# Using the NAV420CA-100 in High Vibration Environments

Dr. Walter Stockwell
Crossbow Technology, Inc.
http://www.xbow.com

## Applications

The NAV420CA-100 is designed specifically to be used in many applications where it might encounter a high vibration environment. Unmanned Aerial Vehicles (UAVs) often have high vibrations because of the combination of a light airframe and a piston engine. Large land vehicles such as tractors can have high vibration levels because of the large diesel engines.

Proper characterization of the vibration environment can be difficult. Generally, one must use a high bandwidth accelerometer designed to measure vibration, along with a high-speed analog sampling system. The important parameters to understand include:

- The frequency range of the majority of the vibration (e.g., 50 Hz to 1000 Hz)
- Are there major frequency components to the vibration? (Propeller frequency, engine RMP, structure resonances)
- The overall intensity or power of the vibration. (e.g., 5 g RMS)

In general, lower frequency vibration will cause more problems to a system like the NAV420. Higher frequency vibration doesn't physically move the sensor and so just aren't relevant to the type of measurement the NAV420 is designed to make. It is very easy to get high peak accelerations at high frequency (such as a shock). As long as these levels do not damage the equipment, which requires very high levels of shock, vibration levels above 1 kHz is probably not relevant to the NAV420 performance.

## Vibration Problems

### *Aliasing*

Aliasing refers to high frequency vibration that is incorrectly measured by the system, and so appears in the measurement at a lower frequency. Aliasing problems can be addressed in a number of ways, but fundamentally, the system needs to be designed with a sampling speed much higher than the actual bandwidth of the sensor. The minimum sampling rate is set by the Nyquist theorem, which states that the measurement needs to sample at least twice the rate of the bandwidth. This is a minimum requirement, but a good system will sample much faster than this.

### *Rectification*

Rectification refers to an effect where vibration can cause a bias shift in the accelerometer output. This can happen from asymmetries in the response to positive and negative accelerations, or from asymmetrical limits on the range of the sensor. This is the main limiting factor to operating performance under vibration. The NAV420CA-100 is using the accelerometers as a long term angle reference to calculate angle output. If the accelerometer bias shifts for any reason (temperature, vibration rectification, ageing) this will translate directly into an angle offset.

### *Vibration Isolation*

Vibration isolation refers to physically mounting the NAV420 on something like rubber mounts or a foam pad that will physically attenuate the vibration experienced by the unit. This is difficult to do well in practice. Vibration isolation is used to reduce vibration felt above a certain frequency, much like an analog low-pass filter will remove signal above the low-pass frequency. Vibration isolation is different from a simple RC electrical filter though, in that you may actually increase the vibration felt by the system at low frequencies. The vibration isolation system itself will have a natural resonance. The mount may end up simply transferring high frequency vibration into its own resonance frequency. Also, a mount with a low natural frequency will be “soft”. This means the unit will easily rock on the mount. Under sustained acceleration, the orientation of the NAV420 will be different from the orientation of the host system. This will cause problems as the user expects the NAV420 to reflect the orientation and dynamics of the whole system.

## NAV420 Architecture

### *Sensor Characteristics*

The MEMS accelerometers used in the NAV420CA-100 were designed for operation in a high-vibration environment. They are designed to have a very linear, very symmetrical response to acceleration. In addition, they use gas damping of the MEMS element to provide a physical limit to the bandwidth response to acceleration. The sensing element simply cannot feel vibration much above 100 Hz. The physical bandwidth of the sensor is set to 50 Hz. This makes the accelerometer a perfect sensor for measuring shifts in orientation, but a lousy vibration sensor, just what we need for the NAV420CA.

### *Analog Filter*

In addition, the NAV420CA-100 data acquisition system includes analog filtering of the accelerometer signal before it is sampled. This is necessary to prevent aliasing. The sensor is already physically filtered at a low frequency, so the analog filter is more to protect from electrical noise, rather than vibration, affecting the measurement. The analog filter is set to 25 Hz.

### *High Speed Sampling*

The NAV420CA-100 samples all the sensors at 1 kHz. This is much higher than the physical or analog bandwidth of the accelerometers. This helps ensure that we are well above any aliasing problems in the data acquisition system.

## Vibration Testing

### *Test Method*

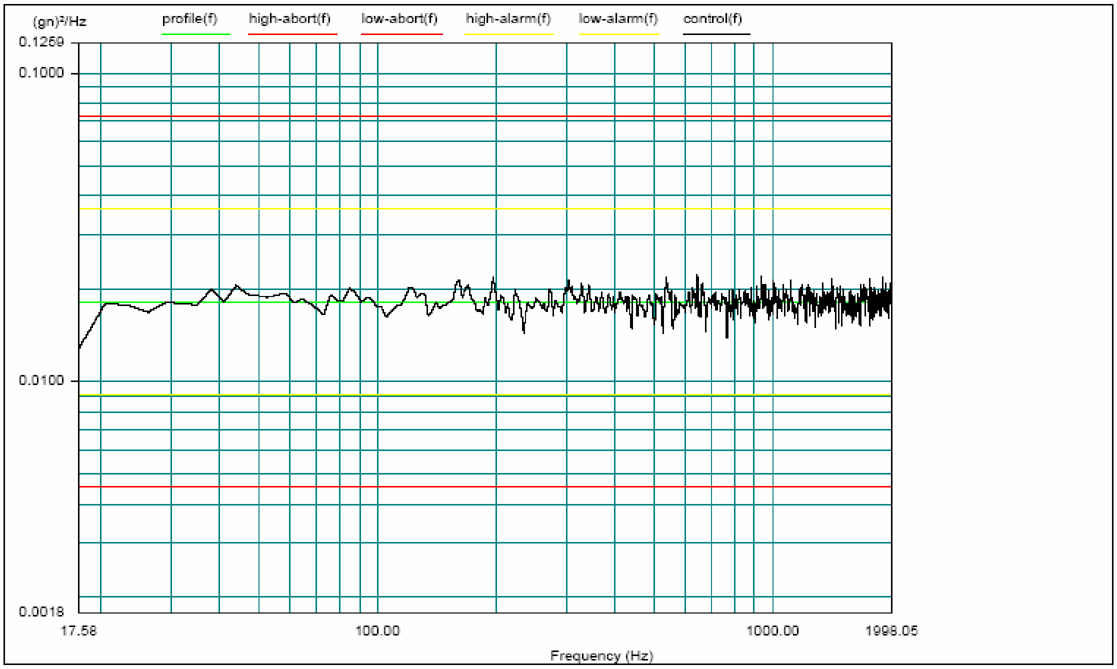
Crossbow Technology has conducted tests to qualify the vibration performance of the NAV420CA-100 under vibration. We have a shaker with a digital control system that allows us to control the vibration spectrum and total level of vibration. We can mount the NAV420 so that we apply the vibration along the X, Y or Z axis independently.

We chose a flat, random vibration spectrum from 20 to 2000 Hz. This is a common specification for a generic vibration environment. It exercises the unit over a wide range of physically relevant vibration.

Measurements were made of the output while the unit was mounted to the shaker. The data included time with the shaker off and on, so that a measurement of the change in output could be quantified.

Figure 1 shows an example of the measured vibration spectrum from the 6 gRMS, Z-axis shake. Vibration tests were performed along each axis, at 2, 4 and 6 gRMS respectively.

NAV420-Int, Qual Test, Random Vibe
5011120, Z-Axis, 6 g RMS
Project File Name: Eng Test.prj
Profile Name: Default Test Type: Random Run Folder: .\RunDefault May 10,2005 16-08-07




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Level: | 100 % | | | | | | |
| Control RMS: | 5.999380 gn | Full Level Elapsed Time: | 00:01:00 | Lines: | 800 | Frame Time: | 0.341333 Seconds |
| Demand RMS: | 6.001910 gn | Remaining Time: | 00:00:00 | DOF: | 154 | dF: | 2.929688 Hz |

**Figure 1. Measured vibration spectrum for 6 gRMS, 20 – 2000 Hz, Z-axis shake.**

*Accelerometer Test Results*

We generally see two effects during the shake. First, the accelerometer will measure a certain amount of the vibration, limited by the bandwidth of the sensor and data acquisition system of the NAV420. This looks like noise when the test is on. Second, we might see a shift in the average value output, or bias shift. Because we know the unit is not physically shifting orientation, this bias shift is a result of vibration rectification in the system. This will limit the usefulness of the system in real-world applications.

The accelerometer bias shift impacts the angle measurement. Remember that a 17.4 milli-g bias shift in the X or Y axis accelerometer is equivalent to 1 degree of tilt near level. The Z-axis accelerometer has a much smaller effect on angle accuracy for orientations near level.

Figure 2 shows the actual acceleration data output by the NAV420CA-100 during a 6 g RMS shake along the X-axis. This shows both the increase in "noise" as the shaker turns on, and a small bias shift with the vibration. Note that the shaker system first vibrates at a 50% level to ensure that the vibration is in control. The RMS value of the vibration measured by the X accelerometer is about 0.3 g RMS. This is so much lower than the actual applied vibration of 6 g RMS because of the physical bandwidth and analog bandwidth of the MEMS accelerometer. The bias shift is hard to see at this scale, but the actual center of the accelerometer output shifted about 5 milli-g. This would translate to less than 0.3 deg angle shift.

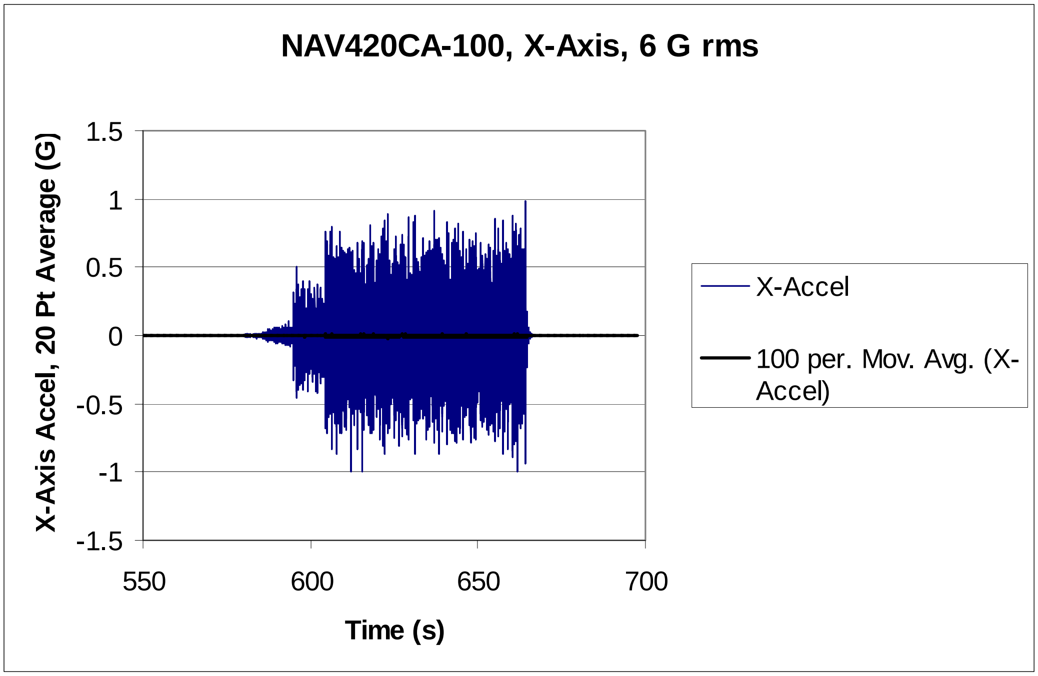



**Figure 2. Output of the X-axis accelerometer during a 6 g RMS, X-axis vibration test**

Figure 3 summarizes the results for all three axes over the vibration tests. A value of zero on this graph means the bias shift was essentially immeasurable. The resulting angle shift depends on the arctangent of the ratio of the horizontal acceleration to the vertical acceleration (for example, roll = atan[Y/Z].) When the unit is near level, a shift in X or Y will be much more important in determining the angle than a shift in Z. At 6 g RMS, we would expect ~0.3 deg offset in attitude.

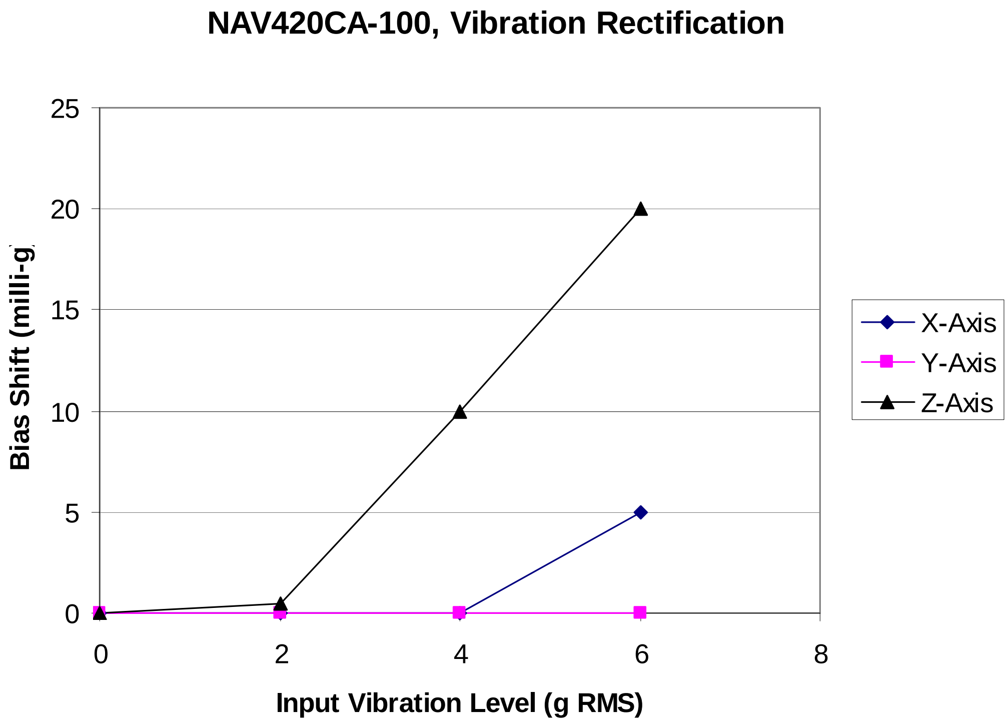



**Figure 3. Summary of bias shift seen on each axis during the vibration testing**

### Conclusions:

The test results show that although NAV420CA-100 has 4g accelerometers, it can behave well though vibration levels within its range and even higher, thus offering superior performance.