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Integration of the Join Direct Attack Munition on the F-14B Tomcat

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To the Graduate Council:

I am submitting herewith a thesis written by Paul J. Filardi entitled "Integration of the Join Direct Attack Munition on the F-14B 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.

Richard Ranaudo, Major Professor

We have read this thesis and recommend its acceptance:

Ralph D. Kimberlin, Charles TN Paludan

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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Anne Mayhew
Vice Chancellor and Dean of
Graduate Studies

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INTEGRATION OF THE
JOINT DIRECT ATTACK MUNITION
ON THE F-14B TOMCAT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Paul J. Filardi

August 2004

DISCLAIMER

All information pertaining to the F-14B Upgrade, the Joint Direct Attack Munitions and Lesson Learned from combat employment were obtained from unclassified sources. The Project to incorporate GPS-Guided Weapons onto the F-14B Upgrade aircraft was accomplished under the direction of the Naval Air Systems Command and the F-14 Program Office.

Data and conclusions were gathered from laboratory, ground and flight-testing in support of this official Department of Defense Test and Evaluation project. Although the author played a significant role in the laboratory, ground and flight tests, this project was not undertaken for the purpose of this thesis.

The views and observations expressed during this thesis were the authors own and do not necessarily reflect the official policy or positions of the Naval Air Systems Command, the Department of the Navy or the Department of Defense. This thesis has been reviewed and is authorized for public release by the Naval Air Systems Command, F-14 Public Affairs Office, reference control number SPR-063.04. All aspects of this thesis are unclassified.

ACKNOWLEDGEMENTS

I would like to thank the F-14B Upgrade Flight Test team at Naval Air Station Pt. Mugu, California. They made this project and others like it possible. In dedicatedly serving the Fleet, they provided the Warfighter's with the best tools available for the job. Those who participate in the F-14 projects continually go beyond the call of duty to keep the F-14 a lethal fighting machine. I would also like to also thank the F-14 Program Office for their support in this endeavor.

Lastly, I would like to thank my wife, Natalie, for her enduring support throughout this project.

ABSTRACT

Leading up to and including most of the Vietnam War, the U.S. military's air-to-ground weapons consisted mainly of unguided freefall bombs. Their accuracy was limited and therefore required multiple aircraft to attack the same target, sometimes over and over again. The costs were high in effort, aircraft and lives. In May 1972, a flight of F-4 Phantom aircraft employed new weapons, called laser-guided bombs, against a seemingly indestructible bridge. When the smoke cleared, the bridge that had taken seven years and almost 900 dedicated attack flights was destroyed and the age of smart weapons had begun.

During the 1990's the US Military's Strike Warfare requirements had to be adjusted to overcome the limitations of the present generation of weapons, including the laser guided bomb. As evident by lessons learned from both the Operation Desert Storm air campaign in 1991 and the Kosovo conflict air campaign in 1999, a "through the weather" weapon capability would be a key factor in the success of any further military action. To accomplish this, a new generation of airborne weapons, deemed GPS-Guided Weapons, had been developed. GPS-Guided Weapons were built based on the requirement to hit within 13 meters of their intended target and be capable of being delivered in any weather conditions, day or night.

After Operation Desert Storm in 1991, the single mission air-to-air only F-14 fighter, was becoming obsolete. The integration of a precision air-to-ground capability with smart weapons was a great accomplishment since they increased its lethality and worth in the Strike-Fighter arena and solidified its future into the next decade.

During the period from Spring 1992 to Winter 2000, the integration of a GPS-Guided weapon, called the Joint Direct Attack Munition (JDAM), had been conceived, planned and flight tested on the F-14B Upgrade Naval Strike-Fighter aircraft. The testing occurred from November 1999 to September 2000 and provided integration challenges during this major modification to the F-14B Tomcat. Limited flexibility in the weapons controls and displays led to multiple system deficiencies and human factors issues. Proposed recommendations for improvements, discussed in detail in this study, included incorporation of dynamic launch acceptability regions, full airborne editing options to the weapons terminal impact parameters, a reduction from three data entry points to one cockpit keypad for navigation and weapon inputs, and an accurate weapon/navigation status display to prevent unintentional delivery of the JDAM with a degraded or no GPS solution.

This study summarizes the evolution of precision guided weapons, the transformation of the F-14 Tomcat to employ modern weapons technology, and the testing of JDAM on the aircraft.

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NOMENCLATURE

A/A	Air-to-Air
A/C	Aircraft
A/G	Air-to-Ground
A-S	Anti-Spoofing
AHRS	Attitude Heading Reference System
AIM	Air Intercept Missile
BC	Bus Controller
BIT	Built In Test
BLU	Bomb Live Unit
C/A	Coarse Acquisition
CADC	Central Air Data Computer
CAP	Computer Address Panel
CAS	Close Air Support
CDNU	Controls and Displays Navigation Unit
CEP	Circular Error Probable
CSDC(R)	Computer Signal Data Converter Replacement
CVW	Carrier Air Wing
DOD	Department of Defense
DoN	Department of Navy
DMPI	Desired Mean Point of Impact
DPPDB	Digital Point Positioning Database
DT	Developmental Test
ECMD	Electronic Countermeasures Display
ECP	Engineering Change Proposal
EGI	Embedded GPS/INS
EHE	Estimated Horizontal Error
EW	Electronic Warfare
F/A	Fighter/Attack (F/A-18)
F-14B(U)	F-14B Upgrade
FEMS	F-14 Engine Monitoring System
FCS	Fire Control Set
FMC	F-14 Mission Computer
FOM	Figure of Merit
FT	Feet
FY	Fiscal Year
GCU	Guidance Control Unit
GDOP	Geometric Dilution of Precision

GPS	Global Positioning System
HSD	Horizontal Situation Display
HUD	Head-Up Display
IBIT	Initiated Built In Test
IFU	Interface Unit
IMN	Indicated Mach Number
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
JDAM	Joint Direct Attack Munition
JPF	Joint Programmable Fuze
Kft	Thousand of Feet
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LAR	Launch Acceptability Region
Lb/lbs	pound/pounds
LCDR	Lieutenant Commander
LGB	Laser Guided Bomb
LT	Lieutenant
MIL-STD	Military Standard
MDL	Mission Data Loader
MDP	Mission Data Processor
MSL	Mean Sea Level
NATO	North Atlantic Treaty Organization
NATOPS	Naval Air Training and Operating Procedures Standardization
NAV	Navigation
NAVBUS	Navigation Bus
NAVCOMP	Navigation Computer
NAVSTAR/GPS	Navigation Satellite and Timing and Ranging / Global Positioning System
NAWCWD	Naval Air Warfare Center, Weapons Division
NFO	Naval Flight Officer
NIMA	National Imagery and Mapping Agency
NM	Nautical Mile
OFP	Operational Flight Program
ORD	Operational Requirements Document
OT	Operational Test
P-Code	Precision Code

PMDIG	Programmable Multiple Display Indicator Group
PPS	Precision Positioning Service
PSU	Power Switching Unit
PTAM	Periodic Transfer Alignment Message
PTID	Programmable Tactical Information Display
RECON	Reconnaissance
RIO	Radar Intercept Officer
RT	Remote Terminal
S/A	Selective Availability
SDC	Signal Data Converter
SETP	Society of Experimental Test Pilots
SITS	Systems Integration Test Station
SPS	Standard Position Service
STT	System Test Team
TARPS	Tactical Air Reconnaissance Pod System
TAS	True Airspeed
TCS	Television Camera Set
TDS	Target Data Set
TLE	Target Location Error
UERE	User Equivalent Range Error
U.S.	United States
VAC	Volts Alternating Current
VDC	Volts Direct Current
VDI	Vertical Display Indicator
VDIG	Vertical Display Information Group
VF	Fixed Wing Fighter Squadron
VX	Fixed Wing Experimental Squadron
WCP	Weapons Control Processor
WCS	Weapons Control System
Y-Code	Encrypted P-Code

GLOSSARY

Circular Error Probable (CEP). The radius of a circle that contains 50 percent of the statistical samples in a two dimensional region. A bomb CEP of 13 meters would indicate that half the bombs fell within a 13 meter radius of the intended target and the other half fell outside of the 13 meter radius from the intended target.

Developmental Test (DT). Testing including initial design, laboratory and flight testing, accomplished by software designers, aircraft and flight engineers and test aircrew. Test objectives measured against specific parameters and detailed system specifications. At completion of satisfactory DT, test items begin Operational Testing.

Ephemeris. Ephemeris data parameters describe GPS satellite orbits for short sections of the satellite orbits. The ephemeris parameters are used with an algorithm that computes the satellites position for any time within the period of the orbit described by the ephemeris parameter set. Normally, a receiver gathers new ephemeris data each hour, but can use old data for up to four hours without much error.

Kalman Filter. Mathematical technique for combining and smoothing a sequence of navigational solutions to obtain the best real-time estimate of the current position.

Operational Test (OT). Testing accomplished with the objectives on meeting operation requirements, conducted by fleet experienced aircrews. Passing grades are provided according to the test items operational effectiveness and operational suitability. At the completion of OT, the tested item is introduced to the Fleet.

CHAPTER I

INTRODUCTION

"In World War II it could take 9,000 bombs to hit a target the size of an aircraft shelter. In Vietnam, 300. Today we can do it with one laser-guided munition from an F-117."

-USAF Gulf War Report, Sept 1991 [1]

Background

In 1991 major events took place that would change the future of the F-14 Tomcat. One event was the cancellation of the Navy's deep strike attack aircraft, the A-12 Avenger II, in January 1991. The A-12 was to be the replacement for the aging and retirement slated A-6 Intruder, which debuted in 1963 and was used as the Navy's primary platform for the night/all-weather precision attack mission. With the A-12 cancellation and A-6 retirement, the Navy was faced with the possibility of a fleet of aircraft carriers without a viable deep-strike all-weather attack platform. To fill the impending gap of strike aircraft, the Navy would upgrade its present fleet of light attack F/A-18 Hornets and F-14 Tomcats to cover the strike mission, while a new development program, called the F/A-18E Super Hornet, began [2]. Additionally, through the lessons of Desert Storm in 1991, precision guided weapons, like Laser Guided Bomb's (LGB's), were credited with achieving 75% of the damage done to strategic and operational targets. This was especially noteworthy since these precision weapons only accounted for 9% of all the munitions dropped in the war. Highly desired attributes of these precision-guided weapons included their accuracy and the associated low collateral damage [3].

During the period from Spring 1992 to Winter 2000, the upgrading of the F-14 Tomcat avionics was under way in order to support the aircraft's transition into a strike-fighter and permit integration of developing weapons and systems. Specifically during the later part of this period, the Global Positioning System (GPS) guided weapon called the Joint Direct Attack Muntion (JDAM), had been conceived, planned and flight-tested on the Navy's F-14B Upgrade Strike-Fighter aircraft. The successful developmental testing of the JDAM on the aircraft occurred from November 1999 to December 2000 under the author's direct involvement as a flight test Naval Flight Officer (NFO) and the F-14B Upgrade Project Officer, at Naval Air Station Pt. Mugu, California. Never before had the Tomcat undergone such modification that allowed two-way communications between aircraft systems and weapons, which in turn increased the platform's lethality in the Strike-Fighter arena. The integration of JDAM was a great accomplishment, especially since the F-14 Tomcat was only employed as an air-to-air fighter from initial operational capability in 1974 through Operation Desert Storm in 1991, and thereafter only began to employ freefall weapons and partially integrated LGB's [4].

Purpose

This thesis will: (a) review the U.S military's combat lessons learned from the past three decades with respect to the technological transformation of air-to-ground ordnance, (b) describe the evolution of the F-14 Tomcat from the introduction as a strictly fighter aircraft to a multi-mission digitally transformed strike-fighter, (c) explain the Global Positioning System and the key role it plays in the military's air warfare, (d) explain the fundamentals of the Joint Direct Attack Muntion including targeting and aircraft interface requirements, and (e) present the results, conclusions and recommendations of the integration of the JDAM on the F-14B. The purpose of this thesis is to provide analysis of the software modifications, system deficiencies discovered during testing and the corrections implemented or recommended for future upgrades. Human machine interface and human factors of the integration in the areas of cockpit controls and displays are also examined.

CHAPTER II

TRANSFORMATION OF THE WEAPONS OF AIR WARFARE

"During the Iran war, my tank was my friend because I could sleep in it and know I was safe ... During this war my tank became my enemy ... none of my troops would get near a tank at night because they just kept blowing up." [5]

- Iraqi General, on the 1991 Gulf War

Combat Employment Lessons Learned

During the Vietnam War, wave after wave of aircraft delivered America's full array of air-to-surface weapons at strategic targets with limited success. One of those targets was a bridge seventy miles south of Hanoi, called the Thanh Hoa Bridge. For seven years, American air power flew 869 bombing sorties at this bridge, which kept a vital North Vietnamese line of communication open across the Song Ma River. After each raid, the bridge remained standing and the North Vietnamese gained another small victory against America's superior air power. In return, America lost another opportunity to further the war effort and from 1965 to 1972 lost 11 aircraft in the process.

On the morning of May 13th, 1972, ten U.S. Air Force F-4 Phantoms raced toward the Thanh Hoa Bridge, armed with LGB's. As each jet delivered its ordnance, these 'smart bombs' locked onto the laser energy illuminating the bridge. Now when the smoke cleared, the bridge had been knocked off of its foundation. The Dragon's Jaw, as the North Vietnamese had called the bridge, had fallen and the transformation of aerial warfare had begun. Figure 2-1 shows the Thanh Hoa Bridge Pre and Post-Strike. Smart weapons like those LGB's, would change warfare forever. The basic facts were that precision strikes using smart weapons could shorten wars, reduce or limit collateral damage and save lives, both civilian and military [3].

Figure 2-1 [6] , [7 inset]
Thanh Hoa Bridge, Vietnam Pre-Strike and Post-Strike (inset)

Two decades later, America was again at war. This time in Iraq for Operation Desert Storm. The technology of the LGB had evolved, but not quite proliferated throughout the U.S. inventory of Air Force and Navy aircraft. This was technology that few air platforms could afford to implement and limited stockpiles of this ordnance existed. LGB's were mainly employed from aircraft like the F-117A Nighthawk stealth bomber and the F-111F Aardvark fighter-bomber. Starting on the night of January 17th, 1991 and lasting the next 37 days, these aircraft with their smart weapons were assigned the hardest and most well defended targets. In Operation Desert Storm, precision weapons were responsible for 75% of the damage done to strategic and operational targets. Command bunkers and air defense sites were classified as strategic targets. The F-111F was particularly effective using LGB's against operational battlefield targets. F-111F's were credited with the destruction of 1,500 tanks and mechanized vehicles [5]. Of the 84,200 tons of total weapons dropped during the campaign, only 7,400 tons (9%) were precision weapons. The small percentage was mainly due to limited stockpiles, as well as a lack of capable platforms. In contrast, a raid on the Yawata steel factory in Japan in 1944 with 47 B-29 Superfortress' resulted in only a single bomb from one plane hitting the factory. By comparison, in the Gulf War, a single F-117 with just two LGB's could produce twice the destructive force of that entire fleet of B-29's [3].

The Gulf War was a success for air power, and some credit it with winning the war based on the fact that the ground war lasted just four days. The war was not perfect and revealed flaws with America's smartest weapons. LGB's, in all their glory, stopped Saddam Hussein's air force, obliterated his air defense systems, shattered the will of the bunkered ground forces and took out key infrastructure. Yet, simple cloud cover would prevent American jets from dropping their LGB's. Also, smoke and dust – typical battlefield environmental conditions, would obstruct the LGB's seeker or break the laser beams line-of-sight, even for just a few seconds, which would send the bomb off on an unguided path away from its intended target. In May 1991, the Pentagon directed the war planners and the scientific and engineering community to develop a new weapon that could overcome these limitations. The requirements were rather simple. The new weapon had to be:

1. All-Weather. Not inhibited by clouds, and day and night capable.
2. Autonomous. It could guide itself, known as "launch and leave". This would reduce aircrew exposure to surface-to-air defenses and reduce the need for onboard support, like a laser, throughout the flight of the weapon.
3. Accurate. In the class of LGB accuracy.
4. Low Cost. It had to be affordable to avoid quick exhaustion of the inventory like that experienced in Iraq [8].

In 1985 military scientists were looking into the idea of an inertial guided bomb. This bomb would have an onboard inertial navigation system (INS) that would use the forces of gravity and acceleration to guide itself to a target. They imagined a bomb with a computer that would be pre-programmed with a target's latitude and longitude coordinates. It would have the ability to accept an INS updated location from the host aircraft prior to release and during the bomb's flight make its own navigation corrections with gyroscopes and accelerometers. The accuracy of an INS bomb would put it within 30 meters of a target, which is outside of the LGB's accuracy, but when dropping a 2000 lb bomb with a 250-meter blast radius, it was close enough to destroy the intended target.

Further, they believed that a kit could be produced and added to existing dumb bomb bodies, like that done for the LGB, to keep costs low. It would be all-weather due to its inertial guidance, and a single aircraft could carry multiple bombs with different targets for each weapon, increasing the lethality of one aircraft.

After the Pentagon's requirements went out in the spring of 1991, it did not take long for this INS bomb to be presented to the Pentagon chiefs. Soon after, the program for the new weapon, named JDAM, began.

A boost to the JDAM program was a system that started in 1973, named the Navigation Satellite and Timing and Ranging / Global Positioning System (NAVSTAR / GPS), better known as GPS. The system consisted of satellites in orbit around the earth, which would transmit radio signals to receivers on earth. Receivers that acquired multiple satellites could determine precise latitude and longitude coordinates of their location on the earth's surface. GPS had been used by the military in the Gulf War for rather simple navigational tasks, such as a tank's location in the desert, to the complicated task of navigating air-launched cruise missiles. Now the military scientists knew with GPS they had a way to increase their JDAM's accuracy, by reducing the inertial guided bomb's biggest weakness, INS drift. With the JDAM's GPS receiver, the INS would still guide the bomb, but now use periodic GPS positional updates. Using the JDAM computer, which was powered by a computer chip developed for an Apple computer, GPS data and INS data were integrated to improve the bombs accuracy to 13 meters or less[3]. Additionally, due to commercial practices and the use of commercially available hardware, a JDAM kit cost under $20,000 (FY 2000 dollars) [9]. This was inexpensive for the military when compared to 30-40 million dollar strike-fighter aircraft, million-dollar cruise missiles and the latest laser guided bombs, which cost around $60,000 each [3].

In 1999, America entered into NATO's War on Serbia, called Operation Allied Force and the Kosovo War. The weather was a major factor; where there was greater than 50% cloud cover over 70% of the time, hampering the use of LGB's. Weather conditions only allowed unhindered air strikes on 24 of 78 days of the air campaign [10]. However, when bad weather barred the use of LGB's against the Zezeljev Bridge, over the Danube in Novi Sad, the bridge was retargeted and destroyed with a JDAM [3] (Figure 2-2). For this war, JDAM were used for the exact reason they were developed and their employment was highly successful. However, the B-2 Spirit stealth bomber was still the only JDAM capable aircraft in the war, and limited supplies of this fledgling weapon were available. For the Kosovo War, a total of 656 JDAM were expended from B-2's, and at nearly the same rate that they were being produced.

Out of the Kosovo War, a few related lessons were learned. The JDAM was now one of the Pentagon's primary weapons, due to its accuracy and all-weather capability. This resulted in further funding, specifically $306 million for 11,000 additional JDAM kits and $3.5 billion for war enhancements, including funding for precision strike onto other air platforms [10]. A less positive lesson was that JDAM's were only as good as the target coordinates programmed into them. During a B-2 strike against a suspected Yugoslav arms agency in Belgrade, five JDAM's were delivered and hit their input coordinates, which was actually the Chinese Embassy [3].

The JDAM's combat successes now solidified the requirement for JDAM on

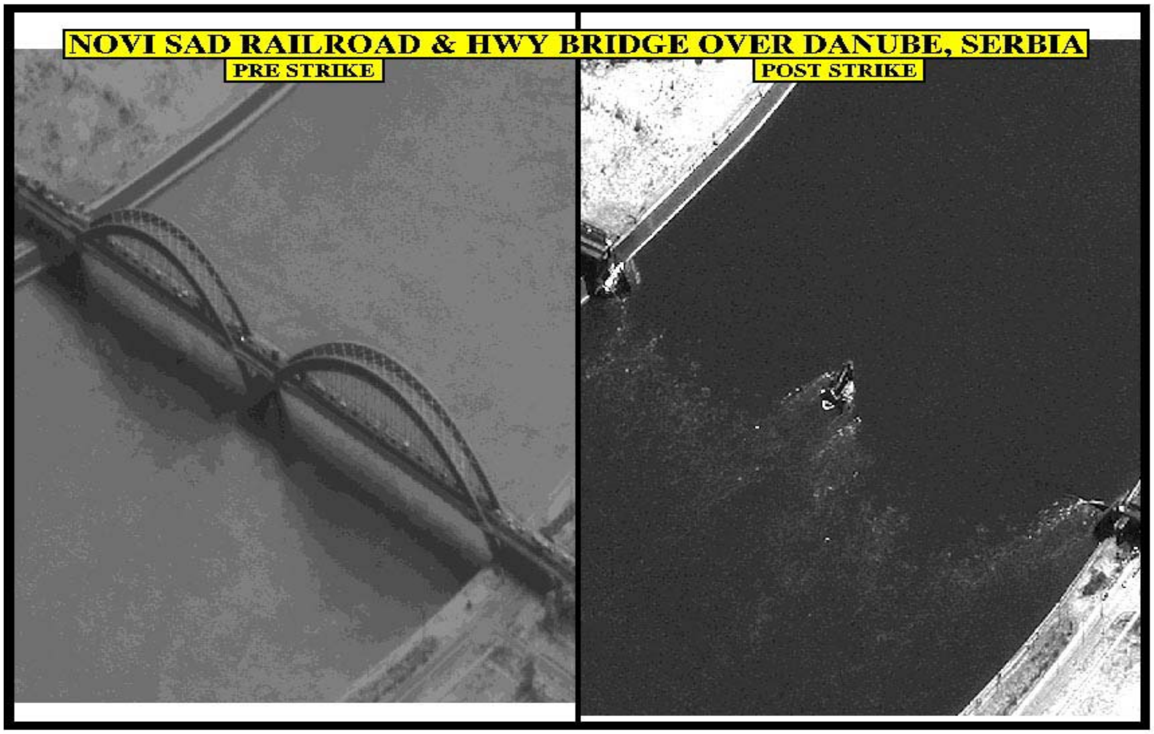


Figure 2-2 (DOD photograph)
Zezeljev Bridge during Kosovo War Before and After JDAM Attack

strike platforms that would be operating in the next war. At the time, integration of JDAM onto Navy aircraft, including the F/A-18 Hornet and F-14 Tomcat, were underway in various stages.

CHAPTER III

TRANSFORMATION OF THE F-14 TOMCAT STRIKE-FIGHTER

"The F-14 was a single-mission aircraft that was not going to be used much anymore because it was a Cold War relic. If we didn't expand our role, the future of the F-14 was in question." [11]

Capt. Ted Carson, U.S. Navy
F-14 Program Manager

Introduction

The U.S. Navy's F-14 Tomcat fighter first flew on December 21st, 1970. The F-14 was the winning design from the Grumman Corporation as the Navy's newest aircraft carrier based fighter. Just 20 months earlier, the contract had been awarded to Grumman for the research, development, test and evaluation plan. The Grumman proposal was designed around the Navy's aerial combat lessons learned from the Vietnam War and this new fighter would add significant improvements to the air-to-air arena. The technologically advanced F-14 Tomcat was the replacement for the combat-proven F-4 Phantom II. Though the F-14 was designed to have conventional air-to-ground weapons capabilities, the Navy would embrace the Tomcat as their finest high-performance fighter aircraft. One most notable improvement was the F-14's weapon systems with the capability to track 24 airborne targets simultaneously and shoot radar missiles at six targets, compared to the F-4's ability to track and shoot only one. Additional improvements included; variable geometry wings, making it a very efficient aerodynamic aircraft at high speeds (> Mach 2.0); a large fuel capacity for long range and endurance flights and; a weapons system developed around the long range Phoenix air-to-air missile system [4].

Basic Aircraft

The F-14 Tomcat is a supersonic, twin-engine, air-superiority, swing-wing fighter that accommodates a crew of two, a Pilot and a Radar Intercept Officer (RIO), in a tandem seat arrangement. Variants of the aircraft include; the original F-14A aircraft, equipped with Pratt and Whitney TF-30 engines and older avionics; and the F-14B, equipped with General Electric F110 engines and older avionics. Additionally, the F-14D, introduced in 1992, was a new production aircraft equipped with the General Electric F110 engines and an advanced digital architecture with modern avionics. The fighter missions of the aircraft are fleet air defense, fighter sweep/escort, and reconnaissance (RECON). The F-14 is capable of employing the AIM-54 Phoenix, AIM-7 Sparrow, and AIM-9 Sidewinder air-to-air (A/A) missiles and is equipped with an internal 20-millimeter M-61A1 Vulcan cannon. In the 1990's, after Operation Desert Storm, the Navy funded the F-14 as a Strike-Fighter multi-mission aircraft and began to exploit its capabilities in the air-to-ground (A/G) role. The F-14 was adapted to employ general-purpose free-fall MK-80 series bombs (500, 1000 and 2000 lb.) and Paveway II /III LGB's, with the latter aided by the Low-Altitude Navigation Targeting Infrared for Night (LANTIRN) laser designation pod. The strike missions of the aircraft included ground attack and close air support (CAS). The Weapons Control System (WCS) is an integrated, multi-mode fire control system designed to operate in the A/A, A/G, or RECON modes [12]. Figure 3-1 depicts the F-14 Tomcat. Appendix A provides additional depictions of the F-14 cockpits in figures A-1 through A-4.

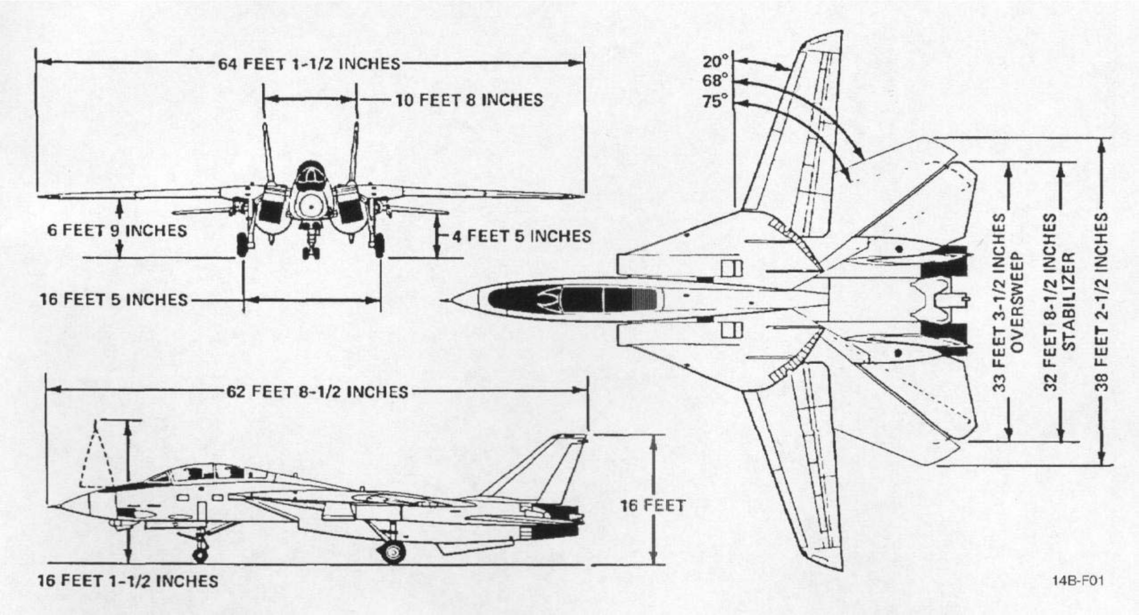


Figure 3-1 [4]
F-14 Tomcat 3-View

The Digital Transformation of the F-14B

In 1978, the Department of Defense (DOD) adopted a new aircraft architecture that would allow modern aircraft the growth potential and flexibility to incorporate new avionics and weapons as they were developed. This was called the MIL-STD 1553B data bus. In the spring of 1992, the F-14B Upgrade (F-14B(U)) program was started to replace the F-14B's old architecture with this modern digital bus system. The main objectives of the F-14B Upgrade program were to incorporate digital technology to gain computing, growth, reliably and maintainability improvements to this still capable, 20 year old aircraft design. The F-14B(U) Weapons Control System would consist of the following hardware additions and improvements over the F-14A/F-14B: F-14 Mission Computer (FMC), AN/AWG-15H Fire Control Set (FCS), Programmable Tactical Information Display (PTID), and the Programmable Multi-Display Group (PMDIG).

Operational Flight Program 317

The hardware and software configuration for the first phase of the upgrade program would be called Operational Flight Program 317 (OFP 317). The F-14B(U) was created with three new digital data buses: Avionics, Armament, and Electronic Warfare (EW). The basic foundation of the MIL-STD-1553B data bus was the requirement for a bus controller (BC) to run the bus. The new F-14 Mission Computer would accomplish this task. The FMC, the 5400B computer, contained two subsystems with a common memory. These were the Weapons Control Processor (WCP) and the Mission Data Processor (MDP). The WCP, interfaced with the other subsystems and correlated the information, and it had twice the speed and about three times as much memory compared to the old 5400 computer. The MDP incorporated a very high speed-processing module and provided the bus control for the avionics bus. Next, to display information in the cockpit, the aircraft needed new displays, which would act as remote terminals (RT's) on the bus. The new displays included: the RIO's main tactical display, the 8 inch by 8 inch PTID; the PMDIG components of the pilot's Vertical Display Indicator (VDI); and the Electronic Counter Measures Display (ECMD) in each cockpit. To integrate with the armament bus, hardware was required to accomplish two roles, one as an RT on the avionics bus and another to act as a BC on the armament bus. The new weapons computer, the AWG-15H FCS, provided control and interface for the selection, preparation, release, firing and jettisoning of all weapons. The AWG-15H would be the key to future weapons expansion in the F-14, as it would provide the functions and distribution processing for the weapons system and weapons stations. To tie all of these systems together, each piece of new hardware had to be programmed with it's own software and then integrated to function on the bus. The F-14B(U) digital architecture is shown in Figure 3-2, with new hardware highlighted and the data buses in bold.

In June 1997, testing was complete on OFP 317 and delivered to the fleet [14]. On a separate test and evaluation path, precision strike on the F-14 was now being provided through the LANTIRN targeting pod. Previously the F-14 could deliver LGB's, but only with the aid of a ground based laser or a laser emitted by another aircraft. Now the F-14 could autonomously deliver LGB's and it had a digital backbone to allow for future expansion.

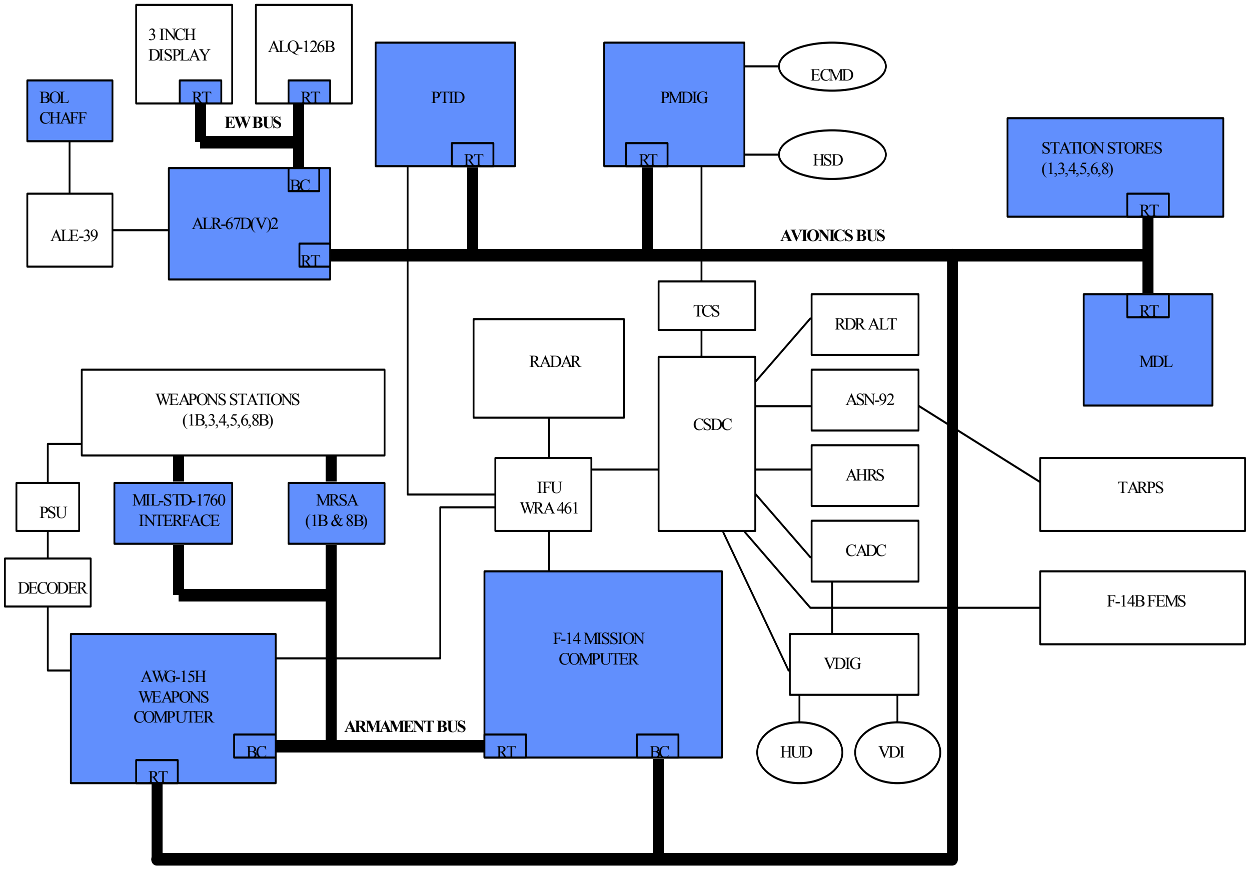


Figure 3-2 [14]
F-14B Upgrade Digital Architecture

Operational Flight Program 320

Prior to the completion of OFP 317, planning began for the next hardware and software configuration, called OFP 320. The next cycle in the upgrade of the F-14B, would outfit the aircraft with GPS navigation and expand the digital architecture to the aircraft weapons stations. Building on the MIL-STD-1553B data bus structure, an Embedded GPS / Inertial Navigation System (INS), called EGI, replaced the unreliable F-14 navigation system. The EGI was a strap-down navigation system that combined a ring laser gyro INS with GPS capability. The three selectable navigation solutions were GPS and INS information blended through a Kalman filter, an INS-only solution, and a GPS-only solution. Additionally, the Controls and Displays Navigation Unit (CDNU), was added to the bus and was the RIO's main EGI input keypad for navigation control and display. The CDNU acted as the BC for the MIL-STD-1553B Navigation Bus (NAVBUS), linking the EGI, Computer Signal Data Converter (Replacement) (CSDC(R)), and CDNU. The CSDC(R) provided the interface between the Navigation System and the F-14 Mission Computer [15]. In addition, the F-14 was modified to provide aircraft data bus information to the aircraft's four underbelly weapons stations through a common MIL-STD-1760 interface. This alteration, known as Engineering Change Proposal (ECP) 329, would also provide GPS satellite signal information to both the new navigation system and to the LANTIRN targeting pod, through the use of a splitter/amplifier [16]. For OFP 320, the weapons stations wiring was installed then capped and stowed, for future use in the next phase of the upgrade program. The F-14 Weapons Station Interface due to ECP 329 is depicted on Figure 3-3. The addition of

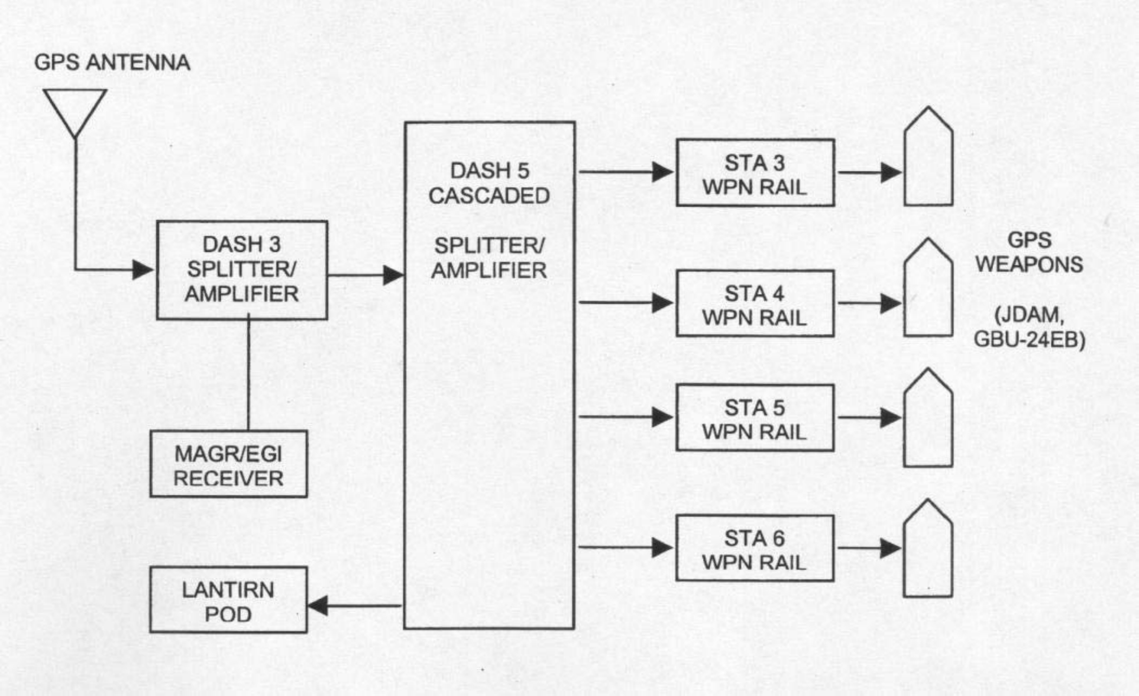


Figure 3-3 [16]
F-14 Weapons Station Interface (ECP 329)

GPS navigation was a significant improvement over F-14's previous system. "It was amazing. Having GPS available to you in the airplane takes a tremendous burden off the aircrew. Now they can spend much more time tactically on weapons employment," stated Capt Garrett, the F-14 Wing Commander at Virginia's main F-14 base [11]. OFP320 entered the Fleet in 1999, after an expeditious operational test and evaluation in order to support the Navy's involvement in the conflict in Kosovo [17].

Operational Flight Program 321

Before OFP320 testing was completed in 1999, planning was underway for the next round of improvements to the F-14B(U). These hardware and software upgrades would be called OFP 321, and included the GPS-guided weapon, JDAM, and a new Head Up Display (HUD) for the pilot. The modifications were: new software in eight of the 16 processors and new MIL-STD-1760 wiring to four of the F-14's four weapons stations - those used to carry and support JDAM.

OFP 321 and JDAM testing began in 1999 with the developmental flight-testing complete by December 2000. In 2001, dedicated operational testing began and by the end of year, the F-14B(U) with JDAM was introduced into the fleet.

CHAPTER IV

GLOBAL POSITIONING SYSTEM

"Lighthouses in the sky serving all mankind." [18]

Dr. Ivan Getting
GPS System Visionary and Co-Inventor

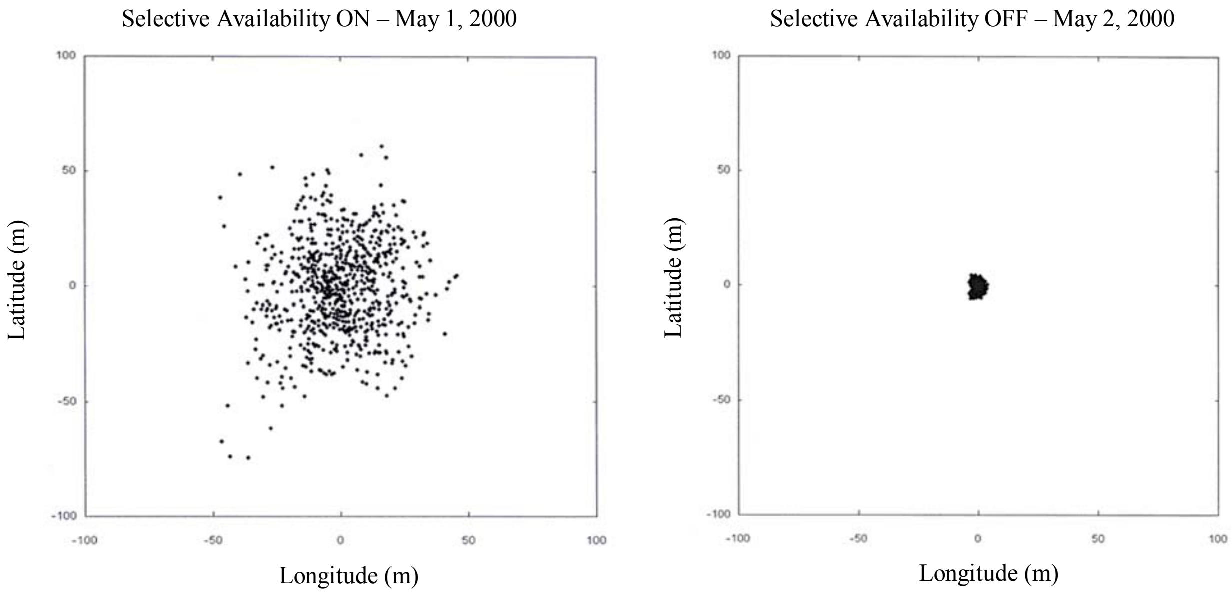
Overview

A discussion on the Global Positioning System (GPS) is required to fully understand how the military uses GPS and how it is used by JDAM to create a "smart weapon". The GPS system is a constellation of 21 satellites with 3 active spare satellites, positioned in 6 orbital planes at greater than 10,900 miles above the earth. There are often more than 24 satellites in operation as new ones are launched to replace older satellites. Satellites complete an orbit every 12 hours and are programmed to pass over the same location on earth every 24 hours. Each satellite transmits radio signals to ground receivers at specified times. The difference between the sent time and the received time is used to determine the position and distance of the receiver from the satellite. If a ground receiver picks up four satellites it can precisely locate itself by triangulation. Signals from the fourth satellite are used to adjust for clock inaccuracies. The earth receiver can then convert this position information into latitude, longitude and altitude.

There are three main segments that make up the Global Positioning System: Space, Control and User. The first segment is the Space segment and is made up of the 24 satellites which transmit on two carrier L-band frequencies centered on 1575.42 MHz and 1,227.60 MHz, called the L1 and L2 navigation frequencies, respectively. The Coarse Acquisition (C/A) code is carried on L1 and allows any receiver access to the

Standard Position Service (SPS), used for civil navigation. SPS users can achieve horizontal position accuracy within 100 meters and vertical position accuracy within 145 meters, 95% of the time. Additionally, a Precision code (P-Code) is transmitted on both L1 and L2 and is the basis for the Precision Positioning Service (PPS), which is only available to authorized users. PPS users can achieve a horizontal accuracy of approximately 21meters, and vertical accuracy of 28 meters, 95% of the time [19].

Two techniques are used to prevent common users from receiving access to the Precision Positioning System. The first is called Selective / Availability (S/A), which intentionally introduces controlled errors into the satellites signals. The intentional errors were originally justified in order to reserve the GPS systems highly accurate signals for U.S. military users, while providing the global civil sectors with a fairly accurate navigation system. On May 1, 2000, S/A was turned off to allow civil and commercial use of un-altered GPS signals. This was done with the understanding that the U.S. military could selectively deny or degrade GPS signals on a global or regional basis when national security was threatened, such as in a time of crisis or war. Figure 4-1 depicts a sample of the positional accuracy of GPS on May 1st, 2000 and after May 1st, 2000. Elimination of S/A now enabled SPS users to achieve as low as 16-meter CEP accuracies, compared to 12-meter CEP of the PPS users. The difference in CEP's is due to the ability of PPS to compare L1 and L2 and correct for errors associated with atmospherics delays. The second method for preventing PPS use is through an Anti-Spoofing (A-S) feature. This alters the P-Code into a code known as Y-code, to negate the potential imitation of the PPS signals. Through the use of cryptographic codes, sometimes known as encryptions keys or crypto keys, PPS users remove the effects of



Selective Availability ON – May 1, 2000

Selective Availability OFF – May 2, 2000

Figure 4-1 [19]
Positional Accuracy of GPS Before and After Selective Availability

S/A, if used, and A-S [20].

The second segment of the GPS system is called the Control Segment. This is comprised of the Master Control Station, operated by the U.S. Air Force in Colorado Springs, Colorado, and globally separated monitoring stations throughout the world. The purpose of the Control segment is to track all satellites and determine the validity of their output signals and the general health of the satellites. Through the multiple monitoring stations, inaccuracies from satellites signals, including reported satellite locations and time, can be determined. If significant errors are noted for a certain satellite, corrections can be uplinked to the satellite to correct the problem. The Master Control Station is also the controlling agency for introduction of GPS errors like S/A.

The User Segment is the final segment in the GPS system. This segment consists of all the receivers that use the satellite information to determine their earth position. These receivers reside in places including military aircraft and weapons, like the JDAM, and are also used by the civil, scientific and commercial entities globally. Military GPS receivers may employ Kalman filtering techniques to quantify navigational quality through the use of a single digit Figure of Merit (FOM). A FOM of 1 would indicate a properly operating GPS in the PPS mode with errors less than 25 meters, while a FOM of 3 would indicate an error of 50 to 75 meters. A FOM of 4 may indicate activation of S/A in the SPS mode and accuracy in the area of 100 meters. A FOM of 9 indicates no GPS reception [21].

GPS Positioning Errors

GPS positioning errors are the result of two major factors called User Equivalent Range Error (UERE) and Geometric Dilution of Precision (GDOP). UERE can be the result of satellite clock and ephemeris deviations, signal delays due to atmospheric conditions and inherent receiver faults like noise. All three segments of the GPS system contribute to UERE. GDOP errors are based on the geometric configuration of the satellites as seen by the receivers. GPS receivers are supplied with the best satellite ranging information when satellites are widely spaced in the viewable sky. A receiver using satellites directly overhead or within a small field of view result in a larger horizontal uncertainly area and therefore larger GDOP. Figure 4-2 illustrates how the geometric orientation of satellites contributes to GDOP [20].

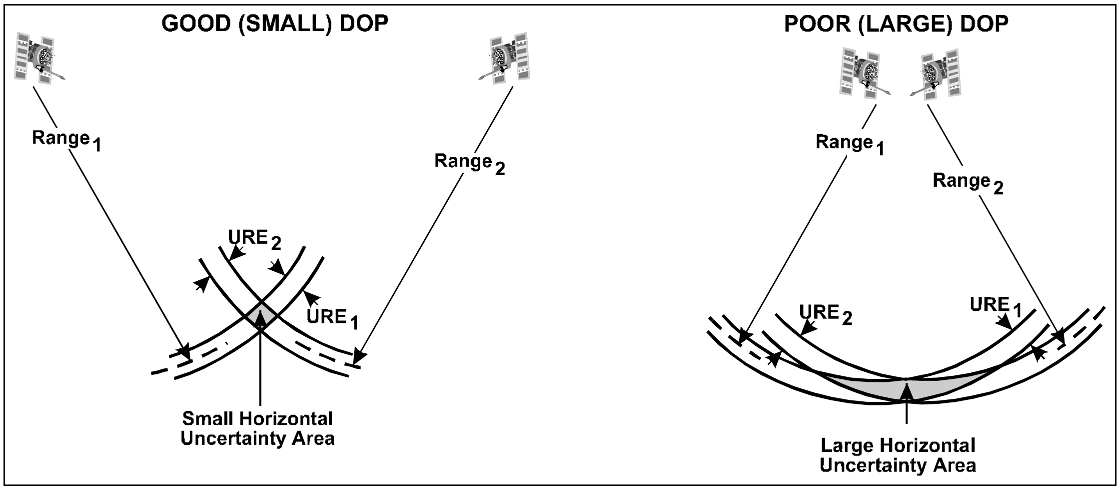


Figure 4-2 [20]
Global Positioning System Geometric Dilution of Precision (GDOP)

CHAPTER V

JOINT DIRECT ATTACK MUNITION

"Shrinking force structure, increased tasking, improved threats and the need to conserve lives and assets drive a demand for a low cost, autonomous, and accurate weapon for use by the warfighter in the 21st Century." [22]

- Combat Air Forces Concept of Operations for JDAM

Weapon Design

As stated in Chapter II, the JDAM had to be deployable under adverse weather conditions, guide autonomously, achieve a 13 meter CEP, and at the same time it had to be affordable. The basic concept of JDAM's design joins a tail section, containing the weapons own INS/GPS guidance system and control fins, with existing bombs bodies. Mid-body aerodynamic surfaces, called strakes, provide the weapon in-flight stability and lift for executing the desired flight profile and impact conditions. Optimal guidance is through the use of a combined INS/GPS guidance solution, to achieve a 13-meter CEP at impact angles greater than 60degrees. However the weapon may also be used in an INS-only mode when employed in a GPS-denied environment. The accuracy of the weapon in the INS-only mode would be reduced to a 30 meter CEP at impact angles greater than 60 degrees and a weapon time of flight less than 100 seconds. JDAM interfaces with the aircraft through mechanical and electrical connections consistent with the MIL-STD-1760 specifications. JDAM is integrated with the MIL-STD-1553 data bus to allow transfer of weapons commands and the required mission information to control, monitor and release the weapon. The weapon guides to the target coordinates, input during pre-flight planning or in-flight by aircrew. The available bomb bodies include the general-purpose MK-83 (1000 lbs) and MK-84 (2000 lbs) bomb bodies. The other options include the penetrator warheads, the BLU-110 (1000 lbs) and the BLU-109 (2000 lbs) bodies. The JDAM components including the Guidance Control Unit (GBU), tail assembly, body-mounted strakes and bomb bodies, are shown in figure 5-1.

JDAM System Accuracy

There are four elements that contribute to JDAM system accuracy: 1) the JDAM system components, including guidance hardware and software; 2) the delivery aircraft transfer alignment time hand-off accuracy, including location and velocities; 3) the GPS satellite error; and 4) the target location error (TLE) and the associated coordinate format.

The JDAM component errors are associated with the inertial measurement unit (IMU), GPS receiver and peripherals, weapon software, and guidance and control unit. The errors related to these items can only be reduced by improvements to the basic JDAM design. Future improvements through technology advancements are planned to lessen these errors, however affordability must always be considered. Once JDAM is released, it initially uses INS only guidance, and then upon GPS-acquisition, the system uses a combined INS/GPS solution. Once GPS-aiding is accomplished, the aircraft hand-off error is removed and is not a factor in system accuracy. Planning can reduce some GPS errors, while others are beyond the control of the aircrew. GPS errors like UERE, can not be reduced by aircrew planning or operational procedures. The GPS Space Command's control and space segments of GPS are mainly responsible for the UERE and only through improvements in these areas can errors be reduced. Planning to a certain mission time for more favorable satellite geometry can reduce the GDOP. Most mission planning systems provide GDOP predication tools to allow this item to be

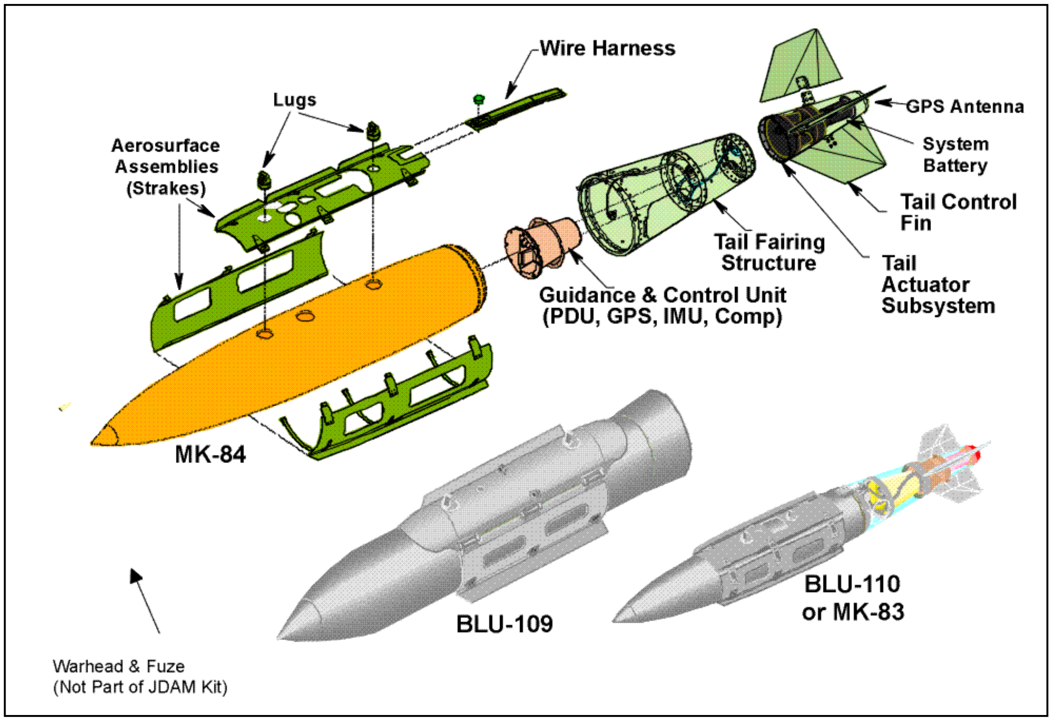


Figure 5-1 [23]
Joint Direct Attack Muntion Components

considered during strike planning. Also, GPS measurements are less accurate in the vertical dimension, therefore weapons delivery at terminal impact angles greater than 60 degrees reduce the vertical error. Impact angles of 90 degrees will eliminate the vertical error, but reduce release range and standoff from enemy defenses.

JDAM is a bomb-on-coordinates weapon; therefore extremely accurate target locations are required. Taking target coordinates directly from a map are not accurate enough for achieving the required CEP. Instead target coordinates are provided by intelligence agencies with very specific coordinate deriving systems and methods. Precise target coordinates can come from the National Imagery and Mapping Agency (NIMA) Digital Point Positioning Database (DPPDB), NIMA Points Program, or the Joint Service Imagery Processor-Navy (JSIPS-N). Additionally, some aircraft systems can produce highly accurate locations through their on-board sensors, such as radar or laser designation systems. The coordinate accuracy parameter is called Target Location Errors (TLE) and is defined as the difference between an actual location and the derived location coordinates. The JDAM system TLE allocation is an error of 7.2 meter CEP and most of the approved coordinate derivation systems meet this requirement. TLE that exceeds this threshold will adversely affect the accuracy of JDAM, and most likely exceed JDAM's overall 13-meter CEP goal.

One additional factor of target coordinates is the format. Target coordinate formats must conform to a desired precision in order to be considered accurate enough for JDAM. JDAM requires coordinates in the format of degrees, minutes, and at least 1000th of minutes (DD° MM.MMM). Use of the DD° MM.MMM format would provide a worst-case tolerance window of ±3 feet, based on a degree of latitude and longitude equaling 60 square nautical miles. As an example, an unacceptable format would be a latitude and longitude entry in degrees, minutes, and 10th of minutes (DD° MM.M). This DD° MM.M format has an error window of ±300 ft from the intended target coordinates. Overall, the TLE is the biggest error associated with JDAM, with GPS satellite error a close second. For the non-GPS-aided case, the major error source is the aircraft navigation hand-off. JDAM accuracy is listed in Table 5-1.

Data Requirements

JDAM requires mission target data and navigation data, including GPS and INS parameters, from the host aircraft. The mission data is the detailed targeting information, called the Target Data Set (TDS), which provides extremely accurate target coordinates, as well as the desired flight profile and impact conditions to the weapon. The TDS can be created during the mission- planning phase before flight on computer workstations. This planning not only creates and formats the JDAM targeting data, but also provides data that is used to present aircrew with weapon management and delivery displays. GPS crypto keys, almanac and configuration data are also part of the JDAM mission planning data load. The TDS and other support information are loaded onto a portable storage drive, called a Mission Data Loader (MDL), for use in the aircraft. Also, targeting data can be manually entered into the aircraft weapons controls system by aircrew via cockpit keypads to adjust target and weapon delivery information. Table 5-2, includes a list of required and optional information in a JDAM Target Data Set.

Launch Acceptability Region

A Launch Acceptability Region (LAR) is a two-dimensional surface area or region where JDAM could be released from and impact the desired target. The LAR is

Table 5-1 [22]
Joint Direct Attack Muntion Accuracy

CEP (m)	Target Orientation	Conditions
13	Horizontal	When impact angle is greater than 60^o & weapon GPS is available.
17	Vertical	When impact angle is greater than 60^o & weapon GPS is available.
19	Horizontal	When impact angle is between 35 and 60^o & weapon GPS is available.
30	Horizontal	When impact angle is 60^o or greater & no GPS updates are received by weapon after release, & flight times are 100 seconds or less for on-axis trajectories or 90 seconds or less for off-axis trajectories.
32	Vertical	When impact angle is 60^o or greater & no GPS updates are received by weapon after release, & flight times are 100 seconds or less for on-axis trajectories or 90 seconds or less for off-axis trajectories.

Notes: All CEP's assume a GPS-quality handoff from the aircraft, and a target location error of 7.2 meters CEP. All impact angles are measured relative to the target face.

Table 5-2 [22]
Joint Direct Attack Muntion Target Data Set

Target Data	Target Data Set*	
	Required	Optional
Target Hardness		X
Target Orientation		X
Attack Mode		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
Target Minimum Impact Velocity		X
Target Offset - North		X
Target Offset - East		X
Target Offset - Down		X
JPF Control Source		X
JPF Mode		X
JPF Arm Time From Release		X
JPF Function Time From Impact		X

*The parameters identified as “Required” in the TDS column constitute the minimum parameters required by the JDAM weapon to complete its mission. The “Optional” data provide enhancements to the weapon operation and performance.

based on release conditions, including aircraft heading, speed, altitude, and flight angle (level, dive or loft) and is centered on a release point. The LAR may become constrained, or shrink in size, by forcing the weapon to meet specific terminal impact conditions such as impact angle, impact azimuth and minimum impact velocity. If specific terminal impact parameters are undefined, such as if no certain impact heading is required, then a bigger envelope for delivery can be provided, known as an unconstrained LAR's. Figure 5-2 depicts Unconstrained and Constrained LAR's displayed against a map. LAR's are constructed during the mission planning process, loaded to the aircraft with the TDS and are displayed in the cockpit to the aircrew. One of the major advantages between JDAM and previous weapons is that the target itself does not have to be acquired visually or by onboard systems. Aircrews simply fly and navigate into the displayed LAR and release the JDAM. The weapon is programmed to do the rest.

Flight Characteristics

While JDAM is powered and being carried by the aircraft before release, critical processes take place between aircraft and weapon. These include the transfer alignment, targeting data and GPS data from the aircraft (Figure 5-3). Before JDAM is ready for release, the Inertial Measuring Unit (IMU) section of JDAM's navigation system must be aligned, calibrated and initialized. This process, called transfer alignment provides high quality navigational information from the aircraft to the lower cost, lower quality weapon IMU. With power applied to weapon, the JDAM INS will update position and velocity information based on the comparison of its internal IMU measurements and the navigation data from the aircraft. The aircraft's higher quality INS is assumed to be the

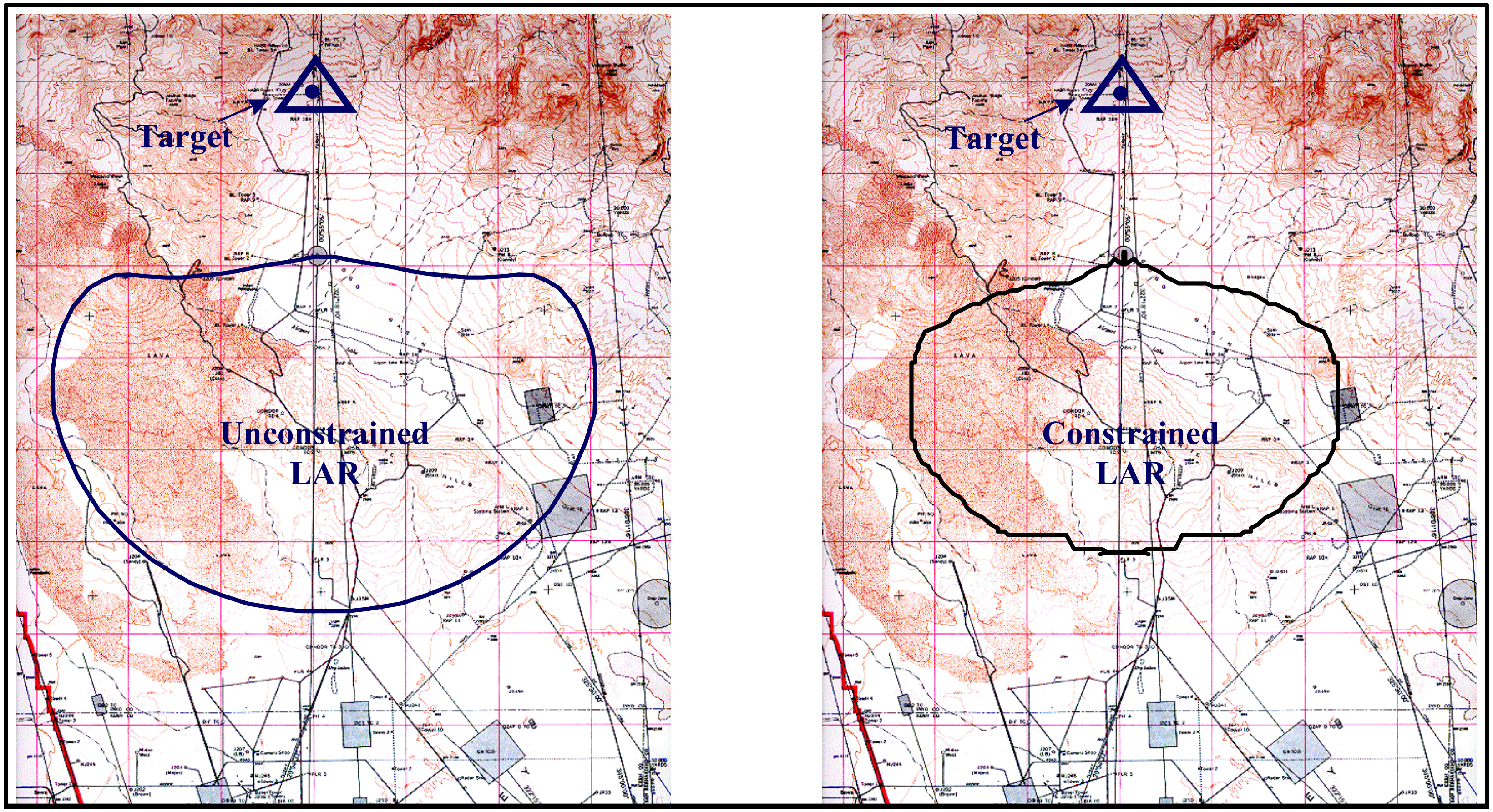


Figure 5-2 [22]
JDAM Unconstrained and Constrained Launch Acceptability Regions

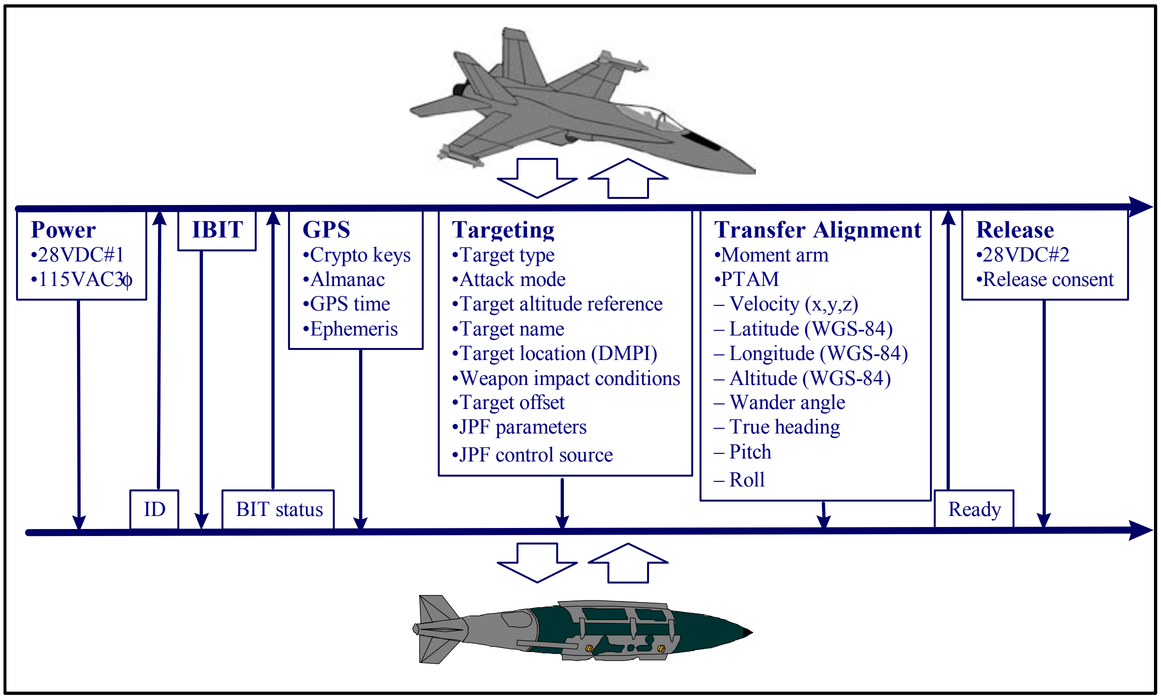


Figure 5-3 [22]
Joint Direct Attack Muntion before Release Processes

most accurate system of the two and is used to update the JDAM INS, accordingly. Transfer alignment is a continuous and automatic process. Transfer alignment cues are provided to the aircrew via cockpit displays and are critical parameters that are checked before weapons delivery.

Additionally, GPS information transfer is critical to JDAM success. When JDAM is attached to the aircraft, it does not process GPS information directly. Therefore, the aircraft provides an INS/GPS-aided position, velocity, time, ephemeris and almanac data to the bomb. The handoff of high quality GPS information to the bomb, allows the JDAM to achieve full position and velocity acquisition within a maximum of 27 seconds and full GPS navigation within 28 seconds after release.

Once the JDAM is released, shown in figure 5-4, its autopilot takes over to provide the optimum delivery profile. A GPS search is initiated at 3 seconds after release, and using the aircraft provided GPS handoff information it attempts to achieve full GPS–aided guidance by 28 seconds post-release. During the weapon time of flight, the path from the weapon's current position to the target is continually computed and adjusted to achieve the pre-planned attack parameters. If the planned impact parameters are unattainable, due to release outside of the planned launch region for example, the guidance laws of the autopilot will make compensations to the target data set. Impact velocity will be reduced to a minimum set value first, then impact angle and impact azimuth will be adjusted, respectively, giving the weapon the greatest chance of hitting the target [22].

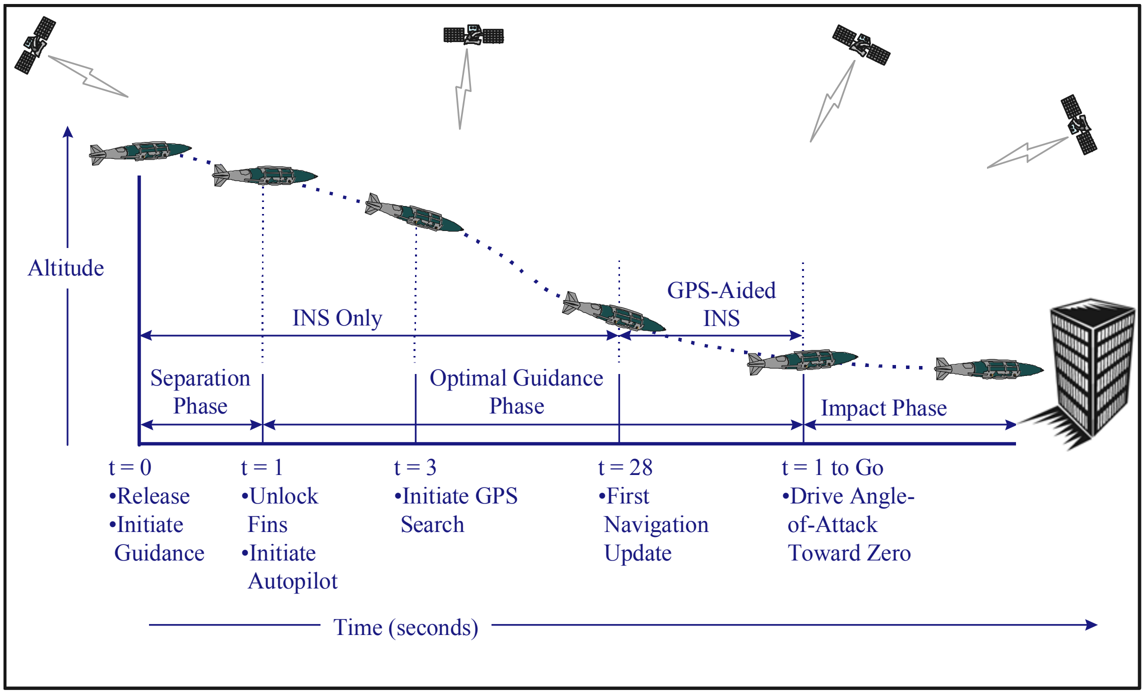


Figure 5-4 [22]
Joint Direct Attack Muntion after Release

CHAPTER VI

SUMMARY OF TESTS

"Test everything. Hold on to the good." [24]
- Thessalonians 5:21

Purpose of Test

The purpose of the test was to evaluate the functionality of OFP 321, including the software and hardware changes required to support the JDAM weapon. Tests were conducted to assess design and operational requirements and to ensure no degradation of the baseline system performance (OFP 320). Specific JDAM evaluation objectives included the capability to: identify and power aircraft carried weapons; test the aircraft and weapons critical systems; perform transfer alignment between the aircraft and weapon navigation systems; download targeting information from mission planning system and access it in the aircraft; edit weapon targeting and employment parameters; and evaluate the accuracy and utility of the added JDAM controls and displays.

Method of Test

During development, the new F-14 software underwent laboratory, ground and flight testing, providing both quantitative and qualitative results. Initially, the software designers performed unit level testing exclusively in the laboratory environment. The designers ensured individual program modules were stable and achieved their specific design objectives. Then the software designers performed inter-subsystem testing which ensured the software modules supported the overall function of the system. The System Test Team (STT), made up of the test engineers and aircrew, performed system level testing in the laboratory, as well as in the ground and flight environments. System level tests supported the test team by refining the designs, verified that functions performed as intended, provided an assessment of mission utility and operational capability, and ensured retention of previous baseline performance.

Testing in the F-14B laboratory, called the Systems Integration Test Station (SITS) Lab, allowed the test team to reduce both safety risk and technical risk, by evaluating the JDAM modifications with the weapons system prior to the first flight. It also provided a first look at the OFP from a human factors and ergonomics standpoint. Additionally, SITS Lab testing was used to practice planned test profiles and to validate problems uncovered in flight. Ground testing was used to verify that the software operated as expected in the actual test aircraft and that it was safe for flight. Moreover, ground tests were used to verify hardware/aircraft interface/communications that could not be accomplished in the SITS Lab. While the laboratory was an effective tool, it was limited in its ability to model the dynamic flight environment. So flight-testing was used to verify system performance in an operationally realistic flight environment.

Flight tests were built upon SITS Lab and ground test results, and included actual carriage of production JDAM, as well as two JDAM weapons deliveries. Although all the interface functions for JDAM could be verified without dropping an actual weapon in flight, a successful release was the ultimate demonstration that the weapons had been properly integrated onto the F-14B Upgrade aircraft. Initial flight test results also were used to validate SITS Lab test results using similar flight profiles. Once the laboratory model was validated, flight test requirements could be reduced. Deficiencies, including recommendations for improvements, noted during any phase of testing were tracked via problem reports and given a priority rating of 1 (critical) through 5 (minor). Deficiencies were then either corrected in the next iteration of the system software or were slated for correction in the follow-on OFP [25].

Controls and Displays Evaluation

Static Launch Acceptability Regions

In order to meet a program goal of incorporation of JDAM onto the F-14 within a 12-18 month developmental test cycle, a decision was made to only provide aircrew with pre-planned static Launch Acceptability Regions (LAR's). The LAR's could only be created during pre-flight planning, and transferred to the aircraft for display in the cockpits. Figure 6-1 depicts a LAR as displayed in on the F-14's cockpit displays. In the F-14, up to eight different TDS could be created for each JDAM weapon. The ability to create up to eight TDS with various parameters, such as release altitude and headings would in theory provide some targeting flexibility while airborne. When changing the target location in the aircraft, the LAR would move to the new input location. However, there was no way to edit the other parameters, like release altitude or release airspeed – that would change the LAR envelope, or edit release heading – that would change the LAR orientation. For example, if the release profile of 35,000 ft on a north heading has to be changed, due to weather or threats, to 20,000 ft on a west heading, the displayed LAR becomes useless. This is because the release altitude is lower and the release heading orientation is now 90 degrees off of that planned and depicted. A properly displayed LAR would be smaller. The software would not display a new LAR to reflect the new launch envelope. In testing, it became evident that the Static LAR's were too constraining, especially when performing multiple simulated delivery runs which needed

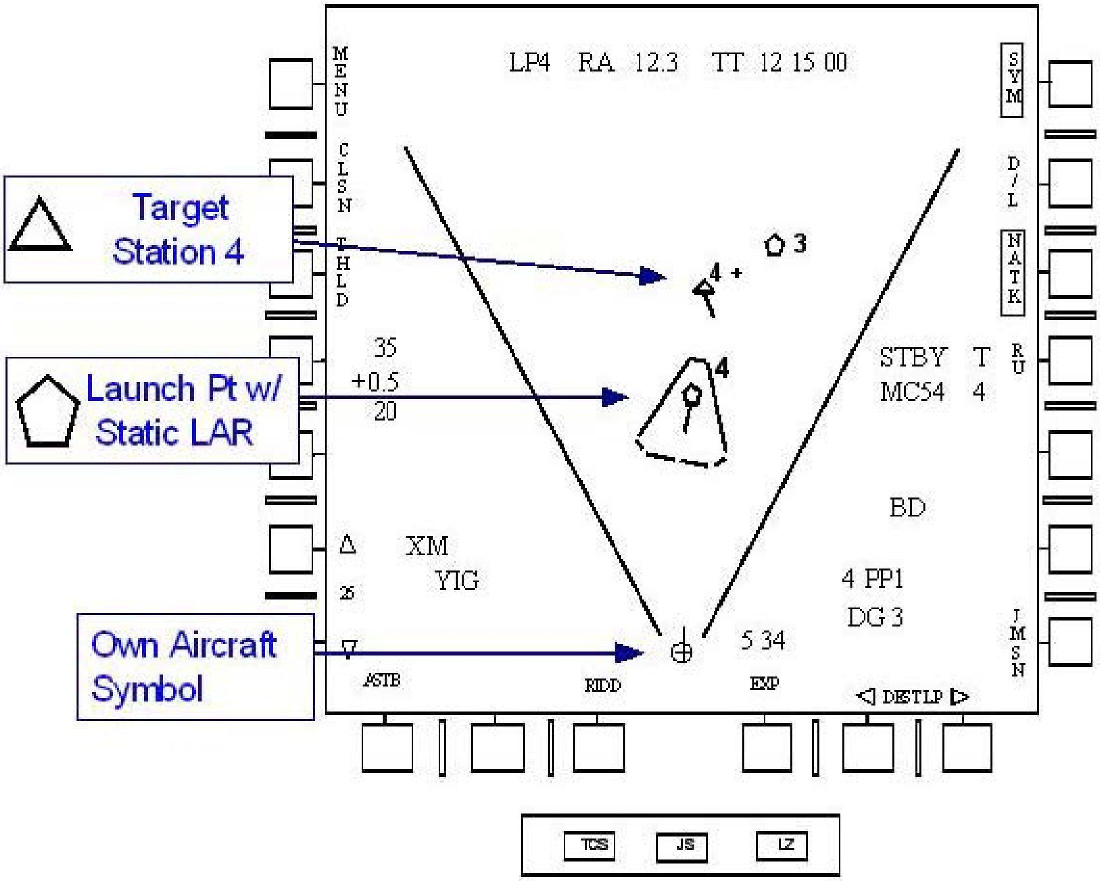


Figure 6-1 [26]
F-14B Tactical Display with JDAM Launch Acceptability Region

To be tested at various airspeeds, altitudes and headings. Operationally, the requirement to allow weapons delivery only at certain altitudes and headings, according to the pre-flight planning, could seriously handicap aircrew during strike missions and increase their vulnerability to surface-to-air threats. It would be very common for the delivery aircraft to be out of the preplanned LAR, since airspeed, altitude and heading would all be changed simultaneously during threat avoidance maneuvers.

The interim solution for this deficiency was to use a manual delivery mode, without the use of a pre-planned LAR, and release the weapon according to the numerically displayed aircraft to target range readout. This provided the aircrew with some flexibility, as it allowed them to release the weapon according to a "manual release table", which could be carried into and referenced in the cockpit. Optimally, the delivery would be programmed in pre-fight planning, but in the situation where none of the eight TDS applied, aircrew could use the "manual release tables". A recommendation was submitted to incorporate a dynamic LAR that would change as the aircraft airspeed, altitude and heading changed. This upgrade would be incorporated a future software release.

Terminal Parameter Editing

In a related deficiency, aircrew had no method of editing any of the JDAM terminal impact parameters. Impact parameters included terminal heading, terminal dive angle, and terminal impact velocity. These parameters would be critical during in-flight targeting in order to generate the greatest target destruction. For instance, a cave entrance would have to be attacked with a low impact angle profile to allow bomb flight into the tunnel entrance for maximum destruction. If none of the pre-flight planned TDS included a low impact angle, then that target could not be properly prosecuted. JDAM was designed to accept in-cockpit changes to these terminal parameters. Other aircraft like the Navy's F/A-18 Hornet have this capability. As shown in table 6-1, this functionality was not provided in the F-14 and a recommendation was submitted to incorporate in-cockpit terminal parameter editing in future software releases.

Multiple Point Editing

Background

Originally the F-14's only cockpit tactical data entry keypad was the Computer Address Panel (CAP) and was located at the RIO's aft cockpit station. The CAP had a six position rotary knob covering the range of input categories available, including Navigation, Waypoint, Built-In Test, and Data-Link. Each rotary selection enabled ten pushbuttons keys for activation of sub-options in the selected category. The CAP also had 10 hard keys, which allowed numerical entries of zero through nine, with some keys having a secondary North, West, South, and East function to allow for navigational latitude and longitude entry. With the incorporation of OFP 320 and the EGI, a second keypad was added to the RIO's station. This keypad was called the CDNU and was now the main navigation input and control system. The CDNU was now critical in the F-14B's digital architecture, in that it acted as a Bus Controller for the MIL-STD-1553B Navigation Bus (NAVBUS), linking the EGI and Computer Signal Data Converter (Replacement) (CSDC(R)). Appendix A details the RIO's cockpit station, and figures A-3 through A-7 shows the various data entry controls.

Table 6-1 [22]
Joint Direct Attack Muntion Target Data Set
With F-14 In-Flight Changeable Options

Target Data	Target Data Set*		F-14 In-Flight Changeable
	Required	Optional	
Target Hardness		X	
Target Orientation		X	
Attack Mode		X	X
Target Altitude Reference	X		X
Target Name		X	
Target Location - Latitude	X		X
Target Location - Longitude	X		X
Target Location - Altitude	X		X
Target Impact Azimuth		X	
Target Impact Angle		X	
Target Minimum Impact Velocity		X	
Target Offset - North		X	X
Target Offset - East		X	X
Target Offset - Down		X	X
JPF Fuze Control Source		X	X
JPF Fuze Mode		X	X
JPF Arm Time From Release		X	X
JPF Function Time From Impact		X	X

*The parameters identified as “Required” in the TDS column constitute the minimum parameters required by the JDAM weapon to complete its mission. The “Optional” data provide enhancements to the weapon operation and performance.

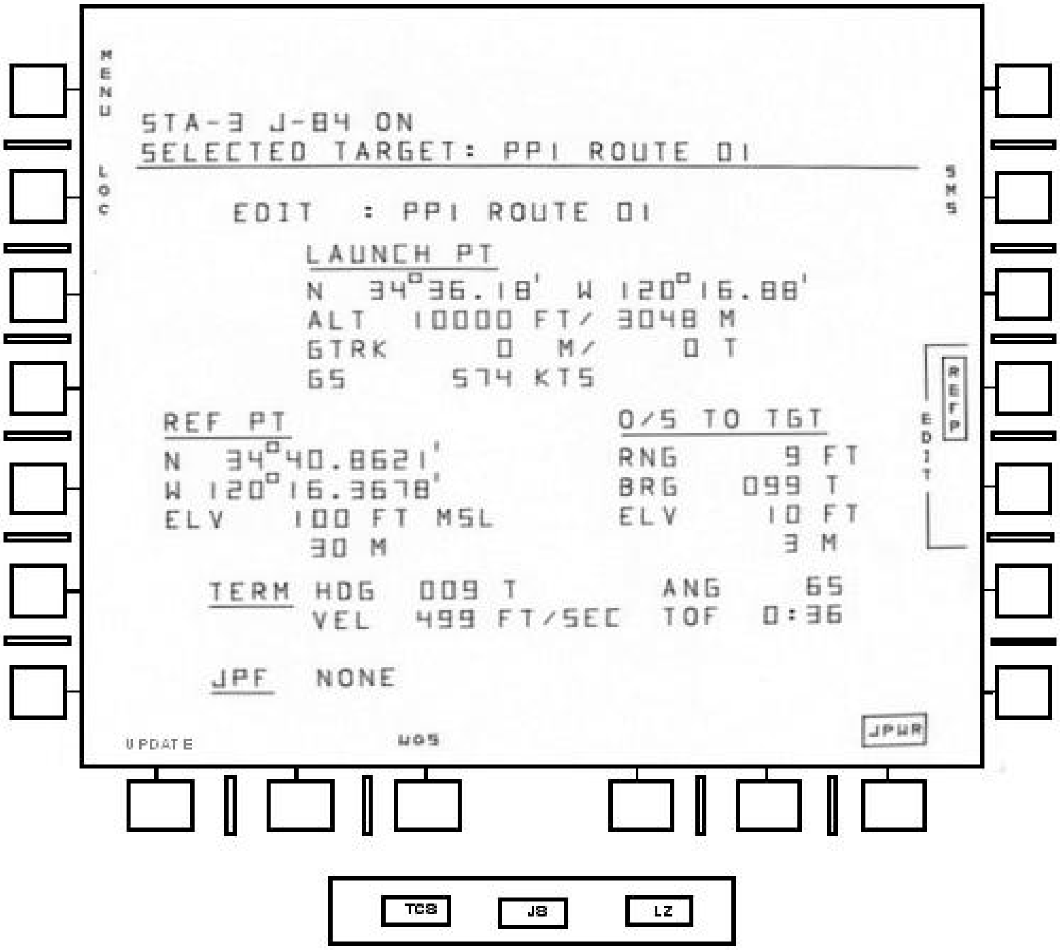
JDAM Editing

With the F-14's integration of JDAM through OFP 321, aircrews were required to have the ability to edit the weapons target parameters. Editable target parameters included latitude, longitude, altitude, offset bearing and offset heading. JDAM required very accurate coordinates, with the required format in degrees, minutes, 1000th of minutes (DD° MM.MMM). A problem arose in that the CAP data entry keypad would only allow latitude and longitude entry in degrees, minutes, and 10th of minutes (DD° MM.M). Three options were available to enable entry in the proper format; modify the F-14 Mission Computer for CAP entries; modify the CDNU software; or create an additional data entry point. For programmatic and schedule reasons, the option to increase software modifications to the F-14 Mission Computer to allow the required target format was not selected. The CDNU did use the proper DD° MM.MMM format for navigation purposes, but the CDNU software was not being modified for OFP 321. To solve the problem software designers created a third data entry location. A numerical keypad was created on the RIO's main tactical display, the 8 inch by 8 inch Programmable Tactical Information Display (PTID). The PTID JDAM target entry became the source for JDAM latitude and longitude entry and the CAP retained the entry location for altitude, bearing and range entries.

During JDAM employment all three displays; the CAP, CDNU and PTID would be used for JDAM administrative operations. Though use of these three controls and displays were part of the original JDAM integration design, actual cockpit manipulation proved to be inefficient. Three different entry locations were cumbersome and awkward for the RIO, especially for the critical tasks of editing precise targeting and navigation data. These tasks required excessive heads down time. A trouble report was written with a recommendation to locate the JDAM entry functions and navigation entries onto a single control in future software upgrades.

Target Data Update Confirmation

One design feature that became an issue was the method by which aircrew confirmed new target data. After entering target data through both the CAP and the PTID entry points, that information was saved to the F-14 Mission Computer. However, in order to pass that information to the weapon, a pushtile on the RIO's main tactical display, the PTID, had to be selected. The pushtile was labeled with the word "update". The PTID had 20 pushtiles with various functions and the pushtile lettering on the 8" by 8" PTID was approximately 1/4" tall. The "update" option only appeared after target data was changed, but was not highlighted to alert the aircrew that changes had not yet been downloaded to the weapon. Figure 6-2 depicts the PTID JDAM Mission Page with the "update" option. During testing it became apparent that aircrew would be required to change target data often and would overlook this final step of downloading targeting changes to the weapon. The recommendation was made to highlight the "update" option during this cycle of testing. It was concluded that highlighting, through the use of flashing near the pushtile would be required. In general, aircrews had asked that limited items flash at them and then only for emergency or critical situations. It was determined that a flashing box around the word "Update" would be a good solution. This was desirable in two ways. First, when aircrew selected any of the PTID pushtiles, a "box" around that selection would appear and the next screen, option or menu would then



STA-3 J-84 ON
SELECTED TARGET: PPI ROUTE 01

EDIT : PPI ROUTE 01

LAUNCH PT
N 34°36.18' W 120°16.88'
ALT 10000 FT/ 3048 M
GTRK 0 M/ 0 T
GS 574 KTS

REF PT
N 34°40.8621'
W 120°16.3678'
ELV 100 FT MSL
30 M

O/S TO TGT
RNG 9 FT
BRG 099 T
ELV 10 FT
3 M

TERM HDG 009 T
VEL 499 FT/SEC

ANG 65
TOF 0:36

JPF NONE

Figure 6-2 [26]
F-14B JDAM Mission Page with Update Option (Lower Left Pushtile)

come up or that function would be enabled. This was a standard convention used by F-14 aircrew, commonly called “boxing”, meaning to turn on or select to reach another menu level. Secondly, flashing was a method already used in the F-14 for providing warning, cautions or advisories. Human factors guidance recommended flashing items at 3 to 10 cycles per seconds to attract attention in a 'warning' type of situation. A study found that a flashing streetlight at 1 to 2 cycles per seconds was effective in attracting attention (in the context of being associated with a non-flashing background) [27]. Since this "UPDATE" pushtile did not require an immediate emergency type response, but was critical for mission accomplishment, a flash of 1 cycle per second was deemed appropriate. This worked well and was different than most other flashing used in the F-14. A few of the F-14’s other flashing items were (1) Built in Test (BIT), performed at 2 Hz, and (2) when an air-to-air weapon was within a launch zone, at 2 to 4 Hz.

Weapon Delivery Flight Test Results

Two actual weapons deliveries were flown and the test weapons were production JDAM tailkits installed with data transmitting telemetry kits. For safety purposes the two guided and fully integrated deliveries were tested with inert 2000 lb. warheads. The first delivery was the more significant of the two during the testing phase. The flight occurred on May 5th, 2000 at the Naval Test Ranges, China Lake, CA. The delivery profile required the aircraft be at an altitude of 35,000 ft MSL and a speed of 0.95 IMN. During the flight from the F-14 test facilities at NAS Pt. Mugu to the ranges, all systems appeared normal. While in the target range in preparation for delivery an F-14 navigation system advisory, called the “NAVCOMP” light, appeared. The advisory light, standing for Navigation Computer, was an indication that a fault was detected in the EGI, CDNU or Signal Data Converter (SDC), which could degrade the navigation solution. Additionally, the light could indicate that a tolerance from one of the EGI parameters was out of limits. Per the EGI Navigation Pocket Guide, aircrew shall treat the NAVCOMP advisory light as a cue to check the status indications and navigation pages of the CDNU.

The F-14 flight test engineers at the range were informed of the system advisory by the aircrew. In the cockpit the systems were checked. The JDAM was not displaying any faults during periodic BIT or during aircrew run IBIT. Additionally, the CDNU status displays for both the primary Blended (GPS/INS) navigation solution and the backup GPS-only navigation, indicated a FOM of 1, the highest navigation quality. According to the EGI Navigation Pocket Guide, a correctly operating GPS receiver with properly loaded crypto keys in the Precision Positioning System (PPS) mode would display a FOM of 1. A FOM of 4 or greater would indicate that the GPS receiver was operating in the less accurate Standard Positioning System (SPS), usually a sign of no or incorrect GPS keys installed [28]. Other than the NAVCOMP advisory, all indications in the aircraft were normal.

System checks at the flight engineers ground station location, using the telemetry data from the aircraft and the weapon, were not indicating any problems either. After much discussion between the aircrew and engineers, the event was given the go ahead. The profile was flown per the plan and at 8.5 nautical miles from the target the JDAM was released. The result was a 9 ft miss (3 meter) from a direct hit, well within the JDAM advertised 13 meter CEP. Figure 6-3 depicts the first F-14B weapon release and impact.

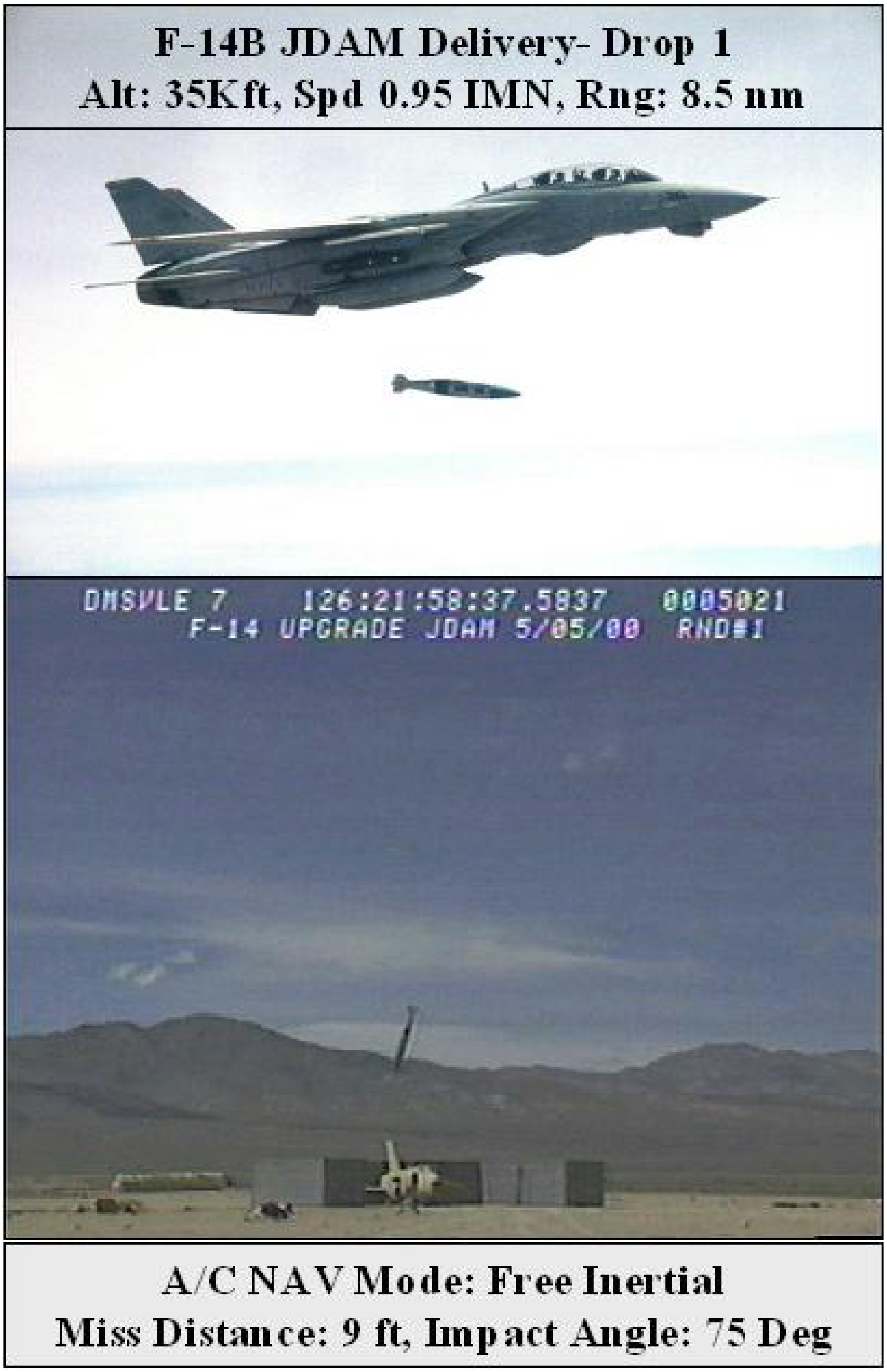
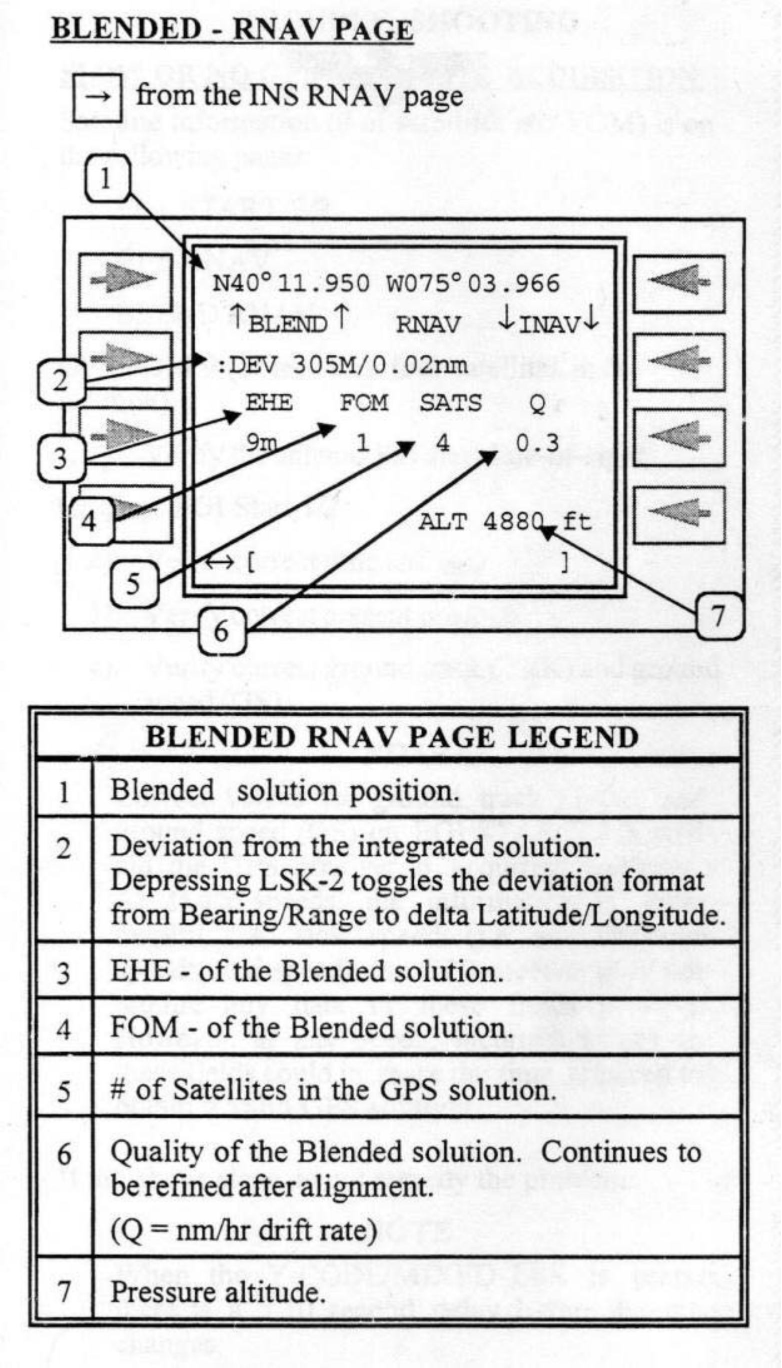


Figure 6-3 [29]
F-14B JDAM Release and Impact

Post-Flight analysis uncovered multiple software and procedural deficiencies. The flight on May 5th was unknowingly flown without the GPS crypto-keys properly loaded into the aircraft's EGI and the weapon was released without any GPS navigation information in the transfer alignment from the aircraft. Both the aircraft INS and the weapon IMU, matched, drifting equally, and therefore no transfer alignment or JDAM faults were displayed. Once released, the JDAM acquired GPS data based on ephemeris data, which was passed to it separately from the transfer alignment, and the JDAM successfully guided to the target.

Prior to May 1st, 2000, NAVSTAR/GPS was operating with Selective Availability (S/A) enabled. After May 1st, S/A was discontinued per a Presidential order. Usually the biggest indication of Navigation/GPS problems in the F-14 was the FOM. However because S/A had been disabled, the F-14's EGI was seeing a very accurate GPS solution and the CDNU was properly reporting a GPS FOM of 1. All the aircrew procedures for F-14 Navigation troubleshooting up to this point were written with S/A enabled. If the flight had occurred May 1st or before, the aircrew would have seen a FOM of 4 on start-up and had the system re-keyed before launch, but instead on May 5th the aircrew saw a FOM of 1. Additionally, errors in the CDNU software were incorrectly posting a Blended FOM of 1, when in fact the aircraft INS was operating without any GPS aiding. Figure 6-4 depicts the CDNU's Blended Navigation Status Display. The blended FOM should have displayed 9, for no GPS information in the navigation solution. Also, a confusing indicator on the Blended Navigation display was the number of GPS satellites. Intuitively, this number would appear to be the number of satellites being used in the blended solution since it was appearing on the Blended Status Page. However, this value



BLENDED - RNAV PAGE

→ from the INS RNAV page

BLENDED RNAV PAGE LEGEND	
1	Blended solution position.
2	Deviation from the integrated solution. Depressing LSK-2 toggles the deviation format from Bearing/Range to delta Latitude/Longitude.
3	EHE - of the Blended solution.
4	FOM - of the Blended solution.
5	# of Satellites in the GPS solution.
6	Quality of the Blended solution. Continues to be refined after alignment. (Q = nm/hr drift rate)
7	Pressure altitude.

Figure 6-4 [28]
F-14B CDNU Blended Navigation Status Page

was actually the number of satellites being used in the “GPS” solution.

It was determined that a more accurate navigation quality indicator was the estimated horizontal error (EHE). The EHE was a similar error estimate like the FOM, but was displayed as a range value in meters (1 through 999). The EHE was correctly displayed on both the GPS and Blended navigation displays on the CDNU. New procedures were written to utilize the EHE vice FOM as a navigation solution indicator. Checking EHE prior to delivery became part of the checklist prior to simulated and actual weapons delivery to preclude JDAM employment without GPS. Additionally, procedures were written to train aircrew to check the validity of GPS keys loaded to the EGI through pre-existing, infrequently used, CDNU lower level status displays.

No corrections were made to the CDNU displays since this software was not being modified for OFP 321. A partial solution was to create a transfer alignment degrade if GPS was not being used in the navigation solution transferred from the aircraft to the weapon. A “GPS DATA” caution was added and would be displayed on the JDAM BIT display causing a degraded weapon state on the top-level tactical display. Overall, the confusing and inaccurate navigation solution status presented to the aircrew could result in delivery of JDAM with a degraded GPS solution, causing large miss distances. This was the most notable, uncorrected deficiency found during testing. New procedures and the “GPS Data” caution were implemented, and will remain in affect until the next software upgrade.

Summary

From November 1999 to December 2000, the developmental testing encompassed 1048 hours in the SITS Lab, 80 hours in ground testing and 107 hours (46 sorties) in flight testing. All testing was completed at Naval Air Station Pt. Mugu, California, utilizing the ranges over the Pacific Ocean and the overland test ranges at the Naval Weapons Station China Lake, California. The testing included over 800 simulated deliveries and two actual deliveries. Further, over the entire test program, 209 problem reports were filed, of which 186 were corrected or closed prior to test completion. No high priority problems were open at the conclusion of developmental testing that would prevent mission accomplishment and commencement of operational testing. OFP 321 met or exceeded the performance level requirements and maintained the baseline system performance [29].

During the developmental test phases, test aircrews were challenged with providing a complex product, which in the end would have to be easy to use and intuitive for the average fleet aircrew. Test aircrew ensured that they scrutinized all aspects of the new functionalities, especially in controls and displays, and identified the “gotchas” or potential areas of human error. A test priority was to identify areas of the new design that would cause aircrew confusion or created other problems, such as the excessive input requirements and the limited flexibility with the LAR’s. It became apparent that designs on paper did not always provide the desired level of performance once they were transferred to the cockpit and actually involved human interface. These problems had to be fixed or documented for correction. In the end, a key objective was for aircrew to make recommendations for improvements in order to minimize any aircrew errors, an important consideration when delivering a 2000 lb weapon.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

"The new features of the OFP 321A enhanced the operational effectiveness and operational suitability of the F-14B and adequately supported the F-14B mission. There were no degradations in the F-14B operational effectiveness and operational suitability from the previous OFP."

- OFP 321 Operational Test Report [30]

Conclusion

Based on the results of the developmental flight-testing, the hardware and software configuration, called OFP 321, entered Operational Testing in January 2001. By late 2001, Operational Test Squadron Nine (VX-9) deemed OFP 321 operationally effective and operationally suitable [30], therefore ready for introduction into the Fleet. The Initial Operational Capability for the F-14B Upgrade with JDAM occurred in 2002 with Carrier Air Wing Seven (CVW-7) aboard the USS John F. Kennedy (CV-67). This deployment was in support of Operation Enduring Freedom in Afghanistan. Air Wing Seven's two F-14 Squadrons, Fighter Squadron Eleven (VF-11) and Fighter Squadron One-Hundred Forty Three (VF-143), entered combat operations in March 2002 with the new capabilities of OFP 321. On March 12th, during a night strike in support of coalition forward air controllers, an F-14B from the VF-11 "Red Rippers" successfully employed the first JDAM in combat [31].

Specific Conclusions

Although OFP 321 and JDAM met the developmental and operational requirements, the following deficiencies of the integration were highlighted.

1. Static LAR's. The static LAR's incorporated with OFP were too constraining and did not provide enough flexibility. The depicted Static LAR's were inadequate since they would only allow JDAM delivery at certain altitudes and headings, and since they could only be created during pre-flight planning. This often led to weapon delivery in the, aircrew intensive, manual mode.
2. Terminal Parameter Editing. Aircrew did not have the option in the cockpit to edit all the parameters of the JDAM Target Data Set. The inability to in-flight edit JDAM terminal impact parameters, such as impact heading, angle and velocity, does not take full advantage of JDAM's capabilities.
3. Single Point Data Entry. From the original F-14 configuration, to the addition of GPS, to the incorporation of JDAM, no real focus was given to efficient system integration. In the case of data entry in the cockpit, each iteration of increased mission capability was implemented as a stand-alone system. The result was a cockpit with multiple data entry paths and excessive aircrew workload required to effectively operate the systems.
4. Navigation Status Displays. Confusing and inaccurate navigation solution displays presented to the aircrew resulted in the delivery of JDAM with a degraded GPS solution during testing. Although the JDAM made its own corrections to overcome the aircraft faults and successfully guided to the target, aircrew must be presented with clear and accurate information, for they bear the ultimate responsibility for the employment of these weapons.

Recommended Improvements

The following are presented as a summary of the recommended improvements based on testing the integration of JDAM on the F-14B Upgrade aircraft.

1. Incorporate Dynamic LAR’s. LAR’s for JDAM need to provide more flexibility to the aircrew. Incorporate LAR’s that reflect the constantly changing position of the launch aircraft. They will automate the process and eliminate the need for aircrew to manually look up release ranges. Dynamic LAR’s will provide the most accurate deliveries of the weapon by reducing the chance of human error.
2. Expand JDAM parameter editing. Allow for full editing of target location and terminal impact parameters. Impact parameters such as impact angle, heading and velocity must be cockpit changeable. This will allow targeting flexibility and the greatest chance of mission success.
3. Create a single point data entry. Though increased capabilities are always desired, they must be integrated with the already present systems. The CDNU should be the single data entry control because it has the greatest selection of data entry keys and has the processing required to perform all the needed functions.
4. Navigation Status Display. Update the software to accurately reflect a degraded navigation solution. Present the aircrew with clear unambiguous displays that indicate when the system is degraded and when it will have adverse effects on the accuracy of JDAM.

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APPENDIX

APPENDIX A

F-14B Cockpit Diagrams

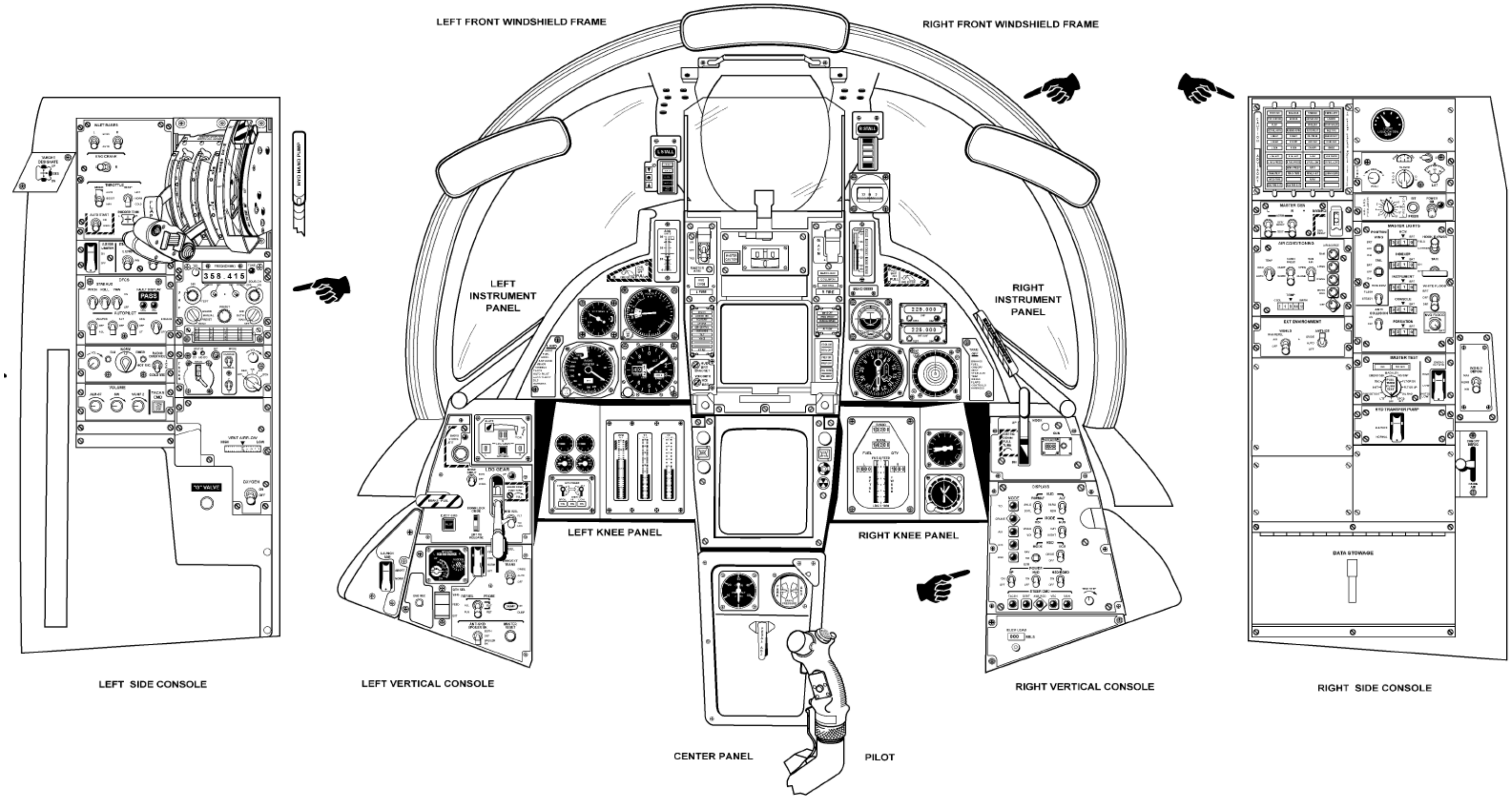
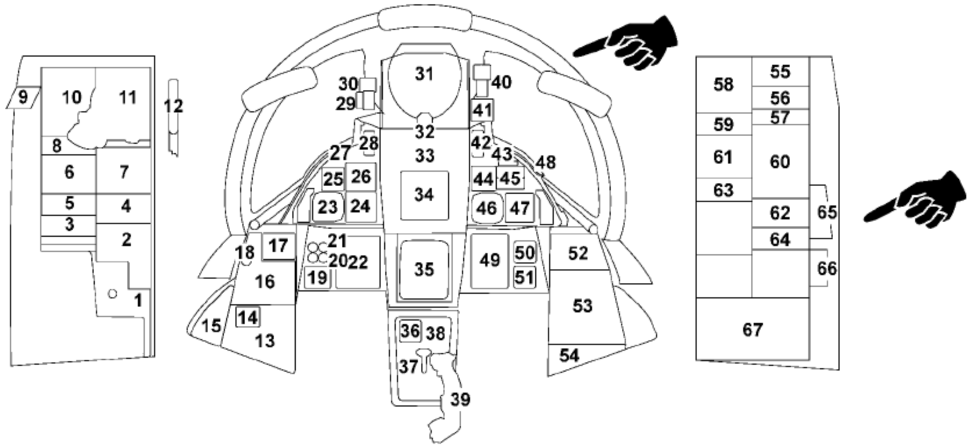


Figure A-1 [13]

F-14B Pilot Forward Cockpit Instrument Panel and Console



LEFT SIDE CONSOLE

1. G VALVE PUSHBUTTON
2. OXYGEN-VENT AIRFLOW CONTROL
3. VOLUME/TACAN COMMAND PANEL
4. TACAN CONTROL PANEL
5. ICS CONTROL PANEL
6. DFCS CONTROL PANEL
7. UHF CONTROL PANEL
8. ASYM LIMITER/ENG MODE SELECT
9. TARGET DESIGNATE SWITCH
10. INLET RAMPS/THROTTLE CONTROL PANEL
11. THROTTLE QUADRANT
12. HYDRAULIC HAND PUMP

LEFT VERTICAL CONSOLE

13. FUEL MANAGEMENT PANEL
14. CONTROL SURFACE POSITION INDICATOR
15. LAUNCH BAR ABORT PANEL
16. LANDING GEAR CONTROL PANEL
17. WHEELS-FLAPS POSITION INDICATOR
18. EMER STORES JETTISON BUTTON

LEFT KNEE PANEL

19. HYDRAULIC PRESSURE INDICATOR
20. OIL PRESSURE INDICATOR
21. EXHAUST NOZZLE POSITION INDICATOR
22. ENGINE INSTRUMENT GROUP

LEFT INSTRUMENT

23. RADAR ALTIMETER
24. SERVOPNEUMATIC ALTIMETER
25. VERTICAL VELOCITY INDICATOR
26. AIRSPEED MACH INDICATOR
27. LEFT ENGINE FUEL SHUTOFF HANDLE
28. ANGLE-OF-ATTACK INDICATOR

LEFT FRONT WINDSHIELD FRAME

29. APPROACH INDEXER
30. WHEELS WARNING / BRAKES WARNINGS / ACLS / AP CAUTION / NWS ENGA CAUTION / AUTO THROT CAUTION LIGHTS

CENTER PANEL

31. HEADS-UP DISPLAY
32. HUD CAMERA
33. AIR COMBAT MANEUVER PANEL
34. VERTICAL DISPLAY INDICATOR (VDI)

CENTER PANEL (CONT.)

35. HORIZONTAL SITUATION DISPLAY INDICATOR (HSI)
36. CABIN PRESSURE ALTIMETER
37. PEDAL ADJUST HANDLE
38. BRAKE PRESSURE INDICATOR
39. CONTROL STICK

RIGHT FRONT WINDSHIELD FRAME

40. ECM WARNING LIGHT
41. STANDBY COMPASS

RIGHT INSTRUMENT PANEL

42. WING SWEEP INDICATOR
43. RIGHT ENGINE FUEL SHUTOFF HANDLE
44. STANDBY ATTITUDE INDICATOR
45. UHF/VHF REMOTE INDICATORS
46. BEARING DISTANCE HEADING INDICATOR
47. ALR-67 INDICATOR
48. CANOPY JETTISON HANDLE

RIGHT KNEE PANEL

49. FUEL QUANTITY INDICATOR
50. ACCELEROMETER
51. CLOCK

RIGHT VERTICAL CONSOLE

52. ARRESTING HOOK PANEL
53. DISPLAYS CONTROL PANEL
54. ELEVATION LEAD PANEL

RIGHT SIDE CONSOLE

55. LIQUID OXYGEN QUANTITY INDICATOR
56. COMPASS CONTROL PANEL
57. ARA-63 CONTROL PANEL
58. CAUTION - ADVISORY INDICATOR
59. MASTER GENERATOR CONTROL PANEL
60. MASTER LIGHT CONTROL PANEL
61. AIR CONDITIONING CONTROL PANEL
62. MASTER TEST PANEL
63. EXTERNAL ENVIRONMENTAL CONTROL PANEL
64. HYDRAULIC TRANSFER PUMP SWITCH
65. WINDSHIELD DEFOG PANEL
66. CANOPY DEFOG/CABIN AIR LEVER
67. DATA STOWAGE COMPARTMENT

Figure A-2 [13]
F-14B Pilots Instrument Panel and Console Description

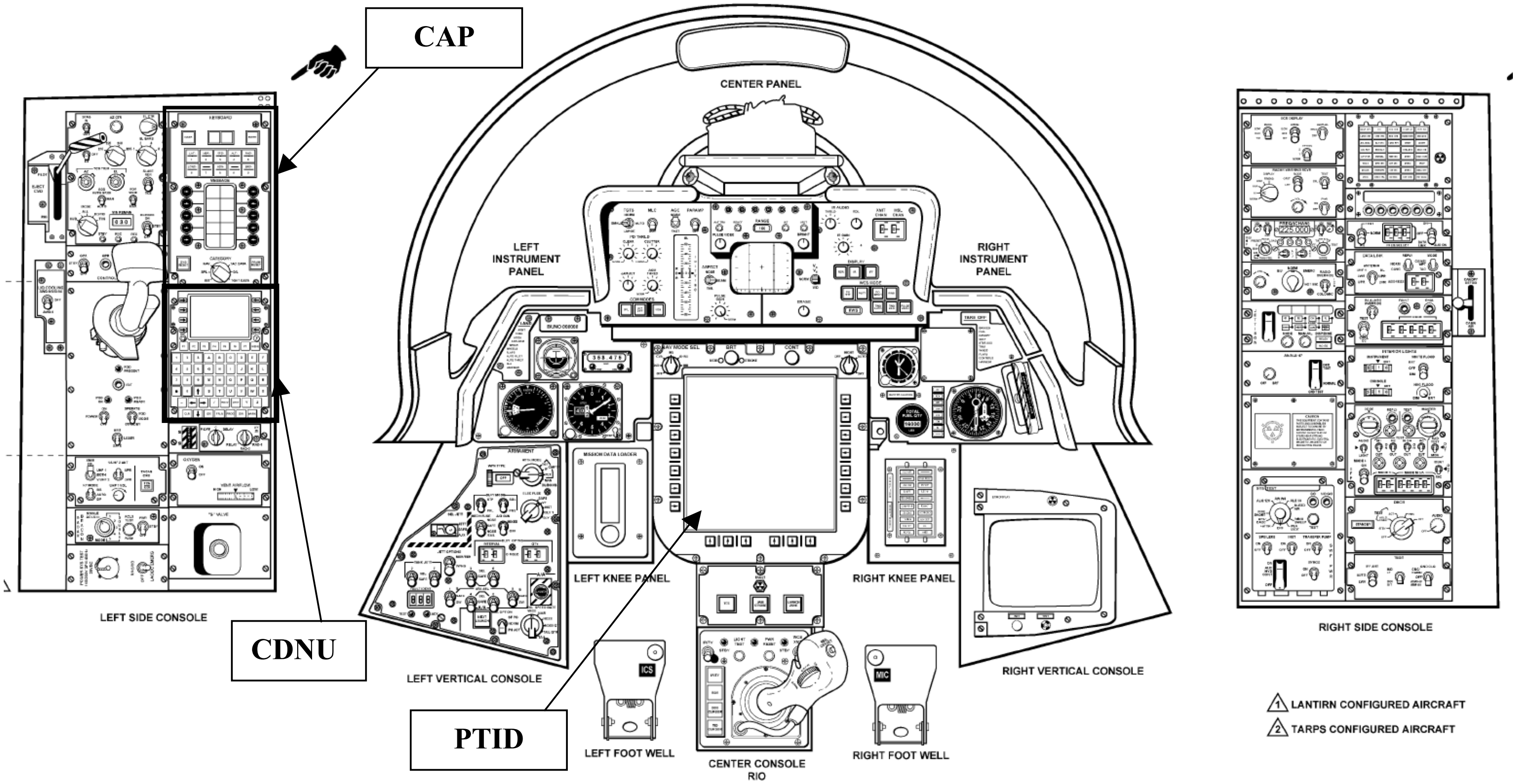
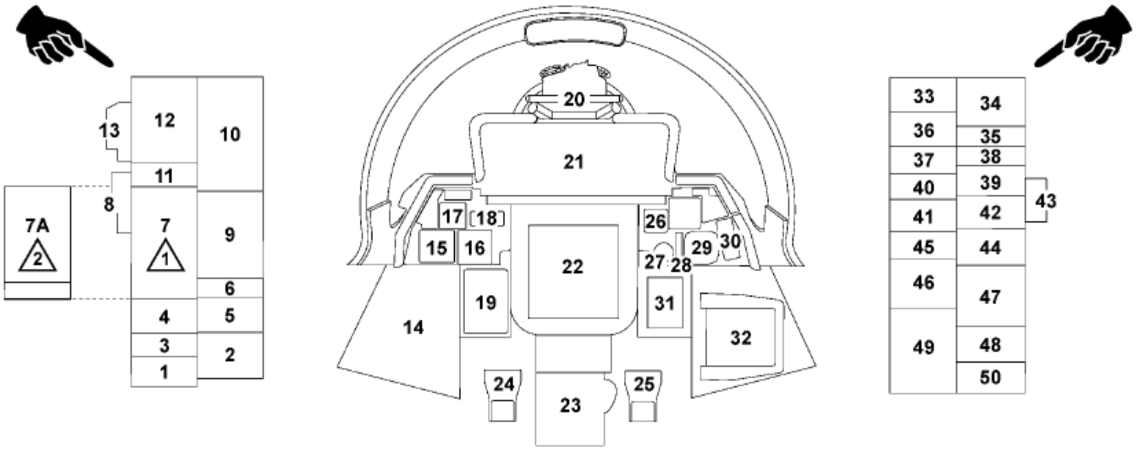


Figure A-3 [13]
F-14B Radar Intercept Officer Rear Cockpit Instrument Panel and Console



LEFT SIDE CONSOLE
1. ELECT PWR SYS TEST PANEL
2. G VALVE
3. ACLS CONTROL
4. COMM/TACAN CONTROL
5. OXYGEN-VENT AIRFLOW CONTROL
6. KY-28 CONTROL
7. LANTIRN CONTROL
A7. RECON CONTROL PANEL
8. LIQUID COOLING CONTROL
9. CONTROL DISPLAY NAVIGATION UNIT
10. COMPUTER ADDRESS PANEL
11. ALQ-167 CONTROL
12. SENSOR CONTROL PANEL
13. EJECT COMMAND LEVER

LEFT VERTICAL PANEL
14. ARMAMENT CONTROL PANEL

LEFT INSTRUMENT PANEL
15. AIRSPEED MACH INDICATOR
16. SERVOPNEUMATIC ALTIMETER
17. STANDBY ATTITUDE INDICATOR
18. UHF REMOTE INDICATOR

LEFT KNEE PANEL
19. MISSION DATA LOADER

CENTER PANEL
20. CHAFF/FLARE DISPENSE SWITCHES
21. DETAIL DATA DISPLAY PANEL

CENTER CONSOLE
22. PROGRAMMABLE TACTICAL INFORMATION DISPLAY (PTID)
23. HAND CONTROL UNIT

LEFT AND RIGHT FOOT WELLS
24. ICS FOOT BUTTON
25. MIC FOOT BUTTON

RIGHT INSTRUMENT PANEL
26. CLOCK
27. FUEL QUANTITY TOTALIZER
28. THREAT ADVISORY LIGHTS
29. BEARING DISTANCE HEADING INDICATOR (BDHI)
30. CANOPY JETTISON HANDLE

RIGHT KNEE PANEL
31. CAUTION-ADVISORY PANEL

RIGHT VERTICAL CONSOLE
32. ECM DISPLAY INDICATOR

RIGHT SIDE CONSOLE
33. ECM DISPLAY CONTROL PANEL
34. DIGITAL DATA INDICATOR (DDI)
35. FTI CONTROL
36. RADAR WARNING RECEIVER PANEL
37. UHF 2 CONTROL
38. DATA LINK CONTROL PANEL
39. DATA LINK REPLY CONTROL PANEL
40. ICS CONTROL PANEL
41. AN/ALE-47 DCDU
42. INTERROGATOR CONTROL PANEL
43. DEFOG CONTROL LEVER
44. INTERIOR LIGHTS CONTROL PANEL
45. AN/ALE-47 DIMMER/TEST
46. AN/ALE-47 PROGRAMMER
47. TRANSPONDER SET CONTROL PANEL
48. DECM CONTROL PANEL
49. SYSTEM POWER/GROUND TEST CONTROL PANEL
50. IFF ANTENNA COMPUTER TEST CONTROL PANEL

Figure A-4 [13]
F-14B Radar Intercept Officer Instrument Panel and Console Description

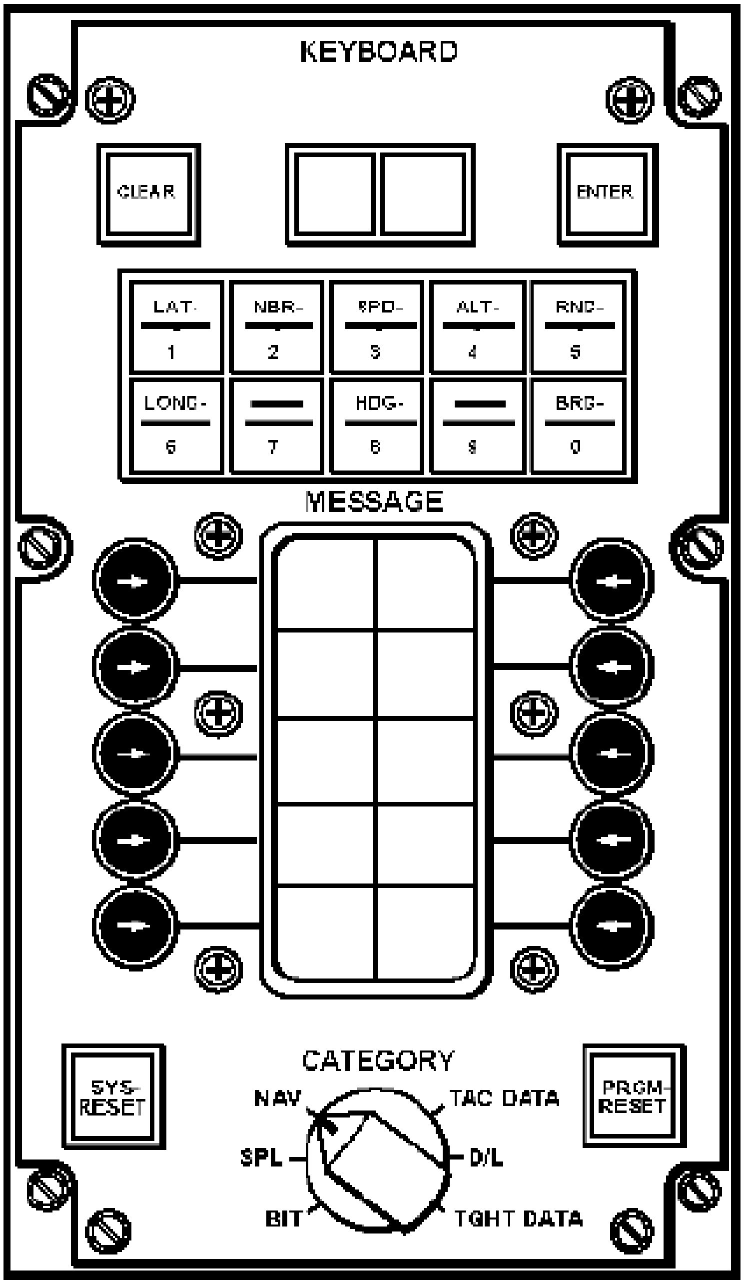


Figure A-5 [13]
F-14B Computer Address Panel (CAP)

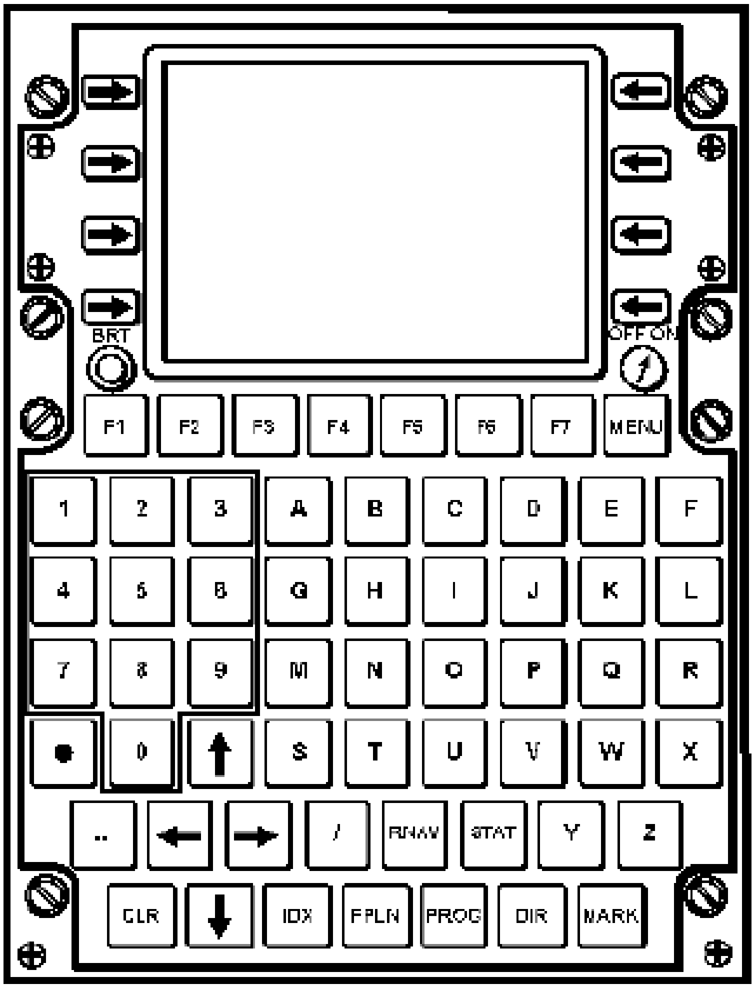
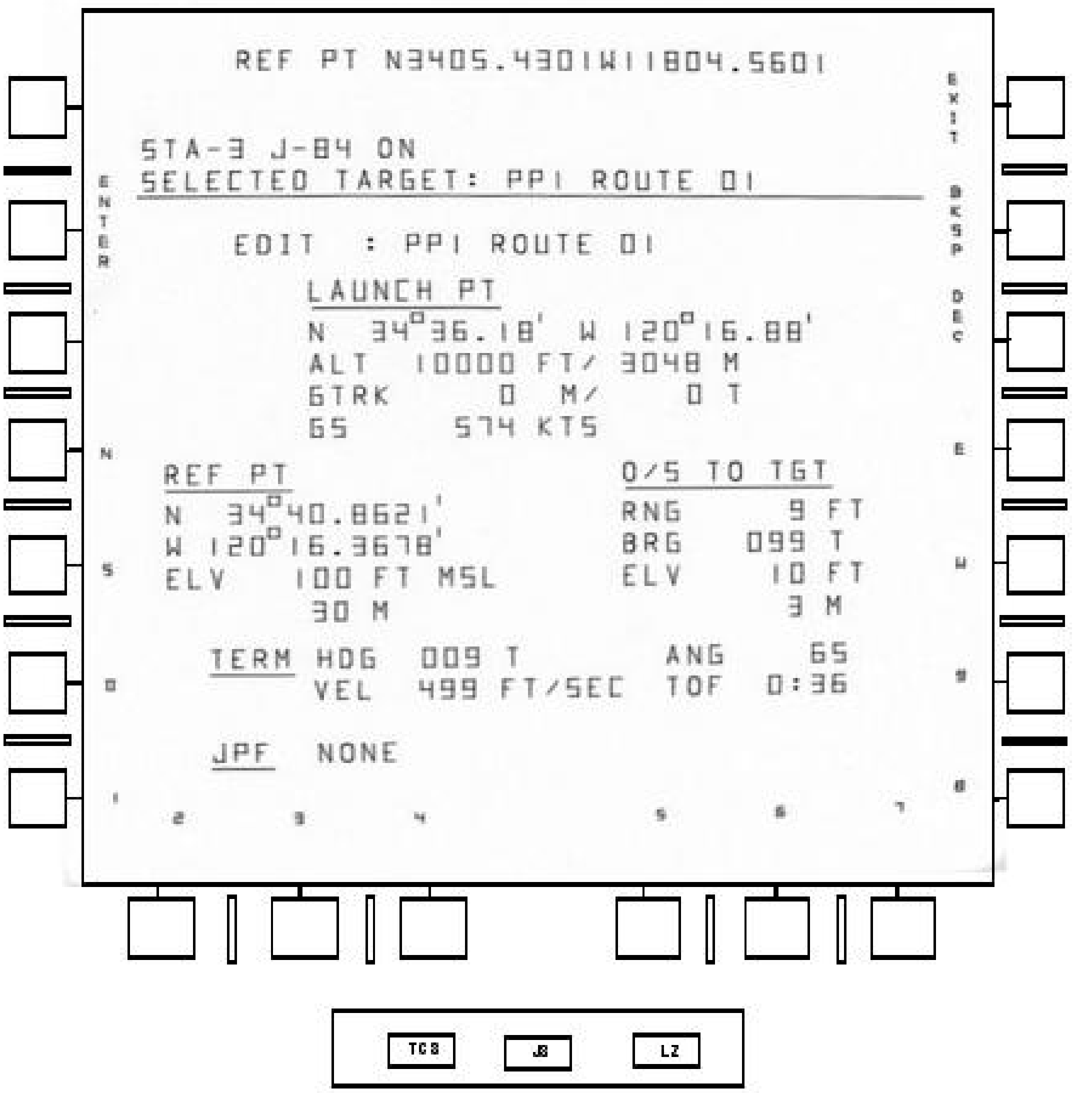


Figure A-6 [13]
F-14B Controls and Display Navigation Unit (CDNU)



```
      REF PT N3405.4301W11804.5601

   STA-3 J-84 ON
   SELECTED TARGET: PPI ROUTE 01

      EDIT  : PPI ROUTE 01
          LAUNCH PT
          N  34°36.18' W 120°16.88'
          ALT  10000 FT/ 3048 M
          GTRK      0  M/     0 T
          GS     574 KTS
    REF PT                          O/S TO TGT
    N  34°40.8621'                  RNG       9 FT
    W 120°16.3678'                  BRG     099 T
    ELV    100 FT MSL               ELV      10 FT
           30 M                               3 M
       TERM HDG   009 T             ANG      65
            VEL   499 FT/SEC        TOF    0:36

       JPF  NONE
```

Figure A-7 [26]
F-14B Programmable Tactical Information Display (PTID) with JDAM Target Edit Page

VITA

LCDR Paul J. Filardi is a 1991 graduate of Clemson University with a Bachelor of Science degree is Mechanical Engineering. He was commissioned an Ensign in the U.S. Navy after completion of Aviation Officer Candidate School in Pensacola, Florida in January 1992. He earned his Naval Flight Officer Wing's of Gold in May 1993. Selected as an F-14 Radar Intercept Officer, he reported to Fighter Squadron 101 at Naval Air Station Oceana, Virginia for F-14 Flight training. At the completion of training, he check aboard Fighter Squadron 41, the Black Aces, where he completed two six month overseas deployments and logged 1000 hours in the F-14 in the 3 ½ year tour.

In January 1998, he reported to the U.S. Naval Test Pilot School in Patuxent River, Maryland. After an intense 11-month course on aircraft performance and systems, he gradated and proceeded to the Naval Weapons Test Squadron located at Pt. Mugu, California. At the test Squadron from 1999 to 2001, LCDR Filardi filled the billets of Mission Planning Project Officer, F-14B Upgrade Project Officer and Tomahawk Chase Project Aircrew. His major projects at Pt. Mugu were Operational Flight Program (OFP) 321, JDAM and he began development of the following-on F-14B software, OFP 322.

LCDR Filardi, then reported to Carrier Air Wing 7 Staff, the first Air Wing with JDAM on their F-14B's. He flew with the Fighter Squadron 11, the Red Rippers, the first squadron to drop JDAM from the F-14B, during Operation Enduring Freedom.

LCDR Filardi is presently serving in Strike-Fighter Squadron 154, the Black Knights, at Naval Air Station Lemoore, California. He now flies the Navy's newest Strike-Fighter, the F/A-18F Super Hornet. He has over 2000 flights hours in 31 fixed and rotary wing aircraft and has over 450 carrier-arrested landings.