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Real time targeting for GPS guided weapons using the on-board systems of the F-14D Super Tomcat

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To the Graduate Council:

I am submitting herewith a thesis written by Daryl J. Martis entitled "Real time targeting for GPS guided weapons using the on-board systems of the F-14D Super Tomcat." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

R. B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Ralph Kimberlin, Fred Stellar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Associate Vice Chancellor
And Dean of the Graduate School

REAL TIME TARGETING FOR GPS GUIDED WEAPONS USING THE ON-BOARD SYSTEMS OF THE F-14D SUPER TOMCAT

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

LCDR Daryl J Martis, USN

May 2000

Disclaimer:

All information pertaining to the F-14D has been obtained only through unclassified sources listed in the Reference section.

All additional information in this thesis, including lessons learned from recent U.S. Air Power combat employment has also been obtained through unclassified, open literature

All aspects of this thesis remain as the source of information was originally published: ***Unclassified.***

DEDICATION

This thesis is dedicated to my wife and my inspiration

Janet Aileen Martis

who was always there when I needed her

ABSTRACT

Precision Strike has been the central doctrine of the Air Warfare Commanders of the U S Navy since this capability was demonstrated and proven during the month long air campaign of Desert Storm Effectiveness analysis immediately following that conflict showed that natural and man made obscurations of targets, such as clouds and smoke, made precision targeting from the air impossible with laser guided munitions during an alarming percentage of attack missions In order to attack a target with a laser guided precision weapon, the striking aircraft had to maintain an unobstructed line of sight until weapon impact in order to provide continuous laser energy on the target. To solve this dilemma, a requirement was set forth that demanded an all weather "through the clouds" precision attack capability. This requirement is being fulfilled by a bevy of new generation weapon systems that are collectively known as GPS guided weapons. These weapons are programmed with target location coordinates and navigate autonomously to the impact point after the aircraft release by using on board inertial navigation computers aided by Global Positioning Satellite technology.

Subsequent military operations have employed these new generation GPS guided weapons with great success against fixed targets A significant deficiency has arisen however with GPS guided weapons in attacking relocatable targets. These targets include mobile missile systems, command and control vehicles, and troop convoys, and usually make up more than seventy percent of the overall target list. While the Navy is currently upgrading the F-14D Super Tomcats with the capability to employ GPS guided weapons, the aircraft does not have the capability of using its own sensors as a source of target coordinates. Therefore, if the intended target moves between the time it is located and the time that it is attacked, the GPS guided weapons will miss their mark.

This study summarizes the F-14D weapon system and its capabilities and deficiencies in order to form a basis for improved GPS guided weapon targeting It proposes three possible sources of accurate targeting information that the F-14D can provide to the GPS guided weapons, and outlines a test and evaluation procedure to verify the integrity and airworthiness of proposed avionics and software modifications, as well as a method to employ a systems approach to determine the capability of the F-14D precision strike system to accurately self-target for GPS guided weapons.

PREFACE

The author became the F-14 LANTIRN and Precision Strike project officer in 1998 During his tenure, the F-14D's precision attack capabilities have improved dramatically with the addition of several low-cost, off-the-shelf components that have enhanced the already potent strike capabilities of the Tomcat He was directly involved with the concept, design, flight test and implementation of the LANTIRN Tomcat Tactical Targeting (T^3) software project, which added a precision target coordinate generation capability to the F-14's FLIR sensor. His involvement included the planning and conduct of the LANTIRN pod accuracy study in 1999, which produced the data required to certify the F-14 LANTIRN system as a source of target location coordinates for all Navy attack platforms This involvement has allowed reference to all of the LANTIRN capabilities and flight test from the perspective of a flight test officer who was the first to fly with the F-14 LANTIRN T^3 software and who subsequently helped certify and define its tactical employment.

Simultaneous to his LANTIRN efforts, the author was also the F-14 Precision Strike project officer, where he led the Naval Air Warfare Center Aircraft Division integration and flight test efforts for GBU-24E/B and JDAM These precision-guided GPS/INS weapons will provide the Tomcat with the capability to strike targets with pinpoint accuracy in any weather, day or night He authored test plans outlining several phases of developmental test of the weapon-aircraft integration, as well as evaluating the supporting aircraft hardware and software modifications to support the weapons As a result of this effort, all reference contained within this thesis are also made from a first-hand, developmental tester point of view

The upgrades to the F-14D radar and JTIDS data link were developed and are being tested at NAWCWD, Pt Mugu, California The author was not directly involved with this phase of the F-14D development, and did not directly work with either the radar high resolution map or JTIDS flight test and implementation. Accordingly, the references contained herein are of a second hand, non-flight test perspective

Lastly, there has never been a documented presentation of the F-14D self-targeting for GPS guided weapons as outlined in this thesis. The author uses this format to examine the capabilities of the precision strike components of the F-14D weapon system, and to explore enhancements to the system that will allow tactical flexibility in a combat environment. The intended result is to provide an approach to furthering the F-14D's attack capabilities, and to propose a flight test protocol that will thoroughly evaluate the upgraded systems' capabilities

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

A/A	Air-to-Air
A/G	Air-to-Ground
AGL	Above ground level
AIM-7	Sparrow medium range radar guided air-to-air missile
AIM-54	Phoenix long range radar guided air-to-air missile
AIRLANT	Commander, Naval Air Forces, Atlantic Fleet
APG-71	F-14D radar
ASPJ	Airborne Self Protect Jammer, AKA ALQ-165
ATF	Advanced Tactical Fighter (Concept Design Aircraft)
BDA	Bomb Damage Assessment
BIT	Built In Test
BLU-110/109	1,000 (110) and 2,000 (109) hard target penetration warheads
CEP	Circular Error Probable (50 % confidence interval implied)
DBS	Doppler Beam Sharpening
DD	Detail Display, the F-14D primary radar display
DECM	Defensive Electronic Countermeasures
DFCS	Digital Flight Control System
DOD	Department of Defense
DOP	Dilution of Precision, a measure of GPS receiver accuracy
ECP	Engineering Change Proposal
EGI	Embedded GPS/INS
EOC	Early Operational Capability
FLIR	Forward Looking Infrared
FMU-152/B	Joint Programmable Fuse (JPF) employed in GGWs
FTI	Fast Tactical Imagery, the F-14D data recorder/imagery data link
GBU-24E/B	Enhanced GBU-24, hybrid laser guided bomb with GPS receiver
GCU	Guidance Control Unit
GGW	GPS Guided Weapon
GHz	Gigahertz (1 x 10^9). Frequency measurement of radars
GPS	Global Positioning System
HRM	High Resolution Map
HUD	Head's Up Display
INS	Inertial Navigation System
IR	Infrared
IRSTS	Infrared Search and Track System
JDAM	Joint Direct Attack Munition
JSOW	Joint Standoff Weapon
JTIDS	Joint Tactical Information Distribution System
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
Lb	Pound

LCP	LANTIRN Control Panel, hand controller/computer for F-14D
LGB	Laser Guided Bomb
LTS	LANTIRN Targeting System
MAGR	Miniature Airborne GPS Receiver
MDL	Mission Data Loader, data cartridge to transfer NAV/weapon info
MFD	Multifunction Display
MIL-STD-1533B	Common digital multiplex databus protocol for U.S military apps.
MIL-STD-1760	Common weapon interface for "smart weapons", including JDAM
Mk-83/84	1,000/2,000 lb. General purpose bomb warheads
NATOPS	Naval Air Training and Operating Procedures
NAVAIR	Commander, Naval Air Systems Command
Nm	Nautical Mile
NVG	Night Vision Goggles (F-14D crews use AN/AVS-9)
OFP	Operational Flight Program, software for mission computers
PPI	Plan Position Indicator, pie shaped radar display of APG-71
PTID	Programmable Tactical Information Display
RIO	Radar Intercept Officer, weapon operator crew member of F-14D
RT	Remote Terminal
SAR	Synthetic Aperture Array
SLAM	Standoff Land Attack Missile
SMS	Stores Management System
SWAT	Subjective Workload Assessment Technique
T^3	Tomcat Tactical Targeting, the current LANTIRN software
TAMPS	Tactical Aircraft Mission Planning System
TCS	Television Camera Set
TDS	Target Data Set, a set of target locations programmed into JDAM
TLE	Target Location Error, usually listed in meters (horizontal error)
UERE	User Equivalent Range Error, GPS system error components
WGS-84	World Geodetic System (1984), refers to the coordinate reference
WSO	Weapon System Operator
X-band	Frequency band that most tactical strike-fighters employ ~10 GHz

CHAPTER I

INTRODUCTION

Background

The month-long air campaign of Desert Storm in 1991 brought to the forefront the importance of tactical aircraft delivery of precision guided weapons These weapons, mostly laser guided bombs, were credited for as high as an 80 percent success rate of targets destroyed[1], illustrating the force multiplier and low collateral damage qualities of precision guided munitions The concept of tactical aircraft delivery of precision weapons was simple yet effective The attacking aircraft acquired the target using on-board television or forward looking infrared (FLIR) tracking systems, released the laser guided bomb (LGB), and maintained a continuous laser pulse on the target until weapon impact. The LGB, using the laser-detecting seeker on its nose, would guide into the desired aimpoint by following the attacking aircraft's laser energy. The key factor in LGB success was the environmental conditions over the target In order for the attacking aircraft to employ an LGB, a clear line-of-sight must be maintained in order to continuously illuminate the target aimpoint with a laser If the line-of-sight could not be maintained, due to smoke, fog, haze or clouds obscuring the target, the LGB would miss its target Poor weather over various targets in Iraq in 1991 caused many aircraft to abort their missions, returning to base with their ordnance [2]

Subsequent Pentagon reviews of the Iraqi Air Campaign concluded that precision bombing with tactical aircraft was very effective, and as a result of the Pentagon's "Bottom-Up Review" of overall doctrine and strategy in 1994, precision guided weapons became the primary weapon of choice for most future conflict scenarios [3] These reports acknowledged that while the benefits of precision weapons were many, the fact that they could not be employed in adverse weather was unacceptable for many possible wartime contingencies. Because of this fact, the Air Force and Navy leadership handed down a requirement for a new class of tactical aircraft precision guided weapons. The new weapons were required to be capable of achieving miss distances of as little as 13 meters, while being capable of being delivered in any weather conditions [4]

The first weapon designs for tactical aircraft to meet this need incorporate global positioning satellite (GPS) technology to aid the weapon's inertial navigation system as guidance to a target aimpoint. Among the first GPS weapons to incorporate this capability are the Joint Direct Attack Munition (JDAM), and the GBU-24E/B. These GPS guided weapons are currently completing flight test, and have in some cases been recently employed in combat in limited numbers using an early operational capability (EOC) version of the weapons Although successfully demonstrating the GPS weapon's all weather capability during flight test and EOC deployments, a significant deficiency has been identified in that there is no proven method in Navy aircraft to update the pre-programmed target information in the GPS weapons using information from the aircraft's sensors[18]. If a target's location changes after it's initial detection, the GPS weapon will miss its mark unless the target coordinates can be updated.

Recent and ongoing conflicts in Iraq and Kosovo have illustrated the important role that the F-14 is playing within the Theater Commander's air campaign The Tomcat has enjoyed great success in locating and destroying fixed political and military targets utilizing its LANTIRN targeting system and employing LGBs To augment its LGB precision attack arsenal, and to provide a precision attack option in any weather, the F-14 is scheduled to implement a GPS guided weapon capability within the next 12 months On initial deployments with this capability, the Tomcat aircrews will have a limited interface with the weapons, such that the aircrew can only manually change the target data programmed into the weapons (by typing new target information). Keyboard entry of target location data in a combat environment is susceptible to inaccuracies and operator error, and is unlikely to be accomplished in the short period of time between potential target detection and weapon release. There are currently no provisions to pass target information from the aircraft's sensors to the GPS weapons in flight. Thus, if an intended target moves between the time it is detected and when the F-14D delivers its GPS guided weapon, the target will be missed In order to successfully attack relocatable (mobile) targets with GPS guided weapons, a provision must be included that allows updates of the target information, once airborne, from F-14D sensor data information (referred to as Real Time Targeting)

Purpose

This thesis will discuss the following topics: (a) literature review of the evolution of the F-14D from a fleet air superiority fighter to a multiple mission precision strike-fighter equipped to deliver GPS guided weapons, (b) review lessons learned from recent conflicts that establish a requirement to provide real time targeting for precision guided weapons, (c) discuss the fundamentals of GPS guided weapons and sources of targeting information, (d) propose of enhancements that will enable the F-14D to locate, prosecute and destroy mobile targets in real time, and finally (e) present a flight test protocol using the systems approach, to determine if the F-14D aircrew can accurately and effectively employ GPS weapons against relocatable targets in real time

CHAPTER II

LITERATURE REVIEW

In this chapter, a literature review is presented which examines the evolution of the F-14 Tomcat as a strike fighter, including proposed upgrades to further increase the Tomcat's precision strike capabilities Secondly, a discussion of recent conflict lessons is presented that establishes a requirement for real-time targeting for GPS guided weapons

F-14 Evolution as a Strike Fighter

By 1988, the U S. Navy began investigating possible upgrades to the F-14's air-to-ground attack capabilities. These upgrades were essential enhancements that enabled the aircraft to perform the multi-role strike fighter mission. Between 1990 and the present, vast improvements and upgrades have been implemented on the aircraft by Northrop-Grumman, Lockheed-Martin and the Navy that have enhanced the combat performance of the aircraft, and have given it the tools required to perform as a precision strike fighter Multiple studies have been conducted, and several Operational Flight Program and hardware upgrades have been designed, tested and installed in fleet F-14 aircraft. From performing only air superiority fighter and tactical reconnaissance missions in 1994, the F-14D is now the Navy's choice for precision attack missions. The additional mission areas being performed by the F-14 came about in response to the retirement of the A-6E Intruder, the service's primary night/all weather precision attack platform Without upgrading the Tomcat as a precision strike fighter, the Navy would have effectively reduced its attack aircraft stable by 30 percent per air wing with the retirement of the A-6.

Northrop-Grumman Corporation and the Navy put forth several proposed upgrades to the F-14 attempting to implement a sophisticated air-to-ground attack capability. Grumman first proposed Tomcat 21 in 1988 as an alternative to the naval version of the Advanced Tactical Fighter (ATF) [5] This upgrade called for radar signature reduction, increased fuel capacity, synthetic aperture (SAR) radar, navigation and targeting FLIR, and provisions to carry stand off weapons such as Harpoon, Maverick and SLAM This proposal was made when the A-12 was consuming the lion's share of the Navy research and development budget, and the future of a naval version of the ATF was in jeopardy The Navy never seriously considered the proposal, except as a backup in case the ATF program was cancelled.

In 1991, Grumman presented a new proposal called the F-14D "Quick Strike" program [6] Quick Strike built upon the Tomcat 21 proposal, including all weather strike capability. Additional features included a digital color moving map, stroke and raster video head's up displays (HUD) to enable FLIR imagery to be overlaid onto the HUD, night vision goggle (NVG) compatible cockpit lighting, global positioning system navigation (GPS) and terrain avoidance radar. Although the Quick Strike proposal offered a solution to the Navy's imminent loss of long range precision attack aircraft, it was deemed too expensive as the Navy opted to proceed with further development of the F/A-18 [7] In 1993, Grumman proposed a stepped upgrade program, which would give the Tomcat the capabilities outlined in Quick Strike This upgrade, outlined by

Kandebo [8], progressed through four steps, the first including laser guided weapon delivery in daytime only, to night delivery, then to all-weather, and finally incorporating advanced weapons Step one included the addition of a targeting FLIR, wiring for advanced weapons, and programmable tactical displays, among others Step two included NVG compatible cockpit lighting and windscreen, navigation FLIR and a color moving map. Step 3 included upgraded F-14D radar software to include SAR, Doppler beam sharpening (DBS), moving target indicator and terrain following modes The final step included incorporation of a new series of advanced weapons such as Joint Standoff Weapon (JSOW) and Joint Direct Attack Munition (JDAM) Again, the Navy determined the Grumman proposal to be too expensive as a whole and restructured its F-14 upgrade program to include only portions of the program, which they called Block I Table 1 shows a comparison between Grumman's 4-step upgrade program, those called for in the Block I program, and the most recent listing of F-14D precision strike systems In mid 1994, Naval Air Systems Command (NAVAIR) F-14 Program Managers determined that a targeting FLIR would be added to the aircraft, expanding the Tomcat's strike capability to include precision weapons, in the form of Laser Guided Bombs. After several months of industry competition and an aggressive down-select process, the Navy awarded a contract for $54 million to Lockheed-Martin Corporation to produce and integrate the company's Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) system onto the F-14. Flight-testing began at Patuxent River Naval Air Station, Maryland, in March of 1995. The results were published in a report by Winfrey [9]. Fifteen months later, in June 1996, ten F-14 aircraft deployed with full LANTIRN capability. Today, all deployable F-14 squadrons have LANTIRN capable aircraft, with over 186 F-14 aircraft scheduled to receive LANTIRN pod carriage capability.

Table 1. F-14 Precision Strike Upgrade Summary

System	Grumman Proposals (1988-1993)	Navy Block I Upgrade (1994)	Current USN F-14 Precision Strike Upgrades (2000)
Targeting FLIR	X	X	X
Navigation FLIR	X		
NVG Cockpit/Windscreen	X	X	X
Raster HUD	X		
Digital map	X		
GPS	X	X	X
Radar DBS modes	X		X
Radar SAR modes	X	X	X
Radar Terrain Avoidance	X		
Reduced Radar Signature	X		
Computer Upgrades	X		X
Programmable Displays	X		X
ALE-50 Towed Decoy	X		
JSOW / JDAM / GBU-24E/B	X		X

Concurrent with the Navy's efforts to incorporate the LANTIRN targeting pod were additional upgrades to the precision strike capabilities of the Tomcat All of the precision strike capable F-14s were outfitted with night vision compatible cockpit lighting, and were equipped with a programmable tactical information display Integration work continues to add the capability to employ GPS guided weapons, with planned initial operational capability for GBU-24E/B scheduled for late 2000, and JDAM functionality is to debut in 2001 Finally, significant radar upgrades to the F-14D APG-71 radar system have been in work for several years, which will incorporate several doppler processing techniques, including DBS and SAR, allowing the creation of very high resolution maps These maps can be used to detect and designate ground targets for attack, as well as to produce highly accurate geo-coordinates of the target's location Appendix D describes radar high resolution mapping in the F-14D in detail.

Recent Conflict Lessons Learned

Over the past 24 months, USN Carrier Air Wings have employed their precision strike fighters, F/A-18 Hornets and F-14 Tomcats, in numerous ground attack operations The two most significant actions took place in December 1998 in Iraq (Operation Desert Fox), and in early 1999, the 78 day air campaign over the former Republic of Yugoslavia (Operation Allied Force). During these campaigns, the F/A-18 and F-14 squadrons utilized radar and targeting FLIR to detect, track and attack targets with laser guided bombs In a limited role, some F/A-18 strikes also included newly integrated GPS guided weapons such as JDAM While the success rates against fixed targets, such as military headquarters and factories was high, targeting relocatable targets such as tanks and artillery produced a 50 percent success rate [10] In an attempt to quickly incorporate lessons learned from these operations to enhance future combat action effectiveness, the theater commanders sanctioned studies to evaluate the true effectiveness of precision guided weapons during the campaigns. In an article in Defense Link by Garamone [11], the author states that NATO military forces, including the U S Navy, have already adopted suggestions from the campaign lessons learned reports. Along with a suggestion of procuring much greater quantities of precision guided munitions, the report states that a major deficiency must be addressed in "Locating enemy forces – The Yugoslav army used cover and concealment to hide from allied strike aircraft. The U.S. military must develop technologies that pinpoint enemy forces. (U.S. Defense Secretary) Cohen and (NATO Commander) Gen. Shelton mentioned high-resolution, cloud-penetrating radar as a promising technology U S forces must also cut the time between detecting targets and attacking them "

Reducing the time between target detection and target attack became increasingly important as Allied Force progressed. BGEN Corley, in his briefing of Kosovo lessons learned in October 1999[10], stated that the location of targets on the battlefield changed continuously. In many cases, aircrew reports and reconnaissance imagery showed that targets located in the morning had been moved by that same afternoon Estimates reported that ". between 90 to 95 percent of the battlefield changed. sometimes in one day or by the next day " Corley also noted that battle damage assessment (BDA) was often difficult because enemy forces would remove the damaged/destroyed vehicles before confirmation of the target attack could be accomplished One pilot report noted that he ".. struck one of five artillery pits later that day, everything was gone "

Time critical targeting is emerging as the newest "buzz-word" for combat employment for Navy Carrier Air Wing strike aircraft It implies the detection, identification and attack of mobile and relocatable targets in any weather, day or night. After review of Operations Desert Fox and Allied Force, the staff of the Naval Air Forces, Atlantic Command (AIRLANT) identified time critical strike as the number one priority in future capability [12] A working group met in September 1999, in which Navy precision strike specialists explored enhancements to carrier precision strike aircraft (F/A-18 and F-14) platforms to support time critical strike missions The working group discussed and prioritized several aircraft capability gaps that need to be filled in order for Carrier Air Wings to effectively perform time critical targeting. The objectives of incorporation of any new strike aircraft capability included improving the sensor-to-shooter-to-weapon link, as well as reducing the overall timeline for strike operations Listed as one of three items that need to be incorporated immediately on carrier based strike fighters was the capability to provide "...precise, all-weather, organically derived . coordinates to engage time critical targets".

The evolution of the F-14 into a Precision Strike Fighter has certainly enhanced the Carrier Air Wing's capability to maintain prolonged ground attack campaigns The incorporation of precision targeting tools, including SAR radar and LANTIRN, will allow the Tomcat crews to detect fixed and relocatable targets in any weather, day and night The addition of GPS guided weapons will allow the F-14 to attack these targets in inclement weather conditions as well. However, as the recent conflict lessons learned have shown, the F-14 must incorporate the capability to utilize its onboard sensors to target the relocatables in order to effectively kill them in real time, thus negating their ability to survive by remaining mobile.

CHAPTER III

F-14D PRECISION WEAPON SYSTEM

Basic Aircraft

The F-14D Tomcat aircraft is a supersonic, two-seat, twin-engine, swing-wing Precision Strike Fighter designed and manufactured by Grumman Aerospace Corporation [13] The F-14D is a major upgrade to the original F-14A design, including digital mission computers, multiple MIL-STD-1533B data bus communications circuits, and an advanced digital radar (APG-71). The F-14D is powered by twin General Electric F110-GE-400 engines The aircraft also features a dual chin pod housing a television camera set (TCS) and Infrared Search and Track System (IRSTS) in a side-by-side configuration For the air-to-air combat role, the F-14D employs Phoenix, Sparrow and Sidewinder missiles and an internal 20-millimeter cannon. For the air-to-ground role, the F-14D can employ a multitude of weapons, including Mk-80 series gravity fall weapons, cluster bomb munitions, Paveway II/III laser guided bombs (LGBs), and GPS guided weapons (including JDAM) A detailed description of the F-14D aircraft and its avionics systems is provided in Appendix A

In order to support GPS weapons, the Tomcat was modified to provide electrical power, GPS satellite signal information and aircraft data bus information via a common MIL-STD-1760 interface at each of four aircraft weapon stations (stations 3,4,5, and 6) The modification, known as Engineering Change Proposal (ECP) 329, includes a signal splitter/amplifier that divides the GPS signals received through the aircraft's antenna, amplifies them, and routes them to the aircraft navigation system, wing station 8B (for

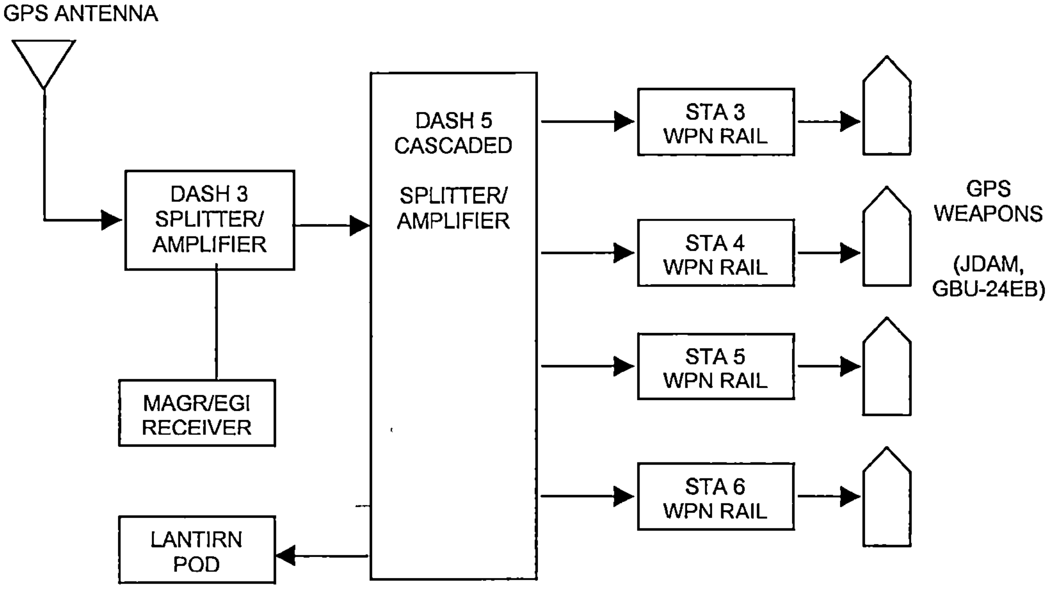


Figure 1
F-14D Precision Weapon Interface (ECP 329)

the LANTIRN targeting pod), and to the four GPS weapon stations on the belly of the airframe (Figure 1).

This design allows the F-14D crew to carry and deliver GGWs in a pre-planned, bomb-on-coordinates mode Target location information programmed into each weapon can be altered manually by the aircrew via the cockpit keyboard. No provision exists in the current installation to allow F-14D sensor data, such as APG-71 radar or LANTIRN, to be passed to the GGWs

APG-71 Radar [14]

The APG-71 is the primary sensor for the F-14D It provides multimode, all-weather surveillance of air space and land/sea surfaces. The APG-71 features digital processing, a low-sidelobe array antenna, digital antenna scan, frequency agility and multiple pulse repetition frequencies. The APG-71 utilizes an X-band radar transmitter, and has over 85% hardware commonality with the F-15E APG-70 radar The APG-71 operates in two major sub-modes, air-to-air (A/A) and air-to-ground (A/G). A/A modes include search, search and track, and various single target track modes A/G modes provide real beam ground maps for display and A/G ranging in support of bombing and strafing. Two additional modes in A/G are being implemented currently which provide very high-resolution maps of terrain and surface features to support navigation and targeting functions A pie-shaped PPI display uses doppler beam sharpening (DBS) techniques to produce a near-real time map of the terrain, while a square shaped Patch Map display utilizes synthetic aperture radar (SAR) techniques to create high resolution maps of a designated area of interest. A more thorough discussion of radar high-resolution maps, APG-71 radar and its mapping modes is presented in Appendix D. To date, no resolution or target location accuracy data has been reported for the high-resolution map modes of the APG-71

LANTIRN Targeting System [15]

The LANTIRN targeting system (LTS) provides the F-14D with the capability to detect and acquire targets using forward looking infrared (FLIR) and to deliver laser guided bombs accurately onto those targets The addition of Tomcat Tactical Targeting (T^3) software enhancements enable the LTS to precisely calculate target coordinates (referenced to the WGS-84 ellipsoid), which can be used as targeting data for own-ship or for third party GGWs. The system consists of two major assemblies. the LANTIRN control panel (LCP) and the targeting set (LANTIRN pod) These assemblies are integrated into the aircraft in a stand-alone configuration without affecting existing aircraft systems. The LTS also includes a GPS antenna/receiver and provisions to display the FLIR video in both cockpits A detailed description of the LTS is presented in Appendix C

The Tomcat Tactical Targeting (T^3) software load was added to enable the LTS to calculate precision targeting coordinates for third party and self-targeting of GPS guided weapons Additional changes were made to optimize normal LTS functionality. T^3 generated coordinates can be used within the aircraft or linked to other airborne strike platforms or command and control networks via Fast Tactical Imagery (FTI), the F-14D cockpit video recording and digital video data link system The entire FLIR display, including data can be transmitted via FTI as still frames or up to 4 frames per second of running video. The target location error (TLE) associated with T^3 coordinates will affect GPS precision weapon circular error probable (CEP). The CEP is an estimate of the miss distance of any GGW such that for a random sample, 50% of the weapons will fall with the CEP value for a given set of known errors, including the TLE The value of TLE will depend on the LTS profile and navigational accuracy at the time of coordinate generation.

Utilizing the T^3 software, an accuracy study was conducted by Naval Air Warfare Center, Patuxent River in which a large number of target designations of a surveyed target were conducted to determine the capability of the LTS to accurately calculate the geo-coordinates referenced to the WGS-84 ellipsoid. The goal of the accuracy study was to determine if the coordinates generated by the LTS were accurate enough to use as a source of targeting data for GGWs. The results of this study, reported by Dyer and Odell [16], showed that the F-14 LTS is capable of providing very high quality coordinates suitable for targeting GPS weapons. The data showed that the calculated TLE is proportional to range in that the errors are lowest at minimum ranges from the target The analysis showed that statistically, the LTS can achieve a TLE of approximately 4 9 meters at a slant range of 1 65 nm, which equates to aircraft overflight at 10,000 feet AGL The TLE increases with slant range to approximately 12 meters at 4 6 nm, which equates to a 3 5 nm standoff range at 20,000 feet AGL As the graph in Figure 2 shows, the TLE approximates a linear equation, thus the predicted TLE for LANTIRN target designations can be computed at any slant range.

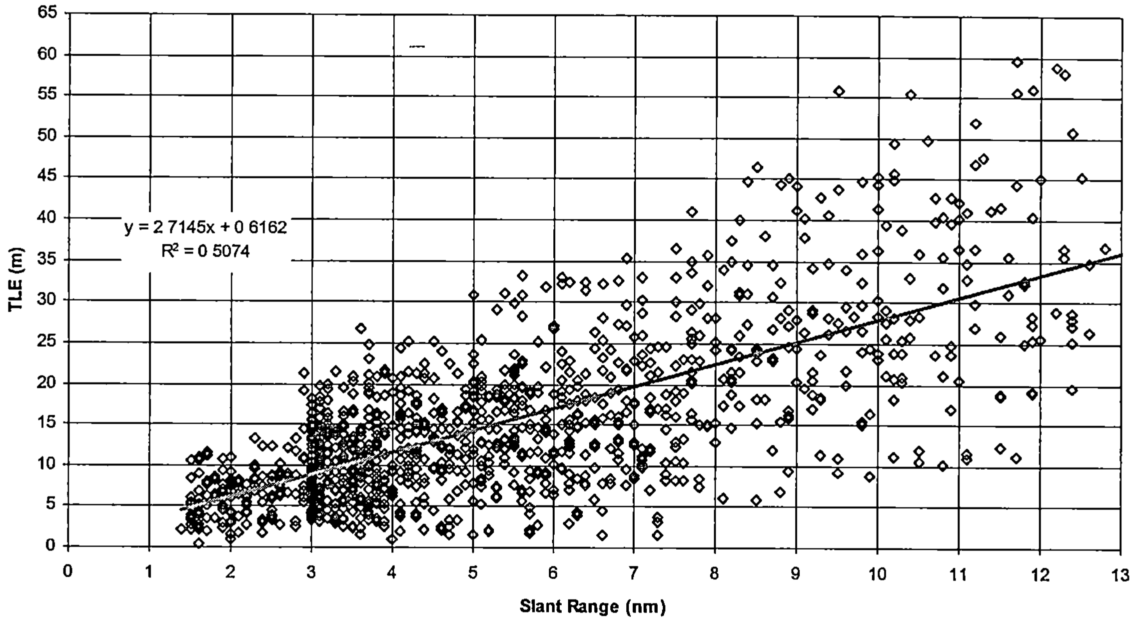


Figure 2 [16]
F-14D LANTIRN Horizontal Target Location Error

In order to accurately guide to a target, GGWs such as JDAM require a TLE of 7 2 meters to achieve their specified horizontal CEP [17]. This TLE requirement can be met using LANTIRN target designations at a slant range of approximately 2.7 nm or less, which equates to target overflight at 16,300 feet AGL If larger TLE is acceptable for a given weapon, the standoff range can be substantially increased. For example, a TLE of 15 meters can be achieved at a standoff range of 6 nm.

The TLE data discussed thus far is referenced to the horizontal plane. Since generating a target location is a three-dimensional problem, the vertical error component must also be assessed. Analysis of the vertical error component at all ranges consistently averaged approximately 8 meters which is well within acceptable vertical error component limits. Figure 3 depicts a plot of the average vertical error of several LANTIRN pods used during testing.

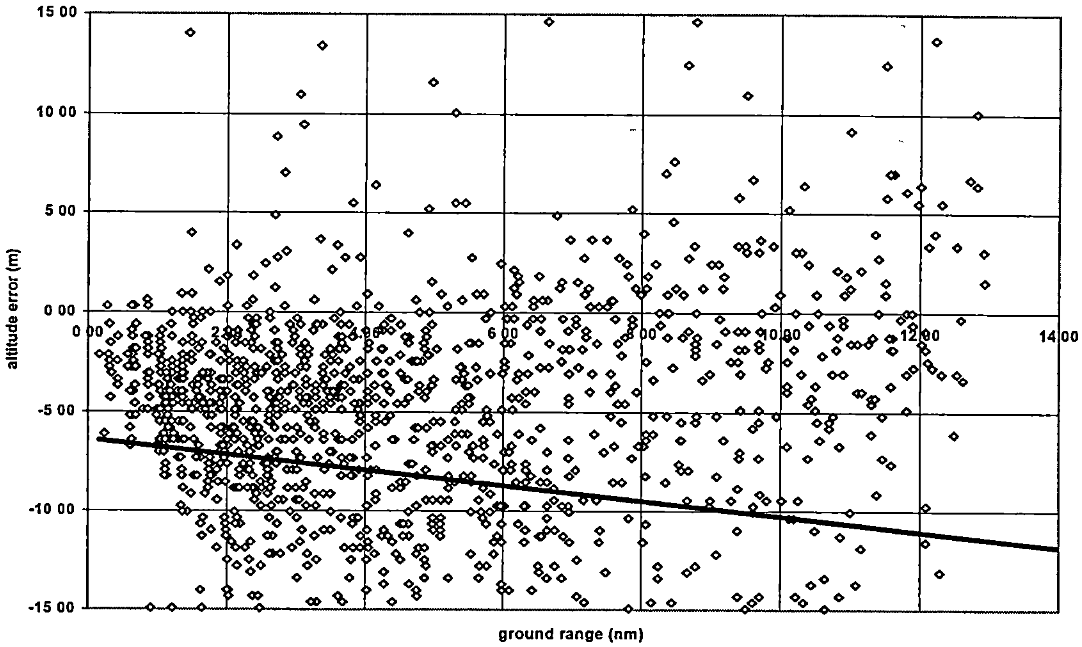


Figure 3[16]
F-14D LANTIRN Vertical Target Location Error

With the inclusion of ECP329 into the Tomcat, and the given accuracy of its on board sensors, it is possible for the F-14D to accurately and effectively self-target for GPS Guided Weapons

CHAPTER IV

GPS GUIDED WEAPONS

Before discussing proposed methods for the F-14D to provide self-targeting for GGWs, it is prudent to first describe their overall design concept, data requirements, and unique sources of targeting errors This discussion will be limited to the weapons that are being integrated onto the F-14D at this time, those being the Joint Direct Attack Munition (JDAM) and the GBU-24E/B.

GPS Weapon Design

The basic concept of GGWs is to incorporate an inertial navigation system (INS)/GPS guidance kit onto an existing bomb body that provides the weapon with precision guidance upon release These weapons interface with the host aircraft through a mechanical/electrical connection that conforms to MIL-STD-1760 Aircraft/Store Electrical Interconnection System Specification This interface includes Class II electrical power (28V DC in the case of the F-14D), discrete messages, and a MIL-STD-1553/B digital interface The JDAM is a family of weapons equipped with JDAM guidance kits. The warheads utilized are the Mk-83 and Mk-84 (general-purpose 1,000 and 2,000 lb. bombs, respectively), and the BLU-110 and BLU-109 (special hard target penetrator 1,000 and 2,000 lb warheads). The GBU-24E/B is an upgrade to the existing GBU-24B/B Low Level Laser Guided Bomb that also incorporates an INS/GPS guidance kit, and utilizes the BLU-109 2,000-lb. penetrator warhead These weapons depend on host aircraft transfer of targeting information and initial GPS data necessary for acquisition of GPS satellites In order to accurately navigate to a target aimpoint after release, the JDAM requires an extensive aircraft-to-weapon transfer alignment, where the aircraft's position, velocity and acceleration information is passed to the weapon prior to release JDAM weapons do not acquire and track GPS satellites until several seconds after release. Conversely, GBU-24E/B weapons require a less extensive transfer alignment and acquire and track satellites prior to release [18] Both weapons require GPS cryptographic keying to support precision guidance. A more detailed description of GGWs is presented in Appendix E

GPS Weapon Data Requirements

Each GGW carried on the F-14 requires GPS and mission data from the aircraft The GPS information allows the GGWs to acquire and track GPS satellites either during captive carriage (GBU-24E/B) or post release (JDAM). The mission data provides detailed information on a total of 8 possible targets for attack (collectively called the targeting data set, or TDS), and an associated point where the weapon is to be released (launch point) The TDS data is downloaded to the weapon while the launch point data is retained in the aircraft for aircrew displays The TDS data is initially pre-planned prior to flight on a Tactical Aircraft Mission Planning System (TAMPS) workstation and then loaded onto a mission data loader (MDL) cartridge for future download to the aircraft and weapons All information needed for successful GGW employment is included in the MDL cartridge with the exception of GPS satellite ephemeris data, which is provided directly by the aircraft's GPS receiver. The GGWs utilize a mass data transfer protocol, which defines the data file format, to pass the following data from the aircraft MDL cartridge to the weapons· Targeting and fuse data (which includes target location, fuse type, and offset aimpoint information), GPS cryptographic keys, GPS almanac data, and satellite anti-spoofing/satellite vehicle (AS/SV) data. The TDS can be manually edited via the aircrew keyboard to adjust target offset aimpoint location Table 2 depicts the components of a GGW TDS.

Table 2
GPS Guided Weapon Targeting Data Set (TDS)

Target Data	**Target Data Set**	
	Required	**Optional**
Target Hardness		X
Target Orientation		X
Target Altitude Reference	X	
Target Name		X
Target Location – Latitude	X	
Target Location – Longitude	X	
Target Location – Altitude	X	
Target Impact Azimuth		X
Target Impact Angle		X
Minimum Target Impact Velocity		X
Target Offset North		X
Target Offset East		X
Target Offset Down		X
JPF Mode *		X
JPF Arm Time From Release *		X
JPF Arm Time From Impact *		X
* - Included in TDS only if Joint Programmable Fuse (FMU-152) equipped		

GPS Weapon Targeting and Sources of Error

Attack missions employing GGWs will employ one of two basic targeting doctrines: pre-planned employment or real-time targeting. Figures 4 and 5 depict each of these targeting scenarios. When employing a pre-planned targeting scenario, the GGW is provided with TDS data that originates from target locations determined by DOD-wide targeting sources, such as satellites and tactical reconnaissance imagery. In this scenario, the GGWs are loaded with the TDS information prior to flight and the weapons are released without altering the TDS. Typically, the time from target detection until GGW employment is 12 hours for a pre-planned scenario.

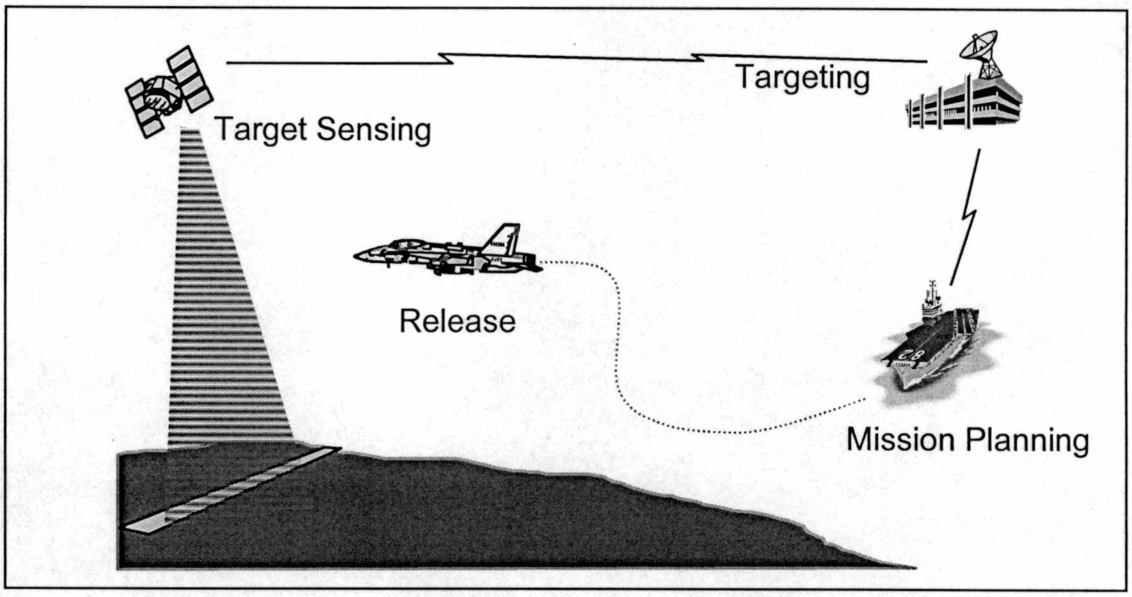


Figure 4
GPS Guided Weapon Pre-Planned Targeting Scenario

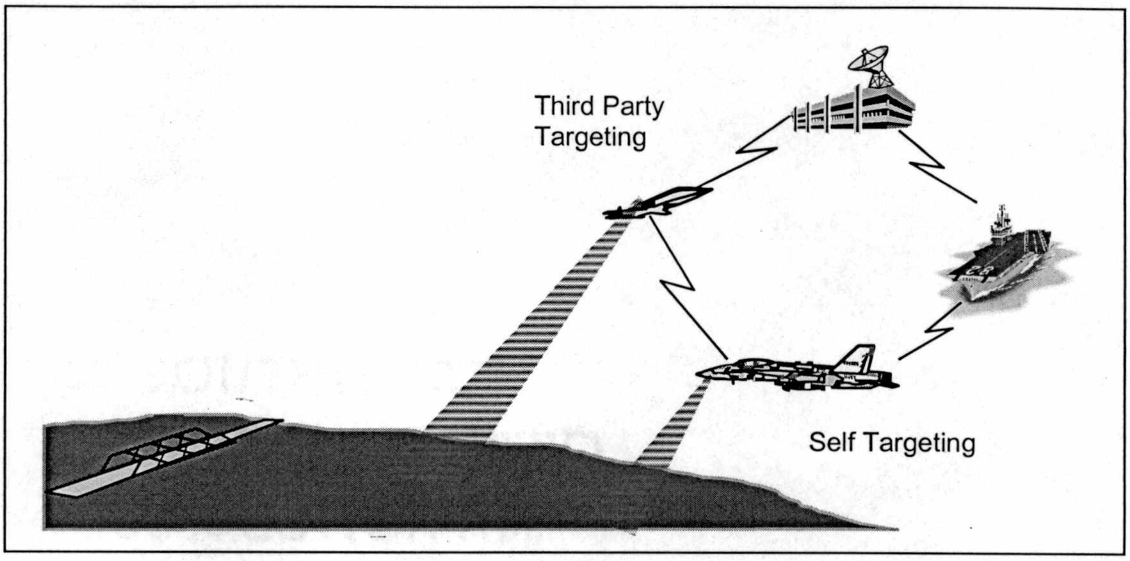


Figure 5
GPS Guided Weapon Real-Time Targeting Scenario

If a real-time targeting scenario is employed, the GGW TDS is edited using information from third party (such as a tactical reconnaissance targeting drone) or from the aircraft's own sensors. The time from target detection until GGW employment in this scenario is essentially simultaneous.

Each GGW dropped on a given target will have a miss distance determined by errors from three sources: GPS errors, GGW guidance and control errors and target location error (TLE). The root sum square of these determines the magnitude of the circular error probable of the weapon: $\mathbf{CEP = [(GPS)^2 + (GGW\ Guidance)^2 + (TLE)^2]^{1/2}}$ The error components that the GPS adds to the overall miss distance can be broken down into two factors: User Equivalent Range Error (UERE) and Dilution of Precision (DOP). UERE consists of three contributing components: space segment, user segment and control segment errors. Space segment errors include satellite clock error and orbital error. Control segment errors include improper updates or corrections from the master

GPS control center at Falcon AFB. User segment errors result from numerous factors including receiver error, clock timing, multipath, atmospheric compensation, etc. Overall UERE can be plotted as a vector summation of space, user and control errors, where approximately 80% of the error is bias-like and 20% is random (noise) [15]. The second component of GPS error is Dilution of Precision (DOP). DOP is an indicator of the accuracy of a GPS derived location based on the geometric orientation of the GPS satellites as seen by the receiver. The magnitude of DOP can be predicted in advance if the receiver location and time are known. Figure 6 depicts examples of good and bad DOP. A detailed description of GPS is presented in Appendix B.

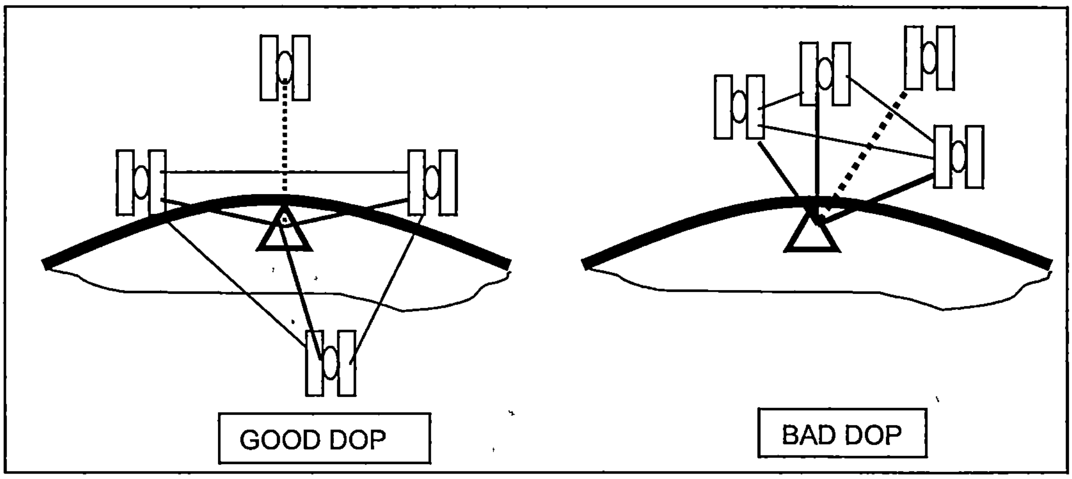


Figure 6
GPS Dilution of Precision

UERE has an average value of 5.3 meters at any given time [15]. Typically, DOP is 2 meters or less for 90% of any given day, but can vary greatly for short time periods (up to 6 meters or more) Therefore, the total error present when employing GGWs in a pre-planned scenario is approximately 10 meters, with short lived excursions out to 20 meters Figure 7 graphically illustrates the errors for a pre-planned scenario.

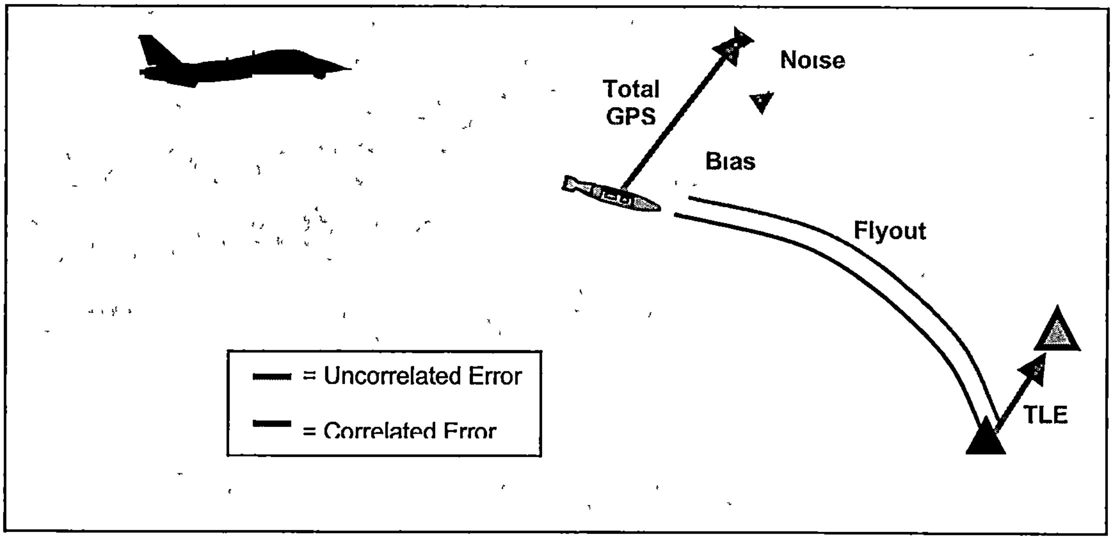


Figure 7
GPS Guided Weapon Pre-Planned Scenario Error Depiction

Real Time Targeting Theory

While the DOP and the magnitude of uncorrelated noise can be predicted for a given receiver for a particular location and time, the bias vector cannot be predicted. The GPS bias is uniform over approximately 100-nm square area and changes slowly in direction and magnitude as the GPS satellite constellation moves. All GPS receivers within the same area will experience the same bias error. When a target coordinate is generated for attack in real-time, much of the GPS bias vector cancels, since the delivery aircraft and the GGW receiver are operating within the same GPS bias error. These GPS bias vector correlations result in a total GPS error of only 2-3 meters vice the 10-20 meters seen in pre-planned scenarios. When substituting this into the previously stated

CEP equation, a smaller overall GPS error allows for a significantly larger TLE (12-14 meters) in order to maintain the same GGW CEP (Figure 8)

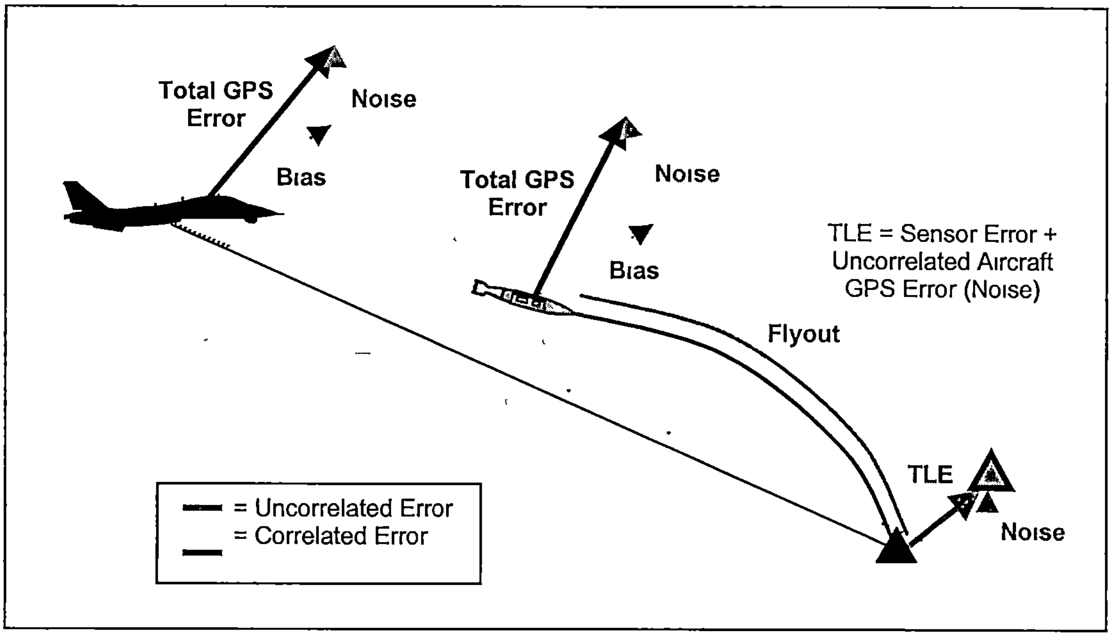


Figure 8
GPS Guided Weapon Real-Time Targeting Scenario Error Depiction

CHAPTER V

REAL-TIME TARGETING FOR GPS GUIDED WEAPONS

Avenues of Data Transfer

GGWs communicate with the host F-14D aircraft via a MIL-STD-1760 interface, and pass data via a MIL-STD-1553/B multiplex databus There are two ways in which a GGW can receive GPS and targeting information from the F-14D Stored data from a pre-flight planned MDL cartridge, and direct communication with the aircraft's mission computers via the 1553 bus. In the current F-14D software configuration, the MDL cartridges provide fixed GGW information (planned and loaded prior to flight), while updates in-flight can be accomplished by hand-typing keyboard entries via the mission computers By modifying the Operational Flight Program (OFP) software and utilizing the same mission computer interface, F-14D sensor data could provide real-time target location information from the two primary F-14D sensors, the LANTIRN targeting system and the APG-71 radar. In addition, the computers could pass GGW target information from the F-14D's data link, the Joint Tactical Digital Data Link (JTIDS) In order to effect this upgrade to allow the passage of targeting information from the F-14D sensors directly to the GGWs, an aircraft OFP software change would be necessary to provide the proper aircrew interface and display functions related to real-time targeting. This proposed OFP change must include "operator-in-the-loop" characteristics, such that the crew must view the new GGW target data and consent to re-programming of the weapon information prior to overwriting the actual weapon data This would be necessary to satisfy Rules of Engagement (ROE) criteria for launching GGWs in combat scenarios [19]. Most importantly, the operator interface should include target location accuracy indicators as part of the target location update data The accuracy information, in the form of TLE, would give the operator a metric to decide whether the data is accurate enough to employ a GGW.

GGW Targeting via LANTIRN

In chapter III, in which the inherent accuracy of the LANTIRN targeting system was discussed, a conclusion was presented stating that the F-14D LANTRIN is capable of providing target location information in support of GGWs. As currently implemented, the only avenue of data transfer from LANTIRN to the GGW is via the aircrew hand-entering the data through a keyboard In order to provide a direct interface of LANTIRN generated target coordinates with GGWs, a hardware interface connecting the LANTIRN Control Panel (LCP) with the mission computer data bus must be added (Figure 9)

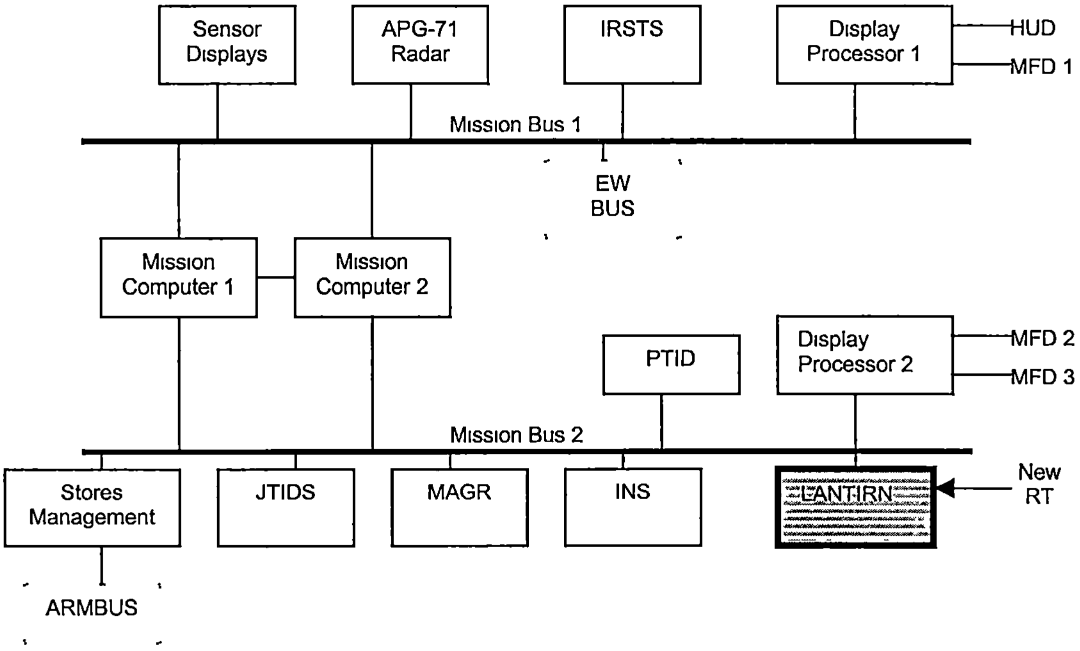


Figure 9
Simplified F-14D Avionics Diagram with LANTIRN
Added as a Remote Terminal

This interface would allow the LCP to act as a new remote terminal on the bus, functioning as an input sensor to the overall avionics package (Note: in its current configuration, LANTIRN operates independently of the F-14D avionics system, performing only a bus monitor role on mission bus #2 – see Appendices A and C for a detailed description). Through this interface, target coordinate and location accuracy (TLE) data could be passed to the mission computers, which in turn would be available for aircrew review and consent to update GGW target data. It is important to note that the LANTIRN video display includes all of the target location data overlaid onto the target infrared scene, as well as a proposed inclusion of calculated TLE data, giving the operator immediate feedback as to whether the LANTIRN target data is valid for GGW attacks (Figure 10).

The greatest advantage of the addition of LANTIRN onto the F-14D databus is an immediate "handoff" of targeting data that would be directly available for download to a GGW for overwrite of the existing target information. This will allow for true "real-

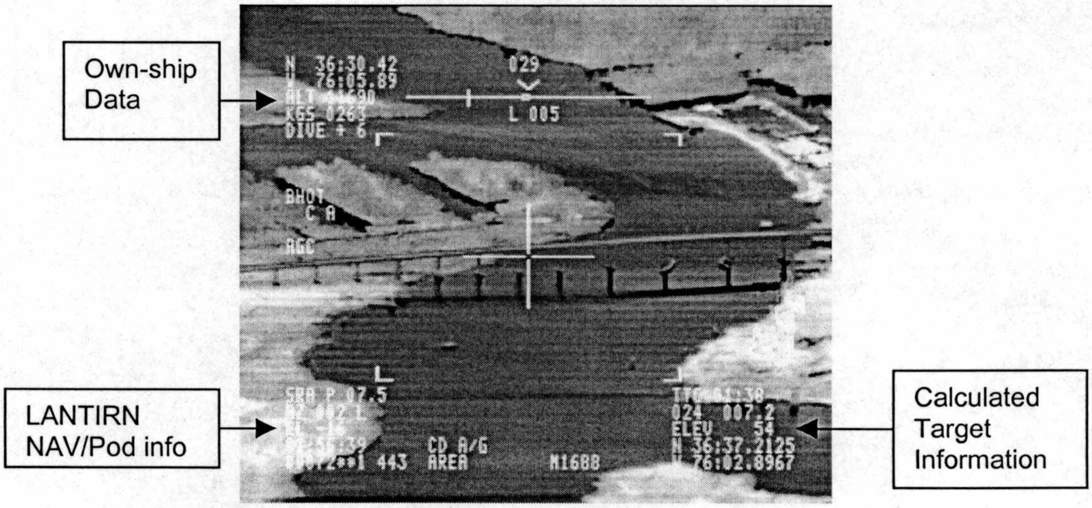


Figure 10
F-14D LANTIRN Video Display

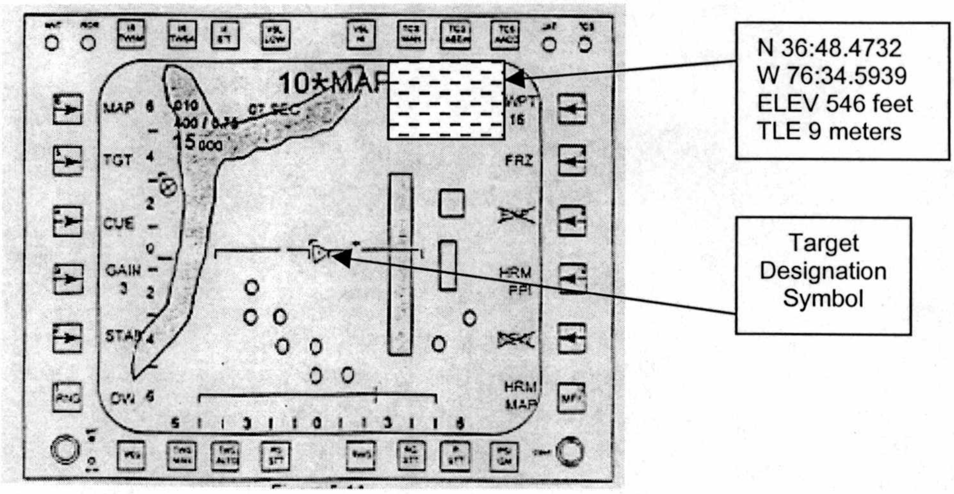
time" targeting since a target could be located, identified, designated, and attacked using a GGW on a single pass inbound to the target. Arguably, to attempt to accomplish this same targeting scenario with the current system design, which requires the operator to hand-type an updated target location, would be much more difficult and error-prone in a combat environment The only limitations associated with LANTIRN targeting for GGWs would be those inherent with FLIR targeting in general; most notably the inability to discern targets through clouds, dust or other atmospheric IR energy inhibitors.

GGW Targeting via APG-71 High Resolution Maps

In order to provide an all-weather GGW targeting option, the same concept of single-pass targeting could be implemented using the F-14D's APG-71 radar as the sensor The addition of this capability would require software modifications only, since the radar is already hardware connected to the mission data buses Similar to the LANTIRN video display in Figure 10, the high resolution patch maps produced by the APG-71 should include a data block overlay with the target coordinates and TLE estimate included To aid in operator map interpretation, symbols should be included that represent the point of designation on the map. Figure 11 depicts a notional APG-71 high-resolution map with proposed target information data block included.

GGW Targeting via JTIDS

A final source of targeting data to support GGWs on the F-14D is the aircraft's digital data link, JTIDS. JTIDS currently can provide the F-14D with target information for airborne targets, displaying symbology of airborne tracks that the operator can designate for attack. Figure 12 depicts an F-14D tactical display showing JTIDS target tracks. Using JTIDS to support ground attack with GGWs would be a natural extension

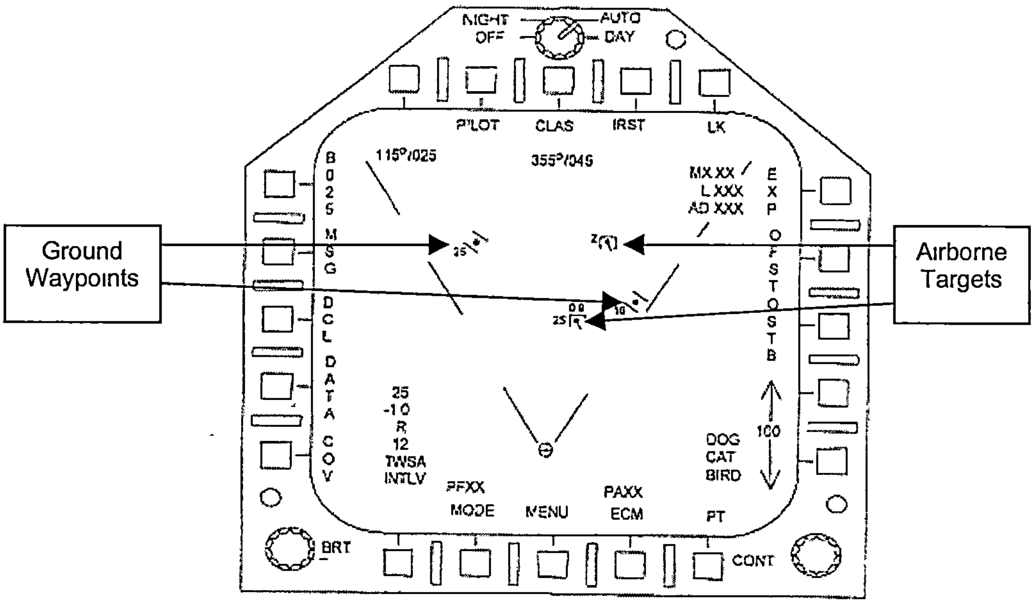


N 36:48.4732
W 76:34.5939
ELEV 546 feet
TLE 9 meters

Target Designation Symbol

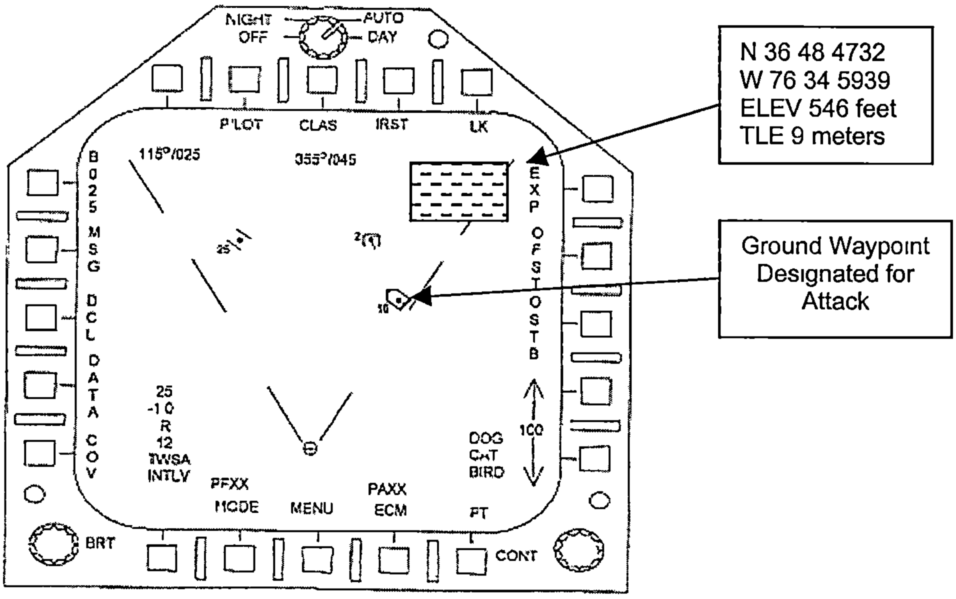
Figure 11
F-14D Radar High Resolution Patch Map With Target Information

of the digital network's capabilities. Similar to radar GGW targeting upgrades, to upgrade JTIDS for this application would be software in nature only since the supporting hardware is already in place. In addition to a target's coordinates, the JTIDS ground target data must also include the source of the data and a TLE estimate. This information is necessary for the operator to determine if the data is sufficiently accurate for use in GGW employment. This information could be displayed on demand by placing a cursor over the JTIDS data link target, which would cause a data buffer to overwrite onto the display. Figure 13 depicts a notional JTIDS ground target display.


Ground Waypoints

Airborne Targets

Figure 12
F-14D JTIDS Display Showing Linked Airborne Target Tracks


N 36 48 4732
W 76 34 5939
ELEV 546 feet
TLE 9 meters

Ground Waypoint Designated for Attack

Figure 13
F-14D JTIDS Notional Ground Target Display

Summary

Of the two sources of targeting information for GGWs currently carried on the F-14D, the MDL cartridge data is fixed (cannot be altered in flight), leaving hand-entered keyboard entries as the only alternative to updating GGW target coordinates once airborne With the addition of minor hardware and software modifications, the F-14D targeting sensors (LANTIRN and APG-71 radar) and the digital data link (JTIDS) can provide target location data directly to a GGW in flight This would allow true real-time targeting in that a target could be detected, designated and attacked on a single pass with a GGW In order to integrate these targeting sources into the precision attack gameplan, the target coordinate information must be accompanied by TLE information so that the operator can determine whether the coordinates are accurate enough to support a GGW attack

CHAPTER VI

INTEGRATED SYSTEMS TESTING OF REAL TIME GGW TARGETING: A SYSTEMS APPROACH

Introduction

Once modifications have been made to a F-14D aircraft to include the targeting upgrades described in Chapter V, a series of ground and flight tests should be performed to confirm the integrity of the installation, prove its airworthiness, and determine its impact on the Tomcat crew's ability to perform any of its strike-fighter missions. Most importantly, the capability of the entire F-14D precision strike system (which includes the aircrew) must be proven to be capable of accurately detecting, targeting, employing weapons on and destroying both fixed and mobile targets in any weather. To prove this, a 'systems approach' will be employed as a tool to a) bound the system (F-14D precision strike mission) and break that system into functional components, determining the inputs and outputs of each component, and b) test the interaction between components [32]. The F-14D precision strike mission can be broken into a system of components as depicted in figure 14. The central components of the system are depicted with solid lines, and the tests critical to defining the system are depicted with dashed lines.

Testing of the F-14D precision strike system will be broken into two phases. The first phase, <u>functional tests</u>, will determine the hardware and software modification integrity, prove the installation's airworthiness, and ensure no degradation of previously existing systems on board the F-14D. The second phase of testing, <u>operational tests</u>, will determine the capability of the overall system to accurately self-target for GPS guided weapons. The following paragraphs detail these ground and flight tests

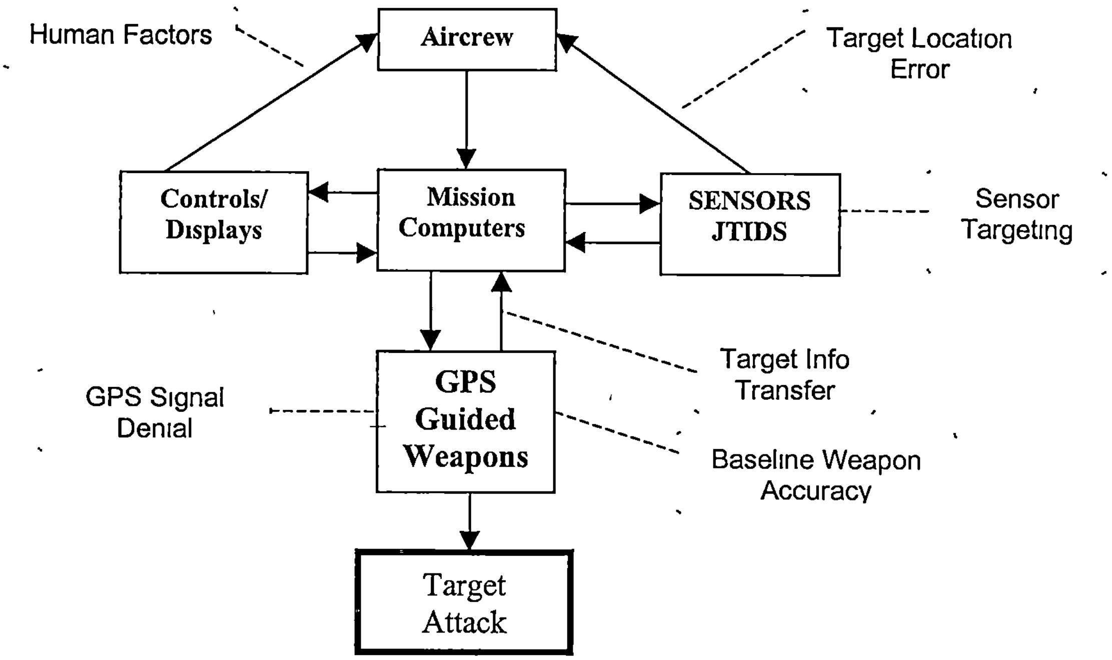


Figure 14
F-14D Precision Strike System Diagram

Functional Tests

Once the hardware and software modifications have been completed on the test aircraft, a series of ground and airborne test will be conducted to verify that the new components function as designed while not interfering with any of the previously existing components of the aircraft These tests will include functional ground runs and electromagnetic compatibility tests, which will ensure that the airworthiness of the aircraft and its vital flight systems have not been adversely effected by the new components Airborne tests will include a functional check flight, which will ensure all basic aircraft functionality still remains, as well as carrier suitability testing, which will determine if the new hardware and software can withstand the Navy carrier flight deck environment (to include wire-arrested landings and catapult takeoffs) Although these functional tests are vital to ensure that the F-14D system modifications will function as designed in fleet aircraft, and must be completed prior to any operational testing, they are not germane to this thesis, and therefore are mentioned here to briefly outline the overall scope of testing The remaining paragraphs will detail the operational tests necessary to prove the accuracy of self-targeting for GPS guided weapons.

Sensor Targeting

If the F-14D's sensors are to be used to generate target locations for GGWs, they first and foremost must be able to detect and identify the potential targets from tactically representative flight profiles This test will examine both the radar and the LANTIRN's capability to detect tactically representative targets while flying a simulated combat attack profile. It is important to note that these test points are not a formal test of either sensor's maximum detection or identification ranges, but rather a very specialized test to provide a baseline for what the performance of the sensors is when attempting to detect representative targets for a GGW mission A set of 12 target types will be utilized, using both the radar high resolution maps and the LANTIRN FLIR as targeting sensors The result of this test will determine the likely target set that would be considered feasible for real-time targeting with GGWs Table 3 outlines the sensor targeting test

Table 3
F-14D GGW Sensor Targeting Tests

F-14D GGW Sensor Targeting		
Test Aircraft Requirements	APG-71 w/ high res map, LANTIRN, video recorders	
Target(1)	Type (Fixed, Mobile)	Data
Command, Control, and Communications Sites and Bunkers	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Electronic Warfare and Ground-Controlled Intercept Sites	Fixed/Mobile	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Surface-to-Air Missile and Anti-aircraft Artillery Sites	Mobile	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Petroleum Refineries and Tank Farms	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Airfields (Aircraft, Shelters, Runways & Facilities)	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Tunnel and Cave Entrances	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Highway and Railroad Bridges	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Railroad Yards and Line-of-Communication	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Missile and Artillery Sites	Mobile	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Ships in Port and Naval Storage and Repair Facilities	Mobile/Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Industrial Sites (Manufacturing Plants, Military Storage Facilities, Electrical Networks)	Fixed	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)
Troop and Equipment Formations	Mobile	Radar Detect and ID Ranges (nmi) LANTIRN Detect and ID Ranges (nmi)

Notes. 1 Target list as delineated in the Combat Air Forces JDAM Concept of Operations, Reference 19

Target Location Error

This test will examine the radar and LANTIRN capabilities to accurately determine a target's location once it is designated for attack The same tactically representative targets used in the sensor targeting tests will be used for this test as well For truth data to compare the sensor derived target location against, each target must be surveyed for its WGS-84 geo-coordinate location. It will be important to have each target accurately surveyed in order to provide the highest confidence in the truth data. For each target, multiple designations will be performed at tactically representative altitudes and airspeeds, and the sensor derived target locations will be recorded. Delta latitude, longitude and altitudes will be calculated from the surveyed position of each target, and target location error (TLE) plots (both horizontal and vertical error) will be derived As seen in chapter IV, a baseline targeting accuracy study using the LANTIRN system against a non-tactical calibration target has already been performed, showing a linear relationship where TLE decreases with decreasing slant range from the target. A similar relationship would be expected with radar targeting. The test matrix will be identical to that shown in Table 3, except the data collected will be multiple target locations derived of each target by both the radar and LANTIRN sensors at various slant ranges

Target Information Transfer

Once a target has been located and designated for attack using either the radar or LANTIRN, the target location information must then be sent to the weapon in order to overwrite the target location with the newly derived coordinates. This test will ensure that the information derived from the sensors is not altered as it is being programmed into the weapons As in the previously described tests, the same surveyed tactical targets will be utilized. An additional test aircraft requirement will be carriage of a GGW on one of the weapon stations. The test will consist of designating a target, viewing and transferring the sensor derived target information to the GGW, and monitoring the GGW data for the proper information transfer. The data that is transferred into the GGW can be monitored in two ways. The first is to electronically monitor via a 1553 data bus tap into the weapon's guidance and control unit, saving the information on electronic media for post flight analysis This data would show the results of a target location update in the weapon, as well as all other data traffic due to communication between the weapon and the aircraft While the bus tap data would be desirable, the cost to install this type of instrumentation and recording system would most likely be prohibitive A second method for monitoring the weapon target data update is to recall the target data from the weapon after the coordinate transfer takes place This action is valid as it queries the weapon and reports what is stored in the weapon's guidance and control unit. This method is most attractive since it requires no additional instrumentation (and adds no additional cost) for the tests. Another important data sample to record is the time required transferring and retrieving the new target location information. This is important information to apply to tactical applicability of GGW targeting in a combat environment

Baseline Weapon Accuracy

This testing will isolate the GGW performance from any aircraft influences by determining the baseline accuracy of the weapons. A series of weapon deliveries using tactical delivery profiles will be performed, allowing the weapons to navigate to the pre-programmed aimpoints using their GPS aided INS systems A circular error probable (CEP) will be determined which would statistically describe the miss distance data. The weapons delivered should employ telemetry transmitters that data link to a ground recording station signals from the weapons guidance control units, allowing post-release analysis of the performance and accuracy of the weapons The data collected here will be compared to aircraft-in-the-loop weapon deliveries to determine if any degradation is present due to the aircraft-to-weapon interface

End-to-End Accuracy Testing

Upon completion of the previously discussed component tests, which will establish the capabilities of each of the critical components of GGW targeting, a series of end-to-end tests can commence This testing will attempt to simulate the employment of GGWs via F-14D self-targeting using its on-board sensors. Prior to takeoff, the aircrew should not know the exact target locations, rather a general area where to expect targets to be located This will force the crew to locate, designate and attack the representative targets based solely on the capabilities of the on-board sensor and weapons. The test conductors on the ground will know the surveyed location of the intended targets, and will verify that the test aircrew has located and the system has calculated the proper target location prior to weapon release. Telemetry should again be employed with the test GGW in order to monitor its performance during the post release and weapon impact phases. Final success criteria would be based on the following:

1. The aircrew was successfully able to locate and designate the target
2. The aircraft sensors were capable of accurately calculating the target location.
3 The weapons were successfully updated with the new target information.
4. The weapon was released and accurately guided to the intended target

5. The weapon impact point was not significantly offset in miss distance relative to the baseline weapon accuracy data (within 10% of baseline CEP).

GPS Signal Denial

In order for precision attacks with GGWs to be successful, full, uninterrupted access to the GPS satellite signals must be maintained If an adversary is capable of interfering with the GPS signals at the aircraft or the weapon, the GGW accuracy will suffer. Both aircraft and weapon systems can operate without GPS signals, navigating solely on the capability of their inertial navigation computers. This mode, usually referred to as *GPS denied* or *unaided* navigation, is inherently less accurate. In the case of JDAM, the weapon specification calls for 13 meter CEP with GPS aiding. If GPS is denied, the specification for the weapon is 30 meters [17]. A series of GPS denial flight tests should be performed which examine the aircraft and weapon system's capability to accurately attack targets in a GPS jamming environment. These flights would consist first of simulated attack profiles, assessing the effects of GPS denial of aircraft GPS on the targeting solution This would provide a subset of data to determine if targets can be accurately located and coordinates generated in a GPS jamming scenario. The second phase would release GGWs based on the GPS denied target location and assess the accuracy of the weapons Since the Navy's primary precision attack emphasis is switching to GGW technology, denial of GPS by an adversary could severely limit attack success. Therefore, the effects of GPS denial on GGW targeting should be examined and tactics to counter this threat should be developed.

GPS Guided Weapon Human Factors Assessment

Employment of GGWs from the F-14D is a complex and high workload-intensive operation In order to understand the effects of the weapon system-operator interface, a test technique should be employed that quantifies aircrew workload and stress factors while performing GGW employment missions Workload and stress will be measured while employing GGWs with the current F-14D GGW and comparing the results to data gathered utilizing the updated GGW interface. The test method employed will be the Subjective Workload Assessment Technique (SWAT) This technique was developed by engineers at Eglin Air Force Base to accurately quantify levels of aircrew workload, stress, and time management during simulated combat employment of aircraft and weapon systems [20] A more complete discussion of SWAT is included in appendix F. This method was successfully implemented to quantify workload reduction for F-15E Weapon System Operators (WSOs) due to incorporation of GPS guidance into the AGM-130 air-to-ground attack missile [21]. SWAT uses three categories in order to quantify workload: time, mental effort and psychological stress During the performance of critical portions of GGW delivery profiles, the F-14D RIOs will be asked to rate each of the three categories using a scale from 1(easiest) to 3 (most difficult) A group workload scale will be established by the test RIOs that will define the most important of the three factors Psychological stress will be defined as the anxiety level of the RIO as he is performing the target acquisition, weapon target update and weapon delivery phases of the mission. Psychological stress is typically considered the most important stress factor, as it naturally tends to increase and is a major source of errors during combat. Mental effort will be defined as the amount of concentration required to complete each of the

GGW targeting tasks In other words, is the RIO capable of performing GGW targeting tasks while still maintaining situational awareness? Time is defined as that spent performing the GGW targeting tasks relative to the total time from target acquisition to weapon release. While performing simulated GGW attack missions, the RIO will be required to perform typical combat aircrew duties, such as maintain visual lookout, monitor air-to-air radar displays and monitor the Radar Warning Receiver displays. The amount of time the RIO has to perform these functions, as well as complete the GGW targeting tasks, will be crucial to assigning a rating in the time category of SWAT.

In-flight SWAT ratings will be tabulated post flight and average ratings for all RIOs with the current GGW interface and the new GGW interface will be compared. A reduction of overall SWAT rating for the new interface of greater than 10 percent will be considered a significant reduction in overall RIO workload, and thus an enhancing characteristic of the overall system.

Too often, the Navy has fielded a new or improved weapon system without investigating its effects on aircrew workload while employing it in a combat environment. Incorporation of the SWAT technique will allow the collection of quantitative data for analysis of the effects on aircrew workload, as well as provide a measurable metric by which to determine the enhancing characteristics of a new or upgraded system.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This study has identified GPS Guided Weapons as the emerging technology to carry a large portion of the precision attack assignments for U S. Navy attack platforms in the near term A deficiency has been identified in that no current capability exists to update GGW target locations with aircraft sensors This has made GGW attacks of the relocatable target set, which in general constitutes 75% of the total targets attacked, a very difficult task If the relocatables cannot be effectively located and targeted using tactical aircraft sensors, a large portion of the Navy's precision attack strategy will be compromised.

This study has also established the capability of the F-14D weapon system to provide accurate target locations in support of GGWs. Using its onboard sensors, the F-14D can accurately detect and geo-locate many relocatable targets The current GGW implementation on the F-14D only allows GGW target updates via hand-entered coordinates A series of upgrades to the F-14D weapon system have been suggested to implement a self-targeting capability. In order to validate the effectiveness of these upgrades, a flight test protocol using a systems approach was also discussed

The direct support of GGW targeting with its onboard sensors would allow the F-14D to attack relocatable targets in real-time, making GGW attacks against them a feasible option. The following is a list of modifications to the F-14D weapon system required to allow real time targeting of GPS weapons using the onboard sensors of the Super Tomcat.

Recommended Modifications

1 Incorporate the LANTIRN Targeting System onto the avionics bus by converting the LANTIRN Control Panel into a Bus Monitor/Remote Terminal on Mission Bus #2 This modification will allow direct communication between the targeting FLIR and the rest of the weapon system, which would provide an avenue of direct data transfer from the LANTIRN to the GGWs

2 Modify the APG-71 High Resolution Map PPI and Patch Map displays to include calculated target locations of designated ground targets, as well as a Target Location Error estimate of those coordinates. This should also be accompanied by a new option on the display to update GGW target coordinates with the displayed radar designated target location.

3. Modify the JTIDS data link information displays of ground targets to provide precision target locations and Target Location Error data for the optional GGW update of targeting information with that linked from third party sources

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REFERENCES

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APPENDICES

APPENDIX A

F-14D AIRCRAFT
DETAILED DESCRIPTION

F-14D Aircraft

The F-14D Super Tomcat is a two seat, twin engine, variable geometry wing, supersonic, carrier based, long range multi-role strike-fighter, designed and manufactured by Northrop Grumman Aerospace Corporation. The F-14D was developed in the 1980's as an extensive upgrade to the F-14A/B Upgraded items include new General Electric F110-GE-400 engines and digital avionics architecture. After initial fleet introduction in 1992, the F-14D completed its first operational deployment in 1994. The overall aircraft layout is depicted in Figure A-1 The significant physical differences (externally) from the F-14A include different exhaust nozzles and a dual chin pod (Figure A-2), which houses a television camera set (TCS) and infrared search and track system (IRSTS) in a tandem configuration below the aircraft's nose A complete description of the aircraft and its systems can be found in Reference 13.

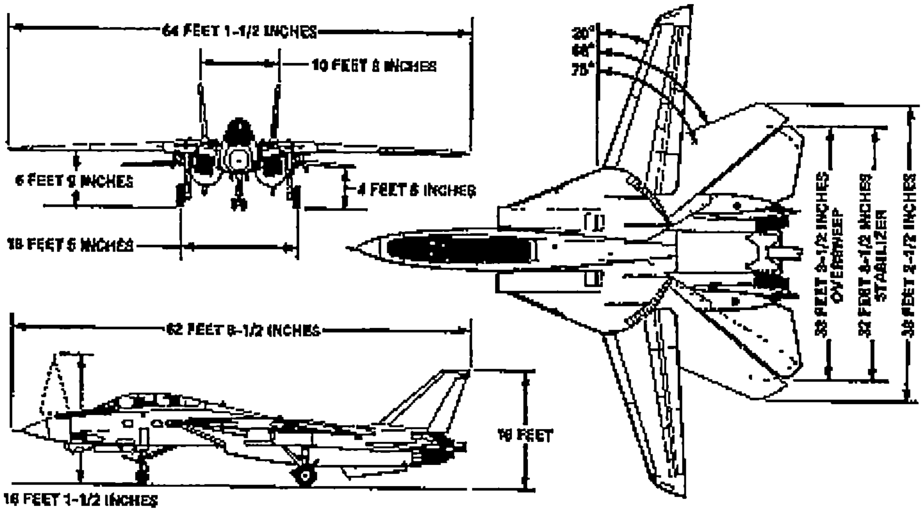


Figure A-1[13]
F-14D Aircraft Layout

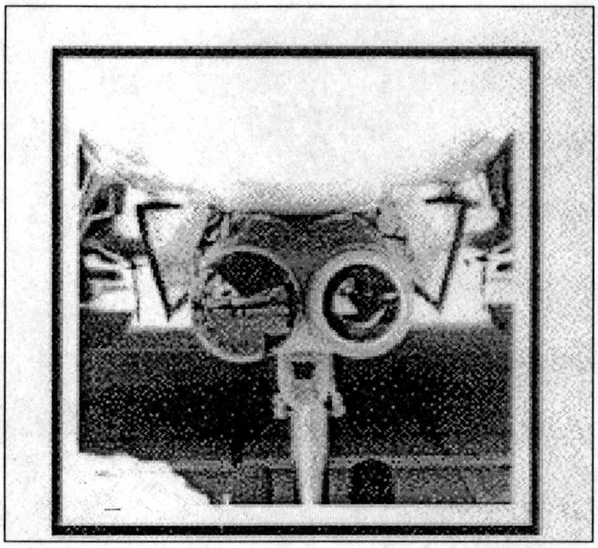


Figure A-2 [22]
F-14D Dual Chin Pod

Three significant design features afford the F-14D a wide speed range for its operational flight envelope: Variable geometry wings, leading and trailing edge high lift devices, and variable geometry engine inlets. The aircraft's General Electric F110-GE-400 engines are capable of producing 13,800 lb. of thrust at military power, and 23,600 lb. each in afterburner. The aircraft incorporates an irreversible, hydraulically powered flight control system controlled by three-axis digital processors known as the Digital Flight Control System, or DFCS. The DFCS gives the F-14D fly-by-wire like handling qualities while maintaining much of the original hydraulically actuated flight control system. Aircraft empty weight is approximately 44,000 lb. Internal fuel capacity is 16,200 lb., and the aircraft has a maximum field takeoff weight of 72,000 lb. (76,000 lb. for carrier catapult launches).

The Super Tomcat is capable of carriage and employment of a wide variety of air-to-air and air-to-ground weaponry. For air-to-air missions, the F-14D is equipped with eight external weapon stations for carriage of AIM-54 Phoenix, AIM-7 Sparrow, and AIM-9 Sidewinder missiles The AIM-54 was the first air-to-air missile to incorporate an active radar seeker It is a long-range weapon with semi-active and active guidance modes The Super Tomcat can simultaneously attack 6 different airborne targets using AIM-54 missiles The missile is launch and leave capable, meaning it can continue to guide to a target without support from the launching aircraft The AIM-7 Sparrow is a supersonic, medium range, radar guided missile. The Sparrow is a semi-active weapon, requiring continuous wave or pulse-doppler radar energy from the launching aircraft to home to the target The AIM-7 requires continuous radar illumination of the target throughout the missile time of flight. The AIM-9 Sidewinder is a supersonic, passive-homing heat-seeking missile. The Sidewinder is a short-range weapon that guides on the infrared signature of a target aircraft, and is launch and leave capable. The aircraft is also configured with a 20-millimeter Vulcan Cannon, capable of firing high explosive rounds at 4,000 or 6,000 rounds per minute

In support of air-to-ground attack missions, the F-14D can employ unguided and guided munitions Unguided weapons include Mk-80 series general-purpose bombs, cluster munitions, mines, and airborne and marine flares. Guided weapons include laser-guided bombs (LGB), and recently cleared MIL-STD-1760 interface class weapons, including GBU-24E/B, JDAM and JSOW. A detailed description of these weapons in included in Appendix E.

The weapons are carried on 10 weapon stations, as depicted in Figure A-3. Wing stations 1A and 8A are capable of carrying AIM-9 missiles only. Wing stations 1B and 8B can carry all three types of air-to-air missile. Station 8B has also been modified to carry the LANTIRN FLIR pod, which is described in detail in Appendix C Stations 2 and 7, under the aircraft engine nacelles, are capable of carrying external fuel tanks, providing an additional 3,800 lb of fuel Weapon stations 3,4,5 and 6, located on the under fuselage (also known as the 'tunnel'), are capable of carrying AIM-7 and AIM-54 missiles, as well as all of the different types of air-to-ground ordnance. Each of the four tunnel weapon stations has been equipped with digital data, video, and GPS data lines to accommodate the –1760 class weapon interfaces.

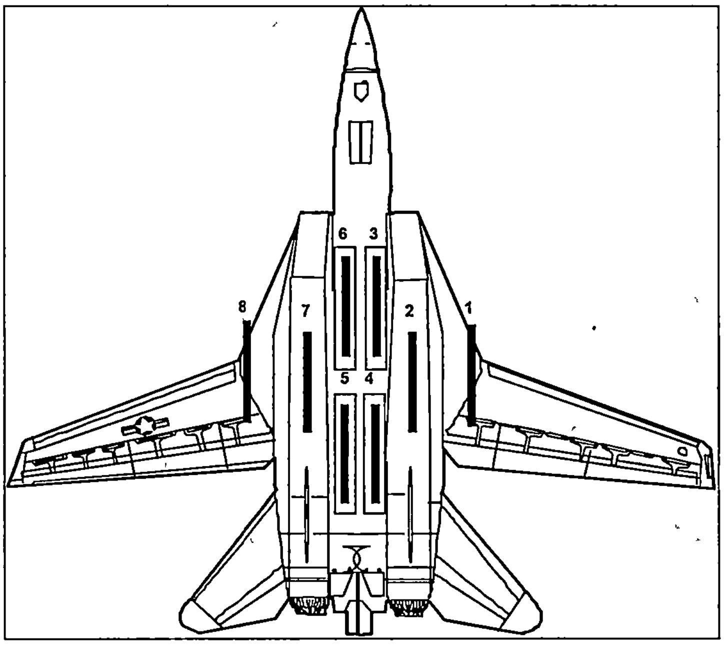


Figure A-3 [13]
F-14D Weapon Stations.

F-14D Weapon System

The F-14D weapon system is centered around two digital mission computers, and consists of the Raytheon (Hughes) APG-71 multiple mode radar, Low Altitude Navigation Targeting Infrared for Night (LANTIRN) Pod, R2512A/U Miniature Airborne GPS Receiver (MAGR), AN/ASN-139 Inertial Navigation System, Defensive Electronic Countermeasures (DECM) Suite including the AN/ALR-67 radar warning receiver, ALQ-165 Airborne Self Protect Jammer (ASPJ), and ALE-39 Countermeasures dispenser, digital AN/AYQ-15-store management system (SMS), IRSTS, TCS, Joint Tactical Information Distribution System (JTIDS), and various controls and displays An avionics system overview is depicted in Figure A-4 A complete description of the weapon systems of the F-14D can be found in Reference 14.

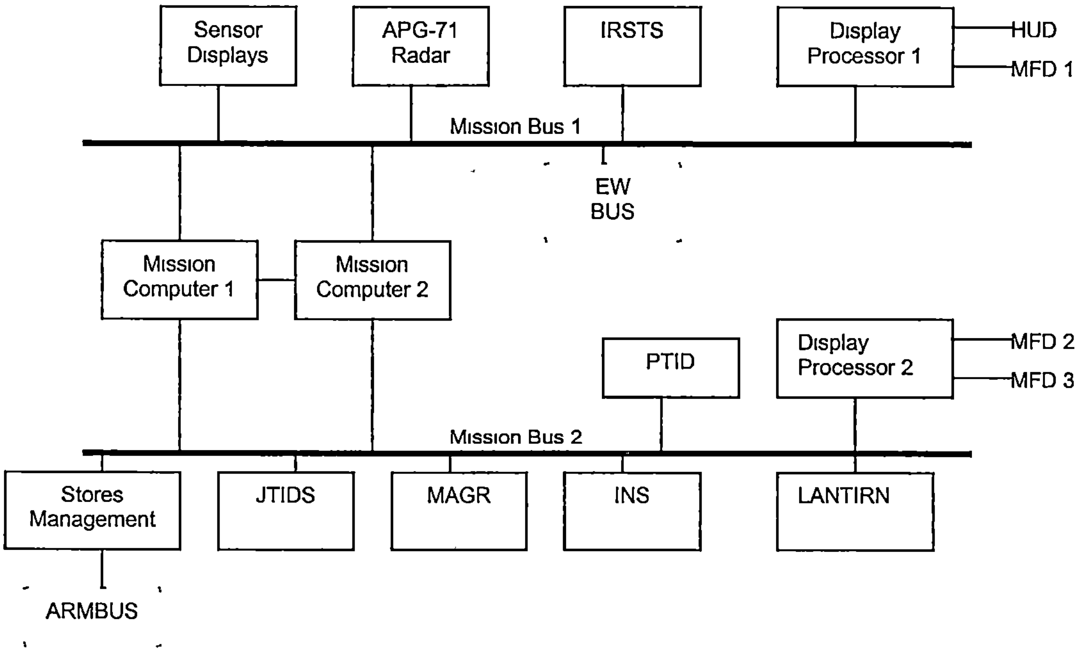


Figure A-4
Simplified F-14D Avionics Diagram

The Mission Computer System (MCS) consists of a MIL-STD-1553B bus network, bus couplers for various interfacing weapon replaceable assemblies, and two AN/AYK-14 computers. Most of the aircraft's systems communicate with the MCS via the 1553B bus, however peripherals that are not compatible with the digital network interface via a converter interface unit (analog-to-digital) The AYK-14 computers operate at 16-MHz clock speed, performing 1 million instructions per second using 1 megabyte of memory.

The AN/APG-71 radar system is the primary sensor for the F-14D, providing multi-mode, all-weather surveillance of air space and land/sea surfaces. The APG-71 features digital processing, a low sidelobe array antenna, digital antenna scan, frequency agility, and multiple pulse repetition frequencies. The radar operates in either low, medium or high PRF for pulse or pulse-doppler detection, acquisition, tack, and target identification of targets in range, range rate, and angle in clear/clutter and jam free/jamming environments. Target illumination, guided missile support, and BIT functions are also provided. The radar, which operates in the X-band, has two major modes. air-to-air (A/A) and air-to-ground (A/G) A/A modes include search, search and track and single target track modes. These modes generate target information for display, as well for use by the MCS for integration with from other aircraft sensors A/G modes provide real beam and synthetic aperture (SAR) ground maps for display and target designation A detailed description of the SAR modes of the APG-71 is contained in Appendix D.

The LANTIRN targeting system provides the F-14D with the ability to detect, acquire, and accurately geo-locate targets using a forward looking infrared sensor, and affords the ability to support laser guided munitions in target attacks The system consists of two major subassemblies, the LANTIRN Control Panel (LCP) and the target set These assemblies are currently integrated into the aircraft in a stand-alone configuration without affecting the existing aircraft data bus scheme. The LANTIRN system includes a GPS antenna/receiver and wiring, as well as provision to display FLIR video on displays in both cockpits. A detailed description of the LANTIRN system is contained in Appendix C.

The F-14D is equipped with the AN/ASN-139 Inertial Navigation System. The ASN-139 is a ring laser gyro based INS, common to the F/A-18. This INS is capable of alignment in 4 minutes, with a nominal drift rate of 0.8 nmi per hour (unaided by GPS) The ASN-139 provides position and velocity information to the mission computers for navigation and weapon control The Miniature Airborne GPS Receiver (MAGR) has been incorporated into the navigation system to aid the INS in positioning. In the GPS aided mode, the F-14D navigates with an average error of less than 0.1 nmi per hour. The MAGR also provides satellite ephemeris and time data to various on board avionics systems

The aircraft includes a robust defensive electronic countermeasures systems (DECM) centered on a MIL-STD-1553B EW bus. The EW bus provides the F-14D with integration between the various DECM components, as well as ensures electromagnetic compatibility with the APG-71. The ALR-67, which acts as the bus controller, is the aircraft's radar warning receiver (RWR), with several receive and transmit antennas arrayed throughout the aircraft The ALR-67 is a digital, programmable RWR that provides 360-degree coverage of RF threats by detecting and classifying the signals, and passing them to cockpit displays and to the other components of the EW bus. IT is able to detect RF signals from C to J bands. The Airborne Self-Protect Jammer (ASPJ) is an active jammer that protects the aircraft against RF threats. It can simultaneously operate in High and Low RF bands The ASPJ provides blanking commands to the EW bus to avoid interference with the APG-71 radar. Figure A-5 illustrates the various locations of the F-14D DECM suite.

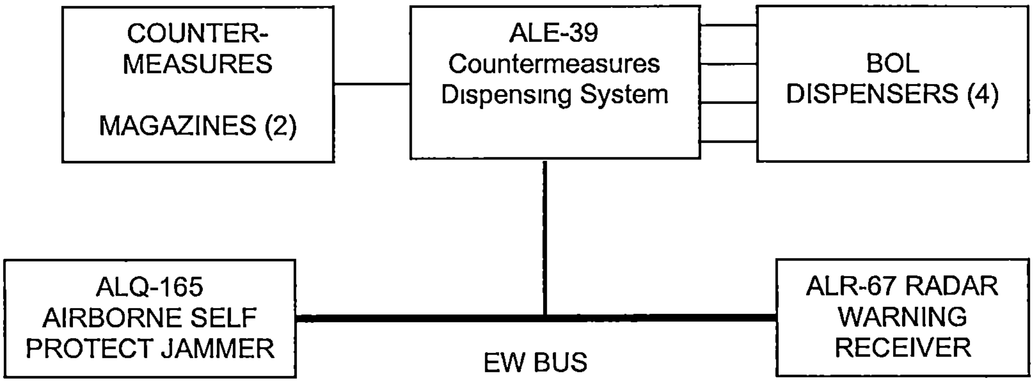


Figure A-5 [14]
F-14D DECM Components

The AYQ-15 Stores Management System (SMS), which is common with the F/A-18, is the interface between the aircraft stores and the mission computers The SMS provides signal processing and logic control required for inventory and identification of all stores carried, preparation and test of missiles, and weapon select, arm and launch functions It utilizes a programmable stores management processor (SMP), to communicate to the mission computers and the weapon stations via a MIL-STD-1553B Armament bus. SMS weapon selection and control is accomplished via a rear cockpit armament panel, pilot control stick switches and MFD displays in either cockpit. (Reference 14).

The IRSTS is a passive infrared scanner optimized for the 8-12 micron wavelength band. The sensor is housed in the left side of the aircraft's dual chin pod (Figure A-2). IT is optimized for air-to-air detection and is capable of detecting aircraft skin friction heating as well as exhaust gas plumes (Reference 24). The sensor is capable of single target track and track-while-scan modes and provides track information to the mission computers via a standard interface. Track information is displayed along with radar and TCS targets on a variety of aircrew displays. The IRSTS has an imaging capability with two levels of zoom and can be used to identify air or ground targets.

The TCS is a contrast seeking television camera system, housed in the right side of the dual chin pod (Figure A-2). The system has two selectable fields of view, providing up to 10 times magnification, and is primarily used to identify airborne targets. The system can be used to identify ground targets, however manual slewing and extremely limited field of view make this an impractical application.

The F-14D is equipped with the Joint Tactical Information Distribution System (JTIDS). It is composed of the ASW-27C digital communications set and the URQ-107 JTIDS terminal. JTIDS can receive one-way or two-way voice, LINK4A, ACLS and LINK16 network protocol information. This high capacity information distribution system is designed for multi-service use, which links many different units, both airborne and on the surface. JTIDS provides a jam resistant, crypotologic secure digital voice and data source for command, communication and intelligence networks. Each participant on the net, thus providing a real-time representation of battle space information continuously updates the pool of information, which is available to cockpit displays and weapon systems

The F-14D aircrew displays include a 20 degrees horizontal by 17.3 degrees vertical heads up display (HUD) and two multifunction displays (MFD) in the front cockpit as well as a programmable tactical information display (PTID), detail display (DD), and a single MFD in the rear cockpit. The HUD provides the primary flight reference for the aircraft, as well as targeting and DECM status information. The MFD's are common with the F/A-18 and feature a monochrome (green) display with stroke or raster video formats Twenty pushbuttons around the MFD's and the PTID offer a menu selection of display options for tactical, navigation or support system use. LANTIRN, TCS, and IRSTS imagery may be displayed on any of the MFD's, DD and PTID Figures A-6 and A-7 depict the front and rear cockpits of the F-14D.

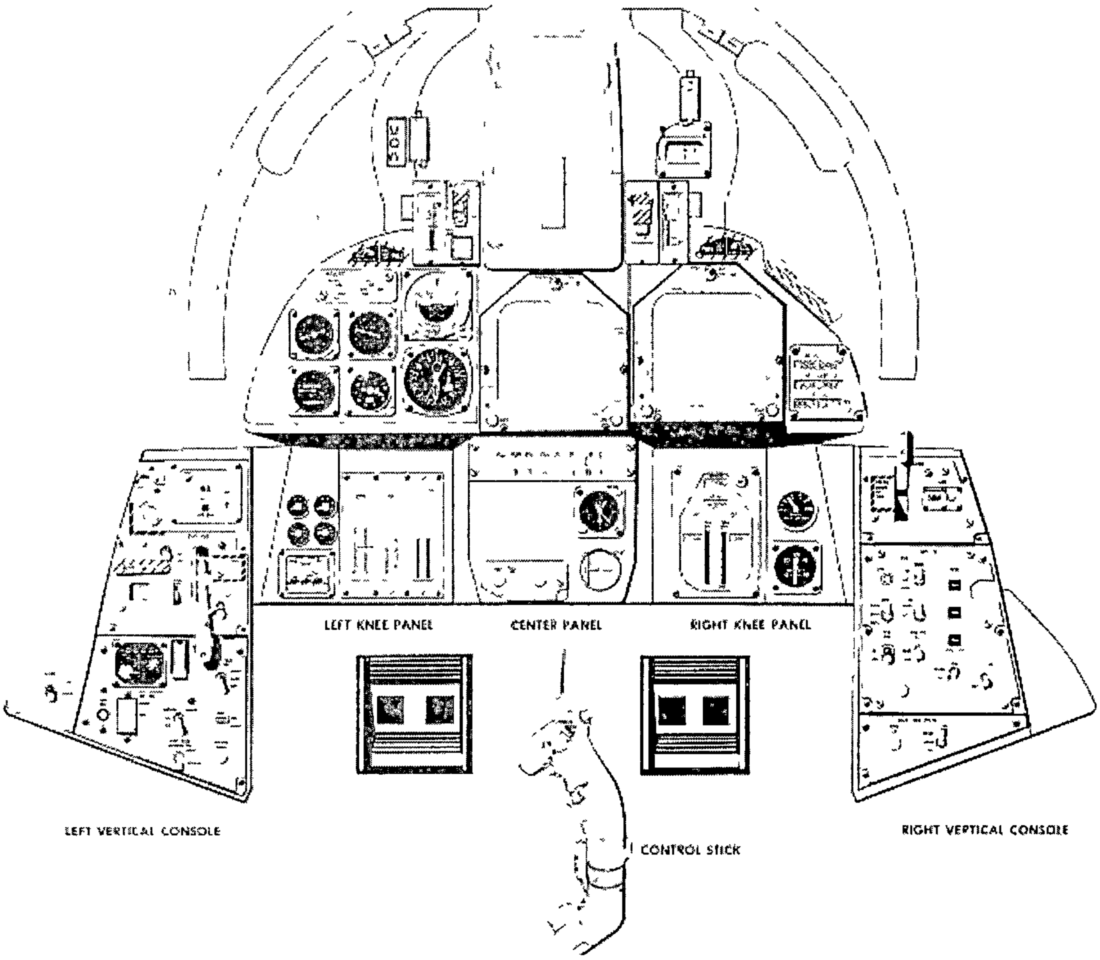


Figure A-6 [13]
F-14D Front Cockpit Layout

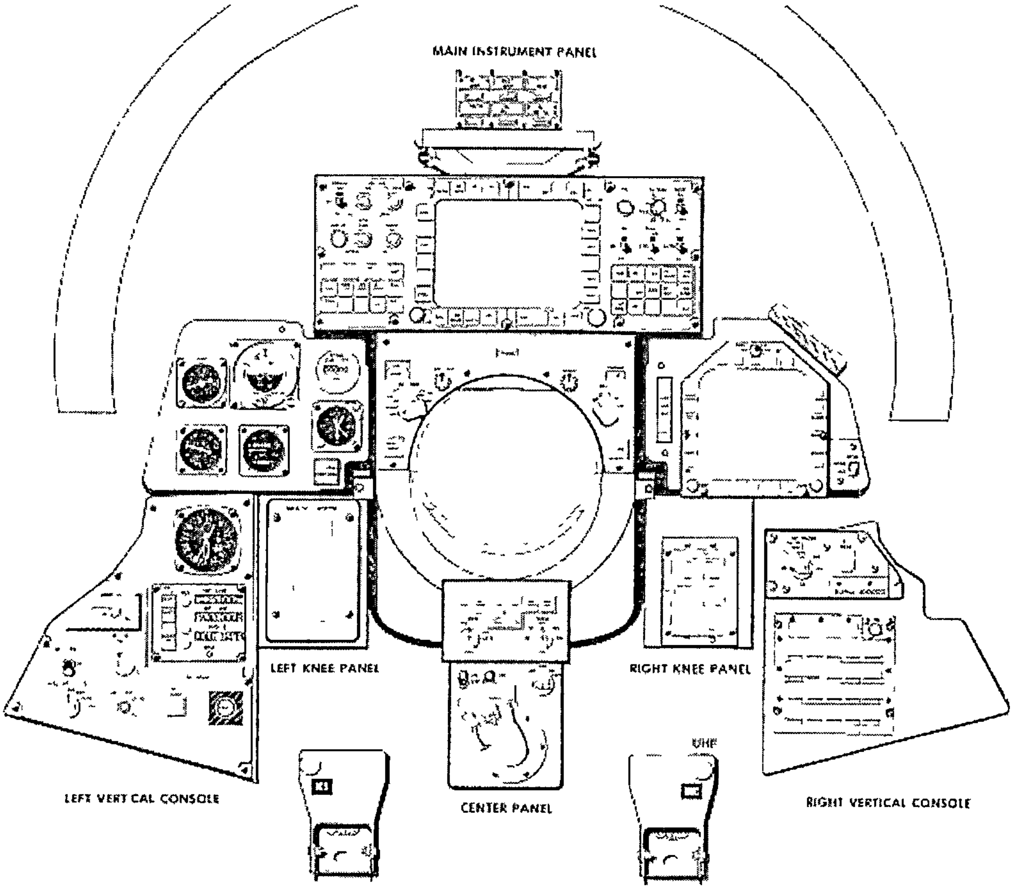


Figure A-7 [14]
F-14D Rear Cockpit Layout

APPENDIX B

GLOBAL POSITIONING SYSTEM

Global Positioning System

Entering the year 2000, the backbone of U.S. military aircraft and weapon positioning and navigation accuracy is dependent largely upon the Navigation Satellite Timing And Ranging / Global Positioning System (NAVSTAR/GPS). This system, developed by the Air Force in the 1980's, was designed originally to provide positioning accuracy of 15 meters (Spherical Error), maintain a velocity accuracy of 0 1 meters per second, timing accuracy in milliseconds, and be capable of operating in dynamic environments and in the presence of jamming GPS is a radio navigation system that utilizes satellites in twelve hour orbits which provide timing signals derived from onboard atomic clocks These signals are used to triangulate a three dimensional position relative to the Earth using a receiver The receiver detects the timing signals, compares them to its own clock, then converts the time delta into a distance to the satellite If four separate satellite signals are detected, the receiver can determine its position (three dimensionally), as well as calculate its own clock error

There are three main elements that make up the Global Positioning System: Space, Control and User The Space Segment comprises the NAVSTAR satellites that are in orbit. There are a total of 24 satellites in orbit (21 operational plus 3 spares). Each satellite has been placed on one of six orbital planes about the Earth, with each satellite in a 12 hour orbit This configuration attempts to provide a minimum of five satellites within line-of-sight to any point on Earth The satellites communicate via two frequencies: L1 (1575 42 MHz) and L2 (1227 60 MHz). The timing signal and other information utilize two distinct spread spectrum techniques (codes) on each frequency.

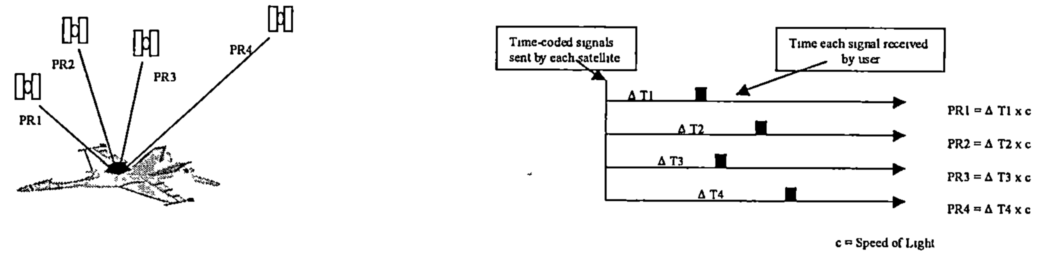
The Coarse/Acquisition (C/A) code is used to allow the receiver to initially acquire the GPS signal and provides hand-over information to the primary navigation signal, which is the Precision (P)-code C/A code is generally only transmitted on L1, whereas P-code is transmitted on L1 and L2. The dual frequencies allow receivers to make estimates of ionospheric refraction and help provide some tolerance for jamming.

GPS provides two levels of accuracy. The Precise Positioning System (PPS) is capable of 16 meter SEP for position, and less than 100 nanosecond timing accuracy. The Standard Positioning System (SPS) accuracy is variable Small, varying errors are injected into the SPS satellite signals in order to reduce the position and time accuracy that the receiver calculates The error magnitudes are encrypted within the navigation messages sent as part of the satellite transmission. In order to receive PPS information, the receiver must have matching cryptographic codes in order to read the error portion of the message and thus resolve them. These intentional errors, known as "selective availability", are controlled by the Air Force so that in conflict, an enemy would not be able to utilize the system. In peacetime, the advertised SPS accuracy is 100 meters horizontally (95% confidence).

The second segment of GPS, Control, is comprised of the Master Control Station at Falcon AFB, Colorado, and several monitoring stations throughout the world. They passively track all satellites in view, collecting ranging data from each satellite. If an anomaly is detected in any of the satellites, the information is passed to Falcon AFB for disposition. If a significant error (clock or otherwise) is noted from a particular satellite, updates are uploaded to correct the problem.

The final segment of GPS is the User Segment This is primarily the receivers that detect and interpret the GPS timing signals and compute a three dimensional position based on those signals Typical GPS architecture for tactical fighter aircraft utilizes a 5-channel (or more) receiver. Four channels will be utilized to track NAVSTAR satellite signals, while the fifth reads the navigation message of the next satellite to be utilized, thus as one satellite signal becomes unusable, a seamless transition to the new signal occurs. The basic concept of user position/time computation involves three phases: Satellite signal reception and measurement, receiver corrections, and position/time solution computation (Figure B-1).

A Data processor obtains psuedorange measurements (PR1, PR2, PR3, PR4) from four satellites



B Data processor applies deterministic corrections

PR_x = PSUEDORANGE (x = 1,2,3,4)

- Psuedorange includes actual distance between satellite and user plus clock bias, atmospheric distortion, relativistic effects, receiver noise, and receiver clock bias
- Satellite clock bias, atmospheric distortion, relativistic effects are compensated for by incorporation of deterministic adjustments to psuedorange prior to inclusion into position/time solution process

C Data processor performs the position/time solution

Four Ranging Equations

$$(x_1 - U_x)^2 + (y_1 - U_y)^2 + (z_1 - U_z)^2 = (PR_1 - CB \times c)^2$$

$$(x_2 - U_x)^2 + (y_2 - U_y)^2 + (z_2 - U_z)^2 = (PR_2 - CB \times c)^2$$

$$(x_3 - U_x)^2 + (y_3 - U_y)^2 + (z_3 - U_z)^2 = (PR_3 - CB \times c)^2$$

$$(x_4 - U_x)^2 + (y_4 - U_y)^2 + (z_4 - U_z)^2 = (PR_4 - CB \times c)^2$$

x_n, y_n, z_n = satellite position (n = 1,2,3,4)

- satellite position broadcast in 50 Hz navigation message

Data Processor Solves For

- **U_x, U_y, U_z = User Position**
- **CB = GPS Receiver Clock Bias**

Figure B-1[25]
GPS User Position / Time Computation Process

APPENDIX C

F-14D AN/AAQ-25 LANTIRN TARGETING SYSTEM DESCRIPTION

LANTIRN Targeting System

The AN/AAQ-25 LANTIRN targeting system (LTS) provides the F-14D with the capability to detect, track and accurately geo-locate targets using a forward looking infrared (FLIR) sensor, as well as the capability to provide laser designation in support of laser guided bombs (LGBs) onto those targets. The system consists of two major subassemblies The LANTIRN Control Panel (LCP) and the LANTIRN targeting pod These subassemblies were originally integrated into the aircraft in a standalone configuration, which was designed to avoid affecting existing aircraft systems (and by doing so, reducing the integration and testing period to less than 1 year). In the proposal for upgrades to the F-14D architecture as part of the development for OFP D04, the LCP has been integrated into the aircraft's MIL-STD-1553/B mission bus number 1 as a remote terminal (RT) This integration will allow the aircraft's weapon system and sensors to directly interface with the LANTIRN system. The LTS also includes a GPS antenna/receiver and displays in both front and rear cockpits for the LTS FLIR video

The F-14D provides three phase 115V AC Power to the pod mounted on station number 8B, and provides 28V DC electrical power to both the pod and the cockpit mounted LCP. The pod's video images are displayed in the cockpit on the Pilot's Vertical Display Indicator (VDI) and on the RIO's Programmable Tactical Information Display (Figure D-1) In the current design, all signal processing for the LANTIRN system occurs directly between the pod and the LCP. There was no tie-in designed into the system to allow communications with the mission computers. A limited amount of MIL-STD-1553/B mission bus input and output data, such as waypoint entry, weapon select and Master Arm status was passively monitored by the LCP and passed to the pod computer. With the incorporation of the LCP as a RT on Mission Bus #2, data could be transferred between the pod and other aircraft sensors and the mission computers. This would provide integrated cueing functions, as well as providing an avenue of automatic data transfer from the pod to the mission computer (such as coordinates of targets imaged and designated using LANTIRN's FLIR sensor).

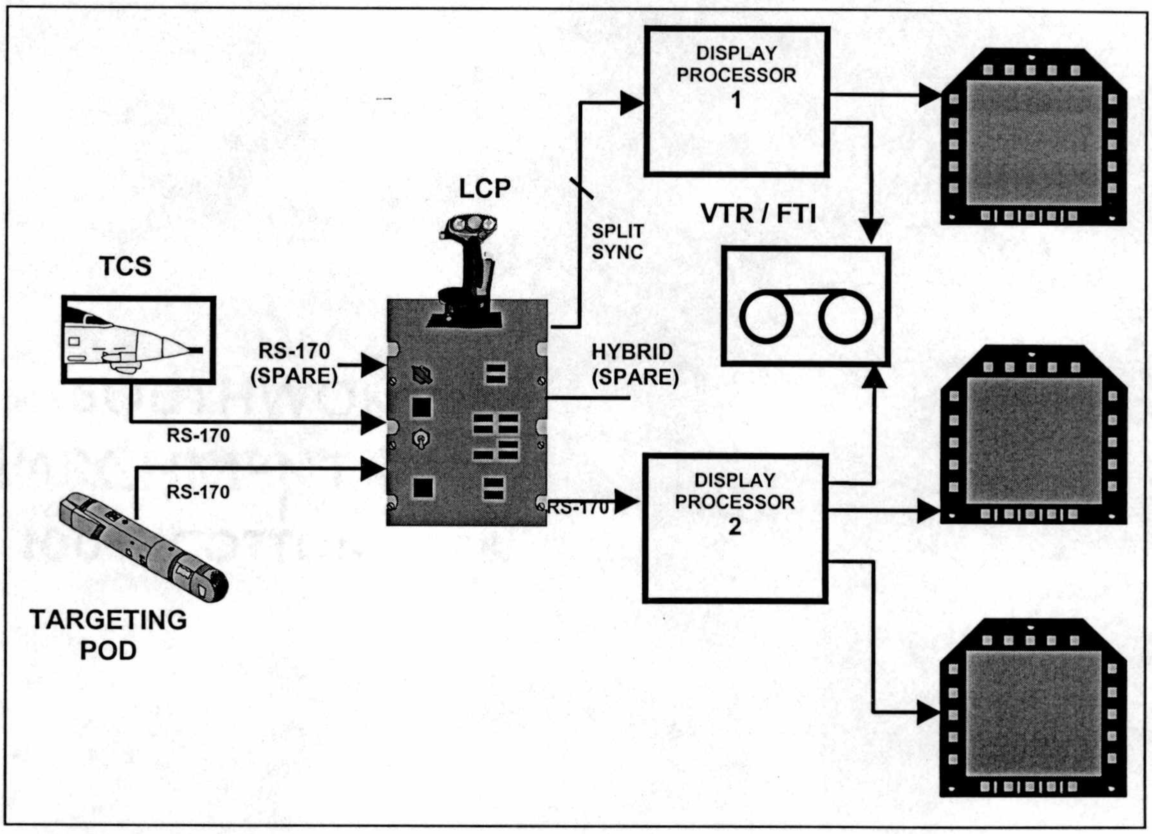


Figure C-1 [15]
LANTIRN Targeting System Diagram

A Global Positioning System (GPS) capability was added to the LTS to enable accurate FLIR cueing. A GPS antenna is mounted on the aircraft turtleback, just aft of the rear cockpit, and signal lines are routed via a splitter/amplifier to the aircraft's Miniature Airborne GPS Receiver (MAGR), stations 3,4,5, and 6 for support of GPS Guided Weapons, and to station 8B to support the LANTIRN pod (figure D-2). A separate GPS receiver within the LANTIRN pod processes satellite reception signals for use in the LTS stand-alone navigation and positioning solutions. The position information from the GPS is filtered through a pod mounted inertial measurement unit to produce a combined or blended GPS/INS solution. This solution is completely independent of the aircraft's MAGR positioning information.

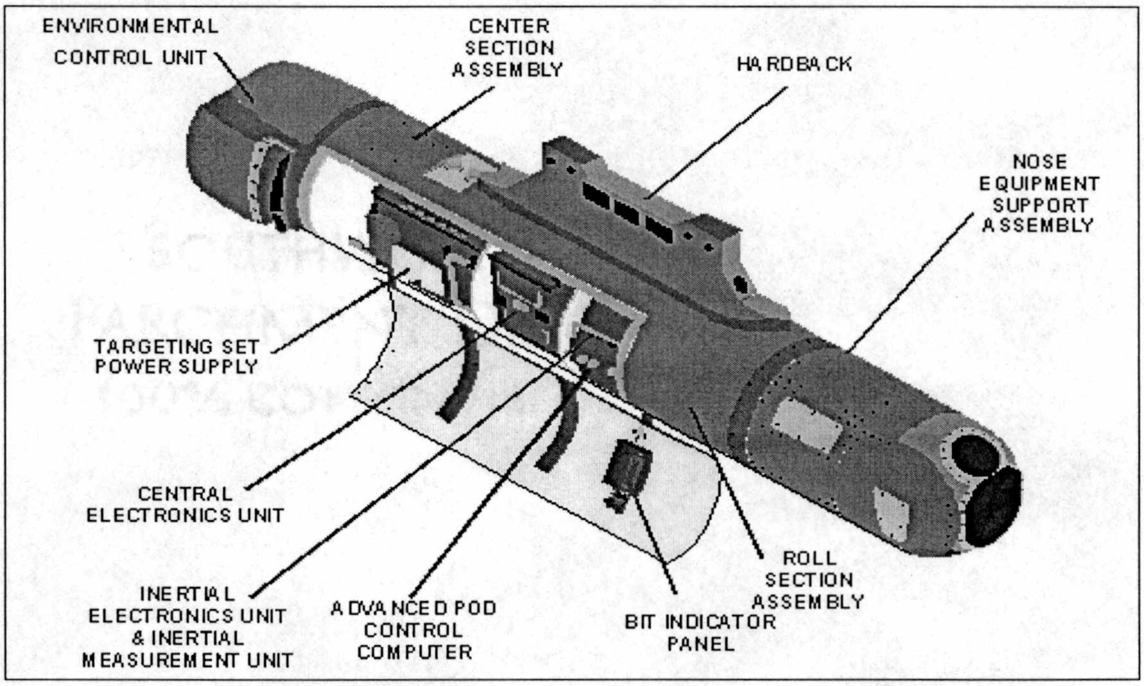


Figure D-2 [15]
AAQ-25 LANTIRN Targeting Pod

The LANTIRN Control Panel (LCP) provides the controlling interface between the aircrew and the pod. The LCP was located on the left outboard console of the RIO's cockpit and consists of the strike processor, the control panel and the hand controller (figure D-3) The strike processor consists of four digital circuit boards mounted below the LCP faceplate They act as an analog-to-digital interface between aircraft information and the pod computer The strike processor also computes all hand control and control panel commands to the pod. The control panel faceplate included the mounting block for the hand controller and various function switches and indicators for the LTS. The hand controller (figure D-4) was a left hand, fixed stick with switches and buttons for controlling the LTS. It is the only aircrew interface for controlling all pod functions including FLIR cueing, slew, track, designation, and firing of the laser.

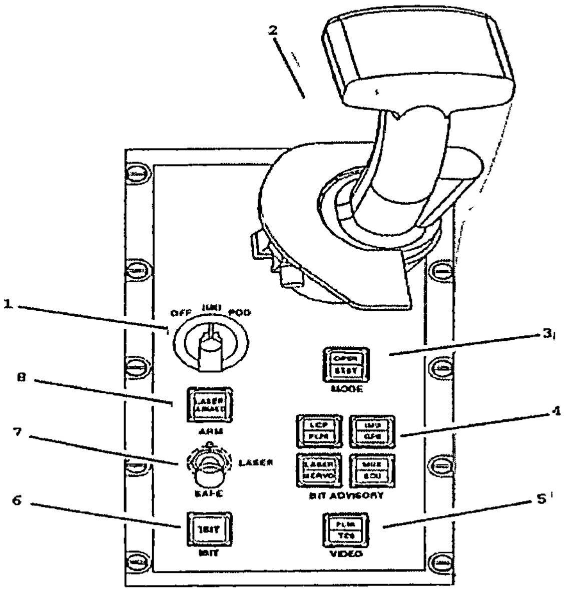


Figure C-3 [15]
LANTIRN CONTROL PANEL

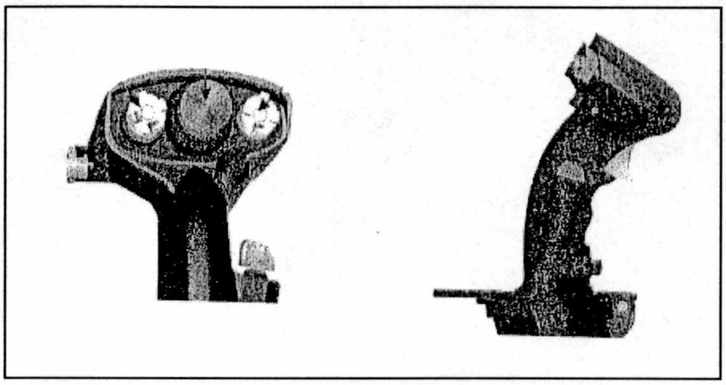


Figure C-4 [15]
LCP Hand Controller

The LANTIRN pod is 98.5 inches long with a diameter of 15 inches. The pod is designed for carriage throughout the flight envelope of the F-14D. A hardback assembly provides the mounting interface between the pod and the aircraft's FLIR adapter, which mounts on station 8B via a universal adapter, which is also used to mount air-to-air missiles such as AIM-7 and AIM-54. The total system weight, including the mounting hardware and hardback, is approximately 610 pounds.

The pod can be physically broken down into ten major subassemblies:

- The Nose Equipment Support Assembly contained the gimbaled optics, laser receiver/transmitter, and laser transmitter control. It provides the optical path to the FLIR assembly, as well as the optical path to and from the laser receiver/transmitter.

- The Roll Section Assembly is between the Nose Equipment Support Assembly and the center section, and contained roll and slip ring hardware that enabled continuos roll and de-roll functions. This section also contains the FLIR detector and associated hardware.

- The Center Section Assembly houses the remaining hardware with the exception of the Environmental Control Unit and the Data Logging Module. This assembly also provides the mechanical and electrical interfaces between the pod and the aircraft.

- The Advanced Pod Control Computer controls and monitors the operation of the targeting system and provides digital communication with the LCP It also continuously monitors the entire LTS for faults and posts these to the aircrew displays as well as storing them for maintenance action later

- The Central Electronics Unit provides data processing and interfacing between the various pod hardware It also provides video processing and interface between the Nose Equipment Assembly and the aircraft, as it reformats FLIR video and controls laser subsystem operation as well as FLIR target tracking

- The LTS Power Supply converts 115V AC electrical power from the aircraft to the appropriate DC voltage required by the pod. It includes the laser power supply which provides the high voltage power for the laser subsystem

- The Inertial Measurement Unit contains combined fiber optic gyros and silicon accelerometers for measurement of aircraft velocity and acceleration in three axes This information is combined with GPS data for the navigation solution and is used to stabilize the FLIR line of sight.

- The Inertial Electronics Unit combines the IMU rate and acceleration data with GPS data to produce the filtered INS solution The solution is passed to the Advance Pod

Control Computer for LTS cueing and stabilization, and to the aircrew displays for navigation.

- The BIT indicator was a set of 10 black and white flags that are visible from the outside of the pod. These flags signal a failure of any of the ten main subassemblies. Initiating a self-test BIT routine while on the ground resets the flags

- The Environmental Control Unit circulates liquid coolant throughout the pod to maintain specified operating temperatures It is capable of adding heat to, or removing heat from, the coolant fluid.

- The Data Logging Module is a write-only memory storage device that monitors all systems while power is applied and records data for use in post-flight maintenance troubleshooting of system failures. All systems failures, mode changes, aircraft parameters, etc are stored in the module and are available for download during maintenance procedures.

APPENDIX D

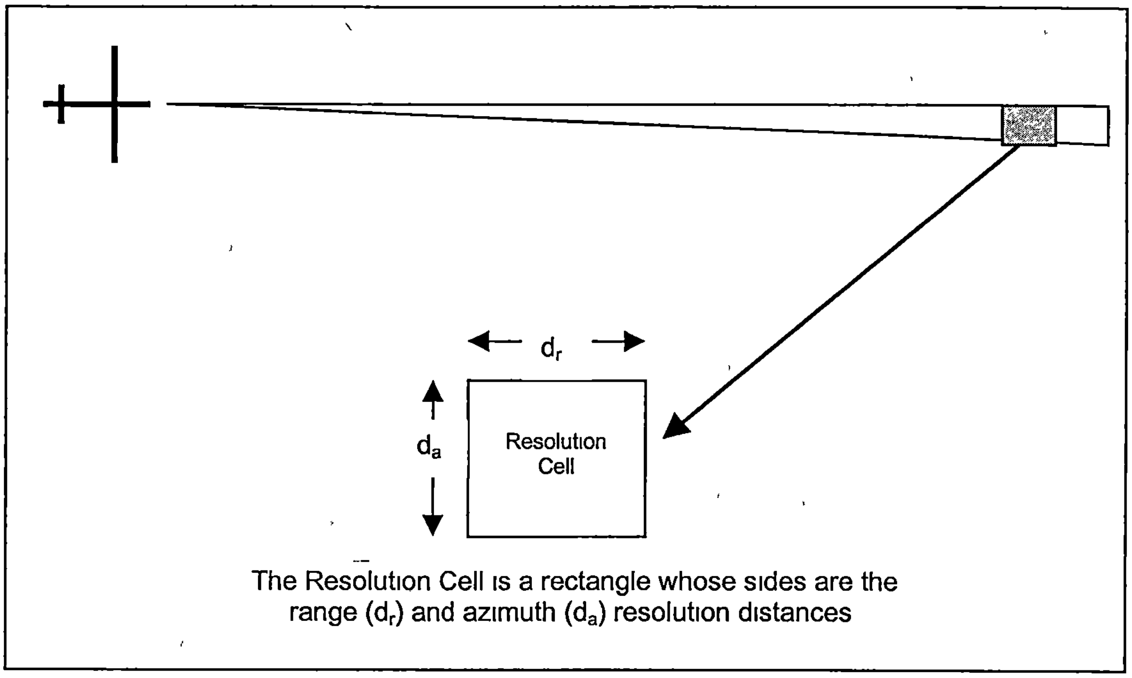
SYNTHETIC APERTURE RADAR (SAR) FUNDEMENTALS

Introduction

It as become increasingly important for airborne tactical radars (such as the F-14D's APG-71) to have the capability of creating ground maps of sufficiently high resolution such that objects and significant topographic features can be identified This appendix will define the types of radar resolution, what methods are optimum for producing that resolution, discuss techniques for creating high resolution maps, and finally will define the high resolution map functionality of the F-14D APG-71 radar. The information presented in this appendix is derived from two references, Introduction to Airborne Radar (second Edition) by Stimson [27], and the Functional Requirements Document for the F-14D Synthetic Aperture Radar Software Change [28].

The quality of a ground map produced by radar is generally defined by the ability of the radar to resolve closely spaced features of the terrain This ability is generally defined in terms of *resolution distance* and *resolution cell size*. Resolution distance is the minimum distance by which two points on the ground may be separated and still be discerned individually by the radar The resolution cell size is defined by a range component, d_r, and a cross range component, d_a (see figure D-1).

There are four primary factors influencing the choice of cell size for a radar map size of the objects to be resolved, amount of signal processing required, the cost to produce the radar and finally interpretation tasks. How large a resolution cell can be and still provide a useful ground map depends upon the object intended to discern. For example, in order to determine course terrain features, such as rivers, mountains and shorelines, a resolution of 500 feet is sufficient. Recognition of much smaller objects requires finer resolution, as depicted in table D-1



The Resolution Cell is a rectangle whose sides are the range (d_r) and azimuth (d_a) resolution distances

Figure D-1
Radar Resolution Cell Illustration

Table D-1
Resolution Required For Various Mapping Applications

Feature to be Resolved	Cell Size
Coast Lines, Large Cities, Mountain Outlines	500 ft
Major highways, field variations	60-100 ft
Road map details, city streets, airports, etc.	30-50 ft
Vehicles, houses, small buildings	5-10 ft

A second factor in determining the appropriate cell size is the amount of processing required to map a given area. In general, the amount of processing required goes up proportionally to the number of cells required to map the given area. If we assume that the resolution cells are square (in reality they are more oval shaped), the number of cells required would be inversely proportional to the square of the resolution distance Therefore, if an application required the resolution to be reduced by ½, then the number of cells required would quadruple. Processing and displaying an increase of resolution cells of that magnitude would therefore require a significant upgrade in computing power to accomplish.

Accompanying the finer resolution and subsequent increased processing power is additional cost. As new systems are being developed, a minimum resolution value is reached at which any finer resolution becomes prohibitively expensive. Fortunately, as technology advances, the cost of providing a given resolution continues to decrease

The final consideration in the determination of the appropriate cell size is the environment in which the images will be interpreted The interpretation environment will define the amount of time required to interpret images, since the finer the resolution, the greater amount of time is required to interpret the details displayed on the map. There are two extremes of application, the first being a mapping satellite, which images large portions of the Earth's surface in order to gather data for a geological survey The data gathered by this method could be reasonably manipulated and interpreted over a period of months, even years. On the opposite end of the spectrum is the application of targeting location in a tactical jet aircraft In this instance, the radar must map and display terrain features while the platform is traveling at over 800 knots (greater than 1300 feet per second), and produce images that are in near-real time, often with resolutions of less than 10 feet In order to make the job of image interpretation feasible, very small patches of landmass are mapped at a given time, and the capability to freeze the imagery for manipulation is added If a finer resolution is required, a correspondingly smaller patch of land is mapped.

Fine Radar Resolution

A radar's capability to differentiate between closely spaced objects is generally broken down into *range resolution* and *azimuth resolution* As a rule of thumb, the range resolution can be manipulated by narrowing the radar pulses transmitted. The yield in range resolution employing this technique is approximately 500 feet per microsecond of pulse width An example would be a radar whose pulse width was 1 microsecond would have a range resolution of 500 feet. If the pulses were decreased to 0.01 microsecond, the resultant range resolution would be 5 feet. The primary limitation on how narrow a pulse may be is the width of the band of frequencies required to be passed by the radar's transmitter and receiver (figure D-2). In order for the radar to pass the power contained in the reduced pulses, the bandwidth must be on the order of 1/(pulse width, τ), therefore, for a 0 01 microsecond pulse width, our radar would require 100 megahertz of bandwidth. Assuming the radar is operating at 10 Gigahertz (X-band), the bandwidth of 100 megahertz would be 1%, which is well within accepted percentages.

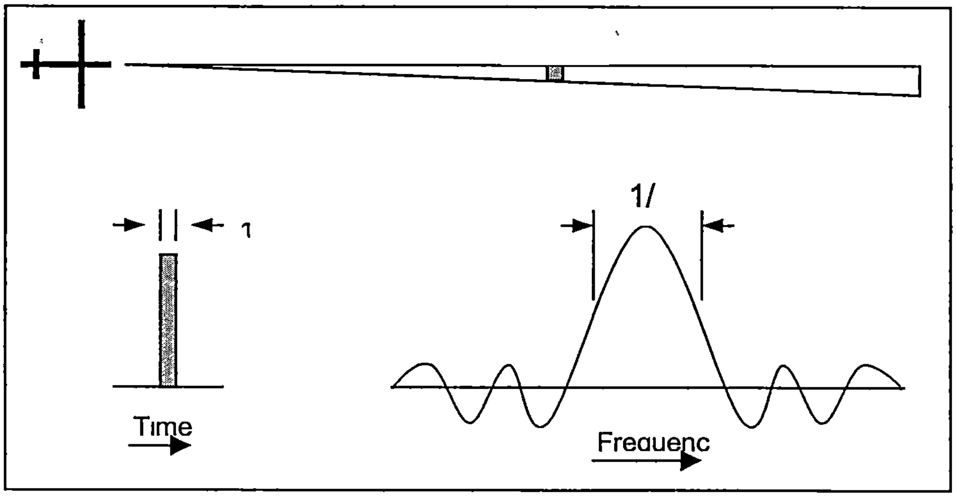


Figure D-2
Radar Range Resolution Illustration

While range resolution can be relatively easily manipulated (within limits), the radar's azimuth resolution is a more complex parameter to alter Generally, the radar's azimuth resolution is equal to the beam width of the antenna multiplied times the range The radar's beam width can be calculated by dividing the wavelength by the length of the antenna (figure D-3)

$$\theta_{3dB} = \lambda / L$$

$$d_a = \theta_{3dB}R = \lambda R/L$$

θ_{3dB} = Antenna Beam Width
λ = Antenna Wavelength
L = Length of Antenna
d_a = Azimuth Resolution
R = Range

Figure D-3
Radar Azimuth Resolution Calculations

Therefore, if fine azimuth resolution is required, the real beam radar must either operate at a very short wavelength, or employ a very long antenna (or both) Due to the phenomena of atmospheric attenuation at shorter wavelengths, the minimum practical for long-range mapping is approximately 3 cm The length of the airborne radar dish is also severely limited since it must be housed within the nose of a strike-fighter aircraft. Since neither option is practical for tactical combat aircraft, the solution to fine azimuth resolutions comes from the creation of a very long antenna *synthetically* This process is called synthetic aperture radar (SAR) SAR uses the forward motion of the aircraft to synthetically create an antenna several thousand feet long A signal processor synthesizes the output of this array after being received by the actual radar antenna over a period of up to several seconds. The processing can be done optically, or more recently digitally. Each time the radar transmits a new pulse, the antenna has moved forward along the synthetic array. Therefore, by pointing a reasonably small antenna to one side of the aircraft's flight path and summing all of the returns from successive pulses, it is possible to synthesize a very long synthetically created side-looking radar array.

Synthetic Aperture Radar Techniques

There are many implementations of SAR techniques in current strike fighter radars. The most significant advantage of using SAR is that a physically small sized antenna operating at a wavelength suitable for long range mapping can provide azimuth resolution as little as 1 foot. Secondly, by increasing the length of the array processed in relation to the range of the area to be mapped, the resolution can be made independent of range In addition to these advantages is the fact that radar maps can be generated day or night, and are not effected by smoke, haze or clouds. The outputs of the maps are "plan views", meaning they are laid out on the display in a fashion closely resembling a road map or aeronautical chart Another significant bonus of SAR techniques is that they are manipulated by adjusting the signal processing (software). Therefore, the techniques can be tailored to the specific application with minor programming changes to the signal processor at relatively small expense

One such specialized technique is known as Doppler Beam Sharpening (DBS) This method of SAR is employed in many tactical fighter aircraft as an intermediate resolution mapping tool. This mode differs from pure SAR in that the length of the array is not increased with the area mapped, but rather is held constant for all ranges. Therefore, the output is similar to the map produced by the radar real beam, expect the

DBS map uses a very narrow beam (hence the name doppler beam sharpening) The antenna will scan a region on both sides of the aircraft, and produce a more coarse resolution than SAR (since the integration time of any given area over the ground is limited) In fact, the integration time across all ranges is equal, causing the azimuth resolution to increase with range Regardless, the resolution across the mapped area is much finer than the real beam, and DBS can provide a near continuously updated map of a very large expanse of ground, which is practically impossible with conventional SAR modes.

F-14D APG-71 High Resolution Maps

In 1997 a final design was approved to implement software changes to the F-14D APG-71 radar to include SAR modes for air-to-ground functionality These changes are being integrated into the aircraft in a phased implementation. Phase I changes are being integrated into the aircraft in Operational Flight Program (OFP) D03B, with Phase II changes accompanying OFP D04 Phase I radar upgrades consist of the following:

1 Addition of High Resolution Map (HRM) into the radar subsystem
2 Addition of a HRM Planned Position Indicator (PPI) mode to a desired resolution of 507 feet at 40 nmi (100 degrees of azimuth scanned – 50 degrees either side of nose).
3. Addition of HRM Patch Map mode to a desired resolution of 127 feet at 10 nmi.

Phase II includes the following upgrades:

1. Radar HRM PPI display to a desired resolution of 59 feet at 4.7 nmi

2. Radar HRM Patch Map display to a desired resolution of 8.5 feet from 2.7 to 40 nmi.

The F-14D APG-71 radar has a greater than 80% commonality with its cousin, the F-15E APG-70 radar [30]. This radar has shown remarkable resolution for a tactical strike fighter aircraft, incorporating several SAR modes for high-resolution maps. The APG-71 will incorporate essentially the same software routines used within the signal processor of the APG-70 for SAR techniques. Since the software will be identical, and the hardware is essentially the same, it is anticipated that the F-14D APG-71 will be capable of demonstrating the same radar resolution as the APG-70 (Table D-2).

Table D-2
F-14D APG-71 Patch Map Resolution (SAR mode)[1]

Map Size (nmi)	Resolution (feet)[1]	Min/Max Map Range (nmi)
0.67	8.5	2.7 / 40
1.3	17	2.7 / 40
3.3	42	2.7 / 40
4.7	59	2.8 / 80
10.0	127	6 / 160
20.0	253	12 / 160
40.0	507	24 / 160
80.0	1014	48 / 160

Notes: 1) The resolution values are theoretical based on actual values achieved by the F-15E APG-70 SAR map modes. Due to the high level of commonality between the F-15E radar and the APG-71, it is anticipated that the F-14D radar can achieve similar resolution figures.

The F-14D PPI display will incorporate Doppler Beam Sharpening techniques to create a near continuously updated high resolution map of 100 degrees azimuth relative to the nose of the aircraft. Figure D-4 illustrates this display. The APG-71 HRM Patch map will incorporate conventional SAR techniques, creating a square map of area (defined by the dimensions in table D-2). Figure D-5 illustrates this display.

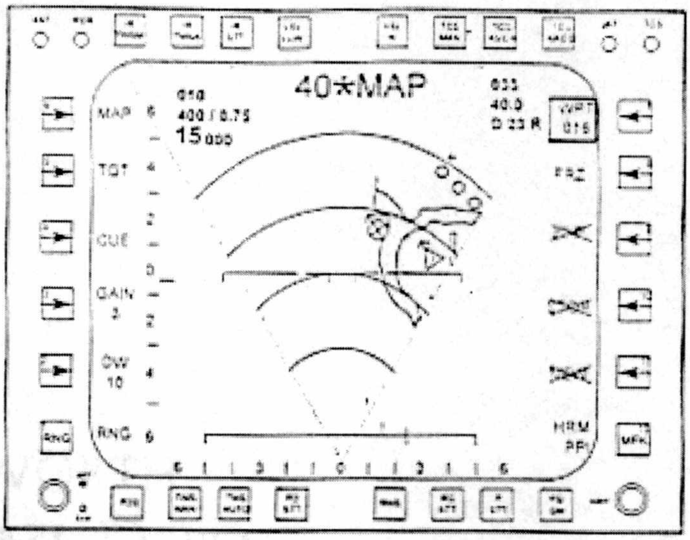


Figure D-4 [28]
F-14D HRM PPI Display

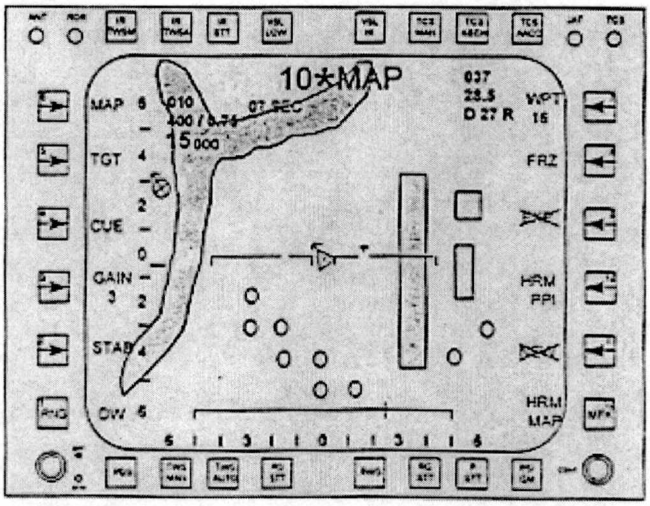


Figure D-5 [28]
F-14D HRM Patch Map display

APPENDIX E

GPS Guided Weapon Detailed Description

Joint Direct Attack Munition (JDAM)

JDAM, manufactured by the Boeing Corp., is a guided, unpowered, air-to-surface weapon. It consists of a tail kit, strap-on mid-body strake panels, conventional warhead, fuze, and essential system interfaces. Interfaces include a built-in-test (BIT) initiated from a ground test set or the cockpit, a Military Standard (MIL-STD)-1760 aircraft store communication interface, mission planning, and cockpit display interfaces for weapon employment. Accurate guidance will be accomplished through a GPS-aided Inertial Navigation System (INS) that will navigate from the release point to the planned target coordinates referenced in a World Geodetic System-1984 (WGS-84) datum. JDAM is designed to achieve a circular error probable (CEP) of 13 meters or less, for impact angles of 60 degrees or greater, against horizontal targets, when GPS is available to the weapon after release. Figure E-1 depicts the various JDAM warheads.

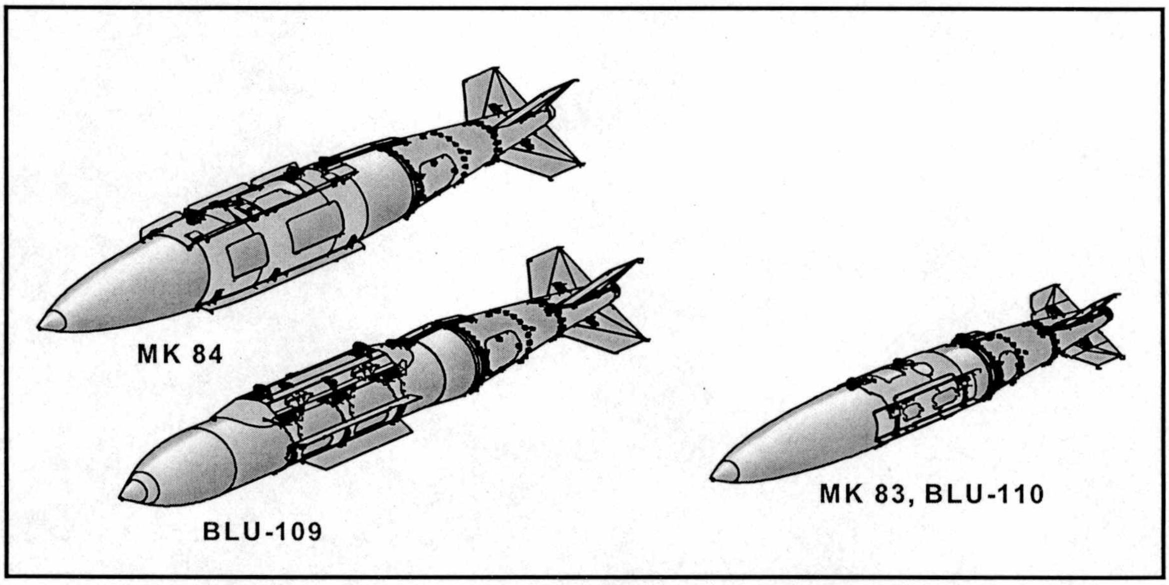


Figure E-1 [19]
JDAM Warhead Variants

The JDAM tailkit consists of the Guidance and Control Unit (GCU), moveable control surfaces and actuators, power supply system, connectors, and GPS antenna (See Figure E-2). Three of the four tail fins for each variant are movable. The tail actuator subsystem electrically moves these three fins based on steering commands from the GCU Following release from the aircraft, the control fins remain locked for one second to ensure safe separation. After the fins unlock, the GCU commands fin position to achieve the desired optimum trajectory to the target to meet the desired impact conditions.

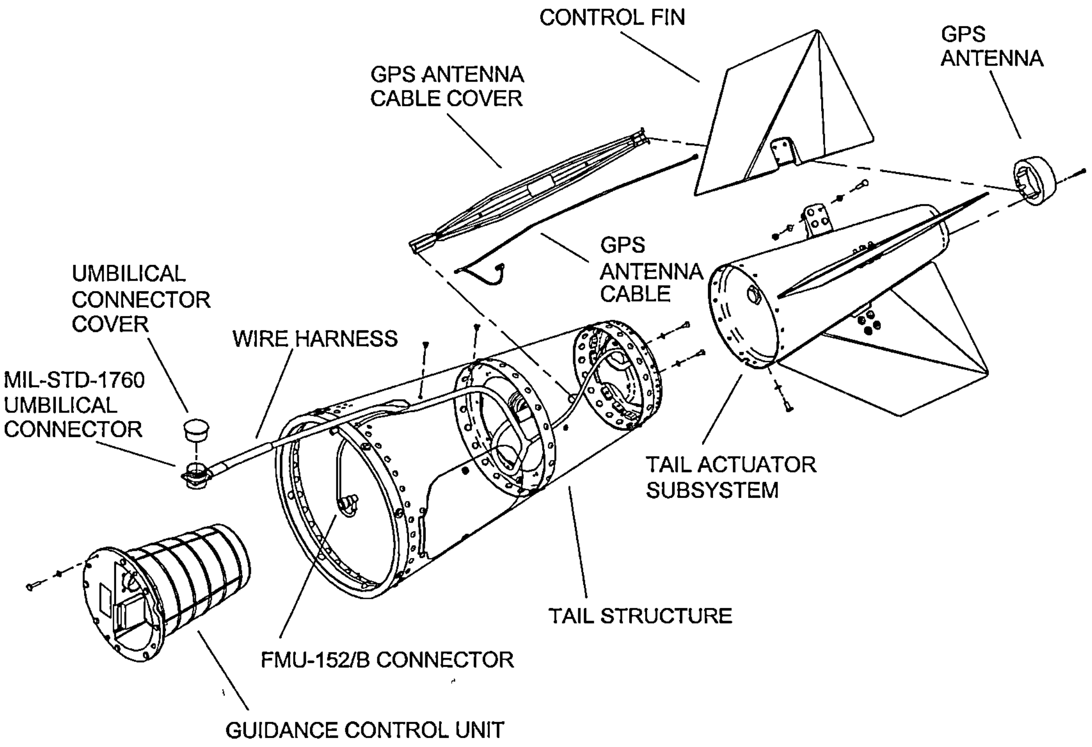


Figure E-2 [19]
JDAM Tail Kit Assembly

A single thermal battery, with a specified minimum life of 194 seconds, provides all electrical power for guidance and control functions after release This battery life limit defines the maximum time of flight (TOF) of the weapon after release.

A set of four mid-body, fixed strake panels strap around the bomb body These give the weapon additional lift and maneuverability required to execute the flight trajectory, while maintaining the stability and separation characteristics of a low-drag unguided bomb For the BLU-109 bomb, the top strake panel is integral to the hardback delivered with the guidance kit.

The JDAM variants are compatible with the FMU-139, FMU-143, and FMU-152 fuzes, dependent on bomb body. The MK 84, MK 83, and BLU-110 variants can use the FMU-139 or the FMU-152/B Joint Programmable Fuze (JPF), with impact or impact delay fuze settings. Both fuzes may be employed with the DSU-33A/B proximity sensor to provide an airburst capability. Currently, the specified battery life for the DSU-33A/B proximity sensor is 60 seconds after release However, demonstrated battery life is greater than 90 seconds and the technical orders are being updated to reflect the new time. The 90 second battery life is a limitation to JDAM employment, and must be considered during mission planning. The BLU-109 JDAM variant is compatible with the FMU-143 tail fuse, with impact delay fuse settings. The FMU-152/B is a multiple arm time and a multiple delay time fuse, with cockpit-selectable settings when used with JDAM

JDAM uses a subset of the Military Standard (MIL-STD)-1760 Class II interface including a MIL-STD-1553 data bus, pylon wiring, and weapon interface on all carriage aircraft The JDAM 1,000-lb (MK 83 or BLU-110) variants offer the potential for multiple carriage on external racks specifically configured with multiple MIL-STD-1760B interfaces such as the BRU-55/A "smart rack" currently in development.

Aircrews will use the Tactical Automated Mission Planning System (TAMPS) to plan JDAM missions A Data Transfer Device (DTD) will be used to transfer information from TAMPS to the aircraft The DTD holds all mission specific planning data, such as target coordinates and release and impact parameters The aircraft avionics system can receive target data from the DTD, onboard sensor(s), or manual entry by the aircrew.

During captive carriage with power-on to the weapon, the JDAM INS will update position and velocity state information based on internal IMU measurements and compare this information with aircraft data to revise alignment quality status The aircrew is continually provided with alignment quality information and can perform additional transfer alignment maneuvers as required to improve alignment quality before weapon release. GPS position and velocity information is not processed by the JDAM weapon during captive carriage The weapon does, however, receive the benefit of GPS position and velocity through the aircraft hand-off After release, the JDAM weapon will enter an initial INS-only navigation phase while the onboard GPS receiver searches for and locks on the available satellites (Figure E-3) The time for this phase is minimized through the use of GPS position, velocity, time, ephemeris, and almanac data provided by the aircraft. Given GPS quality hand-off accuracy data from the aircraft, the GPS receiver will achieve full position and velocity acquisition within 27 seconds and full GPS navigation accuracy within 28 seconds after release. Once satellite acquisition is achieved, precision navigation will be possible and the GPS position and velocity errors replace the aircraft position and velocity hand-off errors.

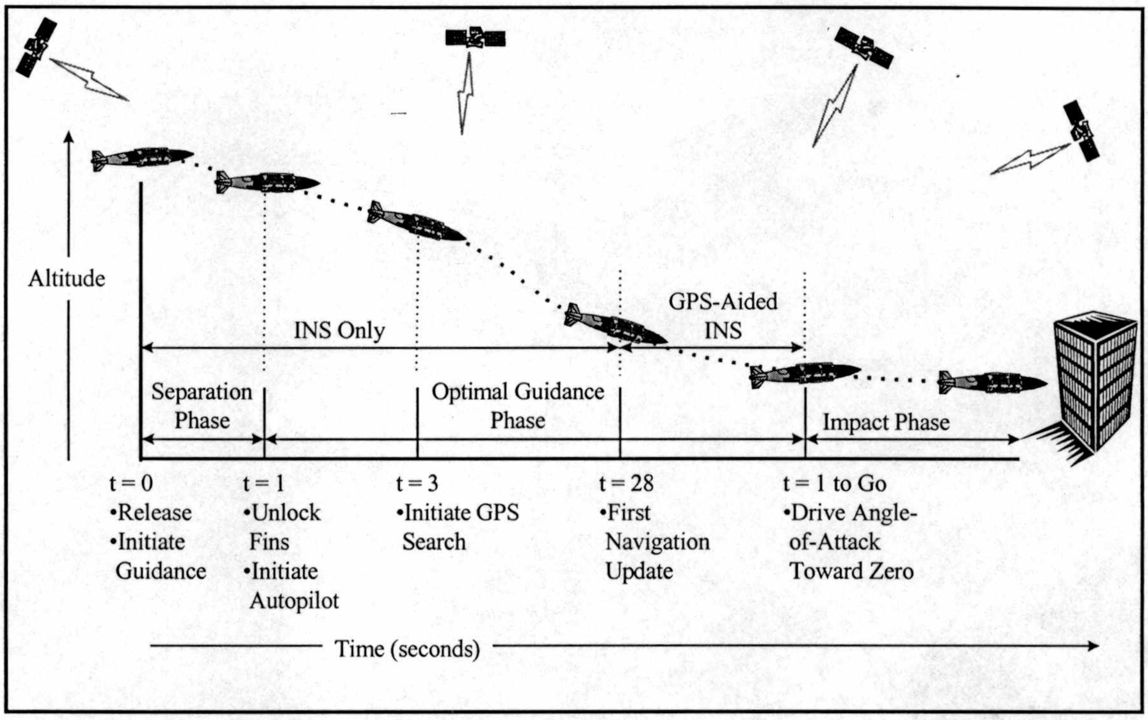


Figure E-3 [17]
JDAM Weapon Flight Profile

GBU-24 E/B

The GBU-24E/B, manufactured by Raytheon Corp., incorporates a hybrid GPS/INS and laser-guidance control interface onto a BLU-109 2,000-lb. hard target penetrator warhead (Figure E-4). The weapon can be employed in a pre-planned, bomb on coordinates scenario similar to JDAM as discussed previously. In this mode, the target does not have to be acquired by an aircraft sensor, and does not have to be visually identified by the aircrew, allowing through the cloud attacks The weapon also includes a laser guidance unit, which will allow the aircrew to update the programmed target location once the weapon is in flight by firing on-board laser energy onto an intended target aimpoint. This gives the GBU-24E/B many advantages over JDAM, including the capability to update the target aimpoint post release It also allows for maximum flexibility in assigning targets, since the weapon can be employed in good or bad weather The most significant advantage of GBU-24E/B is the ease in which the aircrew can adjust to a new targeting assignment in flight Once released from the aircraft, if the GBU-24E/B laser seeker detects the proper laser energy, it will update its preprogrammed target location with the calculated new target location that is being lased. The overall concepts of operations, including major weapon components, mission planning and delivery profiles are essentially the same for GBU-24E/B and JDAM. The only other significant difference in weapon functionality with regards to JDAM is that the GBU-24E/B obtains and maintains a fully aided GPS/INS navigation solution while still on the aircraft Unlike JDAM, which requires a significant time of flight in free inertial until GPS aiding occurs, the GBU-24E/B comes off of the aircraft and immediately enters an aided GPS/INS navigation mode

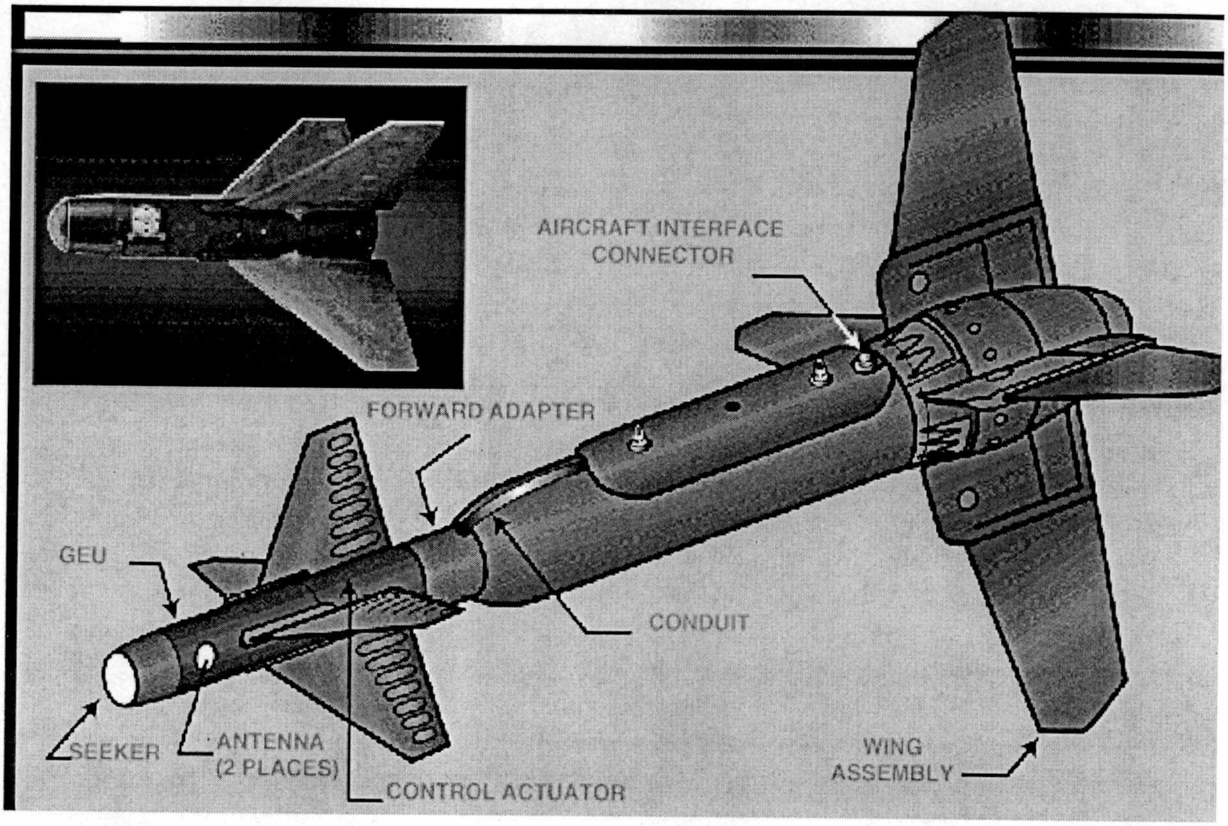


Figure E-4 [30]
GBU-24E/B

APPENDIX F
Subjective Workload Assessment Technique (SWAT)

Subjective Workload Assessment Technique

The Subjective Workload Assessment Technique (SWAT) was developed in response to a need for a workload measure with known metrics that was useful in operational combat environments. SWAT is divided into two distinct phases: Scale development and event scoring. Both phases are important to the success of measuring workload during an integrated system flight test program.

Scale development is accomplished by gathering all test F-14D Radar Intercept Officers (RIOs) prior to the testing and discussing the details of SWAT. Descriptions of each rating category and the definition of each scale shall be given. The three categories are time load, mental effort and psychological stress. The following outlines the definition of the rating scales.

Time Load:

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all
2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.
3. Almost never have spare time. Interruptions or overlap among activities occur continuously.

Mental Effort:

1. Very little conscious mental effort or concentration required.
2. Moderate conscious mental effort or concentration required.
3. Extensive conscious mental effort or concentration required.

Psychological Stress:

1. Little confusion, risk, frustration or anxiety exists.
2. Moderate stress due to confusion, frustration or anxiety notably adds to workload

3 High to very intense stress due to confusion, frustration or anxiety.

Event scoring is accomplished as follows. for any given task that the RIOs are asked to evaluate, there are 27 different combinations of SWAT ratings. It would be naive to simply add the three category ratings to attempt to quantify the overall workload. For example, a task that was rated 1,1,3 is not necessarily equal in workload to a task that had a rating of 2,2,1 To enhance the rating, a scale is developed using a card sort technique, in which all of the test RIOs are asked to collectively prioritize the 27 possible combinations of ratings This prioritization is in terms of the group's perception of each rating category's (time, mental effort, psychological stress) importance with relation to the GGW targeting tasks This scale sort is what makes the SWAT method unique from other rating techniques, and will lend credibility to the results in that they are tailored to the specific tasks of GGW employment in a combat environment

Studies have shown that SWAT may have some drawbacks [31]. In general, it has been shown that when employing the SWAT technique, when one category was rated high (time, for example), mental effort and psychological stress ratings tended to also be rated high [31] . The RIOs must be briefed of this tendency and should be instructed on rating each category on its own merits, without regard for the other two. The test conductor must be especially careful to only allow the RIOs to rate the tasks using SWAT immediately following the performance of each while airborne. In addition, it has been seen that the operators will tend to change their ratings upon review of the mission once on deck. Changing of the ratings post flight must be prohibited.

VITA

LCDR Daryl J. Martis, a native of Indiana, received his Bachelor of Science degree in Microbiology from California State University, Long Beach in 1988. He was commissioned an Ensign in the United States Navy after completion of Aviation Officer Candidate School, Pensacola, Florida in December 1988. After graduating from flight school as a Naval Flight Officer in March of 1990, he reported to NAS Whidbey Island, Washington where he flew the A-6E Intruder as a Bombardier-Navigator. In June of 1994, he was assigned to NAS Oceana, Virginia where he transitioned to duties as a Radar Intercept Officer for the F-14 Tomcat. In 1996, he was selected to attend Naval Test Pilot School at NAS Patuxent River, Maryland, graduating in June 1997. LCDR Martis has accumulated more than 2800 hours in over 40 different aircraft types throughout his 12 years of Naval Service, and has tallied 39 combat missions in the A-6E and F-14A. He is currently the Ordnance Support Team Department Head at the Naval Strike Aircraft Test Squadron, NAS Patuxent River, Maryland, where he has acted as project officer for F-14D LANTIRN, GBU-24E/B, JDAM and various other weapon system upgrades to the Super Tomcat. He will return to Virginia with his wife Janet and his two sons, Christopher and Alexander in June 2000. He has been assigned to Fighter Squadron Thirty-One, NAS Oceana, Virginia, for Operational Department Head duty flying the F-14D Super Tomcat.