InSight Mission: Early Operations

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Abstract— **The InSight Mission is planning for a November 26, 2018 landing on Mars. Over the subsequent several months, the Lander will deploy instruments to the Martian Surface and start the science mission. The science delivered from InSight will uncover the geophysical characteristics of Mars and use comparative planetary geophysical techniques to better understand the formation and evolution of Mars and thus by extension other terrestrial planets. The mission science uses several instrument and sensors, many of which are international contributions to gather the science data. This paper will describe the InSight mission and science objectives with a focus on the activities since the May 5, 2018 Launch including the InSight Mission Design, Navigation, and Cruise Phase Instrument check-out and the plans for the November Entry, Decent and Landing and Instrument Deployment Phases.**

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1. INTRODUCTION

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.

This paper covers some mission background material and provides information about activities performed during launch and early cruise. Additional information is provided covering detailed plans for late cruise, Entry Descent and Landing and Deployment phases of the mission. For more mission background information refer to prior InSight paper by the lead author [2].

2. 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 [2].
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).

Rotation and Interior Structure Experiment (RISE): Radiometric geodesy, to determine precession and nutation of the planet's rotation axis. Measurement made with the spacecraft telecom hardware.

Heat Flow and Physical Properties Package (HP3): Subsurface heat probe, to measure the heat flux from the interior.

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.

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.

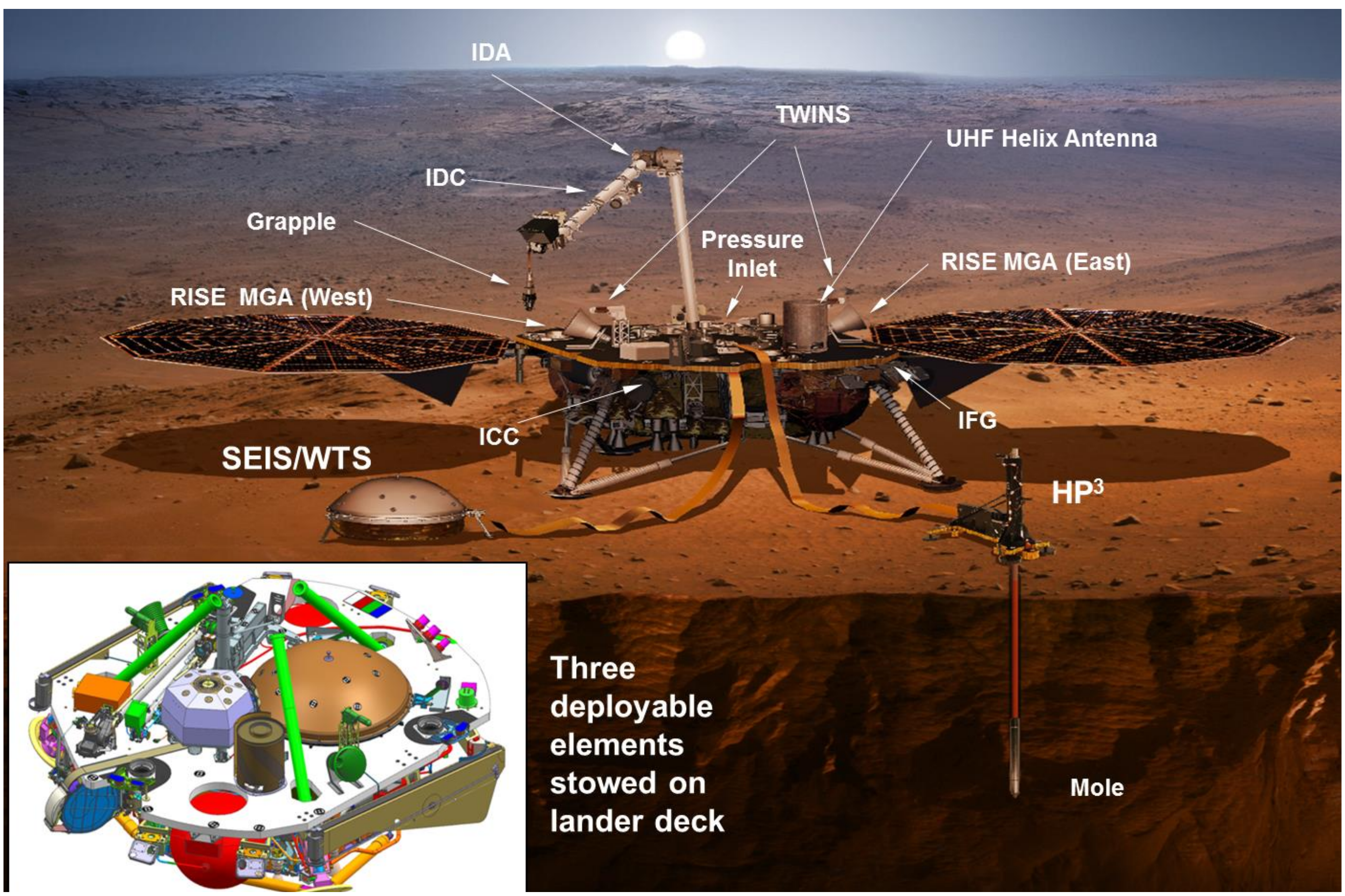

Figure 1: InSight Lander

3. Science Requirements

The science objectives addressed by the InSight mission have been a priority for decades within the science community [3]. Specifically, InSight provides first ever geophysical exploration of the Martian interior using seismic and thermal measurements and rotational dynamics, providing information about the initial accretion of the planet, the formation and differentiation of its core and crust, and the subsequent evolution of the interior. The InSight science goals are simply stated [4].

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*

3. Mission Design

InSight relies on the knowledge gained from past successful missions developed for landing on Mars in the design of the mission. Further, InSight flight systems utilizes the specific knowledge gained from the Phoenix (PHX) mission for the Entry, Descent and Landing (EDL) design. EDL at Mars directly follows the Phoenix design and operations scenario. InSight has chosen a landing site in Elysium Planitia, which meets both engineering and science requirements. Following landing and instrument deployment to the Martian surface, the mission begins a 1-Mars-year monitoring phase of routine, repetitive, continuous data collection. It communicates with Earth via orbiting assets nominally twice per sol [5]. A sol is equivalent to one Martian day.

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 (Figure 2: InSight Trajectory).

The cruise activities are similar to a typical Mars mission and are 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. An early Thruster Calibration activity was designed for June 28 (Entry - 153 days), which would impart 0.4 m/s of velocity change (delta-V). 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.

The Centaur upper stage placed InSight into interplanetary orbit. The performance of the upper stage was exceptional. Reconstruction of the post-separation state shows that the injection errors corresponded to a 1.22σ error, easily satisfying the 3.36σ injection accuracy requirement [6].

Acquisition of the spacecraft signal by DSN assets at Goldstone and Canberra on day of launch was similarly flawless. The spacecraft was in view of Goldstone at separation and the one-way Doppler signal was acquired within 30 seconds, and two-way data 42 minutes later. No trajectory predict update was planned for Canberra acquisition less than two hours later but signal was quickly acquired.

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.

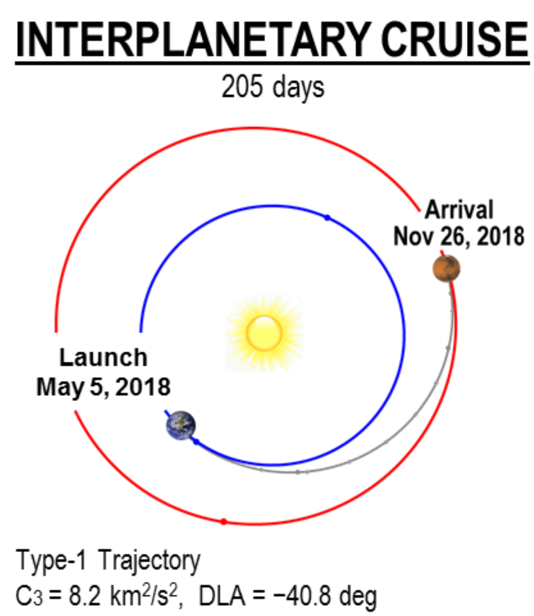

Figure 2: InSight Trajectory

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 InSight attitude control system design is a heritage of the Phoenix lander. This system does not use reaction wheels to maintain attitude but depends on the four RCS thrusters instead. Attitude deadbands are established in each of the spacecraft body axes and the RCS engines are pulsed in pairs for control. Although effective, this is a significant drawback from the navigation point of view as the thrusters are unbalanced, i.e., they impart a translational velocity change as well as a rotation with every firing. Hence the increased activity can be viewed as a form of dynamic noise on the trajectory, and its unpredictability makes precision orbit determination difficult. The tracking and trending of these small forces was a continuous task for Navigation during cruise (Figure 3: InSight RCS Delta-V).

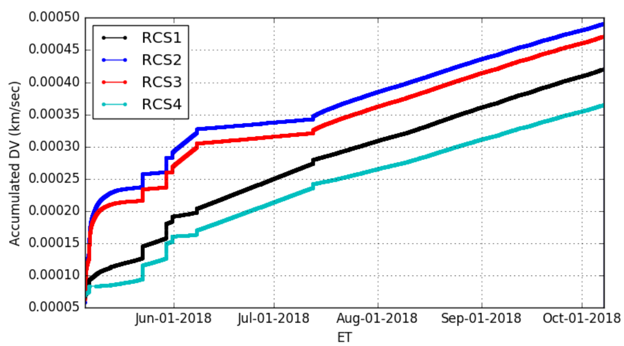

Figure 2: InSight RCS Delta-V

The pre-launch plan for the first trajectory correction had been to collect five days of two-way Doppler and range tracking data and perform the first TCM at 10 days after launch. An early decision was made to delay this schedule, setting the data cutoff at L+10 days and the execution at L+17 days.

The challenge for navigation was to create a valid model for the observed outgassing acceleration, and to predict this outgassing and the expected RCS thruster firings for the rest of cruise. Exponential models with different decay rates were used to reconstruct the observed outgassing, which peaked near 1.E-10 km/s^2 after launch. A delta-V optimization between TCM-1 / TCM-2 delta-V produced magnitudes of 3.78 m/s and 1.03 m/s once the suitable predictions were made. The overall delta-V benefit of this optimization was small but it was an effective way to correct most of the obvious target miss while leaving some delta-V at TCM-2 (with expected improvement in models).

The InSight Thruster Calibration was designed jointly before launch by the Navigation and GNC teams to improve the characterization of the RCS thrusters. In this test the spacecraft turned to four different attitudes and executed 9 "pulse trains" of 4 pulses per thruster at each attitude, giving a total of 144 pulses per thruster overall. High-rate IMU data, star tracker quaternions, and two-way Doppler data were collected throughout the activity. The Navigation team adjusted the tracking data to remove all the dynamics and data effects except those due to the calibration (solar radiation pressure, trajectory dynamics, attitude changes and antenna motion). This data was combined in a Kalman filter to produce updated estimates of the thruster directions and velocity changes. This was used post TCM-2 to reduce the propagation uncertainty and reflect the propagated effect of predicted RCS firings. The calibration activity executed near-flawlessly, without data gaps. Post execution the Navigation and GNC teams determined that the expected velocity change due to these firings had been transmitted from GNC to Navigation in the wrong coordinate frame. This was corrected at TCM-2 with minimal delta-V cost, however. The post-analysis prediction improvement was clearly visible.

At the design of TCM-1, the planned magnitude of TCM-2 was 1.03 m/s. Because of all the above factors this increased to 1.50 m/s at the time of TCM-2 final design (July 23, 2018). The orbit determination data arc began on June 8 and consisted primarily of two-way Doppler and range tracking data from the Canberra DSN complex, due to the generally southern inclination of the trajectory.

A small amount of data from Goldstone was also used as well as 15 differenced wideband VLBI (aka Delta-Differential One-Way Ranging or ΔDOR) measurements. This TCM was accurately executed on July 28, 2018 with a small magnitude error of 0.3% and 0.7 degrees in pointing. This TCM targeted directly to the desired entry conditions above the Mars atmosphere.

The first TCM to target directly to the desired landing site on Mars was TCM-3. This used the DSENDS program in concert with Navigation Monte software to propagate through the atmosphere and account for spacecraft events during EDL. This step allows the inclusion of updated atmospheric density and wind models on approach. The orbit determination accuracy improved greatly with the greater variety of tracking data and weekly ΔDOR measurements (Figure 4: TCM-3 Orbit Determination).

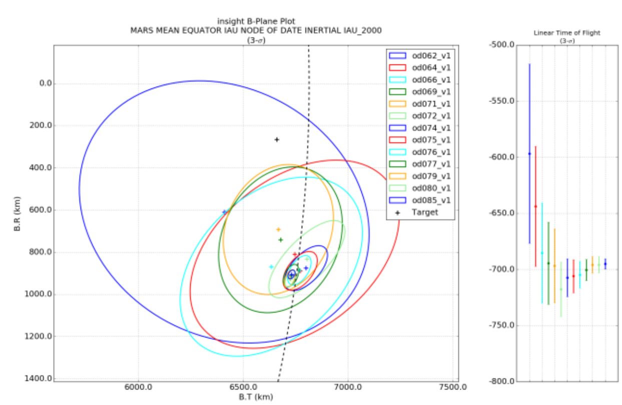

Figure 3: TCM-3 Orbit

There are three more TCMs planned after TCM-3. Each of these is intended to further refine the solution to achieve a landing in the middle of the defined landing ellipse within the landing site.

3.2 Entry, Descent and Landing [7, 8]

The EDL Phase is all about managing and reducing the energy of the spacecraft, which enters the atmosphere of Mars at 5.5 km/s, and touches down on Mars 6.5 minutes later at 2.4 m/s. This dramatic reduction in velocity is accomplished by the elements of the EDL system. The EDL Phase begins at Entry- 19 hours, shortly after the final TCM (TCM-6) is executed. During the initial hours of the EDL Phase, the EDL spacecraft operations team, consisting of member from JPL, LM and Langley Research Center (LaRC), has two opportunities to perform an EDL parameter update (EPU), which is an adjustment to FSW parameters onboard the spacecraft based on the latest spacecraft approach trajectory and observation-based forecasts of atmosphere conditions at landing. The EPU parameters provide updated position, velocity and entry time knowledge to the spacecraft, and adjustments to the parachute deployment trigger algorithm and radar activation algorithm. The final EPU can be uplinked to the spacecraft as late as 1.5 hours before entry into the atmosphere.

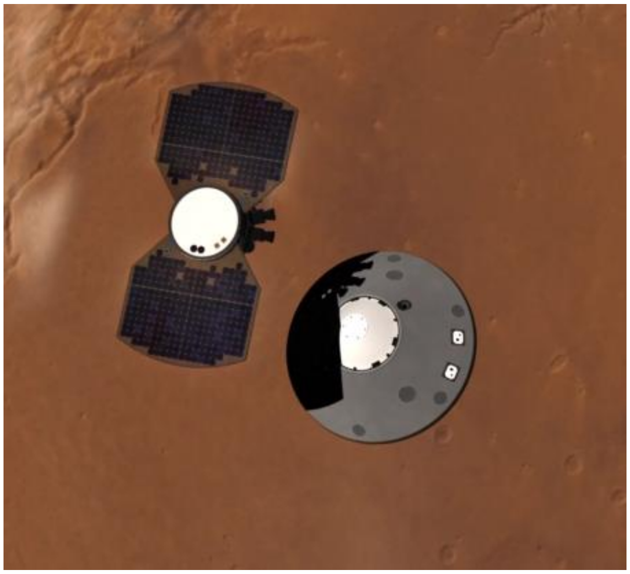

Figure 5: Cruise Stage Jettison

After the final EPU opportunity, the spacecraft operates autonomously until on the surface of Mars. At E-7 minutes, the spacecraft jettisons the Cruise Stage, the support stage that has provided power, communications and navigation aid on the way to Mars. Immediately after separation of the Cruise Stage, the spacecraft begins an attitude slew, called turn to entry, which rotates its attitude from sun point to an attitude providing zero angle of attack at the top of the atmosphere. At 2 minutes before entry, the spacecraft begins transmitting 8 kbit UHF telemetry data to provide real-time updates of the landing event to the operations team.

Figure 6: Lander Descending Under Parachute

Entry occurs at 128 km above the Martian surface, with the first deceleration provided by the atmosphere. The spacecraft flies a ballistic, non-lifting entry. As atmosphere density increases, the spacecraft undergoes increasing heating and deceleration, with peak heating of 44 W/cm^2 happening about 90 s after entry, and peak deceleration of 7.4g happening about 15 s later. This phase of EDL is called the Hypersonic Phase, which removes 99% of the entry energy via aerodynamic drag.

At about 10 km altitude, an 11.8 m diameter supersonic Disc, Gap, Band (DGB) parachute is deployed, beginning the Parachute Phase. Fifteen seconds after parachute deploy, once deploy dynamics have subsided, the capsule heatshield is jettison. Ten seconds later the landing legs deploy; this provides enough time for the heatshield to separate completely and clear the vehicle’s flight path. The landing legs deploy sequentially at 0.5 sec intervals, and each deployment completes within 0.25 sec. The landing radar begins searching for the ground 47 sec after the parachute is deployed, and when within range, it provides the altitude and velocity data needed to determine optimal backshell-separation altitude.

The Terminal Descent Phase begins with separation from the backshell/parachute about 1 km above the Martian surface. A 0.5 sec free fall clears the lander from the backshell, after which the 12 descent engines begin firing. The lander then performs a tip-up maneuver to align its descent engines with its velocity direction to perform a gravity turn descent to arrest its velocity and remove the remain energy from entry. At about 50 m above the surface, the lander enters a constant velocity descent, descending at 2.4 m/s, its desired touchdown velocity. Touchdown is detected by switches in the lander legs and engine shutdown occurs within 0.25 sec of touchdown detection. With a successful touchdown, all the spacecraft energy at entry has been removed via the EDL system, and the EDL portion of the mission completes.

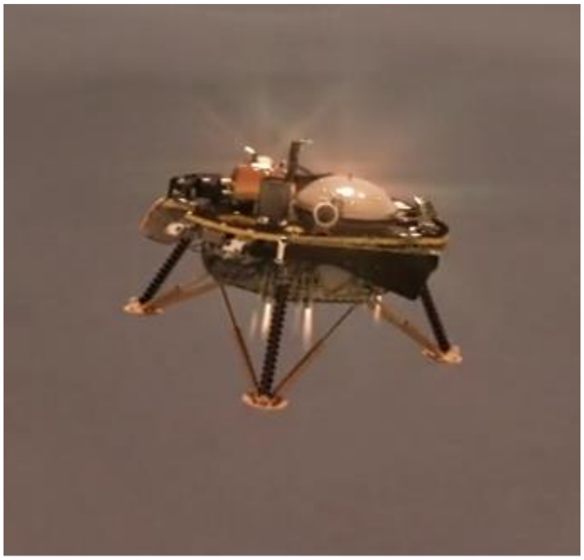

Figure 7: Terminal Descent

3.3 Instrument Deployment

On the day that InSight lands (Sol 0) the first goal is to achieve a power positive state of the landed system. The solar arrays autonomously deploy and all systems not required for surface operations are permanently powered off. Images will be taken before the spacecraft goes to sleep. The first post-EDL orbiter overflight and data uplink opportunity occurs later that evening.

The Instrument Deployment Phase (IDP) begins on Sol 1 with the arrival of the first image data. This phase is encompasses the deployment of the SEIS, WTS and HP3 elements to the surface and commissioning of them for science operations in the subsequent Penetration and Science Monitoring Phase. The IDP is supported by the joint JPL/LM flight team and by the international partners for science and instrument operations. InSight is the first mission to robotically place instruments onto the surface of another planet and represents an area of significant development work on the project.

The IDP is a timeline of 33 Sols of activities spanning the first 54 Sols (Figure 8). The extra Sols account for certain surface activities where the data downlink volume requires multiple Sols for downlink and also allows for the IDP operations team to only work the prime shift and observe institutional holidays [9].

The IDP follows a success-oriented timeline, meaning planning for each Sol's activities depends on successful verification of activities on previous Sol's. These dependencies are managed through nearly 50 Go/No-Go (GNG) decisions. A GNG decision is performed for all key and first-time activities and is comprised of individual assessments that evaluate detailed pre-defined criteria, example data, responsible parties, and other context. The IDP Timeline is the controlling documentation for what GNGs are assessed for each Sol in order to proceed with that Sol's planned activities. The Timeline also identifies post-requisite GNG dependencies for each activity, if applicable.

Sols 1 through 4 include monitoring the spacecraft systems, trending power and thermal performance, initial powering and checking out the instruments, unstowing the arm from its launch position, and releasing camera dust covers. Characterization of the workspace begins on Sol 5. The Instrument Context Camera (ICC) is mounted under the spacecraft deck and provides a fisheye view of the workspace. The Instrument Deployment Camera (IDC), affixed to the Instrument Deployment Arm (IDA), images the workspace so ground operators can identify primary deployment sites for SEIS and HP3. A full workspace mosaic is produced by stitching together 56 IDC images, followed by closer, higher-resolution mosaics of the target placement sites. Images are processed by the Multi-mission Image Processing Laboratory (MIPL) to create tomography maps and other products to aid in payload placement simulation. The Instrument Site Selection Working Group (ISSWG), comprised of deployment engineers, instrument representatives, and geology, physical properties, and imaging experts, reviews these products to certify deployment locations. This group also provides guidance if alternative deployment locations need to be investigated. ISSWG presents final payload site selection to the Project leadership on Sol 15 for certification.

The SEIS is the first element deployed onto the surface. Starting on Sol 16, the grapple on the end of the IDA grabs the SEIS grapple hook. IDA then lifts SEIS and places it in the defined location within the workspace. IDC and ICC images are taken throughout the whole process. Upon placement, SEIS immediately determines if the location is acceptable before IDA releases the SEIS. The SEIS is then imaged to verify proper deployment has been achieved before the SEIS team begins instrument initial commissioning activities to confirm that the deployment will be sufficient to achieve science objectives. Once this is completed, the tether storage box is opened to release the remaining length of tether to the ground and the SEIS load shunt assembly is opened to isolate SEIS from lander and tether noise.

After SEIS is successfully deployed and the location is deemed to be sufficient, the Wind and Thermal Shield (WTS) will be deployed over the SEIS instrument starting on Sol 38. The WTS is necessary to complete SEIS installation by providing a protective cover from the external environment to the SEIS sensor. Similar to SEIS, the IDA grapples WTS and places it over SEIS. The WTS is released when it is confirmed it is not interfering with SEIS's measurements.

The HP3 instrument is the last element to be deployed, starting on Sol 44. The IDP ends on sol 54, when the command to release the HP3's mole is uplinked for execution. The IDP is certified to be complete when mole release is confirmed on the next Sol's downlink. The release of the mole is as the completion of the Deployment Phase.

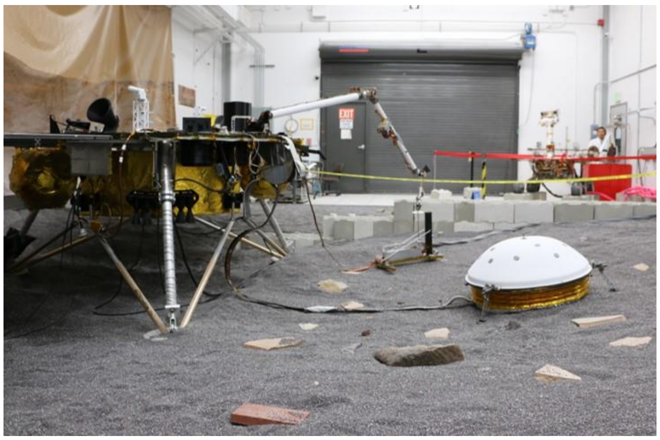

Figure 9: InSight Surface Testbed

3.3.1 Deployment Testbed

Testing is done on InSight's Earth-based twin (Figure 9). This testbed has a flight-like set of avionics, engineering model of the IDA, IDC, and ICC, and weight mockups of the SEIS, WTS, and HP3 payloads. This indoor facility features special lights that mimic the spectrum and intensity of sunlight on Mars and a 'sandbox' that allows terrain to be sculpted. The testbed's primary purpose is for verifying deployment requirements and testing key deployment sequences before execution in the IDP. Before launch and through cruise, the testbed is used for deployment testing, verification and validation of sequences, and team operations testing and training. A primary focus has been robustness testing on plausible spacecraft tilts and workspace configurations. Rocks and other terrain features at the landing site could result in a lander tilt up to 15 degrees off-normal or create obstacles and challenging surface conditions within the payload workspace. The deployment team has completed 28 deployment test cases, simulating various combinations of lander tilts and terrain slopes over 7 unique instrument placement sites.

The test program specifically investigated 'edge cases' and was aimed and understanding workspace challenges including payload tether interactions with the ground and payload placement uncertainties.

The testbed is also used to rehearse tactical operations before landing. Training scenarios are designed to keep the team "in-the-blind", treating the testbed like the flight vehicle to generate flight-like images and telemetry. The operations team must use their tools and available data to understand the vehicle state and make tactical decisions. Several rehearsals have tested nominal and anomalous scenarios as well as validating processes and practices for recapturing a payload and adjusting the SEIS tether.

After landing, the testbed will be 'marsformed' to match the lander orientation and workspace terrain seen on Mars. This process will recreate instrument deployment sites to a fidelity high enough to exercise deployment testing. The team will use a holo-lens headset, which overlays the Mars landscape over the sandbox and aids in general terrain shaping and rock placement. A Vicon system is also used to take absolute height measurements so errors can be reduced. Marsforming will be completed after the IDA mosaic images are delivered and the shaped workspace will be ready prior to testing the SEIS deployment. Placement of each of the deployed elements is thoroughly tested in the deployment testbed prior to flight deployment on Mars.

Sol	Activities
0, 1, 2, 3, 4	Checkout Activities
5, 8, 10	Instrument Site Certification
14, 16, 18, 20, 22, 23, 24, 26, 27, 30, 31, 32, 33, 37	SEIS Deployment SEIS Deployment & SEIS Site Acceptance
38, 39, 40, 42	WTS Deployment
44, 46, 48, 50, 52, 54	HP3 Deployment

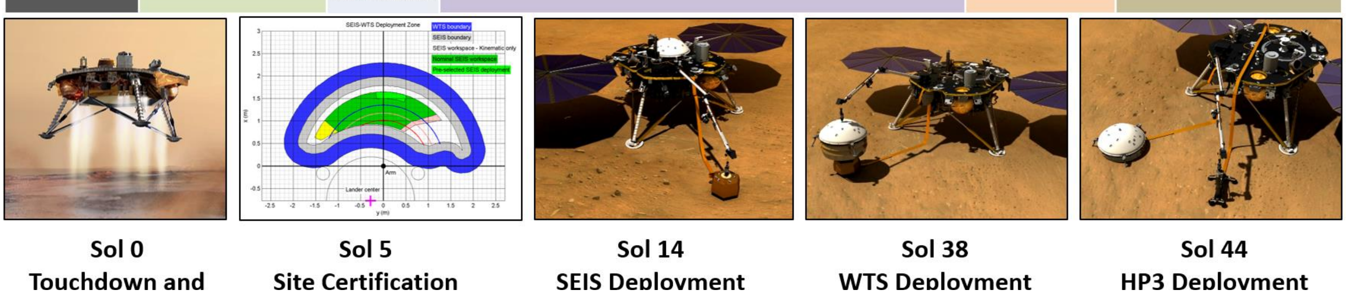

Figure 8: Deployment Timeline

3.4 Surface Science 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. PAYLOAD DESCRIPTION

The payload for InSight was developed to meet the baseline science requirements. The requirements are met by three investigations: a seismometer (SEIS); a heat flow and physical properties probe (HP3); and a radio science investigation (RISE) conducted with the x-band telecom system. SEIS and HP3 are placed on the surface with an instrument deployment system (IDS) comprised of a robotic arm (IDA), deployment camera (IDC), and context camera (ICC). SEIS and HP3 collect data autonomously over one Mars year. The DSN tracks RISE's X-band transponder signal about one hour per day for geodesy measurements. Additionally, the Axillary Payload Sensor Suite (APSS) onboard the lander provides support to the SEIS instrument through monitoring of the Martian environment, which can influence the SEIS measurement [10].Lastly, InSight contains a passive payload called the Laser Retroreflector for InSight (LaRRI) that will enable gravitational science experiments by future Martian orbiters. This was added after InSight's launch slipped to 2018. [11]

4.1 SEIS

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. Both sensor sets are mounted on the precision leveling structure (LVL). The Leveling structure is then encapsulated within a thermal blanketing structure (RWEB) to provide a secondary layer of thermal protection for sensor elements. All of these pieces together comprise the Sensor Assembly (SA), which is the portion of SEIS that is deployed to the Martian surface. The SA is connected to the electronics box (EBox) within the lander by a multi-layer flexible tether.

The VBB sensors are isolated from the Martian environment utilizing three layers of protection. This isolation is critical to achieving the high-performance measurements required to achieve the baseline science. The main environmental factor needing isolation is temperature fluctuations and the secondary factor is wind disturbances. Temperature fluctuations at the sensor assembly are first attenuated by the pressure vessel that the VBBs are enclosed within. The RWEB around both the VBBs and the SP provides the secondary level of protection. The final layer of protection for both temperature and wind noise is the Wind and Thermal Shield (WTS). During deployment the WTS is placed over the SEIS sensor assembly.

SEIS VBB-The VBB displacement transducers are a trio of orthogonal, inverted pendula stabilized with a leaf spring and tuned for Mars gravity; they are packaged in an evacuated sphere with internal temperature compensation. A differential capacitive sensor detects movement of the housing relative to the pendula, which are continuously centered by a magnetic-coil actuator using a force-feedback system.

SEIS SP-The SP is a MEMS device consisting of a triad of monolithic in-plane silicon proof mass/folded-cantilever suspensions, with electroplated coils and capacitive sensors driving analog feedback circuits. The SP is not required for SEIS to meet its baseline science requirements. It provides partial redundancy to the VBB sensor and covers a different spectrum of seismic waves.

SEIS LVL-Once the SEIS is placed on Mars, the LVL provides the capability to compensate for local terrain slopes (≤13º off horizontal at the landing site) while providing mechanical coupling to the ground with minimal signal distortion.

SEIS EBox-The EBox provides conditioned power to the sensor assembly, acquires the seismometer signals, provides feedback, and integrates environmental and housekeeping sensor data into the data stream. It is also used to issue commands to the VBBs, SPs and LVL subassemblies.

4.2 RISE

InSight's Rotation and Interior Structure Experiment (RISE) measures the rotation of Mars to high precision by employing two-way X-band carrier-signal tracking between the Lander and Earth, with up to seven ~1 hour tracking passes per week. 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. Tracking for extended periods in the proper geometry resolves annual and semiannual precession and nutation signatures, which are a small perturbation on the Mars spin-axis direction [2].

4.3 HP3

The Heat Flow and Physical Properties Package (HP3) measures the heat flux coming from the interior of Mars at the landing site of the InSight mission. 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 [11].

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).

The HP3 is equipped with a tether length monitor and an accelerometer to measure tilt for the determination of the mole depth and penetration path. As the mole penetrates, it pulls a tether behind it that both provides power/data to/from the mole, but is also instrumented with temperature sensors. Following the end of the penetration phase (approximately 30 Sols of intermittent operation), these temperature sensors remain in the subsurface and monitor the temperature over a vertical profile for 1 Mars' year. Integration of the data from each of these sensors over time shows the temperature flux along the mole borehole.

HP3 consists of an electro-mechanical hammering mechanism, the mole that penetrates below the Martian surface and contains resistive heaters/thermometers for the active thermal-conductivity measurement as well as tilt sensors to determine its trajectory through the ground. It pulls behind it the Science Tether, with temperature sensors to measure the thermal gradient in the subsurface. A support structure houses both the mole and the Science Tether prior to ground penetration, contains the Tether Length Monitor to determine the amount of Science Tether deployed. An Engineering Tether connects the deployed instrument to its Back-End Electronics (BEE) located in the Lander. There is also a deck-mounted radiometer that measures surface brightness temperature.

4.4 APSS

The Auxiliary Payload Sensor Suite (APSS) provides supporting environmental measurements to understand noise seen in seismic measurements by SEIS. It is comprised of the following sensors:

Payload Auxiliary Electronics-The PAE does all of the command and data handling with the APSS sensors as well as supplying them power.

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 mPa accurate readings of Martian atmospheric pressure. SEIS is extremely sensitive to pressure disturbances and this sensor is required to decorrelate pressure related noise.

Thermal and Wind for InSight – TWINS is essentially a re-fly of the REMS wind sensors from Mars Science Laboratory. Wind will push on the WTS and the lander, which will cause vibrations that SEIS picks up. It is important to understand the strength and direction of the Martian wind while SEIS takes its measurements.

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. [12]

4.5 Payload ATLO Testing

Assembly, Test, and Launch Operations (ATLO) is where all of the spacecraft components come together for system-level testing and launch. The payloads served an integral role in InSight's ATLO, as the system testing relied heavily on the planned use. Successful completion of these activities were a critical preparation step for cruise and surface operations. Many of the operational products, processes and tools planned for use during cruise and surface operations were tested and debugged during the ATLO phase. This was especially important for the payloads

An example of a test was a "day in the life" on Mars where the lander powered on all of the payloads, and proceeded through sleep/wake cycles at the cadence expected on Mars. This test was done multiple times as flight software matured, and helped define the mission operation plans as it was learned how the system truly behaved.

Another integrated payload and flight system test performed was electromagnetic compatibility. In this test, spacecraft and payload components are systematically powered on and off, with the goal of identifying any interference in the ability to operate any given component and to detect any disturbances in scientific measurements by a given spacecraft component. SEIS is the most sensitive payload, so extreme care was taken to run SEIS through its various science collection modes and to identify and perturbations of its measurements as other lander activity occurred. The results were that there were no incompatibilities detected and SEIS is robust to spacecraft generated electromagnetic interference. [13]

Environmental testing is one of the longest and most important tests performed in ATLO. The Landed Thermal Vacuum test was of particular importance. During this test, the lander was installed into a large Thermal Vacuum chamber while temperature and pressure were varied over a three-week period in order to simulate the cruise and surface environments. While in the various test phases the lander and its instruments were cycled through the various modes that they will be operating in once launched and during surface operations. With this, it was proven the InSight lander and its payloads could operate in the harsh environments that they would be subjected to. [14]

5. Cruise Testing

Once launched, the spacecraft undergoes a thorough checkout in order to ensure that all of the components survived launch. Over the course of 4 months after launch, each payload was powered on and run through a self-test.

Each payload self-test was meant to exercise every circuit that is possible exercise while in the cruise environment. Each payload performed its checkout via spacecraft sequencing commands, transferred the results to the spacecraft, and then the spacecraft downlinked the data to Earth. Once on Earth, scientists and engineers combed over the data to ensure that everything operated as expected. The first set of checkouts done were with InSight ICC and IDC cameras. Figure 10 shows the low-light IDC image taken in cruise compared to the last image it took during ground processing prior to launch.

SEIS, HP3, and APSS all underwent self-tests as well. The only sensors on SEIS that were functional in the cruise zero-gravity environment were the two horizontal SP sensors. The self-test showed that these sensors were operating nominally. The quiet environment of space actually proved to have lower noise than even the seismic vault testing done on Earth. This allowed the noise floor of the horizontal SPs to be measured with higher accuracy than what could be done prior to launch.

In addition to the instrument self-tests performed, the SEIS SP sensors, the SEIS tiltmeters, and the APSS IFG underwent 28-hour data collections. This data collected will be used to calibrate these sensors once on the surface of Mars.

The payload self-test sequences used during cruise form the basis of the checkouts that will be done within a couple of days of InSight's landing. Additionally, similar sequences were used prior to InSight's launch while it was on the launch pad. By comparing all of the results of all of these tests, the team is able to understand and trend the payload health. [15]

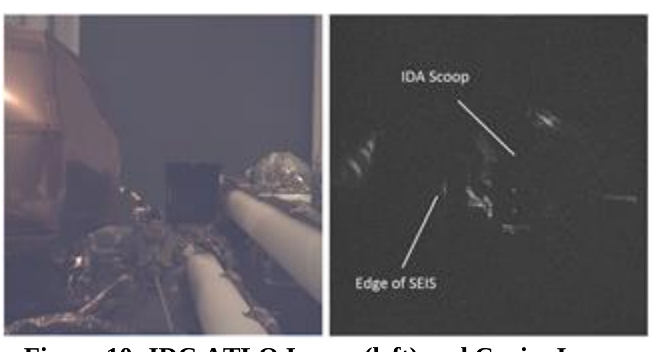

Figure 10: IDC ATLO Image (left) and Cruise Image (right)

6. Current Project Status

The project completed all pre-Launch activities in April of 2018 and successfully launched from Vandenberg Air Force Base in Lompoc CA. on May 5, 2018. Currently the spacecraft is cruising to Mars and preparing for EDL on November 26, 2018.

7. Conclusion

The InSight project has the potential to provide science which will fundamentally change the knowledge of terrestrial planet formation and evolution. In order to have this opportunity for transformative science, the InSight operations team has prepared for the past several years to perform the always challenging EDL process and to robotically deploy instruments on the surface of another planet. It is inevitable that there will be future engineering challenges, but the work that the team has done preparing them for EDL and surface operations will prove valuable in resolving future issues.

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BIOGRAPHY

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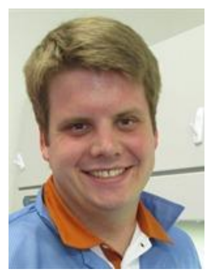

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