FUTURE PROBE INSTRUMENTATION IN TITAN: SEISMOGRAPH?

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ABSTRACT

The only extraterrestrial body we have seismic data for is the Earth's Moon. In this work we examine the advantages and disadvantages of the placement of a seismograph on Titan's surface, as part of a landing probe payload. Thus, we study the heritage of Earth-Moon experiments, technical requirements and restrictions (like weight, power and data transmission), possible areas of location and major science goals of a seismic experiment and its use in future missions.

1. INTRODUCTION

The Cassini-Huygens mission has made exciting discoveries at the Saturnian's system and especially at its largest satellite, Titan. The observations revealed several scientific questions and new frontiers for science. Therefore, the Cassini-Huygens mission achievements encourage scientists to discuss about a future mission to Titan and its payload.

Several models have been proposed to describe the structure of the interior of every rocky planet. The study of geological processes and comparative planetology can resolve problems concerning the origin and the evolution of planet Earth and try to predict future geological events.

The proper geological model for each planet can be defined only by *in situ* measurements. Since Titan is the second largest moon of the solar system it may be representative of other rocky planetary bodies and understanding its internal structure may allow scientists to gain insight into the structure of an entire class of moons and planets. Past experiments on a planet's surface can show which instrumentation can be used as part of the payload of a future mission.

Ground vibrations give data for the nature of the subsurface material, its structure and its chemical composition. Ground vibration on Titan may be due to the local or global tectonic field, meteoroid impacts and moon's tidal deformations induced by Saturnian's gravity field and the temperature and pressure fluctuations.

After the successful landing of the Huygens probe, it is known that Titan has a relatively soft solid surface [16]. Thus, it seems possible to send another lander in order to study the surface and the subsurface material.

This presentation has been generated for the purpose of studying possible problems and scientific achievements of a seismic experiment on Titan. We are trying to give all necessary information and system requirements of seismic equipment included in a future space mission on Titan. The main subjects of this presentation are the following:

a. Description of the seismic instrument, its hardware architecture and its technical requirements.
b. The environmental conditions on Titan's surface which all the instruments of the probe has to face up to proper operation.
c. Extreme limitations of choosing the proper location for the seismic experiment.
d. Experience gained from the Moon seismic experiment.
e. Problems and risks of a future seismic experiment on Titan.
f. Major science goals.

2. DESCRIPTION OF THE INSTRUMENT

The seismograph is the basic instrument for measuring the ground vibration simultaneously. It contains the seismometer and the unit which recording the signal. The seismometer consists of 3 sensors placed in the same sealed case. The sensor is a pendulum, which moves from its equilibrium position according to the ground movement. Each sensor can measure any ground motion in a frequency range of 0.001 Hz to 100 Hz usually, at the North/South, East/West and vertical component in orthogonal system. Both low and high frequencies can be recorded by broadband seismometers on Earth. Newer seismographs measure ground movements smaller than 1 nm. There are several kinds of these instruments depending from the surface's location.

Seismic instruments will extend our knowledge of planets' interior and geological processes at the Solar System and we can conclude more about the origin and the evolution of our planet.

2.1 Instrument's specifications – Technical requirements

Table 1 below indicates the seismic instrument's specifications. To fill this table we consider the specifications of the shortest modern seismic instruments, which operate in extreme conditions on Earth like deep ocean floor [13] and sensors, which can be found easily at the market.

Table 1- Seismic Instrument's Specifications

Sensors • N/S • E/W • Vertical	Mass	0.200g each
	Velocity bandwidth	0.001-100Hz
	Operational temperature	94K
Power	Batteries	0.32W

2.2 System Hardware Architecture

Fig. 1 shows the basic functional procedure of a seismic instrument on Titan according to the requirements above:

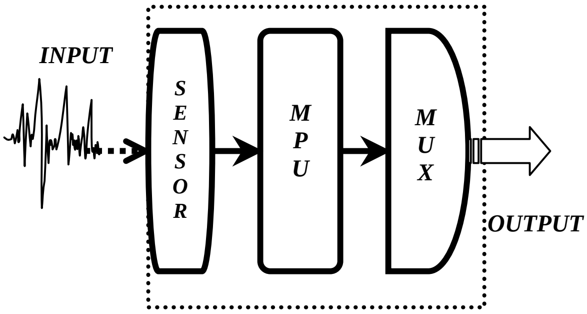

Fig. 1. Functional procedure of a seismic instrument on Titan

The ground vibration is the input to the system. If the ground vibrates in a range of 0.001 Hz to 100 Hz it will be recorded by each one of the 3 sensors. The sensor system contains a transducer, the device that converts the signal from motion into electrical form. A piezoelectric accelerometer can be used as a transducer to sense any weak or strong ground motion in a low frequency range (up to 100Hz) without using extra power to operate [7].
The signal of the sensor will flow at the Main Processor Unit (MPU) of the system. The MPU is responsible for the operation, the administration and the maintenance of the instrument and contains the core of the application software. After having received and recorded the signal from the MPU, it will be transferred at the next component of the instrument, the Multiplexer (MUX) by using a line interface circuit, which provides the connectivity between MPU and MUX.

At the MUX, data files will be compressed, converted to the right format and prepared for transmission. Because of the continuous function of the seismograph, a service for bulky data needed. The transmission frame protocols will be defined like the protocols of the rest lander's instrumentation. All the components inside the dashed line in Fig. 1 are parts of the same physical equipment, the seismograph.
Fig. 1 provides in a simplified manner the configuration of the system and is only included to ease the understanding of its function. It should not be seen as exhaustive representation of the operational infrastructure of the instrument.

3. ENVIRONMENTAL CONDITIONS

Future mission's instruments will operate in abnormal physical conditions during its descent and after landing on the Titan's surface. To achieve the seismograph's accuracy in a location at Titan's surface, the following environmental factors have to be considered:

Temperature: The surface temperature on Titan is determined to be 93.65 ± 0.25K as reported by the Huygens Atmospheric Structure Instrument (HASI) of the Huygens probe [6]. Thus, the mechanical and electronic part of the instrument must be protected and operate in such low temperatures. Moreover, the instrument will face fluctuations in temperature in a range of 70 to 200K [6] during the lander's descent and after landing. Because of the nature of its sensors, special thermal shield for the seismic instrument will be needed.

Pressure: The mean pressure on Titan's surface is determined to be 1.467 ± 1 hPa [6]. This value will can be afforded successfully.

4. PROPER LOCATION FOR THE SEISMIC EXPERIMENT

The ideal location for the placement of a seismic instrument will ensure that its records will represent precisely each ground movement. For this purpose, the seismic instruments on Earth are placed in a hole of approximately 0.5m depths. Thus, less ground noise will be recorded. The source of the ground noise on Titan's surface can be the atmosphere and its seasonal and diurnal effects as described in [8]. Noise can be produced also from the wind. Huygens Doppler Wind Experiment (DWE) has measured the speed and direction of the wind at the surface approximately at 1m/s in the very limited time span of 69 min [1].
One more problem will be the need of good contact between the instrument's feet and the local surface of the landing area. Any *in situ* particles and dust could perturb the seismic sensor during its operation and cause

uncalculated error at the sensor's record. This type of surface features has already found on Titan. The Huygens probe landed on a relatively soft solid surface whose properties where analogous to wet clay, lightly packed snow and wet or dry sand [16]. Moreover, the Descent Imager and Spectral Radiometer's (DISR) surface images give rounded stones approximately 15 cm in diameter lie on top of a finer-grained surface in variable spatial distribution [15]. If the pebbles, which lie over the instrument's feet, move or/and melt, the equipment will move from its equilibrium position and loose its orientation. As a result, the measurements have to be corrected if such a micro-movement of the probe is noticed.
Location in a plain should be considered, away from dunes [9] or possible areas of wind gusts and hydrocarbon rains. If we are planning to place the instrument next to a ridge, we should consider that the dry drainage might be wet from a hydrocarbon rain or runoff. The Cassini's Imaging Science Subsystem (ISS) has identified cloud structures at low altitudes mostly at southern latitudes [12], so hydrocarbon rain is possible to exist.

5. EXPERIENCE GAINED FROM THE MOON SEISMIC EXPERIMENT

Apollo Passive Seismic Experiment (PSE) on Moon gave the scientists the only extraterrestrial seismic data sets until today. It was also the first extraterrestrial network of seismic instruments consisted of four seismometers deployed by the astronauts on the lunar surface between 1969 and 1972. Earth based stations received data for eight years and this was the beginning of lunar seismology. Now the limitation on computer resources has been removed and the seismic data from the PSE are reanalyzed and new events have been discovered [2].
The science objectives of the experiment were to accumulate data in order to determine the Moon's internal structure and its tectonic activity. The determination of the number and mass of meteoroids that strike the Moon and the recording of tidal deformations of the lunar surface were also additional science objectives.
The Apollo seismometers recorded 12,558 events. These events are organized into four main groups:

(a) Deep moonquakes probably caused by tides, concentrated in the depth range of 700 to 1200 km, [11].
(b) Shallow moonquakes occurring at depths of 50 to 220km and their origin are likely to be tectonic [10, 11].
(c) Thermal moonquakes triggered by diurnal thermal variations [4].
(d) Meteoroid impacts.

The number of the lunar seismic stations was small so, accurately locating meteoroid impacts and moonquakes is challenging, because of the poor signal-to-noise ratio of many of the records [2].
One of the major problems in data analysis was the scattering of the seismic waves introduced by the upper lunar crust, which is consisted by a surface layer of loose rock and dust resting on bedrock, called regolith. Seismic waves entered the regolith and were scattered before they reach the stations. Thus, much of the energy in the seismic waves was lost [3].

6. PROBLEMS AND RISKS OF A FUTURE TITAN SEISMIC EXPERIMENT

Installing instrumentation in Titan's environment with such extreme conditions will demand specific manipulation.
Due to Titan's dense atmosphere, damages from impacts will be rare [5], but the corrosion on the instrument from the atmosphere should be considered. Atmospheric phenomena in Titan will certainly affect the seismic instrument and its operation, unless it will be placed under the surface. The accuracy of any seismometer will be affected by instrument's weight and size limitations and by temperature extremes. If a sensor stops functioning, it will be impossible to repair it.
The exact time and location of any seismic event can be determined only if it's recorded by three or more seismometers.
To provide the ground movement's distribution, we need long-term observatories. We have to think the development of a broadband seismic network. The benefits of this network will be the better understanding of Titan's interior, the determination of the global tectonic field and the definition of seismic belts. Then, some ideas of the effort needed to resolve the challenging technological issues associated with such deployments are described.
Using a seismic network we can provide the propagation of the seismic waves along the crust of Titan. Moreover, we should provide much needed data to constrain the three-dimensional structure of the crust. As we know from the Earth's experience, secondary seismic waves will not propagate at any liquid matter. Thus, the existence, the composition and the thickness of subsurface liquid ocean lying under the Titan's crust can be defined as several models propose [14].
The main problem of this network will be the lack of seismometers because it will be impossible to spread them around the surface. In addition, Earth's external core is liquid and it functions like a concurrent lens for the seismic waves. This phenomenon is called core shadow zone. If a shadow zone like Earth's exists on Titan, the network will be useless in this area and will not record any significant seismic event. On the other hand, this will indicate the nature of Titan's core.
According the power limitation, any instrument on Titan will operate continuously from the landing moment

until its battery gets discharged. The use of a radioisotope thermoelectric generator (RTG) is under discussion so, it is a great risk to think the deployment of a seismic network across Titan's surface because of the lack of power sources. Since our knowledge of seismic events is inexistent, more data from a unique seismic instrument and global radar mapping for long periods of time is necessary for this purpose. There are also several technical challenges that need to be addressed before this deployment, for example issues of optimum installation, means of installation and sources of power supply.
Terms and Conditions of the use of seismic instrumentation on Titan and their possible problems and difficulties are listed in the Table 2 below:

Table 2- Scientific and technical problems and difficulties

Terms and Conditions	Possible Problems and Difficulties
Fluctuations in temperature	-Special thermal shield -Accuracy affected -Malfunction of the sensors
Surface characteristics	-Special installation -Stabilization needed -Loose the equilibrium position
Robotic installation of a seismometer at first time ever in space mission	Possible failure of the experiment without any measurements
Maintenance	Impossible to repair
Dense atmosphere	-Chemical Corrosion -Insufficient solar power to recharge batteries
Data transmission	Orbiter needed to receive data/ transmit data in sets
Exact recordings	Seismic network needed
Ground/wind noise	A shallow hole needed
Power	RTG

7. MAJOR SCIENCE GOALS

Titan seems to be active like our own planet, as far as concerned its atmospheric circulation, surface geological processes and tectonics. The Cassini-Huygens observations found several surface features like large hydrocarbon lakes, mountains and channels, dunes, river systems and volcanoes [5, 9, 15, 16].
Although Cassini-Huygens' achievements are extraordinary, the evolution of the surface and its interaction with the lower atmosphere remain to be well identified. The internal structure of the moon might be involved in some surface processes. Since only the seismic instrumentation can map the subsurface layers, determine their composition and structure and measure their thickness, we will consider to use it in a future mission as part of a landing probe payload.
Seismic waves from distant events travel deeper into the interior of a planetary body than waves from nearby events. Therefore, by measuring events at various distances from the seismometer, the variance with depth of seismic velocities can be determined in Titan.
The dense Titan's atmosphere protects its surface from meteoroid impacts - few craters are observed [5] - so the seismometer will record only interior events.
The future mission at Titan will be a great opportunity to study comparative planetology and will give the proof of a living planetary body.
Table 3 describes the features and the benefits will be gained from a future seismic experiment on Titan.

Table 3- Features and the benefits of future seismic instrumentation on Titan

Features	Benefits
• One seismograph in function is a completed scientific experiment • Small • A service for bulky data needed • Low power consumption of the sensors • No special software need to be developed	• New science – Planetary Seismology: data derived from an extraterrestrial seismic experiment will provide new frontiers for physicists and geologists • Regional scale Tectonics • Improvement of proposed models for the three-dimensional structure of Titan's interior • Evolution for modern seismic instruments and applications – seismic technology improvement – innovative applications • Earthquake prediction (?) • Saturn's tidal effects on Titan • Contribution to ESA Cosmic Vision 2015-2025 call

Acknowledgement:

We thank the Chair and the Members of the IPPW5 Student Programme Committee for the finantial support in order to attend the IPPW5.

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