Hyperion Summary

The objective of the Hyperion instrument is to provide high quality calibrated data that can support evaluation of hyperspectral technology for Earth observing missions. The Hyperion is a pushbroom instrument. Each image frame taken in this "push broom" configuration captures the spectrum of a line 30 m long by 7.5 km wide (perpendicular to the satellite motion). Frames are then combined to form a two dimensional spatial image with a complete spectral signature for each pixel. Hyperion has a single telescope and two spectrometers, one visible/near infrared (VNIR) spectrometer and one short-wave infrared (SWIR)) spectrometer. The Hyperion instrument consists of 3 physical units (Figure1): (1) the Hyperion Sensor Assembly (HSA); (2) the Hyperion Electronics Assembly (HEA); and (3) the Cryocooler Electronics Assembly (CEA). The Hyperion performance characteristics are contained in Table 1 on the next page.

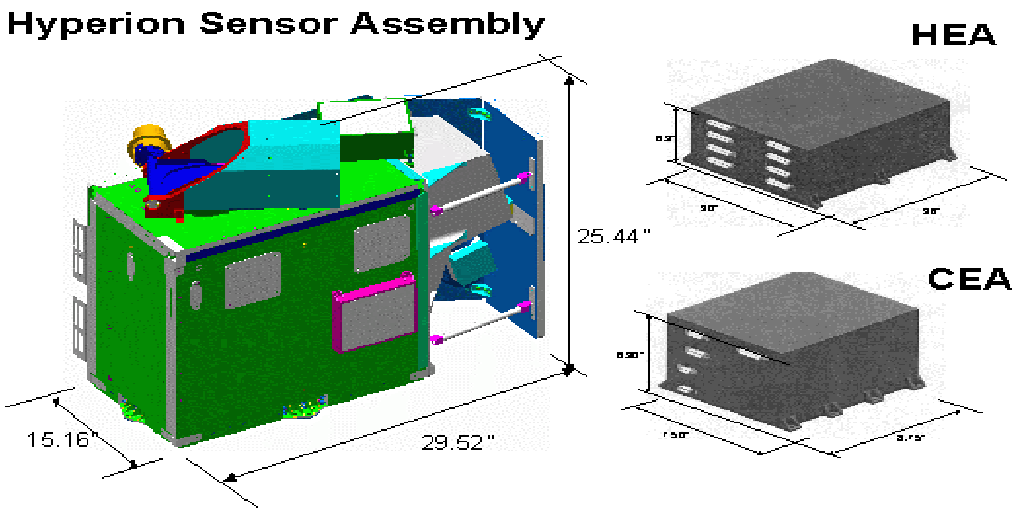

Figure 1. Hyperion Instrument Subsystems

The Hyperion Sensor Assembly (HSA) includes the telescope, the two grating spectrometers and the supporting focal plane electronics and cooling system. The Hyperion telescope (fore-optics) is a three-mirror astigmat design. The telescope images the Earth onto a slit that defines the instantaneous field-of-view which is 10.89 mradian wide (i.e., 7.5 km swath width from a 705 km altitude) by 42.55 μradians (30 meters) in the satellite velocity direction. This slit image of the Earth is relayed at a magnification of 1.38:1 to two focal planes in the two grating imaging spectrometers. A dichroic filter in the system reflects the band from 400 to 1,000 nm to the VNIR spectrometer and transmits the band from 900 to 2500 nm to the SWIR spectrometer. The SWIR overlap with the VNIR from 900 to 1000 nm allows cross calibration between the two spectrometers. Both spectrometers use a JPL convex grating design in a three reflector Offner configuration. The HEA contains the interface and control electronics for the instrument and the CEA controls the cyrocooler operation.

The visible/near-infrared (VNIR) spectrometer has an array of 60 mm pixels created by aggregating 3x3 subarrays of 20 mm CCD detectors. The VNIR spectrometer uses a 70 (spectral) by 256 (spatial) pixel array, which provides a 10 nm spectral bandwidth over a range of 400-1000 nm. The shortwave infrared (SWIR) spectrometer has 60 mm cooled HgCdTe detectors in an array of 172 (spectral) x 256 (spatial) channels. Similar to the VNIR, the SWIR spectral bandwidth is 10 nm. Thus, the spectral range of the instrument extends from 400 to 2500nm with a spectral resolution of 10nm. The HgCdTe detectors in the

SWIR spectrometer are cooled by an advanced TRW cryocooler and are maintained at 110 K during data collections. The telescope and imaging spectrometer are pinned and bolted together, permitting alignment of the two sections to take place independently. All of the mirrors in the system are constructed from coated aluminum; the structure holding the optical elements is also constructed from aluminum so that the mirrors and housing all expand and contract at the same rates. This results in an athermal design over a limited temperature range. In operation, the housing will be maintained at 20° ± 2°C for precision imaging and alignment.

	HYPERION CHARACTERISTICS	
	Volume (L x W x H, cm)	39 x 75 x 66
	Weight (Kg)	49
	Average Power (W)	51
	Aperture (cm)	12
	IFOV (mrad)	0.043
	Crosstrack FOV (deg)	0.63
	Wavelength Range (nm)	430-2400
	Spectral Resolution (nm)	10
	Number of Spectral Bands (cal)	196
	Digitization	12
	Frame Rate (Hz)	223.4
	ON-ORBIT CHARACTERISTICS	
OPTICAL	GSD (m)	30.5
	Swath (km)	7.6
	VNIR Modulation Transfer Function @ 630nm	0.23-0.237
	SWIR Modulation Transfer Function @ 1650nm	0.28
	Spatial Co-registration: VNIR	.18 @ Pix #126
	Spatial Co-registration: SWIR	.21 @ Pix #131
RADIOMETRIC	Abs. Radiometry (1Sigma)	3.40%
	VNIR SNR (550-700nm)	140-190
	SWIR SNR (~1225nm)	96
	SWIR SNR (~2125nm)	38
SPECTRAL	No. of Spectral Channels	198 Processed
	VNIR (bands 8-57)	427-925 nm
	VNIR Bandwidth (nm)	10-19-10.21
	VNIR X-track Spectral Error	2.2 nm
	SWIR (bands 77-224)	912-2395 nm
	SWIR Bandwidth (nm)	10-08-10.09
	SWIR X-track Spectral Error	0.058 nm

Table 1. Hyperion Characteristics

A common calibration system is provided for both the VNIR and SWIR spectrometers. Dual calibration lamps produce reference signals to monitor detector performance following image acquisition. Solar calibration, vicarious ground calibration, and lunar calibration were conducted. The long-term absolute radiometric calibration goal was 6% and 3.4% was achieved on orbit. A calibration baseline was established in the laboratory during instrument checkout. After integration of the instrument onto the spacecraft, the performance was verified. During the initial on-orbit checkout, the internal calibration was cross-referenced against both solar and lunar calibrations. The solar calibration utilized a diffuse reflector on the backside of the optical cover to provide uniform illumination across the focal plane arrays. Direct viewing lunar calibration was accomplished by scanning the instrument across the lunar surface. Solar calibration data will be used as the primary source for monitoring radiometric stability, with ground site (vicarious) and lunar calibration secondary. The internal calibration subsystem was used for field flattening and as an additional source of calibration cross check.

Vicarious ground calibration (viewing target calibration sites on the Earth) was part of both the instrument checkout and continued monitoring of instrument performance throughout the mission. Terrestrial sites were chosen to provide high SNR, geographic and spectral flatness, and minimal atmospheric disturbance. Selected ground calibration activities have included geolocation (measured using the Iowa road system) and contrast (by imaging the San Francisco Bay with its long bright bridges over dark water) scenes.

The calculated Hyperion instrument performance is shown in Figure 2 is based on the measured performance of the focal planes and a model of the optical design. The baseline conditions assumed for the performance model are a 60^{o} Solar Zenith Angle and a 30% uniform albedo; the instrument design assumes F/11 optics, a 10 nm bandwidth and a 224 Hz frame rate.

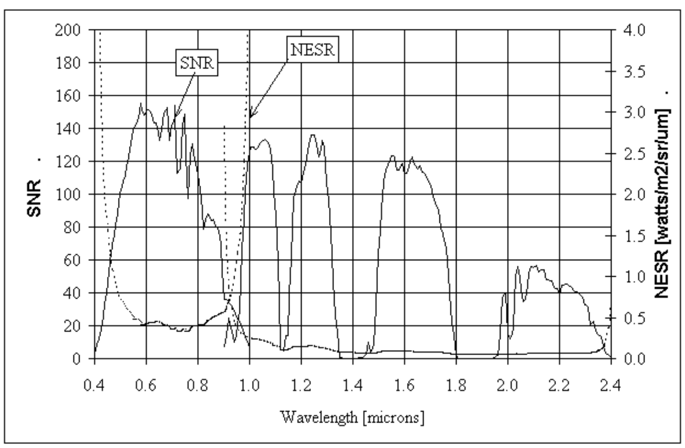

Figure 2. Signal-to-Noise and Noise Equivalent Spectral Radiance (NESR)

The footprint of Hyperion was boresighted with the ALI pan band (at ~5^{o} from nadir) and LAC to allow direct cross comparisons. The data typically is processed into cubes (19.8 km long by 7.5km wide) to facilitate data handling in current desktop computers. Each cube consists of 75 M Bytes of data. A typical acquisition consists of multiple cubes.

The instrument was extensively characterized to provide a performance baseline for the collection of radiometric data for use by the Hyperion Science Team. A Hyperspectral Characterization Facility (HSCF) provided test target inputs to Hyperion while it was in a test vacuum chamber. The HSCF consists of a monochrometer with an output used in one of two optical configurations: either the radiant energy illuminates a pinhole, slit or knife edge which is at the focus of an off-axis parabola reflector or it illuminates a Spectralon panel from which the diffuse reflectance is collimated by the same off-axis parabola. A transfer radiometer was used to characterize the radiance output from the monochromator. The light from the steering mirror was directed onto the transfer radiometer or into the Hyperion aperture through a vacuum window. The measured signal to noise agreed to better than 10% with a system model based on measured optical and focal component data. The image quality characteristics of the radiometer were measured with the HSCF. The cross-track spectral error requirements of <1.5 nm (VNIR) and <2.5 nm (SWIR), spatial co-registration of spectral bands < 0.2 pixel and absolute radiometric accuracy of < 6% were all met during acceptance test performance characterization. The cross-track MTF ranged over spatial and spectral dimensions from 0.35 to 0.47 at the Nyquist frequency. Both the center wavelength and the bandwidth were determined for a selected number of pixels across the VNIR and SWIR focal planes.

Following launch, the initial, on-orbit instrument performance was characterized and compared with prelaunch measurements. The first images were taken one week after launch and were VNIR only. The SWIR FPA cryocooler was turned on three weeks after launch and the full imaging operations for characterization was started a few days later. The characterization was carried out over a four month period. Specific sites were targeted and data collected for use in measuring the instrument image quality parameters of MTF, spatial and spectral co-registration, and VNIR-SWIR FPA alignment. The Mid-Bay Bridge near Denton, Florida, shown in Figure 3, is an example of a site that was imaged and used for MTF measurements.

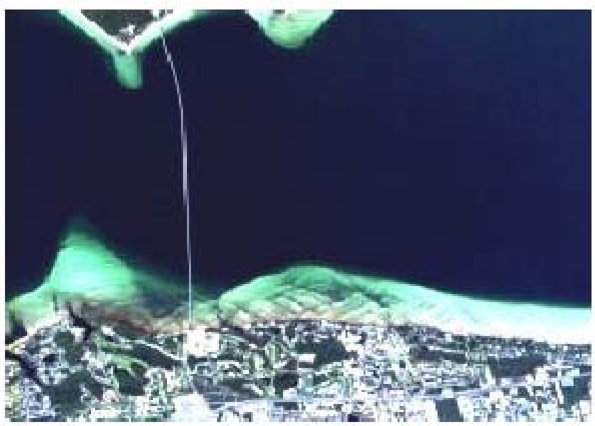

Figure 3. This is a Hyperion image image of the Mid-Bay Bridge near Denton, FL used for MTF characterization

Spectral wavelength calibration was checked using telluric and solar spectral features as well as ground truth sources of spectral band edges. The on-orbit measurements produced the same results as the pre-launch characterization. Absolute radiometric calibration and pixel to pixel relative response performance were directly addressed using the internal calibration system and the solar irradiance. Solar calibration data collections were made every three days from February 16 to March 7, 2001 and then once a week to track both the relative pixel to pixel calibration stability and the long-term repeatability of the radiometer. Successful lunar observations were made and data sets collected on February 2 and February 8, 2001. A comparison of Hyperion pre-launch and post-launch calibration results are given in Table 2 on the next page.

Characteristic	Pre-launch Cal	On-orbit Cal
GSD(m)	29.88	30.38
Swath (km)	7.5	7.75
No. of Spectral Channels	220	200 (L1 data)
VNIR SNR (550-700nm)	144-161	140-190
SWIR SNR (~1225nm)	110	96
SWIR SNR (~2125nm)	40	38
VNIR X-trk Spec. Err	2.8nm@655nm	*
SWIR X-trk Spec. Err	0.6nm@1700nm	0.58
Spatial Co-Reg: VNIR	18%@Pix#126	*
Spatial Co-Reg: SWIR	21%@Pix#131	*
Abs.Radiometry(1Sigma)	<6%	3.4%
VNIR MTF@630nm	0.22-0.28	0.23-0.27
SWIR MTF@1650nm	0.25-0.27	0.28
VNIR Bandwidth	10.19-10.21	*
SWIR Bandwidth	10.08-10.09	*

*similar to pre-launch values within measurement error.

Table 2. Summary of Pre-launch and On-orbit Characteristics

Lake Frome in southeastern Australia was characterized and used as a prime site for cross-calibration of Hyperion. Measurements at the site in December 2000 were correlated with the instrument data for January 5, 2001 and top of the atmosphere radiances were compared. The first step in the process was to test geometric accuracy of the image for overlaying ground sites. This was done using corrected Landsat data as a reference. A set of 26 ground control points were identified in both the January 5, 2001 Hyperion and the geo-rectified (UTM base) January 21, 2001 Landsat images. The standard image cube for Hyperion consists of 660 frames of data (19.8 Km long by 7.5 Km wide) and takes about 3 seconds to collect. An image equivalent to a Landsat scene is nine cubes and takes 27 seconds to collect.

The EO-1 Hyperion instrument is accomplishing a very successful mission and is meeting all the goals for levels of on-orbit radiometric performance and for characterization of those levels. As such, it is providing hyperspectral imagery with excellent radiometric quality suitable for the science community to use further to establish the value for this technology in remote sensing of the Earth's environment.