1. INTRODUCTION

An Optimized Propellant Maneuver (OPM) is used to perform flight attitude maneuvers of the International Space Station (ISS) using less propellant compared to traditional ISS flight software. The savings are achieved by commanding the ISS to follow a pre-planned attitude trajectory, which was optimized to take advantage of naturally occurring environmental torques and available control authority from the thrusters. The trajectory was obtained by solving an optimal control problem that did not require any modifications to flight software. This approach is reported to be applicable to any spacecraft controlled with thrusters.

2. QUALIFY

Figure 1 on page 3 is a color spectrogram computed from Space Acceleration Measurement System (SAMS) sensor 121f03 measurements made in the US LAB. The black arrow annotation in that figure shows the start of a 95-minute span that started at about GMT 15:10 and ended at about GMT 16:45 as shown in Figure 2. This first was a maneuver from +X-axis in Velocity Vector (+XVV) to –X-axis in Velocity Vector (–XVV) flight attitude or "flying backwards" compared to a typical flight attitude. The initial and final Local Vertical Local Horizontal (LVLH) attitudes were [+356.0, +356.4, +0.8] degrees and [+177, +357.36, +0.7] degrees (YPR order), respectively.

Vibratory Features/Characteristics of this Maneuver

As suggested by the train of white, horizontal lines superimposed on the spectrogram in Figure 1, this maneuver imposed a train of spectral peaks spaced about every 0.4 Hz most noticeably below about 0.6 Hz or so. This included excitation of an existing vehicle structural mode at about 0.52 Hz (the orange/red horizontal streak at that frequency). To see this more clearly and check alignment too, we see in Figure 3 that the same train of spectral peaks most notably on the Y-axis as indicated by the red text and faint red vertical line at the structural mode that was getting excited. This figure showing per-axis power spectral density (PSD) plots shows that vibratory excitation was mostly aligned with the Y-axis (port-starboard direction), then some on the X-axis too (in the aft-flight direction), and finally only a small amount on the Z-axis (zenith-nadir direction).

3. QUANTIFY

The Microgravity Acceleration Measurement System (MAMS) would have been the instrument to best measure this OPM in terms of quasi-steady acceleration events. However, the MAMS was out of service during this time, so here we take a look at low-pass filtered SAMS data in an attempt to quantify this event. For an OPM reference using MAMS data in 2012, see the handbook page at this link. In particular, page 4 shows a high-fidelity rendering via MAMS measurements of a low-frequency, low-magnitude OPM from +XVV to -XVV using US thrusters at that time. Also, page 5 shows an OPM from -XVV to +XVV. Note there the bipolar swing of about 4 μg peak-to-peak on the Y-axis while at the same time a step on the X-axis of just under 1 μg. Further, there were two Russian Segment (RS) OPMs on GMT 2018-12-28 & 2018-12-29 as documented at this link and captured by SAMS.

Quantitative Vibratory Impact of this Maneuver

Starting with the plot in Figure 4 on 4, we show interval root-mean-square (RMS) acceleration versus time below 0.6 Hz for SAMS measurements throughout the space station. This frequency range was chosen since it shows the primary impact on the vibratory environment of this maneuver. The color annotations in Figure 4 correspond to two time spans for comparison: (1) magenta "Wake" during the crew wake period and before the OPM began from GMT 06:00 to 15:10, and (2) red "OPM" during the crew wake period and during the OPM from GMT 15:10 to 16:45. We note from the spectral plots presented earlier that the impact is concentrated on the XY-plane albeit mainly on the Y-axis. The values shown in Table 1 are results gleaned from the plots shown in Figure 4 through Figure 8 where a detectable but not significant increase is seen during the OPM time span relative to the crew wake leading up to the maneuver.

4. CONCLUSION

SAMS vibratory sensors cannot fully characterize the low-frequency, low-magnitude impact of OPMs due to transducer temperature dependency. However, SAMS clearly detected the vibratory impact of this maneuver below about 0.6 Hz, especially on the vehicle structural mode at about 0.52 Hz, which is aligned primarily with the Y-axis (port-starboard) direction.

GMT 2021-07-01		Median RMS Accel. f < 0.6 Hz (micro-g)	
SAMS		GMT Span	
Location	Sensor	06:00-15:10	15:10-16:45
COL1A1, ER3, Near ICF	121f02	17.56	26.62
LAB1O1, ER2, Lower Z Panel	121f03	9.53	15.98
LAB1P2, ER7, Cold Atom Lab	121f04	9.65	15.70
JPM1F1, ER5, RTS/D2	121f05	16.65	25.53
COL1A3, EPM, Near PK-4	121f08	20.15	29.84
			DURING OPM MNVR
		CREW WAKE BEFORE OPM MNVR	

Table 1. Comparison of RMS Accel. (below 0.6 Hz) Before vs. During OPM.

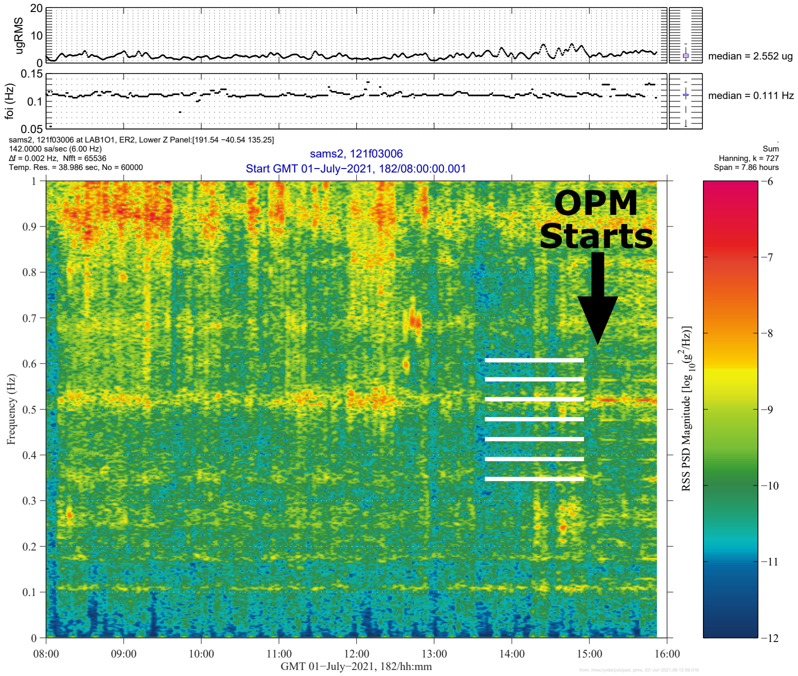

Fig. 1: Spectrogram showing Start of OPM to -XVV on GMT 2021-07-01.

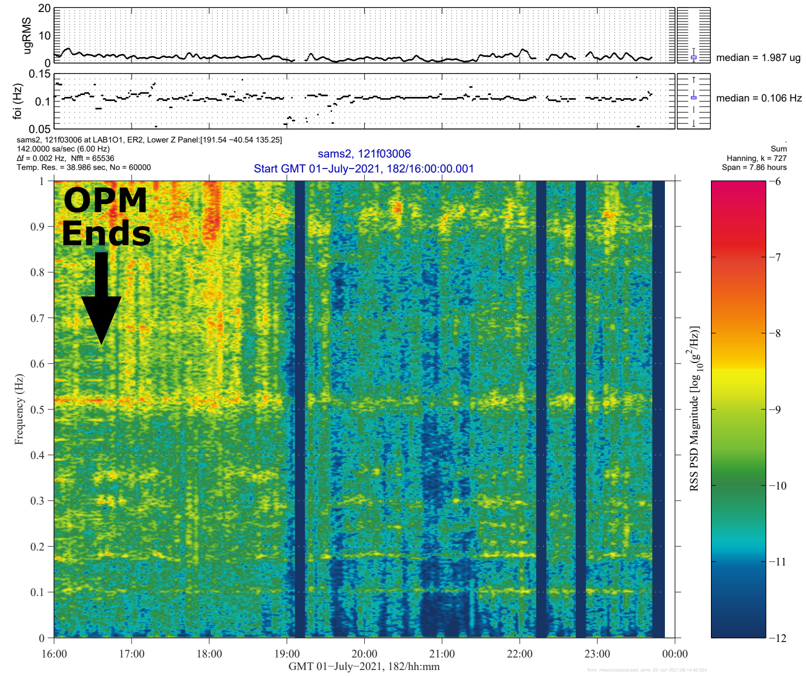

Fig. 2: Spectrogram showing End of OPM to -XVV on GMT 2021-07-01.

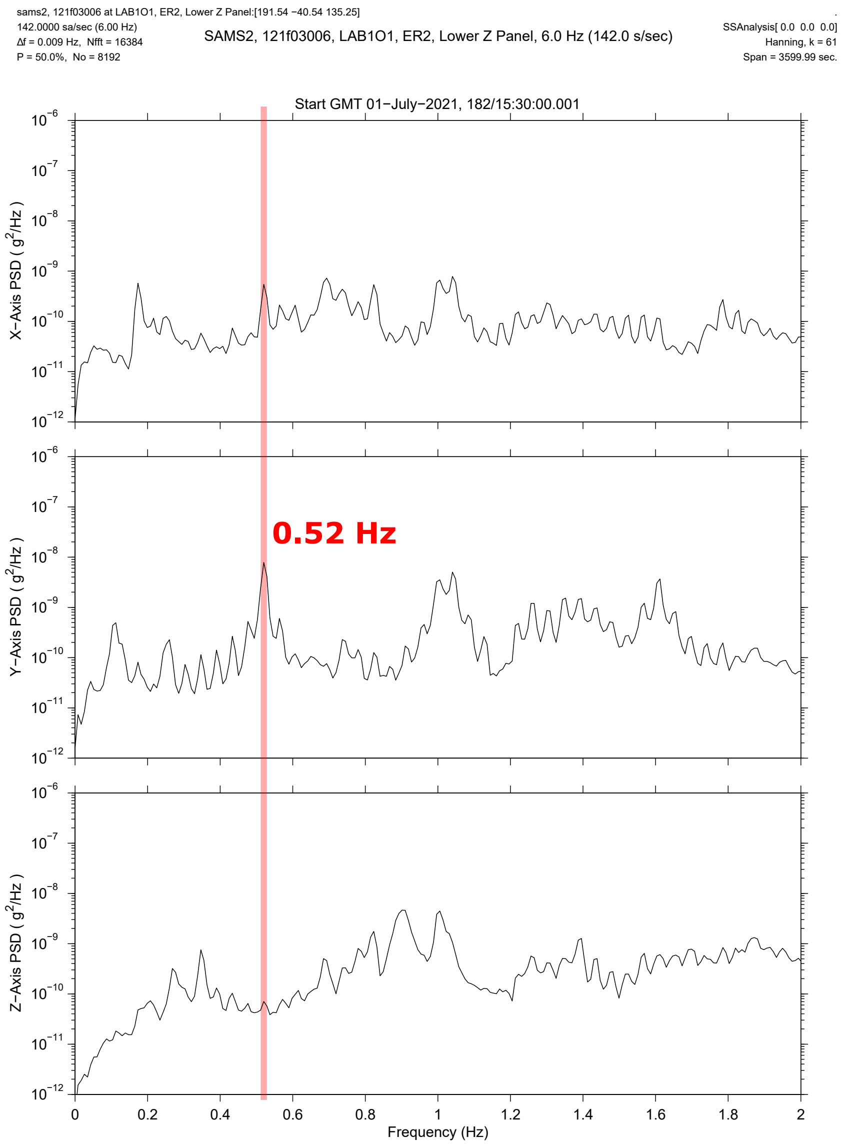

Fig. 3: Power Spectral Density (121f03) for OPM to -XVV on GMT 2021-07-01.

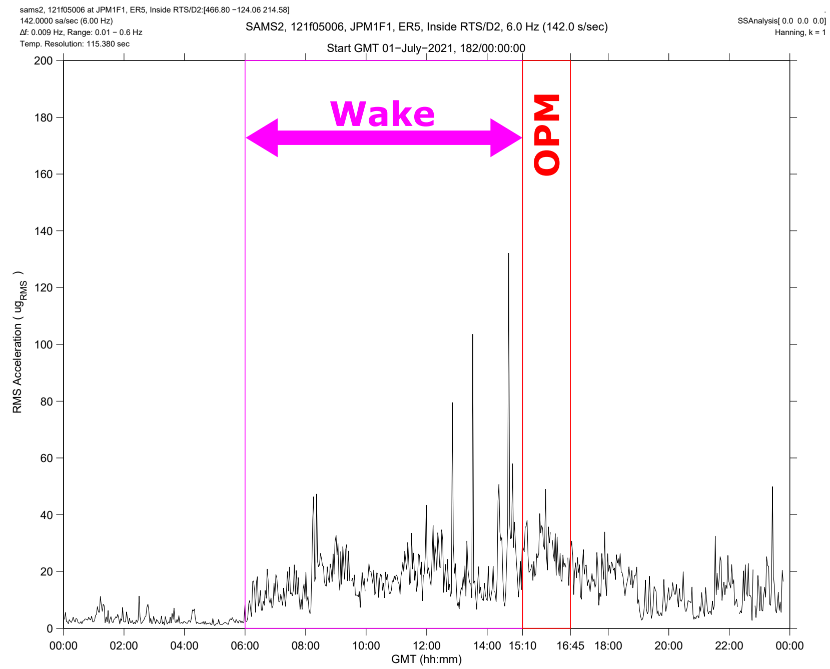

Fig. 4: Interval RMS (below 0.6 Hz) at 121f05 (JEM) for OPM.

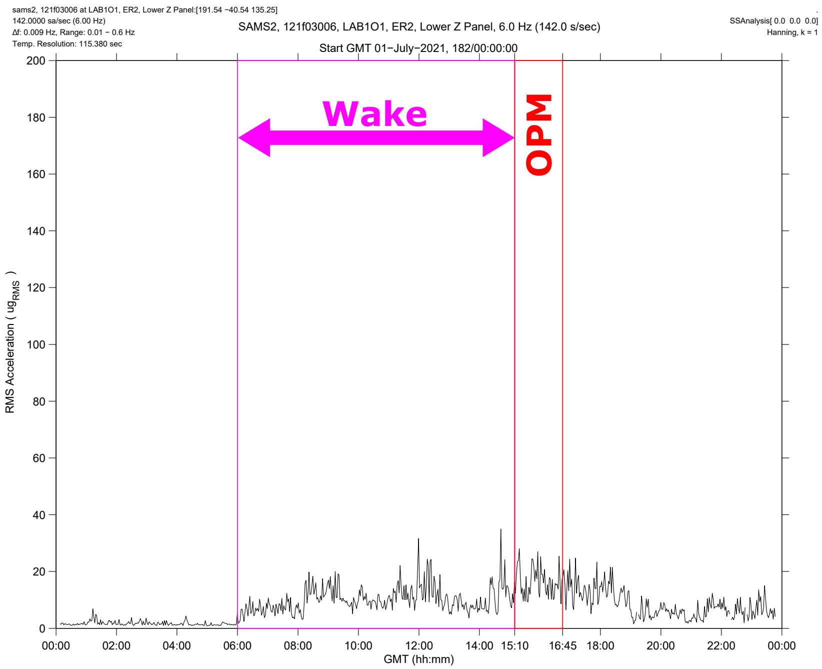

Fig. 5: Interval RMS (below 0.6 Hz) at 121f03 (LAB) for OPM.

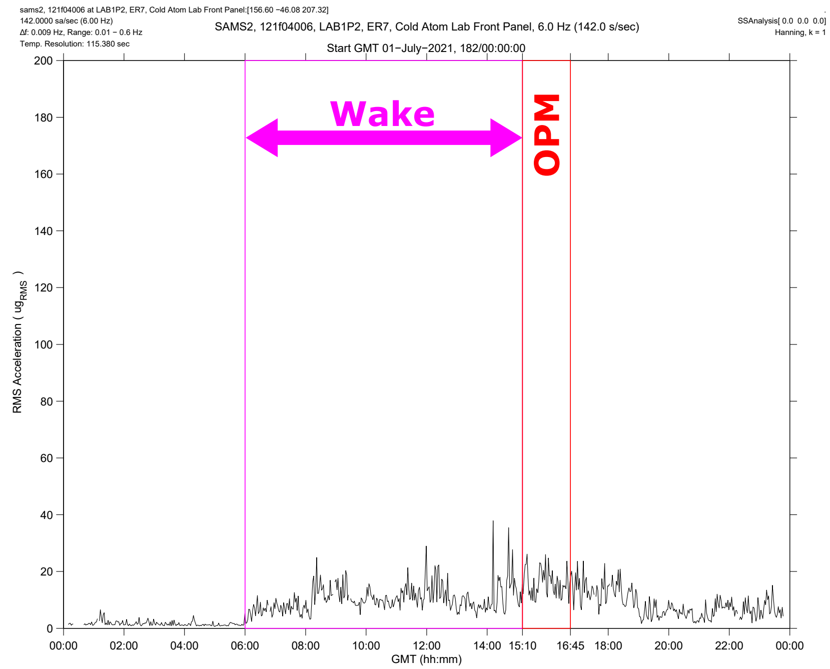

Fig. 6: Interval RMS (below 0.6 Hz) at 121f04 (LAB) for OPM.

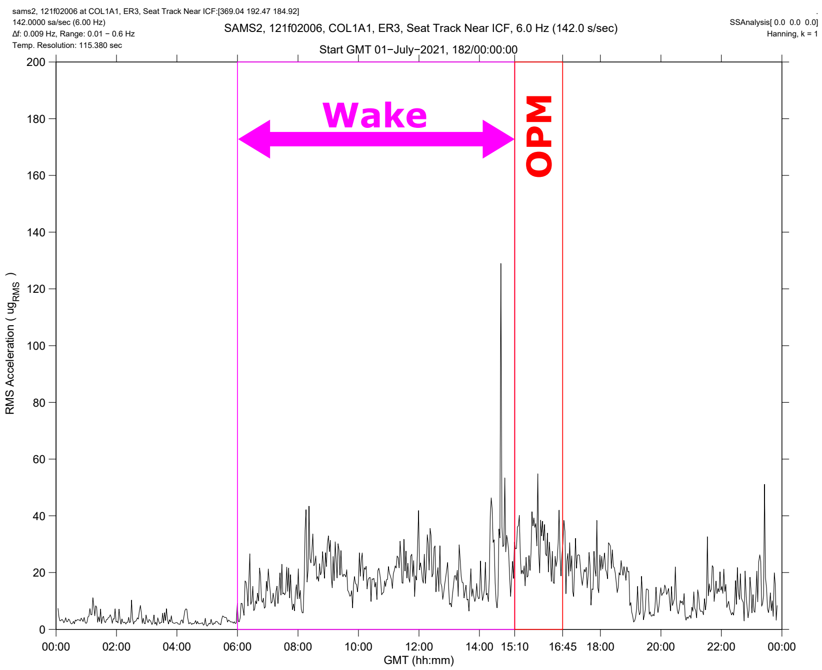

Fig. 7: Interval RMS (below 0.6 Hz) at 121f02 (COL) for OPM.

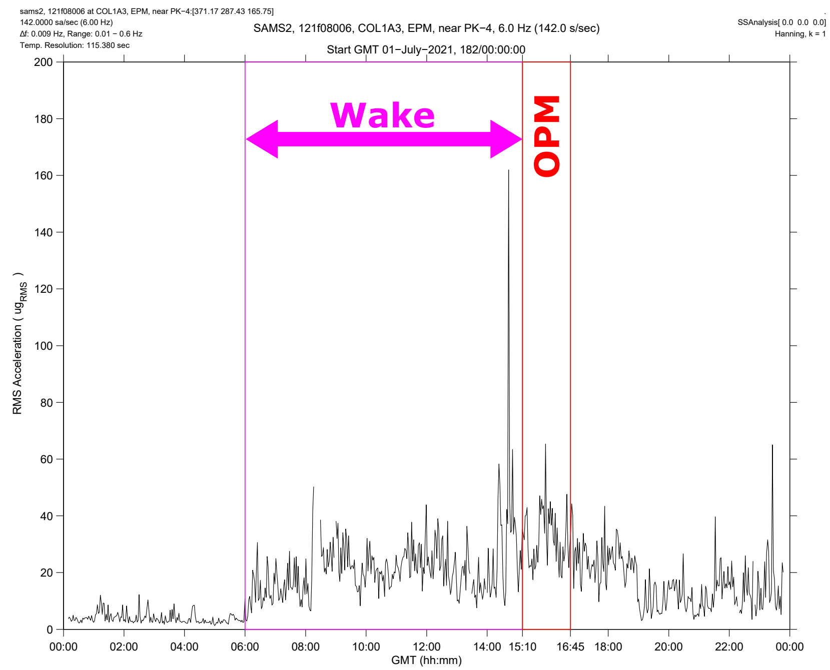

Fig. 8: Interval RMS (below 0.6 Hz) at 121f08 (COL) for OPM.