1. INTRODUCTION

The International Space Station (ISS) performed two reboosts on Thursday, August 15th (GMT 227) 2019 using the Progress 73P Mid-Ring thrusters. The Progress 73P was docked to DC1-Nadir at the time, and had to be used since a Soyuz crew vehicle was docked to the Service Module aft at the time. Since the reboost delta-V required was greater than what could be achieved with a single burn using the Mid-Ring thrusters (due to maximum continuous burn thruster on-time limits), the delta-V was split across two reboosts on the same day, about three hours apart, which is about two orbital periods apart. This pair of reboosts was targeting the conditions for Soyuz 60S 34-orbit rendezvous on August 22nd (GMT 234) and the Soyuz 60S landing on September 6th (GMT 249).

The visiting vehicles graphic of Figure 1 shows the location and alignment of the Progress 73P used for this reboost. To some, it might be obvious that an attitude change was needed in advance to align the Progress thrust vector in a direction counter to the direction of flight. This would help to bring Newton's 3rd law of action/reaction to bear. It is only with an increase in velocity in the forward/flight direction that could properly put orbital mechanics into play to increase the altitude of the space station. During the two reboosts in total, the ISS climbed about 2 km in altitude.

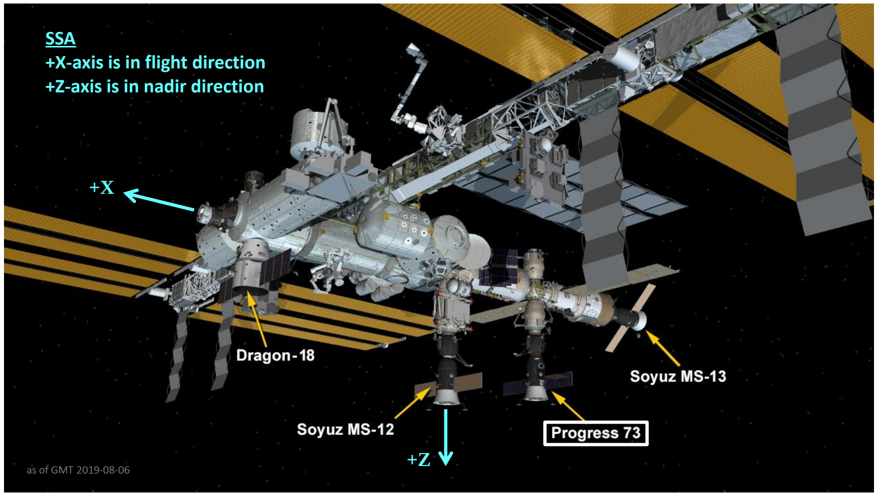

Fig. 1: Service Module's location and alignment during reboost.

2. QUALIFY REBOOST #1 OF 2

The information shown in Figure 2 was computed from Space Acceleration Measurement System (SAMS) sensor 121f05 measurements made in the Japanese Experiment Module (JEM). This plot shows increased structural vibration excitation, especially around or shortly before GMT 227/06:00. Actually, these higher vibration levels started with handover to the Russian Segment (RS) for attitude control prior to this first of two reboosts as noted in Figure 2. RS control took place for a span before, during and some time after the two reboosts took place. The increased structural vibrations are evident as more noticeable horizontal streaks (structural/spectral peaks) that change from quieter (greenish) to more energetic (yellow/orange/red) sporadically during this period of RS control. For science operations and general situational awareness, it is good to be aware that the transient and vibratory environment (primarily below about 10 Hz or so) is impacted not only during the relatively short reboost events themselves, but also during the longer span of RS attitude control as displayed here. Note also the speculative "SARJs Locked" annotation in the very quiet (dark blue) region on the spectrogram. This was speculated to be a period when they locked the Solar Array Rotary Joints (SARJs) before the ISS was maneuvered to reboost attitude.

The bottom Z-axis subplot in Figure 3 on page 3 shows a magenta-colored annotation around a small, negative Z-axis step that also occurred during reboost. It was apparent that the somewhat peculiar mid-ring thruster reboost in combination with the placement and alignment of the Progress 73P vehicle that this was not going to be the most efficient reboost. This inefficiency owes to the fact that alignment of the thrust vector could not be made 100% coincident with the flight direction, and we note this was an atypical situation.

3. QUANTIFY REBOOST #1 OF 2

The as-flown timeline for this first of two reboosts indicated that the reboost would start at GMT 05:53:00 and have a burn duration of about 9 minutes and 45 seconds. Analysis of SAMS data recordings made during the reboost shows the tell-tale X-axis step that nearly matches the start time and the duration as seen on the X-axis subplot in Figure 3, albeit the duration was a bit shorter than predicted.

Four more plots of 20-second interval average acceleration versus time for SAMS sensors distributed throughout the ISS are shown starting with Figure 6 on page 5.

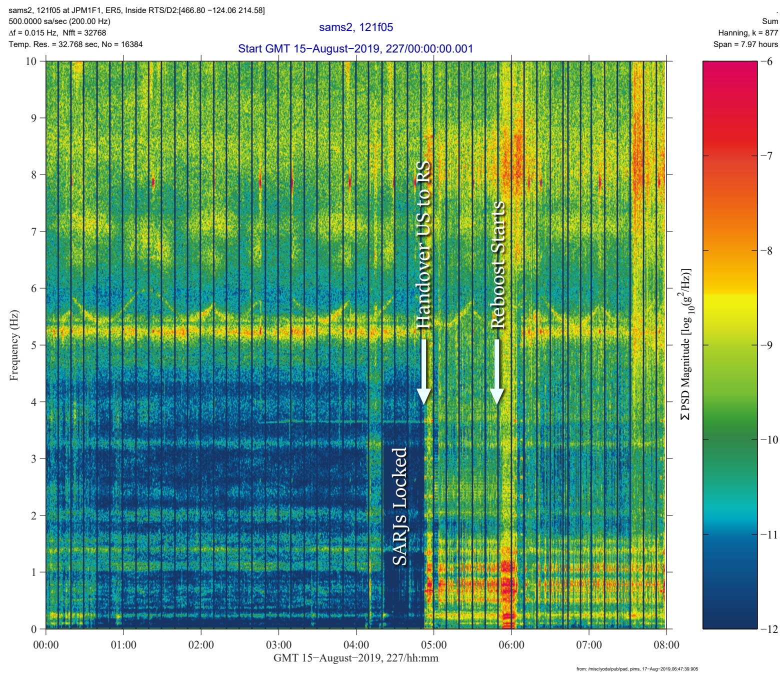

Fig. 2: Spectrogram showing 1st Reboost Event on GMT 2019-08-15.

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 (inverted) each axis in the SAMS plots owing to a polarity inversion issue inherent in SAMS. A somewhat crude quantification of the reboost as measured by the SAMS sensors is given in Table 1.

4. Qualify Reboost #2 of 2

The information shown in Figure 4 on page 4 was computed from SAMS sensor 121f05 measurements made in the JEM. This plot shows increased structural vibration excitation, especially around or shortly before GMT 227/09:00. These

Table 1. X-axis step values during reboost #1 of 2 for 5 SAMS sensors.

Sensor	X-Axis Step (mg)	Location
121f02	0.102	JPM1A6 (RMS Console)
121f03	0.102	LAB1O1 (ER2)
121f04	0.101	LAB1P2 (ER7)
121f05	0.102	JPM1F1 (ER5)
121f08	0.101	COL1A3 (EPM)

higher vibration levels started with handover to the Russian Segment (RS) for attitude control prior to the first of these two reboosts. The increased structural vibrations are evident as more noticeable horizontal streaks (structural/spectral peaks) that change from quieter (greenish) to more energetic (yellow/orange/red) sporadically during this period of RS control.

Again, the bottom Z-axis subplot in Figure 5 on page 4 shows a magenta-colored annotation around a small, negative Z-axis step that also occurred during reboost.

5. Quantify Reboost #2 of 2

The as-flown timeline for this second of two reboosts indicated that the reboost would start at GMT 08:55:00 and have a burn duration of about 9 minutes and 45 seconds. Analysis of SAMS data recordings made during the reboost shows the tell-tale X-axis step that matches the start time and nearly the duration as seen on the X-axis subplot in Figure 5.

Four more plots of 20-second interval average acceleration versus time for SAMS sensors distributed throughout the ISS are shown starting with Figure 10 on page 7. A somewhat crude quantification of the reboost as measured by the SAMS sensors is given in Table 2.

6. Conclusion

While SAMS sensors were designed to characterize the vibratory environment of the ISS, and not so much the quasi-steady environment, they perform well for capturing the relatively large X-axis step induced by reboost events. Despite the underlying low-frequency & low-magnitude baseline being obscured by transducer bias/offset, SAMS sensors easily detect the gross acceleration step of reboost as

Table 2. X-axis step values during reboost #2 of 2 for 5 SAMS sensors.

Sensor	**X-Axis Step (mg)**	**Location**
121f02	0.097	JPM1A6 (RMS Console)
121f03	0.098	LAB1O1 (ER2)
121f04	0.099	LAB1P2 (ER7)
121f05	0.098	JPM1F1 (ER5)
121f08	0.098	COL1A3 (EPM)

demonstrated here. The SAMS sensor data analyzed showed an X-axis step during each of the two reboosts of about 100 µg. Furthermore, calculations based on SAMS sensor (121f03) mounted on EXPRESS Rack 2 in the US LAB indicate a ΔV of about 0.56 meters/second for the first reboost, and about 0.57 meters/second was achieved for the second, and these metrics nearly matched flight controllers' pre-planned values.

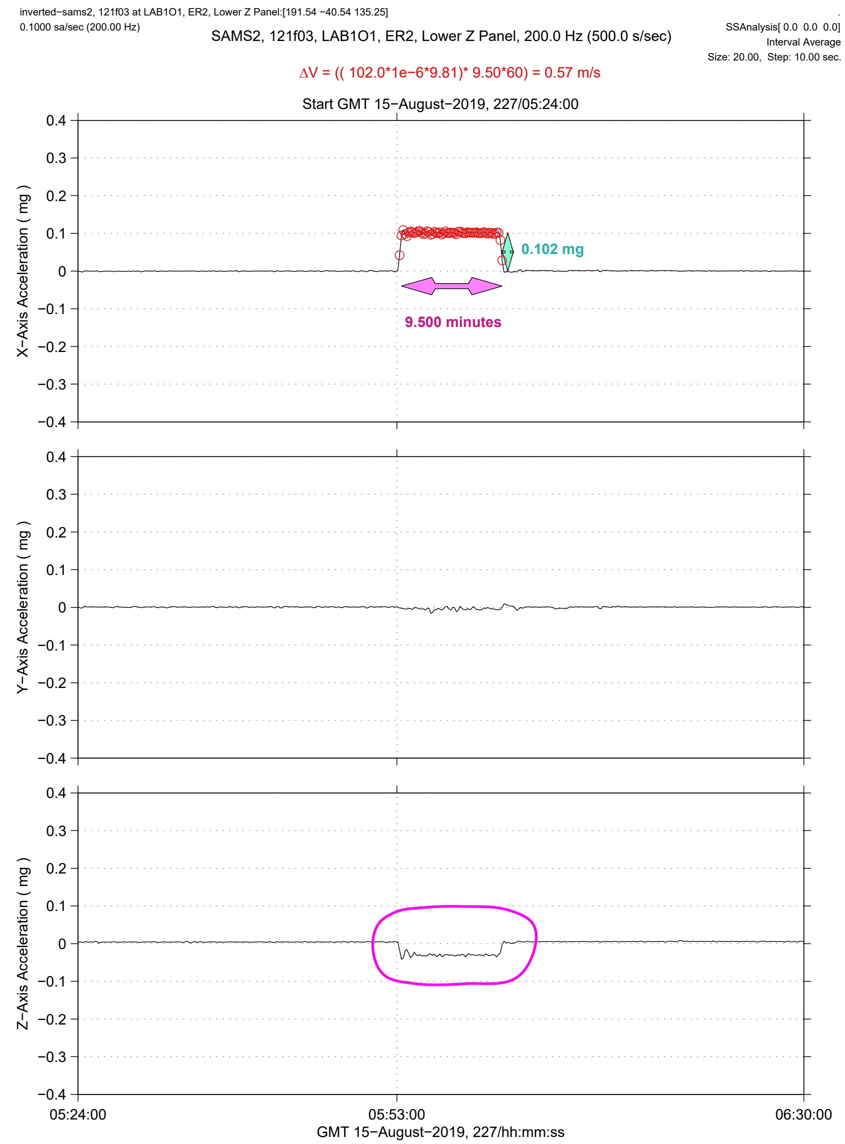

Fig. 3: Interval average of SAMS 121f03 sensor data shows reboost #1 of 2.

Progress 73P Double Reboost on GMT 2019-08-15

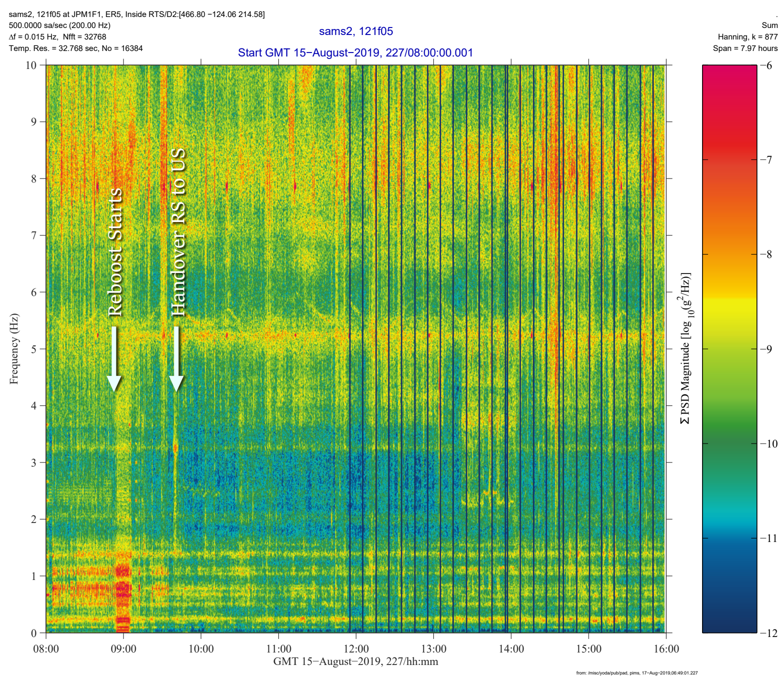

Fig. 4: Spectrogram showing 2nd Reboost Event on GMT 2019-08-15.

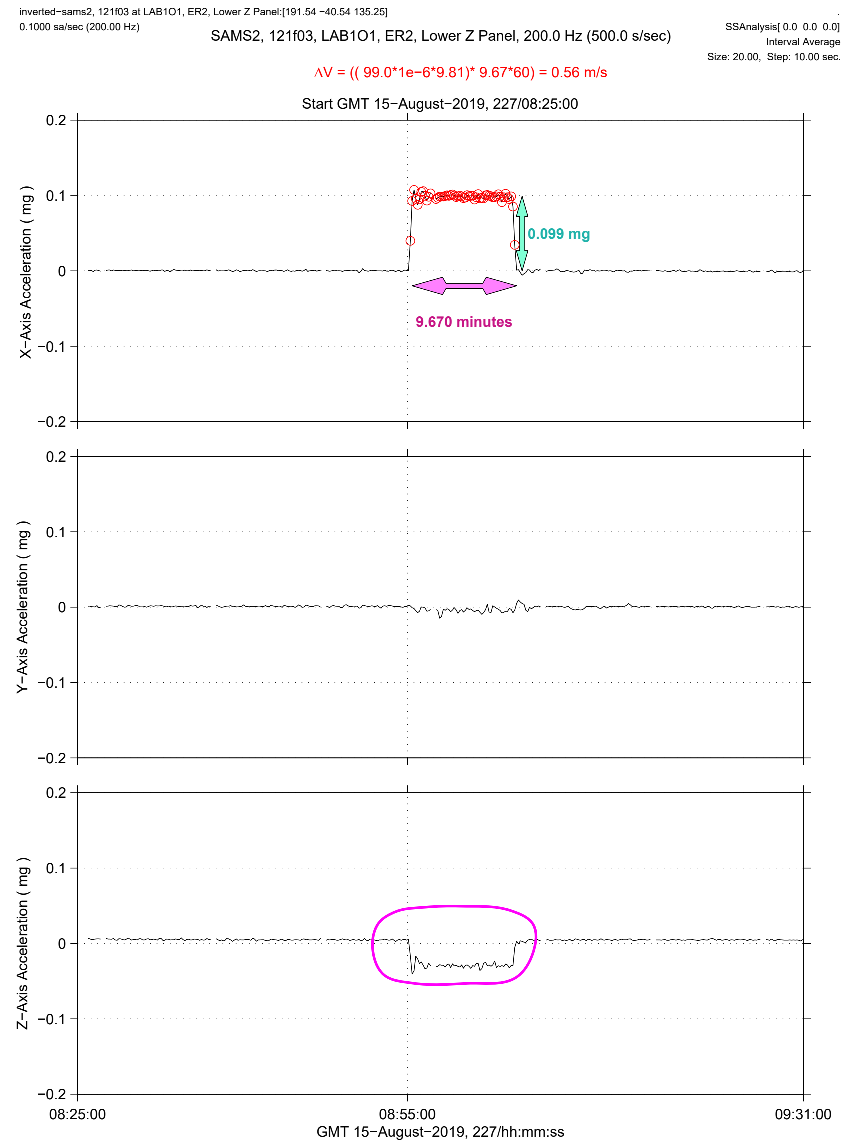

Fig. 5: Interval average of SAMS 121f03 sensor data shows reboost #2 of 2.

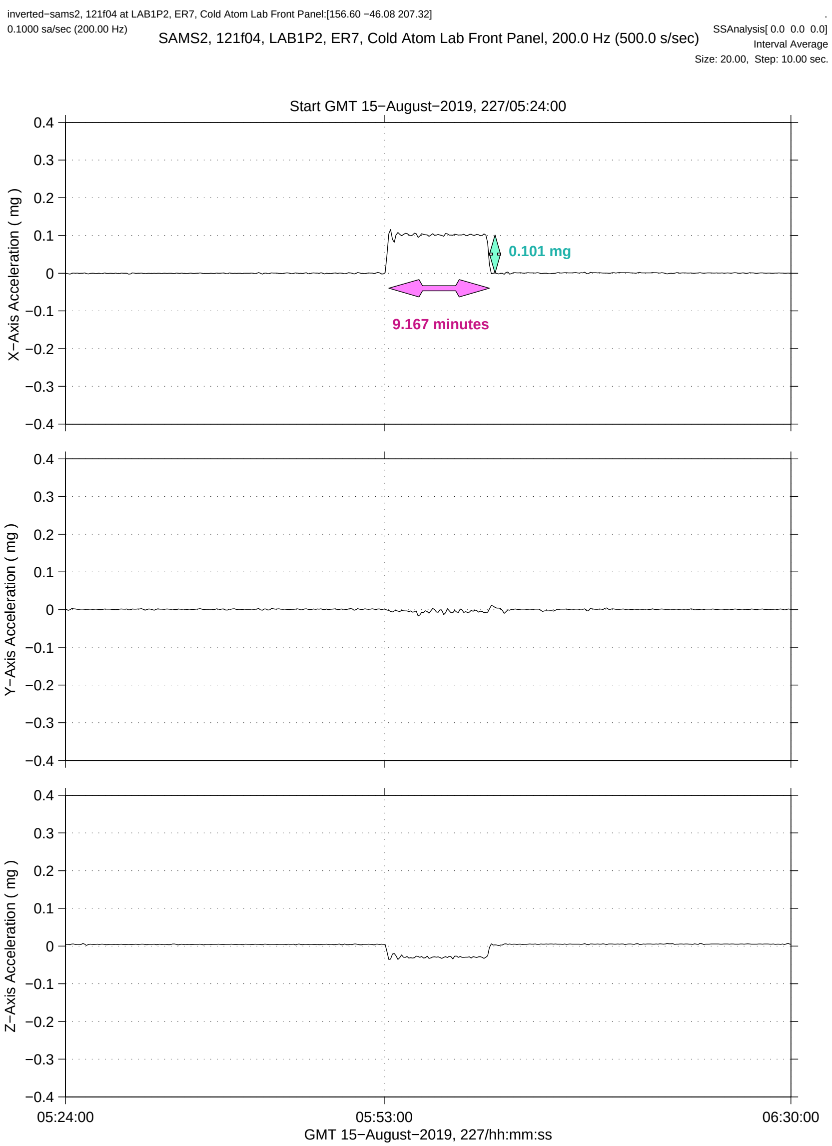

Fig. 6: 20-sec interval average for SAMS 121f04 sensor in the LAB.

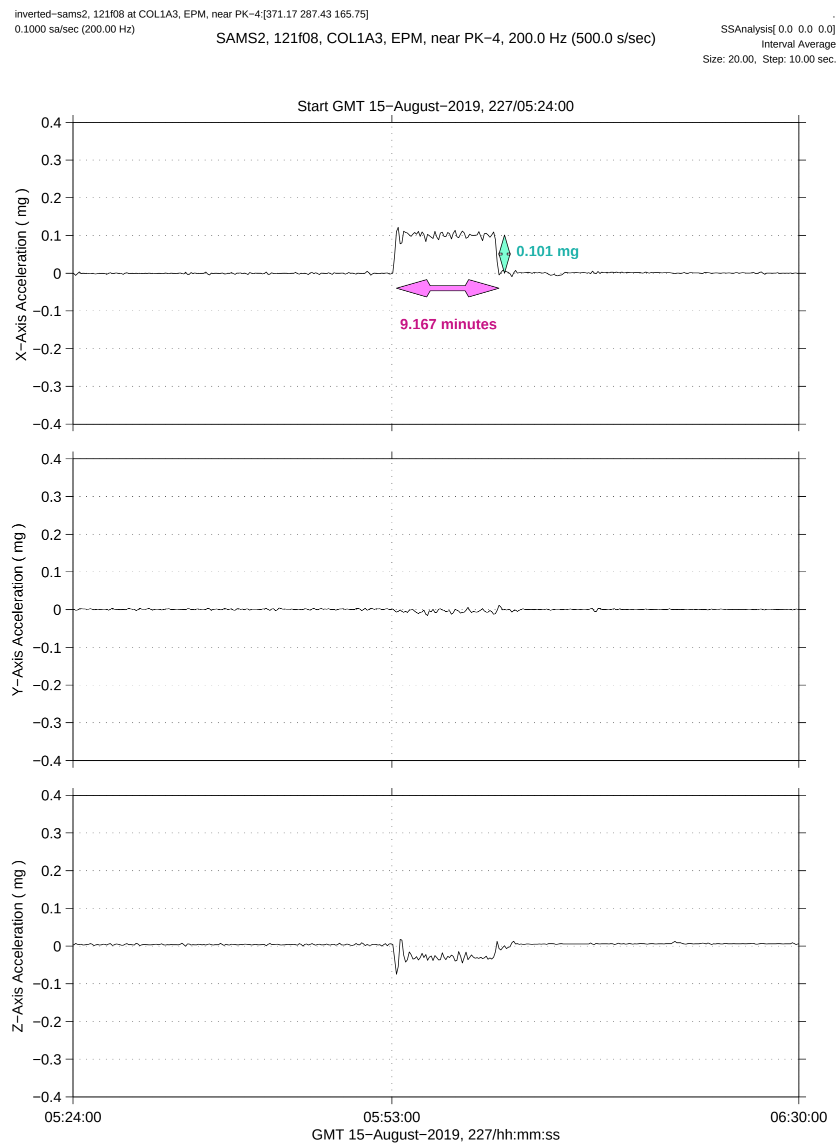

Fig. 7: 20-sec interval average for SAMS 121f08 sensor in the COL.

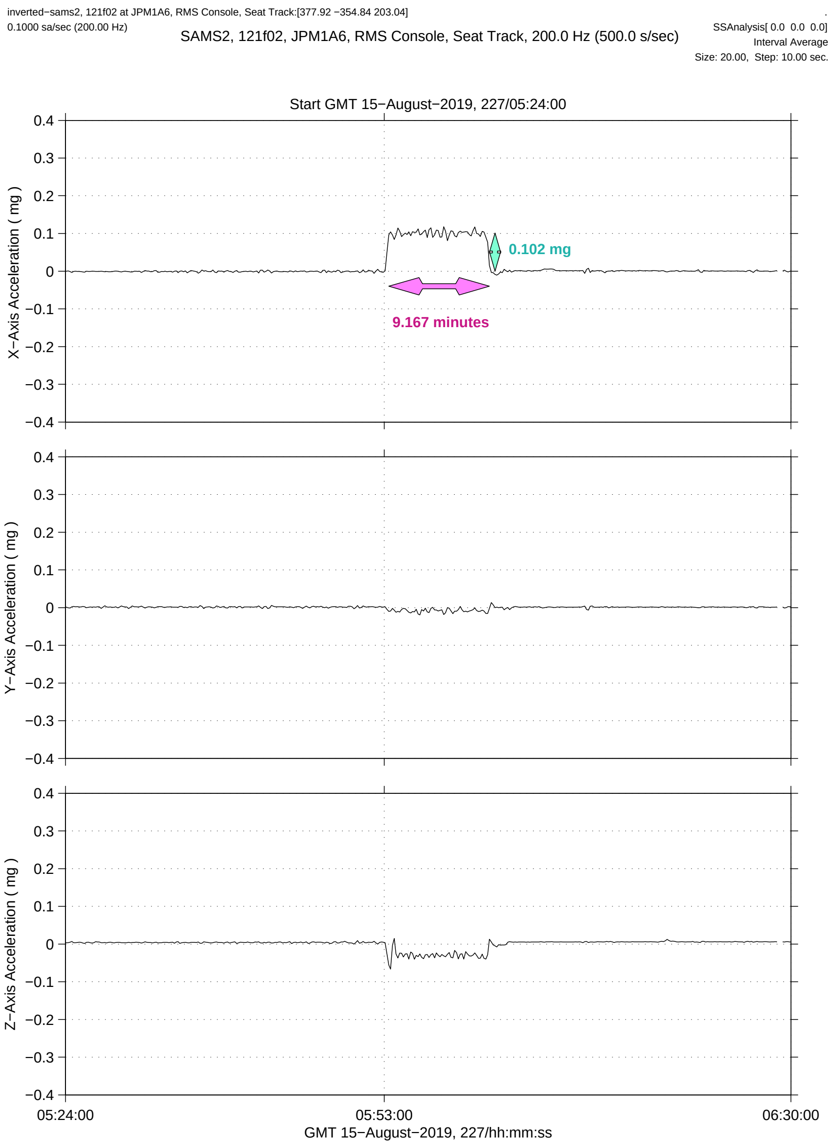

Fig. 8: 20-sec interval average for SAMS 121f02 sensor in the JEM.

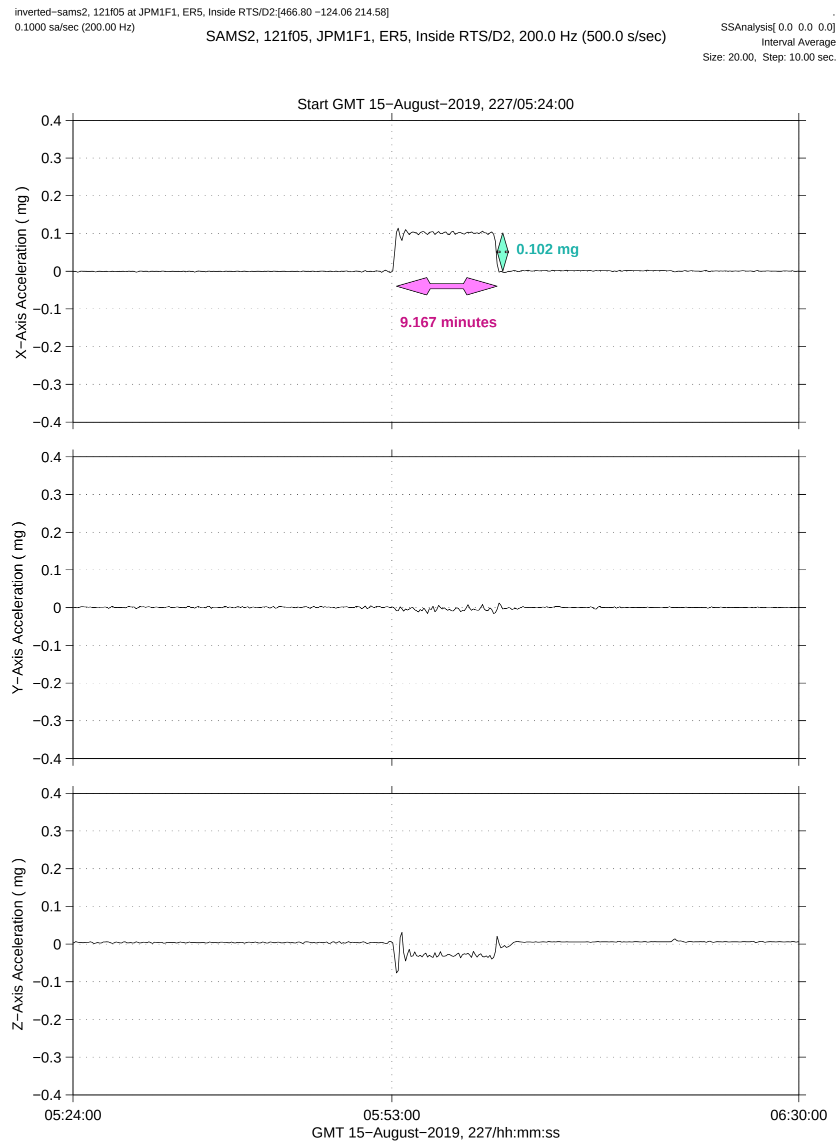

Fig. 9: 20-sec interval average for SAMS 121f05 sensor in the JEM.

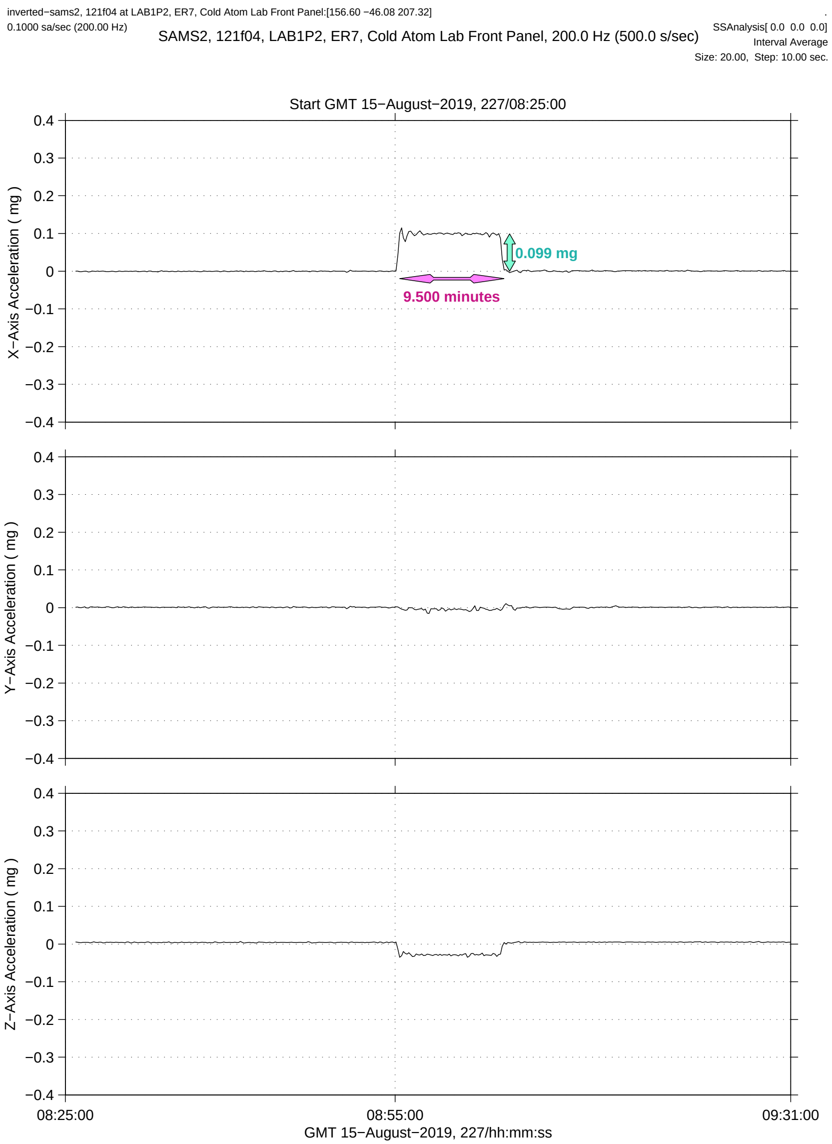

Fig. 10: 20-sec interval average for SAMS 121f04 sensor in the LAB.

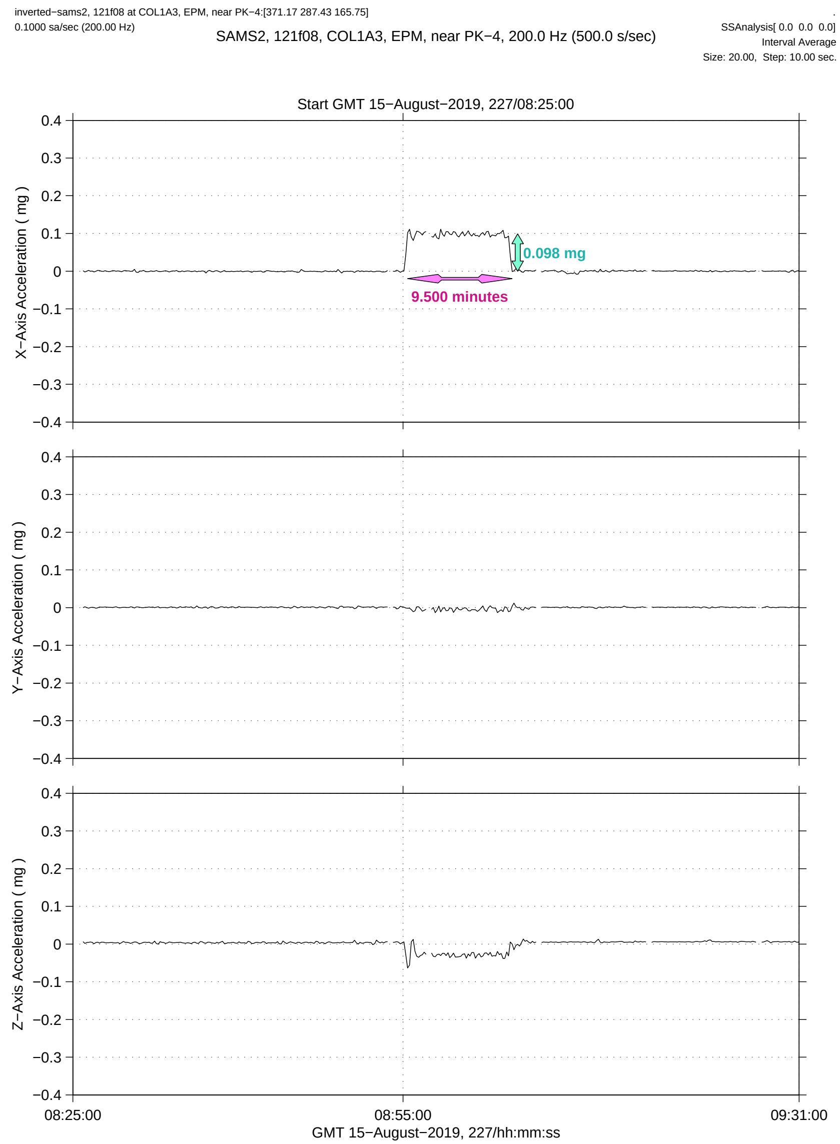

Fig. 11: 20-sec interval average for SAMS 121f08 sensor in the COL.

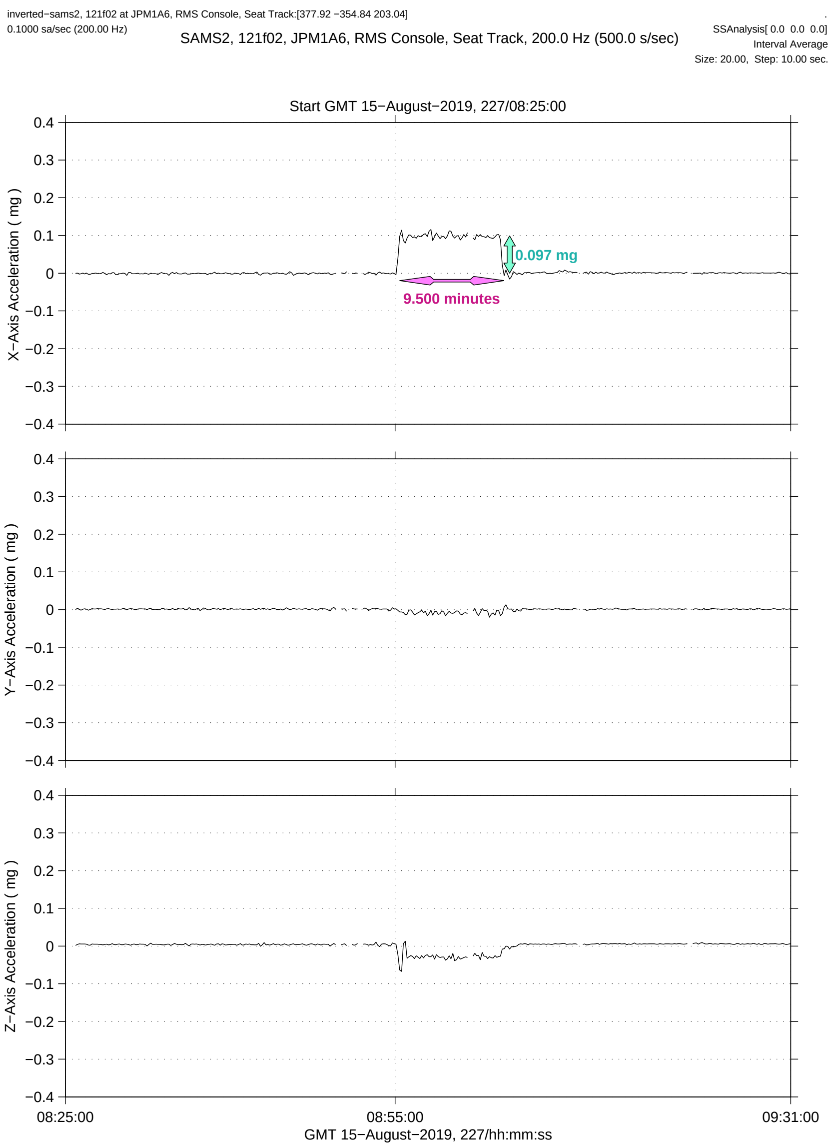

Fig. 12: 20-sec interval average for SAMS 121f02 sensor in the JEM.

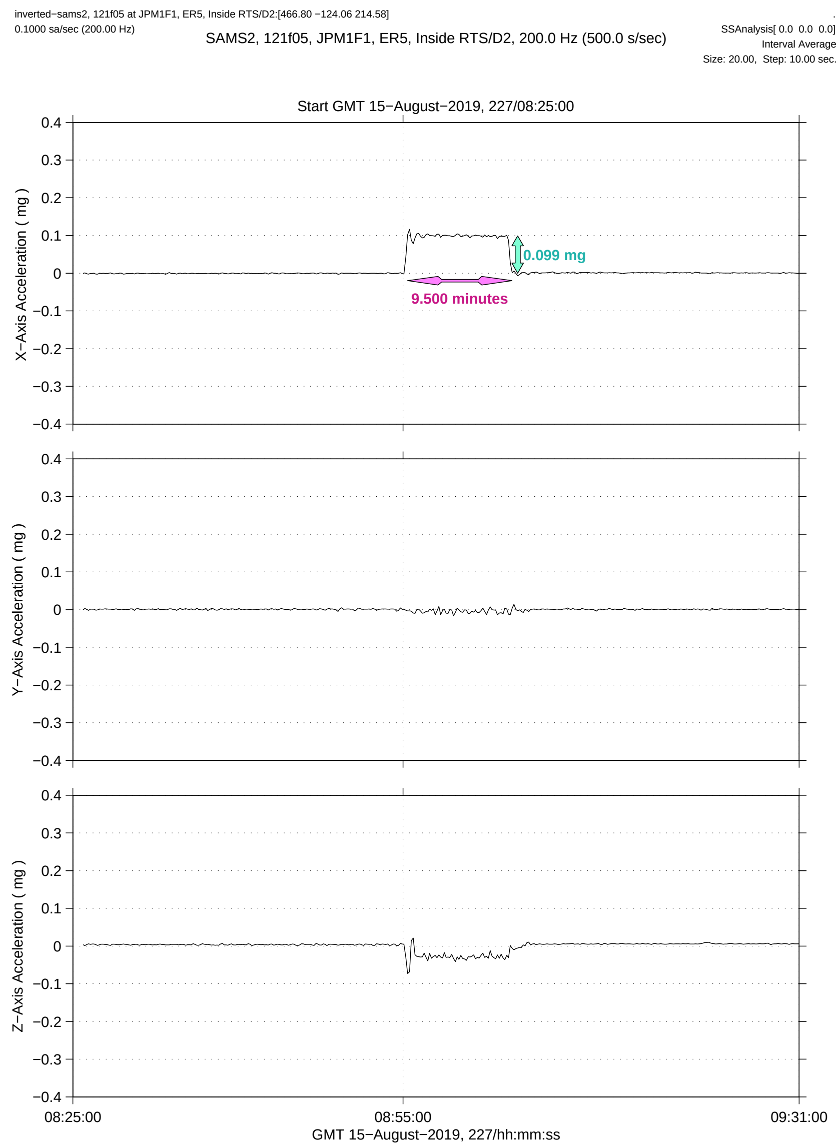

Fig. 13: 20-sec interval average for SAMS 121f05 sensor in the JEM.