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Lessons learned from the developmental testing of the EA-6B night vision device integration program

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To the Graduate Council:

I am submitting herewith a thesis written by Willie DeMoore Billingslea entitled "Lessons learned from the developmental testing of the EA-6B night vision device integration program." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert Richards, Major Professor

We have read this thesis and recommend its acceptance:

Peter Solies, Frank Collins

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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and recommend its acceptance:

Peter Solies
Dr. Peter Solies

Frank G. Collins
Dr. Frank Collins

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

LESSONS LEARNED FROM THE DEVELOPMENTAL TESTING OF THE EA-6B NIGHT VISION DEVICE INTEGRATION PROGRAM

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

Willie D. Billingslea
May 2001

DISCLAIMER

The analyses, opinions, conclusions and recommendations expressed herein are those of the author and do not represent the official position of the Naval Air Warfare Center, the Naval Air Systems Command, or the United States Department of the Navy. The author's recommendations should not be considered attributable to any of the aforementioned authorities or for any purpose other than fulfillment of the thesis requirements. Data and conclusion were gathered from ground and flight testing in support of an official Department of Defense Test and Evaluation project. The author played a significant role in the planning and gathering of both the ground and flight test data. Although the author was the lead test flight officer for this government project, this project was not conducted for the purpose of the thesis.

DEDICATION

This thesis is dedicated to my father, the late Grady Lee Billingslea, who showed me the importance of continuing education and performing your best in whatever you do. If it were not for him, I would not have made it this far in my career.

ACKNOWLEDGMENTS

I would like to thank my wife, Robbin Billingslea, more than anyone. She sacrificed considerably over the past three years to help me towards my Masters degree. If it were not for her patience, unyielding love and support over many late nights, I would not have been able to complete this study. I would also like to thank my son Jonathan, two years old, who has interrupted me at the most inconvenient times while I was working at the computer. However, after each interruption, I had to admit I enjoyed the break. Finally, I have to thank my faithful dog Rex, who always sat and provided companionship for me 'til odd hours of the morning. Rex, you have truly lived up to a dog's reputation as man's best friend. Lastly, I thank my unborn daughter, TBD. She has in her own special way given me the additional drive to perform when I did not want to.

ABSTRACT

During the Kosovo conflict of 1999, EA-6B Prowler fleet commanders experienced the limitations of operating the only Tactical Aviation (TACAIR) platform that was incompatible with Night Vision Imaging Systems (NVIS) and decided as a result that all EA-6B Prowlers must be made NVIS compatible. So keenly did local fleet commanders feel the need for these conversions, they actually considered utilizing Night Vision Goggles without adequately modifying their aircraft. Though this fortunately did not occur, the Department of Defense took unprecedented steps to make EA-6B's NVIS-compatible in the fiscal year 2000 (FY 2000) and these conversions became a priority for the Program Manager of EA-6Bs.

In October 1999 the Department of Defense gave the EA-6B Program Manager directions to make all EA-6Bs NVIS-compatible and to do so as fast as possible. The entire designing, testing, and fielding of the system would normally have taken three to five years with standard acquisition guidelines. However, this NVIS acquisition program was granted permission to employ the rarely used Abbreviated Acquisition Process in an attempt to field the system in six months. The system was actually fielded in approximately fourteen months. Though, by bureaucratic standards, this constituted a huge success, it proved a failure for fleet aviators. What was promised for six months actually took over a year.

This thesis will discuss the programmatic and technical shortfalls experienced in this program. Based on an analysis of this material, the author will make recommendations as to how NVIS modifications to future platforms may be made in a more timely fashion.

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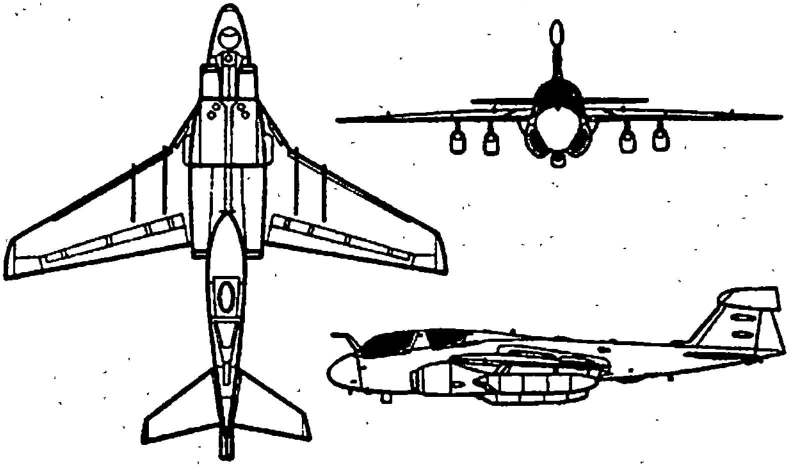
ACRONYMS AND ABBREVIATIONS

AAA	Anti Aircraft Artillery
AGL	Above Ground Level
AGM	Air to Ground Missile
CINCS	Commander in Chief
DDI	Digital Display Indicator
DOD	Department of Defense
DoN	Department of the Navy
DT	Developmental Testing
ECMO	Electronic Counter Measures Officer
EFIS	Electronic Flight Instrument System
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
ft	feet
FY	Fiscal Year
HARM	High Speed Anti-Radiation Missile
HUD	Head-Up Display
IR	Infrared
LCDR	Lieutenant Commander
lux	1 lumen per square meter
MIL-STD	Military Standard
NSATS	Naval Strike Aircraft Test Squadron
NVG	Night Vision Goggle
NVIS	Night Vision Imaging System
OAG	Operation Advisory Group
OT	Operational Testing
PEO(T)	Program Executive Officer Tactical Aviation
PM	Program Manager
QRA	Quick Reaction Assessment
RO	Requirements Officer
RPM	Rotation Per Minute
TACAIR	Tactical Aviation
TEMP	Test and Evaluation Master Plan
TJS	Tactical Jamming System
USS	United States Ship
VAQ	Tactical Electronic Warfare Squadron

TERMINOLOGY

AIRCRAFT DESIGNATIONS

Military aircraft designated by an abbreviation followed by a number and a name. This designation is usually in the format of a 'type', 'model', and 'series'. The 'type' is usually in the form of a letter or letters and it represents the aircraft mission. The designation "EA" in EA-6B represents an Electronic Attack aircraft also known as the Prowler. The 'model' is in the form of a number and it usually represents the lineal version of that 'type' of aircraft. The "6" in EA-6B represents the sixth version in that area of attack aircraft. Finally, the 'series' is usually in the form of a letter and it represents the version of that 'type' and 'model' aircraft. The "B" in EA-6B represents the second version of the previously defined 'type' and 'model'. The image below is a three view of the EA-6B Prowler.



EA-6B Prowler

CHAPTER 1: INTRODUCTION

THE NEED FOR NIGHT VISION GOGGLES

The EA-6B Prowler is the world's premier Tactical Electronic Warfare Aircraft. Its primary mission is to suppress enemy air defenses and so allow fighter and attack aircraft to destroy their targets with minimum opposition from radar-guided enemy air defenses. The Prowler is a tactical aircraft and its missions consist in flying with the strike packages it protects, thus putting itself in harm's way in order to defend others. Unfortunately, the Prowler lacks many of the modern "situational awareness" tools available to the tactical strike aircraft that the Prowler protects. Air-to-air radar, Night-Vision Goggles (NVG), and any type of a shared data link are some of the tools that would provide additional situational awareness. This relative lack of situational awareness has forced Prowler aircrew to rely on preplanned timelines, radio calls, and visual contact with the aircraft they are protecting in order to adequately perform their mission. This worked well from the early 1970s (the EA-6B entered operational duty in July 1971- *Navy Fact File, 2000*) until recently, when technology forced a change of tactics. Since the early 90s, the majority of the United States' tactical strike aircraft (e.g. F-16 Falcon, F/A-18 Hornet, F-14 Tomcat, and F-15 Eagle) have been compatible with Night Vision Imaging Systems (NVIS) and their aircrew fly with Night Vision Goggles.

This technology has allowed aircrew to develop better night tactics and allowed strike packages to ingress and egress under conditions of minimal light while maintaining adequate visual situational awareness of one another. In addition, the Night Vision Goggles allow aircrews to visually detect evidence of Anti-Aircraft Artillery (AAA) and missile launches. Although NVGs have not turned night into day, they have significantly improved aircrews' visual situational awareness. In fact, this improvement was so great that aircrews proficient in the use of NVGs, if they have the option, rarely fly a night event without goggles (Antonio, 2000).

THE EA-6B JUSTIFICATION FOR NIGHT VISION GOGGLES

The prototype Night Vision Goggle EA-6B was a Block 89 EA-6B Prowler assigned to the Naval Strike Aircraft Test Squadron (Bureau Number 163892). The Block 89 EA-6B is a four-place, twin-engine, mid-winged monoplane designed for carrier and advanced base operations (Figure 1). The crew is composed of one pilot and three Electronic Countermeasures Officers (ECMO's). The aircraft is a fully integrated Electronic Warfare weapons system that combines long range all-weather capabilities with an advanced Electronic Attack system. Electronic Attack is accomplished with the AN/ALQ-99 Tactical Jamming System, which uses up to five jammer pods carried on the wing and/or centerline stations. In addition, the EA-6B has a "hard kill" capability

Figure 1
EA-6B on Carrier Approach

against enemy radar installations through the use of the AGM-88 High Speed Anti-Radiation Missile (HARM).

In order to fly safely with Night Vision Goggles, aircraft lighting systems must be modified to be compatible with the goggles. Without compatible lighting, Night Vision Goggle will not perform optimally and, in some cases, does not perform at all, posing a serious safety risk for aircrew. The existing EA-6B internal and exterior lighting was not compatible with Night Vision Goggles and this limitation forced many strike packages to adjust their tactics in order to work around the Prowler's NVIS limitations. During the Gulf war, when new NVIS tactics were just being developed, the fact that Prowlers were not equipped with goggles was simply an annoyance for the war planners (Waters, 2000).

But after the Kosovo War, to be the only tactical aircraft not NVIS-compatible was a major hindrance. In contrast to those flying platforms equipped with NVGs, EA-6B aircrew found it difficult to perform many tasks – from basic administrative matters such as nighttime rendezvous with the strike package to locating support aircraft such as airborne tankers for refueling – without goggles. Moreover, when one platform is in the dark and during the dynamic fog of battle has less visual situational awareness than the others, there is greater confusion as to the location of threats and friendlies. It was the lessons of the Kosovo conflict that propelled an improvement of the nighttime situational awareness of the EA-6B to the forefront of DoD priorities. In fact the European Theatre Commanders-in-Chief stated that all future tactical aircraft flying in their theater of war must be NVG capable (Congressional Testimony, 1999).

The congressional testimony concerning the lessons learned from Kosovo, coupled with Prowler squadron commanders' "Top 10" requests for FY2000 (Fleet commanders October's 1999 annual Operational Advisory Group meeting) ranked NVG's as its fifth priority (DoN Message, 1999). At the Operational Advisory Group (OAG) meeting, fleet representatives demanded that the Prowler be given a Night Vision Imaging System modification in order to achieve the basic nighttime visual situational awareness that was available to every other tactical aircraft supported in battle by the EA-6B, and that the system be fielded within 6 months (March 2000).

THE ACQUISITION OF NVGS FOR THE EA-6B

In October 1999, Department of Defense directed the EA-6B Program Manager to make the entire Prowler fleet compatible with Night Vision Imaging Systems (NVIS). If this conversion were to be carried out under standard acquisition guidelines, the complete designing, testing, and fielding of the system would require three to five years. However, in an attempt to field the system within six months, the EA-6B Program Manager was granted permission to use a streamlined process, the so-called Abbreviated Acquisition Process. This process permitted the EA-6B Program Manager to bypass several time-honored and proven milestones that aided projects to be fielded efficiently and with minimal setbacks.

Unfortunately, the EA-6B Program Manager failed to field NVIS compatible Prowlers in six months, requiring, in fact, 14 months. In the world of military acquisition, fielding a system in 14 months is considered a great success by bureaucratic standards. But for the primary customer, the EA-6B aviator, a system promised for six months that actually took a year constituted a failure. This eight-month delay resulted in approximately six squadrons deploying without this situational awareness tool, and the overall effectiveness of the EA-6B during night operations was correspondingly limited.

The eight-month delay to this program was the result of several programmatic and technical shortfalls that forced the program to stop, re-organize, and redesign the EA-6B

NVIS modification. But these shortfalls could have been prevented through clearer communications between the Program Office (PMA-234) and fleet EA-6B aircrew, through better planning, and by adhering to the spirit of the standard Department of Defense acquisition guidelines, even though a waiver to deviate from them had been granted. In addition, setting a high standard of performance for the new system, rather than accepting the bare minimum required, played a significant role in the delay of the acquisition program.

This thesis will discuss the major programmatic and technical shortfalls encountered in this acquisition program and present the author's recommendations on how the process might be improved. In the course of explaining the shortfalls, the thesis will examine the standard and abbreviated acquisition processes, military instrument lighting guidelines, Night Vision Goggle theory, and the programmatic process utilized to acquire the EA-6B Night Vision capability. In addition, this thesis will describe the NVIS modifications that were finally realized in the EA-6B, the testing results on those modifications, and the lessons learned from them.

CHAPTER 2: REVIEW OF THE ACQUISITION PROCESS

THE TRADITIONAL METHOD

To fully understand the abbreviated acquisition process that the EA-6B NVG team utilized, one must have a basic understanding of the standard acquisition process, which follows the guidelines stated in the Secretary of the Navy Instruction 5000.2B (6 December 1996). This process is mandatory for all major defense acquisition programs unless a waiver is granted.

At the beginning of the process, the need for a capability must be clearly defined. This need, which must be expressed from the fleet, is the basis for all major acquisitions. The fleet expresses this operational need through squadron commanding officers at an annual Operational Advisory Group meeting. That meeting generates a "Top 10 Needs' list that is forward to the "type aircraft" Requirements Officer (RO) at the requirements office located at the Pentagon (N88) and the "type aircraft" Program Manager at the Naval Aviation Systems Command.

The Requirements Officer turns that Top Ten list into official EA-6B requirements and then lobbies for funding to fulfill the fleet's needs. This funding may come from the pre-existing Department of Defense Budget and/or from funds newly appropriated by Congress and directed towards a specific project ("congressional plus up funding"). The new requirements are officially promulgated by a Mission Needs Statement and an Operational Requirements Document (ORD).

After the Requirements Officer approves a requirement and funding is set in place, the "type aircraft" Program Manager then utilizes that funding to acquire, test and field that new system to fulfill the requirement. For the EA-6B, the Program Manager Assistant (PMA-234) is the "type aircraft" coordinator. The Program Manager will then assemble a team of government and contractor personnel that will design, acquire, test and field the new system. The Program Manager stays constantly in touch with the fleet and the Requirements Officer to ensure that the system that he is acquiring is what the fleet wants.

In the acquisition of a new system, the Program Manager must meet certain benchmarks in order to progress to the next stage in the acquisition process. These critical components of the development of a new system are the Functional Requirement Document, the Preliminary Design Review (PDR), the Critical Design Review (CDR), the Aircrew System Advisory Panel and the Test and Evaluation Master Plan (TEMP). They prevent new, unapproved requirements ("requirement creep") from entering the process and ensure that a project stays on track, focused on what it is producing, and meeting the essential objective of the new system.

The Functional Requirement Document expands in more detail the requirements as set forth by the Requirements Officer in the Mission Needs Statement and the

Operational Requirements Document. The Functional Requirement Document is the baseline for technical objectives that must be met in testing as well as for the overall design roadmap of the system. The Preliminary Design Review is a chance for the 'producer' of the new system to present to the Program Manager, the testing agencies and fleet representatives a rough overview of the design and operation of the new system. At the Preliminary Design Review the 'producer' can be put back on track if necessary. The Critical Design Review allows the 'producer' to present a more refined design, though usually at this stage the design requires only minor corrections, if any. Throughout the creation of the Functional Requirement Document, the Preliminary Design Review and the Critical Design Review, the producer is constantly interacting with fleet representative and testers through a forum called the Aircrew System Advisory Panel. At the Aircrew System Advisory Panel, the producer of the system presents snapshots of the system to fleet representatives, who provide feedback. This interaction helps pave the way for a smooth CDR and PDR.

In addition to the above processes, the Program Manager utilizes two test organizations, Developmental Test (DT) and Operational Test (OT), which evaluate the new system at various stages of maturity to ensure that the fleet gets a safe and operationally effective product. The two test organizations report their findings at various stages of the program to a Milestone Decision Authority (usually a high ranking military officer or civil servant) who decides to move the program to its next phase and who also eventually makes the decision to field it. The performance of the system tested by both DT and OT is spelled out in a Test and Evaluation Master Plan (TEMP). This TEMP utilizes the ORD, FRD, and CDR to define in terms as quantitative as possible the level of performance required for this system to pass testing. In addition, the TEMP also spells out the qualitative expectations of the system. With a properly written TEMP and with a well executed test program, there should be no question as to whether a system has met the requirements as set forth by the fleet.

In all, the typical acquisition process for a new system could take three to five years. The Functional Requirements, Preliminary and Critical Design Reviews and the generation of a Test and Evaluation Master Plan could take two years alone. In addition, the production and testing of the prototype system could take another two years. Another year of setbacks and purely administrative matters can easily spell a five-year program (Nahvi, 1999).

ABBREVIATED ACQUISITION PROCESS

As in nature, so in system acquisition: to every rule there is an exception. In special cases the Department of Defense and Congress allow for rapid acquisition of urgently needed systems. One of the provisions in SECNAV 5000.2b is called the Abbreviated Acquisition Program. The abbreviated process allows administrators to bypass many of the normal steps required in a traditional acquisition program. All that is required to start the abbreviated process is a Mission Need Statement and an ORD generated by the Requirements Officer. With these in place, the Program Manager can then proceed as fast as possible to field a safe and reliable system. The Functional Requirement Document, Preliminary and Critical Design Review, Test and Evaluation Master Plan and Operational Testing are not required.

To qualify for the Abbreviated Acquisition Process the program must meet the following guidelines:

1) Cost of such programs are less than all of the following thresholds:
    a) $5 million (FY 1996 constant dollars) in total development cost of all contracts for all fiscal years;
    b) $15 million (FY 1996 constant dollars) in total production or services cost of all contracts for any fiscal year; and
    c) $30 million (FY 1996 constant dollars) in total production or services cost of all contracts for all fiscal years.

2) Such programs do not affect the military characteristics of ships or aircraft or involved combat capability.

3) Such programs do not require an Operational Test and Evaluation (OT & E).

The abbreviated program is tailored to relatively inexpensive systems that do not affect the basic characteristics of the aircraft nor add warfighting capability. The entire EA-6B NVG program would eventually outfit 124 EA-6B aircraft with Night Vision Goggles and compatible lighting for under $30 million as well as meet the other requirements as set forth in (1) above. Changing the EA-6B interior and exterior lighting with NVG-compatible lighting that performed similarly met requirement (2). Since no warfighting capability was added, official operational testing was not required. However, the Milestone Decision Authority for this program requested a Quick Reaction Assessment by the Operational Testers to independently evaluate the operational effectiveness of the new system. A Quick Reaction Assessment is a qualitatively quick look at a system by operational testers and the testing is usually conducted in conjunction with the developmental testing.

TESTING AND EVALUATION

A critical step in the acquisition process is the test and evaluation of the system to ensure it performs as desired and that it is safe. A Test and Evaluation Master Plan is generated to ensure that all the technical and operational requirements are evaluated during the test program. There are two phases of testing for a traditional program: Developmental Test and Operational Test. Developmental testing is done to ensure the new system is safe and that it meets the technical requirements as spelled out in the Test and Evaluation Master Plan generated from the Operational Requirement Document and Functional Requirement Document. Operational testing is done to ensure that it is effective, reliable, and maintainable under real-world conditions.

During the Developmental Test phase, the developmental testers can interface directly with the Program Office and the designers to fix problems discovered during testing. In addition, both the government and the system's producers maintain the system. Developmental Testers consist of government and contractor engineer personnel as well as aviators who are graduates of a test pilot school.

The Operational Test phase is similar to Developmental Test but with one major difference: Operational Testing is done without support of the 'producer' of the system. Operational Testing is conducted under field conditions and the system must stand up to normal use as generated by regular fleet personnel. The Operational Testers consist of fleet aircrew and maintainers. Although the testing aircrew can be graduates from a test pilot school, aircrew directly from the fleet are preferred.

This test phase is of great importance. The systems must be safe and operationally effective. In the past, the bureaucracy of the acquisition process blinded some personnel working the program, who pushed along inadequate systems – a classic example being the Bradley Fighting Vehicle (Pentagon Wars, 1993) – despite glaring performance and safety deficiencies. Due to the poor performance of programs like the Bradley Fighting Vehicle, independent Operational Testing is mandated by law for all programs meeting certain budgetary thresholds as well as for any system that adds a warfare fighting capability.

CHAPTER 3: AIRCRAFT LIGHTING AND NIGHT VISION GOGGLES

THE NEED FOR ADEQUATE INSTRUMENT LIGHTING

Aircraft flight and engine instrument illumination, as well as sub-system controls and displays, must be clearly visible to aircrews during varied flight operations. Good instrument lighting, in conjunction with acceptable instrument placement and design, helps aircrew scan those instruments adequately. In the dynamic world of flight, an adequate scan (a quick and informative reference of the surroundings and various flight and engine instruments) is necessary to maintain situational awareness and control of the aircraft. When a scan breaks down, aircrew begin to "stare" (concentrate on a particular instrument(s) or item in order to ascertain the necessary information required) at the cost of neglecting other essential instruments. A scan breakdown generally results in aircrew becoming somewhat disoriented and reducing their overall situational awareness. Inadequate aircraft flight and engine instrument lighting at night generally reduce aircrew's scan ability and overall situational awareness.

For nighttime operations, two conflicting visual tasks are required of most aircrew:

1) Scanning and interpreting the primary flight and engine instruments, these instruments being – but not limited to – the following: airspeed, altitude, angle of attack, altimeter, attitude, compass, engine RPM, engine fuel flow, hydraulic and oil pressure.

2) Scanning outside the aircraft to maintain situational awareness and prevent mid-air collision and controlled flight into terrain, as well as scanning to visually maintain the navigation solution.

Inability to perform these two conflicting tasks have led to many aircrew losing situational awareness and becoming disoriented, resulting in some form of mishap or near-mishap. During daytime operation, a scan consisting of approximately one or two second looks at each item can determine the general state of the aircraft while maintaining a good picture of the environment outside of the aircraft. It has been shown that when a good scan pattern breaks down, and aircrew starts to stare at an instrument to the neglect of others, the aircrew's overall situational awareness decreases and the aircraft ends up in a trend or state that could be difficult to recover from. To prevent this, the aircraft industry has spent a lot of money and time to ensure that the primary flight and engine instruments are, at a minimum, adequately illuminated to facilitate a scan those instruments.

A BRIEF HISTORY IN AIRCRAFT LIGHTING

Man has been flying powered aircraft since 1903. However the great majority of those flights were restricted to daytime operation due to inadequate lighting of the aircraft's primary flight instruments (e.g. airspeed, altimeter, compass, and attitude instruments). But since the early 1930's, aircraft designers have used various methods to illuminate the aircraft controls and displays. These methods have varied from using an overhead lighting system to illuminate coated ("glow in the dark") flight instruments to adding floodlights to the instrument panel. The color of the lighting has also varied from white to blue to red. These progressive changes in lighting source and color had one objective: to facilitate a scan of the flight and engine instruments without interfering with the aircrew's ability to scan the outside night environment.

The aviation industry is now at a point where it is generally accepted that the preferred lighting scheme is in the form of integral (internal) instrument lighting in red. This arrangement minimizes the amount of stray ambient light in the aircraft while providing illumination adequate to scan a particular instrument. The minimization of background ambient lighting was an important factor in the migration to integral lighting, since the more ambient light present, the less aircrew eyes can adapt to the outside environment and the less the crew's external situational awareness.

This effect arises from the fact that human night vision is "scotopic" – that is, has a unique spectral response. The human eye normally adapts to the frequency and the intensity of light present, but it responds with varying sensitivity over the visual spectrum, being relatively insensitive to blue and red light. Typically, blue and red light, though readily detectable by the eye, are not perceived as bright and so do not conflict with other light sources (e.g. from the outside environment), which remain readily seen (Night Viewing, 2000). Since, of blue, green, and red lighting, red offers the best contrast on flight instruments with a grey and black background, the aircraft industry has determine that red lighting most effectively maintains night vision and facilitates the reading of instruments. In recent studies, green and blue lighting also show promise of effectively illuminating instruments without degrading the aircrew's night vision.

In addition to adequately illuminating the instruments, designers have had to ensure that lighting does not generate glare, reflection or direct-view annoyance to the aircrew at the crew station. This is not a problem with the basic integral lighting of instruments, but many secondary aircraft lighting system and primary lighting on secondary systems rely on floodlights. The placement of these floodlights must be carefully considered so as to avoid creating glare and reflection. For most tactical military aircraft (single seat or tandem seat), glare and reflection from flood lights is not an issue with aircrew, since the floods are usually located directly in front of and below the designed "eye point" of the aircrew. Their illumination, and any glare and reflection, is also directed downwards to the instruments and away from the aircrew's eyes. However, in aircraft with side-by-side seating such as the EA-6B, care has to be taken to avoid reflection and glare from the side.

NIGHT VISION IMAGING SYSTEMS

Night Vision Imaging Systems are devices that detect radiated or reflected infrared energy and produce a representative picture. NVIS systems usually work in the portion of the electromagnetic spectrum that the human eye cannot detect. Two general systems exist that fall in the NVIS category: Forward Looking Infrared Systems (FLIRS) and Night Vision Goggles. FLIRSs generally detect the blackbody radiation that all structures radiate to produce a picture. NVGs generally utilize reflected infrared (IR) and near-IR energy. Both systems can detect the portion of the electromagnetic spectrum they work in with extreme sensitivity. This part of the spectrum is mainly outside that which can be detected by the human eye but there is some overlap (Figure 2).

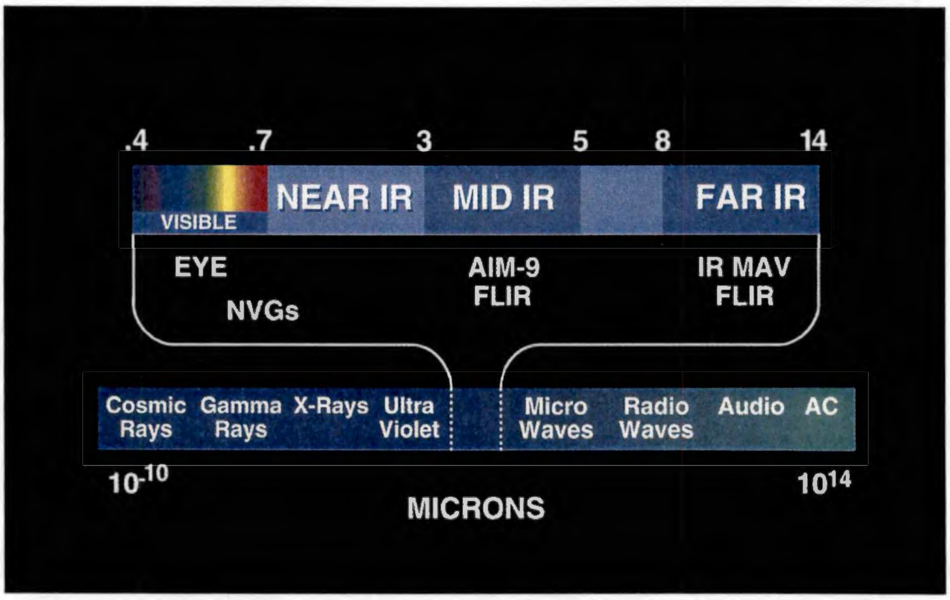


Figure 2
Common NVIS Operational Spectrum

NIGHT VISION GOGGLES

Night Vision Goggles are great tools for providing additional situational awareness at night. They permit aircrew to detect other aircraft, threats, etc. at greater distances than is possible with the naked eye. Unfortunately, this improved situational awareness comes at a price. Most Night Vision Goggles have a limited field of view of approximately 20 to 40 degrees. In addition, since the goggles are fixed to the operator's helmet (thus a fixed, limited field of view); they require the operator to look along a fixed optical axis and turn his head to scan the surroundings (the aircrew field of regard). A further limitation is that Night Vision Goggles cause the operator to lose his stereo depth perception. In order to accurately judge distances while wearing the goggles, aircrew must rely on other tools (e.g. air-to-air radar and size interpretations) to estimate the range of objects viewed through the goggles.

THE AN/AVS-9 NIGHT VISION GOGGLES

The Night Vision Imaging System that the EA-6B considered for its NVG modification was the Army Navy Aviation Vision System version nine (AN/AVS-9) type I goggles, models F4949G and F4949R. The AN/AVS-9 goggles have been in service for the last five years and are the goggles of choice for most U.S. tactical aircraft. The AVS-9 goggles are a lightweight, binocular device with each monocular consisting of an object lens, an image intensifier tube, an eyepiece lens and a monocular housing. The binocular system is attached to a pivot adjust shelf which includes adjustments for interpupillary, fore/aft, up/down and tilt. The binocular eyepieces can be rotated 90 degrees upward to allow aircrew an unobstructed unaided view. The AN/AVS-9 goggles attach directly to the aircrew helmet through an adapter clip (Figure 3).

AN/AVS-9 GOGGLE PERFORMANCE

The AN/AVS-9 goggles have a field of view of 40 degrees, a weight of approximately a pound and half (clip included), and a internal battery source. The AN/AVS-9 goggles can enable an operator to achieve a visual acuity approaching 20/20 when properly adjusted. The controls are fully automatic: automatic gain control will adjust automatically to suit the amount of ambient infrared and near infrared light present; and automatic "brightens protection" shuts the goggles down in the presence of strong incompatible lighting and, once the incompatible light source is removed, turns them back on.

AN/AVS-9 GOGGLE OPERATION THEORY

The AN/AVS-9 goggle utilizes an image intensification tube to intensify ambient light. Ambient visible and near-infrared light enters the goggles though an objective lens that focuses that light onto a photocathode tube. When struck by the light, the photocathode tube releases a corresponding stream of electrons of proportionate energy

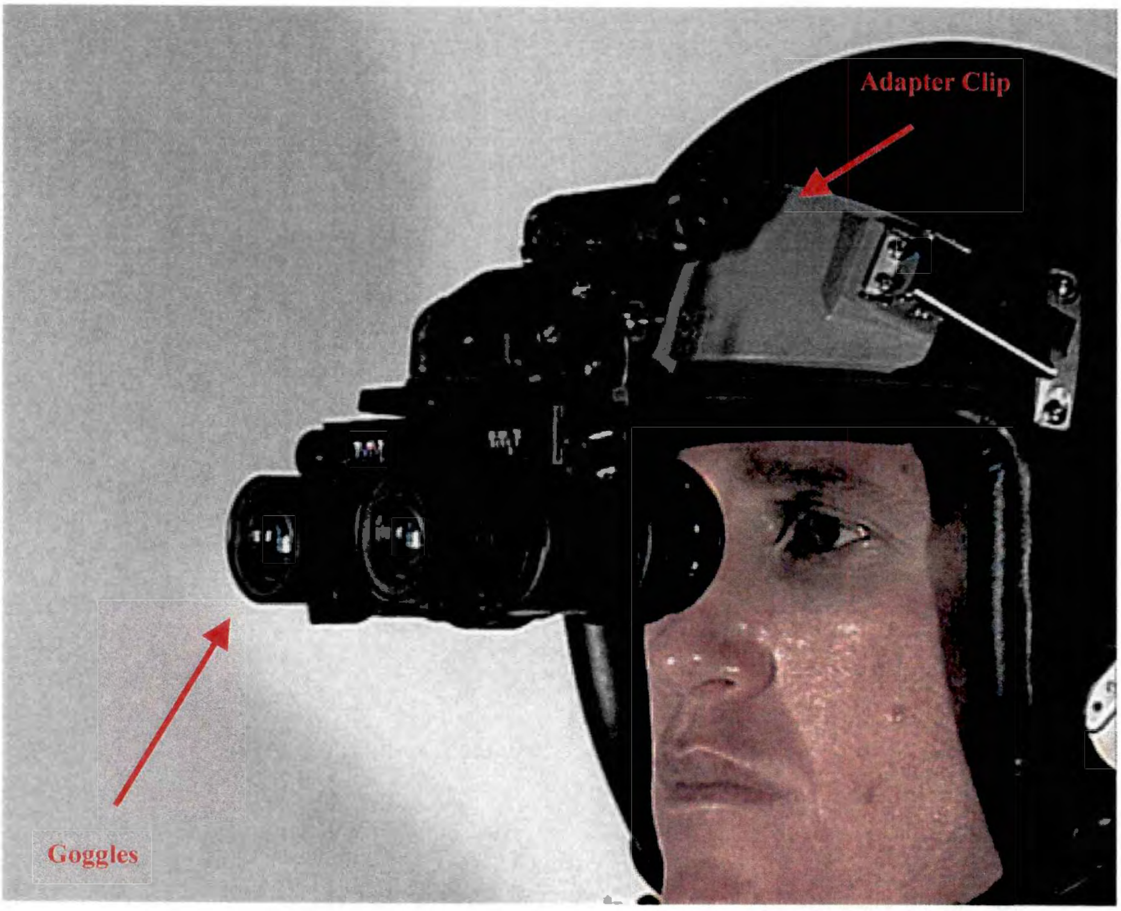


Figure 3
AN/AVS-9 Goggles

that form an 'electron picture' of the original light image. The electron picture is then amplified many thousand of times as it travels through a microchannel plate that consists of a series of electron channels. Each electron channel releases several electrons for every electron that hits it. The released electrons, as they travel through the channels, hit other sections of the microchannel plate and release even more electrons. The effect is that of a pseudo-chain-reaction. Once all the electrons leave the microchannel plate, they are accelerated by a positive charge to a phosphor screen. The electrons hit the screen and the phosphor irradiates a visible image (in a green hue) that the operator sees through a focusable diopter lens. Figure 4 is a graphical representation of the image intensifier tube and its major components.

Both the F4949G 'Leaky Green' and F4949R 'Rotary Wing' AN/AVS-9 goggles work in a narrow frequency band. Figure 5 represents the spectral response for both the F4949R and F4949G goggles. The difference between the models is that the F4949G has a band pass filter that permits some visible light to be detected by the goggles.
This feature is called a leaky green filter. It allows the image from a "heads up" displays (HUD) to be seen through the goggles. The image from the standard tactical aircraft HUD operates at approximately 520 nanometers (in the visible spectrum) and the band pass filter permits some of the HUD light to be seen through the goggles. The F4949R goggles do not have this band pass filter and its performance begins higher on the electromagnetic spectrum.

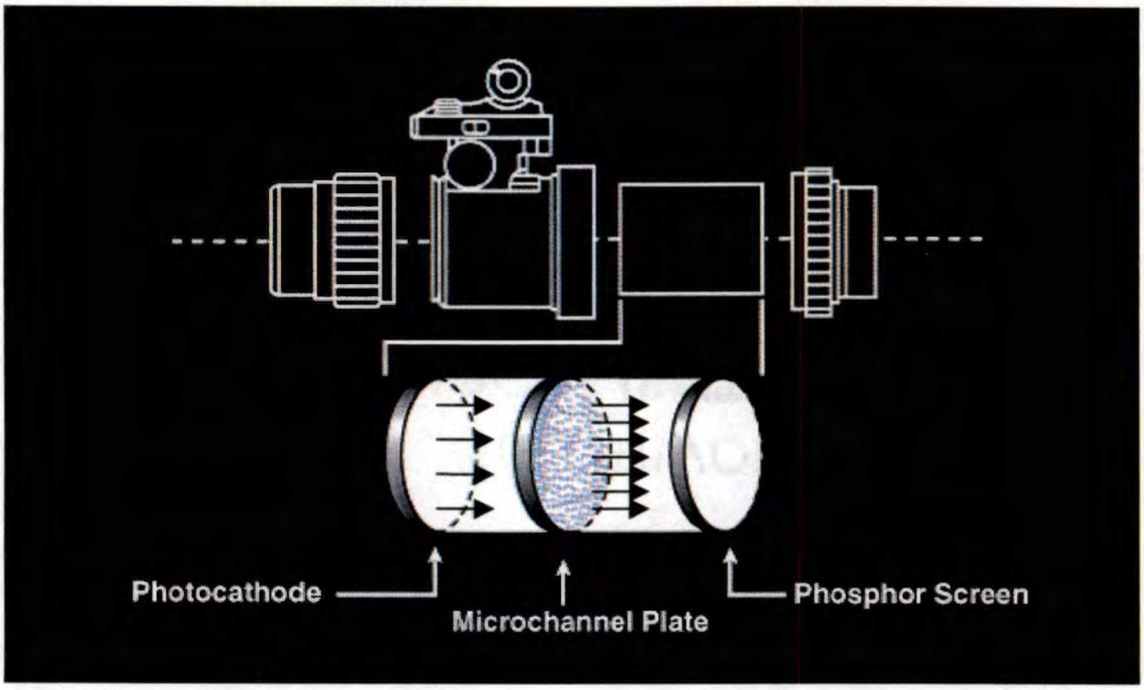


Figure 4
AN/AVS-9 Image Intensifier Tube

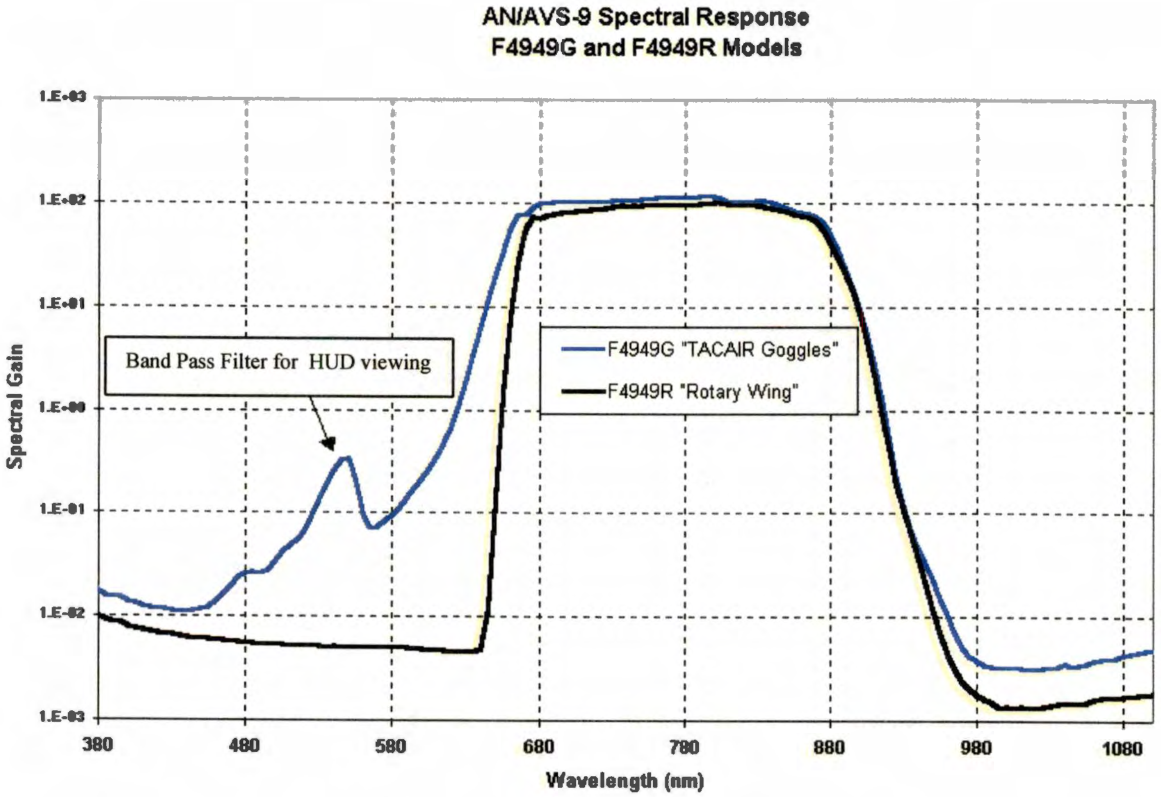


Figure 5
AN/AVS-9 Goggle Spectral Response

NVIS COMPATIBLE LIGHTING AND WHY

Aircrew utilizing Night Vision Goggles usually conduct three different scan patterns in order to safely operate the aircraft. Those scan patterns are: instrument scan, aided scan outside (utilizing Night Vision Goggles), and unaided scan outside (around the Night Vision Goggles). Those three scans are integrated and there is a continuous transition from one to the other depending on the mission, environmental conditions, immediate tasking, flight altitude, and numerous other factors (Antonio, 2000). These transitions as well as the scan themselves are all affected by the quality of the NVIS-compatible lighting present. Incompatible lighting – both internal and external aircraft lighting – hinders the scan pattern, degrades the goggles' performance, and generally reduces the overall situational awareness state of the aircrew. An A-10 mishap, in which one of the causal factors of the mishap was inadequate illumination of the attitude reference indicator during Night Vision Goggle operations, illustrates this. During that flight, the mishap pilot became disoriented after flying into a cloud at an unusual attitude and having to make a rapid transition from a visible discernable horizon to instrument flight while wearing goggles. The pilot was unable to rapidly ascertain his attitude by scanning his attitude reference indicator (gyro), and eventually ejected from a flyable aircraft.

NVIS COMPATIBLE COCKPITS

In order to make a cockpit compatible with Night Vision Goggles operation, two objectives must be met:

1) Remove all lighting in the cockpit that is incompatible with Night Vision Goggles by either shutting them off or replacing them with compatible lighting. Compatible lighting usually consist of lights that have an extremely low IR signature.
2) Maintain interior lighting that allows the aircrew to adequately scan the primary flight and engine instruments as well as operate the critical controls and displays. This lighting (limited to the above-mentioned systems) should be as good as the normal aircraft lighting used for night operation.

Failure to achieve the two objectives above will lead to reduced aircrew external situational awareness and limit the ability of the aircrew to scan their primary flight and engine instruments.

Condition 1 is important because, given the ability of the goggles to amplify by many times the ambient light in their operating band, any incompatible light source will adversely affect the goggles' performance. Typical aircraft lighting is incompatible because of the huge amount of infrared energy it radiates. Typical, an incompatible red light that appears to the naked eye to be off may generate enough infrared energy to fully de-gain the NVG and inhibit the NVG from producing an interpretable picture of the outside environment.

The lessons of aviation history support Condition 2. Night flying generally means an increased workload for aircrew since reduced light means some loss of visual cues.

Many mishaps that are not NVG-related have occurred when normal lighting systems fail to work properly and aircrew become disoriented *in extremis*. With the addition of Night Vision Goggles, aircrew have a tool that improves one aspect of situational awareness (the detection of objects ordinarily impossible to see with the naked eye) but at the same time the direct view goggles reduce aircrew's external field of view. In addition, in non-HUD aircraft, the direct view goggles of the AVS-9 family force aircrew to look underneath the goggles to scan the instrument panel, thus further increasing the aircrew's workload at night. Given these two factors, it has become imperative that the NVIS-compatible lighting for the primary flight and engine instruments be at least as good as the primary lighting system for night and instrument flight.

CHAPTER 4: THE EA-6B NIGHT VISION GOGGLE APPROPRIATION SCHEME

In order to meet the six month deadline, PMA-234 was given 30 million dollars from Congressional Plus Up funds that was specifically targeted to give the Prowler NVG capability. This funding came in February of 2000 in direct response to testimony to Congress after the Kosovo war. With the funds in place and with knowledge that this program could take several years to complete, the fleet proposed a simple, fleet-installable NVG kit. However, the fleet's proposal was rejected and PMA-234 pursued a kit that offered greater capabilities. Nevertheless the fleet's attempt at designing a kit *did* send a clear and loud message to PMA-234 that the fleet wanted NVG-capability sooner rather than later. To that end, PMA-234 requested and received an abbreviated acquisition waiver in order to by-pass the traditional milestones required by an acquisition program.

THE FLEET PLAN

As stated earlier, one of the fleet's requirements was to have Night Vision Goggles by March of 2000. In fact, the fleet initially designed a rudimentary kit and wanted to utilize it for Night Vision Goggle operations. This design would have permitted fleet squadrons to modify their jets themselves, utilizing off-the-shelf materials and technology.

The fleet's design utilized green 'Chemical Lights' (Chem Sticks) taped to the instrument panel to provide primary flight and engine instrument lighting and recommended placing NVIS-compatible filters in the overhead utility lights and over the Electronic Flight Instrument System displays. During NVG operations the Chem Sticks lighting would be used and all incompatible lighting would be turned off. The filtered overhead utility lights would selectively illuminate areas of the cockpit not otherwise adequately illuminated. The fleet design did not propose to modify the external lights.

The primary and most controversial component of the fleet design was the Chem Sticks. The Chem Sticks proposed for use by the fleet were ¼ inch by 4 inch cylinders filled with chemilluminescence fluid that radiates a green NVIS-compatible light once activated (Figure 6). The Chem Stick recommended was once utilized by other

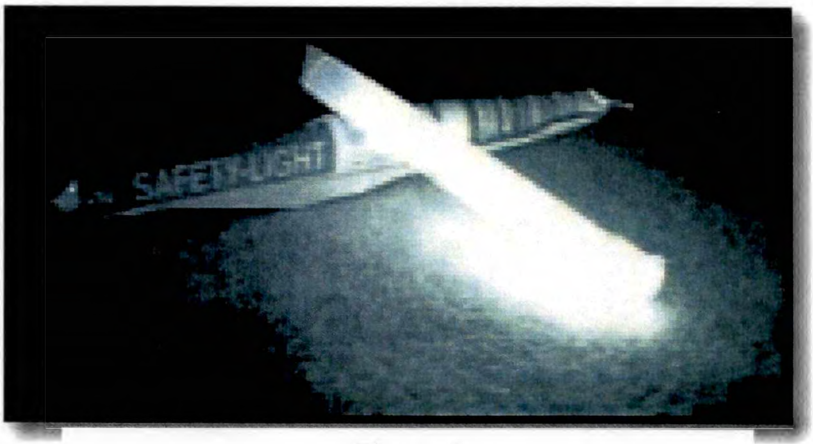


Figure 6
Chemical Light

platforms like the F-16 and A-10 early in their own Night Vision Goggle kit development. The F-16 and A-10 experiences, however, suggested that the Chem Sticks approach had three significant drawbacks (Night Vision Goggle Training Course, 1999). These were:

1. Incomplete illumination coverage of the primary flight and engine instruments. Generally, the 'Chem Lights' placements were determined by where they could be taped rather than the optimum location for illumination.
2. The 'Chem Lights' performance degraded over time and their performance was too dependent on the environment, particularly the temperature and humidity at which they were stored and used.
3. The "Chem Lights" were treated as a consumable and were replaced after every flight. In addition, they had a shelf life of only four years under optimum conditions.

After a few years with the Chem Stick approach, these platforms pursued a more permanent and comprehensive NVIS lighting solution.

When the Navy's flight clearance authority, Aircrew Systems Integration Branch, reviewed the initial fleet proposal to use Chem Sticks for the initial EA-6B NVG kit, they recommended that PMA-234 not take that approach. The Chem Stick approach was deemed unacceptable with respect to safety because of its suspect reliability and its inadequate coverage of the primary flight and engine instruments.

PMA-234 INITIAL PLAN

The EA-6B Program Manager (PMA-234) elected to bypass the traditional acquisition plan and opted for an abbreviated acquisition program in order to meet the timeline as set by the fleet. In choosing this method, PMA-234 formed an acquisition team composed of research and design engineers who had worked extensively on the moderately successful F-14 Night Vision Goggle modification, which had entered fleet service five years earlier. The original EA-6B Night Vision Goggle kit proposed by the Program Manager was a low risk, inexpensive copy of the kit used in the F-14 Tomcat. In this proposal, internal lighting was designed on the theory that the secondary instrument lighting system (instrument and console floodlights) was adequate for instrument/night flight and that system was modified to be NVIS-compatible. Any shortfalls in lighting coverage would be resolved by adding additional floodlights. In addition, NVIS-compatible filters and all other lighting that was not on the secondary system or was not filtered was disabled. The external lighting simply consisted of replacing the upper and lower anticollision, tail, wingtip, and pylon lights with lights that could radiate either in a NVIS-compatible mode with a reduce infrared signature, or in a covert mode with only an infrared signature (no visible lighting).

The Program Manager operated under a loosely written Operational Requirement Document that gave the acquisition team a great deal of flexibility in fielding a kit. This document was in the form of a memo that contained a single broad requirement "to make the EA-6B NVG capable" (EA-6B NVG ORD Memo, 1999). With this non-specific requirement to work from, and with a team with NVG experience in tactical aircraft, the Program Manager decided to bypass generating a Functional Requirement Document, conducting a Preliminary Design Review, Critical Design Review, or conducting any Aircrew System Advisory Panels. Instead, the Program Manager simply allowed the design engineers to produce a kit in a feedback vacuum, without significant fleet or tester input until testing began.

Furthermore, the Abbreviated Acquisition Plan waiver allowed for the Program Manager to bypass all Operational Testing. The program's decision to buy could be made solely on the basis of developmental testing and the recommendations that arose from that testing. However, the decision authority for this EA-6B acquisition program (Program Executive Officer – Tactical Aviation) elected to have Operational Testers perform a "quick look" at the system to ensure it was truly operationally effective and to maintain an independent review. This operational look was conducted by a Quick Reaction Assessment process.

NVG KIT DESIGN AND INSTALLATION

Due to the rapid pace of the program and the perceived low risk of its design concept, the Program Manager elected to by-pass producing a model before modifying an aircraft. This was in contrast to military specifications for NVIS interior modifications

(MIL-L-85762A, 1988), which strongly encourage a model be developed before any prototype installation is undertaken. When it came to incorporating the engineers' designs into the prototype aircraft, the professional installation team had scheduling conflicts that would have delayed the program by three months. The Program Manager decided to utilize regular aircraft maintainers instead. Finally, in the actual design and installation of the kit, a trial-and-error approach was taken. Designers and installers would break down the existing lighting system of the prototype aircraft, make specific measurements and tests on the spot, then design, manufacture, and install the NVIS-compatible components. If the system did not work after installation, then it would be removed, redesigned and re-installed on the spot. Erroneous drill holes and other installation mistakes would be repaired if possible.

TESTING OVERVIEW

Working within the guidelines of the Abbreviated Acquisition Strategy guidelines, the Program Manager elected not to generate a Testing and Evaluation Master Plan. This was appropriate since the only official guideline the program had was the generic Operational Requirement Document. However, the design team's non-binding goal for the EA-6B NVIS lighting was to meet the following requirements:

1. Interior Lighting: the guidelines as set forth in MIL-L-85762A.
2. Exterior: the guidelines set forth in the FAA FAR 25 guidelines when operating in the visible mode.

3. Reliability and Maintainability: close to the performance of the existing lighting.

With no Testing and Evaluation Master Plan, the Developmental Test program concentrated on safety and basic functionality and the Operational Test Quick Reaction Assessment focused on ease of use, reliability, maintainability, and the ability of the Prowler to perform any of its missions at night while wearing Night Vision Goggles.

In preparation for the test program, Developmental Test and Operational Test worked together to generate a joint test plan to ensure a thorough evaluation of the kit. Since the majority of the test aircrew doing the evaluation had never operated the AN/AVS-9 goggles, all participated in an intense training program to qualify with the goggles in a tactical aircraft.

TEST AND EVALUATION SPECIFICS

The evaluation consisted of quantitative and qualitative ground testing followed by qualitative flight-testing. Testers evaluated the aircraft interior lighting system to ensure that day and night (unaided – without goggles) and night (aided – with goggles) NVG operations met performance requirements and enabled aircrew to safely employ the EA-6B in its various missions. They also evaluated the entire modification kit for Electromagnetic Compatibility (EMC) for the EA-6B and Aircraft Carrier harsh electromagnetic environments. Exterior evaluations were made of the modes of normal and night-aided lighting systems during ground and flight tests. The infrared transmittance of the EA-6B's windscreen and canopy infrared transmittance were also evaluated. Based on the transmission responses of the aircraft's transparencies, the transmittance tests determined the impact that various cockpit lighting configurations made on external visibility. Overall, the EA-6B NVG tests focused on, but were not limited to, the following:

1) Daylight readability of NVIS-modified lights and displays.
2) Night readability (unaided) of NVIS-modified lights and displays.
3) Effect of cockpit lighting on the performance of the AN/AVS-9 NVG.
4) Field of regard, range/volume of motion evaluation with goggles on.
5) General "ease of use" evaluation (e.g., donning, doffing, stowage, etc.)
6) Spectral radiance, NVIS radiance, and luminance.
7) Target resolution and effects of display brightness on target resolution for the AN/AVS-9 NVG; conducted in simulated near-mean-starlight (less than 0.0022 lux) and near-full moon conditions (approximately 0.1 lux).

GROUND TESTS

Ground tests were conducted on the flight lines and in the Aircraft Test and Evaluation Facility (ATEF) at Patuxent River Naval Air Station. The ATEF is a light-tight hanger modified to provide simulation of night sky conditions ranging from below starlight to above full moon. The cockpit lighting system was evaluated during approximately 110 man-hours of ground testing. EMC testing was in compliance with Military Standard MIL-STD-464 Electromagnetic Environmental Effects Requirements for Systems. Quantitative evaluation of spectral radiance, NVIS radiance, luminance, transmissivity, and effective visual acuity was performed using the following equipment:

a. Hoffman Engineering Corporation NVG 101A Image Converter
b. Hoffman Engineering Corporation NVG 101-09/07 Calibrated Variable Radiance Source
c. Minolta LS-110 Luminance Meter
d. Harwood VL-4 Ultra Brite 600W Video Camera Light
e. Minolta Illuminance Meter
f. Hoffman Engineering Corporation LS-65-8-B Luminance Standard
g. USAF Resolving Power Target, Medium Contrast
h. Photo Research Model PR-713AM Spectro-Radiometer

During testing, aircrew positioned themselves at seating heights consistent with normal operations. Specific areas of testing are listed below:

a. Daylight Readability. The main instrument panel, consoles, electronic displays and aircrew station signals were evaluated for sunlight readability, brightness capacity, adjustability and effective use of color.

b. Nighttime Readability (Unaided). The main instrument panel, consoles, and electronic displays were evaluated for adequate illumination, legibility, brightness uniformity, stray light, glare, symbol recognition, saturation and separation, legend legibility, and glare. The cockpit was also evaluated for windscreen/canopy reflections. These tests were done with both the goggles off and with the goggles on (looking underneath them).

c. NVG Compatibility. The main instrument panel integral lighting, electronic displays, aircrew stations signals, cockpit flood lighting, and chart flood lighting were evaluated for NVG compatibility. The evaluation parameters included luminance, radiance and chromaticity (color). This test provided a comprehensive evaluation of component level compatibility with NVGs.

ELECTROMAGNETIC COMPATIBILITY TESTING SPECIFICS

The Electromagnetic Compatibility test program was conducted in four phases to investigate the electromagnetic compatibility of the new interior and exterior lights to the normal operating environment of the EA-6B. The four phases were the following:

1) Direct Current (DC) Bonding Resistance Measurements. DC bonding was measured with a digital low-resistance milliohmmeter to determine if the NVG lighting components met the requirements set in MIL-STD-464. Measurements were made between each component and the basic airframe structure. If the value exceeded the specification, additional measurements were made until a high-impedance path was identified and, if possible, corrected.

2) Intrasystem Electromagnetic Compatibility. The intrasystem EMC test was conducted to ensure the NVG-compatible lighting modification did not cause interference in the Intercockpit Communication System (ICS) or Tactical Jamming System Lowband receivers. The performance of the EA-6B aircraft systems and subsystems were monitored for evidence of Electromagnetic interference from the NVG compatible lighting by using audio outputs and video displays to allow maximum detection of an undesired response.

3) Intersystem Electromagnetic Compatibility. The intersystem EMC test facilities at Naval Air Station Patuxent River were designed to simulate land-based, shipboard, and airborne operational Electromagnetic Environment (EME) for the purpose of conducting intersystem EMC tests. Aircraft systems were exercised in the same manner as would occur in the Fleet to determine their survivability and operability when exposed to the simulated operational EME's. The NVG-compatible lighting components were monitored for susceptibility to the simulated EME. Testing commenced at EME power levels that were 75 percent below the main beam levels. Power levels were progressively increased until either the performance of the system degraded to the point of rendering it incapable of performing its mission, or the criteria test level had been reached. When EMI occurred, a susceptibility threshold was determined to identify the severity of the interference.

4) Intrasystem Electromagnetic Compatibility Flight Tests. EMC flight tests were conducted to determine the compatibility between the EA-6B Tactical Jamming

System Low band transmitters and the NVG compatible lighting components. One 1.5 hours of flight test were conducted concurrently with other night flight test events. EA-6B low band jamming was introduced to the modified aircraft and any discrepancies were noted.

AIRCRAFT CARRIER SUITABILITY TESTING

The EA-6B NVG kit was evaluated for its suitability to survive the harsh environment of takeoff and landings from an aircraft carrier. The TC-7 shore-based catapult and MK-7 Mod 3 plus shore-based arrestment gear were utilized to simulate this environment. Five catapult launches and 18 arresting gear events (4 touch and go's, 1 bolter, and 13 traps) were performed to the structural limits of the aircraft. After each event, all of the modified and additional exterior and interior lights were inspected visually or by hand for any damage and continued proper operation. In addition, the AN/AVS-9 goggle storage cases and storage location in the aircraft were evaluated for proper security.

FLIGHT TESTS

Flight-testing consisted of 11 flights totaling 20.1 hours. Test flights incorporated mission-representative Electronic Attack and Electronic Support profiles as well as a carrier-suitability flight profile. Flights consisted of four unaided (three day and one night) and seven aided flights. The day flight consisted of evaluating sun light readability while performing cockpit tasks. This included flying with various sun angles into the cockpit (i.e. sun from behind, straight on, and overhead). In addition, two carrier suitability flights consisting of shore-based catapults and arrestments were conducted to simulate the harsh takeoff and landing environment of an aircraft carrier. The night flights evaluated unaided readability, aided compatibility of cockpit instruments, and the modified external lighting.

Tests included evaluation of cockpit tasks while flying an instrument route, standoff jammer profiles, modified escort, formation work, break ups and rendezvous, and night high value asset defensive maneuvering. At the completion of Developmental Tests, the Quick Reaction Assessment took place with a mixed crew of Operational and Developmental Testers. Table 1 represents the sequence of flights flown.

Table 1
Flight Sequence

Flight	Type of Flight	Notes
1	Day Readability	Unaided
2	Night Readability	Unaided
3	NVG Kit Familiarization and Instrument Route Flight (Military Training Route)	Aided
4	Formation / Outside Lighting Check	Aided
5	Low Illumination Instrument Route (Military Training Route)	Aided
6	Formation / EMC / Low Illumination Outside Lighting Check	Aided
7	Aircraft Carrier Suitability Catapults	Unaided
8	Aircraft Carrier Suitability Arrestments	Unaided
9	Quick Reaction Assessment NVG Kit Familiarization	Unaided /Aided
10	Quick Reaction Assessment Day/Night Readability	Unaided /Aided
11	Quick Reaction Assessment Low Illumination Evaluation	Aided
12	Quick Reaction Assessment Formation Evaluation	Aided

CHAPTER 5: RESULTS AND DISCUSSIONS

EA-6B NVG AIRCRAFT MODIFICATION DESCRIPTION

BLOCK 89 EA-6B LIGHTING

To properly understand the magnitude of the changes made to the EA-6B Prowler, we will begin by examining the aircraft's pre-NVG lighting scheme. This consisted of red integral lighting as the primary lighting system and floodlights as the secondary lighting system. The primary lighting system provided adequate illumination of all the primary flight and engine instruments as well as all the console and subsystems. The secondary lighting system consisted of floodlights strategically placed to provide illumination for the majority of the primary flight and engine instruments as well as all side consoles. While operating under the secondary lighting system, the secondary attitude system (the attitude reference indicator), vertical speed indicator, altimeter and center console required manual illumination to facilitate operation or viewing (Figures 7 and A-1).

The exterior lighting system consists of position, formation, landing, refueling, and taxi lighting. The position lighting meets the guidelines as set forth by the FAA FAR 25 lighting guidelines. The position lighting consists of an upper and lower anticollision

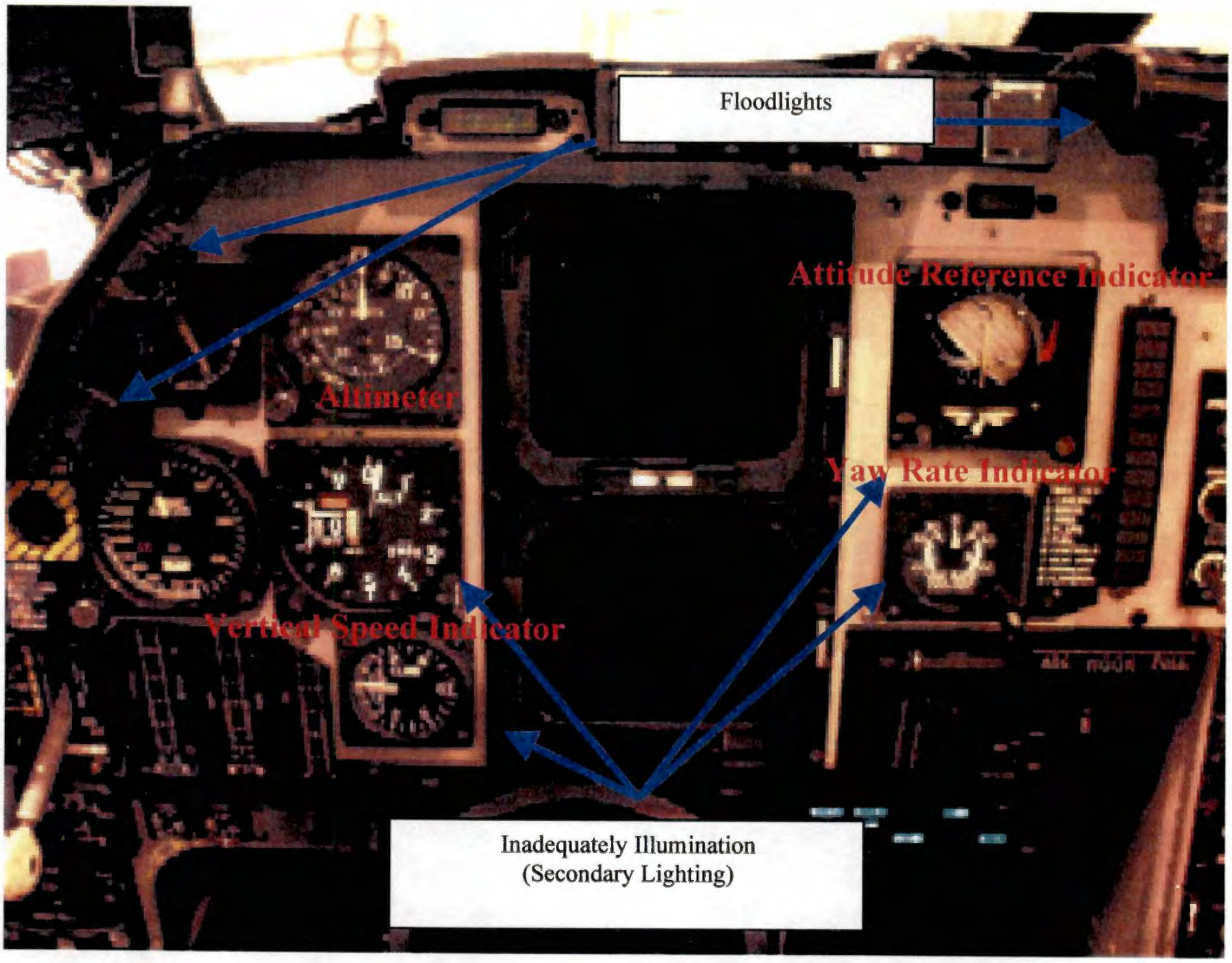


Figure 7
Flood Light Kit

lights, tail, wing, and pylon lights (Figure 8). The formation lights consisted of strip lights attached to the fuselage and wing tips.

INTERIOR KIT

There were essentially two interior kits evaluated: a floodlight-based kit and a kit based on post lights. With both kits, all of the electronic displays (Electronic Flight Instrument System attitude reference and horizontal situational indicator displays, radio control, radar screens, Tactical Jamming System Weapon System Displays) and the warning, caution, and advisory lights were covered with filters compatible for Night

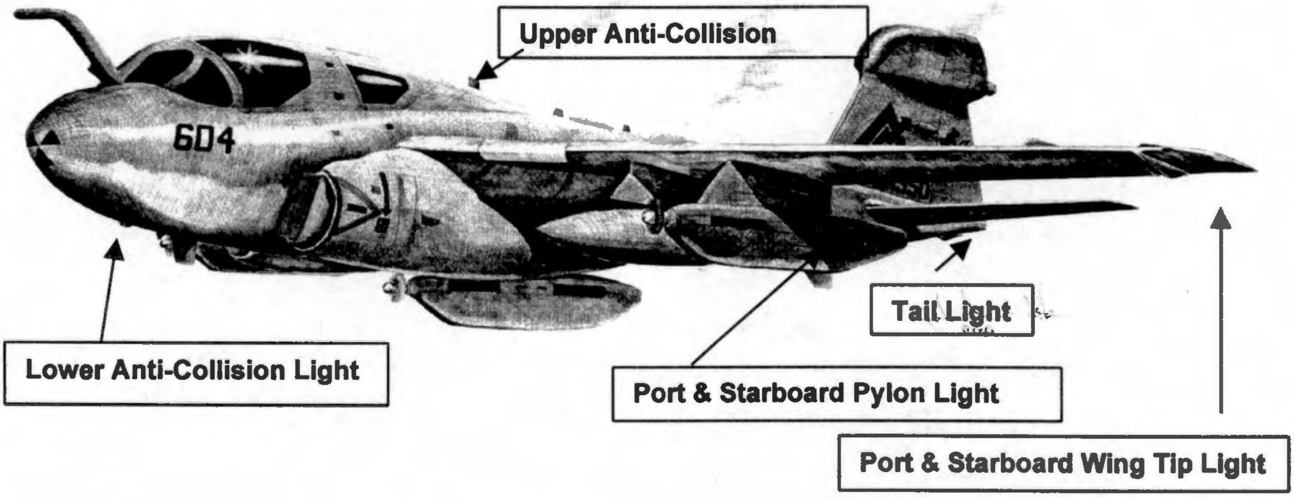


Figure 8
EA-6B Position Lights

Vision Imaging Systems.

The floodlight kit centered on modifying the existing secondary lighting system (floodlights) with filters that were compatible for NVIS. Unfortunately, testing revealed that the secondary lighting system did not illuminate the primary flight and engine instruments well enough to facilitate a scan by aircrew. In particular, the following instruments were not illuminated at all: vertical speed indicator and yaw rate indicator (Figure 9). The secondary Attitude Reference Indicator was illuminated, though the illumination threw shadows across the instrument face, making it difficult to ascertain the sky-ground contrast by a scan (though it could be discerned by a stare). The upper left

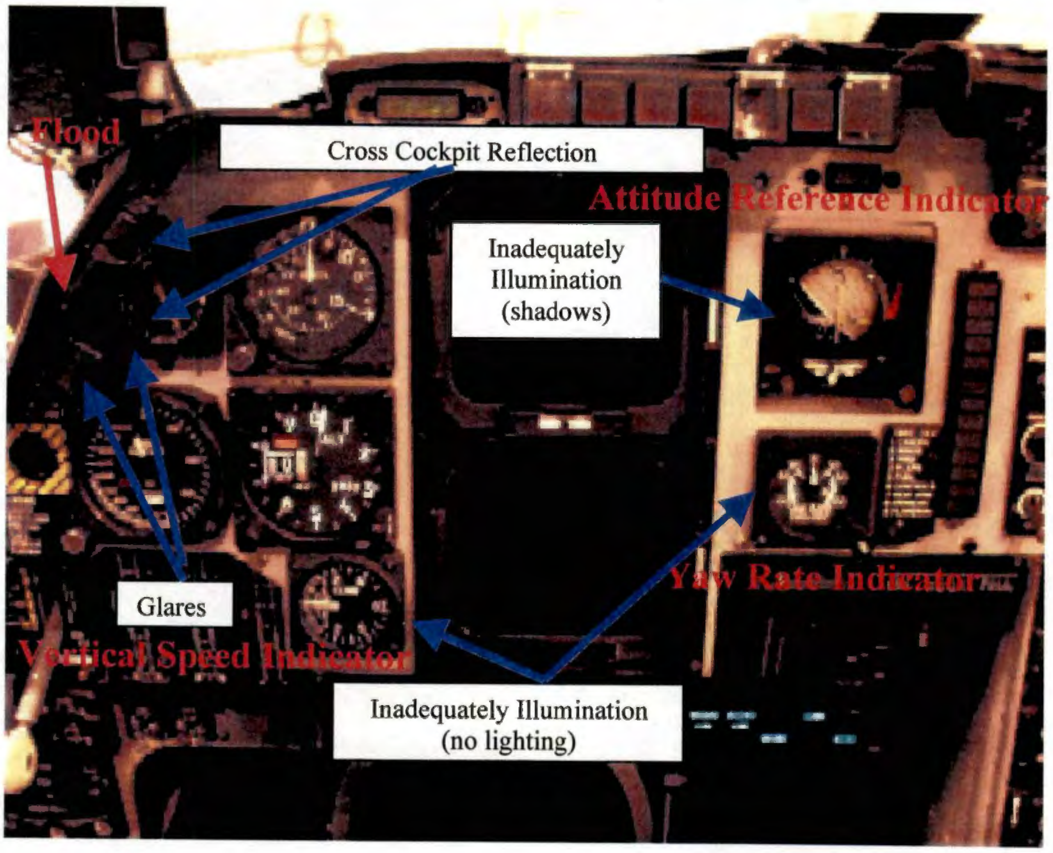


Figure 9
Flood Light Kit Deficiencies

half of the altimeter was illuminated but the instrument as a whole required a stare to ascertain its information during dynamic events such as climbs and descents. Finally, the floodlights located in the upper left hand corner of the instrument panel by the angle of attack gauge produced an extremely annoying reflection for the crewmember in the front right seat and, for both crewmembers, a terrible glare on top of the AOA.

The inadequate illumination of several of the primary flight instruments was deemed a safety-of-flight issue and thus unsatisfactory for fleet release. All other flight testing ceased and the kit was redesigned. In addition, the developmental testers refused to allow further experiments on their aircraft until a model had been tested.

POST LIGHT KIT DESIGN (FRONT COCKPIT)

The post light kit design was based on 1950s technology used in the T-2 trainer aircraft. The T-2 utilizes miniature floodlights (post lights) located directly adjacent to the flight instrument that requires illumination. This design minimizes the amount of light required to adequately illuminate an instrument by confining what light is needed to a specific area. In all, 15 post lights were added to the Pilot's instrument panel in order to adequately illuminate the primary flight and engine instruments (Figures 10 and A-2). In addition, several floodlights were removed or repositioned to provide adequate illumination of secondary systems while not producing any unwanted reflections or

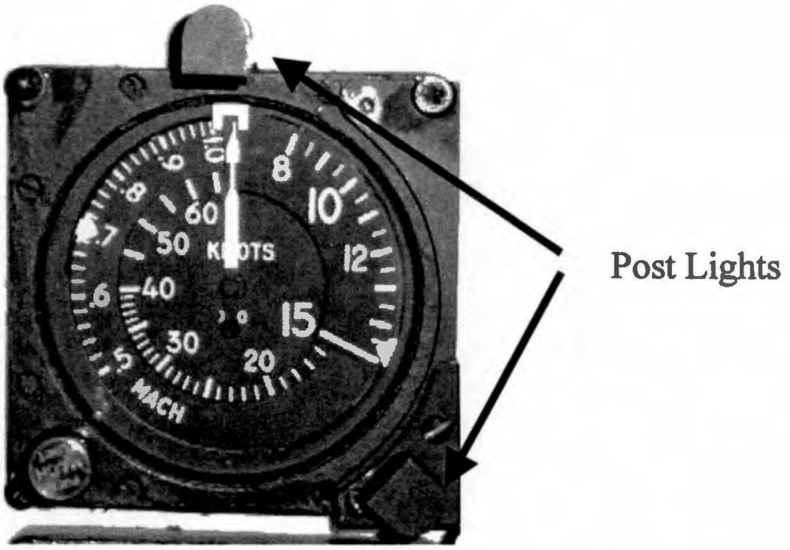


Figure 10
Post Light

glares. The frequency response of both the post lights added and the modified flood and utility lights frequency response was between 540 and 545 nanometers (now known as "NVIS green" since its the same wavelength as the green image as emitted by the AVS-9 goggles).

The displays that required filtering in the front cockpit are listed below (Figure A-3):

1. Electronic Flight Instrument System – Attitude Display Indicator and Horizontal Situational Indicator
2. Inner and Outer Wing Fuel Pressurization Status
3. Radio Control Panels and Repeaters
4. Civilian Instrument Landing System Control Panel
5. Master Caution Light
6. Warning, Caution, and Advisory Panel
7. Fire Warning and Temperature Lights
8. Wheels Warning and Approach Indexers Light

All of the filtered displays were effective in eliminating the incompatible lighting to below the threshold limits of the F4949R 'Rotary Wing' goggles. The spectral response curves of the displays, with and without the filters, are provided in appendix B-1 through B-4. However, this was not the case with the F4949G 'Tactical Aviation' goggles, where the spectral response of the Fire, Warning, and Temperature lights (Figure 11). peak intensity at 610 nanometers and overlapped into the region that was detectable by the F4949G. This was mainly due to the addition of the band pass filter for this particular series of goggles (Figure B-5). Whenever one of the Fire, Warning, or Caution lights would come on, if the aircrew were looking anywhere in the general direction of those lights, the lights' intense brightness relative to the night environment, as detected by the F4949G goggles, would cause the automatic brightness control to gain down the goggles so that the image seen by the aircrew through the goggles became uninterpretable.

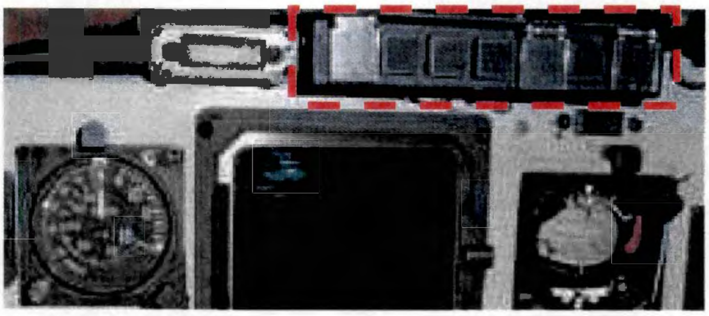


Figure 11
Fire Lights

Incidentally, these same lights when viewed with the naked eye appeared to be a reddish-orange color that simply caught the aircrew's attention but did not destroy their night vision. The F4949R goggles, however, did not demonstrate this deficiency, attributable to their different spectral response (F4949R goggles did not have a band pass filter to facilitate HUD viewing and consequently had a cutoff frequency above that generated by the firelights).

This deficiency could be resolved either by buying F4949R goggles for all the EA-6Bs, or by redesigning the firelights. Unfortunately, the converted firelights utilized in test were not readily available in the national stock supply system and it was far cheaper and quicker to buy additional F4949R goggles (readily available since almost the entire US Navy and Marine Corp helicopter fleet utilized this particular goggle) than to redesign a light and stock it in the supply system.

Since the post lights were an additional lighting system, the master lighting control panel had to be modified to facilitate operation of both the normal lighting system and the NVIS lighting system. This was achieved with the addition of one switch on each crewmember's lighting control box. This switch was labeled "NVIS" or "Norm" and when in NVIS mode, all power was removed from the primary lighting system (integral lighting). In addition, the rheostat that controlled the intensity of the primary lighting system now controlled the intensity of the post lights. Since the post lights did not illuminate the entire cockpit, the secondary lighting system was continued to illuminate those gaps and the secondary lighting system's controls were modified to work independently of the primary lighting system.

An unanticipated deficiency discovered during testing was that the AN/AVS-9 F4949G goggles (Tactical Aviation) were not compatible with the EA-6B kit. Two distracters significantly degraded the performance of the goggles. The fire warning and temperature caution lights deficiency has already been discussed. But in addition, the ambient compatible lighting present inside the cockpit during mean starlight conditions (illumination under .0022 lux which is equivalent to a ¼ moon night or less) would enter the goggles off their optical axis, reflect about within the intensifier tube, and produce a haze-like effect called veiling glare which rendered the goggles unusable. Both the fire light incompatibility and the veiling glare problems were not evident with the AN/AVS-9 F4949R (Rotary Wing) goggles.

Overall, the performance of the post light kit was exemplary. All of the primary flight and engine instruments were adequately illuminated to facilitate aircrew scanning of those instruments. In fact, the post lights worked so well that several aircrew preferred flying with the green NVIS lighting scheme over the red primary lighting scheme. Unfortunately, the illumination of several secondary systems was dependent on floodlights, which did not perform as well as the post lights. This forced aircrew to turn up the intensity of the flood lights to achieve illumination effects equivalent to that provided by the post lights. This increased the overall ambient lighting level in the cockpit and thus reduced the effective unaided night vision of the aircrew. Nevertheless, several aircrew felt the improved readability of their primary flight instruments under green lighting easily outweighed the fact that secondary systems were not adequately illuminated.

AFT COCKPIT

Since the primary responsibility of the EA-6B's aft crew members did not revolve around safety of flight, the Program Office elected to save some time and money by updating the aft cockpit's secondary lighting system based on the floodlight kit. It was necessary however to add several floodlights to provide illumination adequate to operate the weapons system. The following aft cockpit systems required filtering (Figure 12):

1. Tactical Jamming System Advisory Lights
2. Tactical Jamming System Pod Advisory Lights
3. Receiver Control Panel status lights
4. Video Oscilloscopes
5. Digital Display Indicators

Overall, the aft cockpit modifications performed adequately. Aircrew could easily operate the Tactical Jamming System at night while utilizing the NVIS lighting.

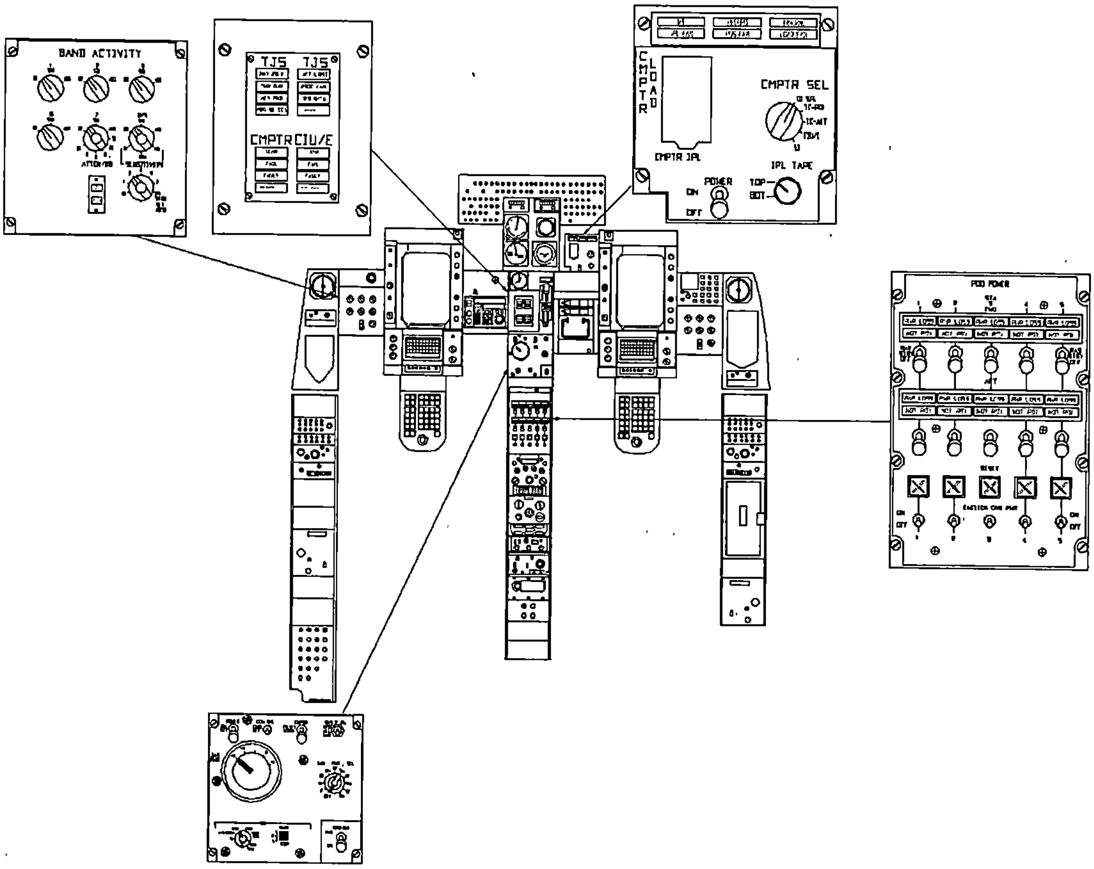


Figure 12
Aft Cockpit Filters

EXTERIOR KIT

The exterior lighting modification consisted of reducing the infrared signature in the anticollision, wingtip, tail and pylon lights (formation and position lights) in the visible spectrum, as well as providing an infrared-only mode for these same lights. To achieve this goal, the formation and position lights (with the exception of the formation strip lights) were removed and replaced with a dual mode system utilizing Light Emitting Diode (LED) technology.

This new dual system incorporated a control box that gave the lighting system additional functionality. In the old lighting scheme, either the lights were on or off and only the tail and wingtip lights could be dimmed. The new lighting system permitted six selectable brightness settings for the wingtip, pylon, and taillights. A code functionality was added, permitting the selected modified lights to flash one of five distinctive patterns for visual identification purposes (Figure 13). Finally, all of the modified lights could either operate in a normal mode (visible spectrum) or in a covert mode (infrared spectrum).

The modified exterior lights performed as well as the original exterior lights and so met the FAA FAR 25 requirements. The new covert mode, flash patterns, and intensity control enhancements of the exterior lights provided additional identification capability for the EA-6B. The Mode Selection function permitted aircrew to select external lights that radiated in either the visible spectrum or the infrared spectrum and aircrew could

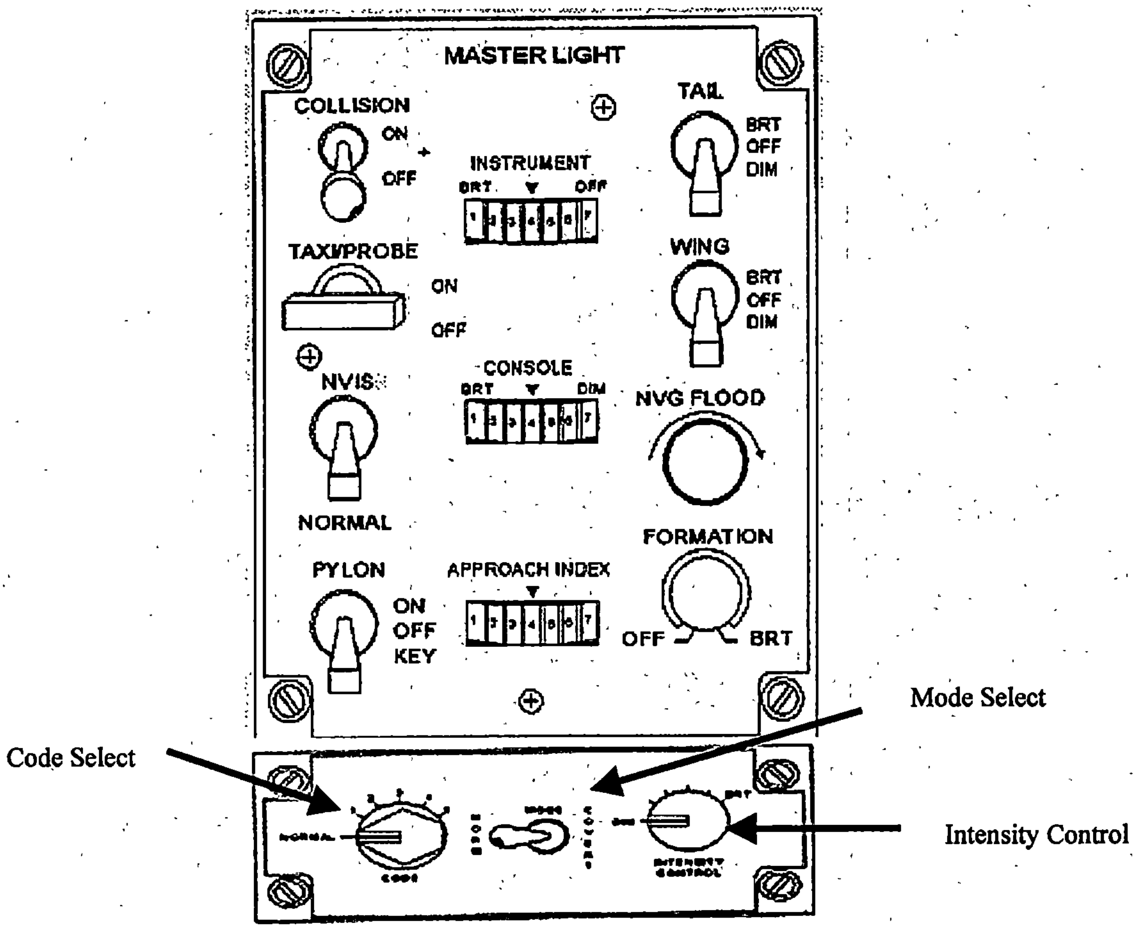


Figure 13
NVIS Lighting Control Panels

easily switch from one mode to the other by touch alone. The performance of the lighting in their respective modes was also satisfactory, with the normal mode lighting on par with the previous lighting system and meeting the requirements set out in FAA FAR 25 lighting guidelines. The infrared lights (the circular modules on top of the glass housing in Figure 14) were designed to concentrate the larger part of their radiated energy away from the ground. The lower anticollision light does not have this module, thus reducing the infrared signature of the platform as seen from below.

The designed covert detection range of the Prowler, as viewed from abeam or from behind through AVS-9 goggles, was approximately 8-10 nautical miles. Testing to qualitatively evaluate the performance of the exterior lights was conducted on a cloudless night during mean starlight conditions (less than .0022 lux, moon below the horizon. To

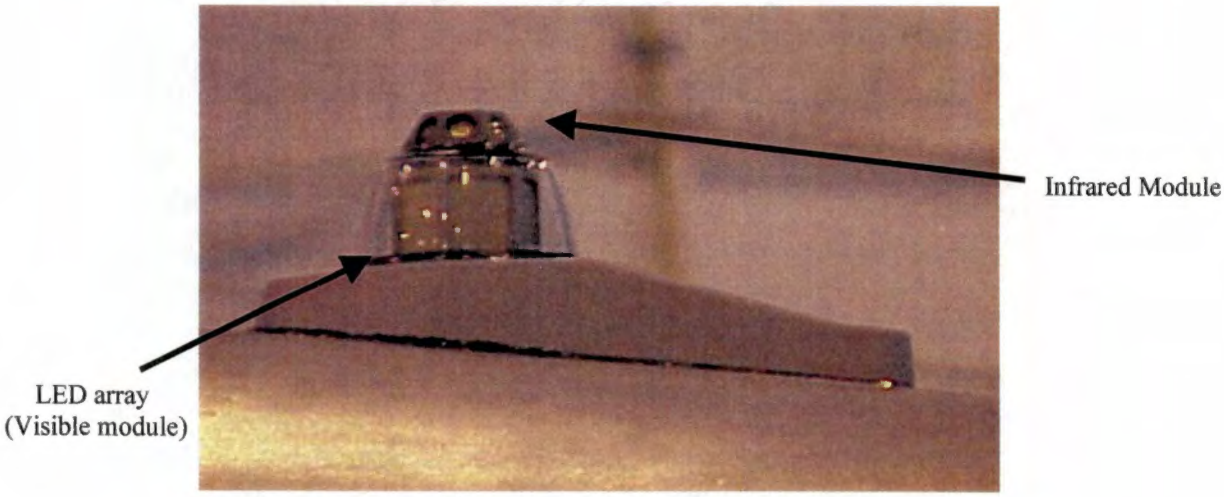


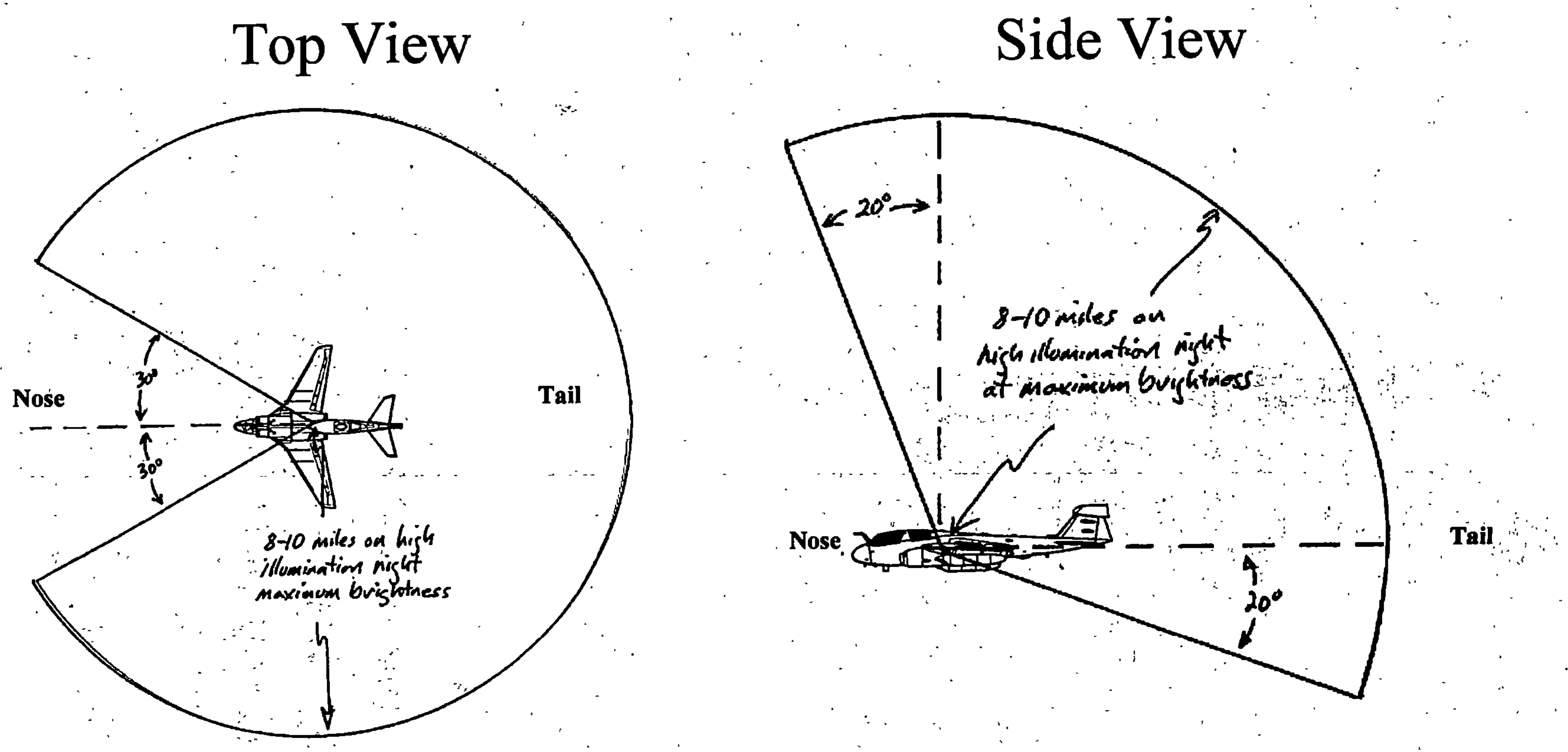
Figure 14
Upper Anticollision Light

obtain the darkest real-world ambient lighting conditions possible, the test aircraft flew out to sea, approximately 100 nautical miles from any source of cultural artificial lighting. The aircraft performed intercepts and section maneuvering, with anti-collision lights off during testing so as to simulate the actual covert lighting that would be used during a combat mission. The qualitative detection range data obtained during this test showed that the covert lights met the design criteria (Figure 15).

The flash pattern selectability worked in both the normal (visible) and covert (infrared) modes. They permitted the Prowler to be easily identified out to 20 nautical miles in the visible mode (high-noise background with other air traffic) and 15 nautical miles in the covert mode (high-noise star-filled background). The flash patterns permitted all or just the selected lights to flash in the following sequences (Table 2):

Table 2
Flash Pattern Description

Code	Flash Pattern
1	1 Flash, pause, 1 Flash
2	2 Flashes, pause, 2 flashes
3	3 Flashes, pause, 3 flashes
4	4 Flashes, pause, 4 flashes
5	Continuous Flash



Top View

Side View

Results

From an Abeam or Aft position and 1,000 feet stepped up

- ~10 nm detection (aircrew scanning, not a stare)
- Flash Pattern 3 & 5 increase this distance to ~ 15 nm
- All lights (minus the anti-collision) on and at maximum brightness

From Head On and 1,000 feet stepped up

- ~5 nm detection (aircrew scanning, not a stare)
- All lights (minus the anti-collision) on and at a maximum brightness

Figure 15
Exterior Lighting Performance

CARRIER SUITABILITY TESTING

The carrier suitability tests were designed to ensure that the new post lights, filters and exterior lighting, plus the AVS-9 goggles storage cases and the case securing mechanism, could all survive the carrier environment up to the structural limit of the aircraft. In the past, the typical storage procedure on other naval tactical aircraft with AVS-9 goggles had been to simply 'stuff' the goggles wherever there was room available. The EA-6B design team elected to place several velcro patches throughout the cockpit as well as attaching velcro to the goggle storage cases in order to facilitate a more secure storage location for the EA-6B. However, velcro as a securing device did not receive initial approval from the Naval Air Systems Command Flight Clearance Authority. But when the Program Office explained that, if no clearance would be granted, the fleet would have to use the 'stuff it' method to secure the goggles during takeoffs and landings, Flight Clearance granted approval to test the velcro as a potential securing mechanism.

The AN/AVS-9 goggles and their cases weigh approximately 1.75 lbs. The maximum longitudinal load factor experienced was 5.2g of acceleration and 4.2g of deceleration. The maximum sink rate experienced was 1,152 feet per second. Throughout the carrier suitability testing, the new exterior lights and interior modifications functioned correctly and held up to the structural loads of the catapults and the arresting gear. The post lights and filters remained intact though a few of the interior post light bulbs came loose. They did not come off, however, and they were easily tightened. The

AVS-9 storage cases protected the goggles from damage and the velcro securing mechanism held the cases firmly attached to the aircraft throughout the entire course of testing.

ELECTROMAGNETIC COMPATIBILITY TESTING

The electromagnetic-compatibility testing was designed to ensure that the NVG modifications could withstand the electromagnetic environment of an aircraft carrier as well as the environment of the world's premier electronic jamming platform, the EA-6B. Testing revealed the following discrepancies:

1) Inadequate direct-current (DC) bonding of the Night Vision Goggles-compatible external lighting. The anticollision and tail light assemblies failed to meet the MIL-STD-464 bonding specification limit of 2.5 milliohms which resulted in increased susceptibility to ground current loops, static charges, and RF-induced electrical potentials that, due to precipitation static effects, produced electromagnetic interference and increased noise levels in onboard radios.

2) Susceptibility of the AN/AIC-14 Intercommunication System (ICS) to the Night Vision Goggles-compatible Anti-collision Lights. The ICS was monitored during operation of the NVG-compatible internal and external lighting. The ICS exhibited a susceptibility to the NVG-compatible Anti-collision Lights. The interference was characterized by an audible "beep" in the ICS each time the anti-collision lights strobed. Susceptibility of the ICS to the NVG-compatible Anti-collision Lights was an annoying characteristic of the modified lighting.

3) Susceptibility of the Night Vision Goggles-compatible External Lighting to a simulated operational electromagnetic environment (EME). Testers monitored the NVG-compatible internal and external aircraft lighting while subjecting the aircraft to a simulated EME. The NVG-compatible Tail Position Lights exhibited a susceptibility to a simulated operational EME, with both the visible and covert Tail Position Lights failing to illuminate in visible or covert mode respectively when the aircraft was subjected to a continuous-wave HF transmission. The lights operated properly when the HF transmission was discontinued. Table 3 shows

Table 3
Tail Position Light Susceptibility Levels

Frequency (MHz)	Visible Tail Position Light Threshold of Vulnerability (V/m)	IR Tail Position Light Threshold of Vulnerability (V/m)
16.060	100	-
17.048	71	100
18.036	100	-
19.270	100	100
20.510	71	100
21.460	50	71
23.180	100	-

threshold data. Inadequate bonding between the Tail Position Lights and the airframe could be a contributing factor to this EMI.

OVERALL RESULTS OF THE POST LIGHT KIT

The post light-based approach proved to be safe, effective and suitable for the EA-6B's Tactical Electronic Warfare Mission. Aircrew could operate with the AN/AVS-9R goggles effectively in performing all aspects of the Prowler mission from 1,000 ft AGL up to the service ceiling of the aircraft. In addition, the NVIS lighting of the primary flight instruments proved to be a better system than the existing secondary lighting and provided aircrew with improved lighting during degraded-lighting conditions such as operating on emergency power. This factor was a major safety improvement over the existing lighting in the EA-6B. Externally, the new position lighting allowed aircrew to fly in close-formation, with visible lighting on, without degrading the performance of the goggles. The flash pattern selectability for aircraft identification as well as the covert modes also performed extremely well and provided Prowler aircrew with additional tools during combat operations.

CHAPTER 6: ABBREVIATED ACQUISITION STRATEGY LESSONS LEARNED

Three significant considerations played key roles in the delay of the Abbreviated Acquisition Program. Those three considerations were:

1) Lack of effective and open communication with the customer (fleet aviators).
2) Lack of a Controls and Display Working Group and the utilization of mock-ups for proof of concept before actual aircraft installation.
3) Lack of a Critical Design Review prior to manufacture.

EFFECTIVE COMMUNICATION

Throughout the program, those responsible for the modification program constantly relayed optimistic schedules and unrealistic results to the Prowler fleet, which consequently developed long-range logistic, training and scheduling plans to fly with the Night Vision Goggles as soon as they arrived. But since the information provided was less than accurate, the fleet had to adjust these plans several times. This eventually became extremely frustrating and the fleet eventually elected to hold off on any future plans until the kit passed all testing. Many fleet members questioned Naval Air Systems Command's ability to produce a system on time as promised. Eventually, towards the end of the program, PMA-234 started to relay accurate preliminary test results and future schedules. This new approach went a long way towards rebuilding the fleet's confidence.

CONTROLS AND DISPLAYS WORKING GROUP

In the design phase of the system the Program Manager elected to go with a kit designed without input from its customer, the fleet, customer or from the testers. Program representatives assured both the fleet and the testers that there was no cause for worry because the design was based on the F-14 NVG kit and would therefore work. The Program's approach for operating with goggles, based on that taken with the F-14, was to use the secondary lighting system (converted to NVIS-compatible) as the primary lighting system and to filter all of the electronic displays. Unfortunately, the designers failed to take into account that, unlike the F-14, the EA-6B's secondary lighting system had significant deficiencies and could not adequately illuminate the primary flight and engine instruments. In addition, the F-14 system uses a Heads Up Display (HUD) as a primary flight instrument (showing heading, attitude, altitude, and airspeed) that could be viewed through the direct view goggles. The Prowler, however, did not have a HUD. Both of these areas of concern were well known to fleet aviators and to the test community, who – had someone asked – could have passed them on to the design engineers. But nobody asked and the kit, as it turned out, was doomed for failure. To prevent similar failures in the future, new programs which involving man-vehicle interface should include a team comprised of those who will be operating the system and that will work directly with the design engineers to ensure that the fleet's needs are met and that the system is on track to pass its developmental tests. This project team – a Controls and Display Working Group – should consist of fleet aircrew representatives and developmental and operational testers. They would report to the fleet on the ongoing status of the project up to the Critical Design Review.

Although this Program did not have a Controls and Display Working Group at the beginning of the program, following the failure of the design of the floodlight kit, a *de facto* Controls and Display Working Group was formed to work with the engineers in the redesign of the kit. This unofficial C-DWG team worked closely with the engineers and reviewed the progress of the kit redesign on paper and in the lab.

Another significant drawback to the Program was the lack of a mock-up that would enable developers to experiment with placement of the new lighting kit. Initially, the test community wanted to see the proposed design in the lab prior to turning over their aircraft for modification. The Program office did not have a mock-up and was unwilling to produce one prior to installing the prototype kit. The PMA justified this decision on the basis of its confidence in the initial kit design and timing. But when the initial design failed, the test personnel refused to allow their aircraft to be further modified until they could see something in the lab. In response, Program managers ordered the construction of a full-scale plywood mock-up of an EA-6B instrument panel – with functional flight instruments and lighting – that was produced in under a week. This mock-up saw extensive use in optimizing the placement of the post lights and eyebrow lights that comprised part of the re-designed kit.

CRITICAL DESIGN REVIEW

The decision to by-pass a Critical Design Review prior to manufacturing a kit for installation in the prototype aircraft was a major mistake which takes precedence over other factors discussed in this chapter. Programs of this nature must pass the milestone of a Critical Design Review before continuing. In the case under consideration, if the Program Manager had such a review in October 1999, many of the assumptions that led to the floodlight kit design could have been challenged and the program might have been spared as much as six months. It should be pointed out that, prior to the installation of the re-designed post light kit, the Program Manager elected to have a design review that involved the testers and the lead engineers. This design review was essentially an unofficial Critical Design Review minus the fleet input. In addition, this design review did not take place until a considerable number of C-DWG team meetings and lab mock-up reviews had been conducted. The entire re-design, including C-DWG meetings and design reviews, took less than two months to conduct.

CHAPTER 7: CONCLUSIONS

ABBREVIATED ACQUISITION STRATEGY

The Abbreviated Acquisition Strategy can be an invaluable tool for acquiring urgently needed systems in a timely manner. However, care must be taken to ensure that developers follow the basic system design process (Sanders and McCormick, 1993). This basic process is ingrained in the traditional acquisition process and reviewed at several stages through events such as a Preliminary Design Review, a Critical Design Review, and by the Aircrew System Advisory Panels. Although these review processes are time consuming, they can be effectively applied to the Abbreviated Acquisition Strategy by involving the Developmental Tester and a few representatives from the fleet in the design of the system at an early stage. Instead of having the Preliminary Design Review and Aircrew System Advisory Panels, the Abbreviated Acquisition Strategy might better utilize a Controls and Display Working Group (C-DWG). This C-DWG team would work hand-in-hand with the design engineers and assist them to the point at which a Critical Design Review can be made. A Critical Design Review should be a mandatory milestone for an Abbreviated Acquisition Program. Had one been conducted during the EA-6B program, the false start experienced with the Floodlight Kit design might have been averted.

The loosely written requirement document mandating testing and evaluation gave the test team a great deal of flexibility in interpreting what was acceptable for the EA-6B mission. Unfortunately, it also gave the Program Manager a great deal of flexibility as to what had to be fixed prior to incorporation of modifications in the fleet aircraft. When discrepancies were discovered, these ambiguities led to many debates between the testers and Program personnel as to what was actually required of the modified system. In the subject project, the fleet's imposed deadline, which was rapidly approaching, was responsible for many of the decisions not to investigate and fix discovered discrepancies. But the outcome of the debates led to the correction of all significant safety of flight concerns and a good-faith effort at correcting other performance limitations. For future abbreviated acquisition programs, this approach is suitable provided it includes the input of a Control and Display working group and a CDR milestone is met to monitor the performance aspects of the new system.

NVG LIGHTING MODIFICATION

Modifying an existing tactical aircraft lighting scheme to be compatible with Night Vision Imaging Systems is a major undertaking. The lighting objectives are as important as those for lighting under conditions of normal night and instrument flight. Although Night Vision Goggles give aircrew additional visual situational awareness, the goggles do not turn night into day and aircrew must still maintain a good instrument scan in addition to operating the weapons system. Use of manual illumination of flight instruments or controls and displays is a distraction that can be readily avoided if an adequate NVIS lighting system is properly designed and installed. An aircraft's external lighting should, at a minimum, exhibit low infrared emissions in its visible mode so that other aircrew equipped with Night Vision Goggles can view them without the external lights "over gaining" their goggles and degrading the overall image they see.

EA-6B NIGHT VISION GOGGLE MODIFICATION PROGRAM

The EA-6B Block 89 Night Vision Goggle modification brings to the fleet a significant situational awareness tool which will greatly aid the Prowler in participating in Night Strike Warfare. It is a safe and reliable kit with no major safety of flight or performance issues still outstanding. This kit permits aircrew to employ the airplane while utilizing NVGs without having to revert to manual illumination of critical flight and engine instruments or of any controls and displays. The external lighting modification maintained its original capabilities plus an additional capability to operate in a covert (infrared only) mode and to utilize distinctive flash patterns for aircraft visual identification.

However, this project took over a year to complete and was 8 months behind schedule. By the standards of most military programs a 30 million dollar acquisition program requiring only 14 months from start to finish is a major success, especially when the system enters service with no major safety of flight or performance issues still outstanding. But the fleet had to deploy approximately six squadrons without this capability, significantly reducing their interoperability with other tactical units flying at night. In addition, there is a significant training timeline for new aircrew flying with Night Vision Goggles. The fleet wasted a great deal of time and effort training units for a system that did not materialize on time. After learning that lesson, the fleet decided to wait until the kit passed testing before resuming the training, further delaying the date by which units would be trained and proficient to work with Night Vision Goggles, now estimated to be June of 2001.

Overall, the Night Vision Goggle kit produced in 14 months met the fleet requirements. The original deadline may have been met if a more realistic design had been developed early in the design phase. We have learned that, during the design phase, it is essential for the design team to maintain a close relationship with the customer and the customer's independent inspector, in this case, the fleet and the test pilots respectively. For future Abbreviated Acquisition Strategy programs this relationship could be achieved through a Controls and Displays Working group consisting of a two or three fleet representatives and the developmental testers. We have also learned that, for future modifications to render tactical cockpits NVIS-compatible, every effort must be made at an early stage to ensure that the modified lighting for night and instrument flight provides the same illumination coverage as that provided by the existing primary lighting system.

REFERENCES

REFERENCES

1. Aircraft Exterior Lighting: Concepts for NVG Operations; Joseph C. Antonio, M.D.; NAWCAD 4.6.4.2, Patuxent River, MD; October 1999

2. Antonio, Joseph C. Dr.; (2000); Aircrew systems, human factors, and Night Vision Goggle expert. Interviewed at Naval Air Warfare Center Aircraft Division, Patuxent River, MD.

3. Clarification of the Night Vision Device (NVD) Requirement in the EA-6B Prowler Aircraft Systems Operational Requirement Document (ORD) Serial #474-88-97 (U); RADM J. B. Nathman; Ser N880C3/9U660788; 18 October 1999

4. Evaluation of Night Vision Goggles in the Dynamic Flight Simulator; Joseph P. Cammarota; Air Vehicle and Crew System Technology Department; Naval Air Development Center, Warminster, PA 18974-5000; Report No. NADC-87006-60 or U87006-60

5. 15th EA-6B Operational Advisory Group (OAG) and Executive Steering Committee (ESC) Top Ten Warfighting Priorities; Department of the Navy message traffic; Date Time Group (DTG) 271019Z OCT 99

6. Fixed Wing NVG Class A Mishaps: Lessons Learned; Joseph C. Antonio, M.D.; Night Vision Conference, London, UK, 4 September 1998

7. Human Factors Design Handbook; Wesley E. Woodson; McGraw-Hill Book Company; New York; 1981

8. Human Factors in Engineering and Design; Mark S. Sanders and Ernest J. McCormick; Mcgraw-Hill, Inc. New York, 1993

9. Implementation of Mandatory Procedures for Major and Non-Major Defense Acquisition Programs and Major and Non-Major Information Technology Acquisition Programs; SECNAV Instruction 5000.2B; 6 December 1996

10. Infrared Physics and Engineering; John A. Jamieson et al; McGraw-Hill Book Company, Inc.; 1963

11. Military Specification for Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible; MIL-L-85762A; 24 January 1986

12. Nahvi, John; (2000); Department of Defense acquisition expert. Interviewed at Naval Air Warfare Center Aircraft Division, Patuxent River, MD.

13. Night Viewing; The American Association of Amateur Astronomers website. http://www.corvus.com/kniffen.htm

14. Night Vision Goggle Training Course; October 1999

15. Operations in Kosovo: Problems Encountered, Lessons Learned and Reconstitution; H.A.S.C No. 106-27; October 26, 1999

16. The Pentagon Wars: Reformers Challenge the Old Guard; James G. Burton; U.S. Naval Institute Press; September, 1993

17. Principles of Display Illumination Techniques for Aerospace Vehicle Crew Stations; G. W. Godfrey; Aerospace Lighting Institute; Tampa, Florida 1991

18. Statement by Brigadier General Robert M. Flanagan, Deputy Commander, II Marine Expeditionary Force, USMC; http://www.house.gov/hasc/testimony/106thcongress/99-10-26flanagan.htm

19. The United States Navy Fact File: EA-6B Prowler; http://www.chinfo.navy.mil/navpalib/tactile/aircraf/air-ea-6b.html

20. Waters, Peter M., Lieutenant Commander, US Navy; (2000); Naval Air Strike Warfare Instructor. Interviewed at Naval Air Warfare Center Aircraft Division, Patuxent River, MD.

APPENDICES

APPENDIX A

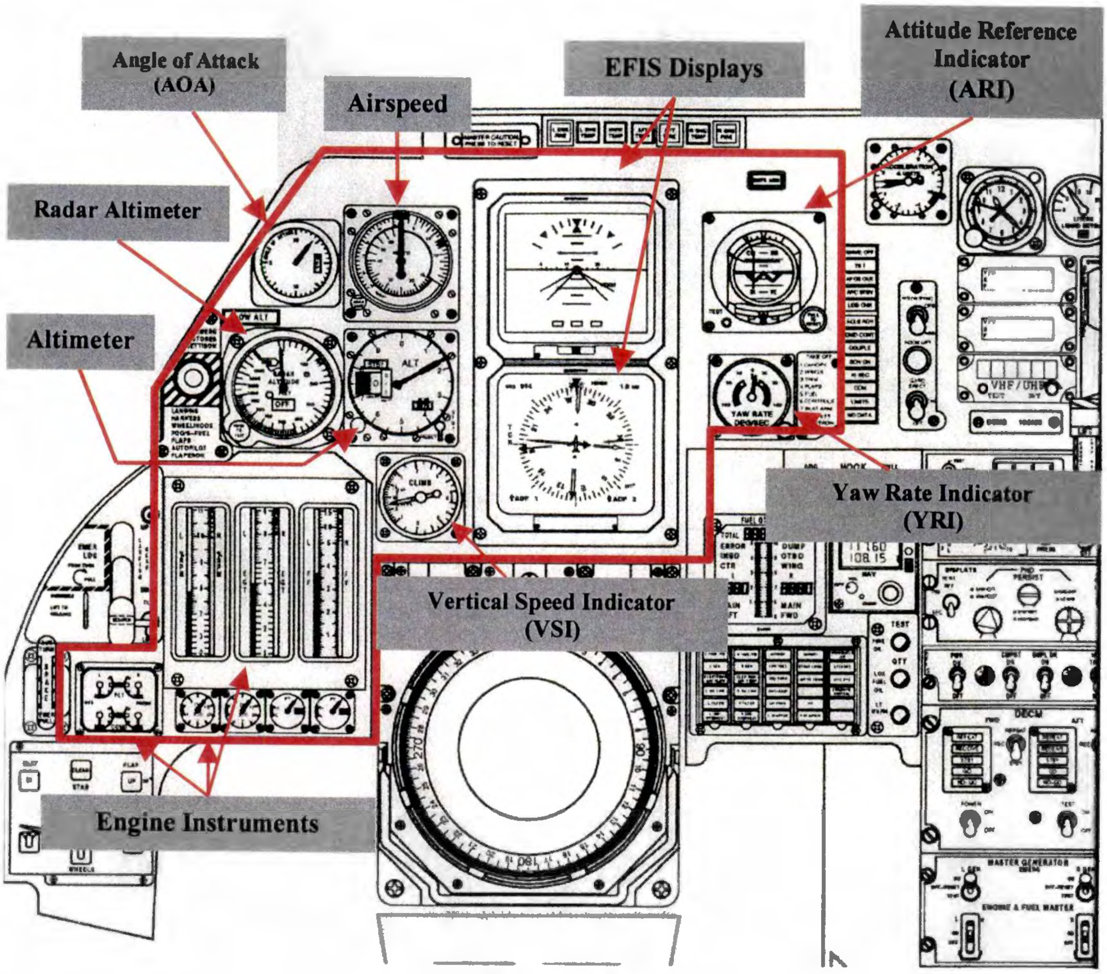


Figure A-1
Pilot's Instrument Panel

Figure A-2
Post Light Kit

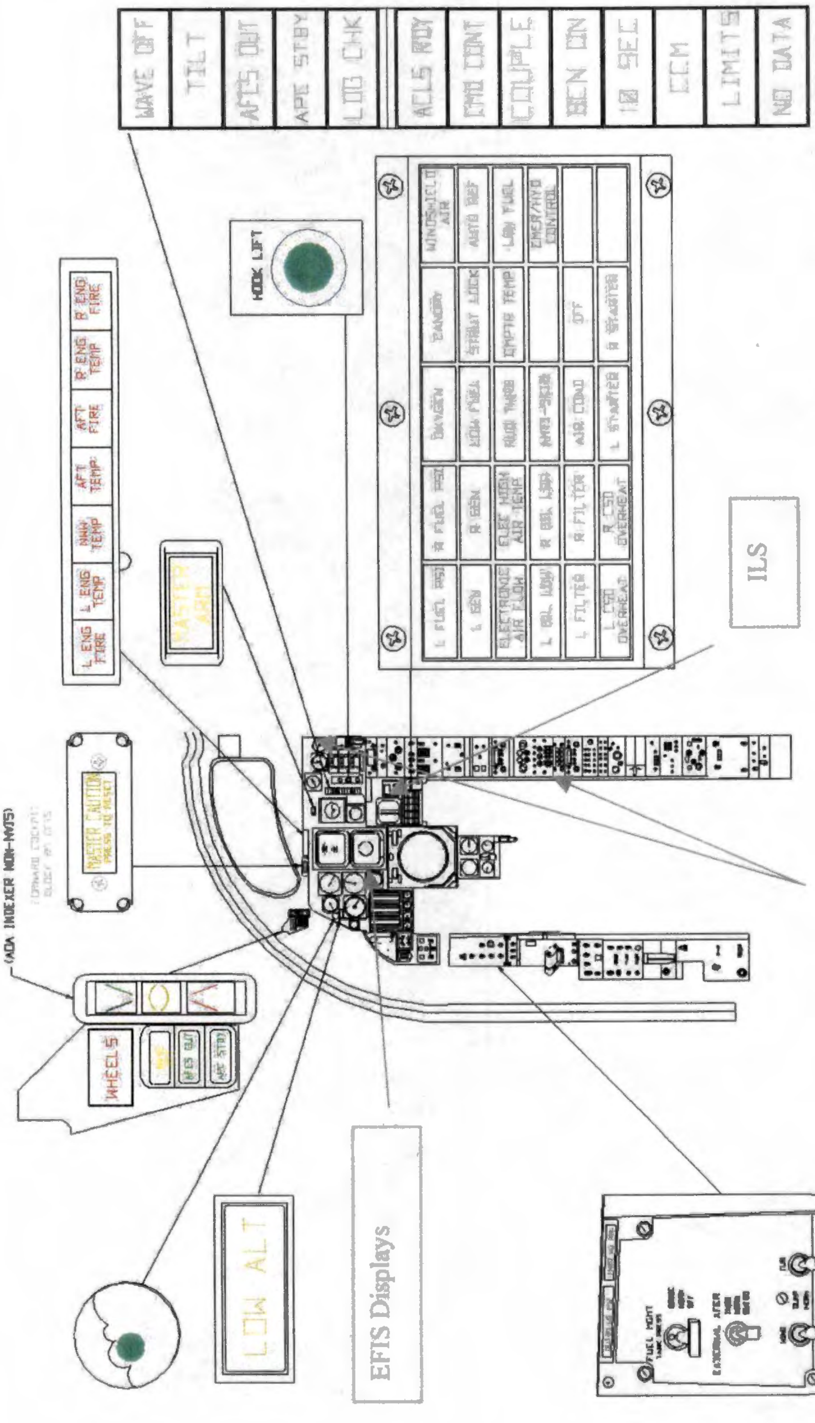


Figure A-3
Pilot Side NVIS Filters

APPENDIX B

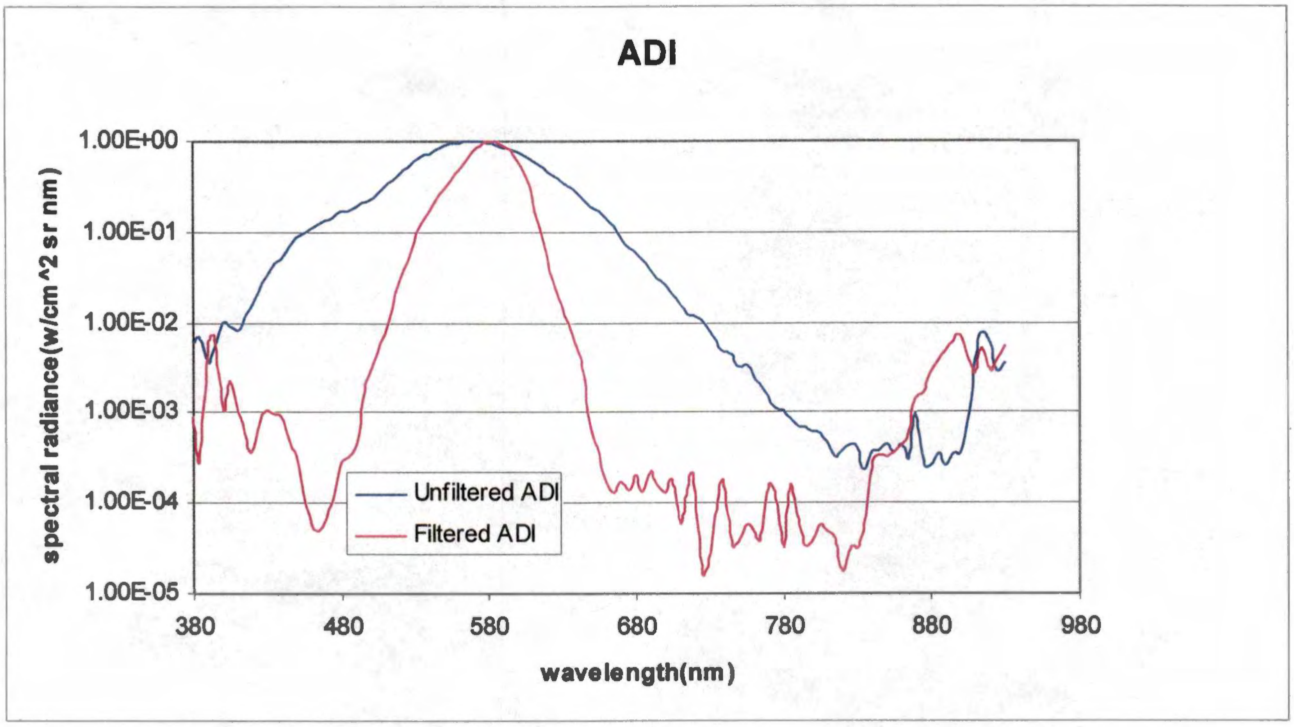


Figure B-1
Attitude Direction Indicator Spectral Response

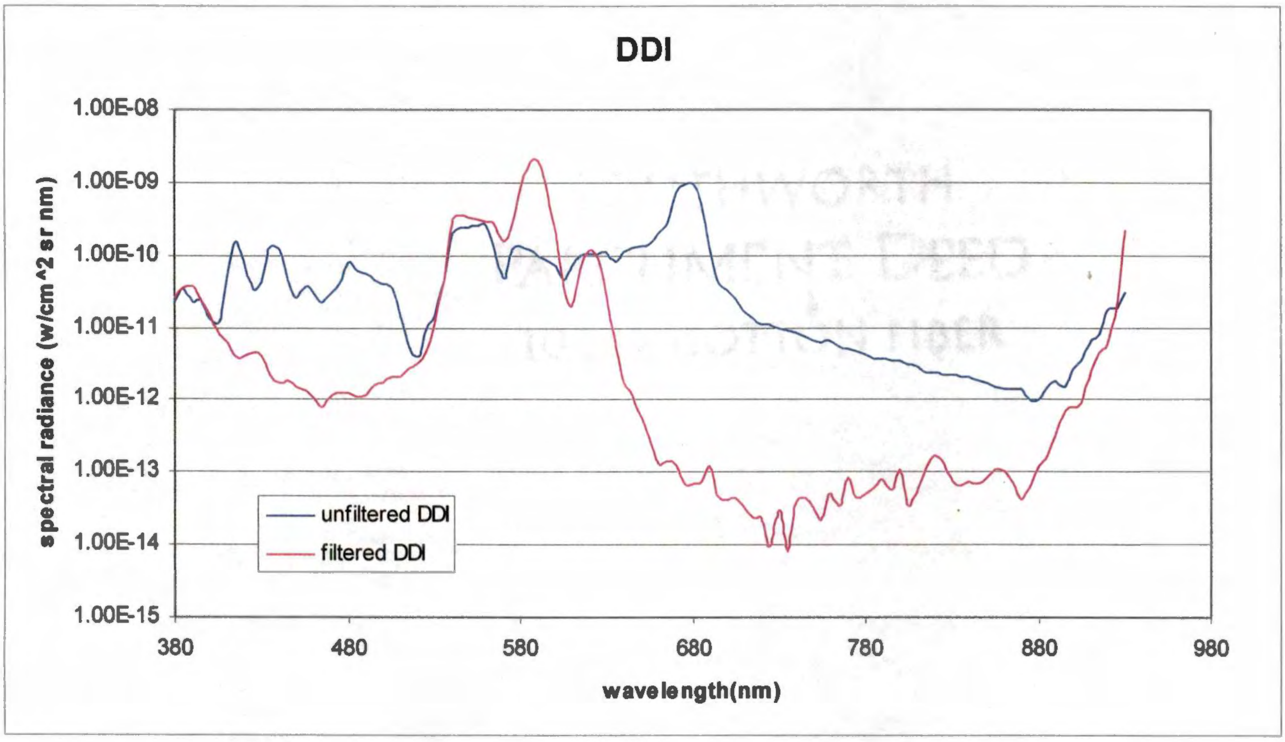


Figure B-2
Digital Display Indicator Spectral Response

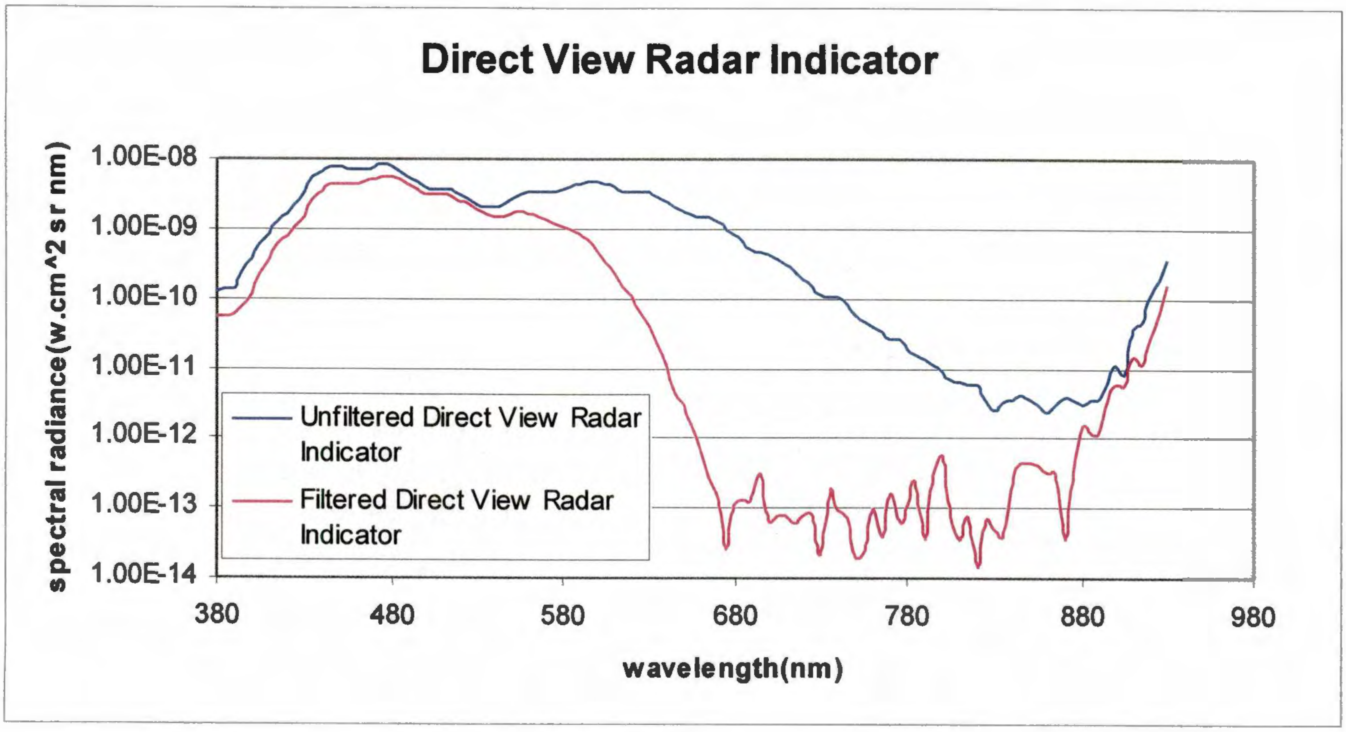


Figure B-3
Direct View Radar Indicator Spectral Response

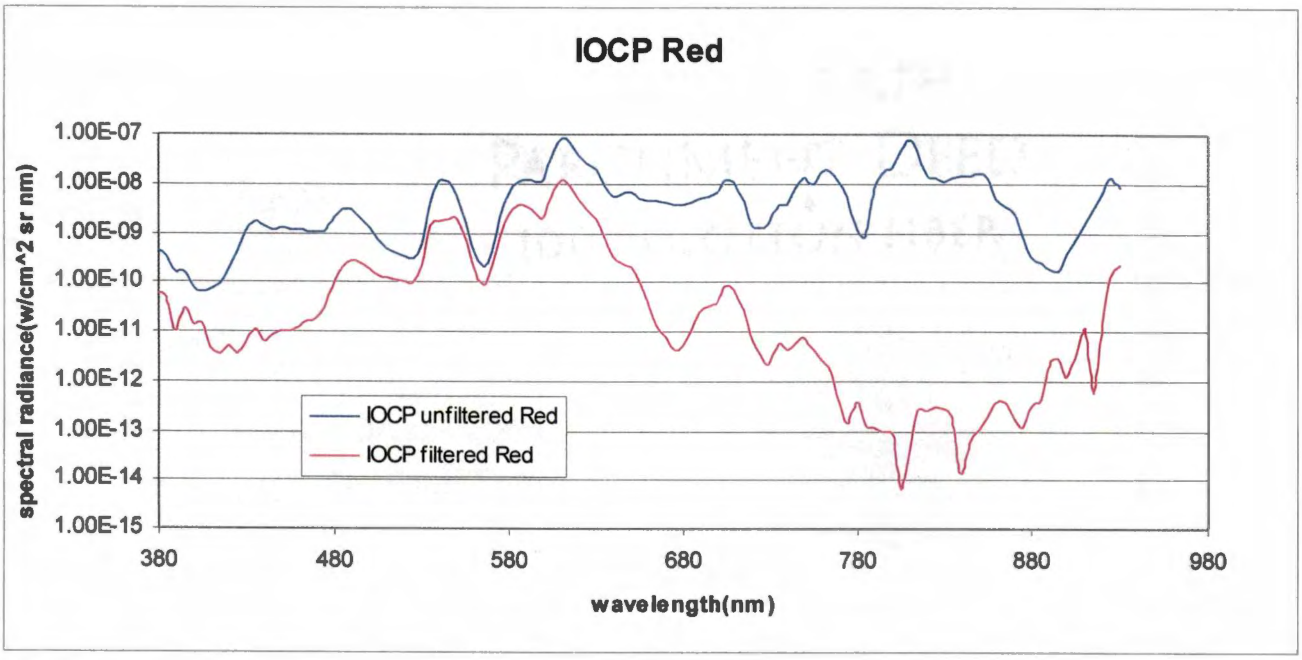


Figure B-4
Improved Operator Control Panel Spectral Response

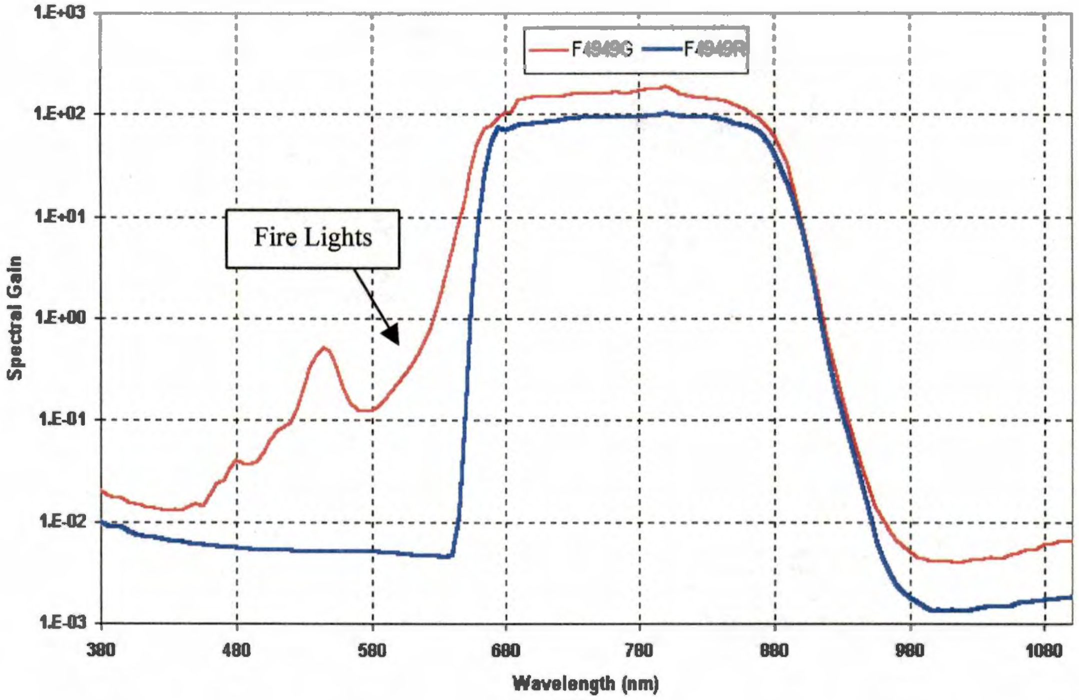


Figure B-5
AN/AVS-9 Goggle Spectral Response and Fire Light

Vita

Lieutenant Commander (LCDR) Willie DeMoore Billingslea is a 1989 graduate of the U.S. Naval Academy with a Bachelor of Science in Physics. He earned his Naval Flight Officer's Wings of Gold in 1990 and was selected to fly the A-6E Intruder as a Bombardier/Navigator. He completed a tour with VA-35, the Black Panthers, and made two deployments to the Mediterranean on the USS Saratoga. After the decommissioning of all A-6E's, LCDR Billingslea transitioned to the EA-6B Prowler where he served with VAQ-131, the Lancers. He made two deployments with VAQ-131 to both the Mediterranean and the Western Pacific/Persian Gulf. Following that tour, LCDR Billingslea was accepted to the U.S. Naval Test Pilot School.

In June 1998, LCDR Billingslea graduated from Test Pilot School and reported to the Naval Strike Aircraft Test Squadron (NSATS). Soon after joining NSATS, he became the Block 89A and Night Vision Goggle Project Officer. LCDR Billingslea has acquired over 30 hours of goggle time in the A-6E, EA-6B, and F-18 aircraft and holds the Night Vision Goggle Instructor-Instructor qualification for both the EA-6B and F-18.

The author will return to the Prowler Fleet in February 2001 as an EA-6B Department Head. Tentatively he is schedule to report to Prowler's Fleet newest squadron, VAQ-143, which should stand up in October 2001 with both the Block 89A and NVIS modifications.