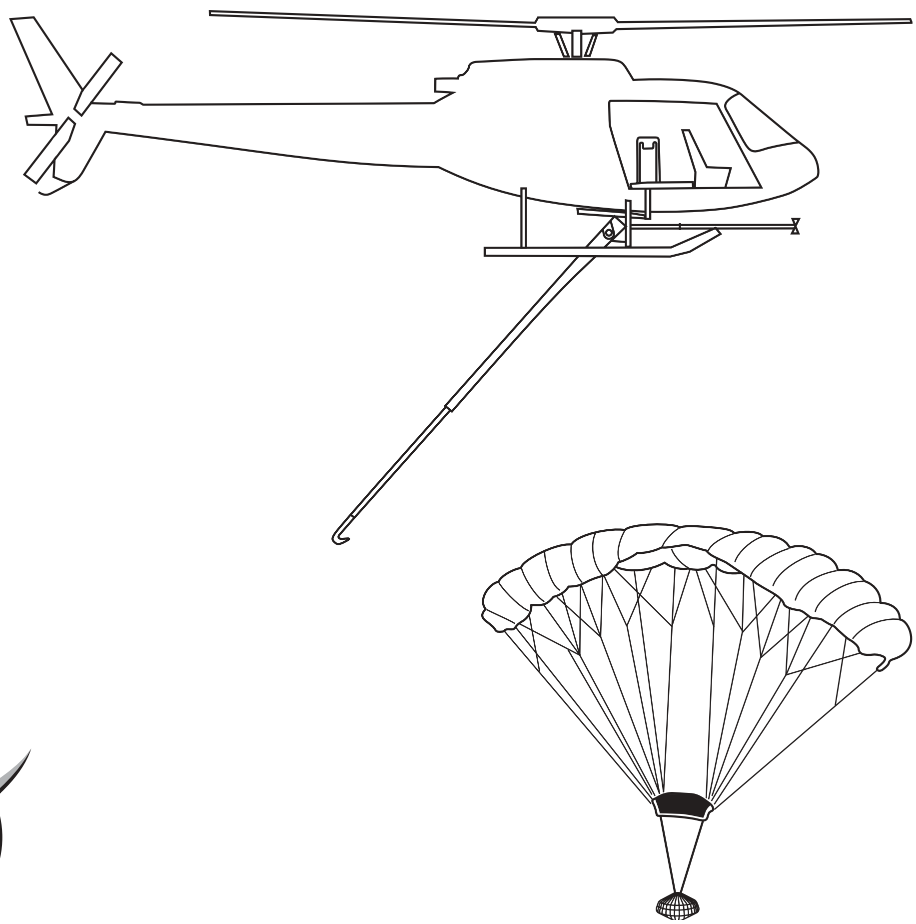
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Genesis Sample Return

Press Kit
September 2004



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GENERAL RELEASE:

NASA MISSION RETURNS WITH A PIECE OF THE SUN

In a dramatic ending that marks a beginning in scientific research, NASA's Genesis spacecraft is set to swing by Earth and jettison a sample return capsule filled with particles of the Sun that may ultimately tell us more about the genesis of our solar system.

On September 8, 2004, the drama will unfold over the skies of central Utah when the spacecraft's sample return capsule will be snagged in mid-air by helicopter. The rendezvous will occur at the Air Force's Utah Test & Training Range, southwest of Salt Lake City, Utah.

"The Genesis mission -- to capture a piece of the Sun and return it to Earth -- is truly in the NASA spirit: a bold, inspiring mission that makes a fundamental contribution to scientific knowledge," said Steven Brody, NASA's program executive for the mission.

"What a prize Genesis will be," said principal investigator Dr. Don Burnett of the California Institute of Technology, Pasadena, Calif. "Our spacecraft has logged almost 27 months far beyond the Moon's orbit collecting atoms from the Sun. With it, we should be able to say what the Sun is composed of at a level of precision that has never been seen before."

The prizes Burnett and company are waiting for are hexagonal-wafers of pure silicon, gold, sapphire, diamond and other materials that have served as a celestial prison for their samples of solar wind particles. These wafers have weathered 26-plus months in deep space and are now safely stowed in the return capsule. If the capsule were to descend all the way to the ground, some might fracture or break away from their mountings. Hence, the mid-air retrieval by helicopter, with crew including pilots who have performed helicopter stunt work for Hollywood.

"These guys fly in some of Hollywood's biggest movies," said Don Sweetnam, Genesis project manager at NASA's Jet Propulsion Laboratory in Pasadena, Calif. "But this time, the Genesis capsule will be the star."

The Genesis capsule - carrying the agency's first sample return since the final Apollo lunar mission in 1972, and the first material collected beyond the Moon --will enter Earth's atmosphere at 9:55 a.m. Mountain Daylight Time on Sept. 8. From that moment on, major operational milestones will happen in short order.

Two minutes and seven seconds after atmospheric entry, while still flying supersonic, the capsule deploys a drogue parachute at 33 kilometers (108,000 feet) altitude. Six minutes after that, the main parachute, a parafoil, will deploy 6.1 kilometers (20,000 feet) up. While all this transpires, waiting below and receiving updates from a ground-based controller, will be two helicopters and their flight crews looking for their chance to grab a piece of the Sun.

"Each helicopter will carry a crew of three," said Roy Haggard, chief executive officer of Elsinore, Calif.-based Vertigo Inc. and director of helicopter flight operations. "The lead helicopter will deploy an 18-1/2-foot pole with what you could best describe as an oversized, space-age fishing hook on its end. When we make the approach we want the helicopter skids to be about eight feet above the top of the parafoil. If for some reason the capture is not successful, the second helicopter is 1,000 feet behind the first one and setting up for its approach. We estimate we will have five opportunities to achieve capture."

The helicopter that does achieve capture will carry the sample canister to a clean room at Michael Army Air Field at the U.S. Army Dugway Proving Ground where scientists await their cosmic prize. The samples will then be moved to a special laboratory at NASA's Johnson Space Center, Houston, where they will be preserved and studied by scientists for many years to come.

"I understand much of the interest is in how we retrieve Genesis," added Burnett. "But to me the excitement really begins when scientists from around the world get hold of those samples for their research. That will be something."

JPL, a division of the California Institute of Technology, manages the Genesis mission for NASA's Science Mission Directorate, Washington D.C. Lockheed Martin Space Systems of Denver, Colo., developed and operates the spacecraft. Los Alamos National Laboratory and NASA's Johnson Space Center contributed to Genesis payload development, and the Johnson Space Center will curate the sample and support analysis and sample allocation.

News and information on Genesis' sample return are available at:

www.nasa.gov/genesis

More detailed background on the mission is available at:

genesismission.jpl.nasa.gov

- End of General Release -

Media Services Information

NASA Television Transmission

NASA Television is carried on the satellite AMC-6, at 72 degrees west longitude, transponder 9, 3880 MHz, vertical polarization, audio at 6.8 MHz. For those in Alaska or Hawaii, NASA TV is now available on AMC-7, at 137 degrees west longitude, transponder 18, at 4060 MHz, vertical polarization, audio at 6.8 MHz. The schedule for Genesis mission television transmission will be available on the NASA website at **www.nasa.gov** .

News Releases and Status Reports

The Jet Propulsion Laboratory's Media Relations Office will issue news releases and status reports about the Genesis launch and mission. They are available online as noted below.

Briefings

A briefing on the Genesis mission is scheduled at the U.S. Army's Dugway Proving Ground, Utah, at 10 a.m. Mountain Daylight Time on Tuesday, Sept. 7, 2004, one day before sample return. A post-event briefing on the Genesis mission will be held at the same location at Dugway Proving Ground shortly after sample return on Sept. 8. Journalists planning to cover these events should check the NASA website for any updates.

Internet Information

News and information on the Genesis mission, including an electronic copy of this press kit, news releases, fact sheets, status reports and images, are available from the NASA website at **www.nasa.gov/genesis** .

More detailed background information on the mission is available from the Genesis project home page at **genesismission.jpl.nasa.gov** .

Quick Facts

Spacecraft

Dimensions: Main structure 2.3 meters (7.5 feet) long and 2 meters (6.6 feet) wide; wingspan of solar array 7.9 meters (26 feet) tip to tip

Weight: 636 kilograms (1,402 pounds) total, composed of 494-kilogram (1,089-pound) dry spacecraft and 142 kilograms (313 pounds) of fuel

Science instruments: Solar wind collector arrays, ion concentrator, ion and electron monitors

Power: Solar array providing up to 254 watts just after launch; storage via a nickel-hydrogen battery

Sample Return Capsule

Dimensions (at helicopter capture): 1.52 meters (60 inches) diameter, 81 centimeters (31.7 inches) tall

Weight: 205 kilograms (452 pounds) at Earth atmosphere entry; 191 kilograms (420 pounds) at helicopter capture

Equipment: drogue parachute 2.03 meters (6.7 feet) diameter; parafoil 10.5 by 3.1 meters (34.6 by 12.1 feet)

Mission

Launched: August 8, 2001

Arrival at Lagrange 1 point: November 2001

Sample collection: Dec. 3, 2001- April 1, 2004 (850 days)

Sample collected: Approximately 10 to 20 micrograms of solar wind elements (equivalent of a few grains of salt)

Earth flyby: May 2, 2004

Return to Earth: September 8, 2004

Total distance traveled from launch to Earth return: 3 million kilometers (1.86 million miles)

Capture Helicopters

Type: Eurocopter Astar 350-B2

Crew: 3 (pilot, flight operations director, payload master)

Capture equipment: Winch; 5.6-meter (18.5-foot) pole; 137.2-meter (450-foot) kevlar cable

Program

Cost: $164 million spacecraft development and science instruments; $50 million launch; $50 million mission operations and science data analysis; $264 million total

Mysteries of the Solar Nebula

A few billion years ago, after generations of more ancient suns had been born and died, a swirling cloud of dust and gas collapsed upon itself to give birth to an infant star.

As the ball-shaped cloud fell in on itself it began to flatten and rotate, eventually resembling a spinning pancake. Mostly the stuff of the cloud was simple atoms of hydrogen and helium, but it was peppered here and there by more complicated elements forged in the internal furnaces and death explosions of older stars. Even as a new sun took shape at the center of the cloud, disturbances formed farther out. In a remarkably short time by astronomical standards -- "just" tens of millions of years, or less -- these disturbances of matter turned into planets.

Today that star system is home to an amazing diversity of environments -- from immense mountains and enormous, jagged canyons on rocky inner planets to sulfur volcanoes and ice geysers on moons circling huge gas planets farther out from the star, their orbits crisscrossed by legions of comets and asteroids.

That is the story, astronomers tell us, of how the Sun, our Earth and the solar system that both of them occupy came to be. There is plenty of evidence from observations over many decades to establish the broad outlines of that story. But exactly how the placental cloud of dust and gas, called the "solar nebula," turned into the solar system that we see around us today still poses many mysteries for scientists.

One of the main ways that scientists approach the question of how the solar system formed is by comparing the elements and isotopes that made up the original cloud of dust and gas to the compositions of the planets, moons, asteroids and comets in the solar system today. (An isotope is a variation of an element that is heavier or lighter than the standard form of the element because each atom has more or fewer neutrons in its nucleus.) But what were the ingredients in the original solar nebula?

Fortunately, nature provides a fossil record of the solar nebula. Like other stars its size, the Sun has an outer atmosphere that is slowly but steadily flowing off into space. This material, consisting mostly of electrically charged atoms called ions, flows outward past the planets in a constant stream called the "solar wind." This wind is a snapshot of the materials in the surface layers of the Sun, which in turn reflects the makeup of the original solar nebula.

This is the rationale of the Genesis mission. By flying out beyond the interfering influences of Earth's magnetic fields, the spacecraft can collect samples of the solar wind revealing the makeup of the cloud that formed the solar system nearly 5 billion years ago.

Solar Studies Past and Present

Past Missions to Collect Solar Wind

Apollo 11, 12, 14, 15 and 16 (NASA): The solar wind composition experiment on these missions that took astronauts to the Moon between 1969 and 1972 was a 1.4- by 0.3-meter (55- by 11-inch) aluminum foil sheet on a pole. This sheet was exposed to the Sun for periods ranging from 77 minutes on Apollo 11 to a period of 45 hours on Apollo 16. On Apollo 16, a platinum sheet was also used. Solar wind particles embedded themselves in the foil, which was returned to Earth for laboratory analysis. The chemical composition of the embedded solar wind included isotopes of the light noble gases helium-3, helium-4, neon-20, neon-21, neon-22 and argon-36. The Apollo foils showed that the ratio of neon-20 to neon-22 in the solar wind was almost 40 percent higher than what is found in Earth's atmosphere. Such a large difference was totally unanticipated. Many scientists believe that this difference was caused by an early major loss of Earth's atmosphere. Comparison of Genesis data with the terrestrial atmosphere for nitrogen and the other noble gases (argon, krypton and xenon) may well provide a definitive test of that theory.

Currently Operating Space-Based Missions

Ulysses (European Space Agency and NASA): Launched October 6, 1990, Ulysses explores the Sun from a perspective above and below the ecliptic, the plane in which most of the planets orbit the Sun, to study the environment around the Sun's north and south poles. Scientists have used Ulysses data to define different types of solar wind, of which Genesis will return separate samples. In addition, they have measured the strength of magnetic fields that surround the Sun and related them to the solar wind.

Wind (NASA): Launched November 1, 1994, the Wind spacecraft is currently in orbit around the same point in space targeted by Genesis -- the Lagrange 1 point, or "L1," where the gravities of Earth and the Sun cancel each other out. It is studying various facets of the interaction of Earth's magnetic environment and the solar wind.

Solar and Heliospheric Observatory (European Space Agency and NASA): Soho also orbits the Lagrange 1 or "L1" point. Launched on Dec. 2, 1995, Soho uses 12 instruments to study the physical processes in the Sun's corona and changes in the Sun's interior by making observations in visible, ultraviolet and extreme ultraviolet light.

Advanced Composition Explorer (NASA): This spacecraft launched Aug. 25, 1997, carries nine instruments to study the formation and evolution of the solar system and the astrophysical processes involved. It does this by sampling low-energy particles from the Sun and high-energy particles from elsewhere in the galaxy. Like Genesis, it orbits the L1 point to get a prime view of the Sun and the galactic regions beyond. The spacecraft measures particles of a wide range of energies and nuclear mass, under all solar wind flow conditions and during both large and small particle events including solar flares. It provides a one-hour warning when solar events will cause a geomagnetic storm that can interfere with the operations of satellites and telecommunications systems on Earth.

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Transition Region and Coronal Explorer (NASA): This spacecraft, called by its acronym Trace, images the solar corona and the transitional region between the Sun and surrounding space. Launched April 2, 1998, Trace enables solar physicists to study the connections between the Sun's magnetic fields and associated plasma structures on the Sun. It does this by taking sequences of images of different areas -- the photosphere, or the Sun's visible surface; the corona, the outermost region of the Sun's atmosphere, consisting of hot ionized gases; and the transitional region between the Sun and surrounding space.

Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics mission (NASA): This mission, known by its acronym Timed, is studying the influences of the Sun and humans on the least explored and understood region of Earth's atmosphere -- the mesosphere and lower thermosphere/ionosphere. This region is a gateway between Earth's environment and space, where the Sun's energy is first deposited into Earth's environment. This mission focuses on a portion of this region at an altitude of about 60 to 180 kilometers (40 to 110 miles). Launched Dec. 7, 2001, the mission is helping scientists understand how conditions vary in this region, allowing predictions of effects on communications, satellite tracking, spacecraft lifetimes, degradation of spacecraft materials and on the reentry of vehicles piloted by human crews. The mission's study of space weather will help scientists gain a better understanding of the dynamics of this gateway region.

Reuven Ramaty High Energy Solar Spectroscopic Imager (NASA): This mission is exploring the basic physics of how particles are accelerated and energy is released in solar flares. It approaches this task by making high-resolution images of solar flares studying the spectrums of released energy across wavelengths from X-rays to gamma rays. It is expected to observe tens of thousands of microflares, more than a thousand X-ray flares and more than one hundred gamma ray flares. The spacecraft was launched Feb. 5, 2002.

More information about Sun-exploring missions can be found on the web at **sec.gsfc.nasa.gov/sec_missions.htm** .

Astronomers have long studied the Sun's composition by breaking down the Sun's color spectrum using instruments on telescopes and satellites. But these observations are not precise enough for today's planetary science. By analyzing the solar wind in terrestrial laboratories, Genesis scientists can find precise ratios of isotopes and elements in the solar nebula. The basic data gained from the Genesis mission are needed to advance theories about the solar nebula and evolution of the planets.

Genesis' main goal is to probe the mystery of oxygen in the solar system. The amounts of oxygen isotopes vary among the solar system bodies, though the reason for the variety is totally unknown. Different parts of the solar system have distinct proportions of three isotopes of oxygen called O16, O17 and O18. O16 is the most common form of an oxygen atom, containing eight protons and eight neutrons to add up to an atomic weight of about 16. O17 has one extra neutron, whereas O18 has two extra neutrons.

Though scientists know the ratio of oxygen isotopes in bodies like asteroids, Earth, the

NASA's Discovery Program

Genesis is the fifth mission in NASA's Discovery Program, which sponsors low-cost solar system exploration projects with highly focused science goals. Created in 1992, the Discovery Program competitively selects proposals submitted by teams led by scientists, supported by organizations that manage the project, as well as partners that build and fly the spacecraft. In recent years, NASA has identified several finalists from dozens of mission proposals submitted. These finalists receive funding to conduct feasibility studies for an additional period of time before a final selection is made.

Other missions in the Discovery Program are:

- The **Near Earth Asteroid Rendezvous** spacecraft was launched Feb. 17, 1996 and became the first spacecraft to orbit an asteroid when it reached Eros in February 2000. A year later, it became the first spacecraft to land on an asteroid when it put down on Eros, providing the highest resolution images ever obtained of an asteroid, showing features as small as one centimeter across. The mission was managed by Johns Hopkins University's Applied Physics Laboratory.

- **Mars Pathfinder** was launched December 4, 1996 and landed on Mars on July 4, 1997, demonstrating a unique way of touching down with airbags to deliver a small robotic rover. Mars Pathfinder was managed by the Jet Propulsion Laboratory.

- Launched Jan. 7, 1998, **Lunar Prospector** entered orbit around Earth's Moon five days later, circling at an altitude of about 100 kilometers (60 miles). Principal investigator was Dr. Alan Binder of the Lunar Research Institute, Gilroy, Calif., with project management by NASA's Ames Research Center.

- **Stardust** was launched Feb. 7, 1999. On Jan. 2, 2004, it collected samples of comet and interstellar dust as it flew through the coma surround the nucleus of Comet Wild 2. The samples will be returned to Earth in January 2006 at the same location the Genesis samples are scheduled to arrive -- the Utah Test & Training Range.

- The **Comet Nucleus Tour,** or Contour, launched from Cape Canaveral on July 3, 2002. Six weeks later, on Aug. 15, contact with the spacecraft was lost after a planned maneuver that was intended to propel it out of Earth orbit and into its comet-chasing solar orbit.

- The **Mercury Surface, Space Environment, Geochemistry and Ranging** (Messenger) mission is planned for launch in August 2004. Entering orbit around the planet closest to the Sun in September 2009, the spacecraft will produce a global map and details about Mercury's surface, interior, atmosphere and magnetosphere.

- **Deep Impact** is slated to reach out and touch comet Tempel 1 on July 4, 2005, providing the world with the first human-made celestial fireworks. Scheduled for launch in December 2004, Deep Impact will make a 7-month journey towards its quarry. At about 24 hours out, the main flyby spacecraft will release a 370-kilogram (approximately 820-pound) impactor that will guide itself into the comet. The collision and resulting material jettisoned from comet Tempel 1's nucleus will be analyzed by the main flyby spacecraft and Earth-based telescopes to identify the comet's composition.

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❑ The **Dawn** mission will undertake a journey in both space and time by traveling to the two oldest and most massive asteroids in our solar system, Vesta and Ceres. Planned for launch in May 2006, the ion-propulsion-powered spacecraft will reach Vesta in 2010 and Ceres in 2014. These minor planets have remained intact since the earliest time of solar system formation.

❑ The **Kepler** mission is designed to find Earth-sized planets in orbit around stars like our Sun outside of the solar system. It will survey our galactic neighborhood to detect and characterize hundreds of terrestrial and larger planets in or near the "habitable zone," defined by scientists as the distance from a star where liquid water can exist on a planet's surface. Planned for launch in fall 2007, Kepler will monitor 100,000 stars similar to our sun for four years.

Moon and Mars, the ratio of oxygen isotopes in the Sun is not well-understood. Genesis will provide this last puzzle piece to determine how the solar nebula evolved into the solar system bodies.

Understanding the origins of the variations of the oxygen isotopes is a key to understanding the origin of the solar system. Does any part of today's solar system contain the same ratios of these oxygen isotopes as what Genesis finds existed in the original solar nebula? Finding out how these isotope ratio differences survived will narrow the possibilities of how the different materials or regions of the nebula mixed or didn't mix.

Mission Overview

Genesis' purpose is to observe the solar wind, entrap its particles and return them to Earth.

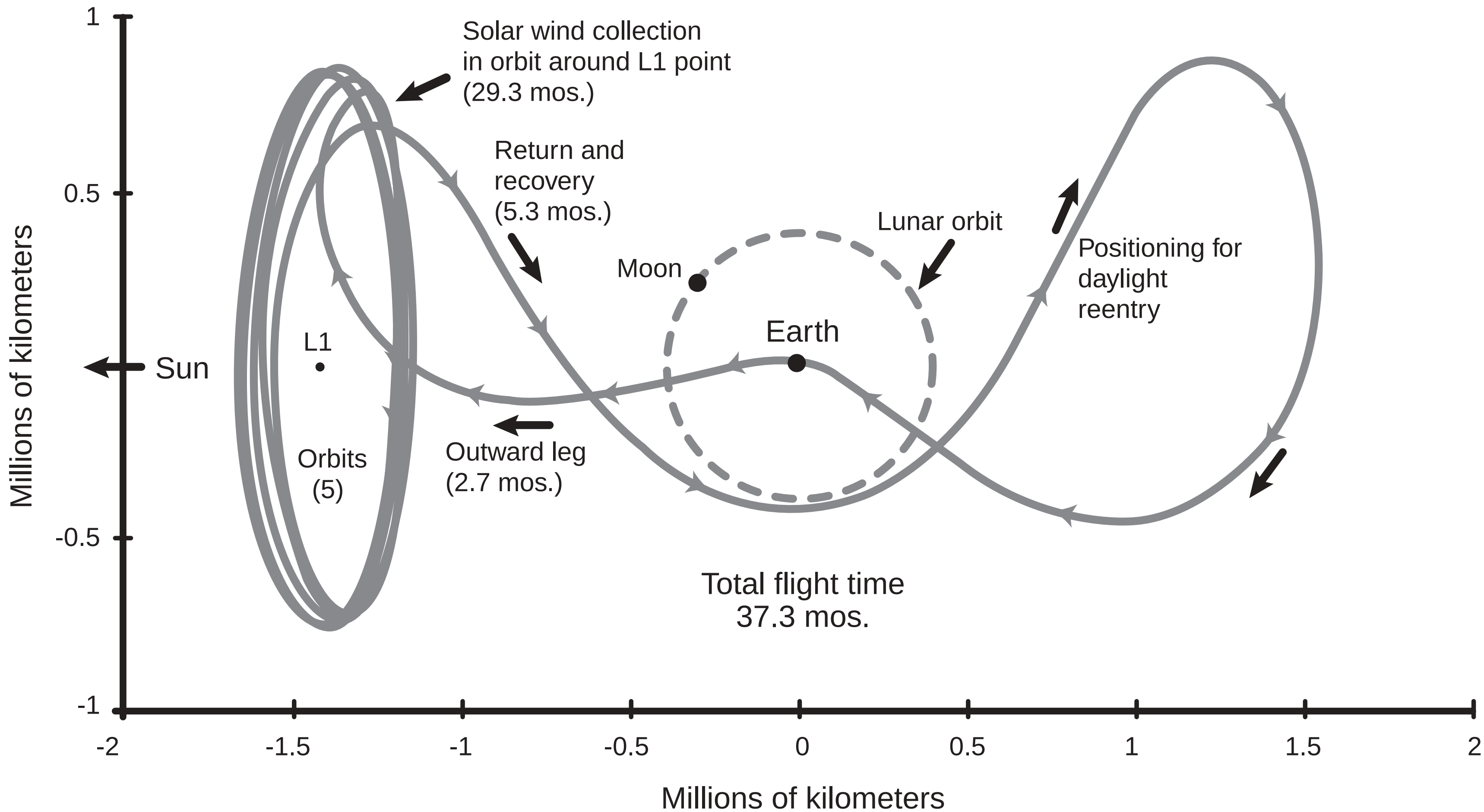
After launch, the spacecraft traveled to a point about 1.5 million kilometers (just under 1 million miles) from Earth where the gravities of Earth and the Sun are balanced: the Lagrange 1 point, or "L1." At this location Genesis was well outside of Earth's atmosphere and magnetic environment, allowing it to collect a pristine sample of the solar wind. Genesis' overall flight path resembles a series of loops: first curving towards the Sun and away from Earth to the L1 point, circling five times around it, then falling back for a brief loop around the opposite Lagrange point, called "L2," in order to position the spacecraft for a daylight return to Earth.

Genesis' sample collection area, the Lagrange 1 point, is named for the Italian-French mathematician Joseph-Louis Lagrange. In 1764, he authored an essay for the Paris Academy of Sciences, defining points between bodies in space where the gravity is balanced between them. The position of the L1 point is stable enough to allow Genesis to orbit it, with assistance from small thrusters on the spacecraft. The L1 point afforded Genesis an uninterrupted view of the Sun. Genesis arrived there in November 16, 2001.

Genesis occupied what scientists call a "halo" orbit, meaning that it orbits around an empty point in space, not a physical object. The spacecraft's orbit was not completely circular. Viewed from the side, so that the Sun, spacecraft and Earth appear to be in a straight line in the plane in which the planets orbit, the halo orbit leans slightly toward the Sun. Looking down on the orbit, so that the north pole of Earth and Sun and the top of the spacecraft are visible, the orbit looks elongated.

The spacecraft's science instruments worked together to categorize and sample the solar wind. The collection period concluded on April 1, 2004. Three weeks later, Genesis executed the first of five thruster firings sending it on a trajectory that will eventually place its sample return capsule in Earth's upper atmosphere on Sept. 8.

As if the return of NASA's first space sample mission since Apollo 17 were not dramatic enough, the technique in which the sample return capsule will be captured adds to the mission's distinctiveness. As the capsule parachutes toward the ground at the U.S. Air Force's Utah Testing and Training Range, two three-person crews flying specially outfitted helicopters will capture the capsule in mid-air to prevent the delicate samples from being disturbed by even the slight impact of a parachute landing. The samples will be taken to NASA's Johnson Space Center, Houston, Texas, where the collector materials will be stored and maintained under extremely clean conditions to preserve their purity for scientific study throughout the century.



Mission trajectory

Pulling A Capsule Out of Thin Air

Mid-air retrieval is not a new idea. The United States has been incorporating the process into its aerial operations for more than half a century. In 1950, both the Air Force and Navy began launching balloons that were later retrieved in the air by aircraft.

In early 1956, a Defense Department effort called Project Genetrix launched numerous high-altitude photo-reconnaissance balloons in Europe that were later retrieved by a specially modified C-119F "Flying Boxcar" transport plane circling at a designated location at an altitude of 20,000 feet. Of the 516 balloons released, only 19 made it as far as the Flying Boxcars, out of which only a total of 16 payloads were recovered.

A decade later, mid-air retrieval was used again with uncrewed reconnaissance vehicles that had evolved from slow-moving balloons to aircraft and even faster vehicles. During Vietnam, uncrewed drones like the Model 147 Firebee deployed parachutes enabling them to be recovered by an HH-3E "Jolly Green Giant" helicopter.

Mid-air retrievals have even been used with space vehicles. In 1960, Discoverer XIV became the first satellite to be ejected from an orbiting space vehicle and recovered in mid-air. Following launch from California's Vandenberg Air Force Base, the satellite took pictures while orbiting Earth 17 times. The payload was then ejected from its upper stage rocket and fired retrorockets to re-enter the atmosphere, where a parachute slowed its descent. Some 2,440 kilometers (8,000 feet) high and 580 kilometers (360 miles) southeast of Hawaii, an Air Force C-119 Flying Boxcar successfully snagged the satellite's parachute on its third try.

The mission is designed to fulfill the goals of NASA's Discovery program to launch many small missions with highly focused science objectives and fast turn-around times, executed as joint efforts with industry, small business and universities.

Launch

Genesis was launched Aug. 8, 2001, at 12:13:40 p.m. EDT from Florida's Cape Canaveral Air Force Station. The launch vehicle was a Delta II model 7326 rocket, similar to Deltas that have launched other recent solar system exploration missions. These rockets have differed primarily in the number of solid-fuel boosters that augment the first stage of the liquid-fuel Delta.

Cruise to L1

The cruise phase was the period of travel 1.5 million kilometers (930,000 miles) from Earth to the Lagrange 1 point that lasted slightly over three months. The main activities during cruise included check-out and monitoring of the spacecraft and science instruments, and navigation activities necessary to determine and correct Genesis' flight path.

Return to Sender: Sample Return Missions

Samples from beyond our planet are brought to Earth because analysis on the ground can usually be much more thorough than what is possible with the limited equipment that can be taken into space. And the practice is not new.

On July 24, 1969, Apollo 11 returned to Earth carrying in its cargo hold 22 kilograms (48.5 pounds) of humanity's first samples from another world -- the Moon. Five more Apollo landings followed, bringing the grand total of NASA acquired lunar material to 381.75 kilograms (841.6 pounds). The Soviet Union also performed successful lunar sample return missions in the 1970s. Luna 16, 20 and 24 retrieved and returned a total of 300 grams of lunar samples between 1970 and 1976. While the process of space sample return is under consideration for future missions by several spacefaring nations, there are three that have been approved so far, and all three are currently flying.

Along with Genesis, the other two current sample return missions include:

- ❑ **Stardust** was launched Feb. 7, 1999. On Jan. 2, 2004, it collected particles as it hurtled past the nucleus of comet Wild 2. In January 2006, Stardust will make its return to Earth at the same site in Utah that Genesis will use.

- ❑ **Hayabusa** is a mission sent by the Japan Aerospace Exploration Agency to land on the asteroid Itokawa and bring a sample of the asteroid's surface. Launched May 9, 2003, the spacecraft will reach the asteroid in the summer of 2005, spend five months there, and return to Earth in 2007.

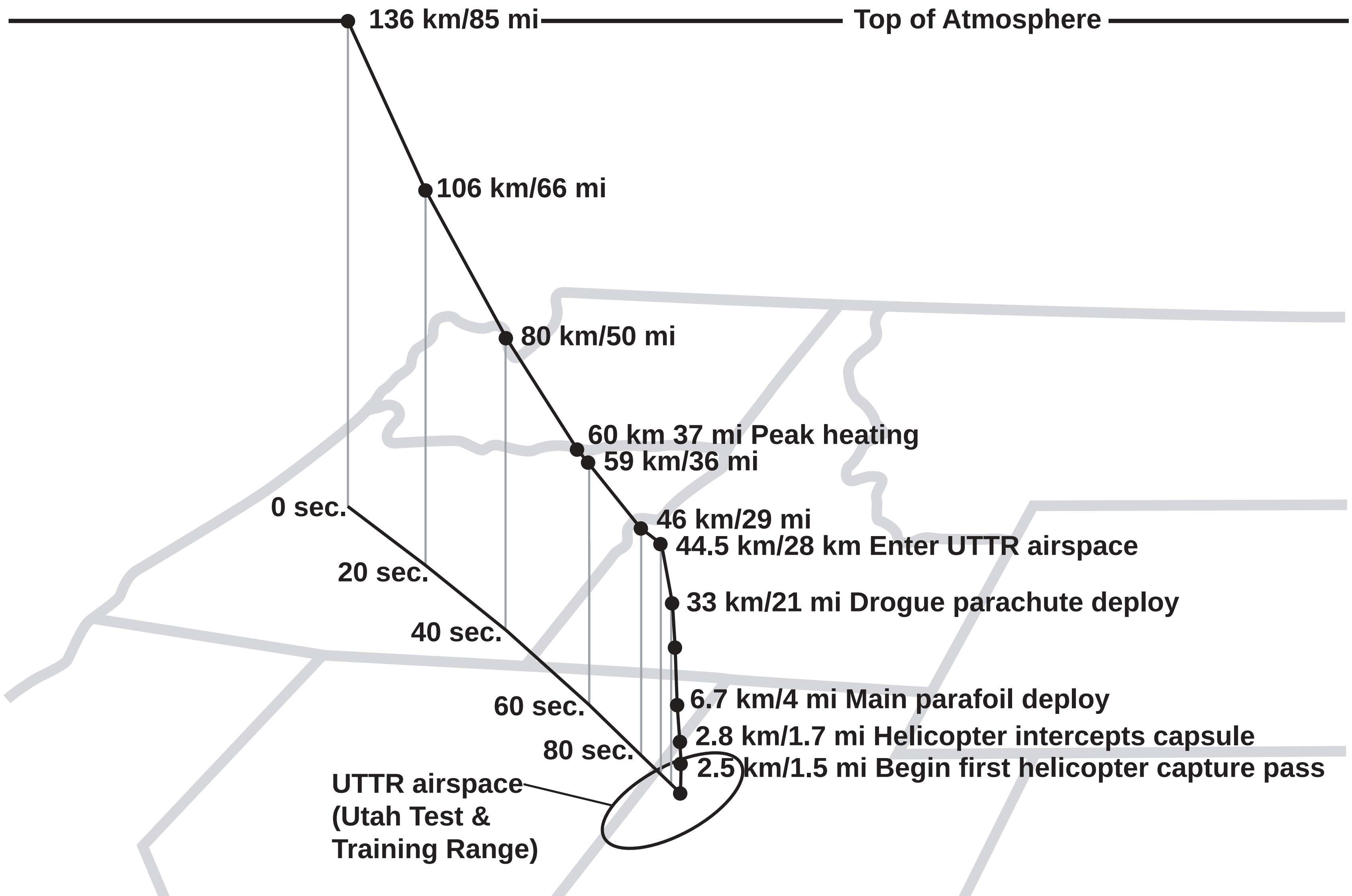
L1 Orbit Insertion

Genesis entered orbit around the L1 point on Nov. 16, 2001. At arrival, the spacecraft's large thrusters fired to put it into an elliptical, or looping, orbit around the L1 point. Genesis completed five orbits around L1; nearly 80 percent of the mission's total time was spent collecting ions from the Sun.

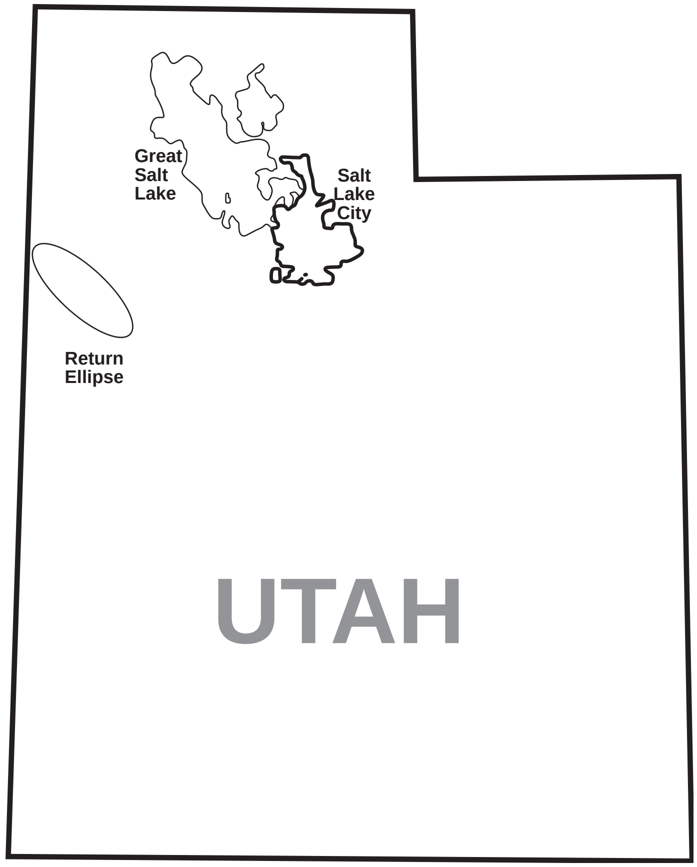
Collecting Solar Wind

Genesis opened its collector arrays and began accepting particles of solar wind on Dec. 3, 2001. A total of 850 days were logged exposing the special collector arrays to the solar wind. These collector arrays are circular trays composed of palm-sized hexagonal tiles made of various high-purity materials such as silicon, sapphire, gold and diamond-like carbon.

After the sample return capsule opened, the lid of the science canister opened as well, exposing a collector for the bulk solar wind. As long as the science canister's lid was opened, this bulk collector array was exposed to different types of solar wind that whistled past the spacecraft.



Ground track



Return location

Genesis' ion and electron monitors, located on the equipment deck outside the science canister and sample return capsule, monitored changes in the solar wind. The monitors relayed information about these changes to the main spacecraft computer, which in turn commanded the collector arrays to change to expose the appropriate collector. The monitors distinguished between three types of solar wind -- fast, slow and coronal mass ejections -- by recognizing the wind's characteristic temperature, velocity, density and composition. There are three collector arrays that can fold out, and each was extended when a certain type of solar wind passed by.

Genesis' other dedicated science instrument, the solar wind concentrator, was designed to do exactly as its name implies, concentrate the solar wind onto a set of small collector tiles made of diamond, silicon carbide and diamond-like carbon. The concentrator was exposed to the solar wind throughout the collection period, as long as the lid of the science canister was opened.

That collection of pristine particles of the Sun came to an end on April 1, 2004, when the Genesis team ordered the spacecraft's collectors stowed. The closeout process was completed on April 2, when Genesis closed and sealed the spacecraft's sample-return capsule. The capsule will remain sealed until NASA technicians open it in a temporary clean-room facility at Dugway, Utah. The canister will then be removed and transported to NASA's Johnson Space Center, where the materials it contains will be removed in a state-of-the art clean room installed specifically for Genesis.

Return Phase

On April 22, 2004, Genesis began its journey back toward its home planet. This was initiated by the first of five planned thruster firings during the mission's return phase designed to fine-tune the spacecraft's flight path for Earth return.

Because of the position of the landing site -- the U.S. Air Force's Utah Testing & Training Range -- and the unique geometry of Genesis' flight path, the spacecraft could not make a direct approach and still make a daytime landing. In order to allow the Genesis helicopter crews an opportunity to capture the return capsule in daylight, Genesis mission navigators designed an orbital detour toward another Lagrange point, L2, located on the other side of Earth from the Sun. After completing one loop around this point in space, the spacecraft will be set up for a daytime return to Earth on Sept. 8.

Deep Space Navigation

Not since the days of Apollo have NASA navigators performed course-plotting designed to bring a spacecraft from beyond Earth's orbit to a predestined landing zone on Earth. To do so, the Genesis navigation team calls upon the giant dishes of NASA's Deep Space Network to provide data on the Genesis trajectory. Navigators analyze the spacecraft's radio signal using techniques called radiometric and Doppler tracking to help pinpoint its distance from Earth as an aid to navigation.

Throughout the Genesis mission, tracking and telecommunications have been provided by NASA's Deep Space Network complexes in California, Australia and Spain. The data rate from the spacecraft ranges from 1 to 47 kilobits per second. Most data from the spacecraft are received by the Deep Space Network's 34-meter-diameter (110-foot) antennas, but 26-meter (85-foot) antennas have also occasionally been used.

Recovery Phase

For planning purposes, the Genesis team refers to the final 30 days of flight -- from Aug. 9 to Sept. 8, 2004 -- as the recovery phase of the mission. The location of the landing footprint for the Genesis capsule will be predicted by tracking the spacecraft before the capsule's release. Since the capsule does not have a propulsion system, there is no way to abort the entry sequence following its release.

Mission navigators are targeting the capsule to hit a "keyhole" at the top of Earth's atmosphere at an altitude of 125 kilometers (410,000 feet) on September 8 at 9:55

a.m. Mountain Daylight Time (MDT). This elliptical-shaped keyhole 33 kilometers (20.5 miles) long and 10 kilometers (6.2 miles) wide is over the Pacific Ocean. If the capsule enters the atmosphere anywhere inside this keyhole, it will come down over the designated spot on the Utah Test & Training Range.

Thruster firings designed to further refine Genesis' trajectory are planned for Aug. 9, Aug. 29 and Sept. 6, 2004. If mission navigators feel a supplementary trajectory maneuver is required to place the Genesis sample return capsule within its designated re-entry corridor, a final "contingency maneuver" may be performed Sept. 7.

At about 2 a.m. MDT Sept. 8, the Genesis team will conduct one final teleconference to discuss the status of the spacecraft's trajectory. If all is "go," they will radio the spacecraft to start executing a series of commands to release the sample return capsule.

Backup Orbit

Throughout the recovery phase, the Genesis team will closely evaluate the spacecraft's re-entry trajectory. If at any point navigators and mission planners feel the spacecraft and/or its sample return capsule will not achieve required entry targeting specifications, they can go to “plan B” -- a backup orbit. Navigators have designed a plan that will place the spacecraft and its capsule in a six-month backup orbit around Earth. If required, the maneuver to place the spacecraft and the sample return capsule in this temporary orbit would take place at entry minus 3.5 hours.

This backup orbit allows for a secondary entry opportunity to take place at the same location over the Utah Test & Training Range on March 17, 2005, at 2:40 p.m. MDT.

Utah Test & Training Range

The Utah Test & Training Range provides the largest overland contiguous block of restricted airspace in the continental United States authorized for supersonic flight, available for aircrew training and weapons testing. The airspace, situated over 6,796 square kilometers (2,624 square miles), is under the jurisdiction of the U.S. Air Force. The remainder is managed by the U.S. Army at Dugway Proving Ground. Airspace boundaries do not necessarily coincide with the boundaries of the Defense Department land beneath the airspace.

Operated and maintained by the 388th Range Squadron based out of Hill Air Force Base some 50 miles to the east, the Utah Test & Training Range supports training numerous branches of the armed services and their allies with capabilities for air-to-ground, air-to-air and ground force exercises. More than 22,000 training sorties and more than 1,000 test sorties are flown out on the range annually. It is used for testing munitions and propellants up to the most powerful ICBM rocket motors and non-nuclear explosive components.

The Air Force range is supporting Genesis by providing range imagery and targeting guidance. The range's mission control center -- located at Hill Air Force Base -- will radio information to the helicopter crews. An Air Force building at the Army's Michael Army Air Field will be home to the clean room erected to temporarily house the Genesis capsule after it is captured.

Dugway Proving Ground

The U.S. Army's Dugway Proving Ground serves as the nation's chemical and biological defense proving ground. It is a large, remote, high-desert closed post that employs about 1,200 military, government civilians and support contractors. The mission of Dugway Proving Ground is to test U.S. and allied biological and chemical defense systems; perform nuclear-biological-chemical survivable testing of defense material; provide support to chemical and biological weapons conventions; and operate and maintain an installation to support test missions.

Dugway is supporting Genesis by providing facilities, logistical, weather and range expertise as well as security and support personnel. The majority of the events surrounding the Genesis capture and return will occur at the facility's Ditto Test Area which approximately 19 kilometers (12 miles) from the installations main gate. Located in Ditto is the Michael Army Air Field, where the Genesis recovery helicopters will be based.

Dugway is located approximately 130 kilometers (about 80 miles) west-southwest of Salt Lake City, in the Great Salt Lake Desert in Tooele County, Utah. The Dugway Proving Ground covers 3,233 square kilometers (1,248 square miles) -- larger than the state of Rhode Island. Surrounded on three sides by mountain ranges, the proving ground's terrain includes mountains, valleys and a large, flat, sparsely vegetated area that extends westward into the southern reaches of expansive salt flats of the Great Salt Lake Desert.

Retrieval Day

Sept. 8, 2004, will be a busy one for the Genesis team. It begins around 2 a.m. MDT when NASA's Deep Space Network transmits a command to the spacecraft to initiate a computer sequence that will later release the sample return capsule.

About 4:30 a.m. MDT, pyro devices will fire to sever two cable bundles connecting the spacecraft to the capsule, and the hinge connecting the two vehicles will retract. Starting about 4:45 a.m. MDT, the spacecraft spins itself up to 10 revolutions per minute. The spinning will provide the unguided sample return capsule with additional stability during entry. The spacecraft then rotates to the proper orientation for release and spins up to 15 revolutions per minute. Shortly thereafter, six push-off springs will push the sample return capsule away from the spacecraft at a rate of 0.914 meters per second (3 feet per second, or slightly over 2 miles per hour). Capsule release will take place at approximately 5:53 a.m. MDT at an altitude of about 65,896 kilometers (40,946 miles).

Approximately 22 minutes after separation, the Genesis spacecraft will fire its thrusters to reorient itself for a divert burn. This time lapse allows the sample return capsule to move away from the spacecraft to avoid re-contact between the two.

Atmospheric Entry

At 9:55 a.m. MDT, the capsule will enter Earth's atmosphere at a velocity of approximately 11.04 kilometers per second (24,706 miles per hour). The only human-made object to re-enter Earth's atmosphere at a higher speed was the Apollo 10 command module, which hit 11.11 kilometers per second (24,861 mph). When it enters the atmosphere, the Genesis capsule will be over northern Oregon. The capsule will stabilize with its nose down because of the location of its center of gravity, its spin rate and its aerodynamic shape.

Forty-five seconds after entry, the capsule will be exposed to a deceleration force three times the force of Earth gravity, or 3 G's. This arms a timer that is started when the deceleration force passes back down through 3 G's. All of the parachute releases are initiated from this timer. Sixty seconds after entry, at an altitude of 60 kilometers (197,000 feet), the exterior temperature of the heat shield will peak at about 2,500 C (4,500 F). Slightly over 10 seconds later, the capsule will be exposed to about 30 G's, the greatest deceleration it will endure during Earth entry. During this time period, the capsule's heat shield will lose an estimated 3 kilograms (about 7 pounds), or about 6 percent of its weight, as a small amount of the ablative material erodes away with the heat generated during entry through the atmosphere.

At 127 seconds into entry at an altitude of about 33 kilometers (108,000 feet), a mortar aboard the capsule will fire, releasing the 2.03-meter-diameter (6.7-foot) drogue parachute to provide stability to the capsule until the main chute is released. The capsule's heat shield will rapidly cool during this subsonic portion of the descent.

Four minutes and fifteen seconds later, at an altitude of 6,700 meters (22,000 feet), three pyrotechnic bolts will release the drogue chute from the capsule. As the drogue chute moves away, it will extract the capsule's main chute, a 10.5- by 3.1-meter (34.6- by 12.1-foot) parafoil. Full inflation of the parafoil will occur in about 6 seconds. Once inflation is complete, the parafoil and its payload will begin a slow, loose spiral descent through the skies of the Utah Test & Training Range.

The landing footprint for the sample return capsule is an ellipse that takes in most of the Utah Test & Training Range, except for some areas that have a high population density. The footprint is an ample area to allow for aerodynamic uncertainties and winds that might affect the direction the capsule travels during its descent.

Mid-Air Retrieval

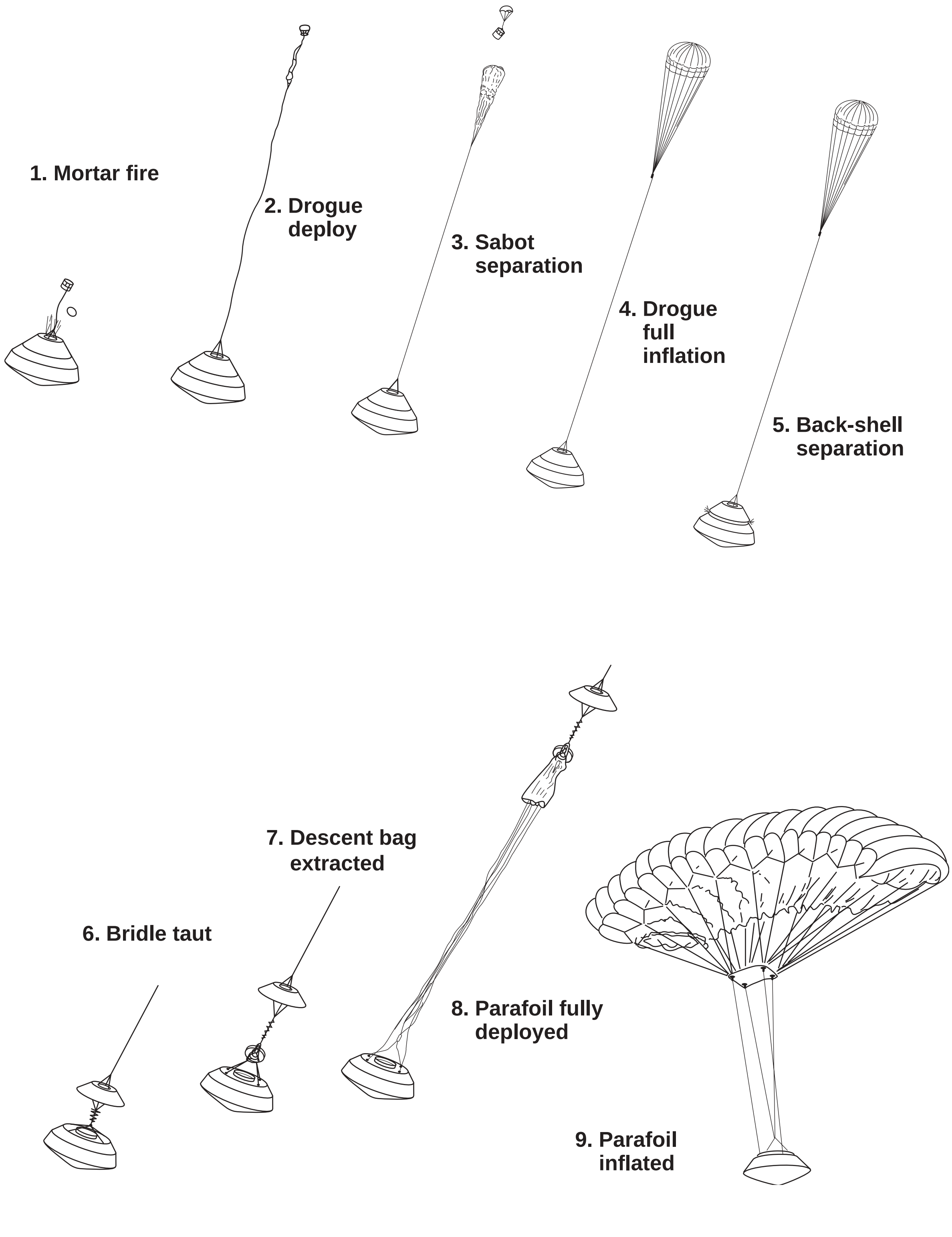
As the Genesis capsule descends through the atmosphere, it will be "painted" by powerful radars located on the Utah Test & Training Range. This will provide tracking information allowing ground-based cameras to spot the capsule. Backup tracking is provided by a Global Positioning System (GPS) unit on the Genesis capsule that transmits position data to a ground station, which in turn relays the information to the mission control center. The radar, visual and GPS data will provide an accurate plot in three dimensions for the capsule's location. This plot is generated at the mission control center located about 160 kilometers (100 miles) away from the range at Hill Air Force Base. A ground control intercept officer based at the Hill Air Force Base mission control will direct helicopter flight crews towards the capsule.

Descending at about 3.7 meters per second (12 feet per second, or slightly over 8 miles per hour), it will take about 10 minutes for the capsule to descend after its parafoil deploys until it reaches the 3,000-meter (10,000-foot) altitude inhabited by the two chase helicopters. By this time, the two flight crews will have been hovering for about 10 minutes when they receive the information on the capsule's location. Each helicopter has the capability of making a successful intercept anywhere on the Utah Test & Training Range.

When the primary flight crew "tally-ho's" (visually spots) the Genesis capsule, they will take over the intercept, flying into position behind the parafoil. The crew will lower the capture pole and its hook to about a 50-degree angle as they fly in a trailing formation and observe the parafoil's flight characteristics. If all looks well, they will accelerate so as to overtake the parafoil at a closing speed of about 7 to 10 meters per second (15 to 20 miles per hour). The pilot will skim the top of the capsule's parafoil with only about 2.5 meters (8 feet) separating the helicopter's landing skids and the top of the parafoil.

As the parafoil strikes the boom, its fabric will wrap around the pole and slide down its length into the hook. When the hook encounters 200 pounds of force, the hook will separate from the boom activating a piston that secures the parafoil to the hook. The hook and its out-of-this-world catch will remain connected to the helicopter via a 137-meter (450-foot) Kevlar cable. The helicopter pilot will then pitch the ship's nose up, quickly decelerating to prevent the possibility that the parafoil will re-inflate and cause mischief with the flight characteristics of the helicopter.

If the approach does not look satisfactory, the lead flight crew can wave off. From the anticipated 2.75-kilometer (9,000-foot) altitude for a first capture attempt, there will be an estimated five additional opportunities to perform a successful mid-air retrieval.



Parachute deployments

Intermediate Landing

While the grab may be considered a highlight of the mission, the mission is not over. Genesis scientists want the interior of the sample return capsule to be bathed in nitrogen gas within two hours of capture to purge out gases from Earth's upper atmosphere that may enter the canister during re-entry. The equipment and the nitrogen required for the purge are located at Michael Army Air Field several miles away. Flights tests have shown that it will be a slow process to fly there directly because of the challenges of flying with the captured parafoil and sample return capsule. So, the first step is to get rid of the parafoil.

Soon after capture, the pair of capture helicopters will begin a slow, controlled descent to a designated landing zone on the range. The helicopter that did not make the capture will land first. The capture helicopter will hover overhead, extending the cable attached to the capsule and its still billowing parafoil down to ground handlers. After the capture helicopter lands, the parafoil will be stripped from the capsule and a new line will be attached directly from the helicopter to the capsule.

The capture helicopter will then fly directly to Michael Army Air Field. Without the drag of the parafoil, the flight crew can travel at a much higher velocity.

Clean Room

Upon arrival at Michael Army Air Field, the helicopter carrying the capsule will hover and, with the assistance of ground handlers, lower the capsule onto a specially designed cradle. The heat shield will be photographed as it is lowered into the cradle. After the capsule is safely on terra firma, it will make a short journey to a clean room where the return capsule will be opened and the nitrogen purge will be applied. Time-critical events will conclude when the purge is in place.

At a later date, the sample canister will be transported to its final destination, the planetary material curatorial facility at NASA's Johnson Space Center, Houston, Texas for archiving and study.

Planetary Protection

The United States is a signatory to the United Nations 1966 Treaty of Principles Governing the Activities of the States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. Known as the "Outer Space Treaty," this document states in part that exploration of the Moon and other celestial bodies shall be conducted "so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter."

The Genesis sample consists of atoms from the Sun. The Genesis mission has been categorized by NASA's planetary protection officer as a mission safe for unrestricted Earth return, because it was concluded that there is no chance of extraterrestrial biological contamination during sample collection at the L1 point. The National Research Council's Space Studies Board has also concurred on a planetary protection designation of unrestricted Earth return. The board determined that the sample has no potential for containing life.

Outreach

The Genesis project has forged partnerships with several educational enterprises to increase public awareness of the mission's goals and strategy, and to broaden the distribution of new knowledge the mission will produce. This includes courses presented as part of the Chautauqua program sponsored by the National Science Foundation and administered nationally by the University of Pittsburgh. "Genesis Grams," 100-character messages from participating members of the public, have been engraved on a microchip and placed aboard the spacecraft.

Education modules are also available on a CD-ROM titled "Genesis in Education" including two series titled "Cosmic Chemistry" and "Dynamic Design," as well as an interdisciplinary module exploring theories of the universe's origins.

Spacecraft

When Genesis' solar arrays are extended in space, the spacecraft resembles an unbuckled wristwatch. The watch's face is the science deck, and the figurative straps are the opened solar panels. The framework of the spacecraft is composed mostly of graphite fiber composite, aluminum and some titanium. Using titanium is an efficient way of conserving mass while retaining strength. Genesis' composite structure is similar to that used in the construction of high-performance aircraft.

The Genesis spacecraft incorporates innovative, state-of-the-art technologies pioneered by other recent missions using off-the-shelf spacecraft components and, in many cases, spare parts and instrumentation left over from previous missions.

There are a total of eight payloads making up the four science instruments on Genesis -- the three specialized collector arrays; the two bulk collector arrays; the concentrator; the ion monitor; and the electron monitor.

Structures

The spacecraft's structure is built around a rectangular equipment deck that supports engineering components and the science instruments.   The medium-gain antenna is on the underside, and the low-gain antennas are mounted on the solar wings. All the equipment is mounted directly onto the equipment deck except for the canister, the concentrator and the collector arrays, which are mounted inside the sample return capsule, which in turn is mounted on the equipment deck.

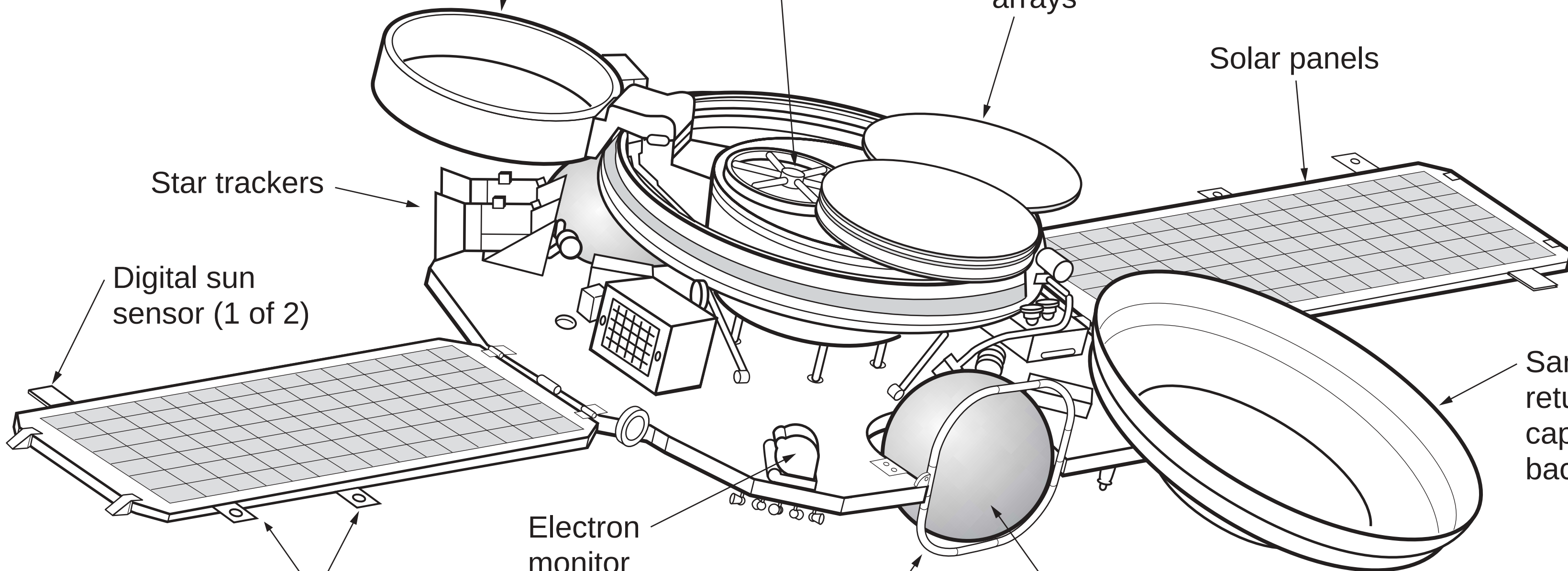
The structures subsystem weighs 98.6 kilograms (217.4 pounds).

Sample Return Capsule

The sample return capsule is a blunt-nosed cone with a diameter of 152 centimeters (60 inches). It has five major components: a heat shield, backshell, sample return canister, parachute system and avionics. The total mass of the capsule, including the parachute system, is 205 kilograms (420 pounds).

A hinged clamshell mechanism opens and closes the capsule. The science canister -- housing the solar wind collector arrays and ion concentrator -- fits inside, with a central rotating mechanism to extend the collector arrays. The capsule is encased in a carbon-impregnated material known as carbon-carbon and an ablative material called SLA-561 to protect the samples stowed in its interior from the heat of reentry. A parachute activated by a mortar unit is carried inside the capsule and will be used to slow its descent.

The heat shield is made of a graphite-epoxy composite covered with a thermal protec-



Genesis spacecraft

tion system. The outermost thermal protection layer is made of carbon-carbon. The capsule heat shield remains attached to the capsule throughout descent and serves as a protective cover for the sample canister at touchdown. The heat shield is designed to remove more than 99 percent of the initial kinetic energy of the sample return capsule.

The backshell structure is also made of a graphite-epoxy composite covered with a thermal protection system: a cork-based material called SLA-561V that was developed by Lockheed Martin for use on the Viking missions to Mars, and have been used on several missions including Genesis, Pathfinder, Stardust and the Mars Exploration Rover missions. The backshell provides the attachment points for the parachute system, and protects the capsule from the effects of recirculation flow of heat around the capsule.

The science canister is an aluminum enclosure containing the specialized collector arrays and ion concentrator. On the inside of the lid of the science canister is a bulk solar wind collector array. The specialized collector arrays are rotated out from inside the science canister. Underneath the stowed collector arrays, the ion concentrator forms the bottom of the science canister. The canister is inside the sample return capsule, which is mounted to an equipment deck suspended between the backshell and heat shield on a set of support struts.

The parachute system consists of a mortar-deployed 2.1-meter (6.8-foot) drogue chute to provide stability at supersonic speeds, and a main chute 10.5 by 3.1 meters (about 34.6 by 12.1 feet).

Inside the canister a gas cartridge will pressurize a mortar tube and expel the drogue chute. The drogue chute will be deployed at an altitude of approximately 33 kilometers (108,000 feet) to provide stability to the capsule until the main chute is released. A gravity-switch sensor and timer will initiate release of the drogue chute. Based on information from timer and backup pressure transducers, a small pyrotechnic device will cut the drogue chute from the capsule at about 6.7 kilometers altitude (22,000 feet). As the drogue chute moves away, it will extract the main chute. At the time of capture, the capsule will be traveling forward at approximately 12 meters per second (30 miles per hour) and descending at approximately 4 meters per second (9 miles per hour).

Mechanisms

The solar arrays were stowed during launch and then released. Mechanisms under the wings allowed them to unfold and move on a hinge until two latches per wing engaged and locked the wings in place.

The sample return capsule has a separation and release system, made of three two-legged struts that hold the sample return capsule in place. The sample return capsule is mounted on its struts with its heat shield atop six spring-loaded cans. The springs push on a ring that presses against the heat shield and gently shoves the capsule away from the spacecraft when pyrotechnic bolts are cut.

The sample return capsule's lid opens and closes on a main hinge, and all the electronic signals that control the collector arrays and concentrator are passed through a wire harness from the spacecraft to the capsule that passes through the hinge. In order to keep the hinge from damaging the sample return capsule as it plunges through Earth's atmosphere, the hinge is retracted away from the capsule before reentry. Elbow joints at the top of the hinge have separation bolts and cable cutters that separate and retract the hinge assembly.

The ion and electron monitors each had a door mechanism that exposed the sensors inside by using pyrotechnics to expand small metallic balloons to open the door.

Four mechanical latch/hook assemblies worked to grab the lid of the sample return capsule and hold it in place throughout launch. The science canister mechanisms are: the lock ring device, sealing lid, canister lid mechanisms, and solar collector array deployment mechanism.

All of the canister mechanisms combined weigh 17.0 kilograms (37.5 pounds)

Flight Software

Genesis receives its commands and sequences from Earth and translates them into spacecraft actions. The flight software is capable of running multiple concurrent sequences, as well as executing immediate commands as they are received.

The software used during the collection mission interpreted data from the ion and electron monitors to deploy the proper collectors depending on the type of solar wind.

The flight software is also responsible for a number of autonomous functions, such as attitude control and fault protection, which involve frequent internal checks to determine whether a problem has occurred. If the software senses a problem, it will automatically perform a number of preset actions to resolve the problem or put the spacecraft in a safe mode for the ground to respond.

Redundancy

Most systems on the spacecraft are fully redundant. This means that, in the event of a device failure, there is a backup system to compensate.

A software fault protection system is used to protect the spacecraft from reasonable, credible faults but also has resiliency built into it so any faults not anticipated can be accommodated without placing the spacecraft in a safe state.

Command and Data Handling

All of the spacecraft's computing functions are performed by the command and data handling subsystem. The heart of this subsystem is a RAD6000 computer, a radiation-hardened version of the PowerPC chip used on some personal computers and videogame systems. With 128 megabytes of random access memory and three megabytes of non-volatile memory, which allows the system to maintain data even without power, the subsystem runs Genesis' flight software and controls the spacecraft through interface electronics.

Interface electronics are used to communicate with external peripherals. They allow the use of redundant, identical sets of computer and interface electronics, so that if one fails the spacecraft can switch to the other.

Communication with Genesis' sensors that measure the spacecraft's orientation in space, or "attitude," and its science instruments is done via another interface card. A master input/output card collects signals from around the spacecraft and also sends commands to the electrical power subsystem. The interface to Genesis' telecommunications subsystems is done through another card called the uplink/downlink card.

There are two other boards in the command and data handling subsystem, both internally redundant. The module interface card controls when the spacecraft switches to backup hardware and provides the spacecraft time. A converter card takes power from the electrical power subsystem and converts it into the proper voltages for the rest of the command and data handling subsystem components.

The entire command and data handling subsystem weighs 11.9 kilograms (26.2 pounds).

Telecommunications

Genesis' telecommunications subsystem is composed of both a radio system operating in the S-band microwave frequency range and a system that operates in the ultra high frequency (UHF) range. The S-band system provides communication capability between Earth and the spacecraft throughout all phases of the mission. The UHF system is located in the sample return capsule; after parafoil deployment, it provides a backup tracking capability.

The spacecraft's radio system communicates with Earth though a medium-gain antenna. The medium-gain antenna is spiral-shaped, about 10 centimeters (4 inches) in diameter, about 12 centimeters (4.87 inches) tall and weighs 105 grams (about 4 ounces). The spacecraft also houses four low-gain antennas, located on the underside of the craft. These are patch antennas, which sit on a coaster-size square (10 by 10 by 1 centimeters (4 by 4 by 0.4 inches)). These have a much wider field of view.

The low-gain antennas will be used to make initial contact with the spacecraft after it leaves Earth's atmosphere, and afterwards only for emergencies. The medium-gain antenna will be used for most of the spacecraft's communication with Earth.

The telecommunication subsystem weighs 10.1 kilograms (22.3 pounds).

Electrical Power

All of the spacecraft's power is generated, stored and distributed by the electrical power subsystem. The system obtains its power from an array of standard silicon solar cells arranged on two panels on either side of the equipment deck. The two solar panel wings, made of silicon and aluminum, are fixed in place. They hold grids of silicon cells which generate 265 watts at Earth's distance from the Sun. A power distribution and drive unit contains switches that send power to various loads around the spacecraft. Power is also stored in a 16-amp-hour nickel hydrogen battery.

The electrical system also contains a pyro initiator unit which fires small explosive devices that configure the spacecraft following launch, performing such tasks as extending Genesis' solar array and opening covers on science instruments. The pyrotechnic system also releases the sample return capsule by actuating cable cutters to allow the heat shield and back shell to separate from the spacecraft's body.

The electrical power subsystem weighs 36.5 kilograms (80.5 pounds).

Guidance, Navigation and Control

Genesis maintains its orientation in space, or "attitude," by continuously spinning in space. The attitude control system will keep Genesis spinning at a rate of 1.6 revolutions per minute. During the science mission, the axis of spin pointed 4 degrees ahead of the Sun, so that ion and electron monitors would face directly into the oncoming solar wind. The slow spin helps maintain inertial pointing at the Sun, and minimizes pointing errors due to solar radiation pressure torques.

Genesis determines its orientation at any given time using a star tracker and Sun sensors. Genesis is the first robotic spacecraft to fly this particular system to determine its orientation, or "attitude." The star tracker can track stars of third magnitude or fainter; in combination with the digital Sun sensor, it can identify stars and generate information on the spacecraft's attitude. Using both the angles of the Sun and of nearby stars, on-board software can determine the spacecraft's orientation and spin rate. As long as the spacecraft is spinning between 1.6 and 2 revolutions per minute, it can identify stars. During the maneuvers when the spacecraft is spinning faster than 2 rpm, the spacecraft will use its spinning Sun sensors to determine its orientation. There are two star trackers, two digital sun sensor and two spinning sun sensors onboard as redundant backups.

The guidance, navigation and control subsystem weighs 10.0 kilograms (22.0 pounds).

Propulsion

The propulsion subsystem features sets of two kinds of small thrusters. The larger are used to make major trajectory correction maneuvers, and the smaller to continually maintain the spacecraft in its orbit.

Firing the thrusters changes the spacecraft's orientation. Two clusters of four small hydrazine thrusters each are mounted on the spacecraft, providing 0.88 newtons (0.2 pounds) of thrust each for small maneuvers to keep the spacecraft in orbit and to increase or reduce the rotation rate. Four more thrusters are also mounted on the spacecraft, each providing 22.2 newtons (5 pounds of thrust) for major trajectory correction maneuvers. These thrusters are only used when the sample return capsule's lid is closed in order to avoid contaminating the solar samples.

In addition to miscellaneous tubing, latch valves and filters, the propulsion subsystem also includes two 55-centimeter-diameter (22-inch) fuel tanks, each containing hydrazine, pressurized with gaseous helium. The outlets of tanks are metered together and will draw together equally.

The propulsion subsystem weighs 36.6 kilograms (80.7 pounds).

Thermal Control

The thermal control subsystem is responsible for maintaining the temperatures of each component on the spacecraft to within their allowable limits. It does this using a combination of active and passive control elements. The active components are the heaters. The passive components are thermal paint, blankets of black kapton on the backside of the spacecraft and blankets of indium-10 oxide on the sunward side.

The thermal control subsystem weighs 15.9 kilograms (35.1 pounds).

Science Objectives

Genesis' purpose is to bring samples of solar matter to Earth. The solar wind is a convenient sample of the surface layers of the Sun, which have preserved the composition of the original solar nebula from which all planetary objects formed. Genesis will be the first mission in the present millennium to return with a package of extraterrestrial material.

Genesis samples will allow scientists to determine the average composition of the solar system with high precision so that the composition of current solar system bodies can be compared.

Today's solar system holds a dazzling diversity of planets, moons, asteroids and other small bodies, which scientific theories say all formed from a homogeneous solar nebula. The elements and isotopes that make up the planets, moons, asteroids and comets contain a record of the processes and events in the early days of our solar system by which homogeneity was converted to diversity. The Genesis samples will provide scientists with new knowledge about the initial composition of the solar nebula, crucial data that is required to test theories that explain how this conversion occurred.

Genesis will focus on determining the ratio of isotopes of different elements in solar matter. There are small but important differences in the abundance of isotopes of some elements, most notably oxygen and nitrogen, among the various solar system materials available for study in Earth's laboratories. These differences are not explained by the standard model for the origin of the solar system.

Observations from the ground and from past spacecraft have provided a baseline set of data that studies of the Genesis samples will greatly improve. Genesis' goal is to improve current knowledge of the Sun's composition for each element by threefold or better. Many elements are very rare, and data about the relative amounts of the different chemical elements are inaccurate or non-existent.

Objectives

❑ Provide data on the isotopic composition of solar matter sufficiently precise for planetary science studies.

❑ Significantly improve our knowledge of the elemental composition of solar matter.

❑ Provide a reservoir of solar matter sufficient to meet the needs of 21st century planetary science.

❑ Provide independent measurements of the different kinds of solar wind.

Science Instruments

The Genesis mission's science instruments worked together to analyze, determine and sample the three types of solar wind.

Genesis' science goals will not be complete until the collector materials are analyzed. This requires developing analytical laboratory instruments on Earth with advanced capabilities beyond those presently available.

❑ **Solar Wind Collector Arrays**. The solar wind collector arrays are large, meter-sized (yard-sized) panels, each containing 55 coaster-sized hexagonal tiles about 10 centimeters (4 inches) in size. The tiles are made of a variety of materials including silicon, germanium, sapphire, artificially created diamond and bulk metallic glass. These materials were selected in order to target specific elements during analysis; for example, collecting some of the solar wind material on a thin silicon layer on sapphire makes it easy to extract noble gases later in the laboratory. The tile materials must be extremely pure to guarantee that the atoms analyzed are of pristine solar origin and not due to terrestrial contamination.

There are five collector arrays mounted inside an ultraclean canister for safe storage when not exposed to the solar wind. One array is mounted in the cover of the canister and is exposed to the solar wind when the cover is opened. The other four arrays are mounted in a stack. The top array is exposed to the solar wind at all times. One of the other three is deployed depending on the type of solar wind the spacecraft is experiencing, as determined by the monitors. The canister was designed, built and tested by NASA's Jet Propulsion Laboratory, Pasadena, Calif. The canister was cleaned and the collector array materials installed in a new clean room, with only 10 airborne particles of dust per cubic meter (called a "class 10" clean room) at NASA's Johnson Space Center in Houston, Texas.

Solar wind ions striking the collector materials embed themselves many atom layers deep in the materials. Typical temperatures of the collector materials in the Sun are around 200 C (about 400 F). The collector materials have been selected so that diffusion is negligible after the atoms embed themselves, so that the collector materials can serve as permanent sample containers for the returned solar matter.

❑ **Ion and Electron Monitors**. Genesis' solar wind monitors were able to determine the properties of the solar wind autonomously and to translate that knowledge into actions for the other two Genesis instruments. The monitors had three functions: to distinguish different types of solar wind in order to deploy the appropriate collector array, to document the properties of the solar wind, and to drive the solar wind concentrator.

Since the three kinds of solar wind can be distinguished by their speed, density temperature, helium-hydrogen ratio and direction of travel of electrons, Genesis' ion and electron monitors worked together to identify the types of solar wind.

The ion monitor measured a broad range of energy in the solar wind for protons -- or hydrogen ions -- as well as alpha particles, which are helium atoms stripped of their electrons, leaving two protons and two neutrons together. About 96 percent of the solar wind is composed of protons, 4 percent alpha particles and less than 1 percent minor ions, of which carbon, nitrogen, oxygen, neon, magnesium, silicon and iron are the most abundant.

The ion monitor faced almost directly into the solar wind. The solar wind entered a 1-millimeter (0.04-inch) slit in the top of the instrument and traveled down between two curved, electrically charged plates. The plates' voltage pulled the ions in the direction of the curvature.

The ion monitor was mounted on the side of Genesis that continually faces the Sun. As the spacecraft spun slowly around a Sun-pointed axis, the instrument's field-of-view swept through a 25-degree arc. The solar wind's supersonic speed can vary from 300 to 1,800 kilometers per second (0.6 to 4 million miles per hour), making its fastest Sun-Earth trip in about 24 hours.

In addition to the average speed, the ion monitor measured the spectrum of speeds, or energies, of the ions, which can determine their temperature. If the energy spectrum measured in the solar wind is broad, then the ions have many different energies reflecting temperatures possibly as high as 500,000 C (900,000 F). If the solar wind's energy spectrum is narrow, the ions can be relatively cool -- about 10,000 C (18,000 F).

The most important function of Genesis' electron monitors was to determine the direction of travel of the solar wind's electrons. They also measured the energy spectrum of the electrons.

The electron monitor was composed of two half-spheres of charged, gold-covered metal, concentrically nested inside a drum with a slit. The solar wind electrons entered the slit between the charged plates. The instrument is located on the edge of Genesis' equipment deck so that it can measure the solar wind coming in all directions.

If the electrons seemed to be coming from two opposing directions simultaneously, the solar wind is part of a coronal mass ejection, a mass of charged particles, or "plasma," that was ejected from the Sun's outer layer and may contain embedded magnetic fields. If the electrons were traveling only in one direction, the solar wind was probably of a different type, either "fast" or "slow" solar wind.

The shoebox-sized ion monitor weighs 3.3 kilograms (7.3 pounds) and uses 4 watts of power. It measures 29.4 centimeters (11.6 inches) long, 23.2 centimeters (9.1 inches)

The Solar Corona and Solar Wind

The outermost layer of the Sun's atmosphere is called the solar corona. The solar wind is a continuous outflow of material from the corona -- mostly nuclei of the simple atoms of hydrogen and helium -- into interplanetary space. By the time this wind reaches Earth, its density is only about 5 to 10 particles per cubic centimeter. The Sun loses about one 100-trillionth of its mass every year from this wind.

The corona can be seen during total solar eclipses and by artificial eclipses produced by instruments called coronagraphs in solar observatories both on Earth and in space. The corona is extremely hot -- more than 1 million degrees Celsius (more than 2 million degrees Fahrenheit). The natural mechanisms within the Sun that heat the corona have not yet been completely determined and are under active investigation by space missions such as the Solar and Heliospheric Observatory (Soho) and the Transition Region and Coronal Explorer (Trace). Scientists say the mechanisms must involve the conversion of turbulent motions just below the solar surface into the twisting and occasional reconnection of magnetic fields and waves that extend into the corona.

The corona is also highly structured. These different structures give rise to three different kinds of solar wind: high-speed solar wind, low-speed solar wind and coronal mass ejections.

Images taken by telescopes with coronagraph instruments attached show some loops of glowing gas with both ends of the loops attached to the Sun, while others are open structures reaching out into space. The loops are made visible by hot, ionized gas (a material called a "plasma" made up of ionized atoms and electrons) trapped by the Sun's magnetic field.

tall and 10.8 centimeters (4.3 inches) wide. The electron monitor is nearly the same size, and has a similar power requirement. The instruments were developed and built under the direction of Bruce Barraclough at the Los Alamos National Laboratory in New Mexico. The two monitors are nearly identical to Los Alamos instruments currently operating on board the Advanced Composition Explorer and on the Ulysses spacecraft.

❑ **Solar Wind Concentrator**. Genesis' solar wind concentrator attacked the problem of collecting a high concentration of oxygen in the solar wind, filtering out the much more numerous hydrogen ions (protons). Oxygen is one of the most important elements in the solar wind because so much of the solar system's make-up includes oxygen, yet the differing amounts of oxygen isotopes in each type of body are puzzling.

All the oxygen that the instrument gathered was concentrated into a collector tile made of the purest materials in order to exclude Earth oxygen. In the process, the ions are concentrated by a factor of 20 over the normal solar wind collectors.

The concentrator is installed in the sample canister, always facing the Sun. The solar wind passed through a series of charged grids into a bowl-shaped mirror, which reflected the filtered stream of ions upwards into the tile, poised in the center.

Solar Wind Regimes

When scientists view radiation given off by the Sun in the X-ray range, some regions of the corona appear dark; these regions are called coronal holes. Instead of forming closed loops, the magnetic fields in coronal holes open out into space and the plasma is free to escape. High-speed solar wind blows out from the coronal holes like hot gas from a rocket engine. The solar wind from large coronal holes can have speeds exceeding 1,200 kilometers per second (720 miles per second).

Low-speed solar wind, moving at about 300 kilometers per second (about 190 miles per second), is thought to come from the boundary regions between coronal holes and certain other regions of the Sun's surface. Here the magnetic geometry keeps the solar matter from escaping easily, and the solar wind that does leave the Sun is relatively slow.

Interrupting these somewhat steady flows of solar wind are occasional events called coronal mass ejections. A coronal mass ejection occurs when a magnetic loop, or a group of magnetic loops, suddenly becomes unstable and blows out into space. The solar wind from such an ejection can be either fast or slow, depending on the energy of the explosion. These events are more frequent when the sunspot cycle is at its 11-year maximum.

Some ejections have solar flares associated with them, and some do not. A solar flare is a sudden, intense brightening emitting a burst of radiation that reaches Earth within a day or two, often interfering with satellite communications and power systems.

Material from a coronal mass ejection often includes a larger fraction of helium ions, also known as alpha particles, compared to the number of hydrogen ions, or protons. (An ion is an atom that has had one or more electrons stripped away from it, leaving it with a positive electrical charge.) Such ejections are also marked by a decrease in the temperature of ions as the material rapidly expands as it leaves the Sun. During an ejection, energetic electrons frequently stream in both directions along a magnetic loop whose ends may still be anchored in the Sun. The loops are made visible by hot, ionized gas (a material called a "plasma" made up of ionized atoms and electrons) trapped by the Sun's magnetic field.

Genesis will provide samples of each of these three types of solar wind so that scientists can analyze them to test for differences in the proportions of elements and isotopes they are made of. (An isotope is a variation of an element that is heavier or lighter than the standard form of the element because it has more or fewer neutrons in its nucleus.)

Data from the ion and electron monitors on Genesis have been used to determine which type of solar wind is passing the spacecraft at any given time. This allowed the onboard computer to select the appropriate collector array for that type of solar wind.

The ions streaming away from the Sun contain all of the isotopes and elements found in nature, but some elements are more readily ionized and picked up by the solar wind than others. This separation, called "elemental fractionation," is somewhat different for the three types of solar wind.

Each of the five collector arrays may pick up different amounts of the elements and possibly isotopes contained in the solar wind. Comparing the data from the collectors will help assure that the composition of the solar wind that Genesis collects is the same as the composition of the Sun's surface.

Several layers of grids made of wires one-quarter the diameter of a human hair manipulate the ions prior to concentrating them. The first grid layer is at ground potential, to keep the electric fields from the highly charged grids inside the collector from escaping and deflecting the surrounding solar wind. The next layer, the hydrogen rejection grid, had a positive charge of up to about 2,000 volts to repel the hydrogen ions that make up most of the solar wind. The next grid had a negative charge of minus 6,500 volts so that surviving particles are accelerated to embed them deeper in the collector tile. The acceleration also straightened stray paths of the incoming particles. The ions then passed through a bowl-shaped domed grid, which is nested above the bottom of the concentrator. The domed grid was also negatively charged to contain the electric field from the mirror just below.

The last element is the parabolic solid mirror, with a strong positive charge. The particles passing through the domed grid were forcefully reflected toward the center of the parabola, where the collector received them. The mirror is a single aluminum piece with a surface consisting of steps 100 microns (.004 inch) tall, which reflected the Sun's incoming light back out of the instrument to avoid damaging the collector tile with focused sunlight.

The concentrator target, 26 square centimeters (4 square inches), is made of four pie wedges of ultra-pure materials: 1 diamond (carbon 13) wedge, 2 silicon carbide wedges and one wedge of silicon coated with thin diamond-like carbon. The entire interior of the concentrator is coated with gold to keep all the surfaces oxygen-free.

The solar wind concentrator was developed at Los Alamos National Laboratory by Drs. Roger Wiens and Jane Nordholt. During flight, scientists at Los Alamos monitored the health of the payload instruments and kept a history of all solar wind conditions and array exposure times. These data will be made available to the scientific community at large for use in providing context for the data obtained from the returned samples.

Program/Project Management

The Genesis mission is managed by the Jet Propulsion Laboratory, Pasadena, Calif., a division of the California Institute of Technology, for NASA's Science Mission Directorate, Washington, D.C.

Within the Science Mission Directorate at NASA Headquarters, Alphonso Diaz is associate administrator for science. Orlando Figueroa is deputy associate administrator for programs, Andrew Dantzler is director (acting) of the Solar System Exploration Division and program director for the Discovery Program, Steven Brody is Genesis program executive and also program executive for the Discovery Program, and Dr. David Lindstrom is Genesis program scientist.

At the Jet Propulsion Laboratory, Don Sweetnam is the Genesis project manager. At the California Institute of Technology, Dr. Donald Burnett is the Genesis principal investigator.

Lockheed Martin Space Systems, Denver, Colo., designed, built and operates the spacecraft, and is overseeing the capture and return of the Genesis sample capsule. Joseph M. Vellinga is Lockheed Martin's Genesis program manager, and Dr. Benton Clark is the company's chief scientist for space exploration systems.

Los Alamos National Laboratory built the spacecraft's electron and ion monitors, and the concentrator within the payload system. NASA's Johnson Space Center contributed to Genesis payload development and will curate the sample and support analysis and sample allocation.

Vertigo Inc., Lake Elsinore, Calif., developed and fabricated the mid-air retrieval system and is coordinating the retrieval.

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