

Short Wave Hyperspectral Imager Specification

1. Introduction

This document contains the description, specifications, acceptance tests, and other requirements for a Short Wave InfraRed Hyperspectral Imager.

2. Overview

The contractor must assemble, test, and deliver a Short Wave InfraRed (SWIR) hyperspectral imager system. The delivered system must contain a hyperspectral imager, a controller, data acquisition and storage, software to operate the system and store and retrieve data, documentation of the optical and electrical specifications of the system, and a users manual. The contractor shall provide any documented test results, if conducted, prior to delivery of the system.

3. SWIR Hyperspectral Imaging System Description

The SWIR hyperspectral imager system will be used to produce hyperspectral images of continuous swaths of the ground from an aircraft 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, a focal plane array, and a computer for control and data acquisition; however, the contractor may supply any system meeting the requirements and specifications set out in this document.

The imager must be capable of imaging while looking in the nadir direction from an aircraft, and shall not require ground motion compensation. The required Ground Sample Distance (GSD), defined as the projection of one hyperspectral pixel (or equivalently one geometrical IFOV) onto the ground, must be 2 meters (m) square STET from an altitude of 2000 m. A goal is the ability to reconfigure the system to achieve 1 m square GSD from an altitude of 2000 m. The required cross-track swath width must be 500 pixels (1000 pixels goal), and the required continuous imaging time must be 15 minutes. The spectral range must include 900 to 1700 nm, with a goal of additional coverage outside this range. The hyperspectral data must be reported in 10 +/- 2 nanometer (nm) wide (or smaller), contiguous spectral bins over the entire spectral range. The imager must not use any expendable cryogenic liquid or a mechanical cryocooler.

Requirements, goals, and other specifications are listed in Table 1. Note, that keystone and spectral smile are defined using Figure 1. Keystone, the change in optical magnification with wavelength, must be less than 0.1 pixel. Spectral smile, defined as a change in dispersion with position, must be no more than 2 nm.

Definitions:

- A pixel is defined as a physical pixel on the focal plan array (FPA).
- 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

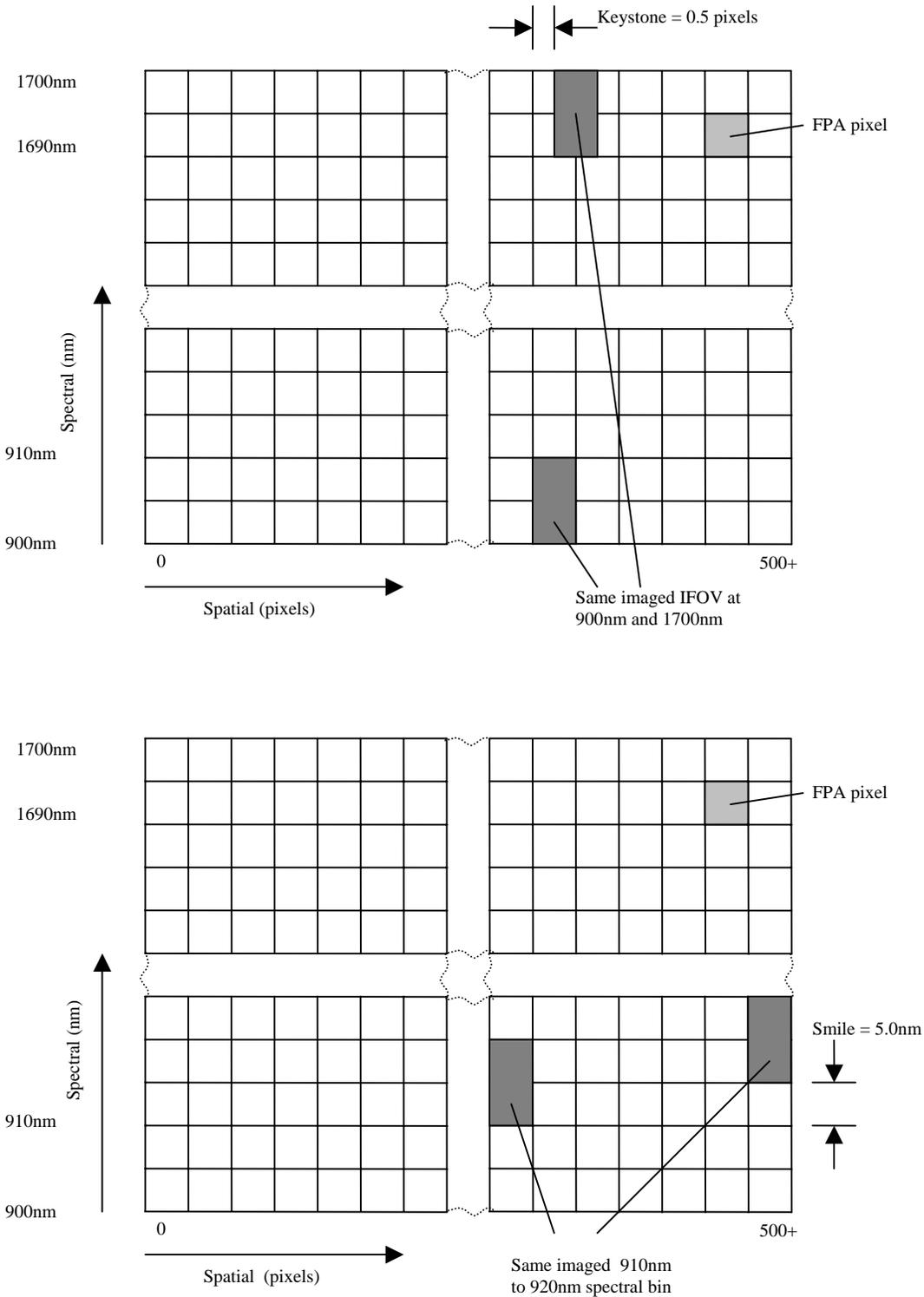


Figure 1. Illustration of 0.5 pixels of keystone and 5.0nm of spectral smile. In this example 2 FPA pixels are used to create one 10nm spectral bin (vertical) and one FPA pixel

corresponds to a single spatial IFOV (horizontal). Less than or equal to 0.1 pixels of keystone and 1.0nm of spectral smile are required.

Parameter	Requirement	Goal
Ground Sample Distance (GSD) from 2000 m	2 m square	1 m square
Spectral Range	900 nm to 1700 nm	Increased Spectral Range
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	
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 2, for a 2 m square GSD from 2000 m, at 30 frames per second. 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 3, for a 2 m square GSD from 2000 m, at 30 frames per second.	
Keystone	Maximum spatial shift between pixels of different wavelengths, and the same spatial bin must be ≤ 0.1 of the pixel's IFOV	
Smile	Maximum spectral shift for a given wavelength bin across the entire FOV must be ≤ 2 nm	

Instantaneous Image Quality (Modulation Transfer Function (MTF))	MTF \geq 0.35 at 0.5 cycles/pixel (Both Cross-Track and Along-Track)	
Parameter	Requirement	Goal
Polarization Sensitivity*	\leq 10%	\leq 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 100% 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 at least 30 frames per second of digital data at the required spatial and spectral resolution. This rate must be continuously adjustable from 5 frames per second (fps) through the fastest required frame rate.	The imager and associated grabbing electronics must be able to image and store 90 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 30 fps and the required spatial and spectral resolution for a minimum of 15 minutes	
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	
External Synchronization	The system must output an electrical	

	pulse (e.g. TTL) for each frame	
Parameter	Requirement	Goal
Storage	Image acquisition system must be capable of storing two hours of data acquired at 30 fps and at the required spatial and spectral resolution	
Integration time	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 full frame time	
Smear	The detector must not integrate the incoming signal during readout.	
Dark levels	The dark current must read out as a positive value in digital numbers for each pixel.	
Mechanical Envelope (excluding external data acquisition system and power supply)	<=20"x12"x12" box	
Weight (excluding external data acquisition system and power supply)	<= 25 lbs.	
Electrical Power (excluding external data acquisition system and power supply)	<= 50 watts steady state	
Operating environment temperature and altitude	-10 Celsius (C) to +50 C and 0 to 30,000 feet	

Table 1. SWIR hyperspectral imaging system requirements and goals.

*Polarization sensitivity = $(I_{max}-I_{min})/(I_{max}+I_{min})$, given as a percentage. I_{max} (I_{min}) is the maximum (minimum) sensor response to linearly polarized radiation with the polarization vector perpendicular to the sensor's optic axis. I_{max} and I_{min} will occur at a specific angles as the polarization vector is rotated about this axis.

Bin Wavelength range (microns)		At sensor spectral radiance (W/cm ² -sr-μ)	Required minimum SNR	Bin Wavelength range (microns)		At sensor spectral radiance (W/cm ² -sr-μ)	Required minimum SNR
0.900	0.910	0.005687	200	1.300	1.310	0.002860	200
0.910	0.920	0.005242	200	1.310	1.320	0.002535	200
0.920	0.930	0.005534	200	1.320	1.330	0.002053	200
0.930	0.940	0.001972	100	1.330	1.340	0.001385	100
0.940	0.950	0.002457	100	1.340	1.350	0.000566	50
0.950	0.960	0.002644	100	1.350	1.360	0.000003	0
0.960	0.970	0.004154	100	1.360	1.370	0.000000	0
0.970	0.980	0.005055	200	1.370	1.380	0.000001	0
0.980	0.990	0.005886	200	1.380	1.390	0.000001	0
0.990	1.000	0.006228	200	1.390	1.400	0.000002	0
1.000	1.010	0.006038	200	1.400	1.410	0.000005	0
1.010	1.020	0.005988	200	1.410	1.420	0.000050	0
1.020	1.030	0.005891	200	1.420	1.430	0.000138	0
1.030	1.040	0.005771	200	1.430	1.440	0.000207	0
1.040	1.050	0.005666	200	1.440	1.450	0.000354	0
1.050	1.060	0.005553	200	1.450	1.460	0.000659	50
1.060	1.070	0.005368	200	1.460	1.470	0.000570	50
1.070	1.080	0.005205	200	1.470	1.480	0.000566	50
1.080	1.090	0.004889	200	1.480	1.490	0.000796	100
1.090	1.100	0.004400	200	1.490	1.500	0.001532	100
1.100	1.110	0.003700	100	1.500	1.510	0.001808	200
1.110	1.120	0.001897	100	1.510	1.520	0.002068	200
1.120	1.130	0.000758	50	1.520	1.530	0.002250	200
1.130	1.140	0.001297	100	1.530	1.540	0.002286	200
1.140	1.150	0.001356	100	1.540	1.550	0.002289	200
1.150	1.160	0.001966	200	1.550	1.560	0.002259	200
1.160	1.170	0.003114	200	1.560	1.570	0.002211	200
1.170	1.180	0.003500	200	1.570	1.580	0.001982	200
1.180	1.190	0.003388	200	1.580	1.590	0.002073	200
1.190	1.200	0.003584	200	1.590	1.600	0.002083	200
1.200	1.210	0.003471	200	1.600	1.610	0.001920	200
1.210	1.220	0.003649	200	1.610	1.620	0.001971	200
1.220	1.230	0.003753	200	1.620	1.630	0.002025	200
1.230	1.240	0.003870	200	1.630	1.640	0.001943	200
1.240	1.250	0.003832	200	1.640	1.650	0.001855	200
1.250	1.260	0.003714	200	1.650	1.660	0.001872	200
1.260	1.270	0.003162	200	1.660	1.670	0.001816	200
1.270	1.280	0.003440	200	1.670	1.680	0.001794	200
1.280	1.290	0.003395	200	1.680	1.690	0.001731	200
1.290	1.300	0.003281	200	1.690	1.700	0.001708	200

Table 2. SWIR Spectral Radiance and required signal to noise ratio. Modeled spectral radiance values assume 30% albedo, 30 deg solar zenith angle, 2 km altitude, nadir viewing. Significant atmospheric absorption bands are shaded.

Bin Wavelength Range (microns)		At sensor spectral radiance (W/cm ² -sr-μ)	Bin Wavelength Range (microns)		At sensor spectral radiance (W/cm ² -sr-μ)
900	910	0.1864	1300	1310	0.0943
910	920	0.1716	1310	1320	0.0835
920	930	0.1814	1320	1330	0.0675
930	940	0.0637	1330	1340	0.0453
940	950	0.0797	1340	1350	0.0184
950	960	0.0859	1350	1360	0.0001
960	970	0.1359	1360	1370	0.0000
970	980	0.1658	1370	1380	0.0000
980	990	0.1936	1380	1390	0.0000
990	1000	0.2052	1390	1400	0.0000
1000	1010	0.1989	1400	1410	0.0001
1010	1020	0.1973	1410	1420	0.0016
1020	1030	0.1941	1420	1430	0.0044
1030	1040	0.1902	1430	1440	0.0067
1040	1050	0.1867	1440	1450	0.0115
1050	1060	0.1830	1450	1460	0.0215
1060	1070	0.1769	1460	1470	0.0186
1070	1080	0.1715	1470	1480	0.0185
1080	1090	0.1611	1480	1490	0.0261
1090	1100	0.1448	1490	1500	0.0505
1100	1110	0.1215	1500	1510	0.0597
1110	1120	0.0618	1510	1520	0.0683
1120	1130	0.0244	1520	1530	0.0744
1130	1140	0.0421	1530	1540	0.0757
1140	1150	0.0441	1540	1550	0.0758
1150	1160	0.0642	1550	1560	0.0748
1160	1170	0.1023	1560	1570	0.0732
1170	1180	0.1152	1570	1580	0.0656
1180	1190	0.1115	1580	1590	0.0686
1190	1200	0.1180	1590	1600	0.0690
1200	1210	0.1144	1600	1610	0.0636
1210	1220	0.1203	1610	1620	0.0653
1220	1230	0.1238	1620	1630	0.0670
1230	1240	0.1278	1630	1640	0.0643
1240	1250	0.1266	1640	1650	0.0614
1250	1260	0.1226	1650	1660	0.0620
1260	1270	0.1043	1660	1670	0.0601
1270	1280	0.1136	1670	1680	0.0594
1280	1290	0.1122	1680	1690	0.0573
1290	1300	0.1083	1690	1700	0.0565

Table 3. SWIR Spectral Radiance that must be imaged without saturation. Modeled spectral radiance values assume 100% albedo, 30 deg solar zenith angle, 2 km altitude, nadir viewing.

4. Acceptance Testing

Acceptance testing must be performed at the Naval Research Laboratory (NRL) by NRL employees. The contractor is not required to participate, but it is highly recommended. The test results must meet the specifications of the system as detailed in the imager description.

Most laboratory testing 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 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	Monochromator 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.

CONTRACT DATA REQUIREMENTS LIST

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 440 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. Please do not return your form to the above organization. Send completed form to the Government Issuing Contracting Officer for the Contract/PR No. listed in Block E.

A. CONTRACT LINE ITEM NO. 0002	B. EXHIBIT A	C. CATEGORY: TDP _____ TM _____ OTHER _____
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D. SYSTEM/ITEM	E. CONTRACT/PR NO. N00173-05-R-MS06	F. CONTRACTOR
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1. DATA ITEM NO. A001	2. TITLE OF DATA ITEM Operational Software	3. SUBTITLE
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4. AUTHORITY (Data Acquisition Document No.)	5. CONTRACT REFERENCE SOW, Section 2	6. REQUIRING OFFICE Code 7230
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7. DD 250 REQ No	9. DIST STATEMENT REQUIRED	10. FREQUENCY 1TIME	12. DATE OF FIRST SUBMISSION EOC*	14. DISTRIBUTION		
8. APP CODE N/A		11. AS OF DATE N/A	13. DATE OF SUBSEQUENT SUBMISSION N/A	a. ADDRESSEE	Draft	b. COPIES

16. REMARKS The contractor shall deliver operational software for the storage and retrieval of data. Block 12: Operational Software delivered with system.				15. TOTAL →	0	1	0
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17. PRICE GROUP
18. ESTIMATED TOTAL PRICE

1. DATA ITEM NO. A002	2. TITLE OF DATA ITEM Optical and Electrical Specifications	3. SUBTITLE
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4. AUTHORITY (Data Acquisition Document No.)	5. CONTRACT REFERENCE SOW, Section 2	6. REQUIRING OFFICE Code 7230
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7. DD 250 REQ No	9. DIST STATEMENT REQUIRED	10. FREQUENCY 1TIME	12. DATE OF FIRST SUBMISSION EOC*	14. DISTRIBUTION		
8. APP CODE N/A		11. AS OF DATE N/A	13. DATE OF SUBSEQUENT SUBMISSION N/A	a. ADDRESSEE	Draft	b. COPIES

16. REMARKS The contractor shall deliver optical and electrical specifications of the system. Block 12: Optical and Electrical Specification delivered with system.				15. TOTAL →	0	1	0
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17. PRICE GROUP
18. ESTIMATED TOTAL PRICE

1. DATA ITEM NO. A003	2. TITLE OF DATA ITEM Test Results	3. SUBTITLE
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4. AUTHORITY (Data Acquisition Document No.)	5. CONTRACT REFERENCE SOW, Section 2	6. REQUIRING OFFICE Code 7230
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7. DD 250 REQ No	9. DIST STATEMENT REQUIRED	10. FREQUENCY 1Time	12. DATE OF FIRST SUBMISSION 10DATC*	14. DISTRIBUTION		
8. APP CODE N/A		11. AS OF DATE N/A	13. DATE OF SUBSEQUENT SUBMISSION N/A	a. ADDRESSEE	Draft	b. COPIES

16. REMARKS The contractor shall provide test results, if conducted, prior to delivery of the system. Block 12: Test results are required 10 days before deliver of the system.				15. TOTAL →	0	1	0
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17. PRICE GROUP
18. ESTIMATED TOTAL PRICE

1. DATA ITEM NO. A004	2. TITLE OF DATA ITEM Users Manual	3. SUBTITLE
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4. AUTHORITY (Data Acquisition Document No.)	5. CONTRACT REFERENCE SOW, Section 2	6. REQUIRING OFFICE Code 7230
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7. DD 250 REQ No	9. DIST STATEMENT REQUIRED	10. FREQUENCY 1Time	12. DATE OF FIRST SUBMISSION EOC*	14. DISTRIBUTION		
8. APP CODE N/A		11. AS OF DATE N/A	13. DATE OF SUBSEQUENT SUBMISSION N/A	a. ADDRESSEE	Draft	b. COPIES

16. REMARKS The contractor shall deliver a users manual of the system. Block 12: Users manuals delivered with the system.				15. TOTAL →	0	1	0
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17. PRICE GROUP
18. ESTIMATED TOTAL PRICE

G. PREPARED BY Code 7230	H. DATE	I. APPROVED BY	J. DATE
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INSTRUCTIONS FOR COMPLETING DD FORM 1423

(See DoD 5010.12-M for detailed instructions.)

FOR GOVERNMENT PERSONNEL

- Item A.** Self-explanatory.
- Item B.** Self-explanatory.
- Item C.** Mark (X) appropriate category: TDP - Technical Data Package; TM - Technical Manual; Other - other category of data, such as "Provisioning," "Configuration Management," etc.
- Item D.** Enter name of system/item being acquired that data will support.
- Item E.** Self-explanatory (to be filled in after contract award).
- Item F.** Self-explanatory (to be filled in after contract award).
- Item G.** Signature of preparer of CDRL.
- Item H.** Date CDRL was prepared.
- Item I.** Signature of CDRL approval authority.
- Item J.** Date CDRL was approved.
- Item 1.** See DoD FAR Supplement Subpart 4.71 for proper numbering.
- Item 2.** Enter title as it appears on data acquisition document cited in Item 4.
- Item 3.** Enter subtitle of data item for further definition of data item (optional entry).
- Item 4.** Enter Data Item Description (DID) number, military specification number, or military standard number listed in DoD 5010.12-L (AMSDL), or one-time DID number, that defines data content and format requirements.
- Item 5.** Enter reference to tasking in contract that generates requirement for the data item (e.g., Statement of Work paragraph number).
- Item 6.** Enter technical office responsible for ensuring adequacy of the data item.
- Item 7.** Specify requirement for inspection/acceptance of the data item by the Government.
- Item 8.** Specify requirement for approval of a draft before preparation of the final data item.
- Item 9.** For technical data, specify requirement for contractor to mark the appropriate distribution statement on the data (ref. DoDD 5230.24).
- Item 10.** Specify number of times data items are to be delivered.
- Item 11.** Specify as-of date of data item, when applicable.
- Item 12.** Specify when first submittal is required.
- Item 13.** Specify when subsequent submittals are required, when applicable.
- Item 14.** Enter addressees and number of draft/final copies to be delivered to each addressee. Explain reproducible copies in Item 16.
- Item 15.** Enter total number of draft/final copies to be delivered.
- Item 16.** Use for additional/clarifying information for Items 1 through 15. Examples are: Tailoring of documents cited in Item 4; Clarification of submittal dates in Items 12 and 13; Explanation of reproducible copies in Item 14.; Desired medium for delivery of the data item.

FOR THE CONTRACTOR

Item 17. Specify appropriate price group from one of the following groups of effort in developing estimated prices for each data item listed on the DD Form 1423.

a. Group I. Definition - Data which is not otherwise essential to the contractor's performance of the primary contracted effort (production, development, testing, and administration) but which is required by DD Form 1423.

Estimated Price - Costs to be included under Group I are those applicable to preparing and assembling the data item in conformance with Government requirements, and the administration and other expenses related to reproducing and delivering such data items to the Government.

b. Group II. Definition - Data which is essential to the performance of the primary contracted effort but the contractor is required to perform additional work to conform to Government requirements with regard to depth of content, format, frequency of submittal, preparation, control, or quality of the data item.

Estimated Price - Costs to be included under Group II are those incurred over and above the cost of the essential data item without conforming to Government requirements, and the administrative and other expenses related to reproducing and delivering such data item to the Government.

c. Group III. Definition - Data which the contractor must develop for his internal use in performance of the primary contracted effort and does not require any substantial change to conform to Government requirements with regard to depth of content, format, frequency of submittal, preparation, control, and quality of the data item.

Estimated Price - Costs to be included under Group III are the administrative and other expenses related to reproducing and delivering such data item to the Government.

d. Group IV. Definition - Data which is developed by the contractor as part of his normal operating procedures and his effort in supplying these data to the Government is minimal.

Estimated Price - Group IV items should normally be shown on the DD Form 1423 at no cost.

Item 18. For each data item, enter an amount equal to that portion of the total price which is estimated to be attributable to the production or development for the Government of that item of data.

These estimated data prices shall be developed only from those costs which will be incurred as a direct result of the requirement to supply the data, over and above those costs which would otherwise be incurred in performance of the contract if no data were required. The estimated data prices shall not include any amount for rights in data. The Government's right to use the data shall be governed by the pertinent provisions of the contract.