



# Venus Seismic Instrumentation

Derek Dayan, Janet Felix, and Evan Wells

Mentors: Il Sang Ahn, Robert Herrick, Tibor Kremic (NASA)  
Senior Design ME F486, Mechanical Engineering Department, University of Alaska Fairbanks



## Background

The U.S. National Aeronautics and Space Administration (NASA) is planning an unmanned mission to Venus to figure out what its crust is made of and to learn more about the extreme conditions and desolate landscapes of this solar system's hottest planet.

The conditions on Venus are challenging for a design to withstand temperatures approaching 900°F, pressures 90 times greater than on Earth, and clouds to form sulfuric acid precipitation. Previous missions to Venus have been conducted with varying success. Most notably, a few of the Russian Venera landers could land on the surface to successfully take measurements and photographs.

The Seismic and Atmospheric Exploration of Venus (SAEVe) mission is an innovative endeavor because conventional techniques, such as insulation or cooling equipment will not be implemented. These missions aim to develop hardware to operate at local ambient conditions. The seismometer package will require a mechanism to level the sensors to optimize data collection.

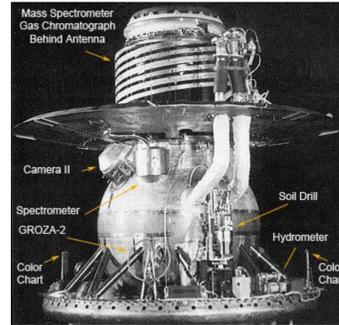


Figure 1: Venera Lander

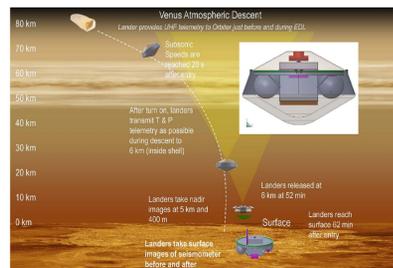


Figure 2: The Lander descent to Venus

## Objectives

The objective of this project is to design a seismometer package that will resist environmental conditions like wind and high temperatures, hold the sensors in an appropriate orientation, and transmit motion from the ground to the sensors. The scope of this project will ignore the high tech instrumentation used by NASA for its SAEVe missions, but will focus on deployment of a correctly oriented seismometer package.

The seismometer package must meet the following requirements:

- Dropped from the lander in its desirable orientation
- Instantaneous leveling to the sensor upon touchdown
- Transmit vibrations from the ground to the sensor
- Minimize parasitic noise from the environment including lander

Design within the scope of following constraints:

- The seismometer package must fit within a 10 cm cube
- Materials must withstand 500°C (surface temperature)
- Weight limit of 2.5 kg

## Design Concepts

Each team member developed their unique design concept for the seismometer prototype. One member proposed a saucer-shaped design with a gimbal suspension system for stability and sensor leveling. Another suggested a spherical shape mechanism to minimize vibration distortion. The third member experimented with a cubic shape to incorporate a gimbal leveling system for varied terrain adaptability.

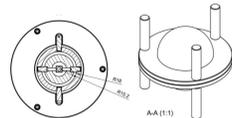


Figure 4: Saucer Drawing

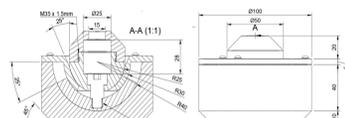


Figure 5: Spherical Drawings

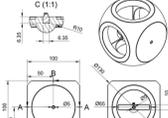


Figure 6: Cubic Drawing

## 3D Printed Prototypes

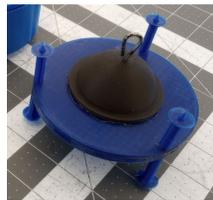


Figure 7: Saucer Package

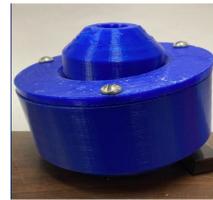


Figure 8: Spherical Package

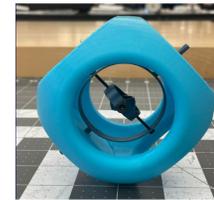


Figure 9: Cubic Package

The Saucer focused on a low center of gravity and a small wind cross-section. Inside the protective dome in the middle, a 2-axis gimbal suspends the sensors, allowing them to be held level regardless of surface conditions. The design is top-to-bottom symmetrical to account for possible flipping during the final drop.

The internal Spherical geometry of the package is intended to deliver seismic vibrations directly to the sensor with minimal distortion that any springy components may influence. A concern to this design is a large body that may dominate the sensibility known as transmissibility.

The Cube allows the package to land on any side or angle, ensuring adaptability to varying surface conditions. The gimbal leveling system inside ensures that the sensors remain level regardless of the landing orientation. Note: The photo above depicts the system opened for visibility. A final product would be fully enclosed.

## Proceeding

The process involved in testing the seismometer prototypes was done systematically under a variety of different surfaces. Testing in a controlled environment using a bin filled with tamped-down sand, which was leveled with cinder blocks overlaid to create a stable testing surface. The main goal is to identify what worked best in each of the three prototypes and to proceed with interpreting the experimental data to describe the features of each design. This process will aid in the recognition of which features may or may not enhance a future iteration.

Surface Variations:

- Three different surface conditions were tested: flat cement, 3/8 inch gravel, and a crushed assortment of charcoal.
- Six cement blocks were arranged to simulate a flat terrain for the initial testing phase.
- Gravel and charcoal were chosen to simulate rough and rocky terrain.

Photographic Documentation:

- Two phones were strategically positioned around the drop rig to capture side and front views, post-dropped.
- The phones were securely fastened at consistent heights to view the sensor leveling mechanism. Each phone lens is 13 inches from the drop pin location, forming two perspectives.
- Markers using green tape designate placeholders for equipment to ensure repeatable data collection.

Data Collection:

- Each prototype underwent a series of ten drop trials on each surface condition to assess its performance.
- A datum line on the backdrop facilitated a reference to a level world. Flashcards were used to timestamp each photo for record-keeping of both perspectives per test interval
- Photographs were taken after each drop to document the angular displacement of the sensor leveling mechanism and as well to the landing orientation. A post-processing analysis will use the photos to develop an order of determination for the next iteration.



Figure 10: Test Setup



Figure 11: Flat Surface



Figure 12: Gravel Surface

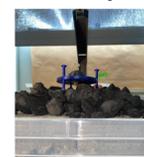


Figure 13: Charcoal Surface

## Order of Determination

		Drop Test Performance					
		Crushed Charcoal Surface					
IN	Tolerance	Spherical Package		Cubic Package		Saucer Package	
		% Reliability	% Reliability	% Reliability	% Reliability		
0.5	+/-1 degree deviation to datum	0	0	0	0	1	10
0.5	+/-5 degree deviation to datum	0	0	0	0	3	30
0.1	datum	1	10	5	50	2	20
0.5	slight landing	4	40	6	60	8	80
Factor of Anomaly		Spherical Package		Cubic Package		Saucer Package	
0.5	+/-1 degree deviation to datum	3	30	1	10	0	0
0.5	+/-5 degree deviation to datum	5	50	4	40	4	40
0.1	datum	2	20	0	0	2	20
0.5	slight landing	10	100	8	80	10	100
Results		Spherical Package		Cubic Package		Saucer Package	
Overall Percent Reliability		10.2 % Overall Reliability		10.3 % Overall Reliability		10.3 % Overall Reliability	
		Mechanical Advantage					
VENUS VIBE CHECK	Design Determinate	Spherical Package		Cubic Package		Saucer Package	
		Number of possible	TOTAL	Number of possible	TOTAL	Number of possible	TOTAL
		Operating Phases	1	Operating Phases	4	Operating Phases	1
		Failures requiring Control Variables	1	Failures requiring Control Variables	4	Failures requiring Control Variables	1
		Unstable Conditions	NO GO	Unstable Conditions	NO GO	Unstable Conditions	NO GO
		Flaking	Flaking	Flaking	Flaking	Flaking	Flaking
		Rolling	Rolling	Rolling	Rolling	Rolling	Rolling

Figure 14: Order of Determination

To determine which features best are suited for an iterated version; a tabulated method is derived from the analysis conducted in the proceeding. The series of tests was determined by sets of 10 drops per surface per design. Each interval of 10 drops per surface condition, has a record kept by tallies based on landing in the intended operating position. Another grouping of tallying is listed above the landing orientation is for the angle of deviation to each mechanism. Graphical analysis was done based on a datum line to represent level conditions and compared to the final placement of the leveling mechanism. Listed beside each placeholder is a percentage of reliability out of the 10 drops. An overall percent reliability is determined after completing all of the tests and processing the graphical analysis. The overall reliability has an accumulation of all of the tests for each design to average together all of the qualities observed based on the data. A factor of anomaly is included in the calculations to be assigned to each category, in an account for the results of interest as opposed to undesirable results. For instance, a higher factor of anomaly is assigned to a final position within a degree of deviation to increase the percent of reliability, whereas a lower factor of anomaly is assigned to a higher angular deviation to decrease percent reliability. The mechanical advantage section on the bottom region of the analysis is designed to provide any further details such as potential situations each geometry may influence based on the series of tests.

## Metal Prototype

Out of the three prototypes, the team decided to manufacture the saucer design because it is the simplest to manufacture. The spherical design would require very precise manufacturing due to its intricate sliding surfaces, while the cubic will be challenging to shape metal to the desired form. The three-legged feature in the saucer design will provide a test subject to compare the post and pre-iterations.



Figure 15: Saucer Prototype

## Next Iteration

The next iteration of the seismic package will include features from all of the designs. The gimbal mechanism will enable degrees of freedom in synchronous with the spherical surface at the base of the package. Resembling a 3 dimensional internally acting pendulum, to range within 40 degrees in any direction. The next iteration has micrometer scale accuracy for calibrating the gimbal concentric to the spherical base. Another improvement is the ability to lock all the set screws in place after calibration is complete. The coupler connected to the accelerometer has fine adjustment to establish contact with the spherical surface.

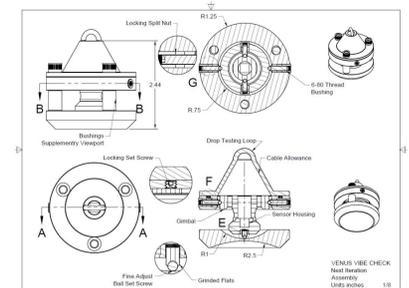


Figure 16: Iterated Design