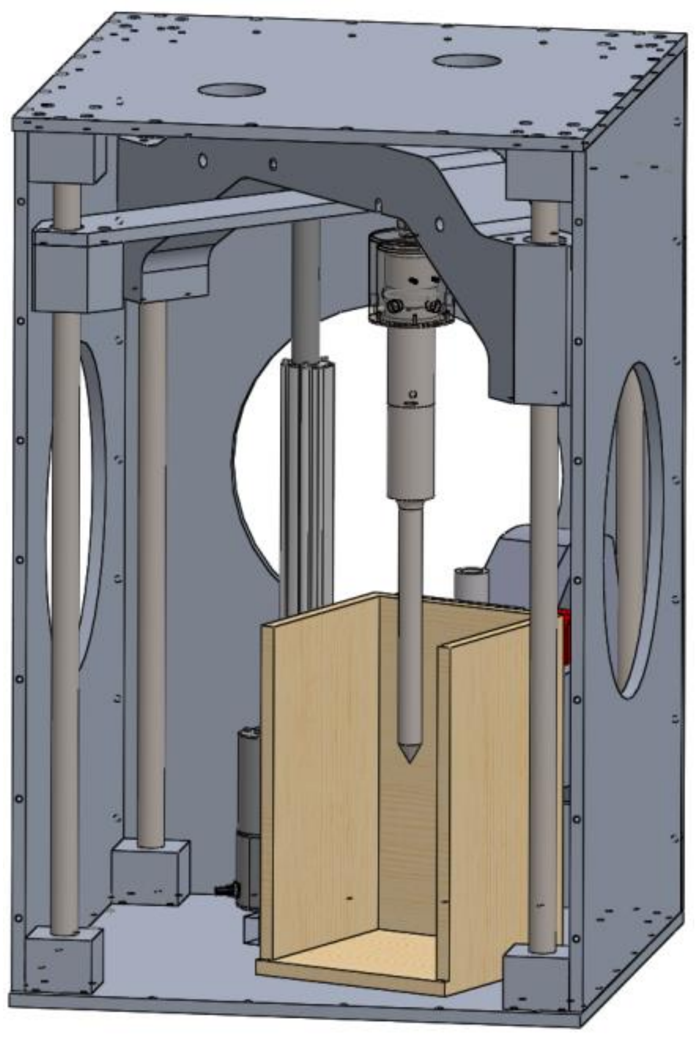
Ultrasonically Assisted Penetration Through Granular Materials

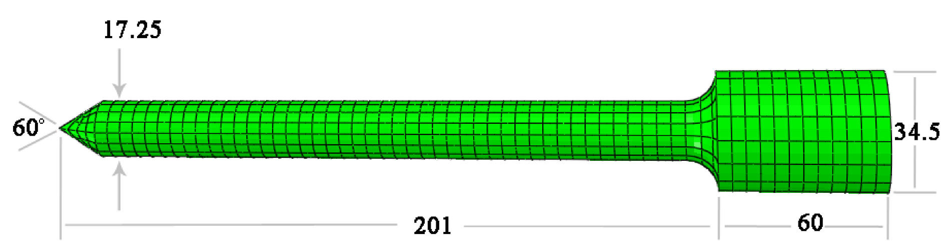
D. Firstbrook, K. Worrall, R. Timoney, P. Harkness, F. Suñol, and Y. Gao.
d.firstbrook.1@research.gla.ac.uk

1 Abstract

Gaining access to the subsurface of planetary bodies is troublesome for a number of reasons, but particularly due to the low gravity encountered resulting in a lower available weight of spacecraft. A lower weight-on-bit (WOB) often results in sub-optimal drilling, and without complex anchoring or thrusting systems a planetary lander can only impart as much force as it weighs. This work investigates the use of ultrasonic vibration in assisting penetration through granular material. Compared to non-ultrasonic penetration, required forces have been observed to reduce by over a factor of 12. Similarly, total consumed power can be reduced by 28%, depending on the substrate and ultrasonic amplitude used. Tests were also carried out in high-gravity situations, displaying a trend that suggests these benefits would strengthen in lower gravity regimes.

2 Experimental Parameters





Penetrator. A titanium probe (above) was designed to vibrate at 20 kHz, with a Langevin transducer providing excitation amplitudes from 0.4 to 10 µm.

Regolith. Several different testing sands were used during the experiments. SSC-1, SSC-2, SSC-3, and ES-3 were provided by the University of Surrey, in addition to a block paving sand from a local builders merchant, BP.

Sample reset. Care was needed when resetting the sand between each experiment, as the packing structure of the sand is altered after one run. For experiments in the lab, each sample of sand was reset manually by re-filled the container from a set height. For other experiments, the container of sand was vibrated for a long duration to ensure complete homogeneity. High density samples all used a vibrated the container to densify the sand.

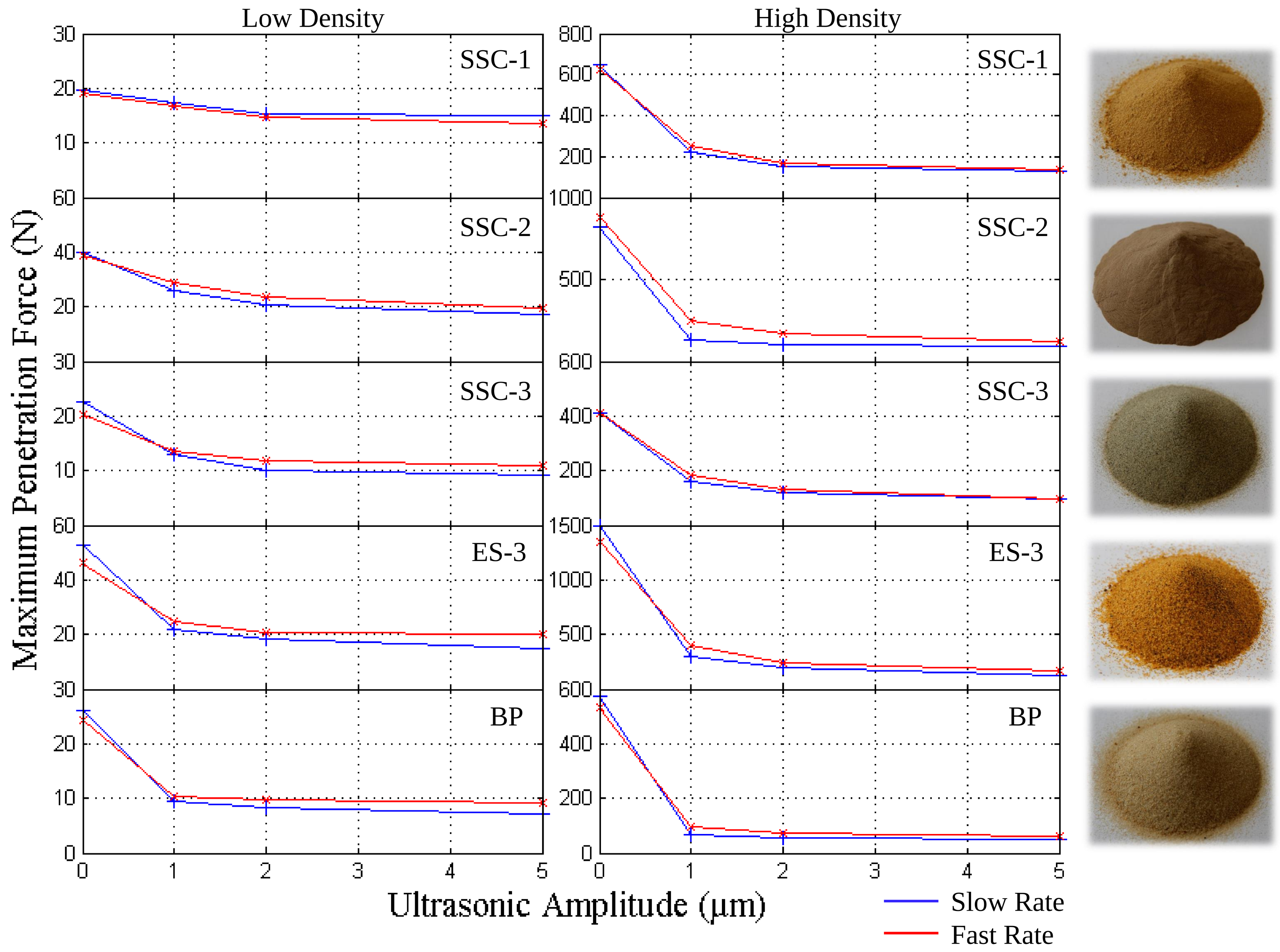
Penetration. A linear actuator provided the movement for penetration. Using different input voltages, a slow or fast penetration rate of 3 and 9 mm/s could be achieved. The penetration depth was measured by a potentiometer within the actuator, with a maximum depth of ~ 12 cm.

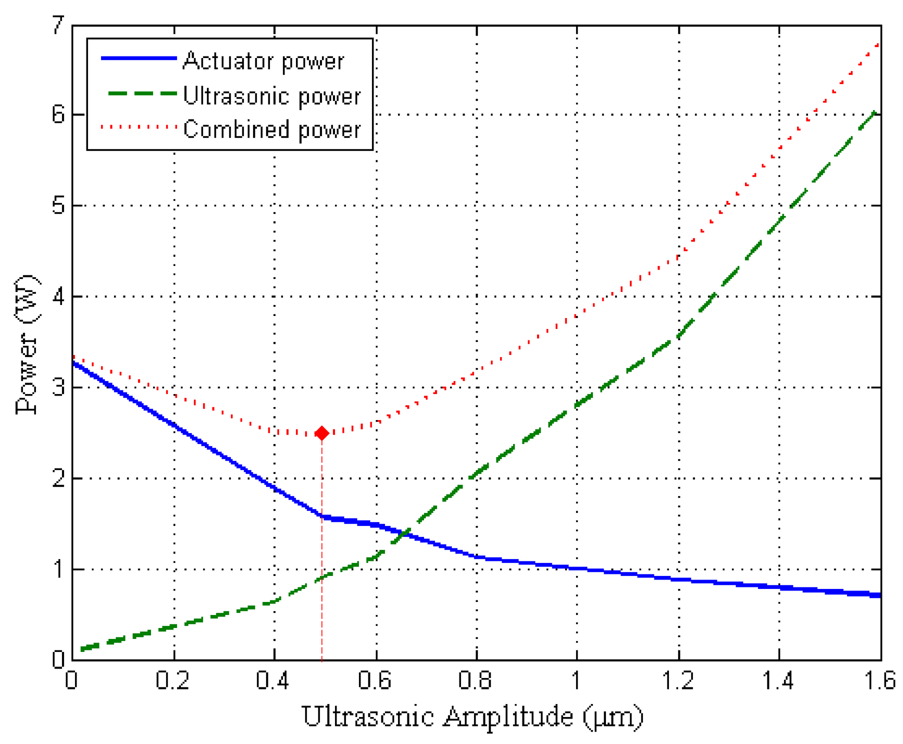
Power. The power consumption of the actuator was measured using the input voltage and current. The ultrasonic power consumption was an output feature of the ultrasonic power supply itself.

High gravity centrifuge. Tests were conducted in high gravity up to 10 g at the Large Diameter Centrifuge (LDC, below) at ESTEC facilities in the Netherlands as part of ESA's 'Spin Your Thesis' program. The rig shown above was used in the gondolas of the LDC.

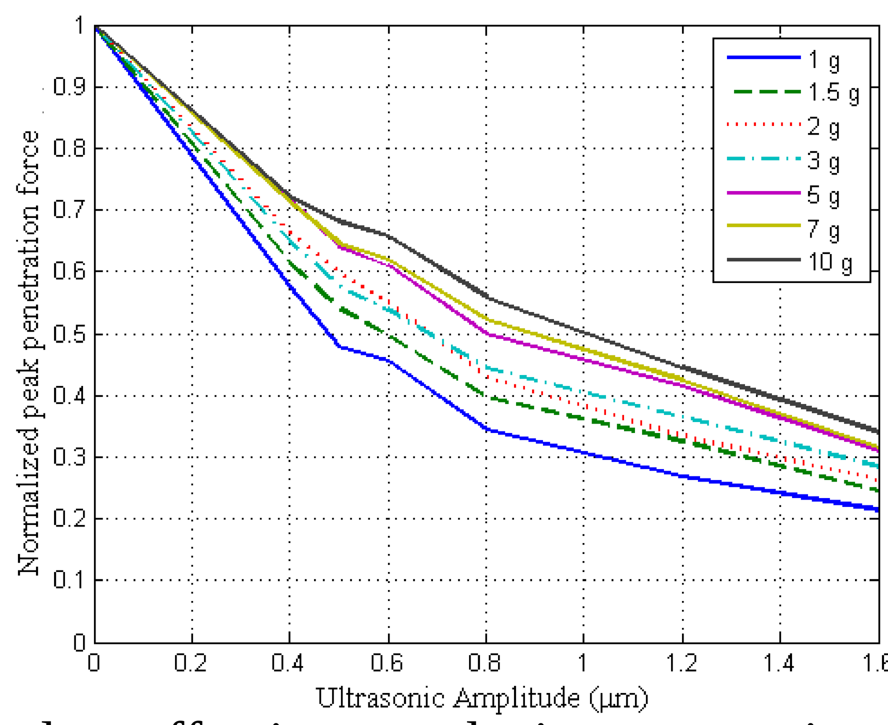
3 Results

Force. Initial tests covering a large range of ultrasonic amplitudes (0 – 5 µm) show a significant drop in peak penetration force with the lowest value of amplitude (1 µm). The greatest reduction, a factor of 12, occurred with high density ES-3 regolith, a large smooth grained sand. Further tests concentrated at amplitudes below 2 µm to understand the sharp transition.





Power. In addition to reducing the required overhead force, ultrasonics can also reduce the total power consumption. An optimum level of vibration can be found which balances the power consumption saved by the actuator, with the additional power consumed required by the ultrasonic transducer.



Gravity. Under high gravity, penetration forces increase. By normalising the peak force at every ultrasonic amplitude to the force encountered at 0 µm, we can see how much ultrasonics has reduced penetration force as a fraction, essentially showing the *specific effectiveness* of ultrasonic vibration in various gravity. The tests show that ultrasonics in higher gravities are less effective at reducing penetration force. Extrapolating this result signifies that ultrasonics could have an even greater impact in low gravity environments, and could potentially be used to great effect in lander missions.

4 Acknowledgements

The authors would like to thank the EPSRC for supporting the PhD work, the ESA Education for running the 'Spin Your Thesis' program, and the IPPW committee for accepting this poster and their assistance with attending this conference.