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InSight Mission to Mars: Early Operational Results
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ABSTRACT

The InSight mission to Mars was selected as part of the NASA Discovery portfolio in 2011. InSight was launched as the first interplanetary mission from Vandenberg Air Force Base in California on May 5, 2018 and Landed successfully on Mars on November 26, 2018. The project management, Principal Investigator, systems engineering and operations were led primarily by the Jet Propulsion Laboratory. The mission utilized a heritage spacecraft and Lander from Lockheed Martin which had successfully landed on Mars before as the Phoenix mission. Significant changes were made to the Lander structure, power system and Entry, Descent and Landing system to adjust to the different mission parameters. Importantly, InSight is the first solar powered stationary lander designed to last a full Mars year. The main science instruments were contributed by CNES and DLR and were designed to provide the first glimpse into the Martian interior using seismometry, heat flux and geodesy. The seismometer (SEIS) is environmentally ruggedized for Mars, but has the sensitivity comparable to that of the best terrestrial seismometers. The development of the SEIS was a multi-national effort led by CNES with significant contributions from JPL and other European partners. The heat flux instrument, the Heat-flow and Physical Properties Package (HP3), was developed largely by DLR with support from JPL.

PAPER

1.0 Mission Overview

The InSight (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) mission is in the Discovery portfolio of the NASA Planetary Science Division within the Science Mission Directorate. The mission selection was made in 2012 as part of the competitive process used for Discovery missions and is managed by Jet Propulsion Laboratory (JPL) for NASA as part of the Planetary Missions Program Office portfolio.

The InSight mission science objectives are to investigate the fundamental processes of terrestrial-planet formation and evolution by performing the first comprehensive surface-based geophysical investigation of Mars. It will provide key information on the composition and structure of an Earth-like planet that has gone through most of the early evolutionary stages of the Earth. Thus, the traces of this history are still contained in the basic parameters of the planet: the size, state and composition of the core, the composition and layering of the mantle, the thickness and layering of the crust, and the thermal flux from the interior [1].

InSight has a focused set of three investigations utilizing two instruments and a spacecraft subsystem. The investigations use seismology, precision-tracking and heat-flow measurements to unlock the secrets of the Martian interior. The knowledge provided by the InSight mission will substantially advance understanding of the formation and evolution of terrestrial planets.

The InSight science goals are simply stated [2].

1. Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars

2. Determine the present level of tectonic activity and impact flux on Mars

From these goals flow a fundamental set of baseline science objectives:

- *Determine the size, composition and physical state of the core*
- *Determine the thickness and structure of the crust*
- *Determine the composition and structure of the mantle*
- *Determine the thermal state of the interior*
- *Measure the rate and distribution of internal seismic activity*
- *Measure the rate of impacts on the surface*

2.0 System Description

InSight investigates the Martian interior using seismic sources (tidal, Marsquakes, impacts, etc.), rotational, and thermal measurements. The two instruments are deployed on the surface using a robotic arm. Once deployed and commissioned, the instruments will gather data for a Martian year (26 Earth Months).

InSight was developed using heritage from past missions for the Flight System, Operations, and Mission Design. The Flight System is being designed, built, and tested by Lockheed-Martin Space Systems Corporation (LM) in Denver, CO. The Flight system design builds off past successful missions. The spacecraft system is based on the Phoenix flight system, upgraded with Juno/Gravity Recovery and Interior Laboratory (GRAIL) avionics. JPL manages delivery of the international payloads and directed, developed and delivered the other payload elements [3].

The payload includes six elements (Figure 1: InSight Payloads):

Seismic Experiment for Interior Structure (SEIS): Three-axis seismometer, to measure seismic waves traveling through the interior. Uses two different type of sensors (broadband and short period) built with different technology. Covered on the Martian surface by the Wind and Thermal Shield (WTS).

This is the primary instrument for InSight and is required to meet the majority of the science requirements. The SEIS consists of two independent, 3-axis seismometers with different underlying technologies: a very broad band (VBB) oblique seismometer contained within a pressure vessel (sphere) and a solid-state short-period (SP) seismometer. The SP sensor provides partial measurement redundancy and extends the high-frequency measurement capability of the SEIS. The VBB's are installed within an evacuated container to protect the measurement from environmental noise sources such as temperature and pressure changes. Additionally the entire sensor set is fully covered on Mars by a Wind and Thermal Shield (WTS) to further isolate it from environmental noise.

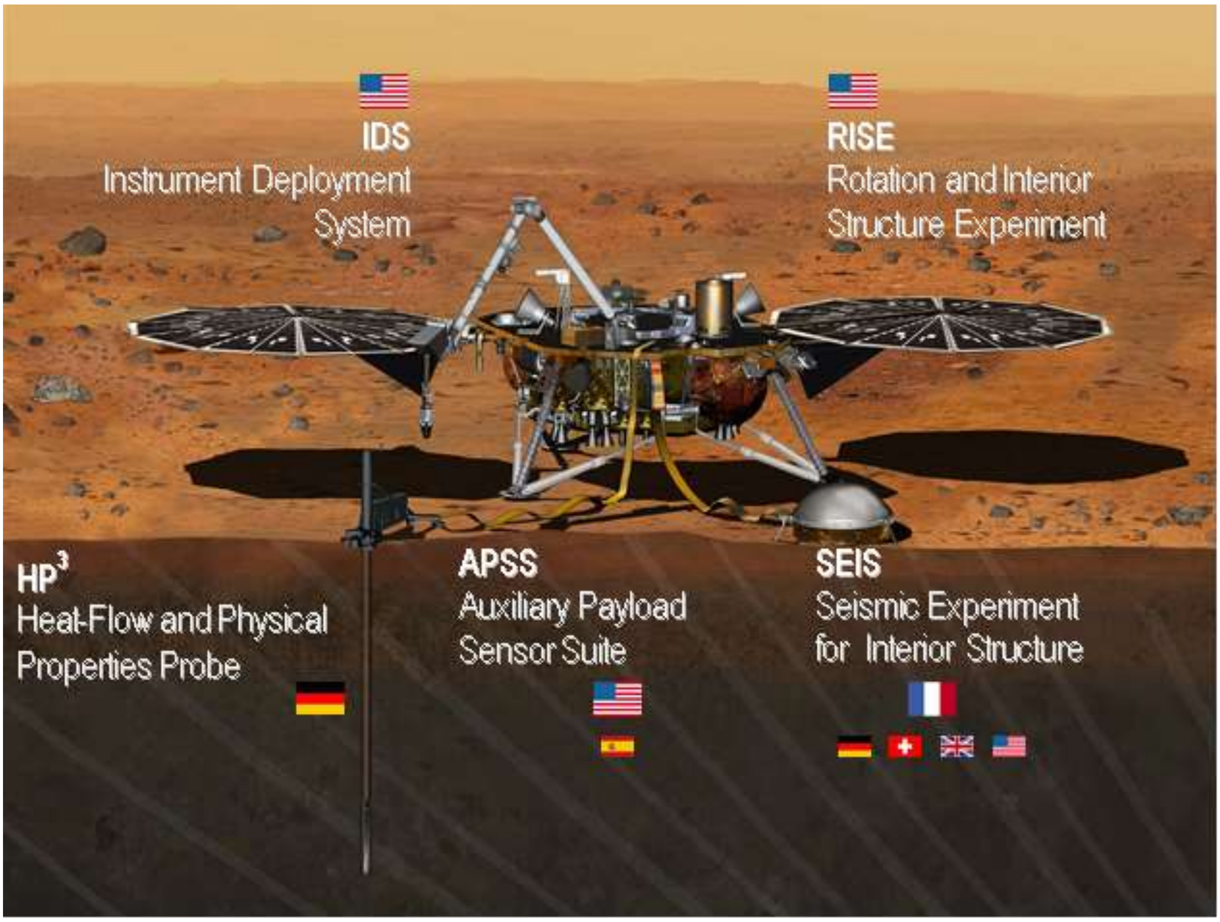

Figure 1: InSight Payloads

Rotation and Interior Structure Experiment (RISE): Radiometric geodesy used to determine precession and nutation of the planet's rotation axis.RISE measures the rotation of Mars to high precision by employing two-way X-band carrier-signal tracking between the Lander and Earth. The Lander X-band transponder receives a carrier signal from an Earth DSN tracking station and transmits a signal back to the tracking station. The station measures the Doppler frequency shift of the round-trip signal, which is proportional to the Lander velocity along the line of sight.

Heat Flow and Physical Properties Package (HP3): Subsurface heat probe, to measure the heat flux from the interior. Heat flow is a major constraint on models of the current state of Mars' interior and is key to understanding the evolution of terrestrial planets in general [4].

HP3 achieves this by penetrating up to 5 meters into the Martian subsurface with a self-contained hammering apparatus called the ‘mole’. The mole science tether, which trails the actual mole, is configured with temperature sensors. As the mole penetrates the regolith, the sensors measure the temperature conductivity of the surrounding regolith as it penetrates (at roughly 50 cm intervals).

Instrument Deployment System (IDS): Robotic arm and two cameras: to map workspace, deploy SEIS elements and HP3 to the surface. Uses upgraded residual flight robotic arm hardware from Mars Surveyor Project 2001 (MSP01) and residual colorized Mars Exploration Rover (MER) flight cameras.

Auxiliary Payload Sensor Suite (APSS): The APSS is a suite of environmental sensors to support the SEIS investigation by allowing correlation of environmental factors to the observed measurements. The sensors are: *InSight Fluxgate Magnetometer*-The IFG provides magnetometer readings to identify lander induced magnetic signals, which SEIS is sensitive to; *Pressure Sensor*-The pressure sensor provides dynamic mPa accurate readings of Martian atmospheric pressure; *Thermal and Wind for InSight* – TWINS is essentially a re-fly of the REMS wind sensors from Mars Science Laboratory. In addition to all of the noise decorrelation for SEIS, these sensors will provide detailed information of and will further our understanding of Martian weather patterns. [5]

Laser Retro-Reflector for InSight (LaRRI): The Laser Retroreflector consists of corner cube retroreflectors. It will facilitate Mars geophysics as well as tests of general relativity investigations by a future orbiter.

3.0 Mission Phases

3.1 Launch/Cruise

InSight launched successfully from Vandenberg Air Force Base (VAFB) aboard an Atlas 401 rocket at the first launch opportunity on May 5, 2018. The injection capability of the rocket allows for a Type-I ballistic trajectory with a constant arrival date at Mars on November 26, 2018. [7] (Figure 2: InSight Trajectory).

The cruise activities are similar to a typical Mars mission and were designed to achieve the proper entry flight angle to support the entry, descent and landing phase of the mission. The first Trajectory Correction Maneuver (TCM-1) was planned for Launch + 10 days to remove the planetary protection bias of 20,000 km and correct upper stage injection errors. TCMs 2 and 3 would continue to correct residual error at Entry - 121 days and Entry - 45 days, respectively, and the final 3 TCMs would occur weekly starting at Entry - 15 days to prepare for EDL. InSight was not required to perform TCM-3 due to the low error from TCM-2. All of the remaining TCMs were performed successfully per the plan, including TCM-6 which was just 22 hours prior to entry.

A surprising trend emerged in the first few days of cruise. The rate of reaction control subsystem (RCS) thruster firing used for attitude control was much higher than expected.

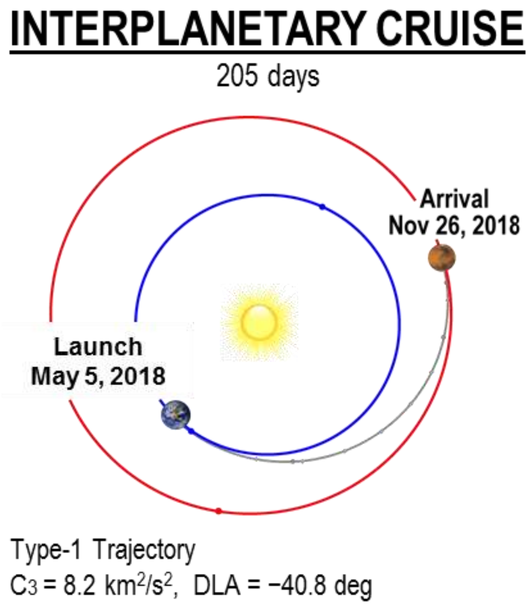

Figure 2: InSight Trajectory

This was clearly noticeable during the first 24 hours after launch, increased greatly once the spacecraft turned to the inner cruise attitude and then began to taper off over the next few weeks.The firings were attributed to outgassing of materials absorbed by the spacecraft during its two-year storage after the slip from 2016 launch, and were observable at other points during the mission as previously-shadowed surfaces became exposed to the sun.

The Cruise Phase culminated in the successful delivery of the entry vehicle to Mars in position to perform the Entry, Descent and Landing (EDL) Phase.

3.2 Entry, Descent and Landing

The EDL Phase was all about dissipating the energy of the spacecraft, which entered the atmosphere of Mars at 5.5 km/s, and touched down on Mars <6 minutes later at 2.4 m/s. This dramatic reduction in velocity was accomplished by the elements of the EDL system. The EDL Phase began at Entry- 19 hours, shortly after the final TCM (TCM-6) executed.

Hypersonic Phase: The initial phase of EDL was the hypersonic phase with started upon atmospheric entry at ~128km above the surface of Mars. During this phase 99% of the energy is dissipated using the atmospheric density of Mars. The entry vehicle used an ablative heatshield as it flew on a ballistic non lifted trajectory to absorb peak heating of ~44W/cm^2 slowing the vehicle from ~5,550 m/s to 385 m/s

Parachute Phase: At about 10 km altitude, an 11.8 m diameter supersonic Disc, Gap, Band (DGB) parachute was deployed, beginning the Parachute Phase. Once deploy dynamics subsided, the capsule heatshield was jettisoned. Ten seconds later the landing legs deployed; this provided enough time for the heatshield to separate completely and clear the vehicle's flight path. The landing radar began searching for the ground 47 sec after the parachute deployed, and when within range, provided the altitude and velocity data needed to complete terminal descent.

Terminal Descent Phase: The backshell/parachute separated from the Lander about 1 km above the Martian surface. A 0.5 sec free fall cleared the lander from the backshell, after which the 12 descent engines began firing. At about 50 m above the surface, the lander entered a constant velocity descent, descending at 2.4 m/s. Touchdown was detected by switches in the lander legs and engine shutdown occurred within 0.25 sec of touchdown detection. With a successful touchdown, the EDL portion of the mission completed.

3.3 Deployment

Upon Landing (Sol 0) the first goal was to achieve a power positive state of the landed system. The solar arrays autonomously deployed and all systems not required for surface operations were permanently powered off. Images were taken before the spacecraft went to sleep and were relayed to Earth via the Mars Cube One (MarCO) spacecraft.

The Instrument Deployment Phase (IDP) began on Sol 1 with the arrival of the first image data. This phase encompassed the deployment of the SEIS, WTS and HP^3 elements to the surface and commissioning of them for science operations in the subsequent Penetration and Science Monitoring Phases. The IDP was supported by the joint JPL/LM flight team and by the international partners for science and instrument operations. InSight is the first mission to have robotically placed instruments onto the surface of another planet and represented an area of significant development work on the project.

The original IDP had a timeline of 54 Sols (Figure 3), with several of these Sols not being planned for any activities. The extra Sols account for certain surface activities where the data downlink volume required multiple Sols for downlink and also allowed for the IDP operations team to only work the prime shift and observe institutional holidays [6]. The actual deployment activities took 87 Sols to complete due to not unexpected complications in the deployment operations.

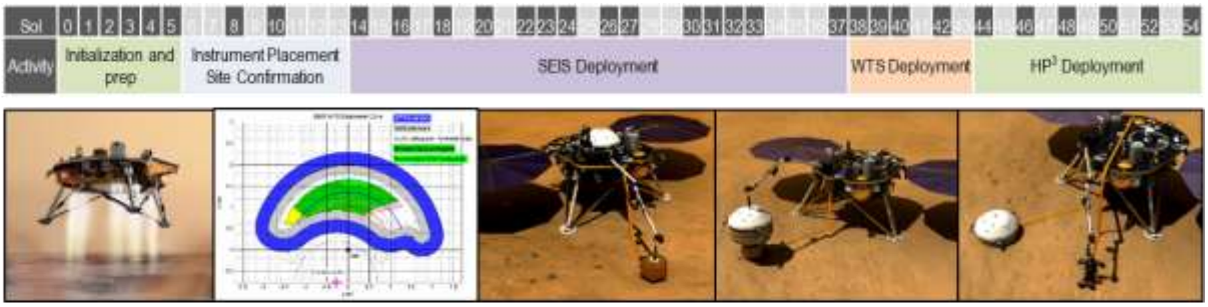

Figure 3: Deployment Timeline

The SEIS was the first element deployed onto the surface. Starting on Sol 20, the grapple on the end of the IDA grabbed the SEIS grapple hook. IDA lifted SEIS and places it in the defined location within the workspace. IDC and ICC images taken throughout the whole process showed the effectivity of this operation. Upon placement on Sol 22, SEIS determined if the location is acceptable before IDA released the SEIS on Sol 25. The SEIS was then imaged to verify proper deployment had been achieved before the SEIS team begins instrument initial commissioning activities to confirm that the deployment was sufficient to achieve science objectives. Once this is completed, the tether storage box was opened on Sol 37 to release the remaining length of tether to the ground and the SEIS load shunt assembly was opened on Sol 40 to isolate SEIS from lander and tether noise.

After SEIS was successfully deployed, all adjustments were made and the location deemed to be sufficient, the Wind and Thermal Shield (WTS) was deployed over the SEIS instrument on Sol 66. The WTS was necessary to complete SEIS installation by providing a protective cover from the external environment to the SEIS sensor. Similar to SEIS, the IDA grappled WTS and placed it over SEIS. The WTS was released on Sol 70 when it was confirmed to not be interfering with SEIS's measurements. The SEIS team began a period of several weeks of commissioning the instrument in parallel with the activities related to completion of the IDP.

The HP^3 instrument was the last element to be deployed on Sol 76. The IDP ended on sol 87, when the command to release the HP^3 mole was executed.

3.4 Surface Operations

Operations during the long-term science monitoring phase are simple, repetitive, and robust. During a typical sol, the Lander wakes for ~25 minutes every ~3 hours to perform a health check and collect housekeeping and science data. During two of the daily wake cycles, the Lander stays awake for an additional 30 minutes to select and transfer data for radiation, then relay them to the available orbital assets. The Lander provides continuous power to SEIS and HP3 throughout this phase, and once or twice a week powers on the RISE Small Deep Space Transponder (SDST) for a one-hour measurement session with the Deep Space Network (DSN). This activity continues for the full Martian year after landing [8].

4.0 Results to date [9]

The cameras on the robotic arm and on the underside of the Lander have sent back to Earth over a thousand pictures. These have ranged from images of the instrument workspace and of the instruments themselves to panoramas of the landing site. The cameras are also used to take images of the Martian Tau (measure of atmospheric opacity) to assist in predicting the energy collection on the Lander Solar array.

The SEIS instrument has been successfully deployed on the surface of Mars and has completed commissioning. The SEIS is the first seismometer to be placed on the Martian surface and should be able to gather data which will reveal the secrets of the interior of Mars.

The commissioning effort has fully prepared the instrument to detect seismic activity and has been successful in demonstrating a very low noise floor. The installation of the WTS and subsequent adjustments to the VBBs have achieved a noise floor well below the requirements and approaching the noise floor seen with the lunar Apollo seismometers.

Prior to deployment, while the SEIS was still on the deck, the SEIS SP sensors recorded wind in their measurement band. These measurements along with similar measurements made by the pressure sensor represent the first time that wind in the audible range was recorded on Mars.

The APSS sensors on InSight are ostensibly there to decorrelate the environmental noise of Mars from the SEIS data. However, together the form the first stationary weather station established on Mars. The data from these sensors are being sent to Earth regularly and are available to weather enthusiasts and to weather reporters to share. They have been used to date to

The HP3 instrument radiometer has been measuring surface temperatures since the beginning of the surface mission with the goal of assisting the subsurface temperature measurements to be made by the HP3 penetrator. At the time of writing of this paper, the HP3 mole is experiencing difficulty in getting to the desired depth of penetration. The project team is working on options to assist the mole in getting to the desired depth, but it is unknown as to the eventual effectivity of any of the planned actions.

5.0 Acknowledgements

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References

[1] InSight Concept Study Report, March 19, 2012

[2] InSight Project Level Requirements, 2014

[3] Tom L. Hoffman, “InSight: Mission to Mars”, 2018 IEE Aerospace Conference, 2018

[4] InSight System Integration Review 2, June 13-14, 2017

[5] InSight APSS Critical Design Review, April 10, 2014

[6] InSight Post-Launch Assessment Review, June 6, 2018

[7] InSight Surface Phase Peer Review, August 31, 2017

[8] InSight Approach/Entry Descent and Landing Phase Critical Events Readiness Review, October 4, 2018

[9] Tom L. Hoffman et al, “InSight Mission: Early Operations”, 2019 IEE Aerospace Conference, 2019