

The Very Broad Band sensor of SEIS/InSight : validation from cruise to mars ground. S. de Raucourt¹, P. Lognonné¹, O. Robert¹, T. Gabsi¹, T. Nebut¹, S. Tillier¹, M. Parise¹, R. Llorca², I. Savin², N. Verdier², E. Beucler⁹, M. Drilleau¹, C. Perrin¹, T. Kawamura¹, R. Garcia³, N. Murdoch³, D. Mimoun³, L. Fayon¹, K. Hurst⁴, R. Wiemer⁵, D. Mance⁶, J. Ten Pierick⁶, J. Mc Clean⁷, T. Pike⁷, P. Zweifel⁶, M. Bierwirth⁸. ¹*Institut de Physique du Globe de Paris, Sorbonne Paris-Cité, université Paris-Diderot/CNRS (IPGP, Paris, France).* ²*Centre National d'Etudes Spatiales (CNES, Toulouse, France).* ³*Institut Supérieur de l'Aéronautique et de l'Espace (ISAE, Toulouse, France).* ⁴*Jet Propulsion Laboratory (JPL, Pasadena, United state).* ⁵*Black Forest Observatory, Karlsruhe Institute of Technology and Stuttgart University (BFO, Wolfach, Germany).* ⁶*Institute of Geophysics, ETH (ETH, Zurich, Switzerland).* ⁷*Imperial College (IC, London, United Kingdom).* ⁸*Max Planck Institute for Solar System Research (MPS, Göttingen, Germany).* ⁹*LPG Nantes, UMR6112, CNRS-Université de Nantes (LPG, Nantes, France).*

Introduction: The NASA discovery Mission Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) has successfully landed on Mars on November 26th 2018. It is dedicated to probe the deep internal structure of Mars. Its main experiment is the Seismic Experiment for Interior Structure (SEIS) [1], a highly sensitive seismometer. SEIS has two complementary sets of seismic sensors: the Short Periods which measure seismic signal from 0.1 Hz to 50Hz and the long period or Very Broad Band (VBB) sensors which are measuring the ground motion from 5Hz down to 0.01 Hz. In order to probe the deep structure with only one station, the performances requirement on the sensor is stringent : $10^{-9} \text{ m.s}^{-2}/\text{Hz}^{1/2}$. Validating this performances on Earth face two main challenges : tests under Earth gravity a pendulum design for Mars gravity and demonstrate an instrument noise 3 order of magnitude below the Earth background seismic activity. We report here how we validate the VBB functionalities and performances by trending its key parameters through Earth tests program, cruise health check, deployment on Mars surface and commissioning in final configuration.

The Very Broad Band sensors: This subsystem of SEIS is composed of a set of 3 sensors: 3 mechanical pendulum enclosed in an evacuated sphere deployed on Mars surface, 3 proximity electronics and 3 feedback board located in the lander. The mechanical pendulum (*fig.1*) function is to transform the ground acceleration in a displacement that is sensed by an electrostatic transducer (*fig.1e*). The oblique leaf spring configuration ensure a high mechanical gain and a low normal frequency for a light mobile part. To ensure the fine equilibrium of the highly sensitive pendulum, a balancing mechanism (*fig.1g*) adjust the center of gravity position. A thermal compensation system (*fig.1h*) displace passively the center of gravity with the temperature. Its gain is adjustable by rotating this device. The pendulum is equipped with a feedback coil (*fig.1f*) that generate the force feedback on the pendulum from the signal generated by the feedback board. This analog feedback erase the normal frequency peak on the

transfer function, enlarge the band pass and set the sensor gain to the desired value. The feedback has two mode an engineering one and a science one with two set of gain. A calibration coil drive by a digital to analog convertor is also implemented in coils assembly (*fig.1f*).

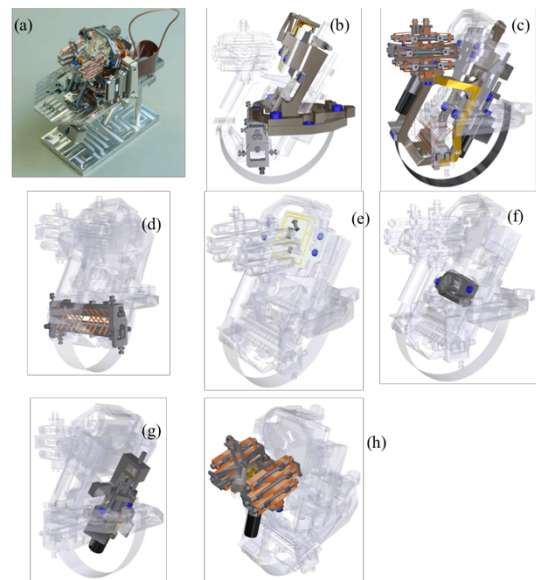


Figure 1. (a) one of the VBB sensor with Earth mass and VBB pendulum CAD views, illustrating the different functions of the sensor (b) the fixed part (c) the moving part with the leaf spring underneath (d) the pivot, (e) the displacement Transducer, (f) the Feedback coils, (g) the re-centering motors, (h) the Thermal Compensation System.

VBB validation, overview of the tests program from Earth to Mars ground: Each VBB sensor underwent a protoflight tests program prior to their integration in the evacuated sphere. During those tests, key parameters for the function and performance of the sensor (normal frequency, displacement transducer gain and noise, coil gains, mechanism performances, thermal sensitivity) have been characterized before and after environment tests. A subset of this key parameters have been tracked along integration in the evacu-

ated sphere, in the SEIS instrument and finally with the lander. Tests at SEIS level and lander level also included performances tests.

To accommodate for Earth gravity, tests were done in a tilted configuration, such that the gravity in the VBB plan is equal to the Mars gravity.

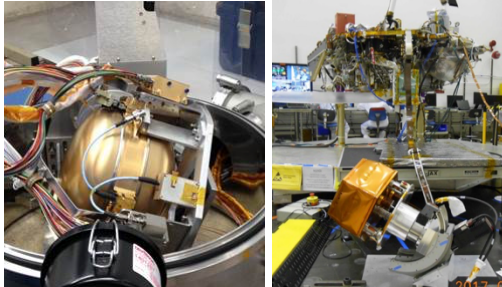


Figure 2. Testing on Earth : the seismometer is tilted to accommodate gravity. Only one VBB can be tested at a time. Left : test after sensor integration in the sphere at IPGP. Right : Performances tests at Lockheed Martin during lander integration.

During cruise under 0g, pendulum can not equilibrate and are saturated. However the saturation polarity gave us the evidence that the springs and pivots were intact. Once landed on Mars, VBBs were also saturated with opposite sign until SEIS was deployed on the ground, leveled and the VBBs BM moved out from their to storage position to their equilibrium ones (VBBs recentering).

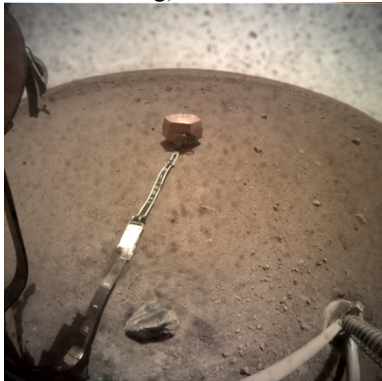


Figure 3. SEIS deployed on Mars surface. The tether that transmit power and signal back and forth between the sensor assembly and the electronics located in the lander is lying on the ground. The tether storage box (top left) has been open to loosen the tether. The tether service loop can be seen at the tether/sensor assembly junction.

The deployment of SEIS is a long sequence of successive steps : placement of SEIS on the ground, leveling and first VBBs operations on the ground, tether release, tether service loop release and adjustment (see fig.3), leveling low and finally wind and thermal shield deployment on top. Once SEIS is in its final configuration, we will proceed with thermal compensation opti-

mization and then complete the commissioning with calibration.

Key parameters and performances: We will present the main key parameters and performances observed on Mars and compared them to reference value obtained during tests program on Earth.

Power consumption and other housekeeping data are observed to be consistent through all SEIS operation.

For their first tests under Mars gravity, VBB equilibrium was achieved with balancing mechanism in the expected range.

A key parameter of the pendulum is its normal frequency and Q factor. Those have been very constant all along the integration and we will present the result of their measurement on Mars after the windshield deployment.

All VBBs contributors to the instrument self-noise (transducer noise, feedback noise, mechanical gain) were proof to be compliant at VBB level. At SEIS level performances tests were performed and showed compliance of the self-noise over a limited bandwidth due the Earth environment which is far above our requirement. We are measuring the instrument noise all along its deployment and will report noise reduction as the tether is released and the windshield deployed.

Thermal sensitivity is another key performances of the VBBs. We will present the thermal sensitivity of the VBBs as observed on Mars, compared it to the one measured on Earth. We will report also about its minimization through the thermal compensator tuning.

At last, calibration process and the estimated transfer function will be presented.

Conclusions: First results on Mars showed a nominal behavior of the VBBs and we expect to report fully nominal performances. Following the deployment and its commissioning, the science monitoring phase will start for a nominal duration of 2 years.

References:

[1] Lognonné et al., in press, Space Science review, 2019.

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