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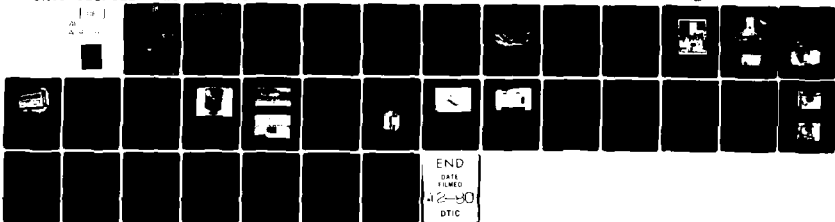
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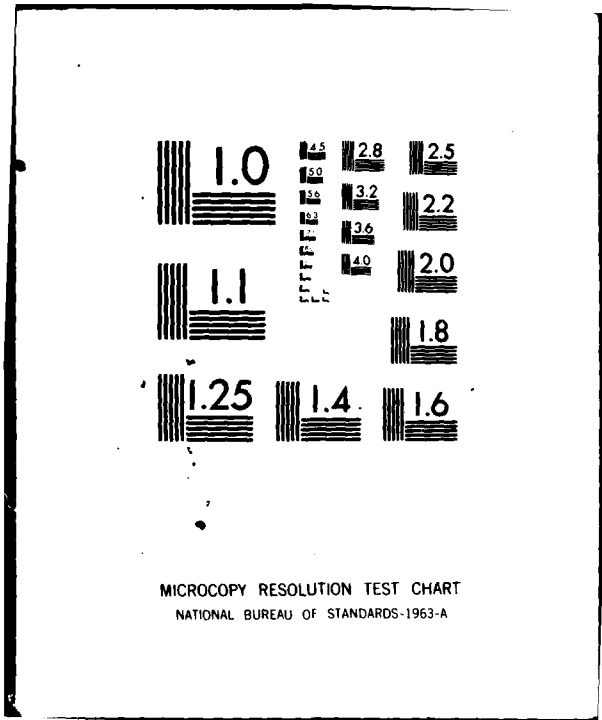
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**CONCEALED ORIGIN OPTICAL
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(COOLS)**

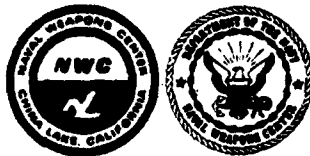
by
Thomas E. Loftus
Fuze and Sensors Department

MARCH 1979

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FOREWORD

This report describes a demonstration test of a helicopter landing aid. Primary applications of the system are for resupply and rescue operations in hostile areas even during periods of reduced visibility. This work was performed during December 1977 through October 1978 under the sponsorship of Code 8105, Naval Ocean Systems Command, San Diego, California.

This report was reviewed for technical accuracy by Roy L. Nichols and is released at the working level.

Released by
R. A. BOOT, *Head*
Fuze and Sensors Department
1 February 1979

Under authority of
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RAdm., U.S. Navy
Commander

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(U) *Concealed Origin Optical Locating System (COOLS)* by T. E. Loftus. China Lake, Calif., Naval Weapons Center, March 1979. 30 pp. (NWC TP 6090, publication UNCLASSIFIED.)

→ (U) This report summarizes a demonstration test of a FLIR-compatible helicopter landing aid conducted at the Naval Weapons Center (NWC) in FY 1978. The system is a means by which the secure landing of helicopters can be accomplished in adverse visibility conditions. For this test, a night vision sensor (FLIR) was mounted with a CO₂ laser illuminator on a UH-1N helicopter. The FLIR image was annotated with range to the landing site and closing rate data provided by a separate airborne electro-optical rangefinder. The landing site was equipped with a portable FLIR beacon (PFB) for long-range (3.5 kilometer) homing and a retroreflector array for landing site identification during short-range (1.5 kilometer) approach and landing. Data were recorded in the aircraft and a video tape showing the results of testing the various elements of the system was generated. ←

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ACKNOWLEDGEMENT

The work described in this report represents the efforts of several NWC scientists and engineers. The modeling section was drawn primarily from the work of W. Tanaka and C. K. Bullock. The contributions of these individuals, as well as R. Hintz in test development and program management, are gratefully acknowledged.

Special appreciation is extended to the Aeronutronic Division of Ford Aerospace and Communications Inc., Newport Beach, California for making their hardware available for the test program.

INTRODUCTION

The concealed origin optical locating system (COOLS) addresses a stated requirement for Marine Corps helicopters to locate and land at specific remote sites.¹ These operations must be conducted in hostile areas, even during periods of low visibility, with a minimum risk of detection to both the aircraft and ground personnel. Typical aircraft missions would include locating, resupply, and rescue of forward ground troops.

The system concept, as depicted in Figure 1, requires the rescue helicopter to be equipped with a CO₂ laser illuminator to be used in conjunction with a forward looking infrared (FLIR) sensor and a remote-actuation unit for the portable FLIR beacon (PFB). The aircraft would be vectored into the search area, to within a few kilometers of the site, using established procedures of low level flight. Upon entering the area, the PFB at the site could be remotely activated by a radio frequency (RF) coded identification friend from foe (IFF) message from the aircraft. The pilot then would search the area with the FLIR sensor. The PFB signal would appear on the FLIR display as a bright flashing spot indicating the exact position of the landing site.

As the pilot homed on the PFB, the CO₂ laser illuminator would begin scanning across the FLIR field of view (FOV). The ground team would have outlined or otherwise marked out a safe landing site and approach path for the helicopter through the use of retroreflector site markers which were spectrally matched to the laser and FLIR sensor. As the retroreflectors were scanned by the laser, the return energy would be presented on the FLIR display as flashing spots resembling landing lights. The same return energy could be used to obtain range as well as approach rate to the site. The pilot now would have sufficient information to safely land without the use of searchlights or exploitable RF emissions.

This report describes the hardware used in a preliminary flight demonstration. Analytical model results are presented regarding laser safety and range performance predictions. Test results are summarized and recommendations are listed. The report covers the period from December 1977 through October 1978.

BACKGROUND

During FY 1977, tests were conducted with a CH-53 helicopter equipped with a serial-scan mini-FLIR. Low altitude nighttime flight capabilities were assessed as well as compatibility with the PFB hardware. Aircraft instrumentation was added which displayed to the pilot a constant glide slope approach to a specific point in the FLIR

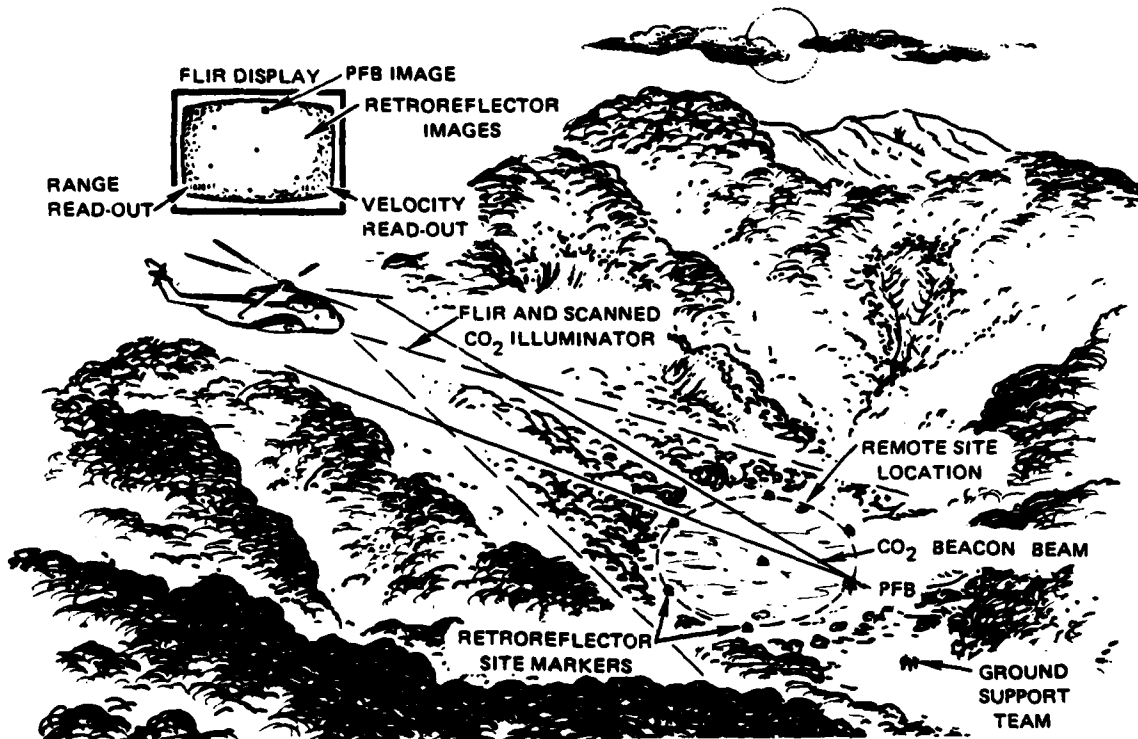


FIGURE 1. COOLS Concept Illustration.

FOV. The results of this testing indicated that pilots required better cueing than is available from the FLIR display alone for safe landing at remote sites. It was reported that the landing site should be easily identified (i.e., IR beacon), be clearly marked (i.e., retroreflectors) and that range and closing rate to the site should be provided to the pilot.

SYSTEM REQUIREMENTS

The atmospheric modeling performed for the PFB and other related programs indicate that the 10.6-micrometer wavelength region affords the greatest penetration of aerosols when compared with visible or near-IR wavelengths.² This wavelength is also compatible with the operating wavelength of the FLIR system.

The search application in the COOLS concept requires a relatively large FLIR FOV. It has been suggested that the FLIR FOV must be larger than 15 degrees by 20 degrees for the required maneuvers.³ An FOV of 30 degrees by 40 degrees can provide a large area of search as well as a horizon for pilot reference.

² Naval Weapons Center, *Extinction and Backscattering by Fog and Smoke in the 0.33- to 12.0-Micrometer Wavelength Region*, by R. E. Bird, China Lake, Calif., NWC, June 1976. (NWC TP 5850, publication UNCLASSIFIED.)

In direct conflict with this large FOV argument are the laser scanner requirements. The instantaneous FOV of the laser must be kept to a minimum to maintain an acceptable power density on the retroreflectors. At the same time the large FOV of the FLIR sensor must be adequately covered at a rate no faster than that which insures a high probability of detection by the FLIR observer. A reasonable tradeoff in this conflict is to illuminate only the center section of the FLIR FOV. The pilot must then hold the beacon spot in the center of the FLIR display during the homing phase (Figure 2).

No attempt was made in this program to determine night vision requirements for low level, limited visibility operations. It has been detailed in other reports⁴ that FLIR equipped helicopters would afford the best probability of mission success in hostile environment when compared with other electro-optical night-vision sensors. The results of this demonstration effort indicate that the COOLS concept can significantly enhance a pilot's capability to pinpoint and land at remote sites with minimum risk of detection.

DEMONSTRATION HARDWARE

The primary objective of the FY 78 effort was to provide a low-cost flight demonstration of the COOLS concept using existing hardware wherever possible. Tests were run the previous year with a mini-FLIR (provided by Ford Aerospace and Communications Inc.) mounted on a CH-53 helicopter based at El Toro Marine Corps Air Station. The original approach of the COOLS demonstration was to supplement this hardware with a CO₂ laser illuminator and an existing rangefinder and to conduct follow-on tests. When the CH-53 became unavailable, a UH-1N helicopter based at NWC was substituted.

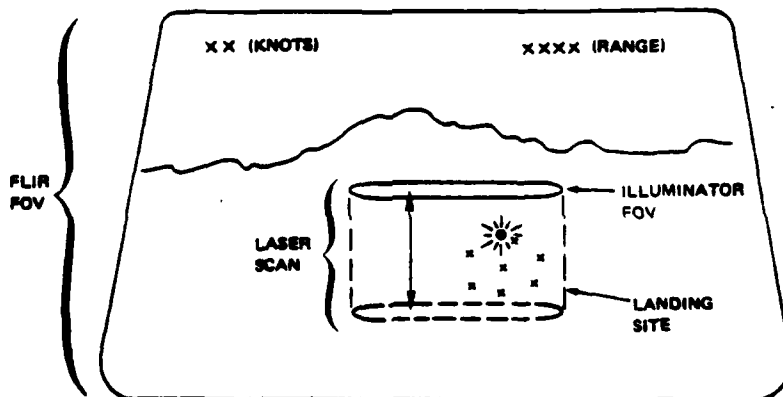


FIGURE 2. Scan Configuration Diagram.

⁴ Electronics Command. *Low Level Night Operations Study*. U. S. Army, June 1976. (EC 4417, DDC AD B012182, publication UNCLASSIFIED.)

AIRBORNE HARDWARE

The aircraft installation involved mounting a night vision sensor (FLIR) and laser illuminator beneath the cockpit of the helicopter with the required control and display equipment in the passenger and cargo area. An additional display was mounted for the pilot's use in flight. A range sensor, together with a TV camera used to aim the rangefinder, were placed on a pantilt platform external to the aircraft with an unobstructed view directly forward and down toward the landing site. The associated signal processing and guidance controls were located in the passenger area for the system operator. The range and velocity output signals were superimposed over the FLIR image and displayed to the pilot and system operator after being recorded on video tape.

Night Vision Sensor. A night-vision capability was provided by the Aeronutronic "Mini-FLIR." This equipment was made available by Ford Aerospace and Communication Inc. under a bailment agreement to NWC. The sensor assembly (Figure 3) included an electro-optical sensor, refrigerator unit, video and logic circuits, DC-to-DC converters, cooling fans and refrigerator/power control unit. Separate photographs (Figures 4 and 5) show the scanner/refrigerator unit and the control panel. This panel was located at the system operator's station.

The FLIR image is serially scanned across a cooled linear array of detectors. The instantaneous FOV is 2 milliradians, while the displayed image represents a total FOV of 30 degrees by 40 degrees. The output video format is RS 170 (525 line standard TV) and therefore directly compatible to standard TV displays. Ranger data were electronically annotated onto the FLIR video before display. Table 1 is a partial listing of sensor specifications.

The sensor package was mounted below the cockpit area between the helicopter skids. This location affords a clear FOV along the centerline, forward of the aircraft. Sensor depression angles from 10 degrees to 40 degrees (with respect to aircraft body) are commanded from the control console.

Illuminator. The FLIR illuminator is a copy of a 10-watt, CO₂ laser/scanner package developed at Honeywell, Inc., under contract from NWC. It is designed to be mounted on a helicopter to be used in air rescue tests. Figure 6 shows the laser package together with its control unit. The laser unit contains a ruggedized CO₂ laser, power supplies and scanning mirrors, shown exposed in Figure 7.

A specification listing describing the illuminator is given as Table 2. The waveguide laser provides 10 watts continuous power output with a beam divergence of 10 milliradians. After a brief warm-up period, operation is limited to high-gain P-lines centered around 10.59 micrometers. The optical scanner provides either a horizontal one-half-degree by 15-degree fan beam or a 4-degree by 3-degree elliptical spot on command of the operator. Either beam pattern may be scanned vertically with selectable scan amplitude and rate. Laser/scanner operation is depicted schematically in Figure 8.

The laser unit was mounted external to the aircraft directly above the FLIR so as to minimize the separation between laser exit aperture and FLIR entrance aperture. The fan beam was boresighted with the FLIR FOV in the unscanned mode. Laser operation and beam configuration were controlled by the system operator.

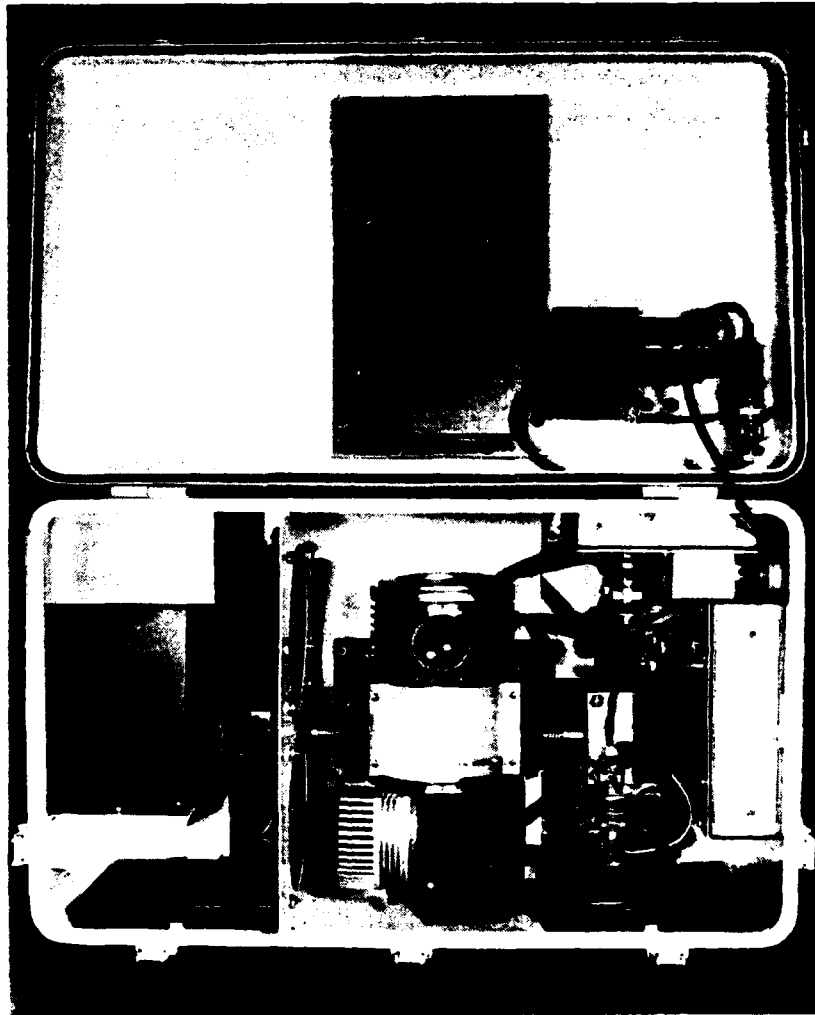


FIGURE 3. Night Vision Sensor Assembly.

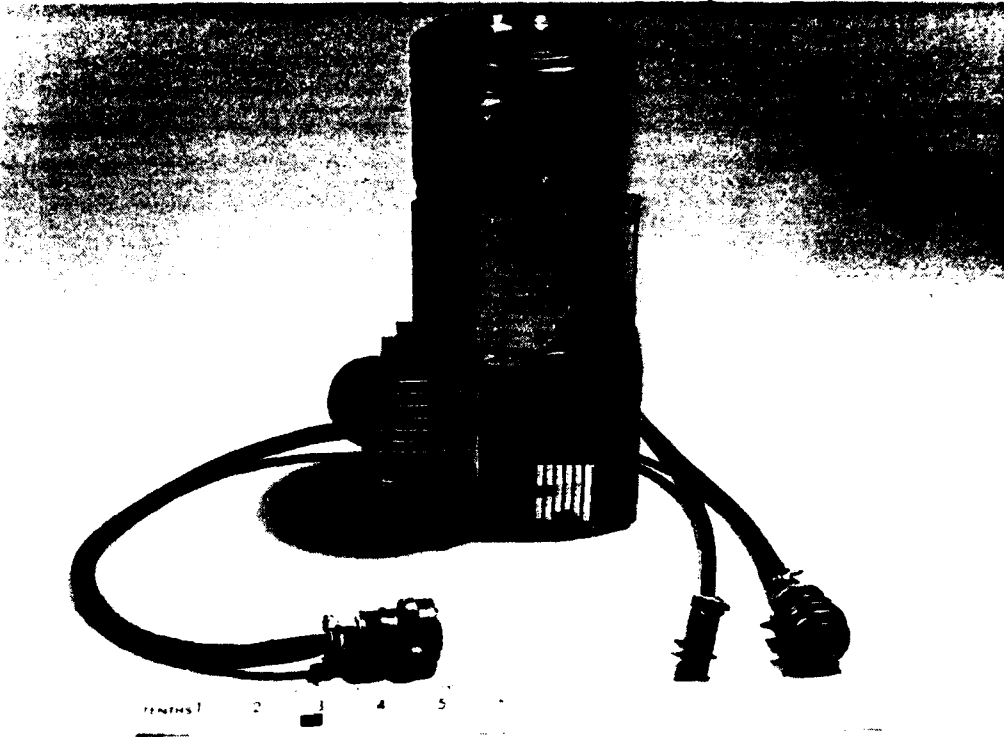


FIGURE 4. Scanner/Refrigerator Unit.



FIGURE 5. Control Panel.

TABLE 1. Night Vision Sensor Specifications.

Item	Requirement
Sensor type	Two row serial scan
Spectral region	8-11.5 μm
Detectors	HgCdTe at 70 to 90 °K
Instantaneous FOV	2 mrad
Scanned FOV	30 X 40 degrees
Power consumption	50 W at 28 VDC

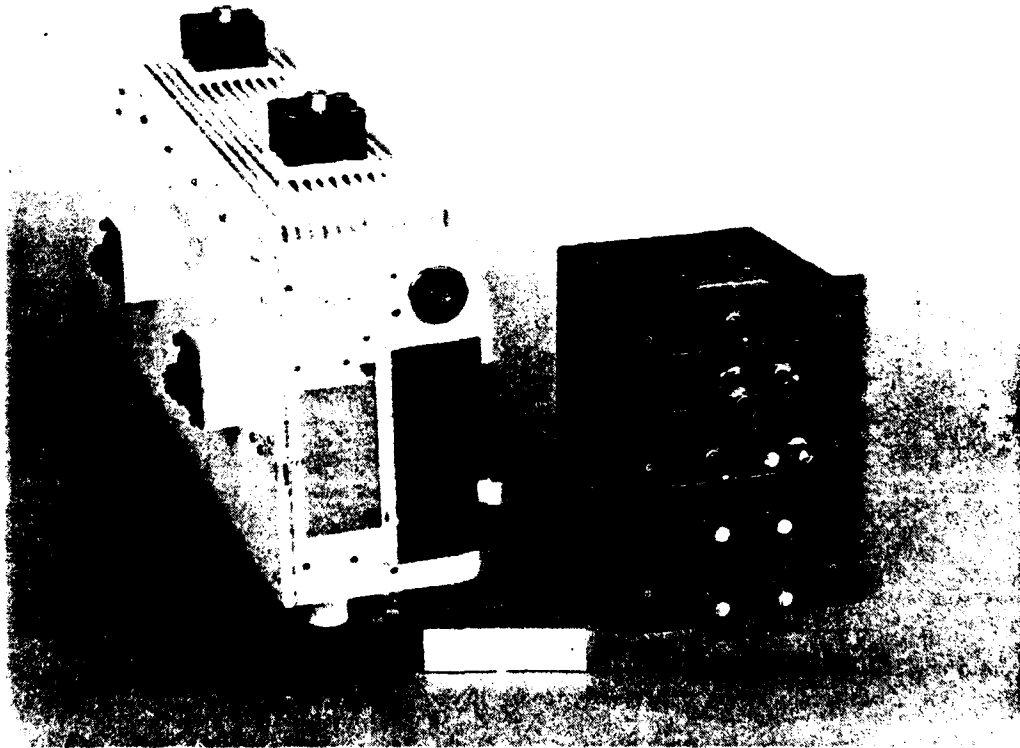


FIGURE 6. CO₂ Laser Illuminator and Control Unit.

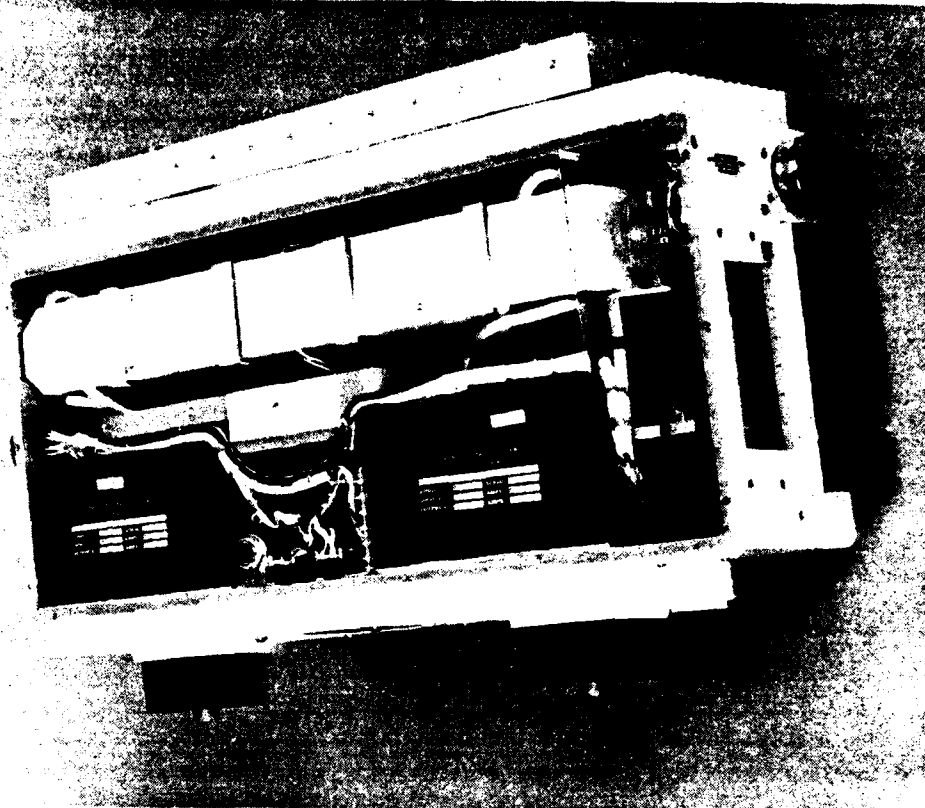


FIGURE 7. CO₂ Laser Illuminator Exposed View.

TABLE 2. Laser Illuminator Specifications.

Item	Requirement
Laser	
Type	Sealed-off waveguide, CW operation
Output power	10 W ± 2 W
Lifetime	≥ 8 W for 200 hours of operation and/or 6 months storage
Output divergence	10 mrad
Wavelength	High gain P-lines centered around the P(20)-line at 10.59 μm
Scanner and optical system	
Beam geometry	(1) 1/2-degree by 15-degree fan (2) 3-degree by 4-degree elliptical spot
Scan amplitude	± 10 degrees
Scan speed	2 to 45 scans/s

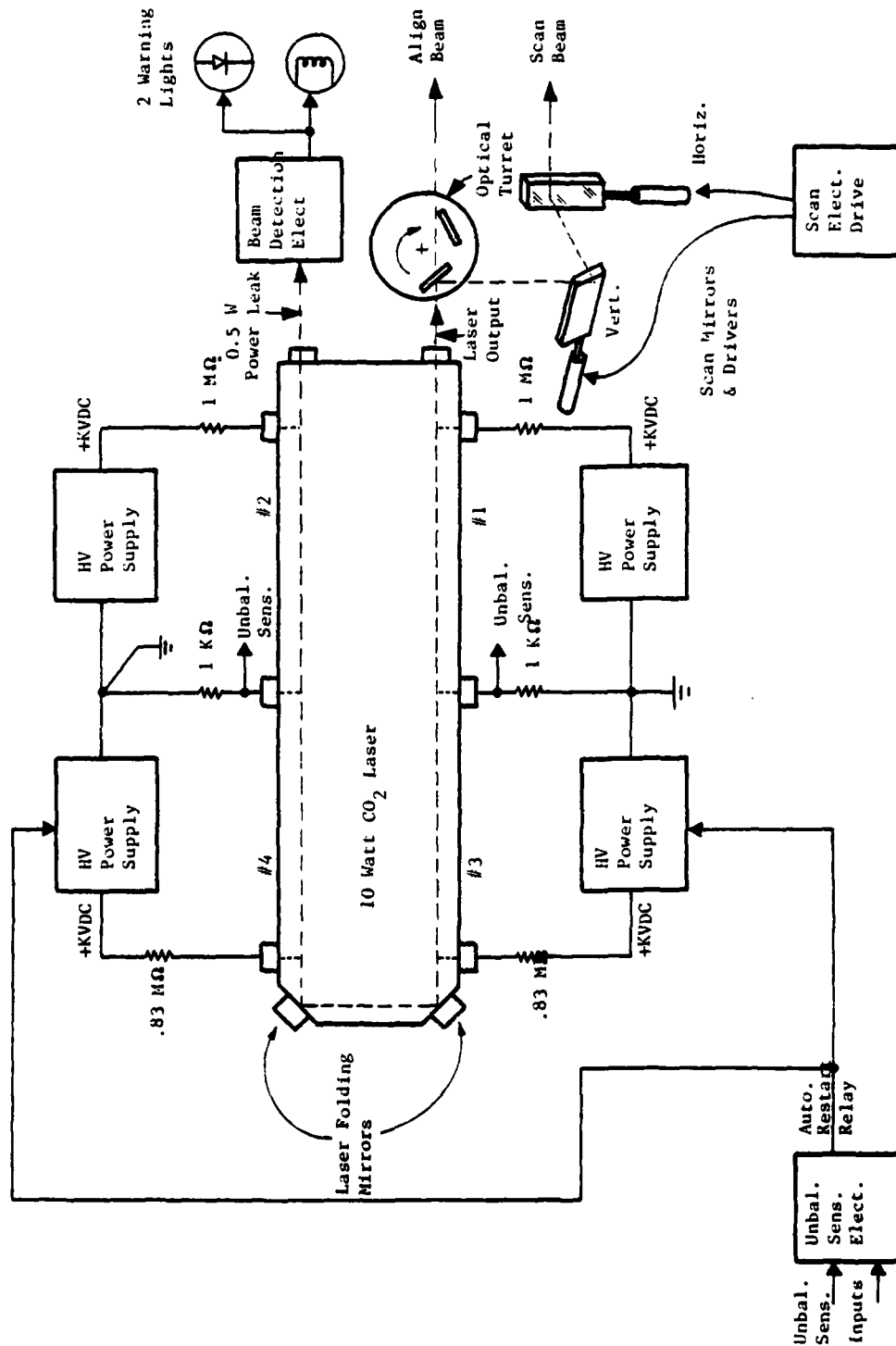


FIGURE 8. CO₂ Laser Illuminator CKT Diagram.

Rangefinder. The compact optical recovery sensor (CORS) ranger used in the COOLS testing is a gallium arsenide (GaAs) rangefinder originally designed as an optical tracking and ranging sensor in an automatic remotely-piloted vehicle (RPV) recovery program.⁵ Designed and built at NWC, CORS (Figure 9) is compact and portable enough to operate on the helicopter, while providing the required resolution and range performance necessary for the COOLS application.

The accompanying listing (Table 3) outlines the CORS system parameters. The transmitter utilizes two separate laser diode source arrays. A low-power source (7 watts peak) with a short (7×10^{-9} s) optical pulse provides high resolution at ranges within 310 meters. A higher-power source (50 watts peak) with 100×10^{-9} s pulse is used for target acquisition and tracking at longer ranges. The pulse repetition frequency (PRF) is controlled through a processor and is determined according to the units of the velocity readout (knots or miles per hour). The higher-power source operates at one-fourth the PRF of the low-power source.

This ranging sensor can operate from 1.5 meters to beyond 1800 meters with the optical return signal from a 6.35-centimeter diameter retroreflector. Range is displayed in feet to a resolution of 0.5 foot. Velocity can be displayed in either knots or miles per hour with a resolution of one unit.

The tracking capability of the sensor provided by the quadrant receiver was not used in the COOLS system. Instead, the ranger was boresighted with a monitor TV camera mounted on a slewable platform controlled by the system operator. The operator aimed the ranger via the TV image at the ground site retroreflector during helicopter maneuvers. A crosshair on the FLIR image indicated to the pilot the aimpoint of the ranger.

Information Display. Primary display to the pilot was provided by a 12.7-centimeter (diagonal) TV screen. Either the annotated FLIR image or the monitor TV camera video could be displayed to the pilot by the selection of the system operator. Both pictures were continuously available to the system operator on secondary monitors. The video signals of both sensors were separately recorded before being displayed. A common audio signal was fed to both recorders to facilitate simultaneous playback for analysis of data tapes.

Aircraft Installation. The installed equipment is shown in Figures 10 and 11. Tests were conducted with two COOLS personnel in addition to the pilot, copilot and flight crew member. All of the COOLS hardware was controlled by the System Operator. His functions included application of primary power, laser operation and direction of the rangefinder. The duties of the Test Coordinator consisted of air-to-ground communication, data recording and assisting the System Operator as needed.

System power was provided by the aircraft's 28-volt DC buss. A rotary inverter provided the necessary 115 volt, 60 Hz power. Distribution to the various COOLS subsystems was provided through individual circuit breakers.

⁵ Naval Weapons Center. *Compact Optical Recovery Sensor*, by T. E. Loftus. China Lake, Calif., NWC, August 1978. (NWC TM 3444, publication UNCLASSIFIED.)

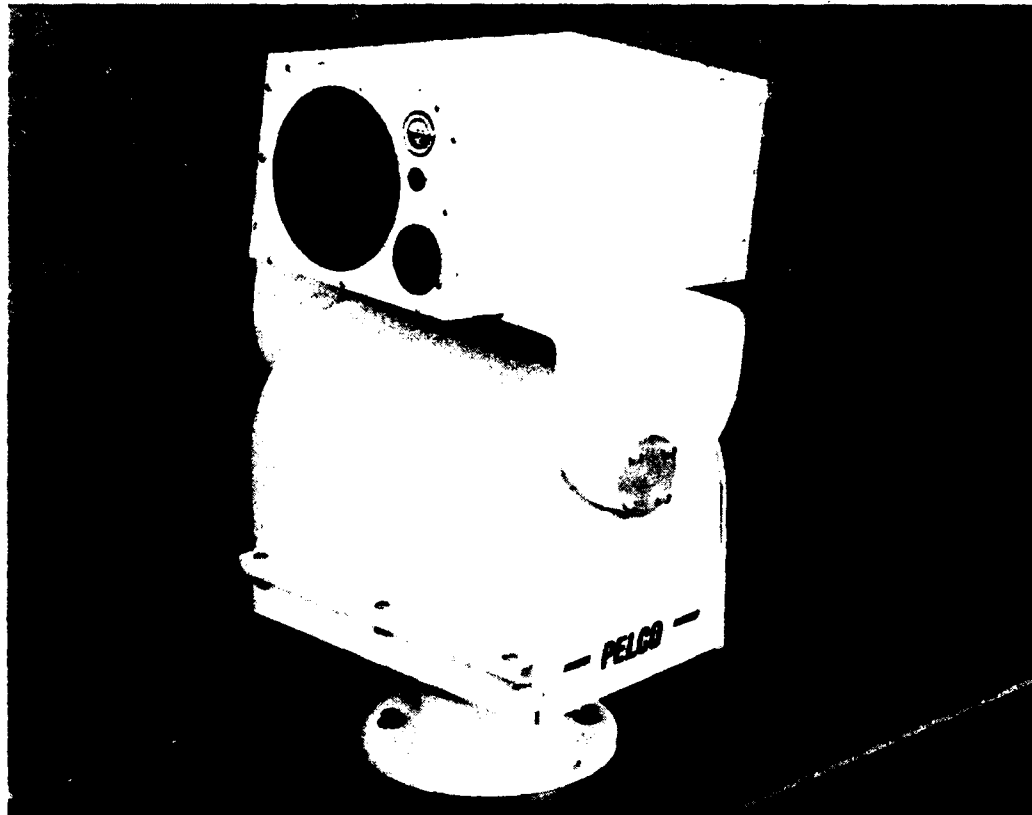


FIGURE 9. CORS Optical Rangefinder.

TABLE 3. CORS System Parameters.

Item	Parameter
Optical source	Gallium arsenide (GaAs)
Optical wavelength	0.91 μm
Radiant power maximum	50 W/peak
Pulse width minimum (50% power)	7×10^{-9} s
FOV	2 degrees
Pulse repetition frequency	Less than 3 kHz
Detector	Silicon quadrant photodiode

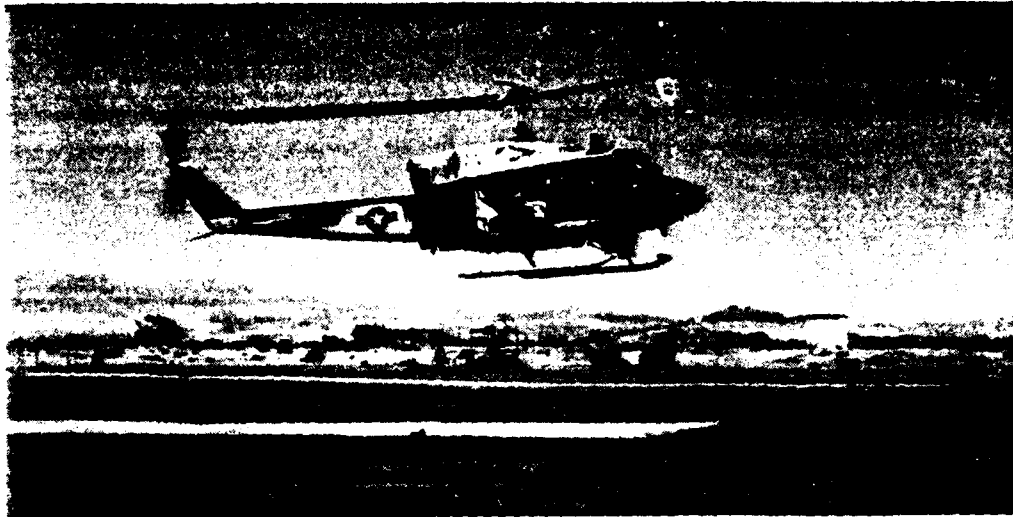


FIGURE 10. COOLS Aircraft Installation.

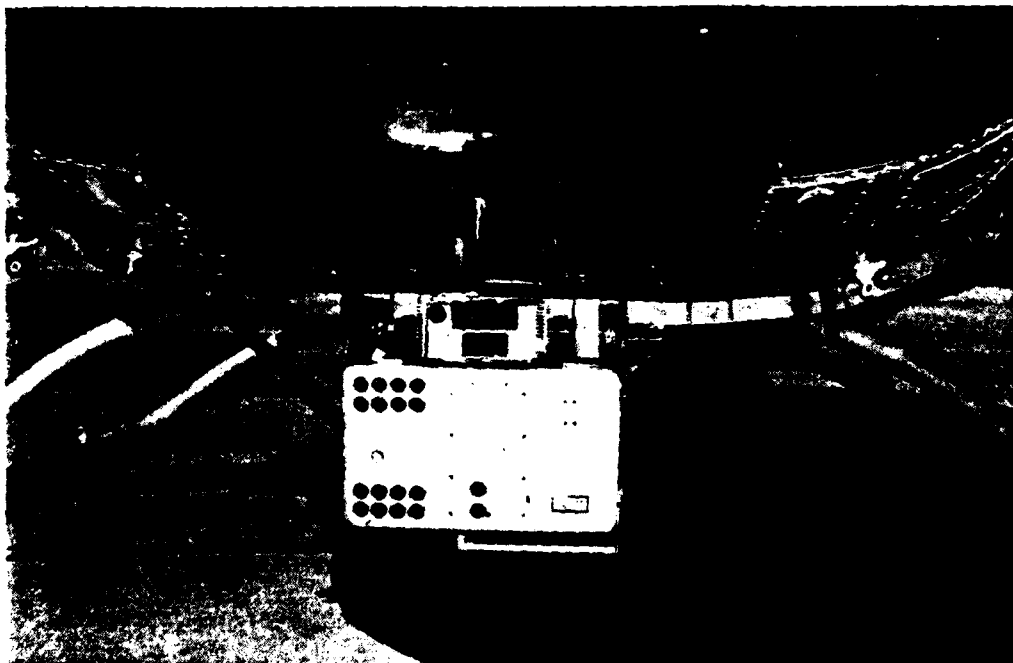


FIGURE 11. COOLS FLIR/Illuminator Aircraft Installation.

GROUND SITE HARDWARE

The remote landing site was equipped with a PFB and a set of retroreflectors in various patterns. To protect the sensor optics as much as possible, the landing site was chosen to minimize the blowing dust and debris caused by the helicopter rotor blades.

Portable FLIR Beacon. The PFB is the result of an exploratory development program at NWC funded by the Marine Corps to provide a first-pass IFF to FLIR-equipped aircraft.⁶ Operating at a wavelength of 10.6 micrometers, the beacon appears as a bright image on the airborne FLIR display of sufficient intensity to be readily discernible against the terrain background, thereby indicating the position of friendly forces. The equipment is battery operated and can be remotely activated by the interrogating aircraft.

The COOLS configuration of this hardware is shown as Figure 12. The remote actuation unit was not used because the rescue receiver was used as a ground-to-air communication link. The laser transmitter is shown with a scanner mounted. As configured, the equipment scanned a 10-degree divergent beam through a 60-degree sector.

An exposed view of the laser package is given in Figure 13. It consists of the CO₂ waveguide laser head, cooling fan, DC-to-DC power converters, control circuits, ballast resistors and Lithium batteries. The entire package weighs 3.63 kilograms and measures 20 by 12 by 11 centimeters.

The PFB was used in the COOLS tests for acquisition of the landing site within the large FLIR FOV (30 degrees by 40 degrees). Detection ranges of 2.5 kilometers are predicted with this beacon/FLIR combination. The pilot homes on the beacon image until the landing site is visible on the FLIR display.

Retroreflectors. The COOLS concept calls for optical corner cube retroreflectors to be used to outline or otherwise mark the landing site. Incident energy from the laser illuminator is reflected back toward the source. When a portion of this return energy falls within the FLIR FOV, it is presented on the display as a point source. If the illuminator beam is scanned across the retroreflector periodically, the source appears to be flashing.

The optimum design for the COOLS retroreflector array, which will be a complex function of FLIR/gimbal capability, source/receiver separation and performance requirements, was not determined in the COOLS test demonstration program. However, several types of retroreflectors have been made available for comparison testing, including those listed below (see Table 4). The accompanying photograph (Figure 14) shows the gold and black chrome surface types. The black chrome deposition over the gold surface results in the spectral response plotted in Figure 15.

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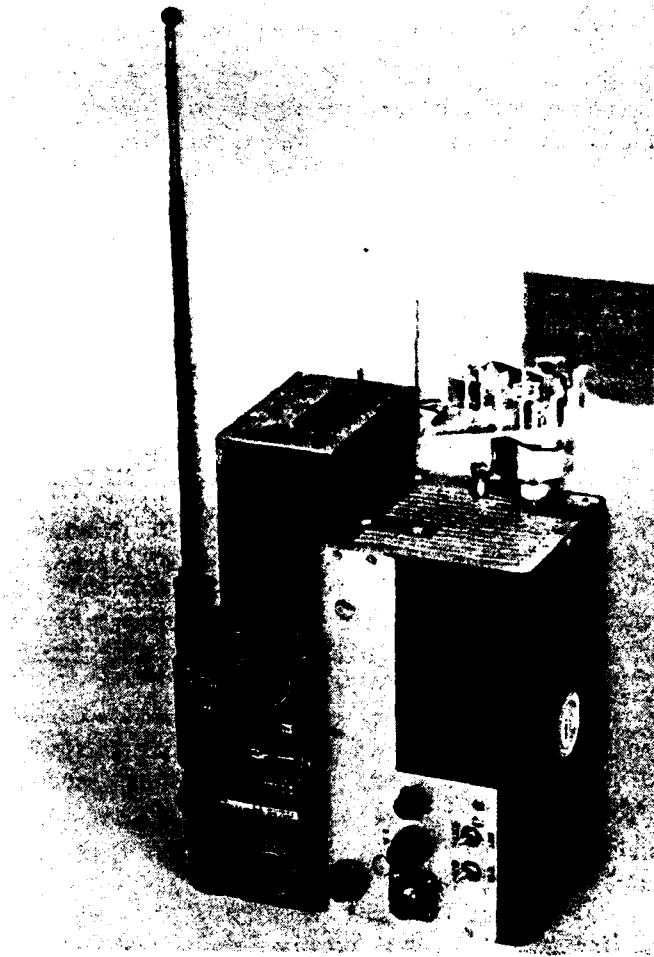


FIGURE 12. PFB Configuration.

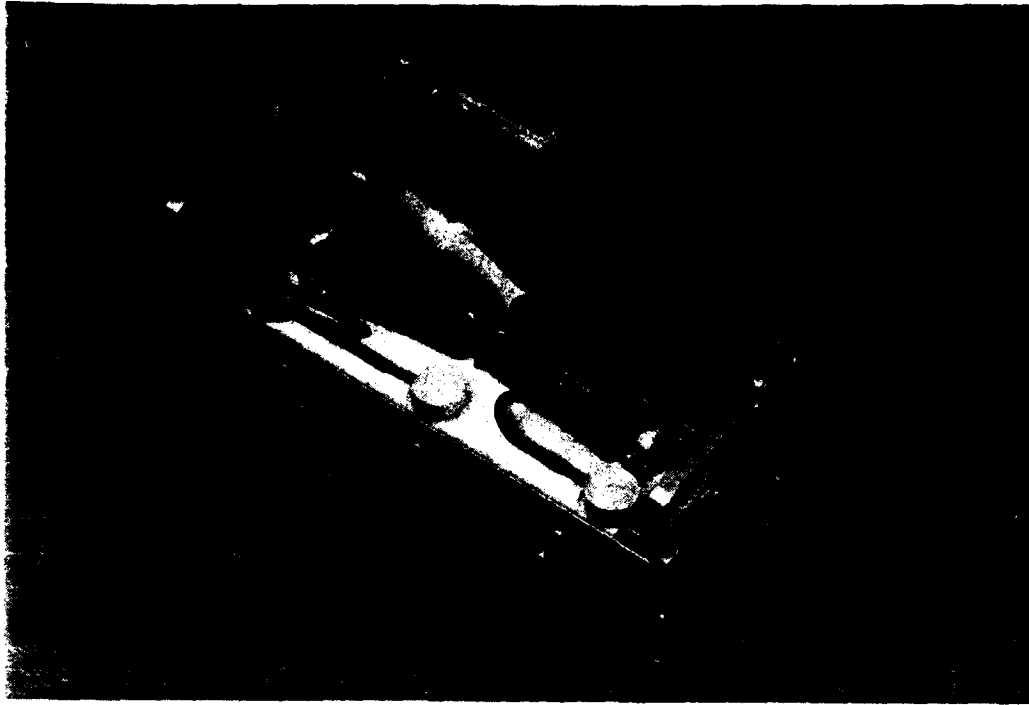


FIGURE 13. PFB Exposed View.

TABLE 4. Retroreflector Types Used in COOLS Testing.

Retroreflector type	Description
Glass	First surface aluminum reflector 6.35 cm diameter effective aperture Square sides 2-5 arc second accuracy
Aluminum	First surface gold reflector epoxied onto aluminum form Circular aperture 6-18 arc second accuracy
Black chrome	Same as aluminum above but with black chrome electroplating 18-20 arc second accuracy
Plastic array	Plastic injection molded array of 60 retroreflectors Right triangle sides of 0.95 cm Accuracy > 1 arc minute

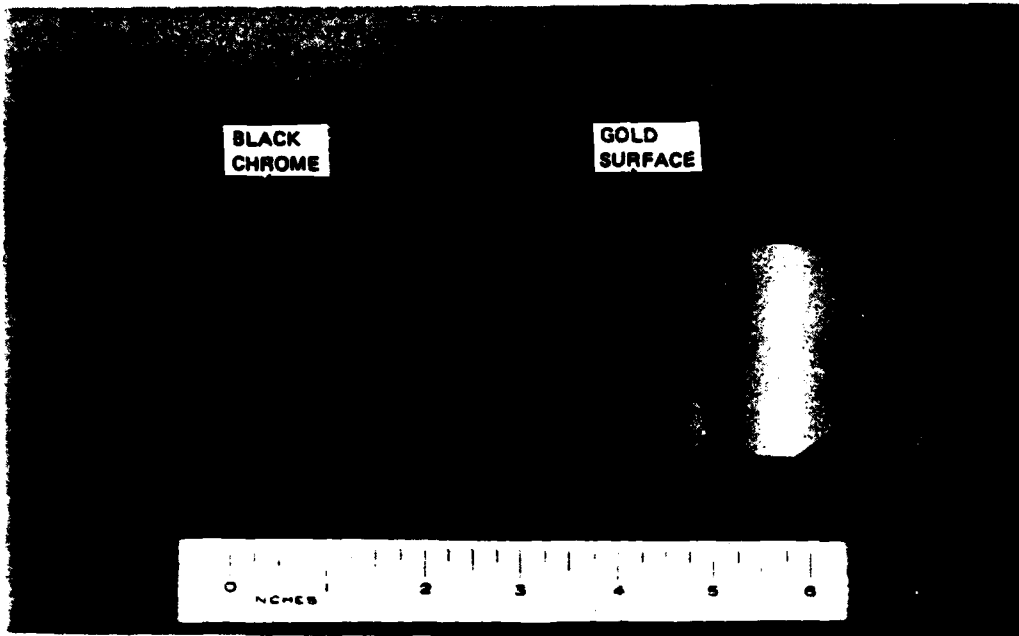


FIGURE 14. Gold Surface and Black Chrome Surface Retroreflector Types.

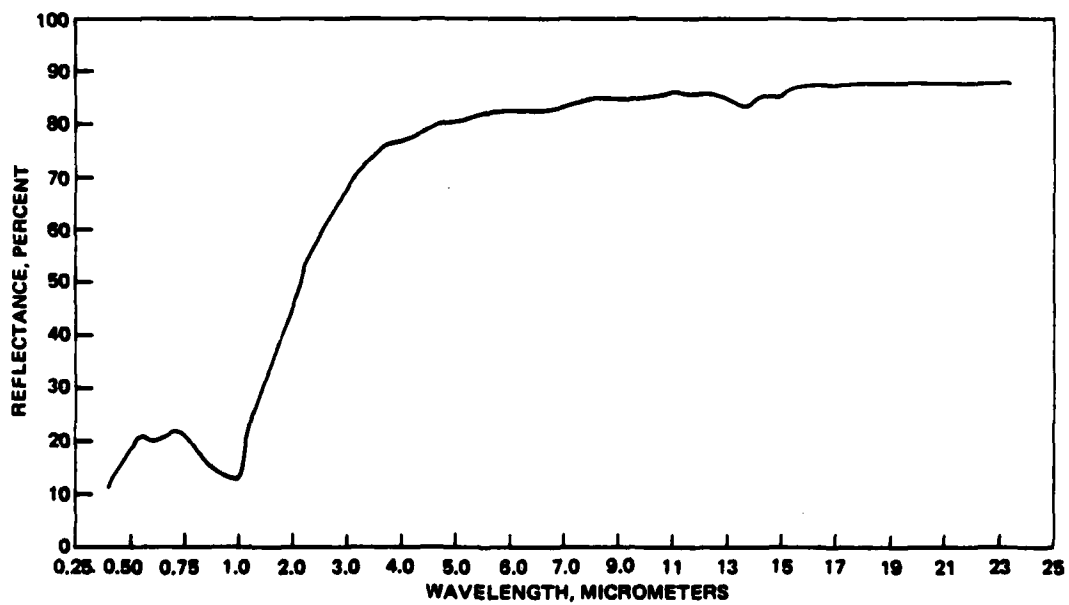


FIGURE 15. Spectral Response Curve of Black Chrome Surface Retroreflector.

FIELD TESTS

Field tests were conducted throughout the year as equipment was available. The objectives of these tests included COOLS subsystem performance evaluations, verification of computer model predictions and comparisons among different display integration techniques. Although these tests were designed and conducted primarily to facilitate the COOLS demonstration flight, important information concerning the feasibility of COOLS concept was obtained and is summarized later.

LASER SAFETY

Evaluation of the COOLS hardware required testing at various sites at NWC. An eye hazard analysis was conducted at each proposed site with all possible laser source configurations. A computer program has been generated at NWC which uses the laser safety standard of the American National Standards Institute Z 136.1-1973 Committee.⁷ A summary of this analysis is presented in Table 5. The alignment configuration of the CO₂ illuminator is intended for laboratory work only and cannot be initiated remotely. All other equipment/configurations are safe beyond 2.0 meters.

TABLE 5. Summary of Eye Hazard Analysis.

Laser source	Beam/source configuration	Output power at wavelength	Minimum safe range*
CO ₂ illuminator	Fan beam	10 W at 10.6 μm	1.89 m
CO ₂ illuminator	Elliptical	10 W at 10.6 μm	1.82 m
CO ₂ illuminator	Alignment	10 W at 10.6 μm	12.2 m
GaAs rangefinder	Low-power	10 W at 0.91 μm	0.0 m
GaAs rangefinder	Higher-power	50 W at 0.91 μm	1.19 m
CO ₂ PFB	10-degree scanned beam	3 W at 10.6 μm	0.35 m

* Unaided eye, direct view intrabeam.

⁷ Naval Weapons Center, *Laser Safety Computer Program*, by K. Labaw and R. T. Hintz. China Lake, Calif., NWC, September 1978. (NWC TP 6054, publication UNCLASSIFIED.)

PERFORMANCE MODELING

The task of determining the maximum operating range for the COOLS system involves analyzing a complex interaction among the various components. The FLIR operator must be able to discern the return signal from the retroreflector out of the background scene presented on his display. His ability to do this is a function not only of his visual acuity but of the FLIR gain and saturation characteristics, type of background, return beam uniformity as well as illuminator scanner coverage. Our approach in the test program was to investigate those factors which are unique to the COOLS concept and define a range of thermal contrast levels which should result in site identification.

An equation used to predict the irradiance at the FLIR collecting optics due to the retroreflected laser return signal is written as follows:⁸

$$H = \frac{A_R P_L \exp[-2R\sigma] \eta \times 10^{-10}}{\pi A_S R^2 \tan^2(\theta_L/2)}$$

where

H	=	Irradiance of FLIR optics (w/cm ²)
A_R	=	Effective aperture area of the retroreflector (cm ²)
P_L	=	Laser power (W)
R	=	Range to retroreflector (km)
σ	=	Extinction coefficient (km ⁻¹)
A_S	=	Area of return spot at the FLIR collector (cm ²)
θ_L	=	Equivalent full beam divergence angle of the illuminator for a circular beam (rad)
η	=	0.84, fraction of energy in primary lobe

If the return beam from the retroreflector is assumed to be a uniform, circular spot whose divergence corresponds to the Fraunhofer diffraction pattern for the retroreflector aperture, then the area of the spot is

$$A_S = \frac{\pi}{4} \left[\frac{1.22\lambda}{D} \times 2R \right]^2$$

where D is the effective diameter of the retroreflector aperture. The criteria necessary for these equations to be valid are that the separation between the laser exit aperture and the FLIR collecting optics be less than the radius of the return spot and that the operating range to the retroreflector be greater than R_{\min} where

$$R_{\min} > \frac{D^2}{\lambda} \cong 340 \text{ m}$$

Shown plotted in Figure 16 is the difference in irradiance at the FLIR collector which results from two thermal contrast levels ($\Delta T = 5 \text{ }^\circ\text{K}$ and $20 \text{ }^\circ\text{K}$) as a function of instantaneous field-of-view (IFOV). These curves represent contrast levels against a uniform $300 \text{ }^\circ\text{K}$ background scene. When used with Figure 17, which is a plot resulting from the range prediction calculation, a band of maximum operating ranges can be found. In the case of the subject COOLS demonstration hardware, the maximum operating range was approximately 1 kilometer, which was more than adequate for the test requirements.

STATIC TEST RESULTS

Ground tests were conducted throughout the year with a number of FLIR/illuminator combinations. The primary objectives of these tests were to certify the applicability of the calculated maximum range performance prediction to the COOLS hardware and to investigate the return signal variations as a function of range within 300 meters. The data collected during these tests pointed out other areas of interest to the COOLS concept which were summarized in the Conclusions section of this report.

A typical test setup included a FLIR (both serial-scan and parallel-scan models were used) directed toward an outdoor test range at NWC. The image was displayed on a TV monitor with a line monitor used to analyze any particular line of the display on a storage oscilloscope. A CO_2 laser, stabilized to reduce power level fluctuations, was mounted with a periscope lens arrangement to adjust separation between transmitter exit and FLIR collecting apertures. Figures 18 and 19 show side-on and front-on views of such an arrangement. The target retroreflectors were positioned at selected sites at a range which was measured by a separate electro-optical rangefinder.

The line monitor provided a means of obtaining relative signal strength information between different setup conditions. However, no absolute radiometric measurement could be made since critical data on the optical receivers were not available.

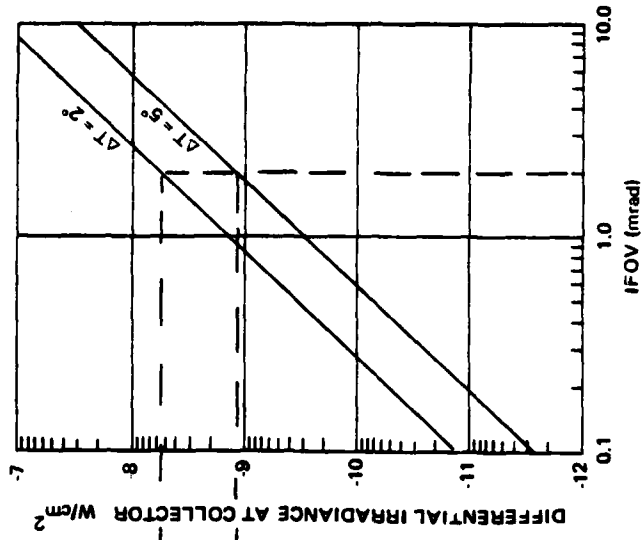


FIGURE 16. Contrast Level Plot.

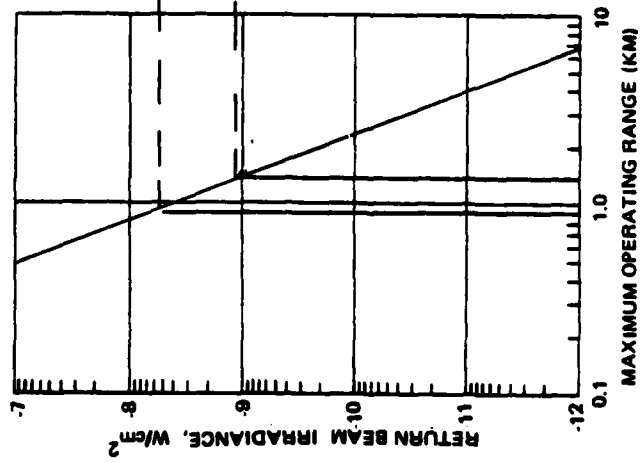


FIGURE 17. Range Performance Prediction Plot.

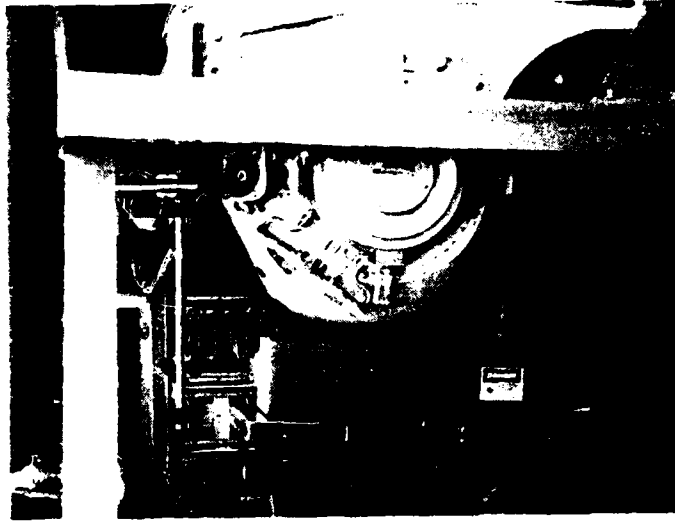


FIGURE 18. FLIR/Laser Setup Side View.

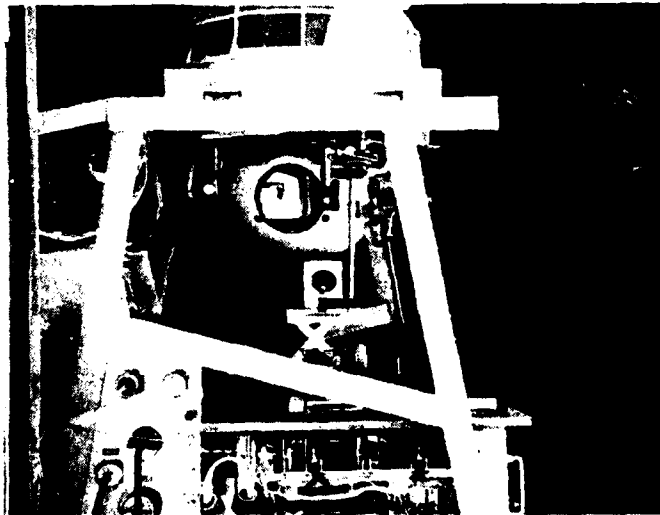


FIGURE 19. FLIR/Laser Setup Front View.

A series of data points is shown plotted on Figure 20 which represents the signal return levels obtained from a retroreflector placed at specific ranges. For comparison purposes, a line is shown which has a slope corresponding to a $1/(\text{Range})^2$ signal. This dependency is because the ranges tested are less than $R_{\min} = D^2/\lambda$. The flattening of the curve at ranges within 100 meters is probably the result of saturation effects. At ranges in excess of 400 meters, the signal level was below the sensitivity of the receiver as a result of using only a 1.5-watt laser for these tests.

An interesting phenomenon with important consequences to the COOLS concept is illustrated in Figure 21. During this test, the 6 centimeter diameter target retroreflector is placed at approximately 100 meters and rotated about the line-of-sight axis of the FLIR. In this way the importance of retroreflector orientation is observed. The return signal level was recorded at 10-degree intervals through an angle of 120 degrees. For this particular laser/FLIR combination, the return signal varied through the FLIR's entire dynamic sensitivity range from saturation through acquisition signal levels during the rotation from 40 degrees to 80 degrees. Other retroreflectors exhibited similar effects with patterns that repeated roughly every 60 degrees. This dependency on orientation was removed from the COOLS tests by determining an optimum orientation for each retroreflector and maintaining this orientation throughout the test program.

Test results on the spectrally selective coating were very encouraging. The illuminator signal return from the black chrome retroreflector was essentially equal to that of the other types, while the GaAs rangefinder (0.9 micrometer system) could not respond to it even at close range as expected. Other data were collected in this phase of the program regarding separation of transmitter and receiver, adverse weather propagation, and the effects of gain and brightness settings on target detection. While consistent with the analysis performed, this data base proved insufficient to confirm that analysis. Video tapes of the tests are available for further analysis in specific areas.

FLIGHT TEST RESULTS

A series of five flights totaling approximately seven flight hours were run in October 1978. The landing site chosen was the breach of the SNORT track at NWC. Figure 22 is a sketch of the area and indicates the general placement of the ground equipment. The flight profile began with an approach from the north at a constant altitude of less than 70 meters at a velocity of approximately 50 knots. The pilot, cued by the range readout superimposed on the FLIR image, slowed to a hover with a slant range to the site of approximately 300 meters. After confirming proper equipment operation with the ground site, the test coordinator signalled the pilot to make a constant glide slope approach to the landing site as outlined by the retroreflectors. Video tapes were recorded simultaneously on both the FLIR image and the TV camera used to direct the ranging sensor.

FLIR imagery was recorded showing beacon homing and retroreflector returns during landing operations conducted both day and night. Daylight tests included both heavy overcast as well as clear conditions. During the night operations the overhead lights at SNORT were used to insure adequate obstacle avoidance.

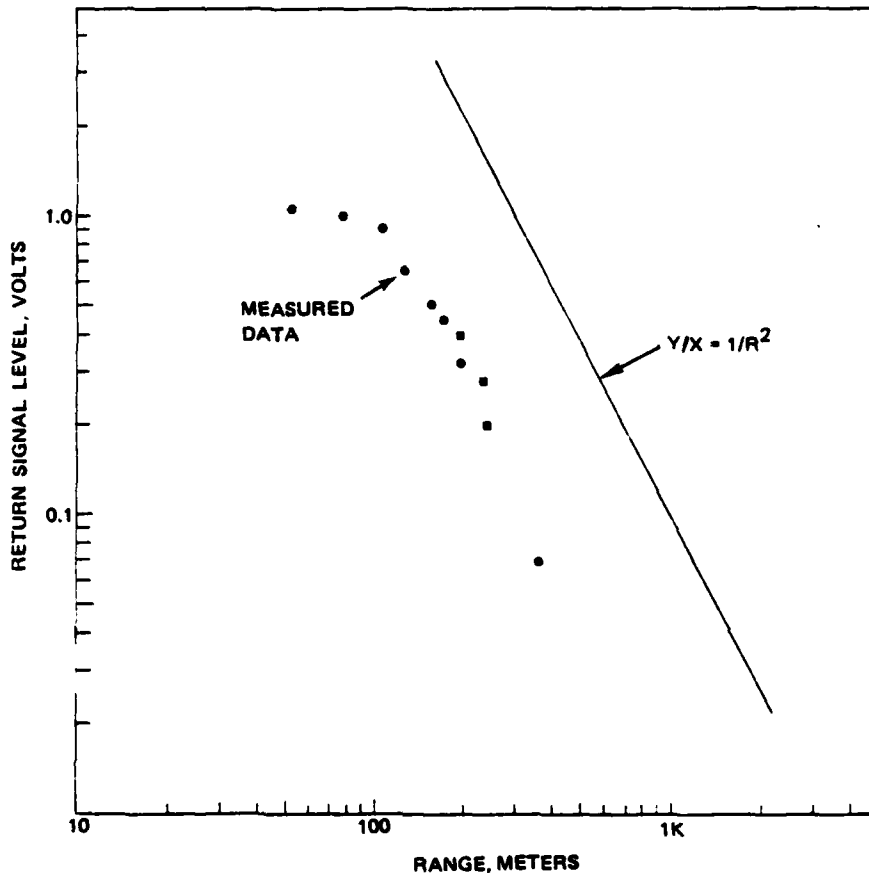


FIGURE 20. Mid-Range Performance Data.

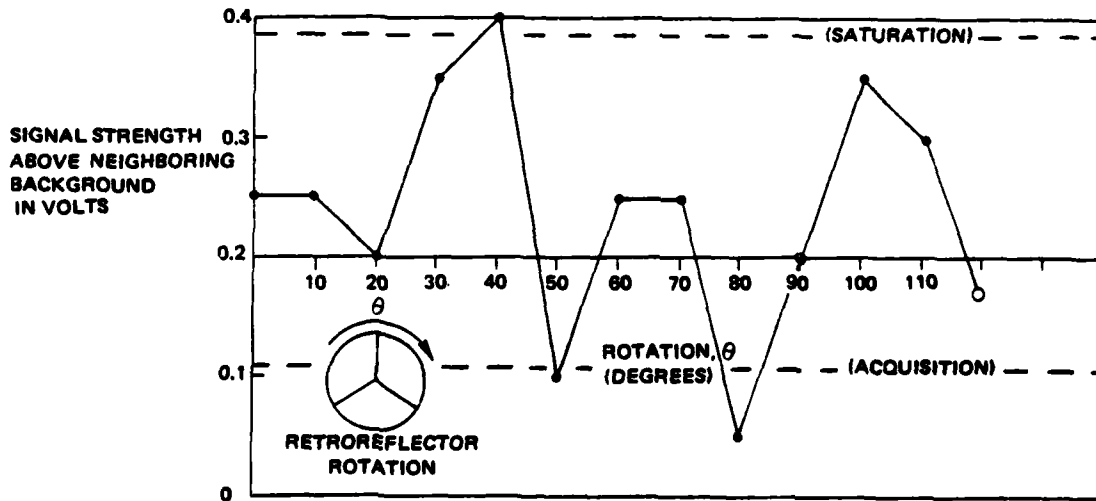
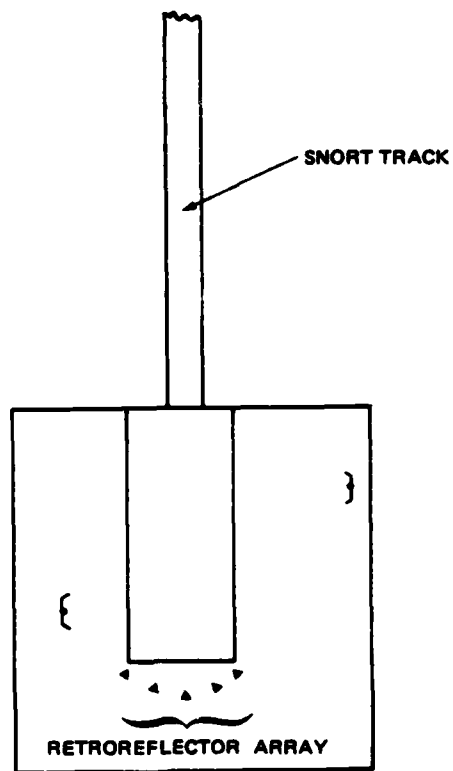
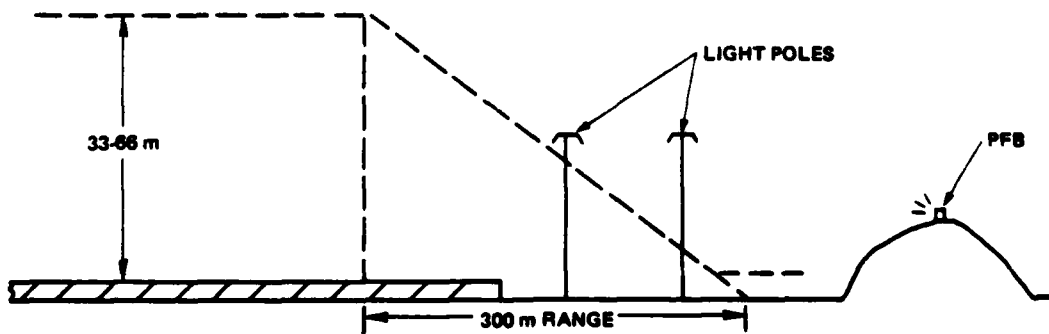


FIGURE 21. Retro Reflector Orientation Sensitivity Plot.



(a) ELEVATED VIEW



(b) SIDE VIEW

FIGURE 22. Flight Test Site.

Due to the very limited flight time available, there was no opportunity to refine the symbology or hardware implementation. Those items which caused difficulty in the test effectiveness were isolated and noted but were not corrected unless significant improvement in the test results were likely.

In addition to the landing operations described above, a demonstration of site recognition based upon retroreflector return alone was made. During this test, individuals were stationed at unmarked positions in a desert terrain. Each individual pointed a retroreflector toward the COOLS-equipped helicopter as it searched the area with the composite FLIR/illuminator FOV. The retroreflector return clearly identified the location of the ground personnel while no other evidence of their presence in the FLIR FOV was available.

CONCLUSIONS AND RECOMMENDATIONS

Demonstration of the COOLS concept required the acquisition of three major components and integration of this hardware onto a helicopter platform. These components consisted of a night vision sensor, a laser illuminator/scanner and a rangefinder. The primary data output of the test phase was a video tape recording of the various aspects of a helicopter approach and landing utilizing this equipment.

Flight tests were conducted in October 1978 at the SNORT test facility located at NWC. Data were recorded during low-level flight, beacon homing and approach, and landing operations both day and night. Although certain hardware limitations were noted and scheduling problems prohibited extensive testing, adequate data were recorded to clearly demonstrate the system concept. In so doing, considerable experience was gained regarding the interactions among FLIRs, lasers, and retroreflectors. While question areas have been identified, the test results offer a data base from which to continue and indications that follow-on efforts will be productive.

There was no opportunity to verify experimentally the predicted maximum retroreflector detection range of 1 kilometer. The test procedure required that signal returns from the site retroreflectors be discernible at ranges of 300 to 500 meters. This capability was shown in both ground and flight configurations with the 6-centimeter diameter retroreflectors. Signal return was also identified from ranges less than 10 meters from the same reflectors although the high accuracy of these retroreflectors is actually a disadvantage at close ranges. The best COOLS configuration may be a high-accuracy reflector for long-range ($R > 300$ m) acquisition surrounded by an array of a small-aperture, low-accuracy type for short range ($R < 100$ m) operation.

The ground test section in this report discusses the nonuniform return pattern from the retroreflectors used. This information questions the value of further model verification until better characterization of the retroreflectors is accomplished.

The black chrome finish on the retroreflector proved to be more durable in the field testing than the standard gold surface. The signal variation between different retroreflectors, plus the critical orientation signal dependance requires a before-and-after-deposition type of measurement to determine the amount of signal attenuation due to the coating process. But from the test results it does not appear to

be significant. The spectral selectivity was clearly shown by the inability of the near-IR ranging sensor to operate with this type of retroreflector even at close ranges.

A debriefing session was held at NWC following the flight test sequence attended by Colonel Madera, Lieutenant Colonel Adams, Major Vacca, Bob Hintz and the author. A short video tape of the FLIR image during the COOLS testing was shown and a general discussion was held which generated the comments listed below. The statements are divided into two general categories. The first statements are observations dealing with FLIR operations in the UH-1 helicopter while the last are related to the COOLS concept.

1. FLIR OPERATIONS DURING COOLS TESTS

a. The pilot workload on the UH-1N is excessive. It has no automatic flight control system (AFCS) as does the CH-53. The need to hover in the COOLS approach made concentration on and adjustment of the FLIR display next to impossible in flight.

b. To be able to fly by the FLIR display, the pilot needs information on sideslip, attitude (roll and pitch), airspeed (closure rate would do) and altitude. To aid in the depth perception with the wide FOV, a pointer on the FLIR image should be used to indicate a particular range from the aircraft.

c. Even with the wide FOV (30 degrees by 40 degrees), the pilot cannot actually navigate by FLIR alone unless he is extremely familiar with the area. He can follow terrain and recognize landmarks.

2. COOLS CONCEPTS

a. Retroreflectors were not very useful in the tests because of small signal return. This may require modifications of laser/FLIR spatial separation, additional persistence on display, or a signal processing aid to enhance recognition.

b. Hover should not be required during the approach. Perhaps the use of two beacons would inform the pilot of the correct approach vector to enhance the return from the retroreflector array.

c. A large retroreflector array is needed, one which gives a better indication of depth and width, such as the examples shown in Figure 23.

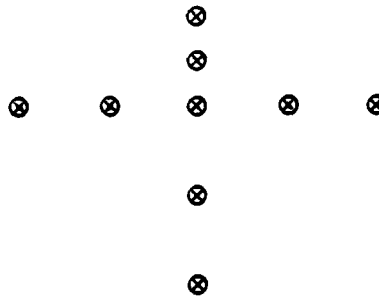
d. The annotated range display should show only significant digits. Higher resolution is needed only at close range. The lower resolution digits should be stable or blanked.

It should also be noted that none of the pilots had previous FLIR experience. Although they liked the FLIR image, they were clearly not comfortable flying strictly from the display. It has been estimated in previous FLIR work reported by the Army that up to 50 hours of FLIR training is needed to become proficient at similar tasks.

The use of the available UH-1N aircraft at NWC, although successful in obtaining the required data, is of limited value in assessing the operation characteristics of the



(a) Segment of Circle.



(b) Cross.

FIGURE 23. Suggested Retroreflector Positioning.

COOLS concept. The human factors aspects of display symbology, pilot workload and retroreflector array configuration should be addressed in an aircraft similar to the CH-46 or the CH-53 variety. Future tests should also be scheduled to provide ample time for pilot training and minor equipment modification.

To remove the variables of FLIR gain and contrast settings from the probability of retroreflector detection, it is suggested that electronic signal processing be utilized. For example, if the video signal were to be examined immediately following the detection and pre-amplification of the scene information, the FLIR operator could optimize the background information without regard to possible saturation or limiting of the beacon or laser return signals. The processor could take advantage of prior knowledge of scan rate, signal bandwidth, etc., to detect the signals and display site location without dwell-time limitations which are inherent in the present display format.

The test results offer several insights into the operational requirements on the COOLS rangefinder. The sensor should be wavelength-compatible with the FLIR to take full advantage of the covert qualities of the retroreflectors. In addition, the functions of illuminator and ranging should be combined into a single package if possible in the interest of aircraft equipment simplicity. Requirements for display resolution, update rate and format can be deduced from the test results. These factors will help direct the rangefinder development scheduled for FY 1979.

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