OPERATION OF THE INSIGHT SHORT PERIOD (SP) SEISMOMETERS DURING CRUISE.

J. B. McClean[1], W. T. Pike[1], C. Charalambous[1], A. E. Stott[1], T. Warren[2], S. Calcutt[2], I. M. Standley[3], P. Lognonné[4] and W. B. Banerdt[5]. [1]Imperial College London (South Kensington Campus, SW7 2AZ, London, United Kingdom, j.mcclean15@imperial.ac.uk), [2]University of Oxford, [3]Kinemetrics Inc., [4]Institut de Physique du Globe de Paris, [5]NASA Jet Propulsion Laboratory, California Institute of Technology.

Introduction: InSight (Interior exploration using Seismic investigations, geodesy and heat transport) is a NASA-led Discovery-class Mars lander. The mission will improve our understanding of rocky planet formation and differentiation by studying the seismic activity, subsurface heat flow, and orbital precession of Mars [1]. Launched on 5 May 2018, InSight landed in Elysium Planitia on 26 November 2018 and will operate as a seismic station for at least one Mars year.

InSight's main instrument, the Seismic Experiment for Interior Structure (SEIS) [2], has two types of seismometer to examine different ground motion frequency bands. Lower frequencies are studied by three Very Broad Band seismometers (VBBs), and higher frequencies by three Short Period microseismometers (SPs). During cruise, the SPs were operated for a total of 31.5 hours. The cruise data set verified that the SPs met their noise requirement and validated the approach used to determine the SP noise floor on Earth. The SPs observed attitude control thruster firings and spacecraft resonances, and are sensitive enough to detect micrometeoroid impacts.

The cruise data set: During cruise from Earth to Mars, the SPs were switched on three times: on 16 July from 15:44:56 to 15:55:20, on 19 July from 16:34:43 to 19:36:43, and on 29 August from 04:15:31 to 30 August 08:30:52 (all times in UTC). Although the vertical SP (SP1) was saturated during cruise as it requires Mars gravity to operate, the two horizontal SPs (SP2 and SP3) were unsaturated and returned velocity, proof mass position, and temperature data.

The velocity data from 16 July were downlinked at the same sample rate as the on-board acquisition, 100 Hz. The velocity data from 19 July and 29 to 30 August were first downlinked at a reduced sample rate of 2 Hz. For the 19 July data, it was possible to make requests for several periods to be downlinked at 100 Hz. These requests are listed in Table 1.

Sensor performance: During testing on Earth, the background noise was above the SPs' noise floor, preventing the noise floor from being directly observed. Therefore, a co-located reference seismometer was used to remove the background noise contribution from the SP signal. During cruise, the free-fall environment was quieter than any seismic vault on Earth and the background noise was below the SPs' noise floor. The lowest noise period in the cruise data set, in terms of the Amplitude Spectral Density (ASD) of the acceleration signal, was compared to the lowest noise observed during testing on Earth. The low-frequency part of the ASD was obtained from the longer duration 2 Hz data, and the high-frequency part of the ASD was obtained from the shorter duration 100 Hz data. Both horizontal SPs met their noise requirement. The SPs' transfer function was obtained using a calibration chirp.

ID	Priority (1 high)	Rationale	Start (UTC)	End (UTC)	Dur'n (s)
27	1	Calibration	16:42:00	16:47:00	300
32	6=	Thruster firing	16:51:14	16:52:54	100
33	6=	Thruster firing	16:53:45	16:55:25	100
29	3	M'meteoroid search	17:06:28	17:14:48	500
34	6=	Thruster firing	17:14:48	17:16:28	100
38	8	M'meteoroid search	17:16:28	17:24:48	500
35	6=	Thruster firing	17:42:12	17:43:52	100
36	6=	Thruster firing	18:12:35	18:14:15	100
30	4	Thruster firing	18:48:39	18:50:19	100
31	5	Thruster firing	19:14:15	19:15:55	100
28	2	Lowest noise	19:15:55	19:24:15	500
37	7	Lowest noise	19:24:15	19:32:35	500

Table 1: List of requests for data at 100 Hz from the 19 July 2 Hz data. Start and end times are on UTC date 2018-07-19.

The angular dependence of the acceleration noise in the plane containing the sensitive axes of the two horizontal SPs was quantified. The amplitude of the noise in this plane varies by a factor of two. This angular dependence aligns favourably with the orientations of the horizontal SPs as currently deployed on the surface of Mars: their most sensitive directions are not aligned with the lander.

Spacecraft dynamics: During cruise, InSight's attitude was maintained by four pairs of thrusters that kept the antennae and solar panels aligned with Earth and the Sun. The firings of these thrusters were the most prominent features in the horizontal SPs' acceleration time series. The horizontal SPs detected seven thruster firings during 19 July and 73 thruster firings during 29 to 30 August (Figure 1). The acceleration delivered by each firing was measured with ng resolution, allowing the delta-*v* as a function of time to be measured and the spacecraft trajectory to be reconstructed. The SP response to each thruster firing followed a similar pattern. Before each firing, the acceleration noise below 1 Hz was stable at approximately 1 ng. After each firing, the acceleration below 1 Hz decayed, falling past 4 ng after 10 s, before returning to approximately 1 ng.

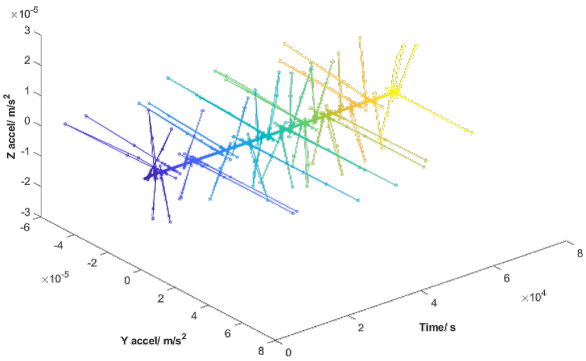

Figure 1: Acceleration during a 22-hour section of the 29 to 30 August data collection period, illustrating the frequency, magnitude, and direction of attitude control thruster firings. Color indicates earlier (blue) and later (yellow) data.

Each thruster firing excited various spacecraft resonances. The most prominent resonances were at 44.7 Hz ($\tau = 4.2$ s, $Q = 590$, attenuated by anti-alias filter), 33.9 Hz ($\tau = 1.0$ s, $Q = 107$), and 6.9 Hz ($\tau = 1.4$ s, $Q = 30$), with other lower-amplitude resonances identified at 45.9, 39.6, 35.2, and 13.8 Hz (Figure 2).

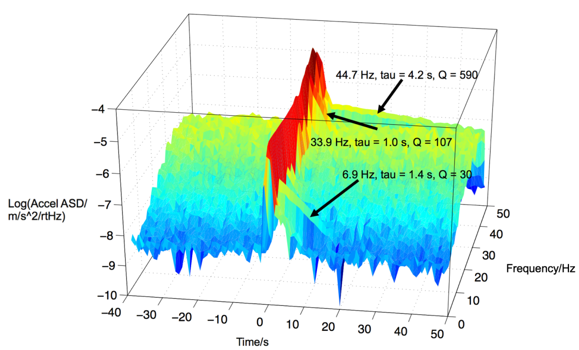

Figure 2: Spectrogram of a typical thruster firing, plotted as the log of the acceleration ASD versus time and frequency. The firing at time = 0 s injects broadband noise. Following the firing, the various spacecraft resonances can be seen decaying with time.

Micrometeoroid impact search: Applying an approach first used for the LISA Pathfinder mission [3], the SPs are sensitive enough to detect micrometeoroid impacts (SNR = 1 at a micrometeoroid momentum of 1.1 μNs), and therefore determine the micrometeoroid momentum in the plane containing the sensitive axes of the horizontal SPs. Assuming a SNR of 8 or greater is required to claim a detection, the estimated rate of detectable micrometeoroid impacts is one every 17 days on average. Although the total duration of SP operation during cruise was much less than this, a micrometeoroid impact search was performed. The acceleration time series was differentiated to jerk, peaks found in the jerk time series, and the peaks ranked in descending order of magnitude. This produced a power law of peak number versus peak magnitude, corresponding to the SP noise. Micrometeoroid impacts would then reveal themselves as peaks with magnitudes above this SP noise power law. Three candidate impacts were found using this method. For each candidate impact, the spacecraft momentum change was estimated by comparing the slope of the displacement time series before and after the candidate impact, and multiplying this change in velocity by the mass of the cruise stage. Assuming that the relative impact speed was 26 km s^{-1} (Keplerian orbital speed between Earth and Mars), and that they transferred all of their momentum to the spacecraft, the candidate impactor momenta were associated with micrometeoroids of masses $(2–3)\times10^{-7}$ g. The most commonly-used model of the interplanetary micrometeoroid environment, that of Grün et al. [4], estimates the flux of micrometeoroids with a mass equal to or greater than this to be 1.5×10^{-7} m^{-2} s^{-1}, or one every 15 days. Since the total duration of 100 Hz data examined was much less than this, the signals associated with these candidate impacts are more likely to be from sources internal to the spacecraft.

Conclusions: Operation of the SPs during InSight's cruise to Mars confirmed that the two horizontal SPs met their acceleration noise requirement, validated the technique used to determine the sensor noise floor on Earth, obtained the transfer function, characterized the noise environment of the spacecraft including thruster firings and spacecraft resonances, and demonstrated signal processing techniques for micrometeoroid impact detection.

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