

UAV Infrared Search and Track (IRST)/Eyesafe Laser Range Finder (ELR) System

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UAV IRST/ELRF FOR ATPF

1.0 INTRODUCTION

Based on the lessons learned from 9/11, the Naval Anti-Terrorism Force Protection (ATFP) program is now considering an airborne IRST as part of a family of sensors, which can be used to monitor air traffic in the vicinity of Naval facilities around the world. This IRST is intended to augment current capabilities by providing a method of detecting and tracking even low flying small aircraft using terrain features or urban canyons to mask their approach. This paper describes an Infrared Search and Track (IRST) system integrated with an eyesafe laser rangefinder (ELRF) and intended for operation from an unmanned air vehicle (UAV) with automated targeting and fire control functionality. The IRST sensor was developed under a jointly funded MDA/ONR contract with Raytheon, but the completion of the eyesafe laser rangefinder and its integration and demonstration was only accomplished recently under NAVAIR internal funding. In addition to low flying aircraft this IRST sensor must also be able to detect and track missiles launched from shipboard platforms readily found around the world, so the capability must be there to operate against a wide range of targets with large variations in their signatures. This sensor possesses the desired dynamic range for all of these applications and the passive IRST sensor participated recently in data collections for Blue Velvet 1 & 2 missions. Infrared imagery and pointing data was collected during the two events. Although the Blue Velvet (BV) target (SCUD) is the oldest and most widely deployed theater ballistic missile in the world its emissions and reflections had never been measured during its boost phase.

The coude path incorporated in this sensor provides a means for an external eyesafe laser rangefinder to share the aperture with the narrow field of view passive MWIR sensor. The fabrication and installation of the coude path mechanical and optical components was completed recently and the evaluation of a short-range eyesafe laser rangefinder with this sensor is described. The demonstration of the eyesafe laser rangefinder pointed by the MWIR IRST, will not only provide precise 3-D tracks from a single platform, but it will also provide a rudimentary form of target recognition based on 1-D profiling. This paper also touches on previous NAVAIR work with LADAR 1-D profiling and discusses how it can be implemented for this passive/active sensor.

Hintz, R.T.; Allen, J.; Chen, M.; Price, T.; Goetz, G. (2005) UAV Infrared Search and Track (IRST)/Eyesafe Laser Range Finder (ELR) System. In *Emerging EO Phenomenology* (pp. 9-1 – 9-14). Meeting Proceedings RTO-MP-SET-094, Paper 9. Neuilly-sur-Seine, France: RTO. Available from: <http://www.rto.nato.int/abstracts.asp>.

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2.0 BACKGROUND

The Naval Anti Terrorism Force Protection (ATFP) program is intended to address a broad range of potential threats to U. S. Naval Facilities around the world. Recently NAVAIR was assigned the lead role for the Air Defense portion of the program, and a UAV mounted IRST with a high level of automation was identified as a critical part of the Air Defense against small low flying aircraft or missile launches from ships in the vicinity of those facilities.

The UAV IRST was based on modifications to the Navy LAMPS FLIR built by Raytheon, and the mechanical structures have been ruggedized for maritime environments. The sensor is integrated with an LN-100G INS/GPS, and can provide absolute tracks in WGS-84 or other coordinate systems. The IRST was flown on a CONVAIR 580 aircraft in data collection exercises coordinated with launches from White Sands Missile Range (WSMR) and Vandenberg AFB. After delivery to NAVAIR in July 2002, the system was installed in a truck, transported to Anderson Peak, California, and used to support data collections against the Blue Velvet targets. Although funded at the same time as the passive MWIR IRST development, the eyesafe laser rangefinder was not completed when NAVAIR took delivery of the sensor. The Raytheon Company was the lead on the IRST development and they elected to have development of the eyesafe source performed by Lite Cycles Corp. Recently Lite Cycles completed the development of this laser and subsequently delivered it to NAVAIR for future integration into the IRST. The characteristics of the coude path, its original checkout with the MELIOS eyesafe laser rangefinder, and the plans for integrating the Lite Cycles source into the eyesafe laser rangefinder system will be discussed later in this paper.

3.0 UAV IRST DESCRIPTION

The UAV IRST program relied upon significant reuse of existing hardware and software to reduce cost, risk and schedule. This is because the primary purpose of the program was to reduce technology and component risk, and to focus the effort on the systems integration key issues of timeline, range performance, and 3-D precision tracking. Reuse legacy is described in section 3.1 and modifications are described in section 3.2. Signal processing (section 3.3) is implemented in commercial off-the-shelf (COTS) hardware. It performs advanced real-time IRST processing (including target detection and the integrated multi-target tracker), provides unique state and mode controls, and provides the external interface to the system. Although the design of the coude path for introducing the eyesafe laser rangefinder was performed under the contracted effort, the completion of the coude path hardware, and subsequent integration of the eyesafe laser rangefinder was performed with NAVAIR internal funding.

3.1 Sensor Legacy

Compact, high-performance, non-developmental FLIR equipment is used for the IRST WFOV search and NFOV fire control. The IRST is derived from the Raytheon AN/AAS-44 LAMPS FLIR product line, which meets military specifications for the Naval Fleet environment.

Figure 3.1-1, shows this IR sensor packaged in a 12-inch gimbal with a high performance, midwave infrared (MWIR) optical subsystem, precision stabilization and pointing, and flexible interfaces. An NDI commercial off-the-shelf (COTS) processor (VME PPC 604e) provides unique IRST processing and precision target state estimation.

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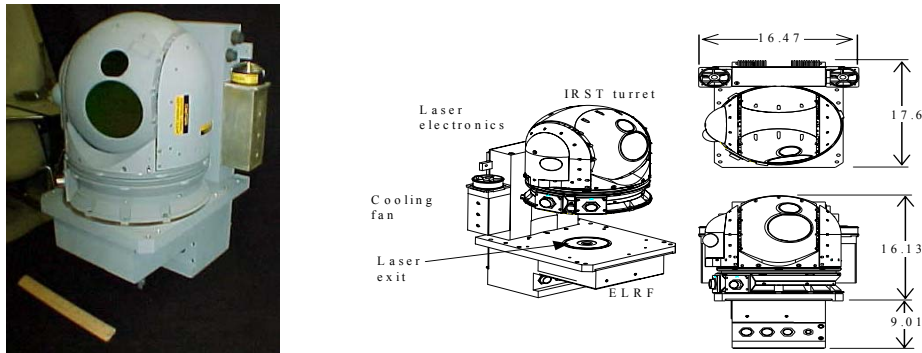


Figure 3.1-1 UAV with ELRF and LN 100G

The UAV IRST sensor system architecture, along with modifications needed to change to RAID recording is shown in Figure 3.1-2. The flight-tested 12-inch Turret Unit features dual fields of view, two-axis gimbal stabilization (pitch and yaw but not roll compensated), and two-axis mirror active stabilization of both video and laser to achieve required system performance. The System Controller provides system command and control interface, pointing and stabilization, video processing, automatic video tracker, and power control functions. The UAV IRST controller is a laptop computer with both control and instrumentation and diagnostics functions. The System Controller is based on the digital signal processor (DSP) TMS320C40, and achieves over 94% hardware reuse and 86% software reuse from the AN/AAS-44 product family. This unit provides the IRST target detection and integrated multi-target tracker functions in addition to aim-point biasing for pointing the ELRF at the TBM hard body.

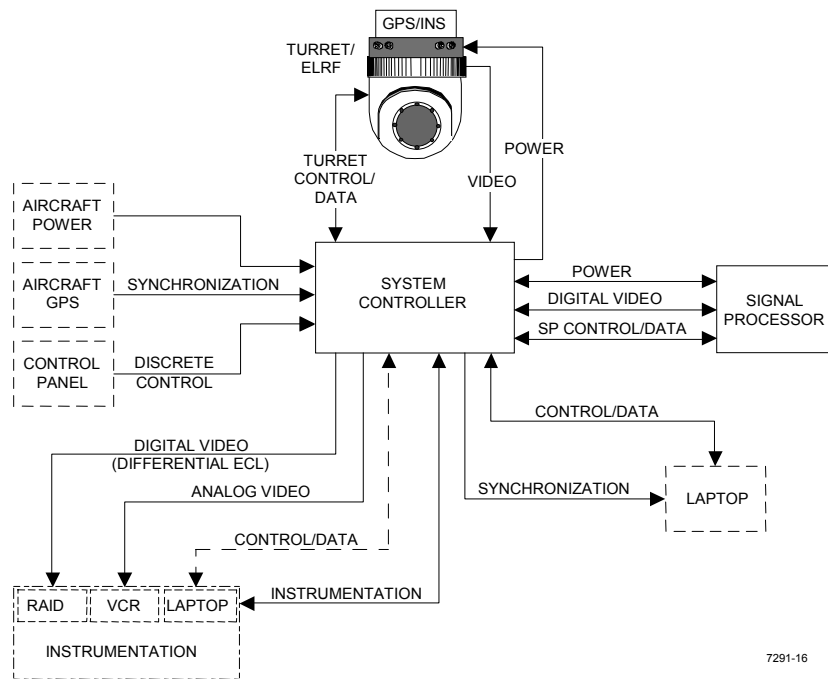


Figure 3.1-2 RMS system architecture

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The baseline ELRF was a Lite Cycles, Inc. Solid State Raman Laser (SSRL) with a diode-pumped Nd:YLF laser coupled to a solid state Raman crystal of barium nitrate, Ba(NO₃)₂. An eyesafe MELIOS laser rangefinder was substituted (as described later in this report) to demonstrate the 3-D tracking functionality at short ranges (rangefinder electronics limit MELIOS performance to 10 km).

3.2 Sensor Description

Timeline analysis showed that a single-IRST sensor could achieve the required field of regard and target update rates for the Boost Phase Intercept UAV IRST program. Therefore, our approach is to add the ELRF functionality to an existing MWIR sensor and to timeshare the sensor for both search and fire control. Figure 3.2-1 depicts the key components of the UAV IRST. The ELRF beam will be injected into the IRST turret through a Coude optical path (COP) arrangement that transports the beam along the rotation axes of the turret gimbals. Packaging for the UAV IRST is shown in Figure 3.2-1.

Turret / ELRF



System Controller



GPS / INS



Signal Processor



Figure. 3.2-1 UAV IRST Packaging

The search function is accomplished by modifying the WFOV from the legacy sensor to achieve additional elevation FOV coverage. The wide field of view (28 x 28 degrees) provides the necessary field of regard for the search function by implementing a 3 position, two bar scan in a step and stare scan method. The sensor field of regard (FOR) is 360-degrees in azimuth by +105-degrees to -50-degrees in elevation, with the operational FOR limited by the aircraft installation. The fire control function requires fine angle resolution and uses the NFOV of the legacy sensor. The fire control FOR is the same as the search FOR.

During IRST operation, the gimbal line of sight (LOS) is controlled by the scan function and the IRST detection processing within the signal processor processes the IR video and provides the target measurements to the integrated multi-target tracker. During closed-loop target tracking, primary control of the gimbal LOS is relinquished to the sensor's internal target state estimator (TSE), which is driven by position measurements from the sensor video tracker. This architecture allows gimbal pointing commands based on inertial target coordinates. The video tracker is responsible for segmenting the target image from background and for producing az/el centroid location measurements for the target, which are provided to the integrated multi-target tracker within the signal processor. This process is coupled tightly with the sensor's internal TSE to transform estimates of target inertial coordinates to pixel space for aiding in clutter rejection and segmenter coasting. The video tracker is an adaptive-gate centroid capable of adapting to single-pixel targets or to those as large as 80% of the FOV. It will lock onto detectable targets when provided with cues generated by either the IRST function or an external command. The video track function, operating in concert with gimbal LOS control, provides for offset track biasing so that the ELRF can be directed at the TBM hardbody. Range data becomes available during closed loop tracking.

UAV IRST SYSTEM CHARACTERISTICS

• Weight (total)	260.6 lbs
- Turret (with ELRF)	69 (121)
- Controller	53
- Processor	65
- GPS/INS	21.6
• Volume (total)	7.2 cu. ft.
- Turret	1.6
- Controller	1.5
- Processor	3.7
- GPS/INS	.4
• Power (total)	1774 watts
- Turret	580
- Controller	214
- Processor	750
- GPS/INS	40
• Performance	
- FOR	90° EL x 165° AZ
- FOV	3° x 3° (NFOV) 28° x 28° (WFOV)
- IFOV	.10 mR (NFOV) 1.0 mR (WFOV)
- NEI (watts/CM ²)	6.2E-15 (NFOV) 2.8E-13 (WFOV)

Figure 3.2.2 UAV IRST System Characteristics

4.0 UAV IRST DEPLOYMENT TO ANDERSON PEAK

For the Blue Velvet test series, it was decided to operate the IRST from an elevated (4000 ft) site operated by Vandenberg AFB. This site was located at Anderson Peak in the Los Padres National forest. The site is only serviced by a long, winding, narrow, dirt road and it was necessary to mount the equipment in a 4-wheel drive vehicle that could navigate this road. Figure 4.1a & b. The entire UAV IRST sensor, 400 cycle power inverter, and RAID recording system were transported in this truck along with the LN 100G and sensor controls shown in figure 4.2.



Figure 4.1 Test Van rearview



Figure 4.2 Sensor Controls

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5.0 BV EVENT DESCRIPTION

A more complete description of the BV events is provided in reference 1. The target on its launcher is shown in figure.5.1.



Figure 5.1 Missile Launcher

6.0 UAV IRST SIGNAL TO NOISE RATIO

The IRST Signal to Noise ratio was derived from the digital video output recorded during the Blue Velvet events. The system is shown in the laboratory test configuration in Figure 6.1 along with a PC based RAID disk drive device in Figure 6.2.



Figure 6.1



Figure 6.2

The system block diagram was shown in Figure 3.1-2 and as indicated the digital video output signal, originally intended to be recorded on an Ampex DCRSi recorder, was routed to the RAID drive. The data stored on the RAID was archived on DVD disks. Recovery and reduction of the data was made difficult due to equipment problems and the peculiar format of the recorded data. Equipment difficulties included 1) the RAID disk drive system required a set up time as long as the desired record time and thus for BV1, the need to reboot the system resulted in a file of only 1200 frames or 40 out of a total 271 seconds launch time and 2) for BV2, the RMS system failed to generate a frame sync word and as a result, the data had no reference header or frame reference. Recovery of the video frames was made very difficult. Data structures and formatting peculiarities also caused data reduction problems. As an example, the 12 bit pixel data was compressed to 1 and ½ bytes. Two byte per pixel processing would have been less complicated. Additionally, output video frames were composed of fields (two per frame) derived from different focal plane array frames. Field to field transmission was not line sequential but rather field sequential.

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Computer processes were developed to translate the archived data from a simple 8 bit format into MPEG, JPEG and Bitmap file types and to recover the garbled data of BV2. From the recovered data, the signal to noise ratio (S/N) of the target to background was determined by finding the peak intensity of the target, subtracting the mean value of a selected area about the target and dividing by the standard deviation of the background for each frame. A PC process (the application window is shown in Figure 6.3) developed by NAVAIR WD was used to easily find the target in the video frame and automatically create an Excel file for the required calculation. A complicating factor encountered in attempting to correlate the perceived S/N of the IRST to the Contrast Irradiance (derivation described in a preceding section of this report) was the lack of time correlation of the data with respect to the missile launch TALO. For BV1, the only known time hack available is the PC file time. For BV2, time could at least be correlated with the point at which the target clears the terrain obscuration in the displayed analog video which includes the countdown time. Actually, a more precise point used was the change from WFOV to NFOV at TALO = 30 seconds.

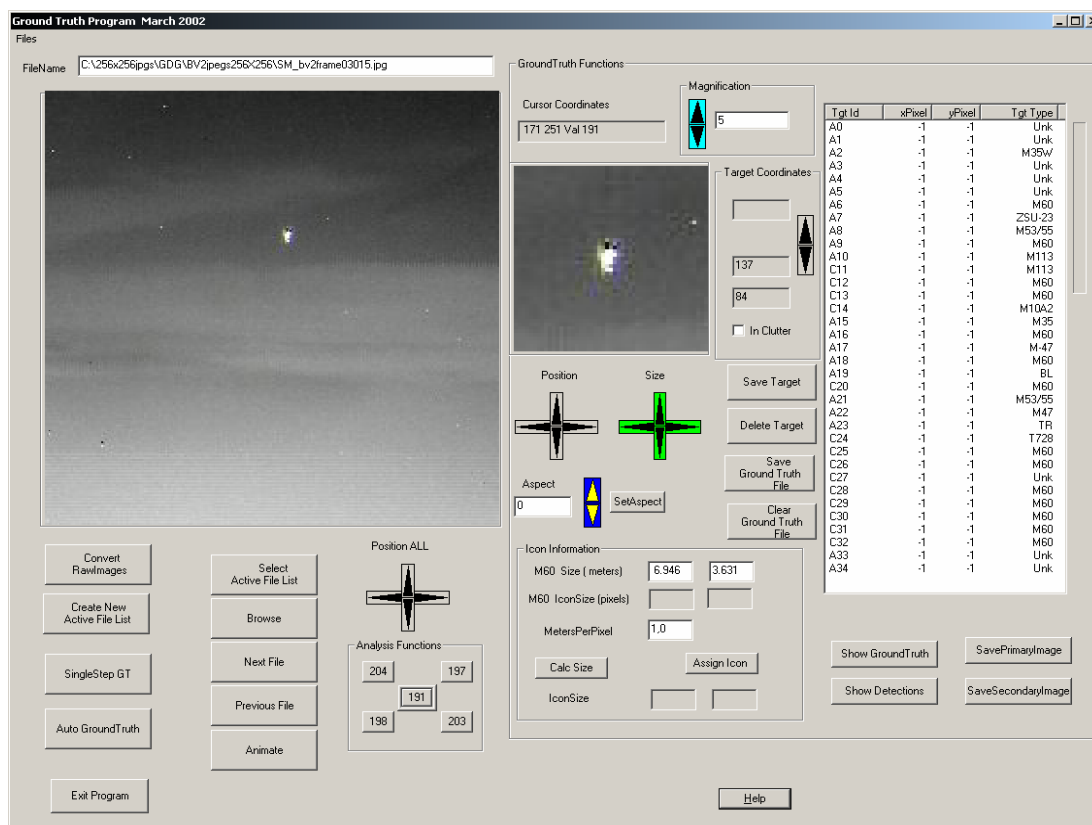


Figure 6.3 (U)

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7.0 1-D RANGE PROFILING AS AN AUTOMATIC TARGET RECOGNITION TECHNIQUE

The eyesafe laser rangefinder can produce a 1-D range profile as shown in figure 7.1. Two approaches were investigated for automating the separability of these aircraft (Chi square metric and pseudo random noise). Both approaches were found to be successful for SNR's > 10 , over a wide range of resolutions. This earlier work did not investigate the applicability of this approach at lower SNR's expected at the maximum range of the laser rangefinder. Although the data was gathered at 1.06 micron, similar results are expected for the 1.53 micron laser systems currently integrated with the IRST.

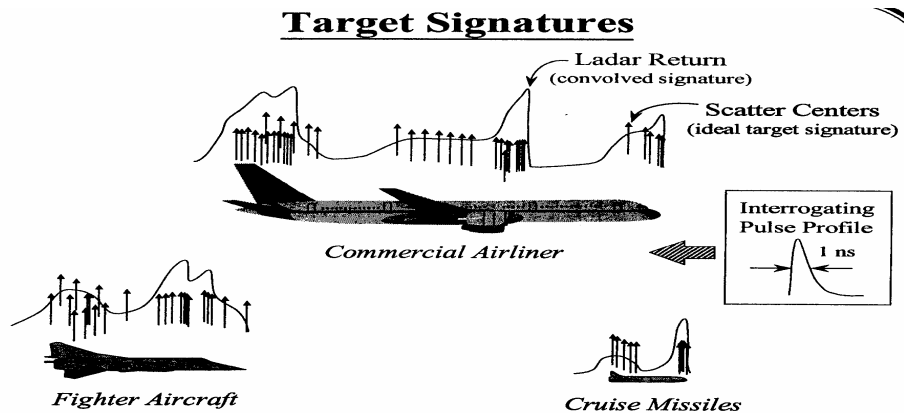


Figure. 7.1 Range Profile Identification

8.0 ADDITIONAL UAV IRST DEVELOPMENT AND TESTING

Since UAV IRST has demonstrated that it is a State of the Art (SOA) MWIR dual FOV imager that has successfully observed boosting and non-boosting TBM's in flight, there is always the question of what other roles could it perform to justify its installation on an unmanned air vehicle. Currently NAVAIR has identified 3 applications for which the UAV IRST is ideally suited as a data collection system. These applications are the following:

- 1) Anti Terrorism Force Protection (ATFP)
- 2) MWIR IRST/Eyesafe Laser Rangefinder precision 3-D tracking T&E asset
- 3) Demonstration of Boost Phase Intercept from BAMS (Navy Global Hawk)

Each area will be discussed in the following sections:

Anti Terrorism Force Protection: Recently the Navy has put together a program to enhance the protection of Naval Facilities around the world. It will be administered by the Commander, Naval Installations (CNI). and is intended to address a broad range of threats to our facilities and servicemen. All the areas of activity under this program were summarized earlier in figure 2.1. The highlighted task led by NAVAIR is the Air Defense role.

In this case there are multiple facets to this defense based on the types of threat. These threats are composed of manned and unmanned aircraft operating at a variety of speeds and altitudes, and even ballistic missiles. Defending against this broad range of threats involves several tiers of sensors and defensive systems which are not currently in place. Current ground based radars at these installations cannot contend with low flying

light aircraft approaching down urban canyons, or masked by terrain, or launches of ballistic missiles from shipping located off the coast. An airborne IRST capable of automatically performing a large area search, simultaneously tracking multiple targets, classifying targets as potential threats, and developing precision absolute 3-D tracks for handoff to facility defenses is an ideal adjunct to enhance situation awareness and provide fire control solutions to defenses. The IRST could be hosted on a UAV which can loiter in the vicinity of the facility, and require minimal human interaction. Figure 8.1 is a notional scenario for this type of application based on a high endurance platform like the Global Hawk UAV.



Figure 8.1 Global Hawk performing ATFP against ship launched missile OR Cessna Raid

The integration of the UAV IRST was already studied for the Global Hawk, and figure 8.2 shows the location for the sensor on this platform. At 65,000 foot altitudes the Global Hawk can maintain 24 hour surveillance of a large area the can readily encompass even a large facility and a broad defense perimeter. If the hard points on the wings of global Hawk were used for missiles, this platform could even provide a first line of defense against a boosting theater ballistic missile or a small aircraft as discussed in UAV IRST for BPI section below.

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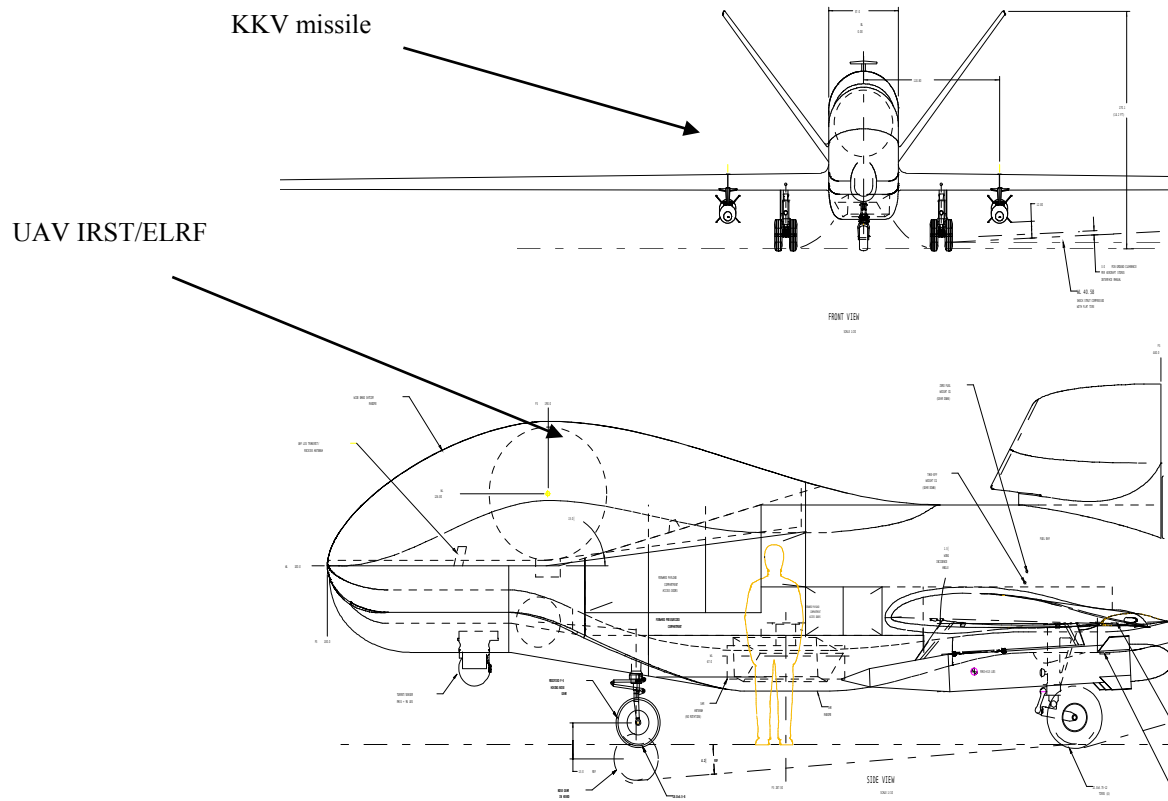


Figure 8.2 Global Hawk BPI Study Demonstration Configuration

UAV IRST as 3-D tracker for Test & Evaluation

Ideally the addition of an eyesafe laser rangefinder to an UAV IRST could provide the data collection information for a variety of applications with manned and unmanned platforms. Since the UAV IRST eyesafe laser rangefinder was not completed it was decided to integrate an existing eyesafe laser rangefinder into UAV IRST using the coude path designed by Raytheon with suitable modifications. A “MELIOS” eyesafe laser rangefinder was available for this integration and it has the following characteristics:

- Wavelength – 1.59 μ m (eyesafe at aperture)
- Range – 0 to 9999 meters
- Range Accuracy – 10 meters
- Data Rate – 1 Hz

Figure 8.3 shows how this integration was accomplished. Since the coude path beamsplitter (fabricated and installed by NAVAIR) was designed for a 1.5 micron eyesafe laser system the MELIOS laser rangefinder became an ideal choice for this demonstration. The complication in its use is the separate transmit and receive apertures which needed to be merged to share the common coude path. The UAV IRST sensor coude path was designed but not completed by Raytheon so 2 mirror mounts, 2 mirror coatings, and a mounting structure were needed to complete the system. These mechanical items are:

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- 1) Elevation #1 coude fold mirror mount
- 2) Elevation #2 coude fold mirror mount
- 3) Laser beam expander mount housing
- 4) Laser beam expander insert
- 5) Mounting bracket

as shown in Figure 8.3.

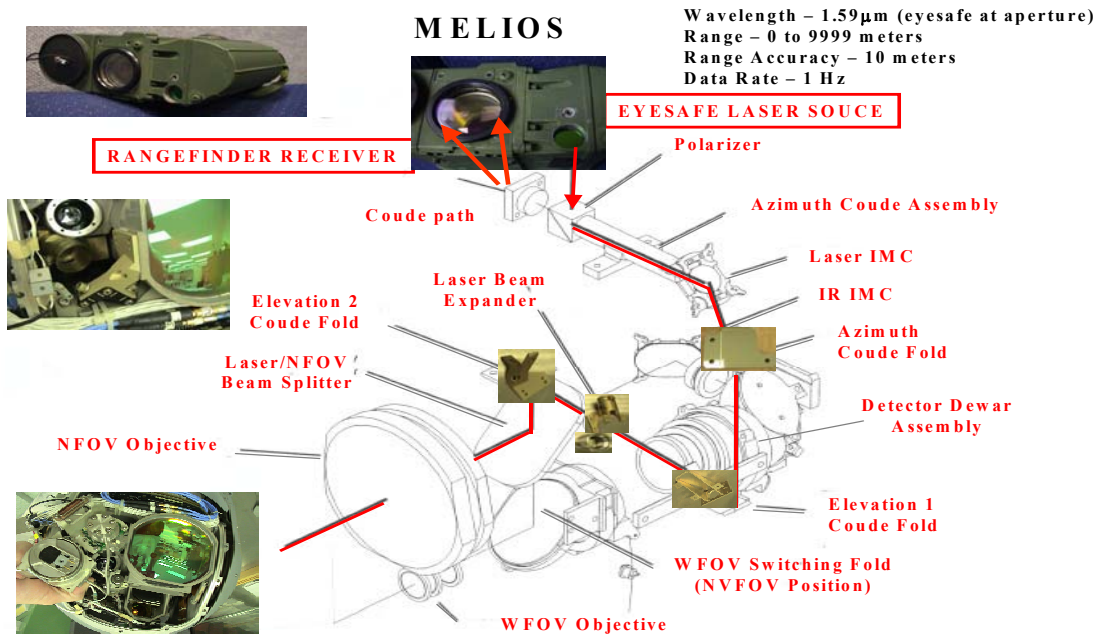


Figure 8.3 MELIOS Eyesafe rangefinder integrated with UAV IRST Coude path with additional mirror mounts and fixtures to complete Coude path

MELIOS has a separate transmit and receive aperture so they had to be combined and sized to match the coude path. The hardware for combining the MELIOS separate transmit and receive apertures with the IRST code path is shown in figure 8.4.



Figure 8.4 IRST with MELIOS & laser path integration

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The initial demonstrations were done with the laser beam expander element removed to maintain higher laser power densities to simplify the alignment. An external detector was used to make an independent measurement of range to compare with the output of the MELIOS rangefinder processor figure 8.5.

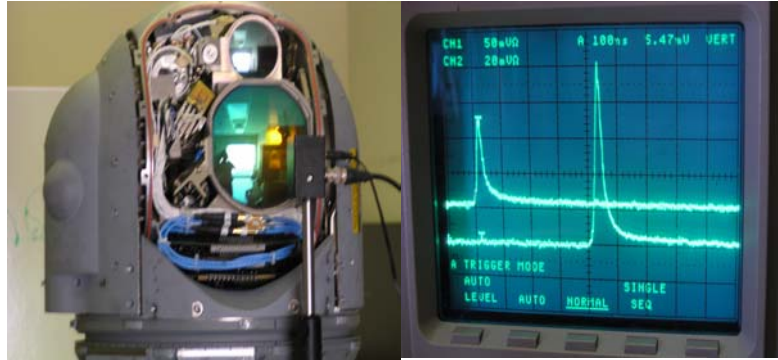


Figure 8.5 External detector for range calibration and test result

The results of this comparison indicated less than 1 meter difference in the measurements. For the maximum range performance the beam expander element is installed so that the eyesafe laser rangefinder can use the entire 3.88 inch aperture for transmit and receive. The MELIOS laser rangefinder signal processor limits the maximum range to 10 kilometers. Lite Cycles recently delivered a more energetic eyesafe laser source which could extend the range performance to 100 kilometers. The details of this source are described in reference 4. When the eyesafe laser rangefinder is used in conjunction with the IRST target tracker, the combined active passive sensor can produce precise 3-D tracks that can be used to make launch point and impact point predictions from a single observation point.

With the sensor mounted on a UAV, there is also the capability to collect data on ballistic missile threats from the most relevant aspect (inside the current keep out zone for manned aircraft surveillance). This would make the UAV IRST a prime T&E data collection asset.

9.0 CONCLUSION

The UAV IRST has successfully been used to support two data collections against the most widely deployed boosting theater ballistic missile. The performance model has been shown to have good agreement with the sensed data from the BV trials. The coude path has been completed and the eyesafe laser ranging has been demonstrated using the MELIOS unit. A higher power eyesafe laser source has been delivered, and when integrated with the IRST could support performance out to 100 kilometers. The combination of the precise angular track and the laser range information allow the system to produce target state estimations that allow prediction of the future positions of targets. In addition the eyesafe laser ranging can also be used to support automatic air target recognition based on 1-D range profiles, as demonstrated on the F/A-18 and MIG-23 database.

10.0 REFERENCES

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