National Aeronautics and Space Administration

Mars InSight Landing Press Kit

NOVEMBER 2018

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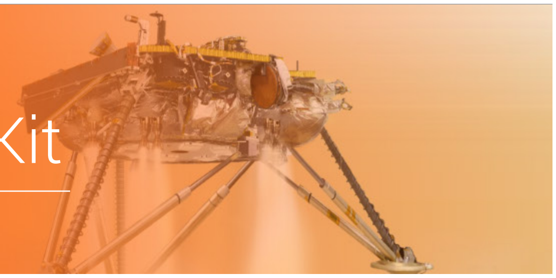
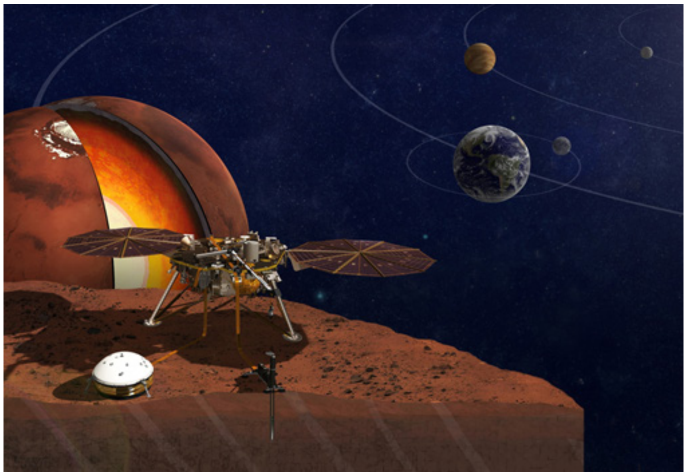




InSight will help us learn about the formation of Mars -- as well as all rocky planets. Credit: NASA/JPL-Caltech

Introduction

NASA's next mission to Mars -- InSight -- is expected to land on the Red Planet on Nov. 26, 2018. InSight is a mission to Mars, but it is also more than a Mars mission. It will help scientists understand the formation and early evolution of all rocky planets, including Earth.

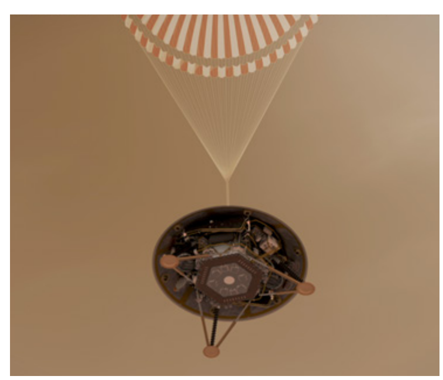
In addition to InSight, a technology demonstration called Mars Cube One (MarCO) is flying separately to the Red Planet. It will test a new kind of data relay from another planet for the first time, though InSight's success is not dependent on MarCO.

Five Things to Know About Landing

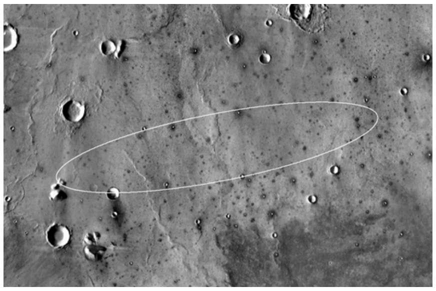
1. Landing on Mars is difficult

Only about 40 percent of the missions ever sent to Mars -- by any space agency -- have been successful. The U.S. is the only nation whose missions have survived a Mars landing. The thin atmosphere -- just 1 percent of Earth's -- means that there's little friction to slow down a spacecraft. Despite that, NASA has had a long and successful track record at Mars. Since 1965, it has flown by, orbited, landed on and roved across the surface of the Red Planet.

2. InSight uses tried-and-true technology



In 2008, NASA's Jet Propulsion Laboratory successfully landed the Phoenix spacecraft near Mars' North Pole. InSight is based on the Phoenix spacecraft, both of which were built by Lockheed Martin Space. Despite tweaks to the heat shield and parachute, the overall landing design is still very much the same: After separating from a cruise stage, an aeroshell descends through the atmosphere. The parachute and retrorockets slow the spacecraft down, and suspended legs absorb some shock from the touchdown.



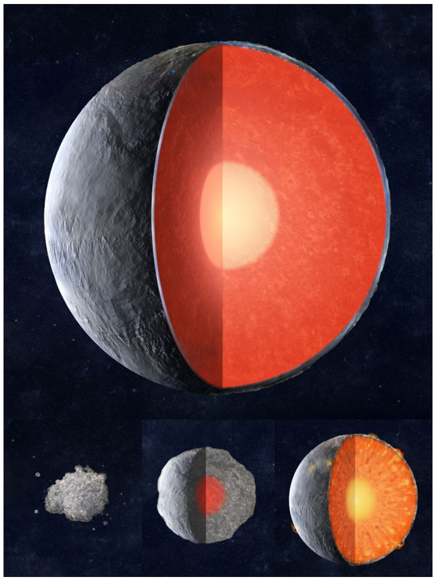
3. InSight is landing on "the biggest parking lot on Mars"

One of the benefits of InSight's science instruments is that they can record equally valuable data almost regardless of where they are on the planet. That frees the mission from needing anything more complicated than a flat, stable surface (ideally with few boulders and rocks). That's why the mission's team considers the landing site at Elysium Planitia "the biggest parking lot on Mars."

4. InSight can land in a dust storm

InSight's engineers have built a tough spacecraft, able to touch down safely in a dust storm if it needs to. The spacecraft's heat shield is designed to be thick enough to withstand being "sandblasted" by suspended dust. It also has a parachute that was tested to be stronger than Phoenix's, in case it faces more air resistance due to the atmospheric conditions expected during a dust storm.

The entry, descent and landing sequence also has some flexibility in handling shifting weather. The mission team will be receiving daily weather updates from NASA's Mars Reconnaissance Orbiter in the days before landing so that they can adjust when InSight's parachute deploys and when it uses radar to find the Martian surface.

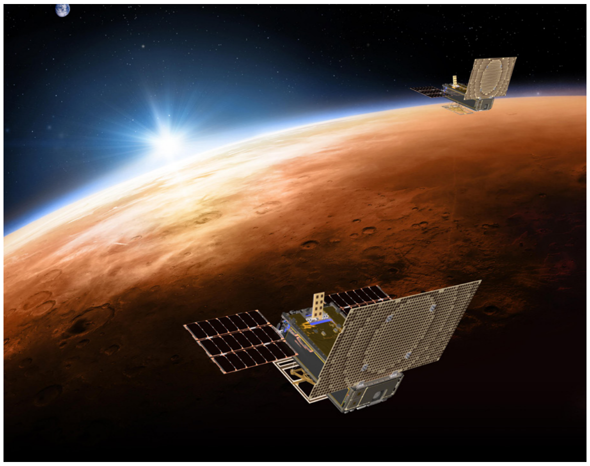


5. InSight will teach us about the interior of planets like our own

InSight's team hopes that by studying the deep interior of Mars, we can learn how other rocky worlds, including Earth and the Moon, formed. Our home planet and Mars were molded from the same primordial stuff more than 4.5 billion years ago but then became quite different. Why didn't they share the same fate?

When it comes to rocky planets, we've studied only one in detail: Earth. By comparing Earth's interior to that of Mars, InSight's team members hope to better understand our solar system. What they learn might even aid the search for Earth-like exoplanets, narrowing down which ones might be able to support life. So while InSight is a Mars mission, it's also much more than a Mars mission.

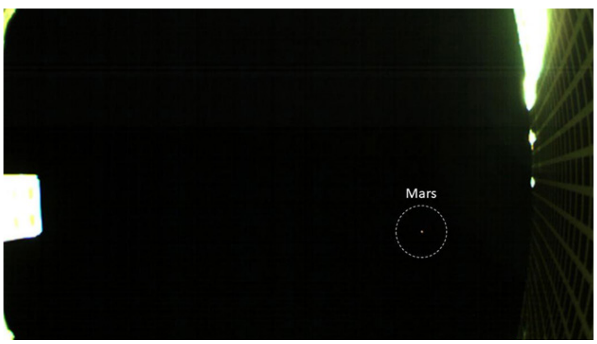
Three Things to Know About Mars Cube One



1. MarCO is a pathfinder mission for small spacecraft technology

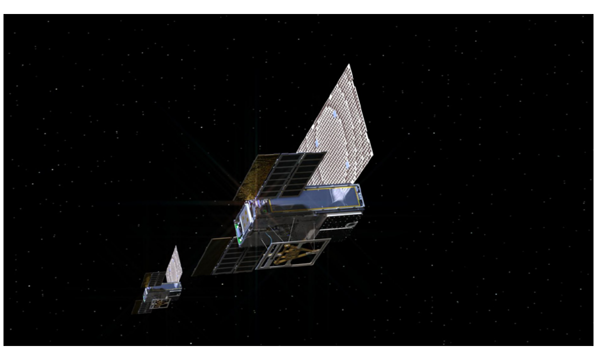
Two mini-spacecraft called Mars Cube One, or MarCO, have been flying on their own path to Mars behind InSight as a separate NASA technology experiment. MarCO is the first deep space mission for CubeSats, a class of briefcase-sized spacecraft that rely on miniaturized technology.

If the MarCOs make it to Mars, they will attempt to relay data from InSight as it enters the Martian atmosphere and lands. If successful, this could represent a new kind of communication capability to Earth.



2. The MarCOs already have made several big achievements, proving the feasibility of operating tiny spacecraft in deep space for the first time.

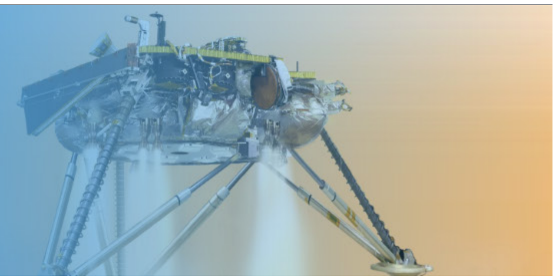
The MarCOs have proved this class of spacecraft can survive the deep-space environment, becoming the first CubeSats to provide images of Earth, its moon and Mars along the way. They've successfully tested several experimental technologies, including their radios, high-gain antennas and propulsion systems. They became the first CubeSats to fly to deep space, performing the first trajectory correction maneuvers by CubeSats (each steering towards Mars).



3. InSight's success is independent of its CubeSat tag-alongs.

InSight and MarCO are separate missions.

The MarCOs were never intended as the primary telecommunications relay for InSight during landing. NASA's Mars Reconnaissance Orbiter and 2001 Mars Odyssey orbiter have that primary responsibility.



Media Services

A media and social media briefing days before InSight's launch from Vandenberg Air Force Base. Credit: NASA/KSC

Media Contacts

Policy/Program Management

Headquarters, Washington

Dwayne Brown
202-358-1726
dwayne.c.brown@nasa.gov

JoAnna Wendel
202-358-1003
joanna.r.wendel@nasa.gov

InSight Mission

NASA Jet Propulsion Laboratory | Pasadena, California

D.C. Agle
818-393-9011
agle@jpl.nasa.gov

Andrew Good
818-393-2433
andrew.c.good@jpl.nasa.gov

Jia-Rui Cook
818-354-0724
jccook@jpl.nasa.gov

Spacecraft

Lockheed Martin Space | Denver, Colorado

Dani Hauf
303-932-4360
danielle.m.hauf@lmco.com

NASA Discovery Program

Marshall Space Flight Center | Huntsville, Alabama

Molly Porter
256-544-0034
molly.a.porter@nasa.gov

Science Payload Instruments

Seismic Experiment for Interior Structure

Paris, France

Claire Dramas
Centre National d'Études Spatiales (CNES)
011-33-6-78-10-91-78
Claire.Dramas@cnes.fr

Philippe Labrot
IPGP - Planétologie et Sciences Spatiales Université Paris
011-33-6-10-27-52-25
labrot@ipgp.fr

Heat Flow and Physical Properties Package

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Berlin, Germany

Manuela Braun
011-49-2203-601-3882
Manuela.Braun@dlr.de

Technology Demonstration

Mars Cube One

NASA Jet Propulsion Laboratory | Pasadena, California

Andrew Good
818-353-2433
626-840-4291 (cell)
andrew.c.good@jpl.nasa.gov

Products and Events

News Releases, Features and Status Reports

Mission news, updates and feature stories about InSight will be available at:
nasa.gov/insight, and
mars.nasa.gov/insight.

Video and Images

Video and images related to the InSight and MarCO missions, including raw video for media, are available at the gallery section of this press kit and also at:
images.nasa.gov.

Images in this press kit should be credited NASA/JPL-Caltech unless otherwise specified.

The NASA image use policy is available at:
https://www.nasa.gov/multimedia/guidelines/index.html

The JPL image use policy is available at:
https://www.jpl.nasa.gov/imagepolicy

Media Events

The most up-to-date information about upcoming InSight media events and where they may be viewed can be found on the **InSight Landing Page** at: mars.nasa.gov/insight/timeline/landing/summary. More information on NASA TV and streaming channels can be found below in the press kit's "**how to watch**" section.

Briefings

A news conference presenting an overview of the mission is taking place at **NASA Headquarters on Oct. 31, 2018, at 1:30 p.m. EDT (10:30 a.m. PDT).**

Pre-landing briefings open to pre-accredited news media are scheduled for Wednesday, **Nov. 21, at 10 and 11 a.m. PST (1 and 2 p.m. EST)**, and **Sunday, Nov. 25, at 10 a.m. PST (1 p.m. EST), at JPL.** A NASA Social speakers' program scheduled for **1 p.m. PST (4 p.m. EST)**, **Sunday, Nov. 25**, is also open to accredited news media. A post-landing briefing will be held on the afternoon of **Nov. 26 no earlier than 2 p.m. PST (5 p.m. EST)**.

Live Landing Commentary

A live video feed of key landing activities and commentary from Mission Control at JPL will be broadcast at **11 a.m. PST (2 p.m. EST)**. Notification of landing is expected to be received in Mission Control around **noon PST (3 p.m. EST)**.

An uninterrupted clean feed of cameras from inside JPL Mission Control, with mission audio only, will be available at the same time on the NASA TV Media Channel, at nasa.gov/ntv and at youtube.com/user/JPLraw/live.

On-Site Media Logistics

Newsroom

The on-site newsroom at JPL, where credentialed reporters may request interviews and file their stories, will be open on **Wednesday, Nov. 21; Sunday, Nov. 25; and Monday, Nov. 26. Media may call the newsroom at 818-354-5011 to arrange interviews on Friday, Nov. 23, and Saturday, Nov. 24.**

Media Credentialing

Media credentialing for the InSight landing at JPL was open from **Aug. 22 to Sept. 24, 2018**.

Tours

Media tours of key locations, including mission control and the InSight testbed, will take place on **Wednesday, Nov. 21**, and **Sunday, Nov. 25**. Media wishing to join a tour must have a JPL media credential and must make a reservation with the JPL Media Relations Office at 818-354-5011 or sign up in person at the JPL newsroom.

Interviews

Members of the media may arrange interviews on site at the JPL newsroom or by calling 818-354-5011.

How to Watch (Live and On Demand)

News briefings and launch commentary will be streamed on NASA TV, NASA.gov/live, YouTube.com/NASAJPL/live and Ustream.tv/NASAJPL. (On-demand recordings will also be available after the live events have finished on the YouTube and Ustream pages.) A clean feed of landing from Mission Control will be streamed and archived on Ustream.tv/NASAJPL2 and YouTube.com/JPLRaw/live. Any additional feeds or streams will be listed in the **"Watch Online"** section of the InSight website.

NASA TV channels are digital C-band signals carried by QPSK/DVB-S modulation on satellite Galaxy-13, transponder 11, at 127 degrees west longitude, with a downlink frequency of 3920 MHz, vertical polarization, data rate of 38.80 MHz, symbol rate of 28.0681 Mbps and 3/4 FEC. A Digital Video Broadcast-compliant Integrated Receiver Decoder is needed for reception. A full schedule of the InSight broadcast, including commentary and clean feed channels, will be available on the NASA TV schedule.

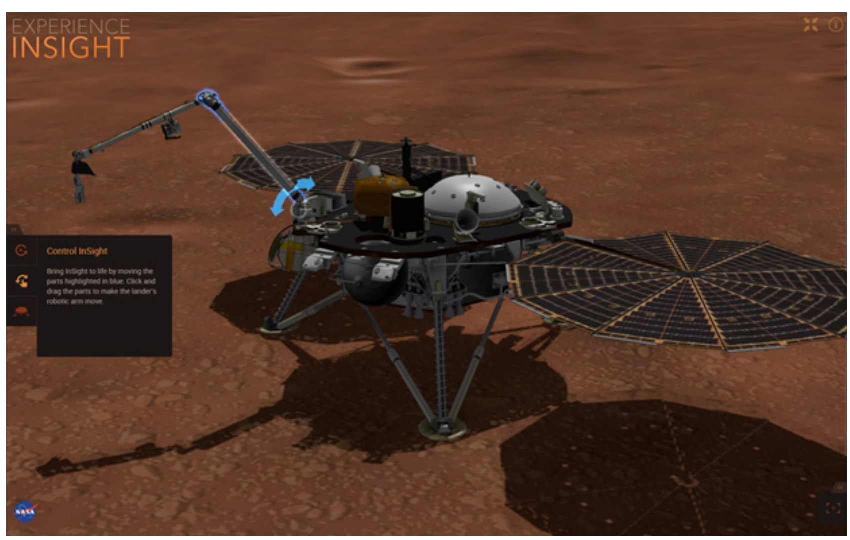
Follow InSight and MarCO in Real-Time

Through NASA's Eyes on the Solar System, the public can follow the path of InSight in real-time as it travels through the inner solar system toward Mars and hits the top of the Martian atmosphere. The two MarCO CubeSats, which expect to fly by Mars when InSight lands, can also be followed in real-time.

Eyes is available on the Web at eyes.nasa.gov/.

Experience InSight

The public can also experience what it's like to open InSight's solar panels and place instruments on the Martian surface after landing in a special web interactive available at https://eyes.nasa.gov/insight/



Additional Resources on the Web

Online and PDF versions of this press kit are available at:
jpl.nasa.gov/news/press_kits/insight/landing/download/mars_insight_landing_presskit.pdf

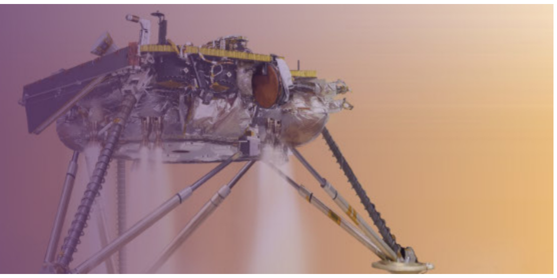
Additional detailed information about InSight is available at:
mars.nasa.gov/insight/

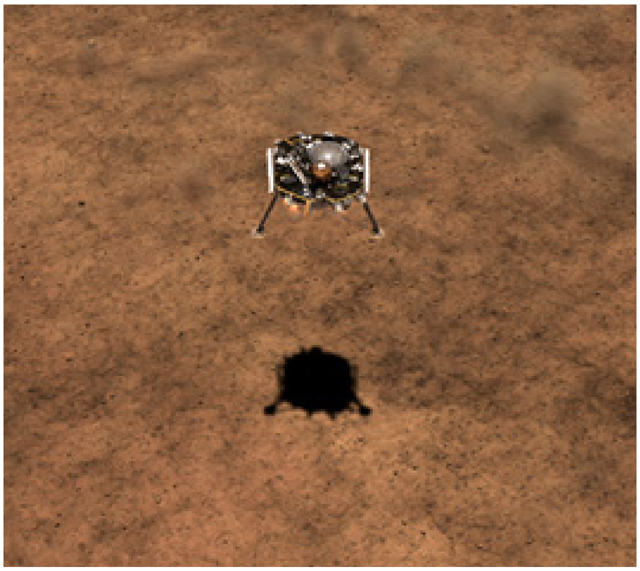
Social Media

Join the conversation and get mission updates from InSight, JPL and NASA via these accounts:

- Twitter: @NASAInSight, @NASAJPL, @NASA
- Facebook: @NASAInSight, @NASAJPL, @NASA
- Instagram @NASAJPL, @NASA

Quick Facts: Landing Facts





Mission Firsts

- First mission dedicated to studying the deep interior of Mars
- First to place a seismometer directly on the surface of another planet to detect quakes
- First to use a robotic arm to place instruments on the surface of another planet
- First to probe as deep as 16 feet (5 meters) under the Martian surface -- 15 times deeper than any previous Mars mission
- First to use a magnetometer on the surface of Mars
- First interplanetary launch from the West Coast

Mission Name

The long form of the mission's name is Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, which includes the three main research techniques to be used by the InSight stationary lander. A dictionary definition of "insight" is to see the inner nature of something.

Spacecraft

InSight Lander Dimensions

Height range (after its legs compress a still-to-be-determined amount during impact): between 33 to 43 inches (83 to 108 centimeters) from the bottom of the legs to the top of the deck; span with solar arrays deployed: 19 feet, 8 inches (6.00 meters); width of deck: 5 feet, 1 inch (1.56 meters); length of robotic arm: 5 feet, 11 inches (1.8 meters)

Parachute Dimensions

Diameter: 39 feet (11.8 meters). Suspensions lines: 40 in total, which tie into 10 risers. Mortar canister: 1; the parachute trails the mortar by about 65 feet (20 meters). Peak load: Up to 15,000 pounds per foot (22,000 kilograms per meter)

Heat Shield

Dimensions: 8 feet, 8 inches wide (2.64 meters). **Back shell and heat shield weight:** 419 pounds (190 kilograms). **Composition:** The heat shield is made of Lockheed Martin's SLA-561V (Super Lightweight Ablator 561V) thermal protection material. This material is primarily made up of crushed cork. SLA-561V was developed and used on the Viking missions in 1976 and for every NASA Mars surface mission with the exception of Curiosity and the upcoming Mars 2020 mission. Though based on the Phoenix Lander design, the InSight heat shield is slightly thicker than the one used for the Mars Phoenix mission.

Power

Solar panels and lithium-ion batteries are on both InSight and MarCO. On InSight, the two solar array panels together provide about 1,300 watts on Earth on a clear day. On Mars, they provide 600-700 watts on a clear day, or just enough to power a household blender. They're estimated to provide 200-300 watts on a dusty day, even with some dust covering the panels.

Mass

About 1,530 pounds (694 kilograms) for the entire InSight spacecraft at launch. The spacecraft includes the lander, which is about 789 pounds (358 kilograms), the 417-pound (189-kilogram) aeroshell, 174-pound (79-kilogram) cruise stage and 148 pounds (67 kilograms) of loaded propellant and pressurant. Mass of each MarCO spacecraft: 29.8 pounds (13.5 kilograms). Total payload mass on the rocket: 1,590 pounds (721 kilograms)

InSight Science Payload

About 110 pounds (50 kilograms), including Seismic Experiment for Interior Structure, Heat Flow and Physical Properties Package, Auxiliary Payload Sensor Suite, Instrument Deployment System and Laser Retroreflector. (The Rotation and Interior Structure Experiment uses the lander's telecommunications system.)

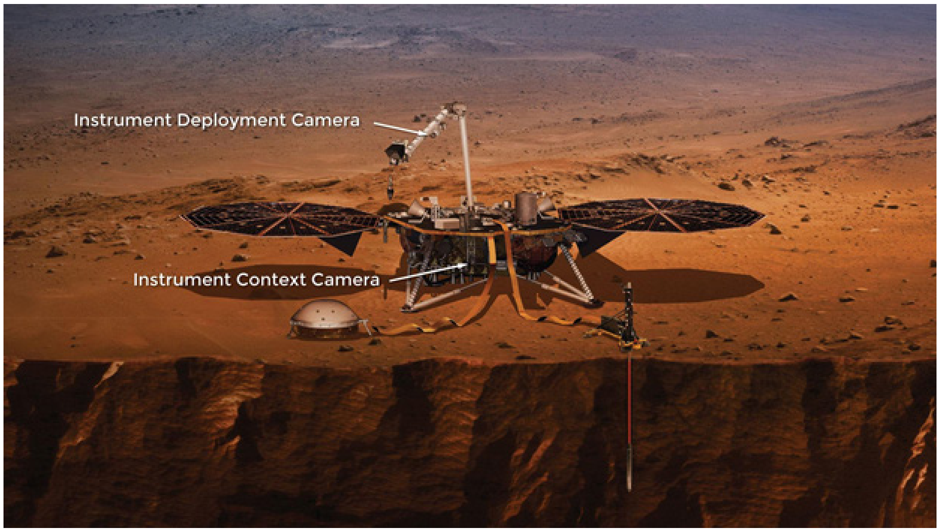
Mars Cube One (MarCO) dimensions:

Twin spacecraft, each 14.4 inches (36.6 centimeters) by 9.6 inches (24.3 centimeters) by 4.6 inches (11.8 centimeters).

Cameras

One pointable camera on InSight's robotic arm and one fixed, wide-angle camera under the spacecraft's lander deck are both capable of producing color images of 1,024 pixels by 1,024 pixels. MarCO-A and B each have a wide-field camera (primarily to confirm high-gain antenna deployment) capable of color images of 752 pixels by 480 pixels in resolution.

Both MarCO CubeSats were also designed with a narrow-field-of-view camera, but MarCO-A's narrow-field camera was found to be inoperable prior to launch.



Mission

Launch: May 5, 2018, 4:05 a.m. PDT (7:05 a.m. EDT), Vandenberg Air Force Base, Central California

Launch vehicle: Atlas V 401, provided by United Launch Alliance

Mars landing time: Nov. 26, 2018, 11:47 a.m. PST (2:47 p.m. EST; 19:47 UTC). Because it takes about 8 minutes for light to travel from Mars to Earth, this means the landing "signal" will be received in Mission Control as early as around 11:54 a.m. PST (2:54 p.m. EST; 19:54 UTC). We refer to this as "Earth Receive Time," or ERT. At the Mars landing site, it will be mid-afternoon on a winter day.

Landing site: Near the equator, about 4.5 degrees north latitude, 135.9 degrees east longitude, in Elysium Planitia

Landing site's distance from: Curiosity: 340 miles (550 kilometers), Spirit: 1,600 miles (2,600 kilometers), Opportunity: 5,200 miles (8,400 kilometers)

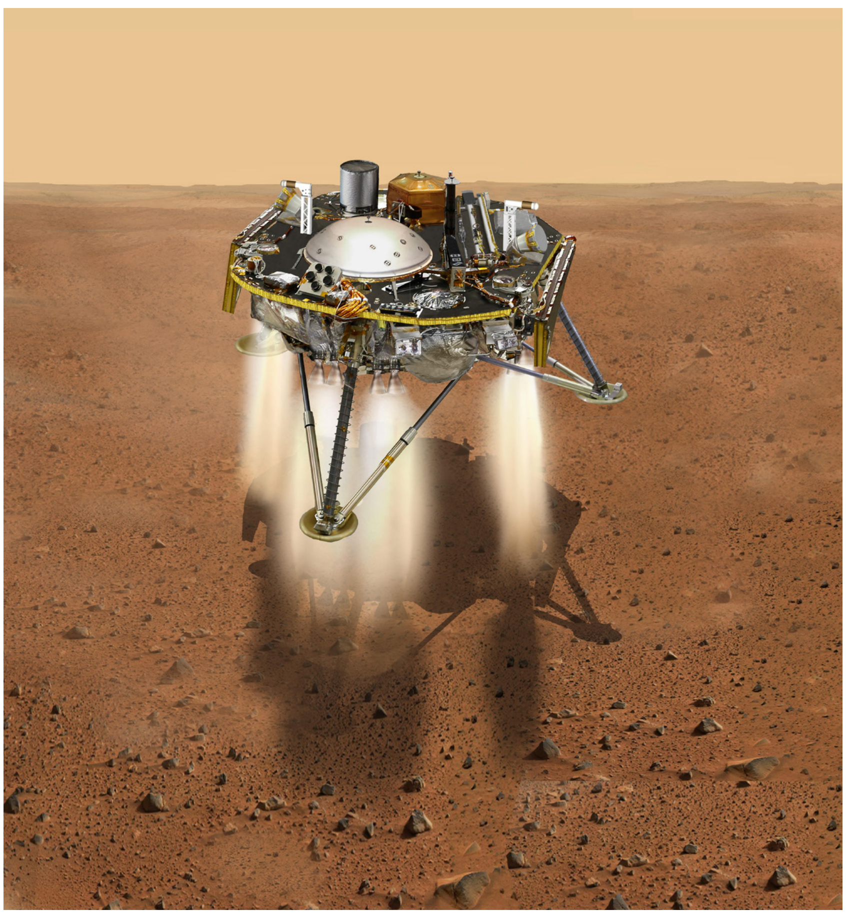
Distance traveled since launch, as of Oct. 31: 269,006,537 miles (432,924,056 kilometers)

Earth-Mars distance on Nov. 26, 2018: 91 million miles (146 million kilometers)

One-way radio transit time, Mars to Earth, on Nov. 26, 2018: 8.1 minutes

Primary mission duration: One Martian year plus 40 Martian days (nearly 2 Earth years), until Nov. 24, 2020

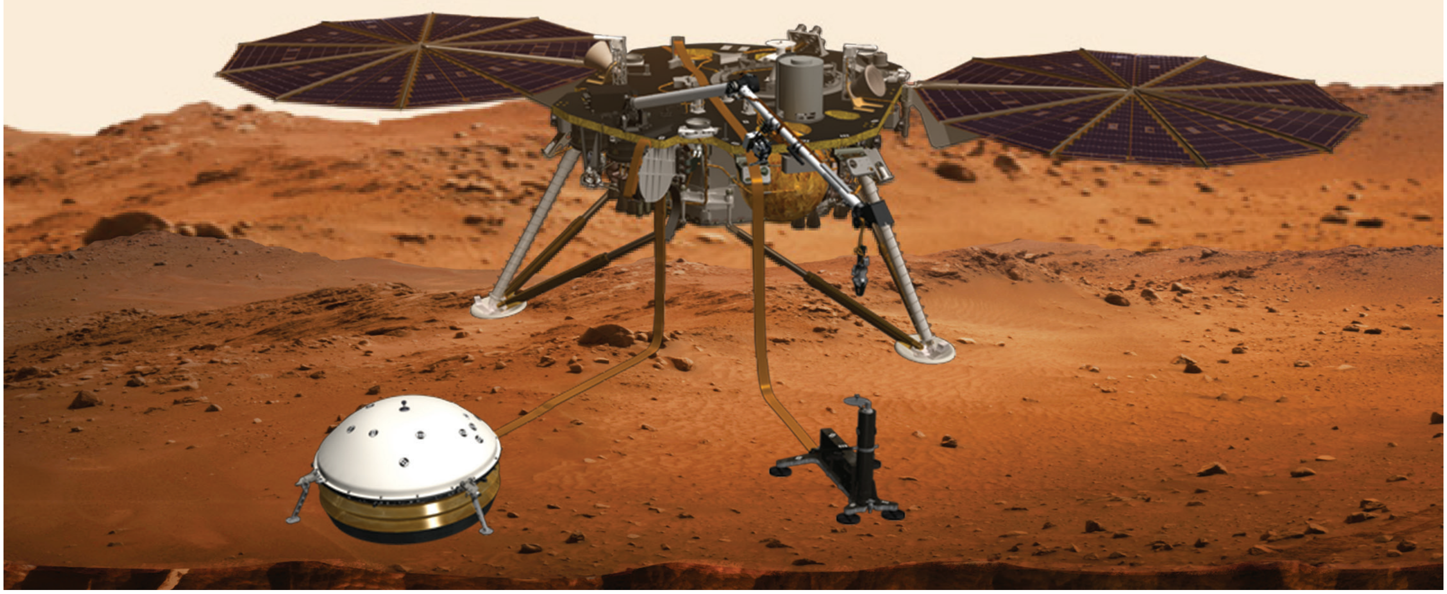
Expected near-surface atmospheric temperature range at landing site during primary mission: minus 148°F to minus 4°F (minus 100°C to minus 20°C)



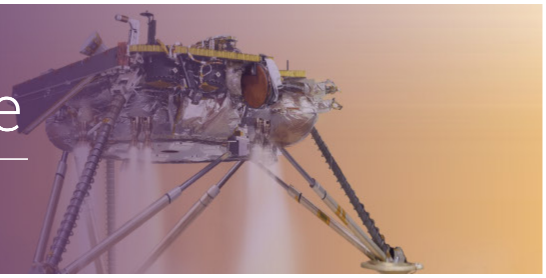
Program

U.S. investment in InSight is $813.8 million, including about $163.4 million for the launch vehicle and launch services, and the rest for the spacecraft and operations through the end of the prime mission. In addition, France and Germany -- the major European participants -- have invested about $180 million in InSight's investigations, primarily the seismometer investigation (SEIS) and heat flow investigation (HP^3).

JPL and NASA are investing about $18.5 million in the Mars Cube One technology.



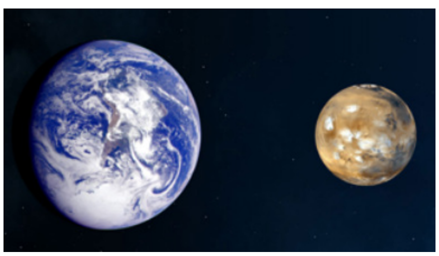
Quick Facts: Mars at a Glance



General

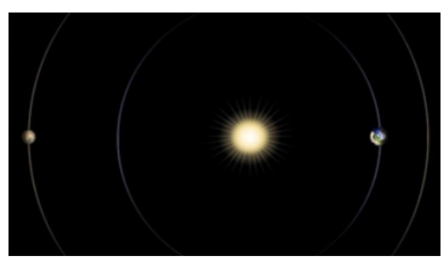
- One of five planets known to ancients; Mars was the Roman god of war, agriculture and the state
- Yellowish brown to reddish color; occasionally the third-brightest object in the night sky after the Moon and Venus

Physical Characteristics



- Average diameter 4,212 miles (6,780 kilometers); about half the size of Earth but twice the size of Earth's Moon
- Same land area as Earth, reminiscent of a cold, rocky desert
- Mass 1/10 of Earth's; gravity only 38 percent as strong as Earth's
- Density 3.9 times greater than water (Earth's density is 5.5 times greater than water)
- No planet-wide magnetic field detected; only localized ancient remnant fields in various regions

Orbit



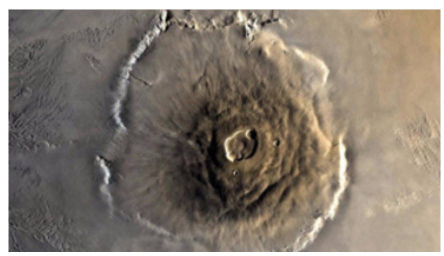
- Fourth planet from the Sun, the next beyond Earth
- About 1.5 times farther from the Sun than Earth
- Orbit is elliptical; distance from the Sun varies from a minimum of 128.4 million miles (206.7 million kilometers) to a maximum of 154.8 million miles (249.2 million kilometers); average is 141.5 million miles (227.7 million kilometers)
- Revolves around the Sun once every 687 Earth days
- Rotation period (length of day) is 24 hours, 39 minutes, 35 seconds (1.027 Earth days)
- Pole is tilted 25 degrees, creating seasons similar to those on Earth

Environment

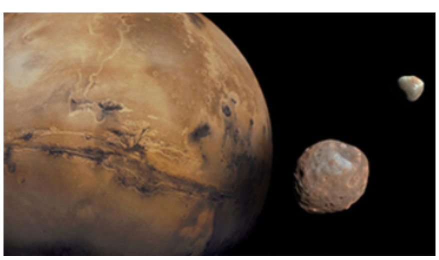
- Atmosphere composed chiefly of carbon dioxide (95.3%), nitrogen (2.7%) and argon (1.6%)
- Surface atmospheric pressure less than 1/100th that of Earth's average
- Surface winds of 0 to about 20 mph (0 to about 10 meters per second), with gusts up to about 90 mph (more than 140 kilometers per hour)
- Local, regional and global dust storms; also whirlwinds called dust devils
- Surface temperature averages minus 64 Fahrenheit (minus 53 Celsius); varies from minus 199 Fahrenheit (minus 128 Celsius) during polar night to 80 Fahrenheit (27 Celsius) at the equator during midday, at its closest point in orbit to the Sun

Features

- Highest point is Olympus Mons, a huge shield volcano about 16 miles (26 kilometers) high and 370 miles (600 kilometers) across; has about the same area as Arizona
- Canyon system of Valles Marineris is largest and deepest known in solar system; extends more than 2,500 miles (4,000 kilometers) and has 3 to 6 miles (5 to 10 kilometers) of relief from floors to tops of surrounding plateaus

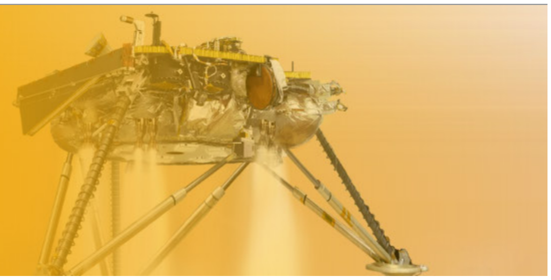


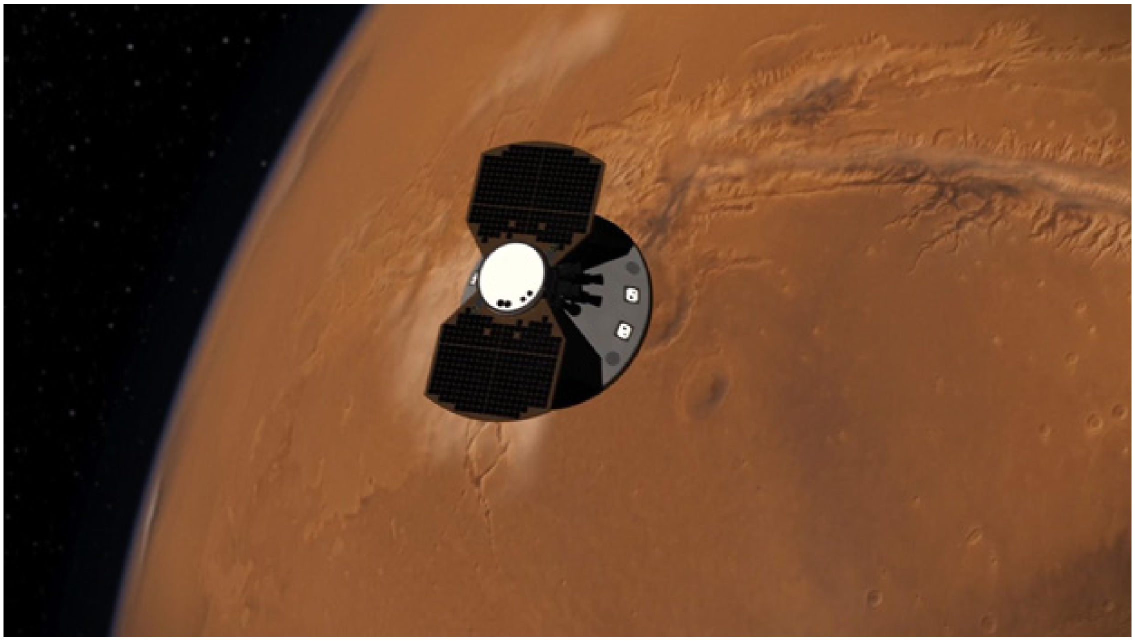
Moons



- Two irregularly shaped moons, each only a few miles (kilometers) wide
- Larger moon named Phobos ("fear"); smaller is Deimos ("terror"), named for attributes personified in Greek mythology as sons of the god of war

Mission: Overview





After launching on May 5, 2018, InSight began a 6.5-month cruise through space. On Nov. 26, it will hit a target point at the top of the Martian atmosphere at about six times the speed of a high-velocity bullet. It will then begin a process known as entry, descent and landing: It will decelerate enough in 6.5 minutes for a safe touchdown on Mars, deploying its three legs to absorb its impact on the Martian surface.

Over the course of a couple months, InSight will prepare for surface science operations by using a robotic arm to grasp its science instruments and place them directly onto the surface of Mars. It will be the first space mission to ever do so. Its heat probe will pound deeper into the Martian ground than any previous space mission has gone. InSight will continue to collect clues about the planet's interior until at least November 2020. More on MarCO

The Mars Cube One (MarCO) technology demonstration, which launched alongside InSight, has been flying separately to Mars.

Interplanetary Cruise and Approach to Mars

InSight's interplanetary flight is called its cruise phase and takes a total of 205 days.

Key activities during cruise included checkouts and calibrations of spacecraft subsystems and science instruments, tracking of the spacecraft, attitude adjustments for changes in the pointing of the solar array and antennas, and maneuvers to adjust the spacecraft's trajectory. InSight's cruise was designed with six scheduled trajectory-correction maneuvers, plus two back-up or contingency opportunities.

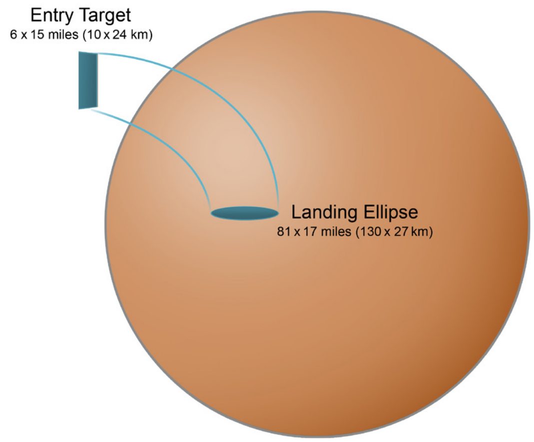
Entry, Descent and Landing

InSight's aeroshell, with the lander enclosed, will enter the top of the Martian atmosphere at about 12,300 mph (5.5 kilometers per second). In roughly 6.5 minutes, InSight will endure heat-generating atmospheric friction on its aeroshell, deploy a parachute and fire descent thrusters to decelerate to only about 5 mph (2.24 meters per second) before touching down on its shock-absorbing legs. This is the riskiest sequence in the entire mission. With dozens crucial steps required for success, it is often referred to as "the seven minutes of terror." Those minutes and the preceding few hours of preparatory events are more formally called the mission's entry, descent and landing (EDL) phase.

The top of Mars' atmosphere is actually a gradual transition to interplanetary space, not a sharp boundary. The atmospheric entry interface point -- the target point for the flight to Mars -- is set at 2,188.6 miles (3,522.2 kilometers) from the center of Mars. At this point, InSight is about 80 miles (128 kilometers) above the ground elevation of the planned landing site at Elysium Planitia, though the entry point is not directly above the landing site, but about 440 miles (708 kilometers) west of it.

At the interface point elevation, the entry target for the mission's navigation team is a rectangle about 6 miles wide (10 kilometers) by 15 miles high (24 kilometers). In proportion to the distance of about 298 million miles (479 million kilometers) that InSight will fly from Earth to Mars, hitting a target that size is like scoring a soccer goal from about 80,000 miles (130,000 kilometers). Or like hitting a fast-moving target the size of a smart phone from the distance between New York and Denver.

Compared to the cross-section area of this target at the top of Mars' atmosphere, the landing ellipse on the surface of Mars is larger -- about 81 miles (130 kilometers) generally west-to-east by about 17 miles (27 kilometers) north-to-south. The spacecraft has odds better than 99 percent of reaching the surface within this landing ellipse. Uncertainties that make the landing ellipse so much larger than the entry target include not only the precision of hitting the entry target but also aerodynamic factors, such as how much lift or drag the spacecraft will experience, and atmospheric variables, such as wind velocity and atmospheric density.



Navigators' target at the top of Mars' atmosphere is smaller than the ellipse covering the area in which the spacecraft has a 99 percent chance of touching down after passing through that target. Dispersion factors include aerodynamic uncertainties and atmospheric variability. This concept illustration is not to scale.

Preparing for Entry

At about 11 a.m. PST (2 p.m. EST) on Nov. 26, heaters will be turned on for catalyst beds of thrusters on the lander.

InSight will jettison its cruise stage seven minutes before entry. The remaining spacecraft after this separation is called the "entry vehicle" and consists of the aeroshell (back shell plus heat shield) and lander. Up to this point, radio transmission from InSight will have come via the medium-gain antenna on the cruise stage, but without it InSight will begin transmitting a carrier-only (no data) signal from an omni-directional antenna on the back shell, called the wrap-around patch antenna.

About 30 seconds after cruise stage separation, the entry vehicle will begin turning toward the orientation required for atmospheric entry, with the heat shield facing forward. The turn will take about 70 seconds. Within the last two minutes before entry, the wrap-around patch antenna will begin transmitting data at eight kilobits per second, in the ultrahigh frequency (UHF) radio band.

Listening for InSight

NASA's Mars Reconnaissance Orbiter (MRO) is expected to be in position to receive the transmissions during InSight's entry, descent and landing. MRO, passing over InSight's landing region on Mars, will record the data for transmitting to Earth during a later orbit.

After carrying out a number of risky communication and navigation flight experiments, the twin MarCO spacecraft may be in position to receive transmissions during InSight's entry, descent and landing as well. If all goes well, the MarCOs may be able to relay data to Earth almost immediately.

At the top of each of InSight's legs is a trigger sensor; when the surface pushes up the leg and hits the trigger, it shuts off the lander's retrorockets. It also sends out two signals that touchdown has been achieved: a "tone beacon" through its UHF antenna and a "beep" through its X-band antenna. This X-band "beep" is expected to turn on about seven minutes after landing, and will be a clear indicator that InSight is functional on the surface.

On Earth, two radio telescopes will be listening for the tone beacon, which is a very basic indicator of InSight's status: They may be able to confirm that InSight is transmitting during descent and after landing. They are the National Science Foundation's Green Bank Observatory in Green Bank, West Virginia and the Max Planck Institute for Radio Astronomy's facility at Effelsberg, Germany.

NASA's Mars Odyssey orbiter is expected to provide information about InSight after the landing because it is scheduled to fly over InSight after the entry, descent and landing process is completed.

Like Phoenix, but Different

The engineering for InSight's EDL system draws significantly on the technology of NASA's Phoenix Mars Lander. The system that performed successfully for the Phoenix landing in 2008 weighs less than the landing systems with airbag or "sky crane" features used by NASA's Mars rover missions. The lean hardware helps give InSight, like Phoenix, a high ratio of science-instrument payload to total launch mass, compared with rovers. InSight will enter the atmosphere at a lower velocity -- 12,300 mph (5.5 kilometers per second) compared to Phoenix, which entered at 12,500 mph (5.6 kilometers per second).

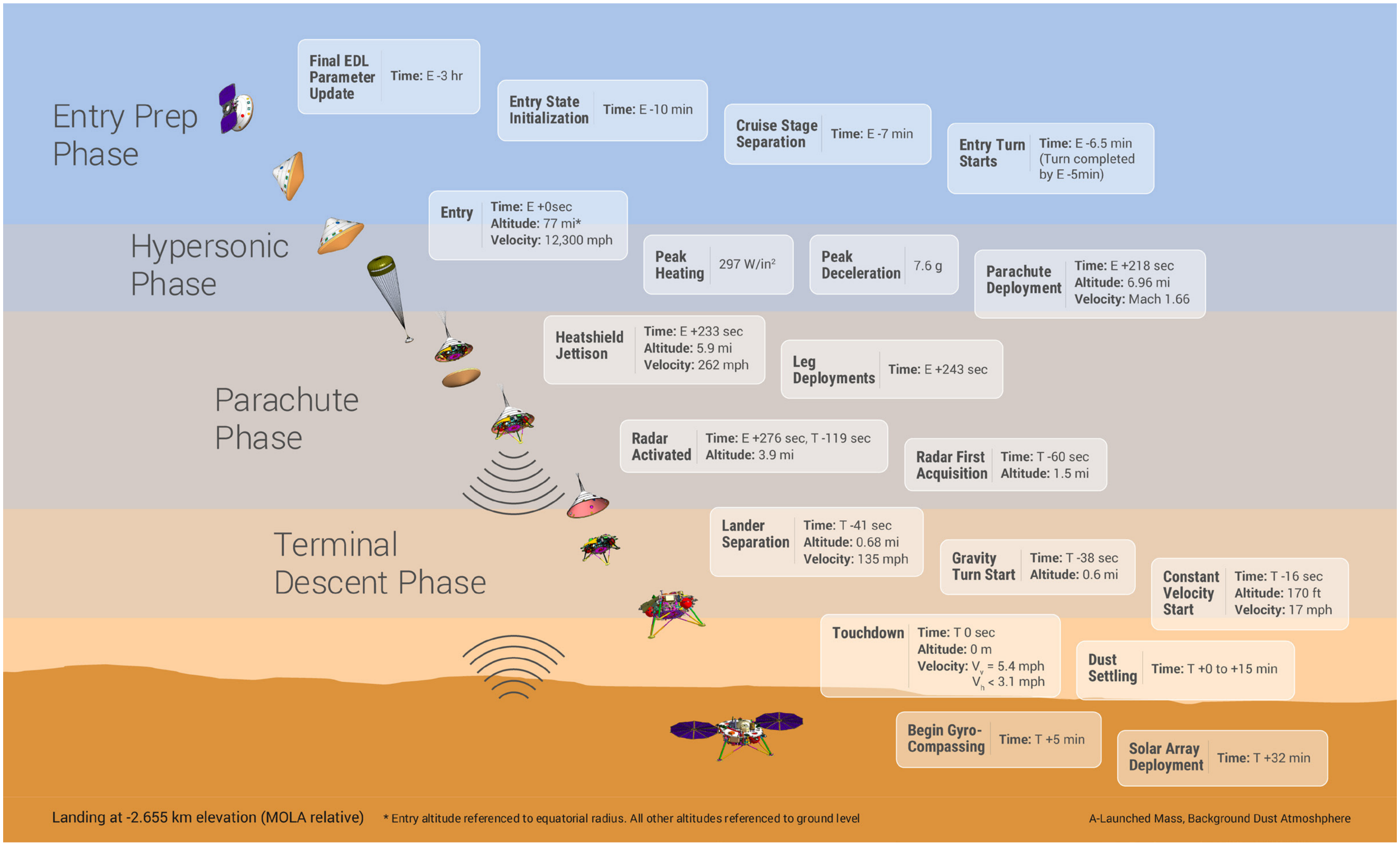
Compared with Phoenix, though, InSight's landing presents three significant challenges:

- InSight will have more mass entering the atmosphere -- about 1,340 pounds (608 kilograms) vs. 1,263 pounds (573 kilograms)
- InSight will land at an elevation about 4,900 feet (1.5 kilometers) higher than Phoenix did, so it will have less atmosphere to use for deceleration
- InSight will land during a Martian season (early winter in the northern hemisphere) when dust storms have grown to global proportions in some prior Martian years

Some changes in InSight's entry, descent and landing system, from the one used by Phoenix, are:

- InSight will use a thicker heat shield, to handle the possibility of being "sandblasted" by a dust storm
- InSight's parachute will open at higher speed
- InSight will use stronger material in parachute suspension lines

The following description of events from entry to touchdown is the latest estimate as of summer 2018.



Profile of InSight entry, descent and landing events on Nov. 26, 2018, for one typical case. Exact timing will be affected by atmospheric conditions on landing day.

Into the Atmosphere

Landing on Mars is an entirely automated process. But up until three hours before entering the Martian atmosphere, a team of engineers works to program the landing based on a variety of conditions. Daily weather updates from NASA's Mars Reconnaissance Orbiter inform a team of EDL engineers who program InSight to complete each step of the landing process at a specific time. The times below are what the team expects as of October 2018. These times may shift depending on unexpected changes or environmental conditions.

The times also mark the moments when the spacecraft team expects to hear about a milestone, so they include the 8.1 minutes it takes to transmit a signal back from Mars. These times do not include the short, but increasing, delay in transmission that will come from the signals going into and out of the MarCO spacecraft on their way back to Earth.

At around 11:41 a.m. PST (2:41 p.m. EST), InSight will begin pivoting to put its heat shield face forward. Six minutes later, InSight will start sensing the top of the atmosphere. Before the parachute is deployed, friction between the atmosphere and the heat shield will remove nearly 99.5 percent of the entry vehicle's kinetic energy. Peak heating will occur approximately 1.5 minutes after atmospheric entry, at around 11:49 a.m. PST (2:49 EST). The temperature at the external surface of the heat shield will reach about 2,700°F (about 1,500°C).

Peak deceleration will happen about 15 seconds later, at up to 7.5 g (greater than seven times the force of gravity at Earth's surface). At this time, ionization of gas around the spacecraft from the intense heating may cause a temporary gap in the receipt of radio transmission from InSight.

Parachute testing for InSight, conducted inside world's largest wind tunnel, at NASA Ames Research Center, Moffett Field, California.

InSight will continue to descend until the proper velocity and deceleration trigger conditions are met to deploy the parachute from the back shell. This is expected at approximately 11:51 a.m. PST (2:51 p.m. EST), at about 6.9 miles (11.1 kilometers) above ground level, at a velocity of about 861 mph (about 385 meters/sec). The anticipated load on the parachute when it first opens is about 12,500 pounds of force (55,600 newtons). Approximately 10 seconds after parachute deployment, electronics in the spacecraft's landing radar will be powered on to warm up, and an auxiliary battery will be activated to supplement the lander's main battery during critical current-drawing events of the next few minutes.

The spacecraft will descend on the parachute for about two minutes. During the first 25 seconds of parachute descent, InSight will jettison its heat shield and extend its three legs. About two minutes after the parachute opens and one minute before landing, the spacecraft will start using its radar to sense velocity and the distance to the ground.

Descent speed will have slowed to about 134 mph (60 meters per second) by the time the lander separates from the back shell and parachute, about two-thirds of a mile (1 kilometer) above the ground and about 45 seconds before touchdown. By design, the separation is triggered by radar sensing of altitude and velocity. A brief pause in communication is anticipated as data transmission shifts from the wrap-around antenna on the back shell to a helical UHF transmitter on the lander.

Illustration of InSight descending toward Mars with its retrorockets firing

Slowing for Touchdown

One second after lander separation, the 12 descent engines on the lander will begin firing. Guidance software onboard for the terminal descent will provide commands for aligning the direction of thrust to the direction the spacecraft is moving, so the thrust will counter horizontal movement as well as decelerate the descent. If the spacecraft senses that its horizontal speed is below a threshold set in the software, it will also perform a maneuver to avoid the back shell that is still descending on its parachute. This maneuver would adjust the direction of thrust to reduce the chance that the back shell and parachute could land too close to the lander after the lander's touchdown. The spacecraft will rotate to land in the desired orientation: with solar arrays extending east and west from the deck and the robotic arm's work area on the south side of the lander.

InSight is still traveling at 17 mph (7.7 meters per second) 164 feet (50 meters) above the ground when it transitions to constant velocity mode in preparation for soft touchdown. Approximately 15 seconds later, the vehicle will touchdown with a velocity of 5 mph (2.24 meters per second)

The local solar time at the landing site in the Elysium Planitia area of Mars will be about 2 p.m. at touchdown (which will be about 11:54 a.m. PST, or 2:54 p.m. EST). If it is a relatively clear day -- no dust storm -- the forecast calls for air temperature at the height of the lander deck to reach about 18°F (minus 8°C) that afternoon and plummet to about minus 140°F (minus 96°C) overnight. The time of year in Mars' northern hemisphere will be about midway between the autumn equinox and winter solstice.

The Martian day, or sol, of the landing will count as Sol Zero of InSight's Mars surface operations.

Uncertainties in EDL Timing

While this is the InSight team's best estimate for landing times, the exact times may change before landing day. Additional trajectory correction maneuvers -- along with atmospheric conditions that change when certain EDL events happen -- could shift the timeline slightly.

Key Locations for Landing

InSight's team in Mission Control preparing for landing at NASA's Jet Propulsion Laboratory, Pasadena, California.

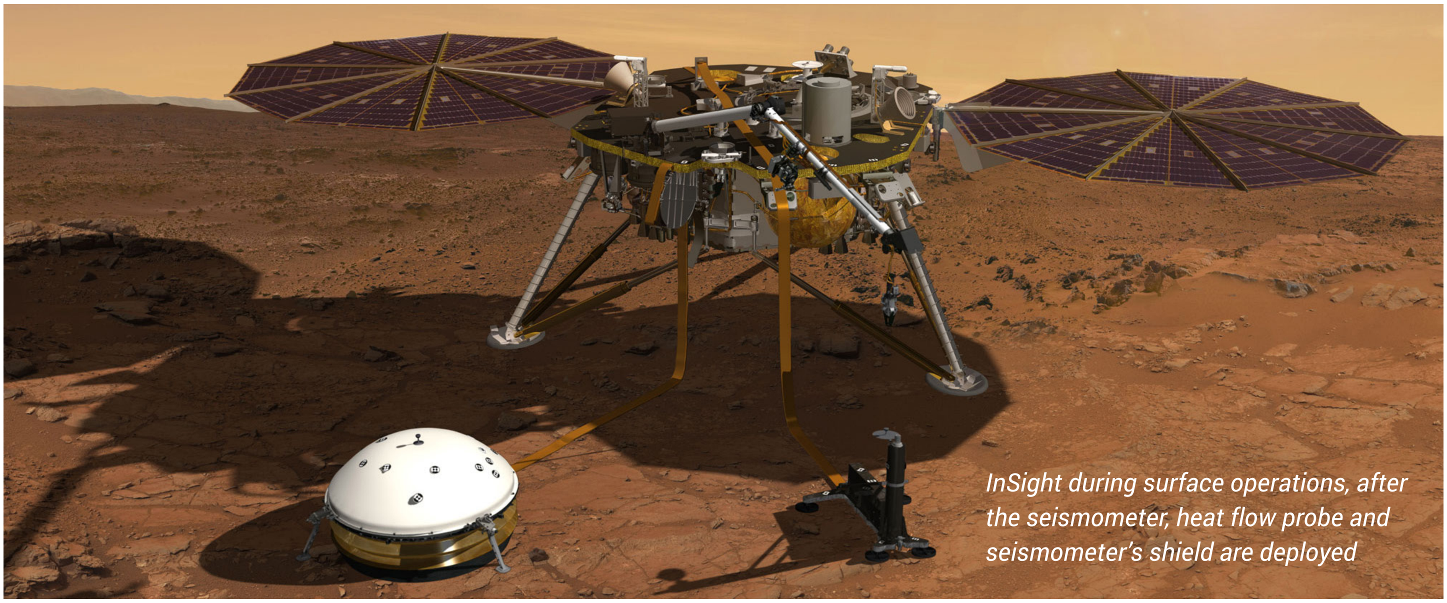
All of NASA's Mars landings and many of its key deep space events are run from the Mission Support Area in JPL's Mission Control. Since 1964, data has come to Mission Control from all of NASA's deep space probes, earning it the nickname "Center of the Universe." JPL's Mission Control is the prime location during InSight's entry, descent and landing.

After InSight lands, surface operations begin. This phase of the mission is directed from another building at JPL. Engineering decisions about the spacecraft, such as where to set down its instruments, will be made here.

InSight team meeting in the Surface Operations Mission Support Area, JPL, Pasadena, California.

Lockheed Martin Space's Waterton Campus in Littleton, Colorado, is where the InSight spacecraft was built and where the spacecraft operations team resides. The Lockheed Martin team is responsible for spacecraft health and safety during all mission phases. During the entry, descent and landing phase, its mission support area will supplement all missions operations and partner with the JPL mission operations support area.

Lockheed Martin Space, Waterton Campus, Littleton, Colorado. Credit: Lockheed Martin Space



InSight during surface operations, after the seismometer, heat flow probe and seismometer's shield are deployed

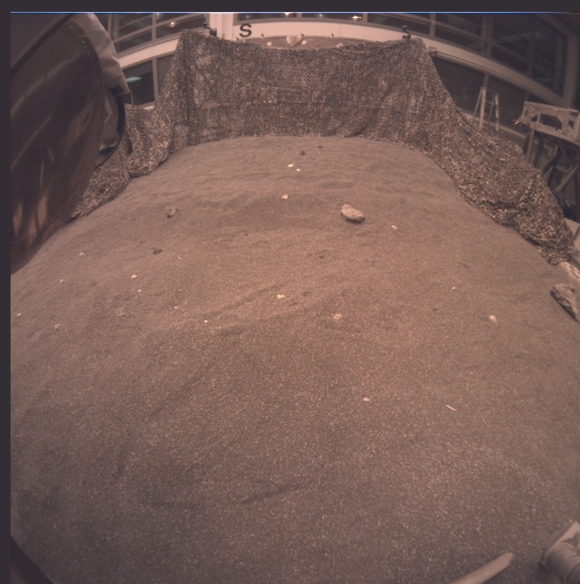
Mars Surface Operations

InSight's surface operations phase will start one minute after touchdown. Tasks on landing day will be programmed to be performed autonomously, without any need for the lander to receive communication from the InSight team on Earth.

The prime mission will operate on the surface for one Martian year plus 40 Martian days, or sols, until Nov. 24, 2020. Some science data will be collected beginning the first week after landing, but the mission's main focus during that time is preparing to set InSight's instruments directly on the Martian ground.

Placement of instruments onto the ground is expected to take about 10 weeks. Sinking the heat probe to full depth (16 feet, or 5 meters) is expected to take about seven additional weeks. After that, the lander's main job will be to sit still and continue collecting data from the instruments.

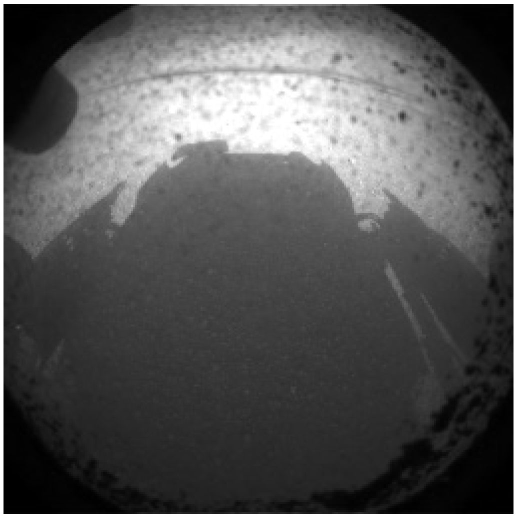
First Images



This image taken by an engineering model of NASA's InSight lander in a Mars-like environment at NASA's Jet Propulsion Laboratory, is expected to be similar to the first image InSight takes on Mars in aspect or geometry. The initial image will not be as sharp as this one, however, because the dust cover will still be on.

Once InSight has touched down on the Martian surface, there are several opportunities for the lander to send back an image from the Martian surface. The cameras will have their covers on for each of these opportunities, which could obscure the images slightly. (The first images from the Curiosity rover included its dust cover.)

The lander has been programmed to take its first images several minutes after touchdown. The transmission of these images back to Earth will take longer. Engineering data are prioritized above images so it's possible that only part of an image (or none at all) will be transmitted in the first hours after landing. The image could be transmitted at various times via MarCO, MRO or Odyssey.



How InSight's First Images Could Be Returned to Earth:

- MarCO, the experimental pair of CubeSats, could relay back a first image just after the entry, descent and landing phase. If this happens, the image (or partial image) could be available within 10 to 20 minutes of touchdown.
- MRO could -- but is unlikely to -- relay back an image. MRO will prioritize relaying engineering data as it is setting over the Martian horizon. An image received via MRO wouldn't be ready until late afternoon.
- Odyssey could -- but is also unlikely to -- relay back images during its first pass, which occurs several hours after InSight lands. At that time, it will receive a recording of the EDL data from InSight. It may not be able to transmit image data before it passes over the horizon; if it did, it would be available in the early evening.
- Odyssey will also pass over InSight the day after landing between 6 and 8 a.m. PST (9 and 11 a.m. EST) on Nov. 27.

Solar Array Deployment

InSight will rely on battery-stored energy as it descends through the atmosphere and until the lander's solar arrays can be opened after touchdown, so deploying the arrays is a crucial early activity. However, the lander will first wait about 16 minutes to let any dust from the landing settle, in order to avoid having the dust settle onto the arrays' photovoltaic cells. During those minutes, the motors for unfurling the arrays will begin warming in preparation.

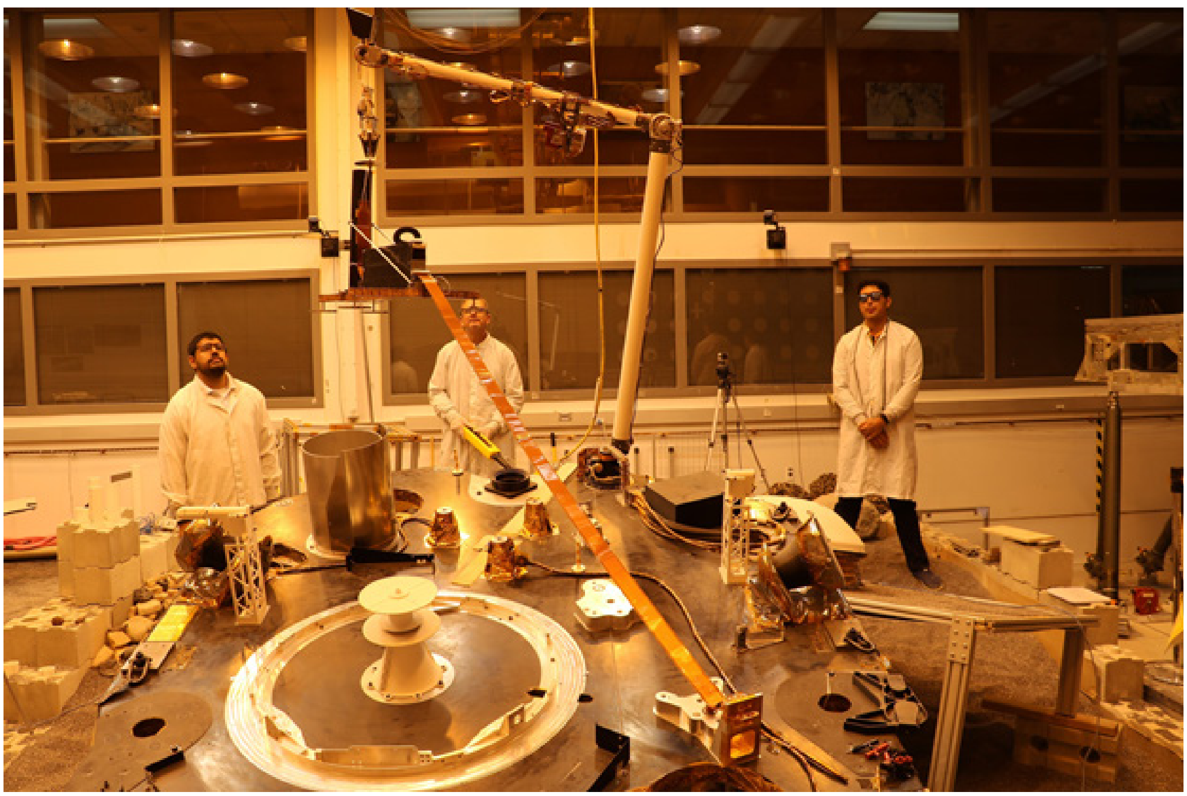
Information about the array deployment won't be relayed by the Mars Odyssey orbiter until several hours after landing.

Other landing-day activities will also include checking the lander's health indicators and powering down to "sleep" mode for the first night on Mars.

First Weeks

In the first week, InSight will continue to characterize the landing site, the payload instruments, the robotic arm and other onboard systems, and begin stereo imaging of the ground within reach of the arm on the south side of the lander. During the next two weeks, InSight will return additional images of the arm's workspace for use by the InSight team in selecting the best locations to place the seismometer (SEIS) and heat probe (HP^3) onto the ground. Stereo pairs of images will provide three-dimensional information.

The seismometer will be the first instrument lifted from the deck and placed on the ground. The transfer will require several sols to verify steps such as the robotic arm's good grasp on the instrument before proceeding to the next step, especially since this will be the first time a robotic arm has ever grasped anything on another planet. Next, the InSight team will use the robotic arm to place the Wind and Thermal Shield over the seismometer. With the shield in place, the mission will begin monitoring Mars for seismic activity.



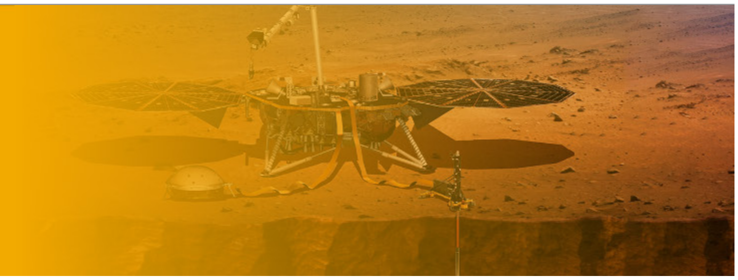
An engineering version of the robotic arm on NASA's InSight mission lifts the engineering version of the Heat Flow and Physical Properties Probe (HP^3) at NASA's Jet Propulsion Laboratory.

Deployments will continue with the placement of HP^3 onto the ground. After it is in place, the instrument will release its self-hammering mole. As the mole burrows downward during the next few weeks, it will pause at intervals to allow heat from the hammering action to dissipate for two or three sols and will then measure thermal conductivity before proceeding deeper.

Phoning Home

Throughout its surface operations, InSight will relay its science data to Earth via NASA's Mars Reconnaissance Orbiter and Mars Odyssey orbiter. The orbiters will receive UHF-band transmissions from InSight and subsequently forward the data to Earth via X-band transmissions to NASA's Deep Space Network antenna complexes at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. At any point in Earth's daily rotation, at least one of these three sites will have Mars in view for radio communication. Each complex is equipped with one antenna 230 feet (70 meters) in diameter, at least two antennas 112 feet (34 meters) in diameter, and smaller antennas. All three complexes communicate directly with the Space Flight Operations Facility hub at NASA's Jet Propulsion Laboratory in Pasadena, California.

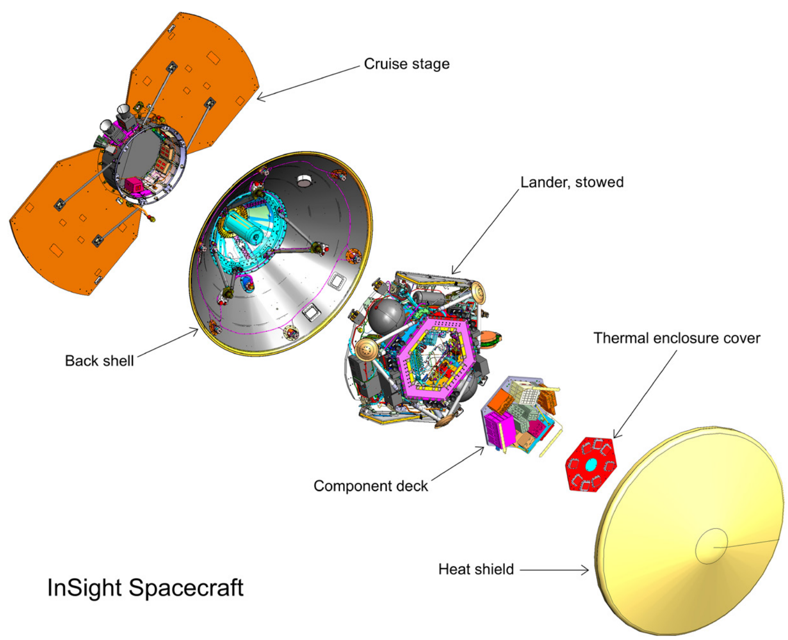
During the weeks until both the seismometer and heat probe have been placed onto the ground, the orbiter will provide relay opportunities an average of twice per sol. This will enable the InSight team, on most days, to use results from each sol's activities for planning the next sol's activities, including arm movements. The mission will use X-band transmission of daily commands directly from Earth to the lander on most Martian mornings during this period. This would provide more planning time each day compared to the time available if commands were relayed via orbiter. Once the deployments using the arm have been completed, planning activity will become simpler and commanding can become less frequent.



Mission: Spacecraft

The lander is the core of the InSight spacecraft. Not only will it be the element carrying out all of the activity on Mars, its computer also controls functions of the three secondary elements of the flight system: the cruise stage, back shell and heat shield.

The InSight spacecraft is based on the design of NASA's 2007-2008 Phoenix Mars Lander, with updates to accommodate InSight's unique science payload and new mission requirements. Some key functions and features of the InSight spacecraft are power, communications, command and data handling, propulsion, guidance and thermal control.

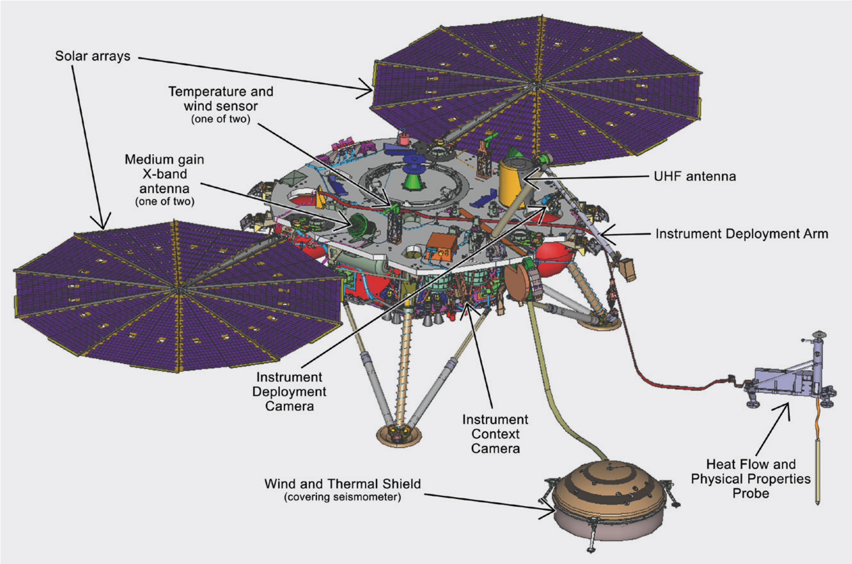


The InSight flight system comprises the lander, with its component deck and thermal enclosure cover, encapsulated in the aeroshell formed by the back shell and heat shield, and topped by the cruise stage.
Credit: NASA/JPL-Caltech/Lockheed Martin Space

Lockheed Martin Space in Denver designed, built and tested the InSight spacecraft. Lockheed Martin Space previously delivered the Phoenix spacecraft and all three NASA orbiters currently active at Mars: Mars Odyssey, Mars Reconnaissance Orbiter and Mars Atmosphere and Volatile Evolution (MAVEN).

Lander

The InSight lander will face south and the mission's workspace will be the ground within reach of the robotic arm on the south side of the lander. Because the site is north of the equator, this will prevent the lander's shadow from passing over deployed instruments. The lander's two solar arrays will extend like circular wings east and west from the central deck, with a wingspan of 19 feet, 8 inches (6 meters). Front to back, the lander is 8 feet, 10 inches (2.7 meters) deep. The top of the deck will be 33 to 43 inches (83 to 108 centimeters) above Martian ground level, depending on how far the three shock-absorbing legs compact after the landing. With its solar panels deployed, the lander is about the size of a big 1960s convertible.



The lander's panels are based on the design of those flown on NASA's Mars Phoenix Lander, though InSight's were made slightly larger for more power output and to increase structural strength. These changes were required to support the two-year landed prime science mission with sufficient margins (two Earth years, one Mars year).

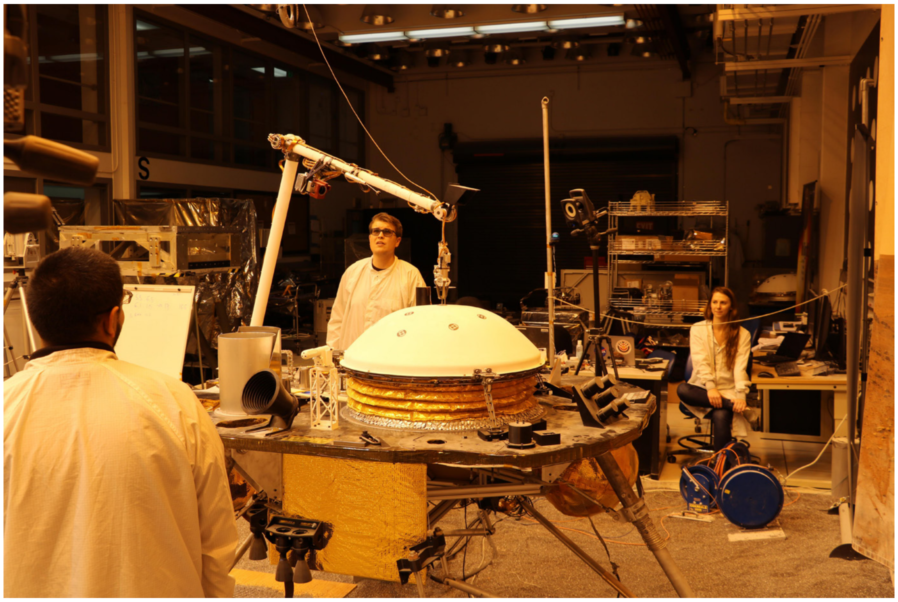
In this illustration of the InSight lander's deployed configuration, south would be toward lower right at the Martian work site, with tethered instruments on the ground and the heat probe's mole underground. Credit: NASA/JPL-Caltech/Lockheed Martin Space

Hardware on top of the deck includes the robotic arm, two dedicated science instruments and their accessories, a laser reflector, a helical UHF antenna and two X-band antennas (which are also used as part of a science experiment). In the weeks after landing, the arm will lift the seismometer, its Wind and Thermal Shield and the thermal probe from the deck and place them onto the Martian surface.

Engineers at Lockheed Martin Space, Denver, test the solar arrays on NASA's InSight lander several months before launch.
Credit: NASA/JPL-Caltech/Lockheed Martin Space

The lander's avionics are mounted to a component deck located within a thermally protective enclosure. This suite of electronics consists of the flight computer, the electrical power system, the landed telecommunications system, the payload electronics and the harness. Other components, such as the inertial measurement units, radiometer, magnetometer and landing radar, are externally mounted under the science deck. Thrusters extend from the sides of the lander.

Instrument Deployment System: One Arm and Two Cameras



NASA's InSight mission tests an engineering version of the spacecraft's robotic arm in a Mars-like environment at NASA's Jet Propulsion Laboratory. The Instrument Deployment Camera is visible at the "elbow" of the arm.

The lander's Instrument Deployment System (IDS) has a robotic arm for moving instruments from the deck onto the ground and two color cameras for finding the best place to put them and documenting the process. One of the cameras is mounted on the arm; the other on the front of the lander, beneath the south edge of the deck.

The Instrument Deployment Arm (IDA) includes a grapple for grasping each piece of hardware that the arm will lift. The grapple's five mechanical fingers can close around a handle that resembles a ball on top of a stem. Each of the three items that the arm will lift has one of these handles. The three items are the Seismic Experiment for Interior Structure (SEIS), the Heat Flow and Physical Properties Probe (HP^3), and the seismometer's Wind and Thermal Shield.

The arm is 5.9 feet (1.8 meters) long, with shoulder, elbow and wrist joints and four motors. The grapple is at the end of the arm. The arm-mounted camera is between the elbow and wrist.

The camera on the arm is called the Instrument Deployment Camera (IDC). The lander's other camera, the Instrument Context Camera (ICC), is mounted just below the deck, on the edge of the lander facing the workspace, which is the area of ground within reach of the arm. Both are modified versions of engineering cameras on NASA's Mars rovers Opportunity and Curiosity, with full-color capability added. Each has a square charge-coupled device (CCD) detector that is 1,024 pixels by 1,024 pixels.

The IDC's field of view is 45 degrees wide and tall. Movement of the arm is used to point the camera. The IDC will image the workspace in detail to support selection of the best specific locations for the deployed instruments. It will also image hardware to verify key steps are accomplished in the deployment process before proceeding to the next step. By moving the camera's position between exposures, the IDC can create stereo views that provide three-dimensional information about the surrounding area. The camera can be pointed in any direction, so it can take images to be combined into a 360-degree panorama of the lander's surroundings.

The ICC has a "fisheye" field of view of 120 degrees. It will provide wide-angle views of the entire workspace.

The basic structure of the robotic arm was originally built for a Mars lander planned for launch in 2001, but that mission was cancelled before launch. JPL refurbished and modified the arm for InSight, including the additions of a grapple and camera. JPL also developed the software for controlling the arm and built both of the Instrument Deployment System's cameras.

Science Experiments

InSight will be using its science experiments to take the “vital signs” of Mars: its pulse (seismology), temperature (heat flow) and its reflexes (radio science).

The Seismic Experiment for Interior Structure (SEIS), a seismometer that measures ground motions in a range of frequencies, features six sensors of two different types. Those sensors are mounted on a three-legged precision leveling structure inside a remote warm enclosure box. That combination will be set directly onto the ground, connected to the lander by a flexible tether containing power and data lines. Then an additional protective cover -- the Wind and Thermal Shield -- will be placed over it. The SEIS electronics box remains on the lander.

France’s national space agency, Centre National d’Études Spatiales (CNES), Paris, leads the consortium that provided SEIS.

InSight’s second dedicated science instrument, Heat Flow and Physical Properties Probe (HP^3, pronounced “H-P cubed”), will provide the first precise determination of the amount of heat escaping from the planet’s interior. InSight’s robotic arm will place the instrument on the ground, where a self-hammering mechanical mole will burrow to a depth of 10 to 16 feet (3 to 5 meters) over the course of about 30 days. InSight’s heat probe will penetrate more than 15-fold deeper beneath the surface than any previous hardware on Mars.

A science tether with temperature sensors connects the upper end of the mole to the HP^3 support structure, which is on the Martian surface. An engineering tether connects HP^3 support structure to the instrument’s back-end electronics box on the lander.

The HP^3 investigation also includes a radiometer to measure ground-surface temperature near the lander based on its infrared brightness.

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR), headquartered in Cologne, provided InSight’s Heat Flow and Physical Properties Probe.

A third science experiment, the Rotation and Interior Structure Experiment (RISE), does not have its own dedicated science instrument; instead, it uses InSight’s direct radio connection with Earth to assess perturbations of Mars’ rotation axis, which can provide information about the planet’s core.

The tools for RISE are the X-band radio on the InSight lander and the large dish antennas of NASA’s Deep Space Network. The lander’s radio link to Earth will provide precise tracking of the location of one site on the surface as the planet rotates, throughout the course of a full Mars year.

Auxiliary Payload Sensor Subsystem

Sensors that measure the local magnetic field, wind, and atmospheric temperature and pressure are attached to the lander deck. Together, these are called the Auxiliary Payload Sensor Subsystem (APSS). The primary reason for including these instruments in the mission's payload is to aid interpretation of seismometer data by tracking changes in the magnetic field or atmosphere that could cause ground movement otherwise mistaken for a seismic event. However, they can also serve on their own for other Mars science investigations.

The University of California, Los Angeles; Spain's Center for Astrobiology (Centro de Astrobiología, or CAB), Madrid; and JPL contributed key parts of APSS.

Laser Retroreflector for Mars

A dome-shaped device, affixed to the top of the InSight lander's deck, holds an array of eight special reflectors. This is the Laser Retroreflector for InSight (LaRRI), which is not part of the InSight mission's own science investigations but may passively provide science value for a future Mars orbiter mission, with a laser altimeter making extremely precise measurements of the lander's location.

Agenzia Spaziale Italiana (ASI), the national space agency of Italy, provided LaRRI.

For more in-depth information on InSight's science payload and goals, go to the Science section.

A spacecraft specialist at Lockheed Martin Space in Denver, where InSight was built, affixes onto the spacecraft deck one of the dime-size chips, etched by NASA's Jet Propulsion Laboratory with about 2.4 million names.
Credit: NASA/JPL-Caltech/Lockheed Martin Space

Your Name Is on Its Way to Mars

Another special feature on the deck of the lander is a pair of silicon chips etched with names of approximately 2.4 million people worldwide who participated in online "send your name to Mars" activities in August 2015 and 2017. Such activities are among many opportunities offered online for participation in Mars exploration. These chips are affixed near the northern edge of InSight's deck.

Cruise Stage

InSight's cruise stage will provide vital functions during the flight from Earth to Mars, and then will be jettisoned before the rest of the spacecraft enters Mars' atmosphere. The core of the cruise stage is a short cylinder about 3 feet (0.95 meters) in diameter, with two fixed-wing solar panels extending out from the cylinder 180 degrees apart, for an overall wingspan of about 11 feet (3.4 meters), which is slightly larger than the wingspan of the world's largest species of condor.

Equipment on the cruise stage includes low-gain and medium-gain antennas, an X-band transponder, two solid-state power amplifiers, two Sun sensors and two star trackers.

Back Shell and Heat Shield

The spacecraft's back shell and heat shield together form the aeroshell that encapsulates the InSight lander from launch to the time the spacecraft is suspended on its parachute on its way to the Martian surface. The lander and aeroshell together, after separation from the cruise stage, are the entry vehicle. The back shell and heat shield are each conical in shape, meeting where the diameter is 8.66 feet (2.64 meters). The aeroshell's height -- about 5.4 feet (1.6 meters) -- is about one-third heat shield and two-thirds back shell.

The spacecraft's parachute and its deployment mechanism are stowed at the apex of the back shell. The parachute has a disk-gap-band configuration and a diameter of 38 feet, 9 inches (11.8 meters). Once deployed during descent, it will extend about 85 feet (26 meters) above the back shell. Pioneer Aerospace Corp. in South Windsor, Connecticut, made the parachute.

A UHF antenna for use during descent is wrapped around the top end of the back shell. At four locations around the back shell near its largest circumference, cutaways expose thrusters mounted on the lander. These are the eight thrusters used during the cruise from Earth to Mars. Each of the four cutaways accommodates one trajectory correction maneuver thruster and one reaction control system thruster.

The heat shield is covered with material that ablates away during the period of high-temperature friction with the Mars atmosphere, protecting the encapsulated lander from heat that is expected to rise as high as 2,700°F (1,500°C). This thermal protective system for InSight uses a material called super lightweight ablator 561, or SLA-561.

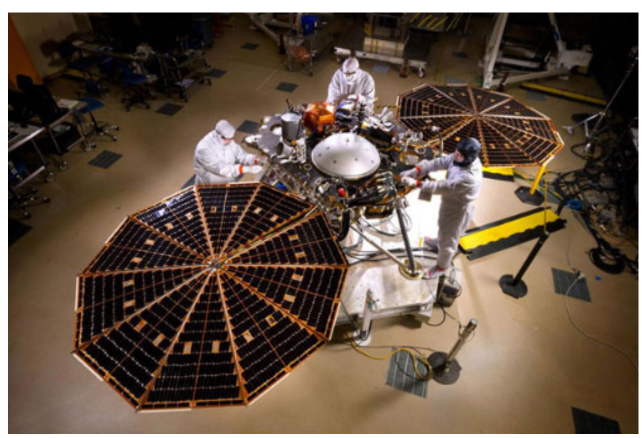
Electrical Power

InSight will use electrical power from solar panels, with batteries for storage, during cruise and after landing.

The fixed-wing photovoltaic panels on the cruise stage were built by Lockheed Martin Space in Sunnyvale, California, with triple-junction photovoltaic cells from SolAero Technologies Corp. in Albuquerque, New Mexico.

About 20 to 25 minutes after touchdown, the lander will deploy two nearly circular, 10-sided solar arrays, each 7.05 feet (2.15 meters) in diameter, extending from opposite sides of the lander. The two arrays combined have almost as much surface area as a pingpong table. Before landing, these are stowed in a radially folded configuration similar to a folded fan. After they have been deployed, the lander's two arrays will together generate up to about 600 to 700 watts on a clear Martian day (or 200 to 300 watts on a dusty one). The UltraFlex panels are from Northrup Grumman Innovation Systems (formerly Orbital ATK-Goleta) in Goleta, California, with photovoltaic cells from SolAero.

A pair of rechargeable, 25 amp-hour lithium-ion batteries located on the lander will provide energy storage. The lithium-ion batteries are from the Yardney Division of EaglePicher Technologies in East Greenwich, Rhode Island. In addition, a single-use, non-rechargeable thermal battery will supplement the main batteries during entry, descent and landing.



The solar arrays on NASA's InSight lander are deployed in this test in a clean room at Lockheed Martin Space, Denver, in April 2015. Each of the two arrays is 7.05 feet (2.15 meters) in diameter.
Credit: NASA/JPL-Caltech/Lockheed Martin Space

Telecommunications

During the cruise from Earth to Mars, InSight will communicate with Earth using X-band antennas on the cruise stage. The cruise stage has a medium-gain, directional antenna and two low-gain antennas -- one for transmitting and the other for receiving. The spacecraft has one X-band small deep space transponder (SDST) on the lander and one on the cruise stage.

InSight, like all other NASA interplanetary missions, will rely on NASA's Deep Space Network to track and communicate with the spacecraft. The network has groups of dish antennas at three locations: California, Spain and Australia. Additional communications support will be provided by the European Space Agency's deep space antennas in Argentina and Australia while InSight is flying from Earth to Mars.

As InSight descends through the Martian atmosphere, it will be transmitting a signal in the ultrahigh frequency (UHF) radio band. The signal is generated by a UHF transceiver on the lander. That signal is transmitted by, first, a wrap-around patch antenna on the back shell and, later, after the lander separates from the back shell, by a helical UHF antenna on the lander deck.

For more on how these signals get back to Earth during entry, descent and landing, go to the Listening for InSight section. From the surface of Mars, InSight will use both X-band and UHF communications.

The primary method for sending data to Earth from the landing site will be via UHF relay to an orbiter, through the lander's helical antenna. Mars Reconnaissance Orbiter and Mars Odyssey each will pass in the sky over InSight twice per Martian day. NASA's MAVEN orbiter and the European Space Agency's Trace Gas Orbiter and Mars Express can serve as backup relay assets for InSight. Orbiters will receive transmissions from InSight via UHF and relay the InSight data to Earth via X-band.

The lander's own X-band communications will use a pair of medium-gain horn antennas on the deck, communicating directly with Deep Space Network antennas on Earth. In the planned orientation for the lander -- with the instrument workspace to the south for instrument deployment -- one X-band antenna faces eastward and the other westward. Viewing Earth from Mars is like viewing Venus from Earth: In either case, the inner planet is a morning or evening "star," above the eastern horizon in morning or above the western horizon in the evening. The main uses for InSight's X-band radio are the Rotation and Interior Structure Experiment (RISE) and for receiving commands directly from Earth.

Computer and Software

InSight's system for command and data handling has avionics derived from NASA's Mars Atmosphere and Volatile Evolution (MAVEN) and Gravity Recovery and Interior Laboratory (GRAIL) missions. The system has two redundant computers -- one active at all times and the other available as backup. The computer's core is a radiation-hardened central processor with PowerPC 750 architecture called RAD 750. This processor operates at 115.5 megahertz speed, compared with 20 megahertz speed of the RAD6000 processor used on Mars Phoenix.

A payload interface card handles the processor's interaction with InSight's various science instruments and robotic arm. It provides 64 gigabits of flash memory for non-volatile storage of science data.

Flight software, written in C and C++ within the VxWorks operating system, monitors the status and health of the spacecraft during all phases of the mission, checks for the presence of commands to execute, performs communication functions and controls spacecraft activities. It will protect the spacecraft by checking commands for faults and being ready to take corrective steps when it detects irregularities in commanding or spacecraft health.

Propulsion

The propulsion for pushing InSight from Earth to Mars comes from the launch vehicle rather than the spacecraft itself, but the spacecraft carries 20 thrusters to control its orientation in space, to adjust trajectory as it coasts from Earth to Mars and to slow its final descent to the surface of Mars. The 20 thrusters are of three different sizes: four reaction control system (RCS) thrusters, each providing 1 pound (4.4 newtons) of force; four trajectory correction maneuver (TCM) thrusters, each providing 5 pounds (22 newtons) of force; and 12 descent engines, each providing 68 pounds (302 newtons) of force.

All of the thrusters are on the lander. The eight used while the lander is encapsulated inside the aeroshell extend out through cutouts in the back shell. One "rocket engine module" with one RCS thruster and one TCM thruster is at each of four cutouts around the back shell to allow maneuvers in any direction. The descent engines are on the underside of the lander, to be used for control of the lander's descent during the last minute before touchdown. All of the thrusters use hydrazine, a propellant that does not require an oxygen source. Hydrazine is a corrosive liquid compound of nitrogen and hydrogen that decomposes explosively into expanded gases when exposed to a heated catalyst in the thrusters.

Guidance, Navigation and Control

InSight will remain oriented as it travels to Mars by using redundant pairs of star trackers and Sun sensors mounted on the cruise stage. A star tracker takes pictures of the sky and performs internal processing to compare the images with a catalog of star positions and recognize which part of the sky it is facing.

During descent through Mars’ atmosphere, the spacecraft’s knowledge of its movement and position will come from an inertial measurement unit, which senses changes in velocity and direction, and a downward-pointing radar to assess the distance and velocity relative to the Martian surface. The inertial measurement unit includes accelerometers to measure changes in the spacecraft’s velocity in any direction and ring-laser gyroscopes to measure how fast the spacecraft’s orientation is changing.

Thermal Control

InSight’s thermal control subsystem is a passive design supplemented with heaters. It uses multilayer insulation blanketing, other insulation, painted radiator surfaces, temperature sensors, heat pipes and redundant heaters controlled by thermostats. An enclosure for key electronics is designed to maintain component temperatures between 5°F (minus 15°C) and 104°F (40°C).

Science-payload components are thermally isolated from the lander and provide their own thermal control.

Planetary Protection

When sending missions to Mars, precautions must be taken to avoid introduction of microbes from Earth by robotic spacecraft. This is consistent with United States obligations under the 1967 Outer Space Treaty, the international agreement stipulating that exploration must be conducted in a manner that avoids harmful contamination of celestial bodies. “Planetary protection” is the discipline responsible for development of rules and practices used to avoid biological contamination in the process of exploration. NASA has a planetary protection office responsible for establishing and enforcing planetary protection regulations. Each spacecraft mission is responsible for implementing measures to comply with the regulations. In compliance with the treaty and NASA regulations, InSight flight hardware has been designed and built to meet planetary protection requirements.

NASA’s primary strategy for preventing contamination of Mars with Earth organisms is to be sure that all hardware going to the planet is clean. One of the requirements for the InSight mission is that the exposed interior and exterior surfaces of the landed system, which includes the lander, parachute and back shell, must not carry a total number of bacterial spores greater than 300,000. The average spore density must not exceed 300 spores per square meter (about 11 square feet) of external surfaces, nor 1,000 per square meter of enclosed, interior surfaces, so that the biological load is not concentrated in one place. Spore-forming bacteria have been the focus of planetary protection standards because these bacteria can survive harsh conditions for many years as inactive spores.

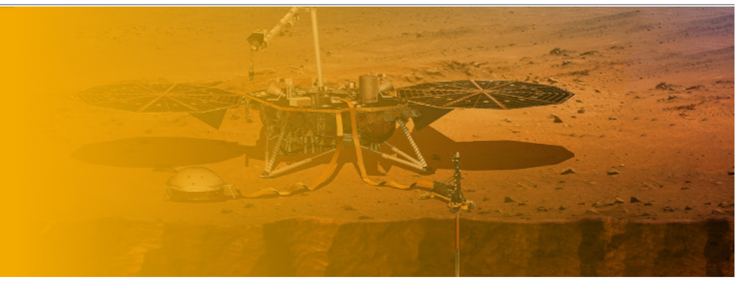
Planetary protection engineers with expertise in microbiology and spacecraft materials have developed three primary methods for reducing the number of spores on the spacecraft: precision cleaning, dry heat microbial reduction and protection behind high-efficiency filters. The strategy also emphasizes prevention of re-contamination in the clean-room facilities, clothing, equipment and processes used.

Technicians assembling the InSight spacecraft and preparing it for launch have routinely cleaned surfaces by wiping them with alcohol or other solvent. Components tolerant of high temperature were heated to reduce spore burden according to NASA specification. This dry heat treatment held components at temperatures from 230 to 311°F (110 to 155°C) for durations of 14 to 258 hours for external surfaces and durations of 97 to 1,290 hours for enclosed surfaces. The planetary protection team carefully sampled the surfaces and performed microbiological tests to demonstrate that the spacecraft meets requirements for biological cleanliness. Whenever possible, hardware was contained within a sealed container vented through high-efficiency filters.

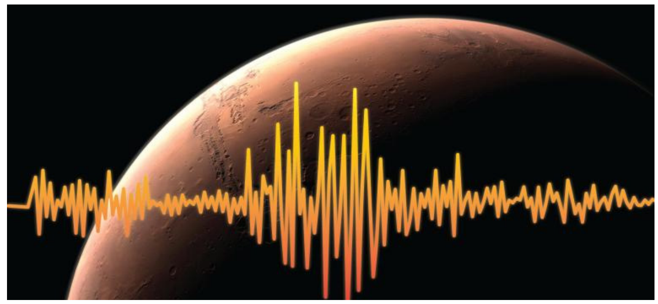
The standard of cleanliness is higher for hardware that will touch parts of Mars judged to have the potential for sustaining life, such as subsurface environments with liquid or frozen water. The near-equatorial region of InSight's landing site, Elysium Planitia, is one of the driest places on Mars. Still, the mission is taking all the necessary planetary protection precautions. This work has included analysis of planned subsurface deployment of the Heat Flow and Physical Properties Probe. At the mission's landing site, this probe could not get deep enough to reach environmental conditions warranting additional precautions.

Another way of making sure InSight doesn't transport Earth life to Mars is to ensure that any hardware failing to meet cleanliness standards does not go to Mars accidentally. When the Atlas launch vehicle's Centaur stage separated from the spacecraft, the two objects were traveling on nearly identical trajectories. To prevent the possibility of the Centaur hitting Mars, the shared flight path was deliberately set so that the spacecraft would miss Mars if not for several trajectory correction maneuvers. By design, the Centaur was never aimed at Mars. For hardware expected to impact Mars, such as the cruise stage after lander separation, a detailed thermal analysis was conducted to make sure that plunging through Mars' atmosphere gets it sufficiently hot such that few to no spores survive.

Mission: Science



A dictionary definition of "insight" is to see the inner nature of something. The mission of InSight is to see inside Mars and learn what makes it tick. So while InSight is the first Mars mission dedicated to studying the planet's deep interior, it is more than a Mars mission, because information about the layers of Mars today will advance understanding about the formation and early evolution of all rocky planets, including Earth. Although Mars and Earth formed from the same primordial stuff more than 4.5 billion years ago, they became quite different. InSight will help explain why.



InSight will be able to detect seismic waves as they travel through Mars.

A planet's deep interior holds evidence related to the planet's formation, which set the stage for what happens on the surface. The interior heat engine drives the processes that lift some portions of the surface higher than others, resulting in a landscape's elevation differences. The interior is the source of most of a planet's atmosphere; its surface rocks, water and ice; and its magnetic field. It provides many of the conditions that determine whether a planet will have environments favorable for the existence of life.

What's in a Name?

The long form of the mission's name is **Interior Exploration** using **Seismic Investigations**, **Geodesy** and **Heat Transport**, which tells the three main research techniques to be used by the InSight stationary lander. These techniques allow scientists to take the "vital signs" of Mars:

Seismic investigations study vibrations of the ground set off by marsquakes (the Mars equivalent to earthquakes) and meteorite impacts, including the analysis of how these vibrations pass through interior materials and bounce off boundaries between layers. For this research technique, InSight will deploy a seismometer provided by an international consortium headed by France. Seismic investigations can be compared to how physicians use sonograms and X-rays to see inside a body.

Geodesy is the study of a planet's exact shape and its orientation in space, including variations in its speed of rotation and wobbles of its axis of rotation. The axis of rotation is very sensitive to conditions deep inside Mars. For this research technique, the lander's radio link to Earth will provide precise tracking of a fixed location on the surface as the planet rotates, throughout the course of a full Mars year. This investigation of the planet's motion can be compared to examining a patient's reflexes during a medical check-up.

Study of **heat transport** is a way to assess a planet's interior energy and its dissipation. For this research technique, InSight will sink a German-made probe more than 10 feet (3 meters) into the ground to measure how well the ground conducts heat and how much heat is rising toward the surface. This investigation can be compared to how a physician reads a patient's temperature as an indicator of internal health.

Other components of the InSight lander's science payload are auxiliary instruments for monitoring the environment to aid the primary investigations, and a deployment system with a robotic arm and two cameras for the task of placing the main instruments onto the ground.

Some of these additional sensors will monitor wind, variations in magnetic field and changes in atmospheric pressure because these factors could affect seismometer readings. Other sensors will monitor air temperature and ground-surface temperature, which will help in subtracting effects of those temperatures from heat-probe and seismometer data. These supplemental instruments will also enable additional investigations, such as magnetic soundings of the Martian interior by the magnetometer and weather monitoring by the atmospheric sensors.

The auxiliary sensors and the two color cameras will provide information about the environment surrounding the InSight lander on the surface of a broad Martian plain near the equator, but for this mission, the science emphasis is to learn about depths that cannot be seen.

Science Objectives

InSight has two official overarching science goals:

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

2) Determine the present levels of tectonic activity and meteorite-impact activity on Mars.

To get to these goals, the InSight mission will pursue these more specific **science objectives:**

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

For additional detail on these objectives see: **Appendix: Science Objectives, Quantified**

Why This Kind of Investigation of Mars?

Several reports setting scientific priorities for planetary science have stressed the importance of investigating the interior of Mars. While the Mars Viking missions of the 1970s were still active, a report by the National Research Council's Committee of Planetary and Lunar Exploration, Strategy for Exploration of the Inner Planets: 1977-1987, said, "Determination of the internal structure of Mars, including thickness of a crust and the existence and size of a core, and measurement of the location, size and temporal dependence of Martian seismic events, is an objective of the highest importance."

In ensuing decades, several missions for investigating Mars' interior were proposed, though none flew successfully. The National Research Council's most recent decadal study of planetary-science priorities, Vision and Voyages for Planetary Science in the Decade 2013-2022, said, "Insight into the composition, structure and history of Mars is fundamental to understanding the solar system as a whole, as well as providing context for the history and processes of our own planet. … Unfortunately, there has been little progress made toward a better understanding of the Martian interior and the processes that have occurred."

A stationary lander capable of placing sensitive instruments directly onto the surface and monitoring them for many months is a mission design exactly suited to studying the interior of Mars. InSight will be the first Mars mission to use a robotic arm to grasp objects (in this case, scientific instruments) and permanently deploy them onto the ground. The mission has no need for a rover's mobility. The heat probe and seismometer stay at a fixed location after deployment. The precision of the geodesy investigation gains from keeping the radio in one place.

Building on Heritage

InSight uses many aspects of a stationary-lander mission design already proven by NASA's Phoenix Mars Lander mission, which investigated ice, soil and atmosphere at a site in the Martian arctic in 2008. The robotic arm for InSight, rather than scooping up samples for laboratory analysis as Phoenix did, will hoist the heat probe, seismometer and a protective shelter for the seismometer one at a time from the lander deck and place them onto the ground.

The first time a seismometer was placed on a world other than Earth was during the Apollo 11 Moon landing in 1969. The only seismometers previously used on Mars stayed on the decks of two Viking landers in 1976. Those were much less sensitive and more exposed to wind effects than InSight's seismometer will be. Nearly 50 years after Apollo, InSight will be the first seismometer placed directly on the surface of the Mars.

InSight's science payload and science team draw heavily on international collaboration and shared expertise. The national space agencies of France and Germany are providing the two main instruments. Austria, Belgium, Canada, Italy, Poland, Spain, Switzerland and the United Kingdom are also participating.

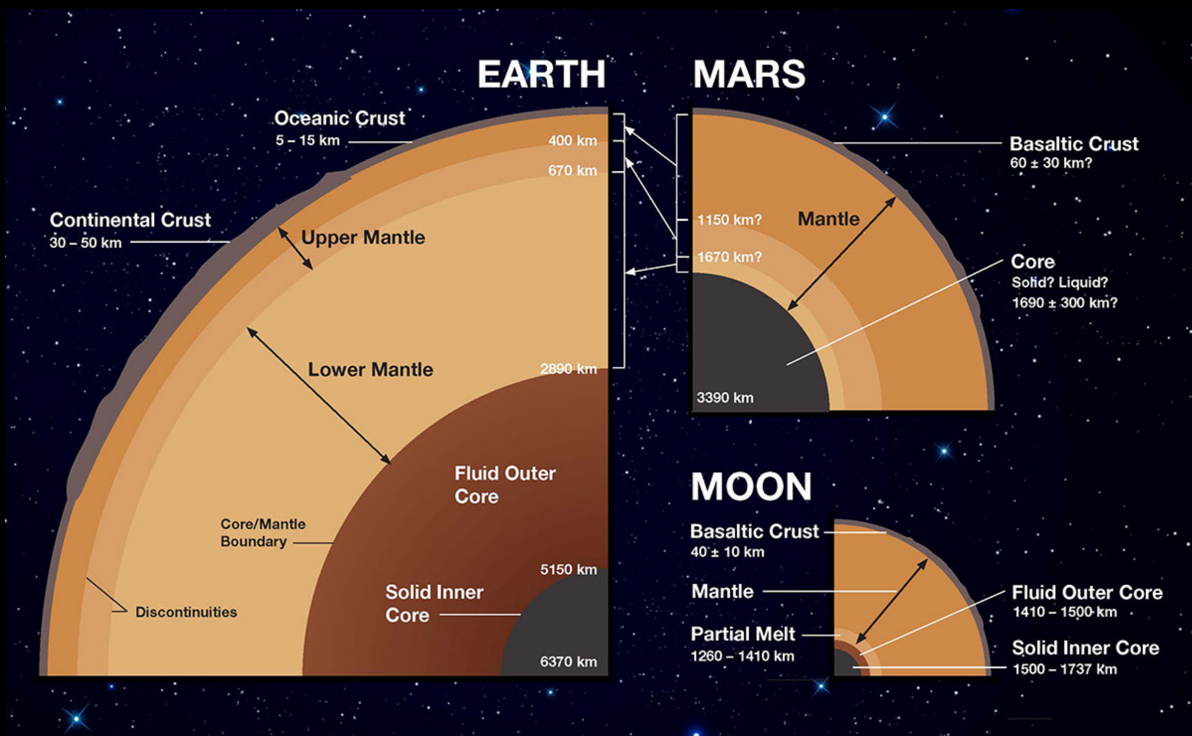
InSight is part of NASA's Discovery Program of competitively selected missions for exploring our solar system. The Discovery Program enables scientists to use innovative approaches to answering fundamental questions about our solar system. Bruce Banerdt of NASA's Jet Propulsion Laboratory in Pasadena, California, now the principal investigator for InSight, led the team that prepared the mission proposal -- originally called Geophysical Monitoring Station (GEMS) -- submitted to NASA in September 2010. That proposal and 27 other proposals for missions to various destinations throughout the solar system were evaluated in a competition for the 2016 launch opportunity of the Discovery Program. InSight was selected in August 2012.

How Does Mars Tell Us About Other Planets?

The four inner planets of the solar system, plus Earth's Moon, are called terrestrial worlds because they share a closer kinship with each other, including Earth, than with the worlds farther from the Sun. Diverse as they are, they all have rocky surfaces; they are also called the rocky planets. They all have high density -- the ratio of volume to mass – indicating their interiors have even denser ingredients than their surface rocks.

All of the terrestrial planets have a three-part layered structure:

- At the center is a metallic, iron-rich core, part of which may be molten.
- Above the core is a thick middle layer called the mantle, rich in silicon, making up most of the bulk of the planet.
- Above the mantle is a relatively thin crust of less-dense rocky material.



Schematic of similarities and differences in the interiors of Earth, Mars and Earth's Moon.

Some of the ever-increasing number of exoplanets identified around stars other than our Sun may be similarly rocky and layered, though Earth-like worlds are smaller than the giant exoplanets whose size makes them easiest to find.

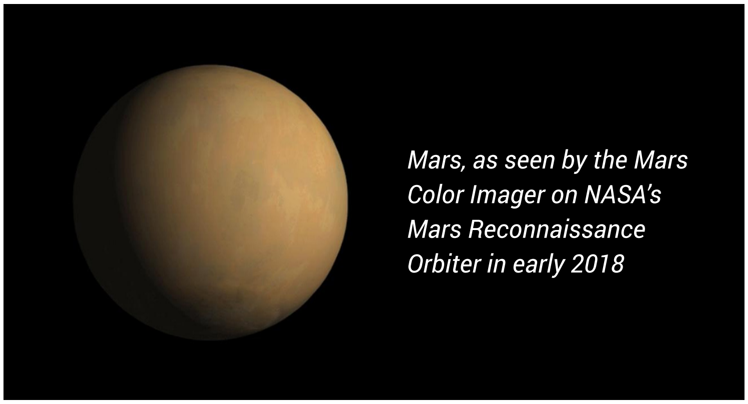
A key challenge in planetary science more than half a century into the Space Age is to understand factors that affect how newly forming planets with the same starting materials evolve into worlds as diverse as the terrestrial planets that have been discovered thus far. As a particularly interesting corollary: What does it take to make a planet as special as Earth?

Planets start as growing coagulations of primordial particles in a disc-shaped swarm around a formative star -- the proto-Sun in the case of our solar system. Meteorites provide information about composition of the planet-forming raw material. Earth formed from the same material as its neighboring planets, but none of the planets now matches the mineral composition of those starting ingredients. They evolved.

As the forming planets grew larger, they heated inside, gaining energy from pieces coming together and from natural radioactivity. Melting due to the heat enabled enough mobility for heavier ingredients to sink toward the center. Temperature and pressure affected the chemistry of the ingredients. Cooling caused some minerals to crystallize out of the melt at different temperatures than others. Multiple models have proposed steps that might explain how different minerals were produced and stratified as Earth's evolution proceeded. Each of these models of terrestrial planet evolution fits the evidence known from studying Earth. Gaining knowledge of a different case -- Mars -- should rule out some of the models. Achieving that will yield both a better understanding of why Earth turned out the way it did and a conceptual framework for studying rocky planets of other stars.

Mars as a Model

The most accessible test case for studying terrestrial planets is Earth. In the past century, research using InSight's main methods – seismology, geodesy and heat transport – has substantially rewritten humans' understanding of Earth's interior and planetary history. But Mars offers advantages that make it the right choice for a mission seeking to learn more about the formation and early evolution of terrestrial planets.



Mars, as seen by the Mars Color Imager on NASA's Mars Reconnaissance Orbiter in early 2018

The major process in Earth's interior that geological science has elucidated in the past century is plate tectonics, a recycling of crust driven by convection in the mantle as heat moves out from the core. The mantle has been vigorously stirred by convective motion driven by warmed material rising and cooled material sinking. Fresh crust is generated at mid-ocean ridges, and cold crust is dragged downward, becoming reabsorbed into the mantle at some plate edges. The churning has erased from both crust and mantle most structural evidence of the first several tens of millions of years of Earth's history after the planet formed about 4.5 billion years ago.

Mars lacks plate tectonics that would have recycled its crust. Isotopic evidence from Martian meteorites indicates that convection has not thoroughly churned the mantle of Mars. Therefore, its interior should provide clues unavailable on Earth about the accretion and early evolution of Earth, Mars and other rocky planets. For example, the mantle of Mars may retain differences in composition at different depths, which convection has blended together on Earth.

Investigations of Earth's Moon, including analysis of lunar rocks returned to Earth, indicate that, although the Moon followed many of the same evolutionary steps as Earth, the path of its evolution was distinctly different because of its much smaller size. For example, it never underwent certain geochemical changes related to the greater interior pressure of Earth.

Unlike the Moon, Mars is big enough to have undergone most of the same processes as early Earth. Unlike Earth, it is small enough not to have erased as much evidence of its early activity. Compared to Venus and Mercury, Mars provides a more accessible destination and less harsh surface environment for sensitive robotic hardware to operate for many months of data collection.

As added benefits, knowledge about the surface and atmosphere of Mars that has been gained from a series of successful missions to the Red Planet will help researchers interpret information that InSight adds about the deep interior, and InSight's findings will improve the context for understanding those missions' results.

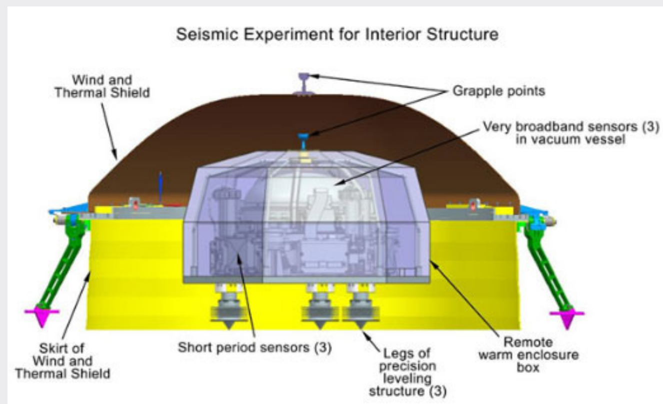
Science Experiments

Seismic Experiment for Interior Structure

The Seismic Experiment for Interior Structure (SEIS) is a six-sensor seismometer combining two types of sensors to measure ground motions over a wide range of frequencies. In each set of three sensors, the sensors are mounted at angles to one another to detect motion in any direction. One set is an ultra-sensitive "very broad band" instrument enclosed in a vacuum vessel. It will measure ground oscillations of medium-to-low frequencies (from a few cycles per second to less than one one-thousandth of a cycle per second). The other is a short-period instrument, adding capability for higher-frequency vibrations (up to 50 cycles per second).

That combination will be set directly onto the ground, connected to the lander by a flexible tether containing power and data lines. Then an additional protective cover -- the Wind and Thermal Shield -- will be placed over it. The SEIS electronics box remains on the lander.

Seismometers are best known as devices to detect, locate and measure the magnitude of earthquakes. One set of goals for SEIS is to provide such information about quakes on Mars, called marsquakes, and other sources of ground motion, such as meteorite impacts and faint gravitational effects of Mars' moon Phobos.



llustration of InSight's SEIS instrument with some key components labeled

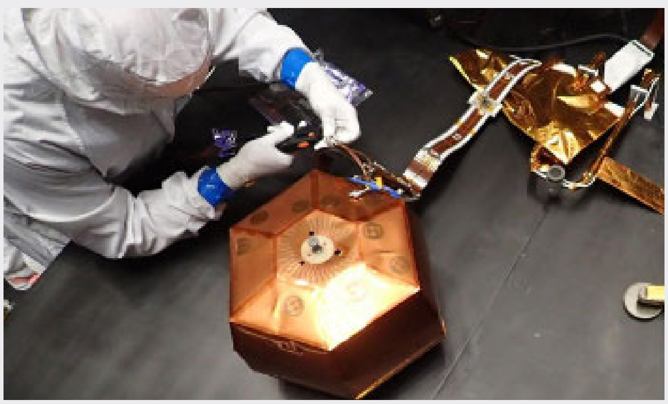
However, it is not just the sources of ground motion that are of interest. Those sources trigger ground vibrations called seismic waves. The waves travel at different velocities and different attenuation rates through different types of material, providing a signal affected by composition and density. Some are reflected and refracted by boundaries between interior layers, comparable to reflection and refraction of light waves at the surface of a lake. Seismometers are the eyes enabling researchers to use ground-motion waves to see into the interior of a planet. Most of our knowledge about the interior of Earth comes from seismometers. SEIS will be the first seismometer placed directly onto Mars.

A ground-shaking event sets off some waves that move through a planet's interior -- body waves -- and others that spread across the surface, known as surface waves. Two types of body waves -- called "P" and "S," for primary and secondary -- travel at different velocities and produce ground motion in distinctively different directions. The time gap between arrival of P waves and arrival of S waves is an indicator of the distance they traveled from their origin to the seismometer, though other factors in the ground also affect their speed. Surface waves travel at different speeds from body waves and also on a different path, along the ground surface.

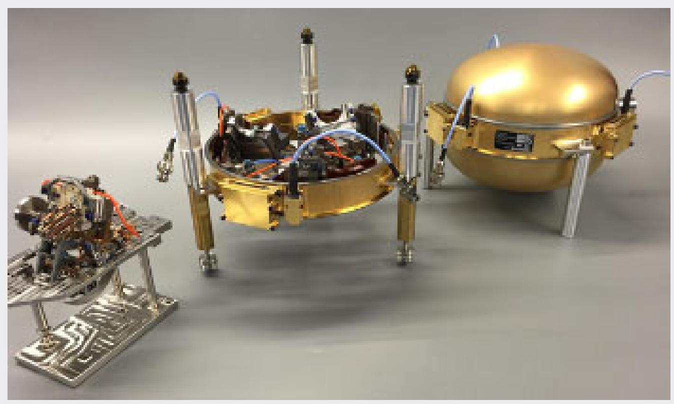
SEIS can measure wave frequencies from more than 10 minutes between wave peaks to about 50 vibrations per second. To gain information from faint or distant sources of ground movement, it has a sensitivity capable of detecting ground motions that are smaller than the diameter of a hydrogen atom. With that extreme sensitivity, many types of disturbances other than seismic waves could add noise to the desired data, so InSight carries countermeasures. Some protection comes from features of the SEIS instrument itself, such as its vacuum vessel and the Wind and Thermal Shield. In addition, InSight's auxiliary sensors will monitor variables such as wind, atmospheric pressure and magnetic field, so that their effects can be accounted for in interpretation of data from the seismometer.

France's national space agency, Centre National d'Études Spatiales (CNES), Paris, leads the consortium that provided SEIS. Other organizations in France, the United Kingdom, Switzerland, Germany and the United States collaborated on building the instrument. The principal investigator for SEIS is Philippe Lognonné of the Institute of Earth Physics of Paris (Institut de Physique du Globe de Paris, or IPGP). SEIS development benefited from the design of a similar instrument developed for a European multi-lander mission to Mars that was planned for a 2005 launch but was canceled before completion.

IPGP supplied the very broad band sensors. Imperial College, London, and Oxford University made the short period sensors. The Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule, or ETH), Zurich, provided the data-acquisition electronics. The Max Planck Institute for Solar System Research (Max-Planck-Institut für Sonnensystemforschung, or MPS), Göttingen, Germany, supplied the leveling system. NASA's Jet Propulsion Laboratory, Pasadena, California, made the vacuum container, the tether and the Wind and Thermal Shield, which includes a skirt of chainmail to accommodate uneven ground beneath a rigid dome. The chainmail comes from MailleTec Industries, Swift Current, Saskatchewan, Canada.



SEIS in preparation for thermal vacuum testing, before being covered by Wind and Thermal Shield.



Some SEIS components before final assembly: a very broad band sensor, three-legged leveling fixture to hold sensors, vacuum vessel.

Heat Flow and Physical Properties Probe

InSight's Heat Flow and Physical Properties Probe (HP³, pronounced "H-P cubed") will use a self-hammering mechanical mole capable of burrowing to a depth of 10 to 16 feet (3 to 5 meters). Measurements by sensors on the mole and on a science tether from the mole to the surface will yield the first precise determination of the amount of heat escaping from the planet's interior.

Heat flow is a vital sign of a planet. It carries information about the interior heat engine that drives the planet's geology. Heat is the energy that powers planetary evolution, shaping the mountains and canyons of the surface. A planet's interior heat affects how primordial ingredients of planetary formation form layers and how volatile components, such as water molecules, are released to the surface or atmosphere. Determining modern temperature flux will help scientists discriminate among models for how the interior of Mars has evolved over time

Heat flow also foretells the destiny of a planet: the pace at which its core energy is diminishing.

InSight's heat probe will penetrate more than 15 times deeper beneath the surface than any previous hardware on Mars. The current record was achieved by the scoop of NASA's Phoenix Mars Lander digging to a depth of about 7 inches (18 centimeters), though radar instruments on Mars orbiters have revealed details of some features much deeper, down to a few miles or kilometers.

The depth of the heat probe's emplacement will get it away from most effects of daily and seasonal temperature changes at the surface. On Earth, experiments to measure heat flow from the planet's interior often must go even deeper because water movement in the ground extends the effects of surface-temperature variations, but 10 feet (3 meters) is calculated as deep enough for useful measurement of heat flowing outward from the interior of Mars.

The instrument's mole is expected to use thousands of hammering strokes of a spring-loaded tungsten block, over the course of about 30 days, to reach its full depth. The total number of strokes needed is expected to be between 5,000 and 20,000, depending on characteristics of the ground the device is traveling through, such as how compacted the soil is. The mole is about 1 inch (2.7 centimeters) in diameter and about 16 inches (40 centimeters) long -- about the diameter of a U.S. quarter and the length of a forearm. The exterior is an aluminum cylinder with the downward end tapered to a point, making it the shape of a finishing nail.

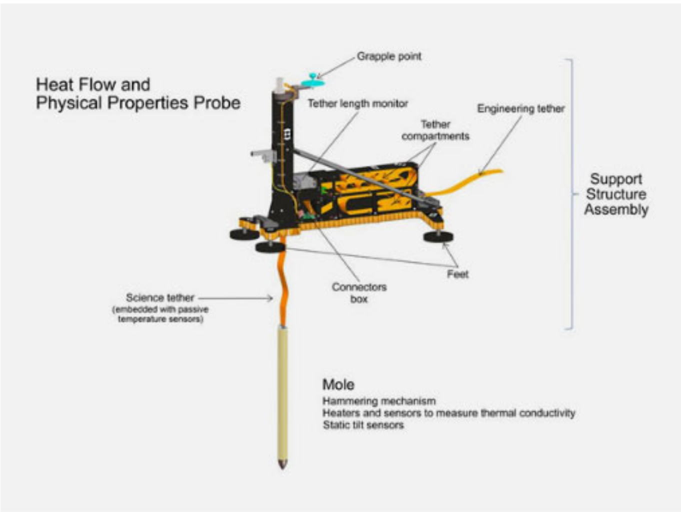
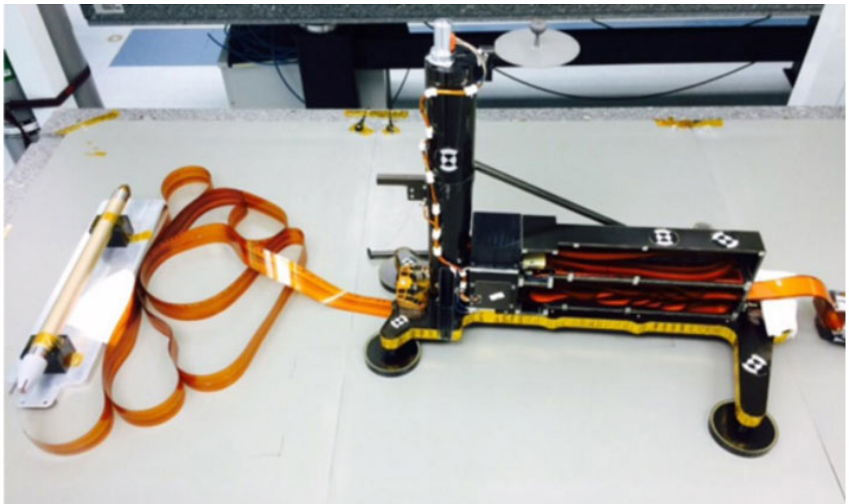


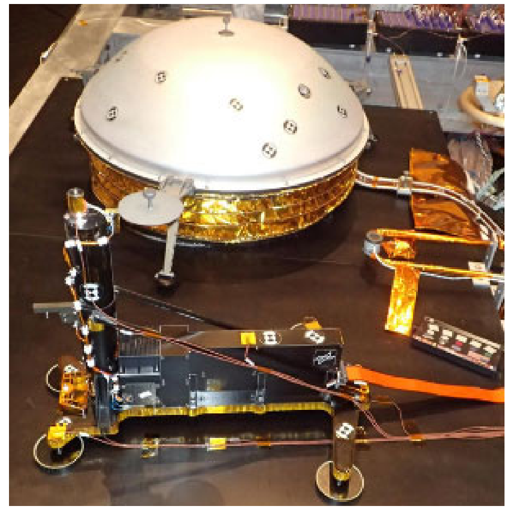
Illustration of InSight's HP³ instrument with some key components labeled.

The mole carries sensors and heaters to determine the thermal conductivity of the ground around it. The thermal conductivity experiment measures how long it takes the ground next to the surface of the probe to cool down after its temperature is elevated by a heating element on the mole's surface. The conductivity information is combined with information from sensors that measure ground temperature along the science tether at different depths -- the thermal gradient -- to determine heat flux. The HP³ sensors can measure temperature differences as small as about two one-hundredths of a degree Fahrenheit (about one one-hundredth of a degree Celsius).

The mole also contains the hammering mechanism and tilt sensors. A motor attached to a gearbox slowly compresses and then quickly releases a spring that drives the tungsten hammer against the interior of the mole tip, at a pace of one stroke every 3.6 seconds. The tilt sensors provide information about how much of the mole's motion is net downward penetration and how much is lateral, out of total burrowing motion determined by monitoring the length of science tether pulled into the ground.



From left to right: HP^3 investigation's mole, science tether, support structure and engineering tether.



HP^3 (foreground) and domed Wind and Thermal Shield (covering SEIS) in preparation for thermal vacuum testing. Credit: NASA/JPL-Caltech/Lockheed Martin Space

The science tether connects the upper end of the mole to the HP^3 support structure, which InSight's robotic arm will place directly onto the Martian surface. The support structure remains connected to the lander by an engineering tether. Both tethers carry data and electricity. The science tether has 14 temperature sensors embedded along it, at distance intervals that increase farther from the mole. The two closest to the mole are 9 inches (23 centimeters) apart; the two farthest from it are twice that far apart. These sensors will continue monitoring the thermal gradient beneath the surface after the mole has reached full depth.

The engineering tether connects the HP^3 support structure to the instrument's back-end electronics box on the lander. This box provides the interfaces to the lander's power system and main computer. It includes half a gigabyte of non-volatile memory, enough to hold all HP^3 data from the mission.

The probe's digging phase is designed to last about 30 to 40 days after the mission's initial phase when instruments are deployed from the deck onto the ground. After about every 20 inches (50 centimeters) of burrowing, the hammering will pause for about four days while temperatures equilibrate and thermal conductivity measurements are collected. After completion of the digging phase, the probe's science tether will continue to make temperature measurements for the rest of the mission.

The HP^3 investigation also includes a radiometer to measure ground-surface temperature near the lander based on its infrared brightness. Data from the radiometer will help account for effects that ground-surface temperature changes may have on temperatures beneath the surface.

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR), Cologne, provided InSight's Heat Flow and Physical Properties Probe. The principal investigator for HP^3 is Tilman Spohn of DLR's Institute of Planetary Research (Institut für Planetenforschung), Berlin, who also is principal investigator for an instrument suite with a similar heat probe on the European Space Agency's Rosetta mission to comet Churyumov-Gerasimenko.

Astronika, Warsaw, and the Polish Academy of Sciences' Space Research Center (Centrum Badan Kosmicznych, or CBK), Warsaw, built the hammering mechanism for the HP^3 mole, which was designed by Astronika.

Rotation and Interior Structure Experiment

One of InSight's three main investigations -- the geodesy study -- does not require its own dedicated science instrument: The Rotation and Interior Structure Experiment (RISE) will use InSight's direct radio connection with Earth to assess perturbations of Mars' rotation axis. These measurements can provide information about the planet's core.

The perturbations resemble the wobble of a spinning top and occur on two time scales. The longer wobble takes about 165,000 years and is the same as the process that makes a top wobble, called precession. The speed of this precession is directly related to the proportion of the body's mass that is close to the center, in the iron-rich core. The shorter-period wobbles, called nutations, occur on time scales of less than a year and are extremely small. Their cause is unrelated to a toy top's wobble. A closer analogy is the traditional method for determining whether an egg is hard-boiled by spinning it. An egg with a solid center spins easily. The liquid center of a raw egg perturbs the spin.

With InSight as the marker for a specific point on the Martian surface, radio tracking will monitor the location of that point in space with an accuracy better than 4 inches (10 centimeters). This will allow scientists to measure how much the rotation axis of Mars wobbles, and that motion indicates the size of the core.

Information about long-term changes (precession) in Mars' spin axis was previously provided by radio tracking of the location of NASA's Mars Pathfinder lander for three months in 1997, combined with tracking data from the Viking Mars landers in the 1970s. Researchers were able to confirm that Mars has a very dense core. A different radio-science investigation, analyzing gravitational effects of Mars on NASA's Mars Global Surveyor orbiter, indicated that some portion of the planet's outer core is molten, based on how much Mars bulges from the tidal pull of the Sun.

A longer tracking period with a stationary lander is the next step for measuring nutations to determine the core's exact size and density, and how much of the core is molten. This is not an experiment suited to Mars rovers, because they change their locations on the planet.

The tools for the RISE investigation are the X-band radio on the InSight lander and the large dish antennas of NASA's Deep Space Network at stations in California, Australia and Spain. This is the same direct radio link by which the spacecraft can receive commands and return data, though it will use relayed radio links through Mars orbiters (using a different UHF radio) for most of its commanding and data return.

The lead investigator for RISE is William Folkner of JPL, who led the 1997 investigation of Mars' core using the radio link between Earth and NASA's Mars Pathfinder.

Auxiliary Payload Sensor Subsystem

InSight carries a suite of environmental-monitoring instruments, called the Auxiliary Payload Sensor Subsystem (APSS), to measure the local magnetic field, wind, and atmospheric temperature and pressure. The primary reason for including these instruments in the mission's payload is to aid interpretation of seismometer data by tracking changes in the magnetic field or atmosphere that could cause ground movement or sensor readings that might otherwise be mistaken for a seismic event. However, they can also serve other Mars science investigations.

InSight's magnetometer will be the first ever used on the surface of Mars. Researchers will use it to investigate variations in the magnetic field, which may be induced at the surface by the variations resulting from interaction of the solar wind with Mars' ionosphere. Effects of the planet's metallic core on the induced magnetic field at the surface could provide information about the size of the core.

The University of California, Los Angeles, provided InSight's fluxgate magnetometer. UCLA has previously provided magnetometers for other NASA missions, including the Galileo mission to Jupiter and the Space Technology 5 mission. The instrument can determine both the magnitude and direction of the local magnetic field.

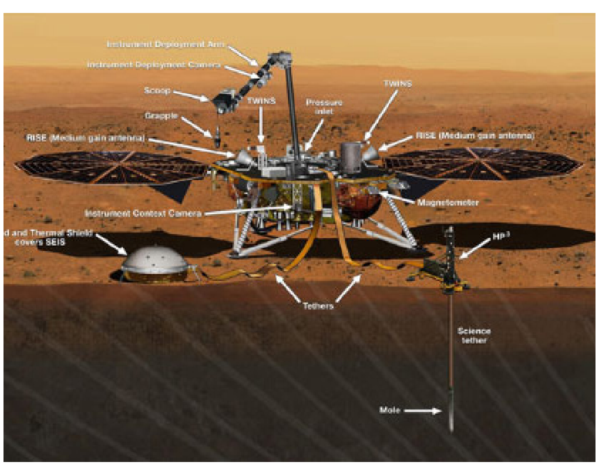
Two finger-size booms mounted on short vertical supports on InSight's deck will monitor atmospheric temperature and the direction and velocity of the wind. The booms face outward in roughly opposite sides of the lander, so that wind from any direction reaches at least one of them before the lander itself perturbs the wind much. Together, they make up the Temperature and Wind for InSight (TWINS) instrument. Each of the booms holds sensors for recording air temperature and detecting air movement in three dimensions.

Spain's Center for Astrobiology (Centro de Astrobiología, or CAB), Madrid, provided TWINS. The instrument's booms are refurbished flight spares from the CAB-provided weather station on NASA's Curiosity Mars rover, called the Rover Environmental Monitoring Station.

InSight's atmospheric pressure sensor sits inside the lander, with access to the atmosphere via an inlet on the lander deck. Tavis Corp., Mariposa, California, built it. The device has more than 10-fold greater sensitivity to pressure variations at seismic frequencies than similar pressure sensors on NASA's Viking and Mars Pathfinder landers.

JPL provided the control and data-acquisition electronics shared by the APSS instruments.

Though not formally part of the APSS, the HP³ radiometer and the color cameras of InSight's Instrument Deployment Subsystem can similarly be used to study the Mars environment. The radiometer can track daily and seasonal changes in ground temperature. The cameras can be used for monitoring changes at the landing site, such as the effect of wind on dust over the course of many months.

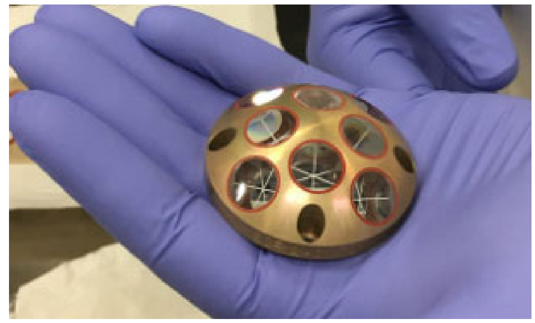


Labeled illustration of InSight with its science payload deployed. Many of the investigation tools are labeled. SEIS is the Seismic Experiment for Interior Structure. HP³ is the Heat Flow and Physical Properties Probe. RISE is the Rotation and Interior Structure Experiment, which uses the lander's two medium-gain antennas. TWINS is the Temperature and Wind for InSight instrument, part of the mission's Auxiliary Payload Sensor Subsystem, which also includes the magnetometer and the pressure sensor (out of view beneath the pressure inlet). The lander's radiometer and laser retroreflector are out of sight, on the other side of the deck.

Laser Retroreflector for Mars

A dome-shaped device about 2 inches (5 centimeters) in diameter and 0.8 inch (2 centimeters) high, affixed to the top of the InSight lander's deck, holds an array of eight special reflectors. This is the Laser Retroreflector for InSight, or LaRRI, which is not part of the InSight mission's own science investigations but may passively provide science value for many years to come.

The national space agency of Italy (Agenzia Spaziale Italiana, or ASI) provided LaRRI to be used by a possible future Mars orbiter mission, with a laser altimeter making extremely precise measurements of the lander's location. Each of the eight reflectors uses three mutually perpendicular mirrors, joining at one point like an inner corner of a box. This gives it the property of returning any incoming light directly toward its source. Apollo astronauts on the Moon placed larger arrays of similar "corner cube reflectors" at several lunar landing sites more than 45 years ago. These have served ever since in experiments that use precisely timed laser pulses sent from Earth and reflected back, for purposes such as determining the rate of change in the Moon's distance from Earth and testing Einstein's general theory of relativity. Scientists plan to use LaRRI -- plus similar retroreflectors on future missions to land on Mars -- for experiments that use reflection of laser pulses emitted by orbiters. Besides providing precise location information for experiments about gravity and planetary motion, such studies could include investigations of the Martian atmosphere and advances in using lasers as an alternative to radio for communications.



Laser Retroreflector for InSight (LaRRI)

InSight Science Team

SEIS Principal Investigator **Philippe Lognonné** of the Institute of Earth Physics of Paris (Institut de Physique du Globe de Paris, or IPGP) leads the seismic study.

HP³ Principal Investigator is**Tilman Spohn**, of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR), Berlin, leads the heat-transport study.

RISE Principal Investigator **William Folkner** of JPL leads the geodesy study.

InSight Principal Investigator Bruce Banerdt and InSight Deputy Principal Investigator Sue Smrekar, both of JPL, lead the mission's international science team.

HP³ Principal Investigator Tilman Spohn of DLR (foreground) speaking at a briefing days before InSight's launch. With him (in the background, from left) are SEIS Principal Investigator Philippe Lognonné of IPGP; Annick Sylvestre-Baron, SEIS deputy project manager at Centre National d'Études Spatiales; and InSight Principal Investigator Bruce Banerdt.

Daniele Antonangeli
Institute of Mineralogy, Material Physics and Cosmochemistry (Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, or IMPMC), Sorbonne University, Paris

Sami Asmar
NASA JPL

Don Banfield
Cornell University, Ithaca, New York

Ulrich Christensen
Max Planck Institute for Solar System Research (Max-Planck-Institut für Sonnensystemforschung, or MPS), Göttingen, Germany

Caroline Beghein
UCLA

Neil Bowles
Oxford University, Oxford, U.K.

Ebru Bozdag
Colorado School of Mines, Denver, Colorado

Peter Chi
UCLA

John Clinton
Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule, or ETH), Zurich

Gareth Collins
Imperial College, London

Ingrid Daubar
NASA JPL

Véronique Dehant
Royal Observatory of Belgium, Brussels

Matthew Fillingim
University of California, Berkeley

Raphael Garcia
National Higher School of Aeronautics and Space (Institut Supérieur de l'Aéronautique et de l'Espace, or ISAE), Toulouse, France

James Garvin
NASA Goddard Space Flight Center, Greenbelt, Maryland

Domenico Giardini
ETH Zurich

Matt Golombek
NASA JPL

John Grant
Smithsonian Institution, Washington, DC

Matthias Grott
DLR Institute of Planetary Research, Berlin

Jurek Grygorczuk
Astronika, Warsaw

Troy Hudson
NASA JPL

Jessica Irving
Princeton University

Catherine Johnson
University of British Columbia, Vancouver, Canada/Planetary Science Institute (PSI)

Günter Kargl
Austrian Academy of Sciences Space Research Institute (Oesterreichische Akademie der Wissenschaften Institut für Weltraumforschung), Graz

Taichi Kawamura
IPGP

Sharon Kedar
NASA JPL

Scott King
Virginia Tech, Blacksburg, Virginia

Brigitte Knapmeyer-Endrun
MPS

Mark Lemmon
Space Science Institute, Boulder, Colorado

Ralph Lorenz
Johns Hopkins Applied Physics Laboratory (APL), Laurel, Maryland

Justin Maki
NASA JPL

Ludovic Margerin
IRAP

Scott McLennan
State University of New York, Stonybrook

Chloë Michaut
Lyon University (Ecole Normale Superieure de Lyon, or ENS Lyon)

David Mimoun
ISAE

Antoine Mocquet
University of Nantes, France

Paul Morgan
Colorado School of Mines, Golden, Colorado

Nils Mueller
DLR Institute of Planetary Research

Claire Newman
Aeolis Research, Pasadena, California

Francis Nimmo
University of California, Santa Cruz

Mark Panning
NASA JPL

Tom Pike
Imperial College, London

Jose Antonio Rodriguez Manfredi
Centro de Astrobiologia (CAB), Madrid, Spain

Chris Russell
UCLA

Nick Schmerr
University of Maryland, College Park

Matthew Siegler
PSI

Aymeric Spiga
Laboratory for Dynamic Meteorology (Laboratoire de Météorologie Dynamique, or LMD), Sorbonne University, Paris

Sabine Stanley
Johns Hopkins University, Baltimore, Maryland

Nick Teanby
University of Bristol, U.K.

Jeroen Tromp
Princeton University, Princeton, New Jersey

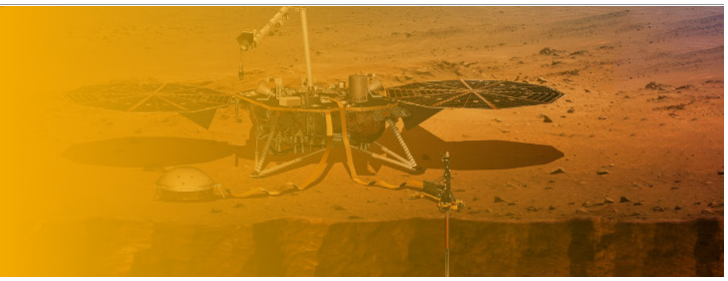
Nick Warner
State University of New York, Geneseo

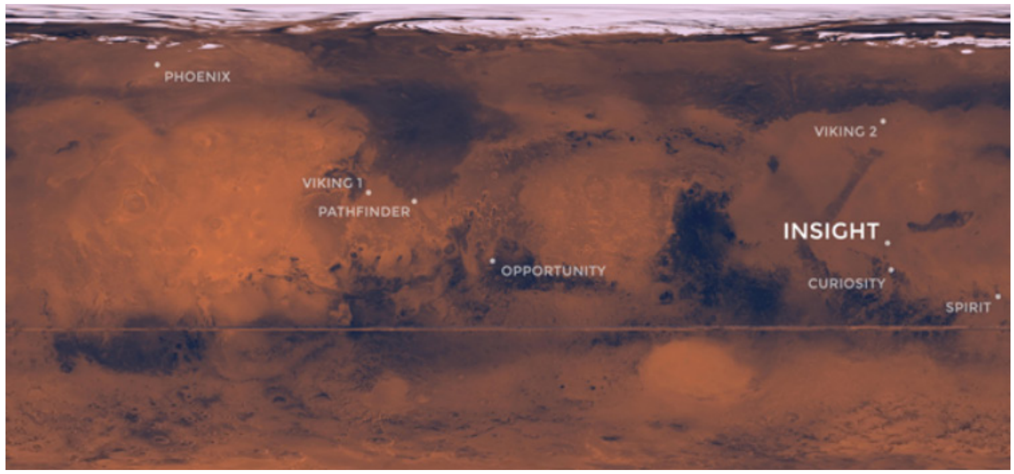
Renee Weber
NASA Marshall Space Flight Center, Huntsville, Alabama

Mark Wieczorek
Observatoire de la Côte d'Azur (OCA), Nice, France

The camera calibration target on InSight's deck is adorned with flags from nations participating in the mission. Credit: NASA/JPL-Caltech/Lockheed Martin Space

Mission: Landing Site





InSight's purpose is to study the interior of Mars, not the surface. Still, location matters. The landing site, a smooth expanse of lava plains called Elysium Planitia, was carefully selected for its safety and sunlight, among other attributes.

InSight's landing site is expected to look much the same in all directions: flat, no big hills nearby and few large rocks in view. That expectation is based on many high-resolution images taken from orbit as part of thorough evaluations for selecting the site.

The site lies in the western portion of Elysium Planitia, centered at about 4.5 degrees north latitude and 135.9 degrees east longitude. The spacecraft has a better than 99 percent chance of coming down within a "landing ellipse" surrounding the targeted center of the site. InSight's landing ellipse is about 81 miles (130 kilometers) west-to-east and about 17 miles (27 kilometers) north-to-south.

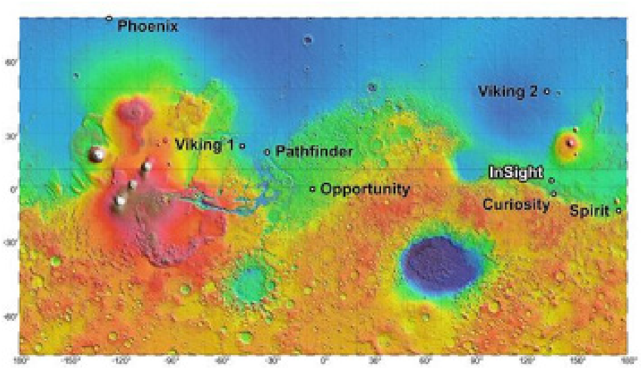
"Planitia" is Latin for a flat surface, geometric plane or geographical plain. "Elysium" is from the ancient Greek name for an afterlife paradise, usually referred to in English as the Elysian Fields.

InSight has several very specific requirements for its landing location. One is being close enough to the equator for the lander's solar array to have adequate power at all times of the year, and another is to have the right conditions for keeping the spacecraft's electronics warm. That combination limits eligible sites to a band just north of the equator, between 5 degrees north latitude and 3 degrees north latitude.

Also, the elevation must be low enough to have sufficient atmosphere above the site for a safe landing, because the spacecraft will rely on the atmosphere for deceleration with a parachute during descent. The safety criterion for elevation of the site is at least 8,200 feet (2.5 kilometers) lower than a reference zero elevation that is used as Mars' equivalent of "sea level."

Only three areas on Mars meet these basic engineering constraints for InSight. Besides Elysium Planitia, the only other two areas are Isidis Planitia and Valles Marineris.

The Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) cameras on NASA's Mars Reconnaissance Orbiter played important roles in evaluating candidate landing sites on Mars. HiRISE images revealed individual rocks down to the size of about 3 feet (1 meter) across and CTX images provided regional context. Stereo pairs of images provided three-dimensional information used for evaluating the steepness of slopes. HiRISE took about 150 images of candidate InSight landing sites.



The landing site for InSight, in relation to landing sites for seven previous missions, is shown on a topographic map of Mars.

Rockiness and slope are factors in landing safety and are also important in determining whether InSight can succeed in its mission after landing. A close, overly steep slope could foil the robotic arm's access to a sufficiently large work area beside the lander. A steep slope in the wrong direction could jeopardize adequate power output from the solar arrays. A large enough rock at the landing site could block one of the solar arrays from opening. Rocks and steep slopes could also prevent placement of the seismometer and heat-flow probe on the surface.

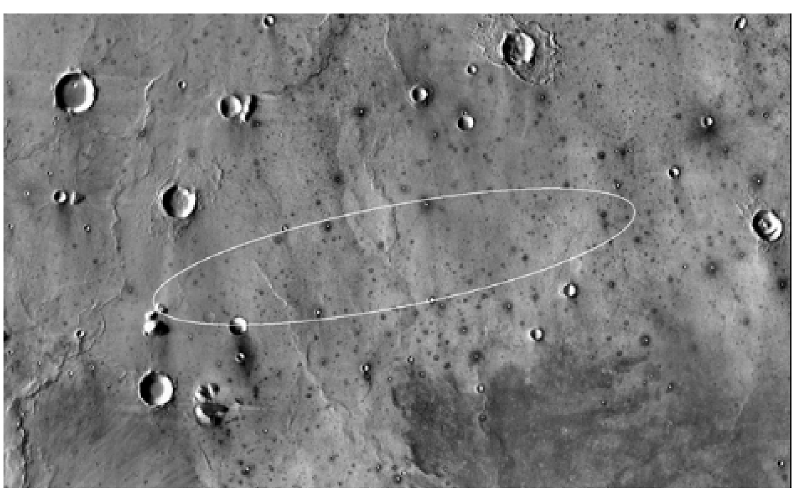
Isidis Planitia and Valles Marineris were assessed as too rocky and windy. Valles Marineris also lacks any swath of flat ground large enough for a safe landing. That left Elysium.

For the first time ever, the site evaluation for this Mars mission also extended beneath the ground surface. For mission success, the ground in the lander's workspace must be penetrable by InSight's heat-flow probe. The probe was designed to hammer itself into the soil to a depth 10 to 16 feet (3 to 5 meters).

Key evidence showing that the ground in Elysium will be loose material suitable for burrowing, rather than solid bedrock, came from an assessment by the Thermal Imaging System (THEMIS) on NASA's Mars Odyssey orbiter. Observations by this camera show how quickly the ground cools at night or warms in sunlight. (Solid rock changes temperature more slowly than softer ground.)

In workshops in 2013, 2014 and 2015, an initial list of 22 candidate landing ellipses in Elysium was narrowed to four finalists, then to the selection location. The final site was judged to be the safest and most likely to lead to mission success.

Elevation within the selected ellipse averages about 8,700 feet (2,650 meters) lower than the reference zero elevation.



Smooth, flat ground dominates InSight's landing ellipse in the Elysium Planitia region of Mars, as seen in this annotated map of thermal infrared images from the Thermal Emission Imaging System (THEMIS) camera on NASA's Mars Odyssey orbiter.

Program & Project Management

The InSight project is managed by the Jet Propulsion Laboratory in Pasadena, California, for NASA's Science Mission Directorate in Washington. JPL is a division of Caltech in Pasadena.

The InSight mission was competitively chosen and funded as part of the NASA Discovery Program. As a complement to NASA's larger "flagship" planetary science explorations, the Discovery Program's goal is to achieve outstanding results by launching many smaller missions using fewer resources and shorter development times.

More information on NASA's Discovery Program can be found in the **Appendix** and at: planetarymissions.nasa.gov.

At NASA Headquarters in Washington, the Discovery Program is managed by the Science Mission Directorate. Thomas Zurbuchen is associate administrator for the Science Mission Directorate. Lori Glaze is director of NASA's Planetary Division. Ramon DePaula is program executive for InSight, and Robert Fogel is the program scientist.

Right to left: NASA Administrator Jim Bridenstine, Associate Administrator for the Science Mission Directorate Thomas Zurbuchen, and Chief Financial Officer Jeff DeWit, watch the InSight launch at NASA Headquarters in Washington NASA.

InSight Principal Investigator Bruce Banerdt, speaking before reporters and social media participants days before launch NASA/KSC

Discovery Program missions are managed for NASA's Planetary Science Division by the Planetary Missions Program Office at Marshall Space Flight Center in Huntsville, Alabama. At Marshall, Brian Key is the acting program manager of the Planetary Missions Program Office, and Rick Turner is Planetary Missions Program Office mission manager.

At JPL, for InSight, Bruce Banerdt is the principal investigator, Sue Smrekar is deputy principal investigator, Tom Hoffman is project manager, Chuck Scott is deputy project manager and Rick Welch is mission manager.

Lockheed Martin Space, Denver, built the InSight spacecraft and collaborates with JPL on mission operations. Stu Spath is InSight program manager at Lockheed Martin.

Joel Krajewski of JPL is project manager for Mars Cube One (MarCO). JPL built MarCO.

InSight Project Manager Tom Hoffman of JPL (foreground), pointing to a model of the InSight spacecraft, with Stu Spath, Lockheed Martin Space's InSight program manager (middle). Credit: NASA

Appendix: Mars Cube One Tech Demo

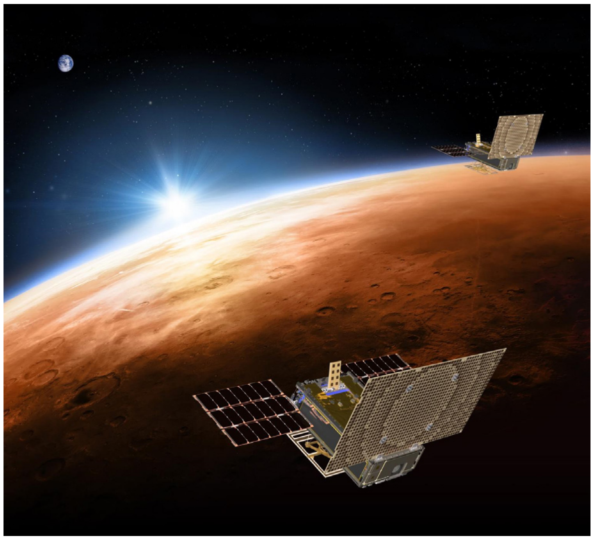
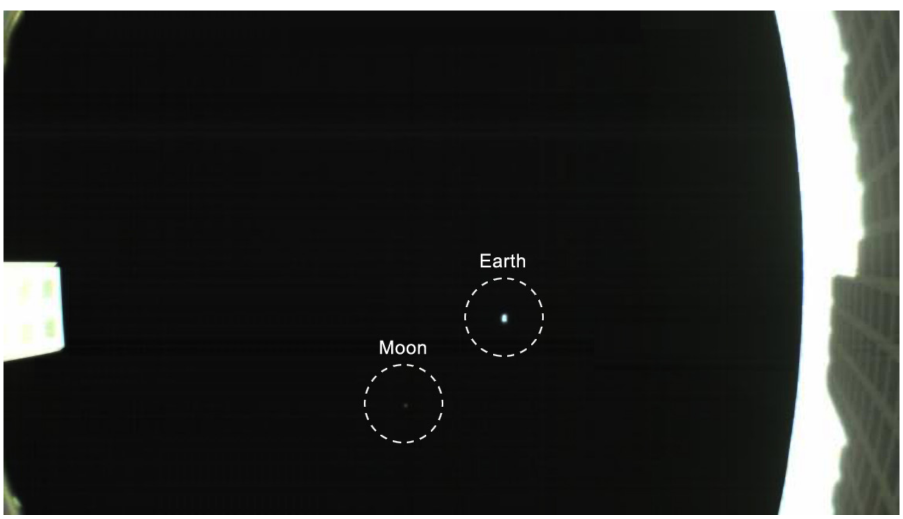


Illustration of MarCo-A and MarCo-B flying over Mars.

A technology demonstration called Mars Cube One (MarCO) is the first deep space use of the miniature, modular "CubeSat" spacecraft design. The pair of briefcase-sized spacecraft -- MarCO-A and B -- launched on the same rocket as InSight. They have already completed a number of risky deep space navigation and communication experiments. During InSight's landing, they will attempt to relay the spacecraft's data as it descends to the Martian surface.



The first image captured by one of NASA's Mars Cube One (MarCO) CubeSats. The image, which shows both the CubeSat's unfolded high-gain antenna at right and the Earth and its Moon in the center, was taken by MarCO-B on May 9, 2018.

Achievements to date

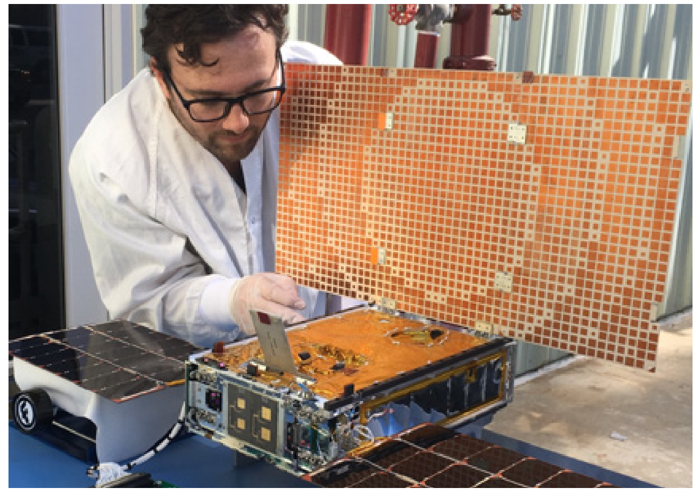
MarCO has already achieved a number of impressive firsts for CubeSats:

- They've successfully tested several experimental technologies, including their radios, high-gain antennas and propulsion systems
- They became the first CubeSats to fly to deep space, providing images of Earth and its moon along the way
- They performed the first trajectory correction maneuvers by CubeSats, each steering toward Mars

An Experiment at Mars

MarCO-A and MarCO-B, also nicknamed EVE and Wall-E, have flown separately toward Mars. Should they reach the planet, they would pass it at about 2,175 miles (3,500 kilometers) away just as InSight is landing. It will take only one of them to receive transmissions from InSight and relay them back to provide status information to Earth about the InSight lander's descent and touchdown.

The success of the InSight mission does not depend on MarCO's performance (see "Listening for InSight" for more detail). Should the MarCO CubeSats make it all the way to Mars, each has the capability to relay a substantive amount of data almost immediately, transmitting status information on a speed-of-light trip to Earth lasting 8 minutes and 7 seconds across about 90.7 million miles (146 million kilometers) between the two planets.



JPL engineer Joel Steinkraus works with one of the MarCO CubeSats during an outdoor test of its solar arrays.

The reason for flying two identical MarCO spacecraft is redundancy in case either one does not operate as planned.

Going Where No CubeSats Have Gone Before

CubeSats are a class of spacecraft based on a standardized small size and modular use of off-the-shelf technologies. Many have been made by university students, and hundreds have been launched into Earth orbit using extra payload mass available on launches of larger spacecraft.

But MarCO is the first attempt to send CubeSats to another planet. By verifying that the technologies for interplanetary missions are feasible and can be developed on a short timeline, this test mission could lead to many other SmallSat applications for exploring our solar system. Some could provide similar support functions as "carry your own" relay providers. Others could have primary scientific research functions of their own, such as radio transmissions through planetary atmospheres, imaging with small cameras, observations with other miniaturized instruments, or in-place measurements of space environments.

The MarCO Spacecraft: Small but Mighty

The basic CubeSat unit is a box roughly 4 inches (10 centimeters) square. Larger CubeSats are multiples of that unit. MarCO's design is a six-unit CubeSat. Each of the two spacecraft has a stowed size of about 14.4 inches (36.6 centimeters) by 9.5 inches (24.3 centimeters) by 4.6 inches (11.8 centimeters).

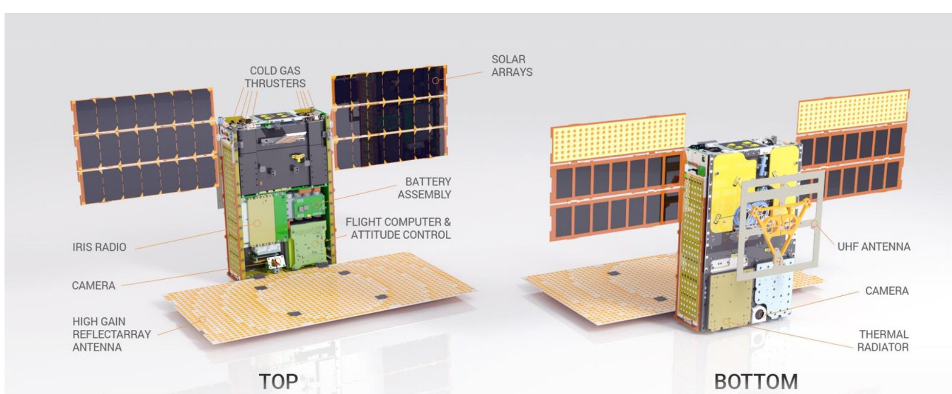


Illustration of one of the twin MarCO spacecraft with some key components labeled. Front cover is left out to show some internal components. Antennas and solar arrays are in deployed configuration.

During the flight to Mars, the MarCO twins each deployed a high-gain X-band antenna that is a flat "reflect array" panel engineered to direct radio waves the way a parabolic dish antenna does. This should allow MarCO to transmit data to Earth from as far away as Mars without needing much power. Two smaller X-band antennas on each spacecraft -- one low-gain and one medium-gain -- work without needing to be deployed. These allowed transmissions earlier in the flight and also receive radioed commands from Earth.

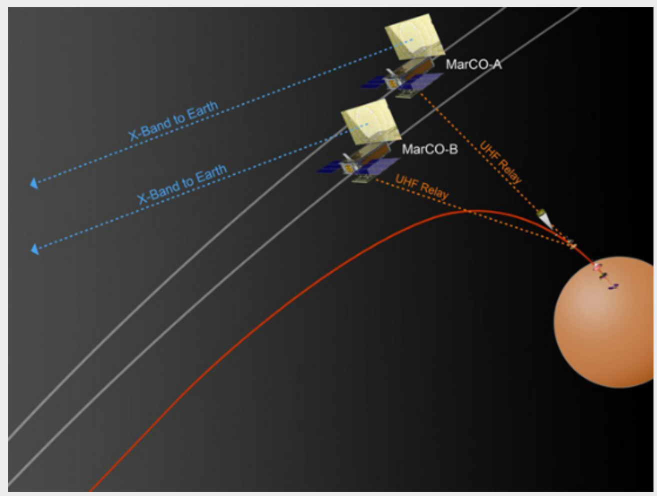
The other deployed antenna is for the MarCO ultra-high frequency (UHF) radio receiver. InSight will be transmitting in UHF during its descent through the Martian atmosphere and from the surface of Mars. Both of the deployed antennas on each MarCO will be in fixed positions after deployment, with the high-gain antenna and UHF antenna facing different directions 90-degrees apart. The MarCOs have also tested new technology using a softball-sized radio, called Iris. This radio provides both UHF (receive-only) and X-band (receive-and-transmit) functions capable of immediately relaying information received over UHF, at 8 kilobits per second.

A color wide-field engineering camera on each MarCO was used to confirm high-gain antenna deployment. The wide-field camera has a 138-degree diagonal field of view. MarCO-B also carries a color narrow-field camera with a 6.8-degree diagonal field of view pointed in the direction of the UHF antenna (the opposite direction from the high-gain antenna). (MarCO-A's narrow-field camera was found to be inoperable prior to launch.) Both kinds of cameras can produce images 752 x 480 pixels in resolution.

Each MarCO's attitude-control system combines a star tracker, Sun sensors, gyroscopes and three-axis reaction wheels for monitoring and adjusting orientation. Accelerating a reaction wheel rotates the spacecraft in the opposite direction from the direction the wheel is spinning.

MarCO's propulsion system uses compressed R236FA gas, a common propellant in fire extinguishers. Each MarCO has eight thrusters that release this cold-gas propellant in different directions from a single, shared tank. The thrusters operate for trajectory adjustments and for desaturating the reaction wheels. MarCO is pioneering CubeSat use of propellant for desaturating attitude-control reaction wheels; Earth-orbiting CubeSats typically control attitude with electromagnet devices that "push" against Earth's magnetic field, an option not available to MarCO in deep space.

Mission controllers have used the "cruise" period of flying from Earth to Mars not only to complete communication and navigation technology demonstration objectives, but also to check out each MarCO's temperatures, power levels and other onboard subsystems. Each MarCO carries heaters, multiple temperature sensors, thermal blanketing and two radiators for thermal control.



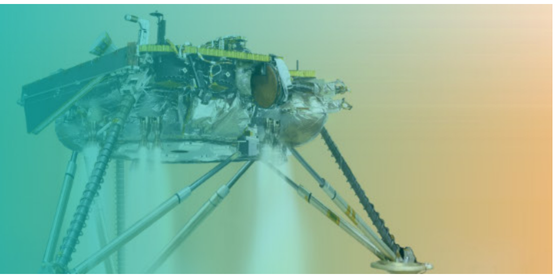
MarCO aim to relay data from InSight to Earth during InSight's descent through Mars' atmosphere and touchdown on the surface. NASA's Mars Reconnaissance Orbiter will also receive these data from InSight.

If all goes well, on Nov. 26, 2018, MarCO-A and MarCO-B will be flying past Mars during the critical minutes when InSight enters the Martian atmosphere, descends toward the surface and touches down. Each MarCO will maintain an orientation with the UHF antenna pointed down toward InSight as it lands on Mars, and the high-gain X-band antenna pointed back toward Earth. In this orientation, the solar panels will not be fully facing the Sun, so MarCO will be operating primarily on battery power. InSight will be transmitting its status information at 8 kilobits per second over UHF. Each MarCO will attempt to receive that data stream, format it and relay it Earthward in near-real-time to NASA's Deep Space Network.

Since MarCO adds formatting information, as well as a small amount of spacecraft information, to the datastream, the delay is expected to increase as more data are sent from InSight. The delay, however, is not expected to be more than a few minutes. Earth will be oriented so that the information relayed via MarCO will go to the Madrid, Spain, station of the Deep Space Network, from which it will be routed to the InSight mission operations team.

NASA's Jet Propulsion Laboratory in Pasadena, California, which manages both InSight and MarCO for NASA, built the two MarCO spacecraft in JPL's CubeSat assembly clean room. At JPL, Joel Krajewski is MarCO's project manager and Andrew Klesh is MarCO's project engineer.

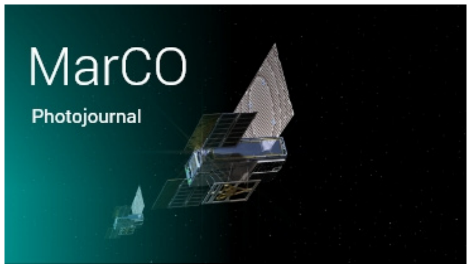
Technology suppliers for MarCO include: Blue Canyon Technologies in Boulder, Colorado, for the attitude-control system; VACCO Industries in South El Monte, California, for the cold-gas thrusters; AstroDev in Ann Arbor, Michigan, for electronics; MMA Design LLC, also in Boulder, for solar arrays; and Tyvak Nano-Satellite Systems Inc., a Terran Orbital Company in San Luis Obispo, California, for the CubeSat dispenser system.



Appendix: Gallery

Images

InSight images on Planetary Photojournal
https://go.nasa.gov/2lOkRm4



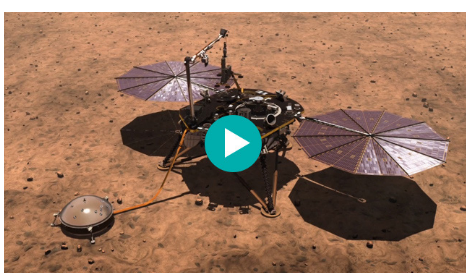
MarCO images on Planetary Photojournal
https://go.nasa.gov/2ILZ2n1

InSight images on InSight website
https://mars.nasa.gov/insight/multimedia/images/

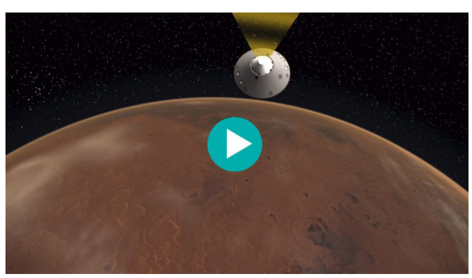
NASA Headquarters Flickr feed
https://www.flickr.com/photos/nasahqphoto/albums

Launch processing images
https://flic.kr/s/aHskrajq2C

Animations and Raw Video

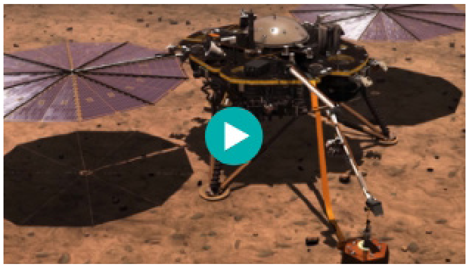


Insight Media Reel
https://vimeo.com/261856765



MarCO Media Reel
https://vimeo.com/265040492

Web Videos

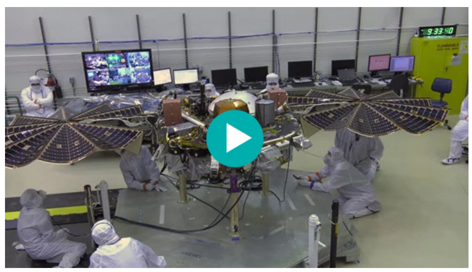


Overview of the InSight mission
https://youtu.be/LKLITDmm4NA

Crazy Engineering Video on InSight's Robotic Arm
https://youtu.be/o1ZlVGpyHXc

InSight Launch Coverage
https://youtu.be/mo6HnBZ7N-Q

InSight: Digging Deep into Mars (News Briefing)
https://youtu.be/y2Hh3FeRrMU

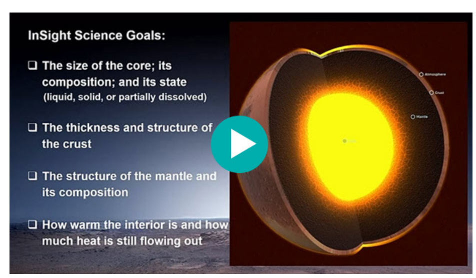


InSight spreads its solar wings
https://youtu.be/Z3twtYCXxNo

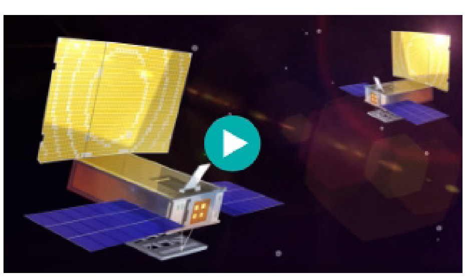
InSight arrives at Vandenberg Air Force Base
https://youtu.be/FQtjra0uEnc

Engineering For Mars: NASA InSight Mission Test Lab (360 Video)
https://youtu.be/ZSXnw-fJbGk

"The InSight Mission: Journey to the Center of Mars"
https://youtu.be/uidTD0Gxh7Y



"Looking Deep: The InSight Mission to Mars" (Public Lecture)
https://youtu.be/kqTR0mrIIEc



Overview of the MarCO mission
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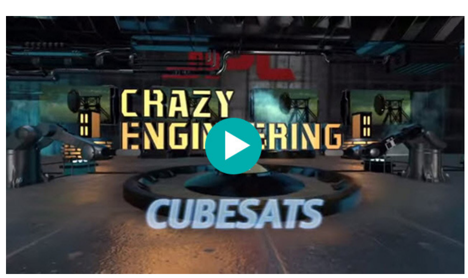


"Crazy Engineering" video on CubeSats such as MarCO
https://youtu.be/7RrWZJHkREI

Appendix: Science Objectives, Quantified

These are the quantifiable success criteria that have been set for accomplishing InSight's science objectives:

Determine the thickness and structure of the crust

- Determine the crustal thickness with a precision of plus or minus 10 kilometers (6.2 miles). The pre-InSight estimates are that the crust is about 65 kilometers (40 miles) thick, plus or minus 35 kilometers (22 miles).
- Resolve crustal layers with a thickness of 5 kilometers (3 miles) or greater. Prior to InSight, there has been no certain knowledge about crustal layering.

Determine the composition and structure of the mantle

- Determine the velocities of seismic waves in the upper 600 kilometers (373-mile) of the mantle to a precision of plus or minus 0.25 kilometer per second (560 mph). Mantle composition can be inferred from seismic velocities. The pre-InSight estimates are that velocity of seismic waves through the mantle is about 8 kilometers per second (about 18,000 mph) with an uncertainty of plus or minus 1 kilometer per second (about 2,200 mph).

Determine the size, composition and physical state of the core

- Positively distinguish between a liquid and solid outer core.
- Determine the radius of the core to a precision of plus or minus 200 kilometers (124 miles). Current estimates are that the core radius is about 1,700 kilometers (about 1,050 miles) plus or minus 300 kilometers (186 miles).
- Determine the core's density to a precision of plus or minus 450 kilograms per cubic meter (28 pounds per cubic foot). Core composition can be inferred from density. The pre-InSight state of knowledge is that the core density is about 6,400 kilograms per cubic meter (400 pounds per cubic foot) plus or minus 1,000 kilograms per cubic meter (62 pounds per cubic foot).

Determine the thermal state of the interior

- Determine the heat flux from the planet's interior at the landing site to a precision of plus or minus 5 milliwatts per square meter (one-half milliwatt per square foot). Pre-InSight estimates are that the heat flux from the Martian interior is about 30 milliwatts per square meter (3 milliwatts per square foot) plus or minus 2.5 milliwatts per square meter (0.23 milliwatts per square foot).

Measure the rate and geographic distribution of seismic activity

- Determine the rate of seismic activity to within a factor of two; determine the distance to the epicenter of a seismic event to within 25 percent; and determine the azimuth (compass direction) to the epicenter to within 20 degrees. None of these values have previously been measured.

Measure the rate of meteorite impacts on the surface

- Determine the meteorite impact rate on Mars to within a factor of two. Current estimates are within a factor of about six.

Appendix: Historical Mars Missions

History

***Mission: Country, Launch Date,** Purpose, Results*

Marsnik 1: **USSR, 10/10/60,** Mars flyby, did not reach Earth orbit

Marsnik 2: **USSR, 10/14/60,** Mars flyby, did not reach Earth orbit

Sputnik 22: **USSR, 10/24/62,** Mars flyby, achieved Earth orbit only

Mars 1: **USSR, 11/1/62,** Mars flyby, radio failed at 65.9 million miles (106 million kilometers)

Sputnik 24: **USSR, 11/4/62,** Mars flyby, achieved Earth orbit only

Mariner 3: **U.S., 11/5/64,** Mars flyby, shroud failed to jettison

Mariner 4: **U.S. 11/28/64,** first successful Mars flyby 7/14/65, returned 21 photos

Zond 2: **USSR, 11/30/64,** Mars flyby, passed Mars but radio failed, returned no planetary data

Mariner 6: **U.S., 2/24/69,** Mars flyby 7/31/69, returned 75 photos

Mariner 7: **U.S., 3/27/69,** Mars flyby 8/5/69, returned 126 photos

Mars 1969A: **USSR, 3/27/69,** Mars orbiter, did not reach Earth orbit

Mars 1969B: **USSR, 4/2/69,** Mars orbiter, failed during launch

Mariner 8: **U.S., 5/8/71,** Mars orbiter, failed during launch

Kosmos 419: **USSR, 5/10/71,** Mars lander, achieved Earth orbit only

Mars 2: **USSR, 5/19/71,** Mars orbiter/lander arrived 11/27/71, no useful data, lander burned up due to steep entry

Mars 3: **USSR, 5/28/71,** Mars orbiter/lander, arrived 12/3/71, lander operated on surface for 20 seconds before failing

Mariner 9: **U.S., 5/30/71,** Mars orbiter, operated in orbit 11/13/71 to 10/27/72, returned 7,329 photos

Mars 4: **USSR, 7/21/73,** failed Mars orbiter, flew past Mars 2/10/74

Mars 5: **USSR, 7/25/73,** Mars orbiter, arrived 2/12/74, lasted a few days

Mars 6: **USSR, 8/5/73,** Mars flyby module and lander, arrived 3/12/74, lander failed due to fast impact

Mars 7: **USSR, 8/9/73,** Mars flyby module and lander, arrived 3/9/74, lander missed the planet

Viking 1: **U.S., 8/20/75,** Mars orbiter/lander, orbit 6/19/76-1980, lander 7/20/76-1982

Viking 2: **U.S., 9/9/75,** Mars orbiter/lander, orbit 8/7/76-1987, lander 9/3/76-1980; combined, the Viking orbiters and landers returned more than 50,000 photos

Phobos 1: **USSR, 7/7/88,** Mars orbiter and Phobos lander, lost 8/88 en route to Mars

Phobos 2: **USSR, 7/12/88,** Mars orbiter and Phobos lander, lost 3/89 near Phobos

Mars Observer: **U.S., 9/25/92,** Mars orbiter, lost just before Mars arrival 8/21/93

Mars Global Surveyor: **U.S., 11/7/96,** Mars orbiter, arrived 9/12/97, high-detail mapping through 1/00, third extended mission completed 9/06, last communication 11/2/06

Mars 96: **Russia, 1/16/96,** orbiter/two landers/two penetrators, launch vehicle failed

Mars Pathfinder: **U.S., 12/4/96,** Mars lander/rover, landed 7/4/97, completed prime mission and began extended mission 8/3/97, last transmission 9/27/97

Nozomi: **Japan, 7/4/98,** Mars orbiter, failed to enter orbit 12/03

Mars Climate Orbiter: **U.S., 12/11/98,** lost upon arrival 9/23/99

Mars Polar Lander/Deep Space 2: **U.S., 1/3/99,** lander/two penetrators, lost on arrival 12/3/99

Mars Odyssey: **U.S., 3/7/01,** Mars orbiter, arrived 10/24/01, completed prime mission 8/25/04, currently conducting extended mission of science and communication relay

Mars Express/Beagle 2: **European Space Agency, 6/2/03,** Mars orbiter/lander, orbiter completed prime mission 11/05, currently in extended mission; lander lost on arrival 12/25/03

Mars Exploration Rover Spirit: **U.S., 6/10/03,** Mars rover, landed 1/4/04 for three-month prime mission inside Gusev Crater, completed several extended missions, last communication 3/22/10

Mars Exploration Rover Opportunity: **U.S., 7/7/03,** Mars rover, landed 1/25/04 for three-month prime mission in Meridiani Planum region, currently conducting extended mission

Mars Reconnaissance Orbiter: **U.S., 8/12/05,** Mars orbiter, arrived 3/12/06, completed prime mission 9/26/10, currently conducting extended mission of science and communication relay

Phoenix Mars Lander: **U.S., 8/4/07,** Mars lander, landed 5/25/08, completed prime mission and began extended mission 8/26/08, last communication 11/2/08

Phobos-Grunt/Yinghuo 1: **Russia/China, 11/8/11,** Phobos lander with sample return and Mars orbiter, achieved Earth orbit only

Curiosity rover (Mars Science Laboratory): **U.S., 11/26/11,** Mars rover, landed 8/6/12, completed prime mission, currently conducting extended science mission

Mars Atmosphere and Volatile Evolution Mission (MAVEN): **U.S., 11/18/13,** Mars orbiter, arrived 9/21/14, completed prime mission, currently conducting extended science mission

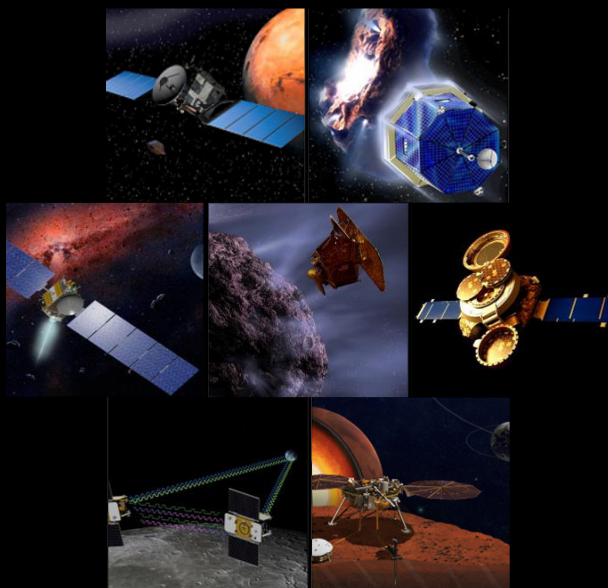
Mars Orbiter Mission (Mangalyaan): **India, 11/5/13,** Mars orbiter, arrived 9/14/14, completed prime mission, currently conducting extended mission

ExoMars 2016: **European Space Agency, 3/14/16,** orbiter and landing-demonstration module, Trace Gas Orbiter arrived 10/19/16, currently conducting prime mission; unsuccessful Mars impact of Schiaparelli module 10/19/16

Future

NASA's next mission to Mars, following InSight, will be the Mars 2020 mission, which is in development to launch in the summer of 2020. It will land a Curiosity-size rover in February 2021 to seek signs of past microbial life at a carefully selected site, using capabilities to examine rocks' composition and texture at microscopic scale and to collect and seal drilled rock cores for possible future return to Earth. The rover will also test extraction of oxygen from the carbon dioxide in Mars' atmosphere, as a useful technology for future astronauts on Mars.

Appendix: NASA’s Discovery Program



In complementing NASA’s larger “flagship” missions, the Discovery Program’s main objective is to enhance our understanding of the solar system by exploring the planets, their moons and small bodies such as comets and asteroids. The program also seeks to improve performance through the use of new technology and to broaden university and industry participation in NASA missions.

Discovery Program missions are designed and led by a principal investigator, who assembles a team of scientists and engineers, to address key science questions about the solar system.

Previous Discovery Program Missions

****Mission: Launch Date,** Description*

Near-Earth Asteroid Rendezvous (NEAR): 2/17/96, first spacecraft to orbit and land on an asteroid, entered orbit around asteroid Eros 2/14/00

Mars Pathfinder: 12/4/96, demonstrated a low-cost method of delivering a set of science instruments and the first rover to the surface of Mars, landed on Mars 7/4/97

Lunar Prospector: 1/6/98, enabled scientists to create detailed maps of the gravity, magnetic properties and chemical composition of the Moon’s entire surface

Stardust: 2/7/99, collected interstellar dust and comet dust during a close encounter with comet Wild 2 and returned the particles to Earth on 1/15/06 for analysis

Genesis: 8/8/01, spent two years collecting atoms of solar wind before returning them to Earth on 9/8/04 for analysis

Comet Nucleus Tour (CONTOUR): 7/3/02, intended to visit and study two comets, but contact lost 8/15/02

Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER): 8/3/04, first Mercury orbiter, examined Mercury from orbit from 3/18/11 to 4/30/15

Deep Impact: 1/12/05, propelled a projectile into comet Tempel 1 on 7/4/05, creating a crater and yielding information about the internal composition and structure of a comet.

Dawn: 9/27/07, orbited protoplanet Vesta and dwarf planet Ceres, largest bodies in the main asteroid belt, to study conditions and processes at the dawn of our solar system

Kepler: 3/6/09, used a unique telescope to find more than 1,000 planets around stars beyond our solar system, spacecraft repurposed as K2 mission in 2014

Gravity Recovery and Interior Laboratory (GRAIL), 9/10/11, put twin satellites into orbit around the Moon 12/31/11 to study the Moon’s interior and its thermal history

Future

Lucy: expected to launch October 2021, will visit a main belt asteroid and six Jupiter Trojan asteroids (asteroids trapped by Jupiter's gravity in two swarms that share the planet's orbit, one leading and one trailing)

Psyche: expected to launch October 2023, will explore the intriguing asteroid, known as 16 Psyche, which is thought to be composed mostly of metallic iron and nickel, similar to Earth's core.

Missions of Opportunity

The Discovery Program also includes "missions of opportunity" that enable the U.S. science community to participate in non-NASA missions or to use an existing NASA spacecraft for a new investigation. Five missions of opportunity selected by the Discovery Program are the Analyzer of Space Plasma and Energetic Atoms instrument on the European Space Agency's Mars Express mission; The Moon Mineralogy Mapper on India's Chandrayan-1 mission; the EPOXI mission repurposing the Deep Impact spacecraft; the Stardust New Exploration of Tempel 1 mission using the Stardust spacecraft; and the Strofio spectrometer instrument on the European Space Agency's BepiColombo mission to Mercury.