Tech Note TN-20120613-2
PIM Boresight Stability Results from Checkout Flight

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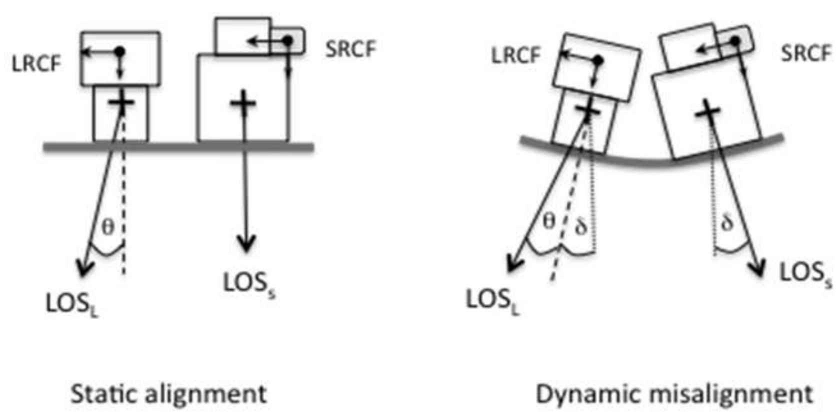
Introduction

In the geolocation processing of the Payload Integration Mount (PIM) data, all of the angular measurements are made relative to the most accurate inertial measurement unit (IMU), which is in the Optech Gemini lidar unit. The types of misalignments, of each instrument to the IMU, can be broken down into two categories, shown below. Static alignment is measured and compensated during the initial checkout flight. With the exception of a small thermal equilibrium issue, the static alignment is unlikely to change from one flight to another because the instruments and the frame have the same thermal expansion coefficient (CTE) and are torqued to a high preload.



Dynamic misalignments can occur over a variety of amplitudes and frequencies. Here is a list of the relevant frequencies

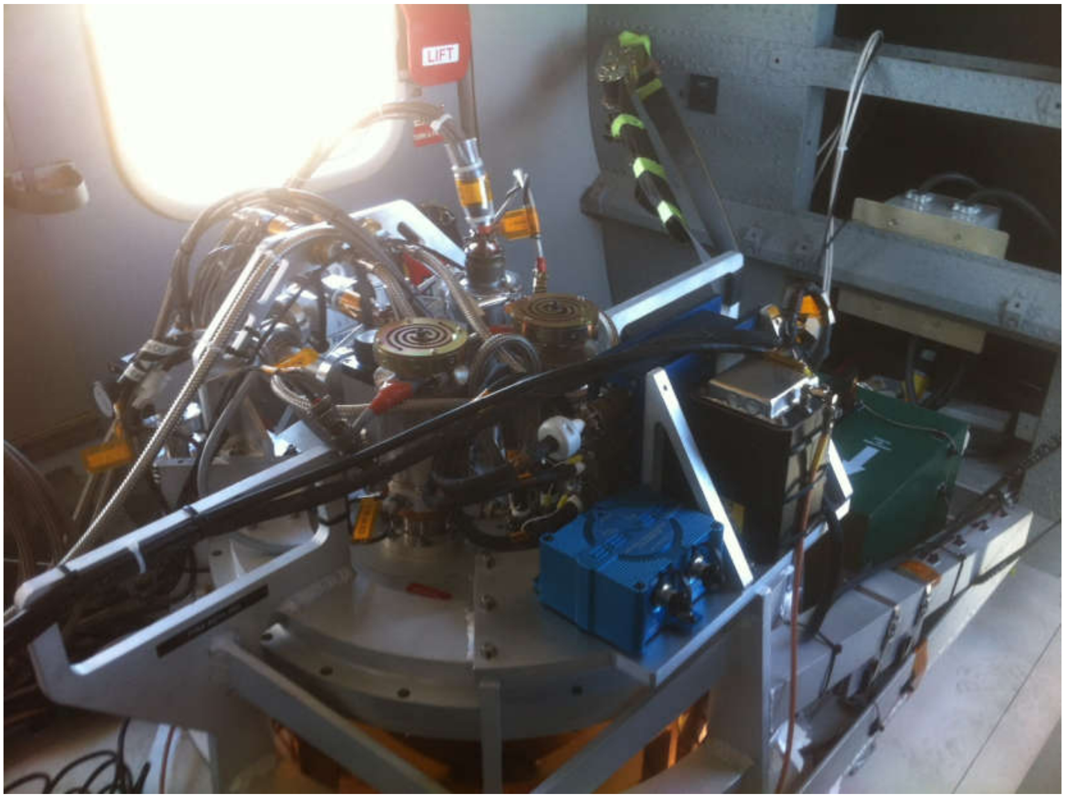
Frequency (Hz)	Description	Note
5	metrology filter stopband	
10	C-MIGITS IMU update freq.	
15	metrology filter passband	
19	lowest isolator translation mode	
34	highest isolator rotation mode	
50	lidar IMU update freq.	
60	cryocoolers	stated by JPL and confirmed by 3 separate measurements
70	max lidar scan mirror freq.	
112	first PIM mode	plate bending
137	Twin Otter blade freq.	

The SouthWest Research Institute (SwRI) anticipates the airplane blades to be the biggest driver. None of the dynamic misalignments are accounted for in the geolocation algorithm; thankfully, in our case, these dynamic misalignments are small.

We have been requiring a 0.4pixel/400µRad (2σ) uncertainty in the geolocation of the spectrometer to the lidar data. Here is the initial error budget:

Error Source	Budget
Boresight Calibration	0.20 pixel
GPS-IMU	0.20 pixel
Thermal stability	0.20 pixel
Mechanical Vibration	0.20 pixel
Total uncertainty (RSS)	0.40 pixel

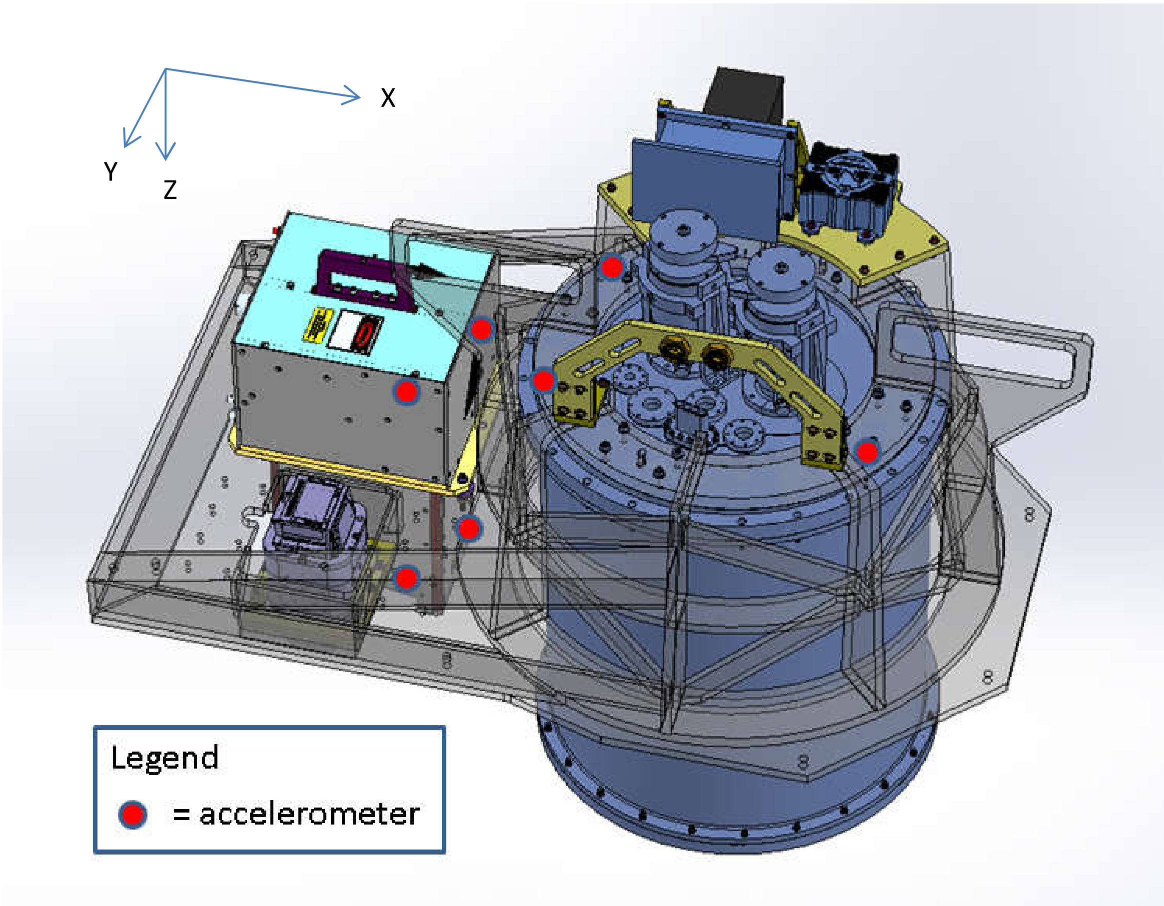
The boresight calibration accuracy can be readily solved during the geolocation process and the GPS-IMU accuracy is stated by the vendor, but the thermal and mechanical stability has been unknown until recent measurements using thermocouples and accelerometers on the PIM.



Methods

Jitter Metrology

The jitter metrology system is constructed from pairs of accelerometers that measure relative accelerations. Each pair is separated by a distance which is measured by digital calipers. The accelerometers are placed roughly as shown below. The lidar has 4 accelerometers and the spectrometer has 3, since they are in the same plane, the corner accelerometer can be used for both Θx and Θy.

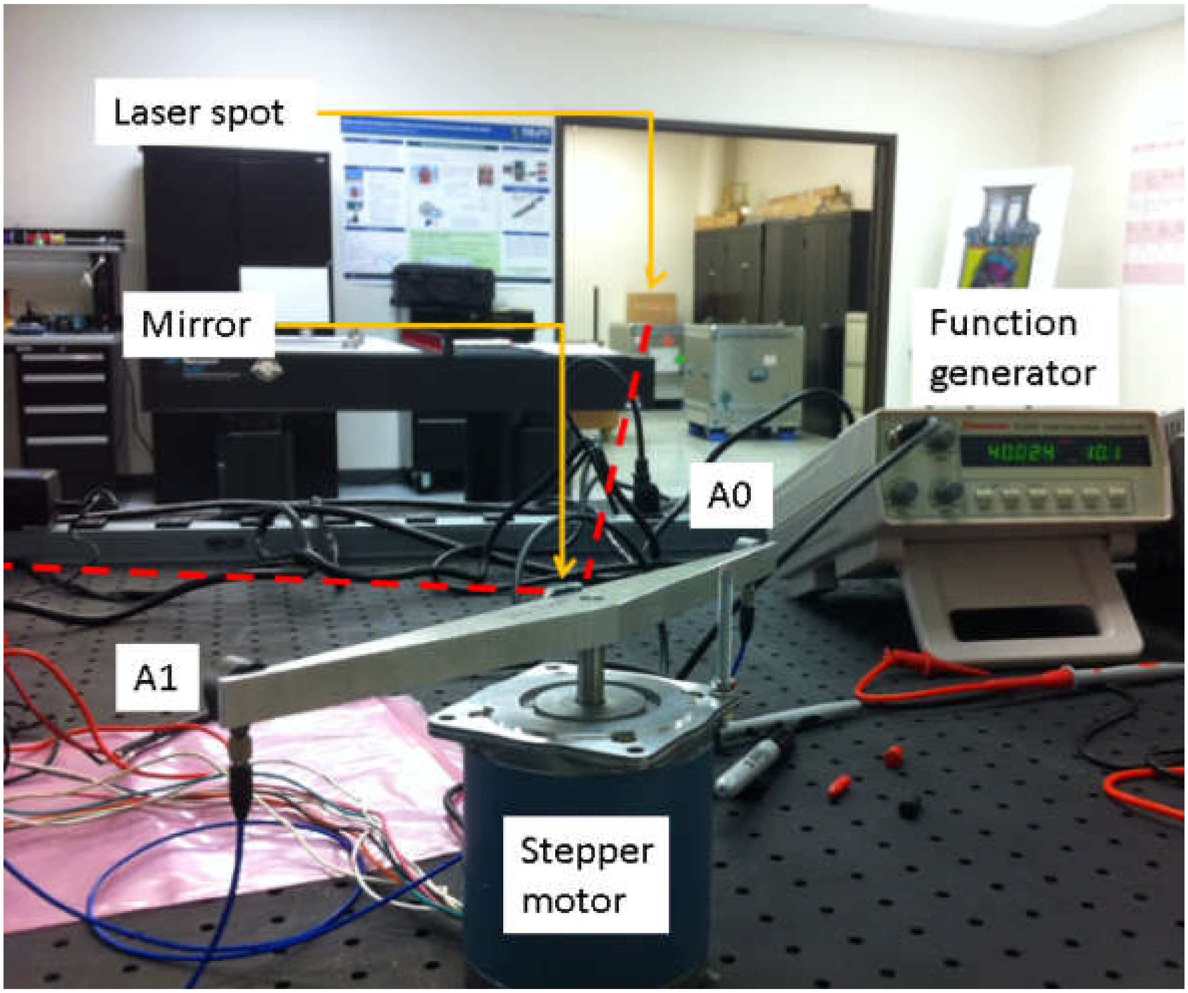


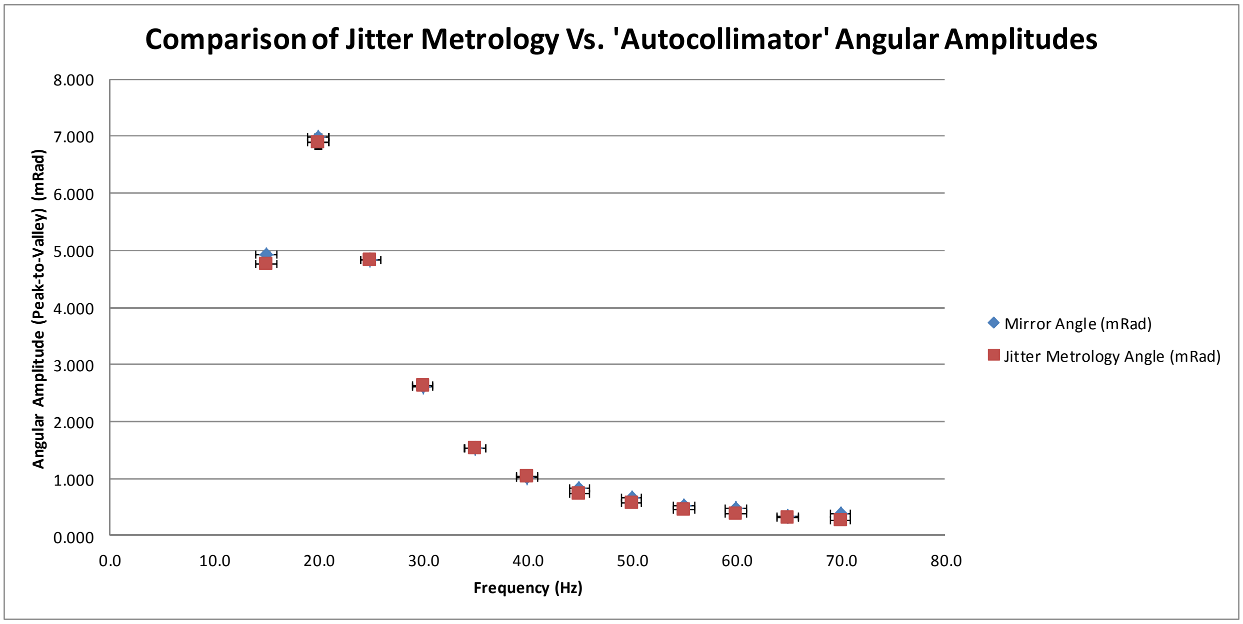
For any rigid object, the periodic angular displacement can be measured by attaching two accelerometers A0 and A1 separated by a distance d. The periodic angular displacement is

$$\theta(t) = \iint \frac{A1 \quad A0}{d} dtdt$$

After integration, this is run through a high-pass filter with a passband of 15Hz, to minimize the low frequency components from the accelerometers and the integration.

To test the code, the setup, pictured below, was devised. 2 accelerometers are attached to either ends of a bar, which is vibrated by a stepper motor . A function generator feeds an oscillating voltage to the stepper motor. The bar has a mirror attached to the center and a laser is reflected off of it and onto a distant wall; mirror oscillation amplitudes of 40μRad can be detected.

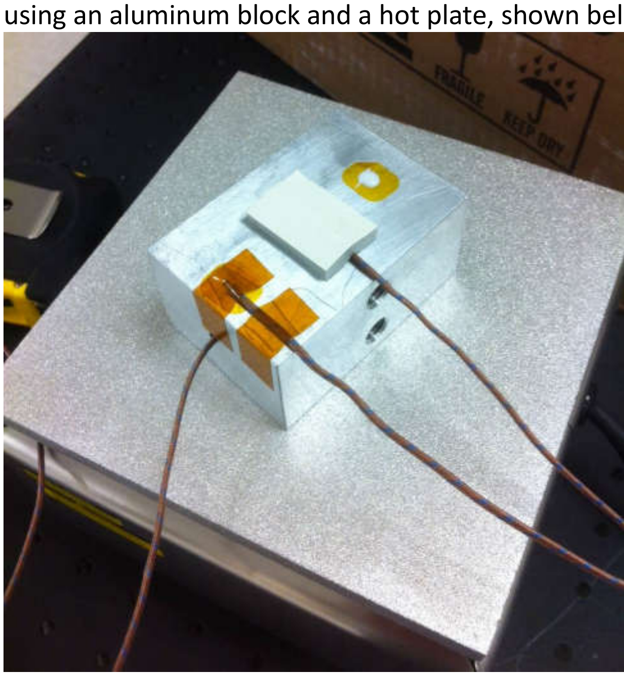

Laser spot
Mirror
Function
generator
A0
A1
Stepper
motor



This test served mostly as a check for systematic errors. The first data point was at 15Hz, right at the filter passband, so ignoring that point, the standard deviation of all of the discrepancies in the two measurements is 46µRad. The actual placement of the accelerometers on the PIM is further apart than on the validation, so the results will be slightly more accurate.

Temperature Metrology

15 thermocouples were added various parts of the PIM. The mounting technique was tested using an aluminum block and a hot plate, shown below.



For the comparison, a reference thermocouple was potted into the block using thermally conductive epoxy. The 3 mounting techniques compared were

1. Foam with paste (thermally conductive)

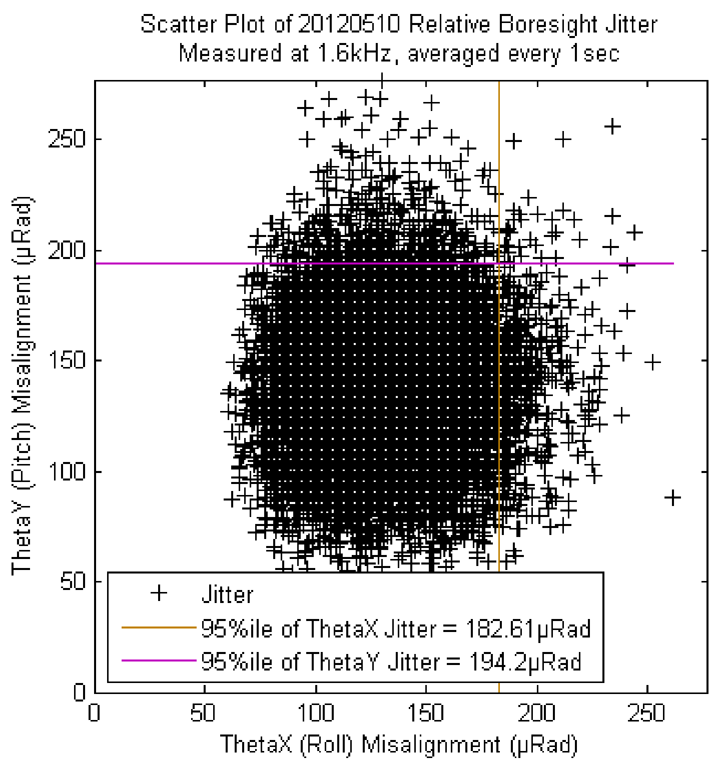
2. Foam with no paste
3. Tape

Each technique had 1 layer of tape in between the block and the thermocouple to minimize induced electronic errors. The block was thrown onto the hot plate. Mounting technique #1 was selected because it had the fastest response time. In the future, more improvement could be made upon this, but for now this is a fast and adequate technique.

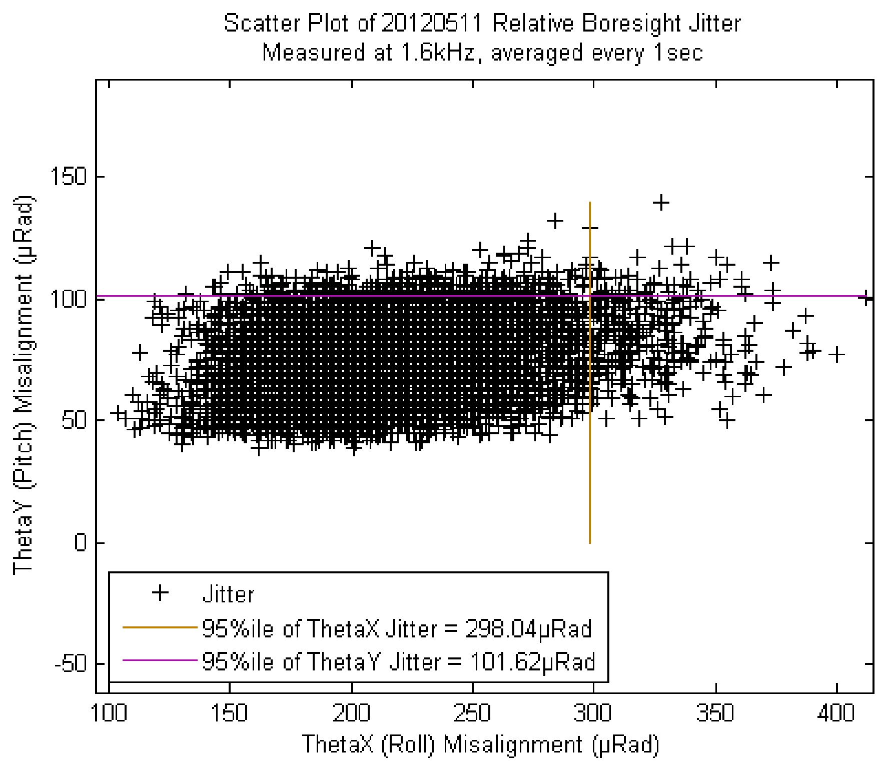
The boresight misalignment due to thermal gradients is estimated through the basic effects of heating and cooling struts made of 23ppm/°C aluminum.

Results

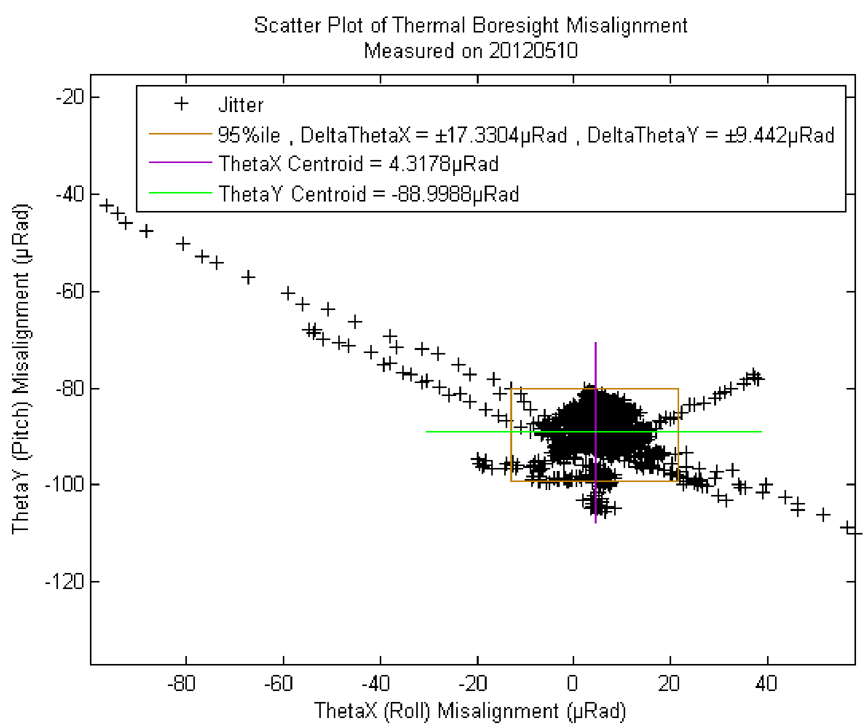
Jitter tests in the hangar measured a relative jitter of ~70µRad with the cryocoolers on. By wedging a chunk of metal between the Lidar body and the PIM, the relative jitter was reduced to ~40µRad.



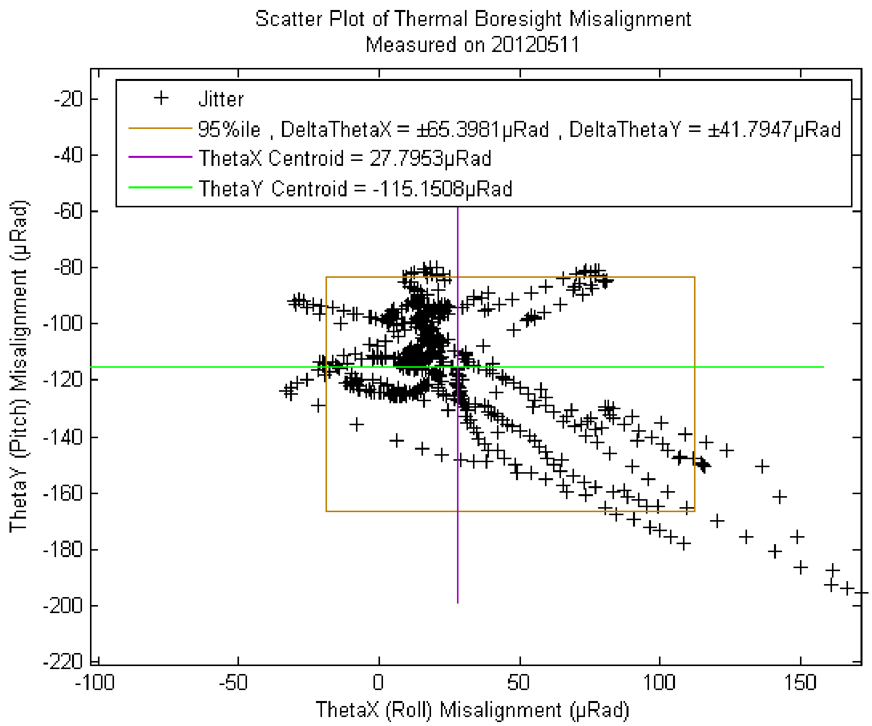
May 10th – Extracted from survey of Grand Mesa



May 11th – Extracted from survey of Senator Beck Basin at 5200m ASL



May 10th – Extracted from survey of Grand Mesa



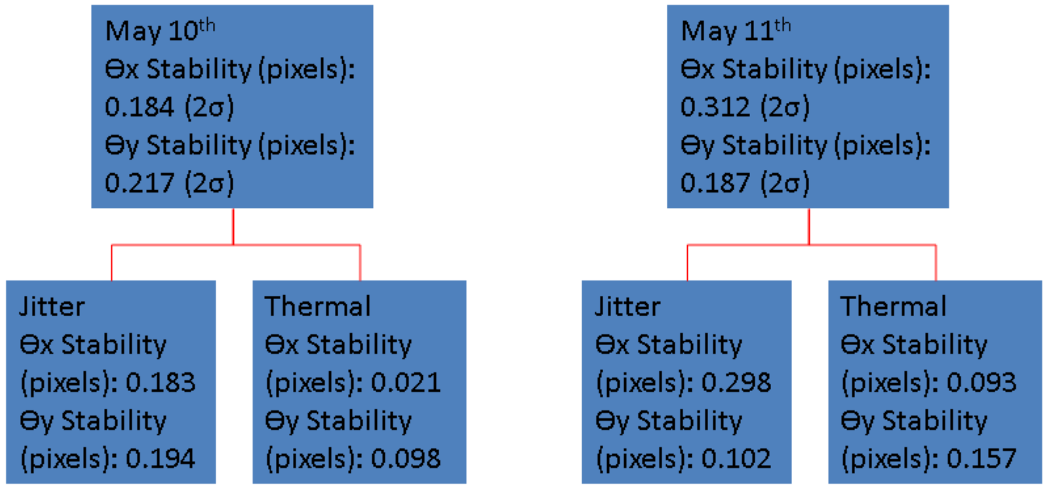
May 11th – Extracted from survey of Senator Beck Basin at 5200m ASL

Discussion

The goal of all of this was to capture the magnitude of the dynamic boresight misalignment to see if it is an issue. There are a lot of subtleties and interesting features that have not been investigated such as flight-to-flight variation, sudden strut temperature variation, and dependence of the PIM compliance on thermal gradients. Also, these are merely two checkout flights and varying conditions are likely to produce new results. Here are the conclusions

1. The jitter metrology system correlates with an autocollimator by 0.092pixels (2σ)
2. The boresight stability on May 10th is within the previous error budget of 0.28pixels (2σ), but on May 11th it is slightly higher than anticipated

   May 11th was flown at a higher than usual altitude of 5200m ASL. Below are the results broken into Θx (roll) and Θy (pitch).



3. The largest boresight instability is from jitter, especially in the Θx (roll) direction.
4. The jitter can be significantly improved by rigidly connecting the PIM to the top of the lidar. This has been shown by briefly wedging a metal bar between the PIM and lidar while monitoring the jitter. It also seems plausible because the lidar mounting plate is thinner than any of the PIM structural members.
5. During flight, the underside of the PIM becomes colder than the struts on top and causes the spectrometer to pitch relative to the lidar on the order of -0.10pixels. This small effect should change, depending on external and cabin temperatures.