UAV-Capable Coastal Hyperspectral Imager

1. Introduction

This document contains the description, specifications, acceptance tests, and other requirements for a UAV (unmanned aerial vehicle)-Capable Coastal Hyperspectral Imager.

2. Overview

This request is for proposals for a UAV-Capable Coastal Hyperspectral Imager, to be delivered and set up at the Naval Research Laboratory (NRL) in Washington, DC. The delivered system must contain a hyperspectral imager, a controller, data acquisition and storage hardware, software to operate the system and store and retrieve data, remote control capability and the capability to acquire and register GPS/INS information to the imagery. Documentation of the optical and electrical specifications of the system, documented test results, and a user manual must also be delivered. The sensor must be capable of meeting the performance specifications as documented in the Section 4.

3. Evaluation Criteria

As stated in the synopsis/solicitation, the specific technical evaluation criteria to be used shall include (a) technical capability of the item offered to meet the Government's minimum needs, (b) past performance, and (c) price. The technical evaluation will consider the Offeror's overall approach to, understanding of, and capability to provide the requirements listed below. Technical scores will be based on an evaluative determination of whether the Offeror's proposal meets, does not meet, or, as proposed, is more advantageous than the Government's minimum requirements.

4. UAV-Capable Coastal Hyperspectral Imager System

The UAV-capable coastal hyperspectral imager system will be used to produce hyperspectral images of continuous swaths of the earth from an airborne UAV platform. One possible implementation of such a system would be a pushbroom imager consisting of foreoptics imaging the scene onto a slit, a system to provide spectral dispersion, and a focal plane array. The system should also include a GPS/INS system with needed antenna(s), a transceiver (with required antenna) for receiving command and control information and for down-linking of data, and a computer for control and data acquisition. The contractor may, however, offer any system meeting the requirements and specifications set out in this document. An additional transceiver/antenna combination is required for use with the base station. Also required is the capability to control the payload (using for example a laptop computer) and to receive the telemetry and data broadcast by the UAV system. A schematic of this system is shown below in figure 1.

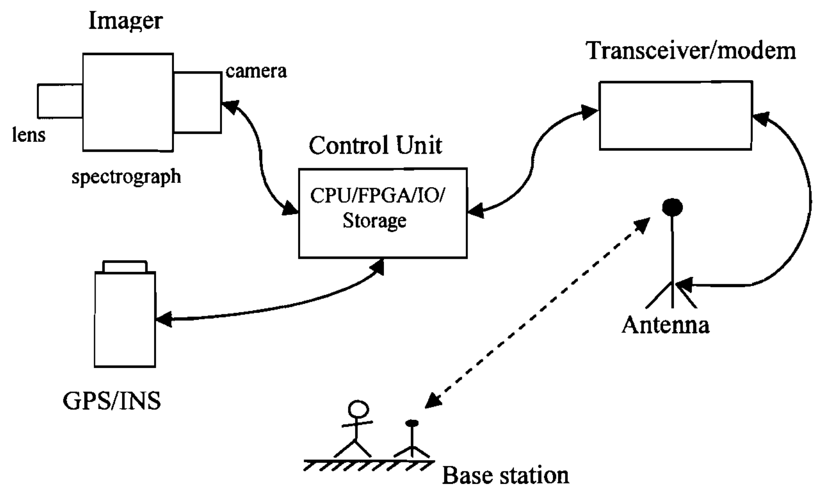


Figure 1. Suggested schematic of the system. The individual units are not drawn to scale.

In figure one, the individual units do not need to be separate if they can fit within the volume of the largest of any grouped units. Specific tasks may also be moved from one unit to the other. For example the GPS/INS unit could possibly be located within the control unit. The schematic is shown to be a guide to the contractor and the contractor is encouraged to consider other designs as long as the basic requirements are met.

During flight imaging operation, the system must be able to transmit at least one user selectable spectral band of data for all spatial pixels at a rate of 10 Hz. The ground station must be able to display this in a waterfall fashion and in real time. A goal is to transmit and view in real time the single band at the operating frame rate of the imager. As an additional goal, the system must be able to transmit and view in real time three spectral bands containing all spatial pixels such that the data can be displayed as a false color RGB on the base station display at the fastest possible frame rate.

The airborne part of the system is constrained by weight, size and power and the required maximum of each is listed in table 1. Note that the required maximum of the total package is less than the sum of the required maxima of the individual units.

Unit	Weight (lb)	Power (W)	Dimension 1 (inches)	Dimension 2 (inches)	Dimension 3 (inches)
Total package	20	54			
Imager	2	17	12	8	6
GPS/INS	3	20	6	4	3.5
Control Unit	10	20	8	6	4
Transceiver*	2	6	7	3	3

Table 1. The maximum allowed weight, power, and size of each unit and the total for the airborne system. The power is listed for a 28V DC input. The dimensions are considered to be independent edges of the same cuboid. *An external antenna (e.g. 7" whip or smaller) may be used and count against the weight and power specifications, but not the dimension specifications.

The airborne part of the system must be capable of operating in the UAV environment with a temperature range of 0 to 50 Celsius and altitude range of 0 to 3000 meters. Furthermore the goal is to operate up to 6000 meters.

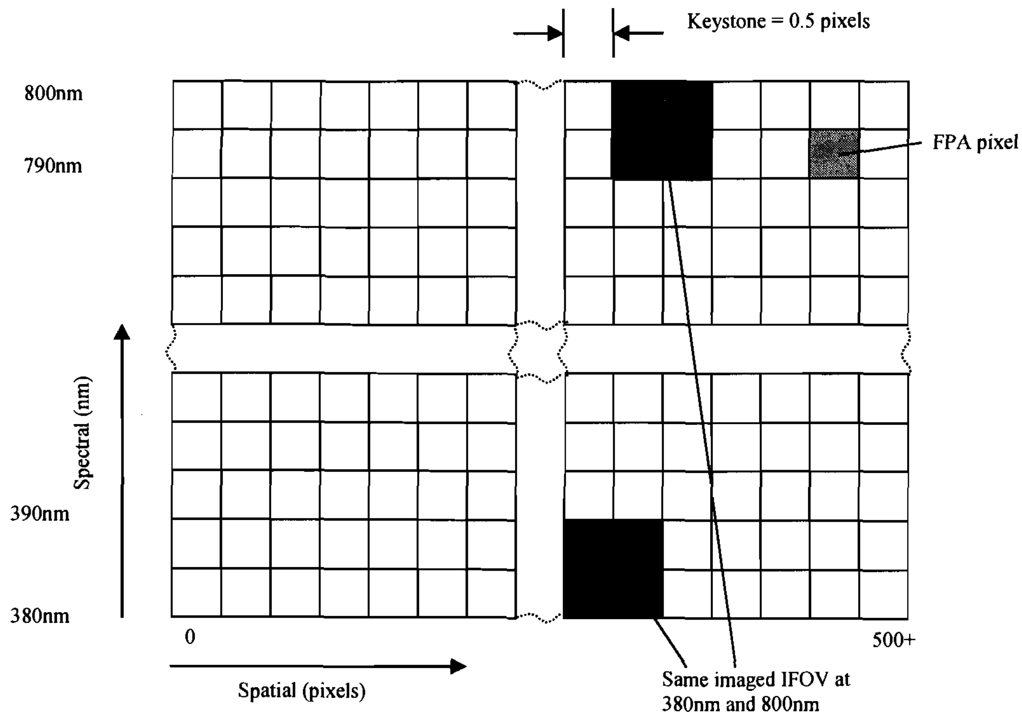
4a. Imager

The imager must be capable of imaging while looking in the nadir direction from the UAV, and shall not require ground motion compensation. **The required Ground Sample Distance (GSD), defined as the projection of one hyperspectral pixel (this may be binned) onto the ground, must be 2 meters (m) square from an altitude of 1000 m and at a speed of 35 meters per second.** A goal is the ability to reconfigure the system to achieve 1 m square GSD from an altitude of 2000 m at a speed of 35 meters per second. **The required cross-track swath width must be 400 pixels (1000 pixels goal), and the required continuous imaging time must be 15 minutes. The spectral range must include 380 to 900 nm,** with a goal of additional coverage up to 1050 nm . **The hyperspectral data must be reported in 10 +/- 2 nanometer (nm) wide, contiguous spectral bins over the entire spectral range**, with a goal of 5 +/-1 nm wide bins.

Requirements, goals, and other specifications are listed in Table 2. Note, that keystone and spectral smile are defined using Figure 2. Keystone, the change in optical magnification with wavelength, must be less than 0.2 binned pixels. Spectral smile, defined as a change in dispersion with position, must be no more than 2 nm.

Definitions:

- An FPA pixel is defined as a single physical detector element on the focal plane array.
- A binned pixel is defined by the smallest spatial and spectral sample, typically obtained using on-chip or off-chip binning of the FPA pixels.
- IFOV- instantaneous field of view corresponding to a given GSD
- FOV- entire cross-track field of view



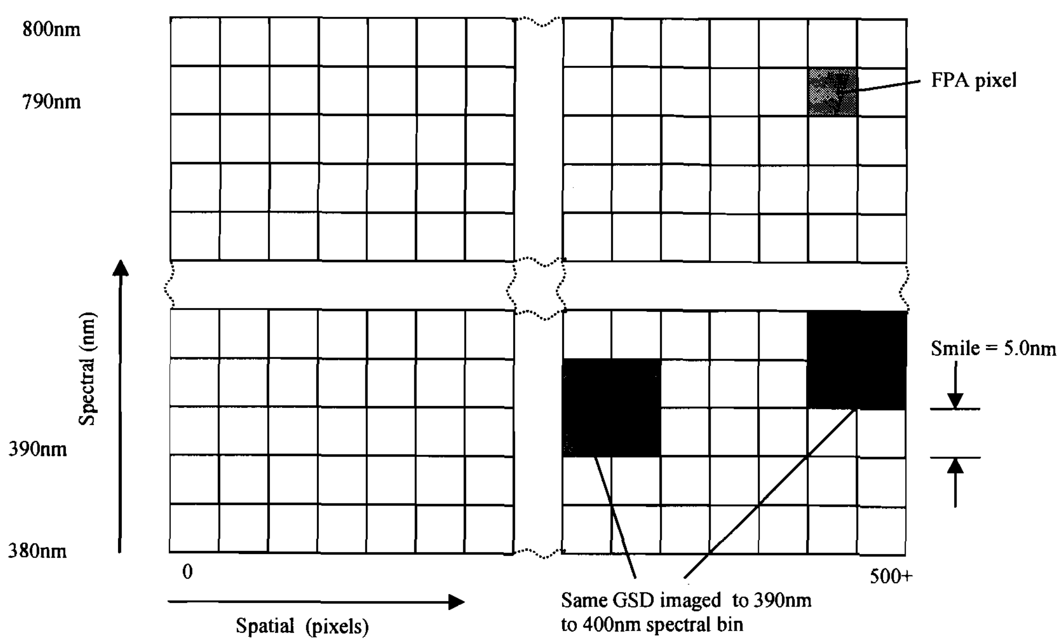


Figure 2. Illustration of 0.5 pixels of keystone and 5.0nm of spectral smile. In this example 2 FPA pixels are used to create one 10nm spectral bin (vertical) and two FPA pixels correspond to a single spatial IFOV (horizontal). Less than or equal to 0.2 pixels of keystone and 2.0nm of spectral smile are required.

Parameter	Minimum Requirement	Desired Characteristics
Ground Sample Distance (GSD) from 1000 m	2 m square	1 m square
Spectral Range	380 nm to 900 nm	Increased Spectral Range to 1050nm
Spectral Bins	Contiguous Bins, 10 +/- 2 nm Full Width. At least 88% of a given detected signal in a given bin must be from the radiation incident on the FPA within the bin's nominal wavelength range. Less than 10% of the signal can come from incident radiation outside the bin with wavelengths ±9 nm from the bin's center wavelength. Less than 1% of the signal can come from incident radiation outside the bin with wavelengths ±12 nm from the bin's center wavelength. Less than 0.1% of the signal can come from incident radiation with wavelengths ±40 nm from the bin's center wavelength	5 +/-2 nm Full Width and the details scaled accordingly.
Spectral Simultaneity	All Spectral Bins for a GSD are acquired simultaneously	
Spectral Jitter	Physical wavelength registration on the FPA must not change by more than 0.4 nm over a three week period or while operating the imager.	Change of less than 0.2 nm over same time period
Signal-to-Noise Ratio	As per Table 3, for a 2 m square GSD from 1000 m. Noise sources must	

	include shot noise from the scene radiance and sensor noise	
Dynamic range	The sensor must not saturate for incident radiation shown in Table 4, for a 2 m square GSD from 1000 m.	
Keystone	Maximum spatial shift between pixels of different wavelengths, and the same spatial bin must be <= 0.2	
Smile	Maximum spectral shift for a given wavelength bin across the entire crosstrack FOV must be <= 2 nm	
Instantaneous Image Quality (Modulation Transfer Function (MTF))	MTF >= 0.35 at 0.5 cycles/pixel (Both Cross-Track and Along-Track)	
Polarization Sensitivity*	</= 10%	</= 2%
Radiometric Calibration Accuracy	Capable of 5% Absolute Radiometric Accuracy	Capable of 3% Absolute Radiometric Accuracy
Radiometric Linearity	There must be a linear response to input scene radiance, for each pixel over the dynamic range from 2% to 90% of brightest anticipated target, to within 1% after processing with a linear function.	
Vignetting	The sensor must not exhibit any vignetting	
Stray light rejection	Assuming a 50% albedo at-sensor radiance illuminating a minimum of 6 spatially contiguous pixels and all other pixels not illuminated, the unilluminated pixels must produce a signal no more than 10e-3 that of the individually illuminated pixels.	

Frame rate	The imager and associated grabbing electronics must be able to image and store digital data at the required spatial and spectral resolution. This rate must be continuously adjustable from 5 frames per second (fps) through the required frame rate derived from the rest of the requirements.	The imager and associated grabbing electronics must be able to image and store 75 frames per second of digital data at the required spatial and spectral resolution.
Operating time**	The imager must be able to continuously acquire and store digital data at the required spatial and spectral resolution for a minimum of 15 minutes without stopping or losing data.	
FPA grade	There must be no more than 0.1% bad pixels	
Lens interface	The system must accept a standard c-mount lens interface in order to change the IFOV	
Storage**	Image acquisition system must be capable of storing one hour of data acquired at the required spatial and spectral resolution	Image acquisition system must be capable of storing four hours of data acquired at the required spatial and spectral resolution
Adjustable Integration time	There is no requirement on the integration time except as required by the SNR, GSD, etc. However, it is desired that the integration time and the frame rate be independently adjustable (see goal)	The integration time, defined as the time per frame that the detector is sensitive to incoming infrared radiation, must be continuously controllable from 1 millisecond to the inverse of the frame rate (less readout time)
Frame transfer smear	If the detector integrates incoming light while transferring/reading out	

	the pixels, this integrated light must produce a signal less than 3% of the total integrated signal	
Dark levels	The dark current must read out as a positive value in digital numbers for each pixel.	
Dark frames	The sensor must have a shutter that can be used to collect dark data during flight	
Time tagging of the data (see control unit specification for more details)	Each frame of data must be able to be registered to GPS time within +/-5% of the inverse of the frame rate. This can be achieved in real time or during post-processing of the data.	

Table 2. UAV hyperspectral imager requirements and goals.

*Polarization sensitivity = (Imax-Imin)/(Imax+Imin), given as a percentage. Imax (Imin) is the maximum (minimum) sensor response to linearly polarized radiation with the polarization vector perpendicular to the sensor's optic axis. Imax and Imin will occur at a specific angles as the polarization vector is rotated about this axis.
** In conjunction with control unit.

Bin Wavelength range (nm)		At sensor spectral radiance (W/m^2-sr-nm)	Required minimum SNR	Bin Wavelength range (microns)		At sensor spectral radiance (W/m^2-sr-nm)	Required minimum SNR
380	390	0.0186012	150	690	700	0.0206941	200
390	400	0.0226863	175	700	710	0.0208196	200
400	410	0.0323918	200	710	720	0.0190356	190
410	420	0.0331344	200	720	730	0.0169253	180
420	430	0.029762	200	730	740	0.0184527	160
430	440	0.0295042	200	740	750	0.0190857	150
440	450	0.0347303	200	750	760	0.0177564	140
450	460	0.0371886	200	760	770	0.0112868	130
460	470	0.0369485	200	770	780	0.0177239	120
470	480	0.0370757	200	780	790	0.0172031	110
480	490	0.0348539	200	790	800	0.0162849	100
490	500	0.0345293	200	800	810	0.0159173	90
500	510	0.0331423	200	810	820	0.0135679	80
510	520	0.0312613	200	820	830	0.0131483	70

520	530	0.0314007	200	830	840	0.013871	60
530	540	0.0315066	200	840	850	0.0143548	50
540	550	0.0307626	200	850	860	0.0135651	40
550	560	0.0302624	200	860	870	0.0134444	30
560	570	0.0294694	200	870	880	0.0133847	20
570	580	0.0291609	200	880	890	0.012993	20
580	590	0.0283451	200	890	900	0.0109867	20
590	600	0.0270635	200	900	910	0.0095812	20
600	610	0.027125	200	910	920	0.008903	20
610	620	0.0259416	200	920	930	0.0088869	20
620	630	0.0254836	200	930	940	0.0035583	20
630	640	0.0251416	200	940	950	0.0042455	20
640	650	0.0244021	200	950	960	0.0046317	20
650	660	0.0232219	200	960	970	0.0068196	20
660	670	0.0239594	200	970	980	0.008312	20
670	680	0.0234686	200	980	990	0.0094178	20
680	690	0.0211214	200	990	1000	0.0099535	20

Table 3. UAV VNIR Spectral Radiance and required signal to noise ratio. Modeled spectral radiance values assume 5% albedo, 45 deg solar zenith angle, 1 km altitude, nadir viewing. Values above 900nm are not required.

Bin Wavelength Range (microns)		At sensor spectral radiance (W/m^2-sr-nm)	Bin Wavelength Range (microns)		At sensor spectral radiance (W/m^2-sr-nm)
380	390	0.0521	690	700	0.0845
390	400	0.0649	700	710	0.0859
400	410	0.0948	710	720	0.0788
410	420	0.0988	720	730	0.0701
420	430	0.0907	730	740	0.0777
430	440	0.0914	740	750	0.0814
440	450	0.1095	750	760	0.0762
450	460	0.1193	760	770	0.0481
460	470	0.1204	770	780	0.0772
470	480	0.1224	780	790	0.0754
480	490	0.1167	790	800	0.0716
490	500	0.1173	800	810	0.0704
500	510	0.1138	810	820	0.0598
510	520	0.1085	820	830	0.0584
520	530	0.1104	830	840	0.0622
530	540	0.1120	840	850	0.0651
540	550	0.1103	850	860	0.0618
550	560	0.1097	860	870	0.0615
560	570	0.1082	870	880	0.0618
570	580	0.1080	880	890	0.0601
580	590	0.1060	890	900	0.0506
600	610	0.1021	900	910	0.0440
610	620	0.1036	910	920	0.0410
620	630	0.1000	920	930	0.0411

630	640	0.0991	930	940	0.0157
640	650	0.0986	940	950	0.0190
650	660	0.0964	950	960	0.0210
660	670	0.0924	960	970	0.0318
670	680	0.0963	970	980	0.0394
680	690	0.0950	980	990	0.0452

Table 4. UAV Spectral Radiance that must be imaged without saturation. Modeled spectral radiance values assume 30% albedo, 45 deg solar zenith angle, 1 km altitude, nadir viewing. If the contractor builds the system with spectral bands outside of the 380-900nm range (a stated goal), then these bands must not saturate at the radiance levels shown above.

4b. Control Unit

One example of a control unit is an embedded processor or FPGA configuration with additional on board memory and I/O interfaces, capable of controlling all of the other subsystems (GPS/INS, transceiver, imager). It must also be capable of storing the imager data and GPS/INS data. The contractor may integrate any or all of these capabilities into the other subsystems as stated at the start of section 4. The speed and storage capacity of the system must be capable of operating and storing the imager data and the GPS/INS data for a minimum of 15 continuous minutes as listed on Table 2. The storage system must be capable of storing one hour's worth of imager and GPS/INS data, with a goal of being able to store four hours worth of data.

4c. GPS/INS

The GPS/INS (position and attitude) system must be capable of providing time, position, speed, and attitude (roll, pitch, and heading) data as specified in table 5 below. The data must be stored at a 10Hz rate or faster (100Hz goal) while the system is imaging. Note that this part of the airborne system can be standalone or integrated into one of the subsystems as stated at the start of section 4.

Parameter	Required accuracy
3D Position	3.9 m (spherical error probable)
Velocity	0.1 m/s, 1 sigma, each axis
Roll and pitch	1.0 mrad, 1 sigma, each axis
Heading (when flying)	1.0 mrad, 1 sigma, w/drift of 3 deg/hr during periods of no horizontal acceleration
Temporal	1 microsecond, 1 sigma, each axis

Table 5. GPS/INS data requirements.

4d. Transceiver

The transceiver, with integrated or separate antenna, must be capable of transmitting and receiving data/commands from the base station and routing them to the control unit. It may be standalone or integrated to any of the other subsystems as stated at the start of section 4. It must be capable of transmitting, receiving and communicating with the control unit at 360 kilobits/second, and have a line of sight range to the ground station of 10 miles. A goal is that it supports a throughput rate of 540kbs and/or a line of sight range of 40 miles.

4e. Base Station

The base station should be able to receive and transmit wireless data/commands to the airborne system in flight and have a hard wire link to it on the ground for testing, downloading data, and software reconfiguration if necessary. It must be capable of producing real time imagery and telemetry as it is transmitted in flight and when the airborne system is on the ground it must be capable of producing real time imagery of the data at the frame rate of the imager. One example of such a system would be a laptop computer linked to a transceiver/antenna combination identical to the airborne system.

5. Commanding

While in flight, the base station must be capable of commanding the sensor to start and stop collecting image data, and operating the shutter.

6. Acceptance Testing

Acceptance testing must be performed at the Naval Research Laboratory (NRL) by NRL employees. A technically-qualified representative of the contract shall be present during testing. The test results shall meet the specifications of the contract detailed in Sections 1 - 6 of this Statement of Work.

Most laboratory testing on the imager will be performed using the following basic setups. The first is a collimating system using an off axis parabola fed with a variety of narrow and wide band sources. An aperture will be placed at the focal point of the parabola creating a collimated beam with an angular extent that is smaller than an IFOV. Generally, it will be used to check image performance. The second is an integrating sphere, which is radiometrically calibrated by comparison to a NIST standard FEL lamp (for a description of NIST calibrated FEL lamps see: http://physics.nist.gov/Divisions/Div844/facilities/fascal/fascal.html). This will be used to test radiometric capabilities such as signal to noise ratio, dynamic range, radiometric linearity, etc. The following table lists which setup will be used to test each specification. Some specifications will be implicitly tested during the testing of those listed on the table (e.g. integration time, frame rate, etc.) and are not specifically called out.

Specification	Test setup
GSD	Collimator fed by narrow band sources at different spatial locations on the array
Keystone	Collimator fed by narrow band sources at different spatial locations on the array
MTF	Collimator fed by narrow band or wide band sources at different spatial locations on the array. This will actually measure the imagers point spread function which will have to be transferred to a value of the MTF.
Polarization	Sphere with polarizer rotated in front of imager
Spectral response	Monochrometer stepped through wavelength, and/or an integrating sphere fed with narrow band sources
SNR, dynamic range, radiometric calibration and linearity	Radiometrically calibrated integrating sphere
Vignetting	Integrating sphere source
Spectral simultaneity, integration time	Chopped white light source
Smile	Small integrating sphere fed by narrow band sources
Stray light	Collimator fed by wide band source through a spatially extended aperture.

The full integrated system test will likely be performed on the ground if a UAV is unavailable at the time of delivery. Either the base station or the airborne system will be transported by land vehicle to a remote location for testing. Because the system will not be in the air, line of sight requirements may be relaxed at the time of testing.

CONTRACT DATA REQUIREMENTS LIST (1 Data Item)	*Form Approved OMB No. 0704-0188*

A. CONTRACT LINE ITEM NO.	B. EXHIBIT	C. CATEGORY:
	A	TDP ____ TM ____ OTHER ____

D. SYSTEM/ITEM	E. CONTRACT/PR NO.	F. CONTRACTOR
	N00173-07-R-RS02	

1. DATA ITEM NO.	2. TITLE OF DATA ITEM	3. SUBTITLE	17. PRICE GROUP
A001	DOCUMENTATION AND OTHER DELIVERABLES		

4. AUTHORITY (*Data Acquisition Document No.*)	5. CONTRACT REFERENCE	6. REQUIRING OFFICE	18. ESTIMATED TOTAL PRICE
	SOW		

7. DD 250 REQ	9. DIST STATEMENT REQUIRED	10. FREQUENCY	12. DATE OF FIRST SUBMISSION
LT		SEE BLOCK 16	SEE BLOCK 16
8. APP CODE		**11. AS OF DATE**	**13. DATE OF SUBSEQUENT SUBMISSION**
		SEE BLOCK 16	SEE BLOCK 16

16. REMARKS

The following items are required deliverables under any resulting contract:

1. The Contractor shall provide optical and electrical specifications for the required system and all of its components on a one-time basis, deliverable with the required system.

2. The Contractor shall provide operation and maintenance manuals for all components of the required system on a one-time basis, deliverable with the required system.

3. The Contractor shall provide test results for the required system pursuant to Paragraph 6 of the Statement of Work on an as required basis.

14. DISTRIBUTION

a. ADDRESSEE	b. COPIES Draft	Final Reg	Final Repro
COR		1	
15. TOTAL →	0	1	0

G. PREPARED BY	H. DATE	I. APPROVED BY	J. DATE
RICHARD D. SEWELL	05 MAR 2007		