Microgravity Experiment to measure the Speed of Sound inside simulated Asteroid Regolith in the ISS environment.

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ABSTRACT

In impact threat assessments of planetary defense options, the aim is to understand how seismic waves travel through the debris, either modifying its shape or its surface. Seismic disturbances can destabilize loose material resting on the slope, causing downward flows. With the Microgravity Experiment for Asteroid Regolith Sound Velocity (MESSAR), it is proposed to measure the sound velocity within the simulated asteroid regolith in the microgravity environment of the International Space Station (ISS). The payload contains several granular samples of simulated asteroid regolith that will be used to measure the influence of grain size and confining pressure on the wave travel speed.

INTRODUCTION

Small asteroids in the near-Earth space are known to be so-called rubble-piles composed of granular material accreted through self-gravity (Walsh, 2018). Their study is of utmost importance both to our understanding of the formation and evolution of our Solar System and for assessing planetary defense threats and mitigation options. Of particular interest is the mechanical structure and dynamical behavior of these granular bodies, as gravitational forces and material cohesion and strength compete with rotational centrifugal forces and impact-induced dismantling. The asteroid material structure and strength, and in particular its response to impact-induced seismic waves, dictates the body's shape, its surface features, and potential activity (Quillen et al., 2019; Tancredi et al., 2016).

EXPERIMENT PLAN:

In order to achieve our project objectives, we will perform measurements both in the laboratory on the ground and under the microgravity conditions of the ISS. On-board ISS, we will measure the speed of sound in regolith samples for three grain sizes, 0.1 (fine grains, FG), 1 (MM), and 10 (CM) mm. We provide more details about the choice of grain sizes below.

Table 1 summarizes the experiment parameters we plan to vary in order to achieve our project objectives. As sound wave measurements in granular material are known to have a large variance, we will perform 10 measurements for each parameter set. This will allow for the determination of error bars and provide a quasi-statistical value confidence for our measurement. This leads to a total of 30 measurements to be performed while the payload remains on the ISS. These 30 measurements will be reproduced in our laboratory on the ground in order to provide for 1g reference measurements.

Parameter	Grain size	Total
# of values assumed	3	3
Total over investigation		30

Table 1: Summary of the number of measurements to be perform to complete the investigation on-board the ISS. The same number of measurements will be performed in the laboratory on the ground for comparison with the microgravity data.

To achieve our project objectives, we produce three types of regolith simulant samples: fine grains (~0.1 mm), mm-, and cm-sized grains. These granular samples are prepared from a high fidelity asteroid regolith simulant (Britt et al., 2019) into irregular grains most representative of material found at the surface of asteroids (Figure 1). The choice of grain sizes is driven by the data collected in-situ on actual grain sizes at the surface of asteroids by space missions (e.g. Lauretta et al., 2019). Simulant samples as shown in Figure 1 are routinely prepared at Co-I Brisset's laboratory at the Florida Space Institute (FSI) and will be provided to IAUPR for the proposed project.

Figure 1 Sample material prepared for our investigation (cm-sized grains, left) compared to regolith at the surface of asteroid Bennu as imaged by the OSIRIS-REx mission (right). While the scale of both pictures are different, we show that our simulant samples represent well the grain shape found on asteroids.

The implementation of the MESS investigation is performed by generating sound waves within regolith simulant samples and recording their arrival at two different distances from their source. To this purpose, three sample tubes are outfitted with a speaker on one end, a microphone in the middle of the tube, and a second microphone at the other end (Figure 2). The microphone located within the sample is affixed to the tube side walls via a cross-like structure minimizing interference with the regolith response to the sound wave. In the current version of the experiment, the tubes have fixed lengths: 50 mm for fine and mm-sized grains and 100 mm for cm-sized grains. This configuration only allows for one confining pressure in each sample.

RESOURCE REQUIREMENTS

The experiment will be fully automated for the performance of measurements. Crew time will only be required for the installation and de-installation of the payload in its rack/location on-board ISS. For this we foresee no more than a total of 40 min.

	Requirement	**Units**
Dimensions	10x10x30	cm
Mass	6	kg
Power	10	W
Data	5	MB/day
Crew Time	0.5	h
Duration Stay on ISS	6	months
Time of Flight	Anytime	

Table 2 Resource requirement summary for MESS payload on ISS.

METHODOLOGY

To design the prototype, we took into consideration the amount of sample to be analyzed and the space that had to be left to organize the electronic components. The design consists of 4 6061 aluminum tubes inside which 3 of them carry the sample and one of them will be empty. The complete structure of the design is composed of 6061 Aluminum and consists of 5 parts that hold all the structure.

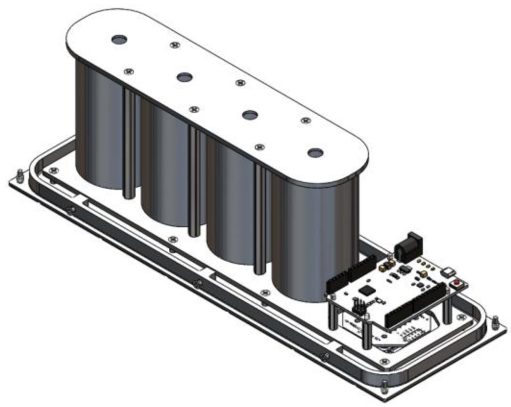

Figure 2: Internal Payload Design

PAYLOAD DESIGN

The payload is composed of 5 parts that make up the structure of the system. As shown in Figure 3, the main structure is the "3U End Cap". This base supports the entire payload structure and has the dimensions of a 3U satellite (100mm x 100mm x 300mm). It is composed of 6061 Aluminum and has a mass of 320g.

Above the main base is attached the Payload Structure Base that holds the tubes. It is made of 6061 aluminum and is attached with 8 Stainless Steel screws to the End Cap Connector. In addition, it has 6 Stainless Steel Standoff that support the 4 tubes by means of the Upper Payload Frame.

Between the Payload Structure Base and the Upper Payload Frame are the 4 aluminum cylinders. These measure 50mm in diameter and 100mm in height.

At the top is the Upper Payload Frame. It is made of 6061 aluminum and is fastened to the Stainless-Steel Standoff with 6 screws. The main function is to seal the aluminum tubes and hold the microphone that will be taking the sample.

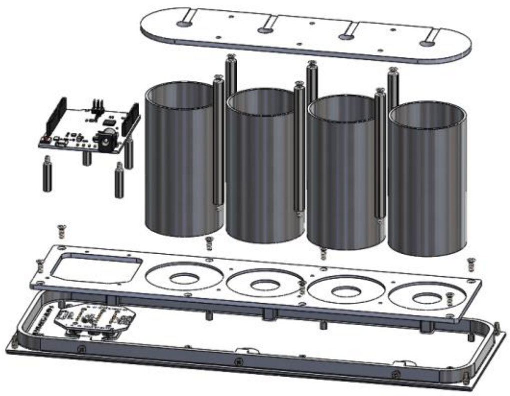

Figure 3: MESSAR Payload Explode View.

INTEGRATING AND TESTING

The MESSAR experiment runs inside the ISS. It basically consists of 4 tubes 2 inches in diameter and 4 inches long. Three of these tubes will be filled with regolith of different sizes, 0.1 (fine grains, FG), 1 (MM), 10 (CM) mm and one of these will be empty. A frequency of 10 Hz will be generated by each speaker and detected by two microphones located at a known distance. The time it takes for the wave to travel through the regolith is measured and the speed is calculated. This procedure will be performed on each tube 20 times for a total time of 40 minutes. The data will be stored on a micro SD card and transmitted through the serial port at a speed of 115200 baud.

RESULTS

The payload experiment will be conducted both on the international space station and on Earth. During the beginning of the research, several tests were performed on the ground to see if the microphones receive the sound. As shown in Figure 4, a test was done by sending a sound frequency and the microphones received it at 236m/s. This test was done with the container filled with the 10 (CM) mm sample.

DISCUSSION

The proposed payload design will be carried out experiments on the International Space Station (ISS). The design is still under development and is currently undergoing ground testing. The idea of the experiment is to understand how seismic waves can affect asteroid surfaces. It is also intended to study whether seismic waves can change the shape of asteroids if they are composed of small pieces.

CONCLUSION

In summary, the payload is expected to be launched to begin sampling at the International Space Station. We hope to be able to measure and collect as many samples as possible across the different regolith sizes. The data obtained will be analyzed in order to understand if sound can affect the shape of asteroids and also to see if in the future we can predict the path of near-Earth asteroids.

Acknowledgments

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APPENDIX

Figure 4: MESSAR Payload

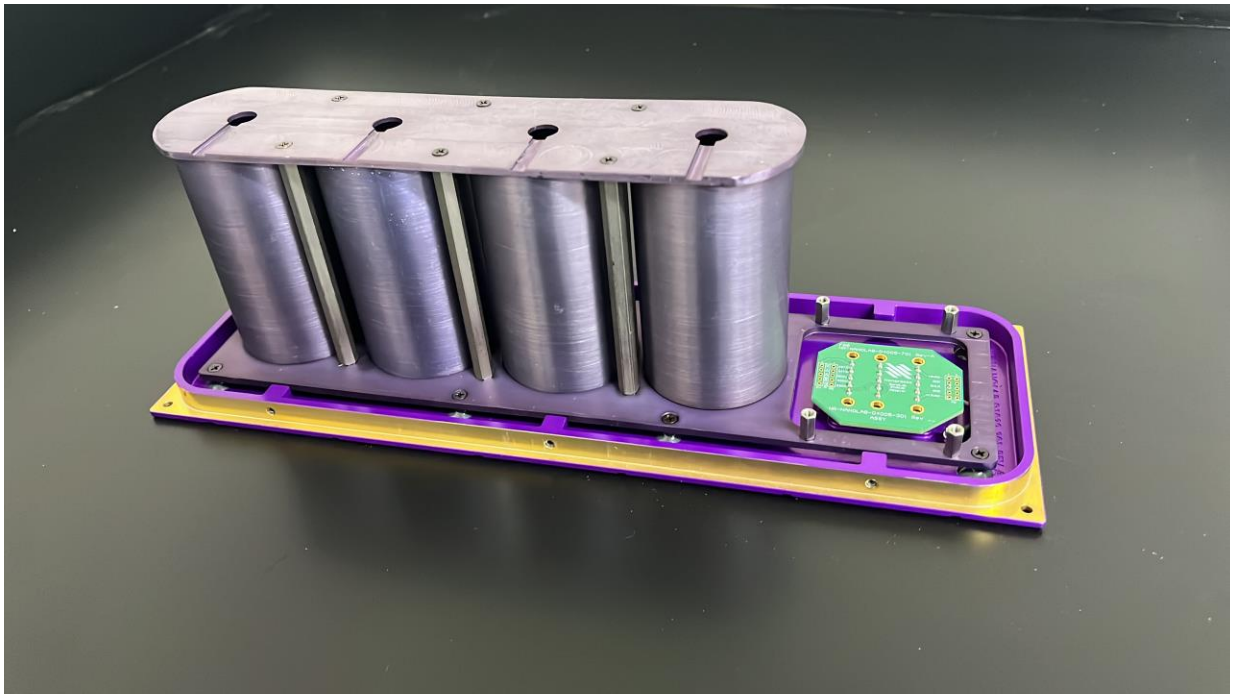

Figure 5: Internal MSSAR Payload

Component	Quantity	Unit Mass (g)	Total Mass (g)	Length (cm)	Width (cm)	Height (cm)	Usage	Manufacturer	Part Number	Spec Sheet (Y/N)
Speaker	**4**	**12**	**48**	**2.63**		**1.09**		**Soberton Inc**	**E-2702**	**Y**
polypropylene							membrane			
Metal							Cover			
Magnet										
Electret Microphone	**4**	**0.5**	**2**	**2.10**	**1.40**	**1.00**		**adafruit**	**1063-MAX4466**	**Y**
FR-4							PCB board			
Metal							**Cover**			
Main Board										
Raspberry PI Pico	**1**	**10**	**10**	**5.10**	**2.10**	**0.30**		**Rasberry Pi**	**SC0915**	**Y**
Micro SD Card	1	2	2					DFRobot	DFR0229	Y
3U_End_CAP	**1**	**320**	**320.00**	**31.12**	**10.16**	**1.21**		**Nanorack**	**D1032**	**Y**
Machine Screw	6	0.51	3.06	0.64				MilitaryFastener	NAS1102E04-4	Y
End_CAP_connector	**1**		**0.00**						**D4005**	
Spring Loaded Connector	3		0.00					MILL-MAX	858-22-005-10-011101	
Blind Threaded Standoffs			**0.00**	**0.79**				**PennEngineering**	**BSOS-440-10**	**Y**
3D_Housing	1	1024.63	1024.63	31.12	10.16	10.00		Nanorack	D1031	Y
Payload_Structure_Base	**1**	**114.8**	**114.80**	**25.58**	**7.24**	**0.32**				
Stainless Steel Phillips Screws	14	0.36	5.04	0.95				McMaster	96877A209	
Threaded Hex Standoff	**6**	**2.97**	**17.82**	**9.52**	**0.42**	**0.42**		**McMaster**	**91075A228**	**Y**
Cylinder	4	58.91	235.64	8.89	0.64	0.64				Y
Upper_Payload_Frame	**1**	**67.8**	**67.80**	**22.23**	**5.72**	**0.32**				**Y**

Table 3: MESSAR Hardware Component