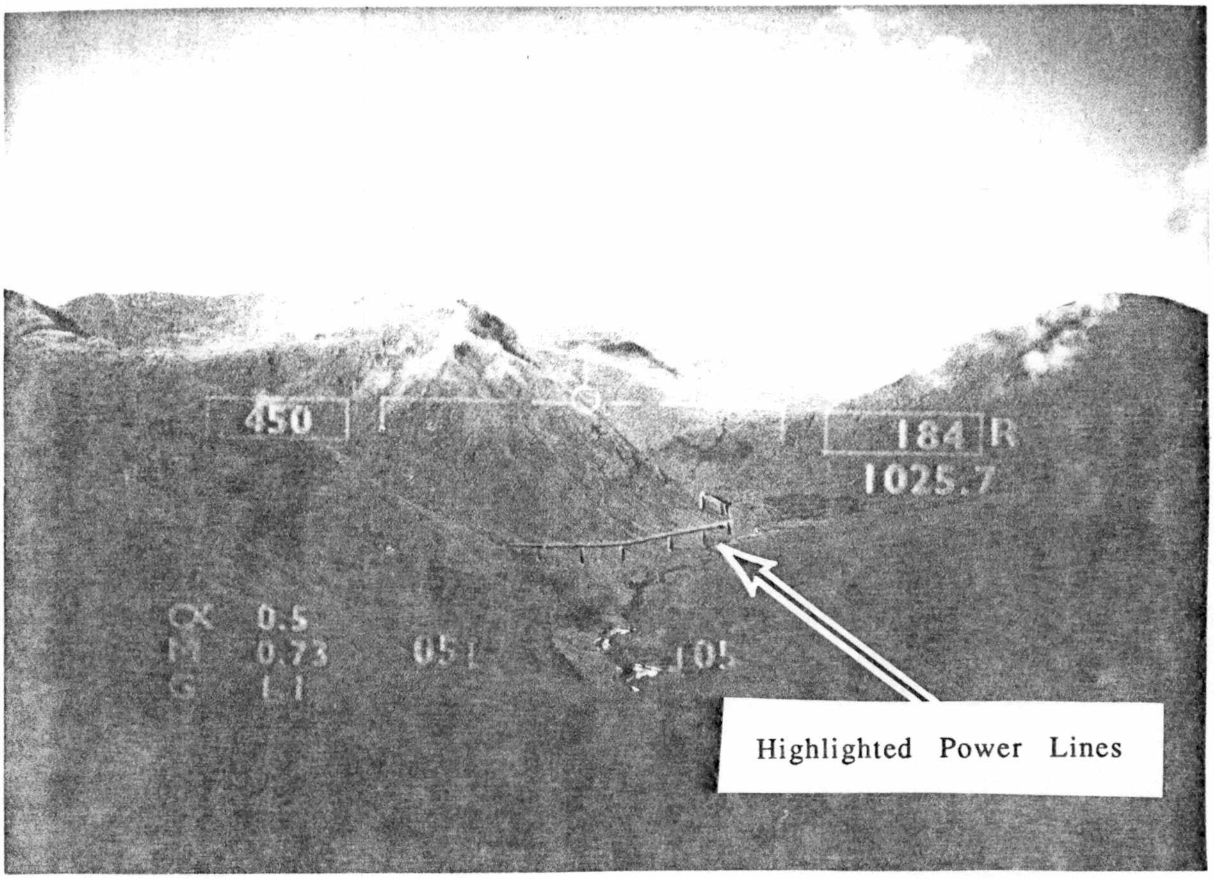


Figure 22
Ferranti International PENETRATE HUD Display
Highlighting Power Lines in the Valley

Figure 23
Ferranti International PENETRATE HUD Display
Ridge Line Enhancement

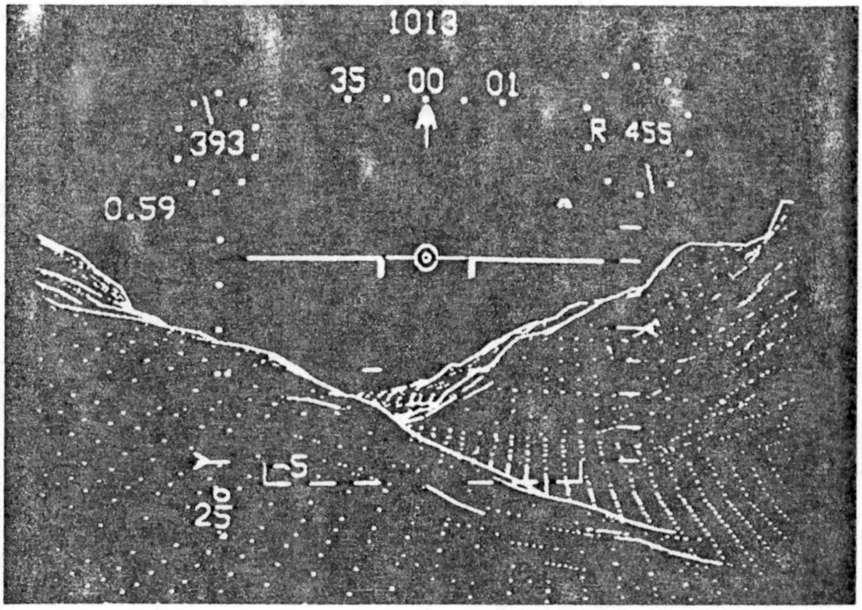


Figure 24
Ferranti International PENETRATE HUD Display
Measles Enhancement

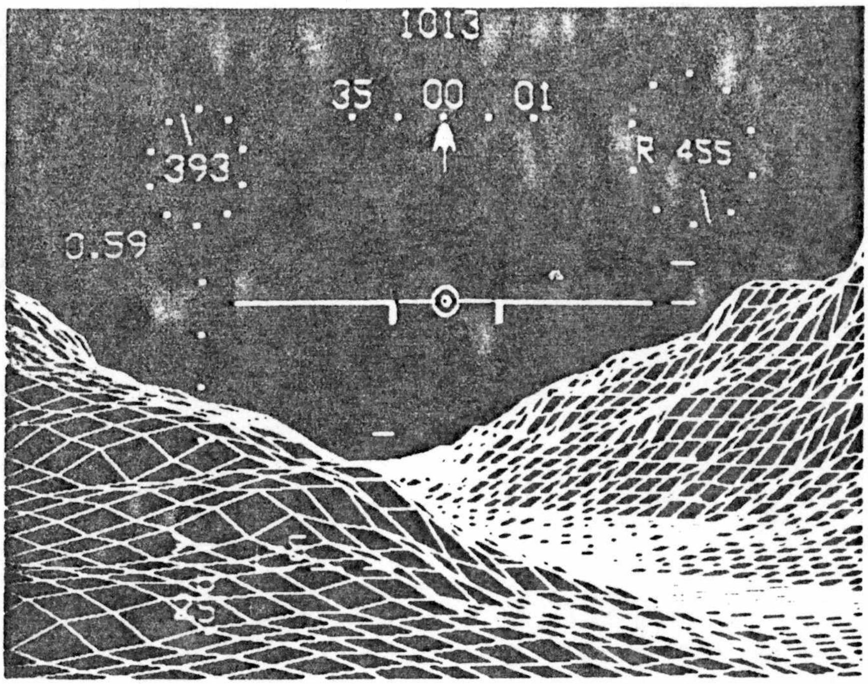


Figure 25
Ferranti International PENETRATE HUD Display
Lattice Enhancement

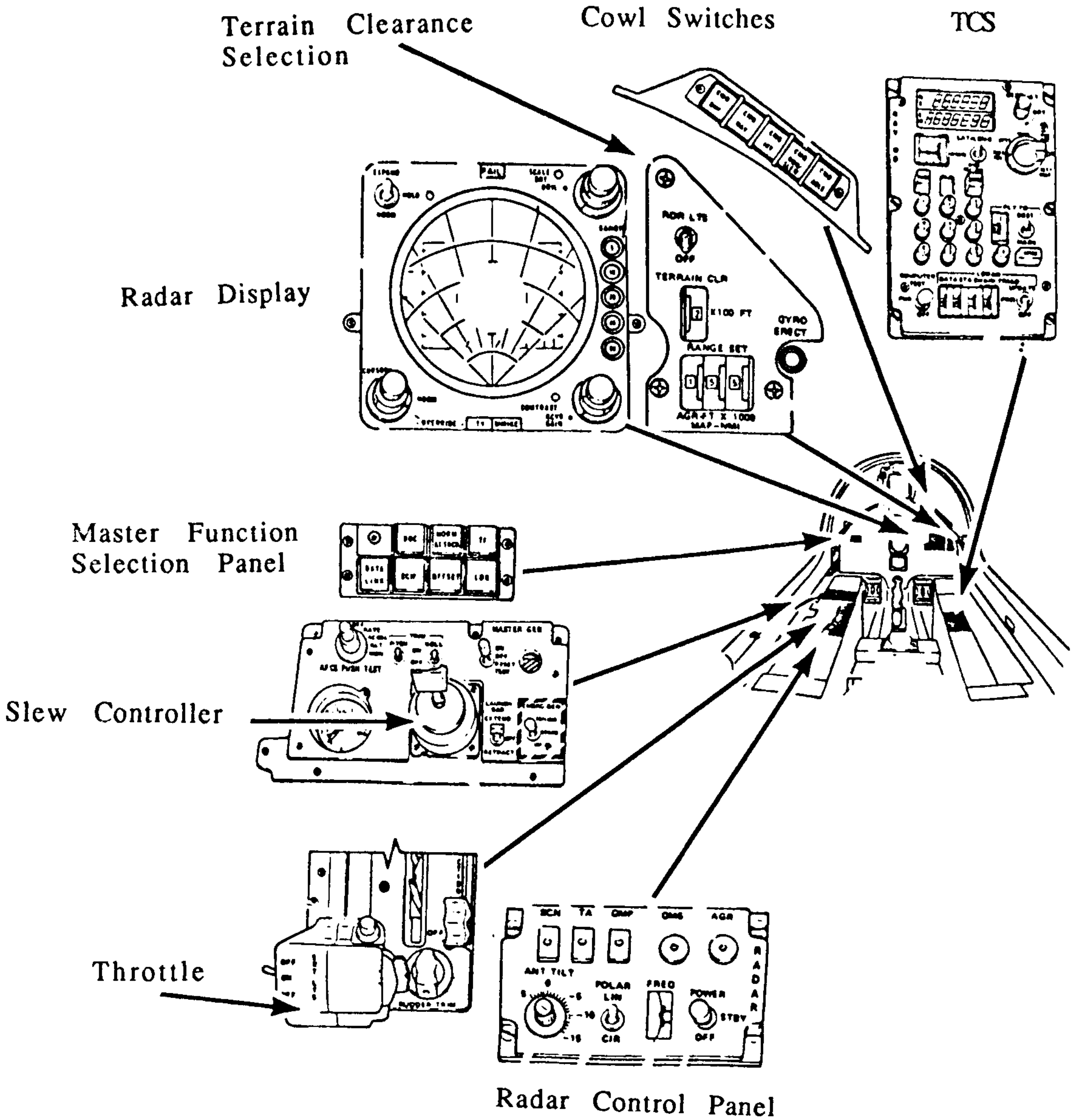
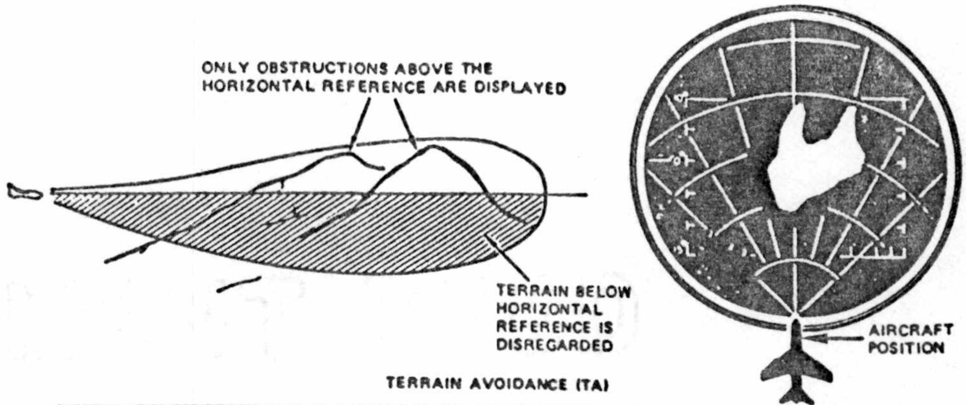
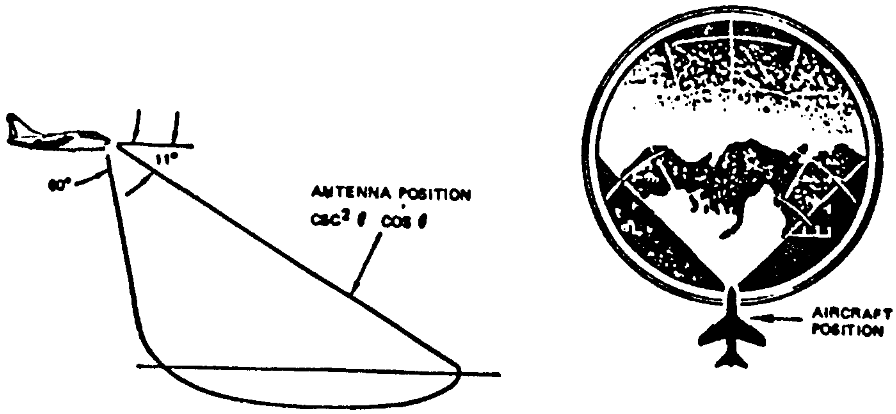


Figure 26
A-7E APQ-126(V) Radar Controls



RADAR MODE SWITCH	MASTER FUNCTION SELECTOR	RADAR DISPLAY	RANGE SELECTION	POLAR-IZATION	TILT AVAIL-ABLE	FREQ SELEC-TIVE	CURSORS
TA	NONE	±45° PPI	5, 10	SELECT	NO	YES	NONE
	LDG						

Figure 27
A-7E TA Mode Display and Operating Characteristics



GROUND MAP, SPOILED (GMS)

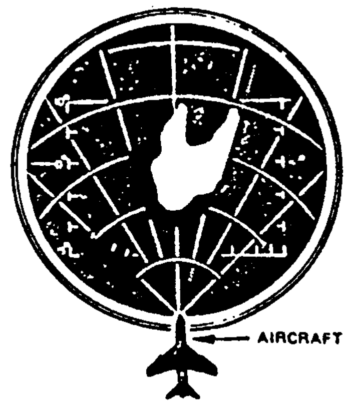
RADAR MODE SWITCH	MASTER FUNCTION SELECTOR	RADAR DISPLAY	RANGE SELECTION	POLAR-IZATION	TILT AVAILABLE		FREQ SELEC-TIVE	CURSORS
					MANUAL	AUTO		
GMS	NONE LDG	±45° PPI	5, 10, 20 40, 80	N/A	YES	NO (See note)	YES	MANUAL RANGE
	BOC BOC OFFSET	±45° PPI	5, 10, 20 40, 80	N/A	YES	YES	YES	DRIVEN RANGE AND AZIMUTH

Figure 28
A-7E GMS Mode Display and Operating Characteristics

GROUND MAP, PENCIL (GMP)

<table>
<tr><th rowspan="2">RADAR MODE SWITCH</th><th rowspan="2">MASTER FUNCTION SELECTOR</th><th rowspan="2">RADAR DISPLAY</th><th rowspan="2">RANGE SELECTION</th><th rowspan="2">POLAR-IZATION</th><th colspan="2">TILT AVAILABLE</th><th rowspan="2">FREQ SELEC-TIVE</th><th rowspan="2">CURSORS</th></tr>
<tr><th>MANUAL</th><th>AUTO</th></tr>
<tr><td rowspan="2">GMP</td><td>NONE</td><td rowspan="2">±45° PPI</td><td rowspan="2">5, 10, 20
40, 80</td><td rowspan="2">SELECT</td><td rowspan="2">YES</td><td rowspan="2">(See Note)</td><td rowspan="2">YES</td><td rowspan="2">MANUAL RANGE</td></tr>
<tr><td>LOG</td></tr>
<tr><td>GMP</td><td rowspan="2">BOC</td><td rowspan="4">±45° PPI</td><td rowspan="4">5, 10, 20
40, 80</td><td rowspan="4">SELECT</td><td rowspan="4">YES</td><td rowspan="4">YES</td><td rowspan="4">YES</td><td rowspan="4">DRIVEN RANGE AND AZIMUTH</td></tr>
<tr><td>TA</td></tr>
<tr><td>BCN</td><td rowspan="2">BOC OFFSET</td></tr>
<tr><td>AGR</td></tr>
</table>

Figure 29
A-7E GMP Mode Display and Operating Characteristics



CROSS SCAN TERRAIN AVOIDANCE (CSTA)

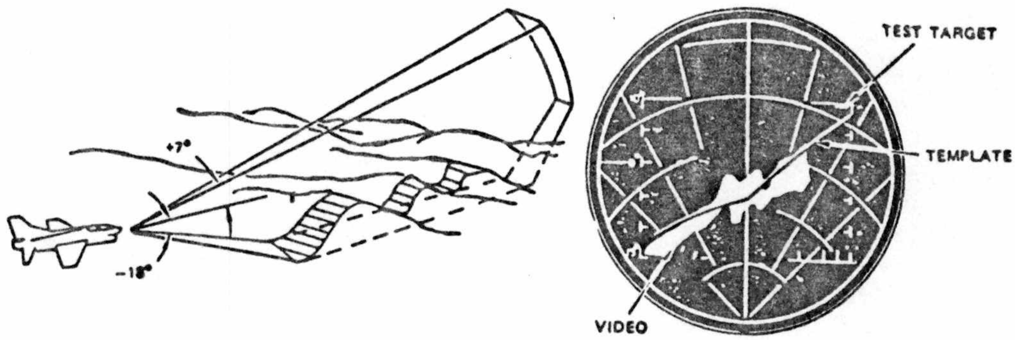
RADAR MODE SWITCH	MASTER FUNCTION SELECTOR	RADAR DISPLAY	RANGE SELECTION	POLAR-IZATION	TILT AVAIL-ABLE	FREQ SELEC-TIVE	CURSORS
TA	TF	±20° PPI	5, 10	SELECT	NO	YES	NONE

Figure 30
A-7E CSTA Mode Display and Operating Characteristics

CROSS SCAN GROUND MAP, PENCIL (CSGMP)

RADAR MODE SWITCH	MASTER FUNCTION SELECTOR	RADAR DISPLAY	RANGE SELECTION	POLAR-IZATION	TILT AVAIL-ABLE	FREQ SELEC-TIVE	CURSORS
GMP	TF	±20° PPI	5, 10	SELECT	YES	YES	MANUAL RANGE

Figure 31
A-7E CSGMP Mode Display and Operating Characteristics



TERRAIN FOLLOWING (TF)

RADAR MODE SWITCH	MASTER FUNCTION SELECTOR	RADAR DISPLAY	RANGE SELECTION	POLAR-IZATION	TILT AVAIL-ABLE	FREQ SELEC-TIVE	CURSORS
BCN	TF	E^2	10	SELECT	NO	YES	NONE
GMS							
AGR							

Figure 32
A-7E TF Mode Display and Operating Characteristics

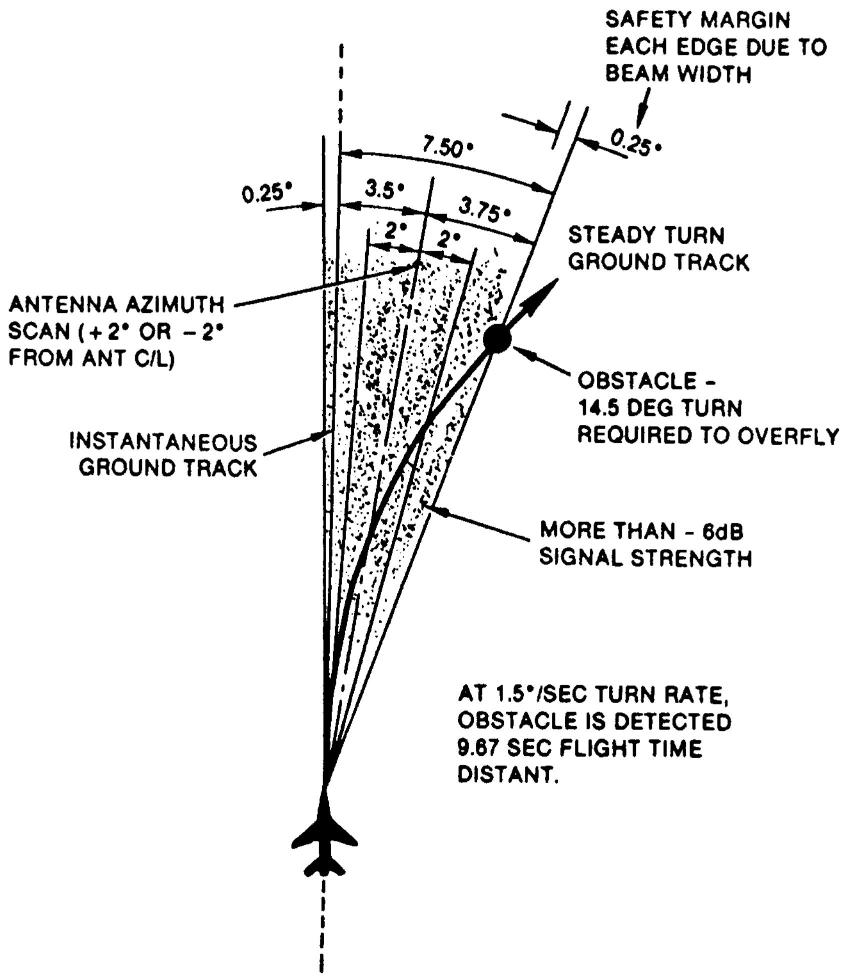


Figure 33
A-7 LANA TF Turn Lead

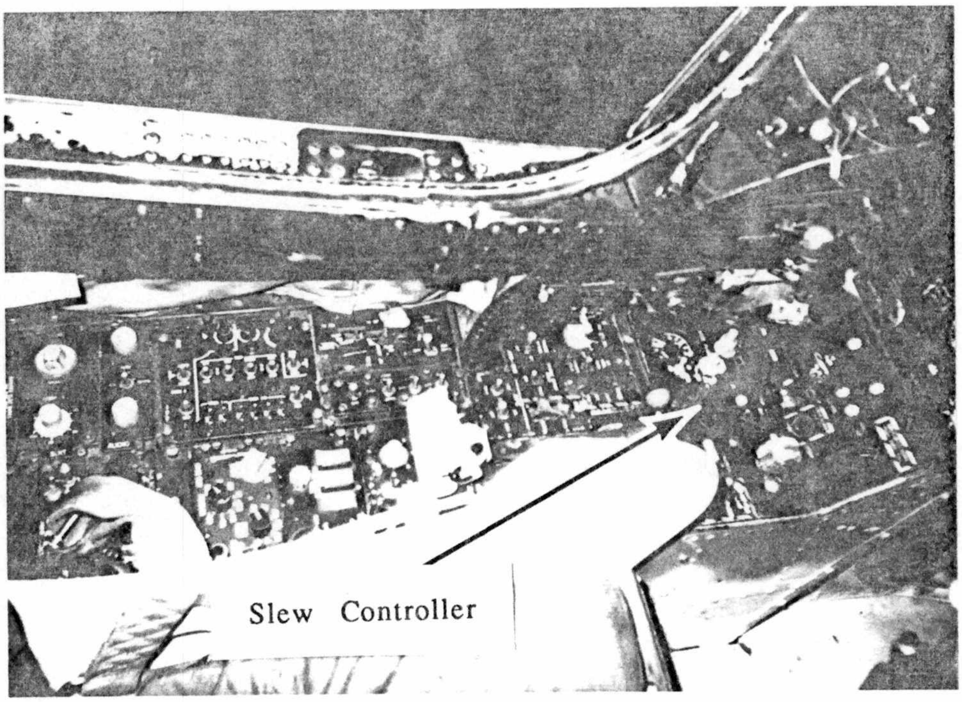


Figure 34
A-7E Slew Controller

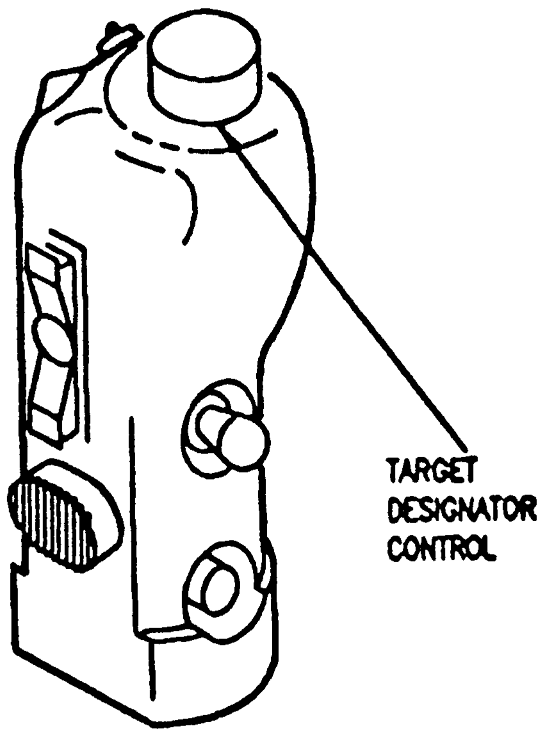


Figure 35
AV-8 TDC

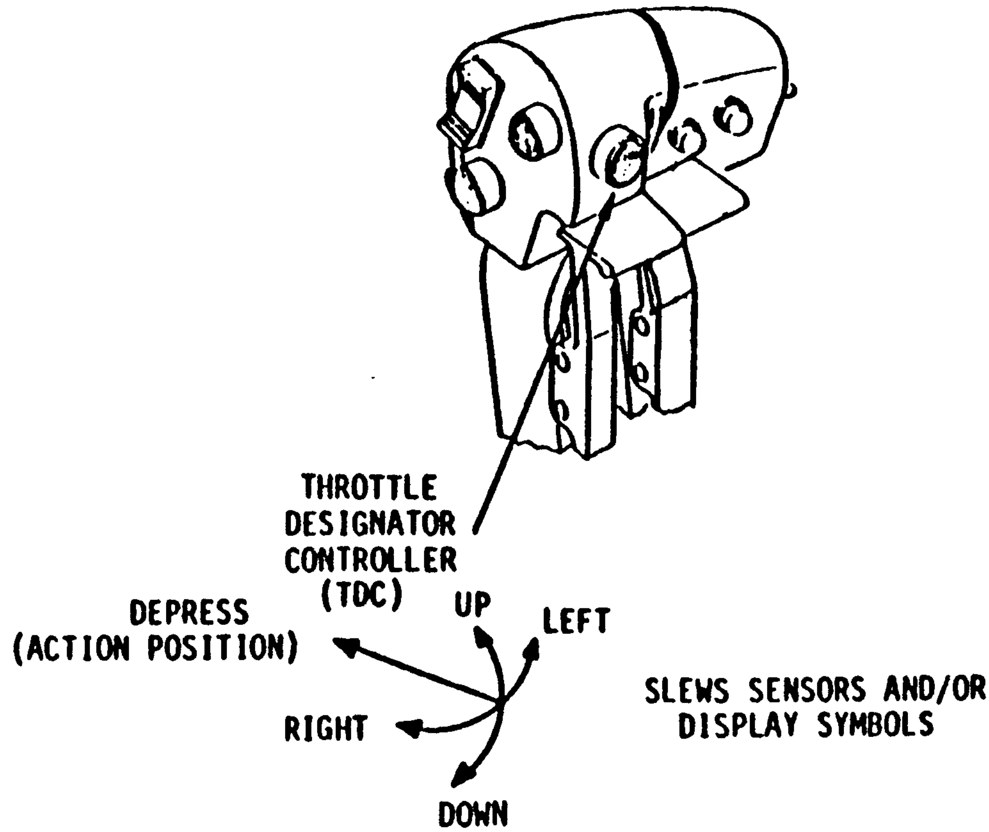


Figure 36
F-18 TDC

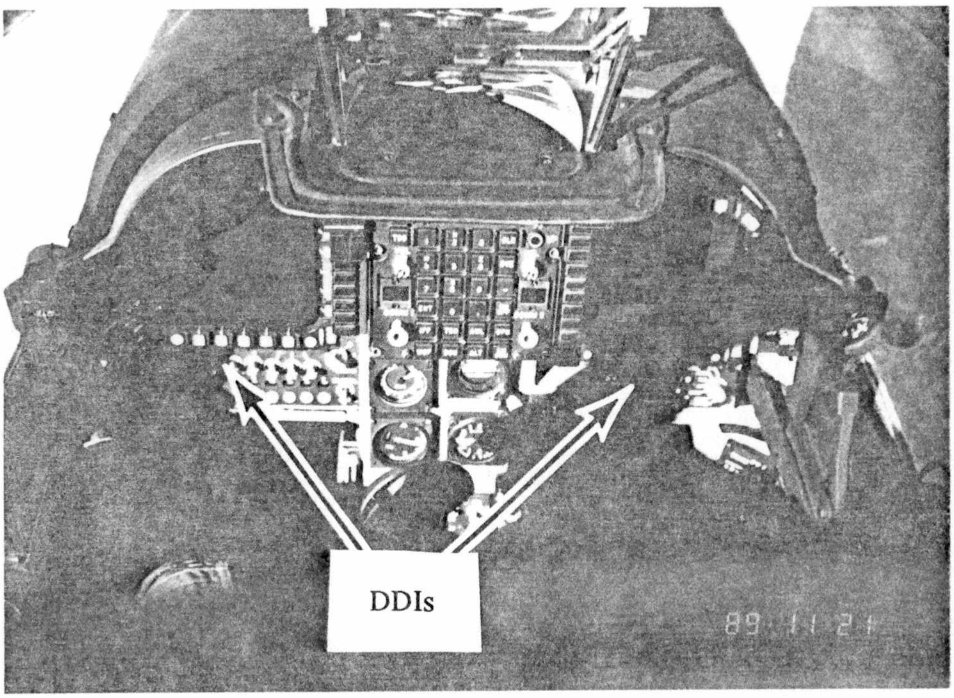


Figure 37
AV-8 DDI

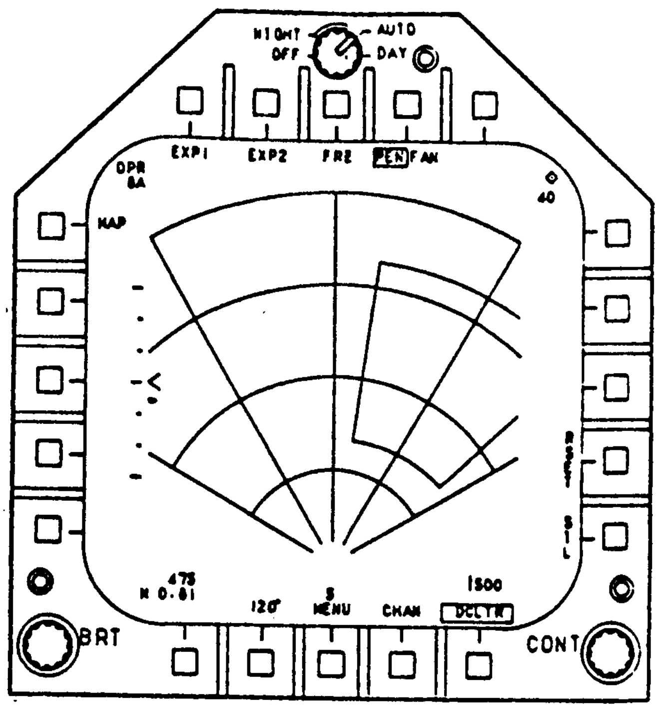


Figure 38
F-18 DDI

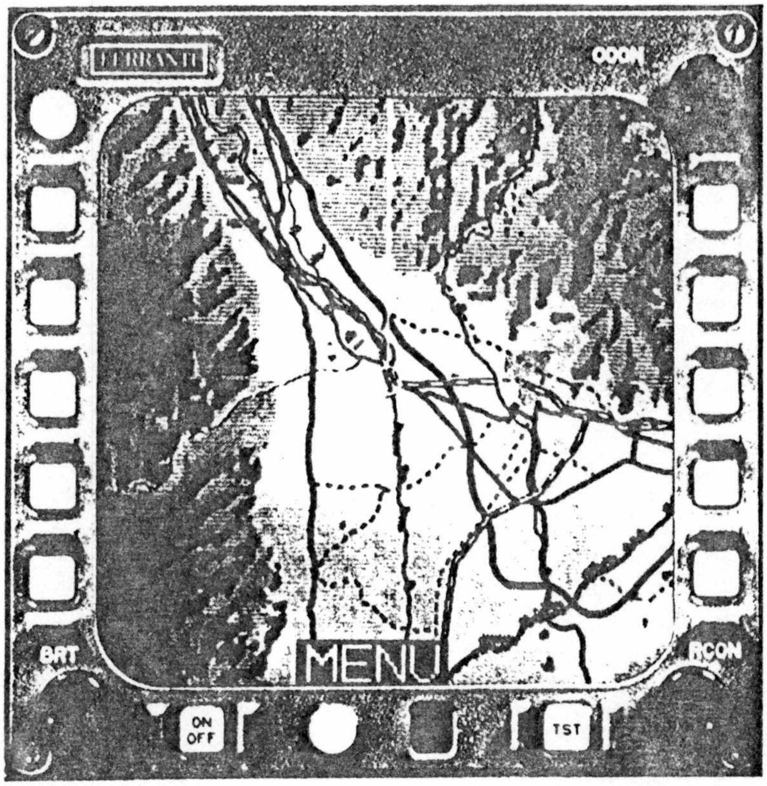


Figure 39
Ferranti International PENETRATE TRN DDI

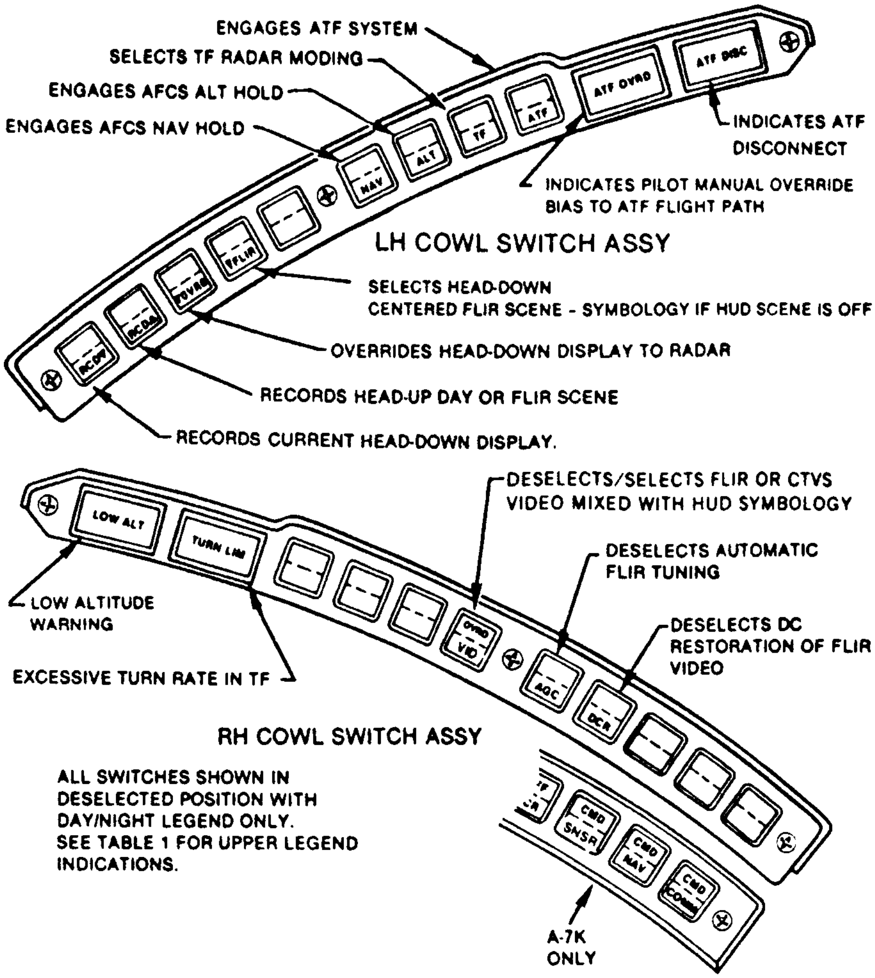


Figure 40
A-7 LANA Cowl Switches

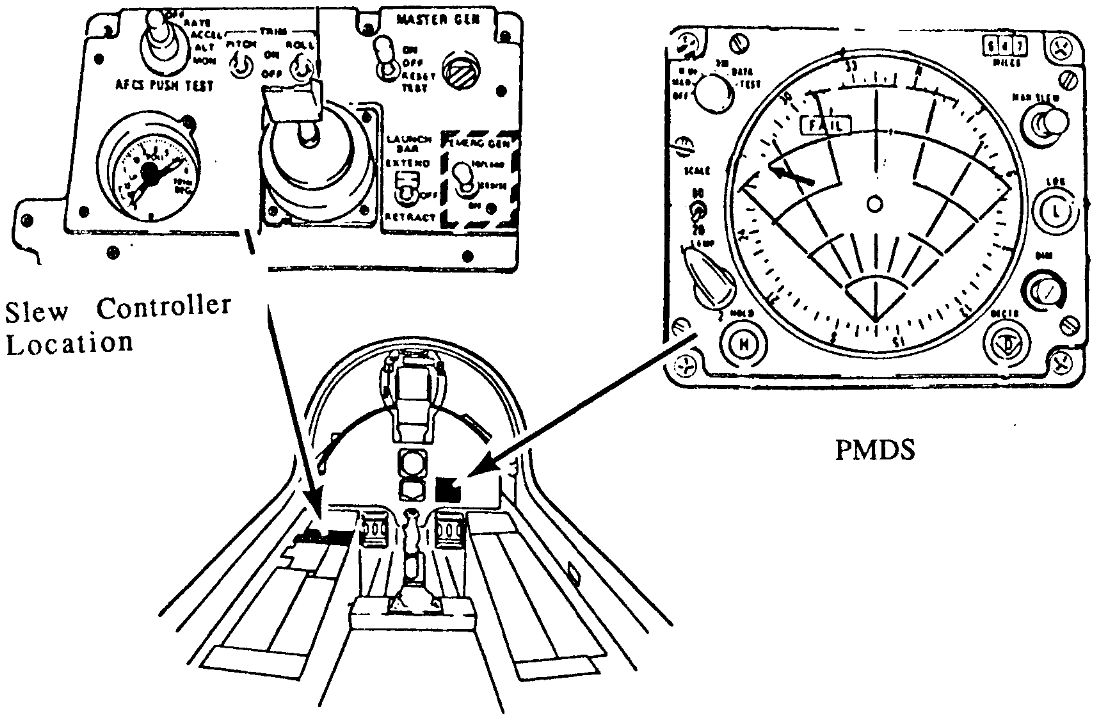


Figure 41
A-7E PMDS Controls and Display

Figure 42
Ferranti International PENETRATE
Digitized Map 2 Dimensional Overlay

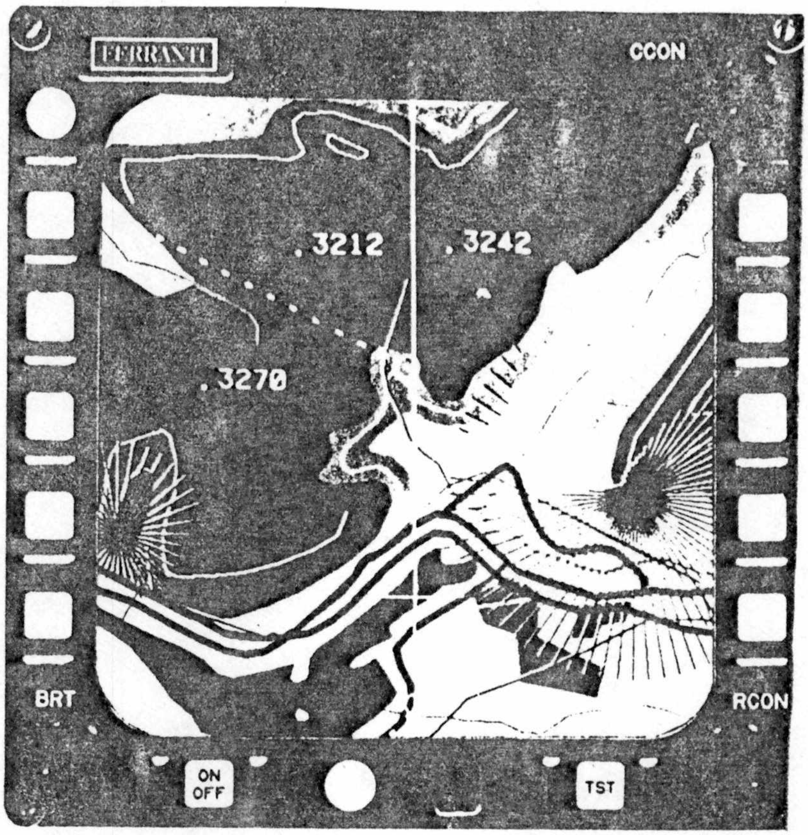


Figure 43
Ferranti International PENETRATE
Digitized Map 3 Dimensional Overlay

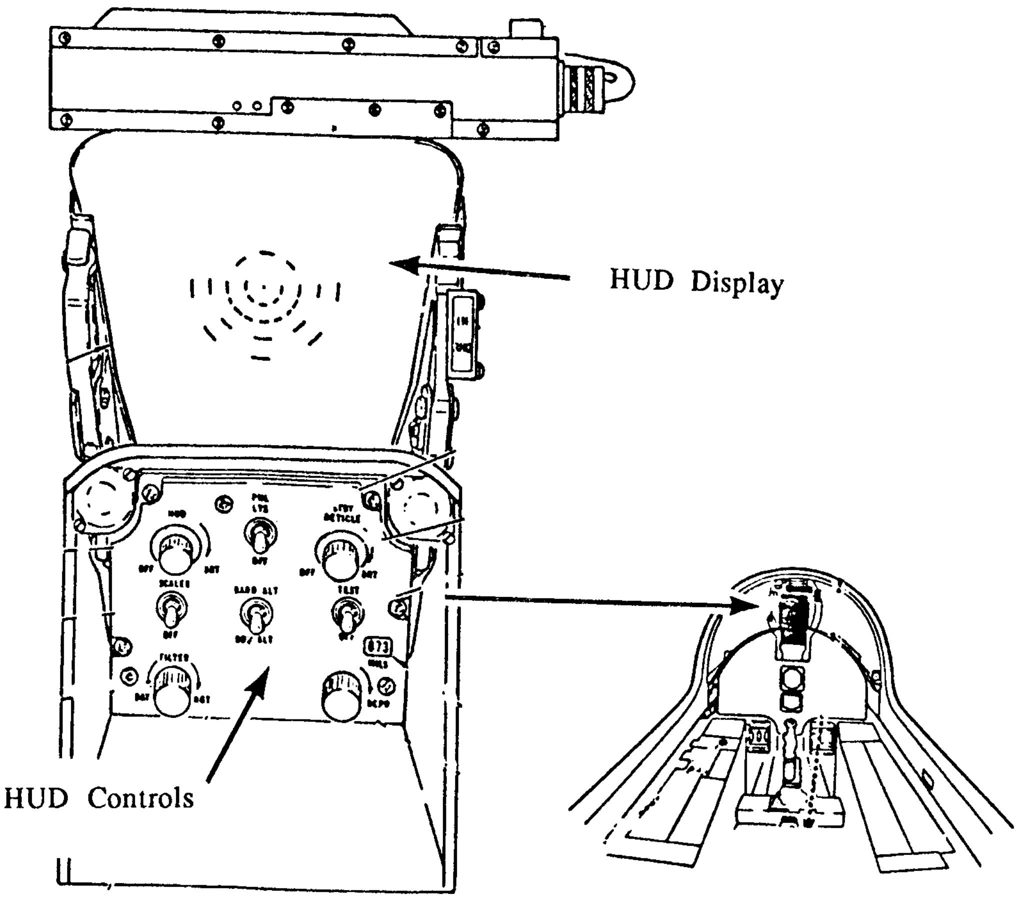


Figure 44
A-7E HUD Illustration

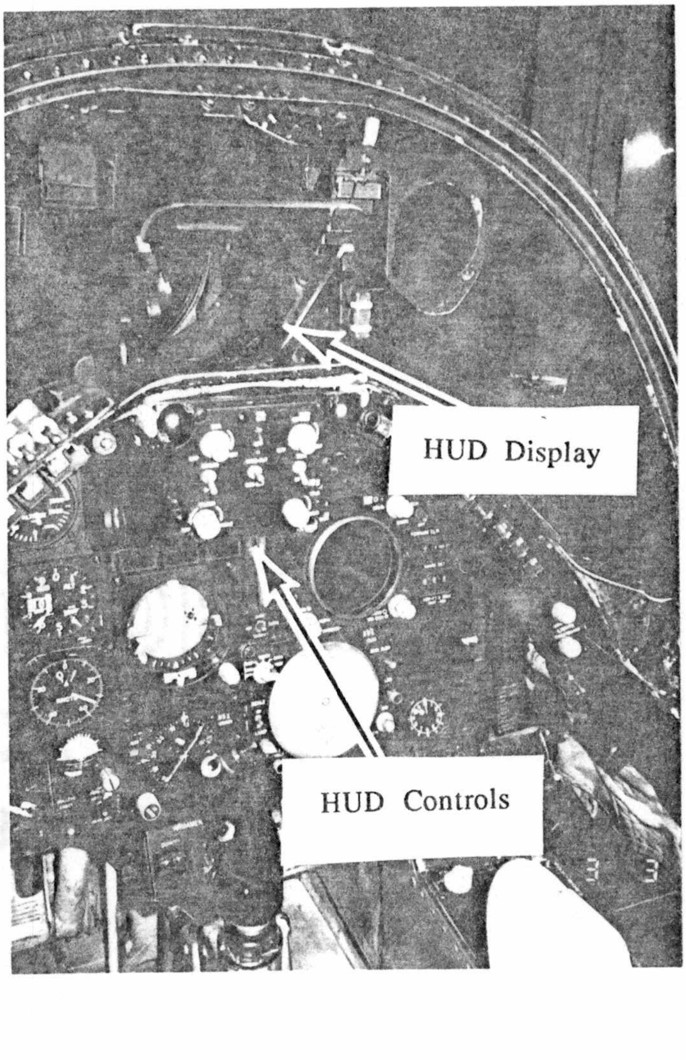
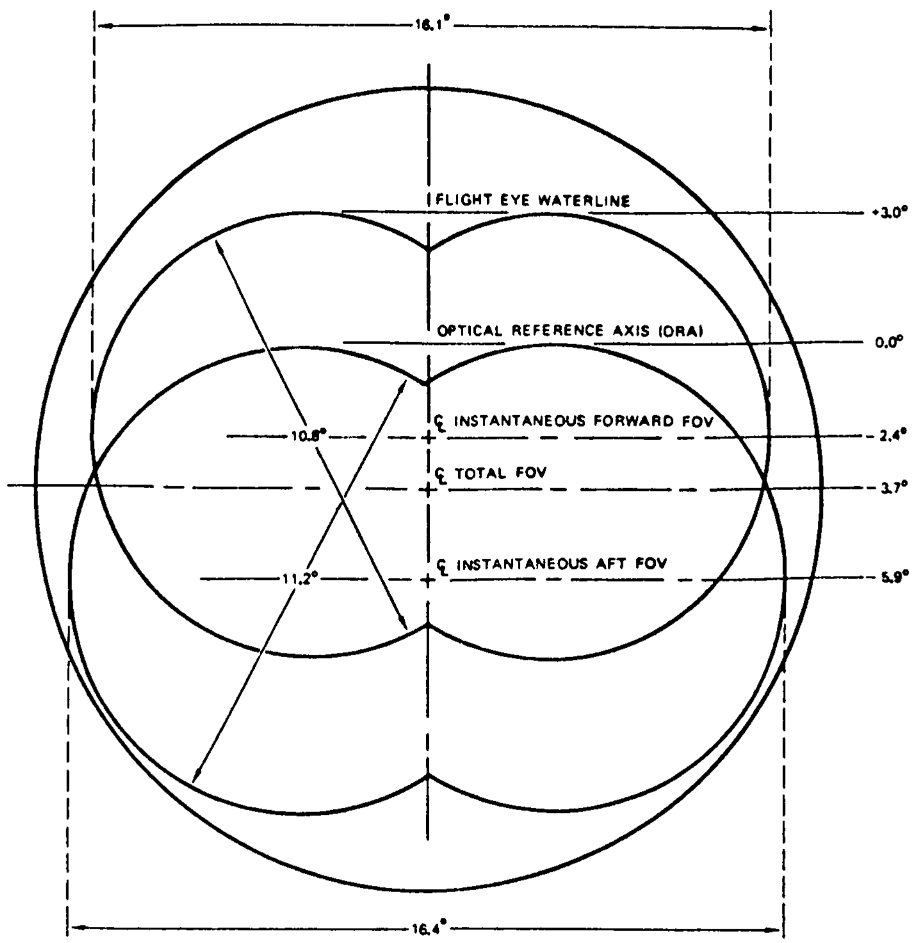


Figure 45
A-7E HUD Photograph



NOTE

Total Field of View 20°
Forward Vertical Instantaneous FOV 10.8°
Aft Vertical Instantaneous FOV 11.2°

Figure 46
A-7E HUD FOV Diagram

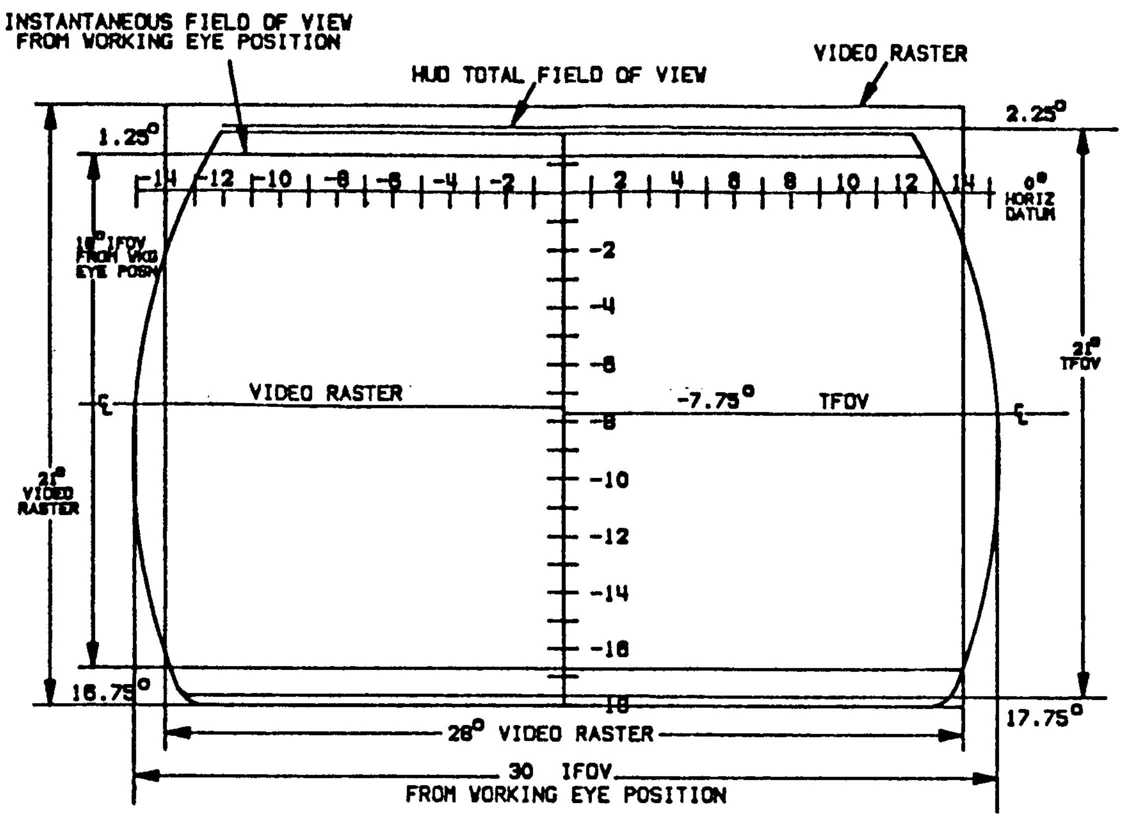


Figure 47
F-16 LANTIRN HUD

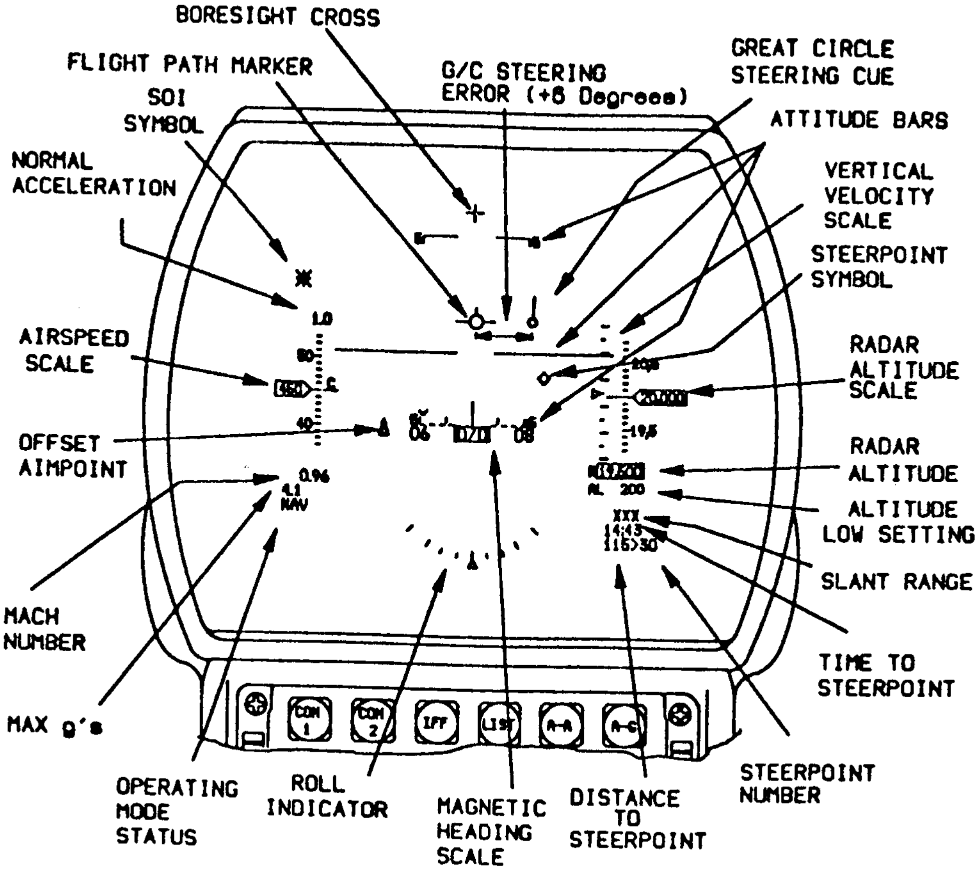


Figure 48
F-16 LANTIRN HUD Symbology

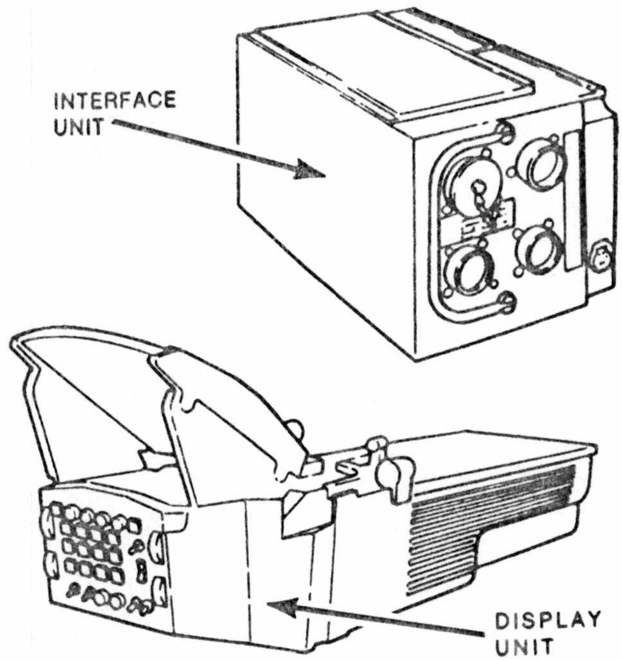


Figure 49
A-7 LANA HUD System Components

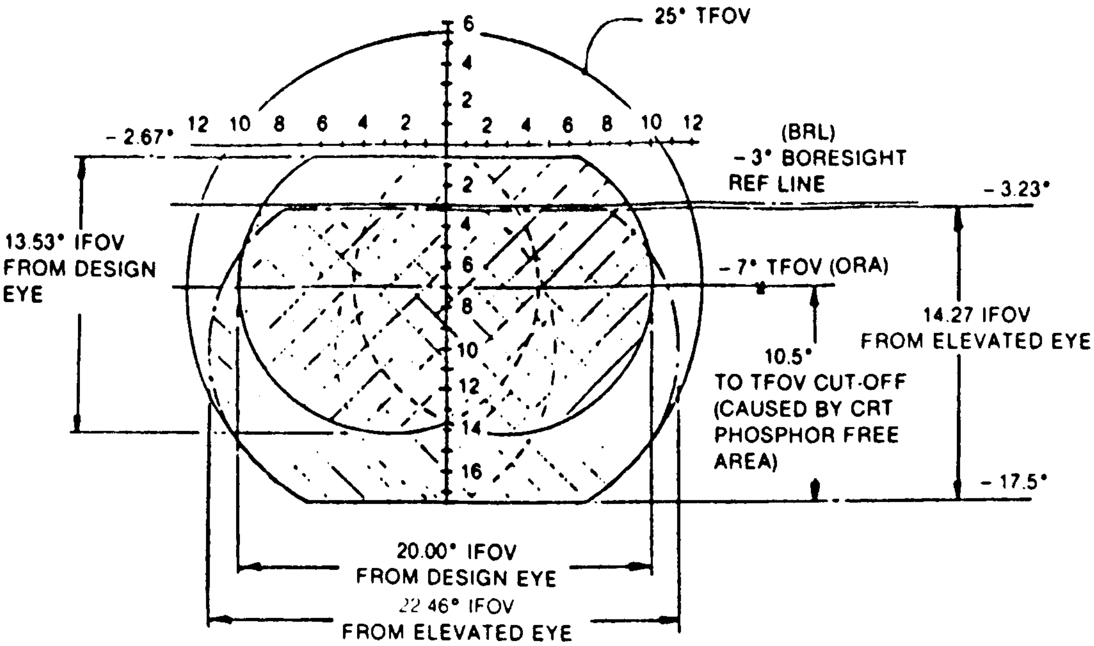


Figure 50
A-7 LANA HUD FOV

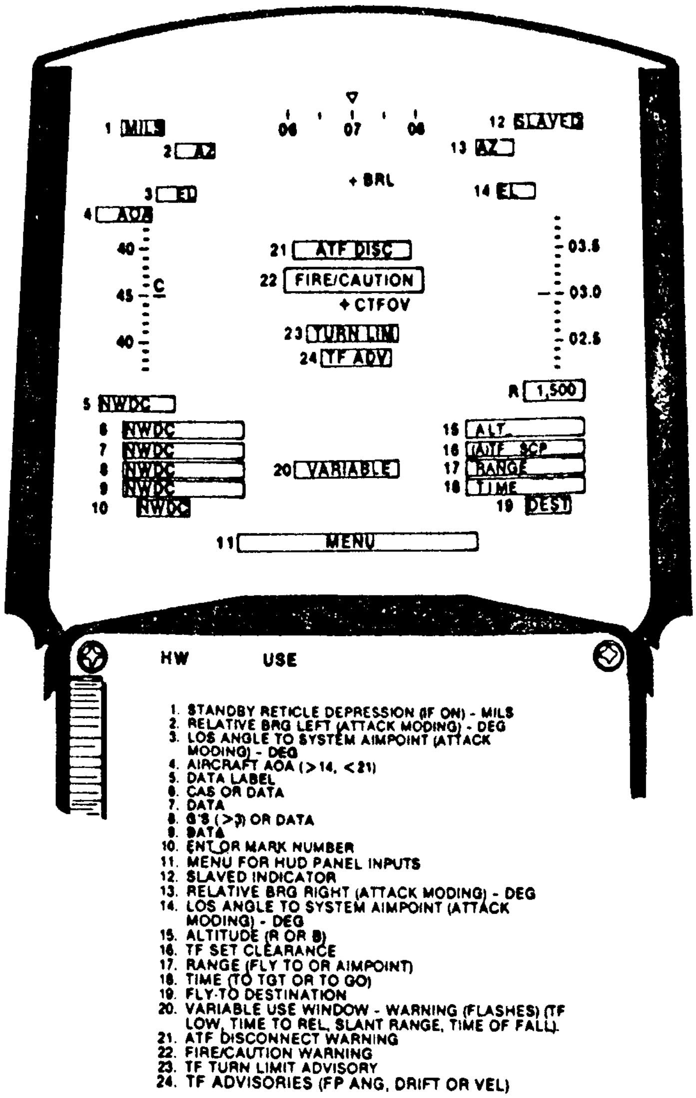


Figure 51
A-7 LANA HUD Window Utilization

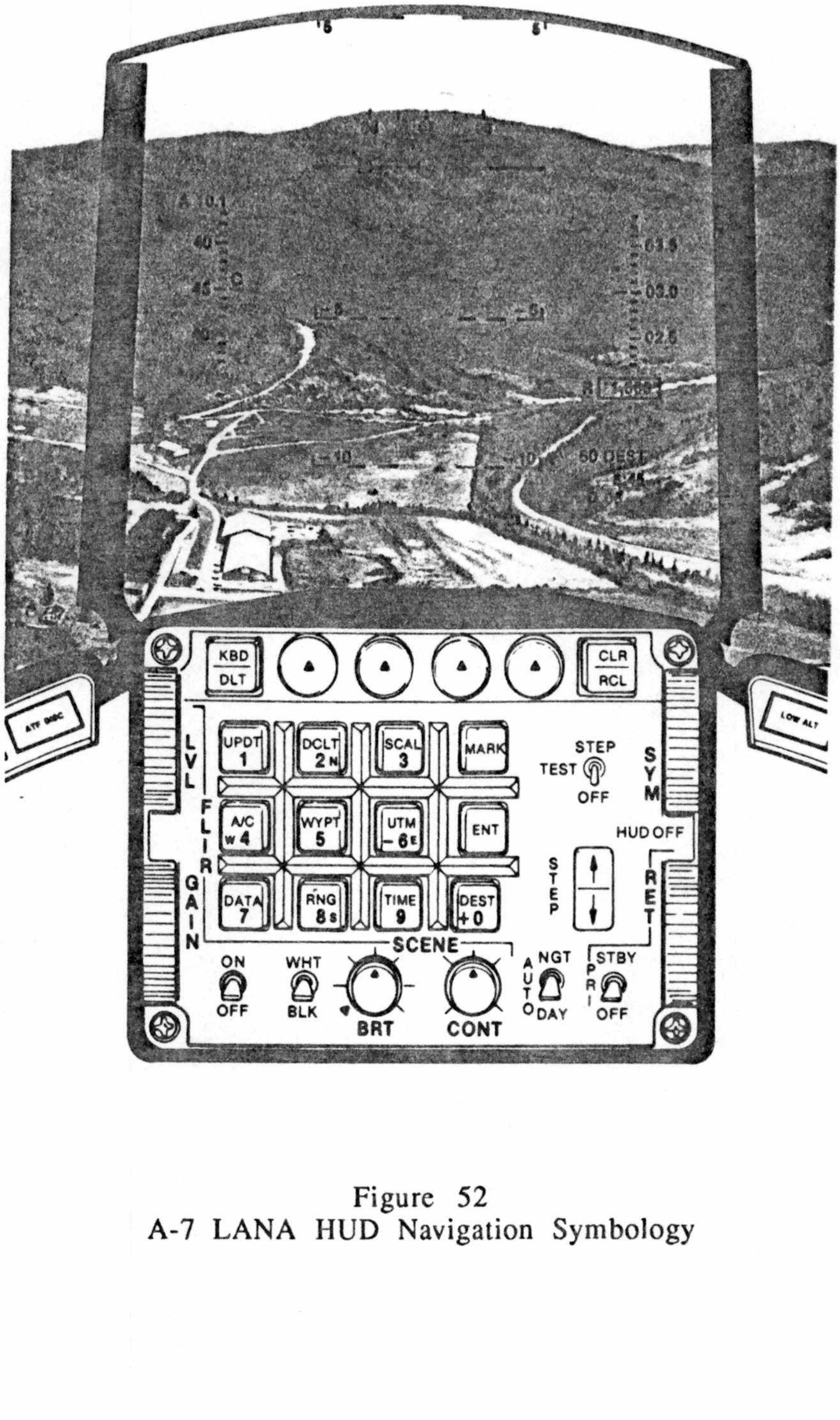


Figure 52
A-7 LANA HUD Navigation Symbology

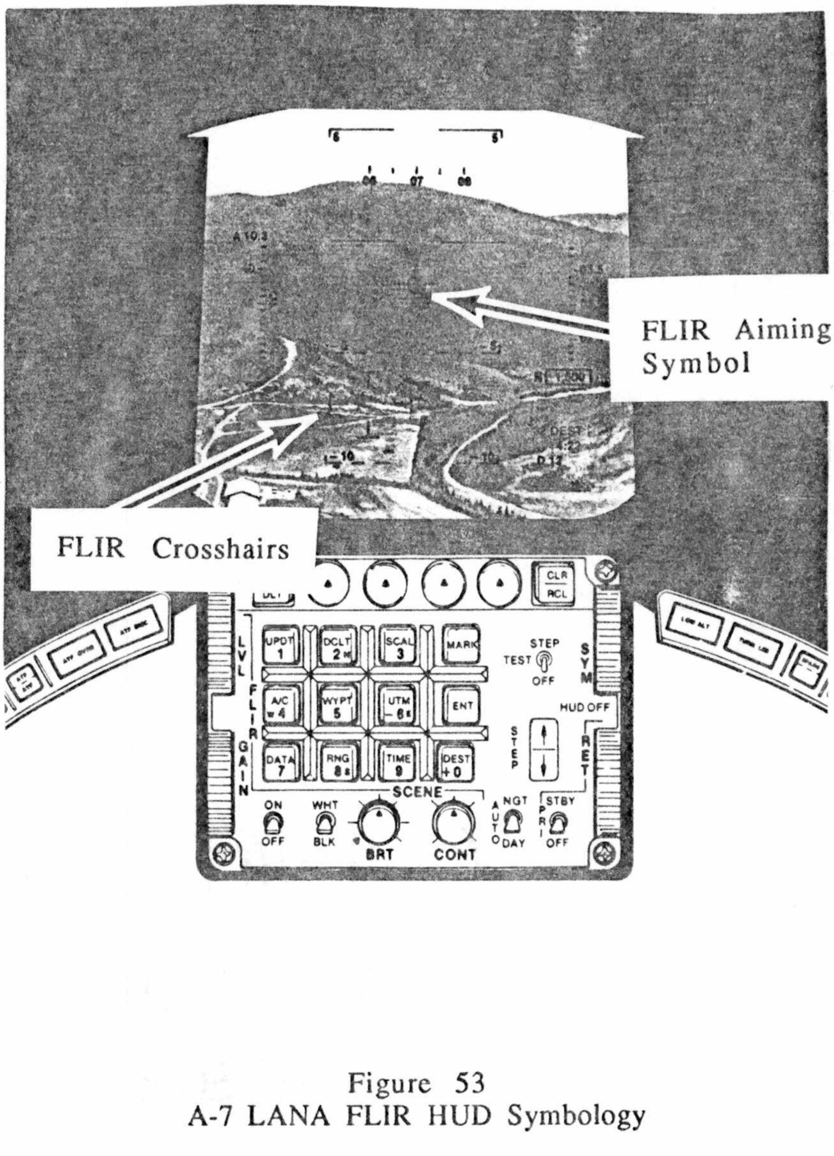


Figure 53
A-7 LANA FLIR HUD Symbology

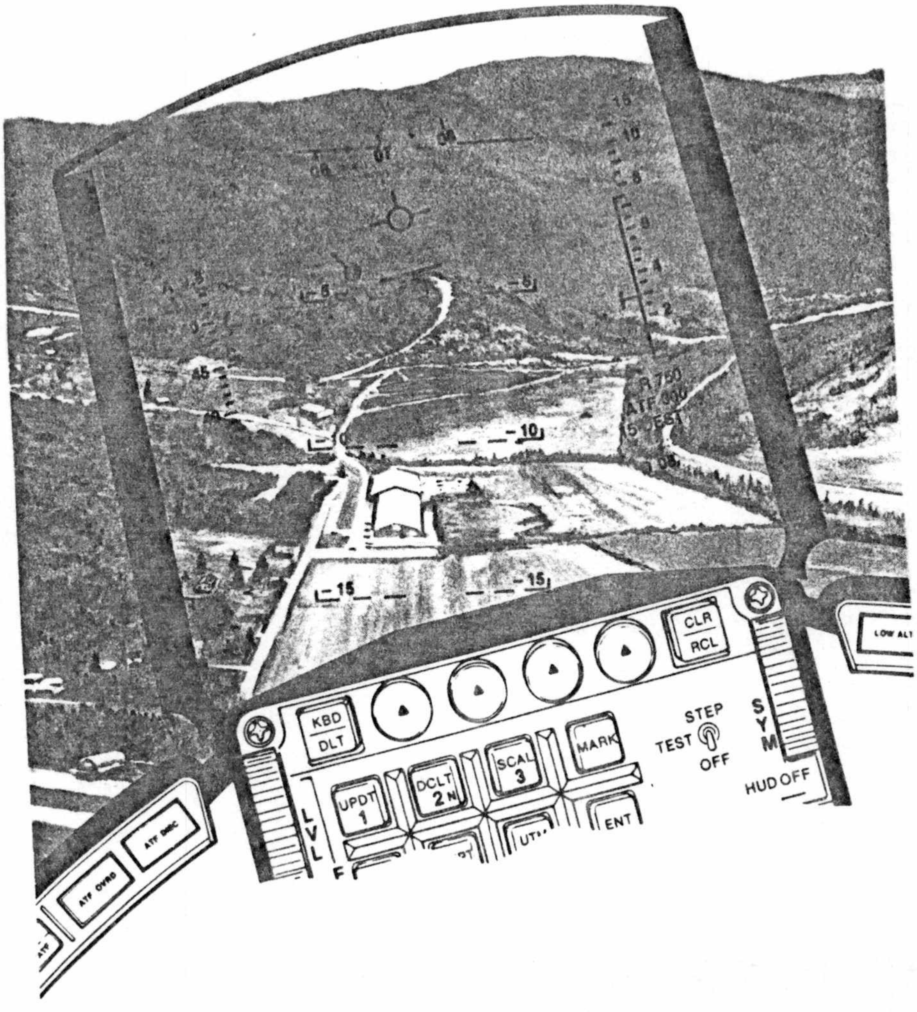


Figure 54
A-7 LANA TF Command HUD Symbology

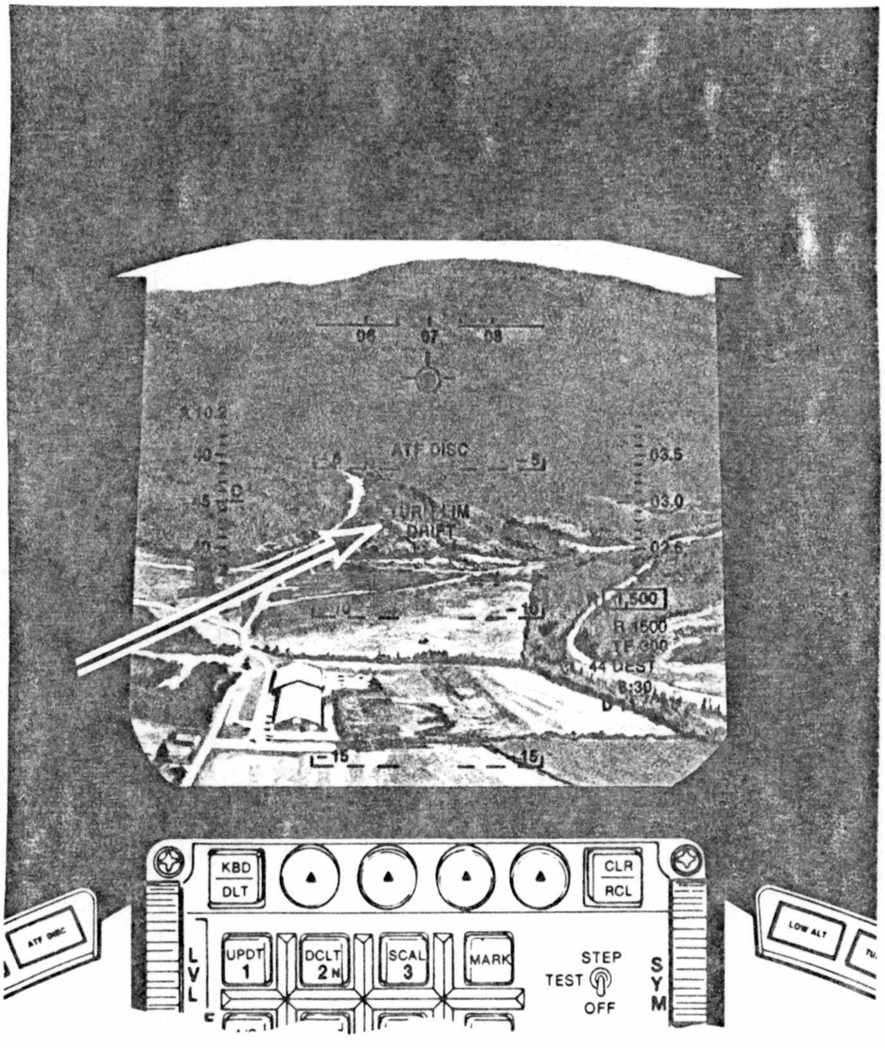


Figure 55
A-7 LANA TF Warning HUD Symbology

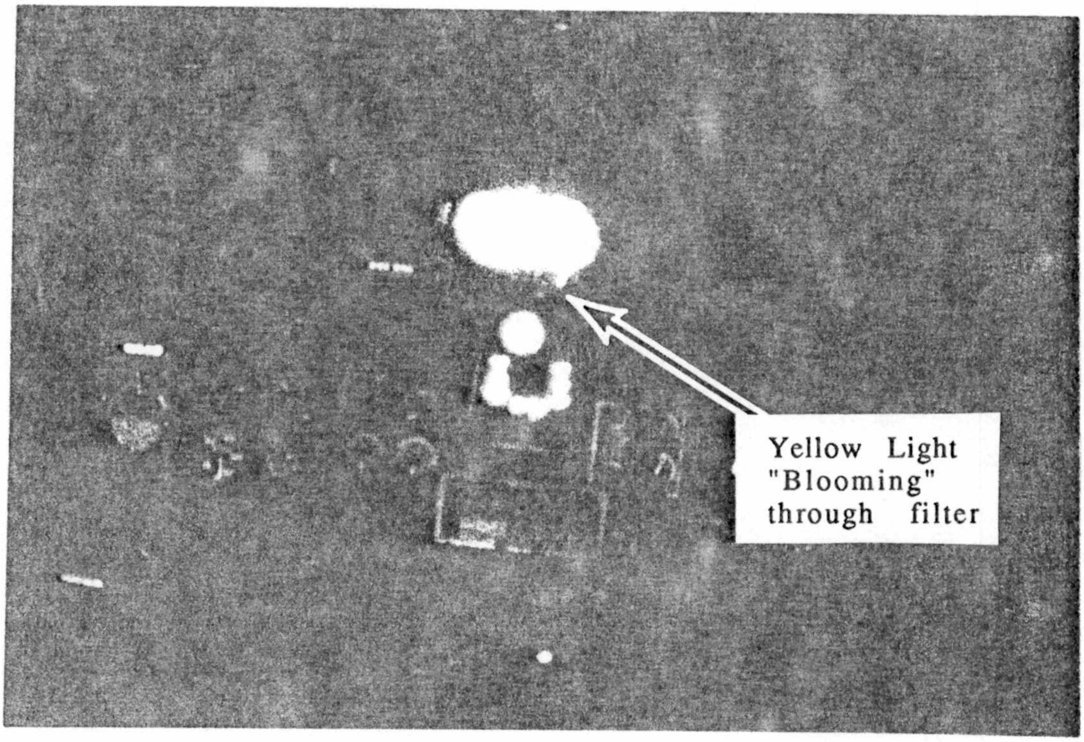


Figure 56
NVG Yellow Light "Blooming"

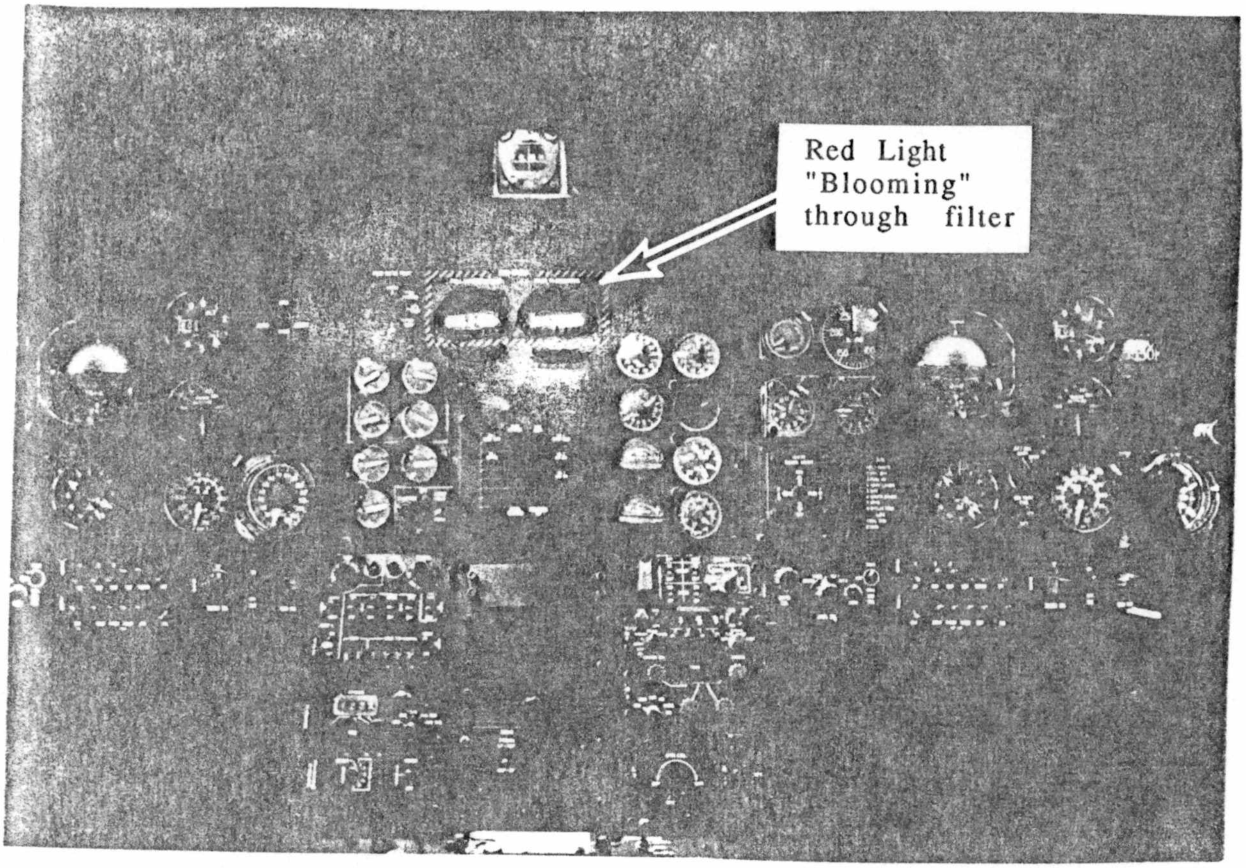


Figure 57
NVG Red Light "Blooming"

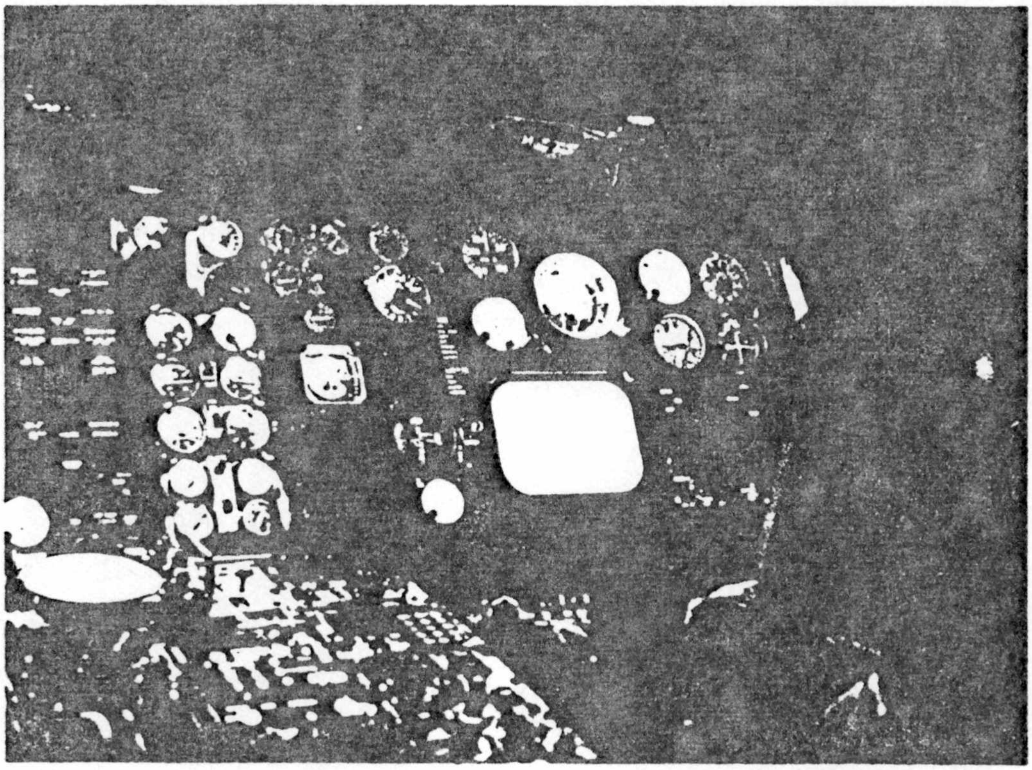


Figure 58
Control Products Corporation
Original Cockpit Display Prior to Lumicon Integration

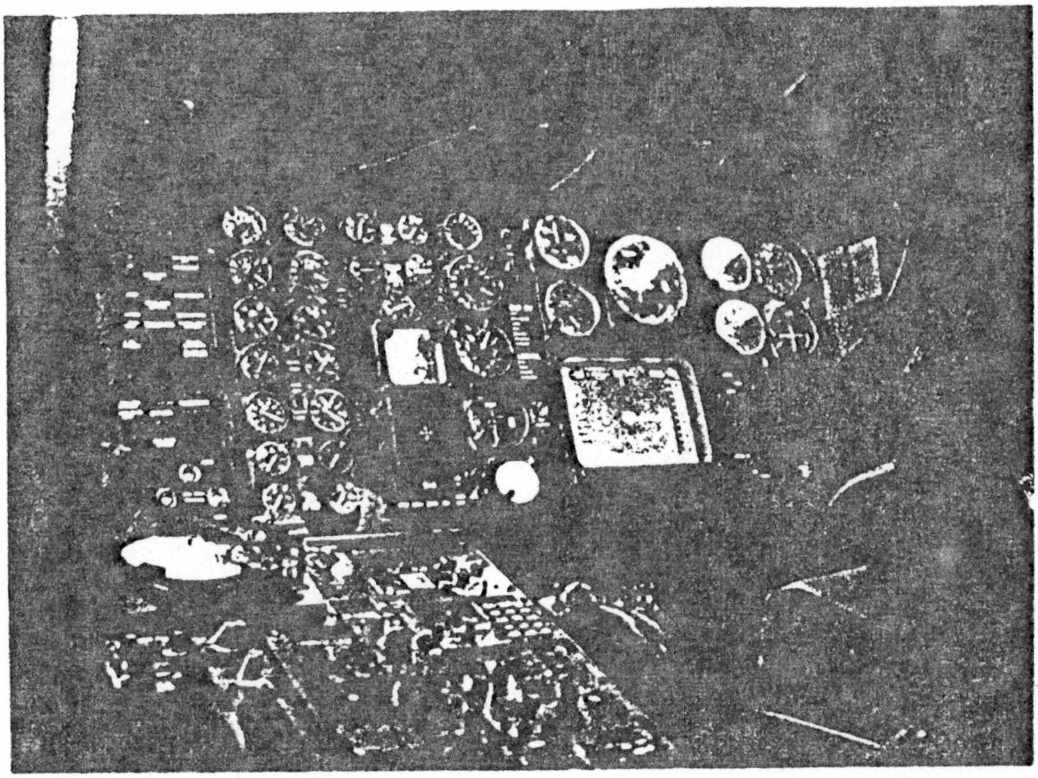


Figure 59
Control Products Corporation
Total Cockpit Lumicon Modified (Unaided Eye)

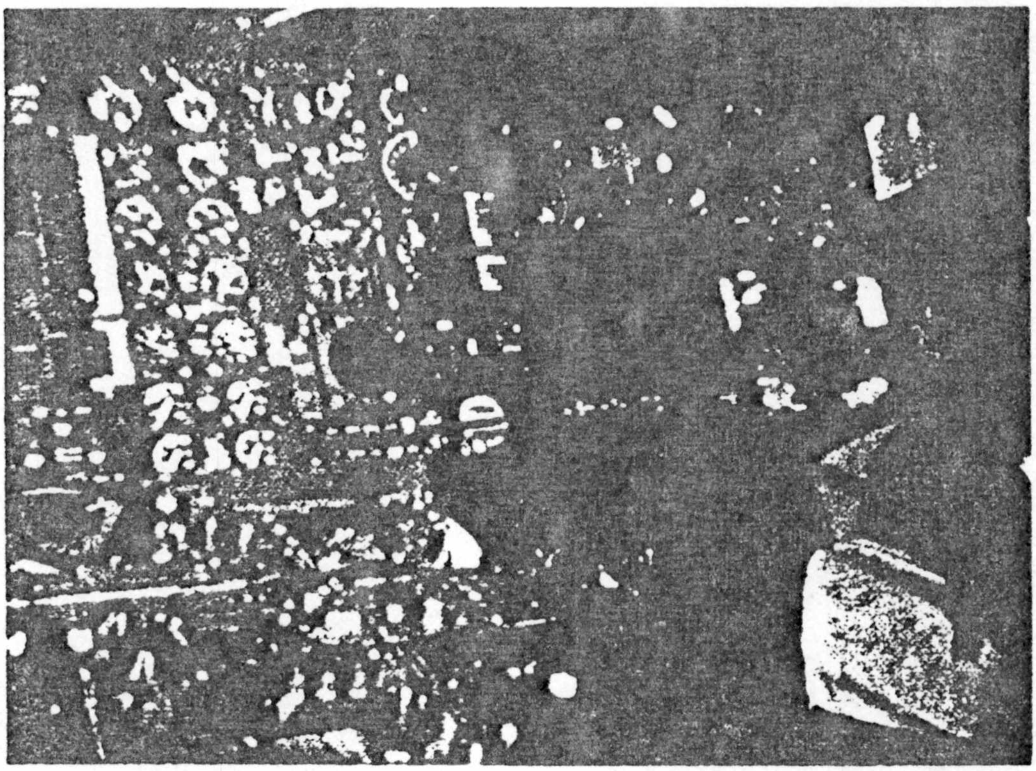


Figure 60
Control Products Corporation
Total Cockpit Lumicon Modified (View through AN/AVS-6)

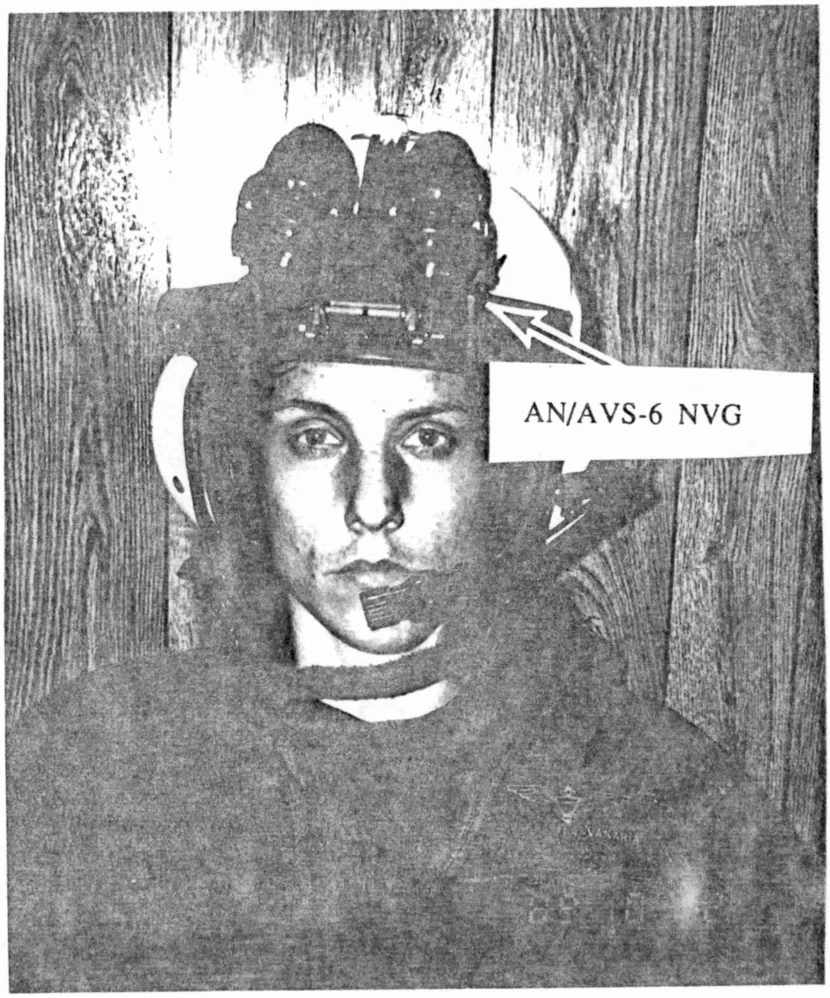


Figure 61
Pilot Wearing AN/AVS-6 NVG

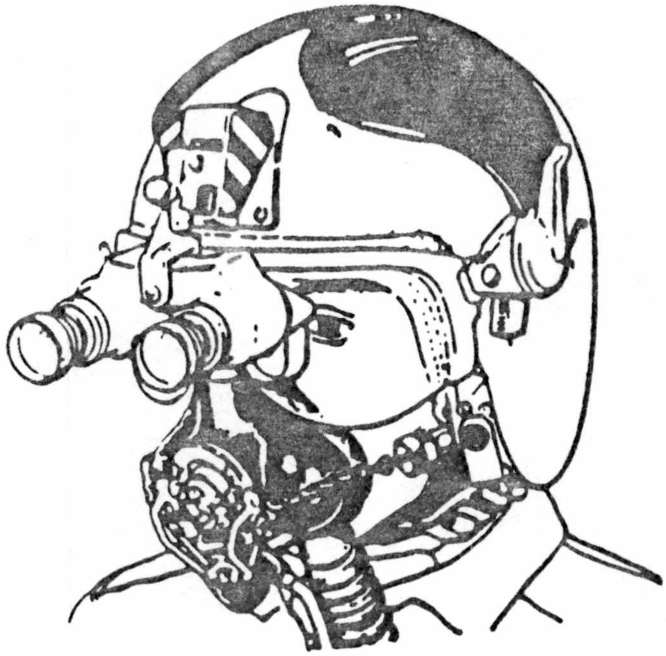


Figure 62
Abstract of Pilot Wearing "Cats Eyes"

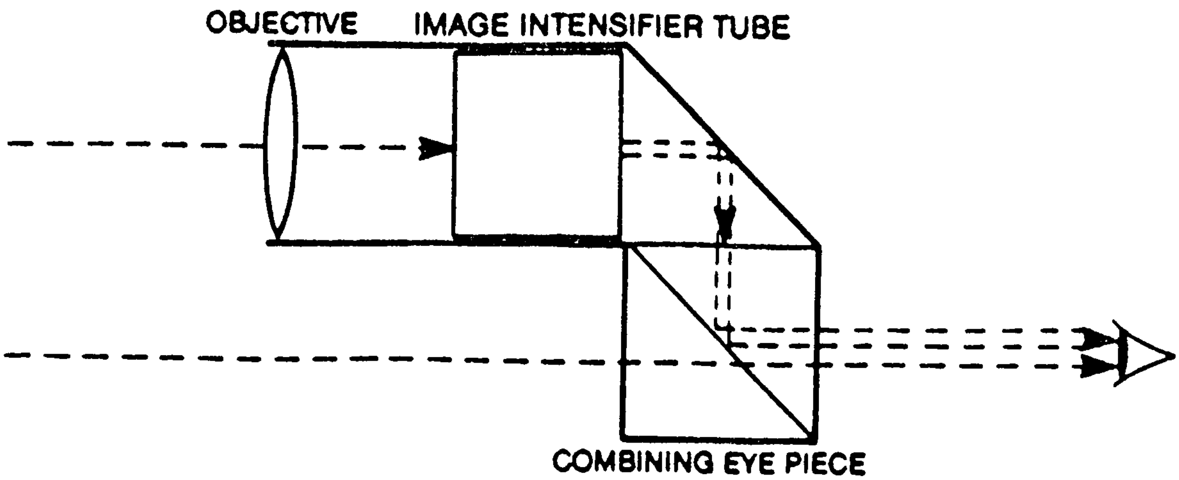


Figure 63
"Cats Eyes" Direct View Concept

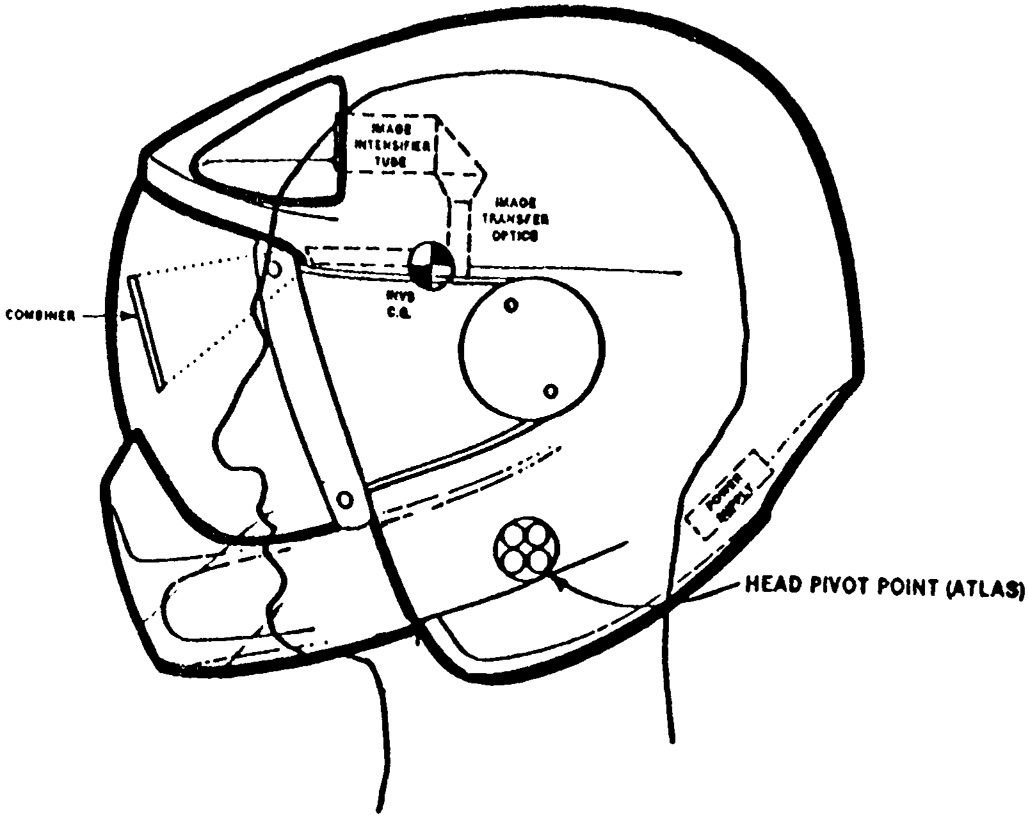


Figure 64
INVIS Abstract

APPENDIX B

TABLES

Table I
TA-7C IMS ALIGNMENT TIME

Date 1988	Temp (deg F)	Humidity (% Relative)	Alignment Time (min:sec)
28 June	70	70	10:06
1 July	65	70	9:57
6 July	68	70	10:16
6 July	72	70	10:20

Table II
TA-7C CLOSEOUT IMS ERRORS IN POSITION

Actual Lat	Position Long	System Lat	Position Long	N-S Error (nm)	W-E Error (nm)	Radial Error (nm)
3407.0	11907.7	3406.5	11907.2	-0.50	-0.41	0.65
3407.0	11907.7	3411.3	11906.3	4.30	-1.16	4.45
3407.0	11907.7	3410.1	11907.8	3.10	0.08	3.10

APPENDIX C

GLOSSARY OF TERMS

GLOSSARY OF TERMS

"ALL WEATHER": Weather capability referred to when evaluating attack aircraft mission performance.

"BLOOMING": Cockpit lighting excesses causing blurriness particularly detrimental for NVG operations.

BOMB ON COORDINATES: Computerized weapons delivery mode with displays and moding described in the aircraft Tactical Manual

"CATS EYES": Direct view NVG utilized in tactical jet aircraft and optimized for low level flight.

DECLUTTER: Refers to removing unnecessary information from a tactical display.

FLIGHT PATH MARKER: Velocity vector indicating actual aircraft flight path.

HUMIDITY: Moisture content of air.

IMAGE INTENSIFIER (I^2): An electronic device that amplifies light.

IMS CLOSEOUT POSITION ERROR: Error measurement performed at end of flight to compare system indicated inertial position to actual aircraft inertial position.

MANAGEMENT BY EXCEPTION: Providing specific cueing only for an undesired situation such as potential ground impact.

MANAGEMENT BY OBJECTIVES: Providing cueing for an objective such as turning right at a certain waypoint.

MARK: An instantaneous computer recallable inertial position taken by the pilot in flight.

OFFSET APPROACH POINT: Designated point near but not at the target utilized in weapons delivery for orientation when target is a small point target or terrain is nondescript.

PERSPECTIVE IMAGES: Images which highlight obstruction cues, ridge lines, etcetera.

POINT TARGETS: Small single target such as a tank or small building.

PURE INERTIAL MODE: Navigation utilizing inertial system only without augmentation of doppler.

SATELLITE EPHEMERIS: A device which provides the position of the satellite to the user.

"SINGLE SEAT": Refers to mission performed with one pilot and no other aircrew on board.

SITUATIONAL AWARENESS: Pilot awareness of everything happening both internal and external to the cockpit to include all mission and aircraft aspects essential to flight safety and mission completion.

TERRAIN MASKING: When the terrain is utilized to mask the aircraft during low level ingress.

"TIGHT" NAVIGATION: Accurate alignment with minimal drift throughout duration of airborne mission.

APPENDIX D

LIST OF ABBREVIATIONS

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A	
A/A	Air-to-Air Ranging
ACLS	Automatic Carrier Landing System
ADC	Air Data Computer
ADF	Automatic Direction Finding
ADI	Attitude and Direction Indicator
AFCS	Automatic Flight Control System
AGL	Above Ground Level
AGR	Air-to-Ground Ranging
AMF	Automatic Maneuvering Flaps
AOA	Angle-of-Attack
ARU	Airborne Refrigeration Unit
AS	Aiming Symbol
ASCU	Armament Station Control Unit
ATF	Automatic Terrain Following
B	
BCN	Beacon
BIT	Built-in-Test
BOC	Bomb On Coordinates
BRL	Boresight Reference Line
C	
CLR	Clear
CNI	Communication, Navigation and Identification Equipment
COMM	Communication
CRT	Cathode Ray Tube
CSGMP	Combined Terrain Following and Ground Mapping
CSTA	Combined Terrain Following and Terrain Avoidance
D	
DDI	Digital Display Indicator
deg	degree(s)
DEST	Destination
DIG	Doppler Inertial Gyrocompassing
DMG	Digital Map Generator
DMS	Digital Map System
DSC	Digital Scan Converter
DTA	Data
DTED	Digital Terrain Elevation Data
DU	Display Unit
E	
ECS	Electronic Countermeasures System
ENT	Enter

F	
FLIR	Forward Looking Infrared
FLR	Forward Looking Radar
FOV	Field-of-View
ft	feet
FPM	Flight Path Marker
G	
GCAS	Ground Collision Avoidance System
GMP	Ground Map Pencil
GMS	Ground Map Spoiled
GPS	Global Positioning System
H	
hr	hour(s)
HMD	Helmet Mounted Display
HOTAS	Hands On Stick and Throttle
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
I	
IFF	Information Friend or Foe
I^2	Image Intensifier
ILS	Instrument Landing System
IMS	Inertial Measurement Set
IMC	Instrument Meteorological Conditions
IMU	Inertial Measuring Unit
INVIS	Integrated Night Vision System
IR	Infrared
IU	Interface Unit
L	
LANA	Low Altitude Night Attack
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LOS	Line-of-Sight
LRFB	Long Range FLIR Boresight
M	
MAN	Manual
MBE	Management by Exception
MBO	Management by Objectives
MARK	Mark
mil	miliradian
mm	milimeter

N	
NATC	Naval Air Test Center
NAV	Navigation
NAVAIRSYSCOM	Naval Air Systems Command
NBC	Nuclear Biochemical
NEFB	Narcissus Effect FLIR Boresight
NFOV	Narrow Field-of-View
n m	nautical mile
NORM	Normal
N UP	North Upward
NVD	Night Vision Device(s)
NVG	Night Vision Goggle(s)
NWDC	Navigation and Weapons Delivery Computer
O	
OAP	Offset Approach Point
OFP	Operational Flight Program
P	
PMDS	Projected Map Display
R	
RLG	Ring Laser Gyro
S	
SA	Situational Awareness
SIDS	Shrike Improved Display
SINS	Ship Inertial Navigation System
SRFB	Short Range FLIR Boresight
T	
TA	Terrain Avoidance
TACAN	Tactical Air Navigation
TCN	Tacan
TCS	Tactical Computer Set
TDC	Target Designator Controller
TF	Terrain Following
TRN	Terrain Referencing Navigation
TV	Television Display
U	
UFC	Up-Front Control
USAFTAC	United States Air Force Environmental Technical Application Center
V	
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

W

WFOV	Wide Field-of-View

VITA

Linda C. Shaffer-Vanaria was born in Philadelphia, Pennsylvania, on 12 June 1956. She attended Upper Merion High School and graduated in 1974. Following high school, she attended the University of Pennsylvania , graduating in May 1978 with a Bachelor of Science Degree in Systems Science and Engineering. Following graduation, she worked for Hughes Aircraft Company in El Segundo, California. There she worked predominantly on the F/A-18 Radar Test Team. In December, 1979, she left California to attend AOCS, receiving her commission as a naval officer in March 1980. Following AOCS she attended and completed pilot flight training and was designated a Naval Aviator in February 1981. Following designation, she completed tours at Fleet Composite Squadron Eight (VC-8), Roosevelt Roads, Puerto Rico and Fighter Squadron Forty-Three (VF-43), Virginia Beach, Virginia. In 1987, she was accepted for test pilot training at the U.S. Naval Test Pilot School, Patuxent River, Maryland, and graduated with Class 93 in July 1988. She is currently assigned as a test pilot at the Strike Aircraft Test Directorate, Naval Air Test Center, Patuxent River Maryland and is involved with A-4 and T-45 flight tests. She enrolled in the Graduate School of the University of Tennessee, Knoxville, in September 1988. She will continue as a test pilot after graduation.