I am submitting herewith a thesis written by Paul C. Schreck, Jr. entitled "Demonstration of a Gimbal Mounted, High Resolution Charge Coupled Device (CCD) Television Camera in Lieu of Direct View Optics for Air to Ground Targeting." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Alfonso Pujol, Major Professor

We have read this thesis and recommend its acceptance:

Ralph D. Kimberlin

Accepted for the Council:

Associate Vice Chancellor
and Dean of The Graduate School

DEMONSTRATION OF A GIMBAL MOUNTED, HIGH RESOLUTION CHARGE COUPLED DEVICE (CCD) TELEVISION CAMERA IN LIEU OF DIRECT VIEW OPTICS FOR AIR TO GROUND TARGETING

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Paul C. Schreck, Jr.

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DEDICATION

This thesis is dedicated to my parents, Paul Curtis and Carolyn Anne Schreck, to whom I am eternally grateful for their sacrifices on behalf of my education, and to my wife Gina Michelle Schreck and my sons, Curtis and Christopher, all of whom remain the greatest inspiration in my life.

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DISCLAIMER

The results contained within this thesis were developed at the Naval Air Warfare Center Aircraft Division, Patuxent River, MD. The discussion of the data, conclusions, and recommendations presented are the opinion of the author and should not be construed as an official position of the United States Department of Defense, the Naval Air Systems Command, or the Naval Air Warfare Center Aircraft Division.

ABSTRACT

The process of air to ground targeting for military attack aircraft involves three distinct, sequential phases of visual discrimination: detection, recognition, and identification (DRI). The intent of this paper is to discuss the tactical merits of charged coupled device (CCD) technology in air to ground target DRI, while contrasting the limitations imposed by the loss of direct view optics (DVO). During an extensive flight and ground test program conducted at the Naval Air Warfare Center Aircraft Division, Patuxent River, MD from October, 1996 to February, 1997, an experimental airborne electro-optical targeting sensor suite featuring high resolution CCD cameras was evaluated by direct comparison to an existing system based on DVO. The results indicated superior performance of the CCD cameras in low ambient lighting conditions, but the absence of color was a major hindrance to rapid target area acquisition. Test results indicated that high resolution and magnification are not the most critical design criteria for an electro-optical targeting suite. A thorough understanding of human factors must also be considered.

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CHAPTER 1

INTRODUCTION AND PURPOSE

In his classic work pertaining to war theory, On War, Carl von Clausewitz alludes to the "fog of war" as a conditioning factor on the modern battlefield. His allusion to the fog of war had a literal and metaphorical meaning. In a literal sense, Clausewitz was referring to the smoke and haze that obscures the battlefield, making it difficult, if not impossible for commanders to obtain an accurate reading of events. Metaphorically, Clausewitz used the idea of fog to represent the obscurity that exists even when one's visibility is unlimited, since a commander can never be sure exactly where an enemy is or what he plans to do. (Muller, n.d.).

United States Marine Corps (USMC) doctrine divides Marine Aviation into six functional areas. Offensive air support (OAS), one of the six functions, involves the delivery of firepower against enemy installations, facilities and personnel. There are two categories of OAS, close air support and deep air support. (DON, 1991). Close air support (CAS) is defined as "air action against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces." (JCS, 1989). Deep air support (DAS) is closely related to CAS, but mainly involves air interdiction designed to disrupt the enemy's fighting capability and allow the commander to "shape the battlefield." CAS allows the commander to concentrate air power with speed and violence at the decisive time and place to exploit opportunity on the battlefield. (DON, 1991).

The successful execution of CAS requires mutual consent between the attack aircraft and the terminal controller located with the ground forces. Mutual consent is dual, verbal concurrence between the attacking aircraft and the terminal controller that positively identifies the target in question as hostile. Mutual consent must be obtained prior to the pilot releasing ordnance on target. A common misconception among young attack pilots regarding mutual consent is that the terminal controller retains ultimate responsibility for the final destination of ordnance once released from his aircraft. This belief, while completely untrue, promotes irresponsibility and carelessness in the deadly serious world of combat. Failure to achieve mutual consent often results in an unacceptable consequence of close combat–fratricide.

During any OAS mission, target acquisition begins once the general target area has been entered. The process of air to ground targeting for military attack aircraft usually begins with some type of search, then proceeds through three distinct, sequential phases: detection, recognition, and identification (DRI). (Erickson, 1986). The detection phase is the operator's first indication to the presence of a potential target. The process continues to the recognition phase, wherein the target is capable of being classified as a certain category of target, e.g., armored vehicle, artillery piece, or personnel. The identification phase is the final phase in which the specific physical characteristics of the target can be ascertained. (Shumaker, Wood, and Thacker, n.d.). The most critical of these phases is the detection phase, for it is the phase from which the other phases naturally flow. The process is complete when weapons are released, fired, or locked on to a target.

Herein lies the crux of air to ground targeting during CAS. The many uncertainties and pressures of combat often cloud the situational awareness of personnel involved in close ground and air combat. The grave responsibility of mutual consent in CAS mandates visual identification. Modern attack aircraft are equipped with various types of optical and electronic sensors for the DRI of ground and airborne targets to aid pilots in obtaining mutual consent. Optical devices for air to ground targeting have evolved through the years from the basic ring and bead gun sights of the World War I era (Shaw 1985), to the optical bomb sights of World War II (WWII), to the television camera (TVC), to the development of advanced electro-optics featuring solid state, photo-electric imaging arrays for day and night applications.

Technological breakthroughs during WWII in radio detection and ranging (RADAR) for surface to air applications paved the way for RADAR employment in air to air applications, and later, to air to ground targeting, originating in the Vietnam conflict. Ground attack RADAR systems decrease pilot workload by aiding in target area acquisition, but mutual consent always applies, and the pilot must still visually identify the target before releasing ordnance. Pure RADAR aided bombing generally only applies to DAS, which requires a lesser degree of coordination with the ground combat element and is not reliant on mutual consent in most cases. Smaller and more mobile targets will be encountered during CAS missions than in deep strike missions. (Erickson, 1986). To achieve mutual consent in close proximity to friendly forces during CAS, *visual* identification is mandatory.

Each step in the evolution of these targeting devices has effectively achieved the same end result. More and more information has progressively been filtered from the final element of every targeting system, the human eye, which is perhaps the most perfect imaging device ever created. The human eye, however, possesses significant limitations on the modern battlefield. Most notable are its susceptibility to physical damage due to the proliferation of targeting systems and weapons based on the laser (light amplification by the stimulated emission of radiation). This vulnerability, along with the increased sensitivity of photo-electric devices to the electromagnetic spectrum, is behind the current revolution in electro-optical devices in air to ground targeting applications. Electro-optics provides a means with which to dramatically improve overall system response and magnification, with obvious benefits for the air to ground targeting mission. The most common design for daylight applications involves the use of television cameras designed around a solid state, visual imaging array known as a charge coupled device (CCD).

CCD based television cameras are the primary means by which direct view optics (DVO) have been replaced in modern air to ground targeting systems. Replacing the DVO in a targeting system currently fielded on the AH-1W helicopter with a system based purely on electro-optics featuring high resolution CCD cameras should improve the overall OAS mission suitability of the aircraft. The loss of DVO will provide an increased measure of survivability for the pilot and increase the range at which targets can be identified, although tradeoffs in reliability and operational effectiveness may be encountered.

CHAPTER 2

BACKGROUND

The AH-1W SuperCobra

In its infancy, CAS was primarily the domain of the fixed wing aircraft. The unique maneuverability of the helicopter made later versions of this aircraft ideally suited for performing CAS missions. Thus, CAS is often referred to by the type aircraft from which fire support is delivered, either fixed or rotary wing. In the USMC, rotary wing CAS is the primary mission of the Marine Light/Attack Helicopter Squadron, a composite unit that operates both AH-1W and UH-1N model helicopters. (DON, 1991).

The Bell Helicopter Textron, Inc. AH-1W SuperCobra is a single main rotor, two place aircraft with tandem seating that serves as the primary attack helicopter platform for the USMC. Capable of employing a wide range of unguided and precision guided munitions, the AH-1W is often touted as the world's most versatile attack helicopter (Figure A-1).

Night Targeting System (NTS)

The sensor suite currently installed on the AH-1W is the Night Targeting System (NTS) (Figure 1). Designed by the Tamam Division of Israel Aircraft Industries Electronics Group, and currently manufactured by Kollsman, Inc., the NTS is

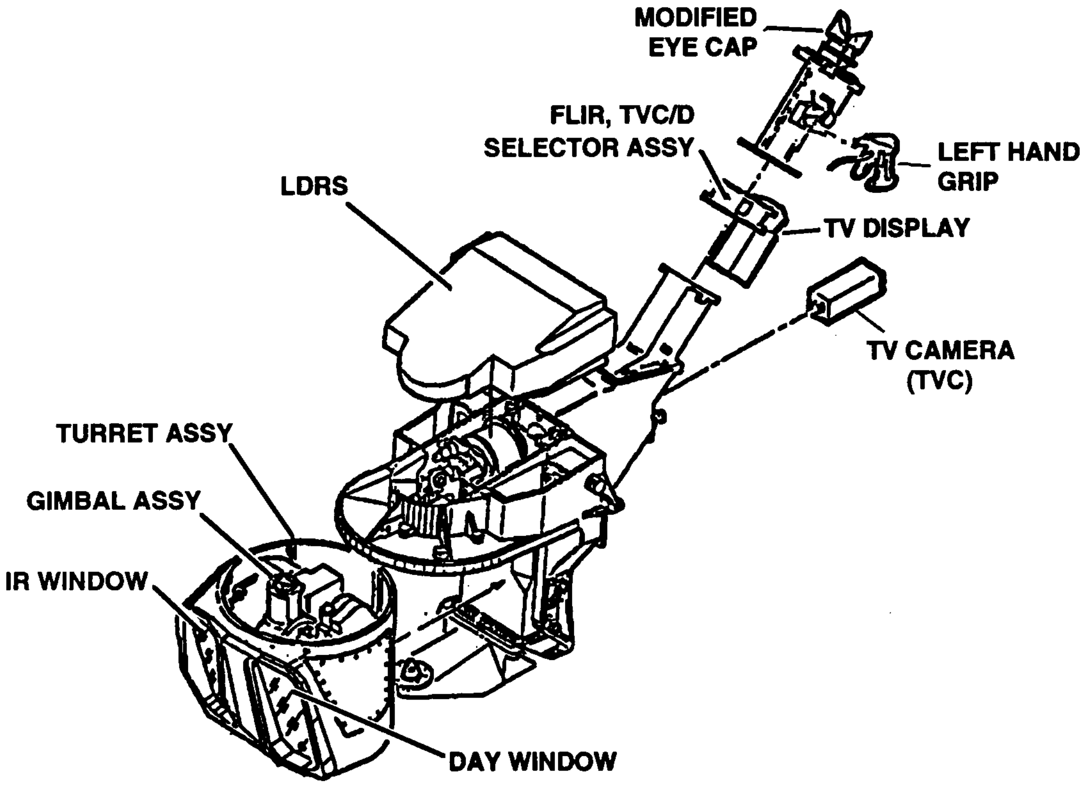

Figure 1: AH-1W Night Targeting System

Source: (IAI, 1993)

a modification to the M-65 Telescopic Sight Unit fielded by Hughes Aircraft Corporation in the early 1970's. The M-65 employs a two field of view (FOV), direct view optics (DVO) system that can be slewed vertically and horizontally for target DRI. The two fields of view provide 2X (two power) and 13X magnification to the operator in the front seat of the aircraft.

The NTS improved upon the basic M-65 by incorporating an onboard laser designator/rangefinder system (LDRS), a forward looking infrared (FLIR) sensor adjacent to the gimbal mounted DVO, and a CCD camera mounted within the M-65, approximately midway in the optical relay tube (ORT) that extends into the forward cockpit (Figure 2). The optical layout of the NTS is presented in Figure 3.

A detailed diagram of the NTS optics is presented in Figure A-2. The optical train of the basic NTS provides a monocular output to the eyepiece lens. Two eyerests are provided on the user end of the ORT, one of which is blank and can be rotated so the operator can use either eye to look through the optics. An operator selectable, single wavelength laser filter is provided near the eyepiece end of the ORT. The CCD camera image is displayed to the operator on either a one square inch cathode ray tube (CRT) within the ORT, or on a five square inch CRT multifunction display (MFD). Both displays are monochromatic. The CCD camera's placement within the optical path provides that sensor with improved magnification over DVO. However, since the M-65/ NTS optics attenuate at least 70% of the light available at the objective lens through the optical train, the low light level (i.e., dusk/dawn) performance of the DVO, along with the

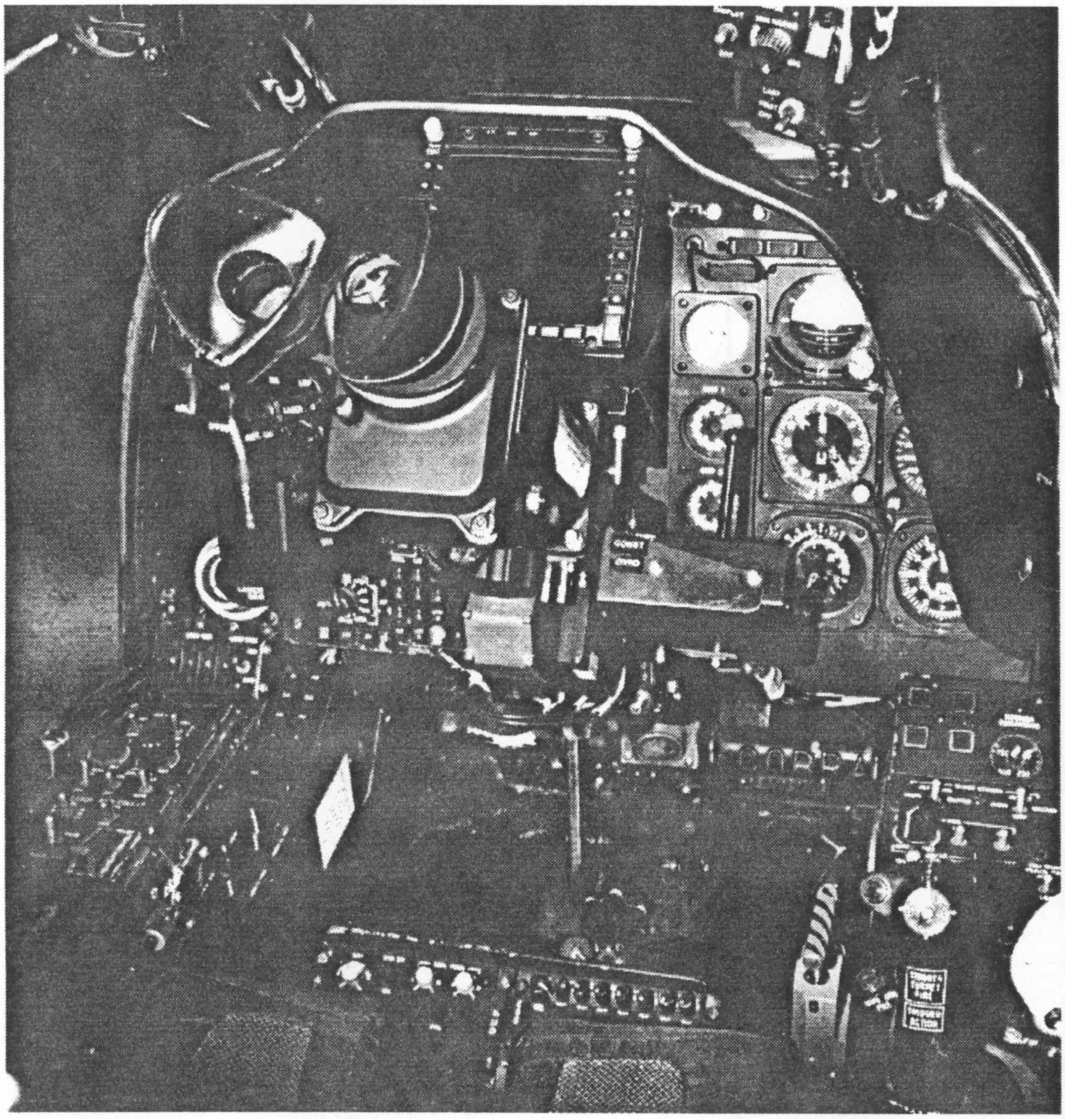

Figure 2: Forward Cockpit of NTS Equipped AH-1W

Source: (Gross, 1996)

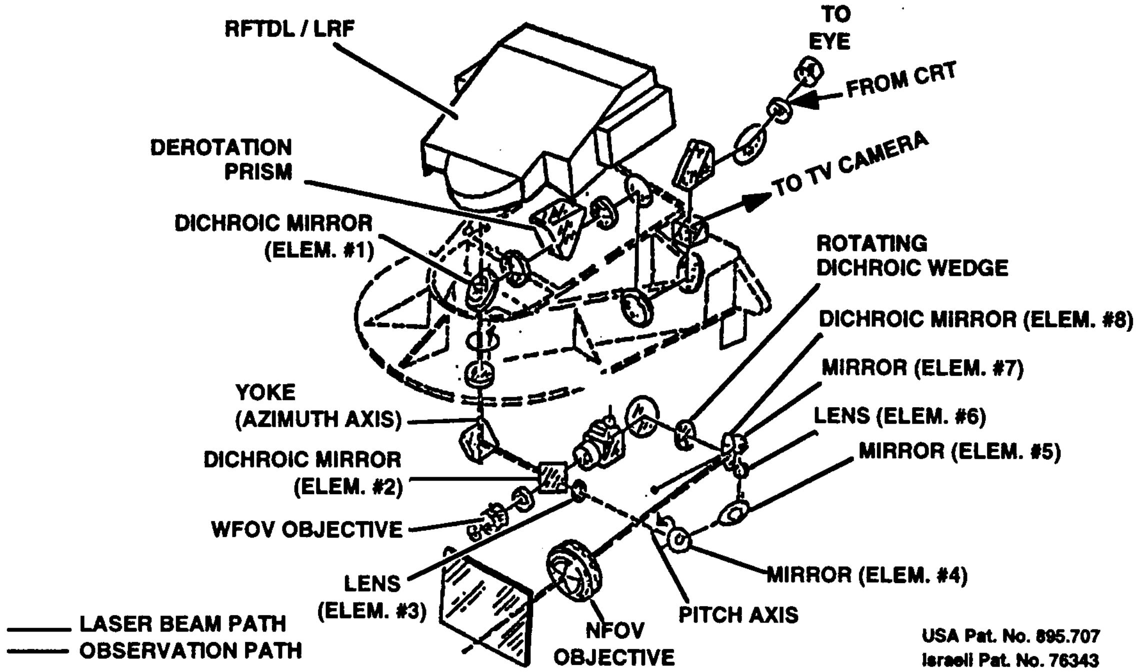

Figure 3: NTS Optical Layout

Source: (IAI, 1993)

internal CCD camera, is degraded. Furthermore, the relatively low magnification of the DVO requires the attack helicopter pilot to close with the target to effectively complete the DRI process, reducing aircraft survivability by decreasing standoff from enemy weapons.

Advanced Night Targeting System (NTS"A")

The NTS"A" intended to improve upon the basic NTS by completely removing the DVO and replacing them with high resolution, gimbal mounted CCD cameras. The NTS"A" incorporated two camera heads mounted on the M-65's slewable gimbal in the space vacated by the optics, adjacent to the FLIR sensor (Figure 4).

Each CCD sensor was a monochromatic solid state imaging array of elements greater than 750 (H) x 488 (W) in 1/2" format (8 mm diagonal). The ORT was removed from the forward cockpit, leaving only the existing five square inch monochrome MFD for sensor output to the operator. The MFD was repositioned for optimum viewing distance and a more normal line of sight to the design eye point than the NTS cockpit arrangement (Figure 5).

The two camera head arrangement provided four fields of view and an order of magnitude increase in magnification. A basic comparison of sensor magnification is presented in Table 1. A graphical comparison of fields of view is presented in Figure 6.

The optical layout of the NTS"A" is presented in Figure 7. Light enters the slewable turret through the outer glass window. The light is directed to the medium/wide

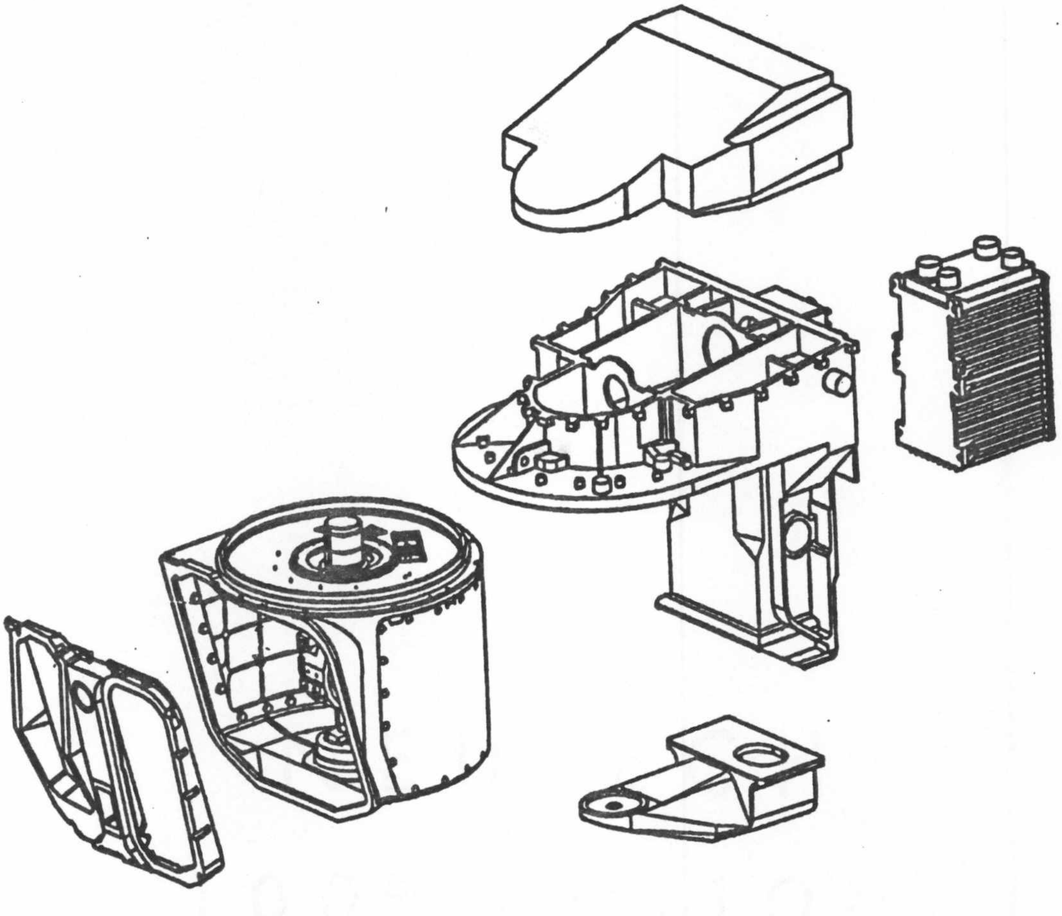

Figure 4: General Layout of NTS"A"

Source: (IAI, 1993)

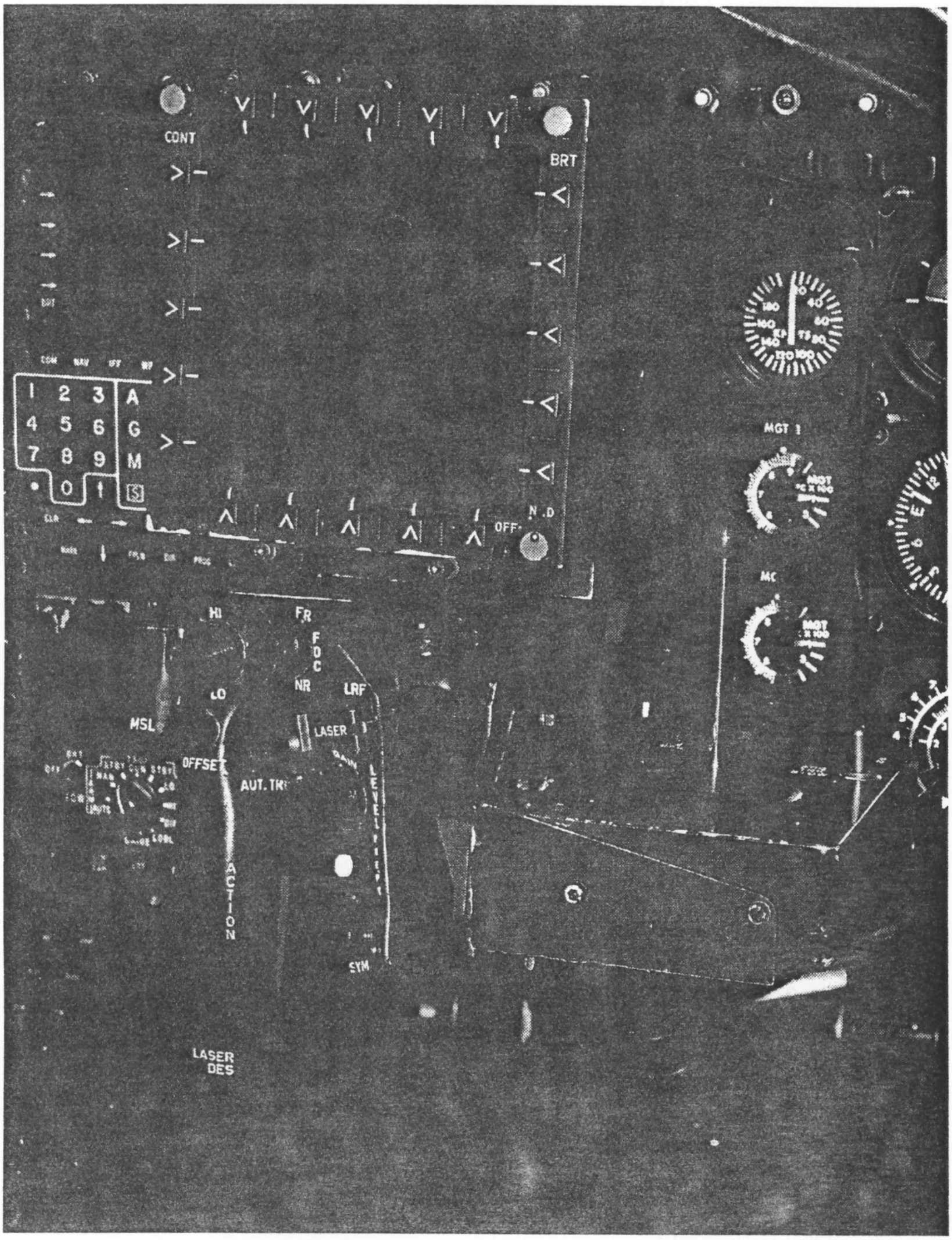

Figure 5: Forward Cockpit of NTS"A" Equipped AH-1W

Source: (Gross, 1996)

Table 1: System Design Magnifications

Source: (IAI, 1993; DON, 1997)

Field of View (FOV)	NTS"A"	NTS DVO	NTS TVC
	(Field of View/Magnification)		
Electronic Zoom Narrow (EZNFOV)	0.45° / 132.8X		
Narrow (NFOV)	0.9° / 65.4X	4.6° / 12.8X	2.0° / 31.3X
Medium (MFOV)	3.5° / 16.8X		
Wide (WFOV)	18° / 3.0X	29.6° / 2.3X	12.5° / 3.2X

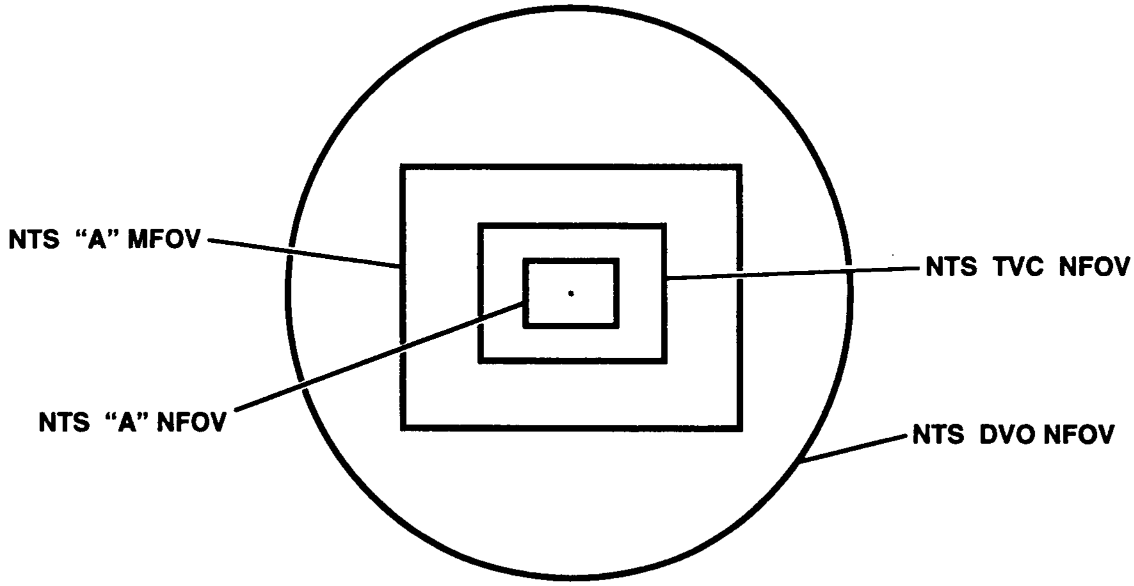

Figure 6: Graphical Comparison of NTS/NTS"A" Fields of View

Source: (IAI, 1993)

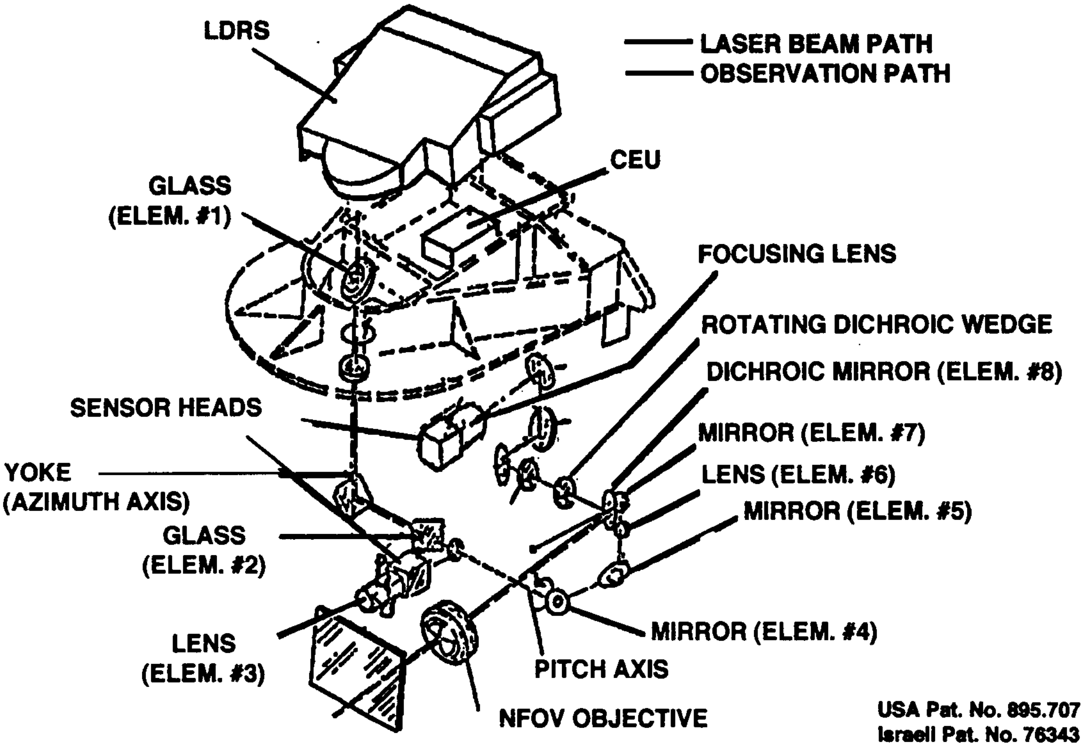

Figure 7: Optical Layout of NTS"A"

Source: (IAI, 1993)

field of view camera head through an objective lens. In MFOV, the light is then focused directly on the CCD. When selecting WFOV, additional optics are positioned between the objective and the CCD to expand the FOV (Figure A-3). Both the WFOV and MFOV are focused at infinity (beyond 200m) and cannot be manually adjusted. Light arrives at the CCD in the NFOV camera head by traveling through an optical path consisting of several fold mirrors, lenses, and wedges (Figure A-3). The NFOV could be zoomed by electronic doubling to twice its normal size with a corresponding loss in resolution.

The NTS"A" TVC focus control located on the left hand grip (Figure 5) was a three-position, rocker-type switch which mechanically positioned the focus lens depicted in Figure 7 to the desired location when depressed up (far focus) or down (near focus). Automatic focus (autofocus) was accomplished by depressing the switch in the center.

TVC light level control (analagous to contrast) was provided in each of the fields of view. Light level control was electronically mechanized by varying the integration time across the CCD, vice a mechanical system that uses a variable aperture or iris-type arrangement, to control the amount of light entering the TVC. The light level of each field of view was automatically adjusted upon changing the field of view. Manual light level adjustment was provided by depressing the "LEVEL" knob on the left hand grip (Figure 5) and toggling the switch left or right. A field of view in the manual light level control mode was indicated by a "MAN" annunciation on the right side of the MFD symbology set.

The primary design detractors of the NTS drove the design of NTS"A". The NTS ORT in the forward cockpit is a major hindrance to rapid emergency egress, as well as a serious impact hazard to the forward cockpit occupant during forced or hard landings. An interim solution to this problem was the development of the inflatable body and head restraint system (IBAHRS). IBAHRS employs cartridge activated, deceleration triggered air bags in the shoulder harness of the five point restraint system in both cockpits. Another limitation of the NTS is the potential for laser inflicted eye damage when utilizing the DVO. The laser filter originally incorporated in the M-65 optics is single wavelength and does not provide adequate protection against all laser threats on the modern battlefield.

NTS"A" Optical Design

The NTS"A" was designed to exploit a wider range of the electromagnetic (EM) spectrum than the NTS DVO and TVC. The day sky contains a wide distribution of the EM spectrum, from cosmic rays to power transmission emissions (Figures 8 and 9). The human eye can only detect the spectrum of visible light, from about 380 to 780 nanometers (nm). As the sun nears and eventually descends below the horizon causing a decrease in total illuminance, the luminance from the visible wavelengths decreases more rapidly as compared to the IR wavelengths. The eye then shifts to scotopic vision, utilizing the rods in the retina for target detection and becoming most sensitive to wavelengths around 500 nm. (Sanders and McCormick, 1993). Since the

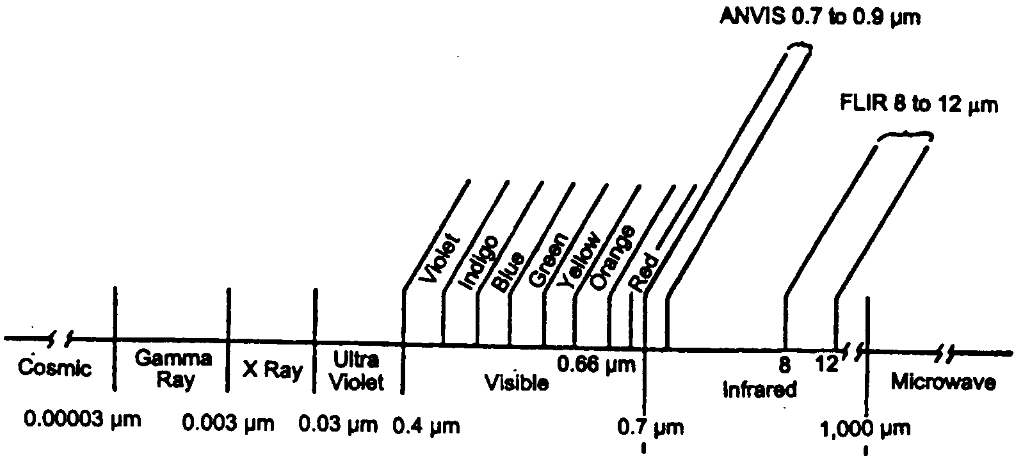

Figure 8: The Electromagnetic Spectrum

Source: (DON, 1997)

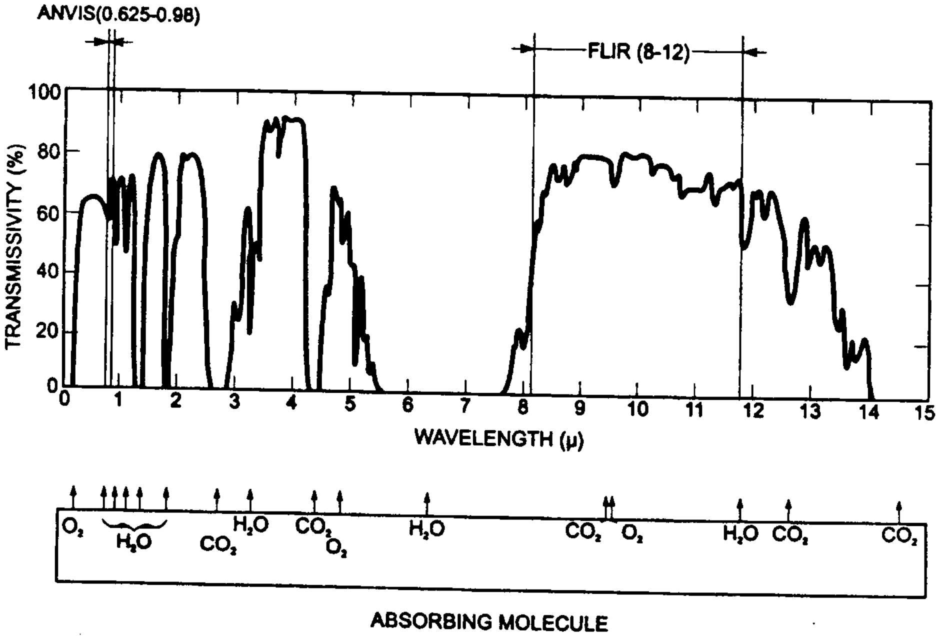

Figure 9: Atmospheric Transmission Windows

Source: (DON, 1997)

optical path of the NTS attenuates approximately 70% of the light striking the objective lens, the optics are essentially worse than the unaided eye for target detection in low light level, i.e., dusk and dawn, conditions. This same design limitation prevents the NTS camera from capitalizing on the increased sensitivity of the CCD, from about 200 to 1100 nm, which includes the near IR region. The NTS"A" cameras were designed to minimize optical losses and take full advantage of the near IR sensitivity of the CCD's by placing them on gimbal, where maximum light can be directly focused with a potentially drastic increase in sensor performance. The responsivity of the CCD to near infrared wavelengths was designed to improve sensor performance through obscurants (e.g., dust, haze, smoke, etc.) that reduce atmospheric transmission (Figure 9). Since the particulates suspended in those obscurants are generally large enough to reduce the luminance of the visible spectrum through scattering, absorption, or refraction, they are less effective versus near IR wavelengths. (MAWTS-1, 1995). Both systems incorporate a 1064 nm Neodymium Yttrium Aluminum Garnet (YAG) laser used for designating targets for laser guided munitions and rangefinding. Both NFOV optical trains contain provisions for directing the laser energy outward through the objective lens toward the target. It was postulated that the sensitivity of the NTS"A" CCD's could possibly provide the capability to view the downrange location of the onboard laser designator spot--a tremendous asset to the operator for precision targeting and increasing laser guided weapon lethality. Tube launched, optically tracked, wire guided (TOW) missile tracking is accomplished by a near IR tracker integrated in both the NTS and NTS"A" NFOV optical trains. As such, the optics are filtered in the near IR wavelengths to improve TOW missile tracking performance at extended ranges.

Figure A-4 depicts the overall transmissivity of the three NTS"A" fields of view. The upper plot in Figure A-4 shows the optical transmissivity of the three fields of view. The responsivity of the NTS"A" CCD cameras is depicted in the center plot. Combining these two plots provides the plot of overall system responsivity presented in the lower plot in Figure A-4. The short optical path of the MFOV depicted in Figures 7 and A-3 results in the higher overall responsivity of the MFOV relative to the WFOV and NFOV as shown in Figure A-4.

CHAPTER 3

SCOPE AND METHOD OF TEST

Measurement of Visual Performance

To accomplish the goals of this project, it was necessary to employ a method for evaluating the visual performance of the NTS"A" cameras. Until recently, most measurements of visual performance have involved either size or contrast, but not both. With a few exceptions, researchers measured either ability to resolve detail in small, high contrast targets, or to distinguish contrast in a very low-contrast, relatively large targets. The first of these abilities is usually referred to as *visual acuity* and the second as *contrast threshold*. Because the imagery display user must resolve edges that include a range of both sizes and contrasts, information on visual performance when both of these parameters are varied is much more useful in system performance. (Farrell and Booth, 1984). The more detailed the target, the higher is its spatial frequency. Typical visual acuity targets such as Snellen letters or Landholt rings are high contrast, high spatial frequency stimuli. Measuring acuity with such targets reveals little about the operator's ability to see low contrast, low spatial frequency targets such as a car on a road at night or a person in a dark movie theater. In fact, contrast sensitivity has been found to be a better predictor than standard visual acuity of people's ability to discriminate highway signs and is a very good predictor of air-to-ground search performance. (Sanders and McCormick, 1993).

Several studies have reported that contrast sensitivity is strongly related to pilots' aircraft detection performance, and, in one case, further suggested that contrast sensitivity should be assessed in pilots and used for initial pilot selection. (O'Neal and Miller II, 1988). Another study found that pilots' visual acuity on both high and low contrast charts related better with their aircraft detection skill than did their contrast sensitivity. (Monaco and Hamilton, 1984). Other studies have shown that neither the visual acuity nor contrast sensitivity of pilots correlates well with flying performance in a simulator or the detection of adversary aircraft. (Kruk, et. al., 1981; Kruk and Regan, 1983). In general, those studies that found no correlation between target detection and contrast sensitivity or visual acuity, or those that leaned toward visual acuity, involved air to air target detection. Studies that involved air to ground search tasks generally favored contrast sensitivity as a measure of performance.

A Historical Perspective

In the mid- and late-1950's the military was developing electro-optical image intensifiers which provided enhanced visual surveillance capabilities under conditions of limited visibility. These intensifiers permitted significant increases in visual target acquisition range and image display capability. The complexity of these intensifiers and associated target acquisition systems required a methodology for evaluating performance characteristics. (Donohue, 1991)

John Johnson of the U. S. Army Engineer Research and Development Laboratories (ERDL), Fort Belvoir, VA (later known as the Army Center for Night Vision and Electro-Optics (CNVEO) or "Night Vision Laboratory (NVL)") presented a paper at the October 1958 Image Intensifier Symposium which addressed "methods and procedures for the solution of problems involving military visual surveillance through image intensifier devices under low light level conditions." (Donohue, 1991). In essence, Johnson placed a set of tri-bar patterns next to a military target as he varied conditions. He noted what tri-bar frequency could just be resolved when a given discrimination task (detection, recognition, and identification) could just be accomplished. Johnson related visual discrimination levels to the Air Force tri-bar target frequencies using the minimum dimension of the target as a reference. The results of this experiment, now known as the "Johnson Criteria" are shown in Table 2. From Table 2 it can be seen that identifying a truck was found equivalent to resolving, under the same conditions, a bar chart whose bars were one sixteenth (1/16) the minimum dimension of the truck. (Note that 8 line pairs are equal to 16 bars on a test target.) (Shumaker, Wood, and Thacker, n.d.).

Even though it provided a simple and straighforward methodology for target transformation, Johnson's paper possessed many shortcomings. Most notable were his omission of definitions for the target discrimination criteria, and the lack of a discussion of

Table 2: The Johnson Criteria, 1957

Adapted from: (Shumaker, Wood, and Thacker, n.d.)

Notes: Johnson's 1974 paper changed the term "Resolution per Minimum Dimension" to "Cycles for 50% Probability"

Target (Broadside)	Resolution per Minimum Dimension (Line Pairs)		
	Detection	Recognition	Identification
Truck	0.9	4.5	8.0
M-48 Tank	0.7	3.5	7.0
Stalin Tank	0.75	3.3	6.0
Centurion Tank	0.75	3.5	6.0
Half-Track	1.0	4.0	5.0
Jeep	1.2	4.5	5.5
Command Car	1.2	4.3	5.5
Soldier (Standing)	1.5	3.8	8.0
105mm Howitzer	1.0	4.8	6.0
Average (N_J)	1.0 ± 0.25	4.0 ± 0.8	6.4 ± 1.5

all the factors which influence target DRI. Table 3 provides a list of factors presented in a paper by Herschel Self in 1969. Many of these factors were downplayed or ignored in Johnson's writings. Despite the shortcomings, Johnson's paper made a significant contribution to defining requirements for military target acquisition systems by enabling measurement of performance requirements in terms of bar target equivalent spatial frequency. (Donohue, 1991). Johnson provided a means from which a mission relatable task could be transformed into a mathematical domain for analysis and comparison, as depicted in Figure 10.

In 1974, Johnson collaborated with Walter Lawson on another paper which modified the original work and extended it to cover IR systems. In the revised work with Lawson, Johnson defined the levels of target discrimination missing from his original work and redefined the term "resolution per minimum dimension" to "cycles for 50% probability," reflecting the less than precise nature of the empirical data. The extension of the criteria to targets with large length to width ratios and the discussion involving the issue of background clutter were also significant contributions of the 1974 paper. (Donohue, 1991; Ratches, et. al., 1975).

Much has been written regarding the validity of, inaccuracies involved with, and potential enhancements to this methodology. A study regarding the effects of noise and overall signal to noise ratio (SNR) claimed that the CNVEO model tends to overestimate the quality of low SNR images while underestimating the quality of high SNR images,

Table 3: Factors Influencing Target Detection and Recognition

Source: (Donohue, 1991)

COMPONENT	INFLUENTIAL FACTORS
The Scene	The size of the picture or displayed image. Numbers, sizes, shapes, and scene distribution of areas contextually likely to contain the target object. Scene objects: numbers, shapes and patterns, achromatic and color contrasts, colors (hue, saturation, lightness), acutance, amount of resolved details, all both absolutely and relative to the target object. Scene distribution of objects. Granularity, noise. Total available information content and amount of each type of information. Average image brightness or lightness. Contextual cues to target object location.
The Target	Location in the image format. Location in the scene. Shape and pattern. Size, color, resolution(s), acutance, lightness, or brightness. Type and degree of isolation from background and objects.
The Observer	Training Experience Native ability. Instructions and task briefing. Search habits. Motivation. Compromise on speed versus accuracy. Assumptions.

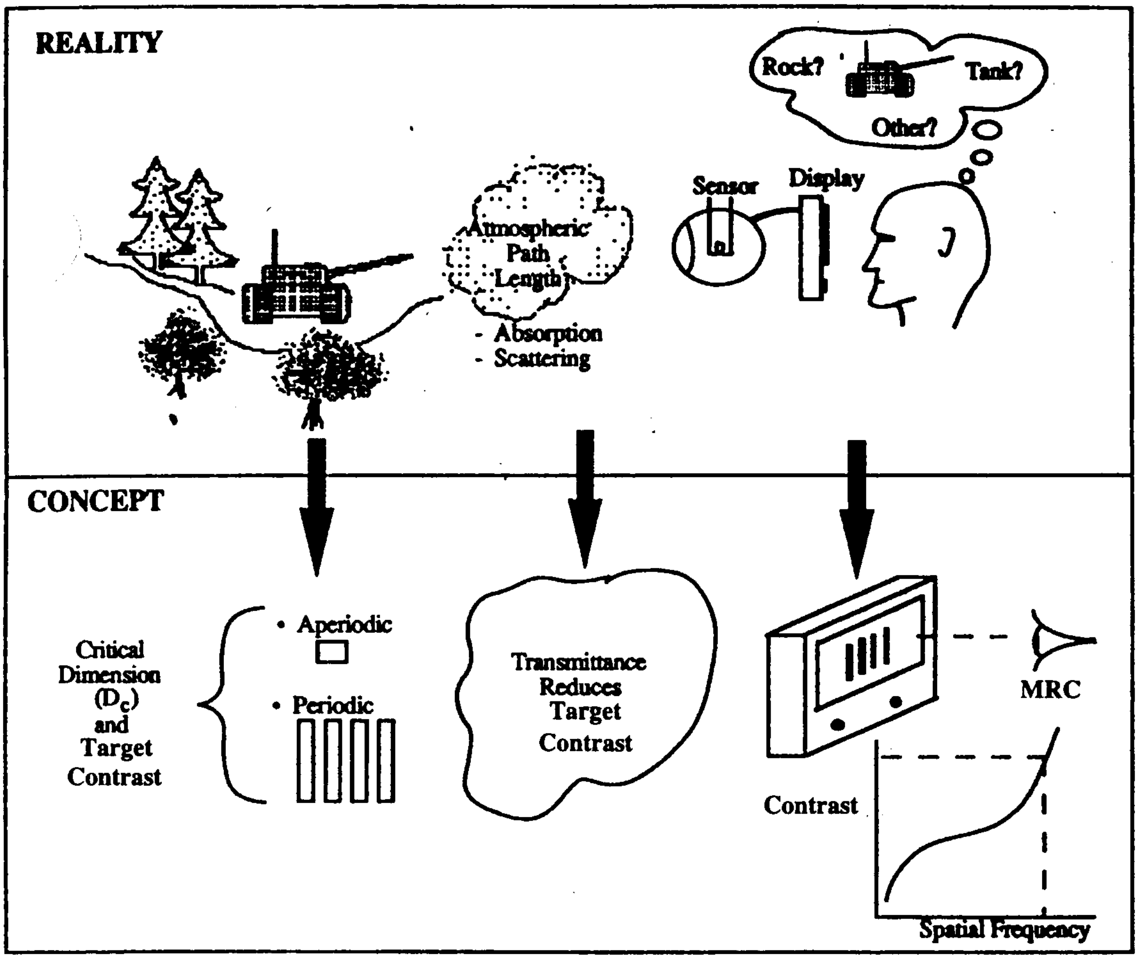

Figure 10: The Target Transformation

Source: (Shumaker, Wood, and Thacker, n.d.)

primarily with respect to large targets, such as ships. (Blumenthal and Campana, 1983). Another study claimed that the CNVEO model approach is limited to foveal interrogation tasks, does not involve peripheral vision and, therefore, does not accurately predict search performance. (Overington, 1981). Yet another set of experiments showed that the effects of background clutter, introduced by Johnson but lightly discussed, had a significant impact on the probability of target detection. (Donohue, 1991). In his 1991 paper, Donohue presents a list of contributing factors to the inaccuracies of Johnson's criteria and their associated estimated impact expressed in percentages. Despite the criticism, the most commonly used model for target acquisition for military applications is still the search model of the Army CNVEO based on the Johnson criteria of 1958. (Rotman, et. al, 1989; Blumenthal and Campana, 1983).

NTS"A" Testing

One AH-1W aircraft configured with the NTS and one AH-1W configured with the NTS"A" were used in this evaluation. The performance of the NTS"A" TVC was measured via direct comparison to the DVO of the basic NTS during ground based and flight testing. The metric for evaluation in both phases of testing was contrast sensitivity based on the Johnson criteria. The Army CNVEO model previously discussed evolved from Johnson's initial work into a tool for measuring the performance of IR imaging systems. In the case of IR imaging systems, contrast sensitivity is determined by measuring the minimum resolvable temperature (MRT) difference or "delta T" (ΔT) between the target bars in a pattern and their background. Contrast sensitivity of purely optical imaging systems is determined by measuring the minimum resolvable contrast (MRC) between the target bars and their background.

During ground based testing, a 50 inch collimator was positioned directly in front of the sensor gimbal. The target utilized for ground based testing was the USAF 1951 Medium Power Resolution Target (Figure A-5). Illumination levels in the collimator were varied from below 10 lux (twilight) to over 18,000 lux (full daylight). (MAWTS-1, 1995). Five target patterns with luminous contrast values of 0.5, 0.22, 0.14, 0.093, and 0.077 were positioned in the collimator in turn at each illumination level. Brightness and contrast levels of the NTS"A" MFD were adjusted prior to data gathering and held fixed. Several subjects were sampled in the front seat of each aircraft to determine the contrast sensitivity of each sensor. Data were gathered for the NTS DVO NFOV and the NTS"A" TVC MFOV and NFOV.

Quantitative inflight resolution testing was designed to validate static ground test results and ascertain the impact of airframe induced vibrations on the sensor operator's ability to resolve a target. Testing consisted of NTS"A" TVC flights versus a low contrast, tri-bar target (Figure 11) with a frequency of 1.093 cycles/meter, and a luminous contrast of 0.33, where luminous contrast is given by Equation 3.1 (RCA, 1974):

$$\text{Luminous contrast} = \frac{L_{max} - L_{min}}{L_{min}} \tag{3.1}$$

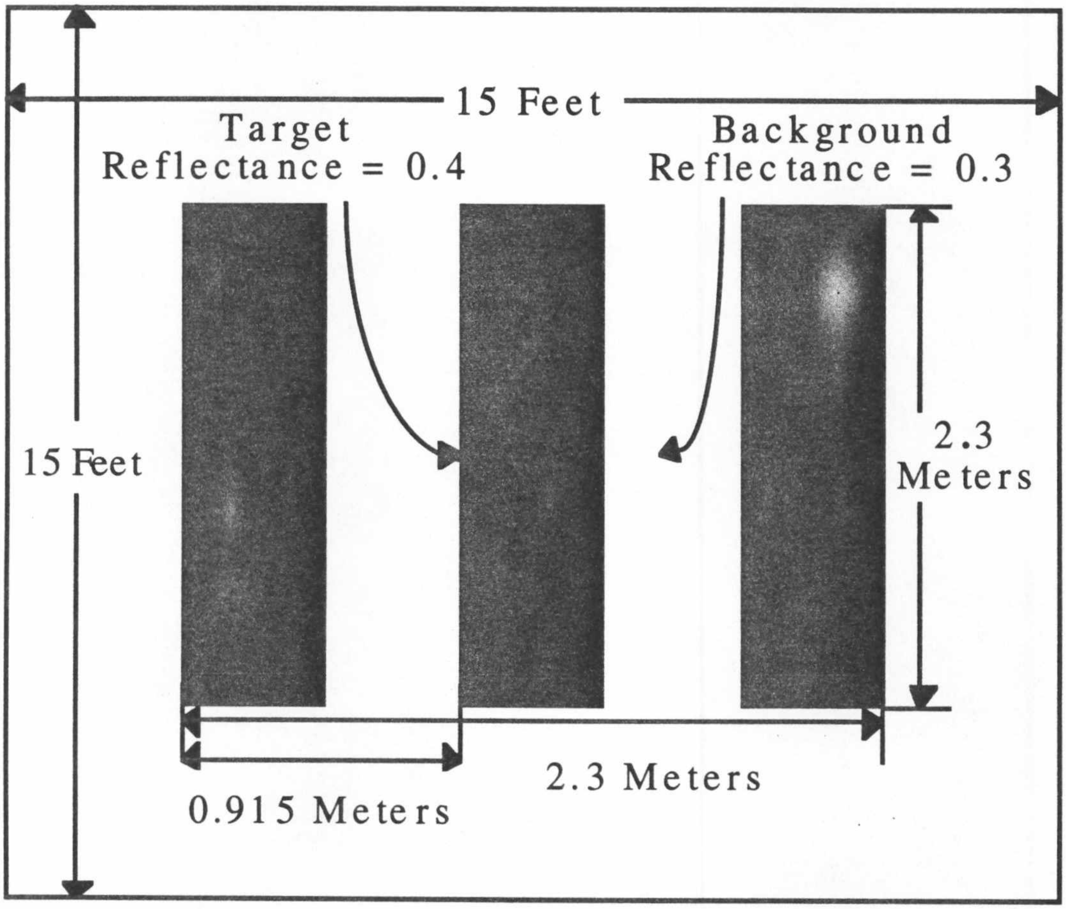

Figure 11: Low Contrast Resolution Target

Notes: Luminous Contrast = 0.33; Frequency = 1.093 cycles/meter where L_{max} and L_{min} are the maximum and minimum luminances in the pattern, 0.4 and 0.3, respectively.

Flights were conducted in periods of high (direct sunlight) and low (overcast) illumination levels. The aircraft was maneuvered to a position whereby the target, but not the bars, was visible and normal to the sensor in NFOV. Slant range was gradually decreased until three distinct bars were detected. Slant range to and luminance at the target were recorded while the sensor was toggled to the next higher field of view and the process repeated through the three optical fields of view. Helicopter indicated airspeed was incremented from 60 knots indicated airspeed (KIAS) to 120 KIAS on subsequent data runs to vary the magnitude of airframe vibrations.

Qualitative inflight testing consisted of direct side-by-side comparative testing between the NTS and the NTS"A" versus vehicular targets in a tactical background. Various tanks, armored personnel carriers, and military utility vehicles were positioned, in turn, in a known target location. The two aircraft were flown in formation a sufficient distance from the target area such that the presence or movement of a vehicle was undetectable in even the highest power magnification. A target vehicle unknown to the system operators was then placed in view in the center of the target area. Beginning in NFOV, the two aircraft were flown side by side in tight formation while steadily decreasing slant range toward the unknown target. Detection, recognition, and identification distances from both aircraft and luminance at the target were recorded on each data run. Detection was defined as the presence of a potential target demanding attention. Recognition was defined as the point where the object was distinguished from similarly classed military objects, e.g., tank versus APC. Identification was defined as the point where the target's specific military designation was discernible, e.g., M-60 versus T-72. (Shumaker, Wood, and Thacker, n.d.). Data runs were conducted in conditions of bright sunlight, overcast skies, and at dusk.

Data Reduction

Data from quantitative ground and flight tests versus resolution targets were reduced and generalized into minimum resolvable contrast (MRC) curves. The data were unreferred to predict minimum detection ranges for various illumination conditions and spatial frequencies for a given prevailing visibility. Data from qualitative flight tests versus tactical targets were reduced via the Johnson criteria.

After computing the observed area of the vehicle target A_T in square meters given the vehicle dimensions[1], the spatial frequencies were calculated by determining the critical dimension (D_c) in meters of the target to be resolved, where

$$D_c = \sqrt{A_T} \text{ (meters)} \tag{3.2}$$

By applying the Johnson criteria to the critical dimension of the test targets, D_c, the spatial frequency (f) is given by

$$f = \frac{R}{X} \text{ (cycles/mrad)} \tag{3.3}$$

[1] Due to the relatively low altitude and extended range at the beginning of each data run, a small angle approximation was utilized to discount the observed target area due to observer elevation, i.e., A_T was simply based on a rectangular area.

where R = range to the target in kilometers and X = the dimension to be resolved in meters given by

$$X = \frac{D_c}{N_J} \text{ (meters)} \tag{3.4}$$

where N_J is the average number of line pairs (cycles) required to perform each discrimination task from Table 2. (Shumaker, Wood, and Thaker, n.d.)

Combining Equations 3.3 and 3.4 provides the relationship between spatial frequency and range to a target:

$$f = \frac{RN_J}{D_c} \text{ (cycles/mrad)} \tag{3.5}$$

The specific vehicles used in the evaluation are listed in Table 4 along with the associated spatial frequency per kilometer required to perform the various discrimination tasks.

Luminance at the target was measured during flight tests with a portable light meter calibrated in kilofootLamberts (kfL). To maintain consistency in the comparison of ground test data in units of illuminance (lux) to flight test data in units of luminance (kfL), a conversion was necessary to determine the approximate illuminance of the target. If the target area is assumed to be a Lambertian surface, then the luminous exitance M, or luminous flux output per unit surface area, in lumens per square meter (equivalent to lux) is

$$M = \pi L \text{ (lm/m}^2\text{)} \tag{3.6}$$

Table 4: Target Spatial Frequencies

Notes: Spatial frequency was normalized by kilometers (km) such that the spatial frequency resolved could be easily determined by the product of these figures and the slant range in km at which each target discrimination task was achieved.

Vehicle (Oriented Broadside)	Spatial Frequency per km (cycles/mrad)		
	Detection	Recognition	Identification
M-60 Rise Passive Tank	0.30	1.21	1.94
M-2 Bradley Armored Fighting Vehicle	0.34	1.37	2.19
M-551 Sheridan Tank	0.38	1.50	2.40
M-548 Tracked Ammunition Carrier	0.37	1.47	2.36
M-813 Five Ton Wrecker	0.35	1.38	2.21
High Mobility Multi-Wheeled Vehicle (HMMWV)	0.46	1.83	2.93
M-113 Armored Personnel Carrier	0.53	2.13	3.41

where L is the luminance in lumens per square meter and steradian (lm/m^2sr) or nit (nt). The Electro-Optics Handbook (RCA, 1974) gives a conversion factor of 3.426 ftL per nit, which when entered into Equation 3.5 gives

$$1 \text{ lux} = 10.76 \text{ ftL} \tag{3.7}$$

Prior to generalizing the static ground test or "laboratory" MRC data, a correction for the atmospheric attenuation of observed contrast was applied. The transmittance of the atmosphere over a path length R for very narrow wavelength bands may be expressed by

$$T_a = e^{(-\sigma R)} \tag{3.8}$$

where σ is the spectral attenuation coefficient or "extinction coefficient." (RCA, 1974)

Visibility refers to the horizontal distance R_V for which the contrast transmission (C_R / C_0) of the atmosphere in daylight is two percent, where C_0 is the inherent contrast of a target and C_R is the apparent contrast at range R. The effective value for σ in Equation 3.8 for the visible spectrum of wavelengths, σ_V, is dependent upon R_V

$$\sigma_V = 3.912/R_V \tag{3.9}$$

where the units of σ_V are determined by the units of R_V. (RCA, 1974)

It has been shown that the apparent contrast C_R reduces exponentially with range R in accordance with Equation 3.8, such that

$$C_R = C_0 e^{(-\sigma_V R)} \tag{3.10}$$

Equation 3.10 was used to account for the effects of the atmosphere on static MRC.

CHAPTER 4

RESULTS AND EVALUATION

General

The specific visual discrimination performance of the NTS"A" has been classified by the U. S. Government as CONFIDENTIAL. General, nondimensional comparisons between the two systems will be sufficient to describe the performance of the NTS"A". Classification of light levels is based on the criteria presented in the Electro-Optics Handbook. (RCA, 1974). Table 5 lists the sky conditions and approximate illuminance values associated with each.

Minimum Resolvable Contrast (MRC)

Minimum resolvable contrast (MRC) data gathered from static, ground based testing versus the Air Force 1951 target are presented in Figure A-6.

The NTS"A" CCD camera significantly outperformed the DVO in low illumination conditions as evidenced by the large disparity in resolved spatial frequency in deep twilight conditions. The performance gap narrowed with increasing illumination to the point where DVO outperformed the CCD camera in illuminations commensurate with overcast skies. Data gathered at higher light levels than those depicted in Figure A-6

Table 5: Natural Scene Illuminance

Source: (RCA, 1974)

Sky Condition	Approximate Level of Illuminance (lux or lm/m^2)
Direct Sunlight	$1\text{-}1.3 \times 10^5$
Full Daylight (Not direct sunlight)	$1\text{-}2 \times 10^4$
Overcast Day	10^3
Very Dark Day	10^2
Twilight	10
Deep Twilight	1
Full Moon	10^{-1}
Quarter Moon	10^{-2}
Moonless, clear night sky	10^{-3}
Moonless, overcast night sky	10^{-4}

indicated an additional increase in DVO performance, while the CCD camera performance remained essentially constant beyond overcast conditions, and, thus, was not plotted.

NTS"A" MFOV MRC data is presented in Figure A-7. The MFOV data is shown in comparison to the NTS DVO NFOV MRC data since the fields of view are similar. The NTS"A" MFOV was capable of resolving contrast levels in illumination conditions commensurate with quarter moon conditions or approximately 10^{-2} lux. The MFOV performance was superior to the DVO NFOV through deep twilight (1 lux), resolving an average of 82% higher spatial frequencies than the DVO NFOV in deep twilight. The performance crossover point was reached near twilight (10 lux), where the MFOV MRC remained constant while DVO NFOV continually improved. This performance was not unexpected due to the measured responsivity of the MFOV as presented in Figure A-4.

WFOV MRC data are presented in Figure A-8 in full daylight conditions (approximately 10,000 lux). In this case, the NTS DVO outperformed the NTS"A" WFOV as evidenced by the ability of the DVO to resolve approximately 63% higher spatial frequencies in high daylight conditions. This effect was probable due to the high optical losses from the WFOV optics that are positioned in the NTS"A" optical path when selecting the WFOV (Figure A-3).

Effect of Vibrations on MRC

The effect of aircraft vibrations on system MRC was evaluated during flights versus the tri-bar target depicted in Figure 11. Data are presented in Figures A-9 and A-10. The effect of vibrations appeared to generalize well, inducing an approximately 37% reduction in resolved spatial frequency in both the narrow and medium fields of view. Varying airspeed did not result in a wide distribution of observed spatial frequency. These data provided the first indications of the unreliability of static, ground test data to accurately predict system performance in dynamic conditions. The observed degradation was most likely due to the cumulative effects of the atmosphere and operator proficiency, in addition to the kinesthetic effects of aircraft vibrations.

Visual Discrimination Range Performance Prediction

Data from static MRC tests were reduced and generalized into range prediction curves for the various visual discrimination tasks. Equations 3.2 through 3.5 show the relationship between resolved spatial frequency and range to the target. Therefore, the MRC curves of a sensor can be converted to the "range" domain by selecting a task to be performed, which determines N_J; selecting a target, which determines D_c; and then solving Equation 3.5 for R. The resulting curves retain the same shape, yet their abscissa is now in the range domain.

Since these data were gathered in a laboratory environment, a correction for the effect of atmospheric attenuation on observed contrast (C_O) was applied. Given an observed target contrast, C_O, Equations 3.8 through 3.10 were used to plot the degradation of C_O as a function of range along with MRC. A prevailing visibility of 30 km, or very clear day conditions (RCA, 1974), was selected for R_V in Equation 3.9. Detection, recognition, and identification curves detailing this process are presented in Figures A-11 through A-13, respectively. In Figures A-11 through A-13, the target selected was a generic tank, viewed from a beam aspect or 90° orientation, with a C_O of 0.3. A small angle approximation was used for the observed target area, A_T, to discount the observed target area due to the observer's elevation above the target. The dimensions of this generic tank, 6.9 m width by 3.3 m height, provided a critical dimension, D_c of 4.77 m, per Equation 3.4. The value chosen for C_O was determined to be representative for a military vehicle with a tactical paint scheme. (Massimi, 1997).

Range prediction as a function of ambient light level was accomplished by determining the intersection of each MRC curve (or its extrapolation) with the atmospheric attenuation curve. Generalized range prediction curves for detection, recognition, and identification of a tank, with a prevailing visibility of 30 km, are presented in Figures A-15 through A-17. Data are presented for the NTS"A" TVC MFOV and NFOV and the NTS DVO NFOV. Figure A-15 shows a nearly constant superiority of the NTS"A" over the NTS across all light levels, with an average increase in detection distance of 62%. Figure A-16 shows a steadily decreasing performance gap of the NTS"A" over the NTS for recognition with increasing light level, with the largest disparity, 67%, observed in deep twilight conditions. Figure A-17 also shows a steadily decreasing performance gap, also with the largest disparity, 72% in this case, observed in deep twilight conditions.

The NTS"A" TVC MFOV data in Figures A-15 through A-17 show the ability of that sensor to conduct DRI down to quarter moon conditions. Superior performance in detection versus the NTS DVO NFOV is maintained until approximately overcast conditions, while superiority over the NTS"A" TVC NFOV is only observed up to deep twilight conditions. Beyond deep twilight (1 lux), both the NTS"A" NFOV and the NTS DVO NFOV are shown to outperform the NTS"A" MFOV.

The final correction to the laboratory model accounted for the effect of airframe induced vibrations. Since the data appeared to show a somewhat consistent effect due to vibrations (Figures A-9,10), a 37% reduction was applied to the predicted DRI ranges prior to comparison to DRI flight test data.

Target Detection, Recognition and Identification

Qualitative flight testing was conducted by performing inflight, side by side DRI runs versus the vehicles listed in Table 4. In general, the NTS"A" was able to detect a tank sized target in moderate background clutter (low contrast) at 25% greater ranges than the DVO of the basic NTS in their respective narrow fields of view during high illumination conditions. Recognition and identification distances were improved by 8% and 16%, respectively, versus the same targets.

The marked improvement of the NTS"A" was more evident in low illumination conditions. The NTS"A" was able to detect a tank sized target in moderate background clutter (low contrast) at an average of over 200% greater ranges than the DVO of the basic NTS during low illumination conditions. Average recognition and identification distances were improved by 55% and 60%, respectively, versus the same targets. The NTS"A" operator was forced to revert to the MFOV for low illumination DRI runs due to the degraded performance of the NFOV with the sun 6° below the horizon (civil twilight). The NTS"A" was capable of performing target DRI at tactically feasible distances versus vehicular targets in civil twilight with a measured luminance of 3 ftL (approximately 30 lux or twilight). In the same conditions, the NTS DVO were totally unusable.

The filtering of near IR wavelengths in the NTS NFOV optics due to the integration of the TOW missile near IR tracker did not affect the operator of the DVO because the eye is not sensitive to that region of the EM spectrum. Conversely, the NTS"A" NFOV was adversely affected as witnessed by the observed reduction in display brightness when compared to the MFOV, especially in low illumination conditions. The MFOV optical path contained the fewest optics en route to a CCD and thus provided the sharpest display in all daytime light levels.

The general trends of the vibration corrected DRI predictions generated from static MRC data coincided well with the flight test data in illumination conditions down to overcast. The NTS"A" maintained superior DRI performance throughout all visual discrimination tasks, with an ever decreasing performance gap with increasing illumination. In low illumination conditions, the model accurately predicted the vast superiority of the NTS"A" TVC over the NTS DVO in very low ambient light levels. None of these results were unexpected, based on the system design and the data gathered from static testing. In comparing the actual DRI ranges with the predictions, the model tended to significantly overestimate the visual discrimination capabilities of both sensors, suggesting that additional factors beyond simply vibrations were contributing.

NTS"A" Human Factors

Throughout the long history of scientific experimentation, some of the world's most notable technological breakthroughs were unexpectedly discovered during the course of unrelated testing. Although a major discovery was not uncovered, some significant human factors issues arose during this phase of testing. The most notable findings were not directly attributable to the quantitative data, but the qualitative data. Each data flight was approximately two hours in duration. Each round trip data run required at least 15 minutes to reach the starting point, orient the flight, track inbound to the target area for DRI, and reposition to the starting point while a new target vehicle was moved into place for the next data run. Each system operator utilized the wider field(s) of view for general target area acquisition, and eventually switched to their particular system's NFOV for target detection.

In high light level conditions, the higher magnification of the NTS"A" improved target detection ranges as previously mentioned, but target area acquisition time was reduced dramatically. Since this research was more experimental than descriptive, more control was placed on the visual discrimination range variable.

The NTS"A" operator, limited to a monochromatic, five square inch display had a difficult time quickly acquiring the target area at the beginning of each data run, even though it was clearly visible with the unaided eye through the aircraft canopy. The NTS operator utilizing DVO had virtually no problem transitioning his DVO sensor to the target area once sighted with the naked eye. Postflight debriefs revealed that although detailed, target area colors were not discernible in the DVO, color reference to large objects in the target area provided excellent cues to orient the sensor in the desired location. The NTS"A" operator was forced to utilize large, high contrast objects (e.g., light brown fields next to evergreen trees) to orient the sensor. Furthermore, the two dimensional image presented on the display provided poor depth cues resulting in frequently misjudged ranges and subsequent false alarms. The 0.9° field of view of the NTS"A" NFOV, as compared to the 4.6° field of view of the NTS DVO NFOV (Table 1, Figure 6), was often disorienting to the operator when switching from the 3.5° MFOV. Pilots claimed a low level of confidence during detection with the NTS"A" due to an increased level of uncertainty about the area being viewed. Often times, the NTS"A" operator delayed his "detection" call until more visual information was available at a decreased slant range to avoid tracking a false target and wasting a data run.

Pilot to system interface caused additional difficulties for the NTS"A" operator. A deficiency in design caused the focus mechanism to stick at the extreme near and far focus positions requiring the operator to select autofocus to regain control of the focus mechanism. Furthermore, no provisions were provided within the NTS"A" symbology presented on the MFD to provide feedback to the pilot regarding manual focus status, focus rate, or deviation from autofocus. Similarly, no symbology provisions were provided to provide feedback regarding light level control adjustment rate or the amount of deviation from the automatic, baseline light level setting. The automatic light level control algorithm in the TVC electronics adjusted scene contrast according to the amount of light present in the entire field of view. This design had an adverse impact on the WFOV due to its wide solid viewing angle, which, in most cases, placed bright light sources, such as a blue sky horizon or a low angle sun, in the WFOV. Thus, the scene presented on the MFD was usually too dark to be of any use, requiring either a switch to the MFOV or manual light level adjustment in the WFOV. During each data run, focusing and adjusting the image was a difficult and frustrating task, at best.

The combined effects of organizational stress factors such as aircraft availability, dwindling financial resources, and limited windows of opportunity provided an unexpected input to the experiment. Achieving high ambient illumination conditions (i.e., clear skies) at the test location required weeks of waiting due to the seasonal effects of weather. The flight testing of any system is subject to the maintenance requirements of the aircraft on which it is installed. Although these factors could be considered nuisance variables within the scope of this test, they provided an additional influence, albeit from completely benign sources and of clearly lesser intensity, that raised the operator stress closer to the level that may be encountered during an actual CAS mission. The end result was a higher stress level on the NTS"A" operator to quickly train the sensor on an area clearly seen by the unaided eye, but difficult to acquire on a system that could not provide similar visual stimuli. Once the NTS DVO and NTS"A" TVC were sighted in on the target area, the high magnification (in high illumination conditions) and near IR responsivity (in low illumination conditions) of the NTS"A" contributed to consistent, superior performance over the DVO of the basic NTS.

Laser Spot Tracking

The ability of the NTS"A" to detect the laser energy reflected from a tactical target was tested while laser designating vehicular targets at various ranges in high (bright sunlight) and low (dusk) illumination conditions. In bright sunlight, the downrange laser spot was not visible in any of the NTS"A" fields of view. In low illumination conditions at dusk, the laser spot was clearly visible only in MFOV, but at limited ranges tactically unrepresentative for target engagement. The inability to view the laser spot in high illumination conditions was probably due to the effect of CCD saturation. In the bright sunlit conditions present in midday, the dominant wavelengths are in the visible spectrum. The energy reflected from the laser designator, operating at 1064 nm, was probably of much lesser magnitude than the high energy, 380 to 780 nm visible light reflected from the target. Since the peak responsivity for the NTS"A" CCD's is 530 nm (Figure A-4) and the lowest CCD responsivity is in the near IR region, the inability of the

NTS"A" to image the reflected laser energy is not surprising. In low illumination conditions, however, the energy differential was probably much less, thus enabling the CCD to sense and display the near IR energy reflecting off the target. The reduced ranges required for the NTS"A" to produce an image of the reflected laser energy may be attributable to atmospheric attenuation due to haze or humidity as well as the collective optical and electronic losses (overall modulation transfer function) as those near IR wavelengths are sensed, processed, and displayed.

Data Analysis

The quantitative data gathered generally supported the expectations of system performance based on an analysis of system design. The increased responsivity of the CCD to the near IR spectrum substantially improved the DRI performance of the NTS"A" in low illumination conditions. The superior performance of the NTS"A" during DRI testing in high illumination conditions was not supported by the static ground test data, which would lead one to expect the DVO to outperform the CCD camera. This was probably due to the laboratory environment presented in the collimator, which provided a level playing field. In actual flight tests, the atmospheric effects of scattering, absorption, and refraction were more detrimental to the DVO than to the CCD camera, resulting in higher contrast sensitivities for the NTS"A" CCD.

Object color has some effect upon resolution. Color adds an order of magnitude to a visual scene. It is easier to see objects of known color, but more difficult if "normal" color is not used. A display using color will allow earlier resolution of the complex visual discrimination tasks of recognition and identification, and, while limiting resolution for detection is about the same without color, a higher confidence level is attained. (Clapp, 1985).

Human evaluation of colors is subjective and dependent not only upon the source of illumination, but also of the colors and brightness of the visual field surrounding the colored object being viewed; the complexity of the scene; what the eye was previously observing; what is thought of the object; the expected color and condition of the object; etc. (Clapp, 1985).

An observer's experience and expectance are major factors in the visual perception of what is viewed. Operational pilots are especially prone to these effects do to the depth and length of pre-mission briefings. The experience with the object type in the past and current conditions of operation can produce a "theory" of how the object will move, act, react, etc., while the actual real world object may in fact bear no resemblance to this model causing considerable confusion to the observer. Task pressure is also a major input to perceptual operation. How an observer operates in a real world scenario is strongly dependent upon the pressures the observer is under. (Clapp, 1985) A graphical depiction of the effects of expectance in presented in Figure 12.

One cannot discuss human information processing without reference to the concept of compatibility. Compatibility refers to the relationship of stimuli and responses to human expectations, and, as such, is a central concept in human factors. The

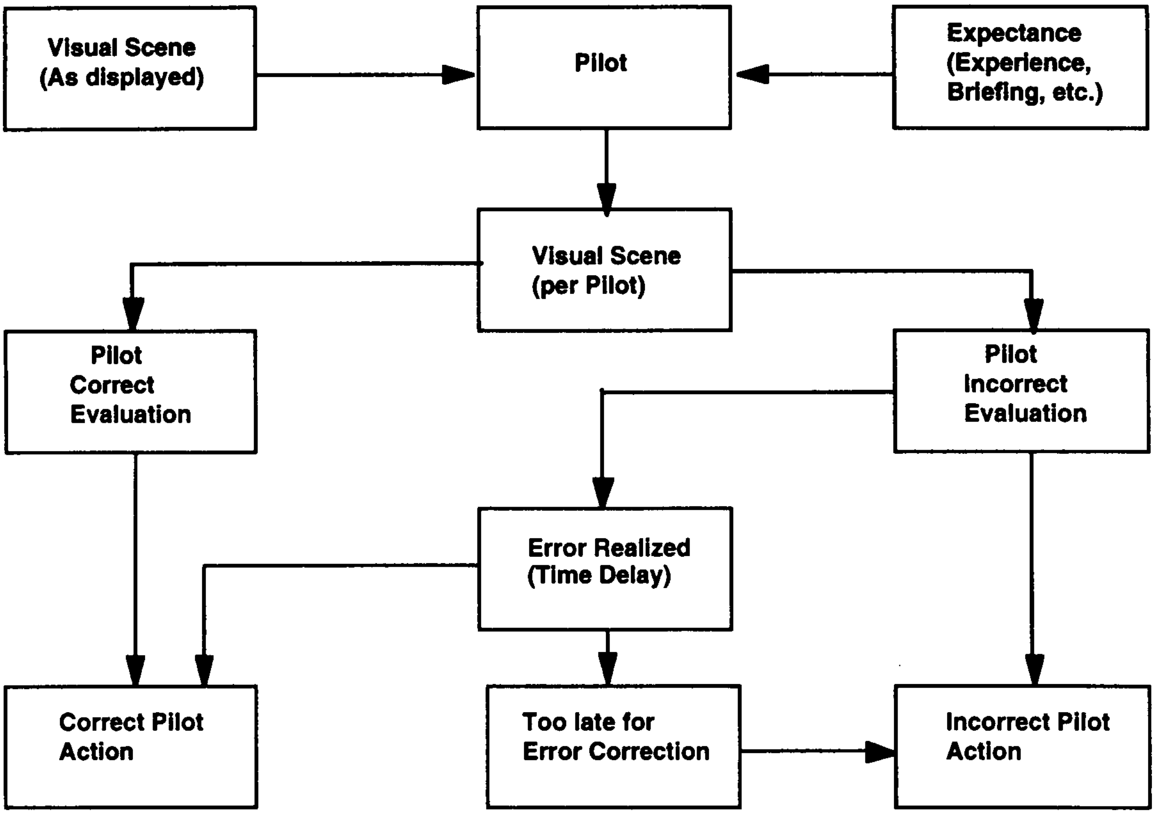

Figure 12: Expectance Flow Chart

Source: (Clapp, 1985)

concept of compatibility implies a process of information transformation, or recoding. It has been postulated that the greater the degree of compatibility, the less recoding must be done to process the information, resulting in faster response times, fewer errors, and a reduced mental workload. (Sanders and McCormick, 1993).

Clearly, these are the major factors that affect the mission suitability of the NTS"A" for air to ground targeting. Pilots prefer the DVO of the basic NTS over the NTS CCD camera in daylight conditions because it provides the clearest, brightest picture for locating and identifying targets. Once targets are identified, pilots employing the NTS switch to the CCD camera for improved tracking and weapons delivery accuracy with more than twice the magnification (Table 1). The NTS"A" provides a distorted view of the real world scene to the pilot. The mental image in the pilot's mind consisting of textures, colors, brightness, and depth is reduced to a five square inch display of green and black shades. The image becomes more disorienting as the field of view becomes narrower and additional contextual information is lost. For example, if an observer can positively identify a road in a target area, the detection threshold for locations on the road can be lowered somewhat to allow the detection of lower contrast vehicles on the road. (Forman, et.al., 1984). Flight tests of the NTS"A" showed that it was often difficult to quickly train the camera on a road clearly seen by the naked eye without a repetitive scan inside and outside the cockpit.

Another human factors issue involves the concept of aircrew coordination. The basic element of an attack helicopter formation is the section, a "flight" of two aircraft.

(DON, 1997). During a CAS mission, a high degree of crew coordination is required within the cockpit and within the flight. The "designated" flight leader is assigned prior to the brief and is responsible for the completion and safe conduct of the mission. During a combat mission, the role of flight leader may shift to any of the four pilots in the two aircraft who has the highest situational awareness. The individual's "tactical" flight lead is usually momentary until the situational awareness of the entire flight is more equal. In the dynamic environment of close combat, the flow of verbal information among the pilots is critical. The pilot who first sights a target must quickly relay that information to his wingman so the flight can be mutually supportive during the attack. Often times the quickest way to describe a target location is by reference to major landmarks or terrain features, differentiating them by color, e.g., "the dark brown hill," "the green farmer's field," or "the red barn." These descriptions were meaningless to the NTS"A" operator. Operations in urbanized terrain raises these problems to an even higher level, since the color of a building or other structure may be the only significant visual cue available to positively identify a target from its surroundings.

CHAPTER 5

CONCLUSIONS

The general conclusion derived from the results of these tests is that the NTS"A" has limited potential for the CAS mission in its present configuration. Removal of the DVO resulted in an unacceptable loss of visual cues for target area acquisition. Although the NTS"A" provides higher magnification and a broader range of sensitivity to the EM spectrum, the DRI process cannot begin without first conducting a target area search. These tests showed that the poor visual compatibility of the NTS"A" caused the pilot to spend an excessive amount of time searching for a target area in a known location, which would cause the aircraft to remain exposed to the enemy for a dangerous length of time. The DVO of the basic NTS provided the pilot with the capability to more rapidly acquire the target area which, despite its reduced magnification, intrusiveness to the cockpit, and vulnerability to the laser, increased the mission suitability of that system above the NTS"A".

The following specific conclusions were also determined within the scope of these tests:

- The NTS"A" design eliminated a measure of redundancy provided in the basic NTS design. In the event of an MFD failure in the basic NTS, the operator still has the ability to perform the mission with the imagery provided in the

ORT consisting of the DVO, the CCD TVC or the FLIR. A hard failure of the MFD in the NTS"A" would render the aircraft blind with respect to its air to ground targeting sensors.

- The inefficient light level control of the NTS"A" WFOV provided insufficient overall contrast across the scene presented on the MFD for target area search and acquisition.
- The inefficient focus mechanism of the NTS"A" caused increased operator stress and time spent exposed to the target.

These tests also revealed the fact that developmental tests performed with an operational mindset will often uncover those deficiencies most likely to hinder a system's overall mission suitability. With regard to system performance measurement, the operator must be taken into account. Static resolution testing provides an excellent metric to compare the performance of different systems. When evaluating a system for its ability to aid the operator in the performance of a specific task or group of tasks, i.e., a mission, the entire system must be evaluated, and that includes the final and most critical component of the system: its human operator.

CHAPTER 6

Recommendations

A cursory look at the specification for the NTS"A" containing numbers such as those shown in Table 1 would lead one to believe that the NTS"A" is a quantum leap from the NTS during air to ground target DRI tasks. While CCD technology has obvious benefits in this application, there are major human factors issues to be addressed in order to optimize the performance of this system.

Target acquisition time, although not specifically tested, is a significant parameter to a pilot intent on locating and destroying an enemy armed with even a rudimentary surface-to-air capability. Extended time spent unmasked by terrain searching for a target increases the very vulnerability that this technology upgrade intended to reduce. This is clearly where design tradeoffs must be considered.

The primary recommendation to correct the degraded mission suitability of the NTS"A" involves the integration of color. Each picture element (pixel) of a monochrome CCD carries a piece of light information reflected from the target. Color CCD's must spread the information carried by a single monochrome CCD pixel among several pixels (e.g., red, green, blue) to generate the display of color to the operator. (Janesick and Lomheim, 1996) The end result for a given CCD size is an overall reduction in resolution with color CCD's, which may serve to reduce target recognition and identification distances in addition to target area acquisition time. An optimum arrangement may involve a hybrid device consisting of a color CCD camera head arrangement for wide field of view target area acquisition and searching, and a higher resolution, monochrome CCD camera head for target area DRI. In the case of the NTS"A," the high resolution of the monochromatic CCD cameras provided increased DRI distances for the CAS mission, but the absence of color was a major design deficiency which significantly reduced that capability because of the human factors impacts. In short, to successfully complete a CAS mission, the pilot must complete the DRI process quickly. Since the process cannot begin without a search, an air to ground targeting system must be designed to have strong visual compatibility. In this application, that means color.

Increasing the amount of information available to the pilot during the DRI process will improve operator efficiency in performing these tasks. Operation of a targeting system must not increase the aircrew workload during CAS because it is already too high. (Erickson, 1986). Potential solutions to the NTS"A" deficiencies listed in Chapter 5 include but are not limited to:

- Increasing operator situational awareness through integration of the targeting sensor with on board navigational equipment which can drive the sensor in azimuth and elevation to a user selected ground coordinate.
- Improvement of the light level control mechanism in the WFOV by decreasing the automatic light level control to a narrower, more concentric field of regard.

- Improvement of the focus mechanism by increasing the focus ramp time and providing visual feedback to the operator of the focus position relative to automatic focus.
- More advanced solutions include the integration of artificial intelligence within sensor processing electronics (Forman, et. al., 1984) and multi-spectral image correlation of sensor output with stored target area imagery supplied by operational intelligence sources. (Ditzler, et. al., 1994).

Regardless of the arrangement, the design of an air to ground targeting system must consider the complete pilot to system interface. The success of every CAS mission is dependent upon the performance of the human beings behind the systems involved in air to ground targeting.

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APPENDICES

APPENDIX A

FIGURES

Figure A-1: AH-1W SuperCobra

Source: (Gross, 1995)

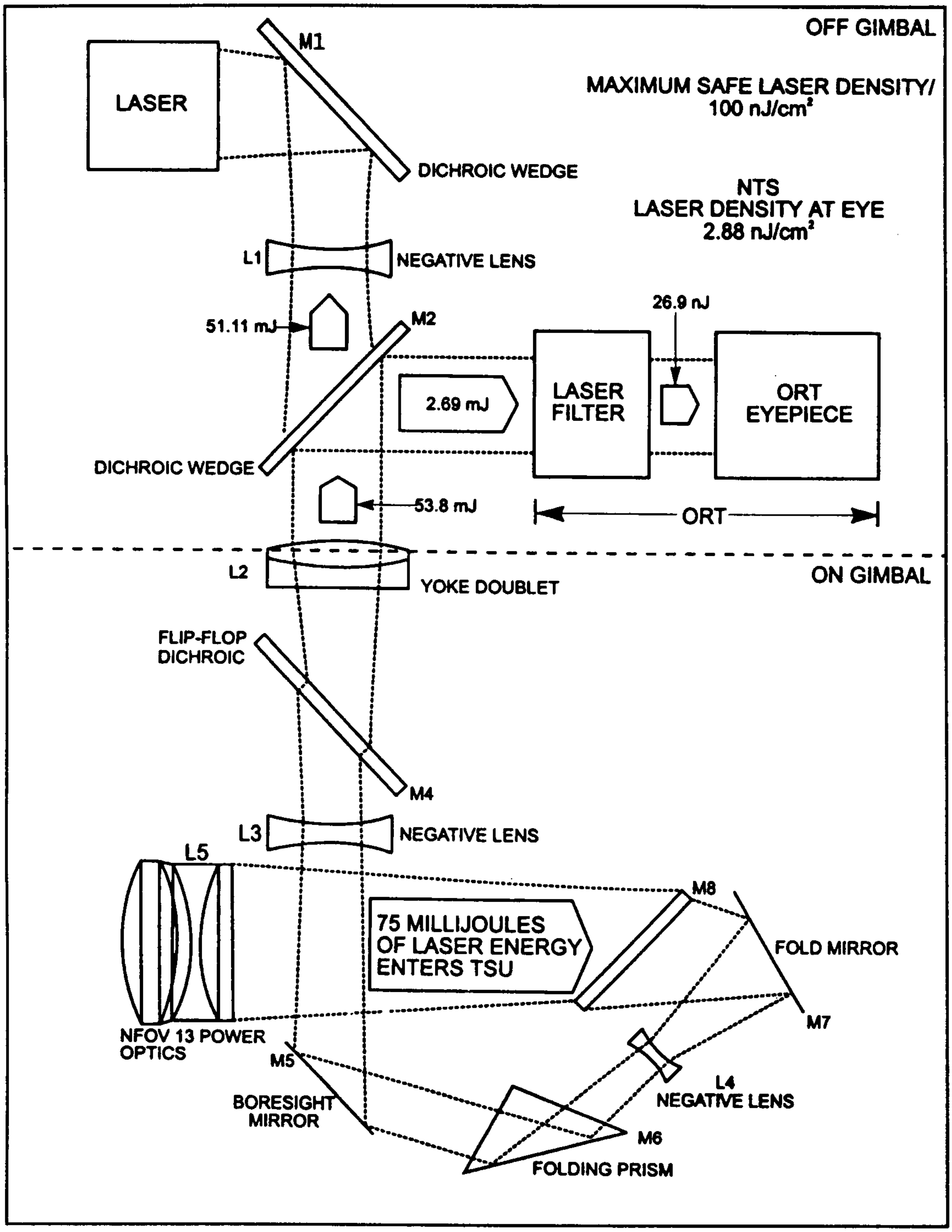


Figure A-2: Detailed Optical Path of the NTS

Source: (DON, 1997)

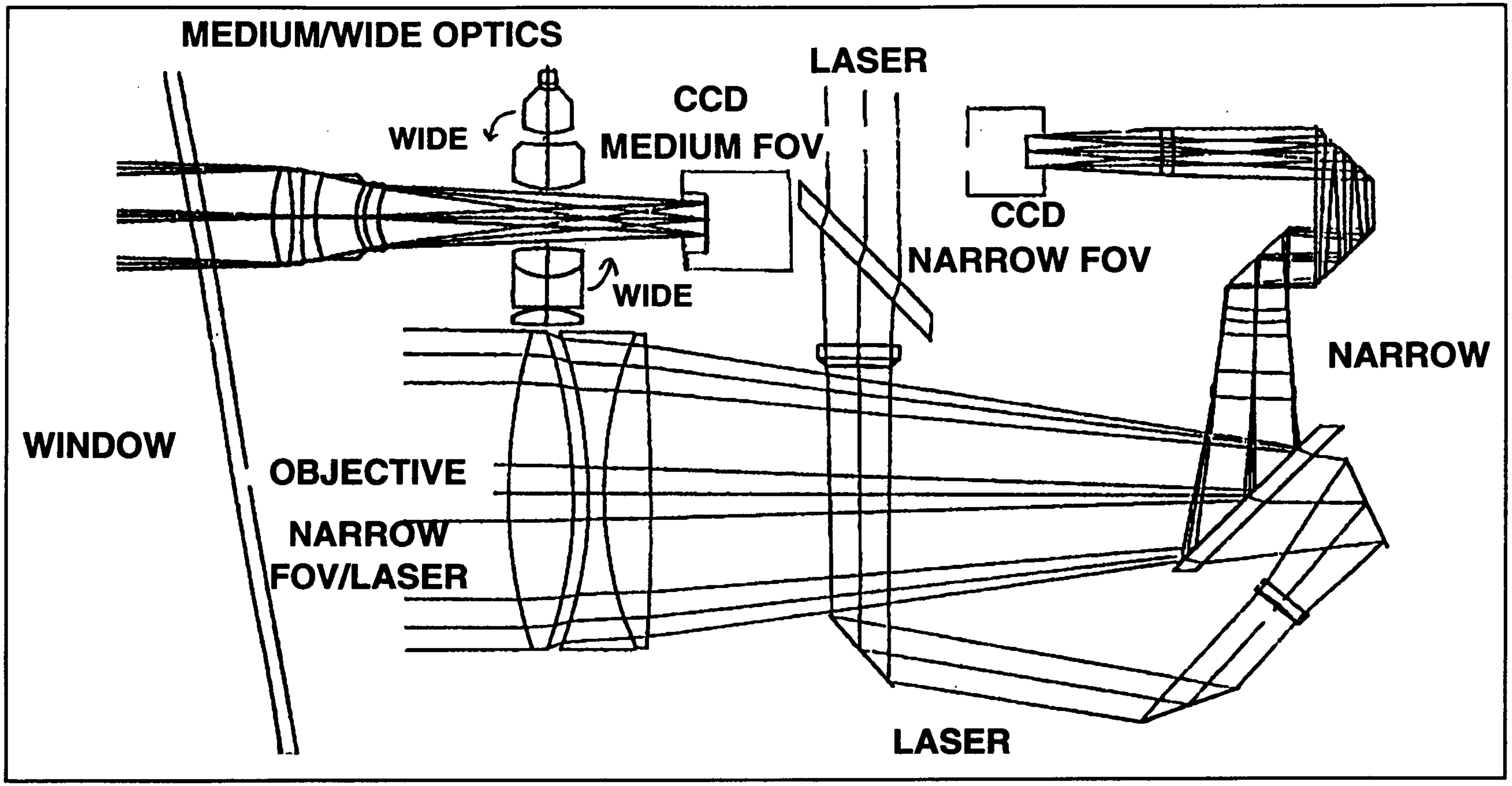


Figure A-3: Detailed Optical Path of the NTS"A"

Source: (IAI, 1993)

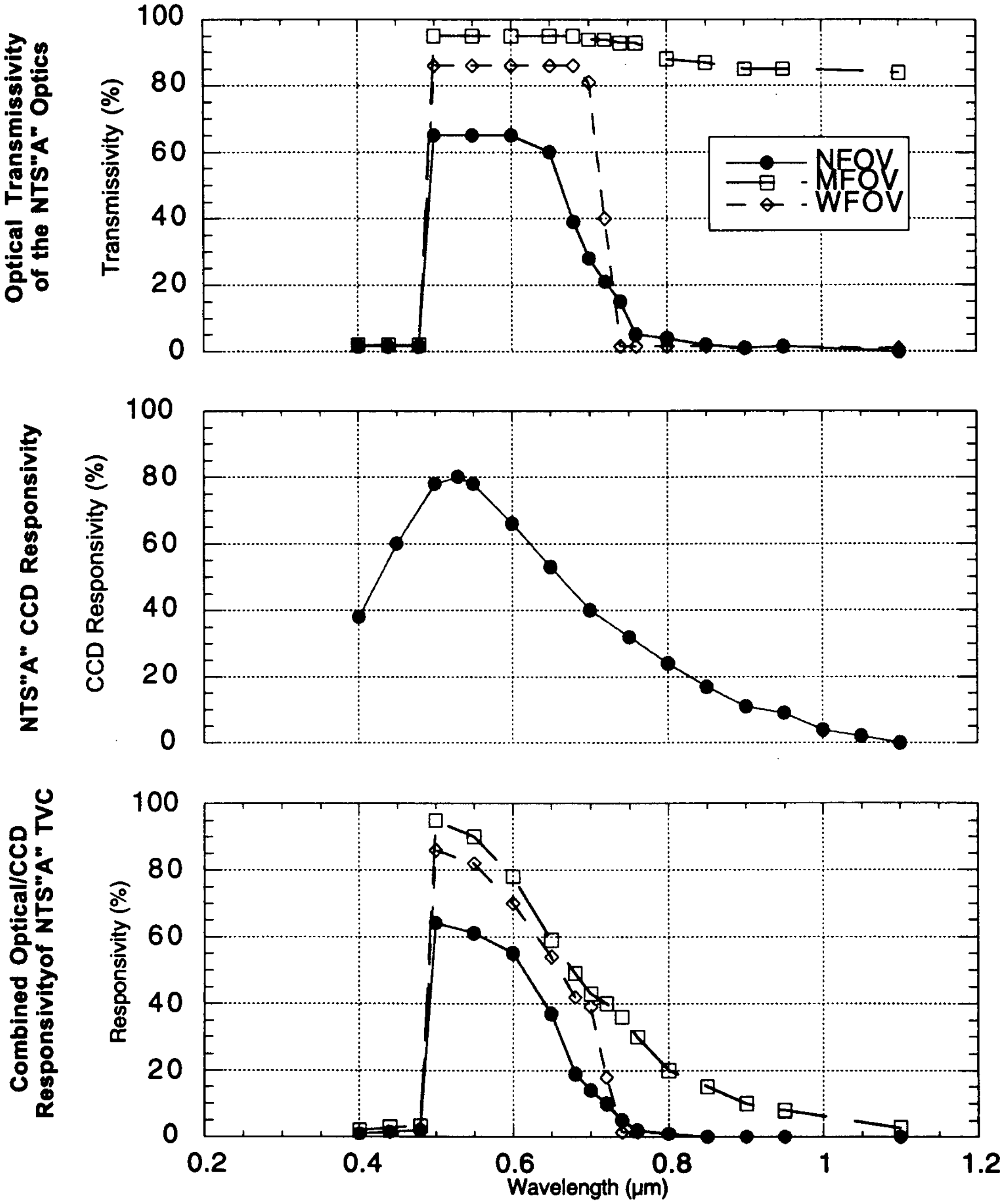
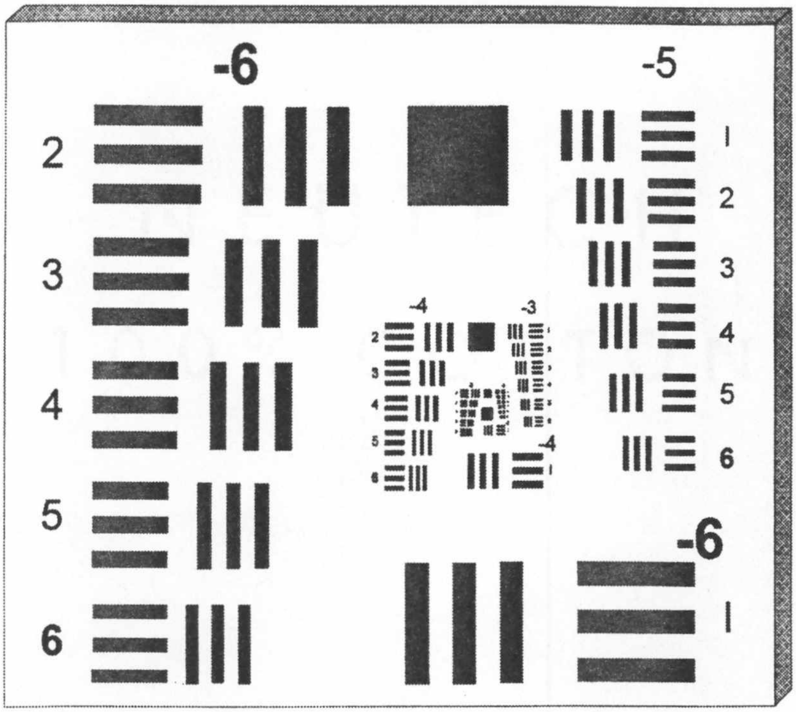


Figure A-4: Optical Transmissivity of the NTS"A" Optics

Source: (IAI, 1993)

USAF 1951 MEDIUM POWER RESOLVING TARGET



xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

USAF 1951 RESOLUTION CHART READING DEFINITIONS

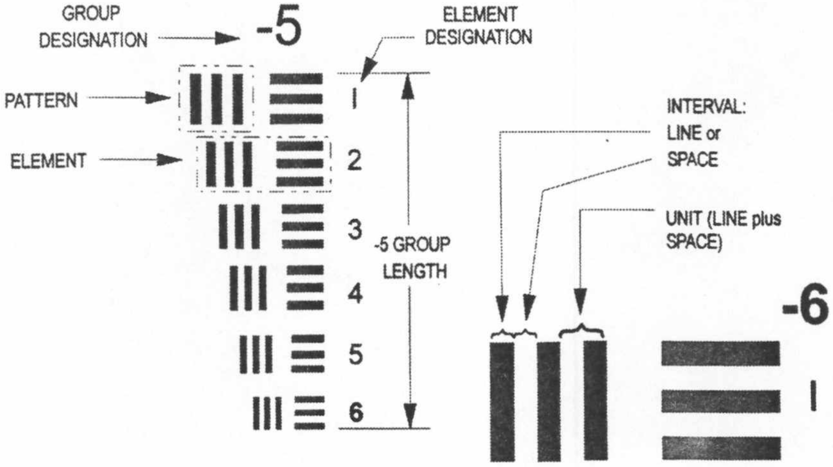


Figure A-5: USAF 1951 Medium Power Resolving Target

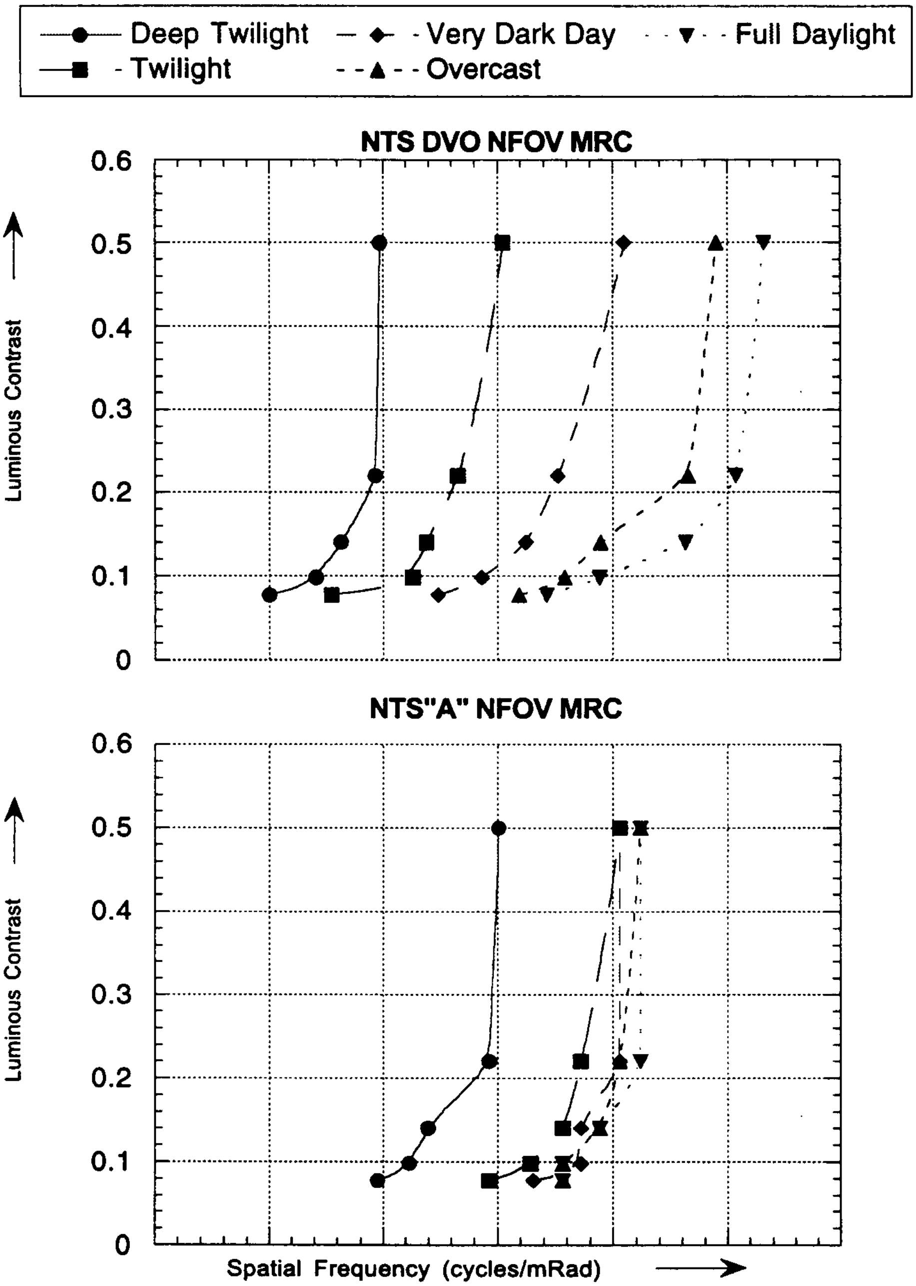


Figure A-6: Narrow Field of View Minimum Resolvable Contrast, Static Conditions

Notes: Spatial Frequency axis of both plots is same scale. Deep Twilight = 1 lux; Twilight = 10 lux; Very Dark Day = 100 lux; Overcast Day = 1000 lux; Full Daylight (Not Direct Sunlight) = 10,000 lux (RCA, 1974)

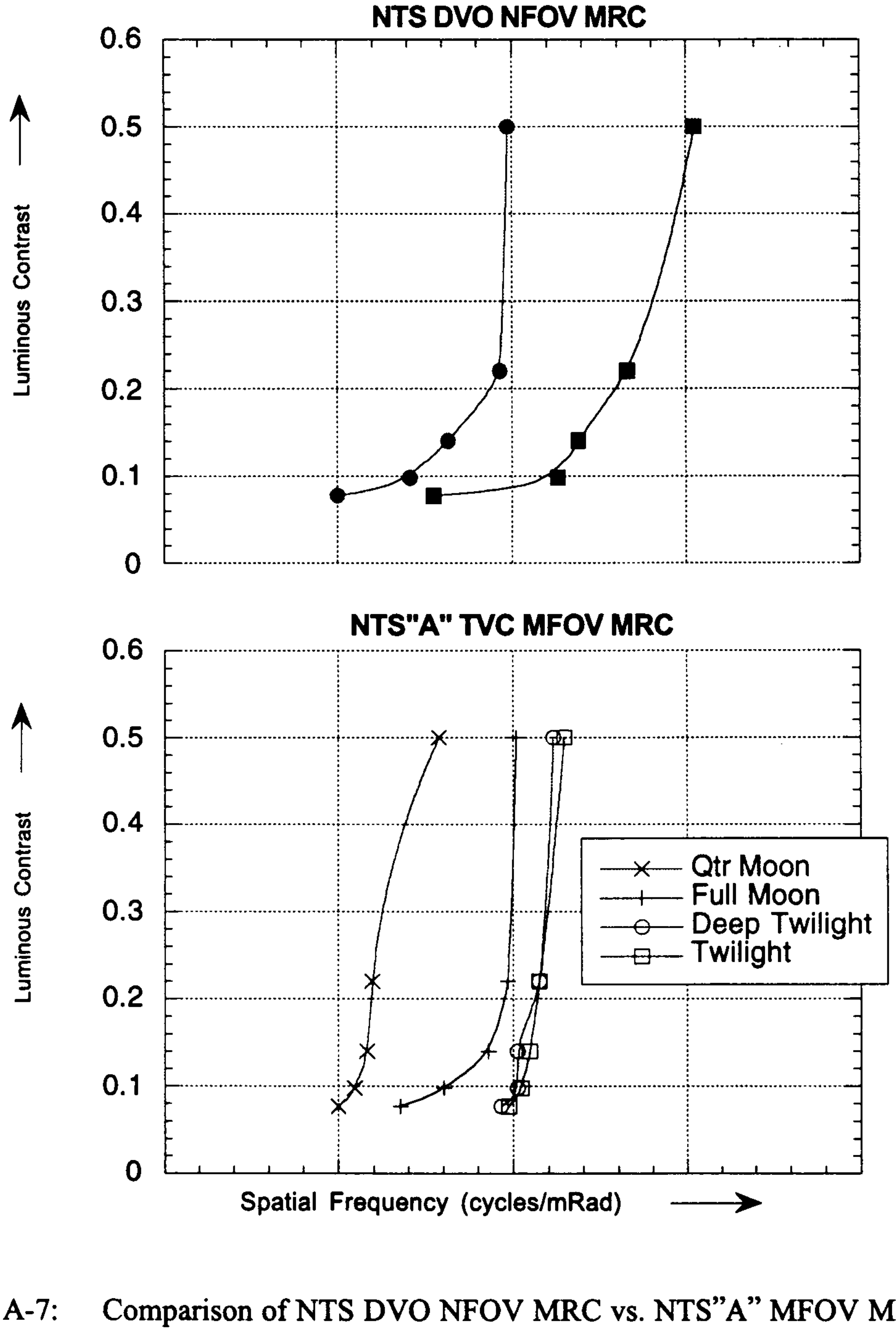


Figure A-7: Comparison of NTS DVO NFOV MRC vs. NTS"A" MFOV MRC, Static Conditions

Notes: Spatial Frequency axis of both plots is same scale. Qtr Moon: 10^{-2} lux; Full Moon: 0.1 lux; Deep Twilight: 1 lux; Twilight: 10 lux (RCA, 1974)

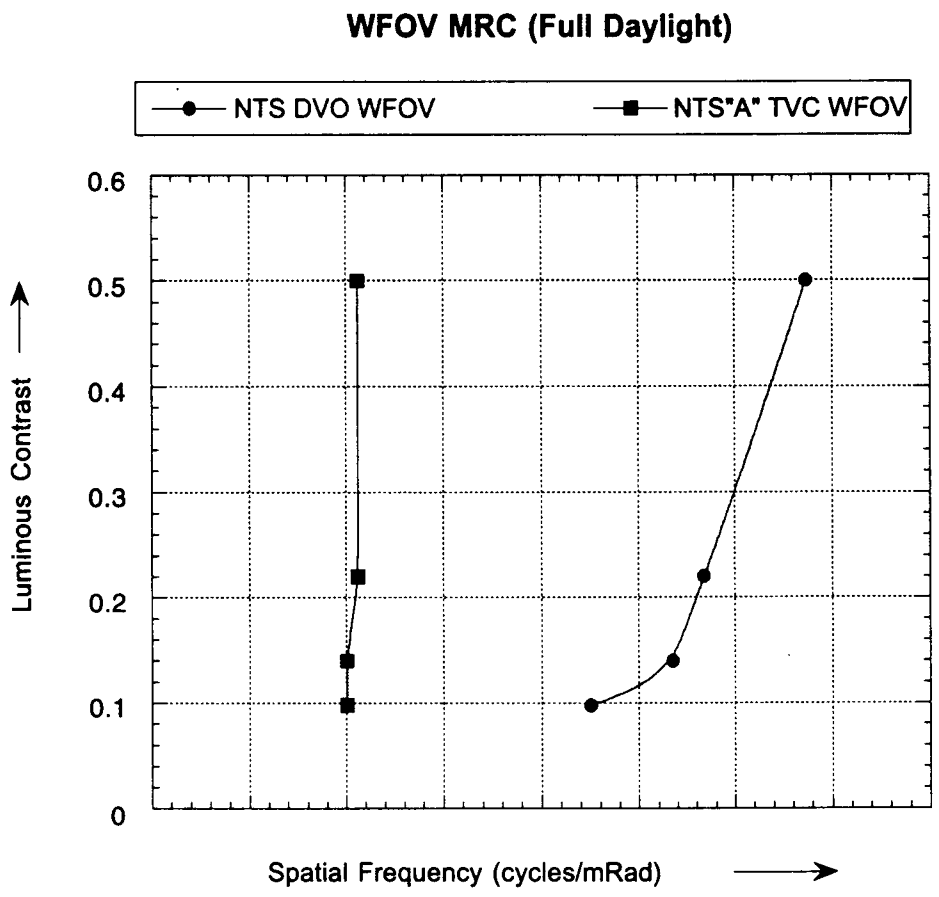


Figure A-8: Wide Field of View Minimum Resolvable Contrast, Static Conditions

Notes: Full daylight conditions are approximately 10,000 lux.

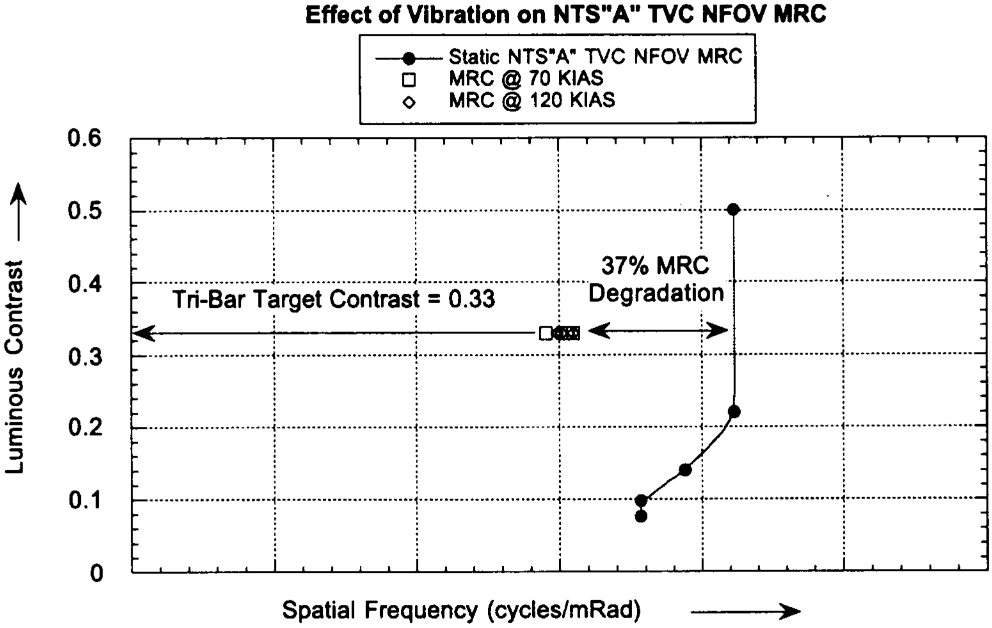


Figure A-9: Effect of Vibrations on NTS"A" TVC NFOV MRC (Full Daylight Conditions)

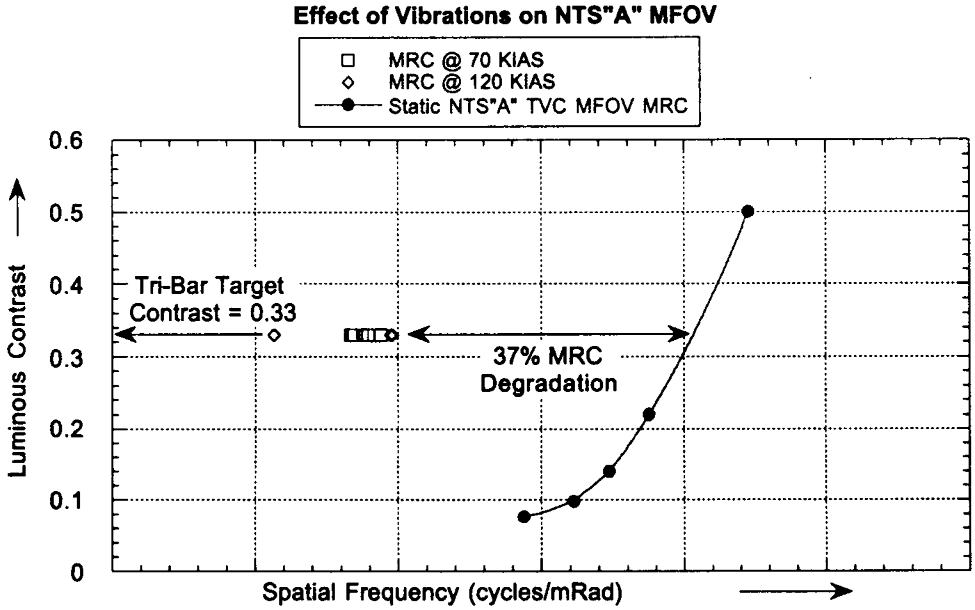
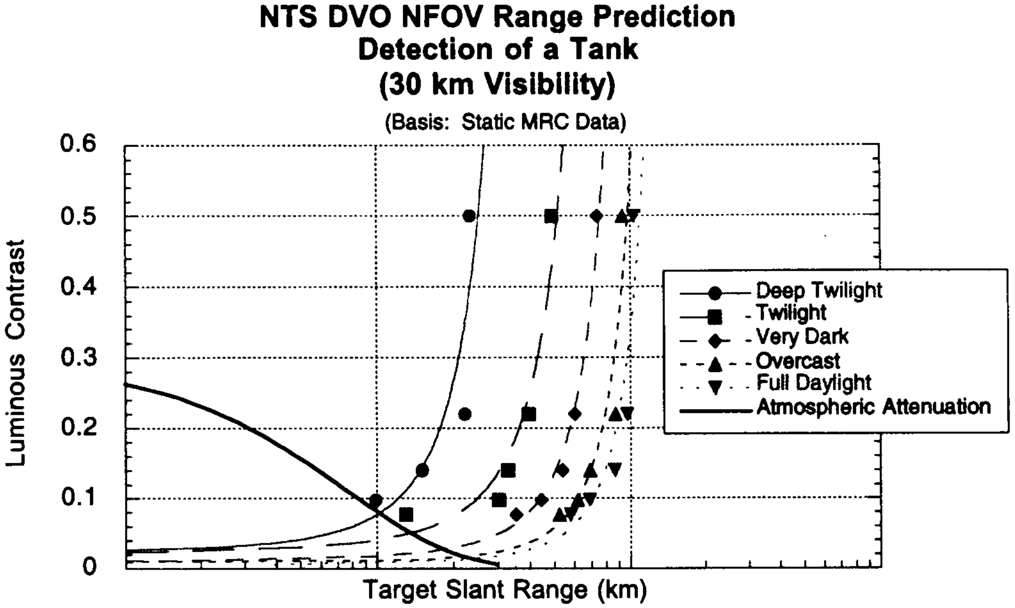


Figure A-10: Effect of Vibrations on NTS"A" MFOV MRC (Overcast Conditions)



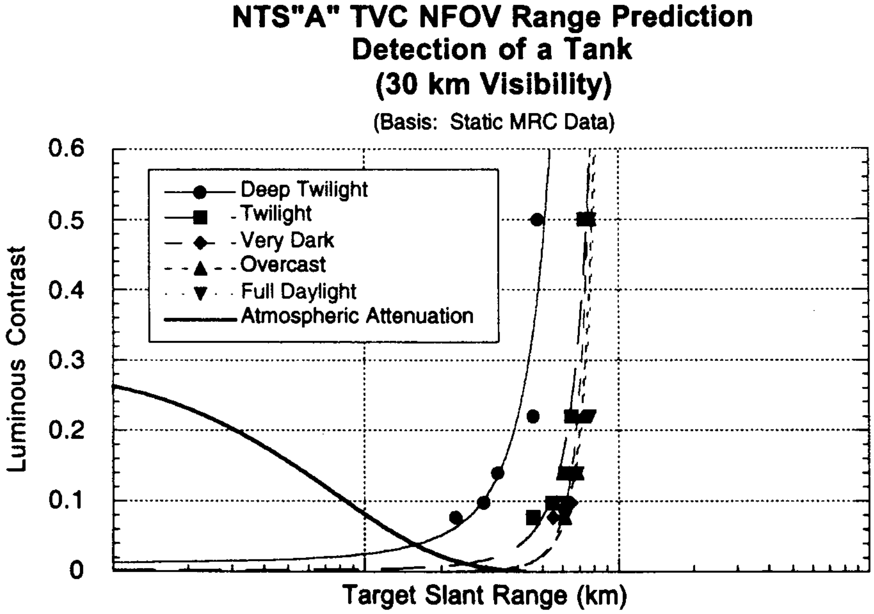
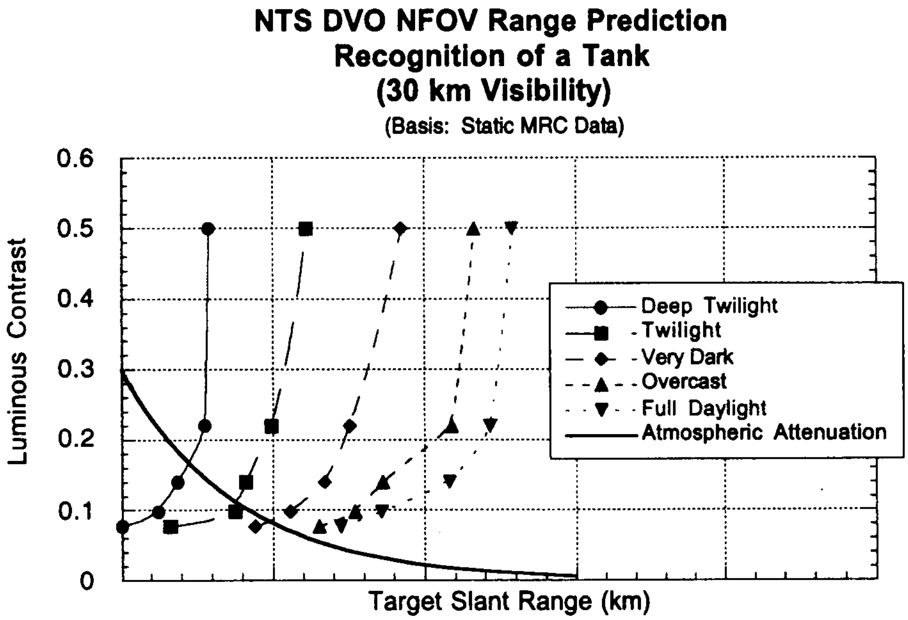


Figure A-11: Range Prediction for 50% Probability of Detection

Notes: Range axis of both plots is same scale. Contrast degradation due to atmospheric attenuation plotted as $C_R = C_o e^{(-\sigma R)}$, where $\sigma = 3.912/R_v$. (C_R= apparent contrast at range R; C_o = apparent contrast at the target (assumed as 0.3 for generic vehicle); Rv = prevailing visibility in km; and σ = the extinction coefficient for the visible spectrum.) (RCA, 1974).



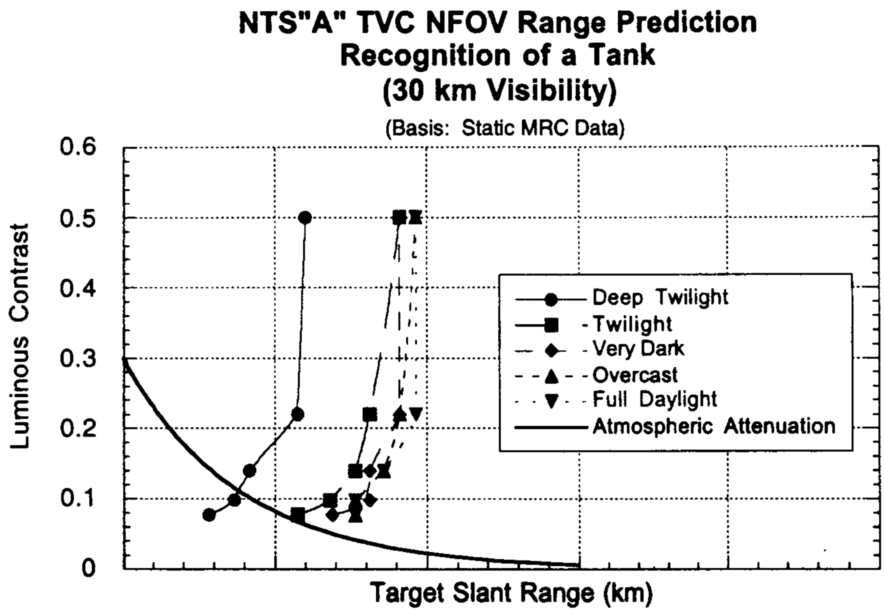
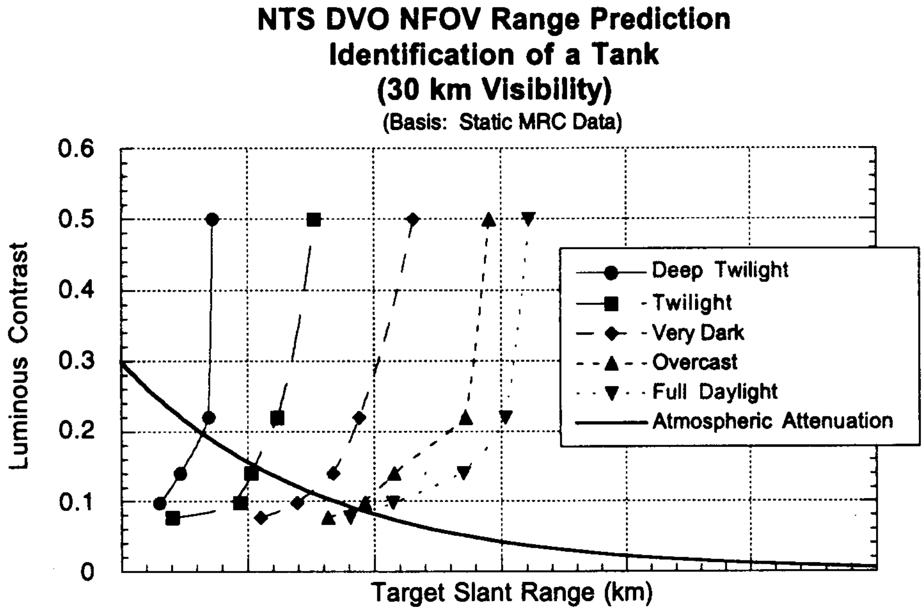


Figure A-12: Range Prediction for 50% Probability of Recognition

Notes: Range scale of both plots is same scale. Contrast degradation due to atmospheric attenuation plotted as $C_R = C_o e^{(-\sigma R)}$, where $\sigma = 3.912/R_v$. (C_R= apparent contrast at range R; C_o = apparent contrast at the target (assumed as 0.3 for generic vehicle); Rv = prevailing visibility in km; and σ = the extinction coefficient for the visible spectrum.) (RCA, 1974).



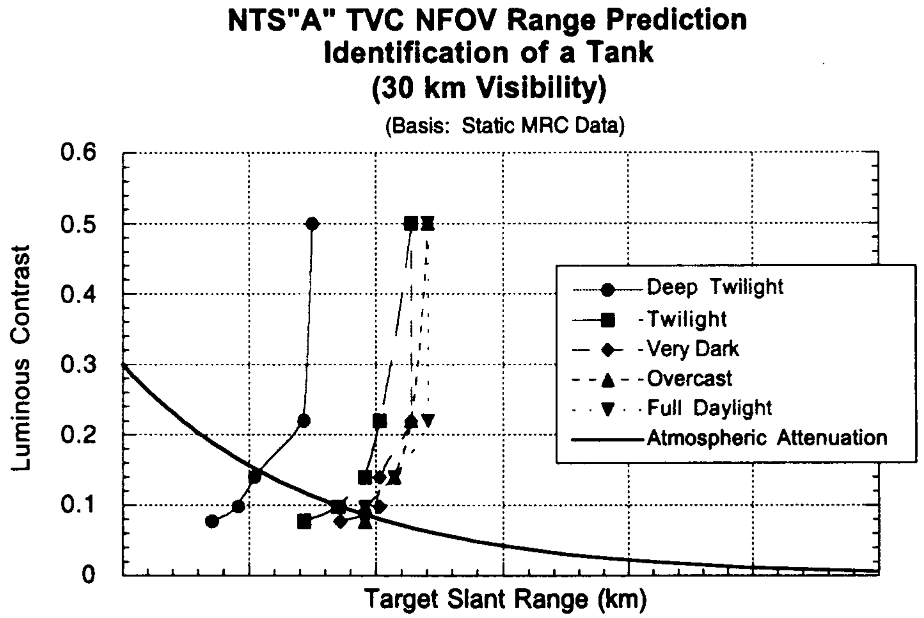


Figure A-13: Range Prediction for 50% Probability of Identification

Notes: Ordinates of both plots are same scale. Contrast degradation due to atmospheric attenuation plotted as $C_R = C_o e^{(-\sigma R)}$, where $\sigma = 3.912/R_v$. (C_R= apparent contrast at range R; C_o = apparent contrast at the target (assumed as 0.3 for generic vehicle); Rv = prevailing visibility in km; and σ = the extinction coefficient for the visible spectrum.) (RCA, 1974).

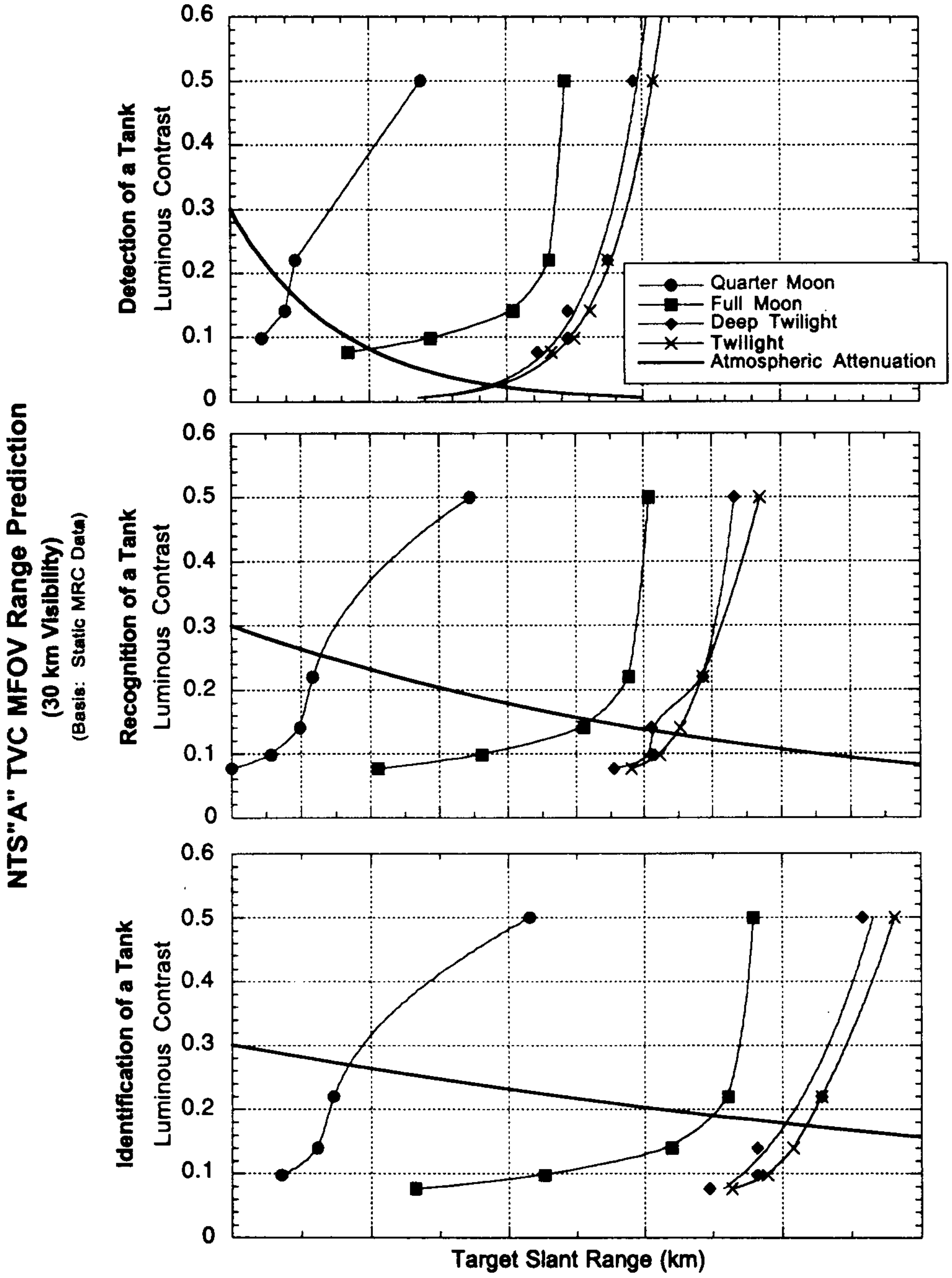


Figure A-14: NTS"A" TVC MFOV Range Prediction for 50% Probability of Detection, Recognition and Identification

Notes: Range axes are different scale. Contrast degradation due to atmospheric attenuation plotted as $C_R = C_o e^{(-\sigma R)}$, where $\sigma = 3.912/R_v$. (C_R= apparent contrast at range R; C_o = apparent contrast at the target (assumed as 0.3 for generic vehicle); Rv = prevailing visibility in km; and σ = the extinction coefficient for the visible spectrum.) (RCA, 1974).

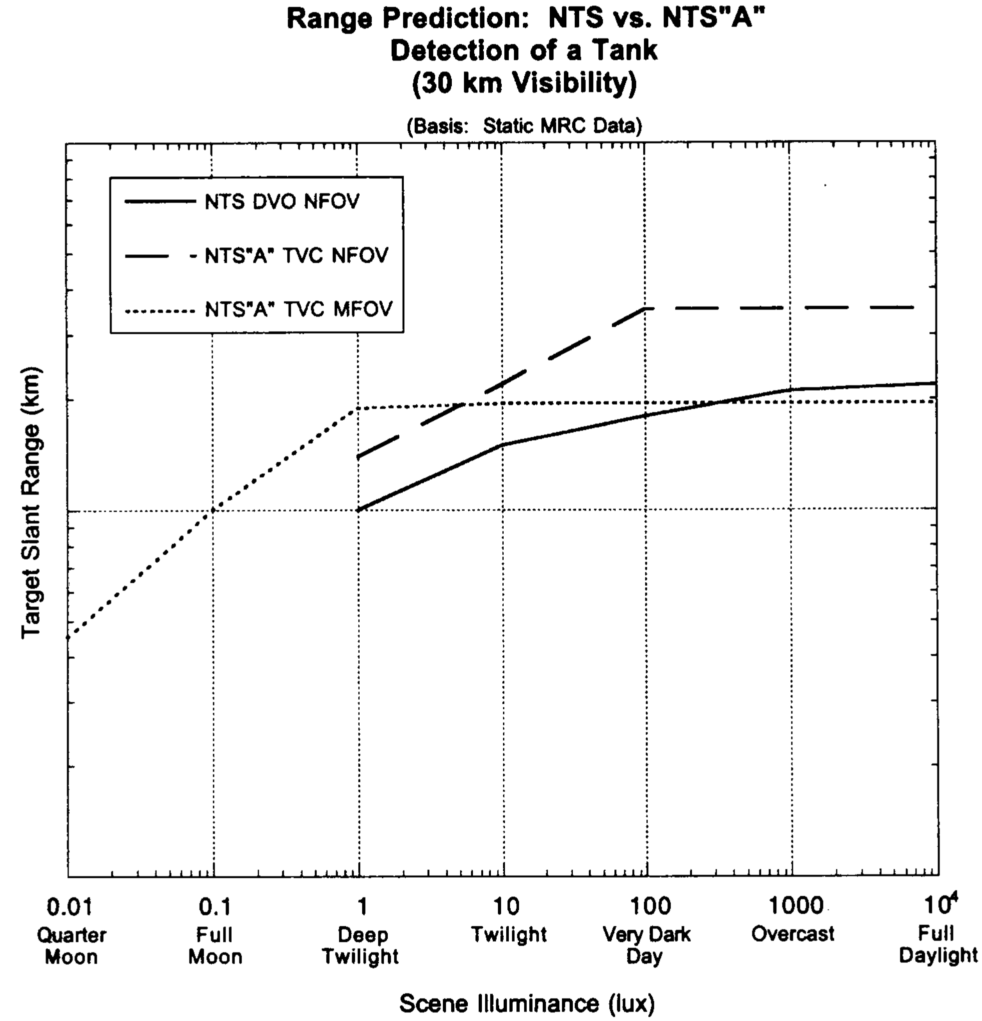


Figure A-15: Comparison of Range Prediction for 50% Probability of Detection of a Tank

Notes: Range axis of plots A-15 through A-17 are same scale.

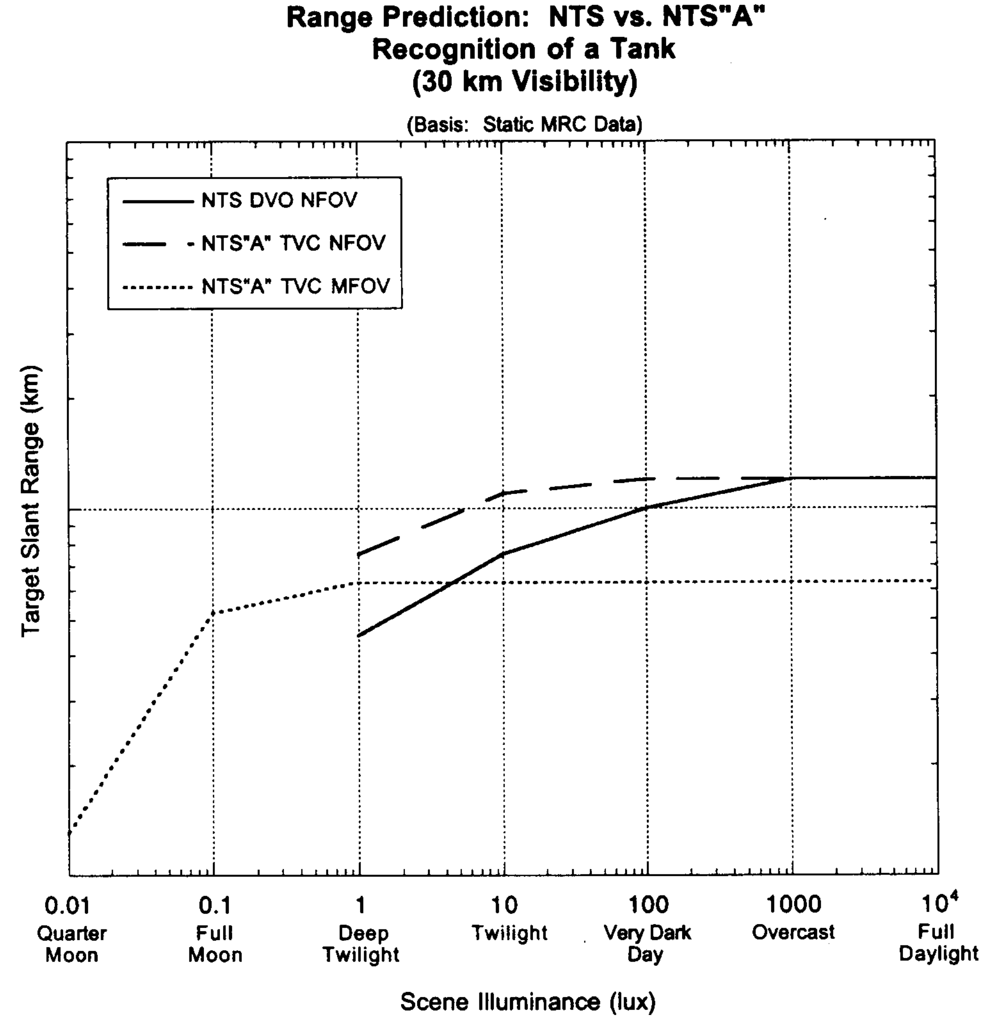


Figure A-16: Comparison of Range Prediction for 50% Probability of Recognition of a Tank

Notes: Range axis of plots A-15 through A-17 are same scale.

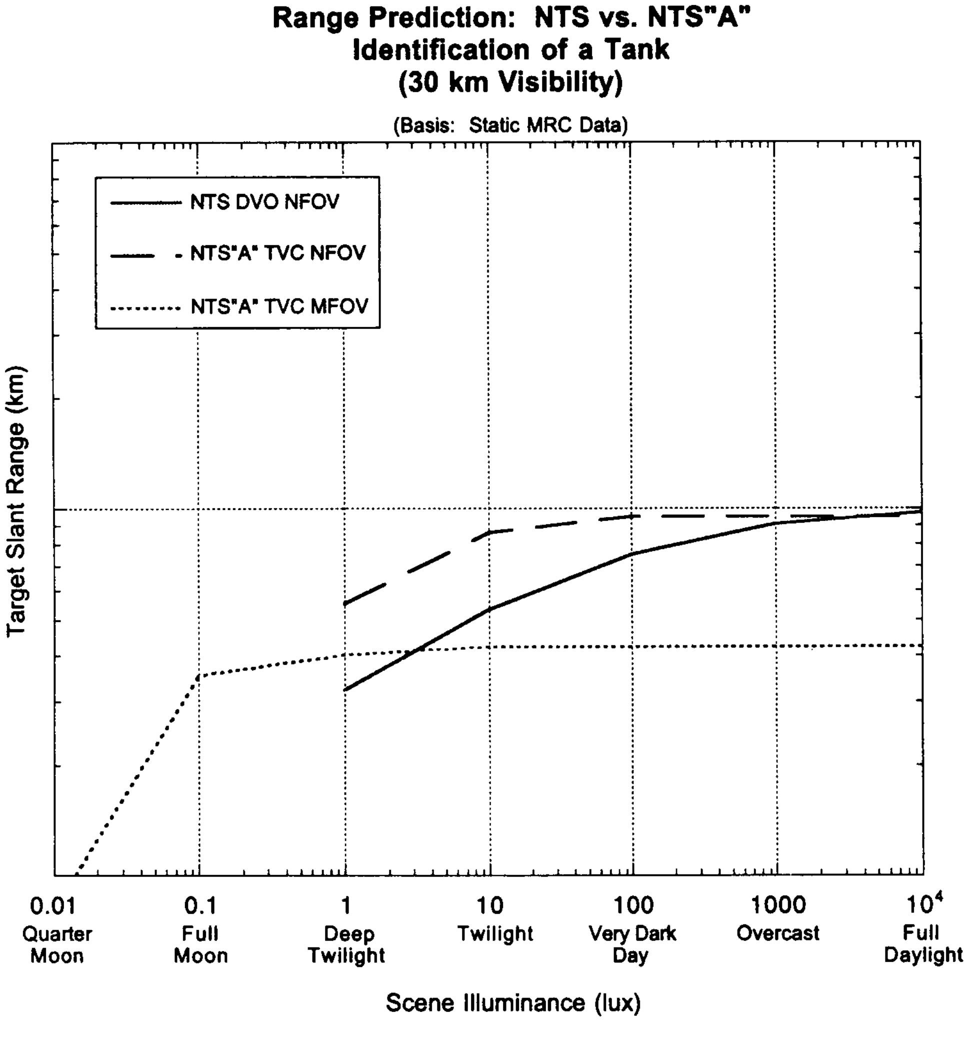


Figure A-17: Comparison of Range Prediction for 50% Probability of Identification of a Tank

Notes: Range axis of plots A-15 through A-17 are same scale.

APPENDIX B

LIST OF ABBREVIATIONS

APC	ARMORED PERSONNEL CARRIER
CAS	CLOSE AIR SUPPORT
CCD	CHARGE COUPLED DEVICE
CNVEO	CENTER FOR NIGHT VISION AND ELECTRO-OPTICS
CRT	CATHODE RAY TUBE
DAS	DEEP AIR SUPPORT
DRI	DETECTION, RECOGNITION, AND IDENTIFICATION
DVO	DIRECT VIEW OPTICS
EM	ELECTROMAGNETIC
ERDL	ENGINEERING, RESEARCH, AND DEVELOPMENT LAB
FLIR	FORWARD LOOKING INFRARED
FOV	FIELD OF VIEW
IBAHRS	INFLATABLE BODY AND HEAD RESTRAINT SYSTEM
IR	INFRARED
KIAS	KNOTS INDICATED AIRSPEED
LDRS	LASER DESIGNATOR RANGEFINDER SYSTEM
MFD	MULTI-FUNCTION DISPLAY
MFOV	MEDIUM FIELD OF VIEW
MRC	MINIMUM RESOLVABLE CONTRAST
MRT	MINIMUM RESOLVABLE TEMPERATURE

NFOV	NARROW FIELD OF VIEW
nm,	NANOMETERS
NTS	NIGHT TARGETING SYSTEM
NTS"A"	ADVANCED NIGHT TARGETING SYSTEM
NVL	NIGHT VISION LABORATORY
OAS	OFFENSIVE AIR SUPPORT
ORT	OPTICAL RELAY TUBE
RADAR	RADIO DETECTION AND RANGING
SNR	SIGNAL TO NOISE RATIO
TOW	TUBE LAUNCHED, OPTICALLY TRACKED, WIRE GUIDED
TVC	TELEVISION CAMERA
USAF	UNITED STATES AIR FORCE
USMC	UNITED STATES MARINE CORPS
WFOV	WIDE FIELD OF VIEW
YAG	YTTRIUM ALUMINUM GARNET

VITA

Paul Curtis Schreck, Jr. was born in Hollywood, FL on October 10, 1963. The son of Paul Curtis and Carolyn Anne Schreck, he was raised in Ft. Lauderdale, FL. After graduating from St. Thomas Aquinas High School in 1981, he attended the University of Florida (UF) in Gainesville, FL. While attending UF, he was awarded a two year Naval Reserve Officer Training Corps (NROTC) scholarship, and subsequently earned a Bachelor of Science in Electrical Engineering in 1986.

Upon graduation from UF, he reported to the United States Marine Corps Officer Candidates School (OCS) in Quantico, VA. Upon completion of OCS, he was commissioned a Second Lieutenant in July, 1986. He reported to flight training at Naval Air Station Pensacola, FL in April, 1987 and received his "wings of gold ," designating him as a Naval Aviator, in June, 1988. Selected to fly the AH-1W SuperCobra, his first fleet Marine Corps tour was with Marine Light/Attack Helicopter Squadron 169 at Marine Corps Air Station, Camp Pendleton, CA, where he completed several overseas deployments to include combat in the Persian Gulf War.

He was selected to attend test pilot training at the U. S. Naval Test Pilot School, Patuxent River, MD in November, 1993, and was designated as an Engineering Test Pilot in June, 1995. He is currently serving as an AH-1W Project Officer in the Naval Rotary Wing Aircraft Test Squadron, Naval Air Warfare Center Aircraft Division at Patuxent River.