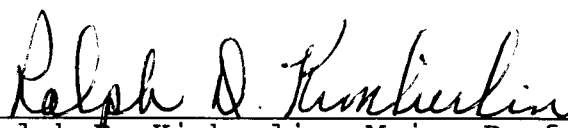


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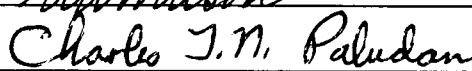


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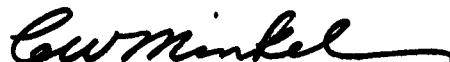
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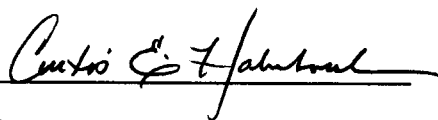


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DEVELOPMENTAL TEST AND EVALUATION
OF FORWARD LOOKING INFRARED SENSORS
IN U.S. MARINE CORPS TRANSPORT HELICOPTERS:
A SYSTEMS APPROACH

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

Maj Curtis E. Haberbosch, USMC

August 1995

DEDICATION

TO MY WIFE, ROBIN,
WHOSE ENDLESS PATIENCE AND DEVOTION
PROVIDED THE SUPPORT I NEEDED
TO COMPLETE THIS PROGRAM

ACKNOWLEDGEMENTS

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ABSTRACT

Forward looking infrared sensors are currently being examined by the U. S. Marine Corps for installation in their transport helicopter fleet. Prior to this, the only enhanced night vision capability for the pilots of these types of aircraft has been that provided by night vision goggles. Infrared sensors can change that. If integrated properly, forward looking infrared systems can provide a vast improvement in the navigational capabilities of the crew, increase their situational awareness and ultimately enhance their survivability. However, if the integration is done incorrectly, the result can be quite the opposite.

Traditionally, developmental testing has addressed only the technical and engineering issues of a system. This is no longer possible or adequate. The larger picture of how a system effects an aircraft operationally must also be considered when evaluating its integration.

A single source is needed for the methodology of conducting developmental test and evaluation of forward looking infrared sensors in transport helicopters using a systems approach to integration. This study proposes a developmental test plan that not only addresses the traditional technical engineering tests, but incorporates the operational and mission suitability issues as well.

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NOMENCLATURE

AGL	Above Ground Level
BIT	Built In Test
COI	Critical Operational Issue
CRT	Cathode Ray Tube
DT	Developmental Test
EMC	Electromagnetic Compatibility
EMC SOFT	EMC Safety of Flight Test
EMI	Electro-Magnetic Interference
EO	Electro-Optical
EOTT	Electro-Optical Test Target
FLIR	Forward Looking Infrared
FOR	Field of Regard
FOV	Field of View
HST	Helicopter Support Team
H-V	Height-Velocity
IR	Infrared
KIAS	Knots Indicated Airspeed
LED	Light Emitting Diode
LOS	Line of Sight
MAF	Maintenance Action Form
MRT	Minimum Resolvable Temperature
MRTD	Minimum Resolvable Temperature Difference
NFOV	Narrow Field of View
NVG	Night Vision Goggle

NOMENCLATURE (CONT'D)

ORD	Operational Requirements Document
OT	Operational Test
PDU	Panel Display Unit
R&M	Reliability and Maintainability
SOP	Standard Operating Procedures
TEMP	Test and Evaluation Master Plan
WFOV	Wide Field of View
WRA	Weapon Replaceable Assembly

CHAPTER I

INTRODUCTION

BACKGROUND

As technological advances in infrared sensors and cockpit displays created the possibility of an increased night warfighting capability, the United States Navy in general, and United States Marine Corps in particular, began to pursue the use of such sensors in their rotorcraft. In 1977, Headquarters Marine Corps approved an Operational Requirements Document (ORD) that stated the need for an improved mission performance at night and during periods of reduced visibility (CNO I-1). This led the acquisition personnel to forward looking infrared (FLIR) sensors. After initially pursuing such systems in the attack helicopter community, the Marine Corps decided to place the emphasis on procurement of FLIRs in transport helicopters.

The initial FLIR installation was envisioned to be a system quite similar to the U S Army's AH-64 Apache FLIR system. Such a system included a single FLIR sensor, slaved to slew corresponding to changes in the position of the pilot's head, that provided information displayed on a helmet mounted display apparatus (visor or monocle) to replace helmet mounted Night Vision Goggles (NVGs). Since the configuration was mounted to the helmet and the pilot would be required to fly looking through the apparatus and its symbology, the setup was known as a "pilotage" system.

Even though the Army has had relative success with their system on the Apache, the system designed and tested on Marine Corps transport helicopters was not so fortunate. It had a variety of deficiencies that prevented it from ever completing developmental or operational testing (Kooistra, Brubacher 2-4). Eventually, night vision sensor systems will mature and overcome many of these flaws (as evidenced by the early development of image fusion technology - the combination of image intensification and infrared sensors). However, in the near term, the Marine Corps' operational requirement still existed to incorporate a FLIR system in transport helicopters. So, in April 1991, the Assistant Secretary of the Navy directed the Marine Corps to restructure the effort. This program incorporated the use of Pilot Display Units (PDUs) mounted on the instrument panel rather than helmet mounted displays. This change shifted the emphasis of the system from that of a "pilotage" FLIR to a FLIR used primarily as an aid to navigation.

PURPOSE

Pure developmental testing can be defined as evaluating a weapons system in terms of its design development intentions in an effort to influence its final design and then further evaluating that design to determine its performance (usually compared to some set of specifications) (USAFTPS 5-A.1). However, the developmental tester can no

longer simply evaluate the system in an operational vacuum. The evaluator must also realize the system will be required to pass some type of operational test (OT), typically performed by the intended users of the system. He, therefore, has to devise a set of tests, above and beyond those traditionally associated with developmental testing, that will address the requirements of the fleet operators. In fact, in the current testing climate, the question; "Is the system, as currently designed, ready for operational test?", must be answered in the affirmative by the developmental test team prior to allowing the system to proceed on to the OT stage of test.

Such a philosophy of test is not unhealthy, and falls in line with the theory of a systems approach to engineering. Systems theory suggests the individual components of a system cannot be examined solely on their own merit but must be evaluated as a whole. How those parts interact as a total system, if accomplished correctly, can provide a synergistic result (Kerzner 77). Of course, the converse is also true. For example, a FLIR system may provide an image on the cutting edge of technology, but if it is too heavy for the aircraft, or draws too much power, or is impossible to maintain, it may well degrade rather than improve the warfighting capability of the aircraft in which it is installed.

It has been the author's experience that various

sources exist that define a portion of the testing necessary to properly evaluate a FLIR system on an aircraft. However, none of those sources provide an overall guide that defines the systems approach required of an evaluator working under the current philosophy of developmental testing. This paper is an attempt to formulate a single source reference for the modern developmental tester of FLIR systems in transport helicopters. It is not all encompassing, since that would certainly take volumes. It is, however, a starting point for the evaluator.

It is important for the tester to have some idea of the physics behind the systems when constructing the test plan, and he must be able to make knowledgeable decisions during the actual system test and evaluation. Therefore, this discussion begins with the theory of infrared sensors. Next, this thesis examines the various test techniques and methodology necessary to properly evaluate a navigation FLIR in a transport helicopter using a systems approach. Finally, a generic developmental test plan is included as a proposed starting point from which a prospective evaluator can proceed - hopefully with only minor changes - in building a test plan for a particular system.

The increased capability in night (and reduced visibility) warfighting garnered from properly integrated FLIR systems will allow the Marine Corps greater flexibility to carry out its doctrine of maneuver warfare. In

particular, it enhances the element of surprise, regarded in Marine Corps doctrine as an important force multiplier:

By surprise we mean striking the enemy at a time or place or in a manner for which he is unprepared ...But, while a necessary condition for superiority, surprise is also a genuine multiplier of strength in its own right because of its psychological effect. Surprise can decisively affect the outcome of combat far beyond the physical means at hand. (Gray 33)

CHAPTER II

FUNDAMENTALS OF INFRARED RADIATION

THE BASIC DETECTION SCENARIO

Figure II-1 (NAWC 7-1.9) displays a generic model of the basic electro-optic sensor detection problem. A target, embedded in a background, must radiate through atmospherics on its way to a detection system. This chapter will discuss the theory behind the radiating target, the path of its radiation to the sensor, and the methods for detection of that radiation.

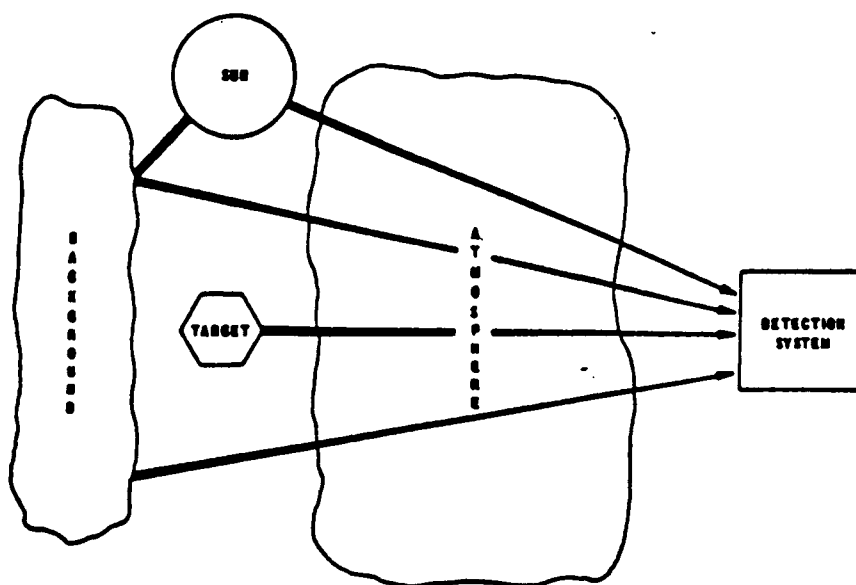


FIGURE II-1. GENERIC DETECTION PROBLEM

THE ELECTRO-OPTIC SPECTRUM

Any object at a temperature above absolute zero (-273.15 °C or 0 K) emits energy in the electromagnetic spectrum called thermal radiation. This radiation is primarily self-emitted due to molecular motion and secondarily reflected from other sources of heat (Lloyd 18; NAWC 7-1.10). Though for imaging system purposes, the exact mechanisms are not crucial. What is crucial is that the differences in these apparent temperatures exist.

Figure II-2 (Frieden 287) illustrates where the electro-optic (visible and thermal radiation) frequency spectrum resides in the entire electro-magnetic spectrum. Since

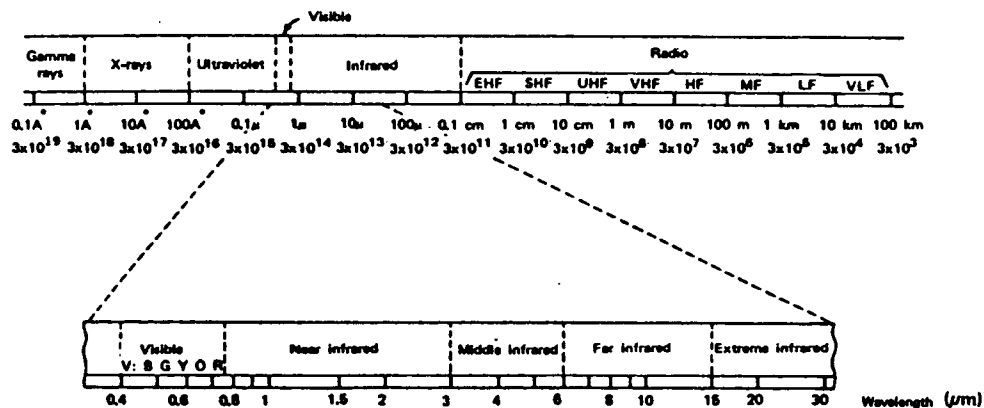


FIGURE II-2. THE ELECTRO-MAGNETIC SPECTRUM

frequencies in the electro-optic portion of the spectrum are measured in the millions of megahertz, it is the recognized standard to refer to wavelength when describing these waves. In particular, the unit most commonly used is the micrometer (μm) which is one-millionth of a meter (Kimmitt 3). The term "infrared" (from the Latin *infra* or below) is used for the segment of the spectrum residing just below the visible red. Other common terms are listed in Table II-1 (NAWC 7-1.6).

As shown in figure II-2, the infrared (IR) spectrum can be further broken down into bands corresponding to near, middle, far and far far or extreme IR. Since this radiation is just outside of the visible spectrum, the underlying purpose of any aircraft IR imaging system is to convert that thermal energy into a visual picture for the pilot.

FOUR LAWS OF IR RADIATION

There are four laws generally recognized as important in the discussion of thermal radiation:

1. Kirchoff's Law
2. Planck's Law
3. Stefan-Boltzmann Law
4. Wien's Displacement Law

Kirchoff's Law. Kirchoff determined that a good absorber of radiation is also a good radiator at any given wavelength.

TABLE II-1
ELECTRO-OPTIC TERMINOLOGY

Name	Description	Symbol	Units
Radiant Power	Rate of transfer of radiant energy	Φ_e	W
Radiant Exitance	Radiant power per unit area emitted from a surface	M_e	W m ⁻²
Radiance	Radiant power per unit solid angle per unit projected area	L_e	W m ⁻² sr ⁻¹
Radiant Intensity	Radiant power per unit solid angle from a point source	I_e	W sr ⁻¹
Irradiance	Radiant power per unit area incident upon a surface	E_e	W m ⁻²
Spectral X	(Quantity) per unit wavelength interval	X_λ	(units) μm^{-1}

For a blackbody (see Planck's Law), the radiated power equals the absorbed power. However, real substances typically are not perfect radiators. The "emissivity" (ϵ) of the object must be determined. Emissivity is the total radiant energy emitted by an object at a given temperature compared to that of a blackbody at the same temperature (thus its value would always be less than one). On the other hand, "absorptivity" (α) is the fraction of the total radiant flux absorbed by the

surface of an object.

Since absorption, transmission and reflection are the only possible results of radiation incident on a surface, and since, for opaque bodies, the transmissivity is negligible, then the sum of the absorptivity and the reflectivity (ρ) must equal one. Kirchoff's law states that emissivity and absorptivity for any surface must be equal (Waldman, Wootton 51). Therefore:

$$\epsilon = 1 - \rho$$

Table II-2 (Wolfe, Zissis 2-77) shows these values for various surfaces (at stated temperatures). A surface such as concrete has an emissivity of 0.92 as compared to a blackbody - it absorbs a large majority of the energy incident upon it and therefore is also a good emitter. Conversely, polished steel, with a low emissivity, cannot absorb as much energy so therefore emits little.

Planck's Law. A body that absorbs all electromagnetic radiation falling on it is referred to as a "blackbody" or a perfect radiator. It is only theoretical in nature, of course, but it is the standard by which any other source is measured. Planck theorized that a body emitting radiation did not do so continuously but rather in discrete quanta whose energy varies with the radiation frequency (Lloyd 18):

$$E = h\nu \quad \text{where } h = \text{Planck's constant} \\ \nu = \text{frequency}$$

Often referred to as the most fundamental law of

TABLE II-2
OPTICAL PROPERTIES OF VARIOUS OPAQUE SURFACES

Material	Temperature (°C)	Emissivity ε	Reflectivity ρ
Blackbody cavity	NA	1.00	0.00
Aluminum: sheet as received	100	0.09	0.91
Steel: polished	100	0.07	0.93
Brick: red common	20	0.93	0.07
Concrete	20	0.92	0.08
Sand	20	0.90	0.10
Skin: human	32	0.98	0.02
Soil: dry	20	0.92	0.08
Water: snow	-10	0.85	0.15
Wood: planed oak	20	0.90	0.10

electromagnetic radiation (Waldman, Wootton 49), Planck's blackbody radiation law can therefore predict the spectral radiant exitance from a blackbody:

$$M_{\lambda} = c_1 / [\lambda^5 (e^{a/\lambda T} - 1)] \quad \text{where } c_1 \text{ and } a \text{ are constants.}$$

Figure II-3 (Wolfe, Zissis 1-15) presents sample blackbody radiation at lower temperatures.

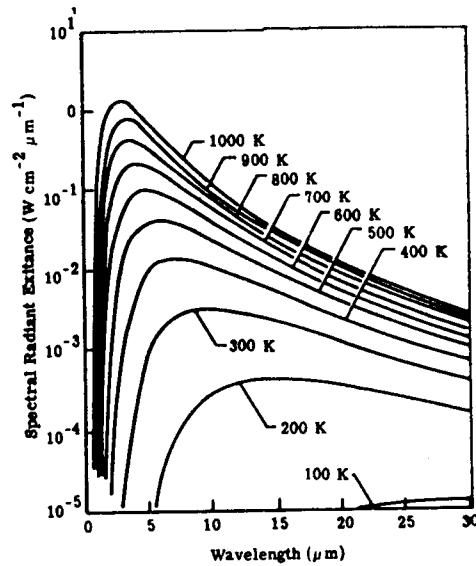


FIGURE II-3. BLACKBODY RADIATION, 100 TO 1000 K

Stefan-Boltzmann Law. The Stefan-Boltzmann law further ties the emissive power of a radiating body to the fourth power of its absolute temperature:

$$M_e = \sigma T^4 \quad \text{where } \sigma = \text{Stefan-Boltzmann constant.}$$

For example, double the temperature of the body and the radiation emitted will increase by a factor of 16 (Frieden 290). The curves of Figure II-3 are a result of this relationship.

Wien's Displacement Law. From figure II-3 it can be noted that radiating bodies emit their energy over a broad

range of wavelengths, but reach a peak at a particular wavelength. It is also apparent from figure II-3 that the peaks of the curves shift to larger wavelengths and the total output decreases as the temperature decreases. The fact that the peak of maximum radiation occurs as a function of temperature is the crux of Wien's Displacement Law (Frieden 293) :

$$\lambda_{\max} = a/T \quad \text{where} \quad \begin{array}{l} a = 2998 \text{ } (\mu\text{m K}) \\ T = \text{temperature of body (K)} \end{array}$$

It is also of interest to note that bodies at a temperature of approximately 300 K (close to average room temperature) exhibit peak radiation at a wavelength of around 10 μm (Wright 3). Along with atmospheric influences, this is an important reason most navigation FLIRs operate in the 8-12 μm band.

ATMOSPHERIC TRANSMISSION

Introduction. The radiation emitted or reflected by a target and its background must pass through an atmosphere on its way to a detection system. There are four basic ways the atmosphere can affect the emissions on their way (Waldman, Wootton 81) :

1. Absorption: Molecular constituents of the atmosphere may absorb some of the radiation.
2. Scattering: The atmosphere and associated particles may scatter target radiation out of, or background radiation into, the line of sight.

3. Emission: Molecular constituents of the atmosphere may themselves emit radiation in the target's spectral band.

4. Turbulence: Inconsistencies in the atmosphere's refractive index varying over time can act to veil the target.

The effects of emission and turbulence on the image portrayed at the sensor are less critical than those associated with absorption and scattering: emission because the entire scene, background and target, if affected at all is affected equally; and turbulence because at night, which is typically the time of interest, the atmospheric variations are much less pronounced. Absorption and scattering can become much more pivotal to the safe passage of the radiation to a sensor and are typically grouped together under the heading of attenuation or extinction.

Attenuation or Extinction. Thermal radiation is attenuated as it passes through the intervening atmosphere by the processes of absorption and scattering by gas molecules, aerosols, water molecules, and suspensions (e.g., smoke, haze, or smog). In the infrared wavelengths from 1 to 14 μm there are some bands of absorption, but there also exist several "windows" where the atmospheric attenuation is minimized (Robinson 91). Figure II-4 (Frieden 298) graphically portrays those windows at sea level conditions as well as the offending absorbing molecules. Water and carbon dioxide are the leading attenuators, with ozone, nitrous oxide, carbon monoxide, and methane having some lesser effects

(Lloyd 30). Note the relatively large window in the 8-14 μm range which is especially "clear" at sea level from 8-12 μm . Again, this is the primary reason for this particular band being used for navigational infrared sensors.

Scattering is dependent on the size of the particles as they compare to the wavelength of interest. If the particles (air molecules, haze) are smaller than the wavelength, the effects of scattering are limited. As the particle size begins to match or exceed the wavelength (fog, rain), scattering can seriously attenuate the radiation - up to 100% in some cases (Waldman, Wootton 84).

The length of the path the radiation follows also has a deteriorating effect on its transmission. The extinction of the radiation is exponential with the distance travelled and is governed by the equation:

$$\Phi = \Phi_0 e^{-\beta R}$$

where Φ_0 is the radiation incident on the attenuating medium, β is the extinction coefficient, and R is the path length (Waldman, Wootton 82). Extinction coefficient values thus correspond to the various atmospheric conditions.

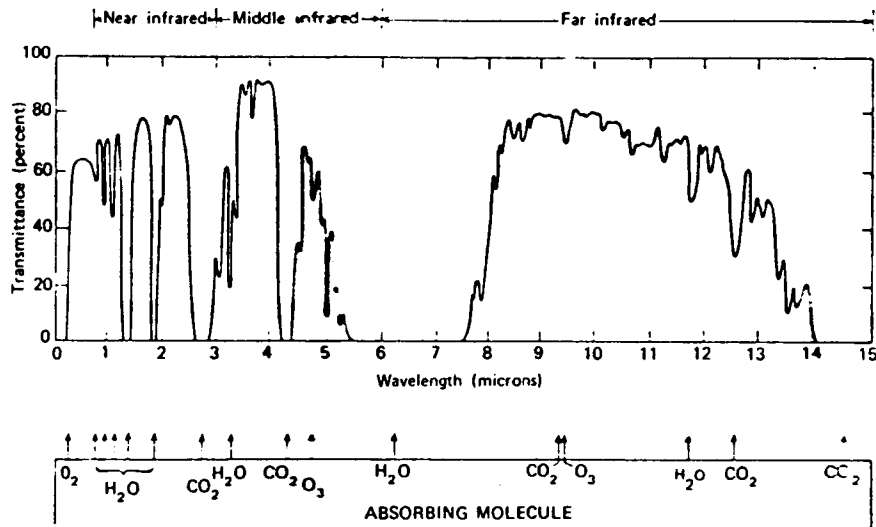


FIGURE II-4. ATMOSPHERIC TRANSMISSION WINDOWS.
TRANSMITTANCE OF THE ATMOSPHERE FOR
1,850 METER HORIZONTAL PATH AT SEA LEVEL

DETECTORS

Introduction. Detectors are the heart of any IR sensing system. A detector is a transducer that transforms the infrared radiation from a target into an electrical signal. If desired, that signal can then be manipulated to present a visual representation of the target. Detectors are typically divided into two classes: thermal detectors and photon detectors.

Thermal Detectors. As their name would indicate, thermal detectors operate by absorbing incident radiant

energy onto a sensor element. This radiation acts to increase the temperature of the sensor element, typically creating a voltage. This type of detector relies on one of four processes to achieve this: bolometric, thermovoltaic, thermopneumatic, or pyroelectric (Wolfe, Zissis 11-20). Since, by definition, all of these thermal types require a measure of the temperature change at the detector itself, they are quite complex and costly. Current technology makes them much more conducive to controlled laboratory work than integration into aircraft. However, recent advances in pyroelectric detectors may eventually make them more favorable for aircraft use, particularly in linear array applications.

Photon Detectors. Of more importance to the military system evaluator are the photon detectors. The two most common are the photoconductive and the photovoltaic. As incident infrared photons are absorbed by the sensor element of the photon detector, free charge-carriers (i.e., electrons) are produced. In response, the sensor element increases its conductivity (photoconductive) or produces conduction electrons (photovoltaic), either of which results in an increase in current signal (Waldman, Wootton 40).

Cryogenics. A detector's voltage output contains noise from both internal and external sources. The external noise

is mostly a function of random fluctuations in the incident radiation. The internal noise originates from several sources but all are related to temperature. Therefore, by cooling the detector, noise can be reduced and, subsequently, the signal to noise ratio can be improved. Under current technology, the detector must be cooled to a temperature range of 77-80 K (Waldman, Wootton 36). In helicopters, this is typically accomplished with liquid nitrogen.

CHAPTER III

FORWARD LOOKING INFRARED SENSORS

BACKGROUND

Infrared sensing systems were first used in aircraft as downward looking single channel mapping systems for air-to-ground IR reconnaissance mapping. In 1956, the University of Chicago, in conjunction with the Air Force, modified a strip mapper to allow the scanner to move in elevation and the first Forward Looking Infrared (FLIR) was created. In the 1960's, the Air Force and Navy, in two independent programs with separate contractors, successfully developed and flight tested two FLIRs. From then on, FLIR use on aircraft rapidly expanded.

Generally speaking, a FLIR has six major components: the afocal telescope, the scanner, the detector-dewar, the cryogenic cooler, the video or signal processor, and the display system. These are shown for a simplified generic FLIR system in Figure III-1 (Lloyd 10).

TELESCOPE

The afocal telescope is a key part of the system that should tailor the FLIR optically for its intended design. It provides the fields of view, magnification, and resolution required for those design intentions. If adapting an existing FLIR design to a new mission or application, this is generally considered the easiest

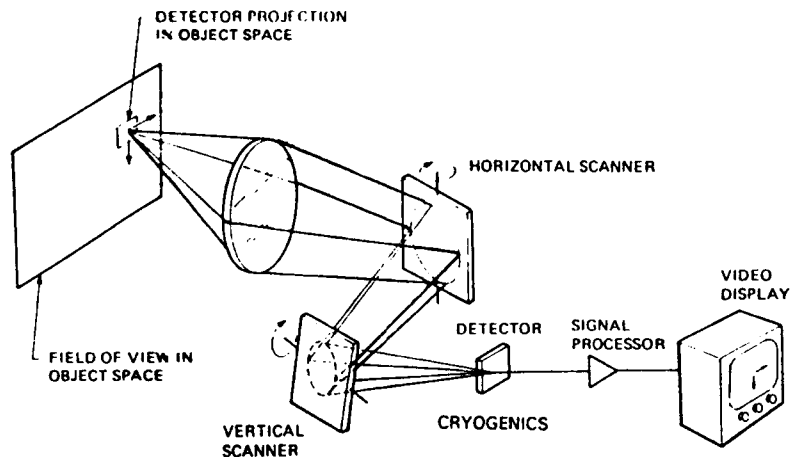


FIGURE III-1. A SIMPLIFIED SINGLE-DETECTOR DUAL-AXIS FLIR

portion to modify (Waldman, Wootton 37).

SCANNERS

Typically, scanning mechanisms are mirrors, used to redirect the incident infrared radiation passing through the telescope onto the detector array. Of course, the forward motion of the aircraft in flight cannot be used as part of the scan since the FLIR unit is usually gimbal mounted and, in the case of a helicopter, there may be no forward motion.

The scan must also be implemented in such a way as to present no apparent flicker - that is, the scan rate must be above the flicker frequency of the human eye (U.S. Army 4-18). Besides the obvious distracting and annoying qualities of flicker, it is particularly important to avoid the alpha rhythm range of 3-10 Hz, known to cause convulsions and other consequences in the viewer (Lloyd 134). The requirement for scanning mechanisms is due to the limitations of current detector arrays. As the technology of two-dimensional, high resolution arrays advances, the need for scanners will disappear.

DETECTOR-DEWARS

The processes by which detectors operate have already been addressed (see Chapter II). The detector-dewar is the heart of the FLIR (and is the most expensive component). It determines the majority of the capabilities and limitations of any given FLIR unit. An example of a FLIR detector currently employed in avionics is a common module detector consisting of a vertical column of 60, 120, or 180 mercury cadmium telluride (HgCdTe) photon detectors (Waldman, Wootton 42).

CRYOGENICS

The reasons for cooling the detector were discussed in Chapter II. So even though this is recognized as a necessary condition for current FLIRs, it is also notorious as the area that interjects most of the unreliability into the system. For many systems, the mean time between failure is on the order of a few hundred hours. Several cooling systems are available. The cheaper systems (non-engine driven) are plagued by logistical and evaporation problems, and the better devices (single piston linear engines), though relatively compact and lightweight, are expensive, vibration inducing, and noisy (Waldman, Wootton 38).

It is easy to see why this is currently a major area for innovation and design efforts. The logical next step in the technology is to develop high resolution systems that need little or no cooling. This would reduce weight, cost, and vibration while markedly increasing reliability and maintainability. Figure III-2 is a typical helicopter turret/FLIR unit housing the telescope, scanning mechanism, detector, and cryogenics together in a gimballed turret assembly (Hughes Aircraft, 1-6).

SIGNAL PROCESSOR

After the detector receives the incident radiation, that radiation is transformed into electrical pulses. The purpose of the signal processor is to take those electrical

pulses and eventually drive a display with them. Initially, the pulses are amplified, filtered and boosted. Typically, the operator is interested in differences in received radiance rather than the actual radiance values - i.e., contrast between the target and the background. To

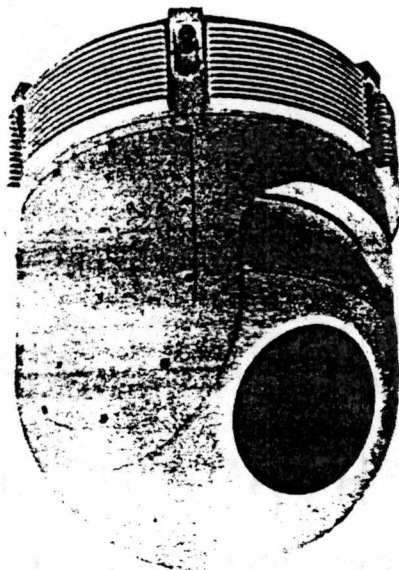


FIGURE III-2. HELICOPTER TURRET/FLIR UNIT

accomplish this, the signal is "ac coupled". This process blocks any constant (dc) component in the signal in an attempt to get good contrast rendition (Lloyd 337).

However, one drawback to this effort is channel nonuniformity. This is triggered by differing charges in the capacitor of the ac coupling circuit as it passes over

each scan line on the image. The result is a uniform target, whose size requires at least two scan lines to be reproduced as an image, to appear nonuniform on each of those scan lines on the display (Waldman, Wootton 160).

A suitable correction for this nonuniformity is the technique of "dc restoration". In this process, an thermally uniform artificial reference source is momentarily scanned by each channel. This source then allows the coupling capacitor of each channel to reset to the same value before scanning across the scene, hopefully resulting in restored uniformity across all channels in the image (Lloyd 345). The penalty is a decrease in scan efficiency. Since each channel is spending a finite (though quite small) amount of time viewing the uniform source, it gets less dwell time on the image (Waldman, Wootton 161).

Usually, the operator is given the capability to choose between ac coupling or dc restoration manually. What is chosen will depend on the characteristics of the target scene of interest.

Another feature commonly provided by the signal processing unit is the automatic setting of gain and level to provide the optimum image to the display. "Gain" refers to the bandwidth of sensed temperatures. Decrease the size of the temperature range of interest and the individual temperature differences sensed within that range decrease, consequently increasing the detail of any target within that

range. However, any target radiating a temperature outside of that range will be "ignored". Conversely, decrease the gain (broaden the range of temperatures to be included in the sensing of the scene) and the target resolution decreases due to the larger temperature differences sensed, but the scene will theoretically include more targets. "Level" refers to where the set gain (temperature range of interest) resides within the overall temperature scale. Adjust the level, and the gain slides as a group toward the warmer or colder end of the scale.

Commonly, systems are designed to allow manual setting of gain and level as well.

Figure III-3 (Hughes Aircraft, 1-7) is an example of a signal processing unit.

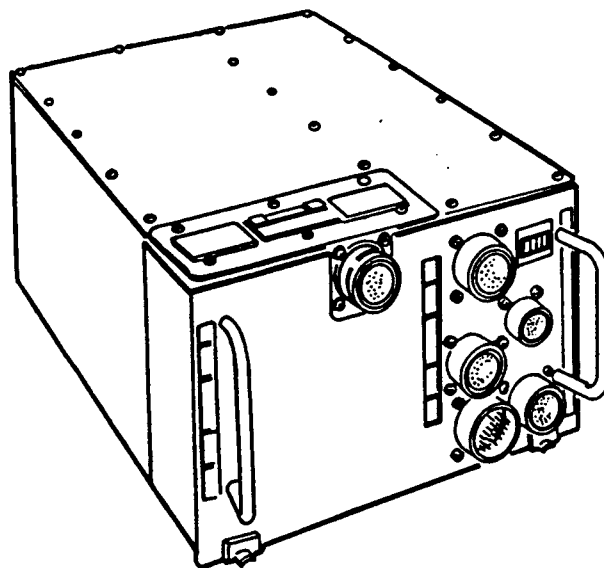


FIGURE III-3. FLIR SIGNAL PROCESSING UNIT

THE DISPLAY

As mentioned previously, the entire purpose of an infrared imaging system is to take the electromagnetic radiation of the infrared band, convert it in some manner to the visual spectrum, and then display it to an observer for use. Therefore the display can be the most critical portion of the entire system and the manufacturer must be cautious not to cancel out the advantages that may be provided by the rest of the system. The display must provide a picture that is easily identifiable, with good resolution and luminance. The two most common display instruments are light-emitting diodes (LEDs) and cathode ray tubes (CRTs).

LED type displays by their nature are low power radiation emitters, so are not as visible in bright ambient conditions. Because of this, and their low resolution capabilities, they are typically viewed through an eyepiece and so are not the display of choice for the panel-mounted-display navigation FLIR (Wolfe, Zissis 18-33).

By far, the most commonly used display device for helicopter applications is the CRT. Figure III-4 (EER 151) is an example of how CRTs might be integrated into a helicopter instrument panel. The CRT works by directing an electron beam across a phosphor screen in a raster pattern. The energy of the scanned beam is converted to a pattern of visible light by the process of electrofluorescence. The usual scan pattern draws every other line across the screen

(known as a field) followed immediately by the next field which fills in the remaining lines. Two fields make up a complete image on the screen. This is known as 2:1 interlacing (Waldman, Wootton 166).

A properly designed CRT allows for adjustment of brightness and contrast to account for ambient conditions surrounding the display and the observer. The brightness and contrast must be capable of providing a clearly visible image even under direct sunlight conditions. Yet, such brightness would likely be a detriment to night vision requirements and thus must be adjustable to accommodate such extremes.

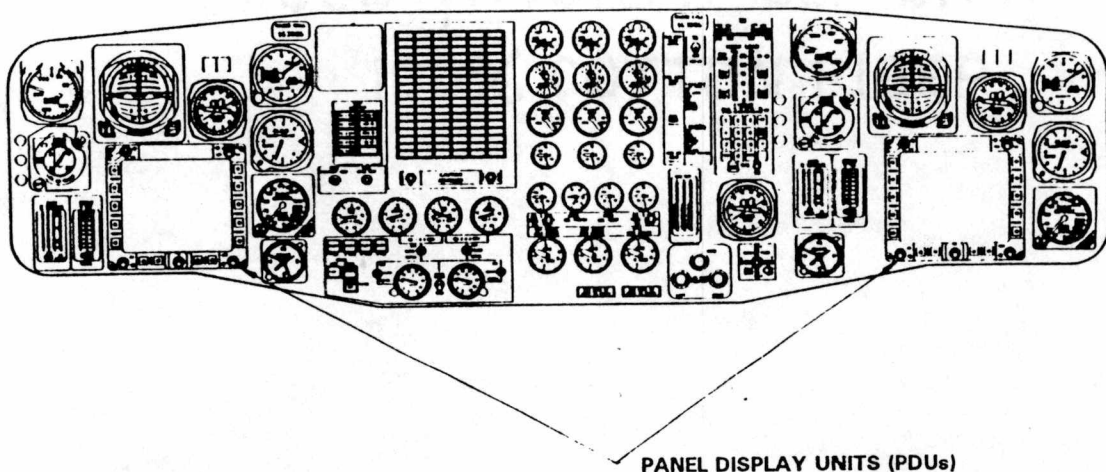


FIGURE III-4. HELICOPTER INSTRUMENT PANEL WITH FLIR DISPLAYS INTEGRATED

A CRT provides image contrast by displaying the scene in differing shades of gray. It has been shown experimentally that for an observer to recognize a target at least 7 shades of gray must be presented. Anything less than that and human recognition performance becomes degraded (Wolfe, Zissis 18-5).

CHAPTER IV

DEVELOPMENTAL TESTING OF INFRARED SENSING SYSTEMS IN HELICOPTERS

INTRODUCTION TO DEVELOPMENTAL TEST AND EVALUATION

The process of acquisition is neither short nor uncomplicated. In an effort to properly develop and evaluate a new aircraft or system, many checks and balances have been instituted. As a project proceeds along the path of development, it must pass through various phases and associated milestones integral to the acquisition system. Developmental test and evaluation is but one step in the process.

As touched upon earlier, developmental testing is primarily accomplished to determine if a system can meet its intended function. Does it meet the appropriate predetermined specifications? Theoretically the designers, armed with the answers, can then go back and make any corrections deemed necessary. Often, due to schedule and budget constraints, these corrections are done concurrently with the evaluation so the "new" results can be analyzed and more corrections can be made if necessary (what is referred to as the "fly, fix, fly" philosophy). Historically, developmental testing (DT) has emphasized engineering techniques - the execution of engineering tests, performed in a standard repeatable manner, to accumulate data to support the answers to specification compliance and system functionality. There has been an emphasis on performance of

mission representative tasks as well, but usually only in an effort to discover any deficiencies. These deficiencies would then be further analyzed by performance of the engineering tests.

This developmental phase of testing should in no way be confused with operational testing. Operational testing (OT) is the phase following developmental. It is performed by the intended operators of the system in an environment resembling, as closely as possible, the environment in which the system was intended to be used. The mission of OT is to determine the system's operational tactical effectiveness and logistical suitability. The OT evaluators identify objectives of the test based on the desired capabilities of the system. For example, the desired capability of an infrared system on a helicopter may be to allow the crew to navigate through mountainous terrain under low light level conditions. The OT pilots will evaluate the system under those conditions using the intended support publications, with fleet representative mechanics maintaining the system.

Once the operational test objectives are determined, certain critical operational issues can be identified in the areas of effectiveness and suitability. All of these requirements are placed in a document that serves as the overall guide to the operational tester - the Test and Evaluation Master Plan (TEMP).

Historically, these two phases of test (developmental

and operational) have been isolated from one another. The developmental testers had their own set of tests and the operational evaluators had another. To some degree, both sides thought their portion of the test would become biased if allowed to be influenced by the other. In some sense this is still true today, particularly with the operational testers. However, even if a system has a successful DT stage of testing, it still must pass OT. Considering the present day budget constraints on defense and procurement of defense systems, it does not make fiscal sense to spend the money required to conduct operational testing if, during the developmental stage, it could have been determined the system had limited or no chance of passing OT. As the direct result of such a scenario happening too often, the Test and Evaluation Master Plan (TEMP) has now become an integral part of the developmental test planning process. The DT test team must now include many of the tests traditionally performed in OT, as well as accomplish all the usual engineering tests.

Besides making developmental test and evaluation more challenging, this should also have a positive effect on the systems being fielded. By evaluating the individual system as it performs as a stand alone unit and as part of the greater weapons system (aircraft) into which it is integrated, more deficiencies can be identified and corrected prior to production. This becomes important

because once production has begun, even minor changes can become cost prohibitive. Any major deficiencies discovered at that point can force cancellation of an entire program.

DEVELOPMENTAL TEST PLANNING OF FLIR SYSTEMS

The Appendix provides a generic developmental test plan created by the author that can be used as the foundation for evaluating any transport helicopter outfitted with a navigational FLIR system. The test plan format presented and the path the developmental tests pursue are those put forth by the U.S. Navy and U.S. Air Force Test Pilot Schools (USNTPS 1992; USAFTPS 1986). Operational testing issues from both Air Force and Marine Corps testing (Summers, Schultz 1989; Osborn, Schultz 1991; CNO 1993; Landry 1994) have been reviewed and included where applicable.

Included in the test plan in the Appendix are several engineering tests that have become almost traditional with aircraft FLIR evaluations. These tests allow the FLIR system capabilities to be quantified for specification compliance. They also provide a relatively easy method by which one FLIR's performance can be compared to another FLIR or to an accepted benchmark. Two of these tests, Minimum Resolvable Temperature and Detection and Recognition ranging, are more fully explained here.

Minimum Resolvable Temperature Test. The minimum resolvable temperature is an image quality test by which an observer attempts to distinguish four bars on the FLIR display. The four vertical bars are each shaped with a 7:1 aspect ratio and are produced with a temperature controlled target that can incrementally increase the temperature difference between the bars and the background (see Figure IV-1). That temperature difference is adjusted until the observer can just barely discern the four bars on the display. Since zero temperature differential may actually produce a non-zero result (i.e., test equipment error may actually present a contrast), the process is repeated for negative as well as positive temperature differentials. The spatial frequency (size) of the bars is varied and the

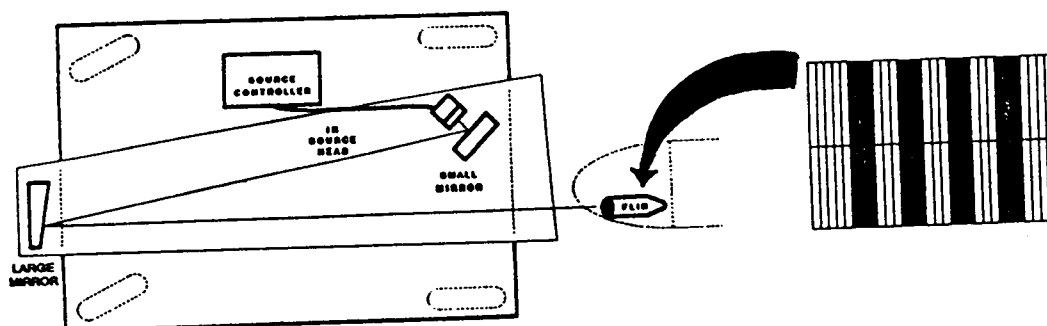


FIGURE IV-1. MRT GROUND TEST HEAT SOURCE AND FOUR BAR TARGET

resulting graph is of spatial frequency of the bars versus threshold temperature differences. This plot can then be compared to one listed in the appropriate specification.

Obviously, several factors can influence these results such as observer visual acuity and experience as well as system noise. However, much of the potential for inconsistency can be removed by increasing observer training. There has been some research done to automate these tests and to remove the human from the loop (Driggers, et al 110; USA NVL 1), but these efforts mostly provide a basis for prediction of system capabilities and the widely accepted test method still involves a human observer.

After completing these tests on the ground in controlled conditions, the evaluation is then repeated airborne. The resulting comparison provides a relatively accurate characterization of the effects of line of sight jitter (aircraft vibration) on the displayed FLIR image.

Detection and Recognition Range Tests. If the purpose of a navigational FLIR system is to locate and identify checkpoints and targets in an effort to aid the aircrew in navigation and threat avoidance, then certainly the capacity of a FLIR system to carry out that purpose needs to be evaluated and quantified. Detection and recognition range testing can provide the evaluation team with the data necessary to quantify the capacity of the FLIR to acquire

targets of interest.

When examining the process by which an observer scans an electro-optical display in search of a target, it is helpful to divide that process into different, but interrelated, levels of acquisition: detection, recognition, and identification. Detection can be defined as the point when the observer has decided that there exists an object of interest in the field of view (e.g., a vehicle). Recognition occurs when the observer can readily determine the class to which the target belongs (e.g., a tank or a truck). Identification further classifies the target to a more specific subclass (e.g., an M-60 tank rather than an M-1) (Waldman, Wootton 186). Whereas it may be important to be able to classify a target to the identification level if interested in weapon engagement (USNTPS 154), detection and recognition are arguably sufficient (and probably more mission relatable) for a navigational FLIR.

The targets chosen to accomplish these tests also should be mission relatable. The TEMP should contain the suggested targets and the required ranges at which they should be detected and recognized. If not, then the operational testers should be consulted for their inputs. For each target, the FLIR should be evaluated in various fields of view and polarities, and the aircraft should be flown at similar run-in headings, altitudes, airspeeds, and

ambient conditions, if possible, to maximize repeatability and comparability (USNTPS 153).

There are several predicted performance models to which the obtained data can be compared, if required. However, it is important to keep in mind that these models are only an approximation of the FLIR's capability and are a factor of many variables (one author lists as many as forty) (Lloyd 390). Some models are more specific to the situation, such as determining the probability of first detection in a multi-target scenario (Rotman, et al 1216). The most commonly used model for target acquisition for military applications, and the one on which many of the others are based, is the acquisition model of the U.S. Army Center for Night Vision and Electro-Optics. It computes the detection, recognition, and identification probabilities by comparing a target to an "equivalent" bar target (what is referred to as the Johnson criteria) (Rotman, et al 1217), and by factoring in several other variables such as target azimuth and an approximation of atmospheric conditions (USA NVL 17).

ADDITIONAL AREAS OF INTEREST TO EVALUATE

Introduction. When devising a developmental test of a helicopter FLIR system, besides some of the obvious areas for test listed above, there are several other subjects that need to be examined - other areas of interest that may not be so obvious to the project officer or sponsor but require

investigation as a result of the system integration. Typically these tests are completed under separate test plans, either before or during the actual system tests. A couple of examples of these tests are listed below. (There may be others necessary depending on the specific aircraft being tested and the nature of the integration.)

Structural Tests. As with any new piece of equipment that is being attached to an aircraft, a FLIR and its associated mounting hardware will most likely require a full structural integrity check. This is a critical early stage of testing and must not be overlooked since it is often the cornerstone to receiving a flight clearance from the appropriate clearance authority. The flight clearance is an important piece of paper without which the test aircraft cannot fly (let alone test) in its new configuration.

Such an evaluation should encompass both ground and flight test. The structural tests should include, but are certainly not limited to: statics, fatigue, vibrations, and dynamics. After a complete analysis of the materials, mounting structure, and proposed mission spectrum for an aircraft equipped with such a system, a proof load evaluation should be completed to validate the paper study. This ground test will ensure the materials can actually withstand the planned acceleration loads (with a built-in margin for safety). After this has been successfully

completed and the data properly analyzed, the certification to move on to flight test can be granted. The ground tests can also determine the proper location for strain gages and accelerometers on the aircraft in preparation for flight test. This instrumentation should be telemetered for "real-time" monitoring - at least for the first few flights until the questions concerning flight integrity can either be answered favorably (continue test) or negatively (stop test).

The flight tests should include tasks representative of the full mission spectrum of the aircraft - what is commonly referred to as a flight loads survey - in a build-up fashion (lesser risk to greater risk). Such tests include: rotor engagement, taxi (air and ground), in and out of ground effect hover, low airspeed regime flight, normal approaches, normal landings and takeoffs, airspeed sweeps to V_{ne} (Velocity, never exceed), practice autorotations, varying angle of bank turns, and climbs and descents. Also to be included are various engineering flight tests such as symmetrical pullups and pushovers, control reversals, and a sideslip envelope evaluation. If the test aircraft is flown at various rotor speeds, gross weights, and centers of gravity, then the tests should be repeated for a representative spread of those values.

Electrical Loads Survey. Again, when a new system is attached to an aircraft, the system's effect on the entire aircraft must be evaluated. Such an evaluation should include a survey of the electrical demands placed on the aircraft by that new system. For many systems, the power drawn from the aircraft's electrical system is minimal and of little consequence. However, a FLIR system with its associated cryogenic cooler often presents a more difficult problem. It is incumbent upon the test team to examine not only the resultant electrical draw from the aircraft but also the effects on the overall aircraft and FLIR system as a result of the electrical busses being loaded and unloaded. The team must first establish the baseline electrical condition of the aircraft. Once this is complete, they then should proceed with a predetermined matrix of activating and deactivating switches and circuit breakers to determine the resultant effect on aircraft systems. Electrical load surveys are primarily performed as ground tests.

Electromagnetic Compatibility Tests. Of course, any system that is integrated into a Navy aircraft must be able to operate in the shipboard environment. Of particular interest is the ability of a system to ward off the electromagnetic interference (EMI) that is peculiar to just such an environment. EMI is defined by Military Standard MIL-I-6181D as "any electrical or electromagnetic

disturbance phenomenon, signal or emission, man-made or natural, which causes or can cause undesired response, malfunctioning or degradation of performance of electrical and electronic equipment" (U.S. Army, 3-287). The ships are fitted with powerful radars, high frequency transmitters, and other such equipment which can have a devastating effect on systems not properly shielded from EMI. So it is important to examine all new systems in their intended configuration to determine the effects EMI might have. Testing facilities are available at the Naval Air Station, Patuxent River, Maryland (as well as one or two other locations) that have the capability to simulate the shipboard electromagnetic environment.

A parallel concern is the effect the new system may have on the aircraft systems already installed and vice versa. A typical requirement is that the new system when integrated must not degraded any present aircraft systems.

These tests compose what is commonly referred to as electromagnetic compatibility (EMC) testing. EMC evaluations require a significant amount of ground test time to include some rotors-turning ground work and must be planned for accordingly.

The sample test plan in the Appendix covers many developmental and operational issues, however, the assumption is that the structural, electrical, and electromagnetic compatibility tests have been completed and

were satisfactory. Therefore, they have not been included.

CHAPTER V

CONCLUSIONS

This paper provides a single source document for the prospective test team to model a developmental test of a navigational FLIR in a transport helicopter. It begins by equipping the test team with some of the theoretical background necessary to understand FLIR systems. Then the concept of operation of infrared systems is outlined to enable the evaluator to devise and conduct a knowledgeable system evaluation. In an effort to gain some understanding and insight into the relationship between developmental and operational testing, the paper discusses principles of developmental testing and the requirements upon which the operational test team will base their recommendations. Finally, using the theory of systems engineering, it outlines a generic test plan that provides a total package that includes the traditional engineering developmental tests as well as several tests necessary to look at the system as a whole - how it affects the aircraft and its mission by testing to the operational testers' Test and Evaluation Master Plan.

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APPENDIX

**PROJECT TEST PLAN FOR THE DEVELOPMENTAL TEST
OF A NAVIGATIONAL FLIR IN A TRANSPORT HELICOPTER**

BACKGROUND

1. [Information as necessary to supply background to the specific test at hand.]

PURPOSE

2. The purpose of this test is to conduct a developmental test of the _____ FLIR as installed in the _____ aircraft for the assault support helicopter mission. Tests will be conducted to determine specification compliance of the FLIR and to examine TEMP critical technical and operational issues. The testing will determine whether the _____ FLIR is ready for operational test.

DESCRIPTION OF TEST AIRCRAFT

3. The test aircraft is a _____ (Bureau number _____).
[Insert specific helicopter description as appropriate or include as an appendix.]

DESCRIPTION OF TEST EQUIPMENT

4. [Insert specific FLIR description or include as an appendix.]

SCOPE OF TESTS

TESTS AND TEST CONDITIONS

GENERAL

5. These tests will provide a determination of the utility of employing the FLIR system as an aid to the assault support mission. The testing of the FLIR system will be performed using a combination of ground and flight tests. The evaluation will be conducted during approximately ____ hours of ground testing and approximately ____ hours of flight testing. The developmental testing will cover critical operational issues of the TEMP with the exception of _____ [fill in the blank as appropriate].

GROUND TESTS

6. The ground testing is primarily concerned with FLIR performance testing. These tests will measure the sensor's minimum resolvable temperature difference (MRTD), field of regard (FOR), field of view (FOV), line of sight (LOS) drift, slew rate, and minimum in-focus range. They also include an evaluation of the controls and displays and FLIR preflight and Built in Test (BIT).

FLIGHT TESTS

7. Flight tests will be conducted under day and night visual meteorological conditions and will include resolution

versus temperature difference, detection and recognition, navigational task effectiveness and tracking performance, and external load tests. They are intended to determine airborne sensor resolution, sensor acquisition ranges, autotracking performance, navigation task effectiveness, and possible FLIR assistance in external load pickup, dropoff, and cruise flight. Detection, recognition, acquisition, tracking, and navigation tests will be flown against tactical targets at a fixed site and along a predetermined, approved low-level flight route. Weather conditions will be documented. Ground test results will be compared with the results of the flight tests to determine the effects on resolution due to the flight environment and FLIR/helicopter interface.

TEST ENVELOPE

8. All flights will be conducted within the limits of the _____ aircraft flight manual, local standard operating procedures (SOP), and the flight clearance located in Appendix [].

FLIGHT CLEARANCE

9. The flight clearance is contained in Appendix []. [Any and all applicable amendments should also be included.]

TEST LOADINGS AND CONFIGURATIONS

10. Test loadings and configurations are presented in _____
_____ [table or appendix as appropriate for the tests].

TEST STANDARDS

11. Test standards applicable to this evaluation are the FLIR System Specification, reference __ , and the TEMP, reference __ . Tests will be used to determine if the FLIR system meets the critical technical parameters and critical operational issues of the TEMP, reference __ .

METHOD OF TEST

TEST METHODS AND PROCEDURES

RELIABILITY AND MAINTAINABILITY

12. All ground tests, flight tests, and maintenance will be monitored by a Reliability and Maintainability (R&M) representative. The following FLIR system data will be recorded: flight and ground test time, system time, individual weapon replaceable assembly (WRA) hour meter times, BIT performance, failures and maintenance performed. This would include on site WRA repairs made or attempted by the contractor.

13. FLIR system R&M will be collected and recorded using maintenance action forms (MAFs) and flight time using the aircraft flight data records. FLIR system failure data will

be based on total FLIR system operating time using WRA hour meter time as the FLIR system time vice flight time. The data collected will be used to determine the requirements of the TEMP, which will include:

- a. Mission Reliability
- b. System Operational Availability
- c. Mean Time Between Failure
- d. Mean Time Between Mission Critical Failure
- e. Mean Time to Repair
- f. Built in Test Evaluation Data
- g. Total Aircraft Flight Time
- h. Total FLIR System Operating Time

14. Operator workload performance evaluations will be conducted concurrently with all flight tests. Operator workload interviews and engineering assessments will be conducted to identify possible high workload tasks. Operator and maintenance publications and training packages will be evaluated for completeness and accuracy.

15. Built in Test (BIT) function and failure indications will be evaluated for completeness, frequency, and comprehension. Frequency of BIT indications will be used as an indication of BIT accuracy, reliability, and maintainability.

16. A normal system turn on will be performed before each test using the published system checklist. Time to cool down, and total time to operationally ready will be noted to include complexity of operation. Preflight BIT will be performed noting the total BIT time, indications, and any correlation between the BIT indications (if any) and the FLIR's operation.

CONTROLS AND DISPLAYS

17. The FLIR display and associated symbology will be evaluated in the various display modes and while switching between modes. The utility of the modes will be qualitatively assessed during all portions of flight testing. Operator control of display functions and overall system control will be qualitatively evaluated during all flights. Factors to be evaluated include: symbol clarity, ease of interpretation of displayed information, functional reach, operating sense, adjustment sensitivity, comprehension, and usefulness.

18. Throughout the flight tests, the aircrew will qualitatively determine display quality by observing any video artifacts or noise present on the displays. The implementation of level, gain, contrast, and brightness will also be qualitatively evaluated along with the functionality of the controls. These qualitative comments will be

recorded on an onboard VHS recorder [if available] and aircrew in-flight notes, and discussed at the flight debriefing.

19. The operation of the FLIR system in the _____ aircraft in various illumination levels will be qualitatively evaluated by both of the pilots. Light level calendars for the test period should be consulted. The effects of FLIR displays and lighting on night vision goggle (NVG) performance under all ambient lighting conditions as well as potential effects on human performance (i.e., vertigo, reduced dark adaptation, etc.) will be evaluated. The new cockpit layout and crew interaction will be evaluated for human factors and crew coordination throughout flight tests, to include simulated instrument flight, low airspeed flight, and flight using NVGs under all ambient lighting conditions.

GROUND TESTS

General

20. Ground tests will be conducted in a closed hangar to minimize varying thermal effects. FLIR video will be set to black hot and white hot polarities as necessary and will be displayed using the panel display units (PDUs). The project aircrew and engineers will be the observers for resolution tests.

Minimum Resolvable Temperature Difference Test

21. Minimum Resolvable Temperature Difference (MRTD) measurements (resolution as a function of delta temperature (ΔT)) will be performed to determine the optimal FLIR resolution performance under controlled conditions. These MRTD measurements will be used to predict in-flight resolution performance and will serve as a baseline of comparison for in-flight FLIR performance. The FLIR will be powered by ground external power [if necessary]. The test observer will use the following procedure:

a. The FLIR will be placed in the optical path of a collimated blackbody heat source and aligned on a common axis.

b. The FLIR will be turned on and allowed a sufficient time to cool down to cryogenic temperatures.

c. Multiple target templates with 7:1 aspect ratios and 4 bar arrays of varying spatial frequencies (SF) will be placed into the optical path of the heat source. The targets will be decreased in size from a predictably small SF (easily resolved by the FLIR) to a SF that is predictably large enough that the FLIR cannot resolve the four bar array. A series of different target sizes will be used and steps between the target sizes will be small enough to accurately measure the FLIR's maximum resolution and provide a detailed MRTD curve.

d. Test observers will be used to determine the data

points. The observers will position themselves at a mission representative position to view the targets on the display (the same position from which the target will be observed while airborne to provide a reasonable comparison basis).

e. Display brightness and contrast, FLIR focus, and FLIR level and gain settings will be adjusted to optimize the displayed image.

f. The temperature of the heat source will be set at a temperature such that the four bar array is not discernible to the observer. The temperature of the heat source will slowly be raised in increments between 0.01° and 0.1° Celsius until the observer can discern the four bar target. The criteria for resolution will be when 50% of the four bar target array can be seen 50% of the observation time.

g. The ΔT between background and source will be recorded with the corresponding SF.

h. The temperature of the heat source will be decreased to $0^{\circ} \Delta T$ and then decreased in increments between 0.01° and 0.1° Celsius until the observer can discern the four bar target.

i. The ΔT between background and source will be recorded with the corresponding SF.

j. Steps c through g will be repeated until all target templates that are resolvable are observed and recorded.

k. The ΔT for each particular template will be the average of the two readings taken.

Sensor Narrow and Wide Field of View Test

22. The sensor Field of View (FOV) will be measured to determine any FOV restrictions because of aircraft installation. With the FLIR in fixed forward mode, FLIR FOV will be determined by measuring the angular deflection of a point source moved perpendicularly to the FLIR sensor and determining when the point source leaves the FOV by viewing the PDU. A thermal point source will be placed on the FLIR boresight line in front of the aircraft and its position will be marked for reference. The point source will be moved perpendicular to the boresight line until it is viewed at the edge of a display. The distance the point source is moved from center for each display will be measured and recorded. The point source will be moved in the opposite direction until it is at the other edge of a display. The distance the point source is moved from center will be measured and recorded. From these measurements the FLIR FOV will be calculated. This procedure will be performed for both azimuth and elevation.

Line of Sight Drift Rate Test

23. FLIR Line of Sight (LOS) drift rate will be tested by the following procedure:

a. Power the FLIR system and wait for FLIR video to be displayed. Cross hairs will automatically come up on-axis to the aircraft with the FLIR in fixed forward mode [if

cross hairs are not available, drawing them on the screen will have the same effect].

b. Align the sensor cross hairs on a prominent, fixed point target at a known distance.

c. After various time intervals (dependent on the observed rate of drift), note the position of the cross hairs in the target plane at which the sensor reference is then directed.

d. Calculate the sensor drift rate using the formula:

$$\theta^{\circ}/\text{sec} = \{\arctan [D(t_1)/R]\}/(t_1-t_0)$$

where, $D(t_1)$ = linear drift distance at range R
at time t_1

R = range from sensor to target plane

t_1 = time of measurement (seconds)

t_0 = time of initial alignment (seconds)

e. The same procedure is repeated for both azimuth and elevation.

Field of Regard Test

24. The Field of Regard (FOR) of the FLIR turret unit will be tested by slewing the FLIR to its maximum horizontal and vertical limits and presenting a thermal target to the system at a known distance from the aircraft. The target will be placed in the center of the FOV. The position of the target will be measured and recorded. The slew limit will then be calculated. The procedure will be repeated for

the edges of the FOV. Obstructions will be noted through the entire FOR.

Slew Rate Test

25. A test will be performed to find the slew rate of the FLIR. The FLIR will be slewed from one slew limit to the other slew limit and the radians per second will be recorded. The test will be repeated for both horizontal and vertical slew rates.

Minimum In-Focus Range Test

26. A qualitative test will be performed to find the minimum in-focus range of the FLIR. A thermal target with defined edges will be presented to the FLIR along the FLIR line of sight. The target will be moved along the line of sight from directly in front of the FLIR and away from the FLIR. When the edges of the target are sharp the FLIR will have the target in focus. The minimum in-focus range will then be recorded. This test will be performed for both wide and narrow fields of view.

FLIGHT TESTS

Sensor Resolution Measurement Test

27. A test of FLIR resolution as a function of temperature difference will be conducted against the Electro-Optical Test Target (EOTT) at night to gather technical performance

data in the flight environment. Radar tracking services will be in constant communication with the aircraft, and will instruct the pilot of local air traffic and his proper flight path. The flight controller will also provide an altitude warning at 80% of target altitude. The test will be conducted with both pilots wearing night vision goggles (NVGs) and the evaluating pilot viewing the FLIR display. All resolution flight tests will be performed in black hot or white hot polarity as determined in the preflight briefing. Inflight FLIR level, gain, focus, and display brightness and contrast will be optimized for the target and surrounding terrain. Each bar on the EOTT will be 21 feet high by 3 feet wide (7:1 aspect ratio) and will provide a 6 foot linear period. The EOTT IR resolution target will be a 4 bar target, heated at a bar temperature difference (ΔT) range between 1° and 10° C. The target will be scanned once per data run. Local weather data will be obtained at the EOTT during the test so that atmospheric transmission loss can be calculated. Temperatures will be recorded from both dry and wet bulb thermometers once every half hour. Relative humidity will be determined by comparing these two values. Ambient air temperature will be recorded from the dry bulb reading. The atmospheric transmission loss will be used to calculate the effective ΔT at the FLIR (i.e., the actual amount of radiant energy received at the sensor window in the 8 to 12 micrometer band). Spatial frequencies

(SF) will be calculated as a function of range (R) to the target by:

$$SF(\text{cycles/mrad}) = \{R(\text{ft}) / 1000 L(\text{ft})\} (\text{cycles/mrad})$$

The calculated ΔT 's and SFs will be used to plot delta temperature versus spatial frequency curves relative to the particular conditions found during the individual flights.

28. These flight tests will be conducted in the following manner:

a. During the flight test the aircraft will operate at _____ KIAS straight and level [select speed as appropriate for platform], on a constant heading. All resolution flights will be flown at 500 feet above ground level (AGL). (The altitude may be adjusted during the test if necessary.)

b. The operator (evaluating pilot) will select wide field of view (WFOV).

c. When nearing the target, the operator will announce "Standby" over the radio to prepare the range personnel to mark the distance to target. Upon barely resolving four bars, the operator will indicate the data point by stating "Mark" over the radio.

d. The range personnel will record the aircraft altitude and slant range to the target. An event mark will be time coded and later merged with the time coded range data obtained from the radar tracking facility.

e. The operator will switch to the narrow field of

view (NFOV) and repeat the procedures.

f. The procedures will also be repeated at various airspeeds and polarities as shown in Table A-1.

TABLE A-1
FLIR RESOLUTION FLIGHT TESTS

FLIGHT	AIRSPEED (KIAS)	ALTITUDE (ft AGL)	ΔT (°C)	NUMBER OF RUNS
Min Resolvable Temp (MRT)	100	500	8,6,4,2,1	6
WFOV/NFOV White Hot	150	500	8,6,4,2,1	6
Resolution vs Airspeed	80	500	TBD ¹	6
WFOV/NFOV White Hot	120	500	TBD ¹	6
Min Resolvable Temp (MRT) with Polarity Switch	100	500	TBD ¹	6
WFOV/NFOV Black Hot				

Note: 1. TBD = Temperature to be determined from results of MRT tests.

29. During each flight, the EOTT personnel will also maintain communication with the pilot. During each data run, the pilot will announce he is inbound to the target, at which time the EO target operators will measure and record the target to background ΔT . There will be six runs per ΔT . [Six should be sufficient to establish a reasonable spread of data points.]

30. Through the flight test, the aircrew will qualitatively determine FLIR display quality by observing any video artifacts or noise present on the Panel Display Units

(PDUs). The implementation of level, gain, contrast, and brightness will also be qualitatively evaluated along with the functionality of the controls. These qualitative comments will be recorded on an onboard VHS recorder and in aircrew data cards.

Detection and Recognition Range Flight Tests

31. Flight tests will be performed to measure the detection and recognition ranges of mission related targets such as a tank, jeep, etc. These tests will be conducted during night conditions. The targets will be placed with the backgrounds and under the conditions of Table A-2 (derived from the TEMP). The aircrew will fly towards the target at 500 feet AGL and 100 KIAS while using the WFOV, and then repeat the test using the NFOV. When the target is detected, the operator will call "Mark one" and the range from the target to the aircraft will be recorded by using either the controlling facility's radar or the aircraft's onboard navigation system [if sufficiently precise such as a Global Positioning System]. When the target is recognized, the operator will call "Mark two" and the range from the target to the aircraft will be recorded again. Six runs will be made at each target to ensure repeatability.

TABLE A-2

MINIMUM OPERATIONAL RECOGNITION RANGE REQUIREMENTS

BACKGROUND	FOV	TARGET				
		Vehicle (Off) ¹	Vehicle (idle) ²	Bridge ³	Dam ⁴	Landing Zone ⁵
Tall Grass	Wide	[] m	[] m	[] m	NA	NA
Mowed Grass	Wide	[] m	[] m	[] m	NA	NA
Dirt Road (dry)	Wide	[] m	[] m	NA	NA	NA
Water	Wide	NA	NA	[] m	[] m	NA
Open Area	Wide	NA	NA	NA	NA	[] m
Closed Area	Wide	NA	NA	NA	NA	[] m

Notes: 1. The FLIR must have the capability to recognize an inactive tank-like vehicle with a 90% Probability of recognition (P_R). For this test the vehicle's engine should be inactive and have been inactive for at least one hour prior to test.

2. The FLIR must have the capability to recognize an active tank-like vehicle with 90% P_R . For this test the vehicle's engine may be active or inactive during test but must have been active for at least two hours prior to the beginning of the test.

3. The FLIR must have the capability to recognize navigational cues such as a bridge with various backgrounds. The bridge specified for this test should be a typical low, flat bridge commonly found on interstate highways.

4. The FLIR must have the capability to recognize navigational cues such as a dam with various backgrounds. The dam may be located around a reservoir or a hydraulic facility and should have at least a 3000 square foot surface area.

32. Off-site detection and recognition range tests will be conducted against mission related targets of opportunity such as other aircraft, bridges, dams, and landing zones as the aircraft is flown over various low-level navigation routes. These tests will be conducted during both day and night conditions. The range from target to aircraft will be recorded by using the aircraft's navigation system [again, if precise enough, otherwise some sort of tracking radar

will be required]. Six runs will be made at each target of opportunity to ensure repeatability. After initial detection and recognition of a target, the FLIR will be placed in the autotracking mode [if available] for subsequent detection and recognition runs to evaluate the system's tracking capability. Pilot comments will be used as a qualitative measure of the tracking performance of the FLIR.

Tracking, Navigation and Task Effectiveness

33. Flight tests will be performed to evaluate the effectiveness of the FLIR system as an aid to navigation and to the mission of _____ helicopter in conjunction with the off-site detection and tracking testing. These tests will be conducted along a series of planned low level flight routes. The pilot will navigate to the preplanned way points at altitudes of 500 AGL or less and at mission relatable airspeeds. A minimum of three runs will be made during day and night to evaluate the mission effectiveness of the FLIR. After initial detection and recognition of a waypoint or target of interest, the FLIR may be placed in the autotracking mode and will be allowed to track the waypoint or target of opportunity at the pilot's discretion to evaluate the tracking capability. Various FLIR settings (e.g., wide or narrow FOV, white hot or black hot polarity, automatic or manual gain and level settings, etc.) will be

selected by the pilot and qualitatively evaluated. Pilot comments will be used to qualitatively evaluate overall FLIR system mission performance. [This testing should be accomplished in close conjunction with the requirements of the TEMP since many of the critical operational issues (COIs) may be addressed during this phase.]

EXTERNAL LOADS EVALUATION

34. The effect of external loads on the FLIR system and the effectiveness of the FLIR system to aid the pilots during the carriage of external loads will be evaluated during day and night flight tests carrying a _____ pound practice external load and a _____ pound heavy external load [whatever weights are appropriate for the type of aircraft]. The lighter practice external load will be used for buildup. The heavy external load will be lifted to evaluate the effects of high gross weight on the FLIR (i.e., vibrations). The panel display units (PDUs) will be monitored for any degradation in the FLIR image due to any resulting vibrations. Concurrently, the FLIR system will be evaluated as an aid to the pilots during external load operations. [Again, this will probably be a COI in the TEMP and therefore should be done closely following the method planned by the operational testers.] All external load operations will be accomplished per the aircraft operating manual and tactical manual.

INSTRUMENTATION AND DATA PROCESSING

35. The video provided by the FLIR's PDUs will be recorded on VHS tape and will be time tagged [both preferable if available].

36. Data will be recorded on pilot kneeboard cards and with on-board video.

PHOTOGRAPHIC DOCUMENTATION

37. Photographic support will be provided by the testing squadron as necessary.

SUPPORT REQUIREMENTS

38. Test support requirements include:

a. The FLIR contractor will be responsible for the maintenance of the FLIR system throughout the developmental testing period.

b. The test squadron will be responsible for the coordination of hangar space, office facilities, photographic support, range usage, and maintenance support of the test aircraft.

c. A Helicopter Support Team (HST) will perform all hook-up operations during the external load portion of this test.

SPECIAL PRECAUTIONS

39. All safety procedures and handling of the aircraft will be per the safety precautions of the aircraft operating manual. All applicable flight restrictions will be noted on the pilots' kneeboard cards. Pilots flying NVGs will be fully qualified and current. Light level calendars for the period of the flight test will be examined and prebriefed prior to NVG operations. Project pilots are familiar with the test ranges and will fly all routes during the day before flying them at night. All project pilots will review area maps prior to flight. In the event of an inflight FLIR system failure, the flight will be terminated and maintenance will be performed.

40. Prior to the first flight with the new system, an Electro-magnetic Compatibility Safety of Flight Test (EMC SOFT) will be conducted by the pilot in command.

41. All flight tests will be conducted per the aircraft operating manual as modified by the flight clearance [if applicable], and the squadron Standard Operating Procedures (SOP). Crew coordination and data collection procedures and responsibilities will be briefed prior to each flight.

42. Special precautions for the external loads tests include:

- a. Fully brief all cargo hookup procedures.
- b. Avoid flight with external loads over populated areas. Flight over water will be maximized. Boating traffic will be noted and avoided to the maximum extent possible.
- c. Flight time in the avoid regions of the H-V diagram shall be minimized.
- d. Adequate ground clearance between the hovering helicopter and ground personnel should be maintained at all times during hookups. The crew chief as well as the plane director advises the pilot of the relative position of the helicopter and the necessary corrective action to maintain it directly over the load through the use of standard intercommunication system (ICS) and hand signals. Liftoff will not start until ground personnel are clear of the helicopter and the load.
- e. For all external cargo operations, the HST personnel will be briefed on the static electricity potential of the helicopter and proper grounding procedures. An approved grounding rod will be used at all times. Insulated gloves will be worn.
- f. HST personnel will also be briefed on the downwash profile of the helicopter and the procedures for emergencies occurring with the aircraft over the external load so as to avoid being struck.
- g. Before conducting external load operations,

helicopter performance capabilities will be verified against Indicated Torque Required to Hover-in-Ground-Effect charts and by performing an operational power check as presented in the aircraft operating manual.

SECURITY

43. [Insert operational security plan here as required. Typically, FLIR testing is not classified except for the actual results of detection and recognition range evaluations.]

MANAGEMENT

FUNDING AND MANPOWER REQUIREMENTS

44. Estimated funds required to complete this effort are \$XXX. Funds presently on station for this project total \$XXX and expire on [date]. A detailed cost breakdown is shown below. [Insert information as required.]

SCHEDULE/MILESTONES

45. [Insert planned test schedule to include planning, ground and flight test, data processing, and reports.]

PERSONNEL ASSIGNMENTS

46. [Insert names as appropriate to include the project officer and project engineer as well as supporting pilots, aircrewmen, and engineers.]

REPORTS

47. [Timely reporting of information on a project can be critical, especially one that is intended to proceed to operational test (OT). Often the decision to proceed to OT hinges on the results of the developmental evaluation. The types and numbers of reports should be decided upon between the test team and the sponsor before testing begins so that all parties understand their responsibilities in this area.]

VITA

Maj Curtis E. Haberbosch, a native of Maine, received his Bachelor of Arts degree in Physics from the College of the Holy Cross in Worcester, Massachusetts in 1982 and was subsequently commissioned a Second Lieutenant in the U. S. Marine Corps. After graduating from flight school in 1984, he reported to MCAS New River, North Carolina flying CH-53A/D/E helicopters. In 1988 he was assigned as a flight instructor at Whiting Field, Florida flying T-34C aircraft where he received Instructor of the Year honors. A 1992 graduate of the U. S. Naval Test Pilot School, Maj Haberbosch has accumulated more than 3000 hours in over 30 different aircraft through 13 years of service. He is currently the Operations Officer at the Rotary Wing Aircraft Test Squadron, NAWC AD Patuxent River, MD, where he resides with his wife Robin and son Colin. He is slated to return to the Fleet Marine Force in the summer of 1995 as the head of the Fleet Introduction Team for the CH-53E Helicopter Night Vision System.