Headwall is the proud recipient of these honors and more...

Comparison of Airborne Hyperspectral Images

From the NASA-JPL AVIRIS-NG and a Headwall UAV Imaging System

Figure 1. Left, Headwall turnkey UAV package with Co-Aligned VNIR-SWIR sensor and LiDAR flies a pre-programmed route in the Colorado sky, Center, National Science Foundation (NSF) Airborne Observation Platform (AOP) Twin Otter manned aircraft containing NASA-JPL AVIRIS-NG sensor prepares for takeoff on a nearby runway. Right, both aircraft flying above the same target area at the same time, but at very different altitudes.

INTRODUCTION

Hyperspectral imaging is an extremely powerful airborne remote sensing tool. The Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) [1] operated by the NASA Jet Propulsion Lab (JPL) has been the standard-bearer for airborne imaging spectrometers since the late 1980s. The next-generation AVIRIS sensor, known as AVIRIS-NG [2], has been flown aboard various manned aircraft since 2010. However, due to extremely high manufacturing and operating costs, AVIRIS-NG is only attainable by remote-sensing agencies with large budgets and operational personnel such as those employed by the JPL or the National Science Foundation's (NSF) National Ecological Observatory Network (NEON) Airborne Observation Platform (AOP) [3].

Headwall has developed miniaturized imaging spectrometers that can be manufactured in high volume and lower cost and can flown on lightweight unmanned aerial vehicles (UAVs) [4]. These sensor payloads and fully integrated systems including UAVs themselves enable small companies and research groups to enjoy the immense power of airborne hyperspectral remote sensing. This technical note compares the performance of the AVIRIS-NG on a manned aircraft and the Headwall turnkey Co-Aligned VNIR/SWIR imaging spectrometer on a lightweight large UAV.

SIZE, WEIGHT, and POWER COMPARISON	AVIRIS	HEADWALL		
	AVIRIS-NG	CO-ALIGNED	NANO VNIR	SWIR 640
SIZE (mm)	830 x 570 (H x dia) plus elec boxes and racks	272 x 211 x 165 (with lens)	76.2 x 76.2 x 87.4 (no lens)	75 x 126 x 212 (no lens)
WEIGHT (kg)	465	2.83	0.52	1.9
POWER (W)	High	26	15	24

Table 1. SWaP comparison of the AVIRIS-NG and the Headwall Co-Aligned VNIR-SWIR, Nano Hyperspec (VNIR), and Micro Hyperspec SWIR 640 payloads.

Lightweight UAV platforms enable users to deploy imaging spectrometers quickly, easily, and without the need for a support team; they also enable lower flight altitudes, resulting in imagery with much higher spatial resolution. AVIRIS and AVIRIS-NG were designed for use on large to medium-sized manned aircraft. The size, weight, and power (SWaP) of AVIRIS-NG are not compatible with small UAVs. Table 1 compares the SWaP of several Headwall UAV-deployable imaging spectrometers to the AVIRIS-NG.

SYSTEMS DESIGN AND CHARACTERISTICS

Both AVIRIS-NG and Headwall spectrographs utilize a modified Offner relay design. This all-reflective optical design has no moving parts and provides very low aberration across a wide spectral range.

Great care was taken to maintain the pointing stability of all optical components in the AVIRIS-NG; the spectrograph and telescope are housed in a cooled vacuum chamber that maintains a constant temperature. A cryocooler keeps the temperature at the focal plane array (FPA) less than 140° K. These features result in a SWaP that is incompatible with operation on a UAV.

Headwall's spectrograph is fabricated in house from a single piece of material, and after alignment all optical components are locked into place within a very compact yet rugged enclosure to ensure pointing stability over a wide range of operational temperatures. Headwall then tests alignment after a series of thermal cycles covering the entire operational temperature range to ensure that alignment is stable even after the spectrograph experiences large temperature changes.

EXPERIMENT

The manned aircraft, a DeHavilland DHC-6 Twin Otter as part of the NEON Airborne Observation Platform (AOP) operated by Battelle, equipped with the AVIRIS-NG flew over the same target at the same time as the Headwall UAV system equipped with a Co-Aligned VNIR-SWIR sensor. Table 2 summarizes the flight parameters of each system.

The test flights were done at Table Mountain in Golden, Colorado. The scene included a 20x10 meter reflectance calibration tarp provided by the NEON team coordinating the manned AVIRIS-NG flight and a 3x3 meter reflectance calibration tarp provided by Headwall. Both aircraft performed five time-coincident passes over the target scene on Tuesday, 9 April 2019. Exact times and the flight direction can be seen in Table 3. The batteries of the Headwall UAV platform were swapped for fresh ones between the third and fourth passes.

Although AVIRIS-NG has a wider swath, the Co-Aligned VNIR-SWIR sensor onboard the Headwall UAV platform has a much smaller ground-sampling distance (GSD). Figure 2 shows two representative flights overlaid onto Google base-map at four different zoom values. This shows the flight location and provides a visualization of the differences in swath width and spatial resolution.

FLIGHT PARAMETERS	AVIRIS-NG	HEADWALL CO-ALIGNED ON UAV	
	VNIR / SWIR	VNIR	SWIR
AGL (altitude in m)	1000	120	120
GSD (cm)	100	7	7.2
SWATH WIDTH (m)	600	44.8	46.1
FLIGHT SPEED (m/sec)	Not Specified	5.4	5.4

Table 2. Flight parameters for the AVIRIS-NG and Headwall Co-Aligned VNIR-SWIR (two sensors on a single UAV) airborne platforms.

RESULTS AND ANALYSIS

The Headwall Co-Aligned VNIR/SWIR system [5] contains two imaging spectrometers – the Headwall NanoHyperspec VNIR and the Headwall MicroHyperspec SWIR640. The sensor package also contains a PPK-capable GPS/IMU, and two 480 GB storage drives (one for each sensor). This sensor package produces separate VNIR (400-1000nm) and SWIR (900-2500nm) data cubes. AVIRIS-NG has a single focal plane array and captures a single data cube covering 400-2500 nm.

The surface illumination at the reflectance tarps was approximately identical in the Headwall and AVIRIS-NG measurements because the measurements were time-coincident. Both sensors packages have a radiometric calibration enabling conversion of the image data to at-sensor spectral radiance. There are some expected differences in the at-sensor radiance measurements due to differences in atmospheric absorption/scattering because of the different flight altitudes. The sensor performances were compared using the at-sensor radiance data cubes.

Three assumptions were made to compare the performance of the two sensors:

- 1. The solar illumination was constant and identical for both imaging spectrometers.
- 2. The surface reflectance (or albedo) of the comparison targets was spatially uniform.
- 3. The comparison targets are perfectly flat Lambertian surfaces, so shadowing and glare can be ignored.

The large 20x10m reflectance tarp provided by NEON gives a convenient, uniform target for comparison. The spatial resolution of the Headwall Co-Aligned system is much higher than AVIRIS-NG because it is flown at a much lower altitude (as was summarized in Table 2).

As can be seen in Figure 3, the third assumption is not perfect; the higher resolution Headwall images show shadowing on the reflectance target. Therefore, the Headwall images were spatially binned to equate the spatial resolution of the two sensor packages.

FLIGHT PASS NUMBER	DIRECTION	START TIME (UTC)
1	S-N	16:35:28.55
2	E-W	16:41:10.2
3	N-S	16:43:02.47
UAV Battery Swap		
4	W-E	17:23:00.81
5	S-N	17:26:00.54

Table 3. Flight times and directions of time-coincident passes.

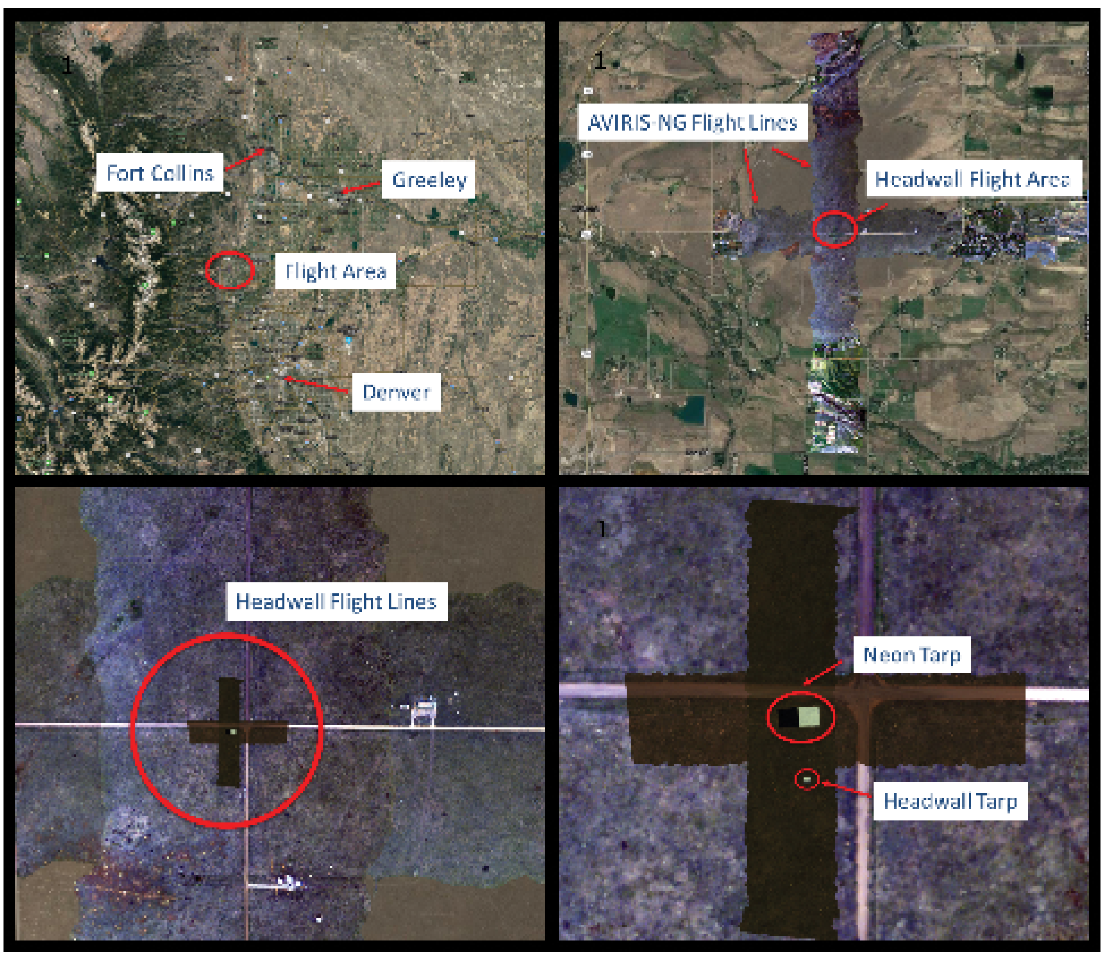

Figure 2. Upper Left: Far zoom out showing the location of the flight area in relation to nearby cities in Colorado. Upper Right: Closer zoom showing the extent of the AVIRIS-NG flight lines. Lower Left: Intersection of the Headwall and the AVIRIS-NG flight lines. Lower Right: Close-up of the Headwall flight lines.

Figure 3. Left to right: AVIRIS-NG image of its reflectance calibration tarp, Headwall image of its tarp, and Headwall image resolution-matched.

The average spectrum of all the spatial pixels in the bright tarp panels can provide an initial assessment of the performance of both sensor payloads.

As can be seen in Figure 4, the averaged spectral radiance measurements of the two sensor payloads are quite similar. The atmospheric obsorption features are a bit deeper in the AVIRIS-NG spectra, as expected because of its higher flight altitude. The radiance at the sensor on the blue side of the spectrum is also lower in the AVIRIS-NG data. This is most likely because conditions were overcast, and atmospheric aerosols scatter more at shorter wavelengths. Figure 5 is a photograph that shows the overcast conditions during the flights.

Plotting the spectra at all the spatial pixels in the bright tarp panel also gives an indication of the noise in the measurement. If all three assumptions are valid, then any differences in the spectra are due to measurement noise. The high-resolution Headwall image shows shadowing on the tarp, so the assumptions are not perfectly valid. Figure 6 plots all the spatial pixels on the bright tarp panel from the first flight. The Headwall plots were done before and after spatial binning.

Finally, the signal-to-noise ratio (SNR) was estimated by assuming that the noise is the standard deviation of measurements at each of the spatial pixels, and the signal is the average spectrum (valid if the 3 assumptions above are true).

This measurement in Figure 7 shows that the AVIRIS-NG sensor produces data cubes with a higher SNR. However, the Headwall sensor payload offers comparable performance in a package on a lightweight UAV operated by a small team. This shows that small companies and research groups can collect extremely high quality remote-sensing data from a convenient UAV platform.

The data and descriptions in this Technical Note were also published as part of presentations [6,7] delivered at the American Geophysical Union (AGU) Fall Meeting.

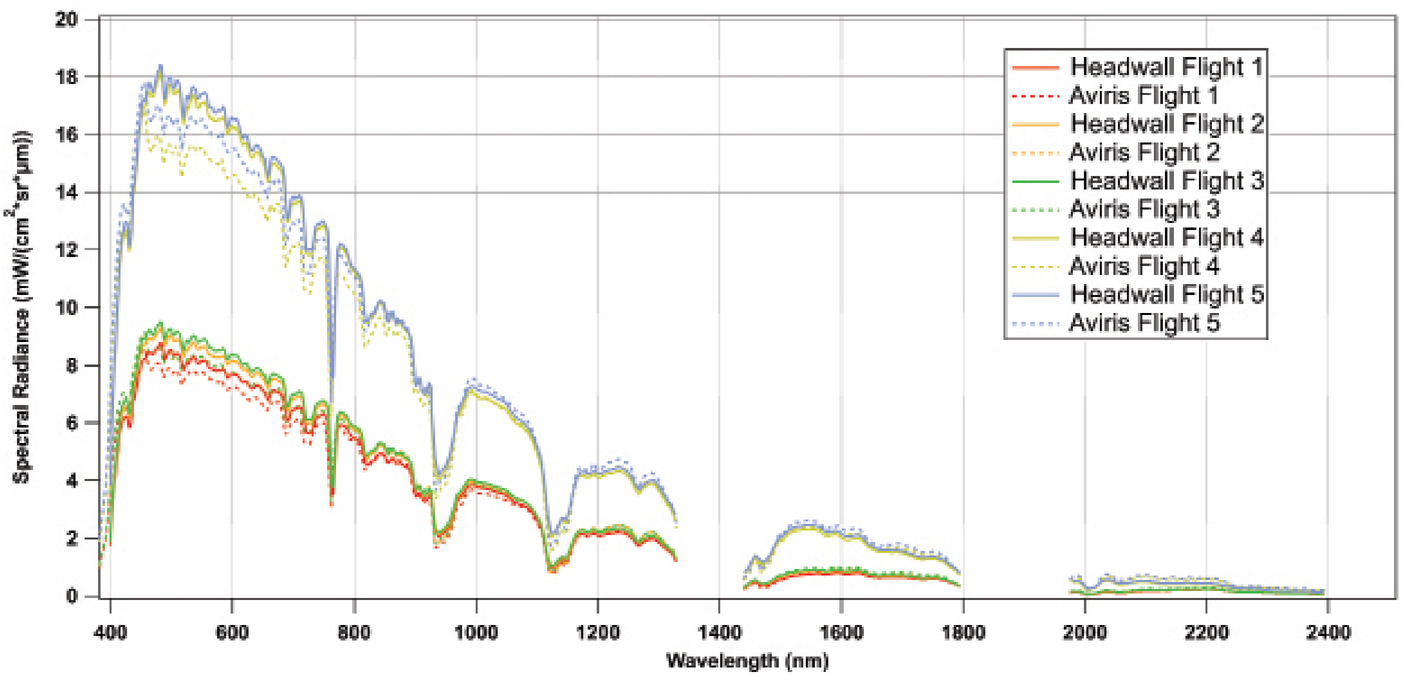

Figure 4. Average spectra of the bright tarp panels from each of the 5 time-coincident passes over the NEON reflectance calibration tarp.

[1] Jet Propulsion Laboratory, AVIRIS Overview: https://aviris.jpl.nasa.gov/aviris/index.html

[2] Jet Propulsion Laboratory, AVIRIS-NG Overview: https://aviris-ng.jpl.nasa.gov

[3] National Science Foundation NEON Airborne Observation Platform (AOP): https://www.neonscience.org/data-collection/airborne-remote-sensing

[4] Headwall Photonics Integrated UAV Solutions: https://www.headwallphotonics.com/uav-integration

[5] Headwall Photonics Hyperspectral Imaging Sensors, including Co-Aligned VNIR-SWIR sensor: https://www.headwallphotonics.com/hyperspectral-sensors

[6] Presentation at AGU Fall Meeting 2019 by NEON Science / Battelle Ecology [A], Exelis VIS [B], and the University of Colorado Boulder [C]; J. Adler [A], T. Goulden [A], D. Hulslander [B], J. McGlinchy [C]

[7] Presentation at AGU Fall Meeting 2019 by NEON Science / Battelle Ecology [A], Headwall Photonics [D], and the University of Colorado Boulder [C]; J. Adler [A], T. Goulden [A], W. Rock [D], J. McGlinchy [C]

Figure 5. Photograph taken at Table Mountain on Tuesday, 9 April 2019 during the comparison flights. The Headwall UAV system can be seen in the sky and part of the NEON tarp can be seen in the foreground.

EXPERIMENTAL ASSUMPTIONS

1. The solar illumination was constant and identical for both imaging spectrometers.

2. The surface reflectance (or albedo) of the comparison targets was spatially uniform.

3. The comparison targets are perfectly flat Lambertian surfaces, so shadowing and glare can be ignored.

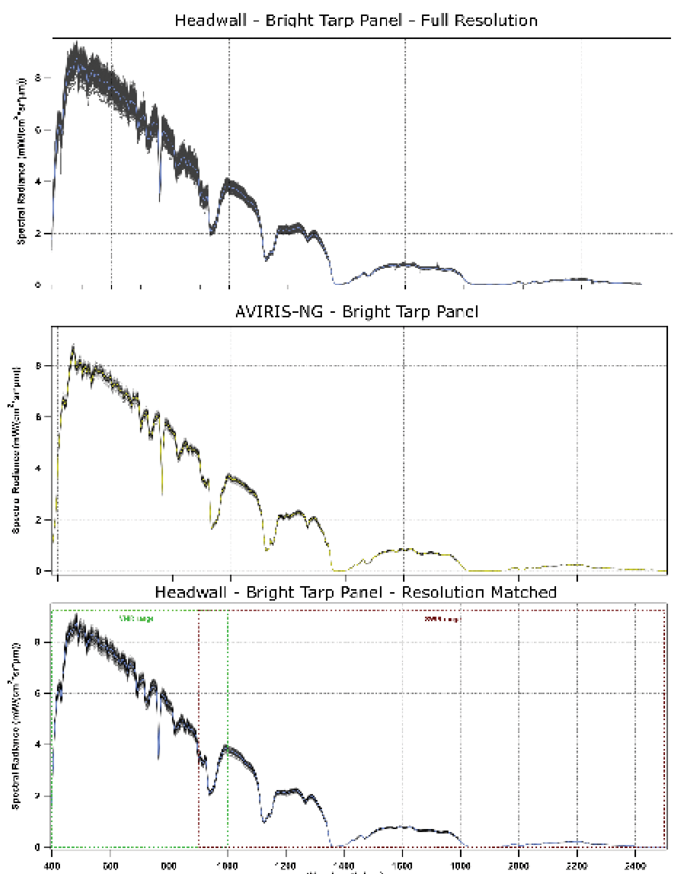

Figure 6. Spectra from all spatial pixels on the NEON bright tarp panel from flight number 1. Top: Full-resolution Headwall data, Middle: Full-resolution AVIRIS-NG data, and Bottom: Resolution-matched (spatially binned) Headwall data matched to the AVIRIS-NG data.

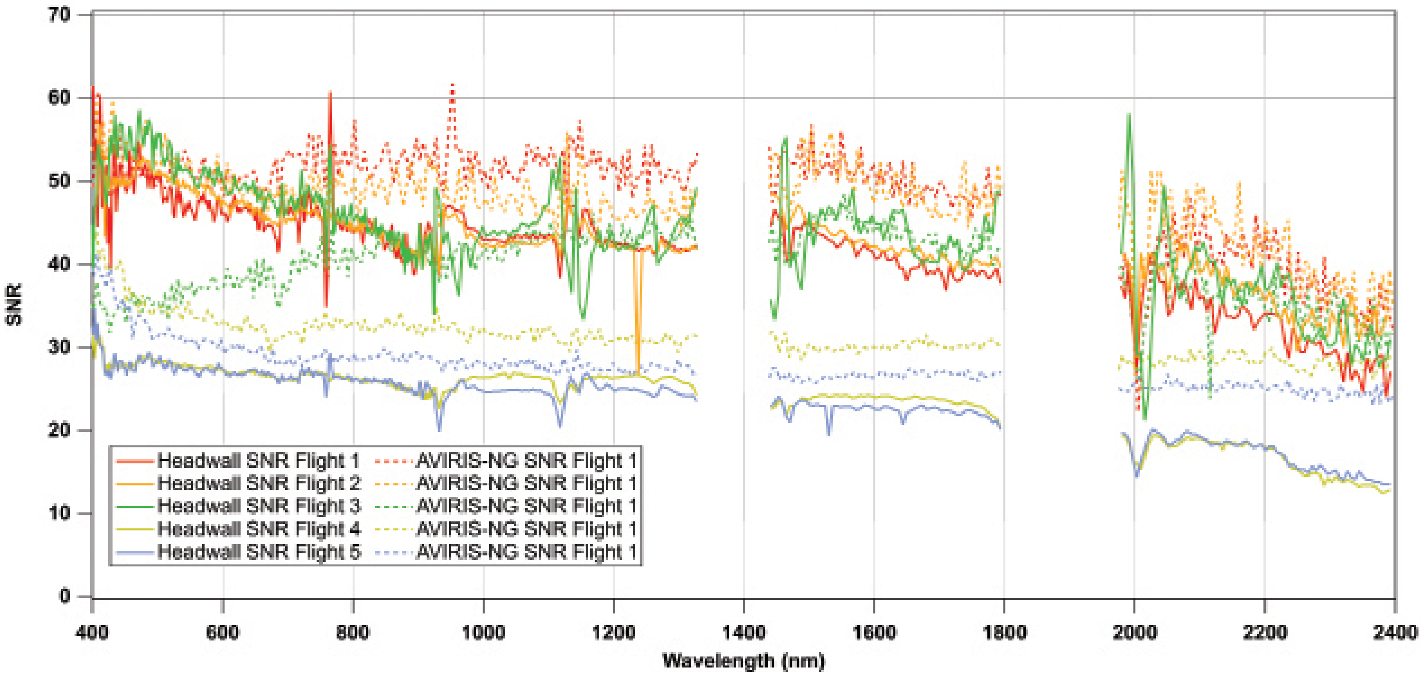

Figure 7. Signal-to-Noise (SNR) of the NEON bright tarp panel measurements calculated by taking the average spectrum divided by the standard deviation of all spatial pixel measurements after spatially binning the Headwall data cube to match the spatial resolution of the AVIRIS-NG measurements.

Figure 8. Photograph of the Headwall lightweight hyperspectral UAV platform being prepared for flight. The total take-off weight (TOW) of the platform including the hyperspectral payload is well within US Federal Aviation Administration (FAA) regulations on commercial drone piloting under Part 107 guidelines, and a large support team is not needed.

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