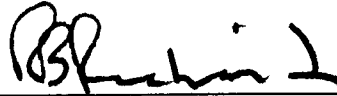


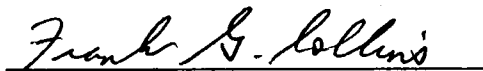
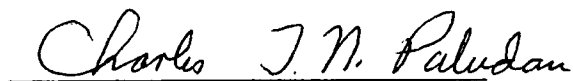
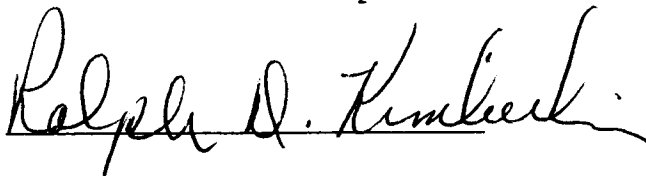
To the Graduate Council:

I am submitting herewith a thesis written by Jeffrey W. Knowles entitled "Follow-on Development of the Navy F-14D Tomcat Aircraft for the Night and All-Weather Strike Mission." I have examined the final 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.



Mr. Robert B. Richards, Major Professor

We have read this thesis
and recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Jeffrey H. Hines

Date 7/22/95

**Follow-on Development of the Navy F-14D Tomcat
Aircraft for the Night and All-Weather
Strike Mission**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jeffrey W. Knowles

August 1995

DISCLAIMER

Some of the technical data included in this thesis are actual flight test data collected during various aircraft evaluations and reported in unclassified technical reports. All enhancing characteristics and deficiencies attributed to the various aircraft and systems discussed are the sole opinion of the author, and do not necessarily represent the official position of the Naval Air Warfare Center, the Naval Air Systems Command, or the United States Navy. Similarly, the recommended aircraft modifications are presented by the author for the sole purpose of fulfilling the requirements of this thesis, and are not attributable to any of the aforementioned authorities.

ABSTRACT

The pending retirement of the A-6E aircraft will leave the U.S. Navy without a long range night precision and all-weather strike aircraft for several years. The F-14D was proposed as a replacement aircraft, but would require modification.

Lessons learned during the Desert Storm war were examined to define the requirements for a long range night and all-weather, carrier based, strike aircraft, and five specific capabilities were identified. Current Navy strike aircraft (A-6E, F/A-18C, F-14A/B, and F-14D) were examined for their capabilities, systems, and mission radii. Capabilities of current U.S. Air Force strike aircraft (F-15E, F-111F, F-117A) were also examined. Finally, a system-by-system analysis was performed to identify those systems that would enable the F-14D to fulfill the defined mission requirements.

The F-14D showed excellent potential for further development as a night precision and all-weather attack aircraft and a list of recommended aircraft modifications was compiled. A forward looking infrared system for targeting with a laser ranger and designator would give the F-14D a precision weapons capability. Addition of a synthetic aperture mode to the F-14D's digital radar, would provide an all-weather bombing capability. Other modification suggestions are provided in order of desirability.

TABLE OF CONTENTS

CHAPTER	PAGE
1. INTRODUCTION.	1
Background.	1
Purpose	3
2. LITERATURE REVIEW	5
Grumman Proposals	5
Navy Research and Flight Test	7
F-14 Ground Attack Testing	7
F-14 Night Vision Development	9
Current F-14 Follow-on Plans.	10
1994 GAO Report to Congress	11
3. DESERT STORM LESSONS LEARNED.	13
Precision Weapons	13
Mission Profiles	17
Environmental Conditions.	18
Mission Lengths	19
Lessons Learned Summary	20
4. CURRENT NAVY STRIKE AIRCRAFT.	21
A-6E Intruder	21
Weapon System	22
LGB Delivery Capability	23
Night Capability.	23
All-Weather Capability.	24
Payload	24
F/A-18C/D Hornet.	24
Weapon System	25
LGB Delivery Capability	27
Night Capability.	27
All-Weather Capability.	27
Payload	28
F-14A/B Tomcat.	28
Weapon System	29
LGB Delivery Capability	30
Night Capability.	30
All-Weather Capability.	30
Payload	31
F-14D Super Tomcat.	31
Weapon System	32
LGB Delivery Capability	32
Night Capability.	33
All-Weather Capability.	33
Payload	33
Current Navy Aircraft Capability Summary.	33

CHAPTER

PAGE

Mission Profile Comparison.	34
High-Medium-High Mission.	34
High-Low-High Mission	35
Mission Profile Range Summary	37
 5. CURRENT U.S. AIR FORCE STRIKE AIRCRAFT.	38
F-15E Strike Eagle.	38
Weapon System	39
LGB Delivery Capability	41
Night Capability.	41
All-Weather Capability.	42
F-111F Aardvark	42
Weapon System	43
LGB Delivery Capability	44
Night Capability.	45
All-Weather Capability.	45
F-117A Night Hawk	46
Weapon System	46
LGB Delivery Capability	48
Night Capability.	49
All-Weather Capability.	49
Capability Summary.	50
 6. SYSTEM BY SYSTEM ANALYSIS	51
FLIR.	51
NAVFLIR	53
TFLIR	54
Lasers.	55
Laser Rangers	56
Laser Designators	56
Radar Systems	56
Real Beam Ground Mapping.	57
Synthetic Aperture.	58
Terrain Following	60
Radar Navigation Aids	61
Navigation Aids	62
Inertial Navigation	62
Moving Map.	64
Global Positioning.	65
Night Vision.	65
 7. F-14D SYSTEM INTEGRATION.	68
Precise Navigation.	69
Precision Weapons Delivery and Guidance	70
Night Precision Weapons Capability.	72
All-Weather Attack Capability	74
Unrefueled Combat Radius.	75

CHAPTER	PAGE
8. CONCLUSIONS AND RECOMMENDATIONS	76
Recommended Modifications	77
Required.	77
Desired	77
LIST OF REFERENCES.	79
APPENDICES.	85
A. F-14 Aircraft and System Description.	85
B. Night Vision Imaging Systems.	102
C. Basic Weapon Descriptions and Delivery Profiles . .	110
D. A-6E Figures.	117
E. F/A-18C Figures	122
F. Mission Profiles and Range Data	128
G. F-15E Figures	137
H. F-111F Figures.	145
I. F-117A Figures.	151
VITA	155

LIST OF TABLES

TABLE		PAGE
2-1.	Components of proposed F-14 upgrades	8
4-1.	Current Navy aircraft strike capabilities.	34
4-2.	Comparison of aircraft unrefueled mission radii with four GBU-16 (1000 pound) laser guided bombs	36
5-1.	Current U.S. Air Force aircraft strike capabilities	50

LIST OF FIGURES

FIGURE	PAGE
Appendix A	
A-1. F-14D aircraft layout	86
A-2. F-14D dual chin pod (left), F-14A/B single chin pod (right).	87
A-3. F-14A/B/D weapons stations.	88
A-4. F-14D avionic system diagram.	89
A-5. F-14D front cockpit layout.	95
A-6. F-14D rear cockpit layout	96
A-7. F-14A/B front cockpit layout.	98
A-8. F-14A/B rear cockpit layout	99
A-9. F-14 station 1B loaded with AN/AAS-38A targeting FLIR and laser designator pod	100
A-10. Modified F-14D avionic system diagram	101
Appendix B	
B-1. Diagram of an image intensifier tube.	103
B-2. Electromagnetic spectrum.	104
B-3. Cats Eyes NVG	105
B-4. Typical NVG installation.	106
B-5. Response of GEN 3 image intensifiers.	107
Appendix C	
C-1. Standard MK-80 series general purpose bomb configuration	111
C-2. Typical laser guided bomb components.	112
C-3. Laser guided bomb release	114
C-4. Buddy lasing for LGB delivery	114

FIGURE	PAGE
C-5.	Dive delivery of unguided weapons 115
C-6.	Level radar delivery of unguided weapons. . . . 115
C-7.	Blind bombing run made with SAR 116
Appendix D	
D-1.	A-6E aircraft layout. 118
D-2.	A-6E cockpit layout 119
D-3.	A-6E avionic system diagram 120
D-4.	A-6E terrain clearance display. 121
Appendix E	
E-1.	F/A-18C aircraft layout 123
E-2.	F/A-18C cockpit layout. 124
E-3.	F/A-18D rear cockpit layout 125
E-4.	F/A-18C avionic system diagram. 126
E-5.	F/A-18C weapon stations and FLIR pods 127
Appendix F	
F-1.	High-Medium-High mission profile. 129
F-2.	High-Low-High mission profile 130
F-3.	A-6E High-Medium-High mission performance . . . 131
F-4.	A-6E High-Low-High mission performance. 132
F-5.	F-14D High-Medium-High mission performance. . . 133
F-6.	F-14D High-Low-High mission performance 134
F-7.	F/A-18C High-Medium-High mission performance. . 135
F-8.	F/A-18C High-Low-High mission performance . . . 136

FIGURE**PAGE**

Appendix G

G-1.	F-15E aircraft layout	138
G-2.	F-15E front cockpit layout.	139
G-3.	F-15E rear cockpit layout	140
G-4.	F-15E avionic system diagram.	141
G-5.	F-15E high resolution map format.	142
G-6.	LANTIRN navigation pod.	143
G-7.	LANTIRN targeting pod	144

Appendix H

H-1.	F-111F aircraft layout.	146
H-2.	F-111F cockpit layout	147
H-3.	F-111F attack radar displays.	148
H-4.	F-111F terrain following radar interfaces . . .	149
H-5.	Pave Tack system.	150

Appendix I

I-1.	F-117A aircraft layout.	152
I-2.	F-117A cockpit layout	153
I-3.	F-117A avionic system diagram	154

LIST OF ABBREVIATIONS

AAA	anti-aircraft artillery
AAM	air-to-air missile
AGL	above ground level
AGR	air-to-ground ranging
AIM	air intercept missile
CIU	converter interface unit
CMDI	color multifunction display indicator
DBS	doppler beam sharpening
DD	digital display
DDD	digital data display
DDI	digital display indicator
DLIR	downward looking infrared
ECCM	electronic counter countermeasures
FMS	flight management system
FOV	field of view
FLIR	forward looking infrared
ft.	feet
GAO	government accounting office
GBU	guided bomb unit
GEN 3	generation three
GEN 4	generation four
GPS	global positioning system
HUD	heads-up display
HRM	high resolution map
HSD	horizontal situation display
IMN	indicated mach number
IRADS	infrared acquisition and detection system
INS	inertial navigation system
IRSTS	infrared search and track system
JDAM	joint direct attack munition
JTIDS	joint tactical information distribution system
JSOW	joint stand-off weapon
KIAS	knots indicated airspeed
LANTIRN	low altitude navigation and targeting infrared for night
lb.	pounds
LGB	laser guided bomb
LRD	laser ranger designator
lux	lumens per square meter
MC	mission computer
MDI	multiple display indicator
MER	multiple ejector rack
MFD	multifunction display
mil	milliradian
MIL-STD	military standard
MSL	mean sea level
NAVFLIR	navigation forward looking infrared
Nd:YAG	Neodymium doped Yttrium Aluminum Garnet

nm. nautical mile
 NVG night vision goggles
 NVIS. night vision imaging system
 PPI planned position indicator
 PTID. programmable tactical information display
 PVU precision velocity update
 SAM surface-to-air missile
 SAR synthetic aperture radar
 SLAM. stand-off land attack missile
 SMP stores management processor
 SMS stores management set
 TA. terrain avoidance
 TARPS tactical air reconnaissance pod system
 TCS television camera set
 TER triple ejector rack
 TFLIR targeting forward looking infrared
 TFR terrain following radar
 TID tactical information display
 TRAM. target recognition attack multisensor
 VDI visual display indicator
 VID virtual image display
 VMC visual meteorological conditions

CHAPTER 1

INTRODUCTION

Background

The Navy's cancellation of the A-12 advanced medium range bomber program in January of 1991 set off a series of debates about the future direction of Naval Aviation and how to best maintain our capabilities within budget restraints. Numerous proposals were presented to the Department of Defense and to Congress with various aircraft mixes to fill carrier decks and different development schedules for follow-on aircraft.

A somewhat cohesive plan emerged from the discussions in Congress in 1992 and the Navy is following that plan at this time, albeit the time line has been dragged out due to yet more budgetary constraints.

The A-6E long range all-weather attack aircraft is scheduled to be phased out by late 1996, leaving the Navy without a long range strike capability. The F/A-18E/F, an upgraded and enlarged version of the F/A-18C, has been chosen to eventually fill the hole left by the retirement of the A-6E, but isn't due to be operational until the year 2001. This plan will leave the Navy without a long range night precision and all-weather attack capability for several years.

The night all-weather long range attack mission has long been touted as one of the key capabilities of the modern aircraft carrier. In this day of terrorist attacks and belligerent third world nations, the threat to an aircraft carrier is immense and the United States simply cannot afford to put a carrier at risk. The ability to keep a carrier several hundred miles off an enemy coastline while maintaining

the capability to strike at targets deep within the country, is the key to protecting our carriers while projecting power.

The Desert Storm conflict of 1991 highlighted the importance of long range delivery of precision guided weapons in modern warfare. Precision guided munitions were credited with up to an 80 percent success rate of targets destroyed (Reference 1) and illustrated the "surgical strike" capabilities of these weapons. Additionally, the ability to deliver weapons at night kept the pressure on the Iraqis around the clock, helping to break down their defenses rapidly.

Numerous U.S. aircraft successfully performed night and all-weather attacks during the war using a variety of systems and weapons to complete their missions. Many of these aircraft have been operational for some time and the war merely underscored their warfighting capabilities. The proven systems on these aircraft have been developed at considerable expense and their tactical utility has been evaluated in developmental and operational tests as well as during the war. Identifying the most effective systems currently in use and adapting them to other airframes would seem to be cost effective.

With the demise of the A-6E, the Navy's only remaining night precision attack platform is the F/A-18C. While a very capable machine, the single seat aircraft is limited by a high pilot workload and a restrictive combat radius. In order to maintain the long range precision night and all-weather attack capability it has touted for so long, the Navy needs to fill the gap until the newer, longer range F/A-18E/F comes along. This gap will be substantial for the next 10 years, because by the year 2005, only half of our carriers will be equipped with F/A-18E/Fs.

The F-14D Tomcat has a proven airframe/engine combination that provides superior dogfighting capability as well as range and speed. It was upgraded in the 1980s with state of the art digital avionics to produce arguably the most capable air superiority fighter in the world. Despite the aircraft's upgrades, no air-to-ground mission capability was included, so the aircraft remains dual mission only: air-to-air and tactical reconnaissance. Software modifications and a series of weapon separation trials are currently in work to provide the F-14D with a day visual attack capability, but only a limited precision guided weapons capability and no all-weather attack capability are planned due to a lack of funding. With its superior range and payload and digital avionics, the F-14D is a likely choice for the Navy's interim long range attack platform. Numerous proven off the shelf systems are available in other U.S. aircraft that could potentially be integrated into the F-14D's digital avionics system to provide the night precision strike as well as all-weather capability. A description of the F-14D aircraft and systems is included in Appendix A.

Purpose

My thesis covers the following areas: (a) literature review of various past proposals to upgrade the F-14, (b) review of Desert Storm lessons learned to establish the requirements for a strike aircraft for the night and all-weather attack mission and precision guided weapons delivery, (c) summary of existing Navy strike platforms and comparison of the range and payload capabilities of the A-6E, F-14D, and F/A-18C aircraft, (d) examination of existing night, all-weather, and precision weapon attack capabilities in various U.S. aircraft to determine the

most effective and easily adapted systems, and finally (e) proposal of a final configuration for the F-14D to enable the Navy to continue to project power at night and in all weather from long range until the F/A-18E/F becomes operational.

CHAPTER 2

LITERATURE REVIEW

As early as 1988 Grumman Aircraft Corporation began proposing follow-on development versions of the F-14 to compete with the Advanced Tactical Fighter program and provide a ground attack capability in the aircraft. Between 1990 and the present, considerable work was done both by Grumman and by the Navy to enhance the ground attack capability of the aircraft. Studies were conducted, stores separation flight tests were flown, and test aircraft were modified for Night Vision Goggle (NVG) compatibility. This literature review includes various proposals to upgrade the F-14 and the results of flight and ground tests that have been conducted to enhance the strike capabilities of the F-14.

Grumman Proposals

"Tomcat 21" was proposed by Grumman in 1988 as an alternative to the Naval version of the Advanced Tactical Fighter (ATF). (Reference 2) The basic plan was to update the F-14D to reduce radar signature, and modify hardware and software to provide a ground attack capability. The aircraft was proposed while the A-12 was consuming a majority of the Navy's research and development budget and funding for a carrier version of the ATF seemed to be in jeopardy.

Details of the Tomcat 21 emerged in an article by Morocco (Reference 3), in mid 1989. Additional modifications proposed at that time included increased fuel capacity, a revised high lift system (single slotted Fowler flap), radar modifications to provide synthetic aperture radar (SAR) capability, navigation and attack forward-looking

infrared (FLIR) systems with laser target designator, and the ability to carry stand-off weapons such as Harpoon, Maverick, and Stand-off Land Attack Missile (SLAM). The Navy's position on the proposal was somewhat subdued, and it was really only considered as a backup in case the Navy ATF program was canceled.

A briefing of the Grumman F-14D "Quick Strike" program was given at the Naval Air Warfare Center in 1991 by Lohneiss (Reference 4). Quick Strike took the Tomcat 21 concept a step further to provide an all-weather strike capability. Additional features included a digital color map, stroke and raster heads-up display (HUD) to enable FLIR images to be superimposed on the real world via the HUD, Night Vision Imaging System (NVIS) compatible cockpit lighting, global positioning position (GPS) navigation capability, radar doppler beam sharpening (DBS) and terrain avoidance (TA) modes.

Although Quick Strike offered a solution to the lack of long range all-weather strike aircraft, it was deemed too expensive and the Navy opted to sacrifice some capability and proceed with further development of the F/A-18. (Reference 5)

In 1993 Grumman proposed yet another modification to the F-14, incorporating existing equipment and systems to give the Navy a deep strike capability similar to that of Quick Strike. This new proposal was outlined by Kandebo (Reference 6) and divided into four steps, progressing from a precision weapon delivery capability in day visual conditions to night, then to all-weather, and finally incorporating advanced weapons. Step 1 would upgrade F-14A/Bs to F-14D configuration and include an attack FLIR, wiring for advanced weapons such as Joint Stand-Off Weapon (JSOW), programmable tactical information display

(PTID), night vision windscreen, survivability enhancements to reduce frontal cross section, an improved AYK-14 mission computer memory, and provisions for future improvements. Step 2 included integration of the ALE-50 towed decoy, navigation FLIR, NVIS compatible cockpit lighting, color moving map display, and modified HUD to allow raster display of FLIR imagery. Step 3 included improved radar software adapted from the 85 percent common F-15E radar, including DBS, SAR, sea surface search, moving target indicator, moving track mode, TA, and a terrain following mode. The fourth and final step included incorporation of advanced weapons such as JSOW and Joint Direct Attack Munition (JDAM). Once again the Navy deemed Grumman's plan too expensive and only portions were folded into the current "Block 1" upgrade program. Table 2-1 provides a comparison of the capabilities provided in the various Grumman proposals and the Navy's Block 1 program.

Navy Research and Flight Test

Significant research and funding have been expended on both the development of a ground attack capability in the F-14 and on night vision system integration. A brief history of the evolution of the program and review of related unclassified technical reports is deemed appropriate to establish a baseline for further discussion.

F-14 Ground Attack Testing

When the F-14 was originally built in the early 1970s, it had a day bombing capability. Due to bomb separation problems reported in early testing (Reference 7) and budgetary constraints, the ground attack mission was shelved and remained unused until the late 1980s when fleet

Table 2-1. Components of proposed F-14 upgrades.

System	1989	1991	1993				1993
	Grumman Tomcat 21	Grumman Quick Strike	Grumman 1	4	Step 2	Prog 3	Navy Block1
Laser Desig	X	X	X				X
Tgt FLIR	X	X	X				X
Nav FLIR	X	X			X		
SAR Radar	X	X	X				X
Incr. Fuel	X	X					
Impr. Lift	X	X					
Standoff Weps.	X	X					
NVIS		X			X		X
Raster HUD		X			X		
Digital Map		X			X		
GPS		X					X
Radar DBS		X				X	
Radar TA		X				X	
NVIS windscreen			X				
Red. signature			X				
AYK-14 Memory			X				
PTID			X				
ALE-50					X		X
JSOW/JDAM						X	

F-14 operators recognized the need for their aircraft to be multi-mission, and pressed for the capability.

The program that resulted used the F/A-18's BRU-32 bomb racks on an F-14. Initial flight testing was completed in mid 1991 (reported in Reference 8), clearing the F-14A/B aircraft for daylight bombing with general purpose bombs. Follow-on flight testing cleared the aircraft for cluster munitions (Reference 9) and for laser guided bombs (LGB) (Reference 10). A description of the F-14A/B aircraft and weapons capabilities is included in Chapter 4, and diagrams are provided in Appendix A.

Unfortunately, the F-14D would have to wait an additional four years to get the same general purpose bomb capability. At the time that

the initial version of the F-14D tactical software was frozen during development, the ground attack mission was still not a priority in the Tomcat, so the decision was made not to include any ground attack features. This decision, along with the exterior airflow changes associated with the F-14D's dual chin pod (see Appendix A, Figure A-2) necessitated a separate and delayed program to clear the F-14D for the ground attack mission. Initial stores separation flight testing for general purpose bombs was completed in 1994 (Reference 11) and a fleet clearance is now awaiting completion of verification of new mission software.

F-14 Night Vision Development

In 1988 the Navy funded modification of an F-14A at Naval Air Warfare Center, Patuxent River, Maryland to evaluate the potential for use of NVGs in the aircraft. The aircraft cockpits were modified to incorporate NVIS compatible lighting and an additional radar altimeter digital display. Extensive ground tests and limited flight tests were conducted and reported by Lawson (Reference 12). Cockpit modifications consisted of replacing backlit panels with NVIS compatible lighting as well as the addition of filters and lumicon overlays. Although the system showed excellent potential to enhance the F-14's mission, several major deficiencies were identified and funding constraints prevented it from being implemented operationally.

A grass roots effort to modify the F-14D to an NVIS compatible configuration was implemented in 1993 by one of the first operational F-14D squadrons, Fighter Squadron Eleven. This effort paralleled early efforts in the helicopter community to achieve NVIS compatibility, in

that, lacking funding and support from the respective aircraft program office at Naval Air Systems Command, the squadron approached contractors to establish a baseline prototype at no cost to the government. The F-14D was considerably easier to modify than the A and B versions due to some displays (multi-function displays) already being NVIS compatible, and the decision to use flood lighting instead of modifying the backlighting on all cockpit panels.

Korry Electronics of Seattle, Washington agreed to complete modifications to an aircraft at no cost, utilizing removable filters and minimal cockpit modifications. These modifications were approved by Commander Naval Air Forces U.S. Pacific Fleet and are contained in a report by Korry (Reference 13). Subsequent interest generated in the F-14 community resulted in an evaluation by Naval Air Warfare Center, Aircraft Division personnel in 1993, the results (reported in Reference 14) being encouraging. Additional modifications to correct deficiencies resulted in a limited flight clearance for use of NVGs from the rear cockpit only. Subsequent modifications in 1994 and another ground evaluation (reported in Reference 15) resulted in an operational in-flight evaluation of the aircraft in early 1995 (reported in Reference 16), and a fleet clearance shortly thereafter. A source of funding for the modification kits was identified and current plans call for VF-11 to modify six aircraft this year. A discussion of NVIS theory and description of the model of NVGs currently in use are included in Appendix B.

Current F-14 Follow-on Plans

A literature review would not be complete without inclusion of the current follow-on plan for the F-14. At the November 1994 F-14 Operational Advisory Group meeting at NAS Miramar in San Diego, Captain Dick Evert, F-14 Program Manager, detailed the following plans. No funding source was yet identified for laser guided bomb separation testing on the F-14D. No funding source was identified for incorporating NVIS on a fleet wide scale or for FLIR pods for precision targeting. Limited Block 1 upgrades of F-14A/B aircraft were still scheduled to begin in 1995, but a funding source was not identified. Subsequent to the Operational Advisory Group meeting, funding was identified for follow-on air-to-ground testing (cluster munitions and LGBs) and for limited NVIS cockpit modifications.

1994 Government Accounting Office (GAO) Report to Congress

In October 1994, the GAO published a study of the Navy's 1993 plan to upgrade 210 F-14 aircraft (53 F-14Ds, 81 F-14Bs, 76 F-14As) to a Block 1 configuration. (Reference 17) The analysis centered around the additional capabilities provided to the F-14A, B, and D aircraft that would be modified versus the existing and future capabilities of other strike aircraft in the Navy's inventory. Block 1 is a modest program, upgrading F-14A/B aircraft with a digital mission computer and F-14D HUD, and providing a targeting FLIR, GPS, NVIS compatible cockpit, and ALE-50 towed decoy for all three versions of the aircraft. This upgrade effectively enables the aircraft to independently deliver and guide precision LGBs in day or night visual meteorological conditions (VMC). Only the F-14D, with its digital APG-71 radar is capable of being

upgraded to provide a SAR mode that would enable accurate all-weather deliveries of non-precision weapons.

The lack of an all-weather capability by three fourths of the aircraft (upgraded F-14As and Bs) was a major detractor according to the GAO, who also argued that by the time the Block 1 aircraft entered the fleet, the gap between loss of the A-6E and introduction of the F/A-18E/F would be only one year. Because of the large program costs and seemingly minimal gains in tactical capability and range over existing F/A-18C aircraft, the GAO recommended against the Block 1 upgrade.

It is interesting to note that no mention was made of just upgrading the F-14D fleet which offers many more easily achievable improvements due to its military standard (MIL-STD) 1553B data bus configuration and state of the art avionics. Additionally, the report failed to detail the extended introduction period of the F/A-18E/F, which according to the latest plans, will see its first deployment in the year 2001 and will be procured in limited quantities (36 per year), sufficient only to fill one additional carrier deck per year. (Reference 18)

CHAPTER 3

DESERT STORM LESSONS LEARNED

Many valuable lessons can be taken from the dramatic events of the Arabian Gulf war of 1991. The air war was a virtual proving grounds for many relatively new weapons systems and provided a realistic assessment of the effectiveness of high technology on the modern battlefield. According to General Merrill A. McPeak, U. S. Air Force Chief of Staff, Desert Storm marked "the first time in history that a field army has been defeated by air power." (Reference 19)

Some of the keys to the successful application of air power against Iraq included highly accurate navigation and weapon delivery systems capable of delivering precision guided munitions with pinpoint accuracy, stealth technology providing an element of surprise, night attack systems, and surveillance and intelligence gathering systems.

A close look at some of the lessons learned from successes in Desert Storm will identify the most effective airborne tactics and systems, and help refine the mission requirements for current and future combat aircraft. This discussion will focus on lessons that can be applied to tailor the effectiveness of future Navy aircraft, specifically a modified F-14.

Precision Weapons

Precision weapons were used extensively for the first time in Desert Storm. Despite only comprising 6.7 percent of the total of over 219,000 bombs delivered by tactical aircraft during the war (Reference 20), precision weapons were one of the major reasons that Coalition

forces were able to paralyze Iraqi air defenses and knock out key strategic targets in the early weeks of the war. According to Rand Corporation analyst Winnefeld (Reference 21), "...the ability to place ordnance precisely on target anywhere in theater, under any weather conditions, day or night, and against an active enemy..." was crucial to the Coalition's success. He also believed that laser and infrared weapons provided the most important contribution (of any weapons used) in the air war.

Precision weapons come in many forms, typically employing laser or electro-optical guidance to achieve pinpoint accuracy. By far the least expensive and most widely employed precision weapon used during the war was the LGB. The LGB consists of a general purpose bomb body, computer control group, guidance canards attached to the front of the warhead for steering commands, and a wing assembly attached to the aft end to provide lift. LGBs are maneuverable, free-fall weapons with an internal semiactive guidance system that detects laser energy illuminating the target and guides the weapon to impact. (Reference 20) The basic idea of employing an LGB is to drop the bomb within the weapon's ballistic range of the target and then maintain target illumination with a laser (from an aircraft or ground source) until weapon impact. Descriptions of various weapons (including LGBs) and a diagram of a typical LGB delivery profile (Figure C-3) can be found in Appendix C.

Because of the location of the majority of strategic targets, deep within Iraq, laser designation by ground troops was largely impractical, requiring aircraft to be able to designate and illuminate their own targets, or have another aircraft provide the laser designation, termed "buddy lasing" (see Appendix C, Figure C-4). Coalition aircraft with

the ability to autonomously deliver and guide LGBs to impact included the A-6E, F-117A, F-15E, and F-111F. (Reference 22) The Navy F/A-18C has subsequently gained this capability also.

The Gulf War Air Power Survey Summary (Reference 23) provides three reasons for the prominence of LGBs in Desert Storm. First, the combination of LGBs with the stealth technology of the F-117A enabled routine delivery of precision weapons in heavily defended areas. Second was the extensive array of hardened bunkers and aircraft shelters, vulnerable only to a precision bomb with a penetrating warhead. Third and finally, LGB attacks were critical to attrition of heavily revetted Iraqi armor in the Kuwait theater. In fact, the systematic destruction of almost 1000 armored vehicles during the air war enabled the Coalition to fight the ground war with a considerably smaller force than would have otherwise been required. (Reference 24)

The beauty of LGBs and other precision weapons is the ability to deliver the weapon with pinpoint accuracy, destroying the objective, while minimizing collateral damage. This accuracy, while achieved at a monetary cost, results in fewer sorties required to destroy the desired targets, fewer aircrews put at risk, and fewer strike aircraft required. Additionally, precision weapons make combat results far more predictable than they have been in the past. (Reference 25)

The F-117A Stealth fighter delivered LGBs exclusively during the war, flying all sorties at night, and mounting some impressive statistics. While flying only 2 percent of the total sorties for the war, the Stealth fighter was credited with destroying 40 percent of the strategic targets. (Reference 21) Additionally, various sources have credited F-117A, F-15E, and F-111F aircraft (the primary deliverers of

LGBs) with 80 to 85 percent success rates in hitting their targets with LGBs. (References 26 and 27)

Precision weapons were so successful during the war that they subsequently became an integral part of the strategy that emerged from the Pentagon's Bottom-Up Review in 1993. In order to fight two major regional conflicts simultaneously, the Pentagon will be relying heavily on air power to stop enemy invasions, and with limited aircraft to do the job, every bomb must count. (Reference 28)

The effectiveness of LGBs can be illustrated by comparing the relative number of bombs necessary to destroy a target with LGBs versus unguided weapons. U. S. Air Force Secretary Donald Rice was quoted on May 7, 1991, "...in World War Two 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!" (Reference 29)

While proving highly effective against point targets, hardened shelters, and targets whose location required minimal collateral damage, LGBs were not the end-all answer to the war. The use of precision weapons in general can be inappropriate or impractical against certain targets, such as large mobile military units. In fact, the "dumb" (unguided) bombs delivered by B-52s were very effective in invoking terror in the Iraqi army. B-52s primarily targeted the Iraqi Republican Guard, averaging one aircraft overhead every hour for the first 39 days of the war. (Reference 24) This systematic and continuous bombing was credited with breaking the will of the Iraqi army (a fact substantiated by captured Iraqi soldiers) and ultimately shortened the ground war, as many units simply surrendered. (Reference 20)

Despite all the accolades given the Coalition's employment of LGBs, there are some definite limitations that should be noted. Laser designation is not possible through overcast layers, fog, or smoke. This fact proved important as weather over Iraq turned out to be much worse than predicted, often resulting in aircraft aborting their missions and returning to base with their ordnance. (Reference 19) Additionally, designating aircraft must remain within line of sight of the target until weapon impact, increasing their exposure to enemy forces.

Mission Profiles

The Coalition strategy early in the war was to capitalize on strengths in night attack and precision weapons and quickly roll back Iraqi air defenses with low-level air strikes. (Reference 30) The Coalition learned the cost of flying at low altitude, as several aircraft were shot down by Anti-Aircraft Artillery (AAA) and Surface-to-Air Missiles (SAM). As the Iraqi Air Defense system (early warning and missile guidance radars) was shut down, a sanctuary was established at higher altitudes for attacking aircraft. While the Coalition forces could jam or target remaining radar systems that came up, AAA was much more difficult to contain, and since its effectiveness is largely only below 10,000 feet (ft) above ground level (AGL), this was chosen as a minimum altitude for Coalition aircraft.

Medium or High altitude profiles, while providing a sanctuary from AAA fire, also had some drawbacks. Haze and dust, prevalent in the Arabian Gulf area, made target acquisition difficult, either visually, or with electro-optical sensors. Delivery of unguided munitions, from

"smart" aircraft, such as the F/A-18 or F-16, yielded little payoff when high accuracy was required, due to system accuracy limitations associated with visual bombing. For example, the pilot's pipper (aiming dot) used to deliver weapons in an F-16 is 2 milliradians (mils) in diameter. This equates to a 56 ft diameter area over the ground at a typical slant range of 20,000 ft from a medium altitude release (45 degree dive). With a system accuracy of 5 to 7 mils, the resulting circular error probable is 141 to 198 ft on the ground, accurate enough for perhaps large buildings, but not for point targets such as tanks. (Reference 25) A typical unguided weapon delivery maneuver is depicted in Appendix C, Figure C-5.

Thus, establishing of a minimum altitude of 10,000 ft AGL for Coalition aircraft actually bolstered the case for precision weapons, as unguided bombs only proved effective against relatively large targets.

Environmental Conditions

Time of day was an important consideration for Coalition forces during the war. As stated earlier, the ability to continue attacks at night enabled the Coalition to keep pressure on Iraq around the clock and was a key to their success. A large majority of precision weapons were delivered at night, both to keep the pressure on and to minimize civilian casualties. Since aircraft such as the F-117A, F-15E, A-6E, and F-111F were capable of delivering the weapons at night, they flew almost exclusively at night, while other aircraft such as the F-16 and F/A-18 concentrated their efforts on daytime weapon deliveries.

As mentioned earlier, weather and environmental conditions played an important role in the effectiveness of the air campaign. Often times

environmental conditions obscured targets, requiring aircraft to either abort their mission, or perform radar bombing. While certainly not providing the accuracy of a laser guided weapon, the capability to deliver bombs via radar mapping provided flexibility for aircrews (both day and night) when targets were obscured. A typical level radar delivery profile is depicted in Appendix C, Figure C-6.

Mission Lengths

The Gulf War was something of a marvel in terms of supply and support. Tanker aircraft flew an average of 275 sorties a day, providing hundreds of thousands of gallons of fuel to enable Coalition strike aircraft to penetrate deep into Iraq. (Reference 23) Typical mission lengths for Navy aircraft were 4 to 6 hours with several refuelings. Typical F-117A mission length was 5.2 hours, while typical F-15E missions averaged over 3.2 hours. (Reference 31)

The ability of the Coalition to mount such a huge air refueling campaign was largely due to the six months of preparation for the war during Operation Desert Watch. According to Morocco (Reference 19), "...the Coalition took full advantage of Saudi Arabian seaports and airfields...to move thousands of troops and tons of equipment into the theater." If not for the extensive buildup time, air refueling assets would perhaps have been more scarce and limited the ability of the Coalition to strike continuously at targets deep within Iraq.

This fact points to the need for strike aircraft to have a significant unrefueled combat radius. If the war had started suddenly, with no Air Force assets in the area, carrier aircraft would have been limited to scarce organic tanking assets. For example, the typical

range of a mission for a Navy strike aircraft based in the Arabian Gulf, to a target on the outskirts of Baghdad is about 450 nautical miles (nm). From a carrier in the Red Sea, this range increases by about 100 nm. Without Air Force assets in the region, Navy aircraft would need to accomplish this mission unrefueled, or with the very limited refueling available from other carrier based aircraft.

Lessons Learned Summary

One additional lesson learned was stated by Admiral Stanley Arthur, Vice Chief of Naval Operations when he said, "The war taught us that the future says we have to have multi-mission aircraft." (Reference 32) That means an aircraft capable of both the air-to-air and air-to-ground mission.

Some of the lessons learned from the air campaign in Desert Storm can be used to define mission requirements for a strike aircraft in a modern war. The following are essential carrier strike aircraft capabilities: (1) precise navigation to targets in any weather, (2) precision weapon delivery (i.e. LGBs with self designation), (3) night precision weapon delivery, (4) all-weather weapon delivery (non-precision weapons), and (5) unrefueled mission radius of at least 500 nm.

For the F-14D to adequately fill the shoes of the A-6E as the Navy's long range night precision and all-weather attack aircraft, it must live up to these requirements. The following chapters will examine how these capabilities could be achieved in the F-14D.

CHAPTER 4

CURRENT NAVY STRIKE AIRCRAFT

Currently the Navy has only three aircraft with the weapons carriage and speed capability to perform in the strike role in a modern air war. This chapter will examine the capabilities of the A-6E, F/A-18C, and F-14A/B, focusing on their ability to fulfill the mission requirements identified in Chapter 3. Additionally, the emerging capabilities of the F-14D will be examined. The aircraft weapon systems will be assessed for their ability to deliver precision weapons (limited to LGBs), and perform night and all-weather attacks. A comparison of range and payload will follow, using postulated mission profiles. This discussion will also highlight the significant loss of capability which will occur when the A-6E is replaced by the F/A-18C in late 1996.

A-6E Intruder

The Intruder is a two seat, twin engine, subsonic, carrier based bomber, capable of carrying a wide variety of air-to-ground weapons. The original Grumman A-6A Intruder was introduced into the Navy inventory in 1965. Subsequent modifications and improvements resulted in an upgraded version, the A-6E, being fielded in 1972. The latest version of the Intruder (introduced in 1978) is the A-6E equipped with a target recognition attack multisensor (TRAM) system. (Reference 33) A comprehensive aircraft and system description is contained in Reference 34. Aircraft and cockpit layout are included in Appendix D, Figures D-1 and D-2.

Weapon System

The Intruder's weapon system is based around an IBM AN/ASQ-155 digital computer and consists of a Litton AN/ASN-92 inertial navigation system (INS), Norden AN/APQ-156 multiple mode navigation attack (search) radar, doppler navigation radar, TRAM improvements, armament computer, and various aircrew displays. Appendix D, Figure D-3 is a basic avionic system diagram.

The A-6E has a terrain clearance mode of the search radar, whereby the pilot is provided steering cues on his primary attitude display and is able to navigate at low level in any weather conditions. The search radar provides a 53 degree (horizontal) by 26 degree (vertical) window of the terrain about the armament datum line and displays it to the pilot along with attack and navigation information. Eight shaded contours are provided, representing specific ranges ahead of the aircraft, from 0.25 to 8.5 nm, along with a radar altitude indication. Appendix D, Figure D-4 is an example of the pilot's display in the terrain clearance mode.

The TRAM is a modification to the original A-6E configuration, providing additional target tracking and weapon guidance capability and modernized inertial navigation. The sensor capability consists of a FLIR receiver, laser rangefinder designator (LRD), and forward air control receiver mounted on a turret-stabilized platform which provides full 360 degree lower hemisphere coverage. The FLIR has a continuous optical zoom providing a field of view (FOV) which varies from 6.4 degrees (vertical) by 8.5 degrees (horizontal) at its widest, to 1.28 degrees (vertical) by 1.7 degrees (horizontal) at its most narrow.

LGB Delivery Capability

The A-6E can deliver 500, 1000, and 2000 pound (lb) LGBs. Navigation to the target or an offset aimpoint is accomplished via the INS, which is updated by the doppler navigation radar (to provide damping of inertial velocities) and can also be updated via the search radar. Initial target identification is accomplished with radar, FLIR, or visually. Once within 10 nm slant range of the target, the LRD can be used to achieve a precise range to the target and for designation using a predetermined designate code (coded pulse repetition frequency which is also set on the weapon). The gyro stabilized turret platform maintains target illumination until weapon impact, with appropriate steering guidance cues to the pilot. An additional option exists via the forward air control receiver, by which the location of targets illuminated by external laser sources can be determined. Thus the aircrew can identify targets lased by other sources prior to weapons release provided they know the appropriate code to enter into the computer.

Night Capability

The A-6E can perform the same LGB delivery profile day or night, providing meteorological conditions permit laser ranging and designation of the target.

Some squadrons of Intruders have also been modified with NVIS compatible cockpits, providing night low level navigation capability and additional situational awareness at all altitudes in the night environment through the use of NVGs. A discussion of NVIS systems and description of NVGs is included in Appendix B.

All-Weather Capability

The A-6E's search radar can be used to fly low level at night as described above, and in bad weather as well. The entire weapon delivery mission can be flown in instrument conditions utilizing INS and radar navigation, radar target designation and computer release. While LGBs are constrained by clouds, haze or smoke, non-precision weapons can be delivered in any weather with the A-6E.

Payload

As alluded to earlier, the A-6E can carry a tremendous variety and quantity of air-to-ground weapons. The aircraft has two weapon stations on each wing as well as a centerline station. The wing stations can be configured with multiple ejector racks (MER) or triple ejector racks (TER) enabling a load of up to six 500 lb weapons per MER and three per TER. Its maximum external load is 14,600 lb, resulting in a maximum catapult launch weight of 58,600 lb. (Reference 34) Typical carrier configuration for an A-6E would consist of a 300 gallon centerline drop tank and weapons on the remaining four stations, or two 300 gallon drop tanks on the inner wing stations and weapons on the remaining three stations.

F/A-18C/D Hornet

The Hornet was developed as a strike fighter in the 1970s and first entered service in the Navy and Marine Corps in 1980. (Reference 33) The aircraft comes in a single seat (A and C model) or two seat (B and D model) version. It is a twin engine, supersonic, carrier based aircraft capable of both the air-to-air and air-to-ground missions. The

aircraft has gone through many improvements since 1980, with the latest version being the Lot 12 and newer F/A-18C/D models, which entered service beginning in 1990. Both have upgraded avionics and are optimized for the night attack mission. The D model has a rear cockpit tailored for a Weapon System Operator, but can also be used as a trainer. The Navy uses the C model exclusively in fleet units, while the Marine Corps flies both, including several squadrons of D models designated for the night attack and forward air controller role. For the purposes of this discussion, the F/A-18C will be referred to, with any relevant differences in the D model explained as appropriate. A comprehensive aircraft and system description is contained in Reference 35. Aircraft and cockpit layouts as well as an avionic system diagram are included in Appendix E, Figures E-1 through E-4.

Weapon System

The Hornet's weapon system consists of a Hughes AN/APG-65 multi-mode digital air-to-air and air-to-ground tracking radar, dual mission computers, Litton AN/ASN-139 (ring laser gyro) INS, digital color moving map, two digital display indicators (DDI), HUD, Hughes AN/AAR-50 thermal imaging navigation set, Loral AN/AAS-38 NITE Hawk targeting FLIR, digital stores management set (SMS), and an NVIS compatible cockpit.

The AN/APG-65 has eleven modes for navigation, search and track of land or sea targets, and detailed mapping of terrain. Relevant modes include basic ground mapping and three increasing levels of resolution, called Expand 1, 2 and 3. Expand 1 and 2 use DBS to provide a high resolution sector map, while Expand 3 uses a SAR mode, providing a detailed map of an approximately 1 square nm area. (Reference 36) A

precision velocity update (PVU) mode is used to update aircraft velocity and an air-to-ground ranging (AGR) mode to provide an accurate slant range and doppler velocity error to the mission computer.

The AN/AAR-50 Navigation FLIR (NAVFLIR) is a pod mounted sensor designed to provide the aircrew with a high resolution video image for low level night navigation. The NAVFLIR FOV is fixed 4 degrees below the aircraft waterline, extending 19.3 degrees (horizontally) by 17.5 degrees (vertically). The unmagnified NAVFLIR video is presented on the HUD, overlaying the real world, and does not affect other symbology. The system is mounted on fuselage station 6 (right side) and weighs 197 lb. (Reference 37)

The AN/AAS-38 targeting FLIR (TFLIR) is designed for day or night detection and designation of land or sea targets exhibiting infrared (heat) contrast with their immediate surroundings. The system FOV is 12 by 12 degrees in "wide" and 3 by 3 degrees in "narrow" (providing a four times magnification). The pod can look 30 degrees above the horizon and 150 degrees aft and is capable of tracking through rolls of 540 degrees. The TFLIR includes a laser ranger and designator, capable of illuminating targets for LGB guidance. The system is mounted on fuselage station 4 (left side) and weighs 371 lb. (Reference 38) One problem with its fuselage mounting is the restricted field of regard on the right side of the aircraft, leading to the necessity to perform left hand turns off target in order to maintain laser illumination, which is a tactical limitation. (Reference 36) The F/A-18C's TFLIR system was not yet operational during Desert Storm.

LGB Delivery Capability

The F/A-18C can deliver 500, 1000, and 2000 lb LGBs. Navigation to the target or an offset aimpoint is accomplished via the INS and digital moving map, along with air-to-ground radar modes, NAVFLIR, and NVGs. INS targets can be designated beyond the range of sensors, and the pilot can simply wait for the sensor (now slaved to the target) to bring it into view. Target identification and designation is accomplished with radar (via expand modes), TFLIR, or visually. Radar provides longer ranges for target detection and once designated, the target can be handed off to the TFLIR. The TFLIR can automatically track a target until weapon impact, alerting the pilot if loss of target occurs due to insufficient thermal contrast. Typical pilot displays during an attack would include NAVFLIR video on the HUD, digital color map, and radar and TFLIR displays on the two DDIs.

Night Capability

The F/A-18C is designed for night attack and can deliver LGBs as well as non-precision weapons at night. Unlike the A-6E, the F/A-18C has no terrain contour mode of the radar to enable low level night navigation via radar. However, the combination of NAVFLIR video displayed on the HUD, and NVGs for additional discrimination of the night environment, make the Hornet an excellent platform for night weapon deliveries at any altitude.

All-Weather Capability

While in many ways the F/A-18C is optimized for night attack, it is somewhat limited in the all-weather attack role. The precise SAR

maps available from the AN/APG-65 radar provide an excellent all-weather (non-precision) bomb capability from medium or high altitudes. However, its FLIR and NVG systems are degraded in poor weather, and the lack of a terrain contour or terrain following radar (TFR) mode eliminates the possibility of low level ingress in poor weather.

Payload

The F/A-18C has nine weapon stations and can carry a variety of air-to-air and air-to-ground weapons. A diagram of the weapon stations is included in Appendix E, Figure E-5. Wingtip stations 1 and 9 are for AIM-9 Sidewinder missiles (described in Appendix C) only, while as previously mentioned, stations 4 and 6 are on the fuselage sides and are used for the NAVFLIR and TFLIR pods. That leaves four wing stations and a centerline station for air-to-air or air-to-ground ordnance. These stations are capable of carrying some weapons on MERs or TERS like the A-6E. The aircraft's maximum external stores load is 14,400 lb, resulting in a maximum catapult launch weight of 51,900 lb. (Reference 35) Typical carrier configuration for an F/A-18C on an air-to-ground mission would be wingtip AIM-9s, NAVFLIR and TFLIR on stations 4 and 6, and either one 330 gallon external fuel tank on the centerline station (station 5) or two 330 gallon external fuel tanks on stations 3 and 7, leaving either three or four additional stations for air-to-ground weapons.

F-14A/B Tomcat

The F-14A Tomcat first became operational in the Navy in 1972. The aircraft was designed as a two seat, twin engine, variable geometry

wing, supersonic, carrier based, long range air superiority fighter with limited attack capability. The subsequent F-14B was introduced to the fleet in 1989 with new General Electric F110-GE-400 engines, an advanced radar warning receiver and various other minor improvements. Both the F-14A and F-14B remain in operational use at this time. Comprehensive aircraft and system descriptions are contained in References 39 and 40. Cockpit layouts are included in Appendix A, Figures A-7 and A-8.

Weapon System

The Tomcat's weapon system is based around a Hughes AN/AWG-9 multi-mode radar and weapons control system and includes the same INS as the A-6E, an AN/AWG-15 fire control set, digital analog computer, television camera set (TCS), various aircrew displays including a limited capability HUD. Forty nine aircraft were also modified to carry a tactical air reconnaissance pod system (TARPS).

The AN/AWG-9 radar is optimized for air-to-air use and is capable of long range detection and tracking of multiple targets. Its air-to-ground mode is rudimentary at best, providing ground elevation information suitable for coarse navigation, but not targeting. The AN/AWG-15 fire control set enables the aircrew to fire or release a variety of air-to-air or air-to-ground weapons. The TCS operates via a contrast lock on targets and is used primarily for identification of airborne targets. It has two selectable FOVs with different magnification levels. The TCS could be used for identification of ground targets, but only in a limited capacity due to its restricted gimbal limits and the requirement for manual slewing (it cannot be automatically slaved to an INS waypoint).

LGB Delivery Capability

The F-14A/B can deliver 500, 1000, and 2000 lb LGBs, but is not equipped to laser designate or illuminate its targets. Navigation to the target or an offset aimpoint is accomplished via the INS and visual navigation. Target identification and weapon delivery must be accomplished visually. While the aircraft is an accurate visual bombing platform, successful LGB delivery would be dependent on another aircraft or ground personnel providing the reflected laser energy for the weapon to guide to impact. There is no capability whereby the aircrew can determine if the target they are attacking is illuminated with laser energy from another source (i.e., buddy lasing).

Night Capability

The F-14A/B has a limited night attack capability. The aircraft is not equipped for low level navigation at night and has no sensors to provide accurate targeting information for weapons release. Its night visual bombing capability would be subject to the lighting conditions of the target. If the aircrew could visually identify the target from the air at night, a weapon delivery profile could be flown, but as mentioned above, in order for an LGB delivery to be accomplished, an external lasing source would be required.

All-Weather Capability

The F-14A/B has no all-weather attack capability. Its only method of weapon delivery during bad weather would be to release weapons based on an INS waypoint. Even the smallest amount of drift in the most precise INS would result in large target errors, and the Tomcat's 1970s

era INS, while accurate enough for the air-to-air mission, simply cannot provide the accuracy for successful INS bomb delivery.

Payload

The F-14A/B has ten external stores stations and can carry a variety of air-to-air and air-to-ground weapons. A diagram of the weapon stations is included in Appendix A, Figure A-3. Wingtip stations 1A and 8A are for AIM-9 Sidewinder missiles only, while stations 2 and 7 beneath the engine nacelles are used exclusively for 280 gallon external fuel tanks. The remaining two additional wing stations are capable of carrying air-to-air missiles and four fuselage stations (between the engines) are available for air-to-air or air-to-ground ordnance. The aircraft's maximum external stores load is 12,000 lb, resulting in a maximum catapult launch weight of 72,000 lb. (Reference 39) Typical carrier configuration for an F-14A/B on an air-to-ground mission would be AIM-9s on stations 1A and 8A, optional AIM-7 Sparrow missiles on stations 1B and 8B, 280 gallon external fuel tanks on stations 2 and 7, and air-to-ground weapons on the remaining four fuselage stations.

F-14D Super Tomcat

The F-14D and its weapon system are described in detail in Appendix A and in Reference 41. While incapable of delivering air-to-ground ordnance currently, weapon separation tests have been conducted on the aircraft. A new computer software tape is due for delivery by August 1995, which will enable the aircraft to deliver general purpose bombs, cluster munitions, and LGBs.

Weapon System

Relevant aspects of the F-14D weapon system that will affect its capability to deliver air-to-ground weapons include its digital AN/APG-71 multiple mode radar, dual mission computers, advanced Litton AN/ASN-139 (ring laser gyro) INS, digital SMS, infrared search and track system (IRSTS), joint tactical information distribution system (JTIDS). It is interesting to note that the F-14D's mission computers, INS and SMS are the same ones used in the F/A-18C.

The AN/APG-71 has limited ground mapping capability, being optimized for the air-to-air mission as was the F-14A/B's AN/AWG-9. The aircraft's new ring laser gyro INS system provides greatly improved system accuracies and can be continuously crosschecked and updated with the JTIDS. The IRSTS is optimized for use against air-to-air targets but can also function in a ground mapping mode similar to a FLIR. With two levels of zoom, the sensor can aid in locating targets at night or in hazy conditions, but is not integrated with the INS to provide automatic slewing to an INS ground target. This lack of integration limits the usefulness of the IRSTS in acquiring ground targets as the operator must manually slew the narrow FOV of the sensor to find the target.

LGB Delivery Capability

The F-14D has successfully completed initial weapons separation trials with general purpose bombs and plans are in work for trials with LGBs, with the same carriage as the A/B models. Navigation to targets will be more precise than that of the F-14A/B due to the improved INS and JTIDS update capability. Target identification may be enhanced

through use of the IRSTS. Weapon delivery will still have to be accomplished visually, with an external laser source required to illuminate the target for LGB guidance.

Night Capability

With the introduction of an NVIS compatible cockpit, the F-14D will have a genuine night attack capability. Coupled with the improved accuracy of the INS, the visual navigation capabilities offered by NVGs should enable the aircrew to navigate successfully to targets at night, even at low level. The aircraft would still be limited to night visual bombing as is the F-14A/B, but NVGs offer significant advantages in target identification at night, even if the target is not illuminated.

All-Weather Capability

The F-14D has no all-weather attack capability. As discussed with the F-14A/B, weapons delivery based on an INS waypoint is not considered a worthwhile option.

Payload

The F-14D's external stores configuration and weapons carriage capability are identical to that of the F-14A/B.

Current Navy Aircraft Capability Summary

A summary of the relevant strike capabilities of the current Navy inventory of aircraft is presented in table 4-1.

Table 4-1. Current Navy aircraft strike capabilities.

<u>Capability</u>	<u>A-6E</u>	<u>F/A-18C</u>	<u>F-14A/B</u>	<u>F-14D</u>
Visual Attack	X	X	X	X
LGB Carriage	X	X	X	X (pending)
Targeting FLIR	X	X		
Laser Designator	X	X		
<u>Night:</u>				
NAVFLIR		X		
NVIS	X	X		X
<u>All Weather:</u>				
Radar Bombing	X	X		
SAR Mapping		X		
Terrain Clearance Radar	X			

Mission Profile Comparison

In order to establish the range and payload capabilities of the Navy's attack arsenal, aircraft performance on two mission profiles will be compared. Because of its antiquated analog avionics system, the F-14A/B is considered unsuitable for the night or all-weather strike mission and is not included in the comparison. Mission profiles and fuel calculations are included in Appendix F. All performance figures were taken from applicable aircraft manuals (References 34, 42, and 43).

High-Medium-High Mission

This mission profile was typical in Desert Storm. Aircraft flew in at high (optimum) altitude, avoiding the AAA threat, dropped to medium altitude and accelerated for tactical run-in and weapons release, then returned to high altitude for return to base. A weapons load of four GBU-16 (1,000 lb) LGBs was chosen as representative, providing

considerable effectiveness while offering the option of striking several different targets. Any unused weapon station that could be configured with fuel tanks was considered to be so configured and when possible, air-to-air missiles were included on remaining stations for aircraft self defense. Additional assumptions in the profile included optimum range climb, optimum range cruise, 100 nm dash at 20,000 ft mean sea level (MSL) for weapons delivery run, optimum range descent on return, 15 minutes of low holding, enough fuel for two visual carrier approaches and a minimum fuel on deck consistent with normal carrier operations. The only differences in the profiles were due to different optimum cruise altitudes and the limited top speed of the A-6E, which is considered a tactical deficiency. During the tactical runs the F/A-18C and F-14D were assumed to be at a reasonable tactical speed of 420 knots indicated airspeed (KIAS)/0.9 indicated mach number (IMN) at 20,000 ft MSL and 540 KIAS/0.82 IMN at 500 ft AGL), while the A-6E's speed was constrained to the maximum it can achieve at military rated power.

The results of the analysis are summarized in Table 4-2, showing the aircraft comparison based on mission radius in nautical miles. The numbers indicate that the A-6E has the longest range capability with the given load. The F-14D, while achieving nine percent less range, is

Table 4-2. Comparison of aircraft unrefueled mission radii with four GBU-16 (1000 lb) laser guided bombs.

<u>Mission</u>	<u>A-6E</u>	<u>F-14D</u>	<u>F/A-18C</u>
High-Medium-High	612	555	388
High-Low-High	512	470	316

still capable of a mission radius in excess of 500 nm. The F/A-18C falls a distant third with a radius less than 400 nm.

High-Low-High Mission

The High-Low-High mission profile is often used when comparing aircraft combat radii, assuming a low level target ingress and egress to avoid hostile early warning and SAM radar systems. Low altitude ingresses early in Desert Storm resulted in several aircraft being shot down by AAA. The subsequent destruction of Iraq's integrated air defense system enabled aircraft to fly with impunity at higher altitudes, avoiding the difficult-to-contain AAA threat. Although this mission profile was certainly not the standard used in Desert Storm, low level deliveries enable better accuracy by reducing time and distance between the release point and target. Thus, the High-Low-High mission profile is still considered realistic in other threat environments, and as such, a comparison was made.

For the High-Low-High profile, aircraft were assumed to fly an optimum range climb and cruise, descend to 500 ft AGL for a low level target ingress and egress totaling 100 nm, then fly an optimum range climb, cruise and descent on the return. As with the High-Medium-High profile, additional fuel was required to hold overhead the carrier for 15 minutes, perform two visual approaches, and land with minimum fuel consistent with standard carrier operations. The High-Low-High profile used identical aircraft configuration and loading to the previous profile to enable the differences in the profile alone to be illustrated.

The results of the High-Low-High mission profile comparison are contained in Table 4-2. As in the case of the High-Medium-High profile, the A-6E achieved the longest range, followed by the F-14D (eight percent less) and the F/A-18C was a distant third (38 percent less range).

Mission Profile Range Summary

As mentioned in Chapter 3, unrefueled combat range is a critical measure of the effectiveness of a carrier strike aircraft. Greater ranges provide flexibility to the Carrier Group Commander to position his battle group far from threats and to conduct operations without requiring external support (i.e., tankers). The F-14D, while falling short of the ranges achieved by the A-6E, still offers sufficient range (over 500 nm) to perform a typical Desert Storm High-Medium-High mission unrefueled. Unfortunately, the F/A-18C cannot achieve the same range performance.

When the A-6E is retired in late 1996, the effective unrefueled precision striking range of Navy air wings will be cut from 615 nm to 388 nm (High-Medium-High profile). Only with the incorporation of a precision strike capability in the F-14D, will the Navy be able to maintain its ability to strike targets at greater than 500 nm range, unrefueled.

CHAPTER 5

CURRENT U.S. AIR FORCE STRIKE AIRCRAFT

The U.S. Air Force has several tactical strike aircraft capable of delivering precision guided weapons at night and performing all-weather attacks. In order to get a more comprehensive idea of the various systems that are currently in use in the U.S. inventory, this chapter will examine three Air Force assets that proved themselves in Desert Storm. Specifically, the weapons systems of the F-15E, F-111F, and F-117A will be assessed for their ability to deliver precision weapons (LGBs), and perform night and all-weather attacks. Range and payload of these aircraft will not be considered as they are not capable of operating from an aircraft carrier and thus would not be an acceptable replacement for the A-6E. Aircraft systems are the focus of this chapter, but additional characteristics are included for completeness.

F-15E Strike Eagle

The F-15E Strike Eagle is a two seat, twin engine, supersonic, dual role attack and air superiority fighter. The aircraft is a highly modified version of the F-15A (first introduced into the U.S. Air Force in 1973) with conformal fuel tanks, upgraded engines, and significant radar and weapon system upgrades to enable all-weather attacks. The Strike Eagle first became operational in 1989 and is capable of carrying up to 24,500 lb of air-to-air and air-to-ground weapons on 17 integral store stations and has a maximum takeoff weight of 81,000 lb. (Reference 44) Aircraft configuration and cockpit diagrams are included in Appendix G, Figures G-1 through G-3.

Weapon System

The F-15E's weapon system is designed to provide an all-weather attack capability from any operating altitude, as well as a precision weapons capability. The system is designed around the Hughes AN/APG-70 radar and Martin Marietta Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) navigation (AN/AAQ-13) and targeting (AN/AAQ-14) pods. The system includes an IBM high speed digital computer, wide FOV HUD, Honeywell ring laser gyro INS, programmable armament control system, and a total of seven monochrome and color multipurpose displays for moving map (film strip type), radar mapping and terrain following information. An avionic system diagram is included in Appendix G, Figure G-4.

The AN/APG-70 radar is a high frequency pulse doppler attack radar designed for air-to-air and air-to-ground operations. The radar has five air-to-ground modes designed to help the crew navigate, detect, and designate ground targets as well as improve weapon delivery accuracy. PVU and AGR modes are available, similar to those of the F/A-18C radar (see Chapter 4). The high resolution map (HRM) mode is designed to provide high resolution radar maps via SAR techniques. The HRM mode has a planned position indicator (PPI) presentation (aircraft at the bottom of the display tracking up) that provides terrain surveillance information over a relatively large area, and a "patch map" presentation that provides a higher resolution over a smaller, velocity stabilized area. Patch maps are available in eight sizes (down to 0.45 square nm), providing various levels of resolution (down to 8.5 ft), enabling the aircrew to precisely detect and identify targets as well as aiding navigation. (Reference 44) Patch maps typically require 2.5-12 seconds

to make and once made, the display can be frozen and the image used for targeting. An example of the HRM map display format is included in Appendix G, Figure G-5.

The LANTIRN system consists of two pods mounted underneath the engine nacelles. The AN/AAQ-13 navigation pod contains a NAVFLIR and TFR and is carried under the right engine, as depicted in Appendix G, Figure G-6. The NAVFLIR is designed to provide the pilot with a 1:1 scale representation of terrain on the HUD. The NAVFLIR has a "look-into-turn" feature which can be used to shift the FLIR image six degrees laterally into the direction of turn for a better view of terrain on that side. Additionally, a "snap look" feature provides eleven degree off center slewing of the FOV either horizontally or vertically. (Reference 45)

The TFR provides steering commands to the aircrew and automatic flight controls to enable the aircraft to be flown manually or automatically at a preselected low level altitude between 100 and 1,000 ft AGL in all weather conditions. For manual TFR flight, the pilot simply maneuvers the aircraft to keep his flight path marker inside a TFR "box" on the HUD. Automatic TFR has a ride control feature which establishes acceleration limits for the flight control system (hard or soft). The TFR is designed to limit emissions (and therefore probability of detection) and uses a wide azimuth scan pattern that automatically shifts into the direction of turn based on turn rates.

The AN/AAQ-14 targeting pod contains the TFLIR and a laser designator and ranger. The pod has a wide (6 degree) and narrow (1.69 degree) FOV and is capable of automatically tracking targets, even through aggressive delivery and egress maneuvers. (Reference 45) The

TFLIR pod is mounted under the left engine as depicted in Appendix G, Figure G-7.

It is interesting to note that the fully integrated LANTIRN system was just being fielded when units first deployed to the Arabian Gulf for Operation Desert Shield. In fact, the system's operational evaluation was continued in theater. During Desert Storm, all F-15Es as well as some F-16s were equipped with the AN/AAQ-13 (NAVFLIR) pod, while only six operational AN/AAQ-14 (TFLIR) pods were available, all being used on F-15Es. (Reference 20) Currently several units of U.S. Air Force F-16s are also equipped with full LANTIRN capabilities (both pods).

LGB Delivery Capability

The F-15E can deliver a wide variety of air-to-ground weapons including LGBs up to 2000 lb, and did so with great success in Desert Storm. Navigation to a target is accomplished by some combination of INS, moving map, NAVFLIR, air-to-ground radar modes, and TFR, depending on the environmental conditions and pilot preference. Target acquisition and identification is typically accomplished via a SAR patch map, with the TFLIR being slaved to the target once identified. The TFLIR maintains target track and fires the laser designator to illuminate the target for LGB tracking. Aircrew displays would include NAVFLIR video on the HUD, and radar and TFLIR on the multipurpose displays.

Night Capability

The F-15E systems were specifically designed to enable the aircraft to accomplish its mission at night. The aircrew have the

option of using the TFR, NAVFLIR, or both for low level navigation at night. The only low level limitation comes from the limited FOV of the HUD NAVFLIR display and TFR data. Despite both systems' look-into-turn feature, low level maneuvering is somewhat restricted when compared to an aircraft being flown on NVGs where the pilot can simply turn his head and see into the turn. The aircraft's combination of TFR, NAVFLIR, an extremely accurate INS, and radar mapping via SAR techniques, give it an excellent capability to deliver weapons from any altitude at night.

All-Weather Capability

In addition to being effective in the night arena, the F-15E is capable of completing its mission in virtually any weather. The TFR option of the LANTIRN system enables the aircrew to complete a low level ingress in instrument conditions, while the SAR mapping capability provides accurate targeting solutions for radar bombing at any altitude.

F-111F Aardvark

The F-111 Aardvark is a two seat (side by side), twin engine, variable geometry wing, supersonic attack aircraft. The aircraft was initially developed in the 1960's and a carrier version was evaluated, but turned down by the Navy. The aircraft entered U.S. Air Force service in 1967, and has seen several versions, the latest being the F-111F, introduced in 1977. (Reference 33) The F-111F was upgraded with the Pave Tack weapon system in 1980, providing a TFLIR and LGB self designation capability. The aircraft is capable of carrying up to 14,000 lb of air-to-air and air-to-ground ordnance on two internal and six external stores stations, with a maximum takeoff weight of 100,000

1b. (Reference 46) Aircraft and cockpit diagrams are included in Appendix H, Figures H-1 and H-2.

Weapon System

The F-111F weapon system is designed to enable the aircraft to deliver a variety of air-to-ground weapons at low or high altitude in any weather condition. The system consists of a General Electric AN/APQ-169 attack radar, Texas Instruments AN/APQ-171 terrain following radar, Ford Aerospace AN/AVQ-96 Pave Tack system, digital computer complex, combined altitude radar altimeter, INS, optical display sight, and a variety of controls and displays. (Reference 46)

The AN/APQ-169 attack radar is a pulse, multiple mode radar designed for long range navigation and targeting, target detection, and fixing. Secondary design functions include search and track of airborne targets. The radar's Ground Automatic mode provides a PPI display with automatic or manual antenna angle adjustment. The Ground Velocity mode is similar, but is velocity stabilized with the target or fix at the center of the display, and can be magnified up to three times. Radar information is displayed on one of two virtual image displays (VID) positioned in front of the Weapon System Operator (right seat). Typical radar displays are included in Appendix H, Figure H-3.

The AN/APQ-171 TFR is a separate radar system designed to provide automatic flight at a preset altitude. The main component is a dual channel forward looking radar designed to detect obstacles within 30 degrees of the aircraft's flight path. Radar data is used as an input to the automatic flight control system for climb and dive flight path commands as well as being displayed to the aircrew (on the optical

display sight, attitude direction indicator, and TFR display) for manual terrain following. Terrain clearance height can be selected down to 200 ft AGL and a ride control is incorporated to allow the aircrew to select the maximum dive (pushover) commanded by the system. The system has a lead-into-turn feature similar to that of the F-15E to enhance situational awareness during maneuvering. The TFR is also equipped to command blind let-downs to a preselected terrain clearance, utilizing a maximum 12 degree dive angle. A diagram of TFR interfaces with other F-111F systems is included in Appendix H, Figure H-4.

The AN/AVQ-96 Pave Tack system is basically a TFLIR designed for infrared sensing and laser ranging and designation. The infrared sensor provides real-time passive thermal imagery for target identification, displayed on either of the VID screens. The sensor can be slewed a full 360 degrees in azimuth and from +10 degrees to -90 degrees in elevation and has wide (8 by 10 degrees) and narrow (2 by 2.5 degrees) FOV options, providing a maximum of four times magnification. The AN/ASQ-25 laser rangefinder target designator produces precise slant range information via laser ranging for navigation system updates and unguided weapon delivery as well as laser designation for delivery of LGBs. The Pave Tack is a pod mounted system weighing 1290 lb. The pod is mounted on a cradle, attached to the aircraft's internal weapons bay, and capable of rotating 180 degrees in five seconds to expose the sensors for operational use. (Reference 46) A Pave Tack system diagram is included in Appendix H, Figure H-5.

LGB Delivery Capability

The F-111F can deliver a variety of LGBs, and was the only aircraft that carried the GBU-28 (4,623 lb) hard target penetrating weapon used late in Desert Storm. Navigation to a target is accomplished via INS, attack radar, and TFR. Target acquisition and identification is accomplished via radar, with the TFLIR being slaved to the target once identified. The TFLIR maintains target track and fires the laser designator to illuminate the target for LGB tracking. Aircrew displays include attack radar and TFLIR video on the VID screens, and TFR steering on the optical sight, attitude direction indicator, as well as the TFR display.

Night Capability

The F-111F systems enable the aircrew to accomplish their attack mission in daytime or at night. The aircrew have the option of using the TFR for low level navigation at night, only limited (like the F-15E) by a restricted FOV into turns. The attack radar can be used as a navigation aid at higher altitudes, as well as to detect and identify targets at any altitude. The aircraft's combination of TFR, attack radar, and TFLIR capability proved very effective against fixed and mobile targets at night during Desert Storm.

All-Weather Capability

The F-111F's attack radar and TFR enable it to complete its mission in any weather and at any altitude, the only limitation being the inability to deliver precision LGBs in poor weather, which is a limitation of all current systems.

F-117A Night Hawk

The F-117A Night Hawk, commonly referred to as the "Stealth Fighter," is a single seat, twin engine, subsonic, precision attack aircraft designed with stealth elements to inhibit detection. Developed in complete secrecy at Lockheed's "Skunkworks," the aircraft reached initial operational capability in 1983, but it was not until five years later that the U.S. Air Force publicly acknowledged the existence of the aircraft. The F-117A has undergone two significant avionics upgrade programs since introduction, the most recent being the Offensive Combat Improvement Program, introduced operationally in late 1990. The aircraft has a maximum takeoff weight of approximately 52,500 lb and utilizes two internal weapons bays, capable of housing a maximum of one 2,000 lb LGB apiece. (Reference 33) Aircraft and cockpit diagrams are included in Appendix I, figures I-1 and I-2.

Weapon System

The F-117A weapon system is designed for delivery of precision guided weapons, relying completely on passive systems for navigation, target acquisition, and weapon delivery. In fact, in its stealthy mode, the aircraft is incapable of any emission which may cause detection, except for laser ranging and designation. The system was designed using off-the-shelf hardware where possible to save development time and costs. The current configuration consists of three IBM digital computers, a Honeywell SPN-GEANS INS unit (from the B-52 program), HUD (from the F/A-18), Texas Instruments Infrared Acquisition and Detection System (IRADS), two color multi-function display indicators (CMDI), digital moving map, SMS, and a sophisticated flight management system

(FMS). Future avionics upgrades currently in flight test include incorporation of a new ring laser gyro INS, GPS integration, and a new IRADS turret system. (Reference 47) A diagram of the avionic system is included in Appendix I, Figure I-3.

The entire design philosophy of the F-117A's weapon system is a departure from other U.S. aircraft. Most other aircraft rely on the pilot manually flying and navigating to the target (with a variety of systems to help him) and then rely heavily on automatic target tracking during the weapon delivery phase. The designers of the F-117A took somewhat the opposite approach, using highly automated navigation and piloting, and enabling the pilot to concentrate on manual target acquisition and tracking.

The F-117A's ability to accurately deliver weapons is based on the underlying principle that it can navigate precisely to the target via its INS system. System accuracy as well as target location are critical to enable the INS to precisely point the FLIR and get the target within its very limited FOV. The Honeywell INS system used in the aircraft has achieved impressive results, averaging a 0.12 nm per hour drift rate. This impressive accuracy is not without cost, however, as the normal ground alignment time to achieve this accuracy is 43 minutes. (Reference 47) As a comparison, the ring laser gyro INS in the F-15E is designed to align in 4 minutes and achieve a 0.8 nm per hour drift rate. (References 44 and 48)

The F-117A's IRADS system is at the heart of its ability to deliver LGBs. Because of the stealth requirements of the aircraft, requiring all systems to maintain its unique exterior shape, the IRADS was designed as a twin turret system, consisting of a FLIR (mounted just

below the pilot's windscreen) and a downward looking infrared (DLIR) (mounted underneath the aircraft just right of the nosewheel door). Both turrets are covered with woven wire screens to maintain the aircraft's low observable signature. The FLIR and DLIR have been fully integrated to enable multiple target handoffs between them as the target's position changes. The laser designator incorporated into the IRADS system is designed to fire only under specific conditions in order to minimize the aircraft's vulnerability to detection.

The F-117A's FMS enables the aircraft to automatically fly complex pre-programmed routes, providing speed and time-on-target control. Additionally, the FMS has an unusual attitude recovery feature to be used in case of pilot disorientation.

The aircraft's digital tactical situation display system enables the pilot to view digitized color maps or data generated from certain electronic world data bases on the CMDI's. This information can be utilized for navigation and as a target identification aid.

LGB Delivery Capability

The F-117A can deliver the full range of air-to-ground weapons, but delivered 2,000 lb LGBs almost exclusively during Desert Storm. Although limited to only two weapons, the aircraft's incredible accuracy provided impressive results. Navigation to a target is accomplished automatically via the FMS, or manually via INS and digital color map. When within range of the target, the computer system automatically cues the FLIR/DLIR to the target position. Once target acquisition is achieved, the pilot refines the aiming, designates the target, and consents to weapons release. The F-117A designers have overcome the

high workload associated with the single seat night attack mission by providing a sophisticated FMS system to fly the aircraft to the target precisely and on time, leaving the pilot free to fine tune the targeting solution.

Night Capability

The F-117A operated exclusively at night during Desert Storm. Its systems can be utilized just as effectively day or night, the only additional advantage at night being its reduced visual signature. The aircraft has no system to provide situational awareness in the low level arena, simply due to its basic design premise of stealth. If the aircraft is invisible to radar by virtue of its stealth design, then there is no need for it to perform terrain masking from radar by flying low.

All-Weather Capability

The F-117A is limited in the all-weather arena. While capable of accurately navigating to an INS located target in any weather, it relies solely on its infrared sensors to pinpoint its targets. Lack of an air-to-ground radar mode to pinpoint targets in bad weather will limit the aircraft's effectiveness. As mentioned earlier, releasing unguided weapons on INS targets is not considered worthwhile due to small system inaccuracies resulting in large weapon errors. While INS bombing might be effective as exercised by the B-52's in Desert Storm to terrorize the Republican Guard army, the limited carriage capability of the F-117A makes it an unlikely platform for such efforts.

Capability Summary

A summary of weapon systems used in the F-15E, F-111F, and F-117A is included in Table 5-1. It is interesting to note that all aircraft have a TFLIR system with laser designation, but beyond that, each platform has its own unique approach to the problem of night and all-weather attack. The F-15E, being the most modern platform, seems to have incorporated all available options, utilizing a NAVFLIR, as well as TFR, and radar with SAR mapping. The older F-111F accomplishes the same mission without NAVFLIR or SAR. And the stealthy F-117A accomplishes the mission without any active systems other than its laser designator. It is also interesting to note the lack of NVIS in any of the front line U.S. Air Force attack aircraft. While it seems to be a high priority in the Navy, NVIS is simply not a priority in the Air Force.

Table 5-1. Current U.S. Air Force aircraft strike capabilities.

<u>Capability</u>	<u>F-15E</u>	<u>F-111F</u>	<u>F-117A</u>
Visual Attack	X	X	X
LGB Carriage	X	X	X
Targeting FLIR	X	X	X
Laser Designator	X	X	X
<u>Night:</u>			
NAVFLIR	X		
NVIS			
<u>All Weather:</u>			
Radar Bombing	X	X	
SAR Mapping	X		
Terrain Following Radar	X	X	

CHAPTER 6

SYSTEM BY SYSTEM CONSIDERATIONS

Now that a variety of the current U.S. strike aircraft have been reviewed for their various weapon systems and capabilities, those systems will be analyzed one at a time for their merit in enhancing the night and all-weather attack mission and for any limitations they may have. Specific categories that will be addressed include FLIRs, lasers, radar systems, navigation aids, and night vision.

FLIR

Forward looking infrared systems are used in several attack aircraft to enhance their capabilities. In order to evaluate the utility of NAVFLIR and TFLIR, some background information is required. Typical attack type FLIR systems operate in the 8 to 12 micron wavelength (far infrared) region of the electromagnetic spectrum. The two main limiting factors associated with FLIRs are thermal contrast and FOV. (Reference 49)

Thermal contrast is primarily determined by environmental factors. The atmosphere can attenuate an infrared signal by refraction, absorption or scattering. The effect of refraction is almost negligible, however, the amounts of absorption and scattering are a function of the wavelength of the infrared energy.

The molecules principally affecting absorption in the 8 to 12 micron wavelength region are water vapor, carbon dioxide and ozone. While carbon dioxide and ozone concentration are fairly constant in the atmosphere (increasing somewhat in urban areas), water vapor

concentration is highly variable. The apparent transparency of the atmosphere to the FLIR depends heavily on the humidity. Relative humidity is commonly used to express the amount of moisture in air compared to the maximum amount which could be held at that temperature. As an example of the effect of humidity, on a nominal 70 degree Fahrenheit day in a maritime environment, a relative humidity of 50 percent would reduce the transmission of infrared radiation by 45 percent. (Reference 49)

Aerosol scattering occurs when radiation is reflected by particles in the air and causes attenuation by redirecting the radiation away from a sensor. The magnitude of scattering is a function of the ratio of the particle size to the wavelength of the radiation. Particle sizes equal to or greater than 8 to 12 microns (wavelengths in the region sensed by a FLIR) have the greatest impact on system performance and include dust, fog, and clouds. On the other hand, smoke and haze have very small particles and correspondingly have little effect on FLIR performance. Particles that are large in comparison to the wavelength (i.e., raindrops, snow) tend to absorb as well as scatter the signal.

Several additional environmental considerations are worth mentioning. Falling precipitation tends to strongly attenuate FLIR signals. After a rain or snow, the cooling of the background tends to "wash out" the FLIR image. Clouds not only prevent radiation from reaching the FLIR, but they also emit their own radiation in the 8 to 13.5 micron band and thus will show up on a FLIR system. Wind tends to attenuate a FLIR image by reducing thermal signatures.

Environmental factors are not the only ones affecting the thermal contrast of a FLIR. Discrimination in a thermal scene is based on

objects radiating more or less infrared energy than their immediate background. Solar heating, the emissivity of individual substances, and individual cooling rates all affect thermal contrast.

The second limiting factor for FLIRs is FOV. A NAVFLIR typically has a fixed FOV of approximately 20 degrees by 20 degrees. The relatively small FOV makes aggressive maneuvering difficult because of the pilot's limited ability to look into turns. TFLIRs typically have an even smaller FOV which is slewable to a target. The limitation with a TFLIR is the requirement to precisely point it at a target in order to achieve acquisition. Looking for a target with a TFLIR would be comparable to searching through a soda straw.

NAVFLIR

NAVFLIR units are used in the F/A-18C and F-15E aircraft to enhance night low level navigation and general situational awareness. While the system is lauded by both communities for its mission utility, as with all infrared systems it is limited by meteorological conditions, being significantly affected by high humidity, precipitation, clouds, fog, and dust. However, it can be used effectively to see through smoke or haze.

The NAVFLIR design is somewhat of a compromise between FOV and resolution, and typically cannot provide the same resolution as NVGs in ideal conditions. Additionally, NAVFLIRs generally provide poor depth perception, which can lead to pilot confusion. (Reference 49)

Despite these limitations, the NAVFLIR is a proven part of the F/A-18C and F-15E night attack systems. However, other platforms (A-6E, F-111F) also perform the night attack mission (including low level

flight) effectively without a NAVFLIR. Thus, while the system offers definite enhancements in the low level environment, it is not essential for the night attack mission and its environmental limitations restrict its usefulness in poor weather.

TFLIR

The TFLIR is the one common element in all platforms discussed, except the F-14. There are several methods used to point the TFLIR at a target (radar, NAVFLIR, INS), but all aircraft use the TFLIR image to refine targeting solutions, designate the target, and record bomb damage assessment.

A TFLIR system typically has two different FOVs available for the user, but both are rather narrow compared to that of a NAVFLIR (i.e., the F-15E TFLIR selectable FOVs are 6 by 6 degrees and 1.69 by 1.69 degrees). While not a limitation in itself, the narrow FOV requires precise aiming of the TFLIR in order for the target to show up within its FOV. This precise aiming requires an accurate INS and exact target position data.

The TFLIR offers improved resolution over a NAVFLIR and typically up to four times magnification of the infrared scene. Its excellent resolution (providing favorable atmospheric condition) enables the aircrew to discriminate objects in a scene and pinpoint the correct target. The target position can then be updated into the aircraft's weapon system ensuring the weapons are released at the proper point and directing the laser designator (in the case of an LGB release). As an example of resolution capabilities, the F-111F's Pave Tack system is

capable of identification of a two lane bridge structure at 15 nm in nominal atmospheric conditions. (Reference 45)

The effectiveness of the TFLIR was demonstrated in both precision and nonprecision attacks in Desert Storm and that is underscored by its widespread use among attack aircraft. The TFLIR with laser designator is essential to accurately designate targets for precision weapons delivery at night. In fact, Reference 50 states that one lesson of the Desert Storm war was that strike fighters such as the F/A-18 need laser designators of their own (they were not so equipped during the war). The aforementioned environmental limitations associated with FLIR systems severely limit the TFLIR's effectiveness in dust, fog, clouds, or rain and thus it is not an all-weather system.

Lasers

All aircraft considered in this report, except the F-14, currently utilize a laser ranger and designator in conjunction with their TFLIR to guide their precision weapons. Some sort of laser designation is essential to guide LGBs, and aircraft with "self designation" capability offer much greater flexibility than relying on ground designation sources or the extensive coordination required to perform "buddy lasing" from other aircraft.

Typical military airborne lasers use Neodymium doped Yttrium Aluminum Garnet (Nd:YAG) as a lasing medium. Nd:YAG has an output wavelength of 1,064 nanometers, which corresponds to the near infrared region of the spectrum, situated between the regions used by NVGs and FLIRs. (Reference 51) Being in the near infrared region, Nd:YAG lasers are subject to limitations of aerosol scattering as discussed in the

section on FLIR systems. Dust, fog, clouds, and smoke (to a lesser extent) can attenuate the energy of a Nd:YAG laser.

Laser Rangers

Laser rangers are extremely accurate and can be used to determine range to a target, update an aircraft's INS, or provide precise inputs to the weapons computer to determine the proper weapon release point. Laser rangers use very short laser pulses (10 to 30 nanoseconds) at a high pulse repetition frequency. The laser pulses are directed at the target, and the time measured until a reflected signal is returned. The speed of the laser pulses is known precisely, so the distance to the target can be calculated very accurately. (Reference 51) Typical maximum effective range of a laser designator is less than 10 nm.

Laser Designators

Laser designators utilize a coded laser beam directed at the target. The reflected pulses from the target are detected by an LGB's laser target seeker (programmed to respond to the same pulse repetition frequency code), which guides the weapon to impact.

The laser ranger and designator is an essential element of the capability to deliver and guide LGBs. As with the TFLIR, the laser's environmental limitations associated with dust, fog, or clouds severely limit its effectiveness in marginal weather conditions and thus, it is not an all-weather system.

Radar Systems

All of the attack aircraft discussed with the exception of the F-117A (due to its design concept of stealth) utilize some form of radar to enhance their capability. The F-14A/B and F-14D radars are specifically optimized for the air-to-air mission, providing extremely limited air-to-ground functionality. The other aircraft use a combination of three basic radar modes to aid in navigation and targeting: real beam (conventional) ground mapping, SAR mapping, and TFR. The older vintage A-6E and F-111F aircraft rely on pulse radar systems for real beam ground mapping. The F/A-18C and F-15E radars can perform real beam ground mapping, but also take advantage of high speed digital processing to enable them to produce high fidelity SAR maps. Additionally, the F-15E and F-111F utilize TFR for low level navigation, and the A-6E's search radar can be used for a similar "terrain clearance" manual capability. In addition to these three radar modes, there are several other techniques used by the various radars to help update the aircraft's INS position. These modes will be discussed under "Radar Navigation Aids."

Real Beam Ground Mapping

As mentioned above, several of the aircraft examined in chapters 4 and 5 utilize real beam ground mapping for navigation. The radar simply transmits pulses of radar energy and senses the energy reflected back from the ground. The time delay associated with the radar return is used to determine range. Range resolution is a function of pulse width and a technique called pulse compression is used to enable the radar to send many very small pulses of energy and achieve very precise range

resolutions. (Reference 52) As an example, the F-111F's attack radar can achieve an 83 ft range resolution at 6 nm in the Ground Automatic mode and at 18 nm in the Ground Velocity mode. (Reference 45)

Azimuth resolution is more difficult to refine, being limited by the beam width of the radar system. For example, the 0.39 degree beam width of the F-111F's radar provides 250 ft azimuth resolution at 6 nm. (Reference 45) Azimuth resolution for a given range can be improved by shortening the wavelength or enlarging the antenna. Unfortunately, extremely short wavelengths are subject to severe attenuation in the atmosphere and antenna size in tactical aircraft is limited, so azimuth resolution with this type of radar is physically limited.

The real beam ground map capabilities of A-6E and F-111F have proven themselves to be adequate for navigation and precise targeting in combat. The real beam ground map provides a true all-weather attack capability, as the long wavelengths of radar energy are unaffected by weather. However, because of their limited resolution, real beam ground maps rely on somewhat coarse navigation at longer ranges (over 50 nm), and high resolution targeting solutions are only achievable at shorter ranges (approximately 10 nm), limiting the time available to find and designate a target (see Appendix H, Figure H-3). The next higher level of resolution was achieved when digital processing became available and is called synthetic aperture, discussed below.

Synthetic Aperture

Of the aircraft discussed, only the newer digital radars of the F/A-18C and F-15E have the ability to produce a SAR map. Compared to real beam ground maps, SAR maps offer greater accuracy and versatility.

An example from the F-15E radar will help illustrate the significance of the SAR map. As a review, the F-15E radar produces two high resolution maps (HRM) via SAR techniques: an HRM PPI map, similar in format to a real beam ground map, and a patch map. The range resolution of an HRM PPI map is half of that of a real beam ground map made by the same radar, while the azimuth resolution is twelve times smaller. In fact, when making the smallest patch map available (0.67 by 0.67 nm), the F-15E radar can achieve a resolution of 8.5 ft at ranges of up to 20 nm. (Reference 44)

SAR takes advantage of an aircraft's velocity to provide fine azimuth resolution. The antenna is pointed at a constant angle off the nose of the aircraft (at least 8 degrees in the case of the F-15E), and acts effectively as a single radiating element in a very long antenna. By virtue of the aircraft's forward speed, each time a pulse is transmitted, the antenna is progressively farther along on the flight path. By storing the doppler returns received over a period of time and integrating them, the radar can synthesize the equivalent of an array antenna hundreds of feet long. The points at which successive pulses are transmitted can be thought of as elements of the array. Additionally, azimuth resolution can be made virtually independent of range by increasing the array length in proportion to the range of the region being mapped (i.e., increased look time enables the same quality map to be made at greater ranges). (Reference 52) As with the real beam ground map, SAR uses pulse compression to achieve fine range resolution. The end result is an extremely high resolution map that is stored digitally and thus can be manipulated (frozen or enlarged) by the aircrew.

The tactical advantages of SAR maps are many. The ability to build a high resolution map while still a long way from the target (i.e., 40 nm) provides the aircrew with plenty of time to study the map, find the target and designate it for an automatic weapon release. The flexibility of freezing a display or zooming it cannot be overemphasized in the target identification phase. Additionally, use of SAR can significantly reduce aircraft emissions, as the radar can be turned off or to standby once the SAR map is built (see Appendix C, Figure C-7). SAR can also distinguish moving targets on the ground (i.e. tanks or vehicles) and display them. Finally, as mentioned above, radar is not affected by weather, so a SAR map can be made, target designated, and automatic weapon release accomplished in any weather conditions.

Terrain Following

The F-15E and F-111F both utilize TFR systems that provide manual or automatic flight at low level. The A-6E uses a terrain clearance mode to provide steering for manual flight at low level. The F-15E's TFR is housed in a LANTIRN pod while the systems in the other aircraft are integral.

TFR or terrain clearance systems use pulsed radar signals transmitted at a high pulse repetition frequency and high scan rate to map an area in front of the aircraft, achieving very accurate ranging out to a nominal 6 to 8 nm. Scan patterns vary from 30 degrees either side of the nose (F-111F) out to a maximum of 55 degrees (A-6E) and typically cover 25 to 40 degrees in elevation. Wider scan patterns take longer to update, but provide increased situational awareness for maneuvering. Elevation profiles are built up in computer memory, and

manual and automatic flight path commands are provided to the aircrew and flight control system. Appendix D, Figure D-4 shows construction of a typical terrain clearance display from an A-6E.

Terrain following systems are the only current method to achieve true all-weather low level capability. They are used routinely in very poor weather to achieve ingresses as low as 100 ft AGL at speeds over 500 nm per hour. Low level ingress to a target area can provide the element of surprise, as attacking aircraft avoid detection by early warning radars, and can also enhance survivability, by avoiding SAM systems. The option of having the aircraft fly automatically at low level using the TFR reduces aircrew fatigue on long missions and frees up time for other cockpit tasks. Overall, TFR can greatly enhance the flexibility of an all-weather attack aircraft by providing a low altitude sanctuary.

Radar Navigation Aids

While modern aircraft inertial navigation systems are extremely accurate, inevitably random errors and inherent errors that build up with time are introduced. By periodically updating the INS with radar generated velocity or position, these errors can be minimized. Two basic methods for updating via radar are in use and will be covered briefly.

The first and most common method of radar update is simply a precision position update, based on a target of known position that has been imaged on a radar map. The best resolution map and therefore most accurate update would be achieved using a SAR map, designating the target and updating the system relative to the target's known position. All the aircraft reviewed (except the F-117A) have the ability to

perform a radar update, but only the F/A-18C and F-15E can do so from a SAR map.

Precision Velocity Update (PVU) is another update method whereby the pencil beam of a pulse doppler radar is trained on the ground ahead of the aircraft in three or more symmetrically located directions. The resulting echoes reveal a precise magnitude and direction of the aircraft's velocity, which is fed back into the mission computer to update aircraft position. Both the F/A-18C and F-15E utilize PVU. The A-6E has a pulse doppler radar that essentially accomplishes the same task. The radar sends signals, receives echoes, measures the doppler frequency shift, and then uses the frequency shift to drive the antenna in azimuth until it is aligned with the aircraft ground track. Thus the system computes ground speed and drift angle which are displayed to the aircrew and also used to update the aircraft INS and minimize targeting errors.

Radar navigation aids are an integral part of the night and all-weather attack missions. Even with modern INS systems, having a precise method of updating the system is just one more assurance for the aircrew that when they arrive at the target, it will be there.

Navigation Aids

Inertial Navigation

All modern tactical aircraft are equipped with INS for navigation. Older aircraft (A-6E, F-111F, F-14A/B) have traditional INS consisting of a gyro stabilized platform with three accelerometers to monitor accelerations in three orthogonal axes. Newer aircraft (F/A-18C, F-15E,

F-14D, and soon the F-117A) are equipped with ring laser gyros.

Ring laser gyro based INS have the advantages of being smaller, lighter, and not containing any moving mechanical parts. They typically consist of three accelerometers to provide linear acceleration in each axis and three orthogonally mounted ring laser gyros. The ring laser gyro is triangular in shape, with mirrors at each corner to reflect a laser beam that is split and sent in opposite directions around the circumference. Velocity differences measured between the light beams are used to detect any rotation of the instrument in the plane of the ring. (References 44 and 51) Inertial velocities can be measured very accurately with improved reliability over traditional INS.

Two important considerations when discussing INS are drift rate (accuracy) and alignment time. The F-117A is the perfect example, as it relies completely on its INS to arrive in the window to point its narrow FOV FLIR and detect its target. Without extreme system accuracy, this would not be achievable. Of the systems reviewed, the INS of the F-117A was the most impressive in terms of drift rates, averaging only 0.12 nm drift per hour. However, one of the costs associated with this accuracy is the incredibly long alignment times necessary (average of 43 minutes). Typical alignment times for aircraft using ring laser gyro based INS are on the order of 4 to 6 minutes, with an advertised drift rate of approximately 0.8 nm per hour. (References 41 and 44) Long alignment times can be a tactical limitation in the case of a short reaction strike or alert launch, especially when operating from an aircraft carrier, where five minute alert launches are standard.

Ideally, an INS would align quickly, exhibit small drift rates, and be extremely reliable. Reliability as well as decreased alignment

times are the primary reasons modern aircraft are shifting to ring laser gyro based INS. (Reference 53) The F-117A program is changing to a ring laser gyro system for these very reasons. (Reference 54) The INS is a critical part of the avionics suite of a night all-weather attack platform.

Moving Map

Moving maps are used as navigation aids in the F-15E, F/A-18C, and F-117A (incorporated after Desert Storm). There are basically two forms of moving maps, the older film storage/imaging type and the newer digital storage/imaging type. Both offer the same basic situational awareness, providing a continually updated map picture (of selectable scale) depicting the exact location of the aircraft in relation to terrain features.

Film storage/imaging maps have some limitations when compared to digital maps, including a limited database. The F-15E makes up for this by enabling the aircrew to carry extra film cartridges and plug them into the system in the cockpit. Additional limitations include limited zoom and display options with film maps when compared to digital maps.

While F/A-18C and F-117A have digital map systems, all three aircraft have the ability to display additional information superimposed on their moving maps. Using a data storage unit, aircrew can program their navigation route and threat information (such as the location of SAMs) before flight and download that information into the aircraft mission computer, which subsequently displays it on the moving map. This provides complete situational awareness of position relative to landmarks, planned route, and threats with a quick glance at the

display. One limitation of moving map systems is the generally agreed upon need for a color display (adding to equipment costs), as monochrome displays don't provide sufficient detail and discrimination.

Moving map systems, while not essential for navigation, can significantly add to the situational awareness of aircrew and simplify navigation during high workload missions. Digital maps are far more powerful and flexible than film type map systems, yet more expensive to procure.

Global Positioning

A modern discussion of navigation aids in tactical aircraft would not be complete without some mention of GPS. GPS offers worldwide coverage by a series of satellites and can provide precise position location by triangulation. Although GPS is not a new system, the tactical air community has been slow to integrate GPS into their aircraft. Hand held GPS receivers are regularly used by Navy aircrews for navigation system checks and search and rescue efforts. However, none of the aircraft discussed in this report are flying operationally with GPS integrated into the aircraft navigation system. Ongoing programs are working on integrating GPS into the F-117A (Reference 47) and F-14D (Reference 55) and a congressional mandate has made it a requirement in tactical aircraft within the next few years.

GPS, when it finally is implemented in tactical aircraft, will offer tremendous advantages. The passive update capability of GPS will enable aircrew to avoid any emissions while updating their INS position and velocity (as opposed to a radar update) and enhance their ability to find a target, especially in the night or all-weather attack role.

Additionally, in the event of INS failure, the aircrew could still navigate via GPS alone.

Night Vision

The final system to be examined is NVIS. Appendix B contains an in depth discussion of NVIS and NVGs. This section will focus on tactical advantages and limitations of NVIS.

NVIS is currently utilized in the F/A-18C, and in limited numbers in the A-6E. NVIS has just recently been introduced into the F-14D fleet and modifications have been designed and verified for the F-14A/B, but not funded. All aircraft use MXU-810/U Mark IV Cats Eyes NVG and cockpits modified to limit emission of light waves above the blue-green area of the visible spectrum.

As discussed in Appendix B, NVGs amplify light in the visible and near infrared regions. This amplified light enables aircrew to navigate at high speed and low level at night, and to a limited degree identify targets. Resolution while using NVGs is highly dependent on atmospheric conditions (i.e., humidity, dust, haze) but under nominal night lighting conditions, aircrews can identify large landmarks (i.e., lakes and streams) at 3 to 5 nm, and smaller landmarks (i.e., road crossings or railroad tracks) at approximately 1 nm. (Reference 49) The biggest advantage of NVGs over other night systems (i.e., FLIR) is simply that they are attached to the pilot's helmet, and thus he/she is free to look anywhere and still enjoy the advantages they provide. This factor is most important when maneuvering aggressively at low level.

NVGs also have several limitations. Clouds, fog, and haze can render NVGs ineffective. NVGs need some ambient light to work

(generally 20 percent moon at 30 degrees above the horizon, although flight in mean starlight conditions is conducted). Depth perception when flying over water is very poor when using NVGs. The limited FOV (30 degrees) is somewhat like looking through a soda straw and requires the pilot to keep moving his/her head to maintain situational awareness. NVGs also weigh 28 ounces, often causing excessive neck fatigue and must be removed prior to ejection.

Overall, NVGs can improve situational awareness for the night attack mission and enable low level target ingresses. They offer a less expensive alternative to NAVFLIR systems with similar capabilities. Because of their limitations in weather, they do not significantly enhance the all-weather mission capability.

CHAPTER 7

F-14D SYSTEM INTEGRATION

This chapter will consolidate the work of the previous chapters and examine some possible modifications to the F-14D aircraft weapons system to meet the Navy's need for a long range strike aircraft. The mission requirements for a Navy strike aircraft replacement for the A-6E were defined in Chapter 3. Current operational aircraft systems in the U.S. inventory were explored in Chapters 4, 5, and 6. Now these systems will be superimposed upon the F-14D weapon system to identify the most likely modifications to enable the Tomcat to meet the defined mission requirements. Specific cost and system integration details are beyond the scope of this study and will not be addressed. Instead, priority will be given to meeting the defined mission requirements to enable the F-14D to fill the shoes of the A-6E as the Navy's long range precision night and all-weather attack platform.

In Chapter 3, five individual mission requirements were defined to fulfill the long range precision night and all-weather strike aircraft role. The requirements were: (1) precise navigation to and from targets, (2) precision weapons (LGB) delivery and guidance, (3) night precision weapons capability, (4) all-weather attack capability, (5) minimum unrefueled mission radius of 500 nm on a High-Medium-High profile. Although a low altitude capability at night or in poor weather was not identified as a specific requirement based on the lessons learned from Desert Storm, it provides additional mission flexibility, especially when facing a functioning integrated air defense system. In fact, all of the aircraft discussed (except the F-14A/B and F-117A) have

some method of low level navigation at night or in poor weather. Because of these facts, low altitude capabilities will also be examined.

Precise Navigation

Precision navigation is a critical element of an aircraft's ability to deliver weapons on target, especially at night or in poor weather. The ability to precisely point the narrow FOV of a FLIR system for target acquisition is critical in the dynamic high speed environment of a tactical attack. Additionally, in poor weather, an aircraft's navigation system will be relied upon to point the radar for target identification. After a low level ingress to the target, the aircrew may have precious few seconds to get the radar or FLIR systems pointed in the right direction, identify and designate the target, and release the weapons. A poor or imprecise navigation system could easily result in failure to identify the target and an aborted attack.

The F-14D currently uses a ring laser gyro INS, which provides precise navigation and quick alignment times. It is a state of the art INS, which when compared to the other tactical aircraft discussed, is only surpassed by the performance of the INS in the F-117A. The F-14D also has the unique additional capabilities offered by JTIDS, including navigation system updates based on other platforms in the net.

While the F-14D has significant precise navigation capability, additional navigation update options would further enhance the system. GPS is already planned for incorporation, and will provide passive system updates or function as a stand alone navigation system. A PVU capability (similar to that in the F/A-18C or F-15E) could be incorporated into the aircraft's digital radar to provide velocity

updates. Additionally, a moving map system would significantly enhance aircrew situational awareness, especially under heavy mission tasking.

The navigation capability of the F-14D is sufficient to support the defined mission requirements in its current configuration. Additional system update capabilities will provide added flexibility and situational awareness.

Precision Weapons Delivery and Guidance

As mentioned in Chapter 2, the F-14A/B has already been successfully tested for carriage and release of LGBs and funding has been allocated for F-14D LGB testing. Thus, within a few months, a fleet clearance could be released, enabling the aircraft to deliver LGBs, if supported by another aircraft or ground source for laser target designation. However, one of the mission requirements established from Desert Storm lessons learned is for aircraft self designation of an LGB target.

All the other aircraft discussed utilize a combination TFLIR (for target identification) and laser designator to perform target designation. Pod mounted systems would seem to be the most practical to integrate into the F-14D. The F/A-18C and F-15E TFLIR pods weigh less than 500 lb each and are largely self contained, except for bus connections with aircraft mission computers for control and displays. The added advantage of the LANTIRN pod is an internal cooling device, while the F/A-18C pod relies on cooling supplied by the aircraft. One of these pods could easily be hung on station 1B or 8B on the F-14D, which are designed for up to 1000 lb loads. In fact, a fit test of the F/A-18C's AN/AAS-38 TFLIR pod was successfully accomplished in 1992 (see

Appendix A, Figure A-9), and a similar test was accomplished in 1995 with a LANTIRN pod. (Reference 56) System integration would involve installing the TFLIR as one of the remote terminals on the F-14D's MIL-STD-1553B Mission Bus number 1, similar to the installation of the infrared search and track system (IRSTS). This proposed modification is illustrated in Appendix A, Figure A-10.

Mounting the TFLIR pod on a weapon station would have certain disadvantages. It would take away one station that would otherwise be available to carry ordnance. However, the aircraft could still carry four air-to-ground weapons and three air-to-air missiles. Another concern with this mounting would be the aircraft fuselage blocking part of the sensor's FOV (i.e., a pod mounted on the left side would have limited FOV to the right of the aircraft). This constraint would be similar to that experienced with the F/A-18C's fuselage mounted TFLIR and possibly necessitate off target turns be performed to the side where the sensor is located to avoid losing illumination of the target. While this would be a tactical limitation, the F/A-18C has proven that with proper planning, this limitation can easily be overcome.

Another option for TFLIR and laser designator incorporation would be to use the IRSTS. The IRSTS operates in the same 8 to 12 micron waveband as the F/A-18C's TFLIR, and is already mounted in the aircraft's dual chin pod. The benefits of using the IRSTS would include some weight savings as well as not taking up a weapon station. Potential integration difficulties include optimizing the IRSTS for ground mapping and tracking ground targets, as well as installation and integration of a laser designator. Also, the IRSTS dome is fixed, which would negate the ability to track a target beyond approximately 60 to 70

degrees below the nose (i.e., tracking through target overflight would be impossible). These difficulties might make this modification more difficult or more expensive than just adding a proven pod mounted system. However, the concept seems worthy of some investigation.

Incorporating a TFLIR and laser designation system is the single critical item required for the F-14D to be capable of the night precision attack mission. The combination of its ring laser gyro INS coupled with a TFLIR system would give the F-14D a targeting capability very similar to that of the F-117A.

Night Precision Weapons Capability

As mentioned above, the TFLIR with laser designator will enable the F-14D to function as a precision night bomber with similar systems capabilities to those of an F-117A. However, without the option of stealth technology, the F-14D is vulnerable to enemy air defense systems and some operating sanctuary is desirable. The common answer among tactical aircraft is to avoid enemy radars and SAM systems by flying at low level.

Three options have been identified to enable low level flight at night: NVGs, NAVFLIR, and TFR. Of the three, NVGs have already been the source of extensive test and evaluation in the F-14 community. An NVIS compatible F-14D cockpit has been approved and initial funding has been allocated to modify a limited number of aircraft for NVG use. The aircraft's current flight clearance limits flight to that above 3,000 ft AGL due to low windscreen transmissivity and the lack of a need to go lower for its current mission areas (the air-to-ground mission hasn't been included yet). (Reference 16) The windscreen transmissivity

problem may be resolved with introduction of the next generation of NVGs (GEN 4), currently in development, which are sensitive to a broader range of the electromagnetic spectrum. When tested with the GEN 4 goggles, the windscreen transmissivity was found to be acceptable. With incorporation of the air-to-ground mission and experience with NVGs, the aircraft should eventually achieve a low level (below 1000 ft AGL) capability.

Incorporating a NAVFLIR would complement the aircraft's NVG capability by expanding the waveband of radiation within which the aircrew could see. NAVFLIR systems on the F/A-18C and F-15E are externally pod mounted systems and could be carried on F-14D stations 1B or 8B, with similar restrictions to those discussed for the TFLIR (limited FOV and loss of a weapon station). One additional requirement would be the addition of a raster scan capable HUD to enable the NAVFLIR video to be superimposed over the real world scene. As with the TFLIR, the NAVFLIR could be installed on Mission Bus number 1 to communicate with the mission computers (see Appendix A, Figure A-10). The IRSTS offers a possible option for a NAVFLIR system, as it can easily achieve the required FOV. The IRSTS could use a fixed pointing angle or a high speed scan to build a FLIR picture of the environment in front of the aircraft.

A terrain following mode of the radar would enable the F-14D to fly at low level at night or in instrument conditions. The F-15E LANTIRN pod would provide both NAVFLIR and TFR capabilities (in the same pod) and would appear to be the simplest method to achieve a terrain following capability. Other options would be to modify the AN/APG-71 to include a terrain clearance mode (similar to the A-6E), or add another

separate radar system specifically for terrain following (similar to the F-111F).

With the three options available for night low level navigation there are a variety of configurations which might work for the F-14D. A minimum capability could be achieved by going ahead with NVIS integration into the aircraft and resolving the windscreen transmissivity problem. The addition of NAVFLIR and or TFR systems would complement the night low level capability, but might involve extensive modification and integration efforts.

All-Weather Attack Capability

All-weather attack implies nonprecision weapons delivered as precisely as possible. By far the most efficient way identified to accomplish this is via use of a SAR map. Superior resolution and the ability to freeze a map and designate a target with the radar off are two of the biggest advantages of utilizing synthetic aperture techniques.

One of the primary considerations for a SAR map capability is the requirement for digital processing. The F-14D's AN/APG-71 radar not only has a digital processor, but has up to 85 percent parts commonality with the F-15E's AN/APG-70 radar. (Reference 6) Both radars, as well as the AN/APG-65 of the F/A-18C are made by Hughes Aircraft Company. Incorporating a SAR capability into the F-14D, similar to that of the F-15E and F/A-18C would seem to be very practical.

The other aspect of the all-weather mission is the capability to navigate at low level in poor weather. The terrain following systems of the F-15E and F-111F, and the terrain clearance mode of the A-6E are the

only proven methods in use at this time. As discussed above, incorporating the LANTIRN pod mounted TFR system seems to be the simplest solution for the F-14D.

For a true all-weather bombing capability, the F-14D needs a synthetic aperture mode of its radar to precisely map target locations and enable accurate weapon delivery. In order to achieve a low altitude all-weather capability, the aircraft needs a terrain following radar mode.

Unrefueled Combat Radius

A minimum unrefueled combat radius of 500 nm for a High-Medium-High mission was chosen as one of the mission requirements. For example, this would be the equivalent of an aircraft launching from a carrier in the Arabian Gulf, hitting targets in Baghdad, and returning to the carrier. Chapter 4 provided a range comparison of the A-6E, F/A-18C, and F-14D aircraft for two different mission profiles. The incorporation of a pod mounted TFLIR system on the F-14D, as discussed in this chapter, would add approximately 500 lb and increase the aircraft drag count by 8 to 10 points. Using the performance charts in Reference 42, this additional weight and drag would result in a negligible decrease in aircraft mission radius. The F-14D met the mission radius requirements for the High-Medium-High profile and, in its current configuration, can fulfill the long range attack role for the Navy.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

This study has identified a deficiency in the Navy's strike capabilities due to the retirement of the A-6E in late 1996. Until its replacement aircraft, the F/A-18E/F, reaches initial operational capability in 2001, the Navy will be without a long range night and all-weather attack aircraft capable of delivering precision weapons. The F-14D, appropriately modified, is proposed as an option to maintain this capability.

A review of Desert Storm lessons learned identified several mission requirements for an aircraft to be effective in a modern air war and fill the shoes of the A-6E. This study of the A-6E, F/A-18C, and several other U.S. tactical strike aircraft revealed various approaches to the challenges of the night and all-weather attack missions. Examining the various systems currently in use and considering the existing capabilities of the F-14D, several modifications are proposed to enable the aircraft to complete both the night precision strike and all-weather strike missions.

The F-14D has excellent potential to succeed the A-6E as the Navy's next long range night and all-weather strike aircraft. The following is a prioritized list of modifications that would be required or desired to enable the aircraft to fulfill this role.

Recommended Modifications

Required

1. Incorporating a targeting forward looking infrared system with laser ranging and designation capability. This modification may be accomplished using the existing infrared search and track system, or by adding the pod mounted system on the F/A-18C or F-15E. This modification alone will provide the aircraft with a night precision strike capability.

2. Modifying the F-14D's AN/APG-71 radar to incorporate synthetic aperture radar mapping capabilities, integrated to enable aircrew to designate radar targets for computer weapon releases in instrument conditions. This modification alone will provide the aircraft with a medium and high altitude all-weather attack capability.

3. Continuing with current plans to modify F-14D aircraft with night vision compatible cockpit lighting for night vision goggle use. This modification will enable low level ingresses at night.

4. Incorporating a terrain following radar mode either within the AN/APG-71 or by adding another system, to enable low level high speed flight to be accomplished regardless of weather conditions.

Desired

5. Adding navigation system upgrades to include integration of global positioning system, and radar precision velocity update capability.

6. Incorporating a navigation forward looking infrared system for low level night navigation. Pod mounted systems are available from

the F/A-18C and F-15E or the existing infrared search and track system could possibly be modified.

7. Installing a digital color moving map display to each cockpit to enhance aircrew situational awareness.

LIST OF REFERENCES

LIST OF REFERENCES

1. Lambeth, Benjamin S. The Winning of Air Supremacy in Operation Desert Storm. Santa Monica: RAND, 1992.
2. Morocco, John D. "Grumman offers Tomcat 21 as alternative to Navy ATF." Aviation Week and Space Technology, 7 November 1988, pp. 18-19.
3. Morocco, John D. "Tomcat 21 will include technologies to reduce F-14's radar signature." Aviation Week and Space Technology, 22 May 1989, pp. 30-31.
4. Lohneiss, R. F-14D Quick Strike Plus. Grumman Aerospace Corporation briefing at Naval Air Test Center, Patuxent River, Maryland, 29 May 1991.
5. Kandebo, Stanley W. "Grumman makes 11th-hour offer to get F-14 into Fiscal '92 budget." Aviation Week and Space Technology, 6 May 1991, pp. 24-25.
6. Kandebo, Stanley W. "Grumman offers to field upgraded F-14s by 1996." Aviation Week and Space Technology, 25 October 1993, pp. 55-59.
7. Dwyer, K. R. and Troutman, M. D. Navy Technical Evaluation of the F-14A Air-to-Ground Weapons Compatibility, Sixth Report (Final). Naval Air Test Center, Patuxent River, Maryland Technical Report SY-189R-77, 7 February 1978.
8. Knowles, J. W.; Curbeam, R. L.; and Pratt, J. F-14A/B Air-to-Ground Weapons Separation (Phase I-MK 76, MK 80 Series), Final Report. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland Technical Report SA-107R-91, 3 May 1993.
9. Curbeam, R. L. and Neel, M. F-14A/B Air-to-Ground Weapons Separation (Phase II-Cluster Munitions), Final Report. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland Technical Report SA-9R-93, 22 March 1993.
10. Neel, M. F-14A/B Air-to-Ground Phase Two (GBU-16), Third Interim Report. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland Technical Report SA-186R-94, 27 July 1994.
11. Ferguson, C. et al. F-14D Pre-Deployment Update (PDU) Store Certification Program (Phase 0), Final Report. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland Technical Report SA-17R-94, 29 June 1994.

12. Lawson, L. F. et al. F-14 Night Vision System, First Interim Report. Naval Air Test Center, Patuxent River, Maryland Technical Report SA-14R-90, 18 March 1991.
13. Korry Electronics and Nightshield: F-14D Cockpit Upgrade Synopsis. Seattle: Korry Electronics, 16 December 1993.
14. Easter, M. and Klaasse, D. Quick Look Evaluation of Fitron Eleven F-14 NVG Cockpit Lighting Kit. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland, 1 February 1994.
15. Lukasik, R. and Klaasse, D. Second Interim Evaluation of Fitron Eleven F-14D NVG Cockpit Lighting Kit. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland, 6 January 1995.
16. Klaasse, D. and Lukasik, R. Third Interim Report on the NVIS Compatible Cockpit as Installed in the F-14D Aircraft. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland, 10 March 1995.
17. U.S. Congress. Naval Aviation: F-14 Upgrades are not Adequately Justified. United States General Accounting Office Report to Congressional Committees. Washington D.C.: General Accounting Office, 19 October 1994.
18. Wirt, Robert O. Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland. Interview 12 May 1995.
19. Morocco, John D. "War will reshape doctrine, but lessons are limited." Aviation Week and Space Technology, 22 April 1991, pp. 37-43.
20. Cohen, Eliot A., ed. Gulf War Air Power Survey. Vol. 4: Weapons, Tactics, and Training and Space Operations. Washington D.C.: Government Printing Office, 1993.
21. Winnefeld, James A.; Niblack, Preston; and Johnson, Dana J. A League of Airmen: U.S. Air Power in the Gulf War. Prepared for the U.S. Air Force. Santa Monica: RAND, 1994.
22. Cohen, Eliot A., ed. Gulf War Air Power Survey. Vol. 2: Operations and Effects and Effectiveness. Washington D.C.: Government Printing Office, 1993.
23. Cohen, Eliot A., ed. Gulf War Air Power Survey. Vol. 5: A Statistical Compendium and Chronology. Washington D.C.: Government Printing Office, 1993.
24. "Strategic campaign focused on targets and cut casualties, Pentagon maintains." Aviation Week and Space Technology, 27 January 1992, pp. 64-65.

25. Frostic, Fred. Air Campaign Against the Iraqi Army in the Kuwaiti Theater of Operations. Project Air Force. Santa Monica: RAND, 1994.
26. Dornheim, Michael A. "F-117A pilots conduct precision bombing in high threat environment." Aviation Week and Space Technology, 22 April 1991, pp. 51-53.
27. Lenorovitz, Jeffrey M. "Air crew training, avionics credited for F-15E's high target hit rates." Aviation Week and Space Technology, 22 April 1991, pp. 54-55.
28. Morocco, John D. "PGM strategy faces budget, technical traps." Aviation Week and Space Technology, 27 February 1995, pp. 43-47.
29. Braybrook, Roy. "On target! A review of precision air attacks in the Gulf War." Air International, October 1991, pp. 177-182.
30. Morocco, John D. "U.S. tactics exploit advances in avionics, air-to-surface weapons." Aviation Week and Space Technology, 18 February 1991, pp. 52-53.
31. Bond, David F. "Troop and materiel deployment missions central elements in Desert Storm success." Aviation Week and Space Technology, 22 April 1991, pp. 94-95.
32. Morocco, John D. "U.S. uses Gulf War to frame new strategy." Aviation Week and Space Technology, 17 January 1994, pp. 40-41.
33. Lambert, Mark, ed. Jane's All the World's Aircraft. Coulsdon, United Kingdom: Jane's Information Group Limited, 1977, 1993, 1994.
34. NATOPS Flight Manual Navy Model A-6E TRAM/KA-6D Aircraft. NAVAIR 01-85ADF-1. Philadelphia: Naval Air Technical Services Facility, 15 January 1992 (Change 3).
35. NATOPS Flight Manual Navy Model F/A-18A/B/C/D. NAVAIR 11-F18AC-NFM-000. Philadelphia: Naval Air Technical Services Facility, 15 August 1994 (Change 1).
36. Kochman, Steven G. Phase II-A Developmental Testing of the F/A-18D Night Attack Hornet Aircraft for the Night Attack Mission, Final Report. Naval Air Test Center, Patuxent River, Maryland Technical Report TPS-99R-91, 29 May 1991.
37. F/A-18D NAVFLIR Manual (171.8). Tustin, California: VMFAT-101, 22 August 1992.
38. F/A-18D TGT FLIR Manual (171.8.1). Tustin, California: VMFAT-101, 22 August 1992.

39. NATOPS Flight Manual Navy Model F-14A. NAVAIR 01-F14AAA-1. Philadelphia: Naval Air Technical Services Facility, 1 January 1989 (Change 1).
40. NATOPS Flight Manual Navy Model F-14B. NAVAIR 01-F14AAP-1. Philadelphia: Naval Air Technical Services Facility, 1 September 1987.
41. NATOPS Flight Manual Navy Model F-14D. NAVAIR 01-F-14AAD-1. Philadelphia: Naval Air Technical Services Facility, 15 September 1993 (Change 1).
42. NATOPS Flight Manual Performance Charts Navy Model F-14B/F-14D Aircraft. NAVAIR 01-F14AAP-1.1. Naval Air Technical Services Facility, 1 February 1992.
43. NATOPS Flight Manual Performance Charts Navy Model F/A-18A/B/C/D Aircraft. NAVAIR 01-F18AC-NFM-200. Naval Air Technical Services Facility, 15 January 1992.
44. Flood, Christopher H. Developmental Testing Phase IIA (DT-IIA) of the F-15E Airplane, Final Report. Naval Air Test Center, Patuxent River, Maryland Technical Report TPS-05R-91, 29 May 1991.
45. Scott, William B. "Lantirn provides breakthrough in night-fighting capabilities." Aviation Week and Space Technology, 25 April 1988, pp. 34-42.
46. Eddy, Michael J. Phase II-A Developmental Testing of the F-111F Airplane, Final Report. Naval Air Test Center, Patuxent River, Maryland Technical Report TPS-10R-90, 30 May 1990.
47. Silz, Richard. An Overview of the F-117A Avionics Flight Test Program. Presented to the 1992 Aerospace Design Conference, Irvine, California. Washington D.C.: American Institute of Aeronautics and Astronautics (92-1228). 3 February 1992.
48. Scott, William B. "F-15E's night attack capability assessed in low-level flight." Aviation Week and Space Technology, 30 April 1990, pp. 36-46.
49. F/A-18D: Introduction to the FLIR (171.7). Tustin, California: VMFAT-101, 27 June 1990.
50. Friedman, Norman. Desert Victory: The War for Kuwait. Annapolis: United States Naval Institute, 1991.
51. Anderberg, Bengt and Wolbarsht, Myron L. Laser Weapons: The Dawn of a New Military Age. New York: Plenum Publishing, 1992.

52. Stimson, George W. Introduction to Airborne Radar. El Segundo, California: Hughes Aircraft Company, 1983.
53. Laser Inertial Navigation System: LINS 300. Berkshire, United Kingdom: British Aerospace, 1988.
54. Seat, James C. and Morgenfeld, Thomas A. F-117A Flight Test Update. SETP 1994 Report to the Aerospace Profession: Thirty Eighth Symposium Proceedings. Lancaster, California: Society of Experimental Test Pilots, September 1994.
55. Morocco, John D. "Navy readies F-14 for 21st century." Aviation Week and Space Technology, 8 February 1993, pp. 36-38.
56. Holzer, Robert. "F-14 bomber conversion in danger." Navy times, 19 June 1995, p. 30.
57. System Description Report: F-14D Avionics, Radar and Engine Upgrade. New York: Grumman Aerospace Corporation, 1988.
58. Civilikas, R. "F-14D IRST." Tomcat News. Vol. 1, No. 2. Point Mugu, California: Pacific Missile Test Center, Winter 1990, pp. 9-11.
59. Night Vision Imaging Systems, NVIS Illumination and Korry's lighted displays. Seattle: Korry Electronics, 1991.
60. F/A-18D: Electro Optics and the Eye (171.3). Tustin, California: VMFAT-101, 1 December 1989.
61. F/A-18D: Introduction to Cats Eyes (171.4). Tustin, California: VMFAT-101, 14 November 1991.
62. Snedeker, John. Night Vision Goggle Training in Fixed Wing Aircraft. Patuxent River, Maryland: Naval Air Test Center, March 1987.
63. Kinney, R.; Price, S.; and Simpson, R. F/A-18C/D Night Attack Crew Station Lighting, Final Report. Naval Air Test Center, Patuxent River, Maryland Technical Report SY-11R-91, 24 May 1991.
64. F/A-18D: Night Attack Safety Considerations (172.5). Tustin, California: VMFAT-101, 10 June 1993.
65. Commander Strike Fighter Wing U.S. Pacific Fleet. Night Vision Goggle (NVG) Standard Operating Procedures. CSFWPACINST 3500.9. Lemoore, California: 29 July 1993 (Change 1).
66. Airborne Weapons/Stores Loading Manual: Navy Model F/A-18 Aircraft. NAVAIR A1-F18AE-LWS-000. Philadelphia: Naval Air Technical Services Facility, 1990.

APPENDIX A
F-14 AIRCRAFT AND SYSTEMS DESCRIPTION

F-14D Aircraft

The F-14D Super Tomcat is a two seat, twin engine, variable geometry wing, supersonic, carrier based, long range air superiority fighter, designed and manufactured by Grumman Aerospace Corporation. The F-14D was developed in the 1980s as an extensive upgrade to the F-14A/B. Upgraded items include new General Electric F110-GE-400 engines (also installed on the F-14B) and a digital avionics system. The aircraft was introduced into the fleet in 1992 and completed its initial deployment in 1994. Aircraft layout is depicted in Figure A-1. Significant external differences from the F-14A aircraft include different engine exhaust nozzles and a dual chin pod (depicted in Figure A-2) housing the television camera set (TCS) and infrared search and track system (IRSTS) under the nose of the aircraft. A comprehensive aircraft and system description is contained in Reference 41.

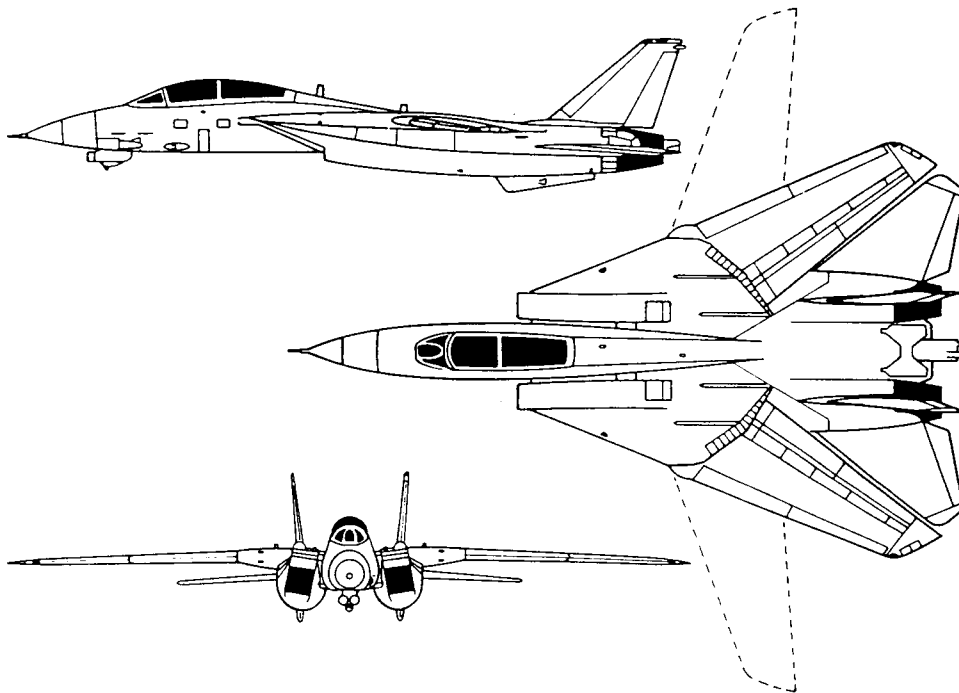


Figure A-1. F-14D aircraft layout. (Reference 41)

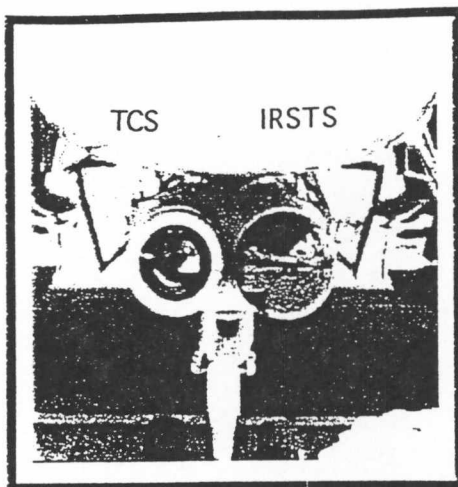


Figure A-2. F-14D dual chin pod (left), F-14A/B single chin pod (right). (Reference 11)

The F-14D enjoys a wide speed envelope due to variable geometry wings with leading and trailing edge high lift devices as well as variable geometry engine inlets. The General Electric F110-GE-400 engines are capable of producing 13,800 lb of thrust each at military power (full throttle) and 23,600 lb each in afterburner. The aircraft incorporates an irreversible, hydraulically powered flight control system with stability augmentation features. Aircraft empty weight is approximately 43,675 lb. Internal fuel capacity is 16,200 lb and maximum take off weight is 72,000 lb.

The Super Tomcat is optimized for the air-to-air mission, but also performs tactical reconnaissance and close air support. The aircraft is equipped with an internal 20 millimeter cannon and configured with eight external weapons stations for carriage of AIM-54 Phoenix, AIM-7 Sparrow, AIM-9 Sidewinder air-to-air missiles. Missile descriptions can be found in Appendix C. Stations 1A and 8A are limited to carriage of AIM-9

missiles, while stations 1B and 8B can carry any of the missiles and stations 3, 4, 5, and 6 are for AIM-54, AIM-7 or air-to-ground stores. Air-to-ground weapons including MK-80 series general purpose bombs, cluster munitions, and laser guided bombs (LGB) are authorized on the F-14A/B aircraft, while flight clearance for the F-14D is pending cluster munition and LGB testing and a new mission software release. The aircraft has two additional external stations (stations 2 and 7) under the engine nacelles for carriage of fuel tanks, providing an additional 3,800 lb of fuel. The Tactical Air Reconnaissance Pod System (TARPS) can be carried on station 5 for aerial reconnaissance missions. Weapon station configuration is the same for all versions of the F-14 and is depicted in figure A-3.

The F-14D weapon system is based around two digital mission computers and consists of the Hughes AN/APG-71 multiple mode radar, Litton AN/ASN-139 ring laser gyro inertial navigation system (INS), AN/ALR-67 radar warning receiver, digital AN/AYQ-15 stores management set (SMS), IRSTS, TCS, joint tactical information distribution system (JTIDS), and various controls and displays. An avionic system diagram is depicted in Figure A-4.

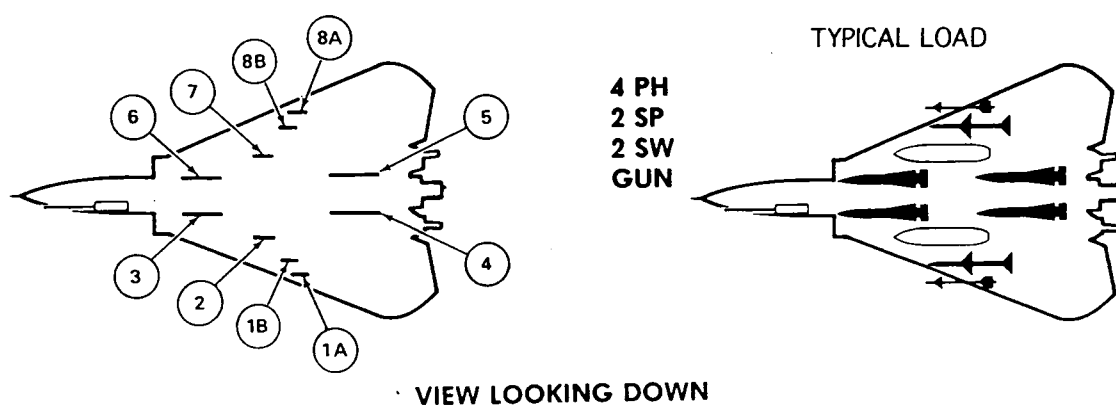


Figure A-3. F-14A/B/D weapons stations. (Reference 41)

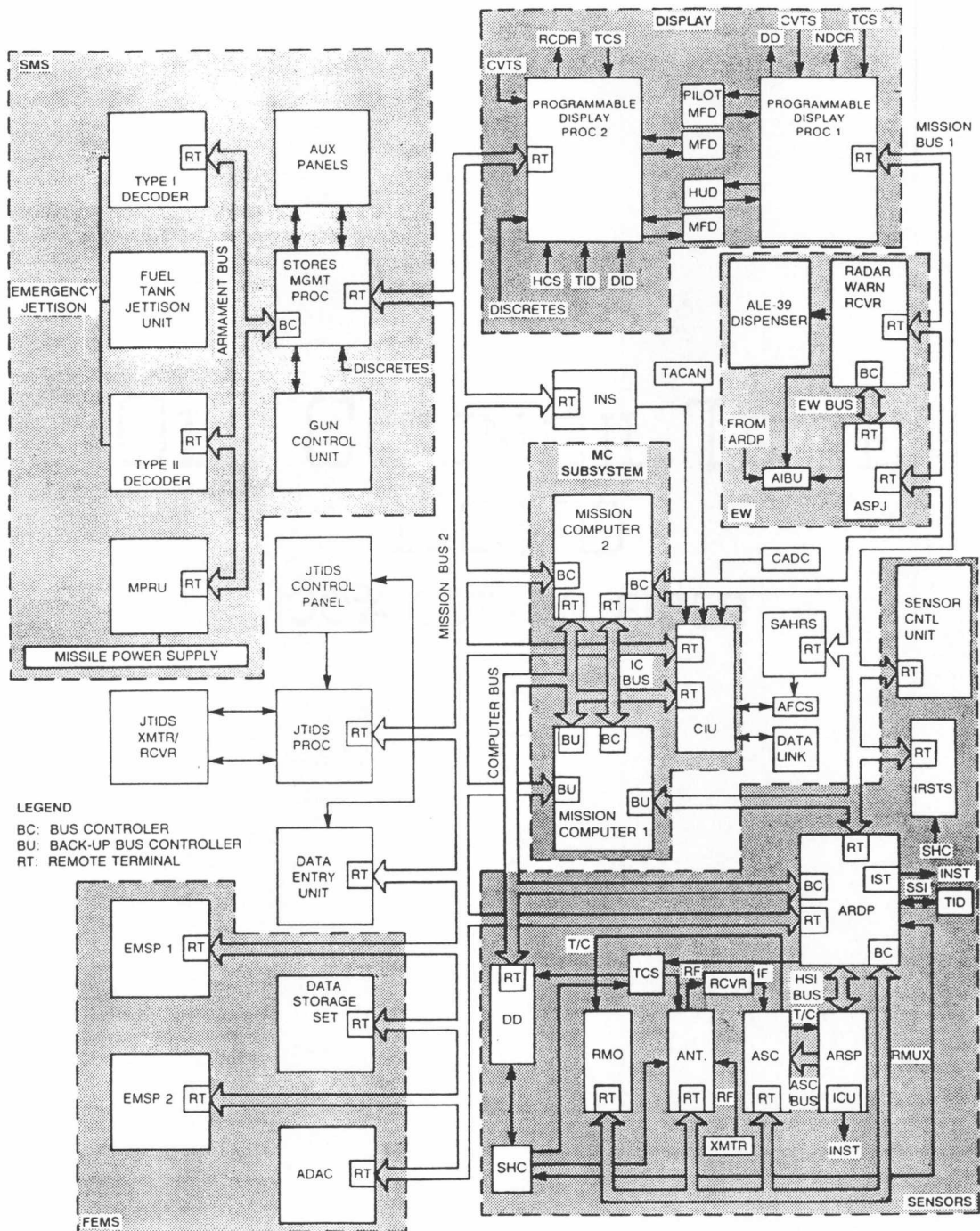


Figure A-4. F-14D avionics system diagram. (Reference 41)

Mission Computers

The F-14D's dual mission computers (MC1 and MC2) interface with subsystems via three separate dual redundant MIL-STD-1553B data buses, each capable of addressing up to thirty remote terminals. Each mission computer can act as a bus controller or remote terminal. The mission computers are common with those used in the F/A-18C. Aircraft functions which cannot be interfaced with the multiple 1553B buses are interfaced via a converter interface unit (CIU).

Radar

The AN/APG-71 is a multiple mode digital pulse doppler radar optimized for long range detection and targeting of airborne threats. It is a state of the art system providing multiple target tracking, electronic counter countermeasure (ECCM) techniques, and launch and guidance support for air-to-air missiles. The radar uses many of the digital elements of the F-15E's AN/APG-70 radar, including up to 85 percent commonality among standard replaceable assemblies. (Reference 6) The AN/APG-71 utilizes an advanced digital display (DD) for control and display functions and interfaces with TCS and IRSTS for slaving as well as displays. An air-to-ground mapping feature of the radar provides for coarse radar navigation via real beam ground mapping.

INS

The AN/ASN-139 is a ring laser gyro based INS, common to the F/A-18C. This INS is capable of alignment in 4-6 minutes, with a nominal drift rate of 0.8 nm per hour. (Reference 41) The AN/ASN-139 provides position and velocity information to the mission computers for

navigation and weapons control. A standard attitude heading reference system (SAHRS) is provided as a backup for the INS. A more detailed description of ring laser gyros is included in Chapter 6.

Radar Warning Receiver

The AN/ALR-67 is an advanced digital radar warning receiver, also common to the F/A-18C. The AN/ALR-67 provides 360 degree coverage to detect and identify hostile electromagnetic emissions from airborne interceptors, surface fire control systems and surface-to-air missiles. The AN/ALR-67 interfaces with the Avionics data bus and provides various warning tones and displays to the aircrew.

Stores Management

The AN/AYQ-15 SMS, also common to the F/A-18C, 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, 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 weapon stations via separate MIL-STD-1553B data buses. SMS weapons selection and control is accomplished via a rear cockpit armament panel, pilot control stick switches, and multi-function displays (MFD) in either cockpit. (Reference 57)

Infrared Search and Track

The IRSTS is a passive infrared scanner optimized for the 8-12 micron waveband. The sensor is housed in the left side of the

aircraft's dual chin pod. It is optimized for air-to-air detection and is capable of detecting aircraft skin friction heating in addition to engine exhaust energy. (Reference 58) The sensor is capable of single target track and track-while-scan (for multiple targets) 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 feature with two levels of zoom and can be used to identify air or ground targets. IRSTS, radar, and TCS can be slaved interchangeably, but no method is currently available to slave the IRSTS to a ground or INS target.

Television Camera

The TCS is a contrast seeking television camera system, housed in the right side of the dual chin pod. The system has two selectable fields of view (FOV), providing up to ten times magnification, and is used primarily for identification of airborne targets. The system can be used in a limited capacity to identify ground targets, but must be slewed manually, which is difficult due to the restricted FOVs available.

Joint Tactical Information Distribution System

The JTIDS is a high capacity information distribution system providing jam-resistant, cryptologically secure digital voice and data information for command, control and communication, relative positioning navigation and user community identification among all participants (aboard carriers, cruisers, destroyers, E-2C aircraft or the F-14D).

Individual participants are assigned time slots during which they can transmit or receive data on any one of 127 JTIDS nets. This pool of information is continuously updated by each participant and can be tapped to the degree desired by any participant. Probably the biggest advantage offered by the JTIDS is the situational awareness provided to all participants as they can see the positions of other friendly platforms, as well as targets detected by those other platforms. A relay function provides the capability for JTIDS to retransmit voice or data messages for extended range communications. JTIDS also internally computes relative navigation and position location information. All participants in the same net determine their relative position to each other. With data from multiple participants with equal or better position information plus navigation information from the INS and SAHRS, JTIDS can compute an excellent estimate of ownship position and velocities. (Reference 41)

Aircrew Displays

Aircrew controls and displays include a 20 degree (azimuth) by 17.3 degree (vertical) FOV heads up display (HUD) and two MFDs in the front cockpit as well as a tactical information display (TID) (common with the F-14A/B), DD, and single MFD in the rear cockpit. The HUD offers full flight reference information as well as targeting and radar warning data. The MFDs are common with those used in the F/A-18C and feature a monochrome display with stroke or raster options. Twenty pushbuttons around the edges of the MFDs offer a menu selection of display options for tactical or navigation use. Additionally TCS and IRSTS images may be displayed on any of the MFDs. The TID is limited to

TCS or a tactical (radar) type of display. Figures A-5 and A-6 depict the cockpit layout for the front and rear cockpits respectively.

Tactical Air Reconnaissance Pod

The TARPS consists of a rear cockpit control panel and a 1750 lb non-jettisonable pod mounted on weapon station 5. The pod is capable of housing several different cameras capable of producing forward oblique, panoramic (horizon-to-horizon), and infrared images. The TARPS is used for order-of-battle generation, pre-strike and post-strike photography and maritime surveillance.

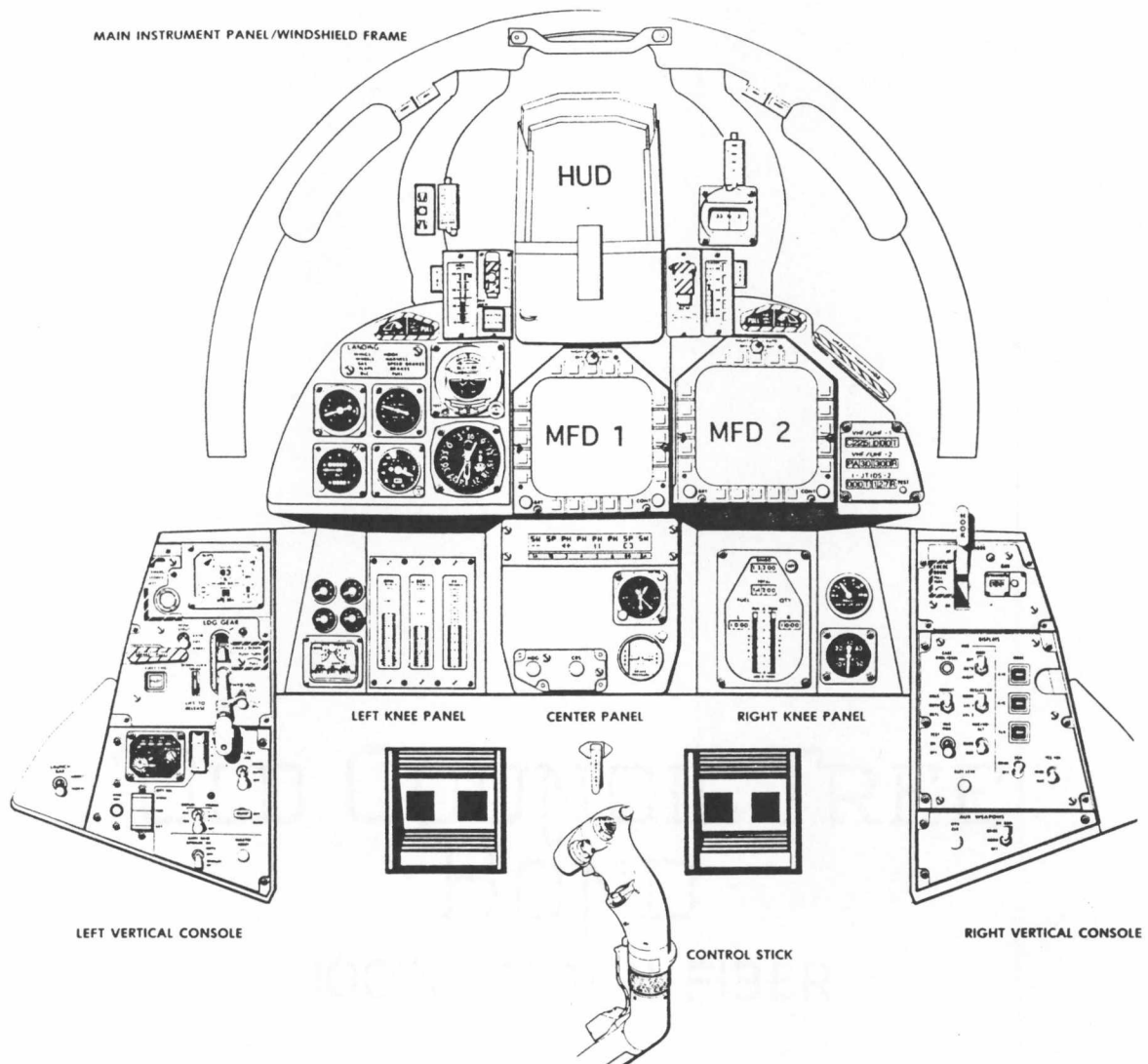


Figure A-5. F-14D front cockpit layout. (Reference 41)

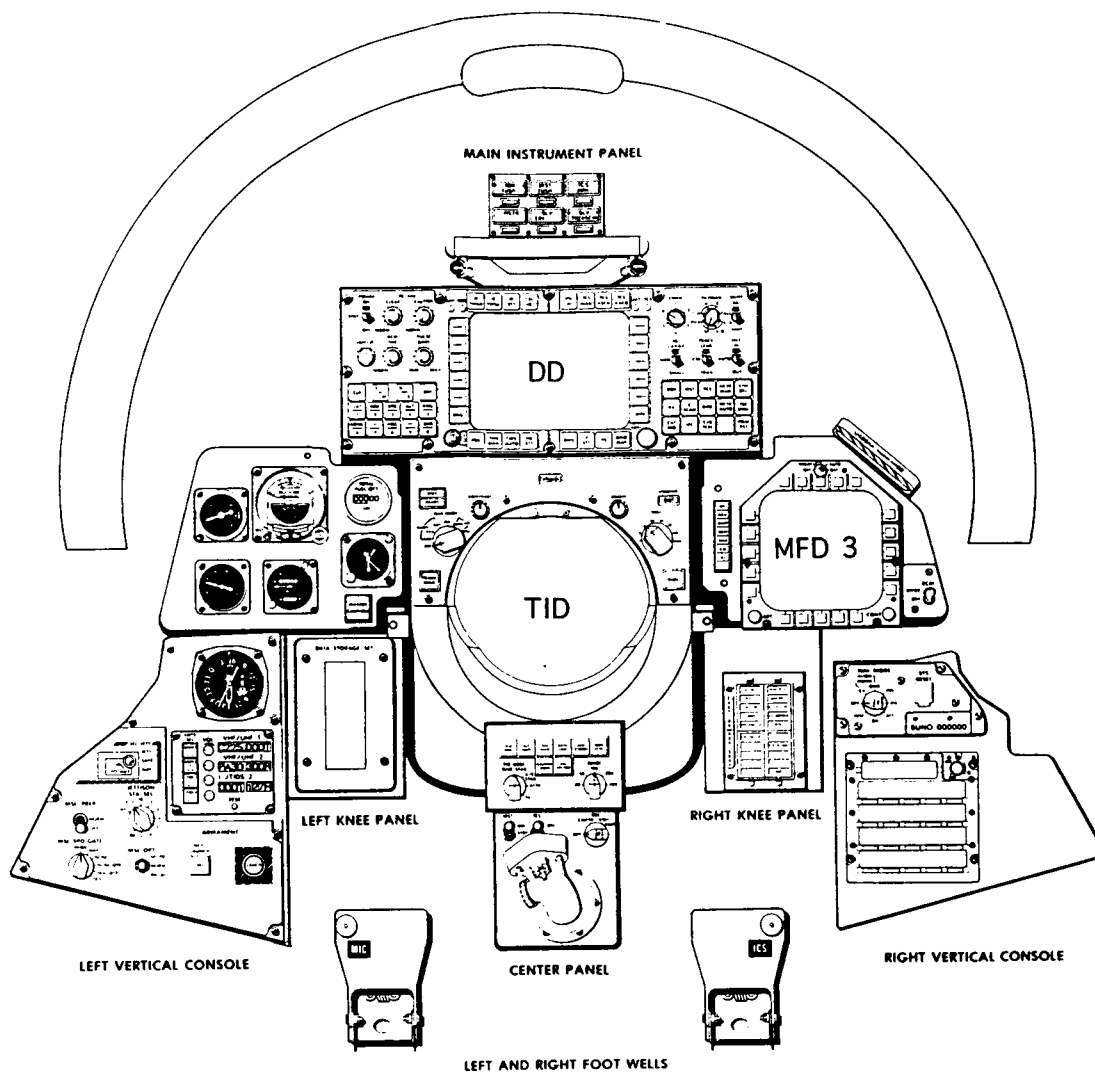


Figure A-6. F-14D rear cockpit layout. (Reference 41)

F-14A/B Aircraft

The F-14A/B aircraft and weapons system are described briefly in Chapter 4 and in detail in References 39 and 40. Significant weapon system differences from the F-14D include an analog avionics system, older generation (non-ring laser gyro) INS, single chin pod with TCS installed, and very limited aircrew displays. The pilot's HUD display contains basic attitude, steering and aiming information only and is not used as a primary flight reference instrument. Additionally, the pilot's vertical display indicator (VDI) is limited to an attitude display or TCS picture, while his horizontal situation display (HSD) can only show an HSD format, repeat of the rear cockpit TID, or a radar warning display. The rear cockpit displays feature the same TID as the F-14D, a multiple display indicator (MDI) capable of displaying an HSD format or radar warning display, and a digital data display (DDD) for displaying raw radar video. Figures A-7 and A-8 show the front and rear cockpit layouts.

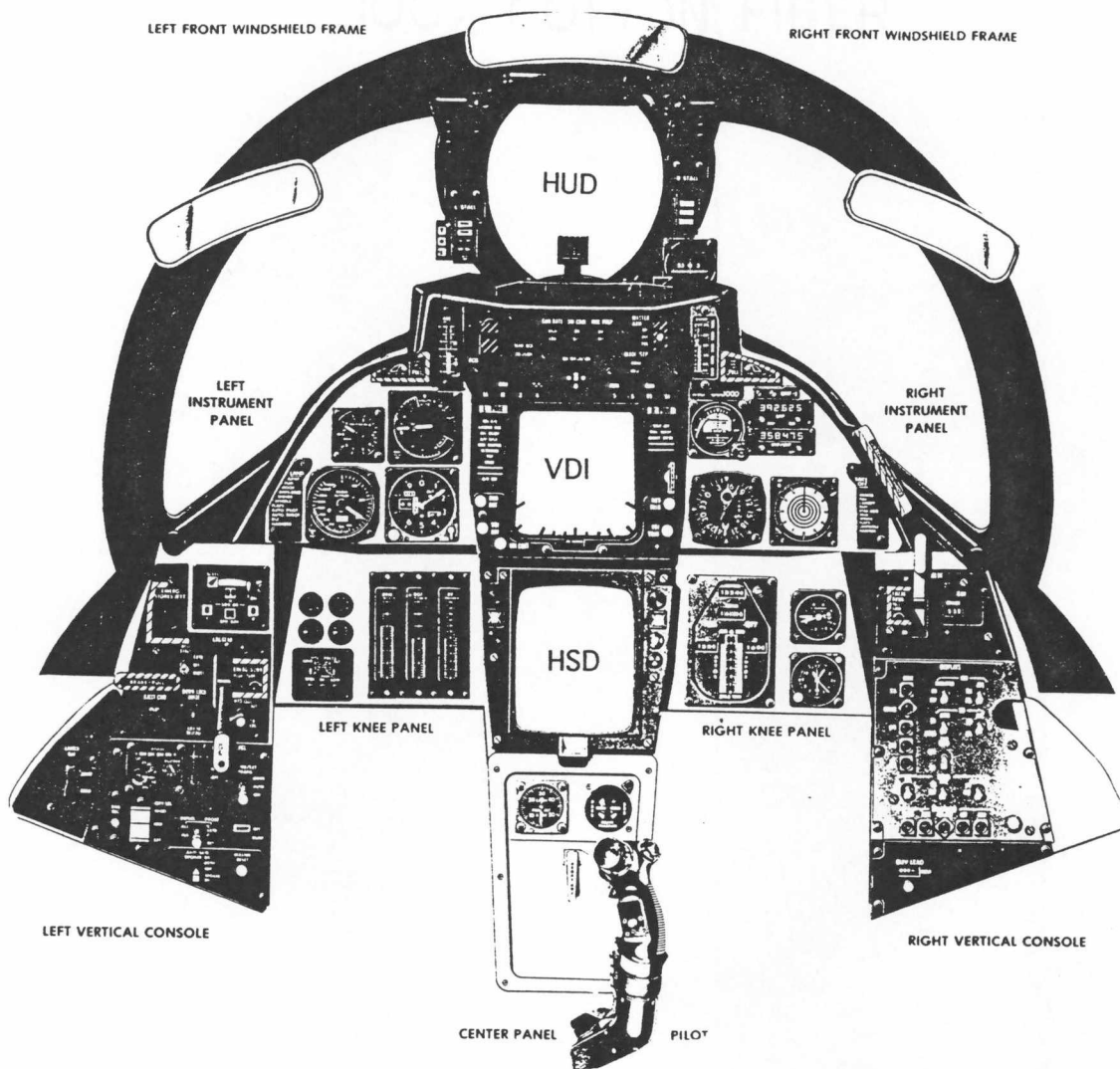


Figure A-7. F-14A/B front cockpit layout. (Reference 40)

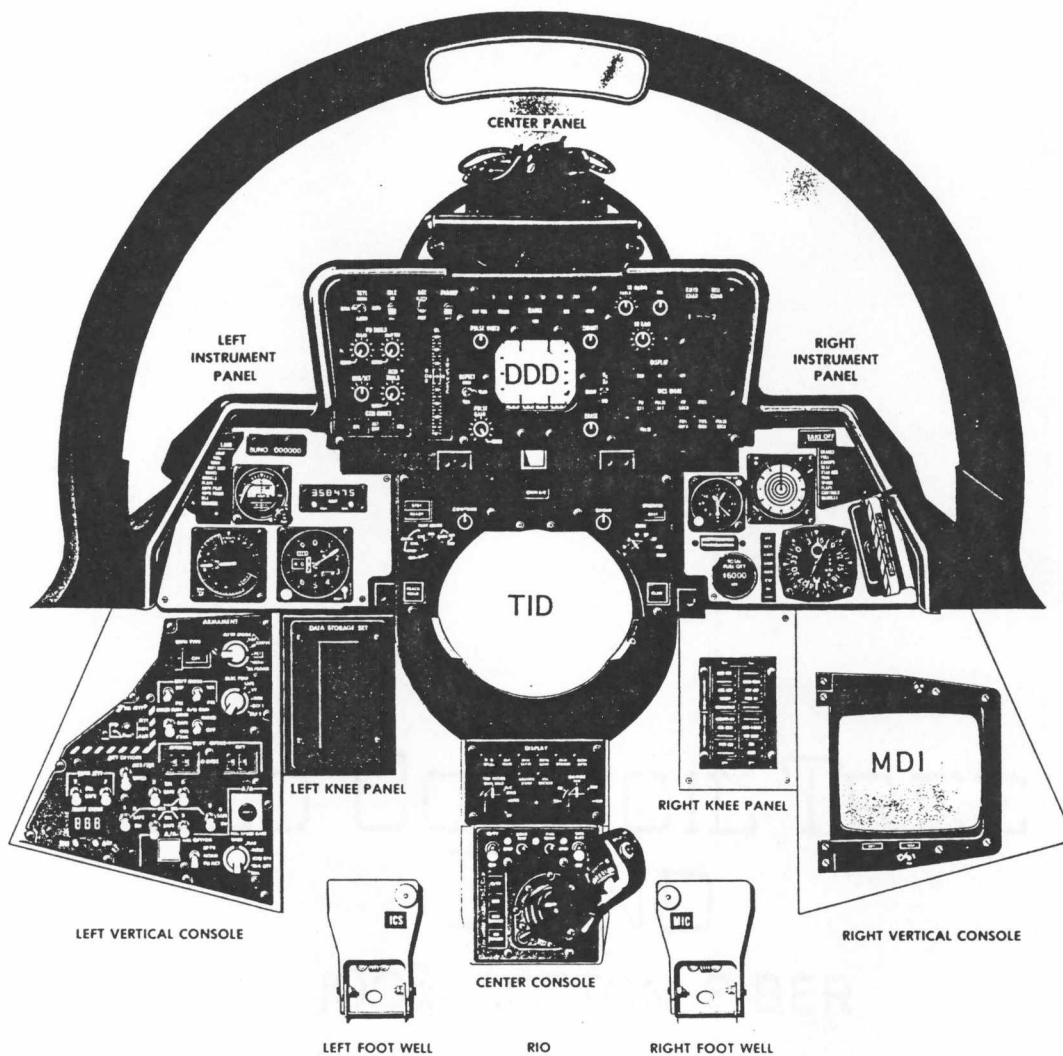


Figure A-8. F-14A/B rear cockpit layout. (Reference 40)

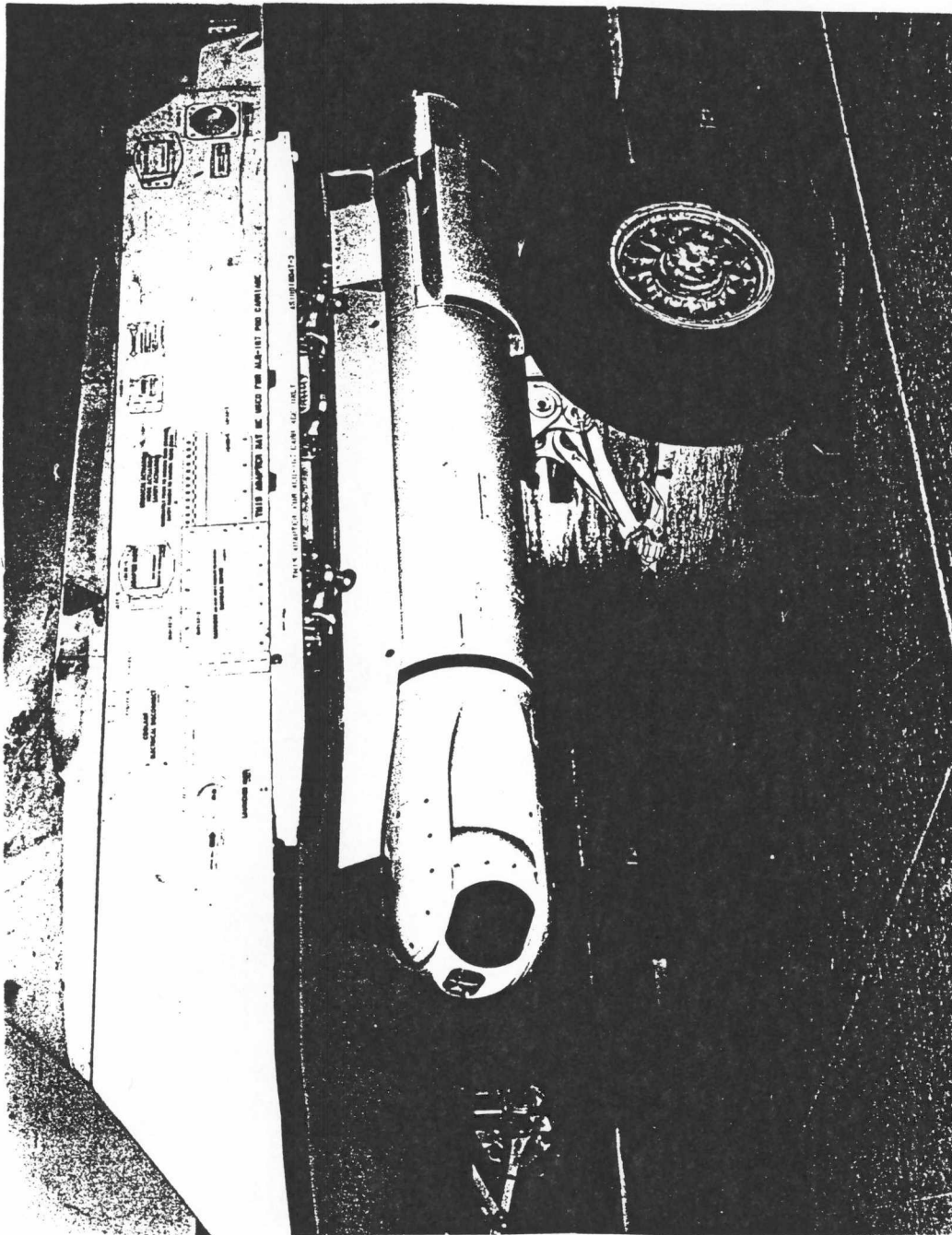


Figure A-9. F-14 station 1B loaded with AN/AAS-38A targeting FLIR and laser designator pod.

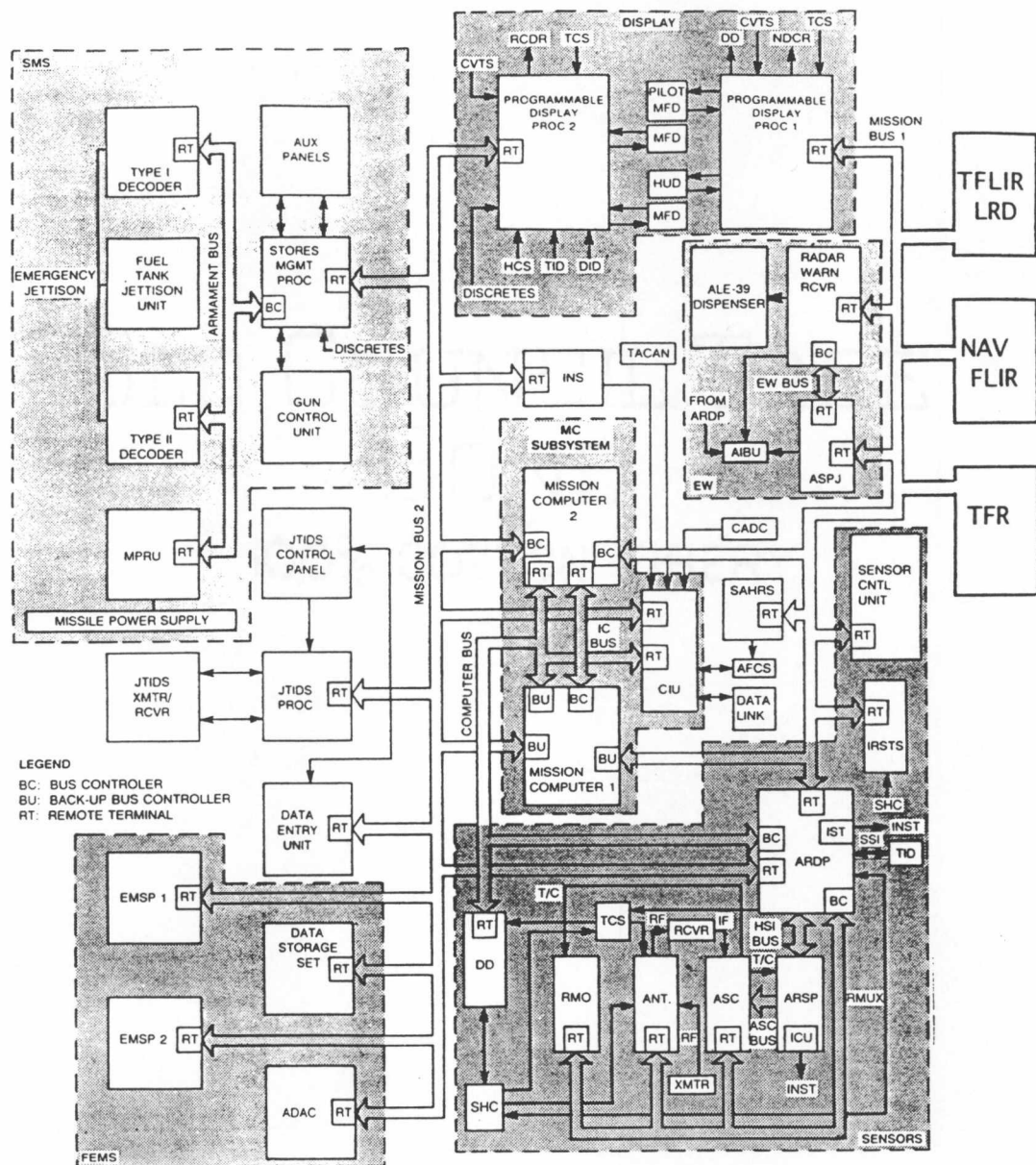


Figure A-10. Modified F-14D avionic system diagram.

APPENDIX B
NIGHT VISION IMAGING SYSTEMS

Night Vision Imaging Systems

Night Vision Imaging Systems (NVIS) have been used to enhance night situational awareness in Naval aircraft for almost ten years. NVIS are currently used on A-6E, F/A-18C/D, and Marine AV-8B aircraft and have been approved for limited introduction in the F-14D.

For Navy purposes, NVIS simply consists of an aircraft with night vision compatible lighting and an aircrew with Night Vision Goggles (NVG). Current Naval aircraft use the MXU-810/U Mark IV Cats Eyes NVG manufactured by GEC Avionics of the United Kingdom. The Cats Eyes will be described in detail after a discussion of how they work.

NVGs work simply by amplifying existing light and near infrared radiation up to 30,000 times and displaying it to the aircrew. The process is accomplished via an image intensifier tube, consisting of three basic parts. A photocathode receptor converts visible and infrared light energy into electrons. A microchannel plate multiplies the number of electrons emitted by the photocathode. Finally, green phosphor screen converts the electrons back into a correspondingly increased visible image. Figure B-1 is a diagram of an image intensifier tube. (Reference 59)

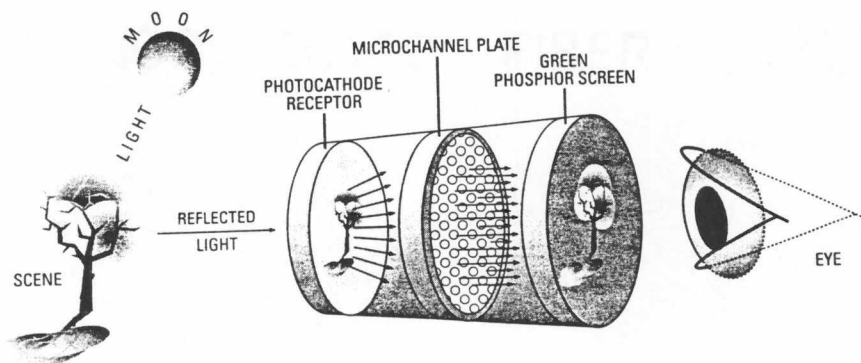


Figure B-1. Diagram of an image intensifier tube. (Reference 59)

The latest generation of image intensifiers is referred to as Generation 3 (GEN 3). GEN 3 tubes use gallium arsenide as a photocathode, which is sensitive not only to the visible portion of the electromagnetic spectrum, but its sensitivity peaks in the near infrared region. Figure B-2 depicts the electromagnetic spectrum and the region of sensitivity for GEN 3 image intensifiers (600-900 nanometers). This sensitivity makes the GEN 3 tubes far more useful for night vision than a device that just amplifies visible light. Many materials (including foliage, concrete and stone) reflect infrared energy more efficiently

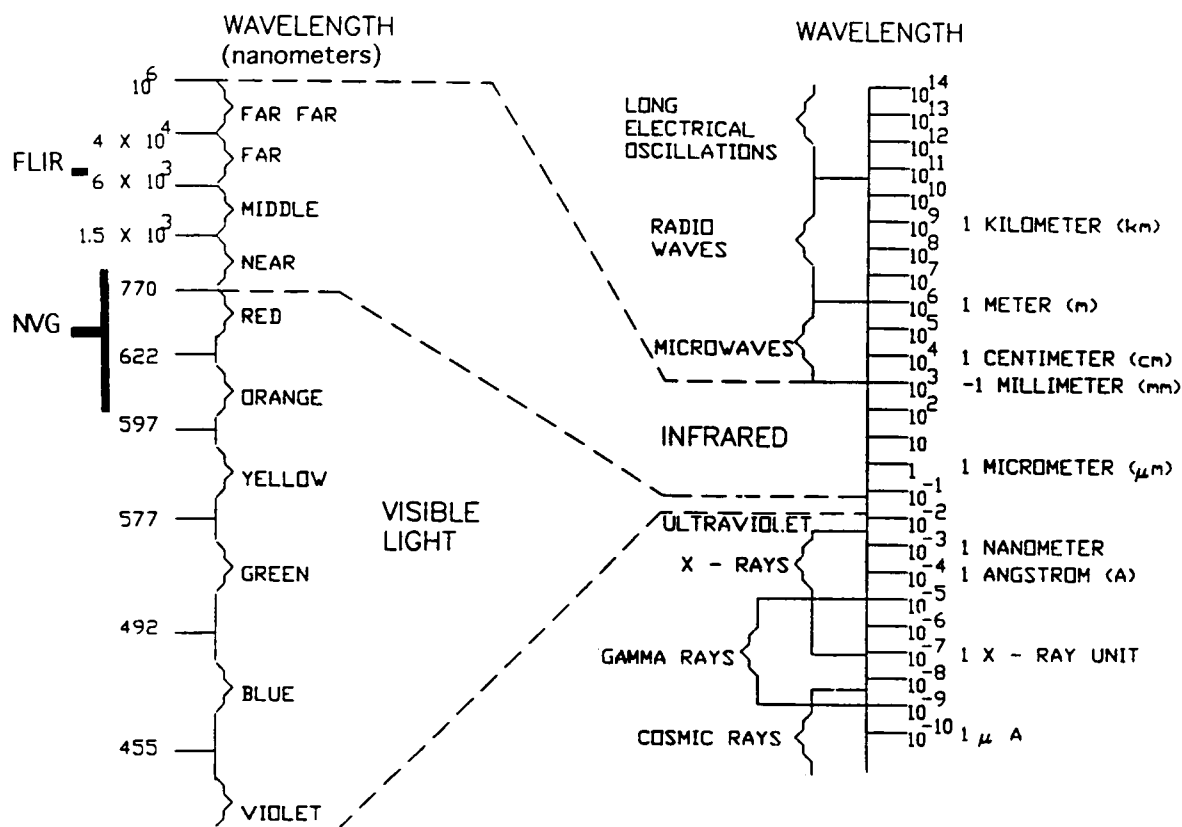


Figure B-2. Electromagnetic spectrum. (Reference 60)

than they do visible light. Additionally, the natural night sky spectral irradiance peaks in the near infrared region.

The Cats Eyes NVG (depicted in Figure B-3) use a "see through" design incorporating two small combiner glasses in front of the pilot's eyes. The image intensifier tubes are located 1.5 inches above the combiner glasses and the image is optically relayed to the combiner elements which act like a small HUD in front of each eye. The elements

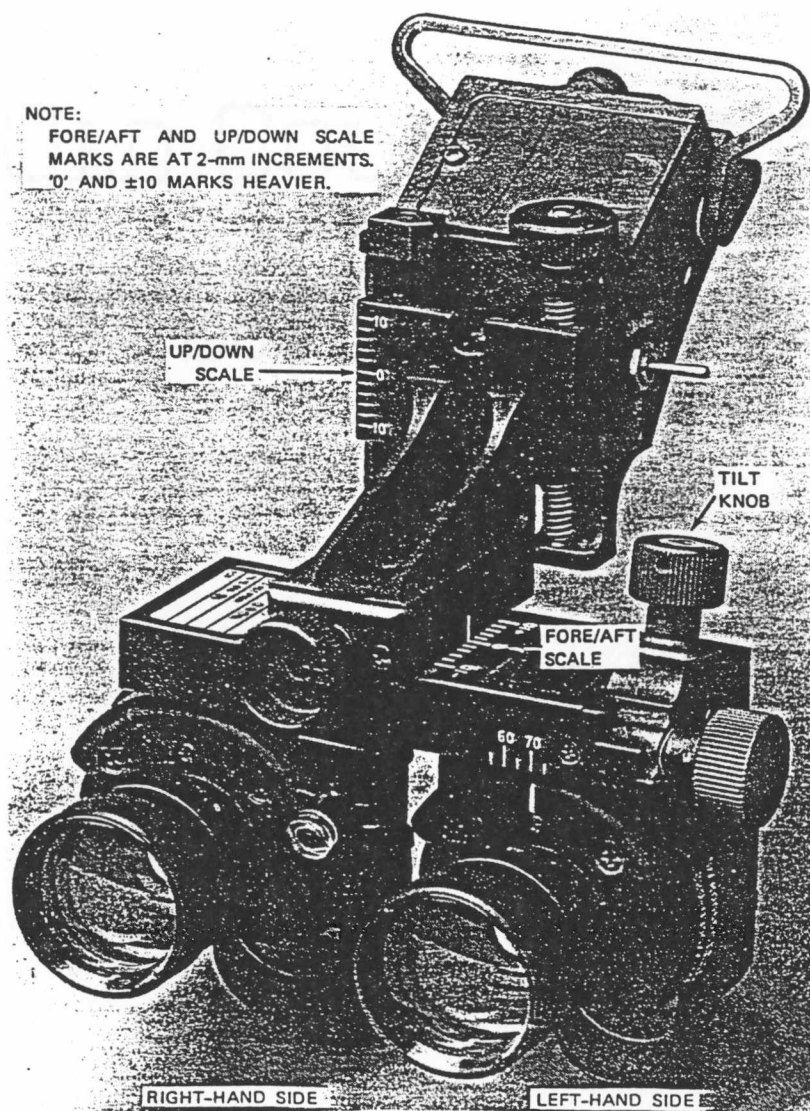


Figure B-3. Cats Eyes NVG. (Reference 36)

are thin enough for some ambient light to pass through and cockpit scanning can easily be accomplished by looking around or under the combiners. (Reference 61)

The Cats Eyes offer a maximum field of view of 30 degrees, and the intensified image is green in color. An automatic gain control is incorporated to reduce sensitivity when exposed to bright light or near infrared sources. Typical resolution degradation for an individual with 20:20 vision is on the order of 20:40 or worse when using NVGs. The Cats Eyes weigh 28 ounces and are mounted by snapping into a bracket installed on the pilot's helmet. Typical installation is depicted in Figure B-4.

In order to take advantage of the sensitivity of the GEN 3 tube and still be able to view cockpit instruments, some of the light reaching the tube must be filtered. The Cats Eyes utilize a filter to eliminate the shorter wavelengths in the visual spectrum (below 665 nanometers). (Reference 61) This effectively makes the Cats Eyes

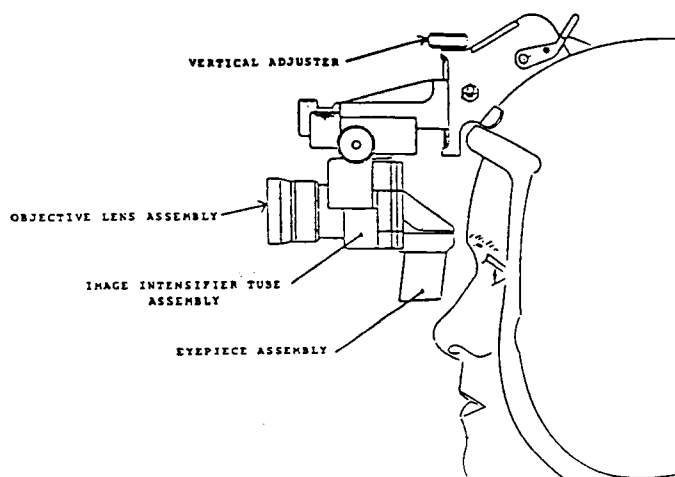


Figure B-4. Typical NVG installation. (Reference 62)

blind to blue-green wavelength light, which is used to illuminate cockpit instruments. The blue-green area of the spectrum also corresponds to the peak of the human eye's natural sensitivity at night (scotopic response), making it optimum for cockpit illumination. (Reference 59) Figure B-5 depicts response of GEN 3 tubes, and the relationship of night sky radiation, photopic response (day sensitivity), scotopic response (night sensitivity), and filtering.

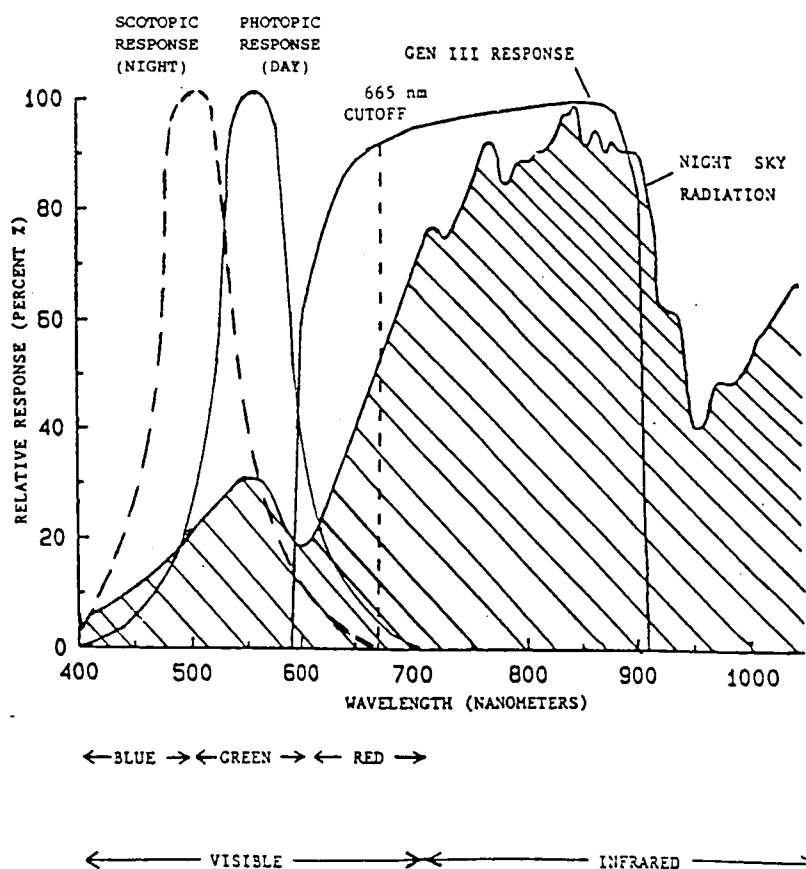


Figure B-5. Response of GEN 3 image intensifiers. (Reference 62)

Cockpit lighting is a key part of an effective NVIS installation. Any cockpit light or reflection within the sensitive range of the NVG's photocathode will be intensified and quickly saturate the goggles. Therefore NVIS compatible lighting typically consists of the aforementioned blue-green lights, their wavelengths being specifically beyond the filtered capability of the NVGs, so they don't affect performance.

While lighting may seem like a trivial issue, it is not. Traditional military cockpit lighting has been red in color (right in the middle of the NVG sensitive region). Additionally, many aircraft use integral lighting in displays and instruments, requiring significant modification to change their color (wavelength). One common fix for NVG operations adopted by the AV-8B Harrier and F-14D is to turn off normal cockpit lighting and illuminate cockpit controls and displays with blue-green floodlights. Aircraft HUDs must also be carefully adjusted or filtered to enable the NVGs to be used while looking through the HUD. While many current components are simply manufactured as NVG compatible, others require the addition of filters to fine tune the wavelength of the light they emit (the F-14D HUD is one example). The digital color map used in the F/A-18C is a good example of the precision which can be achieved with lighting and filtering. Using very specific wavelengths of light, the map includes special NVIS compatible yellow and red colors that are effectively filtered out by the 665 nanometer filter in the NVGs.

Aircraft windscreens and canopies can also severely impact the effectiveness of NVGs. Many windscreens are laminated, causing a substantial loss of transmissivity, which degrades the NVG picture by

reducing the available energy in the spectrum in which NVGs are sensitive. Add to this the need to look through a HUD combining glass along with its associated transmissivity losses, and the pilot's forward vision can be significantly impaired. Initial tests of the F/A-18C windscreen and HUD during NVIS integration revealed a combined degradation of 48 percent of transmissivity. (Reference 63)

No discussion of NVIS and NVGs would be complete without a few comments about meteorological conditions. As NVGs operate in the visible and near infrared spectrums, they depend almost exclusively on reflected energy (i.e. some source of illumination is required). Illumination is expressed in terms of lux (lumens per square meter) and is dependent on both natural and artificial sources. The best natural source is the moon, whose illumination depends on the lunar cycle and angle above the horizon. (Reference 64) Clouds, smoke, or haze affect NVGs at night just as they would affect normal vision during the day. Current Navy policies generally require a minimum of .0022 lux (equivalent to 20 percent moon at 30 degrees above the horizon) in order to fly on NVGs. However, with appropriate prerequisites, aircrews are allowed to fly in mean starlight conditions (less than 15 percent moon and less than .0022 lux). (Reference 65) Moonless nights can provide significant usable light for NVGs due to the large near infrared composition of night sky illumination.

APPENDIX C
WEAPON DESCRIPTIONS AND DELIVERY METHODS

Weapon Descriptions

General Purpose Bombs (GPB)

1. MK-82. Free fall, unguided 500 lb GPB. Low drag (conical) or high drag (snakeye) fin. Nose and/or tail fuse. See Figure C-1.
2. MK-83. Free fall, unguided 1,000 lb GPB. Low drag (conical) or high drag (parachute type) fin. Nose and/or tail fuse.
3. MK-84. Free fall, unguided 2,000 lb GPB. Low drag (conical) fin. Nose and/or tail fuse.
4. BLU-109/B (I-2000). Improved 2,000 lb steel encased bomb body designed as a penetrator with no forward fuse well. Always mated with laser guidance kits during Desert Storm. Tail fuse only.

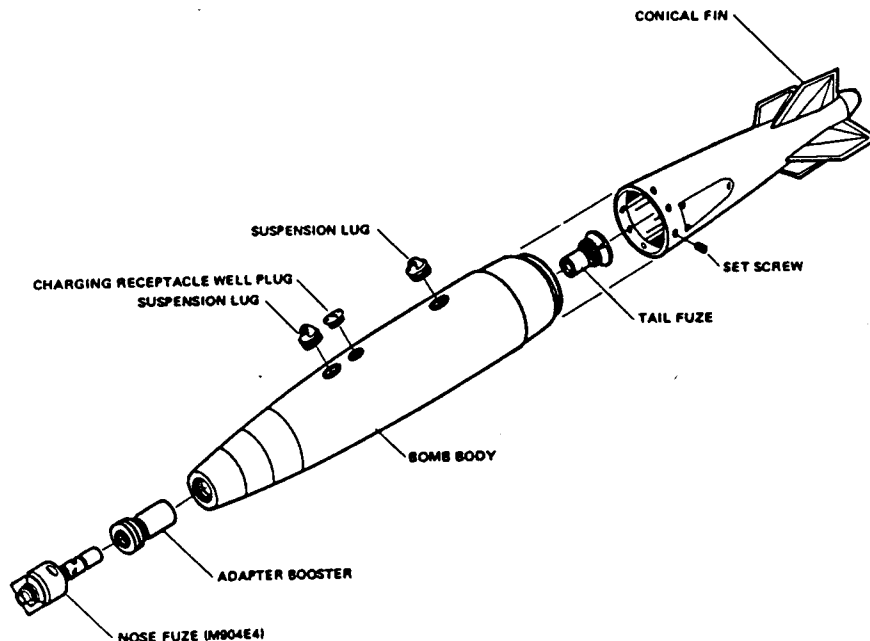


Figure C-1. Standard MK-80 series general purpose bomb configuration.

Laser Guided Bombs (LGB)

1. GBU-10. MK-84 (2,000 lb) GPB with laser guidance kit.
2. GBU-10I. BLU-109B bomb with laser guidance kit.
3. GBU-12. MK-82 (500 lb) GPB with laser guidance kit.
4. GBU-16. MK-83 (1,000 lb) GPB with laser guidance kit.
5. GBU-22. MK-82 (500 lb) GPB with improved low level laser guidance kit featuring larger wings, improved maneuverability and seeker sensitivity, and terminal trajectory shaping for vertical attacks. (Reference 29)
5. GBU-24. MK-84 or BLU-109B bomb with the same laser guidance kit improvements as the GBU-22.
6. GBU-27. BLU-109B bomb with low level laser guidance kit, modified GBU-24 seeker head, and smaller GBU-10 tail assembly necessary for internal carriage by the F-117A. (Reference 23)
7. GBU-28. Special deep bunker penetrator weighing 4,637 lb and fitted with GBU-27 LGB kits. Only two were dropped during Desert Storm, both by F-111Fs. (Reference 23)

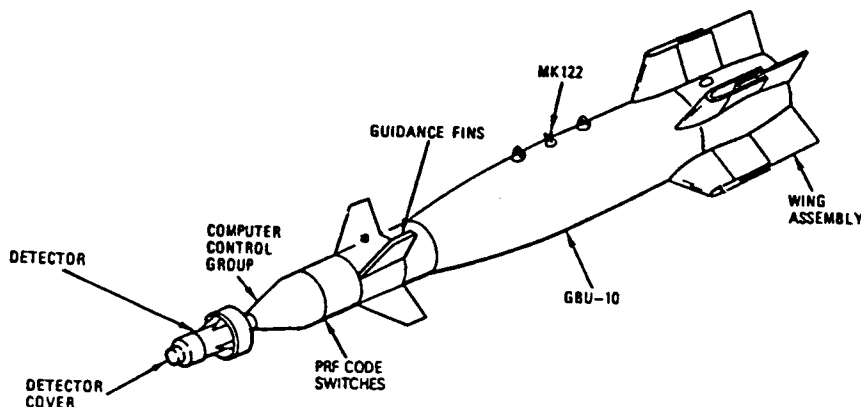


Figure C-2. Typical Laser Guided Bomb components. (Reference 66)

Air-to-Air Missiles (AAM)

1. AIM-9 Sidewinder. Supersonic passive-homing heat-seeking missile. Short range, but extremely fast. Guides on infrared radiation generated by a target. Launch and leave, requires no support once fired. Weighs 195 lb. Carried by most U.S. and NATO fighters.

2. AIM-7 Sparrow. Supersonic radar-guided missile. Medium range. Guidance is semiactive, utilizing continuous wave or pulse doppler energy from launching aircraft. Requires radar illumination of target throughout missile time of flight. Weighs 500 lb. Carried by most U.S. and NATO fighters.

3. AIM-120 AMRAAM. New generation radar homing missile designed to replace AIM-7. Medium range. Incorporates active radar homing in conjunction with an inertial reference unit. Capabilities enable simultaneous launch of missiles at multiple targets. Launch and leave, requires no support once fired. Weighs 333 lb. Carried by F/A-18C, some F-15 and F-16 aircraft.

4. AIM-54 Phoenix. First AAM to incorporate active radar seeker. Long range with semiactive and active seeker guidance options. Capabilities enable simultaneous launch of missiles at multiple targets. Launch and leave optional. Weighs 985 lb. Carried by F-14 only (up to six at a time).

Weapon Delivery Methods

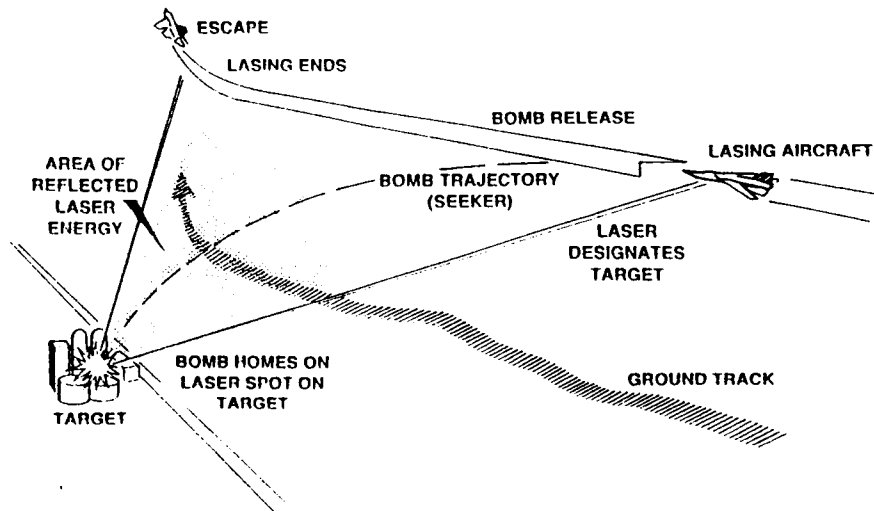


Figure C-3. Laser guided bomb release. (Reference 20)

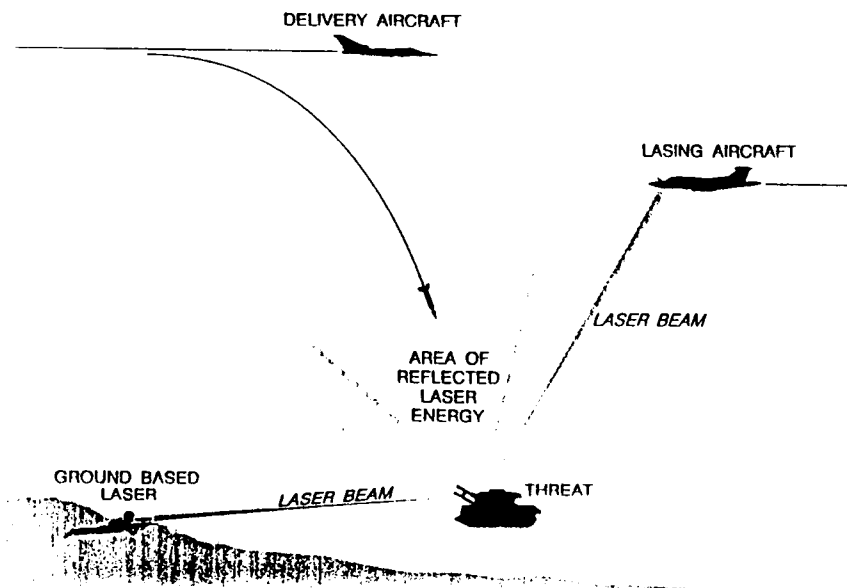


Figure C-4. Buddy lasing for LGB delivery. (Reference 20)

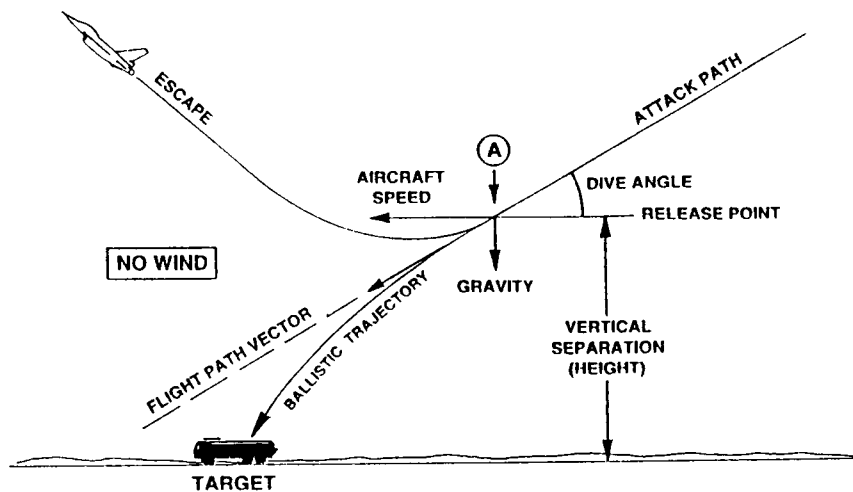


Figure C-5. Dive delivery of unguided weapons. (Reference 20)

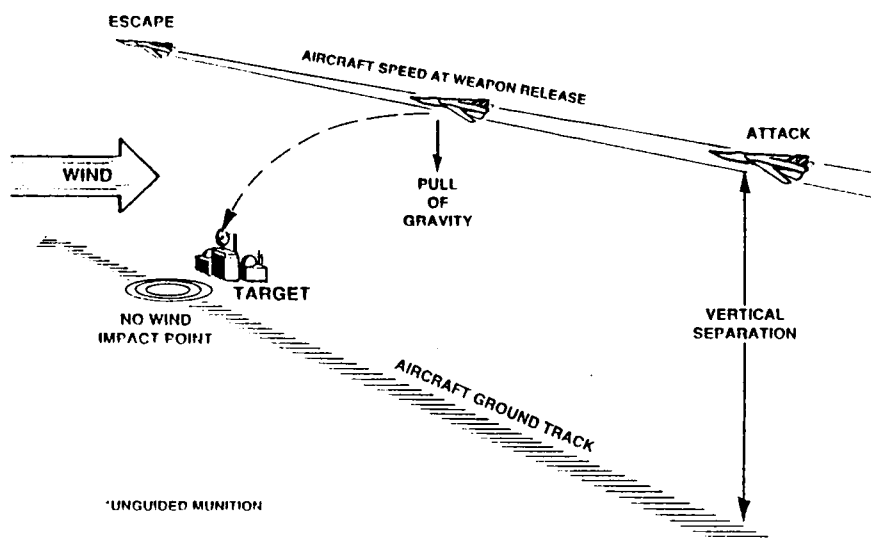


Figure C-6. Level radar delivery of unguided weapons. (Reference 20)

AREA PHOTO

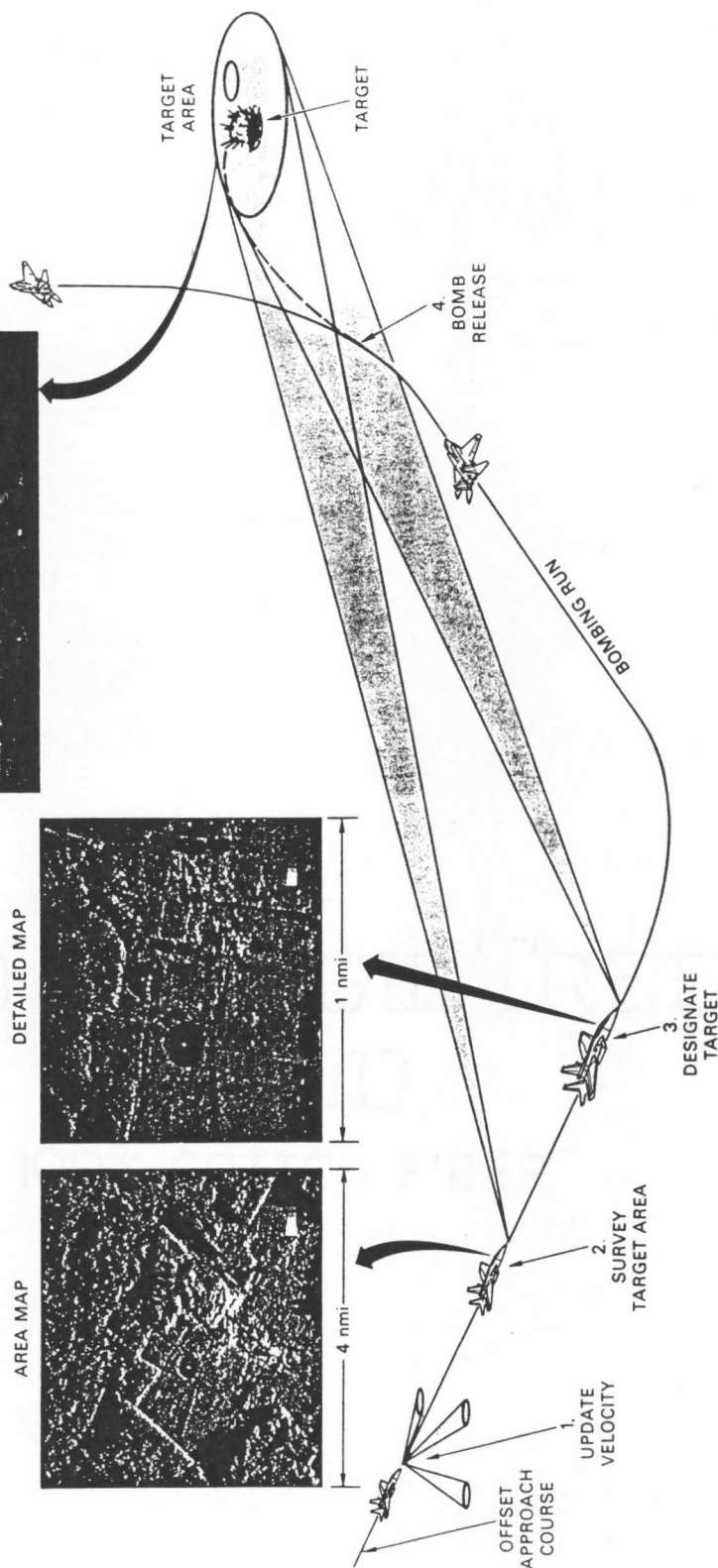


Figure C-7. Bombing run made with synthetic aperture radar. (Radar is only turned on three times: for velocity update, initial area map, and detailed map. Radar is off for final run-in and bomb release.) (Reference 52)

APPENDIX D
A-6E FIGURES

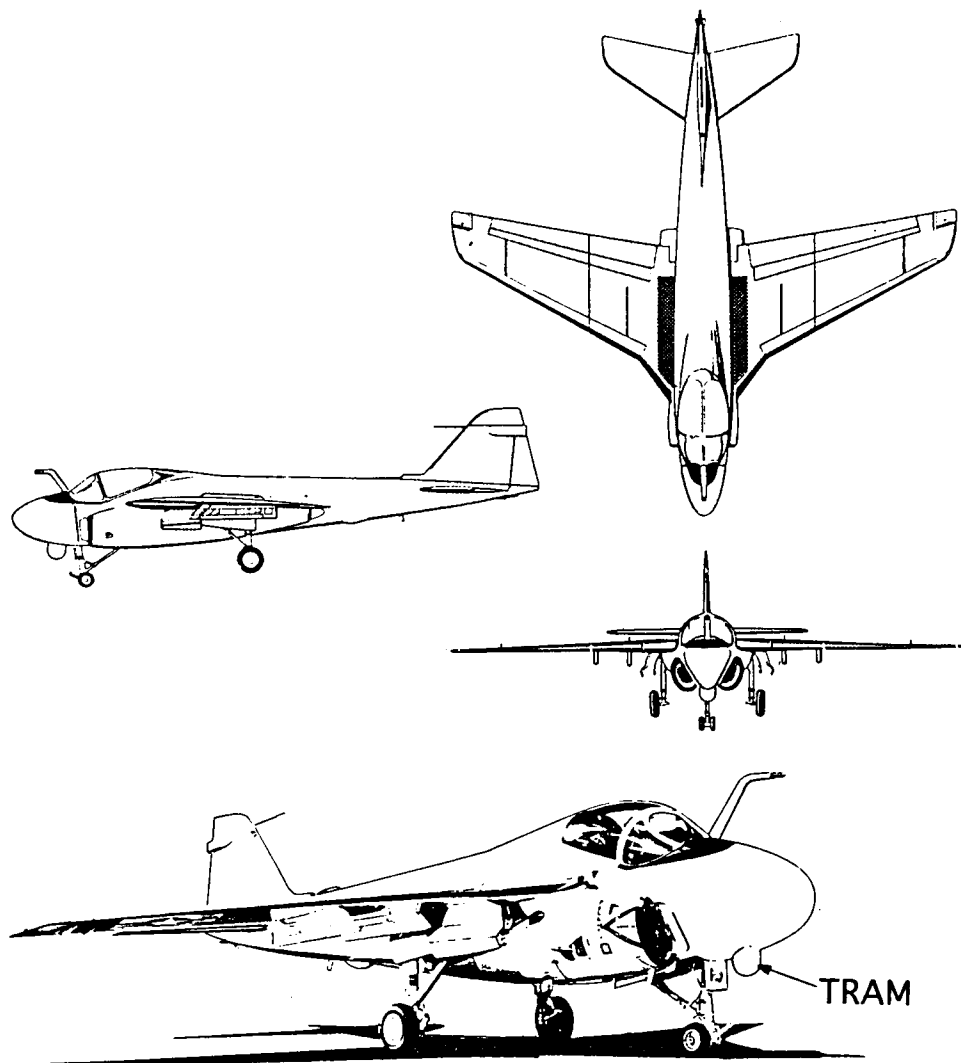


Figure D-1. A-6E aircraft layout. (Reference 34)

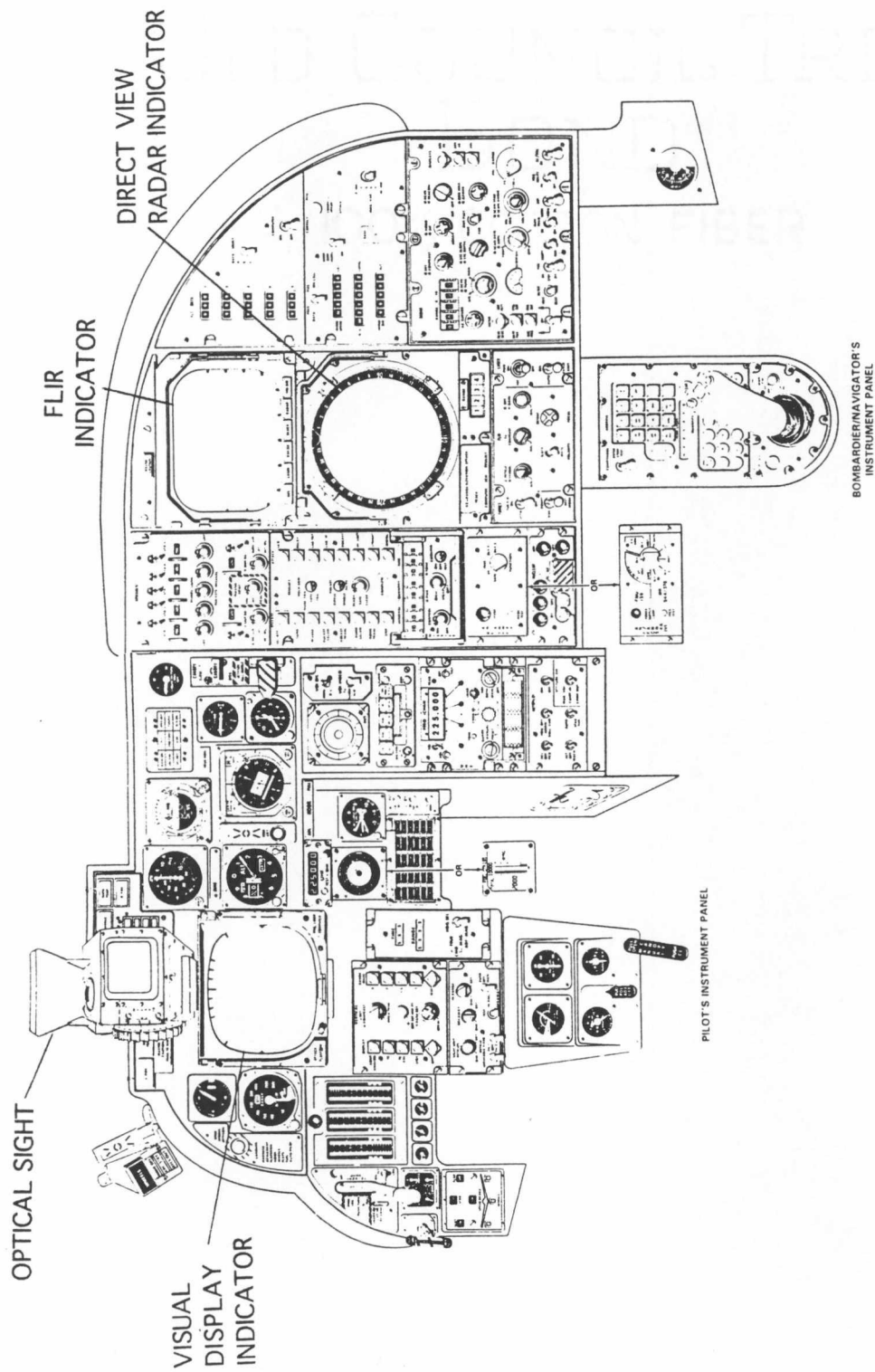


Figure D-2. A-6E cockpit layout. (Reference 34)

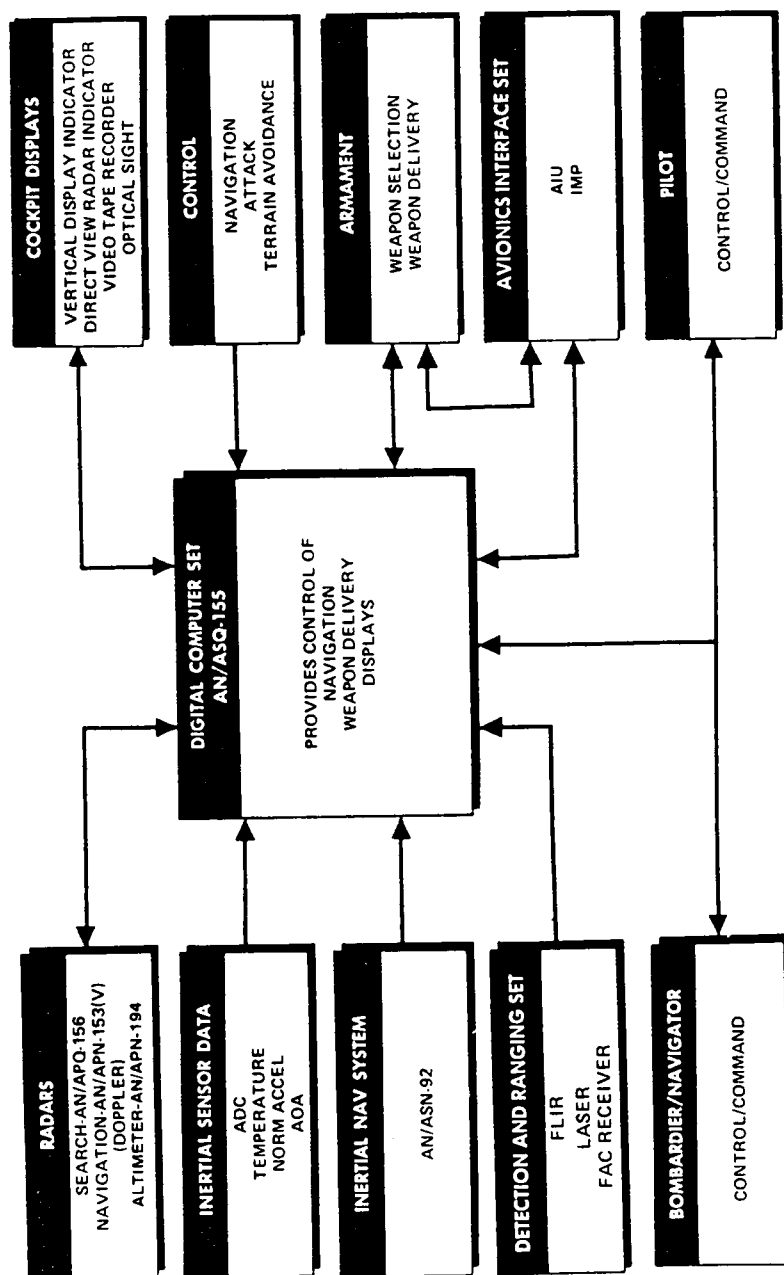


Figure D-3. A-6E avionics system diagram. (Reference 34)

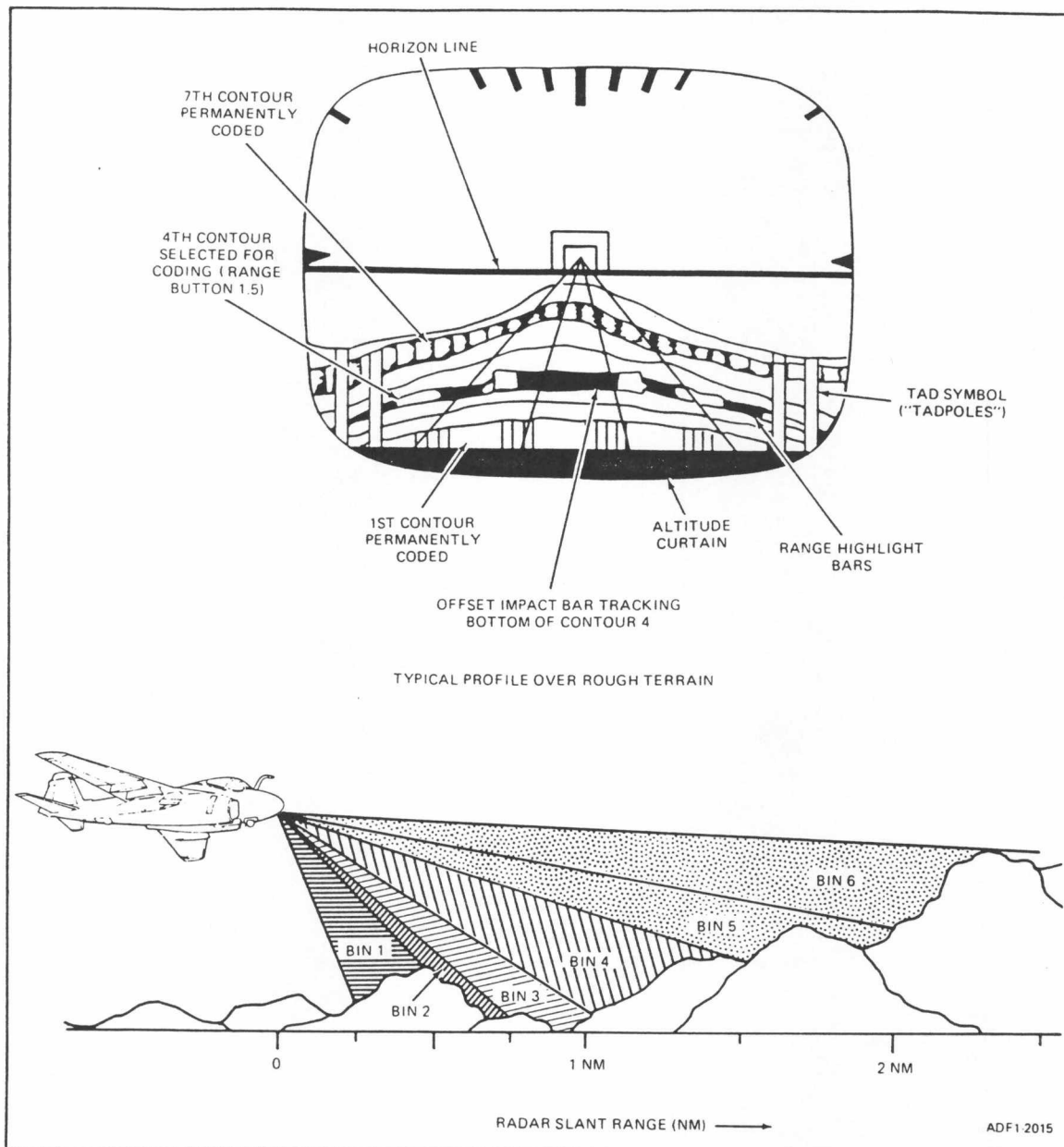


Figure D-4. A-6E terrain clearance display. (Reference 34)

APPENDIX E
F/A-18C FIGURES

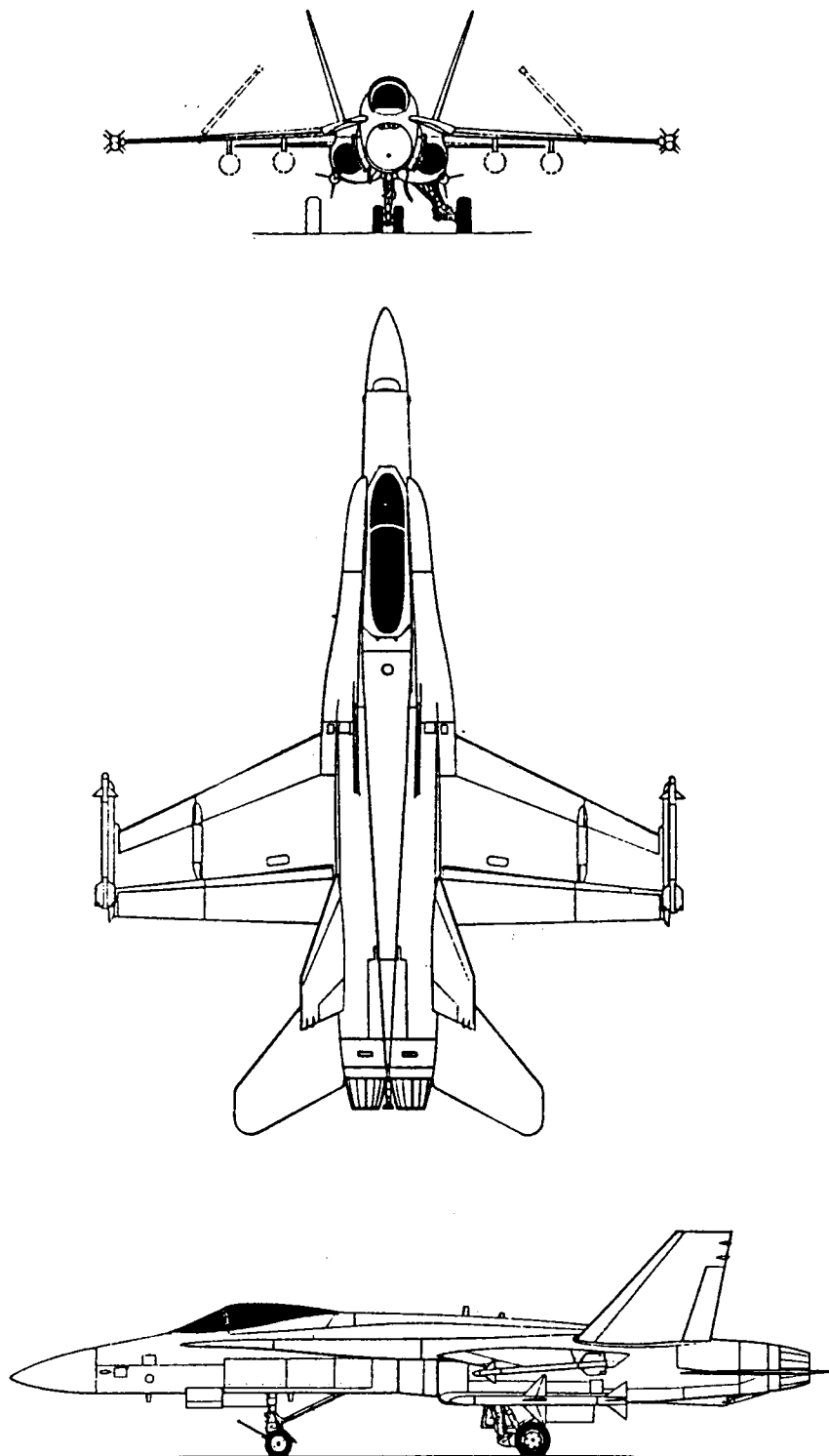
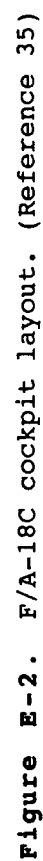


Figure E-1. F/A-18C aircraft layout. (Reference 33)



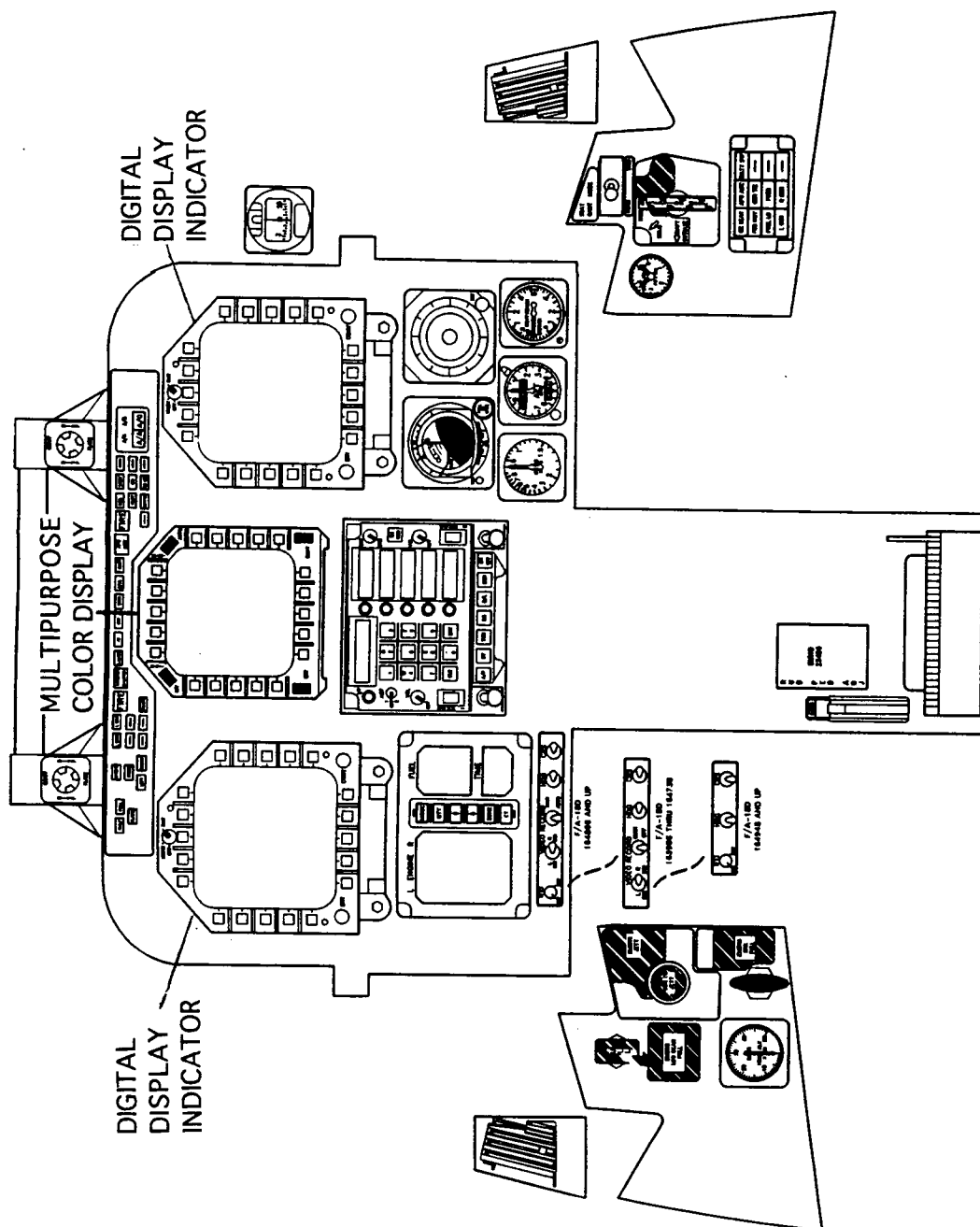


Figure E-3. F/A-18D rear cockpit layout. (Reference 35)

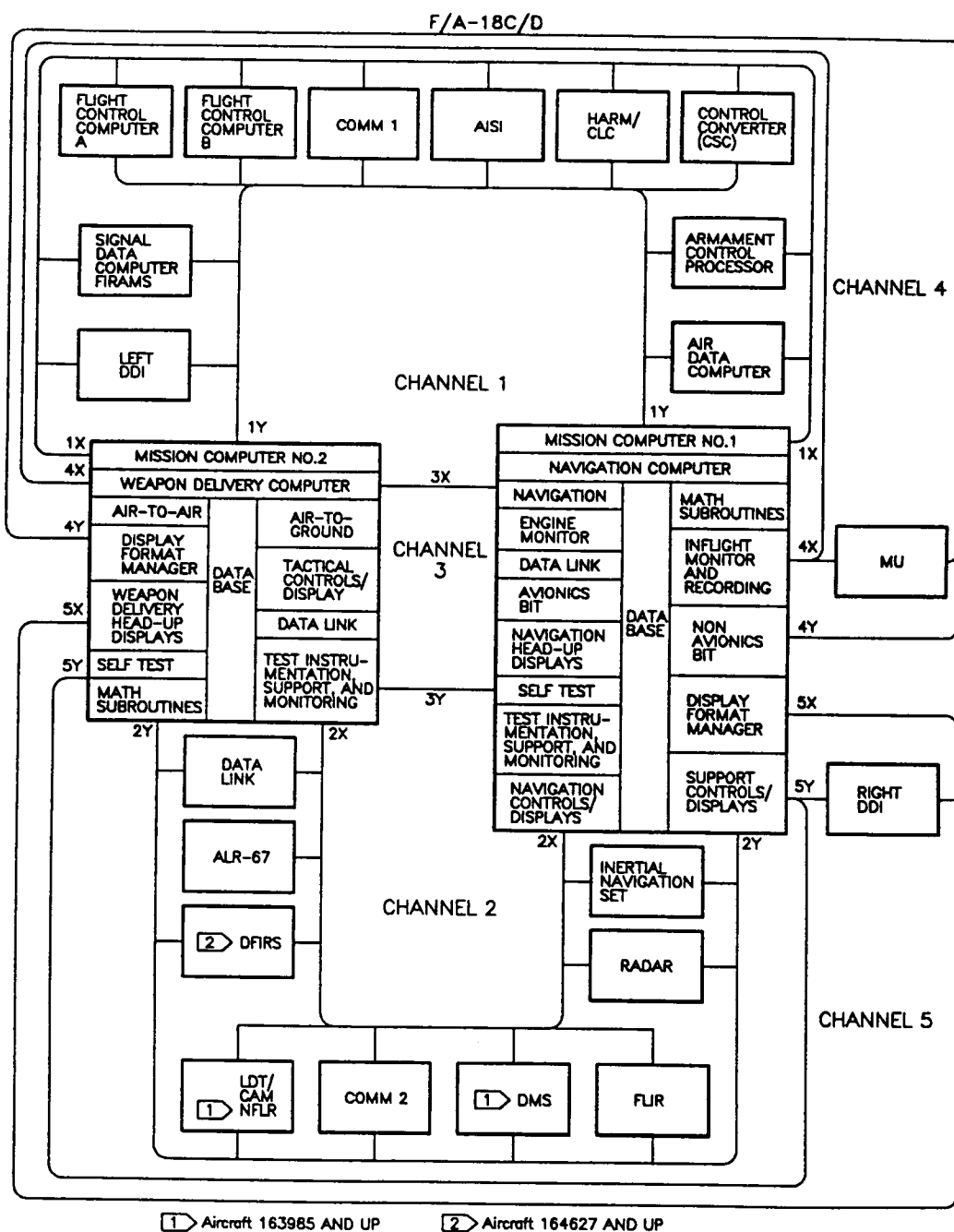


Figure E-4. F/A-18C avionic system diagram. (Reference 35)

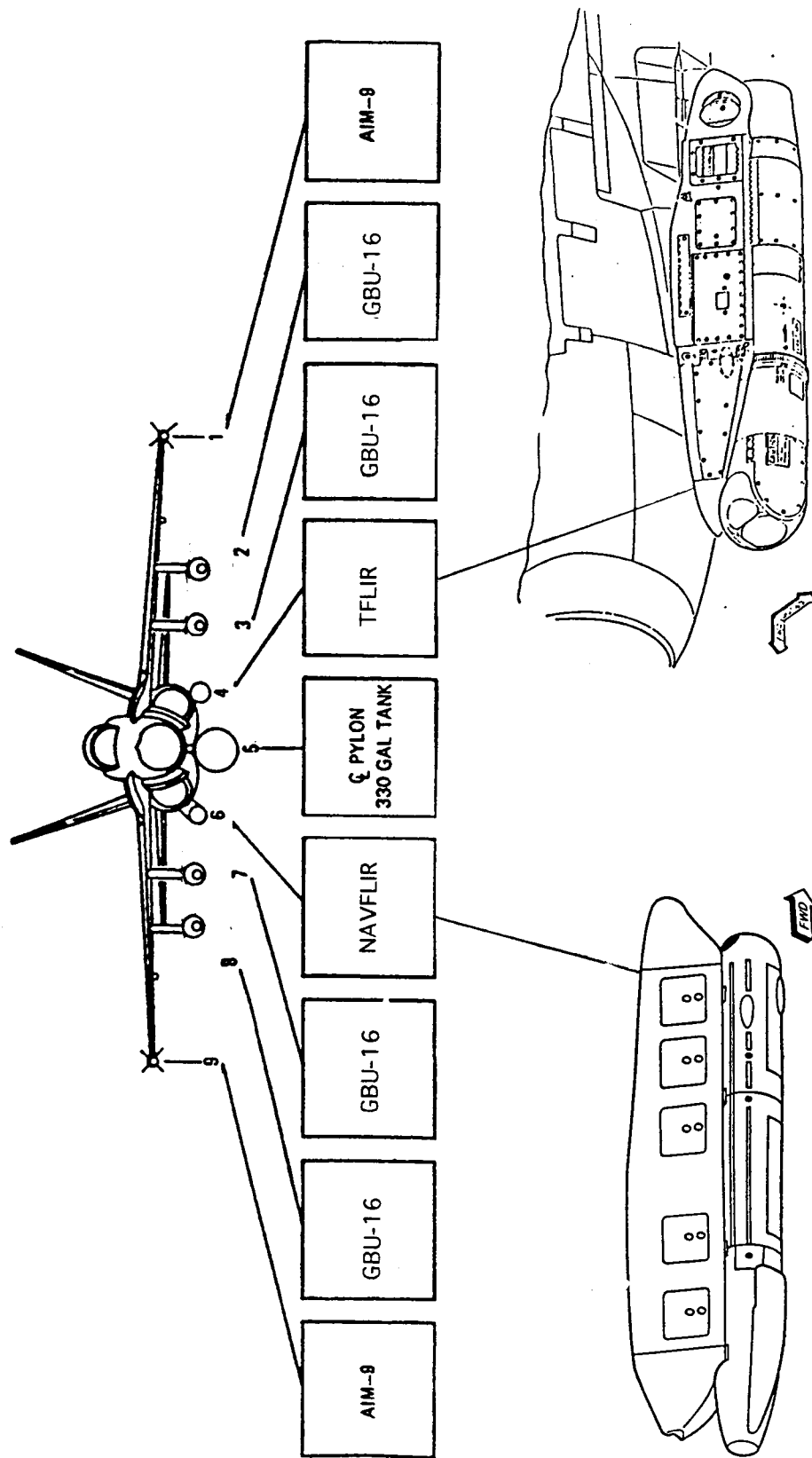


Figure E-5. F/A-18C weapon stations and FLIR pods. (References 36 and 43)

APPENDIX F
MISSION PROFILE COMPARISON DATA

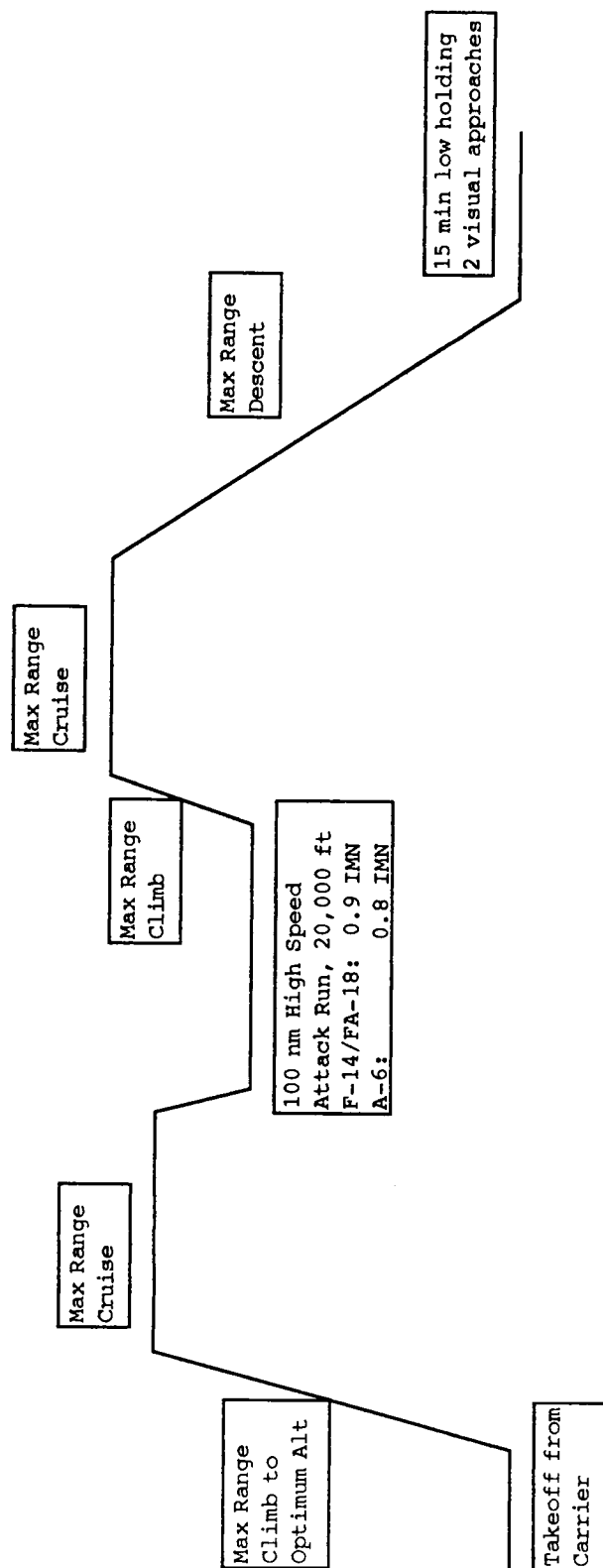


Figure F-1. High-Medium-High mission profile.

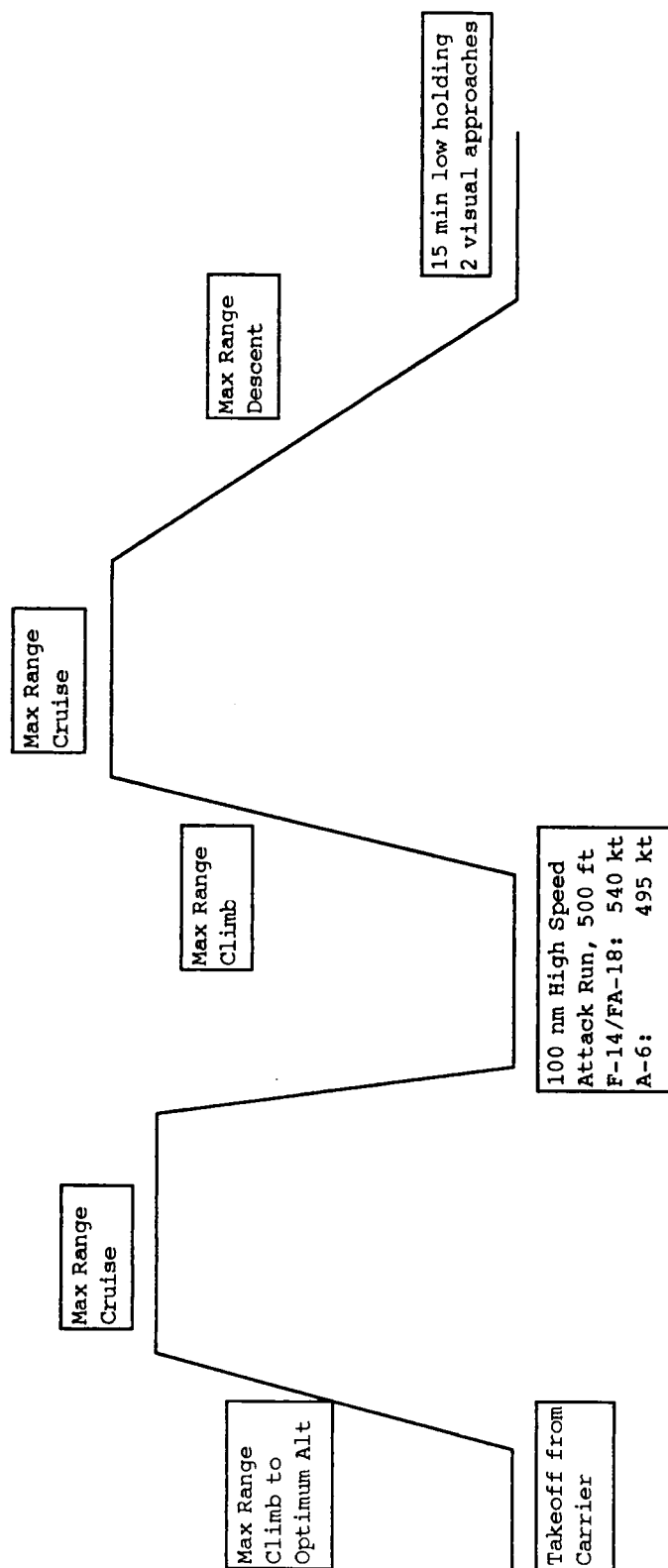


Figure F-2. High-Low-High mission profile.

AIRCRAFT: A-6E		PROFILE: HIGH-MEDIUM-HIGH	
LOADOUT:	4 x GBU-16	DRAG CT: 85	NO BOMB DRAG CT: 31
	1 x 300 gal tank		
EMPTY WT:	28,300		MAX T.O. WT: 58,600 lb
SUSPENSION EQUIP:	212		
WEAPONS:	4,440		
FUEL TANKS:	252		
FUEL:	<u>17,900</u>		
START WT:	51,104 lb		
<u>FLIGHT PHASE</u>		<u>FUEL (lb)</u>	<u>RANGE (nm)</u>
Start, taxi, takeoff		800	0
Max range climb			
270 KIAS to 0.7 IMN		2020	73
Max range cruise inbound			
33,000 ft MSL, 0.7 IMN		4732	454
Combat run			
20,000 ft MSL, 0.8 IMN		2000	100
Max range climb			
270 KIAS to 0.7 IMN		800	39
Max range cruise outbound			
40,000 ft MSL, 0.7 IMN		3498	454
Max range idle descent			
200 KIAS		500	105
Low alt holding for 15 min:			
200 KIAS		750	0
Pattern: 2 visual approaches		800	0
Min fuel on deck:		<u>2000</u>	<u>0</u>
TOTAL		FUEL 17,900	RANGE 1225
MISSION RADIUS: 612 nm			

Figure F-3. A-6E High-Medium-High mission performance.

AIRCRAFT: A-6E		PROFILE: HIGH-LOW-HIGH	
LOADOUT:	4 x GBU-16	DRAG CT: 85	NO BOMB DRAG CT: 31
	1 x 300 gal tank		
EMPTY WT:	28,300	MAX T.O. WT: 58,600 lb	
SUSPENSION EQUIP:	212		
WEAPONS:	4,440		
FUEL TANKS:	252		
FUEL:	<u>17,900</u>		
START WT:	51,104 lb		
<u>FLIGHT PHASE</u>		<u>FUEL (lb)</u>	<u>RANGE (nm)</u>
Start, taxi, takeoff		800	0
Max range climb 270 KIAS to 0.7 IMN		2020	73
Max range cruise inbound 33,000 ft MSL, 0.7 IMN		3592	345
Combat run 500 ft MSL, 495 KIAS/0.75 IMN		3333	100
Max range climb 270 KIAS to 0.7 IMN		1400	57
Max range cruise outbound 40,000 ft MSL, 0.7 IMN		2654	345
Max range idle descent 200 KIAS		500	105
Low alt holding for 15 min: 200 KIAS		750	0
Pattern: 2 visual approaches		800	0
Min fuel on deck:		<u>2000</u>	<u>0</u>
TOTAL		FUEL 17,900	RANGE 1025
MISSION RADIUS: 512 nm			

Figure F-4. A-6E High-Low-High mission performance.

AIRCRAFT: F-14D		PROFILE: HIGH-MEDIUM-HIGH	
LOADOUT:	4 x GBU-16	DRAG CT: 90	NO BOMB DRAG CT: 46
	2 x 280 gal tank		
	2 x AIM-9		
EMPTY WT:	43,735	MAX T.O. WT: 72,000 lb	
SUSPENSION EQUIP:	2,426		
WEAPONS:	4,830		
FUEL TANKS:	650		
FUEL:	<u>20,000</u>		
START WT:	71,641 lb		
<u>FLIGHT PHASE</u>		<u>FUEL(lb)</u>	<u>RANGE(nm)</u>
Start, taxi, takeoff		1200	0
Max range climb 0.72 IMN		1600	46
Max range cruise inbound 35,000 ft MSL, 0.72 IMN		5143	417
Combat run 20,000 ft MSL, 0.9 IMN		2222	100
Max range climb 0.73 IMN		700	30
Max range cruise outbound 38,000 ft MSL, 0.72 IMN		4385	417
Max range idle descent 210 KIAS		700	100
Low alt holding for 15 min: 220 KIAS		1250	0
Pattern: 2 visual approaches		800	0
Min fuel on deck:		<u>2000</u>	<u>0</u>
TOTAL		FUEL 20,000	RANGE 1110
MISSION RADIUS: 555 nm			

Figure F-5. F-14D High-Medium-High mission performance.

AIRCRAFT: F-14D		PROFILE: HIGH-LOW-HIGH	
LOADOUT:	4 x GBU-16	DRAG CT: 90	NO BOMB DRAG CT: 46
	2 x 280 gal tank		
	2 x AIM-9		
EMPTY WT:	43,735	MAX T.O. WT: 72,000 lb	
SUSPENSION EQUIP:	2,426		
WEAPONS:	4,830		
FUEL TANKS:	650		
FUEL:	<u>20,000</u>		
START WT:	71,641 lb		
<u>FLIGHT PHASE</u>		<u>FUEL(lb)</u>	<u>RANGE(nm)</u>
Start, taxi, takeoff		1200	0
Max range climb 0.72 IMN		1600	46
Max range cruise inbound 35,000 ft MSL, 0.72 IMN		4048	327
Combat run 500 ft MSL, 540 KIAS/0.82 IMN		3704	100
Max range climb 0.73 IMN		1250	41
Max range cruise outbound FL 38,000 MSL, 0.72 IMN		3448	327
Max range idle descent 210 KIAS		700	100
Low alt holding for 15 min: 220 KIAS		1250	0
Pattern: 2 visual approaches		800	0
Min fuel on deck:		<u>2000</u>	<u>0</u>
TOTAL		FUEL 20,000	RANGE 941
MISSION RADIUS: 470 nm			

Figure F-6. F-14D High-Low-High mission performance.

AIRCRAFT: F/A-18C		PROFILE: HIGH-MEDIUM-HIGH	
LOADOUT:	4 x GBU-16	DRAG CT: 99	NO BOMB DRAG CT: 61
	1 x 330 gal tank		
	2 x AIM-9		
EMPTY WT:	24,500	MAX T.O. WT: 51,900 lb	
SUSPENSION EQUIP:	1,668		
WEAPONS:	4,830		
FUEL TANK:	431		
FUEL:	<u>13,050</u>		
START WT:	44,479 lb		
<u>FLIGHT PHASE</u>		<u>FUEL (lb)</u>	<u>RANGE (nm)</u>
Start, taxi, takeoff		1100	0
Max range climb			
360 KIAS to 0.81 IMN		1400	54
Max range cruise inbound			
36,000 ft MSL, 0.82 IMN		2583	253
Combat run			
20,000 ft MSL, 0.9 IMN		1850	100
Max range climb			
0.83 IMN		540	36
Max range cruise outbound			
41,000 ft MSL, 0.83 IMN		1917	253
Max range idle descent			
212 KIAS		460	81
Low alt holding for 15 min:			
220 KIAS		900	0
Pattern: 2 visual approaches		800	0
Min fuel on deck:		<u>1500</u>	<u>0</u>
TOTAL		FUEL 13,050	RANGE 777
		MISSION RADIUS: 388 nm	

Figure F-7. F/A-18C High-Medium-High mission performance.

AIRCRAFT:	F/A-18C	PROFILE:	HIGH-LOW-HIGH
LOADOUT:	4 x GBU-16 1 x 330 gal tank 2 x AIM-9	DRAG CT: 99	NO BOMB DRAG CT: 61
EMPTY WT:	24,500	MAX T.O. WT: 51,900 lb	
SUSPENSION EQUIP:	1,668		
WEAPONS:	4,830		
FUEL TANK:	431		
FUEL:	<u>13,050</u>		
START WT:	44,479 lb		
<u>FLIGHT PHASE</u>	<u>FUEL</u> (lb)	<u>RANGE</u> (nm)	
Start, taxi, takeoff	1100	0	
Max range climb 360 KIAS to 0.81 IMN	1400	54	
Max range cruise inbound 36,000 ft MSL, 0.82 IMN	1778	174	
Combat run 500 ft MSL, 540 KIAS/0.82 IMN	2703	100	
Max range climb 0.83 IMN	1090	50	
Max range cruise outbound 41,000 ft MSL, 0.83 IMN	1319	174	
Max range idle descent 212 KIAS	460	81	
Low alt holding for 15 min: 220 KIAS	900	0	
Pattern: 2 visual approaches	800	0	
Min fuel on deck:	<u>1500</u>	<u>0</u>	
TOTAL	FUEL 13,050	RANGE 633	
MISSION RADIUS: 316 nm			

Figure F-8. F/A-18C High-Low-High mission performance.

APPENDIX G
F-15E FIGURES

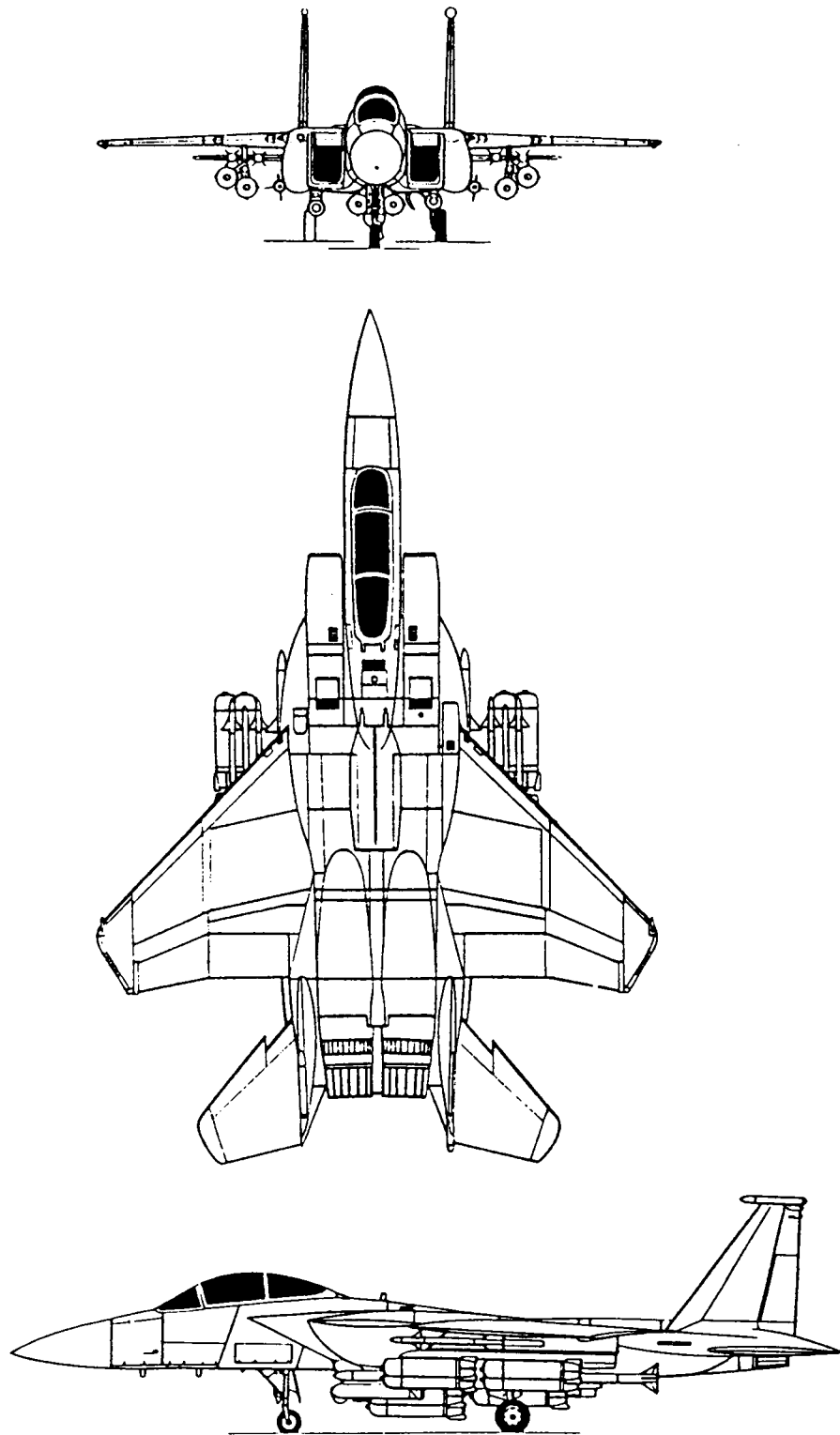


Figure G-1. F-15E aircraft layout. (Reference 33)

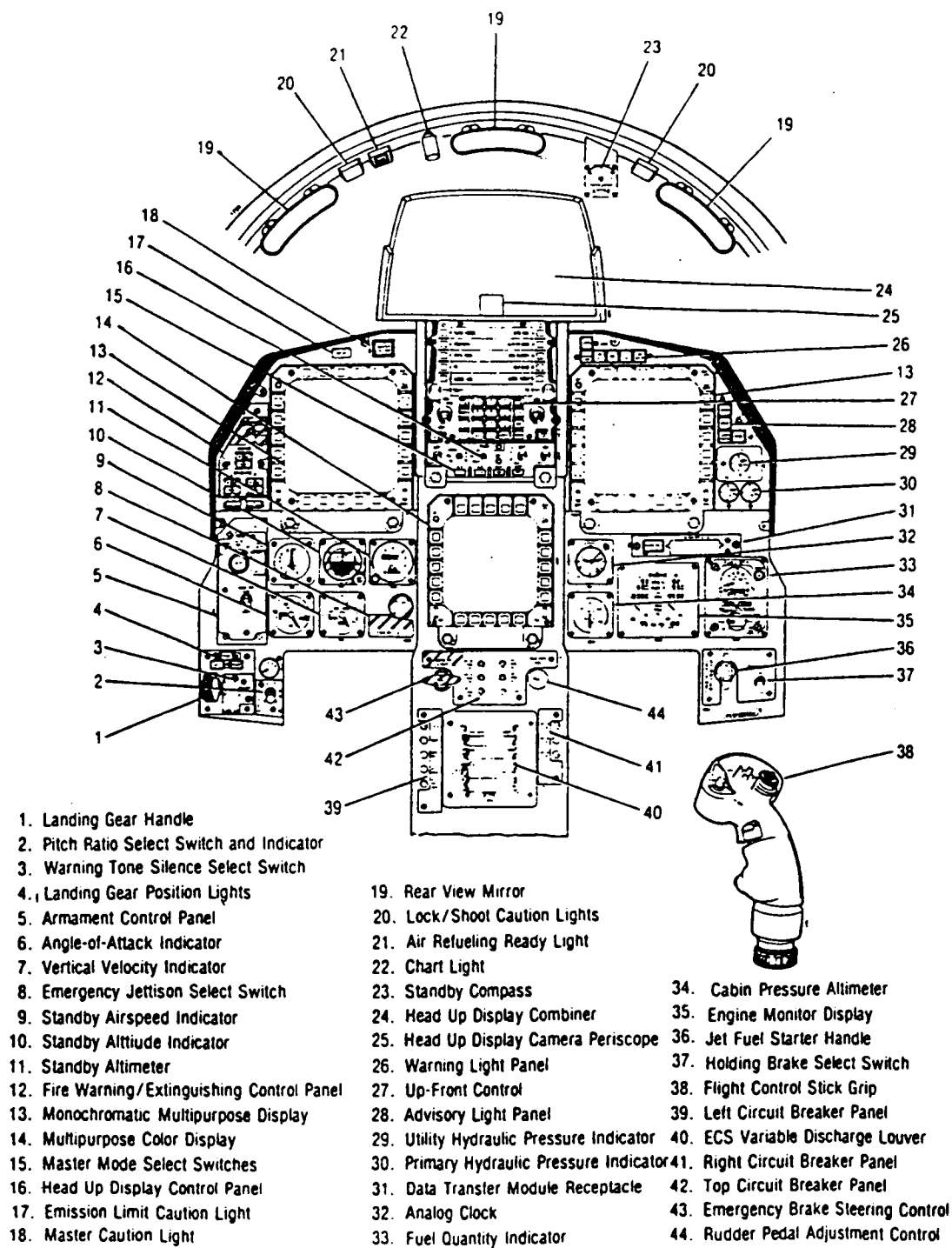


Figure G-2. F-15E front cockpit layout. (Reference 44)

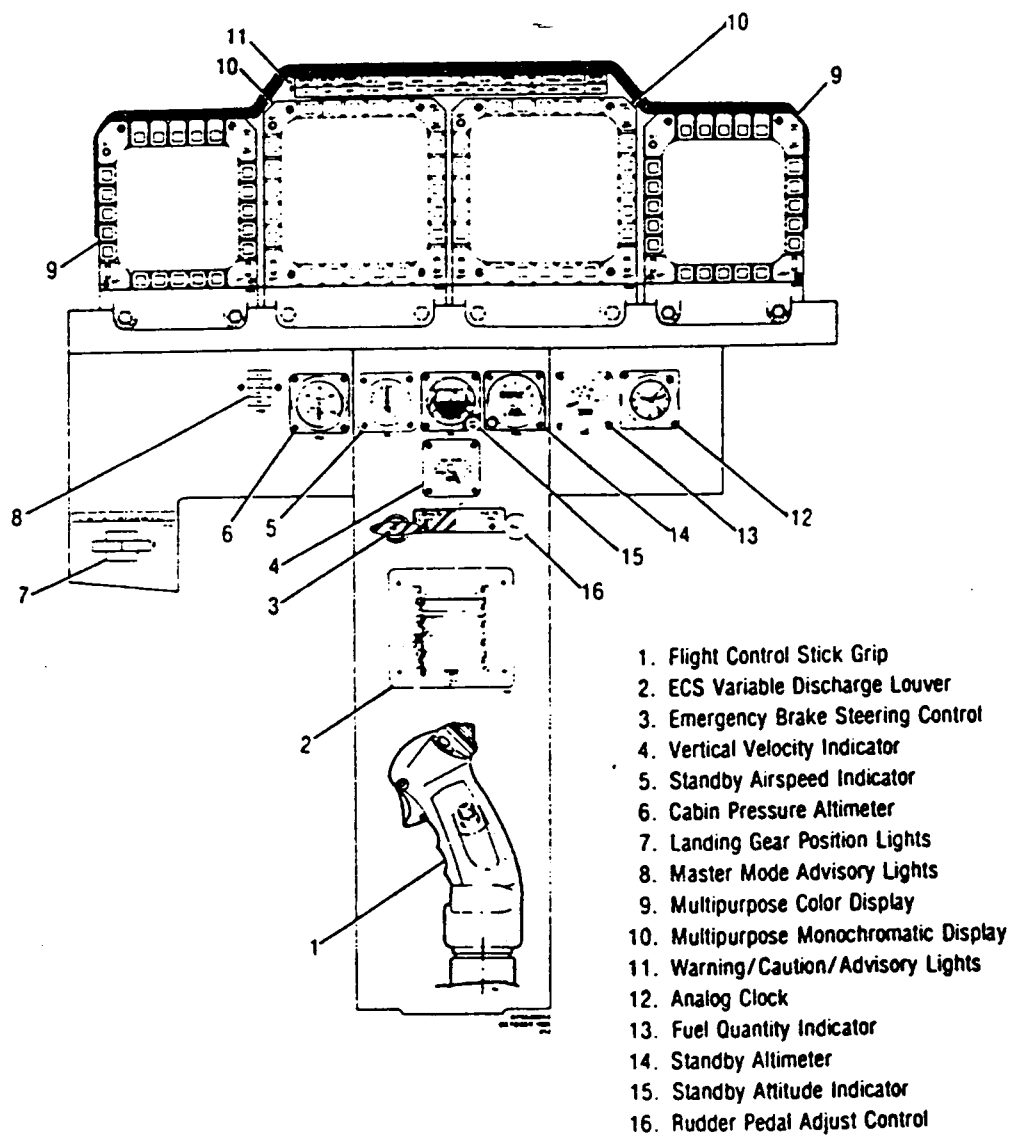


Figure G-3. F-15E rear cockpit layout. (Reference 44)

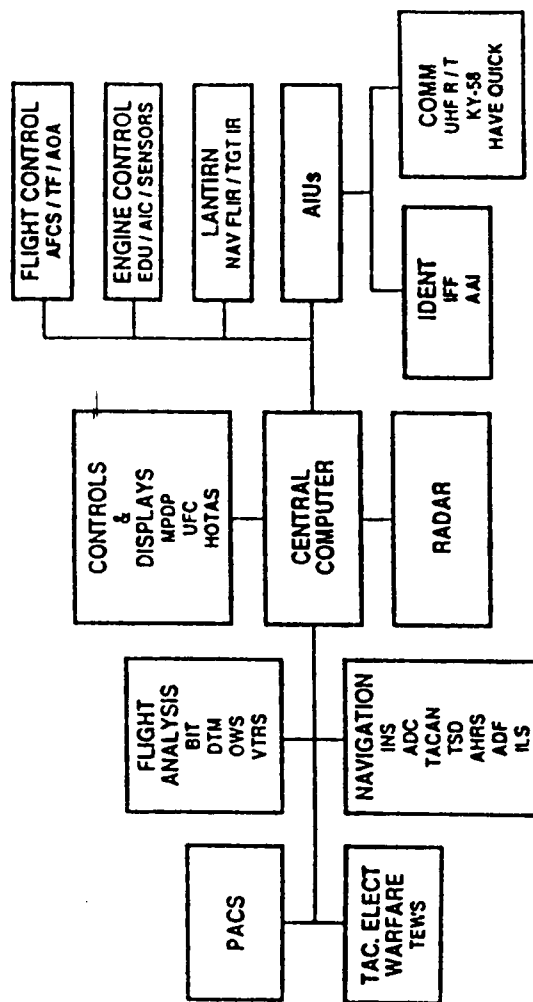


Figure G-4. F-15E avionics system diagram. (Reference 44)

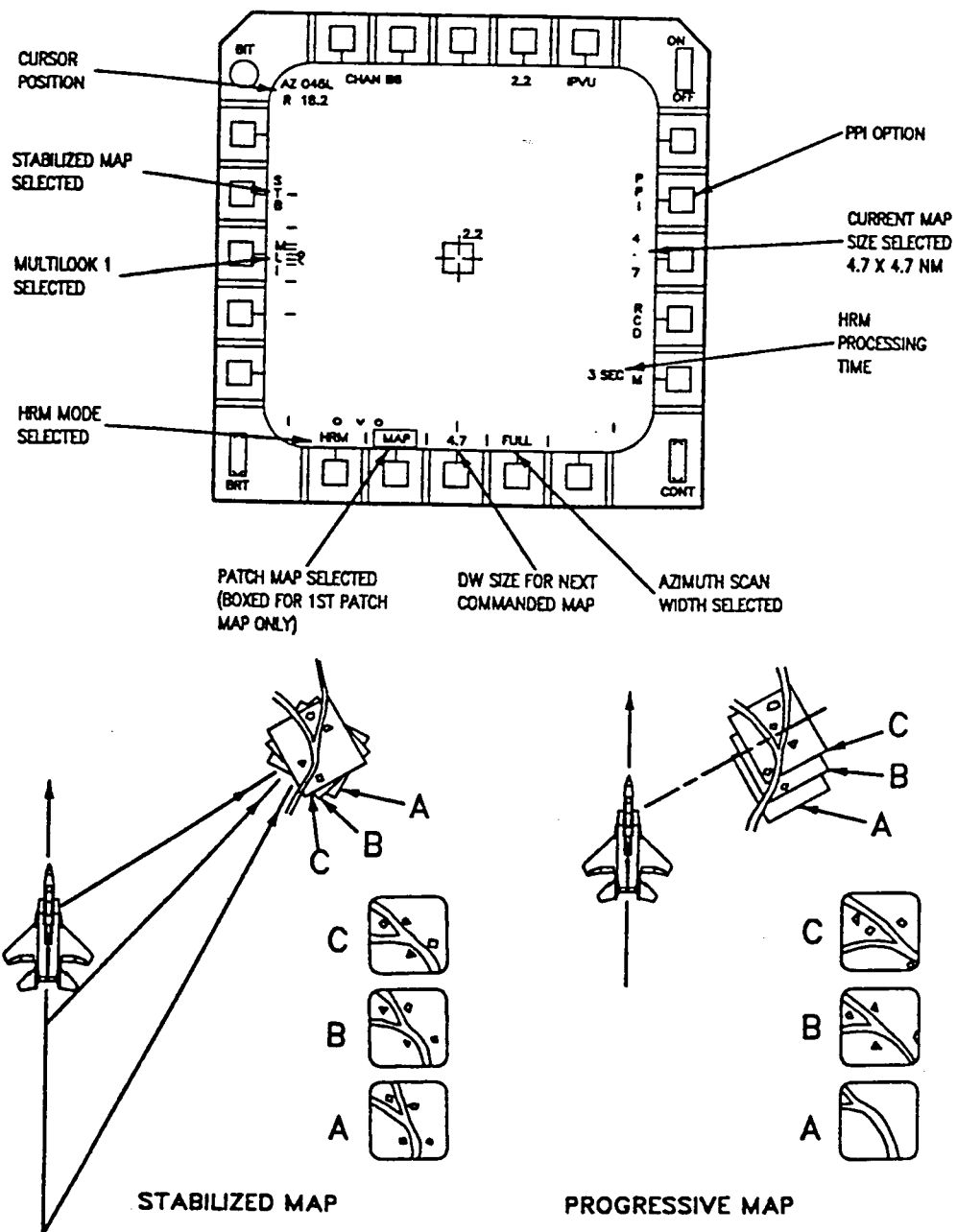


Figure G-5. F-15E high resolution map format. (Reference 44)

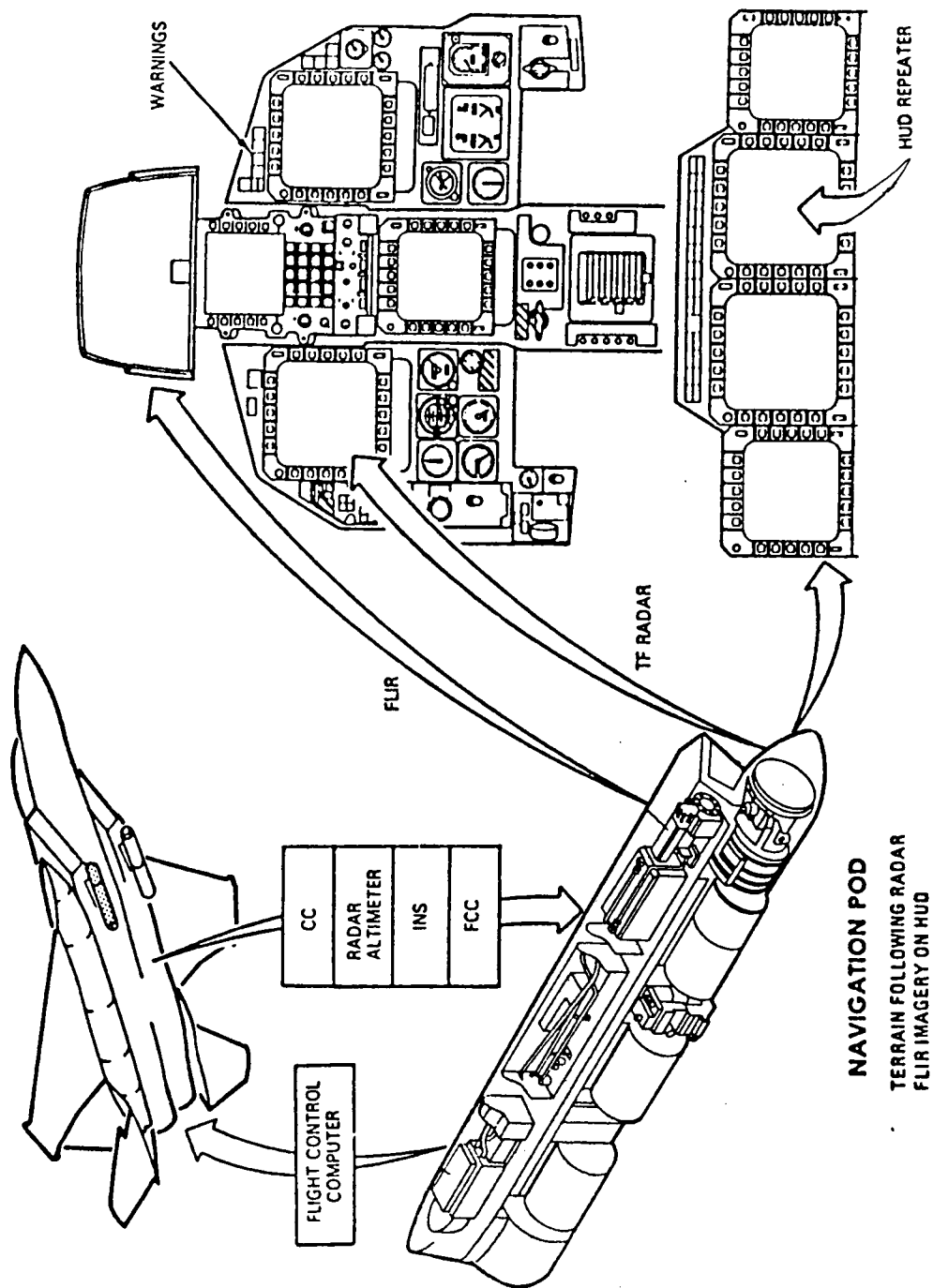


Figure G-6. LANTIRN navigation pod. (Reference 44)

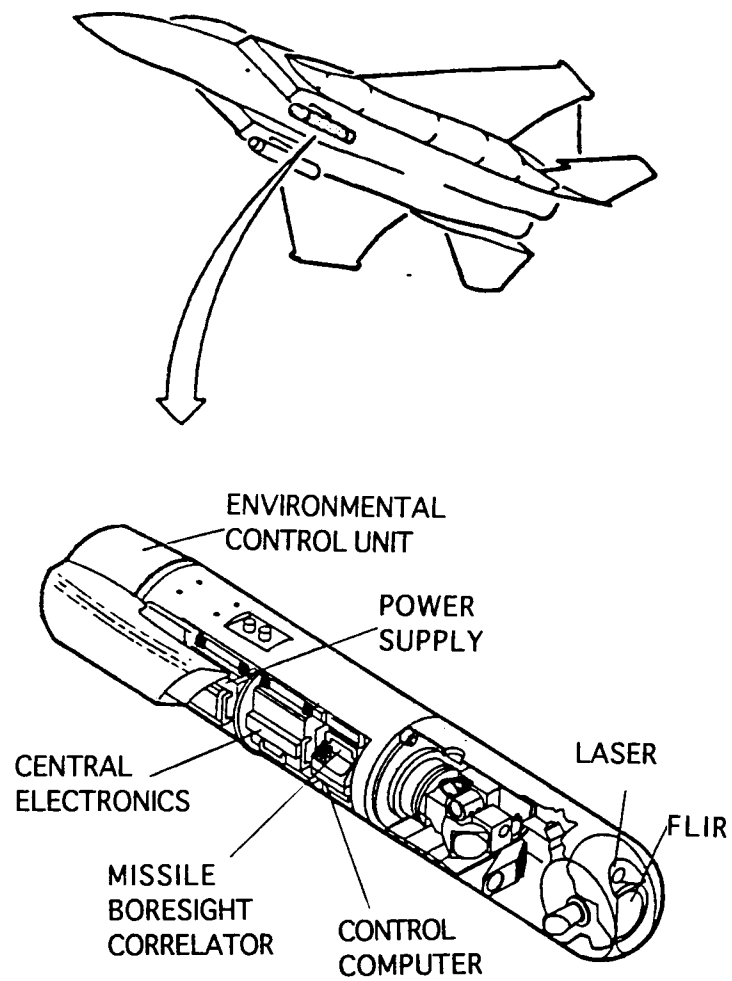


Figure G-7. LANTIRN targeting pod. (Reference 44)

APPENDIX H
F-111F FIGURES

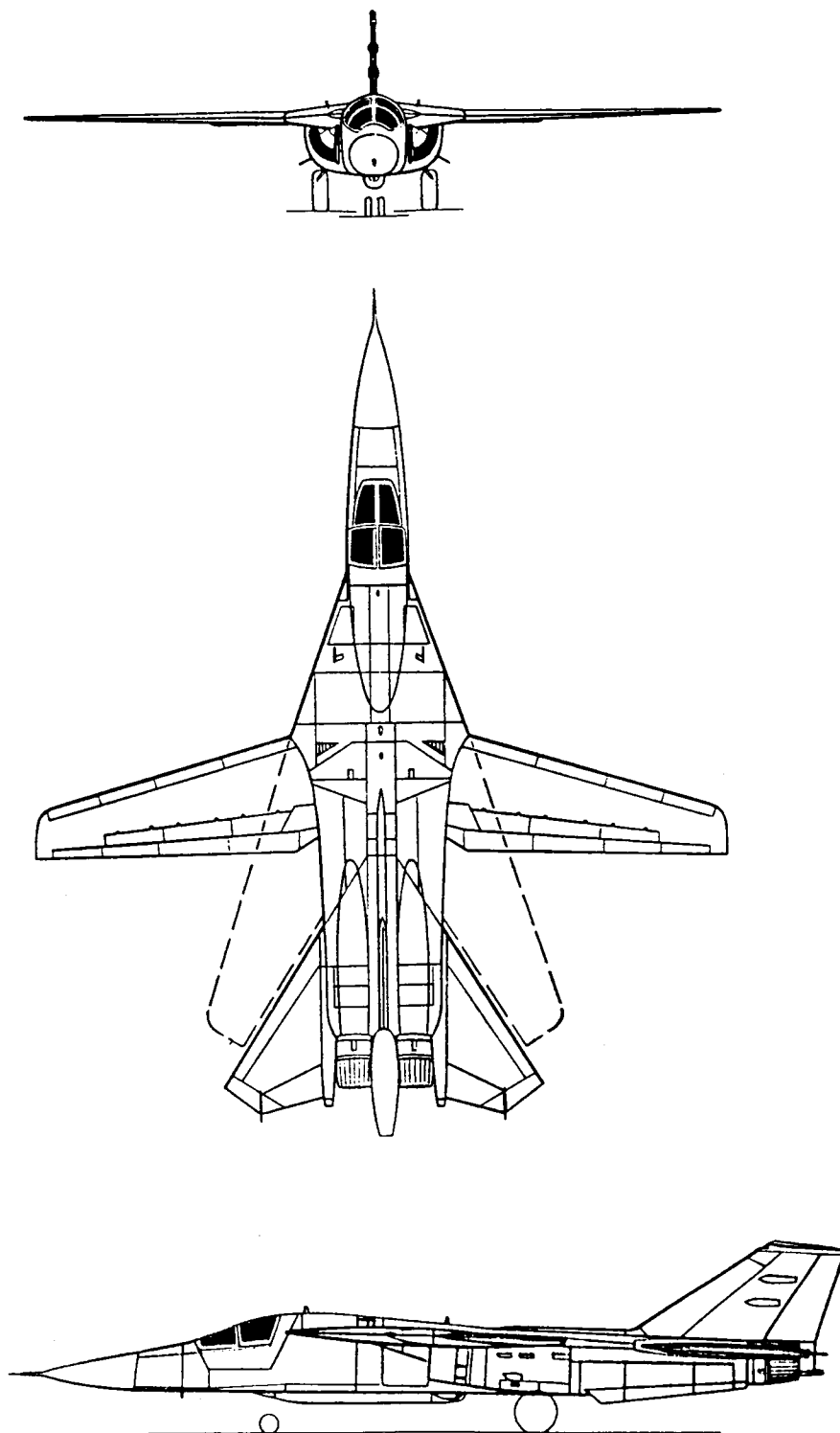


Figure H-1. F-111F aircraft layout. (Reference 33)

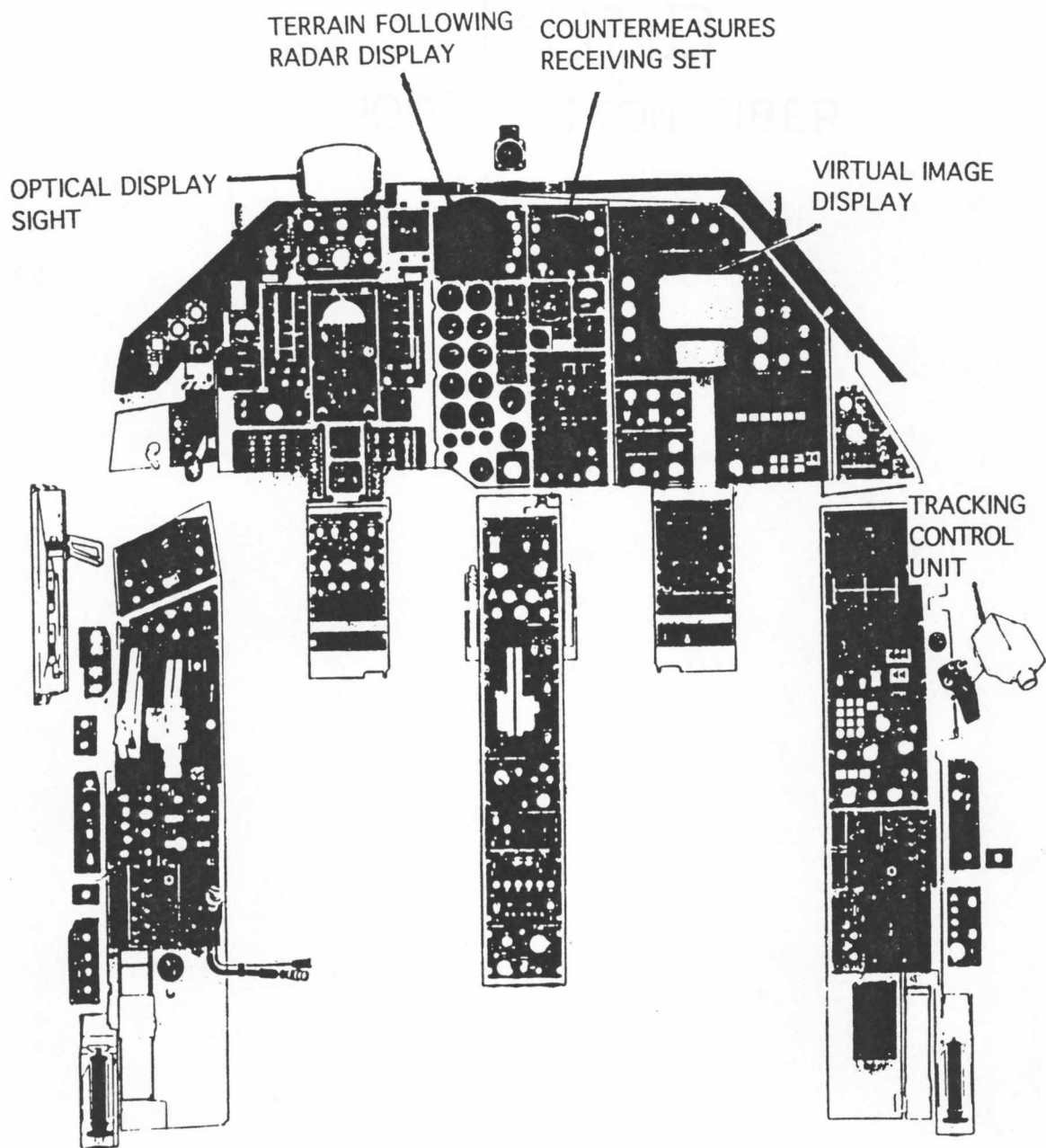
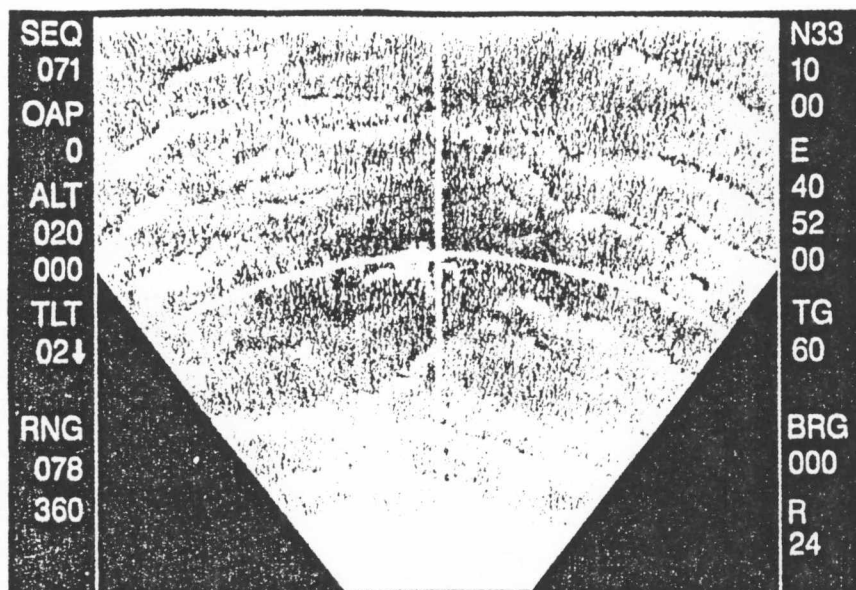


Figure H-2. F-111F cockpit layout. (Reference 46)

GROUND AUTOMATIC (PPI) DISPLAY (APPROXIMATELY 13 NM RANGE)



GROUND VELOCITY DISPLAY AT 3 TIMES MAGNIFICATION (APPROXIMATELY 6 NM RANGE)

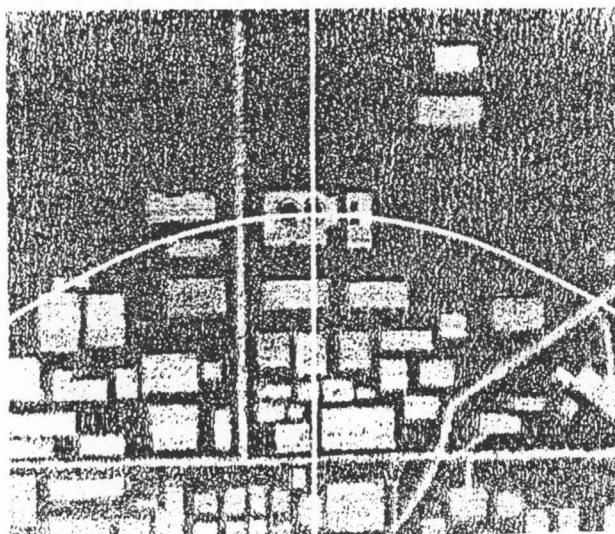


Figure H-3. F-111F attack radar displays. (Reference 20)

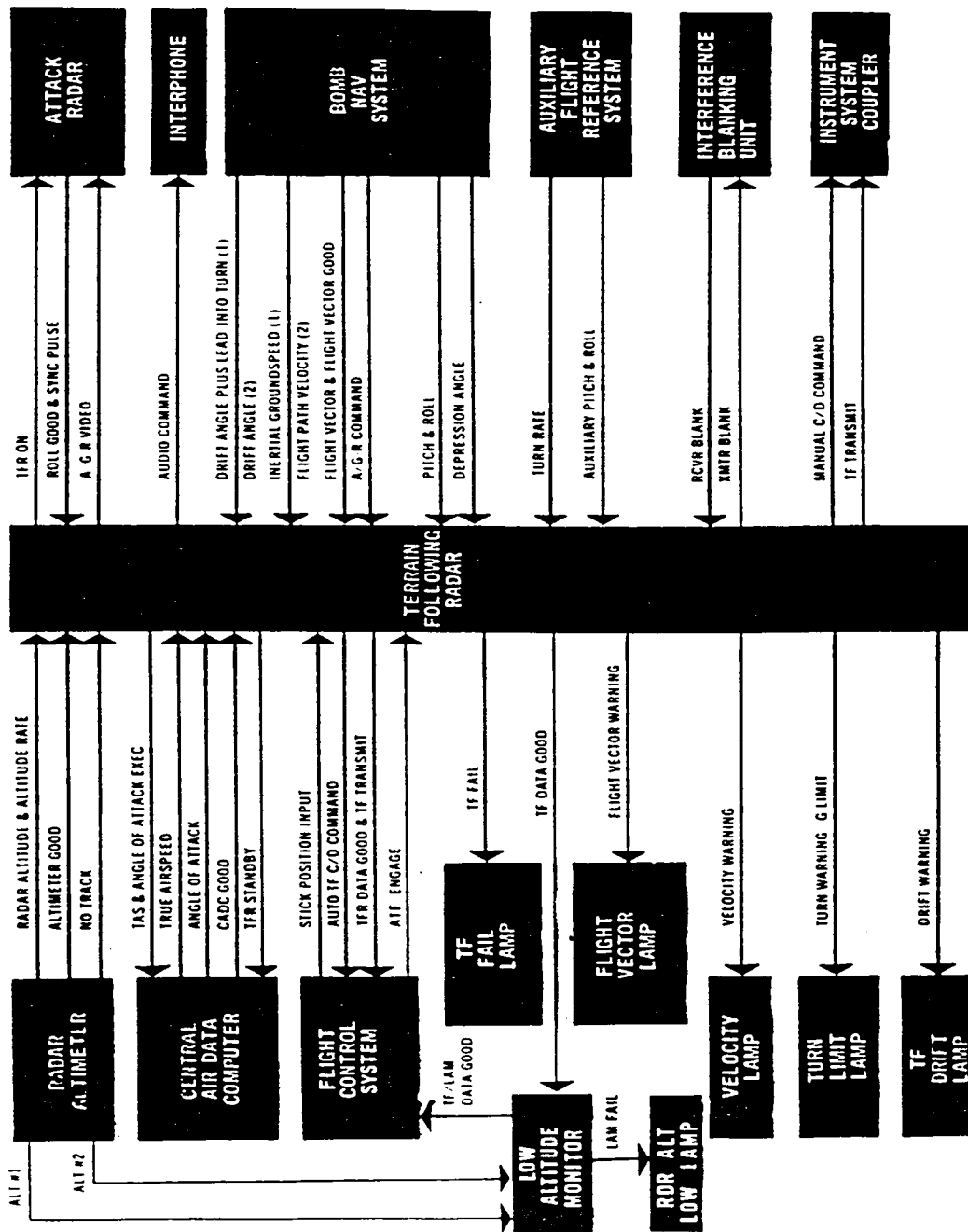


Figure H-4. F-111F terrain following radar interfaces. (Reference 46)

APPENDIX I
F-117A FIGURES

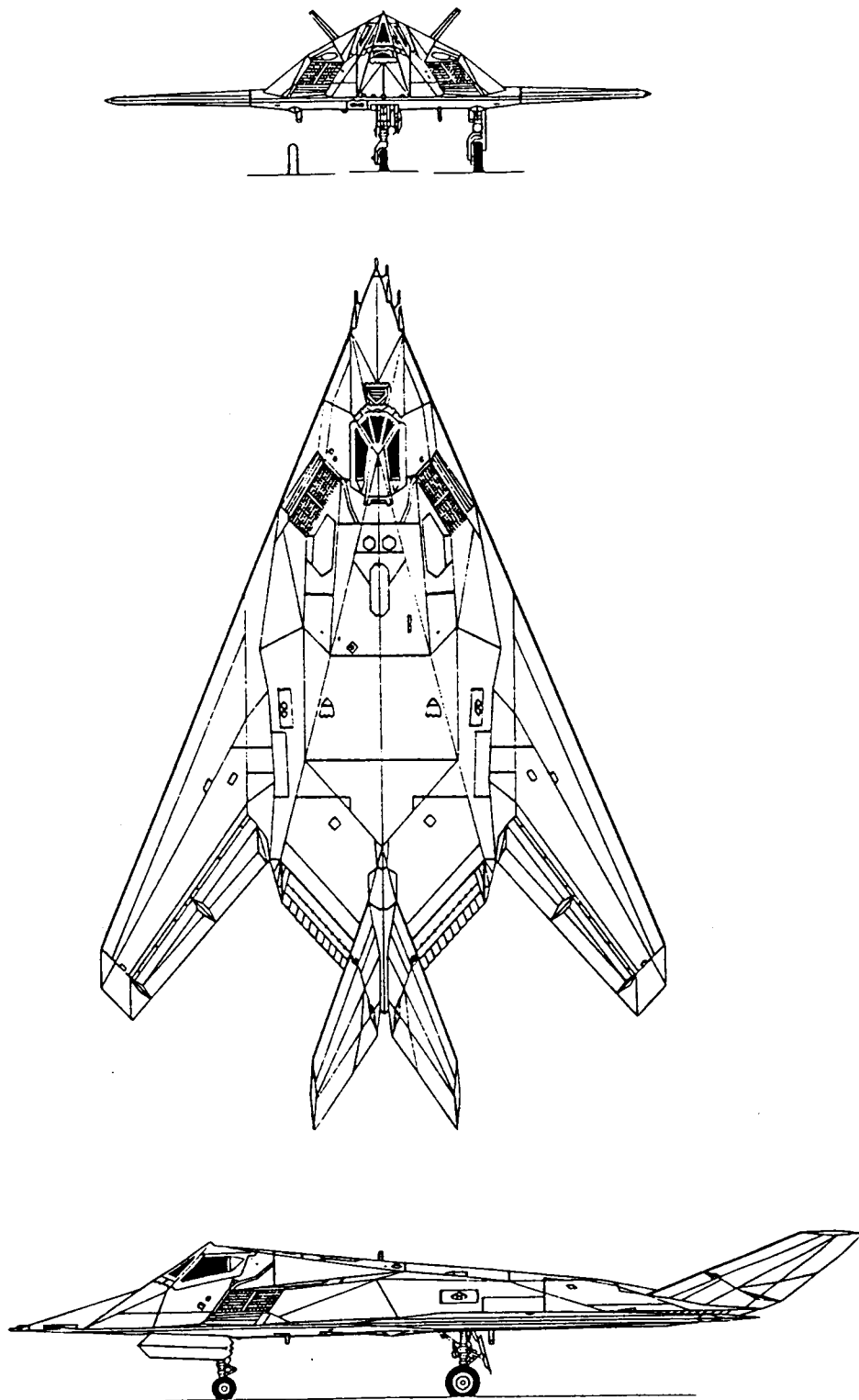


Figure I-1. F-117A aircraft layout. (Reference 33)

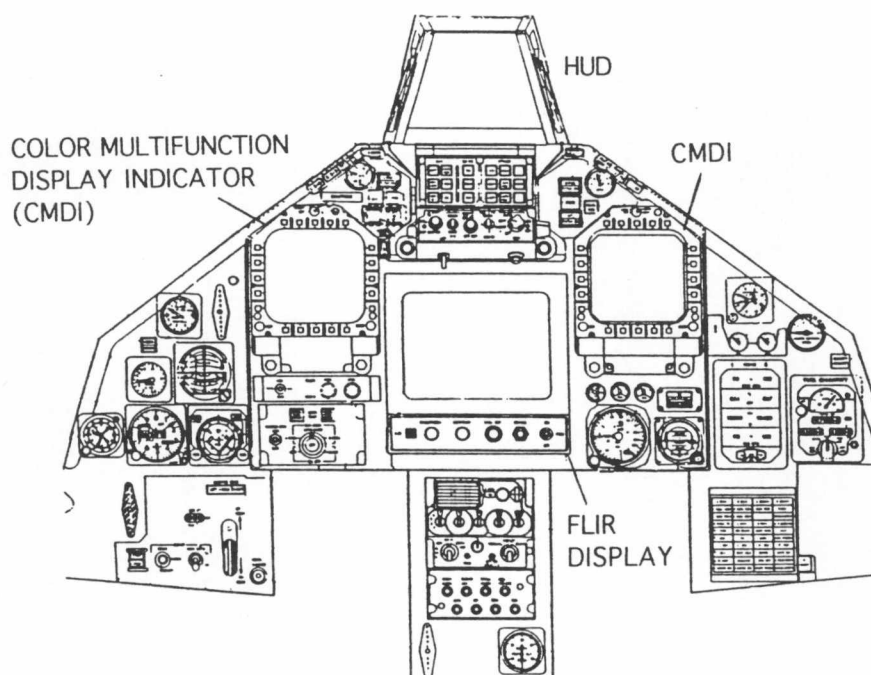
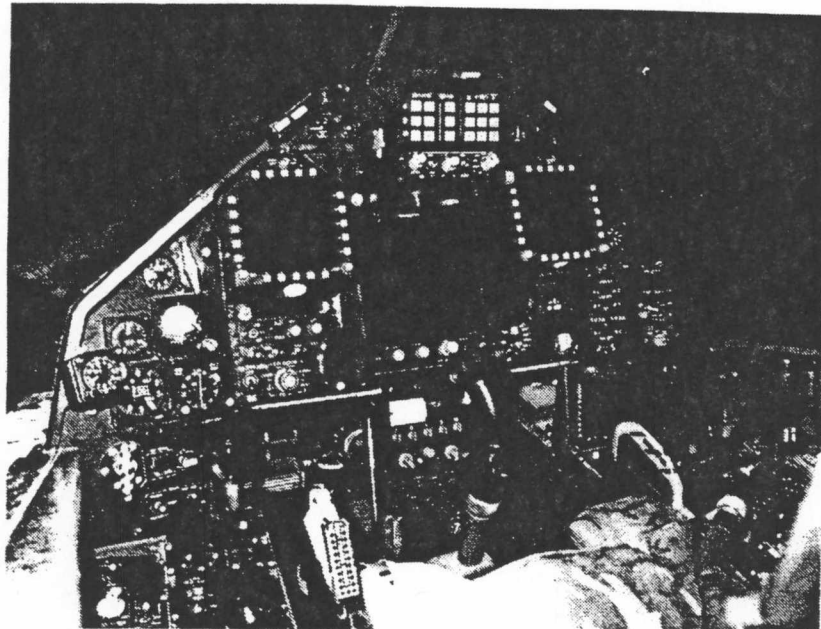


Figure I-2. F-117A cockpit layout. (Reference 47)

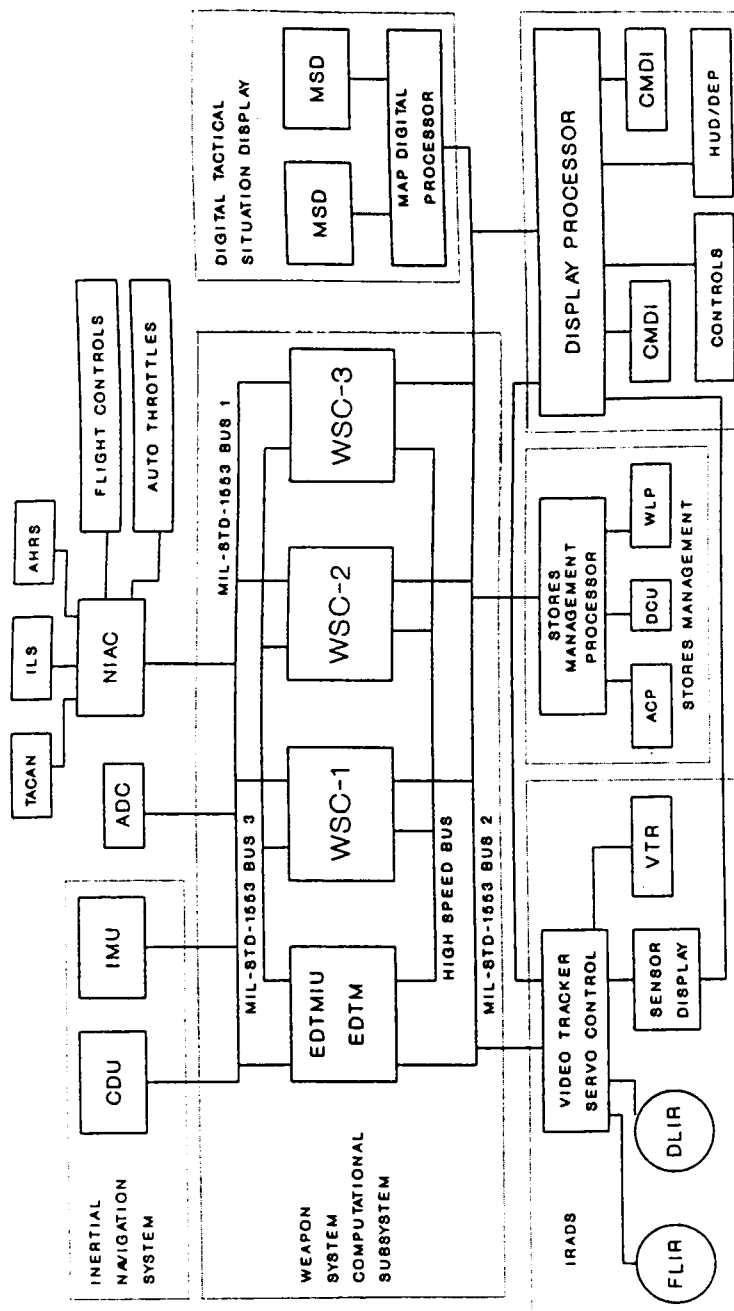


Figure I-3. F-117A avionic system diagram. (Reference 47)

VITA

Jeffrey W. Knowles was born and raised in San Diego, California. He attended Stanford University, receiving a Bachelor of Science degree in Civil Engineering in 1981.

Upon graduation, he joined the Navy and attended Aviation Officer Candidate School, where he was commissioned an officer. He attended flight training in Corpus Christi and Kingsville, Texas, earning designation as a naval aviator in 1983. Subsequently he spent four years as a fighter pilot flying the F-14A with VF-1, embarked on USS Ranger, homeported in San Diego. He transferred to VX-4, Point Mugu, California in 1988, performing operational test and evaluation on F-14A/B aircraft. While at VX-4, he was selected to attend Empire Test Pilot's School in the United Kingdom, where he graduated in December 1989. His next assignment was at Naval Air Warfare Center, Patuxent River, Maryland, where he served as an engineering test pilot on A-4 and F-14 aircraft, performing ordnance separation, carrier suitability, and systems testing. Subsequently he was assigned to VF-11 in San Diego, and took part in the establishment of the first fleet F-14D squadrons. During his tour at VF-11 he served as squadron Operations officer and Maintenance officer, and completed the first deployment of the F-14D aboard USS Carl Vinson in 1994.

Jeffrey W. Knowles enrolled in the Graduate School of the University of Tennessee, Knoxville in June 1990. He left the Navy in early 1995 and plans to continue a career in flight test.