

## 1. INTRODUCTION

At GMT 2023-11-09, 313/21:11, the International Space Station (ISS) was to begin about a 15.4-minute reboost using the Progress 85P thrusters. Figure 1 shows vehicle layout updated as of 2023-08-26 with the Progress vehicle as it was docked with its thrusters facing aftwards, putting thrust and the necessary orbital mechanics into play so as to speed up the ISS in its direction of flight. Reboost events such as this one are crucial for maintaining the ISS's orbital path. Aerodynamic drag is still a factor (however slight) in low-Earth orbit, slowly decaying the space station's altitude over time. Reboosts exemplify the challenges of orbital mechanics when trying to gain even a slight velocity change for such a massive spacecraft. You see, the way to increase the altitude of, or "reboost", an orbiting spacecraft is to increase its orbital velocity. The ISS weighs in at well over 900,000 pounds (over 400,000 kilograms), and orbits the Earth at a nominal altitude of approximately 420 kilometers with nominal orbital velocity of over 7,000 m/s. Space station maneuvers such as this reboost activity require a meticulously-calculated application of thrust, and showcases the interplay of physics and engineering in controlling spacecraft in low-Earth orbit. The resultant directional acceleration (increase in orbital velocity) for this reboost, resulted in the desired altitude elevation of the space station. Flight controllers on the ground predicted a  $\Delta V$  metric of 1.43 m/s for this reboost.

## 2. QUALIFY

The information shown in Figure 2 on page 3 was calculated from the Space Acceleration Measurement System (SAMS) sensor 121f08 measurements made in the Columbus module from a sensor mounted on in rack COL1A3. This color spectrogram plot shows increased structural vibration excitation contained mostly below 2 Hz or so, and a ~15.3-minute reboost (thruster firing) event was observed as annotated in black. We attribute much of the structural vibration increase to Russian Segment (RS) attitude control from about GMT 20:20 to about 22:06 as marked with white annotations. The RS thrusters are usually used for station attitude control during the time around the reboost activity. This is expected, and typical behavior. The increased structural vibrations are evident as more noticeable horizontal streaks (structural/spectral peaks) that change from quieter (green/yellow) to more energetic (orange/red) sporadically during this period of RS control. The flare up of these nebulous horizontal (spectral peak) streaks are the tell-tale signatures of large space station appendages as they flex, twist, or bend at their natural frequencies in reaction to impulsive attitude control thruster forces. The actual reboost activity itself lasted

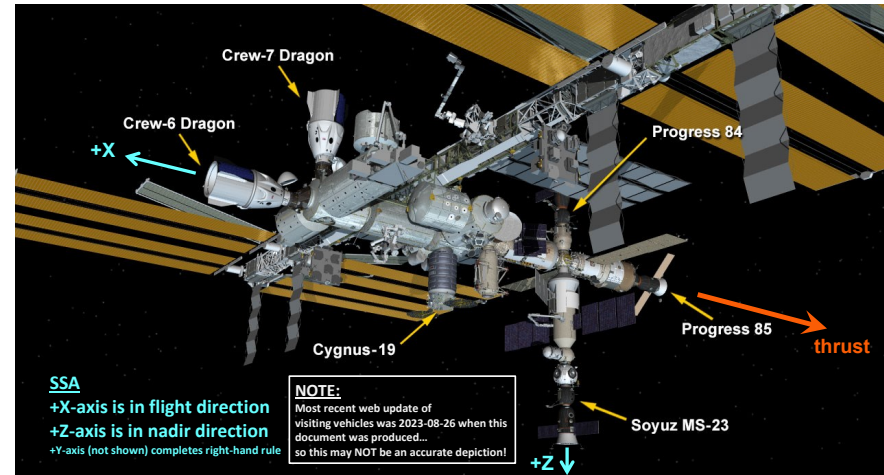


Fig. 1: Progress 85P's Location and Alignment during Reboost.

~15.3 minutes as evidenced by slightly more pronounced, vertical and horizontal orange-red streaks in Figure 2 starting about GMT 21:11:17.

Comparing the same reboost event across all 3 laboratories of the ISS we expect the most energetic vibratory response from the SAMS sensors in the European lab (Columbus module), followed by sensors in the Japanese lab (JEM), and lastly from SAMS sensors in the US lab. This stems from the location of these sensors with respect to structural dynamics of large, massive space station. This analysis focused on the power spectral density of vibratory accelerations below 10 Hz, which provides a measure of the intensity of vibratory motion at the natural frequencies of the larger space station structures (e.g. solar array panels and main truss). At higher frequencies (up to 200 Hz), the SAMS sensors usually diverge greatly in terms of acceleration magnitude and frequency components as higher frequency vibrations tend to be more localized, i.e. "mostly" in/around the rack where the sensor is mounted, and due to equipment operations or crew activity in the vicinity.

For science operations and general situational awareness, it is prudent to be aware that the transient and vibratory environment (primarily below about 10 Hz or so) is impacted not only during the relatively brief reboost event itself, but also during the

relatively longer span of Russian Segment (RS) attitude control too. The difference being that during the reboost itself, the dominant factor might be considered to be the highly-directional step in the X-axis acceleration, while in the much longer case of RS attitude control, the dominant impact was the excitation of lower-frequency vibrational modes of large space station structures.

### 3. QUANTIFY

While the spectrograms in the previous “Qualify” section crudely show acceleration magnitude on a color scale – actually, power spectral density magnitude – we now seek to better quantify the microgravity environment impact of the reboost event across multiple SAMS sensor heads distributed across all 3 main laboratories of the ISS with more intuitive metrics. Figure 3 on page 4 through Figure 9 on page 7 show interval average acceleration results computed from SAMS measurements. Note for each sensor the tell-tale X-axis step that started at GMT 21:11:17 and had a duration of ~15.3 minutes. Information from flight controllers indicated that this reboost event would provide a space station rigid body  $\Delta V$  of 1.43 meters/second and the SAMS analysis indicated with red annotations in these interval average plots closely match the predicted value. SAMS does not directly measure altitude, but flight controllers indicated that the ISS would gain ~2.53 km in altitude above the Earth as a result of this reboost activity.

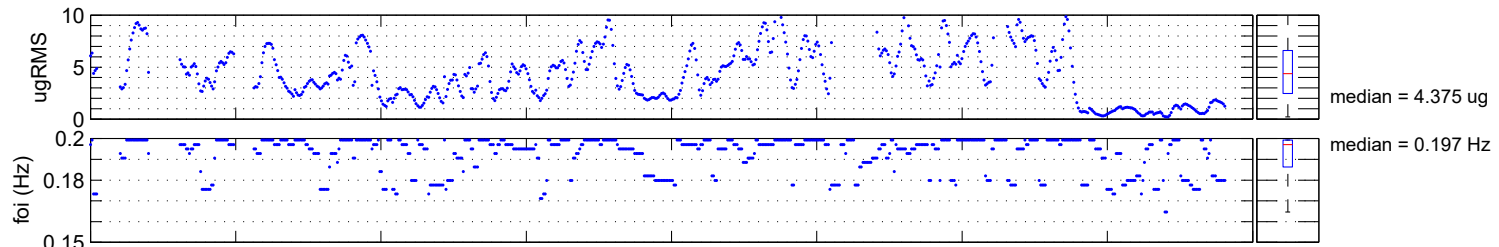
Note that the interval average processing effectively low-pass filtered the data so as to help emphasize the acceleration step that occurs on the X-axis during the reboost event. It should also be noted that we flipped the polarity of each axis (inverted each) in the SAMS plots owing to a polarity inversion issue inherent in SAMS transducers. A somewhat crude quantification of the reboost as measured by these distributed SAMS sensors is also given in Table 1 – expectedly consistent impact results measured by SAMS throughout the space station structure.

### 4. CONCLUSION

The SAMS measurements for multiple sensor heads distributed across all 3 main labs of the ISS was analyzed and showed an **X-axis step during the Progress 85P reboost of just under 0.2 mg**. Furthermore, calculations based on SAMS sensors indicate a  $\Delta V$  metric of just about 1.43 m/s was achieved, while flight controllers predicted a value of 1.43 m/s.

Table 1. **X-axis** steps (mg) during reboost event for multiple SAMS sensors.

Sensor	X-Axis (mg)	Location
121f02	0.158	COL1A1 (ER3)
121f03	0.158	LAB1O1 (ER2)
121f04	0.158	LAB1P2 (ER7)
121f05	0.158	JPM1F1 (ER5)
121f08	0.158	COL1A3 (EPM)
es18	0.160	MSRR (ER6)
es20	0.159	4BCO2 (LAB1P4)



sams2, 121f08 at COL1A3, EPM, near PK-4:[371.17 287.43 165.75]  
500.0000 sa/sec (200.00 Hz)  
 $\Delta f = 0.015$  Hz, Nfft = 32768  
Temp. Res. = 32.768 sec, No = 16384

sams2, 121f08

Start GMT 09–November–2023, 313/16:00:00.001

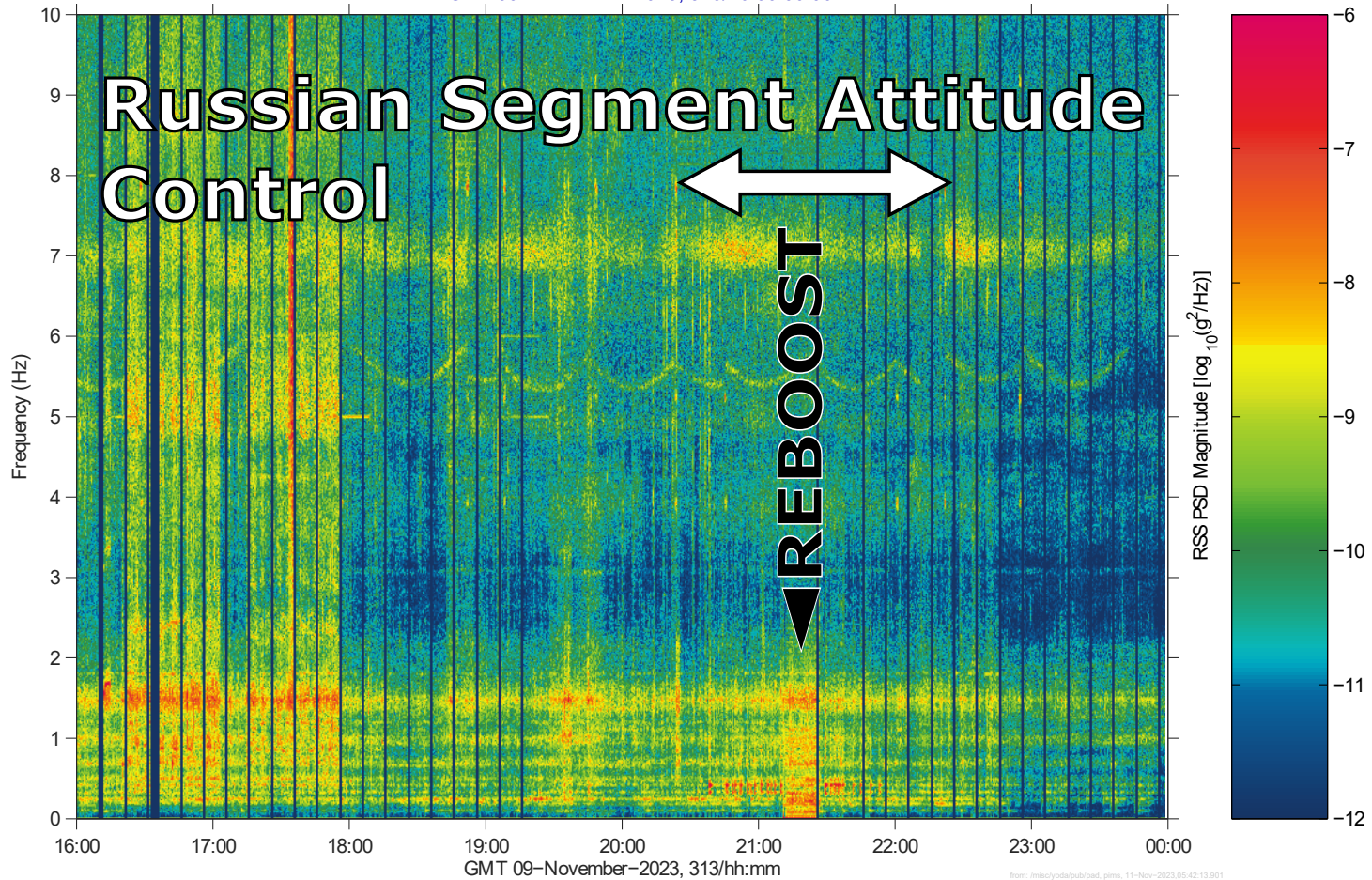


Fig. 2: 10 Hz Spectrogram showing Progress 85P Reboost on GMT 2023-11-09 from a SAMS Sensor in Columbus Module.



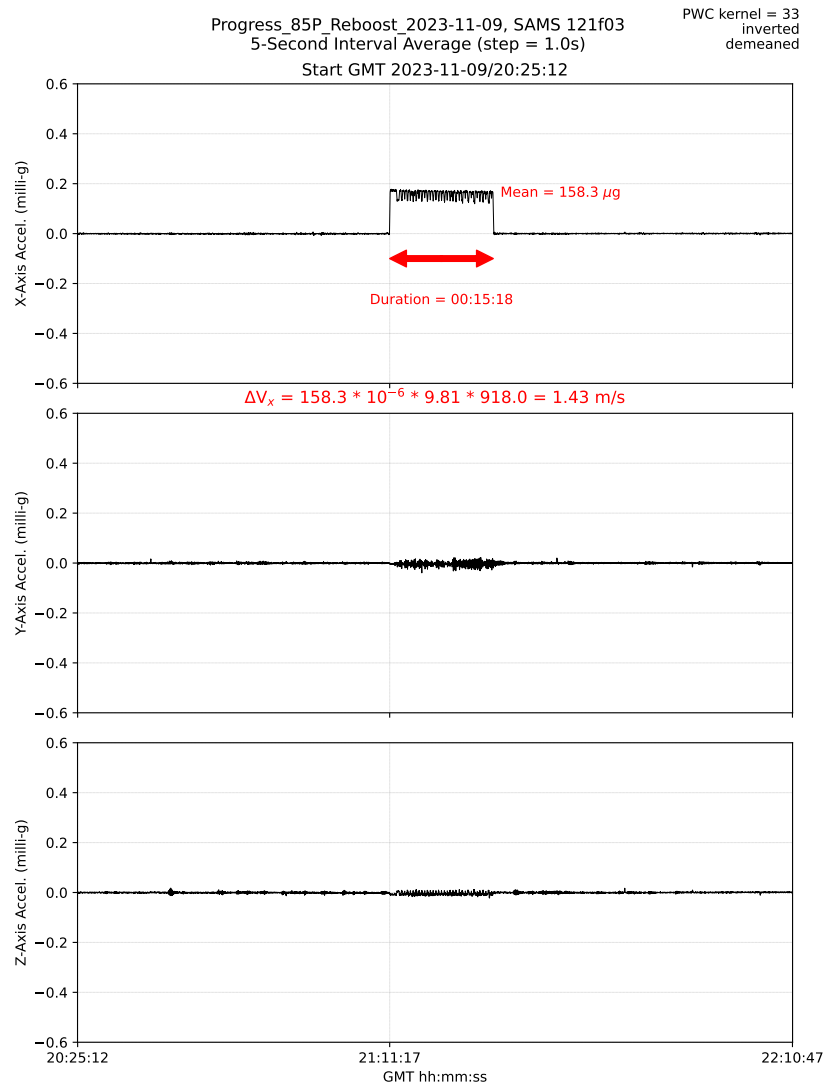


Fig. 3: 5-sec interval average for SAMS 121f03 sensor in the LAB.

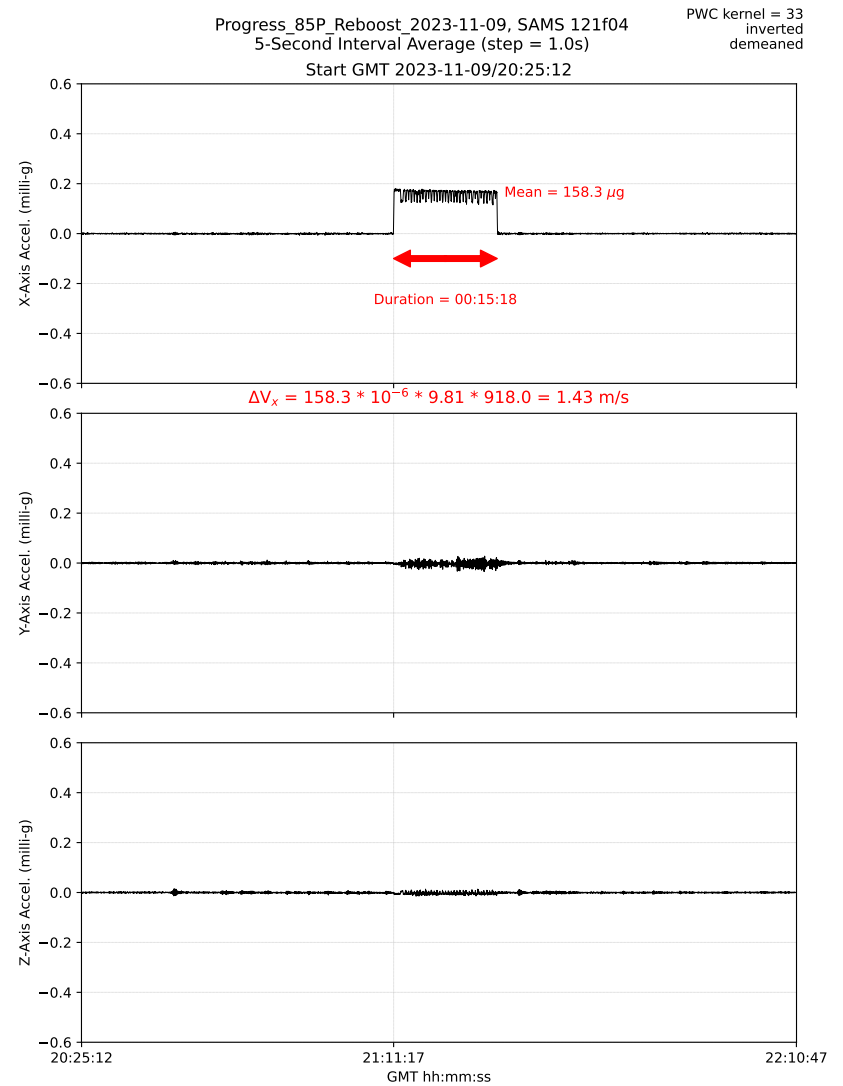


Fig. 4: 5-sec interval average for SAMS 121f04 sensor in the LAB.

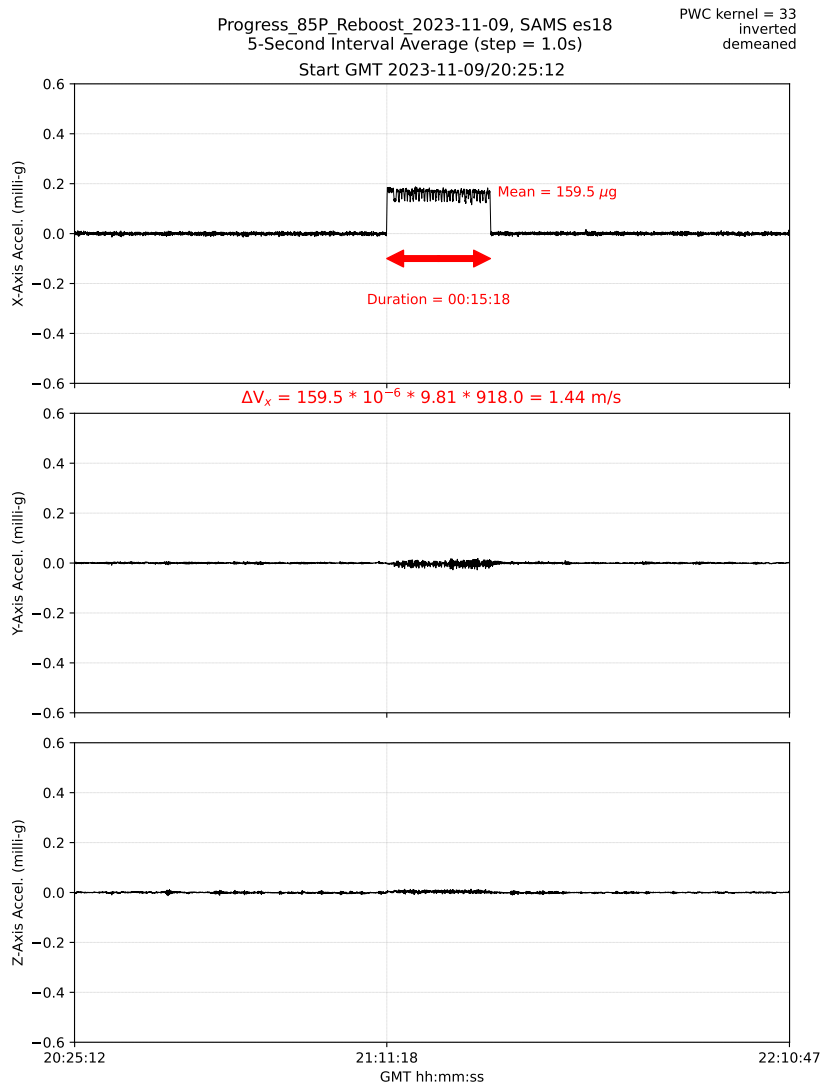


Fig. 5: 5-sec interval average for SAMS es18 sensor in the LAB.

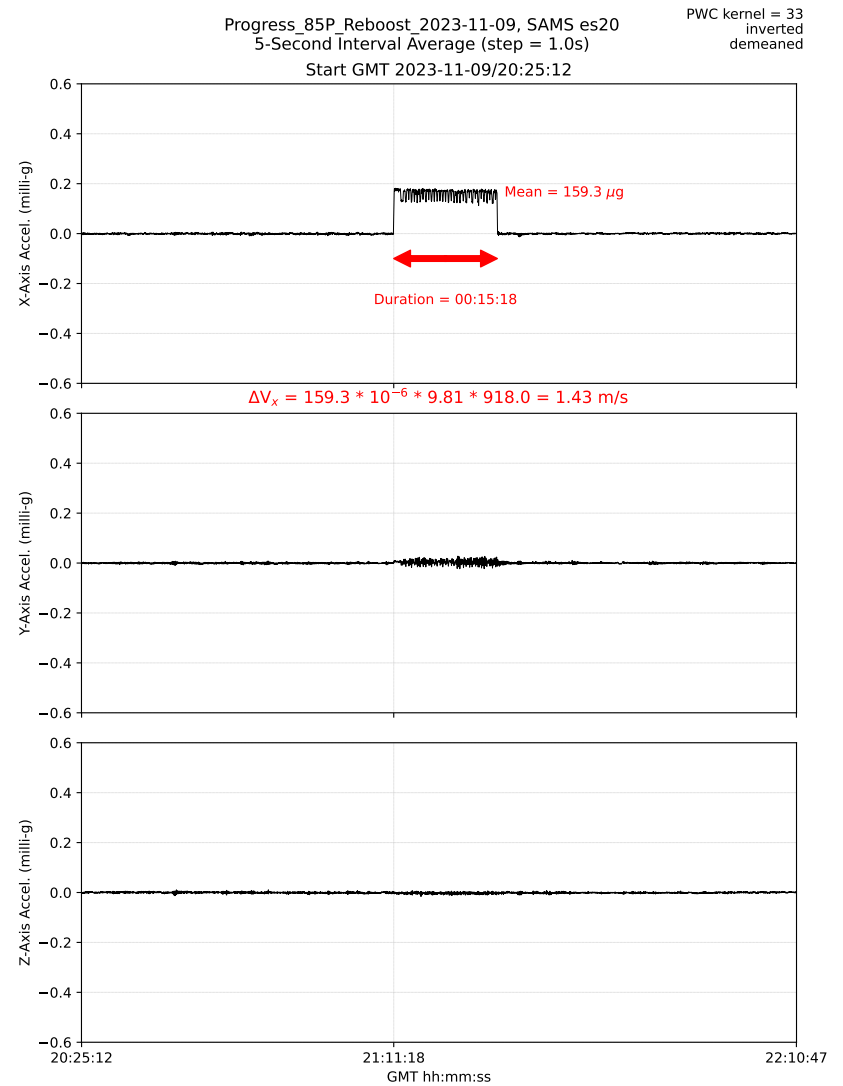


Fig. 6: 5-sec interval average for SAMS es20 sensor in the LAB.

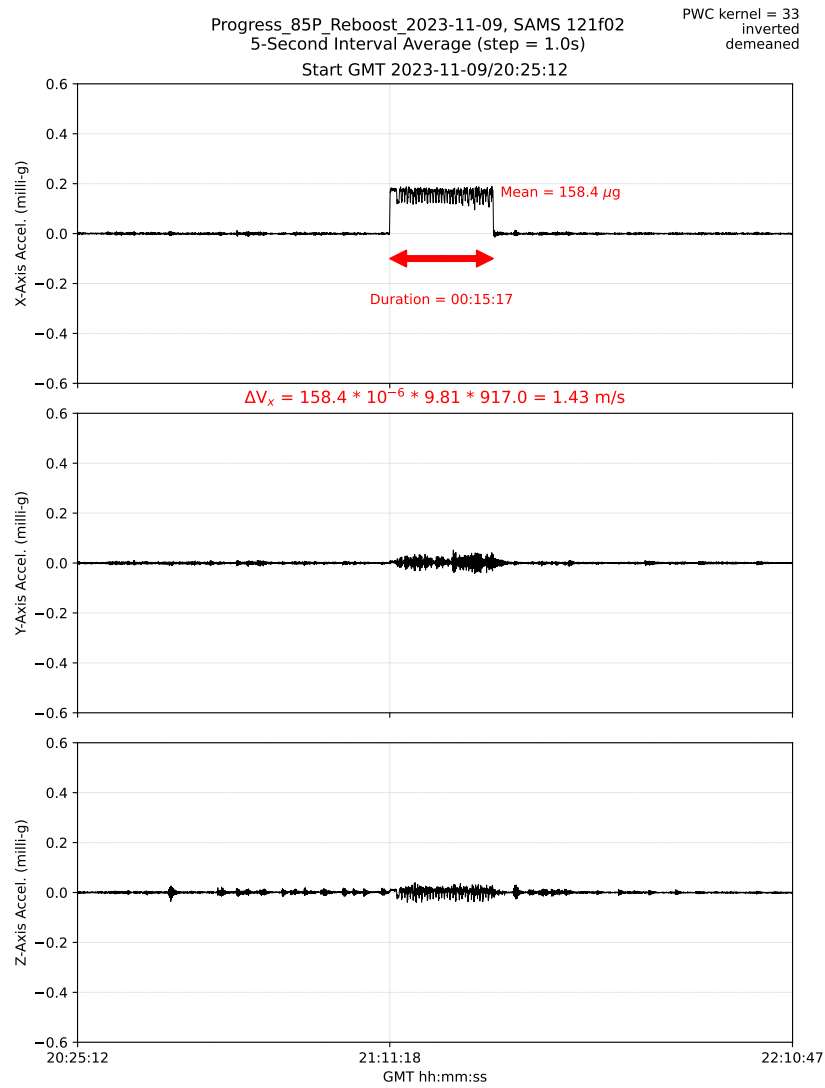


Fig. 7: 5-sec interval average for SAMS 121f02 sensor in the COL.

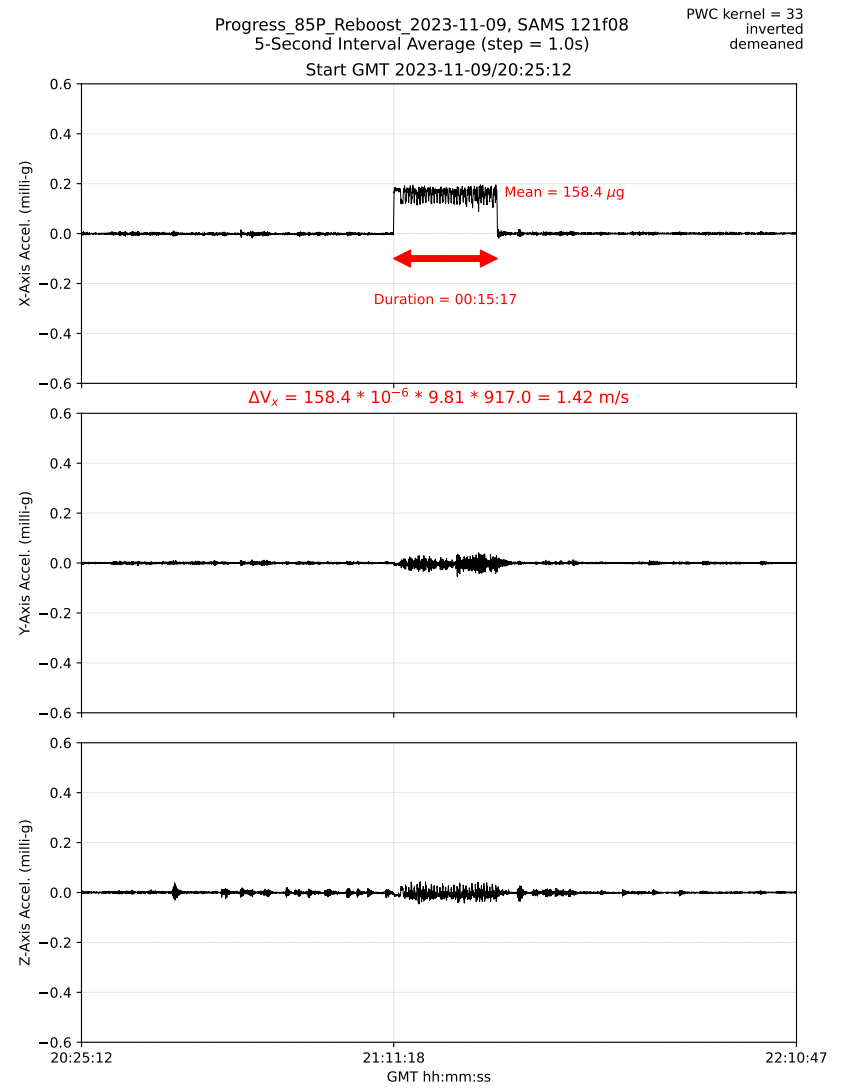


Fig. 8: 5-sec interval average for SAMS 121f08 sensor in the COL.

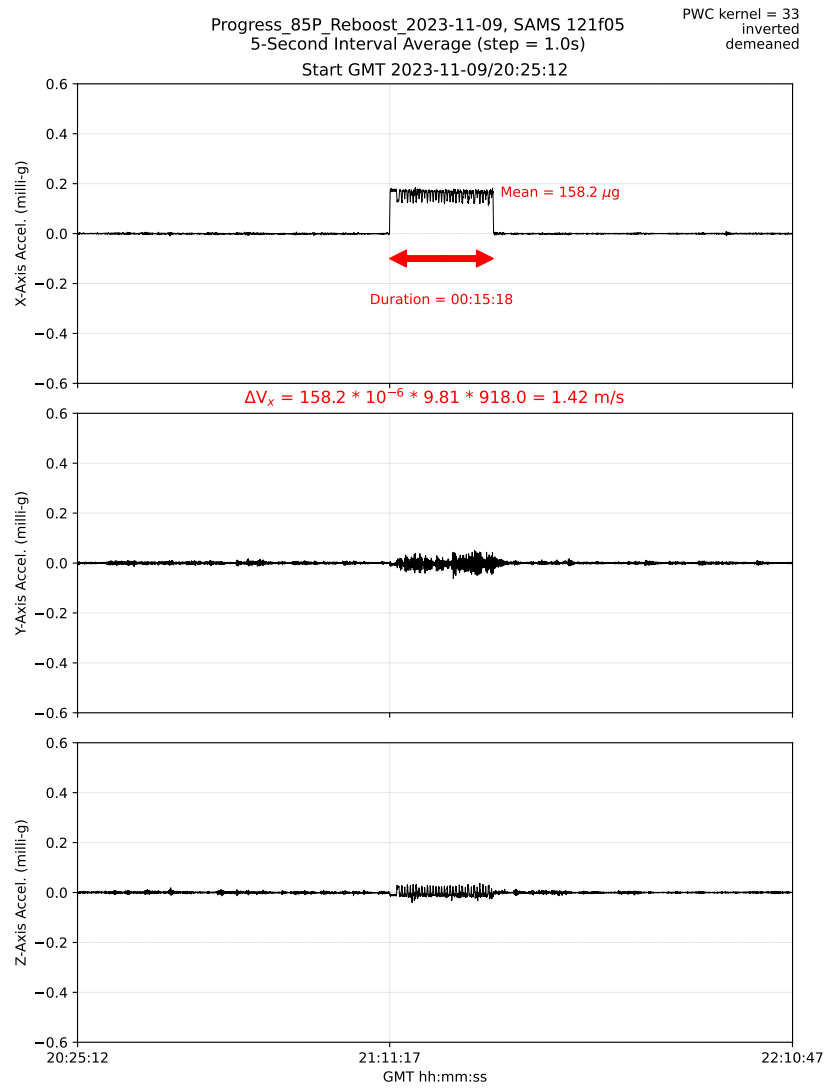


Fig. 9: 5-sec interval average for SAMS 121f05 sensor in the JEM.