

# 'Coast to Coast' Amusement Ride Data

A collection of inertial measurement data from over 50 different rides across 8 US theme parks.

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## Instrumentation

Data was recorded with a MEMS type inertial measurement device operating at 400Hz across 6 degrees of freedom. The optimal G-range was determined from trial runs and thereon fixed at  $\pm 8G$ . Similarly, the rotational velocity range was fixed at  $\pm 250$  degrees per second.

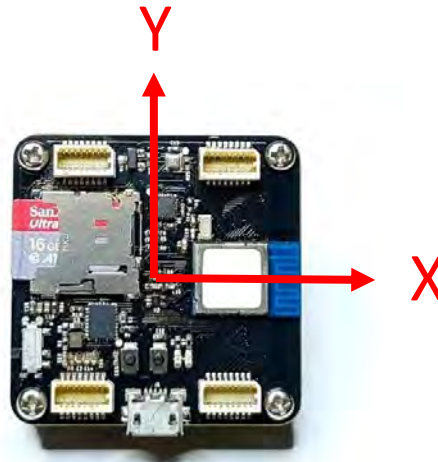


Figure 1 - The LadyBug research platform, shown here with no additional sensor modules attached, measures 40mmx40mm. Data is recorded to the onboard memory card while feedback is provided via the Bluetooth low energy interface.

For these experiments, the device was mounted at the waistline – a location determined to be close to the rider's centre of gravity, relatively robust to upper and lower limb movements and naturally unobtrusive with a belt-buckle like form factor.

MEMS (micro electro-mechanical systems) type devices are well suited to applications such as this due to their size and minimal power consumption. A MEMS accelerometer works by measuring the deflection of a very small internal mass. The mass itself has arms that extend between fixed capacitive plates. As the mass deflects, the arms move relative to the fixed plates thereby altering their capacitance and allowing for the deflection magnitude to be measured. Something to keep in mind is the fact that this is an inertial measurement system – inertia being the tendency to resist change – thus the mass will always 'deflect' in the opposite direction to the applied acceleration. Something to note is that MEMS accelerometers measure 'true' acceleration which includes acceleration due to gravity.

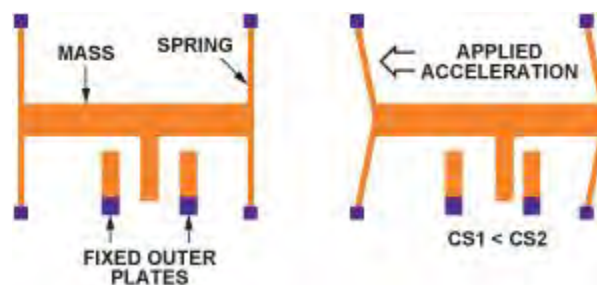


Figure 2 - Structure of a MEMS accelerometer (Analog Instruments, 09)

It is not possible to fasten the device directly to the ride carriage, let alone perpendicular to the natural gravity vector, thus we need to solve the problem of axial misalignment that will inevitably and severely skew the data. This is better illustrated in the diagram below.

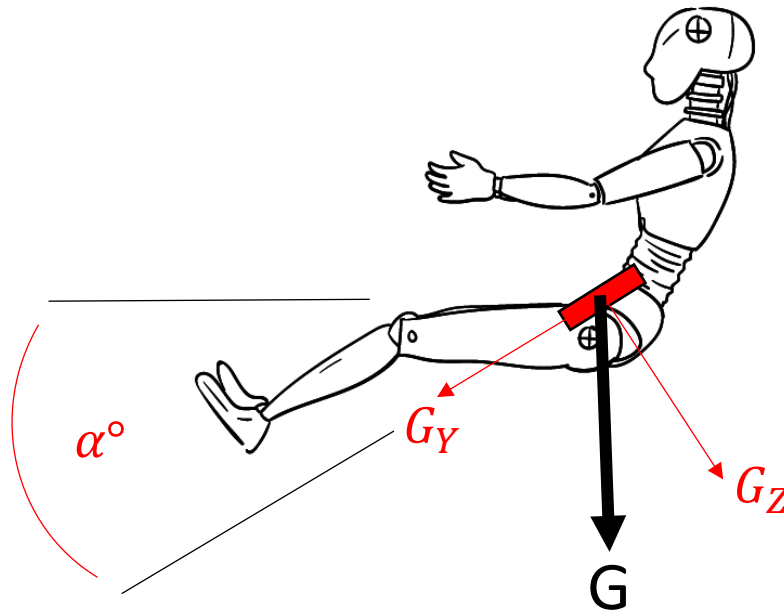


Figure 3 – The device (red rectangle) is originally mounted perpendicular to the horizon but as the rider moves to a seated position the device is now at angular offset  $\alpha$ . Observed acceleration  $G_z$  no longer aligns with  $G$  causing a portion of  $G$  to now be observed in the Y axis.

As you can see there is an angular displacement  $\alpha^\circ$  when the rider sits in the carriage. This value can change vastly between different roller coasters (some by up to  $90^\circ$  e.g. Tatsu) and even different runs of the same roller coaster (slightly different sitting positions, device position, etc). The result of this unwanted pitch angle is that a cotangent of the acceleration in the Z axis will be present in the Y axis and vice-versa. Additionally, accelerations along their original axes will be proportionately smaller. Since no ride in this study requires a sitting position with an observable roll angle, the X axis remains unaffected.

Solving this problem is a three-step process:

- 1) Determine the angular offset  $\alpha$
- 2) Determine the angle of the resultant acceleration for any given time  $t$
- 3) Transform the component accelerations from the device frame to the world frame

The first step can be solved by analysing the first few seconds of data once the rider is seated and stationary. This can range anywhere from 10 seconds to a minute depending on environmental factors such as restraint checking procedures and number of staff. Under these initial conditions, we can assume that the applied net resultant acceleration on the rider is 1G in the downwards direction with respect to the world frame. Armed with this knowledge, the offset angle  $\alpha$  between the device frame and the world frame is therefore equal to the angle between the observed Z component and the resultant at  $t = 0$ .

Determine angular offset:

$$r_0 = \sqrt{a_{y0}^2 + a_{z0}^2}$$

$$\alpha = \cos^{-1} \frac{a_{y0}}{r_0}$$

$$\beta = \frac{\pi}{2} - \alpha$$

Apply world frame transform:

$$r = \sqrt{a_y + a_x}$$

$$\theta = \cos^{-1} \frac{a_y}{r}$$

$$\dot{a}_y = r \cdot \cos^{-1} \beta + \theta$$

$$\dot{a}_z = r \cdot \sin^{-1} \beta + \theta$$

Each graph provides a detailed mapping of the acceleration forces and rotational velocities experienced by the rider at every instant. At a glance we can see the characteristic profile of each ride and even infer a wealth of information without having been on the ride including the presence of loops, drops, rolls, climbs, stops and even direction reversals (see Montezuma's Revenge, Revenge of the Mummy, etc). We can also see the direction, magnitude and duration of applied G-force. Differentiating rotational velocity  $\omega$  gives rotational acceleration  $\alpha$ . Similarly, differentiating acceleration provides jerk  $J$  – a measure of the rate of change in acceleration. Finally, we can obtain a reasonable estimation of the rider's angle with respect to the horizon by integrating the rotational velocity.

Notes on graphical interpretation:

- A stationary rider will show  $\sim 1G$  in the Z axis.
- Positive Gs in the Y axis indicate a forward accelerating rider or a positive angle of pitch.
- Conversely, negative Gs in the Y axis indicate a forward decelerating rider or a negative angle of pitch.
- Any periods of zero G in all axes indicate a drop.
- Spikes indicate abrupt movements such as direction reversals, drop tower braking or forward launches.
- Loops can be identified from sustained pitching velocities typically occurring between 50 to 100 deg/s.

# Walt Disney World

## Animal Kingdom

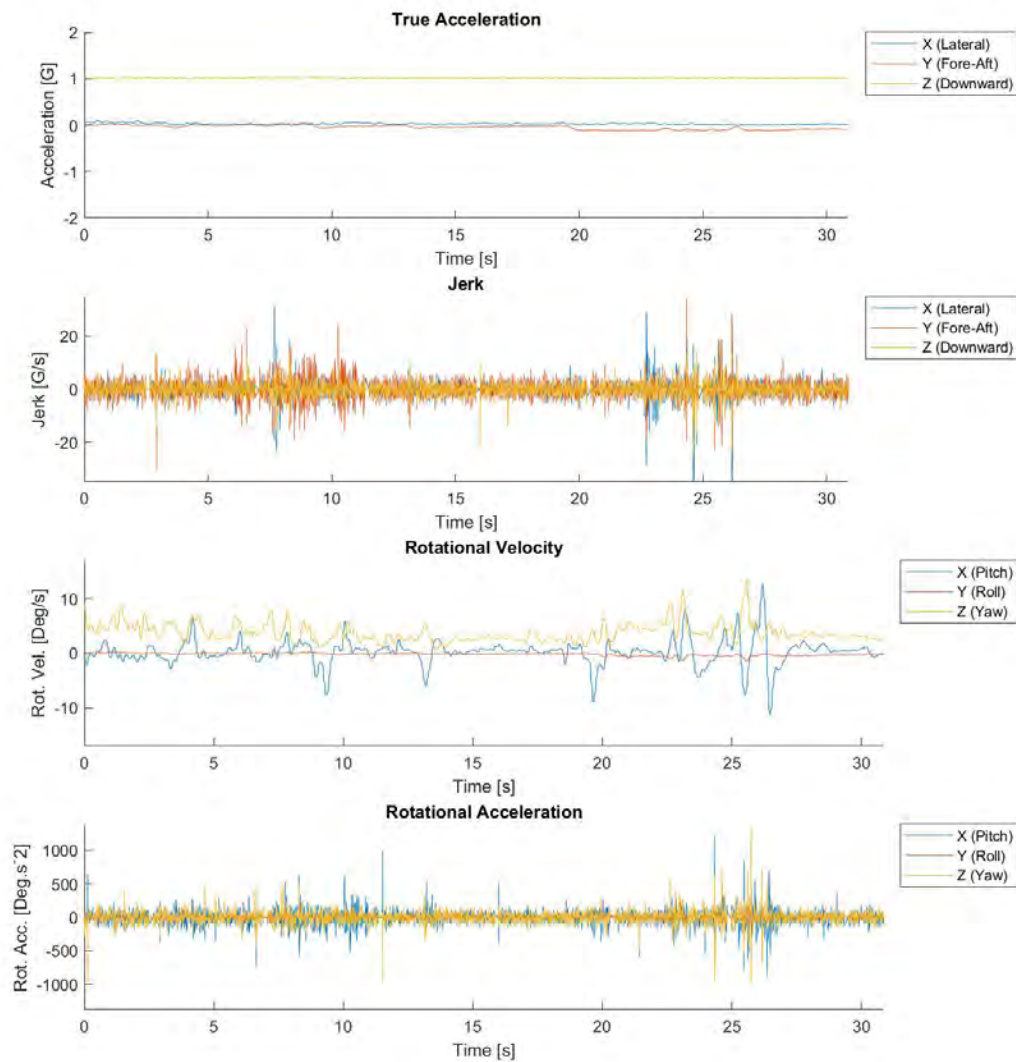


Figure 4 - Na'vi River Journey



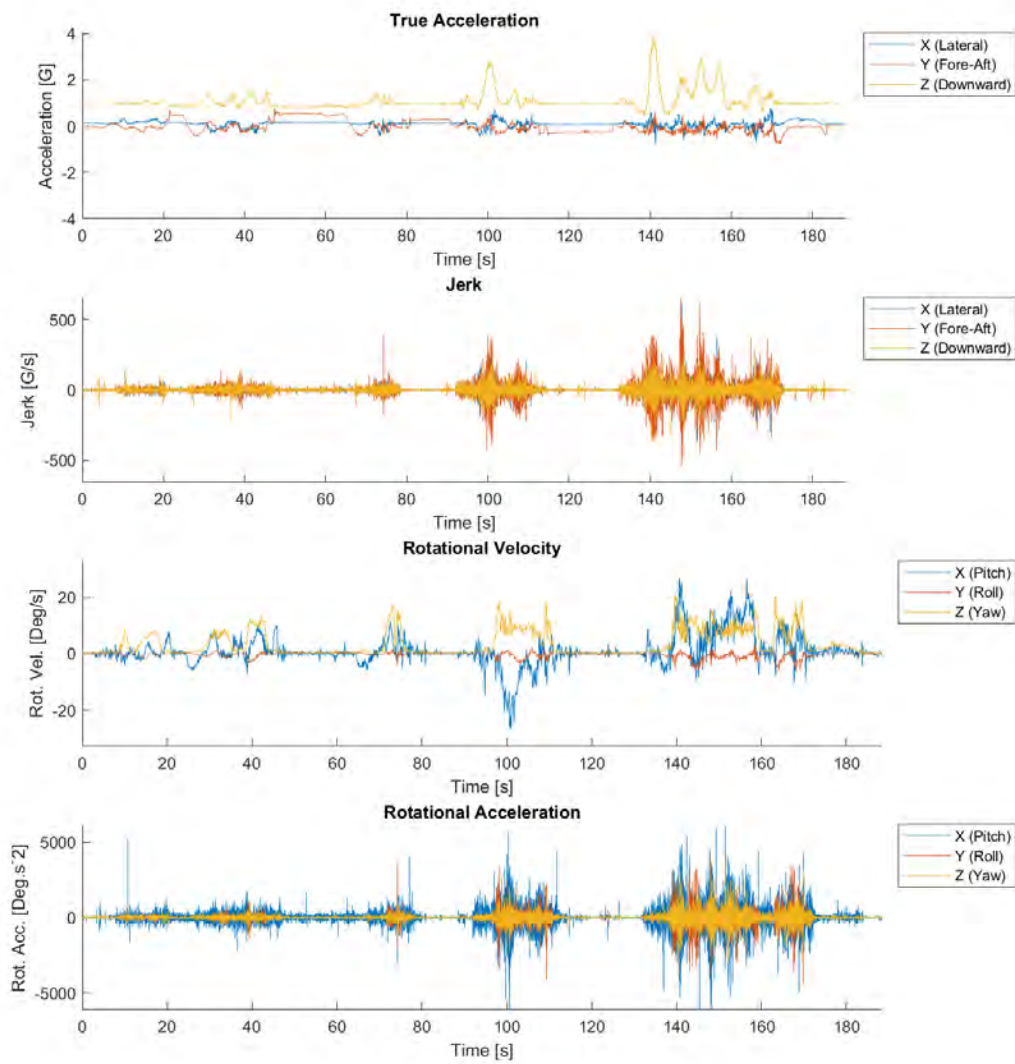


Figure 5 - Expedition Everest - Legend of the Forbidden Mountain

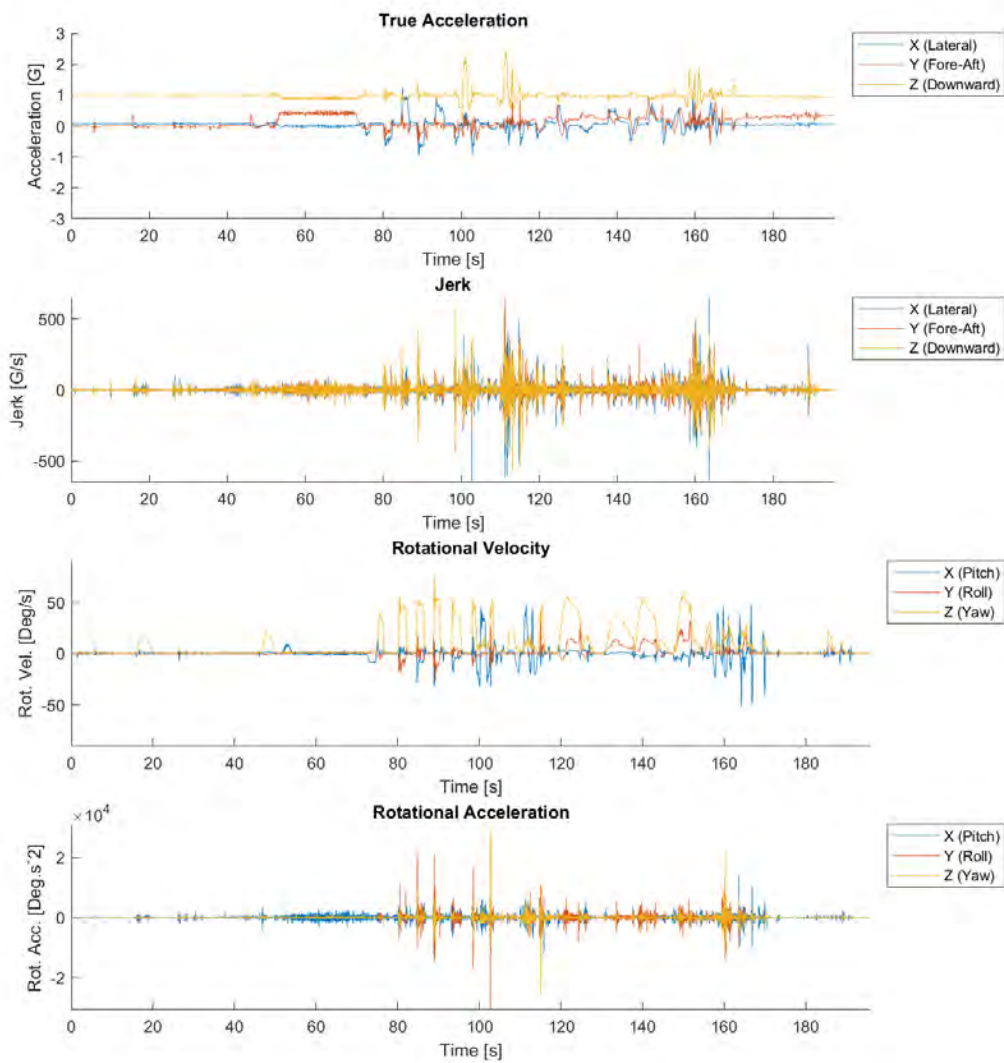


Figure 6 - Primeval Whirl



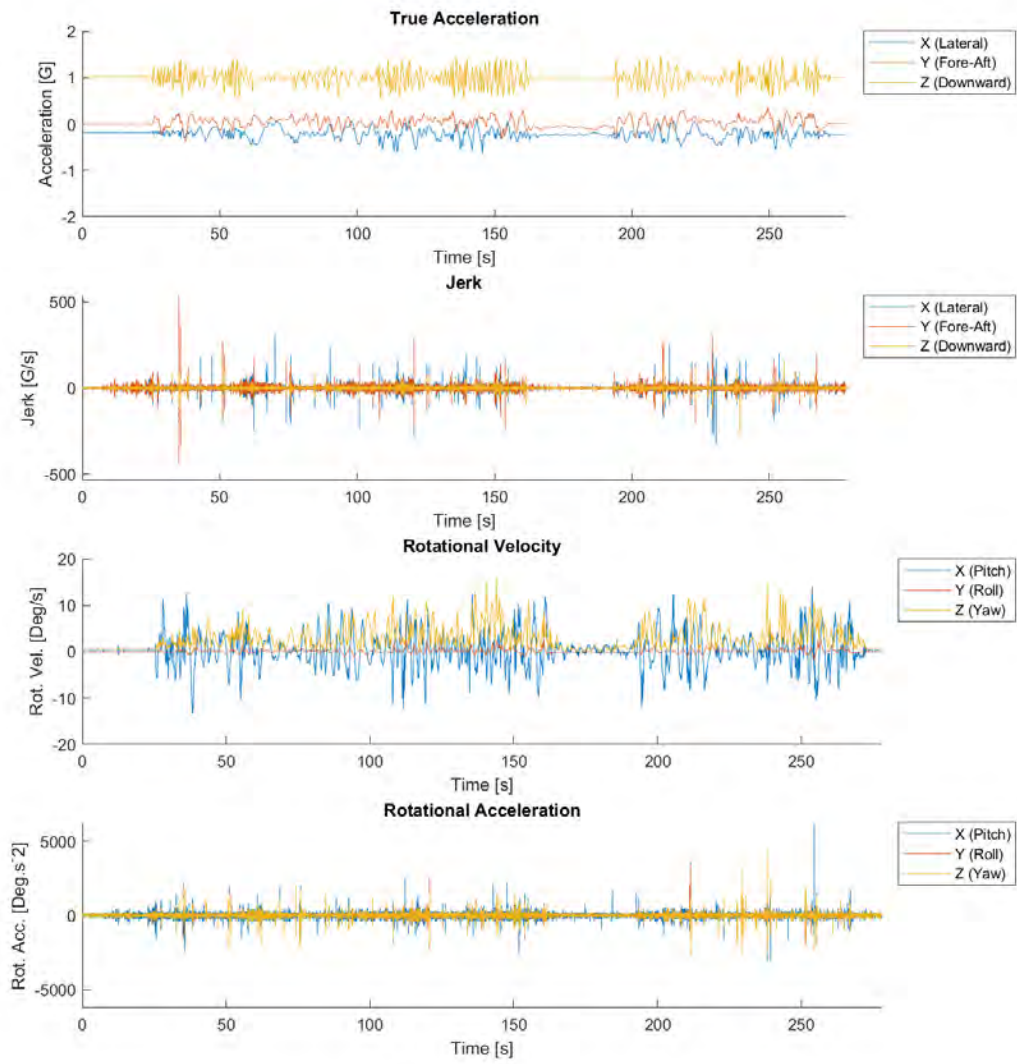


Figure 7 - Avatar Flight of Passage

# Magic Kingdom

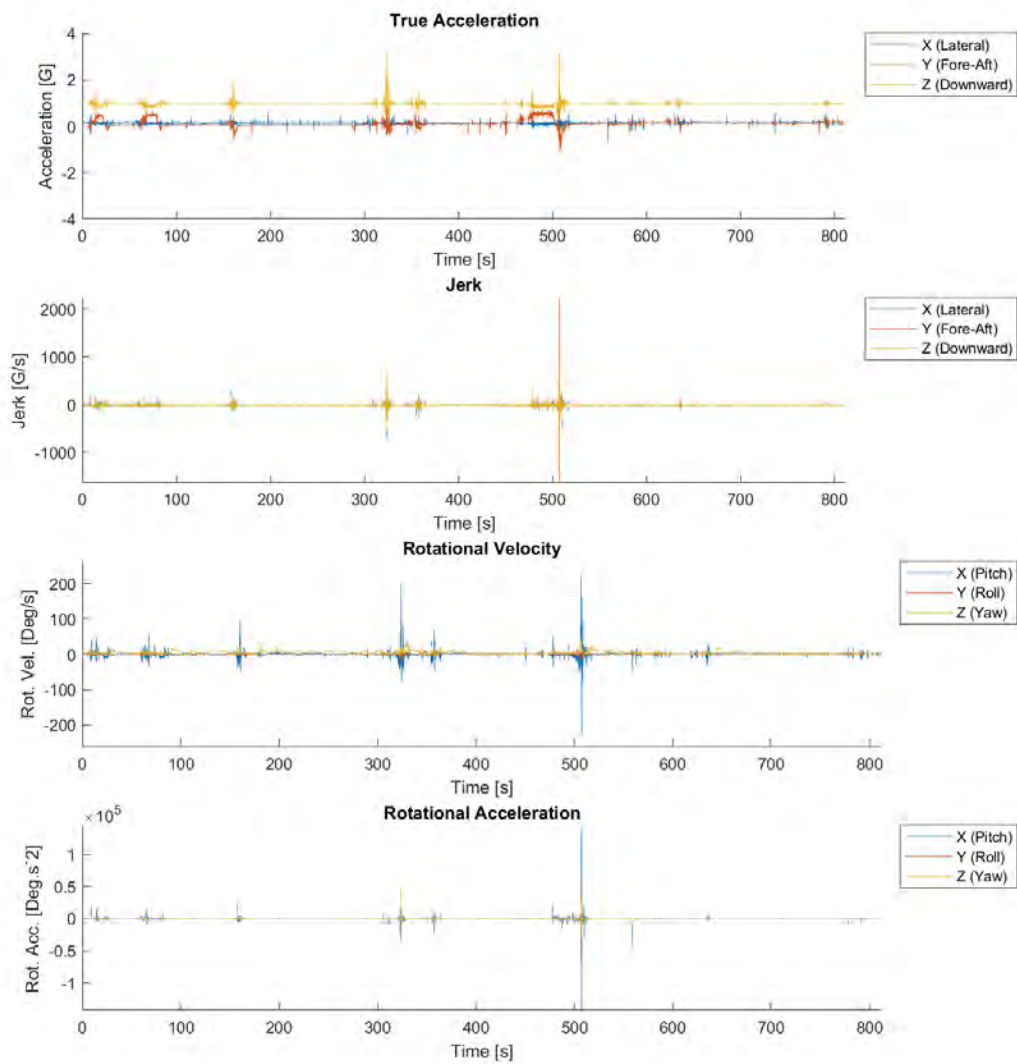


Figure 8 - Splash Mountain

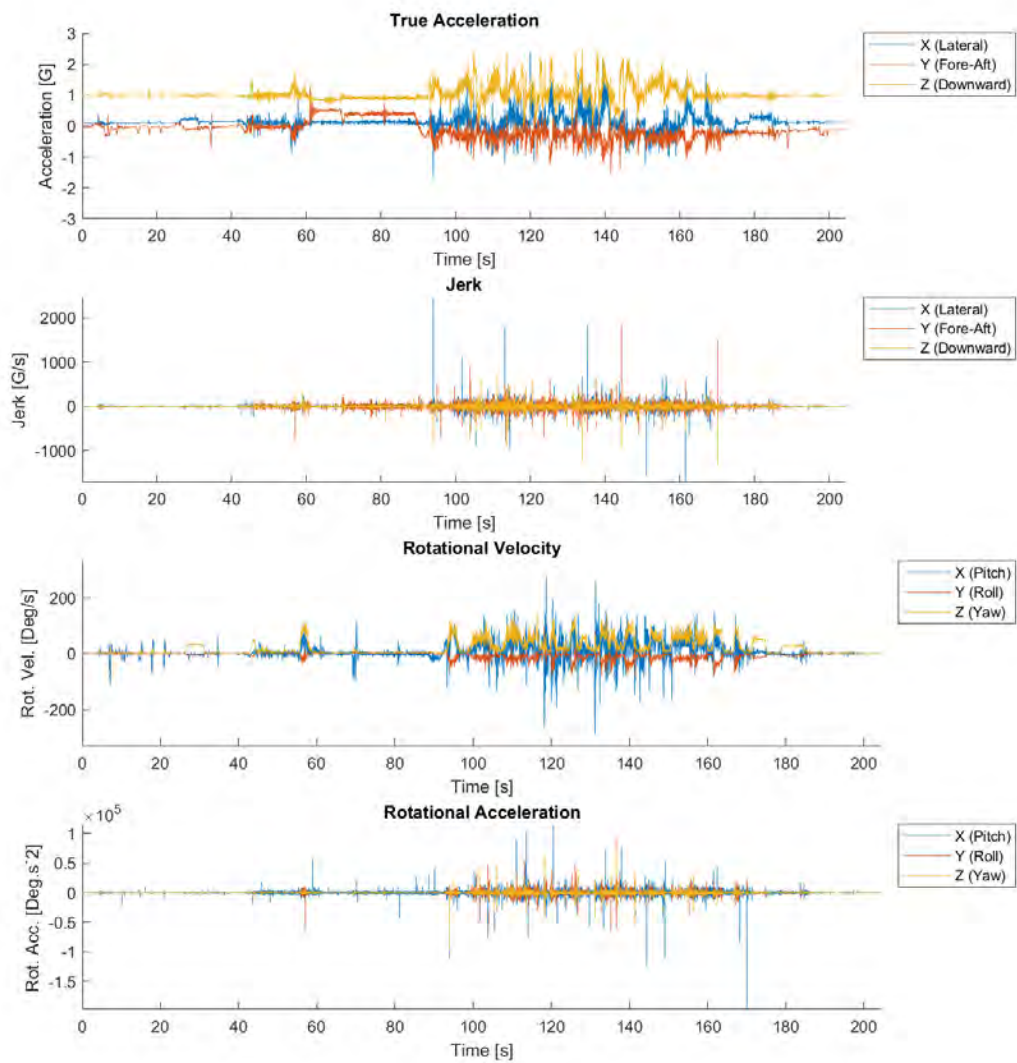
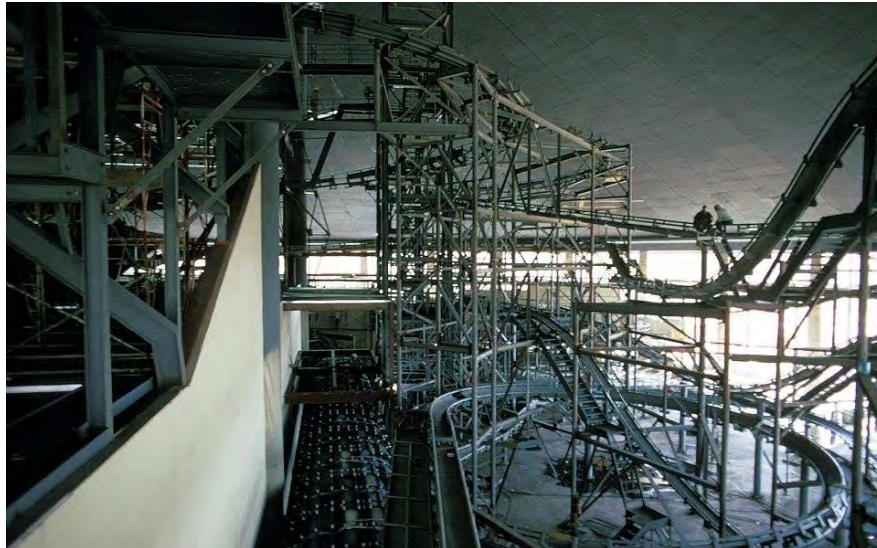


Figure 9 - Space Mountain



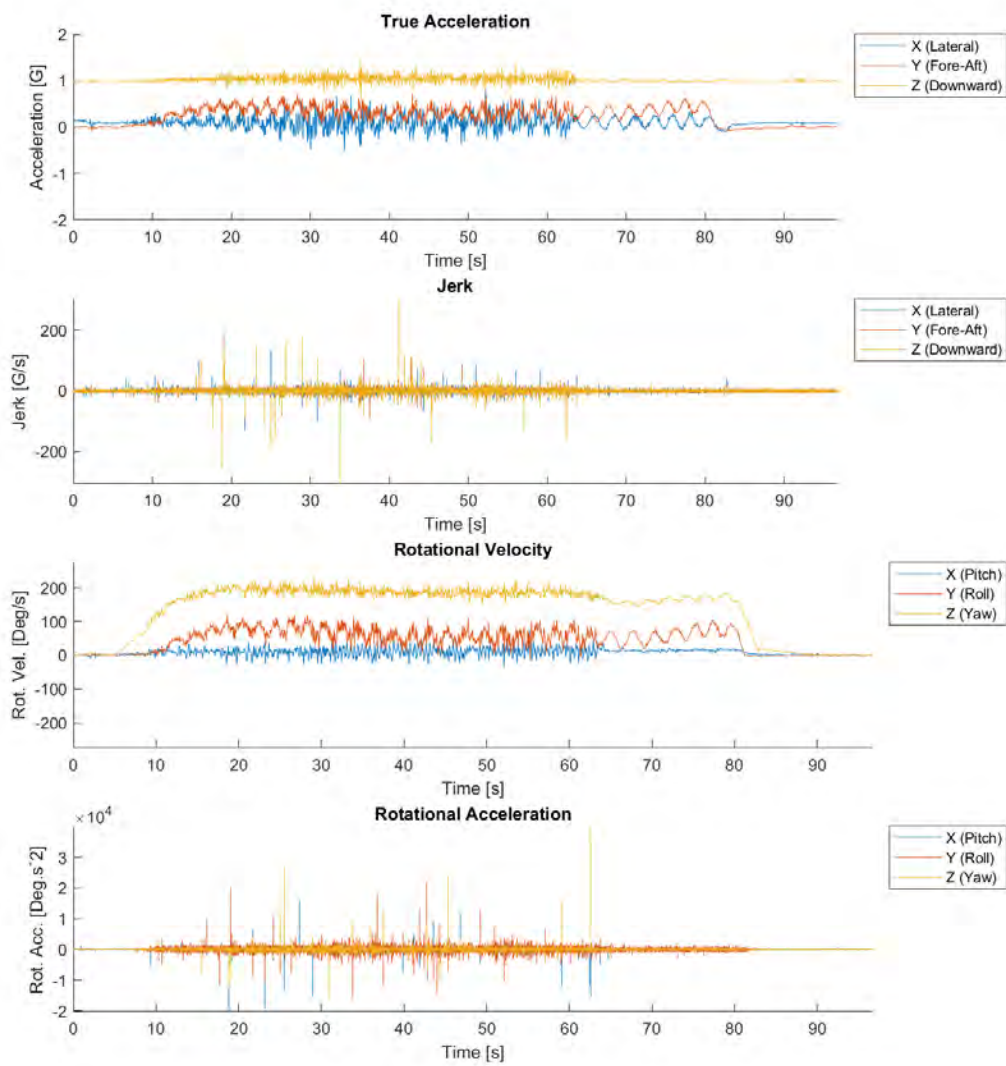


Figure 10 - Mad Tea Party

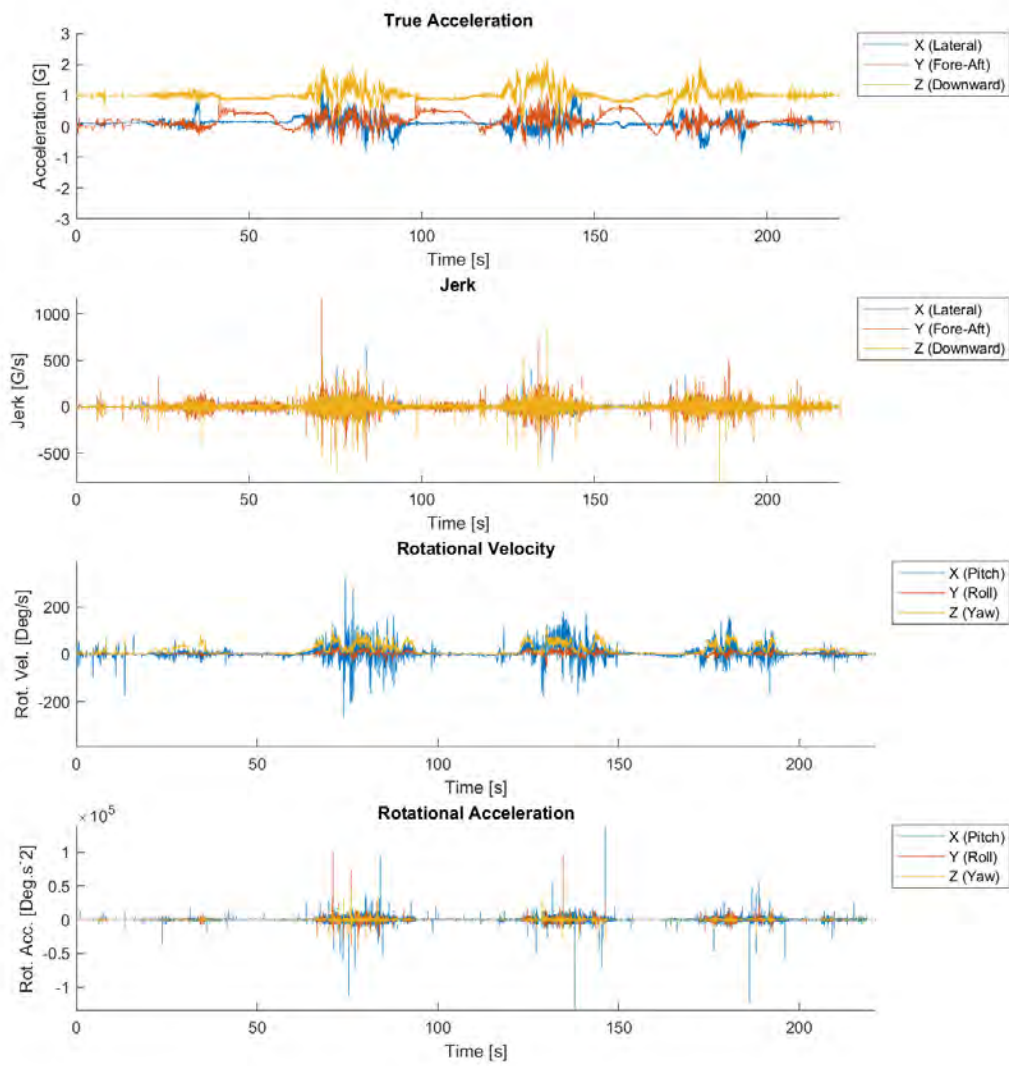


Figure 11 - Big Thunder Mountain Railroad

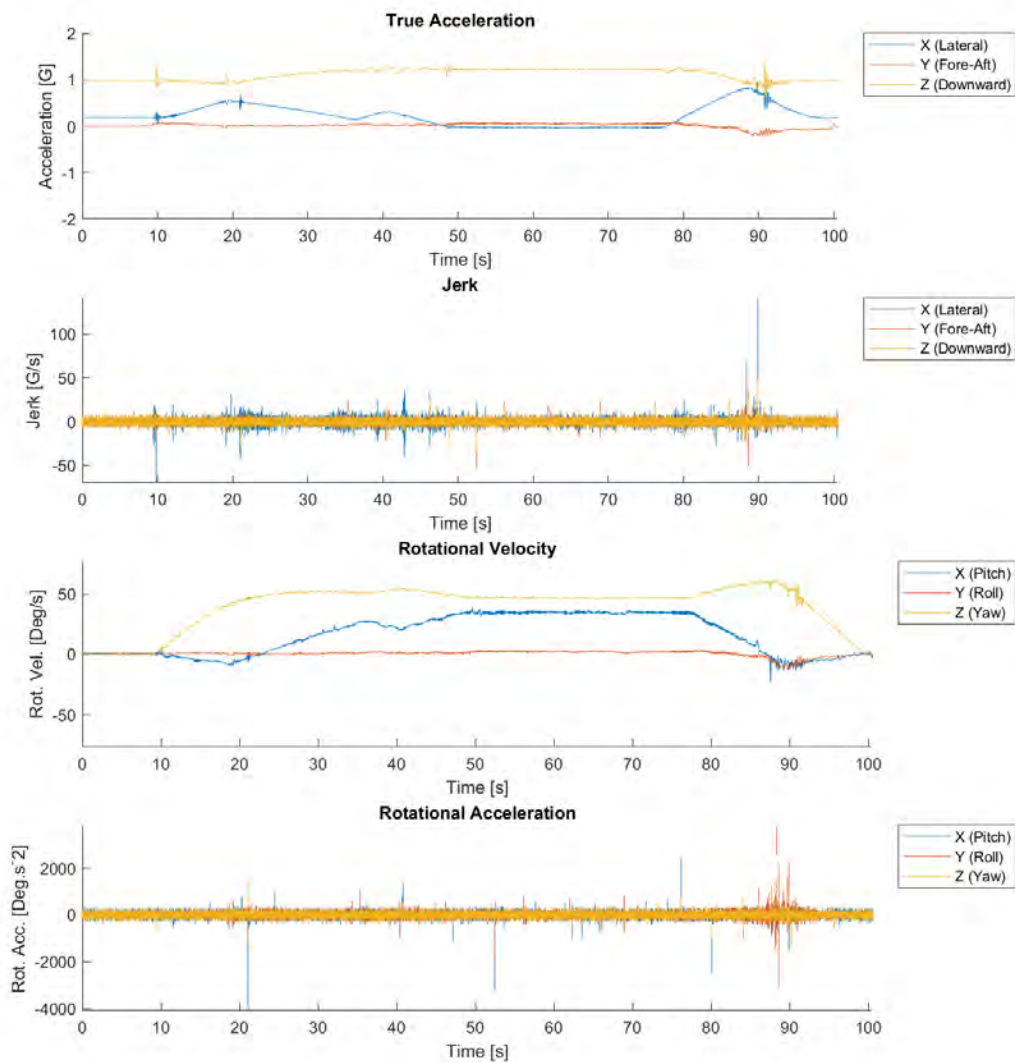


Figure 12 - Astro Orbiter



Epcot

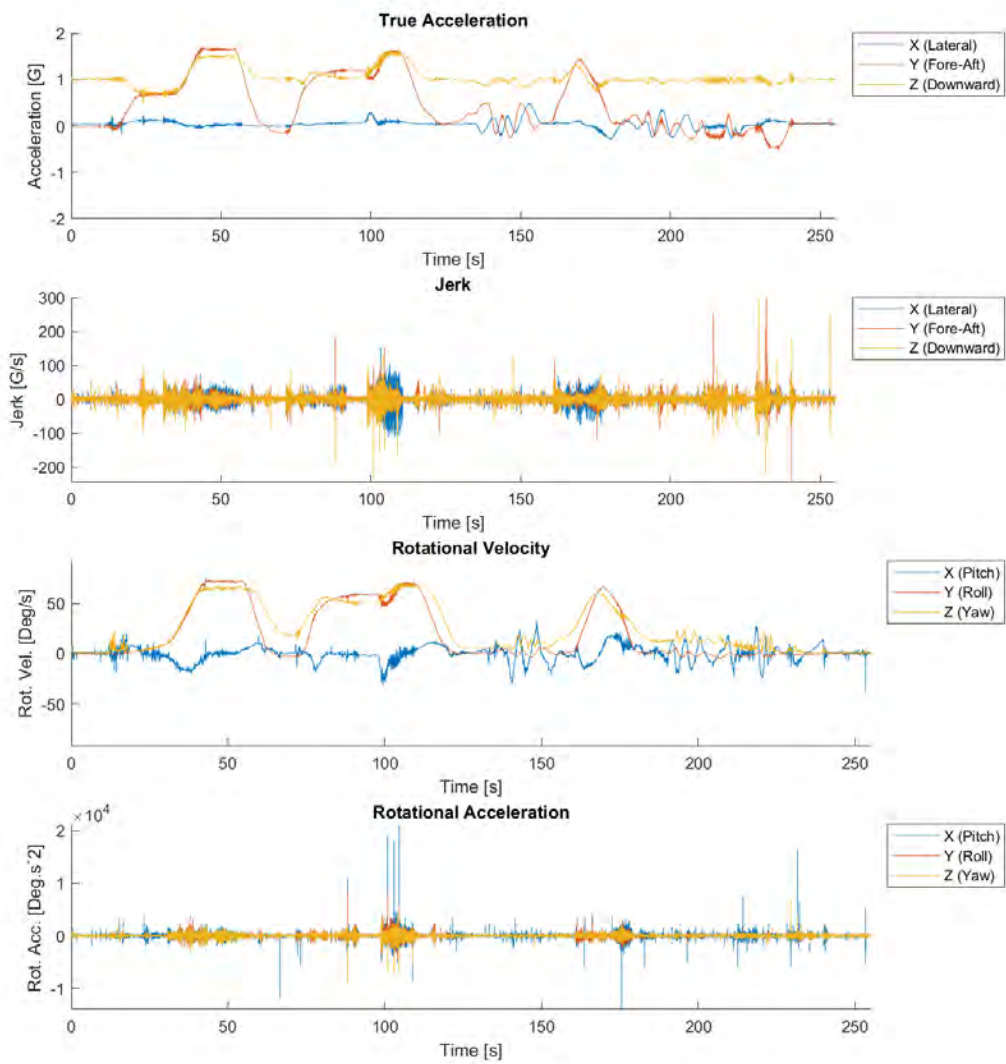
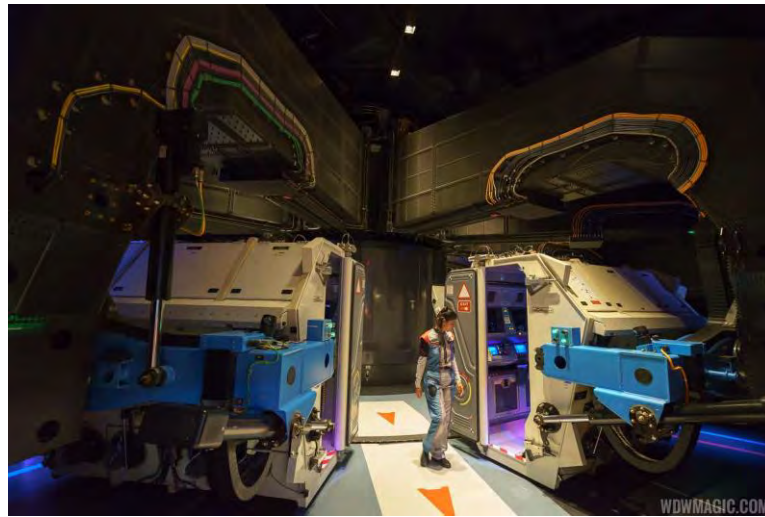


Figure 13 - Mission: SPACE

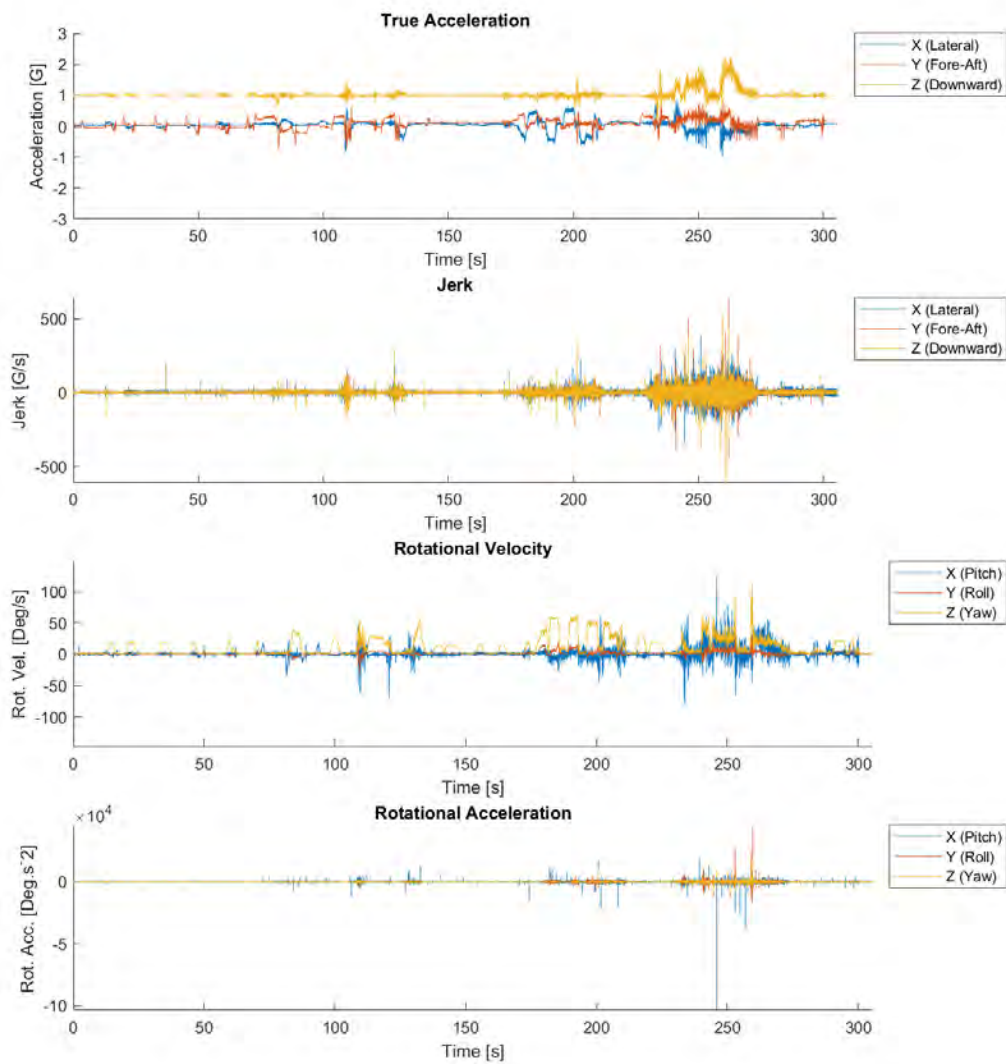


Figure 14 – Test Track

# Hollywood Studios

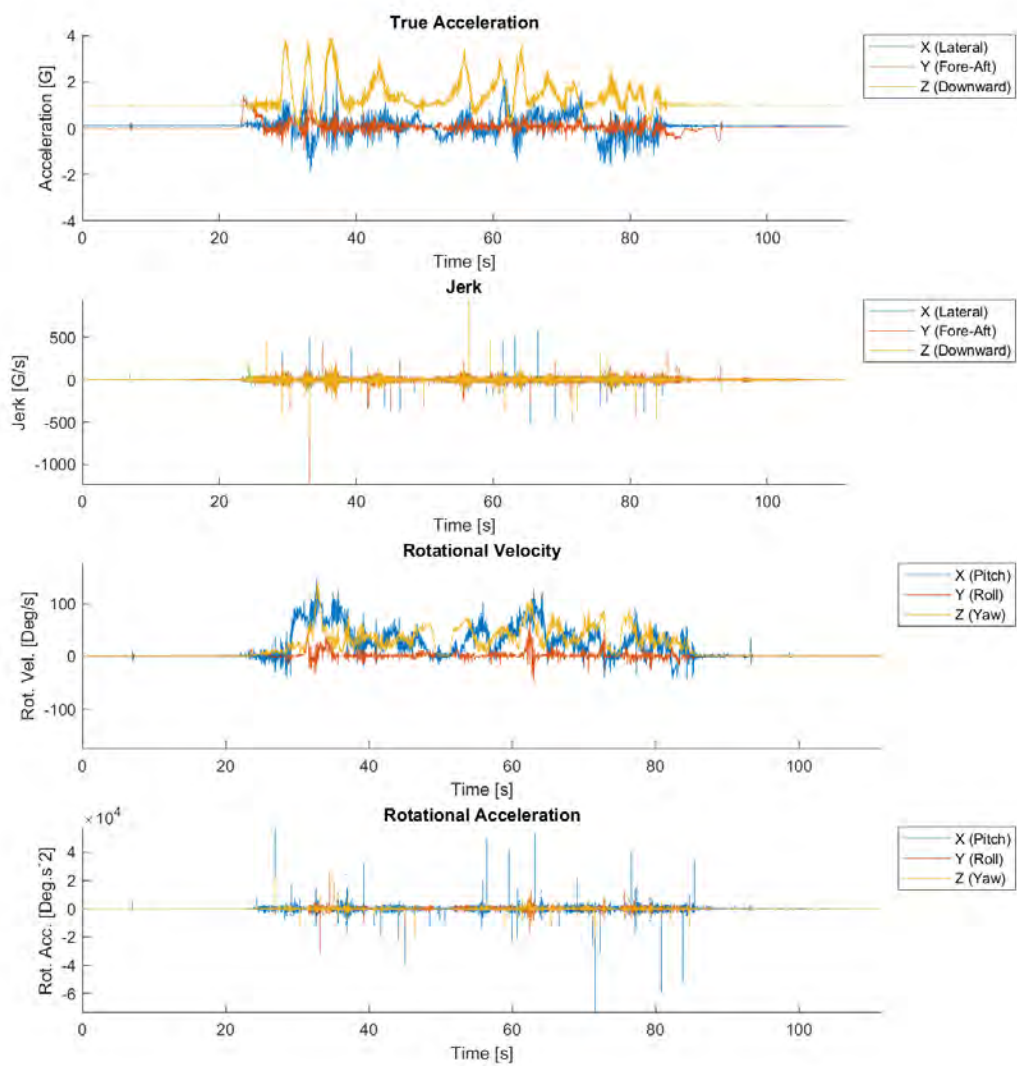


Figure 15 - Rock 'n' Roller Coaster



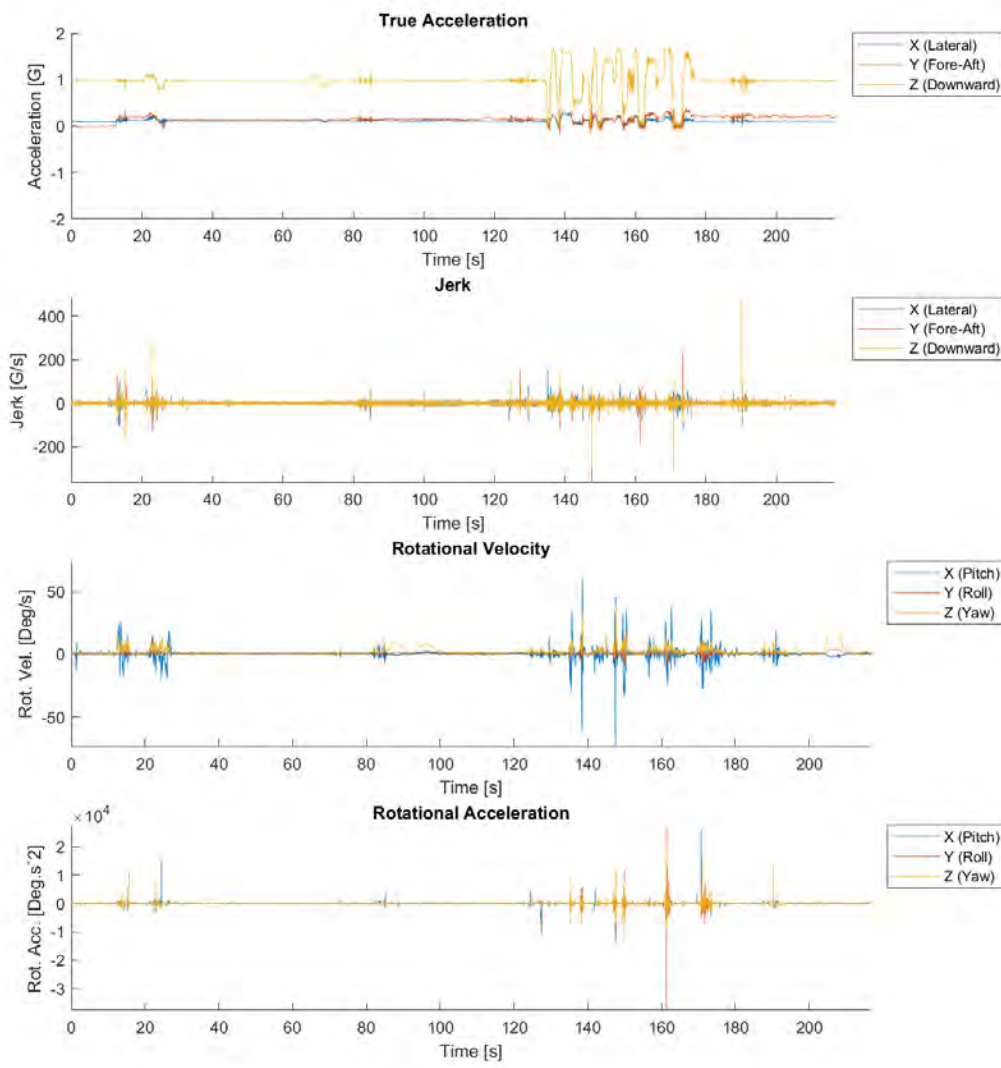


Figure 16 - The Twilight Zone Tower of Terror

# Universal Studios

## Universal Studios Florida

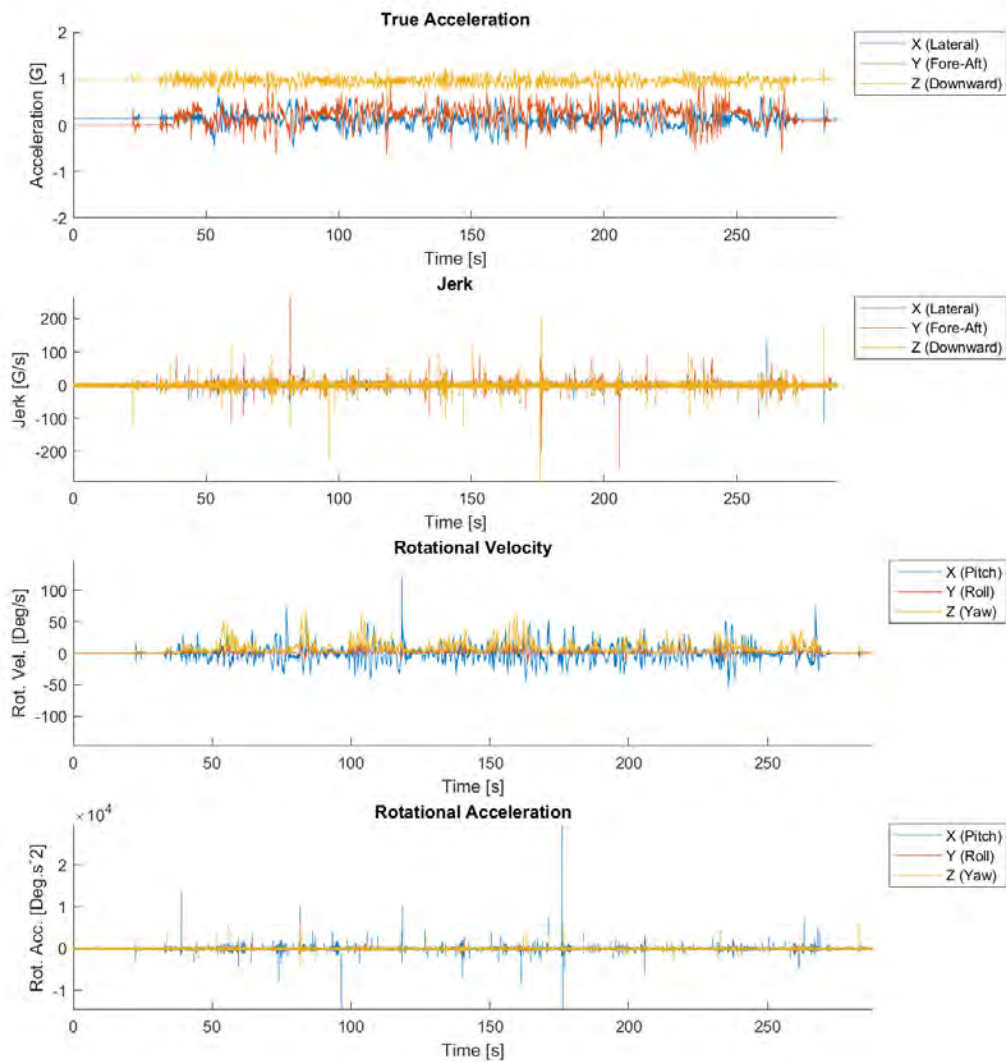


Figure 17 - The Simpsons

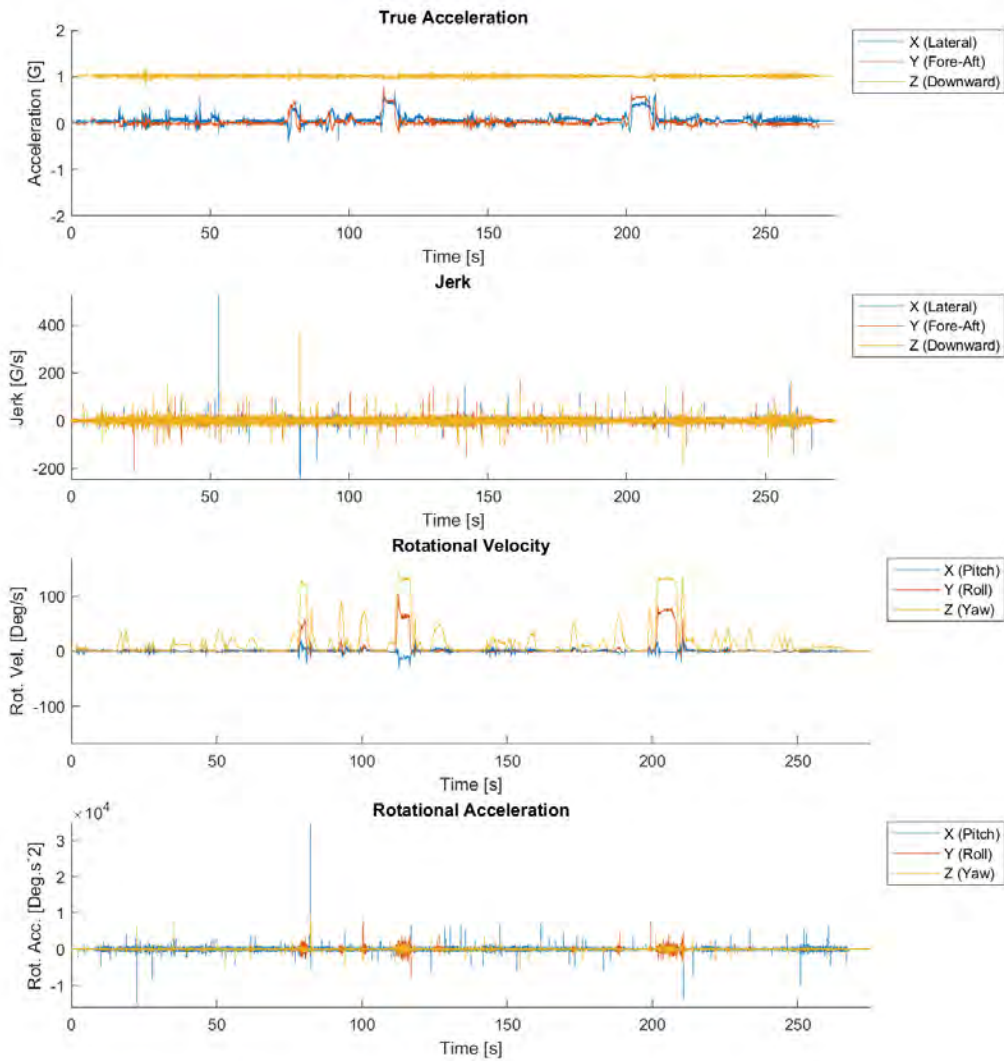


Figure 18 – Men in Black: Alien Attack

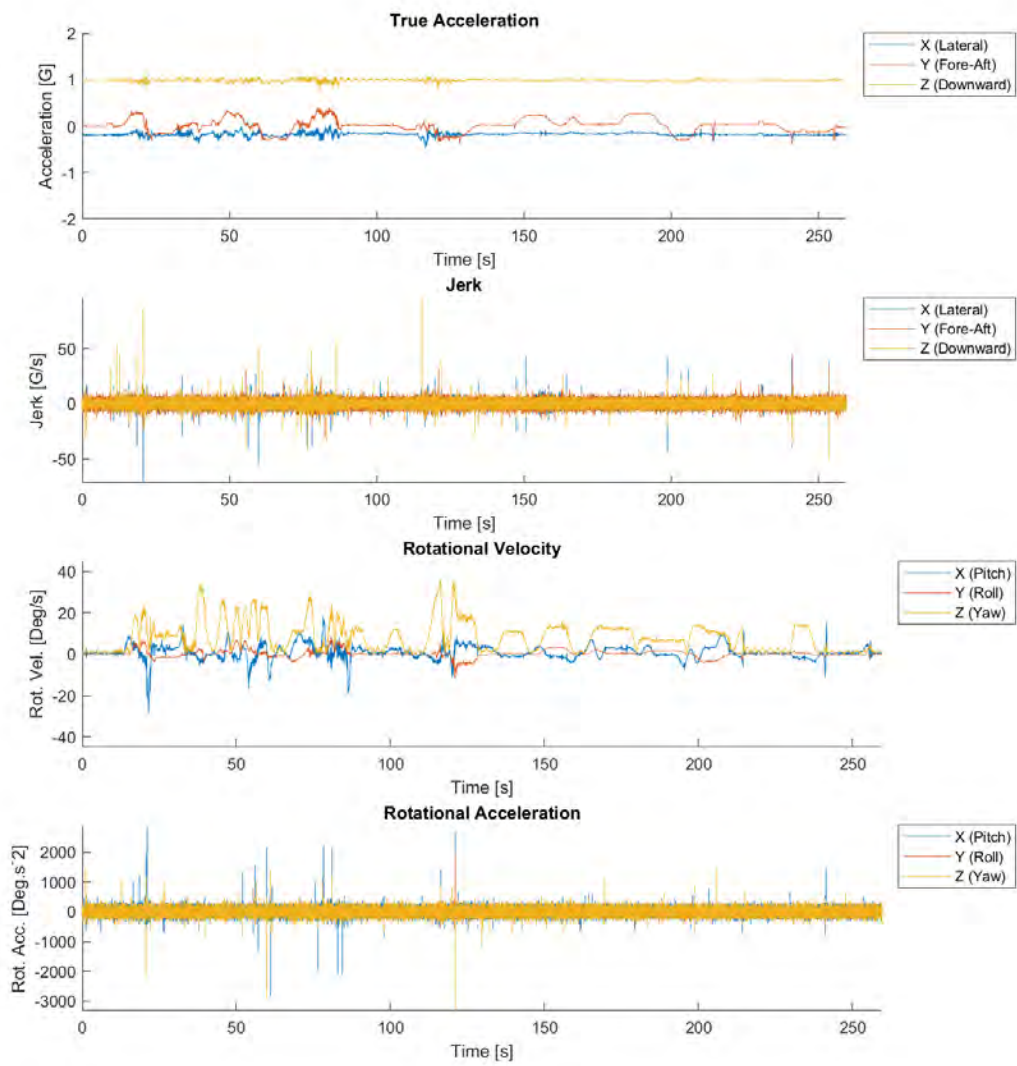


Figure 19 - ET



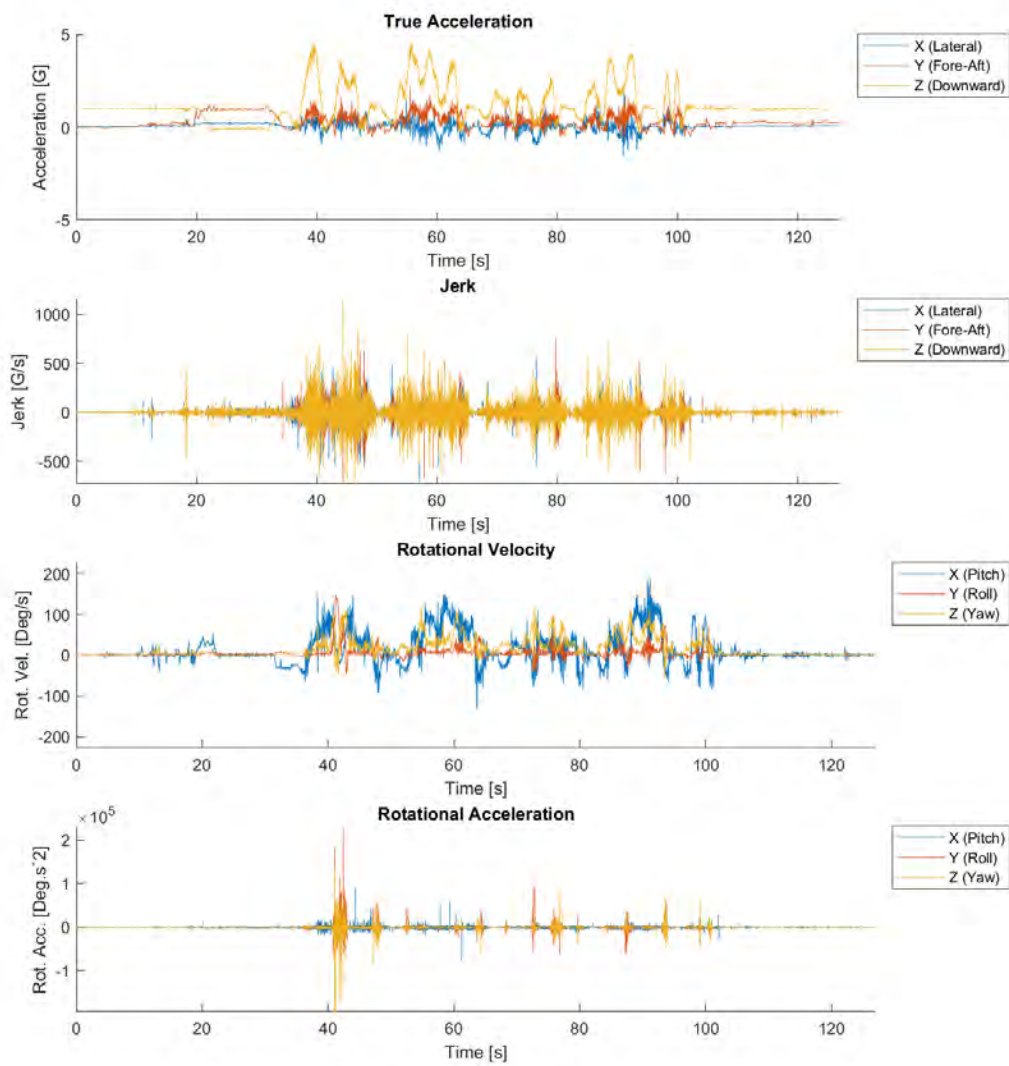


Figure 20 - Rip Ride Rocket



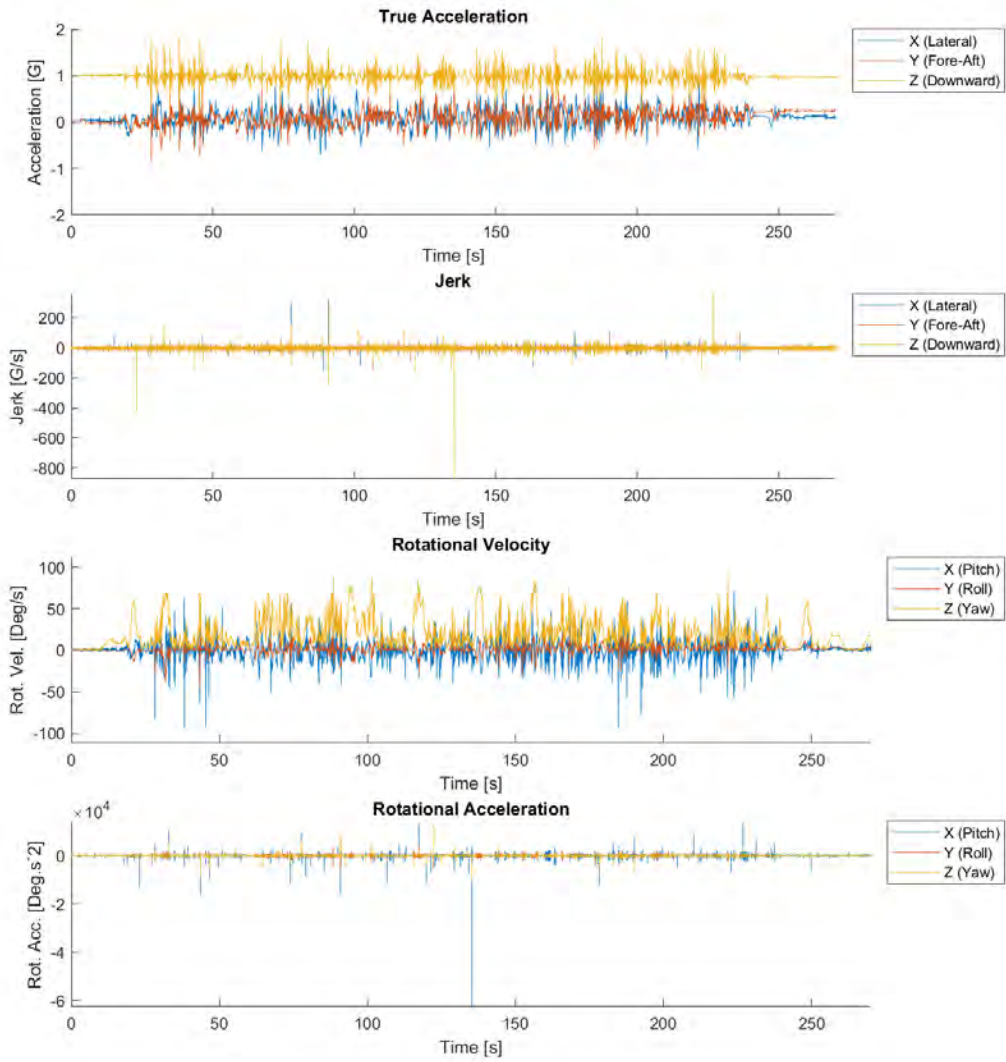


Figure 21 - Transformers

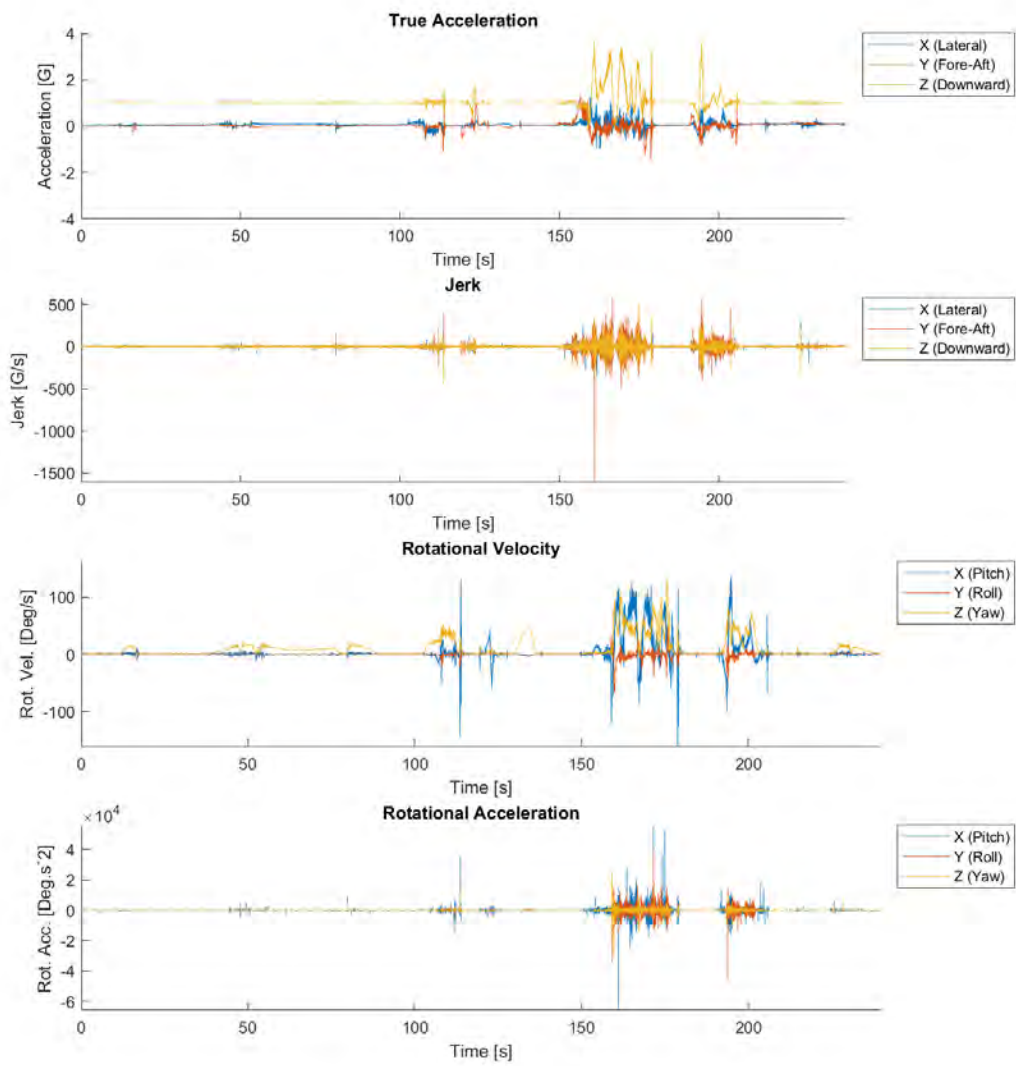


Figure 22 – Revenge of the Mummy

# Islands of Adventure

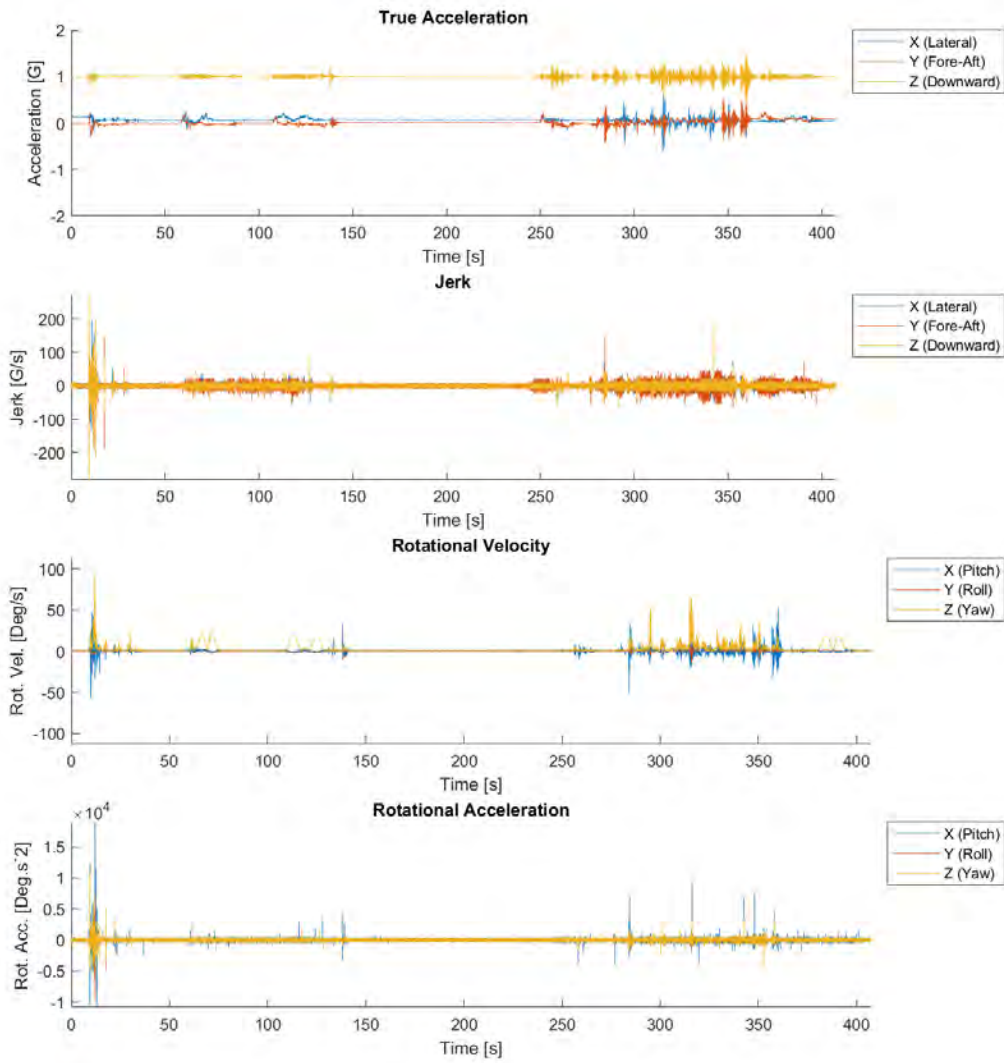


Figure 23 - Harry Potter and the Forbidden Journey

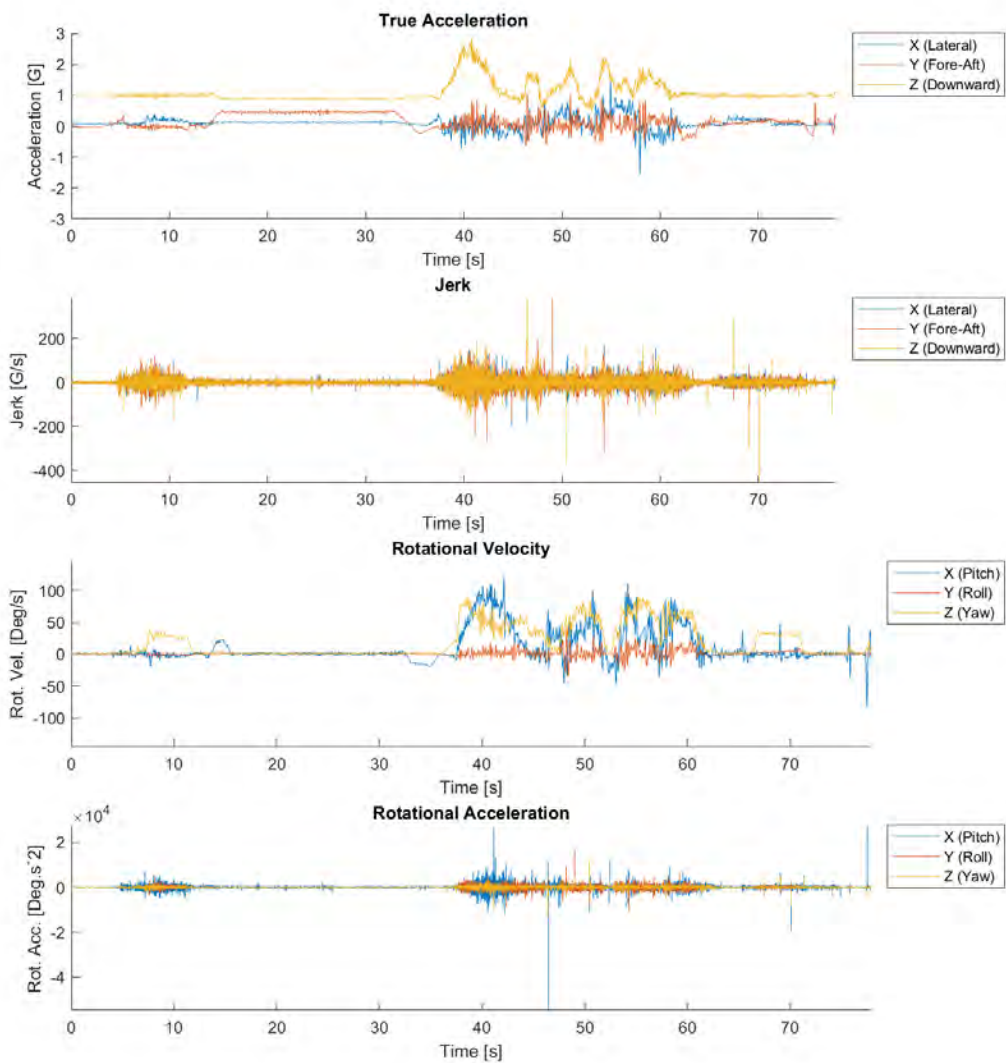


Figure 24 - Flight of the Hippogriff



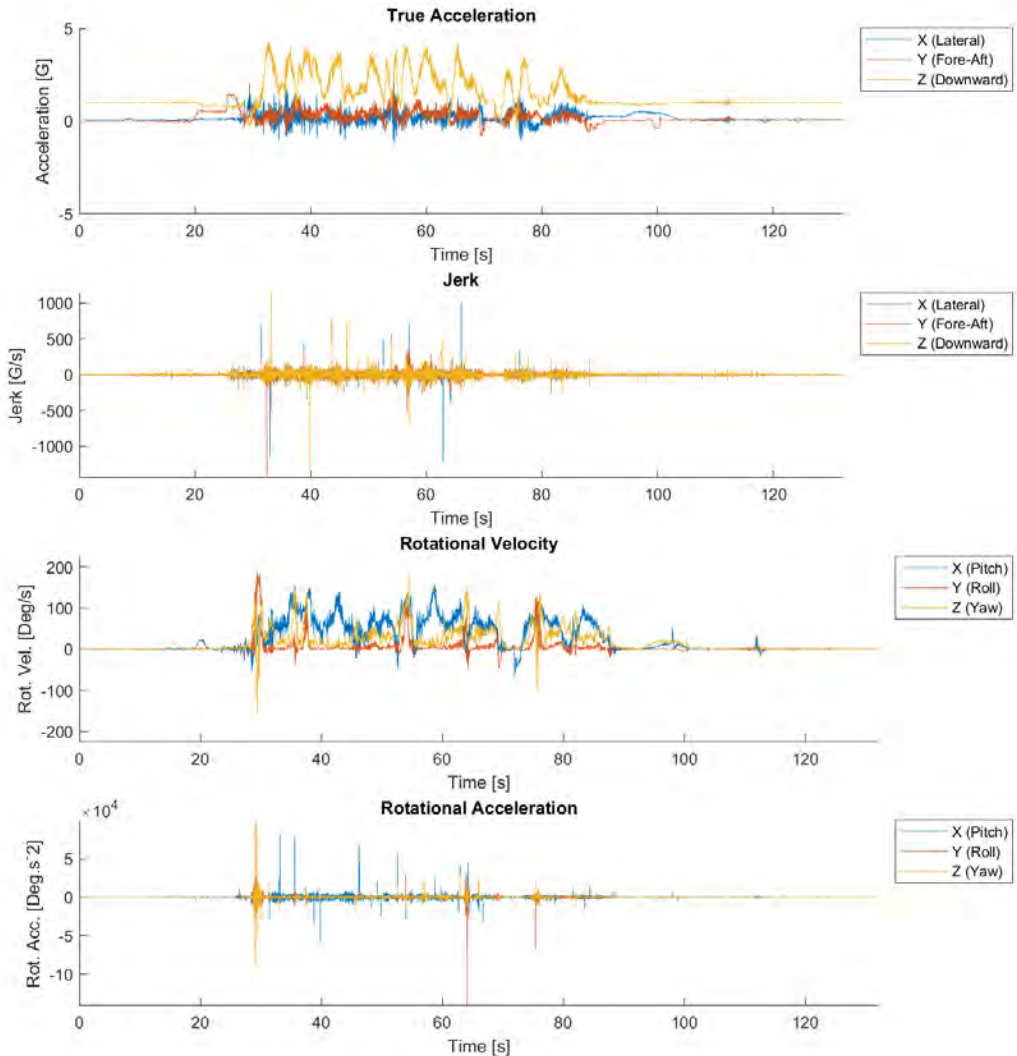


Figure 25 - The Hulk

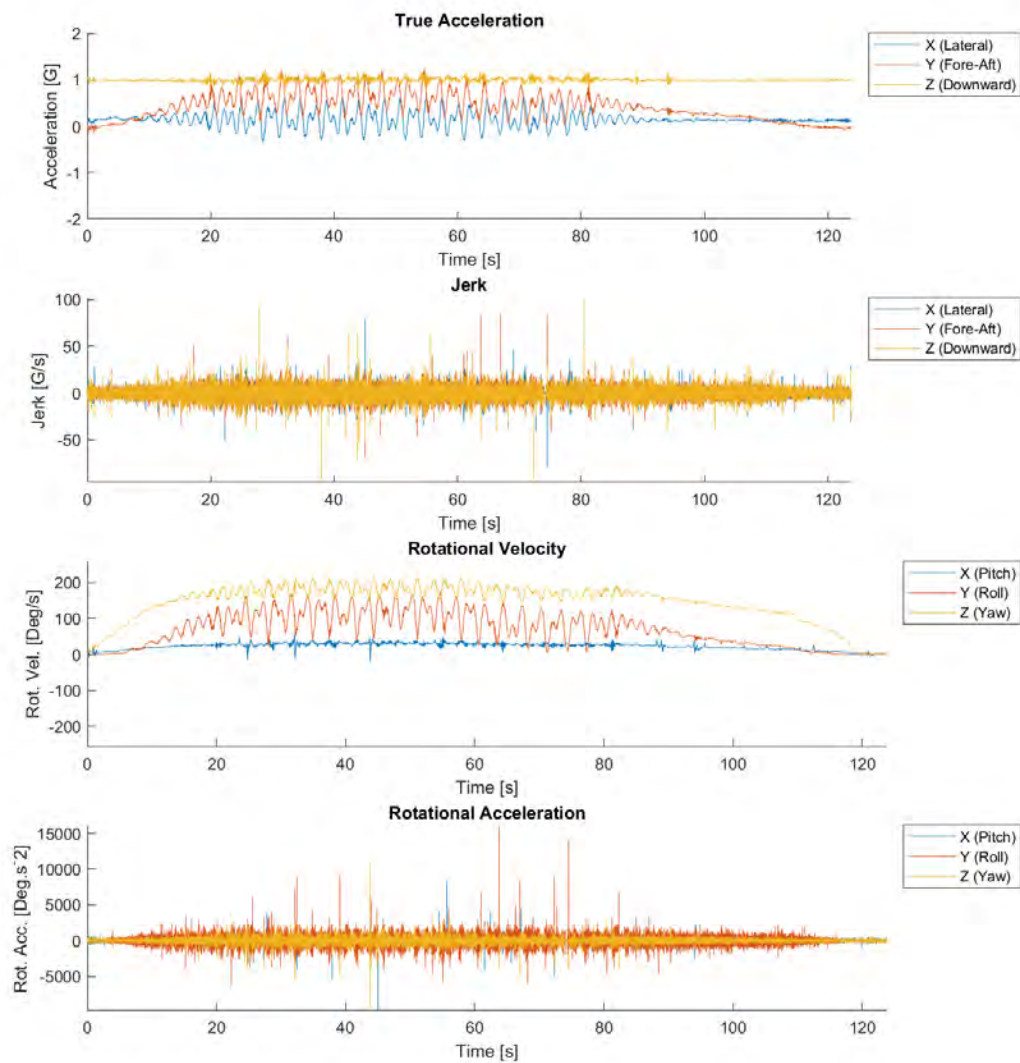


Figure 26 - Accelerator

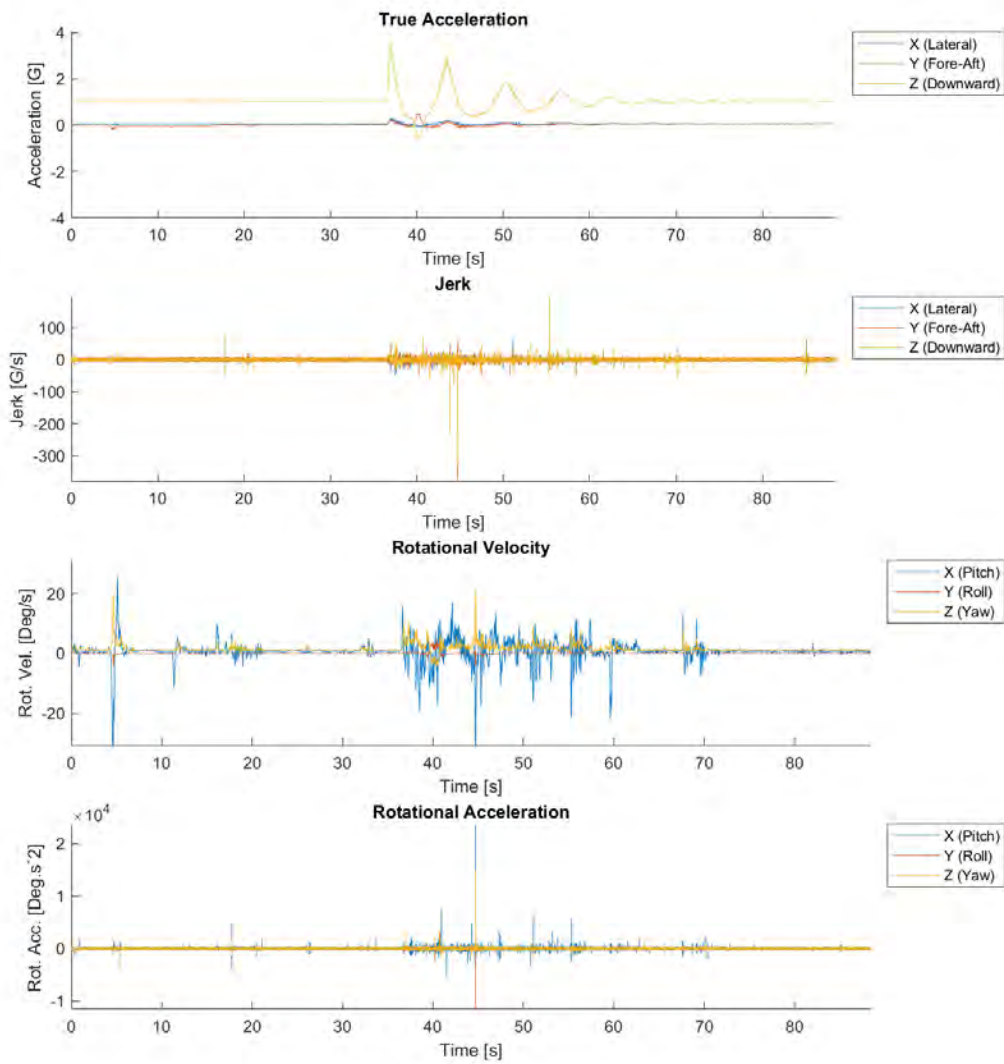


Figure 27 – Doctor Doom's Fear Fall



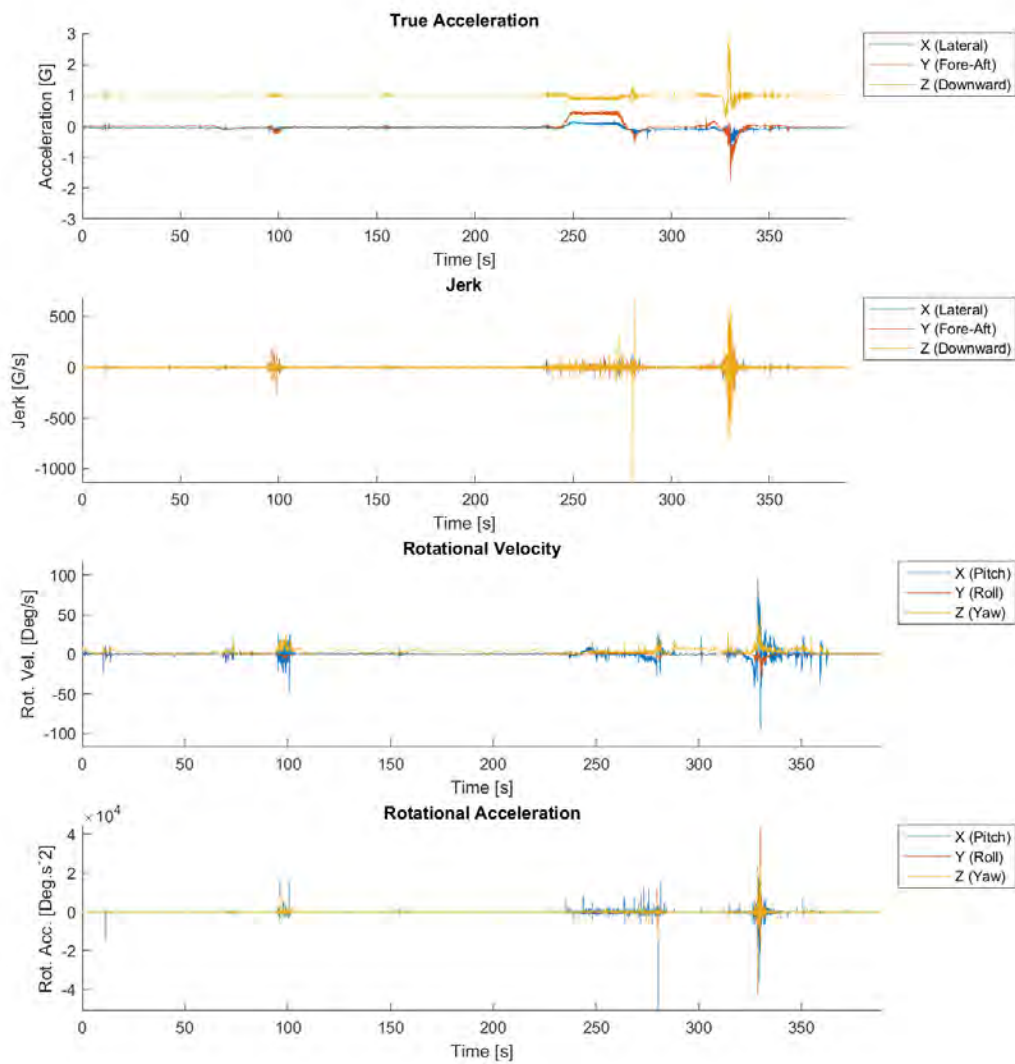


Figure 28 - Jurassic Park



# Six Flags

## Magic Mountain

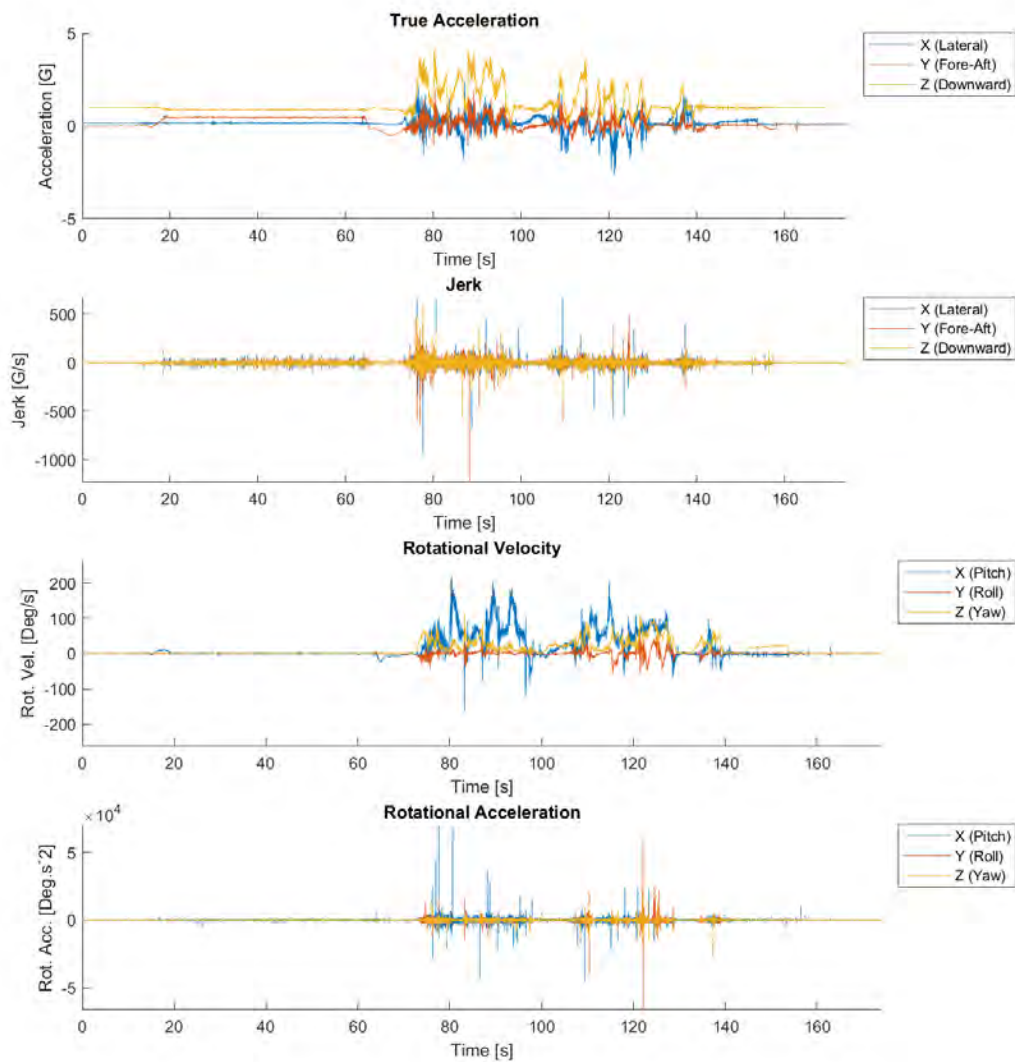


Figure 29 - Viper

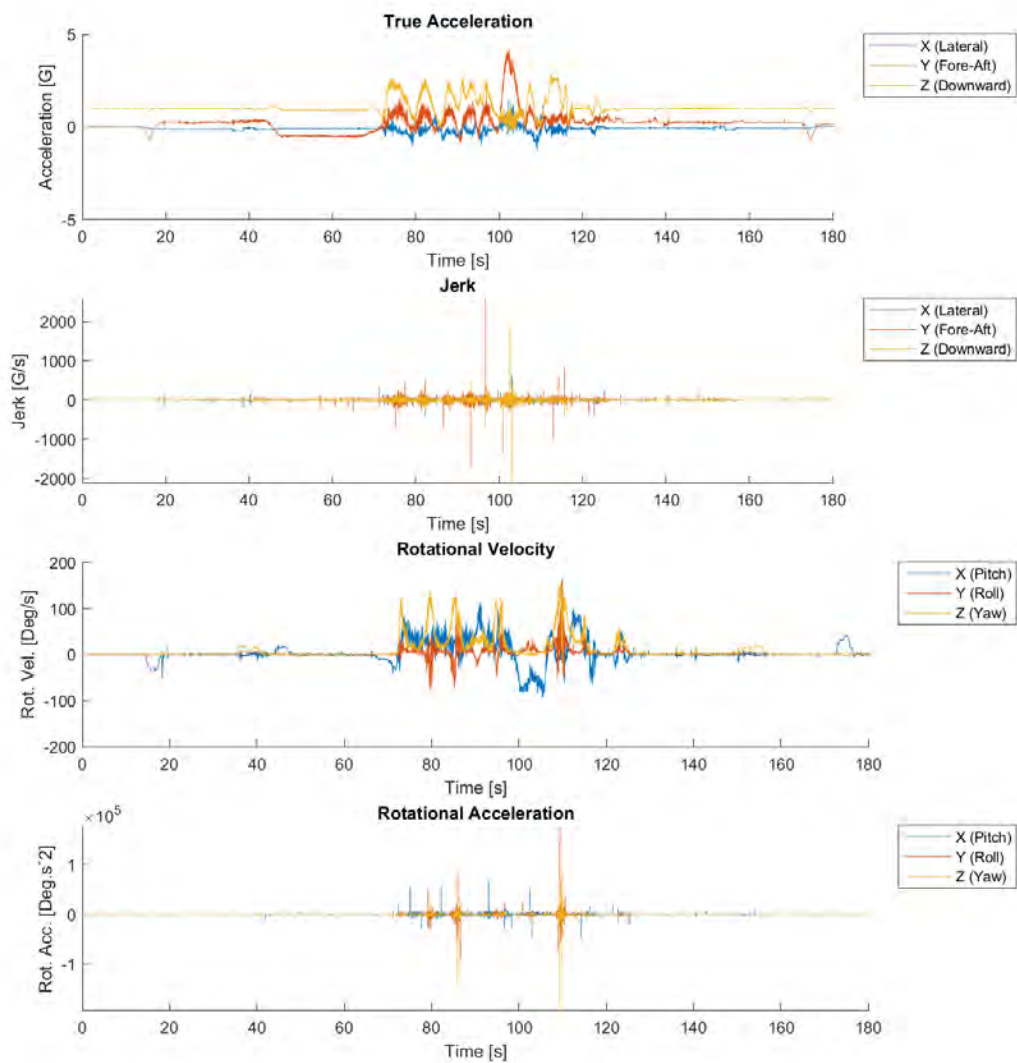


Figure 30 - Tatsu

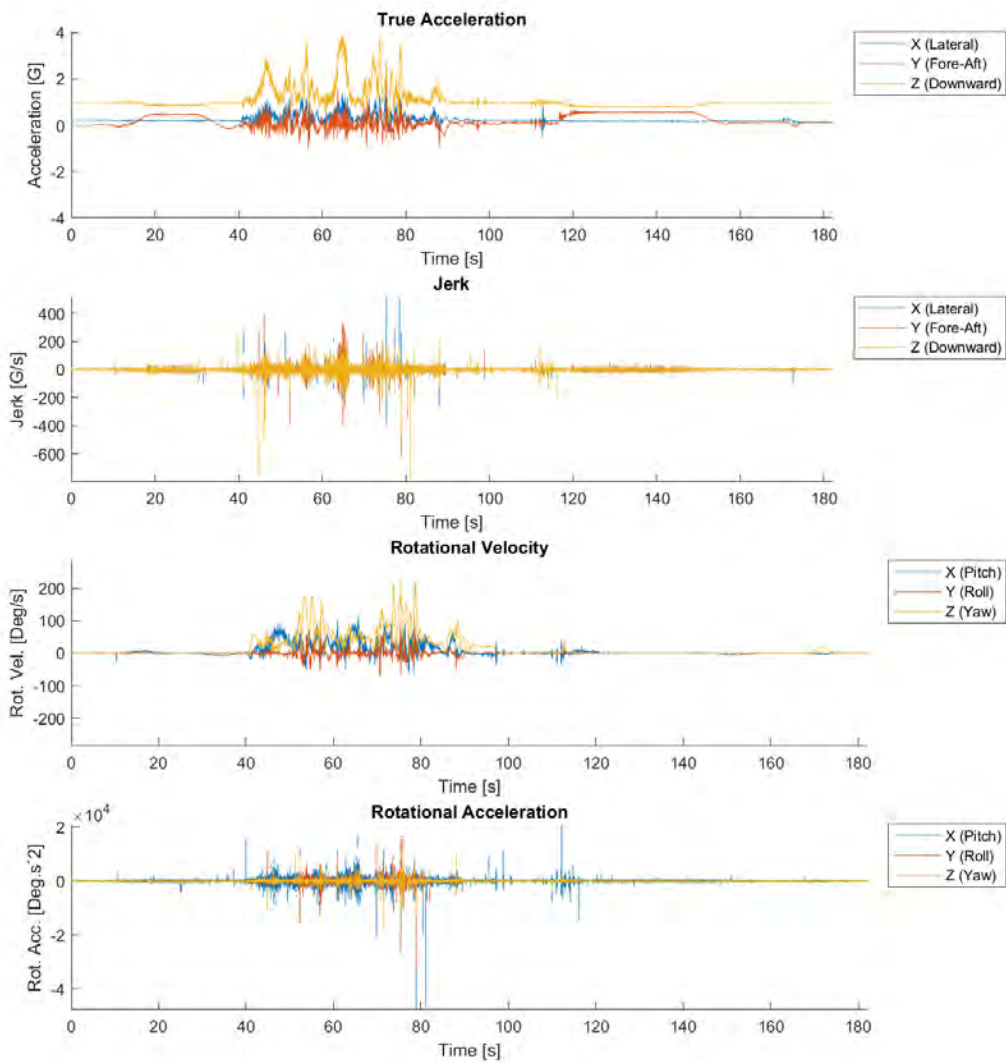


Figure 31 - Ninja



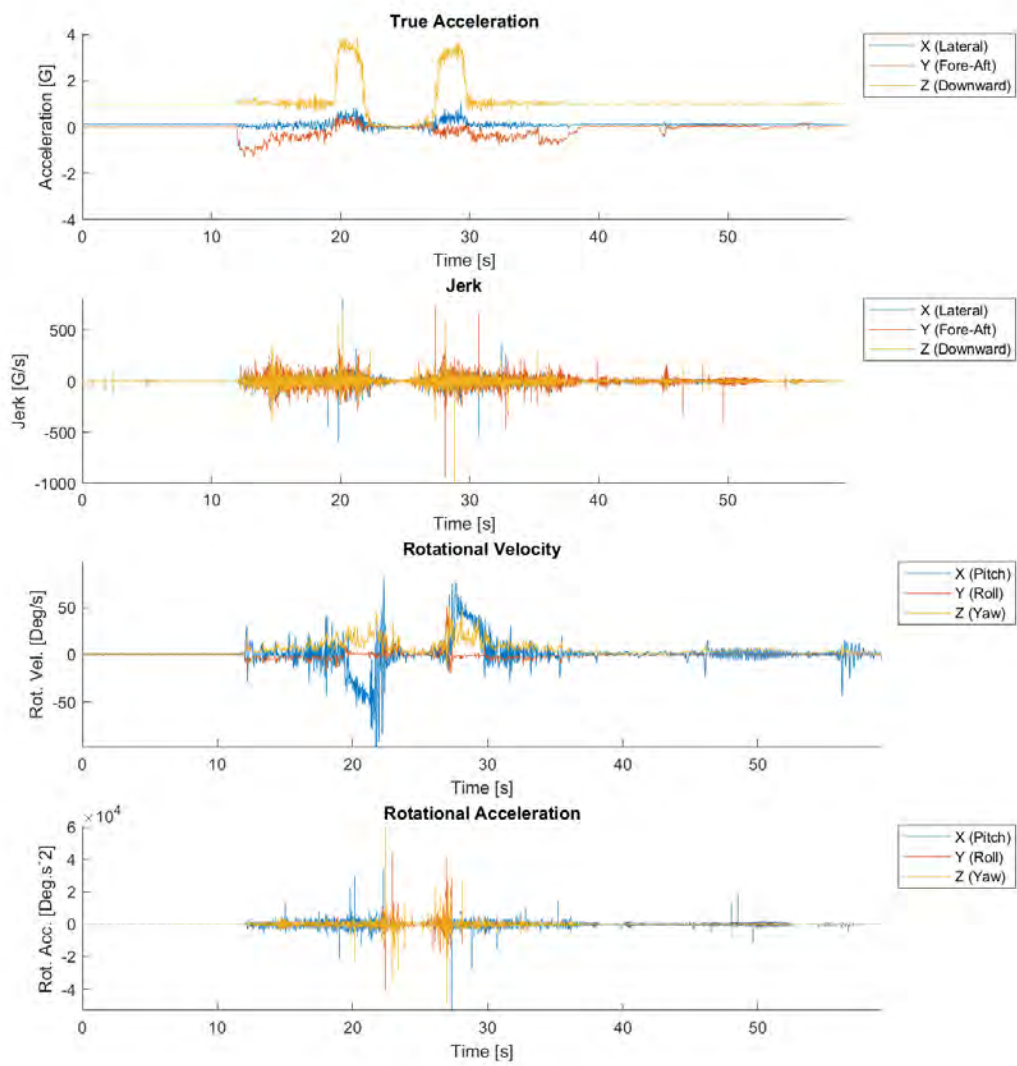


Figure 32 - Superman

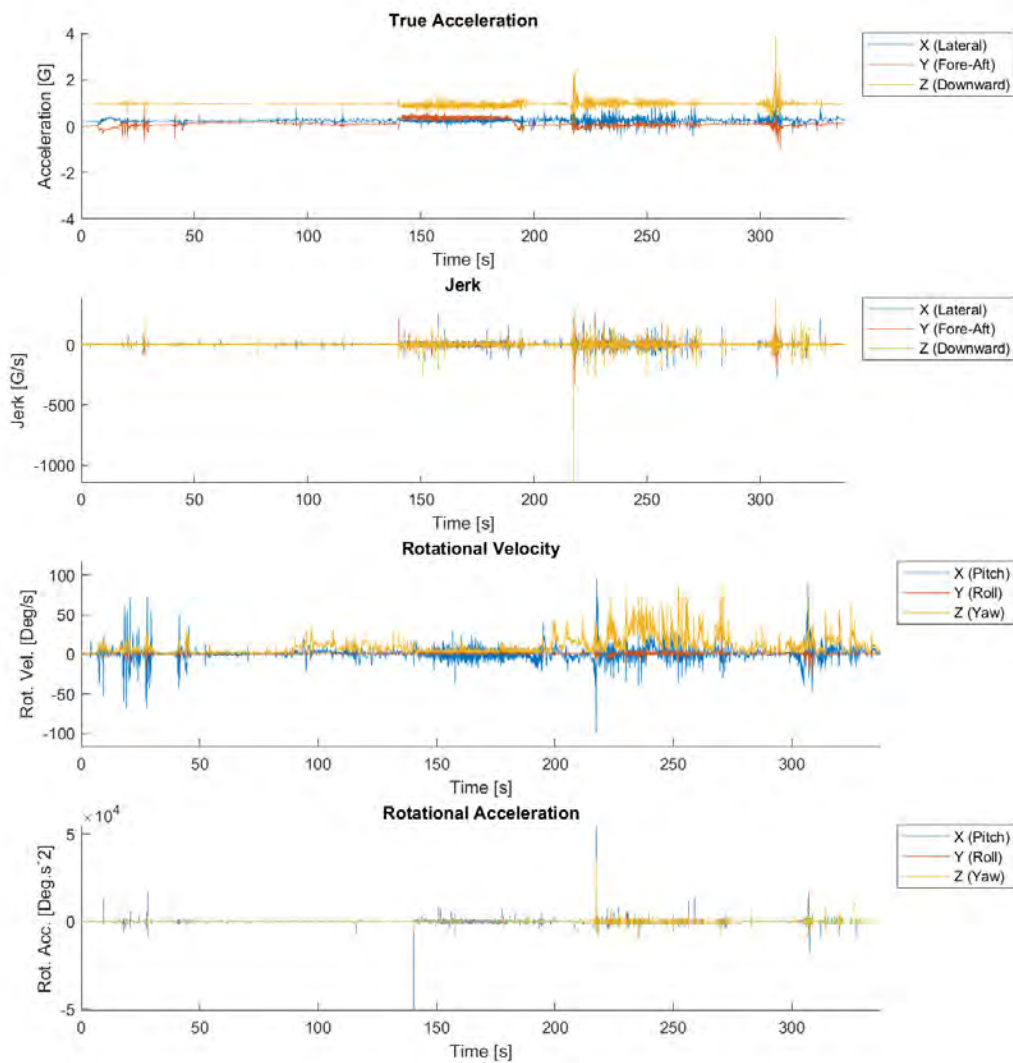


Figure 33 - Jet Stream

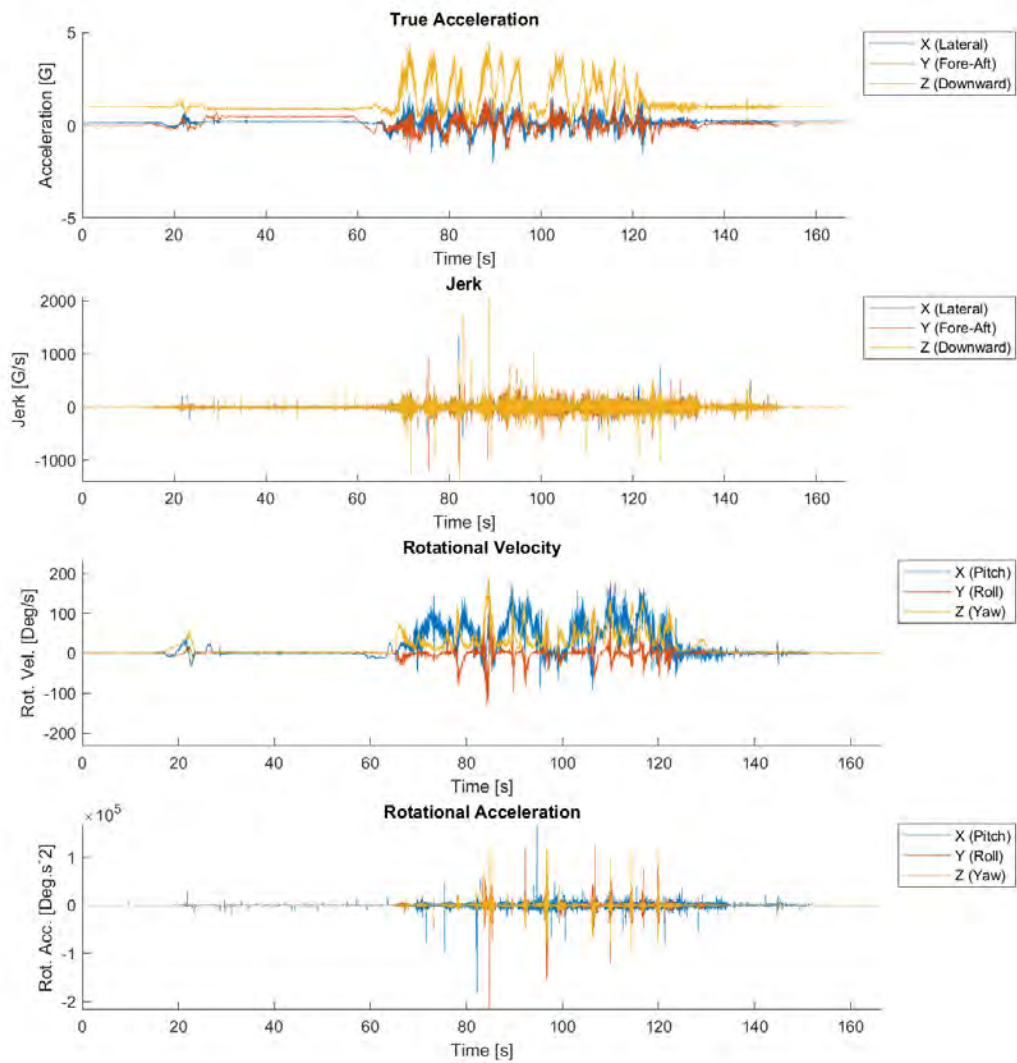


Figure 34 - Scream



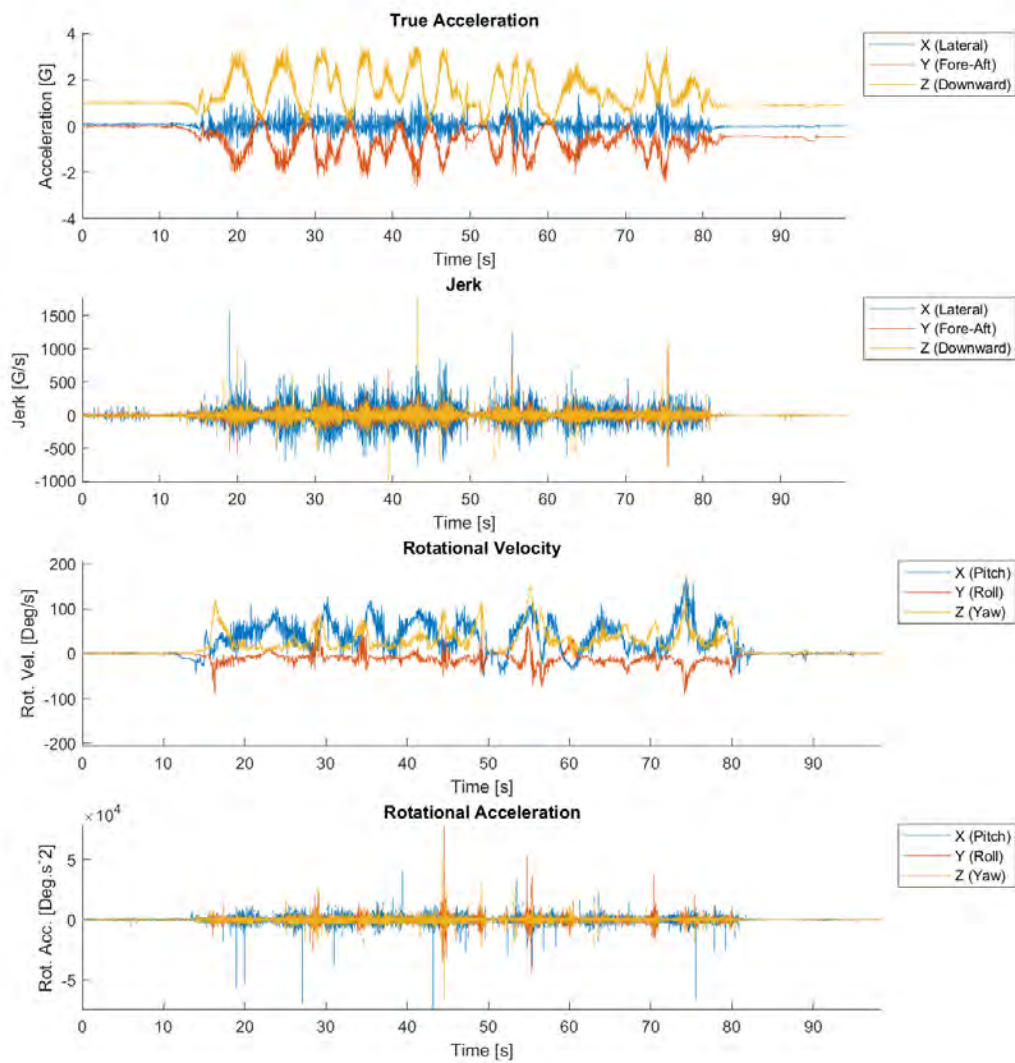


Figure 35 - Riddler's Revenge

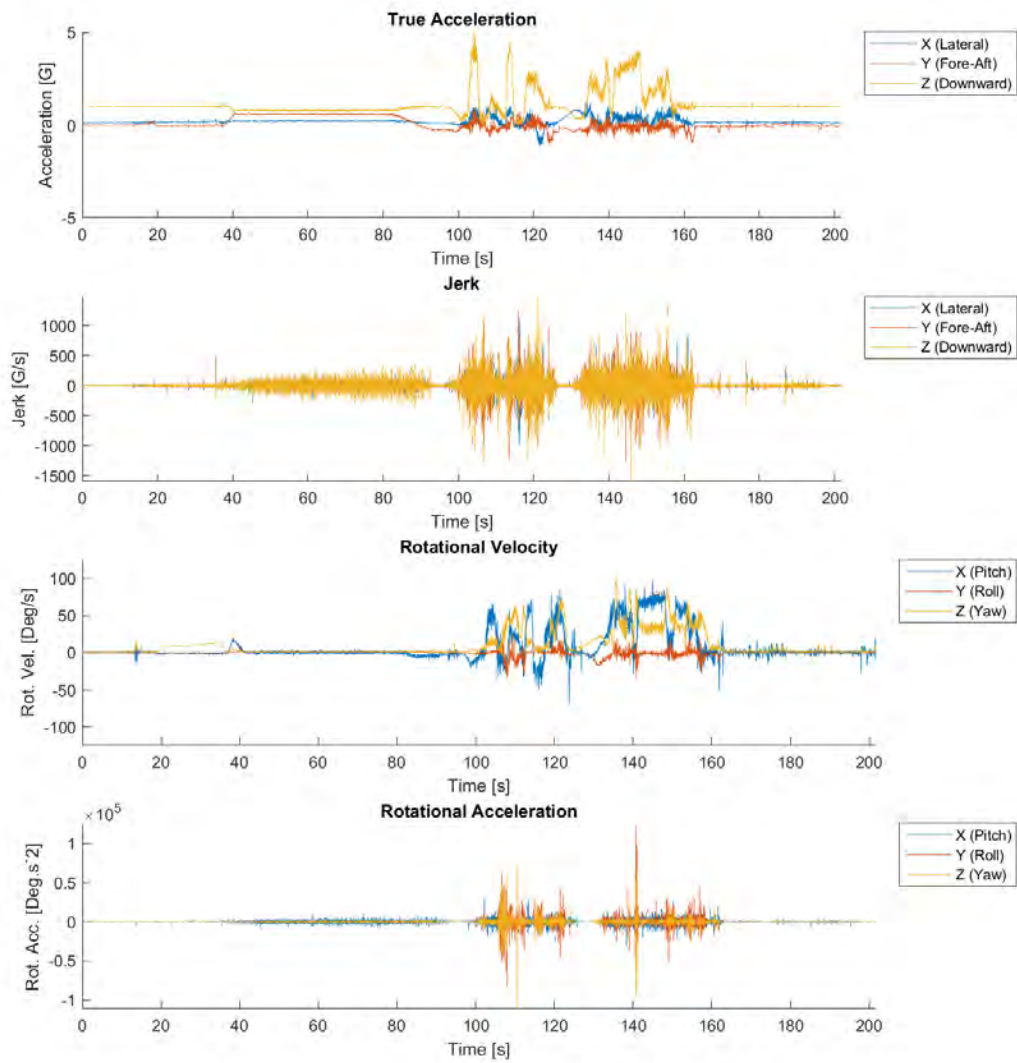


Figure 36 - Goliath



# Knott's Berry Farm

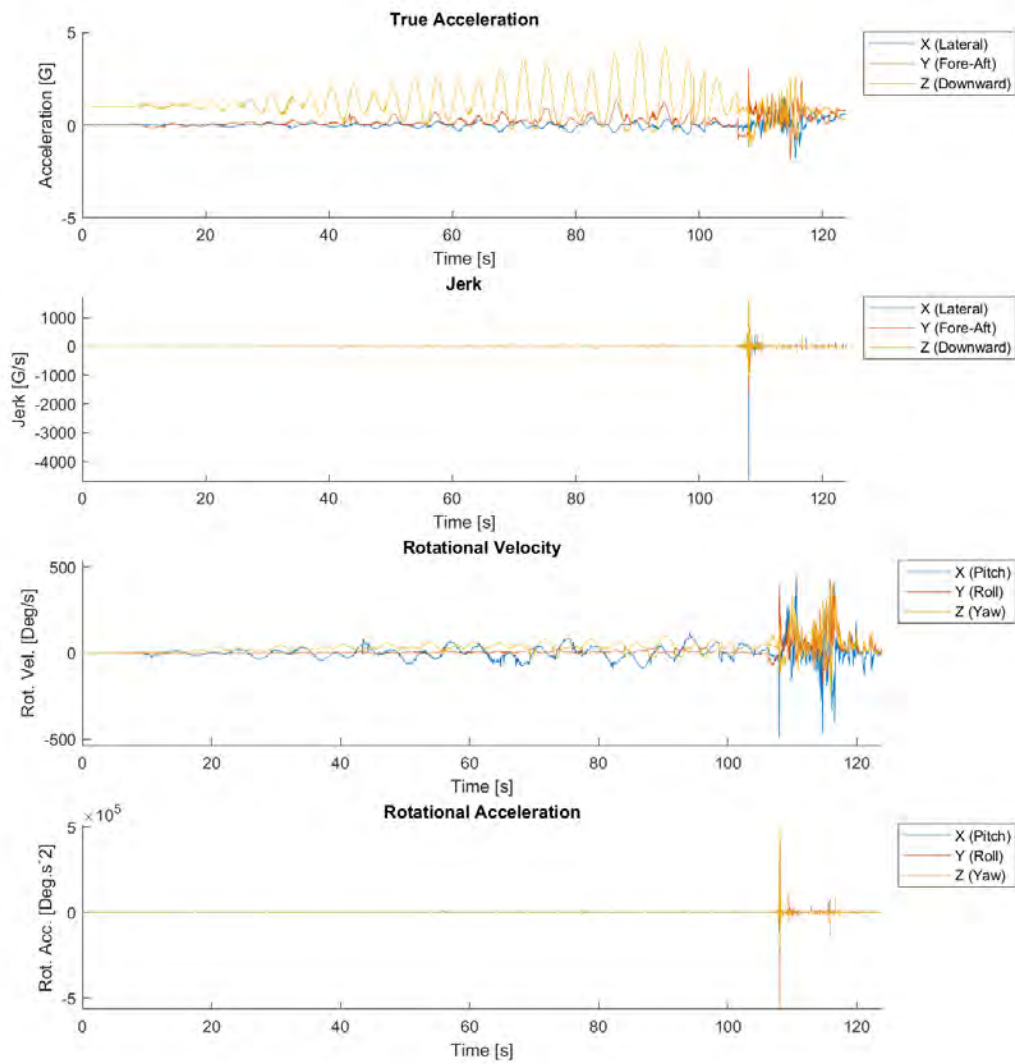


Figure 37 – La Revolution

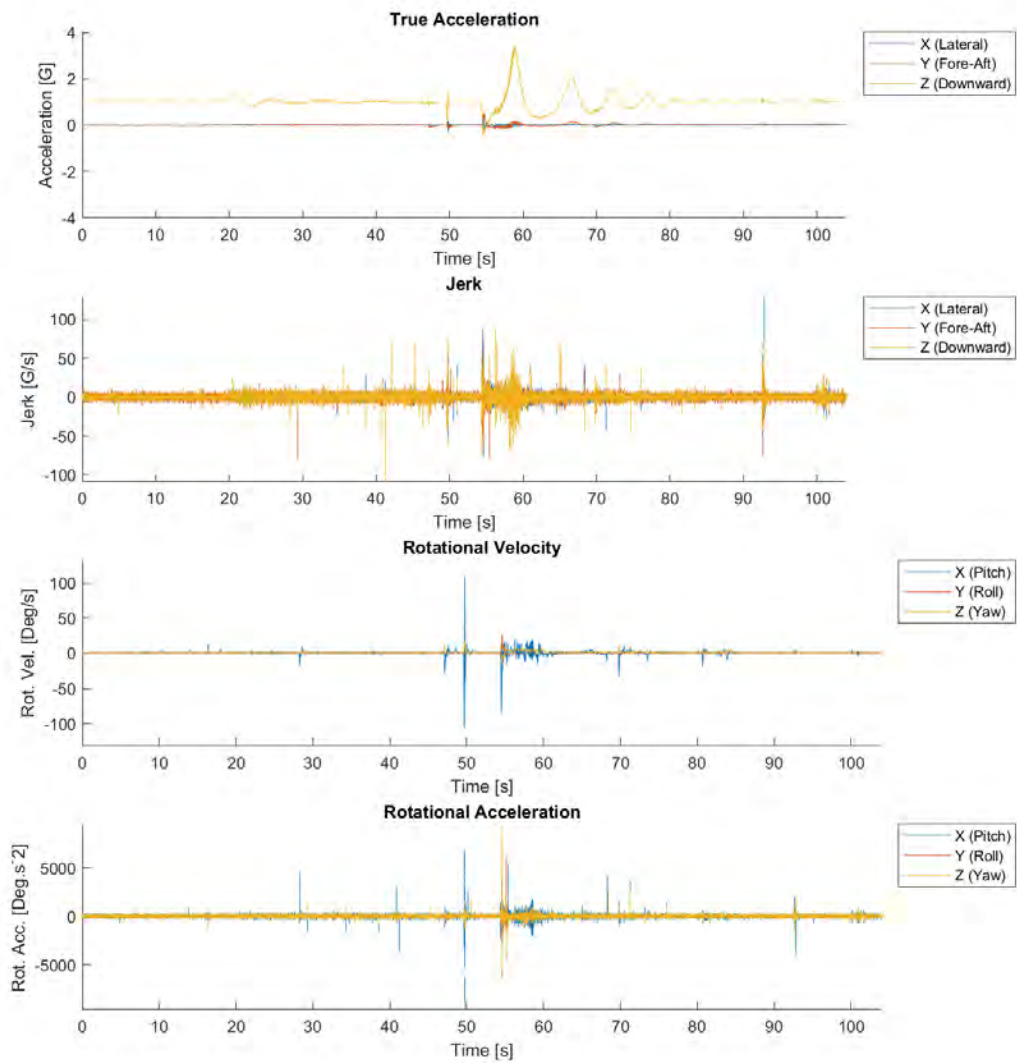


Figure 38 - Supreme Scream

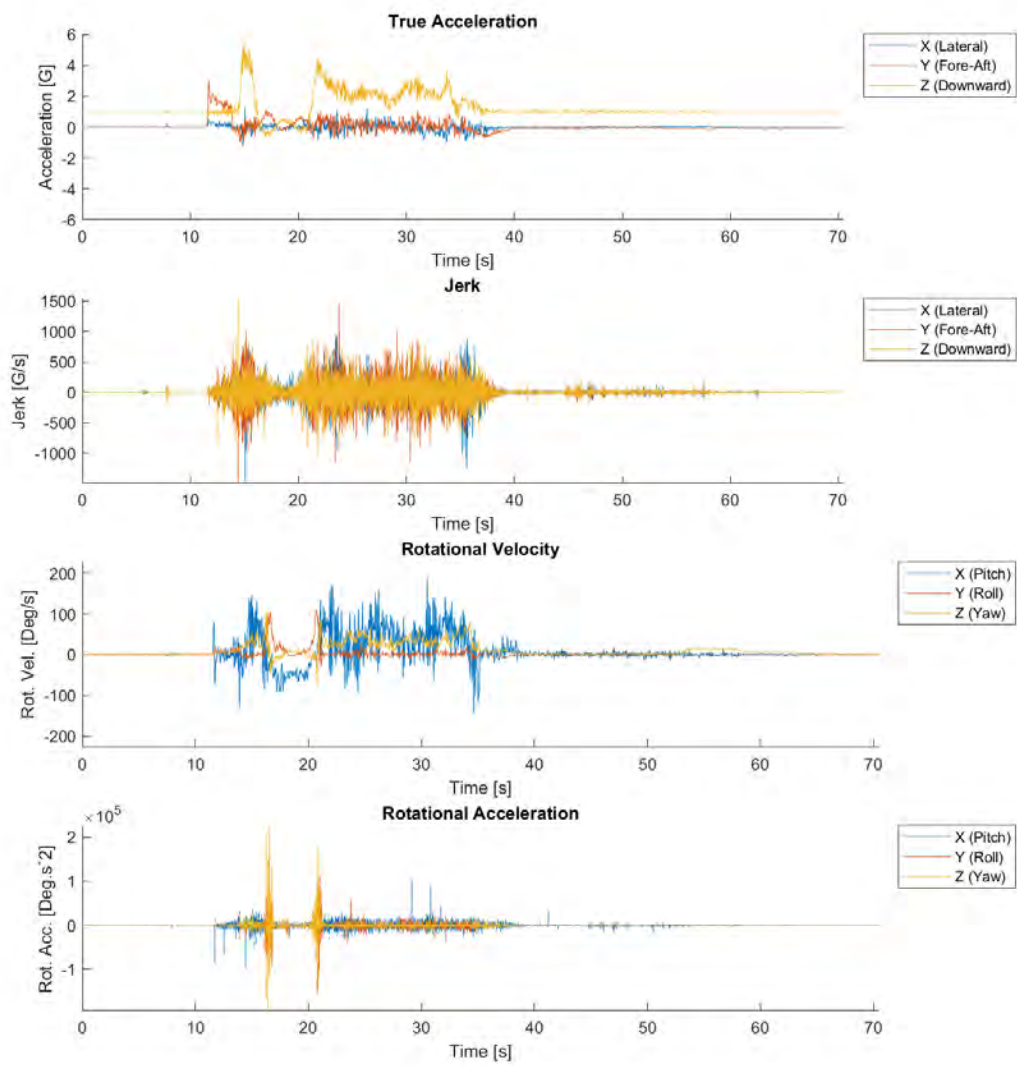


Figure 39 - Xcelerator

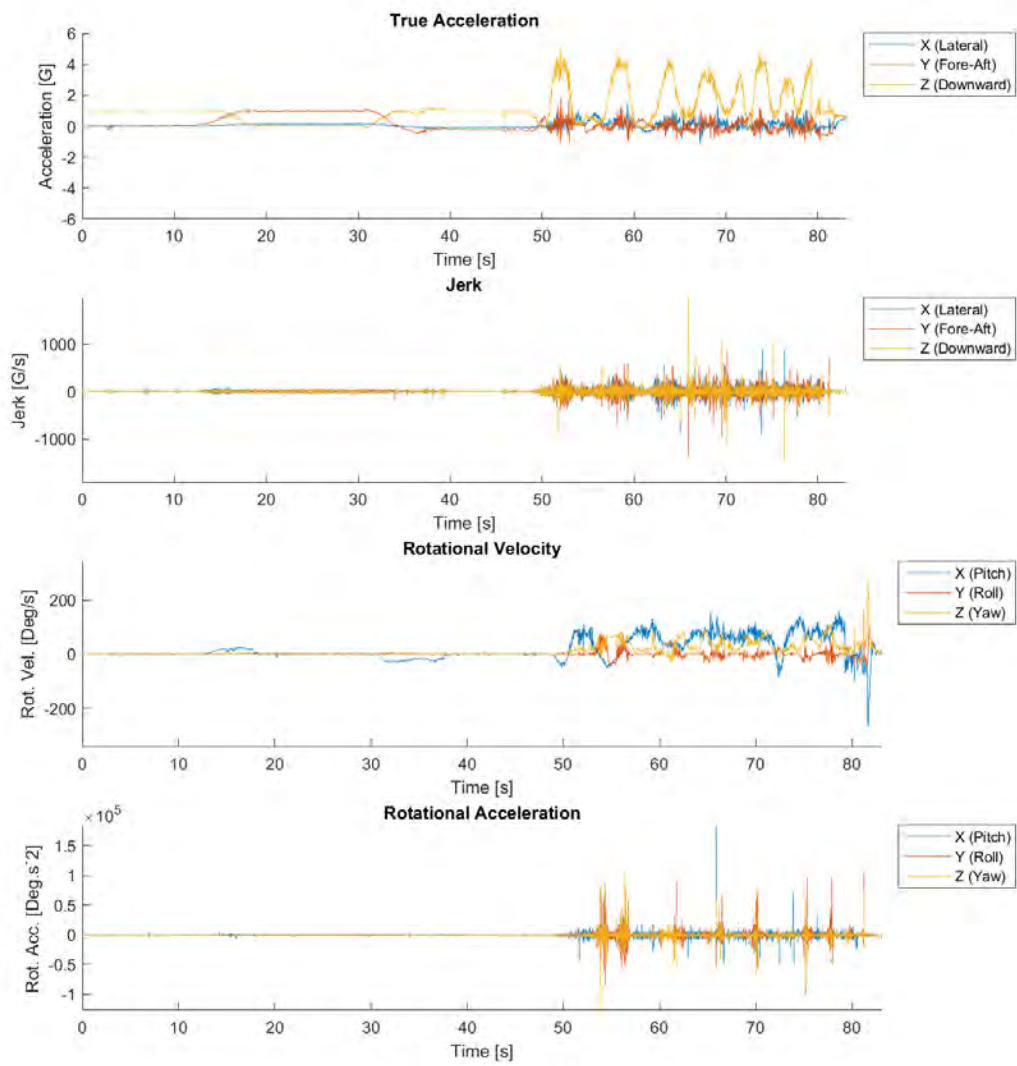


Figure 40 - Hang Time



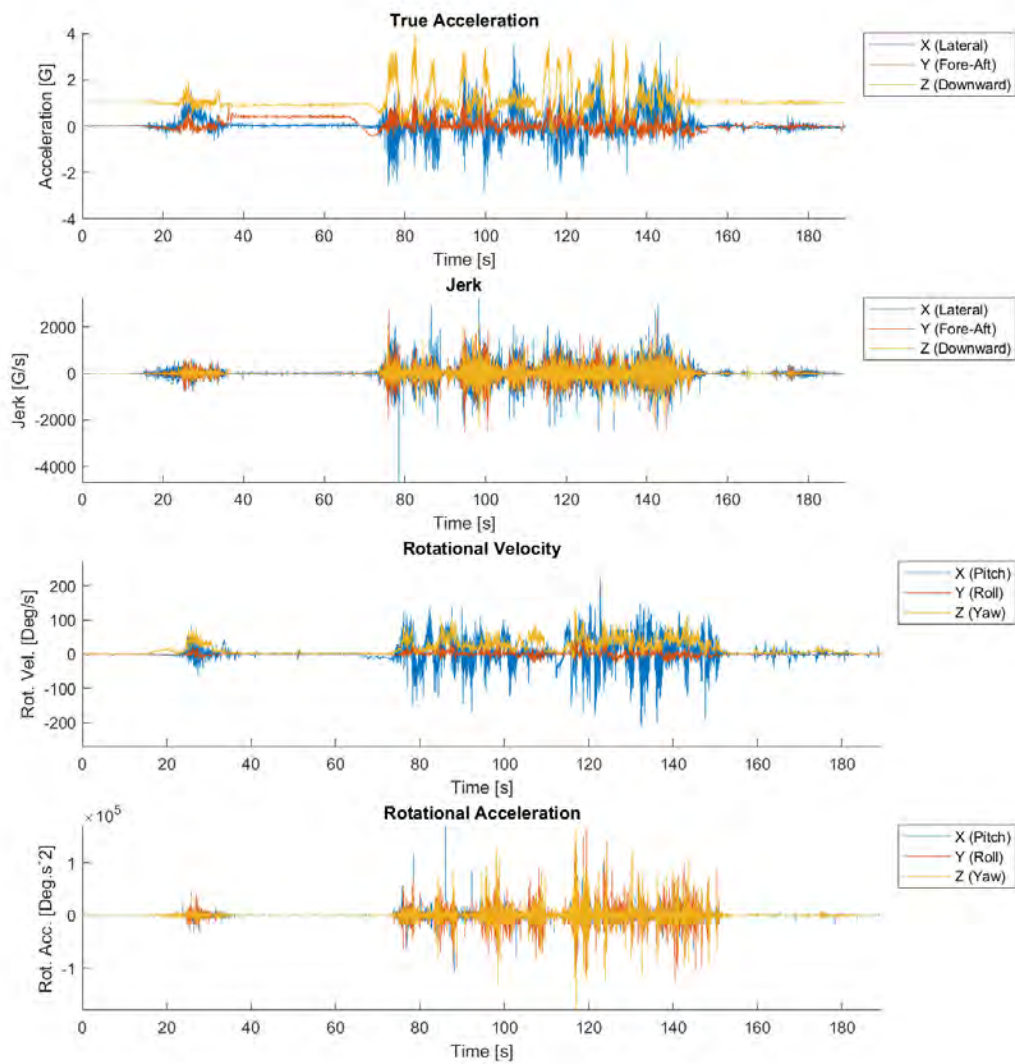


Figure 41 - Ghost Rider (Front)

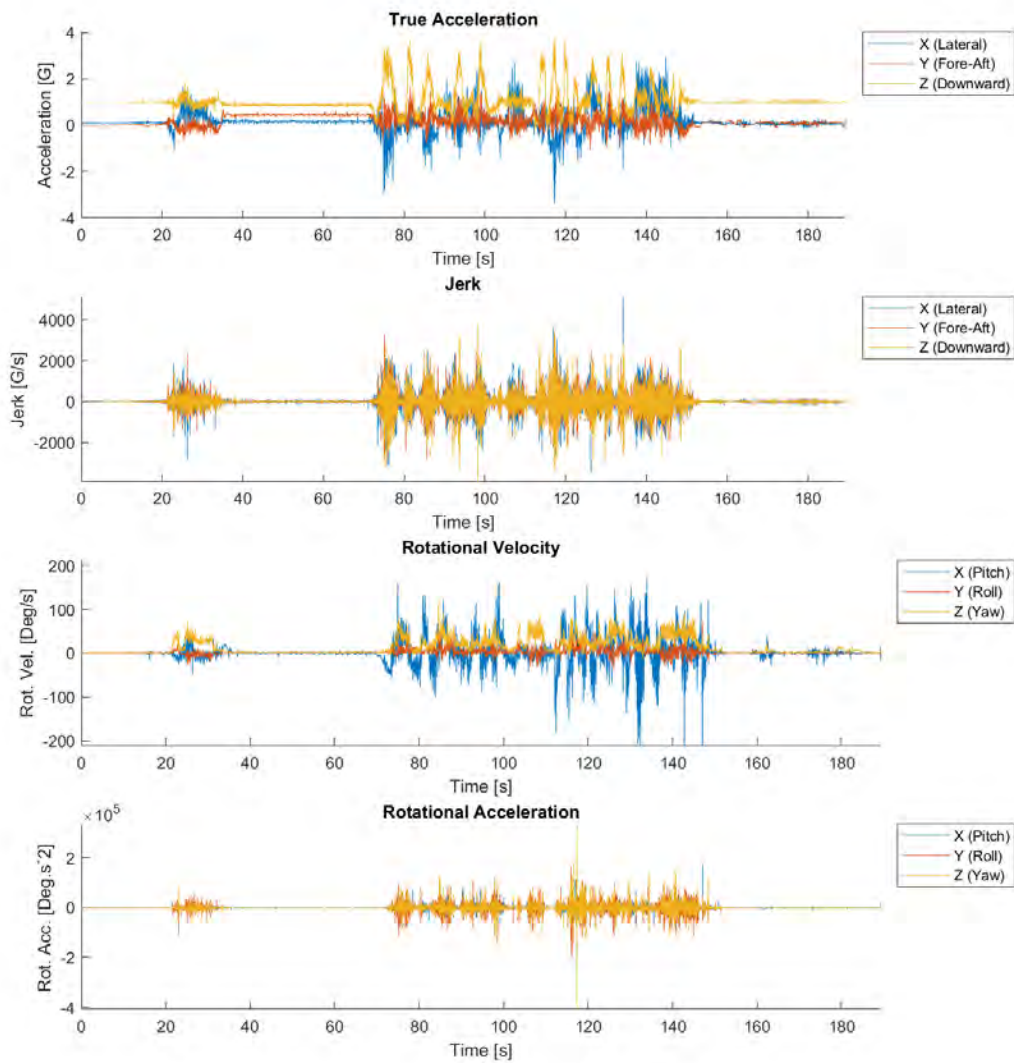


Figure 42 - Ghost Rider (Rear)

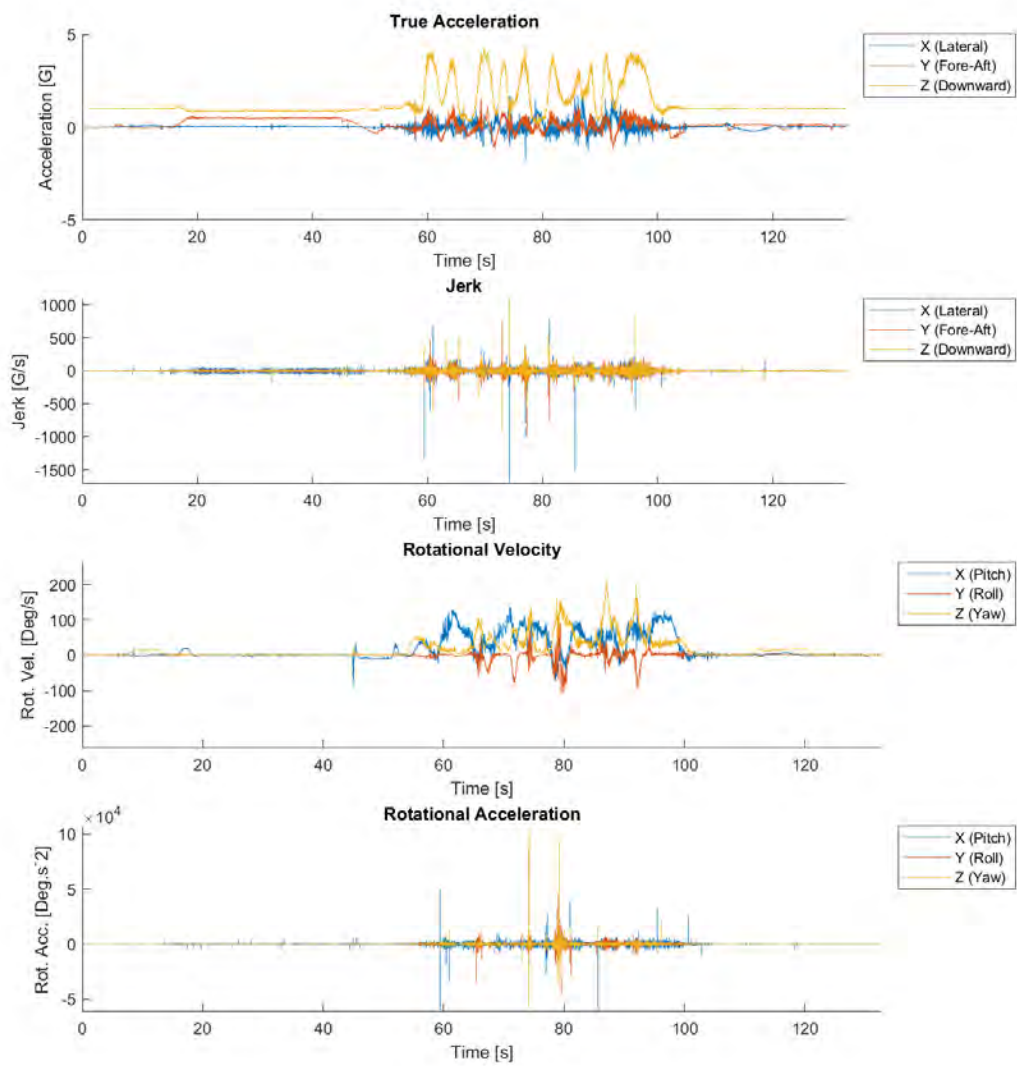


Figure 43 - Silver Bullet



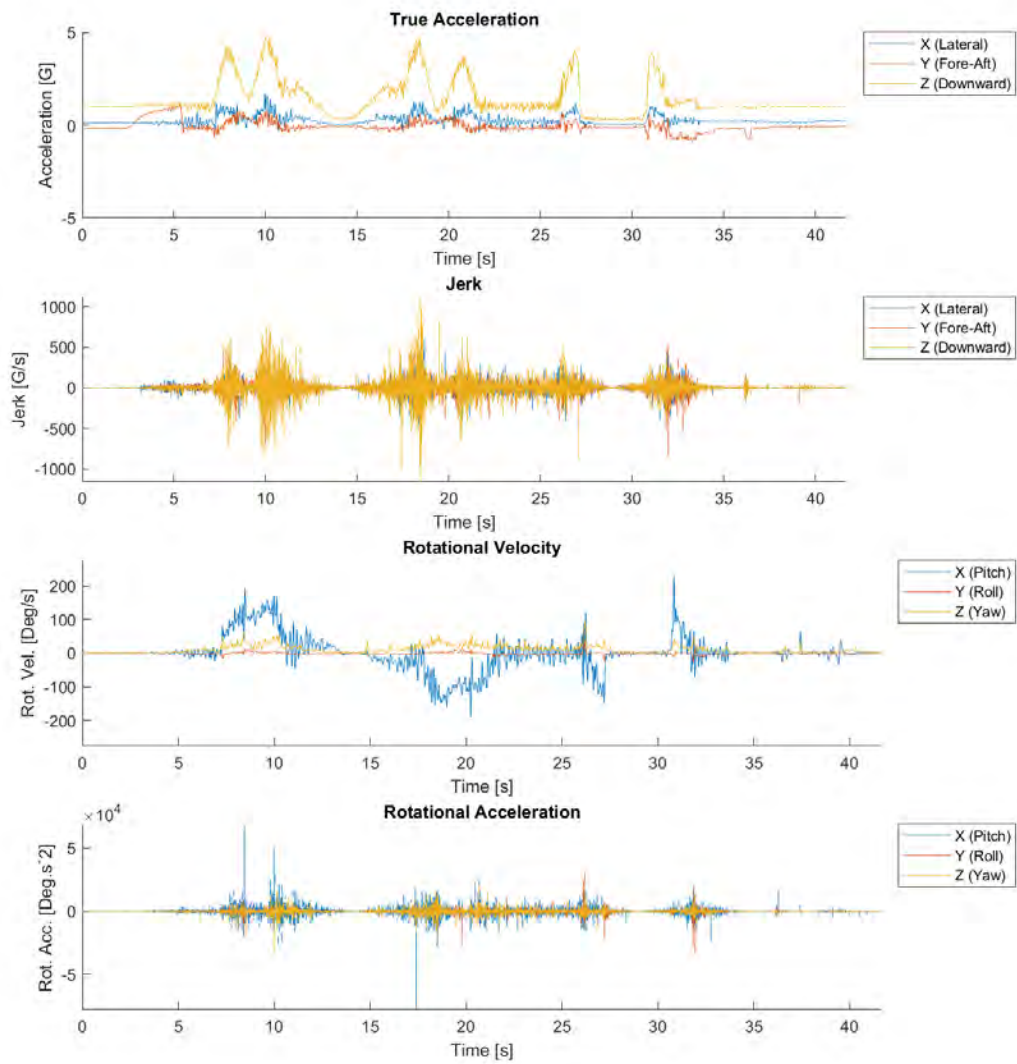


Figure 44 - Montezumas Revenge



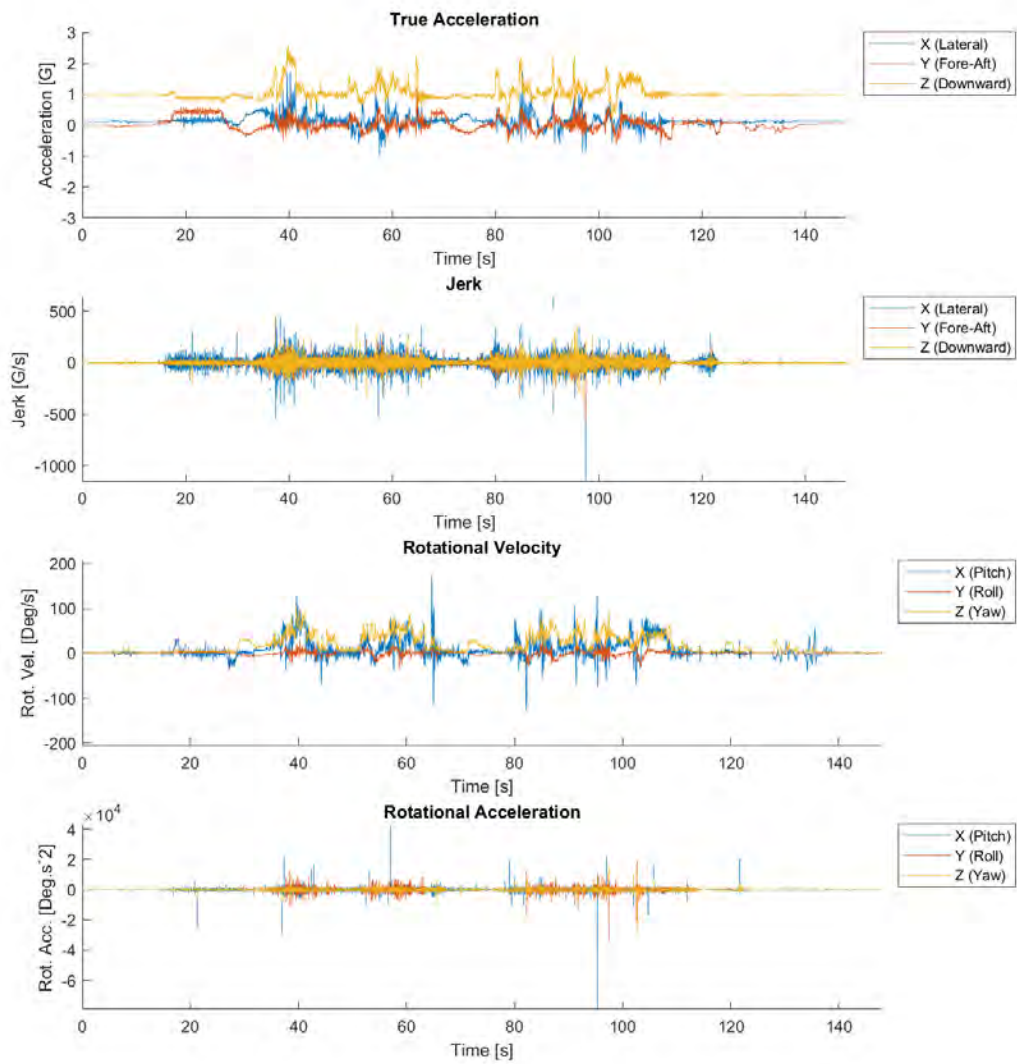


Figure 45 - Jaguar

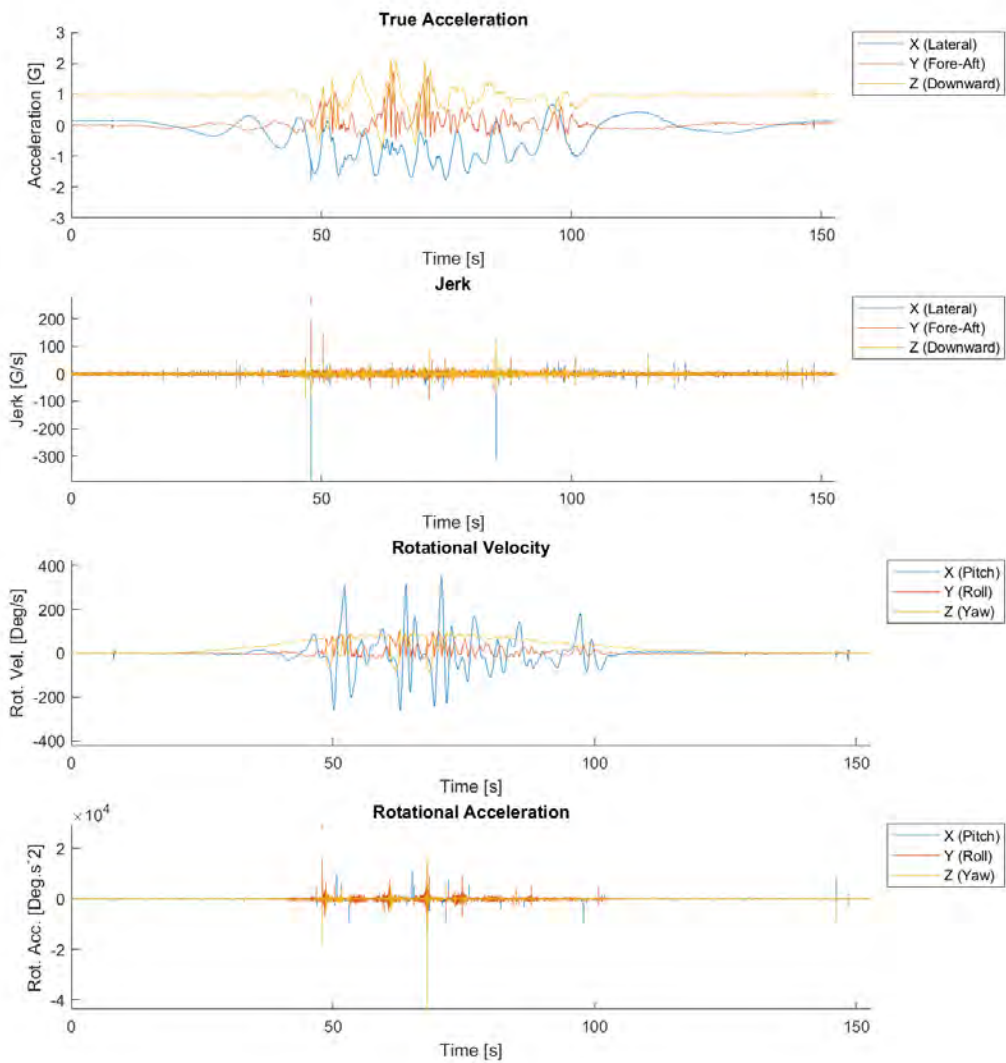


Figure 46 - Sol Scream

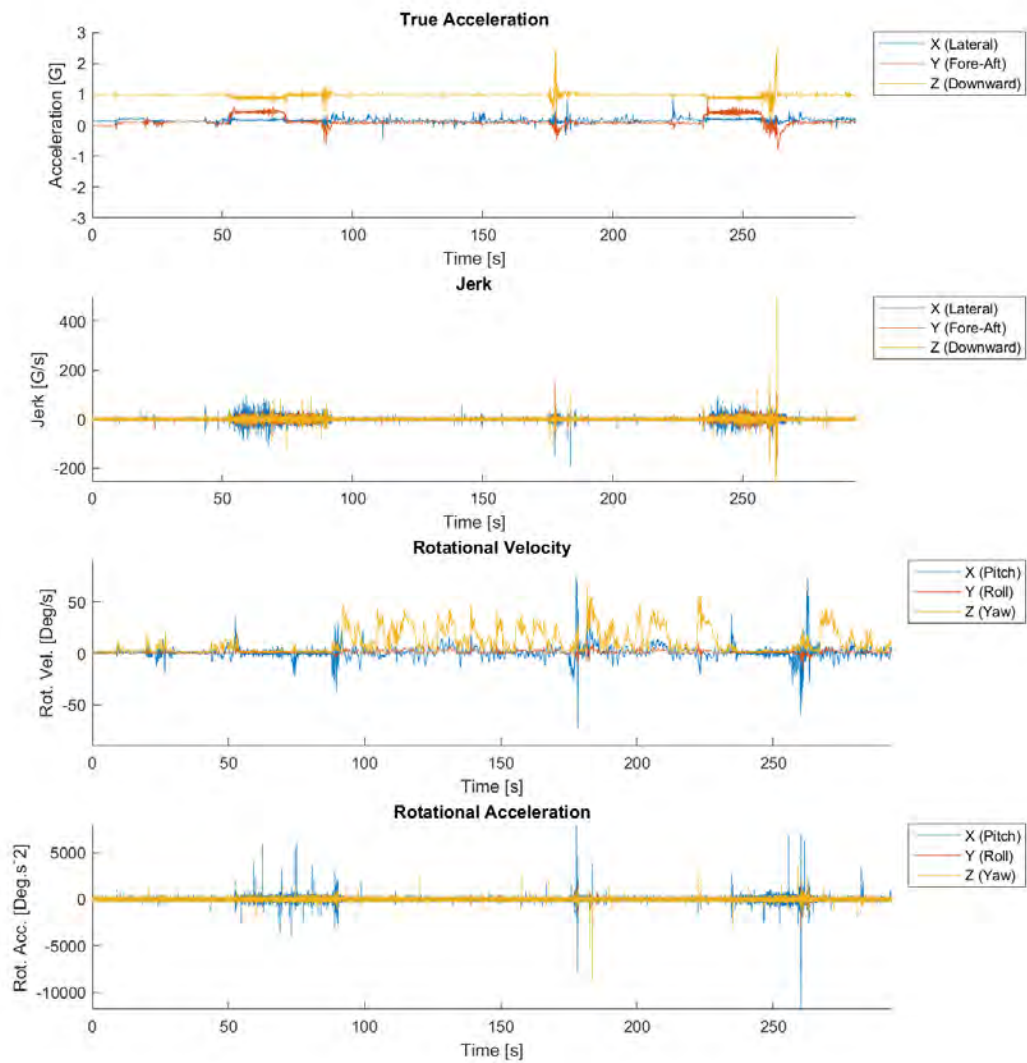


Figure 47 - Log Ride