1. KEY POINTS

From the vantage point of structural dynamics and acceleration data analysis, the key points for those interested in the SpaceX Dragon reboost that took place on GMT 2025-11-07 are as shown in the bullets below (*more details on page 5*).

- **Coordinate System** In this document – unless explicitly stated otherwise – we reference the body-fixed Space Station Analysis (SSA) coordinate system.

- **GMT 2025-11-07/04:28** End of about a 2-hour maneuver to -XVV (retrograde) attitude, which took place at a very slow rate of 0.001 deg/second to align Dragon's thrusters for the upcoming reboost event.

- **GMT 2025-11-07/17:16** Handover from US Momentum Management to Russian Segment (RS) for attitude control. This gives tighter control and quicker response, *but at the cost of thruster firings* instead of control moment gyros (CMGs). Those firings tend to excite low-frequency structural vibrations.

- **GMT 2025-11-07/17:43:17** Start of about 3-minutes duration of settling burn pulses (once every 10 seconds, a total of 18 pulses) by the Dragon vehicle thrusters. For these 3 minutes, due to their 10-sec period, we see this stimulus give rise to global structural modes (particularly the main truss "mode one" near 0.1 Hz) and produce distinctive harmonics in the SAMS measured response throughout the ISS.

- **GMT 2025-11-07/17:46:21** At this time, just after the 18th settling burn pulse, the Dragon started continuously firing thrusters for another ~5.5 minutes – the remainder of the reboost.

- **GMT 2025-11-07/18:23** Handover from RS to US Momentum Management for attitude control. This resumes typical attitude control via CMGs.

- **GMT 2025-11-08/00:24** Begin ~2-hour maneuver to +XVV (nominal, prograde) attitude, which happened (again) at slow rate of 0.001 deg/second.

- The analysis in this document focuses on SAMS data, using interval-averaged accelerations and time–frequency spectrogram visualizations. Together, these plots provide insight into the reboost and related events. Calculations based on SAMS measurements show that the flight controllers' prediction of 0.7 m/s for the desired ΔV was nearly achieved via a negative X-axis step with a steady-state, ~5.5-minute plateau of nearly -0.15 mg.

2. INTRODUCTION

At GMT 2025-11-07, 311/17:43, the International Space Station (ISS) was to begin about an 8.5-minute reboost using the Dragon SpX-33 thrusters via its trunk kit. Figure 1 shows the most recent available visiting vehicles' layout with the Dragon vehicle as it was docked with its thrusters pointed in the direction shown and thereby providing thrust in opposition to the velocity vector – a pre-maneuver was needed so that the ISS' "negative X direction" was aligned with the velocity vector at the time of the reboost. This arrangement brings the necessary orbital mechanics into play so as to speed up the ISS in its direction of "flight" (retrograde), that is, along its velocity vector at the time. This ultimately resulted in an altitude increase of about 1.14 km for the space station after this dynamic event. An intended ΔV metric of 0.70 m/s for the massive space station was predicted and comparing to computations derived from SAMS measurements, this metric was nearly achieved.
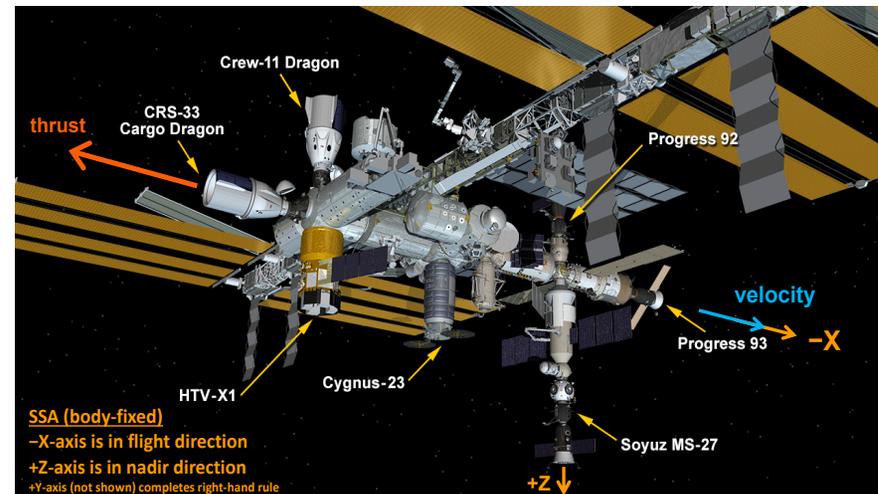

Fig. 1: SpX-33 Dragon's Location and Alignment during Reboost.

3. QUALIFY

Maneuvers to Align Thrusters

To perform a reboost using the SpaceX Dragon while it's docked at the ISS Node 2's PMA-2 port (as shown in Figure 1 on page 1), two attitude maneuvers are typically required. The first maneuver rotates the station so the Dragon's thrust vector is anti-velocity (opposite to the station's direction of travel). After the reboost is complete, a second maneuver returns the station to its nominal Torque Equilibrium Attitude (TEA). The as-flown timeline on page 5 details these two maneuvers and the intervening reboost event.

Main Truss Structural Response/Excitation

The information shown in Figure 3 on page 6 was calculated from the Space Acceleration Measurement System (SAMS) sensor es20 measurements made in the LAB module from a sensor mounted on the LAB1S2 (MSG) rack location. The most salient feature in this time-frequency spectrogram (with color indicating acceleration power spectral density) comes from the Dragon's preliminary settling burn pulses spaced every 10 seconds, which gave rise to the black annotated train of spectral peaks that start at 0.1 Hz with notable harmonics up to nearly 20 Hz or so. We know from historical data that 0.1 Hz is "mode one" of the ISS, the lowest structural resonance associated with the large, main truss structure. The duration of this train of spectral peaks corresponds to the ~3-minute settling burn span seen most clearly in Figure 4 on page 7. Less prominent in this plot, though routinely observed in previous reboosts, is the sporadic excitation of large ISS structures during Russian Segment attitude control. This appears as intensified horizontal bands below 2–3 Hz—visible as color shifts from yellow to orange or red corresponding to increased acceleration power spectral density—indicating increased vibrational energy in larger ISS structures when attitude control thrusters fire. These low-frequency vibrations are global vibrations in that SAMS sensor heads distributed throughout the space station all register these, albeit to varying degrees.

Distributed SAMS Sensor Head Locations' Response

With regards to thruster firings (RS thrusters for attitude control and Dragon settling burn pulses) comparing the same reboost event across the three ISS main laboratories, we anticipated the most energetic, low-frequency, structural vibratory response from the SAMS sensor heads located in the Columbus module, specifically at the Endcone, and in the Japanese Experiment Module (JEM)—our most portward sensor head. SAMS sensors in the U.S. Laboratory were expected to experience lesser excitation.

This differential response is directly attributed to the structural dynamics and modal response of the space station, specifically the sensors' locations relative to various, large, vibrating structures and the primary thrust vector stimulus.

A quick-look analysis leveraging Parseval's theorem confirmed these higher vibration levels by quantifying the energy within the 0.1 Hz–3.0 Hz band, especially during the Dragon's preliminary settling burn pulses. While the supplementary time-series and narrowband RMS plots (derived from PSDs via Parseval's theorem) are omitted here for brevity, the underlying data and analysis methodology are available to interested readers upon request by contacting our team at the following email address: pimsops@lists.nasa.gov.

Operational Considerations

The transient and vibratory environment of the space station (primarily below 10 Hz) is influenced by both the brief reboost event and the longer span of Russian Segment (RS) attitude control. The reboost generates a relatively short, quasi-steady step change in X-axis acceleration. Conversely, RS attitude control principally excites low-frequency vibrational modes of large space station structures, which globally affects phenomena sensitive to this low-frequency regime to varying degrees.

Note: For SAMS data, the best temporal fidelity comes from as-measured, time domain data. Transformed or otherwise processed data can skew timing due to altered temporal resolution resulting from the processing applied. You may notice timestamp discrepancies on various figures in this document for this very reason.

4. QUANTIFY

To complement the visual, pattern analysis of acceleration (PSD magnitude) color spectrograms shown in the previous section, we now quantify the microgravity environment impact of the reboost event across multiple SAMS sensor heads in the three main ISS laboratories using explicit metrics.

Figure 7, Figure 9, and Figure 10 (on pages 10, 11, and 12, respectively) show the consistent rigid-body response across the three main ISS laboratories. These

figures display 5-second interval-averaged SAMS acceleration data from the sensor heads in LAB (Fig. 7), COL (Fig. 9), and JEM (Fig. 10), demonstrating that all 3 sensor heads register the same global event. This global consistency is expected when viewing the enormous space station as a single, unflexing rigid body ("a big brick") reacting to a highly-directional force. Specifically, the data reveals that for this Dragon reboost, initiated in a -XVV attitude, **all rigidly-attached structures on the ISS experienced ~5.5-minutes of "a gentle Dragon push" – a negative X-axis acceleration step magnitude of 133–134 µg** that began at GMT 17:43:18, which is within the time resolution of this plot type and (as usual) just about 16-18 seconds after the advertised start time.

The assertion of a *"gentle Dragon push"* is, of course, relative to a specific phenomenon's vulnerabilities. Analysis and plots quantifying the sensor-specific, location-dependent impact (such as the local structure's response to "mode one" excitation) are omitted here. The underlying SAMS data and suggested analysis methodology are available upon request by contacting pimsops@lists.nasa.gov.

For the 3 figures discussed above, the SAMS data was analyzed using a 5 s averaging window to independently determine timing information for each sensor head. Flight control data predicted the space station rigid-body ΔV for this reboost would be 0.70 m/s. Analysis of the SAMS interval-average data (indicated by red annotations in the corresponding three figures mentioned above) yielded computed values between 0.66 m/s and 0.67 m/s, affirming the prediction but falling slightly below the expected value. SAMS does not directly measure altitude, but flight controllers indicated that the ISS would gain ~1.14 km in altitude above the Earth as a result of this reboost activity.

The interval-averaging process referenced in this Quantify section, acted as a low-pass filter, attenuating high-frequency vibrations and making the X-axis acceleration step during the reboost more evident. For this Dragon reboost, the required docking position necessitated the ISS maintain a "-XVV attitude" (flying backwards). This maneuver successfully aligned Dragon's thrusters opposite to the station's velocity vector, enabling acceleration in the direction of orbital motion, and thus giving the push to increase the station's altitude.

We also note that the polarity of each axis in the SAMS plots was inverted owing to an inherent polarity inversion issue in the SAMS signal conditioning.

A quantification of the reboost impact measured by the distributed SAMS sensors is provided in Table 1.

Table 1. Magnitude of -X-axis steps (mg) for reboost event from 3 SAMS sensors.

Sensor	|X-Axis| (mg)	Location
121f02	0.134	COL1A1 (ER3)
121f05	0.133	JPM1F1 (ER5)
es20	0.134	LAB1S2 (MSG)

A Look at the Reboost Events via As-Measured (200 Hz) SAMS Data

Compare the 2 figures on page 10 to realize this **punchline:** The right-side, as-measured 200 Hz SAMS data makes it difficult to discern or detect reboosts or the settling burn pulses. You need to low-pass filter the native 200 Hz SAMS data to get rid of (what is considered here to be) "noise". To see what disturbance is driving the peak-to-peak envelope of the top subplot X-axis of Figure 8 (repeated and juxtaposed on page 15), we computed the acceleration power spectral density of all 3 (XYZ) axes as shown on the left side, in Figure 13 of page 15. The "head-and-shoulders above the rest" spectral peak on the X-axis is a very narrowband 60 Hz disturbance, which is most likely due to nearby cryocooler equipment operation.

For unobstructed clarity, we have repeated two of the previously discussed (and annotated) figures and reshow those without annotations in Figure 11 on page 13 and Figure 12 on page 14.

5. CONCLUSION

Quantitative Summary

- Station rigid-body ΔV achieved: ~ 0.67 m/s (vs. 0.70 m/s predicted)
- Negative X-axis acceleration step magnitude: $133\,\mu g$ to $134\,\mu g$ consistent across all 3 SAMS sensor heads
- Duration metrics: 3 min (just over) settling burn sequence, 5.5 min main thrust period
- Altitude increase: 1.14 km (presumed as planned, not derived from SAMS)

Measurment Validation

- SAMS distributed measurements confirmed uniform rigid-body response across ISS
- Interval-averaging (5 s windows) effectively suppressed high-frequency vibrations (primarily from assumed, nearby cryocooler ops)
- Raw 200 Hz data obscured reboost signatures due to 60 Hz narrowband disturbance (assumed to be cryocooler operation nearby)

Operational Insights

- Settling burn pulses excited global structural patterns at 0.1 Hz ("mode one" of main truss) with harmonics up to nearly 20 Hz
- Differential laboratory responses observed: Columbus and JEM SAMS sensors showed higher vibrational energy than U.S. Lab
- Vibratory impact extends beyond reboost window, so consider longer span that includes RS attitude control period, and perhaps before/after attitude maneuvers
- Low-frequency excitation (< 10 Hz) tends to affect ISS globally but with location-dependent intensity

Broader Significance

- Data provides operational teams with quantified vibration environment
- SAMS again demonstrated effective capability for characterizing ISS structural dynamics during reboost events
- Measurements validate flight predictions and possibly serve toward future Dragon reboost operational planning

|	As-flown Timeline								
OPM to nXVV with Timeliner Profile 5 (M25_311_A_03.UAF)								**11/07/2025**	← Maneuver to "negative XVV" [i.e. "flying backwards"]
68	311/02:43:00 —	Y	35	+XVV +ZLV TEA	LVLH	356 353.5 0.9	MMT UST	Transition to USTO	
69	311/02:43:01 311/04:14:40	Y	35	-XVV +ZLV	LVLH	176 354.59 0.85	UST UST	Mnvr to -XVV using OPM	Not a pure Eigen axis rotation - reference chit 19640 for attitude profile; One Rev Late Maneuver 311/04:16 - 311/05:48 ← There might be nuances to this, & we can contact ADCO.
70	311/04:28:00 —	Y	35	-XVV +ZLV	LVLH	176 354.59 0.85	UST MMT	Transition to Momentum Management using USTO	OPM Ending Attitude
71	311/04:28:01 311/04:40:00	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	MMT MMT	Mnvr to TEA on Momentum Management	Maneuver rate 0.001 deg/s; TEA for VV#2z N1nCN2nHzDfD, PSARJ Auto, SSARJ Auto; Post-OPM thermal dwell GMT 311/04:15 - 13:15 ← OPM for "Optimized Propellant Maneuver" (not optimized for rate)
SpX-33 Dragon Reboost (M25_311_B_06.UAF)								**11/07/2025**	← Dragon Reboost (with Settling Burn)
72	311/17:16:00 —	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	MMT THR	Handover US to RS	
73	311/17:21:00 311/17:26:00	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	THR THR	Quaternion update for reboost in TEA (Dragn2 on N2 Forward)	Settling burns beginning at 17:43:00, TIG 17:46:00 DUR 00:05:20 ← TIG = Time of Ignition = Start Reboost, and DUR is duration
74	311/17:54:00 311/17:59:00	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	THR THR	Quaternion Update	
75	311/18:23:00 —	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	THR MMT	Handover RS to US Momentum Management	TEA for VV#2z N1nCN2nHzDfD, PSARJ Auto, SSARJ Auto
OPM to pXVV with Timeliner Profile 13 (M25_312_A_09.UAF)								**11/08/2025**	← Maneuver back to "plus XVV" [nominal, TEA]
76	312/00:24:00 —	Y	35	-XVV +ZLV TEA	LVLH	176 353.9 0.9	MMT UST	Transition to USTO	
77	312/00:24:01 312/01:55:40	Y	35	+XVV +ZLV	LVLH	356 354.24 0.85	UST UST	Mnvr to +XVV using OPM	Not a pure Eigen axis rotation - reference chit 19640 for attitude profile; One Rev Late Maneuver 312/01:57 - 312/03:29
78	312/02:09:00 —	Y	35	+XVV +ZLV	LVLH	356 354.24 0.85	UST MMT	Transition to Momentum Management using USTO	OPM Ending Attitude
79	312/02:09:01 312/02:22:00	Y	35	+XVV +ZLV TEA	LVLH	356 353.5 0.9	MMT MMT	Mnvr to TEA on Momentum Management	Maneuver rate 0.001 deg/s; TEA for VV#2z N1nCN2nHzDfD, PSARJ Auto, SSARJ Auto; Post-OPM thermal dwell GMT 312/01:56 - 10:56 ← OPM so very slow rate again.
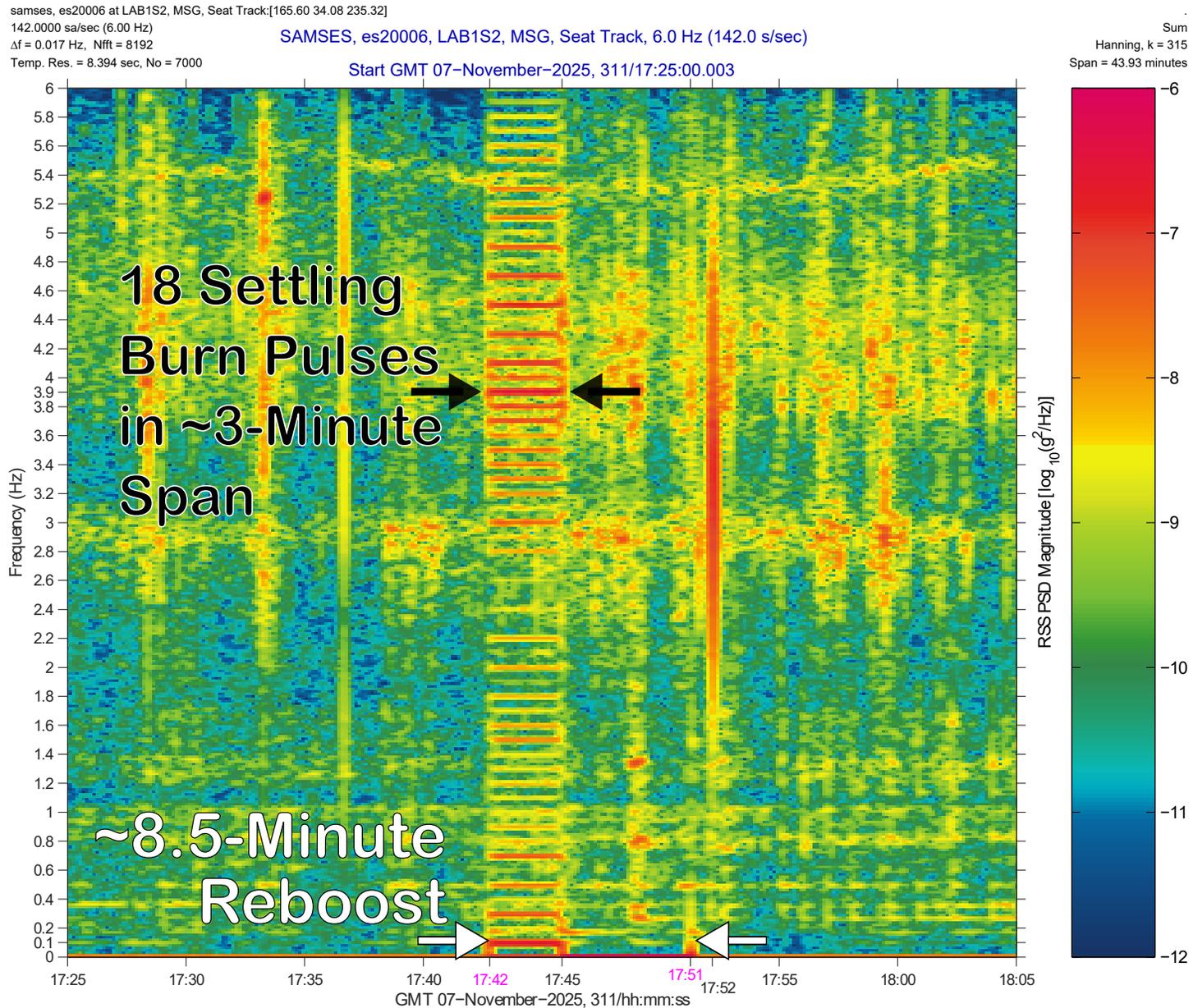
Fig. 3: 6 Hz Spectrogram showing Dragon SpX-33 Reboost on GMT 2025-11-07 from SAMS Sensor in the LAB module on LAB1S2 (MSG).

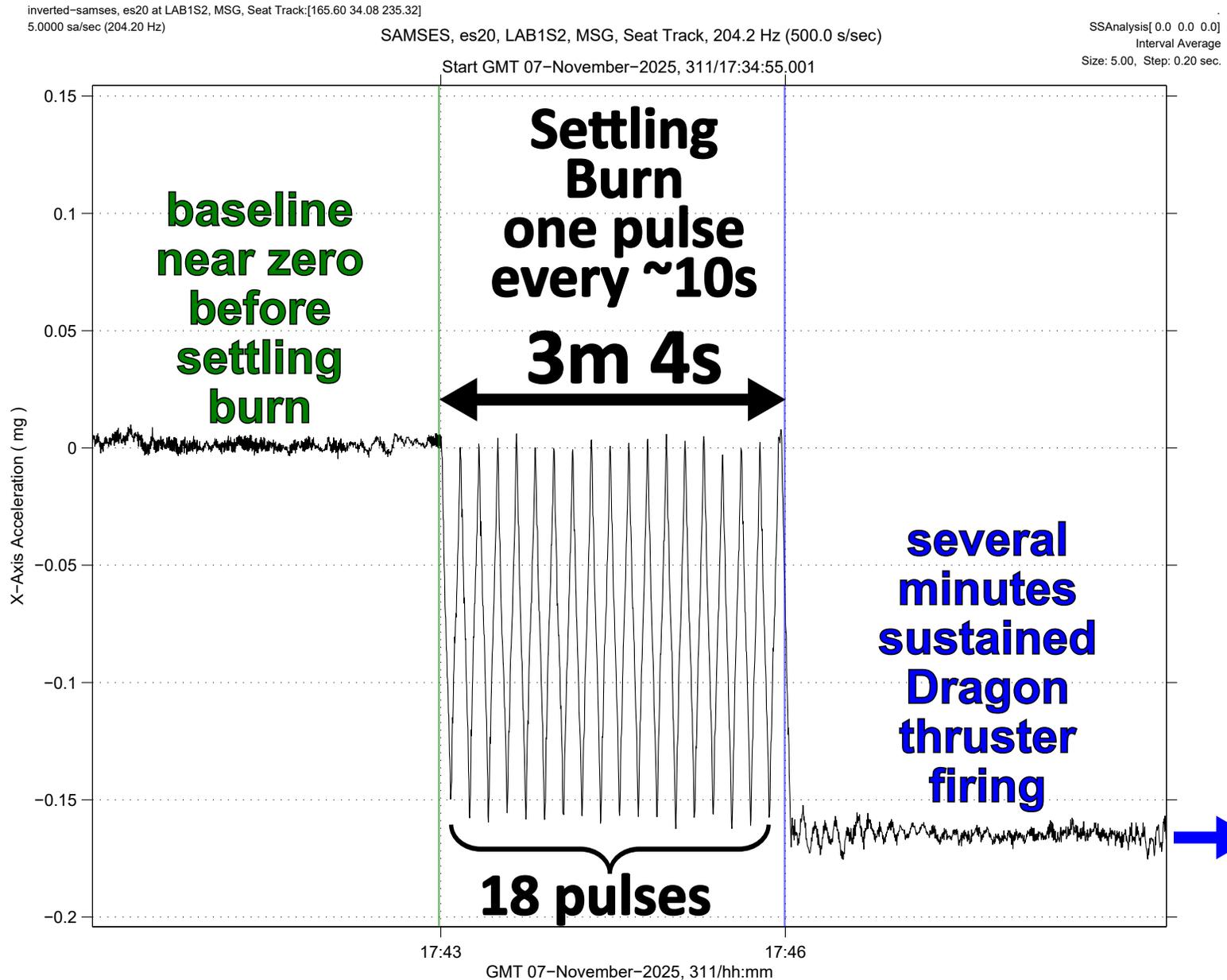inverted−samses, es20 at LAB1S2, MSG, Seat Track:[165.60 34.08 235.32]
5.0000 sa/sec (204.20 Hz)

SAMSES, es20, LAB1S2, MSG, Seat Track, 204.2 Hz (500.0 s/sec)

Start GMT 07−November−2025, 311/17:34:55.001

SSAnalysis[0.0 0.0 0.0]
Interval Average
Size: 5.00, Step: 0.20 sec.

baseline near zero before settling burn

Settling Burn one pulse every ~10s

3m 4s

18 pulses

several minutes sustained Dragon thruster firing

X-Axis Acceleration (mg)

GMT 07−November−2025, 311/hh:mm

VIBRATORY

MODIFIED NOVEMBER 20, 2025

Fig. 4: Annotated Zoom-In X-Axis 5-Sec. Interval Average Accel. showing Dragon SpX-33 Reboost on GMT 2025-11-07 from SAMS Sensor at LAB1S2 (MSG).
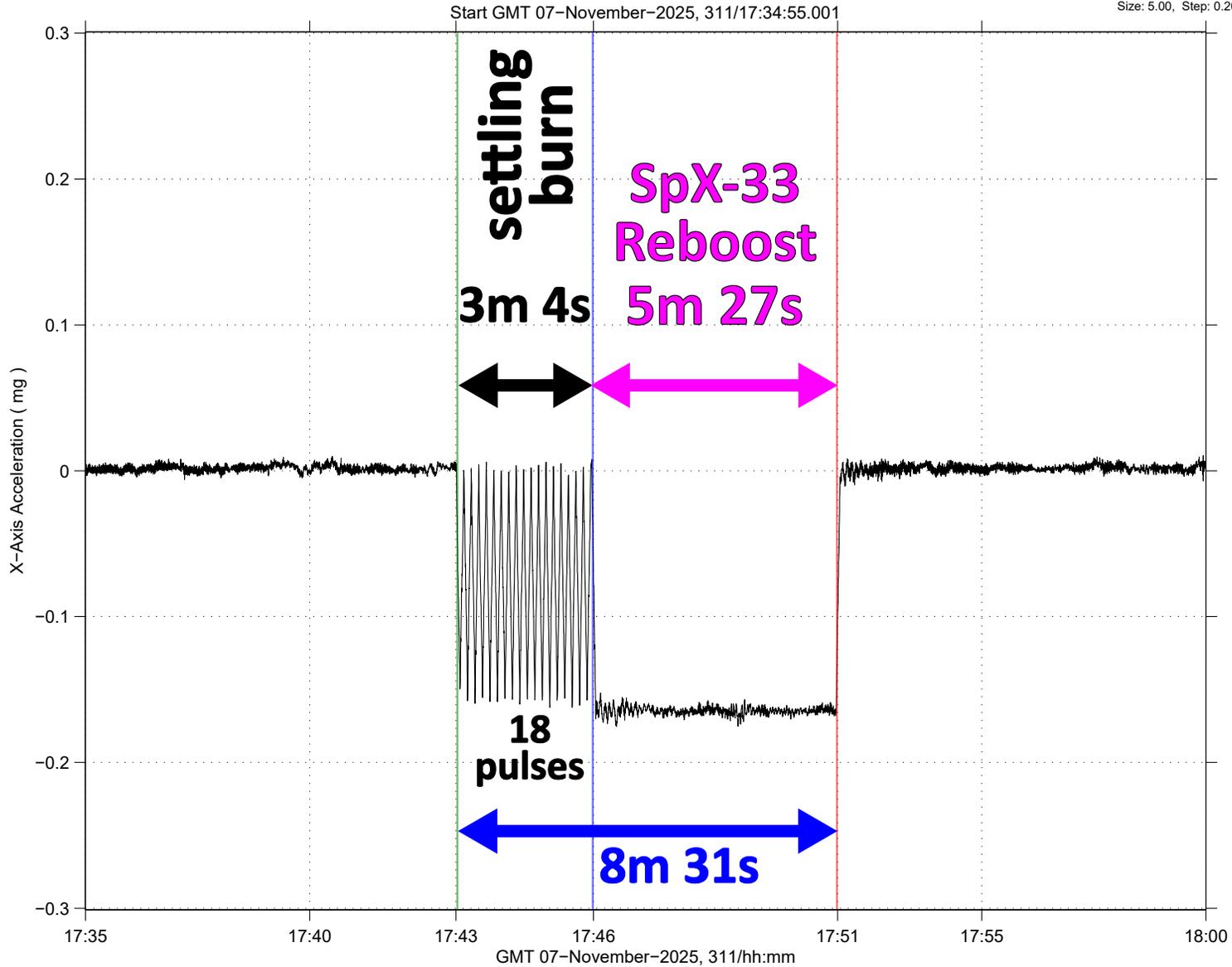
Fig. 5: Annotated X-Axis 5-Sec. Interval Average Accel. showing Dragon SpX-33 Reboost on GMT 2025-11-07 from SAMS Sensor at LAB1S2 (MSG).

Fig. 6: Accel. Vector Magnitude (low-pass filtered, f < 6 Hz) showing Dragon SpX-33 Reboost on GMT 2025-11-07 from SAMS Sensor at LAB1S2 (MSG).
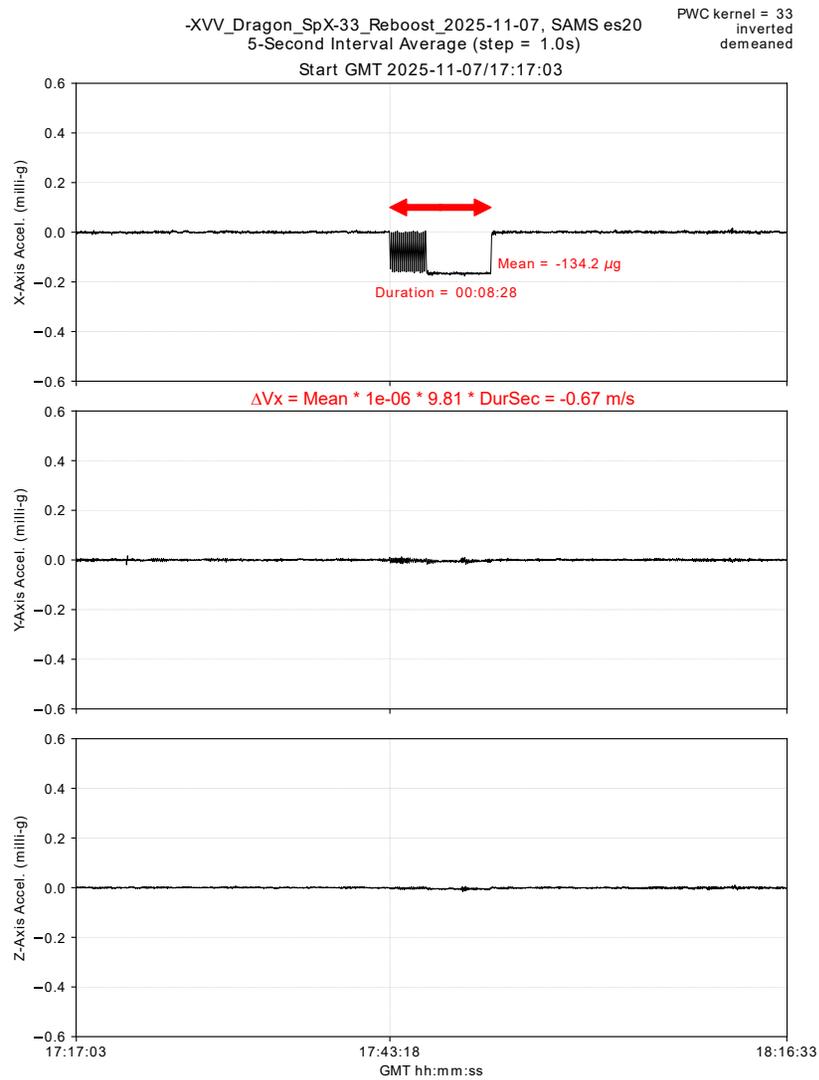
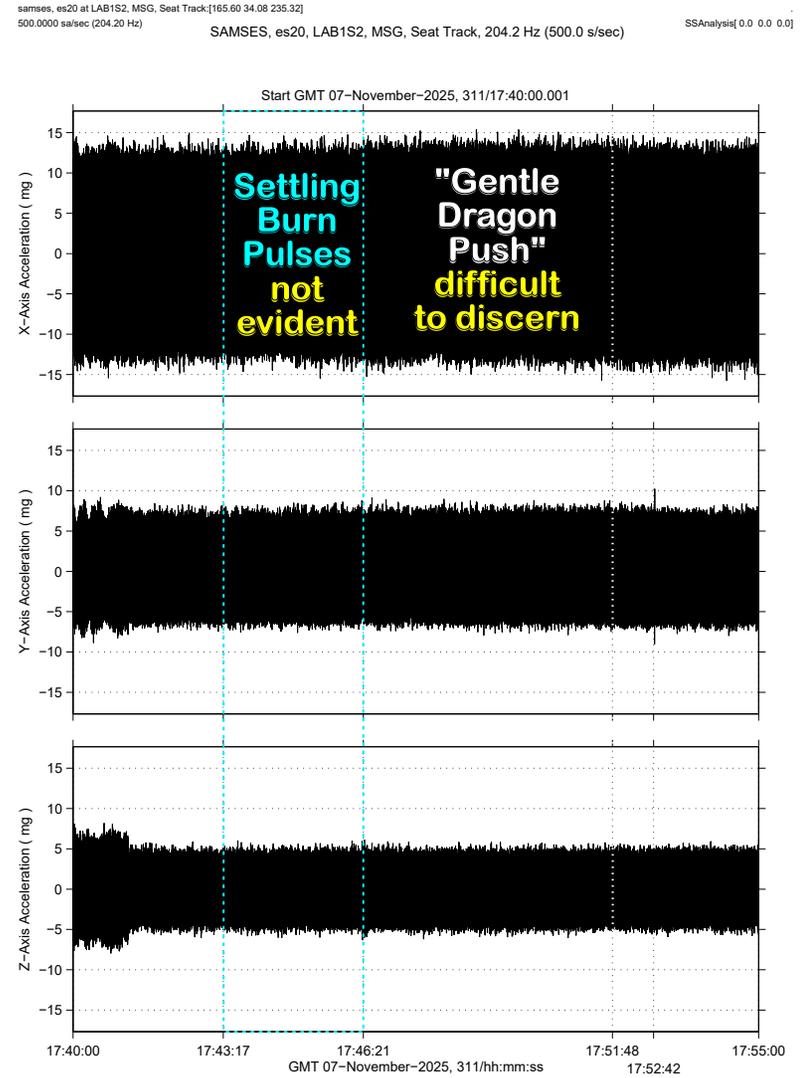Fig. 7: 5-sec interval average for SAMS es20 sensor at LAB1S2 (MSG).

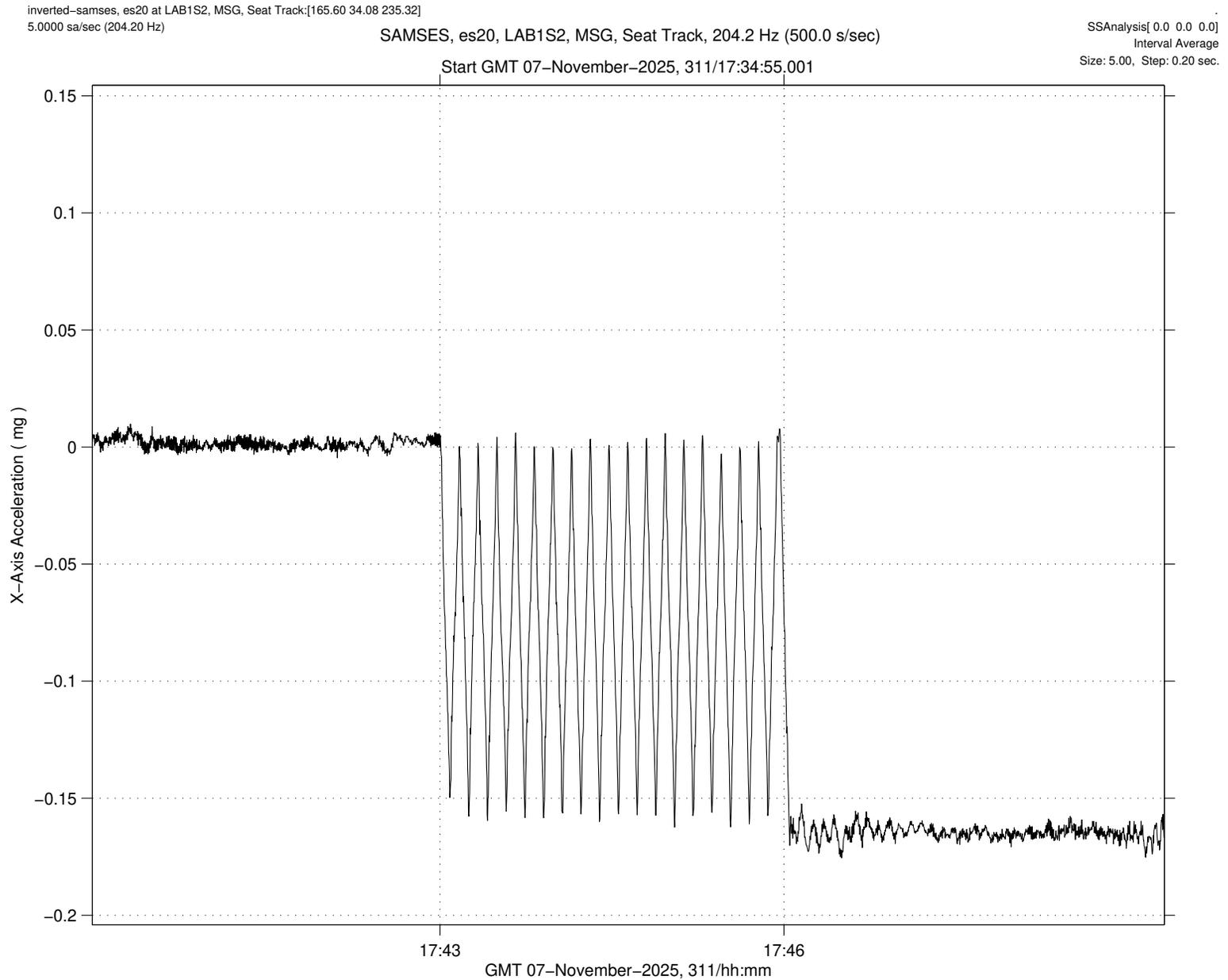Fig. 8: As-Measured 200 Hz Accel. vs. Time During Reboost (es20 on MSG).

Fig. 9: 5-sec interval average for SAMS 121f02 sensor in the COL on the Endcone.

Fig. 10: 5-sec interval average for SAMS 121f05 sensor at JPM1F1 (ER5).

inverted−samses, es20 at LAB1S2, MSG, Seat Track:[165.60 34.08 235.32]
5.0000 sa/sec (204.20 Hz)

SAMSES, es20, LAB1S2, MSG, Seat Track, 204.2 Hz (500.0 s/sec)

Start GMT 07−November−2025, 311/17:34:55.001

SSAnalysis[0.0 0.0 0.0]
Interval Average
Size: 5.00, Step: 0.20 sec.

Fig. 11: Same as Figure 4, except here without annotations.

inverted−samses, es20 at LAB1S2, MSG, Seat Track:[165.60 34.08 235.32]
5.0000 sa/sec (204.20 Hz)

SAMSES, es20, LAB1S2, MSG, Seat Track, 204.2 Hz (500.0 s/sec)

Start GMT 07−November−2025, 311/17:34:55.001

SSAnalysis[0.0 0.0 0.0]
Interval Average
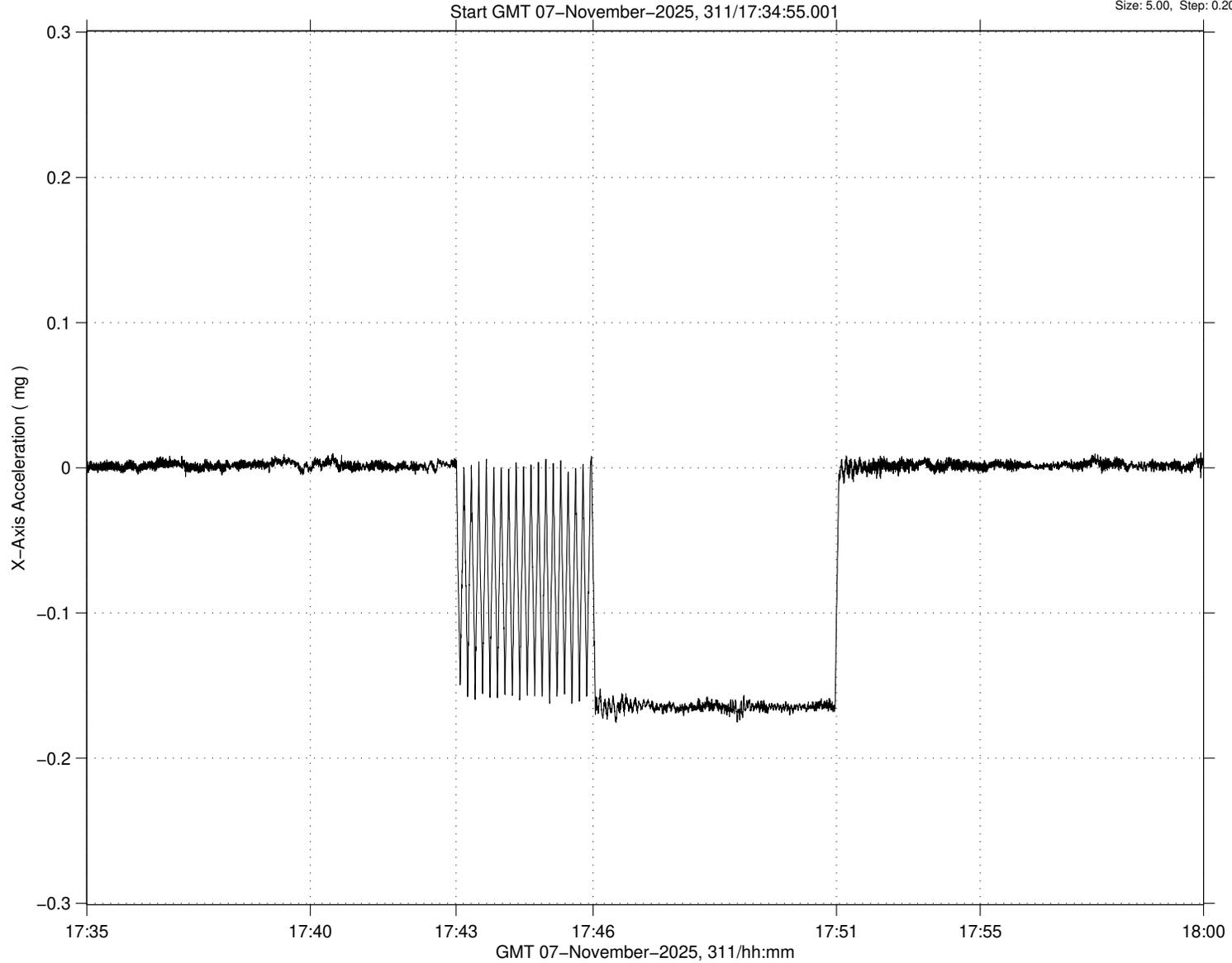Size: 5.00, Step: 0.20 sec.
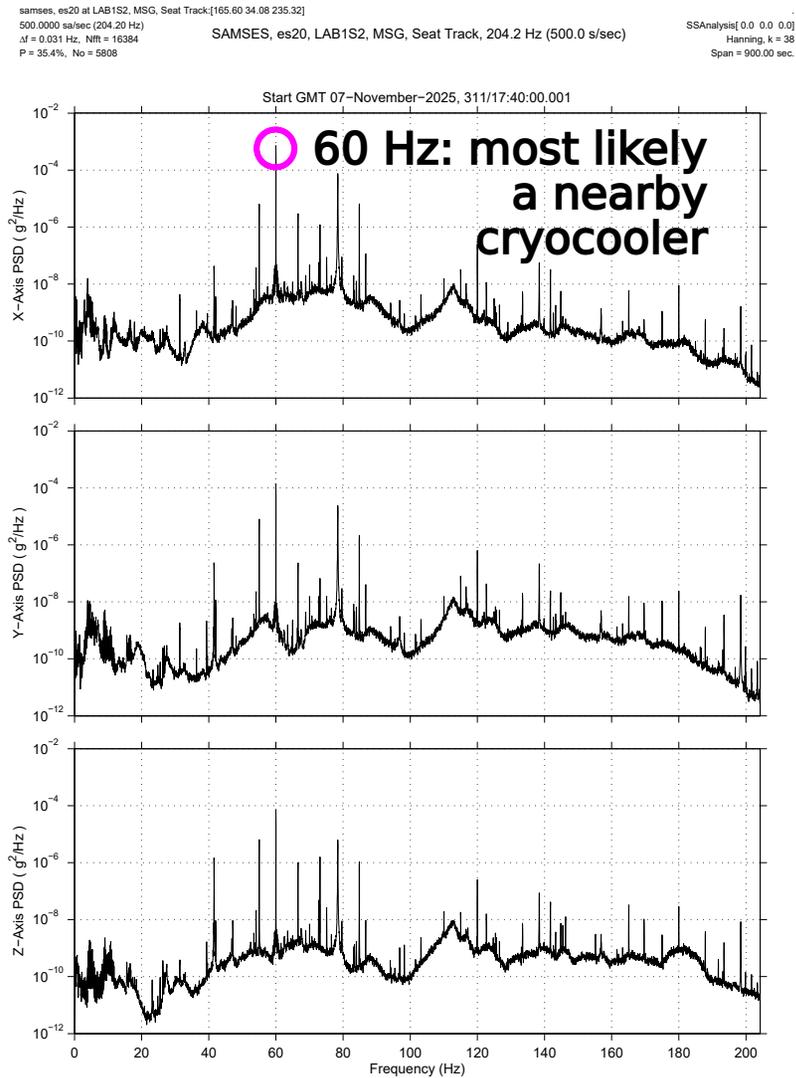
Fig. 12: Same as Figure 5, except here without annotations.

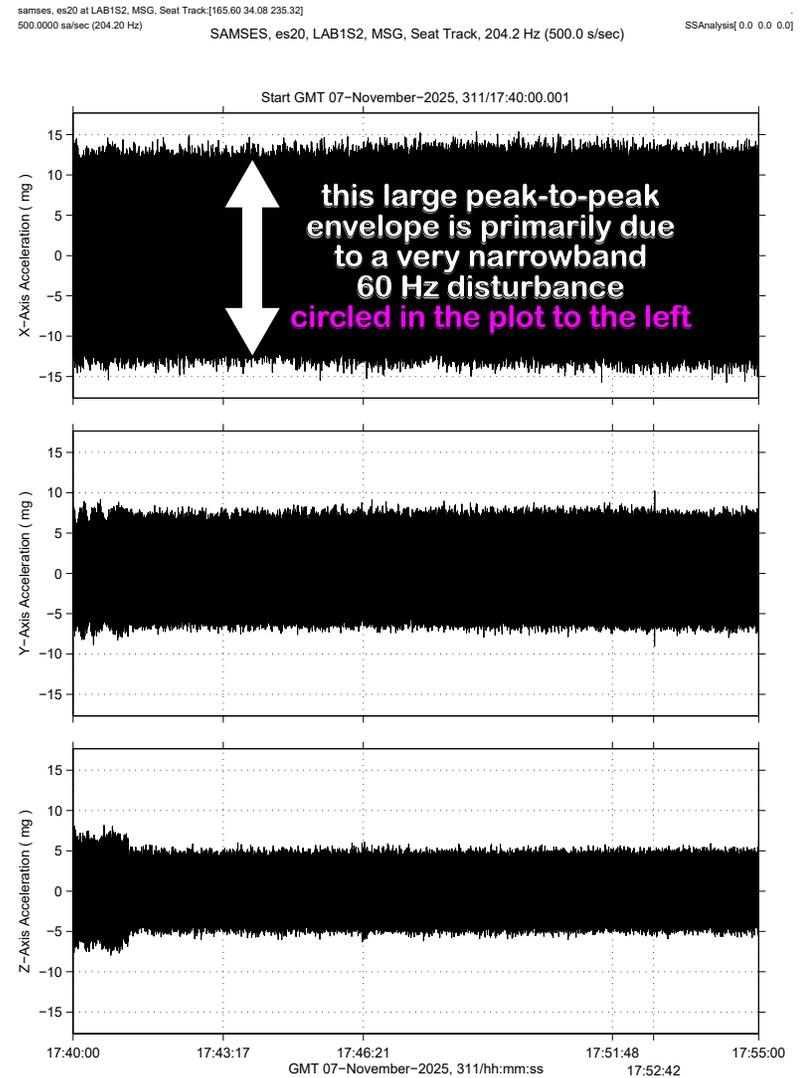Fig. 13: PSDs Derived Accel. Data Shown to the Right.

Fig. 14: As-Measured 200 Hz Accel. vs. Time During Reboost (es20 on MSG).