1. INTRODUCTION

On GMT 2023-08-11, at just about 233/14:35, the International Space Station (ISS) began about a 23-minute reboost using Northrop Grumman's Cygnus vehicle's (NG-19) Delta Velocity Engine (DVE). It elevated the station's altitude by about 2.36 km with a ΔV metric of about 1.35 meters/second, closely matching the planned value.

Figure 1 shows where the Cygnus vehicle was docked. This docking location and orientation required the space station to first get to the so-called "-ZVV" attitude before firing Cygnus' thrusters. This attitude pointed the Cygnus vehicle's thrust direction opposite to a vector aligned with the velocity vector (flight direction) of the space station. In this way, Newton's 3rd law of action/reaction could be brought into play for the necessary orbital mechanics to speed up the ISS in its direction of flight. See direction notes on page 2.

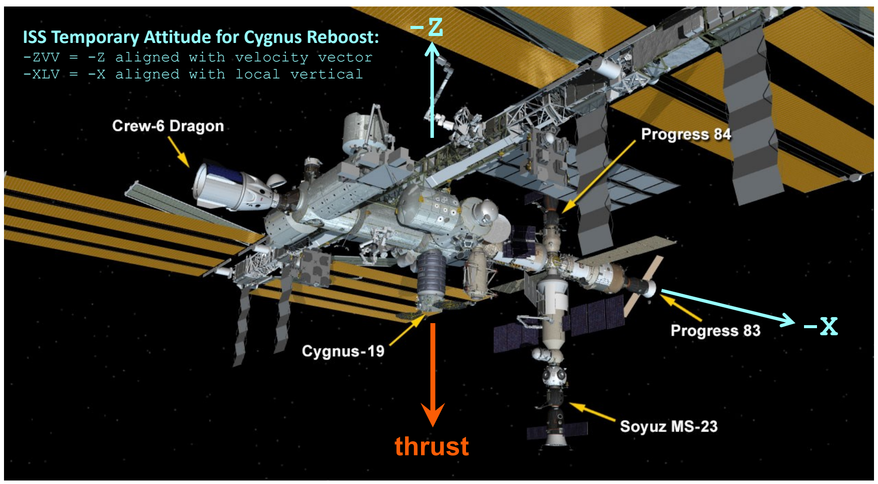

Fig. 1: Cygnus NG-19's Location and Alignment during Reboost.

2. QUALIFY

The information shown in Figure **??** was calculated from the Space Acceleration Measurement System (SAMS) sensor 121f08 measurements made in the Columbus module from a sensor mounting location on the European Physiology Module (EPM) COL1A3 rack. This color spectrogram plot shows increased structural vibration excitation contained mostly below 2 Hz or so, and approximately a 23-minute reboost (thruster firing) event itself that started at about GMT 14:35. We attribute much of the structural vibration increase evident in the span of this spectrogram plot to maneuvers to the "-ZVV attitude" and back to the "-XVV attitude" along with during the reboost itself. 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 throughout these events. 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 in reaction to impulsive thruster forces. 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 just during the actual reboost event itself, but also during maneuvers before and after the event. The difference being that during the reboost itself, the dominant factor is a highly-directional step on an axis aligned with the velocity vector of the space station, while in the much longer case of attitude control or changes, the dominant impact was mostly the excitation of lower-frequency vibrational modes of large space station structures. We see from the as-flown timeline and in the SAMS spectrogram of Figure 2 that there was an maneuver to get to reboost, "-ZVV", attitude from GMT 13:20 to 13:40 and another maneuver back to "-XVV attitude" from GMT 15:16 to 15:46, after the reboost ended. These maneuvers show in the SAMS spectrogram as a regular train of red/yellow, horizontal streaks below 3 Hz for both maneuvers.

For comparison, a similar spectrogram computed from measurements by another SAMS sensor, this time in the US Lab, is shown in Figure 3. This plot shows similar features over the maneuers and reboost time frame, but lower magnitude vibrations, that is, "less red" on the Power Spectral Density color scale.

3. QUANTIFY

The as-flown timeline for this event indicated the reboost started at GMT 14:35. Analysis of Space Acceleration Measurement System (SAMS) data recordings in the Columbus Module and the US LAB – see Figure 4 and Figure 5 on page 5 – shows the tell-tale Z-axis step (in the negative direction) that started at that time, with a step duration of just under 23 minutes or so. The data in this plot are 20-second interval average of the SAMS data (with polarity inverted due to intrinsic polarity flip in SAMS transducers). Interval average processing was used to glean the "reboost step" signal feature from otherwise noisy measurements, and this processing effectively low-pass filtered the data so as to help emphasize the acceleration step that occurred on the Z-axis during the reboost event. In addition, and particularly for the SAMS sensors in the COL and in the JEM (see Figure 6 too), we see the impact of the pre- and post-reboost maneuvers on the low-frequency environment in those modules, ostensibly due to relative distances from from the eigen axis of rotation of those maneuvers.

Information from flight controllers indicated that this reboost event provided a rigid body ΔV of about 1.35 meters/second and the SAMS analysis agreed that this magnitude was achieved – see red annotations in Figure 4 through Figure 6.

A somewhat crude quantification of the reboost as measured by three distributed SAMS sensors is also given in Table 1. As expected, we saw consistent impact measured by SAMS throughout the space station for just under 23 minutes or so via (effectively) low-pass filtered results.

Table 1. **Z-axis** steps (mg) during reboost event for 3 SAMS sensors.

Sensor	Z-Axis	Location
121f03	-0.100	LAB1O1 (ER-2)
121f05	-0.100	JPM1F1 (ER-5)
121f08	-0.100	COL1A3 (EPM)

Off-The-Cuff Observation

Historically, a Russian Progress cargo vehicle docked on the after end of the ISS with its thrusters already pointing aftward in its docked position, required neither pre- nor post-maneuvers to adjust attitudes surrounding a reboost. With Cygnus (NG-19) vehicle docked as shown in this document, we need those maneuvers to properly put orbital mechanics and Newton's 3rd law into play. Furthermore, the Cygnus DVE produced an acceleration step magnitude about half that the Progress vehicle did, and therefore to achieve about the same ΔV metric, it had to be fired for about twice the duration.

4. CONCLUSION

The SAMS measurements for 3 sensor heads distributed across all 3 main labs of the ISS were analyzed and showed a **-Z-axis step magnitude of about 0.1 mg during the reboost**. Furthermore, calculations based on SAMS sensor (121f03) mounted on EXPRESS Rack 2 (LAB1O1) in the US LAB indicate **a ΔV metric of about 1.35 meters/second was achieved**, and this derived result closely matched what the flight controllers' were expecting.

NOTES ON DIRECTION

SAMS sensors (and data alignment) are fixed to the ISS, so when the space station changes attitude/orientation, so too does the Space Station Analysis (SSA), *fixed body*, coordinate system used by the SAMS. Therefore, a typical Progress reboost with a positive X-axis step in a nominal attitude for the ISS is now a negative Z-axis step given the location of the Cygnus and the required attitude adjustments.

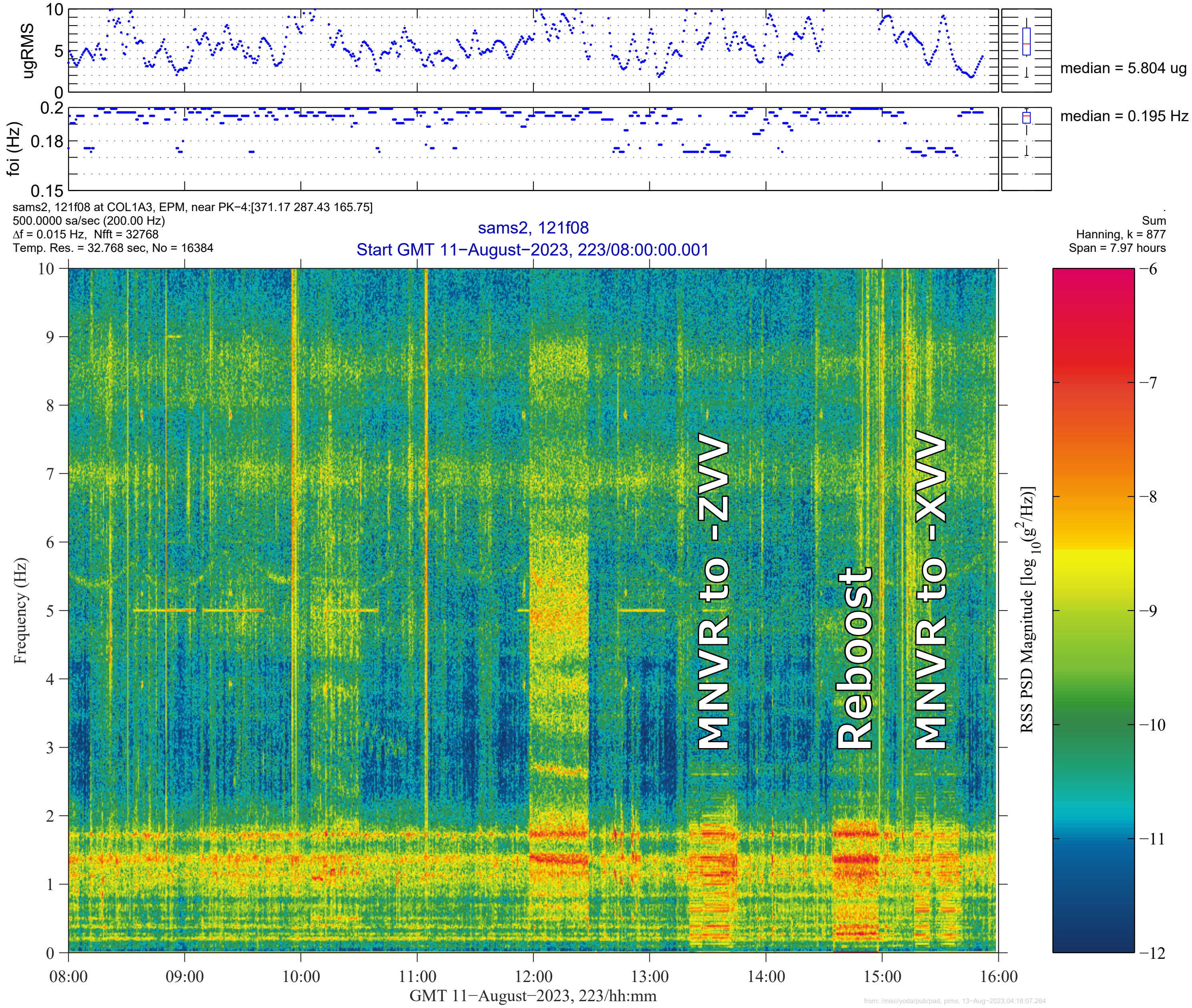

Fig. 2: 10 Hz Spectrogram showing Cygnus Reboost from a SAMS Sensor in the Columbus Module.

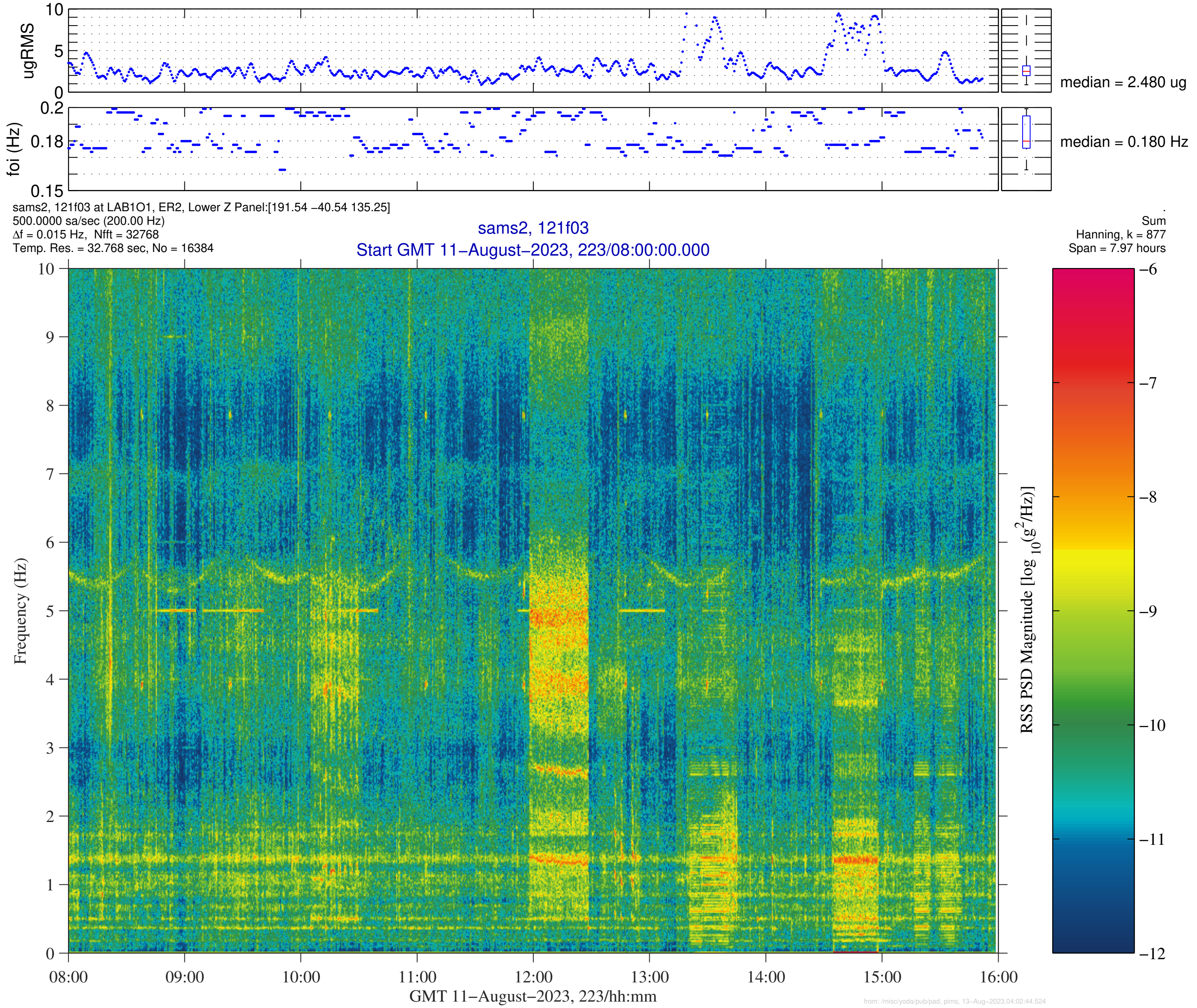

Fig. 3: 10 Hz Spectrogram showing Cygnus Reboost from a SAMS Sensor in the US Lab.

-ZVV Cygnus NG-19 Reboost on GMT 2023-08-11

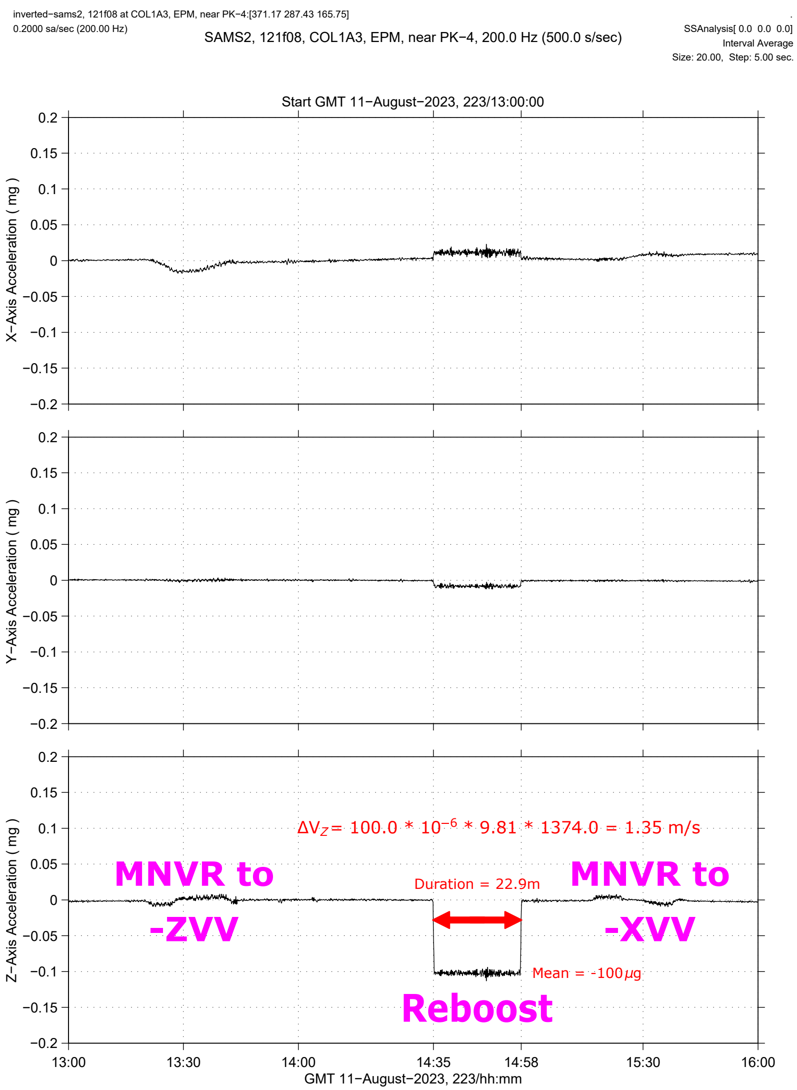

Fig. 4: 20-sec interval average for SAMS 121f08 sensor in the COL.

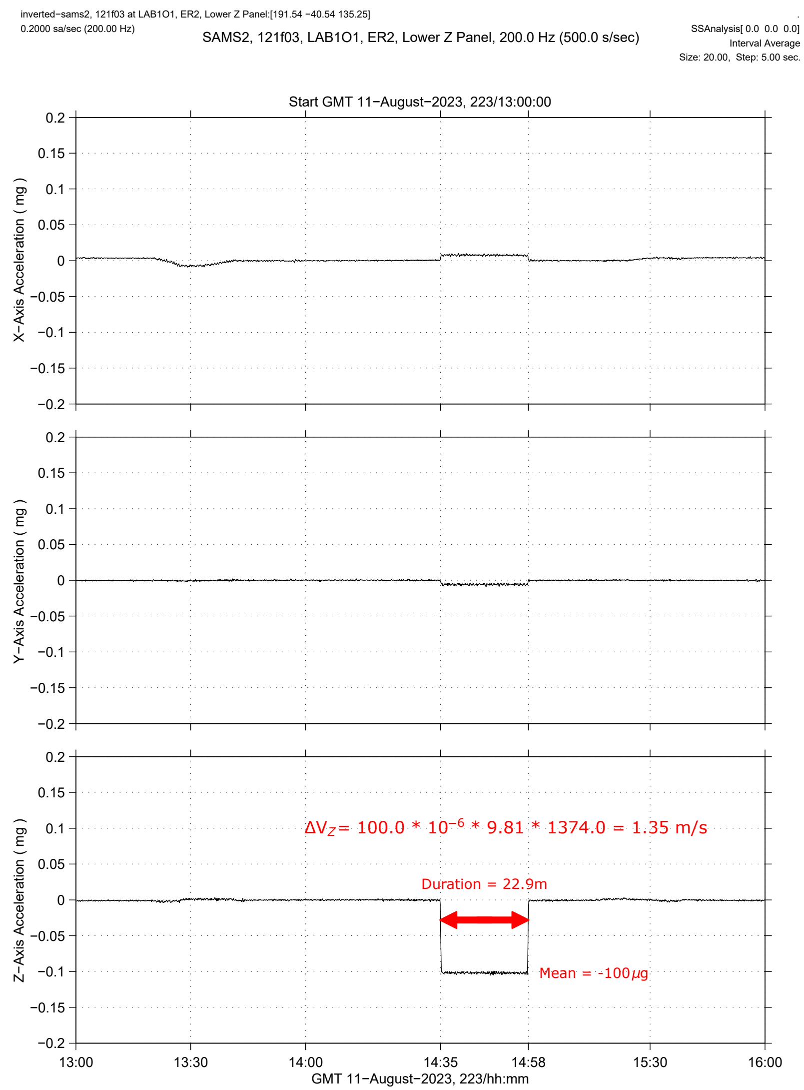

Fig. 5: 20-sec interval average for SAMS 121f03 sensor in the LAB.

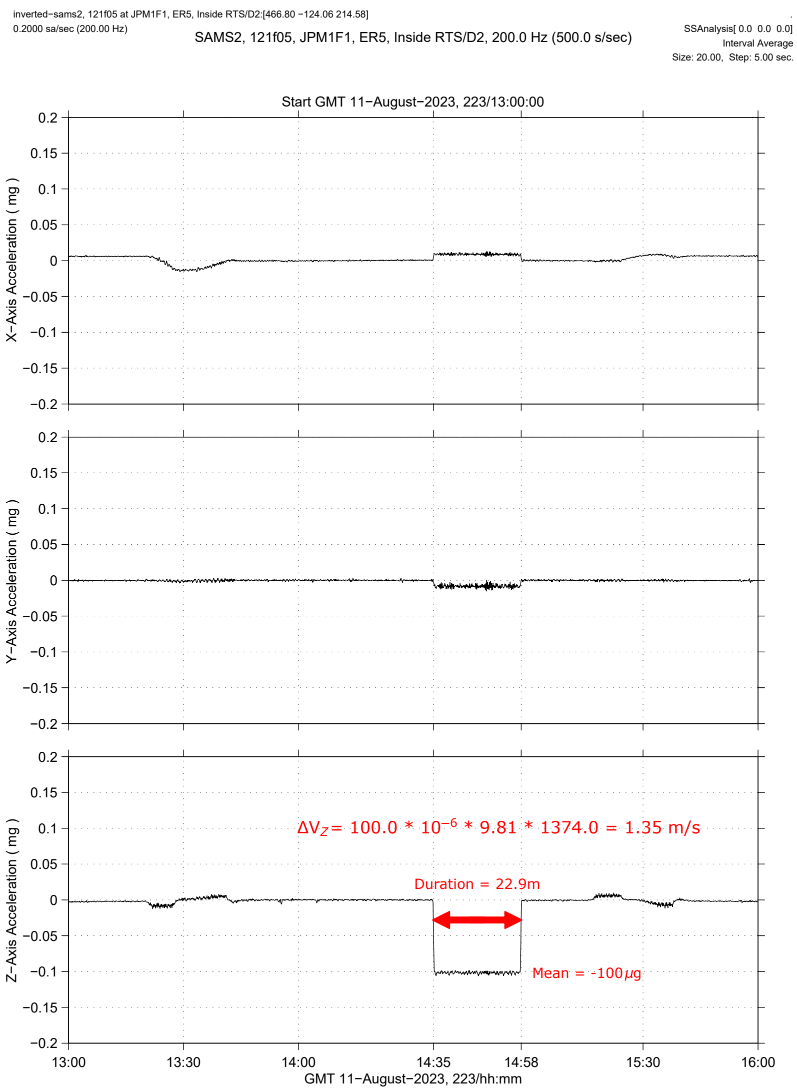

Fig. 6: 20-sec interval average for SAMS 121f05 sensor in the JEM.