Hawkeye Absolute Position Calibration

Alan Holmes

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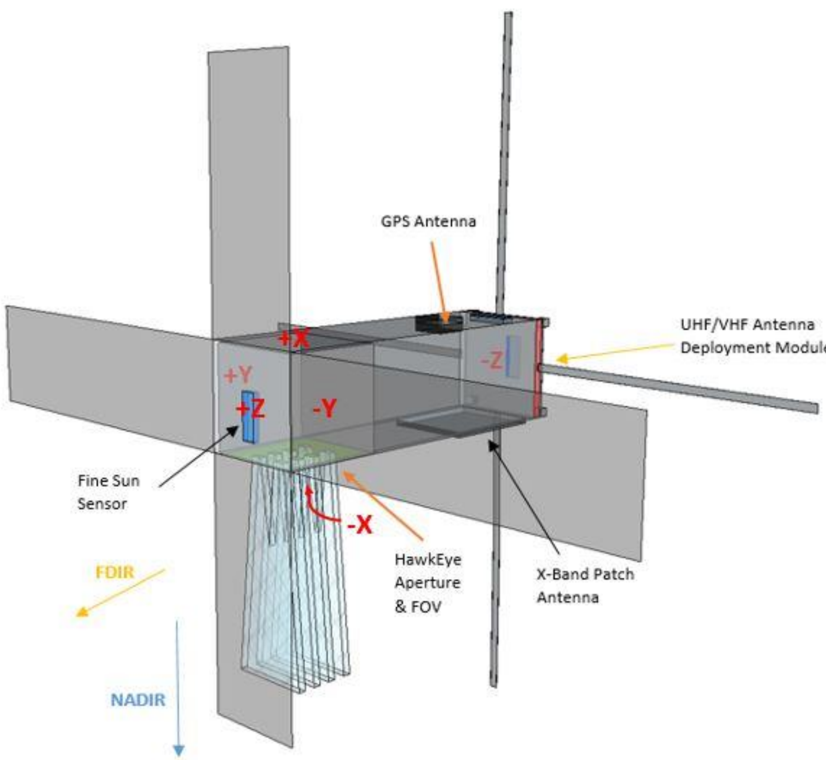
Knowledge of the absolute pointing for each Hawkeye pixel is important in geolocating the image data. In this report I present the values for Flight Unit One and Two.

The coordinate system for this instrument is defined in Figure 1. The downward Nadir direction, perpendicular to the instrument face (our reference mirror) is the –X direction. The spacecraft is flying in the +Z direction. The linear CCDs are nominally parallel to the XY plane. We will define an increment of angle from the XZ plane, from –X toward the +Y direction to be a positive angle Alpha, and an increment of angle from the XY plane, from -X toward the +Z direction to be a positive angle Beta. In the Hawkeye instrument we will refer to the three linear arrays within each CCD as Chroma-Green, Chroma-Red, and Chroma-Blue. A point of the ground will illuminate them in the order of green-Red-blue. For Hawkeye, pixel 1 of the linear CCD views a positive angle Alpha.

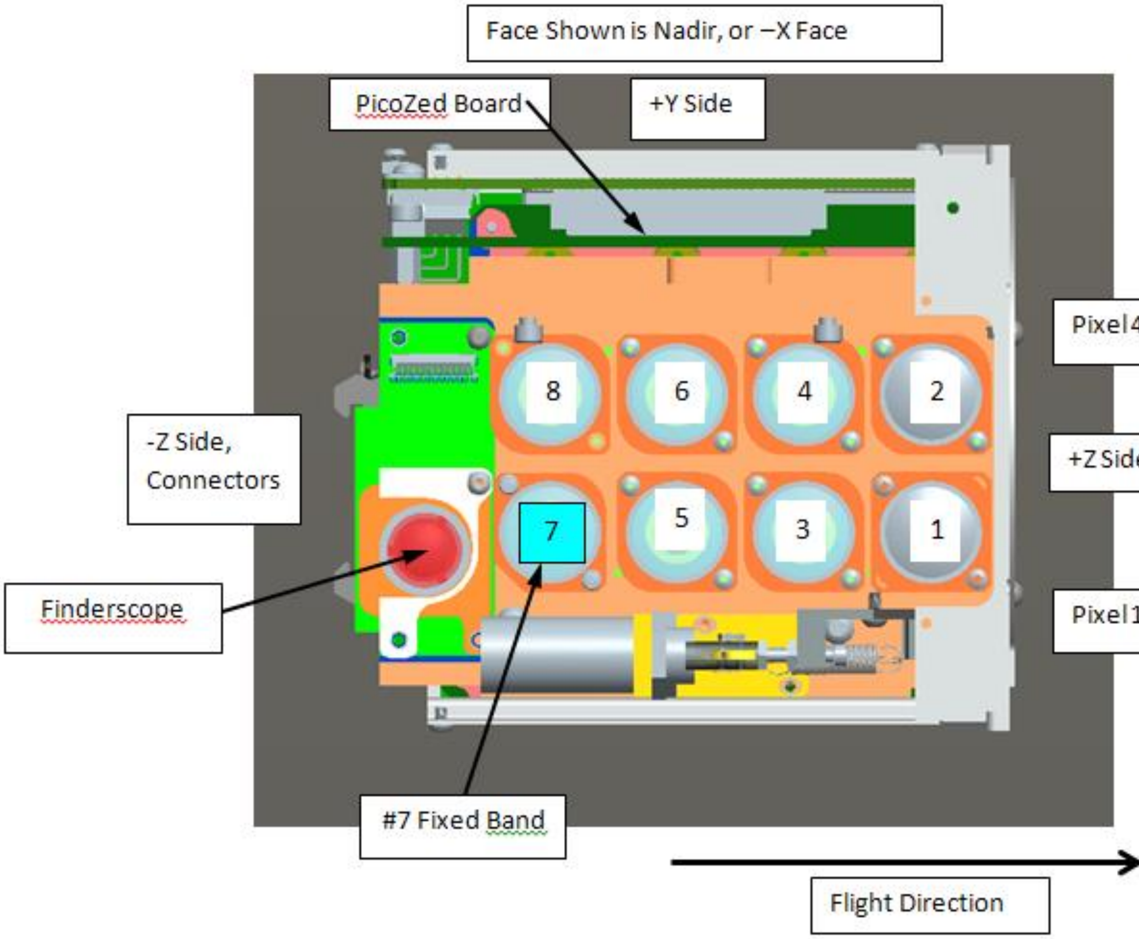
Figure One: Coordinate System



For reference, Figure two below shows the aperture face of the instrument in more detail, along with the coordinate system.

Figure Two: Minus X Face of Hawkeye Instrument

(THIS IS AN IMPORTANT FIGURE!)



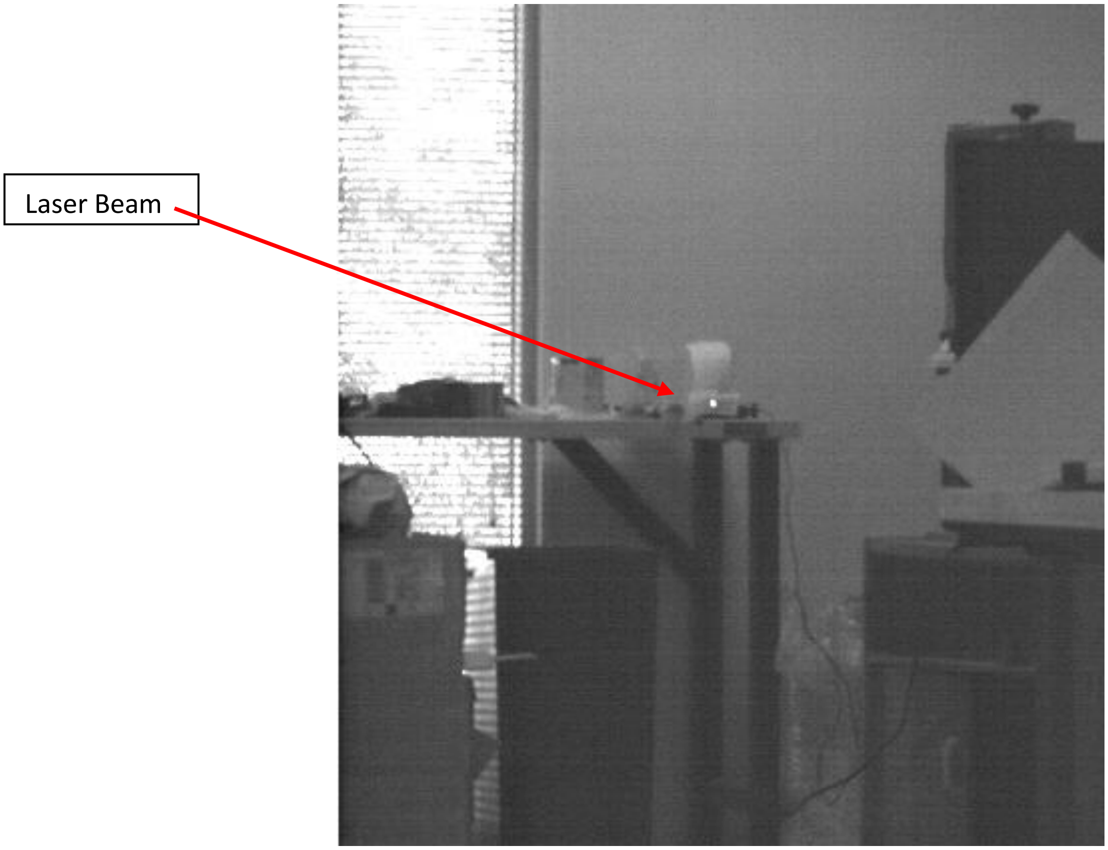
If you are flying along with the instrument in orbit, traveling in the direction that your head is pointing toward, arms outstretched, Facing down, your right arm is pointing at the portion of the scene nearer pixel one in the final image. Pixels 1 to 4080 are right to left below you. In Figure Two a positive alpha angle is light coming in from above (to the right for our flying observer), and that corresponds to lesser pixel numbers. A positive Beta angle corresponds to light coming in from the right. As an image is collected, the projected image of the ground on the CCD moves from left to right on the CCD as oriented in Figure Two. So, an image stripe of an object at a positive Beta angle will be collected later in time. This can get pretty confusing!

We performed the absolute position calibration of unit 1 by directing a laser beam from a distant point onto band 6. We placed a glass disk against the face of the unit and oriented it to retroreflect the light back to the laser source. That meant that the laser beam was perpendicular to the unit at band 6. We then scanned the unit across the scene to see where the laser beam (or a piece of white tape marking it) appeared in the image. We use Band 6 since it passes a little bit of the laser light. The image of the glass near the instrument face is shown in Figure Three. In the test it was pressed up against the apertures.

Figure Three: Glass Disk against Instrument Face, Laser Spot on Band 6

An example image of the laser in the room is shown in Figure Four.

Figure Four: Band 6 scan of room showing Laser Spot



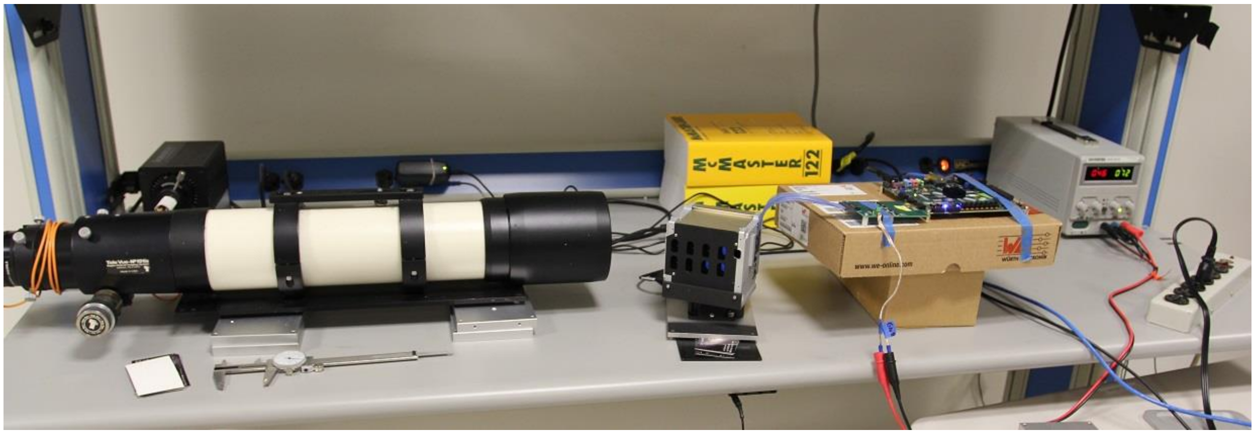
Based on this information, we concluded the normal to the surface is located at Band 6 pixel 982 using CCDOPS. We define the center of the field of view as pixel 900. However, when the image is extracted to CCDOPS there are 18 dark pixels preceding the light data, so in CCDOPS the center is at pixel 918. So, the center of the field of view is 64 pixels off the normal to the instrument, in the positive alpha direction. Since there are nominally 78.54 pixels per degree, the CENTER of the field of view for Unit 1 band 6 is 0.815 degrees positive in alpha from the surface normal. This offset is due to the 1.5 degree wedge in the polarization scrambler. For Unit Two the offset was 0.52 degrees in the same direction. For our flying observer, this means what he sees as straight down shows up around pixel 982 in the image, so the center of the field of view is slightly to his right.

In the other direction we found the normal to be 0.1 degree offset from the perpendicular in the negative beta direction for Unit One, and 0.05 degree in the positive direction for Unit Two.

Band-to-Band Differences

The band-to-band differences in alignment were measured by projecting a star-like point into the Hawkeye instrument and measuring the position of the spot for each band. The setup is shown below in Figure Five. A fiber optic tip was placed at the focus of a Televue NP101 F/5.4 refractor and projected into the instrument. This refractor has an aperture large enough to illuminate all bands at once.

Figure Five: Televue Refractor illuminating Instrument on Rotary Stage



The instrument was mounted to a rotary stage that rotated the instrument across the projected starlike image. The final positions noted before shipping for each Unit are tabulated in Table One.

Table One: Final Relative Alignments – near On-axis

Band	Unit 1 Along CCD	Unit 1 Along Track	Unit 2 Along CCD	Unit 2 Along Track
1	-3	3	1	-3
2	-2	0	2	0
3	-2	1	1	2
4	-1	0	1	0
5	0	-2	-1	1
6	0	0	0	0
7	1	1	-2	3
8	1	-3	-1	1

(Error is shown in pixels)

The units were manually aligned to get them to be this close in registration. Considering that the pixels are only 10 microns on a side, this is pretty good alignment for 8 separate optical systems. The instrument firmware was customized for each unit to optimize the agreement in the along-CCD direction by selecting the pixels used for each band (there is a bit of cushion on each end to accommodate this). The data shown in Table One is all post-vibration and post-thermal-vacuum testing. The files used for unit 1 are contained in:

C:\FlightOneCalibrationBackup\Alan2\Unit1\PostTV-AlignmentData-061217

For unit 2 the files can be found at:

C:\FlightTwoCalibrationBackup\Alan3\Unit2\Post-VibePosition-070817

Of course, this is not the final word, since the focal length, and therefore scale factor (pixels per degree) varies from band-to-band.

Focal Length as a function of band number

We measured the absolute focal lengths in a bit of an odd manner. We mounted the instrument so the CCD line was parallel to the scan plane and then scanned the instrument horizontally while reading the CCD out vertically. As a result, any spot of light in the field of view will nominally trace out a 45 degree line in the final image. The image is illustrated below in Figure Six.

Figure Six: Band 8 scan of room

We scanned the stage at 0.692 degrees per second, which means a 10 micron pixel at a 45 mm focal length, and a row interval time of 18.4 ms, should trace out a line at exactly 45 degrees. The slight band to band differences allow an accurate measure of focal length. The results for Unit One are summarized in Table Two.

Table Two: Unit One Derived Focal Length

			Pixels
		Nominal	Mis-Registration at 900
Band	Wavelength	Focal Length	Pixels off axis
	(in nm)	(mm)	(Pixels)
1	412	45.236	1.0
2	443	45.106	-1.5
3	490	45.184	0.0
4	510	44.978	-4.1
5	555	45.029	-3.1
6	670	45.184	0.0
7	751	45.314	2.6
8	865	45.366	3.6

Band 2 is a bit anomalous, and it also has a poor focus. No doubt the discrepancies are related. Similar data for Unit Two is contained in Table Three.

Table Three: Unit Two Derived Focal Length

			Pixels
		Nominal	Mis-Registration at 900
Band	Wavelength	Focal Length	Pixels off axis
	(in nm)	(mm)	(Pixels)
1	412	45.340	3.1
2	443	45.366	3.6
3	490	45.184	0.0
4	510	45.106	-1.5
5	555	45.081	-2.1
6	670	45.184	0.0
7	751	45.340	3.1
8	865	45.497	6.2

At the focal length for band 6, for both units, an on-axis pixel is 221.3 micro-radians on a side. From 540 km altitude this is a ground footprint of 119.5 meters at Nadir.

The data used in this calculation is contained in:

C:\DellOffice-Images17\HawkeyeFocalLengthCal-0562317 (Unit 1 – not yet archived)

C:\FlightTwoCalibrationBackup\Alan3\Unit2\FocalLengthMeasure-062917 (Unit 2)

FInderscope Measurements

Based on design, the focal length of the Finderscope is 11.8 mm. The field test data agrees well with this, but it is hard to be more accurate than +/- 0.1 mm. Since the pixel size for this array is 6 microns on a side, the pixel size is 508 microradians, or 275 meters from 540 km altitude. So, a Finderscope pixel is 2.295X larger than a linear Chroma array CCD pixel in projected size. The alignment of the Finderscope array axes with the mechanics for Unit 1 and Unit 2 is within 0.2 degrees of perfect, but once again, it is hard to be more accurate based on the data available.

Pixel 900 for band 6 (the center pixel of the active area) in Unit 1 falls on pixel 369 in the Finderscope array. For Unit 2, Pixel 900 for band 6 falls on pixel 371 in the Finderscope array.

Field of View (FOV) Summary:

Based on focal length measurements, which agree very well with design, the field of view of each linear array is +/- 11.31 degrees. The Finderscope array has a field of view of +/- 11.1 degrees (parallel to the linear array) by +/- 7.1 degrees.