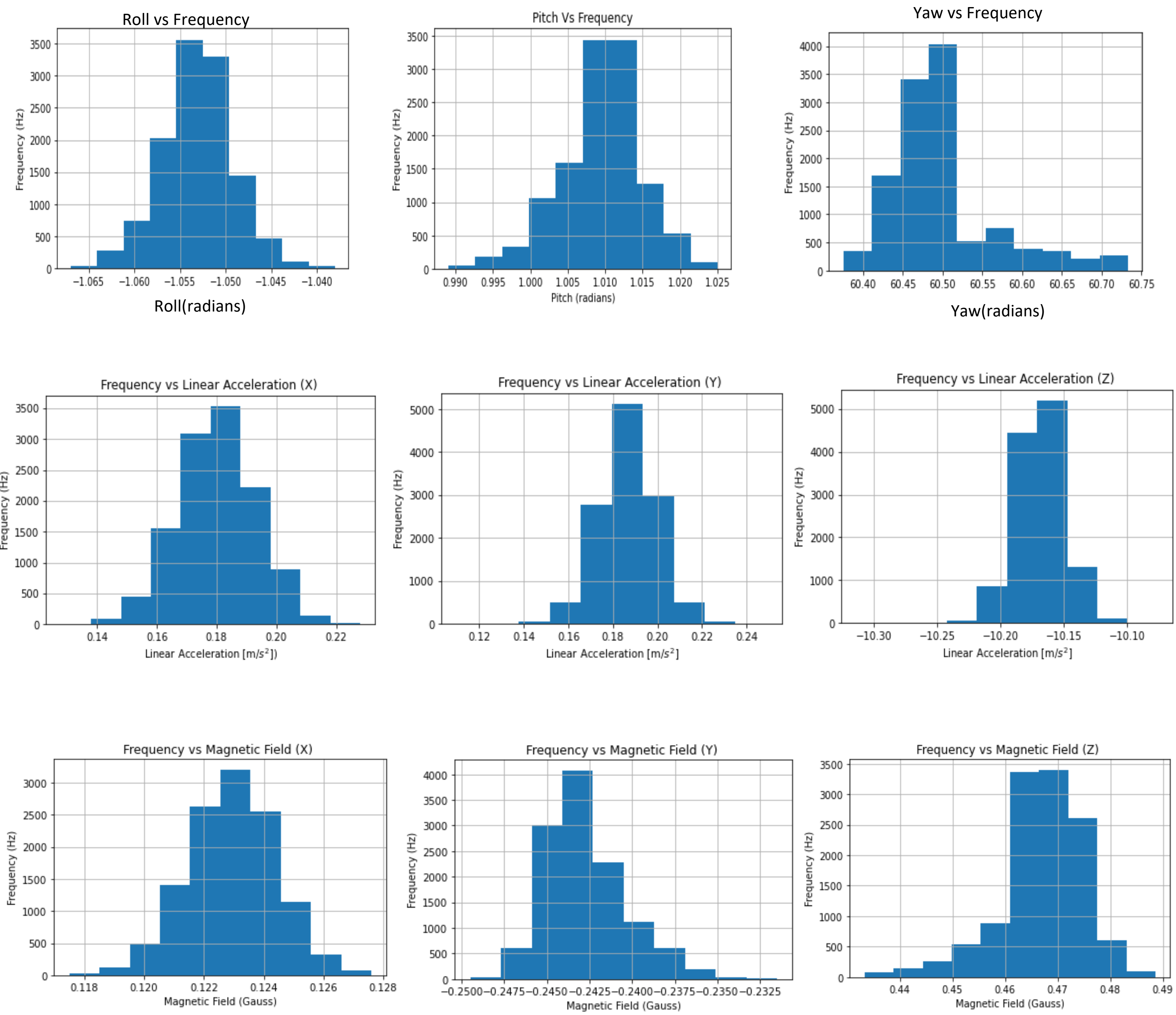
Introduction

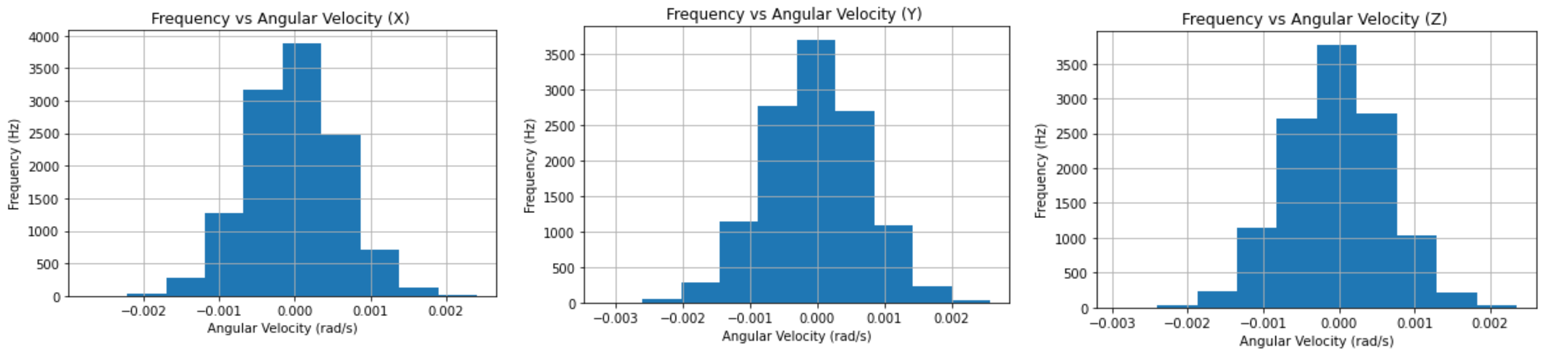
The data is collected usign a Vector Nav-100 IMU ,9 axes consisting of accelerometer, gyroscope, magnetometer. The 5hr long data was collected in a house basement free from vibrations of any electronics or people around the IMU.The 5 min data was collected in Northeastern Basement Tunnels in Forsynth Building.

5 Min Data Analysis

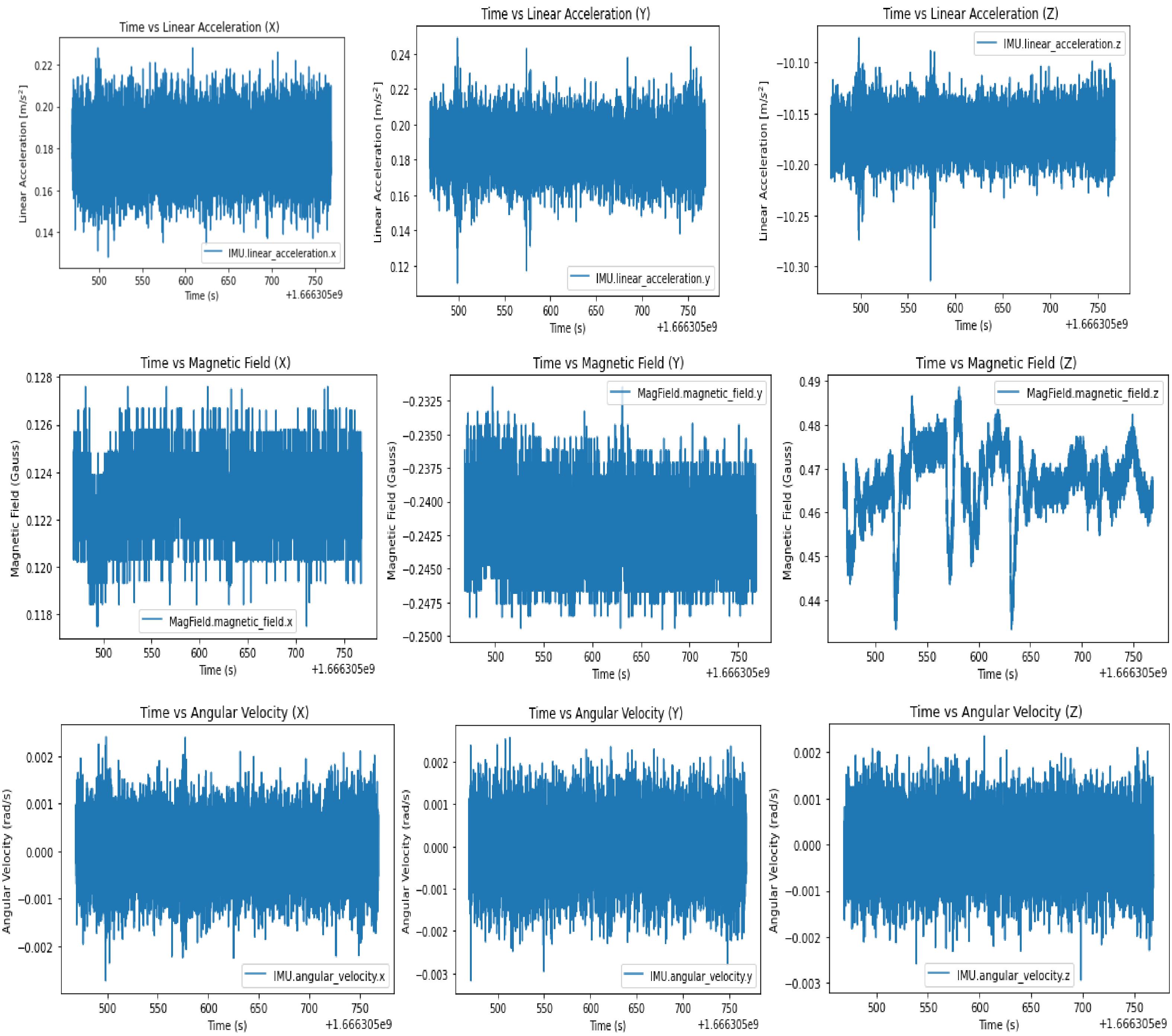
A) Frequency Plots

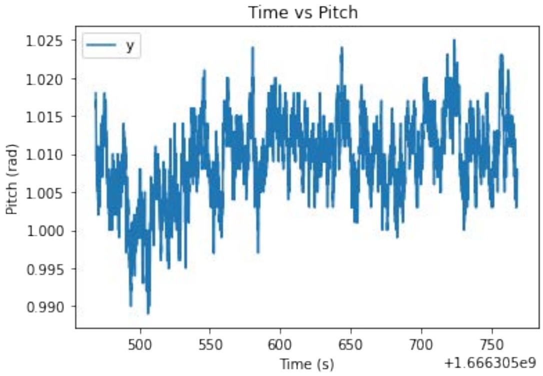


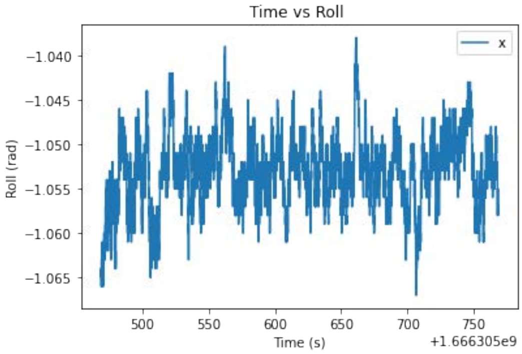
From the above graphs, we can conclude that all the plots are distributed out to be almost Gaussian curve i.e. normal distribution.

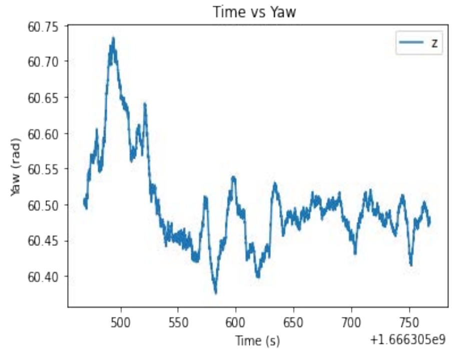


B) Time Series Plots

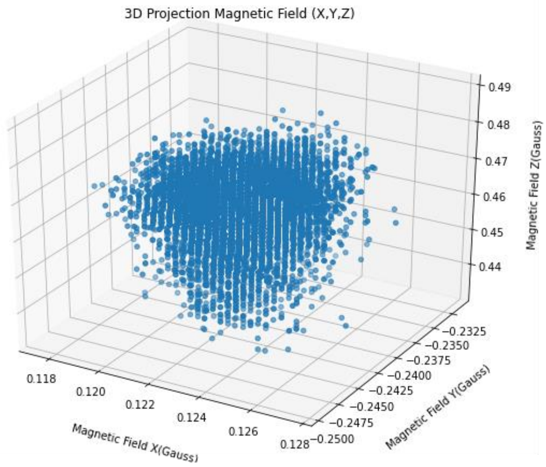


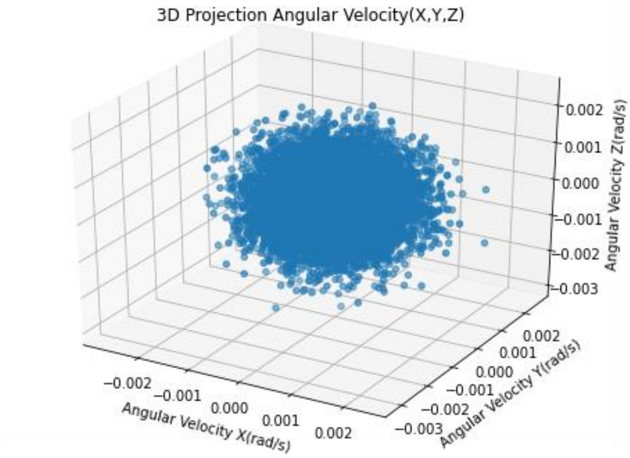


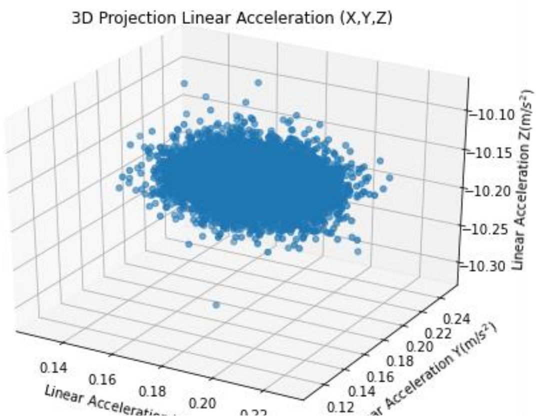


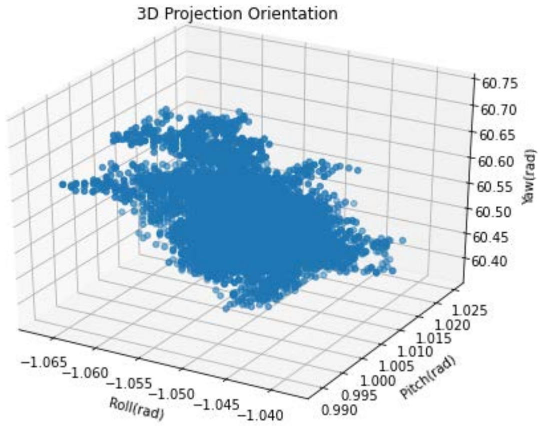


C) Distribution of Data in 3D









The above 3D graphs of Linear Acceleration, Magnetic Field or Angular Velocity (X,Y,Z) and Orientation show the distribution of stationary data with respect to each of the axes. Potential outliers can be identified and a set of points falling within a range can be verified from these graphs. Magnetic field is varying due to presence of electronic equipments near the IMU like mobile phone and computers.There is also bias present in accelerometer as well as gyroscope.For eg: It is seen from the values of Z axis of linear acceleration being different (the constant is 9.8 m/s^2). Vibration from the laptop could also affect the orientation parameters of the IMU.

The negative value of near -9.8 m/s^2 in the Z axis of linear acceleration means that the IMU is being accelerated about 9.8 m/s^2 upwards , an amount proportional to the acceleration due to gravity and so the object is staying stationary.

```
Accelerometer X summary statistics
Min: -0.114
Mean: -0.04850691946366519
Max: 0.013
```

```
Accelerometer Y summary statistics
Min: -0.149
Mean: -0.0980555862655174
Max: -0.042
Median: -0.098
Interquartile range (IQR): 0.016
```

```
Accelerometer Z summary statistics
Min: -10.274
Mean: -10.182994120817
Max: -10.084
Median: -10.183
Interquartile range (IQR): 0.025999999999998
```

```
Angular Velocity X summary statistics
Min: -0.00319
Mean: -1.0279750777085511e-07
Max: 0.002911
Median: 3e-06
Interquartile range (IQR): 0.000847
```

```
Angular Velocity Y summary statistics
Min: -0.003852
Mean: -3.7834410651140673e-07
Max: 0.003334
Median: 1e-06
Interquartile range (IQR): 0.001001000000000002
```

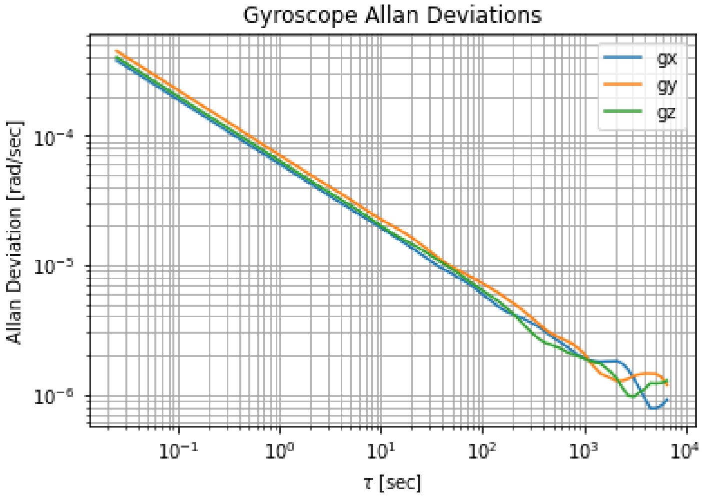
```
Angular Velocity Z summary statistics
Min: -0.003135
Mean: -2.3339231497865322e-07
Max: 0.00319
Median: 0.0
Interquartile range (IQR): 0.0008960000000000001
```

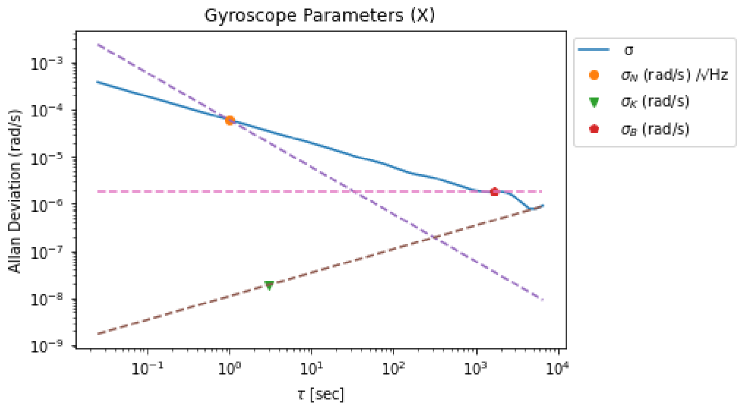
5 Hr Data

A) Allan Deviation Plots

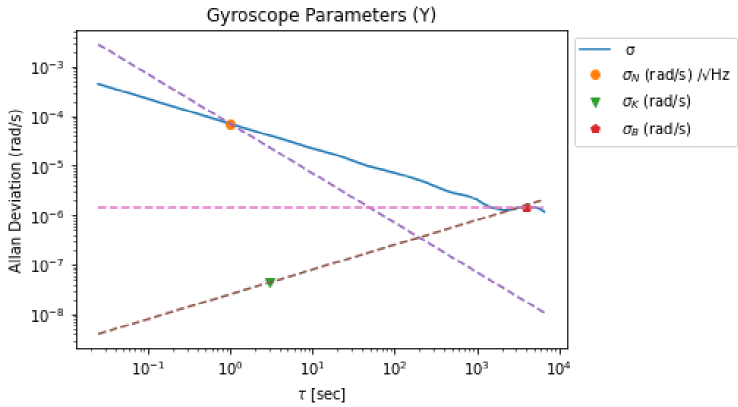
1) Gyroscope

From this graph,the green line(gz) bottoms out first so good estimate of noise could be obtained but for more time , the noise starts to increase)

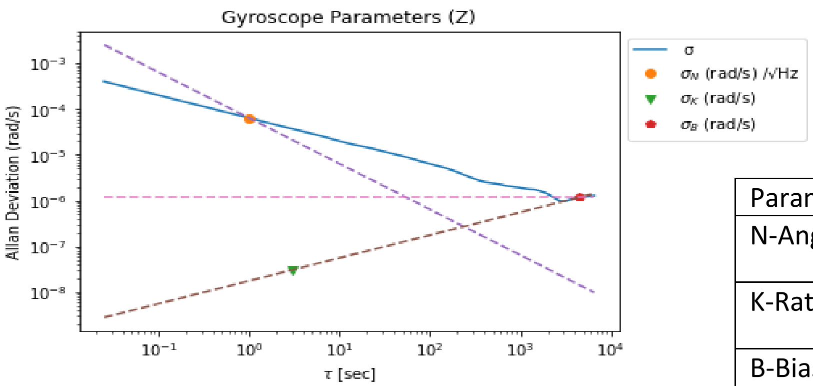





```
N (angle random walk) is 5.9885891247131225e-05 rad/s/√Hz
K (rate random walk) is 1.8976991253872744e-08 rad/s
B (Bias instability) is 1.7941526735512457e-06 rad/s
```




```
N (angle random walk) is 7.074639042791686e-05 rad/s/√Hz
K (rate random walk) is 4.3894229834703224e-08 rad/s
B (Bias instability) is 1.449689446738982e-06 rad/s
```

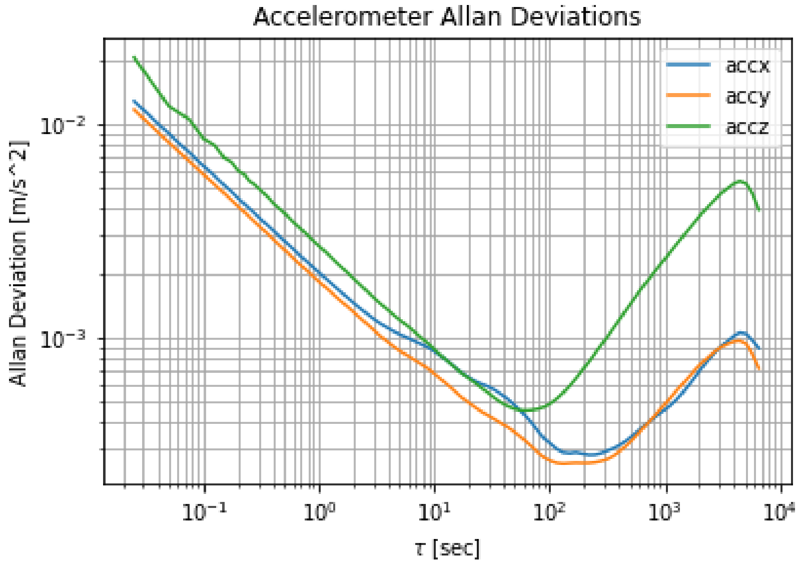


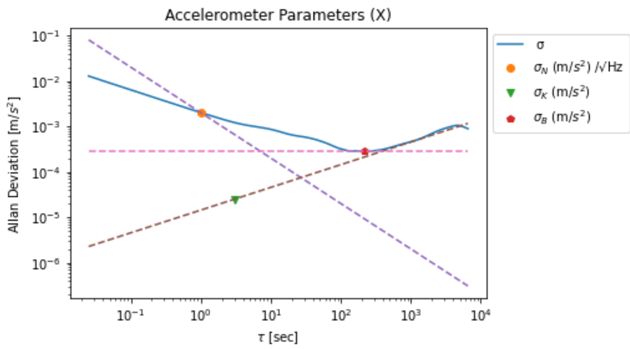

```
N (angle random walk) is 6.366206883385852e-05 rad/s/√Hz
K (rate random walk) is 3.0315326589705974e-08 rad/s
B (Bias instability) is 1.2213357156888478e-06 rad/s
```

Parameters	
N-Angle Random Walk	0.00006476478350296886 rad/s/√Hz
K-Rate Random Walk	0.00000003106218255942 7 rad/s
B-Bias Instability	0.0000014883926119930252 rad/s

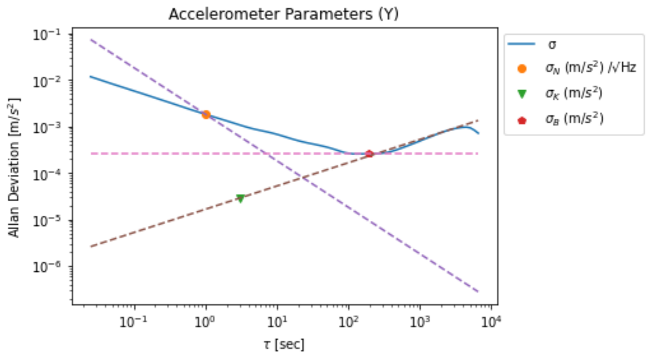
There is a drift observed in gyroscope over time due to intergration of noise and some other imperfections within the device. Angular error is also observed. This drift is mostly due to bias instability and angular random walk as seen in the above graphs.

2) Accelerometer

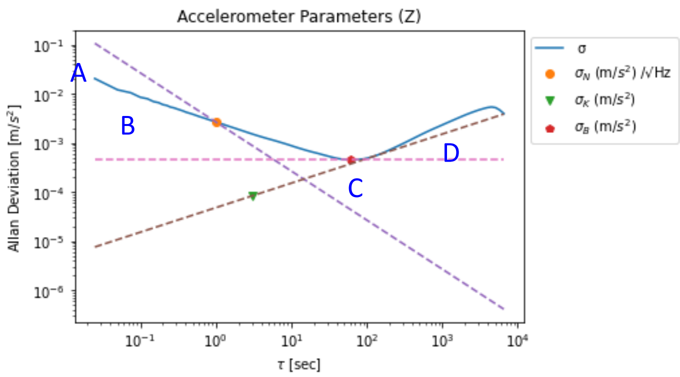




N (Velocity random walk) is 0.0020054079428904236 m/s^2/√Hz
K (rate random walk) is 2.4820491754219047e-05 m/s^2
B (Bias instability) is 0.00028097552868288907 m/s^2



N (Velocity random walk) is 0.001836347317339025 m/s^2/√Hz
K (rate random walk) is 2.868624073148245e-05 m/s^2
B (Bias instability) is 0.00025712087367915377 m/s^2



N (Velocity random walk) is 0.0026834571511836465 m/s^2/√Hz
K (Rate random walk) is 8.296164910187833e-05 m/s^2
B (Bias instability) is 0.00045347794465500036 m/s^2

Parameters	Value (mean of X,Y,Z)
N-Velocity Random Walk	0.002175070803804365 m/s^2/√Hz
K-Rate Random Walk	0.000045489460529193276 m/s^2
B-Bias Instability	0.00033052478233390144 m/s^2

Understanding the Graph

1) Point A : the standard variance of the linear acceleration of Z axis.
2) Point B : With more samples and by averaging them ,better and better corrections are being obtained . These varying amount of noise reduction can let us fine-tune our signal
3) Point C : The minimum bias is obtained and the most desired point for analysis.
4) Point D: low frequency noise which is due to various factors like vibration,angle random walk etc.

As we keep on increasing data for longer periods of time , the averages between different chunks of data would become smaller and smaller and the average of each chunk would closer to the 'real' average.

B) Deviation from Specified Parameters in the Manual

-	Manual		Calculated (from above graphs)	
Parameters	Accelerometer	Gyroscope	Accelerometer(mean)	Gyroscope(mean)
Bias Instability(B)	<0.04 mg	5-7°/hr	0.033704 mg	0.307 °/hr
Noise Density (N)	0.14 mg /√Hz	0.0035°/s/√Hz	0.22179 mg/ √Hz	0.0037107 °/s/√Hz

1 m/s^2=0.10197 g
1 rad = π/180 °

$TN = RND \times \sqrt{f_{NBW}}$

where:

RND = Rate noise density, $^{\circ}/_{sec}/\sqrt{Hz}$

f_{NBW} = Noise bandwidth, Hz

TN=Total Noise

TN= 0.0035 * √256 Hz (from datasheet)
TN= 0.056 °/s

With Bias instability value as 0.307 °/hr , we can classify the IMU as Tactical grade and RLE(ring laser gyroscope).
Low bias instability also means that gyro biases are relatively stable and dont change much.

C) Sources & Types Of Errors with its parameters

1) Random Walk: If a noisy output signal from a sensor is integrated, for example integrating an angular rate signal to determine an angle, the integration will drift over time due to the noise. This drift is called random walk, as it will appear that the integration is taking random steps from one sample to the next. Two types are Angle Random walk (for gyroscopes) , Velocity Random walk (for accelerometers) and Rate Random Walk .
   - The angle random walk (N) is characterized by the white noise spectrum of the gyroscope output .
     $\sigma^2 = N^2/\tau$. Unit of N is (rad/s)/√Hz
   - The rate random walk (K) is characterized by the Brownian noise spectrum of the gyroscope output .
     $\sigma^2 = K^2\tau/3$. Unit of K is (rad/s)√Hz.
2) Bias Instability (B): It is defined as the drift the measurement has from its average value of the output rate. The Bias Stability measurement tells you how stable the gyro output is over a certain period of time. It is characterised by the pink noise of the gyroscope output.
   $\sigma^2(\tau) = 2B^2 ln2/\pi$. There is a scaling of $\frac{\sqrt{2ln2}}{\pi}$ ≈0.664. Unit of B is rad/s
3) Calibration errors: These refer to errors in the scale factors, alignments and linearities and can result in an additional drift.
4) Orthogonality Errors: When mounting and aligning sensors to an IMU, it is impossible to mount them perfectly orthogonal to each other. As a result, orthogonality errors are caused by a sensor axis responding to an input that shouldbe orthogonal to the sensing direction
   a) Cross –Axis sensitivity: caused by a sensor axis being sensitive to an input on a different axis.
   b) Misalignment : the internal sensing axes do not align to the axes marked on the case of the IMU)

5) Input range : Maximum angular rate or acceleration the IMU can meaningfully measure .

D) Measuring Noise

A noise spectral density curve acts as a metric to measure and specify sensor noise based from the above formulas and by Fourier transform analysis it can be done to represent the frequency and their corresponding amplitude. The Allan variance also measures the various error components.

E) Noise Model

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x(t)=x_1(t)+x_2(t)+x_3(t)+x_4(t)+x_5(t),

where $x_1(t)$ is acceleration (or angle rate) linear drift;
$x_2(t)$ is random walk of acceleration (or angle rate);
$x_3(t)$ is bias instability;
$x_4(t)$ is random walk of angle or velocity;
$x_5(t)$ is quantization noise of angle or velocity.

F) Types of Noises present

a) White noise associated with N (angle random walk)
b) Brownian noise associated with K (rate random walk)
c) Pink noise associated with B (Bias instability)

References

1) https://www.vectornav.com/resources/inertial-navigation-primer/specifications--and--error-budgets/specs-imuspecs
2) https://www.mathworks.com/help/nav/ug/inertial-sensor-noise-analysis-using-allan-variance.html
3) Characterization of Errors and Noises in MEMS Inertial Sensors Using Allan Variance Method
Leslie Barreda Pupo,MS Thesis,University Of Barcelona
4) Development of Stochastic IMU Error Models for INS/GNSS Integration Elisa Gallon,Illinois Institute of Technology, Mathieu Joerger, Virginia Tech,Boris Pervan, Illinois Institute of Technology