

American Robotics

The image features three futuristic, spherical robots floating on a body of water. The robots are metallic and have a complex, multi-lobed design with several protruding arms or sensors. They are illuminated from within, casting a warm glow. The background is a sunset or sunrise over the water, with a soft, golden light. The overall aesthetic is high-tech and futuristic.

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First Edition, 2011

ISBN 978-93-81157-93-0

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Published by:

The English Press

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

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Chapter- 1

Introduction to American Robotics

Robots of the United States include simple household robots such as Roomba to sophisticated autonomous aircraft such as the MQ-9 Reaper that cost 18 million dollars per unit. The first industrial robot, robot company, and exoskeletons as well as the first dynamically balancing, organic, and nanoscale robots originate from the United States.



NASA's ATHLETE hexapod

History



The first Unimate

In 1898 Nikola Tesla publicly demonstrated a radio-controlled torpedo. Based on patents for "teleautomation", Tesla hoped to develop it into a weapon system for the US Navy.

In 1926, Westinghouse Electric Corporation created Televox, the first robot put to useful work. In the 1930s, they created a humanoid robot known as Elektro for exhibition purposes, including the 1939 and 1940 World's Fairs.

Unimate was the first industrial robot, which worked on a General Motors assembly line in New Jersey in 1961. It was created by George Devol in the 1950s using his original patents. Devol, together with Joseph F. Engelberger started Unimation, the world's first robot manufacturing company.

In 2008 the U.S. Air Force 174th Fighter Wing transitioned from F-16 piloted planes to MQ-9 Reaper drones, which are capable remote controlled or autonomous flight, becoming the first all-robot attack squadron.

Domestic Robot:-

PatrolBot



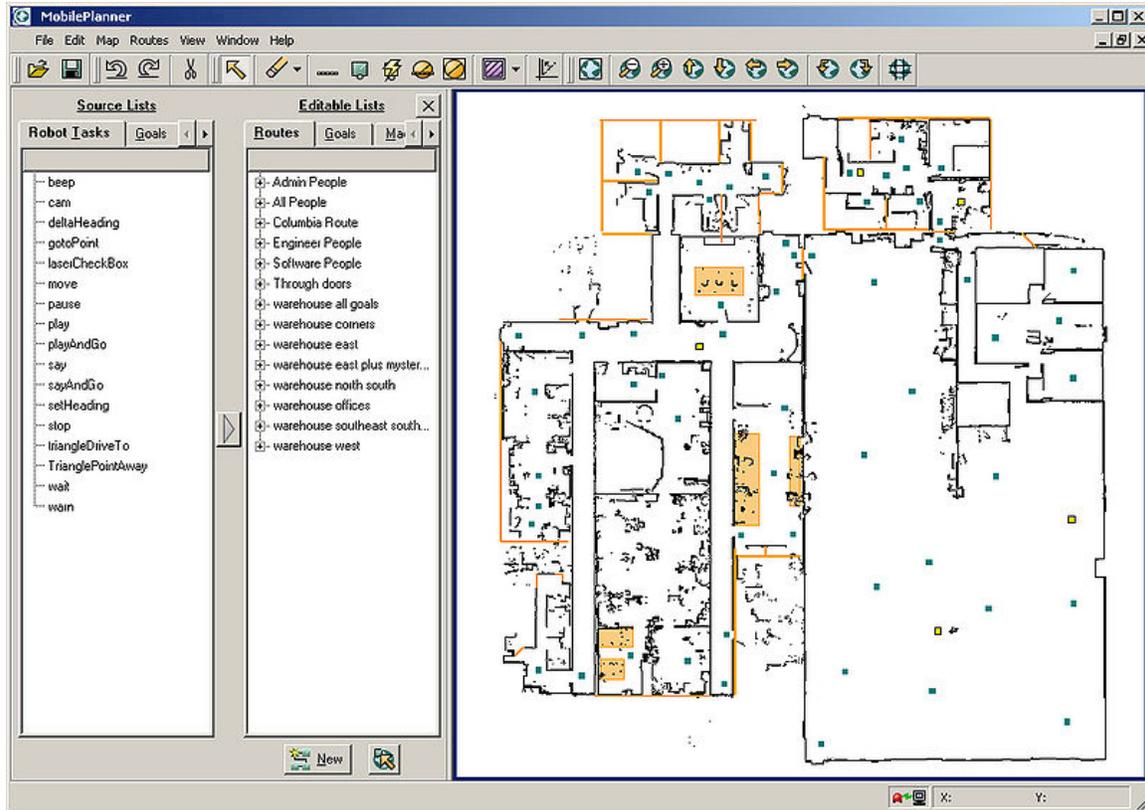
PatrolBot

PatrolBot is a programmable autonomous general purpose service robot rover built by MobileRobots Inc. PatrolBots are manufactured in various configurations and serve as bases for companies developing delivery robots, security robots, environmental monitoring rovers, robot guides and other indoor service robots.

Capabilities of PatrolBot

PatrolBot can scan buildings, create floor plans and navigate them autonomously using a laser range-finding sensor inside the robot. It employs Monte Carlo/Markov-style localization techniques using a modified value-iterated search technique for navigation. It searches for alternative paths if a hall is blocked, circumnavigates obstacles and re-charges itself at its automated docking/charging station as needed. Using a Wi-Fi system the device can operate autonomously or be controlled remotely.

Applications



Robot software "drag-and-drop" interface for setting up goals, tasks and routes for autonomous robots.

PatrolBot is a robotic base used for delivery, security, sensor monitoring, inspection and guidance tasks. It is a reference platform added onto with various carrying attachments, sensors, touchscreens and cameras. While it began primarily as a security robot the platform is now used as a base for a broad range of applications.

Robot Control

Users set up the robot using a GUI interface to give goals, docking location and constraints such as forbidden areas into the robot's map. Then, using drag and drop, an operator can give goal names, tasks and macros into a "route" or program for the robot to follow. Users can then use set or random sequences for the robot to follow by dragging routes into a weekly schedule. Advanced users can communicate with the robot from external systems or program more advance actions over a command language interface as well as add new sensors.

PatrolBot can be sent to goals on demand or can patrol a sequence of goals. Status windows in the control GUI provide read-outs from the sensors as well as proprioceptive information such as battery levels. The robot's data logs are available for security and energy optimization as well as troubleshooting.

Roomba



Roomba in action

Third Generation Roomba docked in base station

The **Roomba** is an autonomous robotic vacuum cleaner sold by iRobot. Under normal operating conditions, it is able to navigate a living space and its obstacles while vacuuming the floor. The Roomba was introduced in 2002; as of January 2008, over 2.5 million units have been sold. Several updates and new models have since been released that allow the Roomba to better negotiate obstacles and optimize cleaning.

Description



Roomba Discovery

The unit is a disc, 34 cm (13.4") in diameter and less than 9 cm (3.5") high. A large contact-sensing bumper is mounted on the front half of the unit, with an infrared sensor at its top front center. A carrying handle is fitted on the top of the unit. Depending on the model, it may come with between one and three "Virtual Wall" infrared transmitter units.

There have been three generations of Roomba units: The original Roomba, Pro, and Pro Elite; the second-generation "Discovery" series with a larger dustbin, dirt detection, and optional home base; and the newest 5XX series.

The Roomba operates with internal nickel-metal hydride batteries (NiMH) and must be recharged regularly from a wall plug, although newer second and third-generation models have a self-charging homebase they automatically try to find (via its infrared beacon). Charging on the homebase takes about three hours. All second and most third-generation Roombas can be used with the homebase, even if they do not come packaged with it.

First and second-generation models came packaged with a twelve-hour charger, although a three-hour rapid charger could also be used with them.

First-generation models needed to be told the size of the room via three room size buttons (Small, Medium, and Large), but this is no longer required with second and third-generation models.

Operation



This EU Roomba is similar to the second-generation US Roomba Sage.

Using a second- or third-generation Roomba consists of carrying it to wherever the owner would like it to start, pressing the "power" button, then pressing the "clean", "spot", or "max" (if applicable) button. Third-generation Roombas no longer have the "max" button, but include a "dock" button allowing the owner to instruct the Roomba to dock with its homebase. A second- or third-generation Roomba may also be used with the Scheduler accessory. It allows the Roomba to begin cleaning automatically at the time of day that the owner desires. This can be useful for people who want the Roomba to clean while they are at work.

The Scheduler accessory is not compatible between second and third-generation Roomba.

When the "clean", "spot", or "max" button is pressed, the Roomba begins its work. The contact bumper detects bumping into walls and furniture, and the Virtual Walls limit the Roomba to the areas that the owner desires with an infrared signal. Special Scheduler Virtual Walls can be programmed to turn on at the same time the Scheduler-enabled Roomba is activated. Four infrared sensors on the bottom of the unit prevent it from falling off ledges. Second- and third-generation models have additional dirt sensors that allow them to detect particularly dirty spots and focus on those areas accordingly.

Unlike the Electrolux Trilobite vacuuming robots, Roombas do not map out the rooms they are cleaning. Instead, they rely on a few simple algorithms such as spiral cleaning (spiraling), room crossing, wall-following and random walk angle-changing after bumping into an object or wall. This design is based on MIT researcher and iRobot CTO Rodney Brooks' philosophy that robots should be like insects, equipped with simple control mechanisms tuned to their environments. The result is that although Roombas are effective at cleaning rooms, they take several times as long to do the job as a person would. The Roomba will cover some areas many times, and other areas only once or twice.

After a period of time in "clean mode", the Roomba stops and sings a few triumphant notes. The duration in "clean mode" depends on room size and volume of dirt. Third-generation models estimate room size by measuring the longest straight-line run they can perform without bumping into an object. First-generation models must be told the room size. After cleaning, if a home base is detected a second or third-generation Roomba will try to return to it. While in contact with the home base, a Roomba will charge its battery. The owner then removes the dustbin from the unit's rear and empties debris into a trash can. With the exception of the first-generation Roomba, an infrared remote control can also be used to control the unit, which is useful for a disabled person.

The Roomba is not designed for deep-pile carpet. The first and second-generation Roombas would get stuck on rug tassels (though they could be tucked under for running a Roomba) and electrical cords. The third generation has a release mechanism in the brush deck and will not only pass over tassels and electrical cords, it will actually clean them. It is low enough to go under a bed or other furniture. If at any time the unit senses that it has become stuck, no longer senses the floor beneath it, or it decides that it has worked its way into a narrow area from which it is unable to escape, it stops and sounds a mournful tone to help its owner find it.

The third-generation Roomba, which moves faster than previous Roombas, has an infrared bumper so it can go slower when the device senses it is about to run into an object.

Models



First generation Roomba

The first-generation Roombas have three buttons for room size.

The second-generation Roombas (dubbed "Discovery") replaced their predecessors in July 2004, adding a larger dust bin, better software that calculates room sizes, fast charging in the home base (or wall hanger in the Discovery SE), and dirt detection. All second-generation Roombas are functionally identical, though some have more or fewer buttons, accessories, or casings, and all featured updated programming after mid 2005. The low-end models continue to be available as of 2007 with new model names. All 2G Roombas can be updated to 2.1G Roombas.

The third-generation 5xx Roomba was introduced in 2007 and features an infrared sensor to detect obstacles, a dock button, and improved mechanical components. Some second-generation models remain on sale, however, as the 4xx series.

Roomba Budget models (Dirt Dog and Model 401) have a simplified interface (a single "Clean" button) and lack some of the program generated flexibility of other versions. They are positioned to be less expensive versions of the Roomba for first-time purchasers. The Roomba Dirt Dog contains sweeping brushes and a larger dust bin but lacks the vacuum motor. It uses the space required for the vacuum for additional dust bin volume. It is designed for home shop or home garage environments. The Roomba Model 401 is similar but has a 'standard' size dust bin and vacuum system. They are compatible with the extended-life batteries, fast charger and schedulers of the Discovery series.

Accessories

- Easy Clean Brush: A brush that is designed specifically for cleaning pet hair, and being easier to clean off (standard on "for pets" models).
- Remote Control: Allows the owner to control the Roomba remotely (works with all second and third generation Roombas).
- iRobot Scheduler: Allows the owner to program the Roomba to clean at certain times automatically. Schedule Upgrade accessory will also update a pre-2.1 Roomba to the 2.1 software (for third generation Roombas).
- Homebase: The Roomba automatically returns to here for recharging (for second and third generation Roombas).
- Virtual Wall: Used for keeping the Roomba out of certain areas (for all Roombas).
- Virtual Wall Lighthouse: Functionality of Virtual Wall in addition to 'Lighthouse' mode which will contain Roomba in one room until the room is completely vacuumed before moving on to the next.
- OSMO: A dongle that attaches to the serial port on the Roomba. This updates a pre-2.1 Roomba's firmware to version 2.1 and can also correct the "circle dance" problem (for all second generation Roombas).
- Advanced Power System (APS) Battery: Rechargeable battery for all Roomba models that holds enough power to clean for 200 minutes.
- Roomba Serial Control Interface (Roomba SCI) exposes all the functionalities and sensor information from the iRobot Roomba vacuum cleaner. Using the Roomba SCI a roboticist can command and control the Roomba by interfacing to the 7pin Mini Din UART port.
- Roo series of products: RooTooth, RooStick and Roo232 by RoboDynamics
 - RooTooth: A Bluetooth module that converts the Roomba to Bluetooth control from any bluetooth device.
 - RooStick: A Bluetooth dongle to allow control from Bluetooth enabled devices
 - Roo232: Allows programming input through a serial port connector.
- RoombaFX - A C# class by RoboDynamics that implements the entire Roomba SCI command set. Available on Source Forge for download and your contributions.

Hacking and extending Roomba

Roomba comes with a Mini-DIN TTL serial interface, which is incompatible with standard PC/Mac serial ports and cables, both electrically and physically. However, third-party adapters are available to access the Roomba's computer via Bluetooth, USB, or RS-232 (PC/Mac serial). New, 500-series, and 410/420 series Roombas upgraded with the OSMO hacker device allow the user to monitor Roomba's many sensors and modify its behavior. The Roomba Open Interface (formerly "Roomba Serial Command Interface") API allows programmers and roboticists to create their own enhancements to Roomba. Several projects are described on Roomba hacking sites. In response to this interest, the company manufactures the iRobot Create, with the vacuum cleaner motor replaced by a "cargo bay" for mounting devices like TV cams, lasers, and even non-mobile robots. The Create provides a greatly enhanced, 25-pin interface providing both analog and digital bidirectional communication with the hosted device. Thus, it can then be used as the mobile base and wireless interface for completely new robots.

Scooba



Scooba is an automated robotic floor washer produced by iRobot. It was released in limited numbers in December 2005 for the Christmas season at \$399.99 USD, with full production starting in early 2006. The company introduced a \$299 version, the Scooba 5800, in the second half of 2006.

The Scooba uses a special non-bleach cleaning solution made by The Clorox Company that cleans the floors and prevents rust or skidding and has been nicknamed *Scooba juice*. The robot preps the floor by vacuuming loose debris, squirts clean solution, scrubs the floor, and then sucks up the dirty solution leaving a nearly dry floor behind. The robot is safe to use on sealed hardwood floors and most other hard household surfaces, but it cannot be used on rugs. Scooba avoids rugs and stairs, and can clean about 200 square feet (19 m²) on a single tank-load of solution.

The Scooba is the second major commercial product made by iRobot, which popularized vacuum robots with the Roomba. The Scooba is available in over 40 countries.

Details

The Scooba uses approximately 2 fl.oz. (63 ml) per cycle, mixed with a quart (1.1 L) of water to fill the clean solution tank. The Scooba comes with one 8 oz (240 ml) bottle of the Clorox Scooba Cleaning Solution, which is enough for about four washings. Additional Clorox Scooba Cleaning Solution comes in five-packs and nine-packs of 32 oz (960 ml) bottles, which provide enough solution for about 16 washings per bottle. Polysorbate 20 and tetrapotassium EDTA are the primary ingredients. It can also use white vinegar in place of the proprietary solution.

Recharge times may vary, but typically takes 3 hours.

Models

Generation 1

Scooba 5900 was the first Scooba, it could only be used with the Scooba Cleaning Solution and was discontinued in favor of the slightly improved Scooba 5800 (basic floor washing model).

The Scooba 5800 can clean about 250 square feet (23 m²) per battery charge (\$299)

Generation 2

Scooba 330 can clean 250 square feet (23 m²) per battery charge (\$299)

Scooba 350 (intermediate floor washing model) can clean about 500 square feet (46 m²) per battery charge (\$399)

Scooba 380 (premium floor washing model) can clean 850 square feet (79 m²) per battery charge. Also includes charging base, storage mat, and an extra virtual wall (for a total of two) (\$499)

Looj

The **Looj** is a rain gutter cleaning robot made and sold by iRobot.

Description

The Looj is a 2¼ in. (≈5.72 cm.) tall and 3¼ in. (≈8.26 cm) wide robot that fits inside most gutters to clean out debris stuck inside them, such as leaves and pine needles. It has long treads on its side that allow it to move inside the gutter and an auger attached to its front. The auger, spinning at 500 RPM, dislodges and removes almost all of the debris

inside the gutter by flinging it into the air. It also has a detachable handle/remote, with a 75 ft. (≈ 23 m.) range, that is used to carry and operate the robot. The Looj can move in forward and backward directions, and the auger can also spin in both directions, controlling the direction the debris is flung. The Looj is waterproof up to 1 ft. (≈ 30 cm.), and can be cleaned by washing it off with water. It comes with a 7.2V Nickel Cadmium rechargeable battery. On a single charge, which takes 15 hours, the robot can run for 30 to 45 minutes, depending on use.

The Looj is not an autonomous robot like the company's well-known Roomba brand vacuum cleaners. It is a remote-controlled device patterned after a toy tank with a power drill mounted on it.

Operation

To operate, the user places the Looj on the belt clip or holster that comes with the robot. The user then places the Looj inside the gutter, removing the detachable handle/remote. After driving the robot back and forth through the gutters, it is driven back to the starting position, where the user can pick it up by attaching the handle/remote. After finishing cleaning, the robot can be washed with running water.

Chapter- 2

Extraterrestrial Robots

All-Terrain Hex-Legged Extra-Terrestrial Explorer



Half-scale ATHLETE prototype, with principal investigator Brian Wilcox in foreground.

The **All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE)** is a six-legged robotic lunar rover test-bed under development by the Jet Propulsion Laboratory (JPL). ATHLETE is a testbed for systems and is designed for use on the moon.

The system is in development along with NASA's Johnson and Ames Centers, Stanford University and Boeing

ATHLETE is designed, for maximum efficiency, to be able to both roll and walk over a wide range of terrains.

Systems



The ATHLETE rover in a test facility at JPL. Taken August, 2008.

The project aims to develop a multi-purpose system capable of docking or mating with special-purpose devices including refueling stations, excavation implements and/or special end effectors. The legs have 6 degrees of freedom for generalized robotic manipulation. Each ATHLETE is intended to have a payload capacity of 450 kilograms (990 lb), with the capability of docking multiple ATHLETE vehicles together to support larger loads.

The ATHLETE is much larger than robotic systems previously used and has a diameter of around 4 metres (13 ft) and a reach of around 6 metres (20 ft). Even with this larger size the project has allowed the facility for multiple units to be stowed and docked compactly for launch into an annular ring. This would mean that many vehicles can be efficiently stacked around a main payload on a single lander.

The 6 DOF legs allow more capabilities than other robotic systems such as Sojourner or the Mars Exploration Rovers. These mean that the slopes it could climb would be up to 35° on solid surfaces and 25° on soft surfaces, such as the soft deposits of dust found on the Moon. Plans are to develop the system's capability of travel over rougher terrain and to increase the speed of ATHLETE to 10 kilometres (6.2 mi) per hour, 100 times faster than the Spirit and Opportunity rovers.

Future improvements

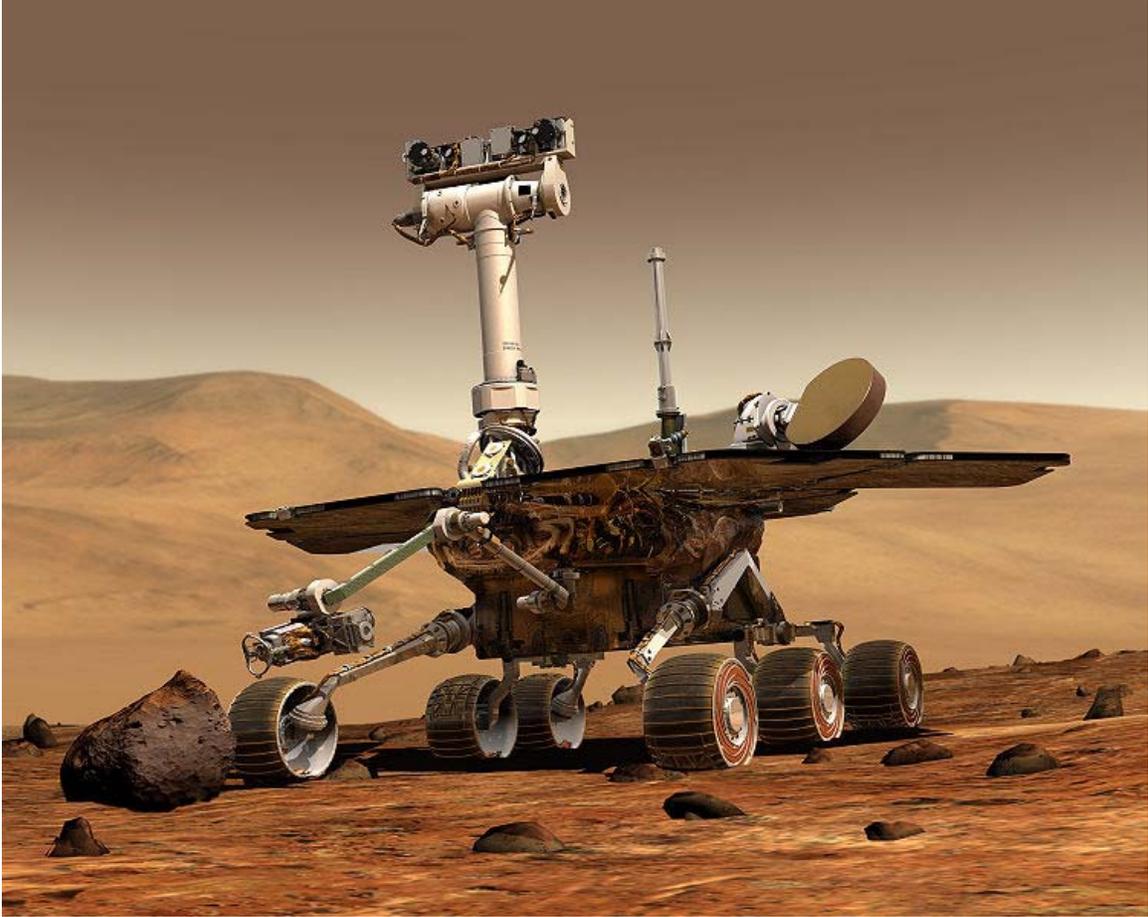
Planning for the future of the ATHLETE include the ability to scale difficult obstacles by means of employing a launchable/releasable grappling hook and line which it will use to haul itself up even vertical slopes. There are also plans to introduce provisions for voice and gesture commands from suited astronauts in proximity to the ATHLETE, the ability to self deploy from their storage facilities and the capability for "*autonomous footfall placement*".

Goals

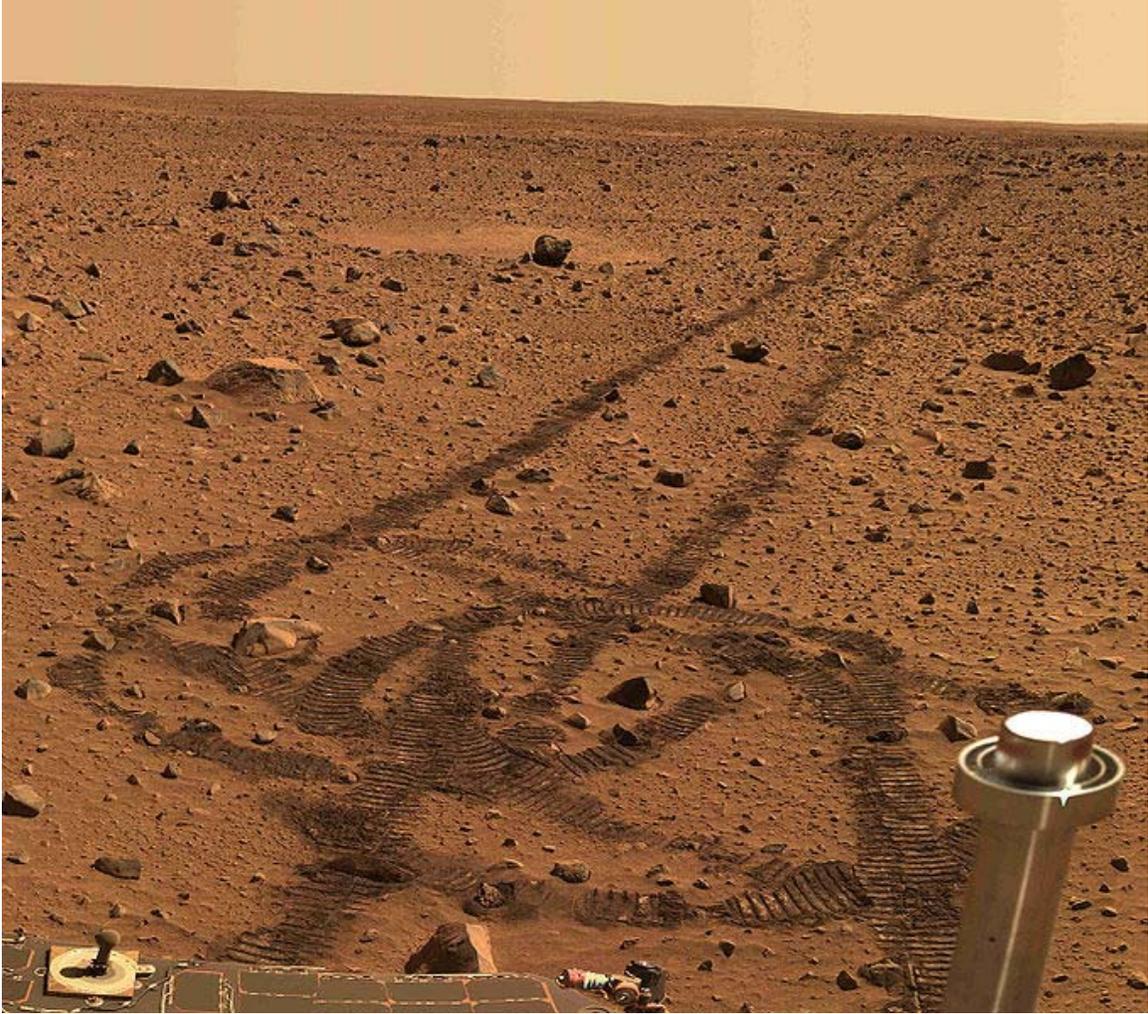
JPL are aiming for a 10 year life span and the capability for re-usable delivery vehicles would mean that the goal of "*an affordable lunar-surface flight experiment that demonstrates this technology on the Moon and subsequently uses it as part of the Human Lunar Return campaign to perform the needed robotic/human vehicle functions on the lunar surface.*"

ATHLETE's purpose is to support lunar exploration operations. One hypothetical mission scenario features a mobile manned "base" supported by ATHLETES capable of traversing thousands of kilometers and setting down temporarily to study interesting features along the way.

Mars Exploration Rover



Artist's conception of rover on Mars



Part of a panorama taken by the Spirit rover in 2004

NASA's **Mars Exploration Rover Mission (MER)** is an ongoing robotic space mission involving two rovers, *Spirit and Opportunity*, exploring the planet Mars. It began in 2003 with the sending of the two rovers — MER-A *Spirit* and MER-B *Opportunity* — to explore the Martian surface and geology.

The mission's scientific objective was to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. The mission is part of NASA's Mars Exploration Program, which includes three previous successful landers: the two Viking program landers in 1976 and Mars Pathfinder probe in 1997.

The total cost of building, launching, landing and operating the rovers on the surface for the initial 90-Martian-day (sol) primary mission was US\$820 million. Since the rovers have continued to function beyond their initial 90 sol primary mission, they have each received five mission extensions. The fifth mission extension was granted in October 2007, and runs to the end of 2009. The total cost of the first four mission extensions was \$104 million, and the fifth mission extension is expected to cost at least \$20 million.

In July 2007, during the fourth mission extension, Martian dust storms blocked sunlight to the rovers and threatened the ability of the craft to gather energy through their solar panels, causing engineers to fear that one or both of them might be permanently disabled. However, the dust storms lifted, allowing them to resume operations.

On May 1, 2009, during its fifth mission extension, *Spirit* became stuck in soft soil on Mars. After nearly nine months of attempts to get the rover back on track, including using test rovers on Earth, NASA announced on January 26, 2010 that *Spirit* was being retasked as a stationary science platform. This mode will enable *Spirit* to assist scientists in ways that a mobile platform could not, such as detecting "wobbles" in the planet's rotation that would indicate a liquid core.

In recognition of the vast amount of scientific information amassed by both rovers, two asteroids have been named in their honor: 37452 Spirit and 39382 Opportunity. The mission is managed for NASA by the Jet Propulsion Laboratory, which designed, built, and is operating the rovers.

Objectives

The scientific objectives of the Mars Exploration Rover mission are to:

- Search for and characterize a variety of rocks and soils that hold clues to past water activity. In particular, samples sought include those that have minerals deposited by water-related processes such as precipitation, evaporation, sedimentary cementation, or hydrothermal activity.
- Determine the distribution and composition of minerals, rocks, and soils surrounding the landing sites.
- Determine what geologic processes have shaped the local terrain and influenced the chemistry. Such processes could include water or wind erosion, sedimentation, hydrothermal mechanisms, volcanism, and cratering.
- Perform calibration and validation of surface observations made by Mars Reconnaissance Orbiter instruments. This will help determine the accuracy and effectiveness of various instruments that survey Martian geology from orbit.
- Search for iron-containing minerals, and to identify and quantify relative amounts of specific mineral types that contain water or were formed in water, such as iron-bearing carbonates.
- Characterize the mineralogy and textures of rocks and soils to determine the processes that created them.
- Search for geological clues to the environmental conditions that existed when liquid water was present.
- Assess whether those environments were conducive to life.

During the next two decades, NASA will conduct several missions to address whether life ever existed on Mars. The search begins with determining whether the Martian environment was ever suitable for life. Life, as humans understand it, requires water, so the history of water on Mars is critical to finding out if the Martian environment was ever

conducive to life. Although the Mars Exploration Rovers do not have the ability to detect life directly, they offer important information on the habitability of the environment in the planet's history



NASA's Mars Exploration Rover *Spirit* casts a shadow over the trench that the rover is examining with tools on its robotic arm. *Spirit* took this image with its front hazard-avoidance camera on February 21, 2004, during the rover's 48th martian day, or sol 48.



Opportunity's discarded heat shield

History

On January 21, 2004, the Deep Space Network lost contact with *Spirit*, for reasons originally thought to be related to a thunderstorm over Australia. The rover transmitted a message with no data, but later that day missed another communications session with the Mars Global Surveyor. The next day, JPL received a beep from the rover, indicating that it was in fault mode. On January 23, the flight team succeeded in making the rover send. The fault was believed to have been caused by an error in the rover's flash memory subsystem. The rover did not perform any scientific activities for ten days, while engineers updated its software and ran tests. The problem was corrected by reformatting *Spirit's* flash memory and using a software patch to avoid memory overload; *Opportunity* was also upgraded with the patch as a precaution. *Spirit* returned to full scientific operations by February 5.

On March 23, 2004, a news conference was held announcing "major discoveries" of evidence of past liquid water on the Martian surface. A delegation of scientists showed pictures and data revealing a stratified pattern and cross bedding in the rocks of the outcrop inside a crater in Meridiani Planum, landing site of MER-B, *Opportunity*. This suggested that water once flowed in the region. The irregular distribution of chlorine and bromine also suggests that the place was once the shoreline of a salty sea, now evaporated.

On April 8, 2004, NASA announced that it was extending the mission life of the rovers from three to eight months. It immediately provided additional funding of US \$15 million through September, and \$2.8 million per month for continuing operations. Later that month, *Opportunity* arrived at Endurance crater, taking about five days to drive the 200 meters. NASA announced on September 22 that it was extending the mission life of the

rovers for another six months. *Opportunity* was to leave Endurance crater, visit its discarded heat shield, and proceed to Victoria crater. *Spirit* was to attempt to climb to the top of the Columbia Hills.

With the two rovers still functioning well, NASA later announced another 18 month extension of the mission to September 2006. *Opportunity* was to visit the "Etched Terrain" and *Spirit* was to climb a rocky slope toward the top of Husband Hill. On August 21, 2005, *Spirit* reached the summit of Husband Hill after 581 sols and a journey of 4.81 kilometers (2.99 mi).



Spirit's "postcard" view from the summit of Husband Hill: a windswept plateau strewn with rocks, small exposures of outcrop, and sand dunes. The view is to the north, looking down upon the "Tennessee Valley". This approximate true-color composite spans about 90 degrees and consists of eighteen frames captured by the rover's panoramic camera.

Spirit celebrated its one Martian year anniversary (669 sols or 687 Earth days) on November 20, 2005. *Opportunity* celebrated its anniversary on December 12, 2005. At the beginning of the mission, it was expected that the rovers would not survive much longer than 90 Martian days. The Columbia Hills were "just a dream", according to rover driver Chris Leger. *Spirit* explored the semicircular rock formation known as Home Plate. It is a layered rock outcrop that puzzles and excites scientists. It is thought that its rocks are explosive volcanic deposits, though other possibilities exist, including impact deposits or sediment borne by wind or water.

Spirit's front right wheel ceased working on March 13, 2006, while the rover was moving itself to McCool Hill. Its drivers attempted to drag the dead wheel behind *Spirit*, but this only worked until reaching an impassable sandy area on the lower slopes. Drivers directed *Spirit* to a smaller sloped feature, dubbed "Low Ridge Haven", where it spent the long Martian winter, waiting for spring and increased solar power levels suitable for driving. That September, *Opportunity* reached the rim of Victoria crater, and Spaceflight Now reported that NASA had extended mission for the two rovers through September

2007. On February 6, 2007, *Opportunity* became the first spacecraft to traverse ten kilometers (10,000 meters) on the surface of Mars.

Opportunity was poised to enter Victoria Crater from its perch on the rim of Duck Bay on June 28, 2007, but due to extensive dust storms, it was indefinitely delayed until the dust had cleared and power returned to safe levels. Two months later, *Spirit* and *Opportunity* resumed driving after hunkering down during raging dust storms that limited solar power to a level that nearly caused the permanent failure of both rovers.

On October 1, 2007, both *Spirit* and *Opportunity* entered their fifth mission extension that could possibly extend operations into 2009, allowing the rovers to have spent five years exploring the Martian surface, pending their continued survival.

On August 26, 2008, *Opportunity* began its three-day climb out of Victoria crater amidst concerns that power spikes, similar to those seen on *Spirit* before the failure of its right-front wheel, might prevent it from ever being able to leave the crater if a wheel failed. Project scientist Bruce Banerdt also said, "We've done everything we entered Victoria Crater to do and more." *Opportunity* will return to the plains in order to characterize Meridiani Planum's vast diversity of rocks—some of which may have been blasted out of craters such as Victoria. The rover had been exploring Victoria Crater since September 11, 2007. As of January 2009, the two rovers had collectively sent back 250,000 images and traveled over 21 kilometers (13 mi).

After driving about 3.2 kilometers (2 mi) since it left Victoria crater, *Opportunity* first saw the rim of Endeavour crater on March 7, 2009. It passed the 10-mile mark (16 kilometers) along the way on sol 1897. Meanwhile, at Gusev crater, *Spirit* was dug in deep into the Martian sand, much as *Opportunity* was at Purgatory Dune in 2005.

On January 3 and January 24, 2010, *Spirit* and *Opportunity* marked six years on Mars, respectively. On January 26, NASA announced that *Spirit* will be used as a stationary research platform after several months of unsuccessful attempts to free the rover from soft sand.

NASA announced on March 24, 2010, that *Opportunity*, which has an estimated remaining drive distance of 12 km to Endeavour Crater, has traveled over 20 km since the start of its mission. Each rover was designed with a mission driving distance goal of just 600 meters. One week later, they announced that *Spirit* may have gone into hibernation for the Martian winter and might not wake up again for months.

On September 8, 2010, it was announced that *Opportunity* had reached the halfway point of the 19-kilometer journey between Victoria crater and Endeavour crater.

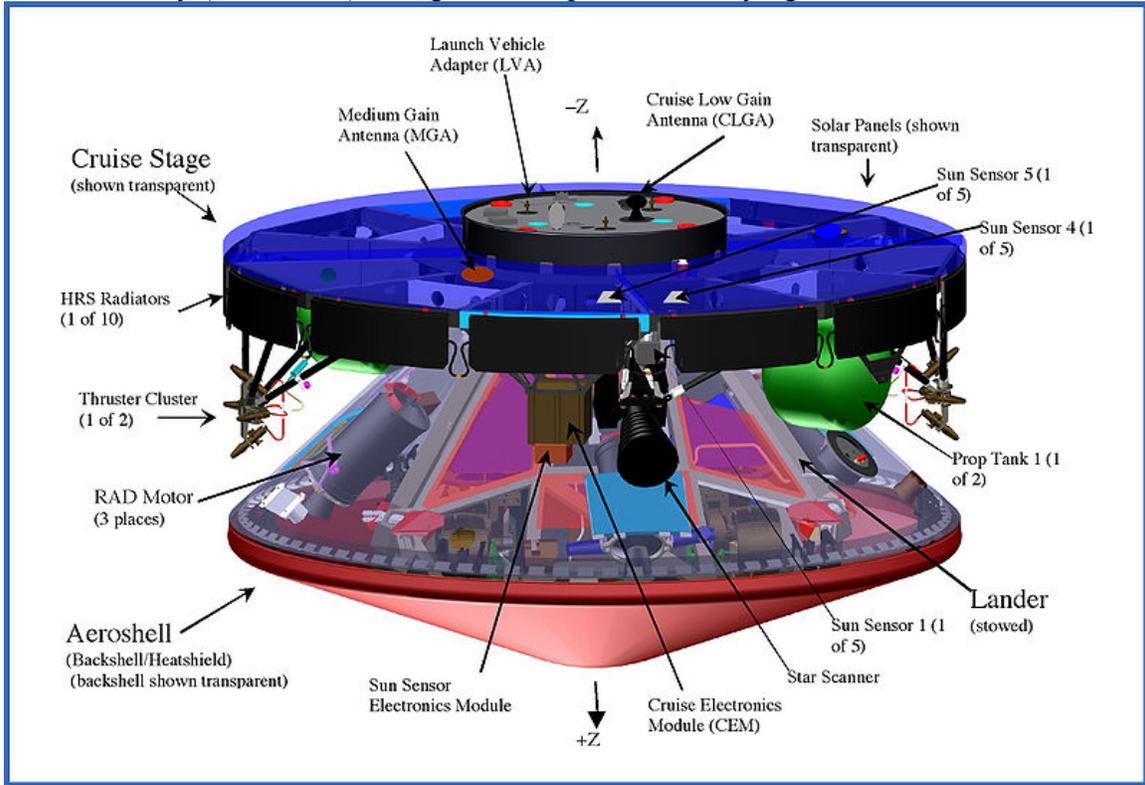
Spacecraft design



Delta II Heavy lifting off with MER-A on June 10, 2003



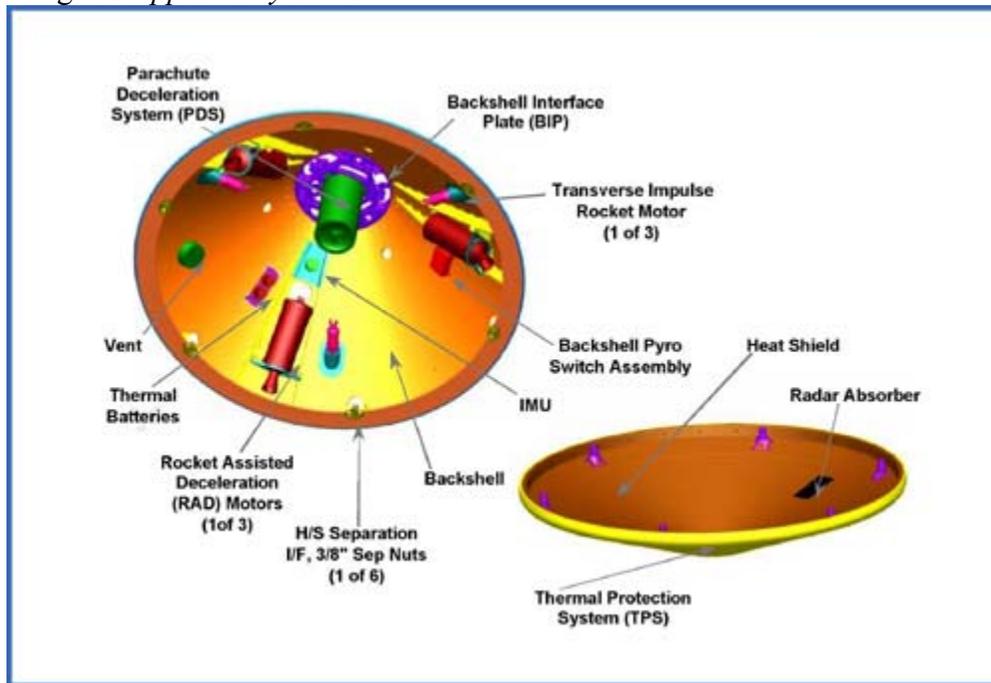
Delta II Heavy (7925H-9.5) lifting off from pad 17-B carrying MER-B



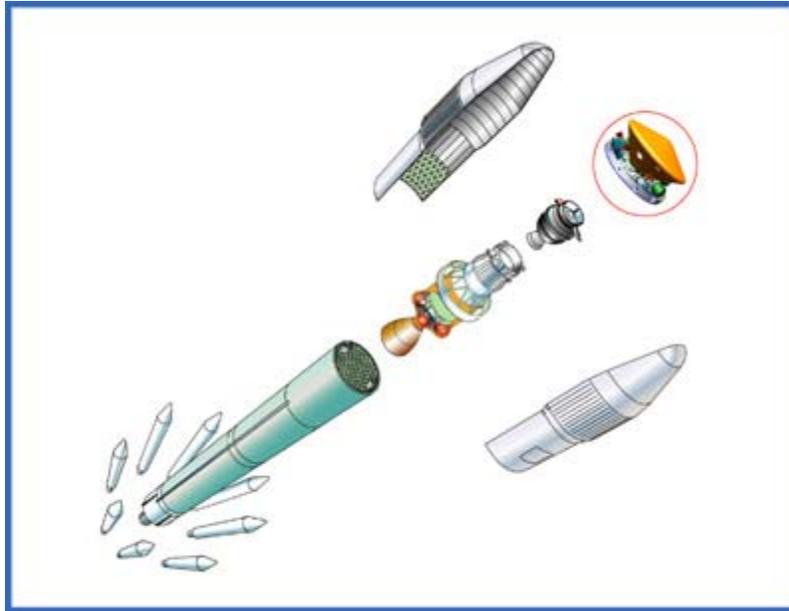
MER cruise stage diagram



Cruise stage of *Opportunity* rover



Overview of the Mars Exploration Rover aeroshell



MER launch configuration, break apart illustration

The Mars Exploration Rover was designed to be stowed in the nose of a Delta II rocket. Each spacecraft consists of several components:

- Rover: 185 kg (408 lb)
- Lander: 348 kg (767 lb)
- Backshell / Parachute: 209 kg (461 lb)
- Heat Shield: 78 kg (172 lb)
- Cruise Stage: 193 kg (425 lb)
- Propellant: 50 kg (110 lb)
- Instruments: 5 kg (11 lb)

Total mass is 1,063 kg (2,343 lb).

Cruise stage

The cruise stage is the component of the spacecraft that is used for travel from Earth to Mars. It is very similar to the Mars Pathfinder in design and is approximately 2.65 meters (8.7 ft) in diameter and 1.6 m (5.2 ft) tall, including the entry vehicle (see below).

The primary structure is aluminium with an outer ring of ribs covered by the solar panels, which are about 2.65 m (8.7 ft) in diameter. Divided into five sections, the solar arrays can provide up to 600 watts of power near Earth and 300 W at Mars.

Heaters and multi-layer insulation keep the electronics "warm". A freon system removes heat from the flight computer and communications hardware inside the rover so they do not overheat. Cruise avionics systems allow the flight computer to interface with other electronics, such as the sun sensors, star scanner and heaters.

Navigation

The star scanner (with a backup system) and sun sensor allowed the spacecraft to know its orientation in space by analyzing the position of the Sun and other stars in relation to itself. Sometimes the craft could be slightly off course; this was expected, given the 500 million kilometer (320 million mile) journey. Thus navigators planned up to six trajectory correction maneuvers, along with health checks.

To ensure the spacecraft arrived at Mars in the right place for its landing, two light-weight, aluminium-lined tanks carried about 31 kg (about 68 lb) of hydrazine propellant. Along with cruise guidance and control systems, the propellant allowed navigators to keep the spacecraft on course. Burns and pulse firings of the propellant allowed three types of maneuvers:

- An axial burn uses pairs of thrusters to change spacecraft velocity;
- A lateral burn uses two "thruster clusters" (four thrusters per cluster) to move the spacecraft "sideways" through seconds-long pulses;
- Pulse mode firing uses coupled thruster pairs for spacecraft precession maneuvers (turns).

Communication

The spacecraft used a high-frequency X band radio wavelength to communicate, which allowed for less power and smaller antennas than many older craft, which used S band.

Navigators sent commands through two antennas on the cruise stage: a **cruise low-gain antenna** mounted inside the inner ring, and a **cruise medium-gain antenna** in the outer ring. The low-gain antenna was used close to Earth. It is omni-directional, so the transmission power that reached Earth fell faster with increasing distance. As the craft moved closer to Mars, the Sun and Earth moved closer in the sky as viewed from the craft, so less energy reached Earth. The spacecraft then switched to the medium-gain antenna, which directed the same amount of transmission power into a tighter beam toward Earth.

During flight, the spacecraft was spin-stabilized with a spin rate of two revolutions per minute (rpm). Periodic updates kept antennas pointed toward Earth and solar panels toward the Sun.

Aeroshell

The aeroshell maintained a protective covering for the lander during the seven month voyage to Mars. Together with the lander and the rover, it constituted the "entry vehicle". Its main purpose was to protect the lander and the rover inside it from the intense heat of entry into the thin Martian atmosphere. It was based on the Mars Pathfinder and Mars Viking designs.

Parts

The aeroshell was made of two main parts: a heat shield and a backshell. The heat shield was flat and brownish, and protected the lander and rover during entry into the Martian atmosphere and acted as the first aerobrake for the spacecraft. The backshell was large, cone-shaped and painted white. It carried the parachute and several components used in later stages of entry, descent, and landing, including:

- A parachute (stowed at the top of the backshell);
- The backshell electronics and batteries that fire off pyrotechnic devices like separation nuts, rockets and the parachute mortar;
- A Litton LN-200 Inertial Measurement Unit (IMU), which monitors and reports the orientation of the backshell as it swings under the parachute;
- Three large solid rocket motors called RAD rockets (Rocket Assisted Descent), each providing about a ton of force (10 kilonewtons) for about 4 seconds;
- Three small solid rockets called TIRS (mounted so that they aim horizontally out the sides of the backshell) that provide a small horizontal kick to the backshell to help orient the backshell more vertically during the main RAD rocket burn.

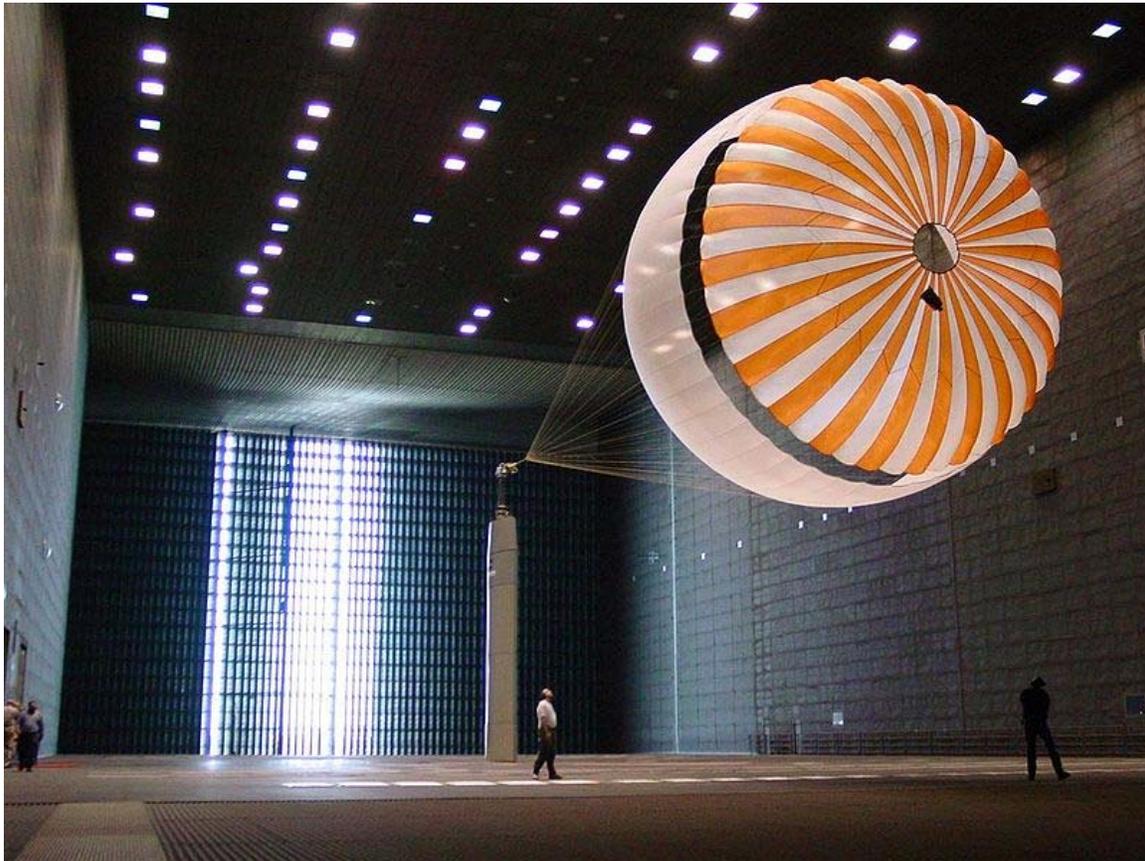
Composition

Built by the Lockheed Martin Astronautics Co. in Denver, Colorado, the aeroshell is made of an aluminium honeycomb structure sandwiched between graphite-epoxy face sheets. The outside of the aeroshell is covered with a layer of phenolic honeycomb. This honeycomb is filled with an ablative material (also called an "ablator"), that dissipates heat generated by atmospheric friction.

The ablator itself is a unique blend of cork wood, binder and many tiny silica glass spheres. It was invented for the heat shields flown on the Viking Mars lander missions. A similar technology was used in the first US manned space missions Mercury, Gemini and Apollo. It was specially formulated to react chemically with the Martian atmosphere during entry and carry heat away, leaving a hot wake of gas behind the vehicle. The vehicle slowed from 19000 km/h (about 12000 mph) to about 1600 km/h (1000 mph) in about a minute, producing about 60 m/s² (6 g) of acceleration on the lander and rover.

The backshell and heat shield are made of the same materials, but the heat shield has a thicker, 1/2 inch (12.7 mm), layer of the ablator. Instead of being painted, the backshell was covered with a very thin aluminized PET film blanket to protect it from the cold of deep space. The blanket vaporized during entry into the Martian atmosphere.

Parachute



Mars Exploration Rover's parachute test

The parachute helped slow the spacecraft during entry, descent, and landing. It is located in the backshell.

Design

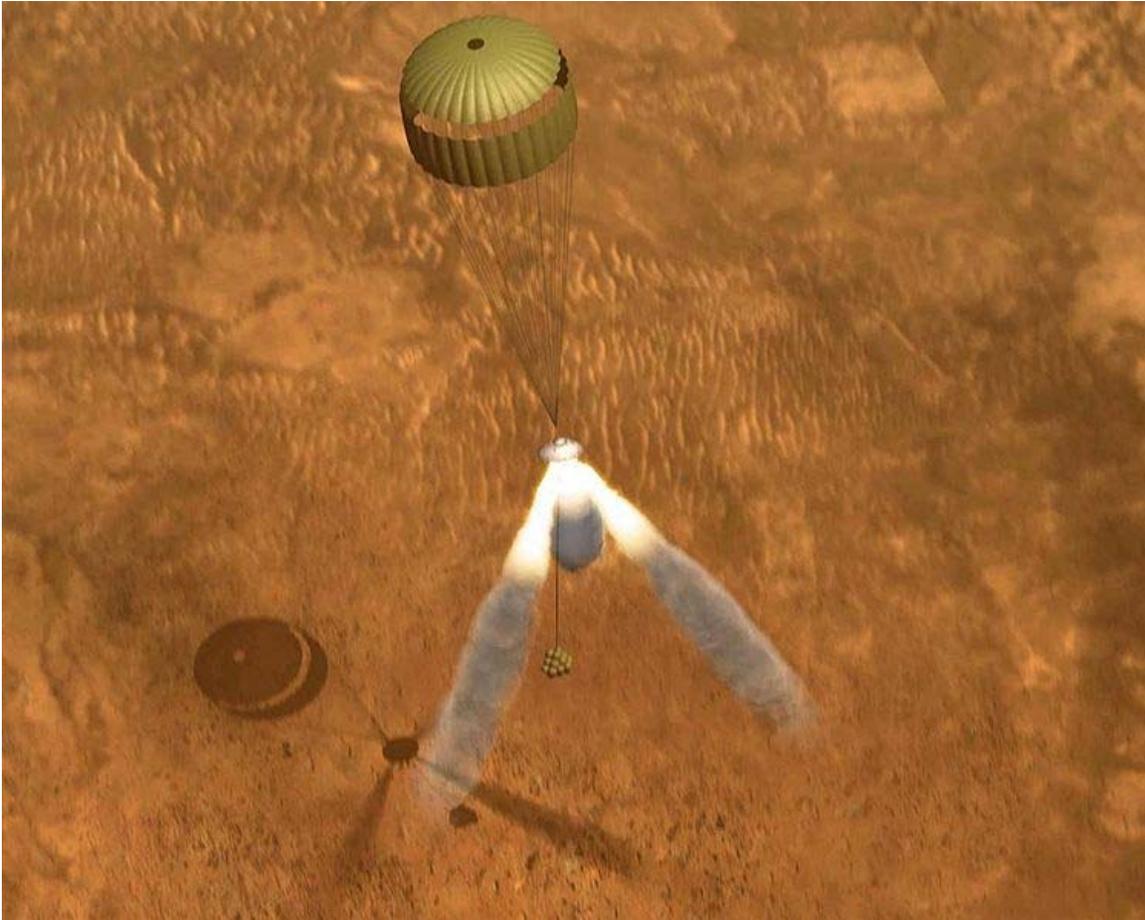
The 2003 parachute design was part of a long-term Mars parachute technology development effort and is based on the designs and experience of the Viking and Pathfinder missions. The parachute for this mission is 40% larger than Pathfinder's because the largest load for the Mars Exploration Rover is 80 to 85 kilonewtons (kN) or 18,000 to 19,000 lbf (85 kN) when the parachute fully inflates. By comparison, Pathfinder's inflation loads were approximately 35 kN (about 8,000 lbf). The parachute was designed and constructed in South Windsor, Connecticut by Pioneer Aerospace, the company that also designed the parachute for the *Stardust* mission.

Composition

The parachute is made of two durable, lightweight fabrics: polyester and nylon. A triple bridle made of Kevlar connects the parachute to the backshell.

The amount of space available on the spacecraft for the parachute is so small that the parachute had to be pressure-packed. Before launch, a team tightly folded the 48 suspension lines, three bridle lines, and the parachute. The parachute team loaded the parachute in a special structure that then applied a heavy weight to the parachute package several times. Before placing the parachute into the backshell, the parachute was heat set to sterilize it.

Connected systems



Descent is halted by retrorockets and lander is dropped 10m (30 ft) to the surface in this computer generated impression.

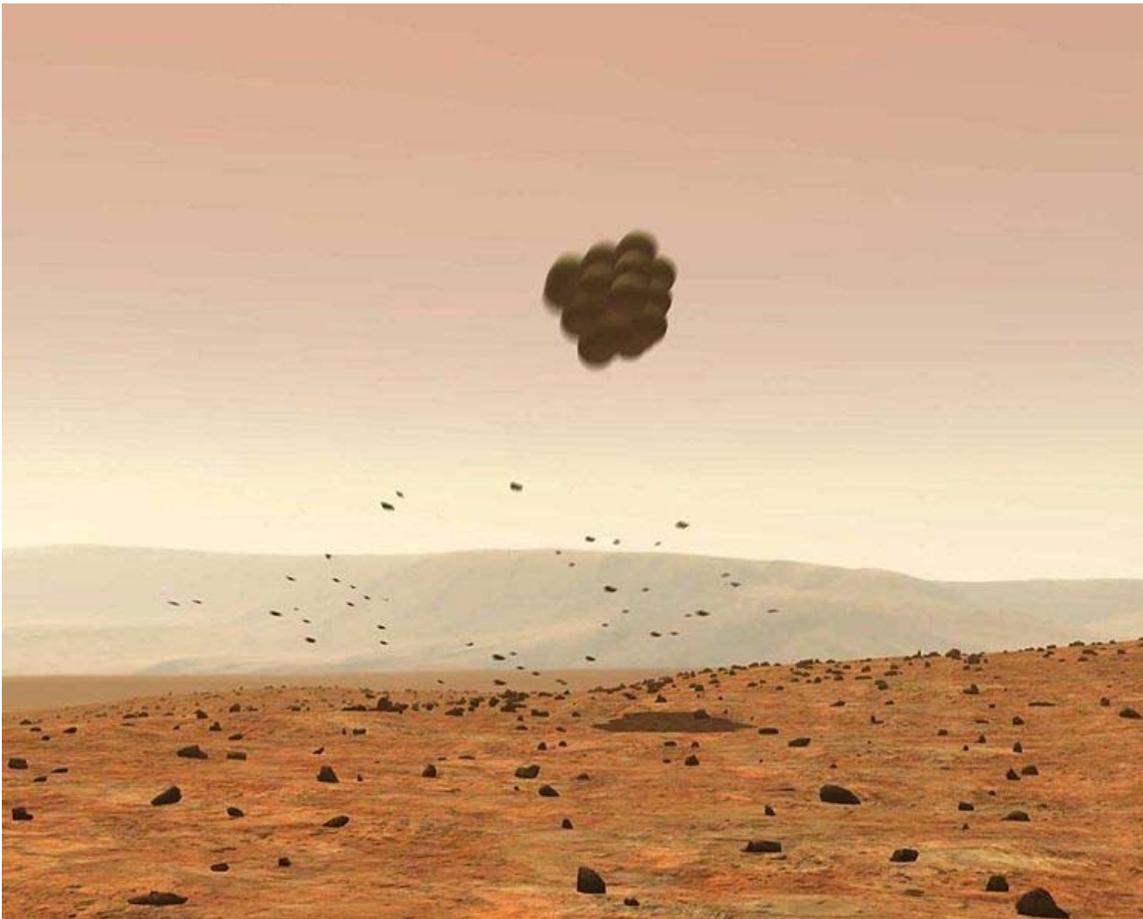
Zylon Bridles: After the parachute was deployed at an altitude of about 10 km (6 miles) above the surface, the heatshield was released using 6 separation nuts and push-off springs. The lander then separated from the backshell and "rappelled" down a metal tape on a centrifugal braking system built into one of the lander petals. The slow descent down the metal tape placed the lander in position at the end of another bridle (tether), made of a nearly 20 m (65 ft) long braided Zylon.

Zylon is an advanced fiber material, similar to Kevlar, that is sewn in a webbing pattern (like shoelace material) to make it stronger. The Zylon bridle provides space for airbag deployment, distance from the solid rocket motor exhaust stream, and increased stability. The bridle incorporates an electrical harness that allows the firing of the solid rockets from the backshell as well as provides data from the backshell inertial measurement unit (which measures rate and tilt of the spacecraft) to the flight computer in the rover.

Rocket assisted descent (RAD) motors: Because the atmospheric density of Mars is less than 1% of Earth's, the parachute alone could not slow down the Mars Exploration Rover enough to ensure a safe, low landing speed. The spacecraft descent was assisted by rockets that brought the spacecraft to a dead stop 10–15 m (30–50 ft) above the Martian surface.

Radar altimeter unit: A radar altimeter unit was used to determine the distance to the Martian surface. The radar's antenna is mounted at one of the lower corners of the lander tetrahedron. When the radar measurement showed the lander was the correct distance above the surface, the Zylon bridle was cut, releasing the lander from the parachute and backshell so that it was free and clear for landing. The radar data also enabled the timing sequence on airbag inflation and backshell RAD rocket firing.

Airbags



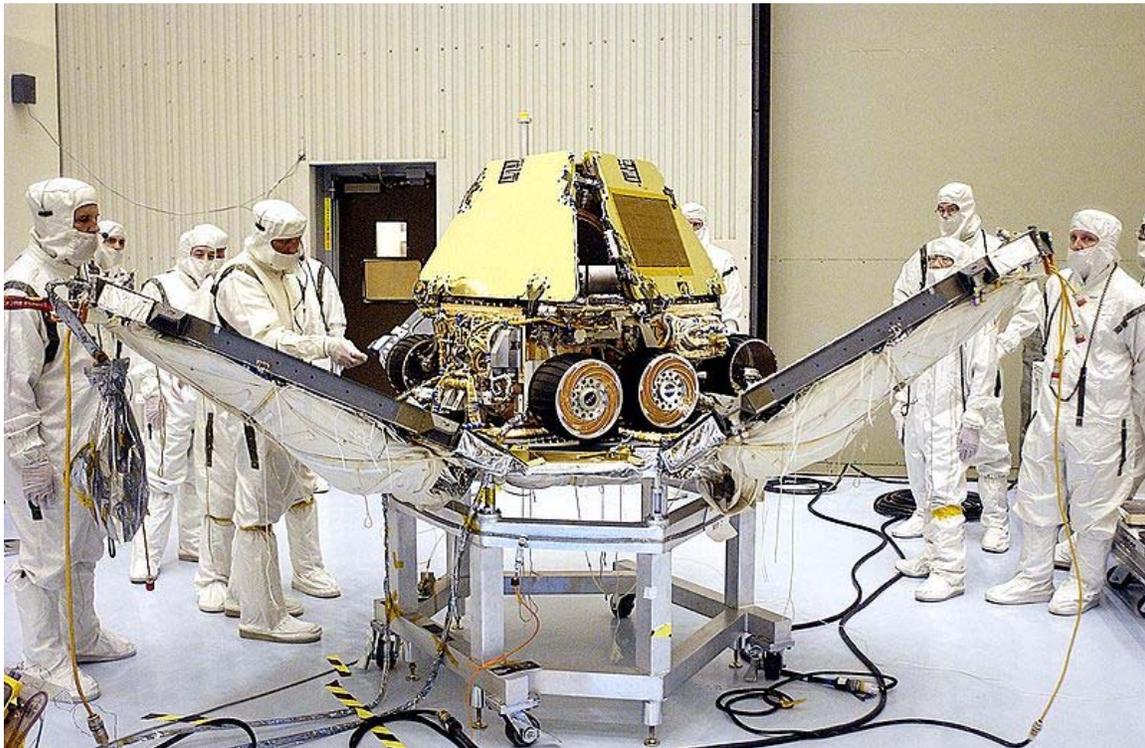
Artist's concept of inflated airbags

Airbags used in the Mars Exploration Rover mission are the same type that Mars Pathfinder used in 1997. They had to be strong enough to cushion the spacecraft if it landed on rocks or rough terrain and allow it to bounce across Mars' surface at freeway speeds after landing. The airbags had to be inflated seconds before touchdown and deflated once safely on the ground.

The airbags were made of Vectran, like those on Pathfinder. Vectran has almost twice the strength of other synthetic materials, such as Kevlar, and performs better in cold temperatures. Six 100 denier (10 mg/m) layers of Vectran protected one or two inner bladders of Vectran in 200 denier (20 mg/m). Using 100 denier (10 mg/m) leaves more fabric in the outer layers where it is needed, because there are more threads in the weave.

Each rover used four airbags with six lobes each, all of which were connected. Connection was important, since it helped abate some of the landing forces by keeping the bag system flexible and responsive to ground pressure. The airbags were not attached directly to the rover, but were held to it by ropes crisscrossing the bag structure. The ropes gave the bags shape, making inflation easier. While in flight, the bags were stowed along with three gas generators that are used for inflation.

Lander



MER lander petals opening

The spacecraft lander is a protective "shell" that houses the rover, and together with the airbags, protects it from the forces of impact.

The lander is a tetrahedron shape, whose sides open like petals. It is strong and light, and made of beams and sheets. The beams consist of layers of graphite fiber woven into a fabric that is lighter than aluminium and more rigid than steel. Titanium fittings are glued and fitted onto the beams to allow it to be bolted together. The rover was held inside the lander by bolts and special nuts that were released after landing with small explosives.

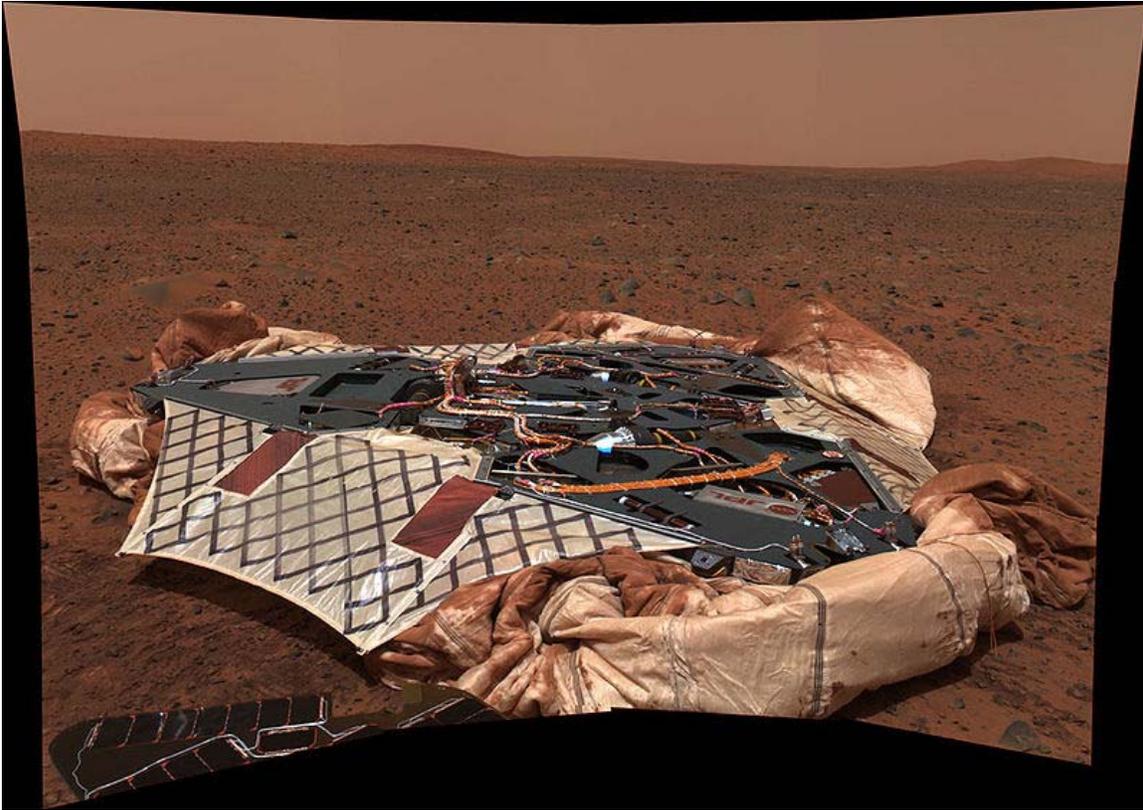
Uprighting

After the lander stopped bouncing and rolling on the ground, it came to rest on the base of the tetrahedron or one of its sides. The sides then opened to make the base horizontal and the rover upright. The sides are connected to the base by hinges, each of which has a motor strong enough to lift the lander. The rover plus lander has a mass of about 533 kilograms (1,175 pounds). The rover alone weighs about 185 kg (408 lb). The gravity on Mars is about 38% of Earth's, so the motor does not need to be as powerful as it would on Earth.

The rover contains accelerometers to detect which way is down (toward the surface of Mars) by measuring the pull of gravity. The rover computer then commanded the correct lander petal to open to place the rover upright. Once the base petal was down and the rover was upright, the other two petals were opened.

The petals initially opened to an equally flat position, so all sides of the lander were straight and level. The petal motors are strong enough so that if two of the petals come to rest on rocks, the base with the rover would be held in place like a bridge above the ground. The base will hold at a level even with the height of the petals resting on rocks, making a straight flat surface throughout the length of the open, flattened lander. The flight team on Earth could then send commands to the rover to adjust the petals and create a safe path for the rover to drive off the lander and onto the Martian surface without dropping off a steep rock.

Moving the payload onto Mars



Spirit's lander on Mars

The moving of the rover off the lander is called the egress phase of the mission. The rover must avoid having its wheels caught in the airbag material or falling off a sharp incline. To help this, a retraction system on the petals slowly drags the airbags toward the lander before the petals open. Small ramps on the petals fan out to fill spaces between the petals. They cover uneven terrain, rock obstacles, and airbag material, and form a circular area from which the rover can drive off in more directions. They also lower the step that the rover must climb down. They are nicknamed "batwings", and are made of Vectran cloth.

About three hours were allotted to retract the airbags and deploy the lander petals.

Rover design



Mars Exploration Rover vs. Sojourner rover

The rovers are six-wheeled, solar-powered robots that stand 1.5 m (4.9 ft) high, 2.3 m (7.5 ft) wide and 1.6 m (5.2 ft) long. They weigh 180 kg (400 lb), 35 kg (80 lb) of which is the wheel and suspension system.

Drive system

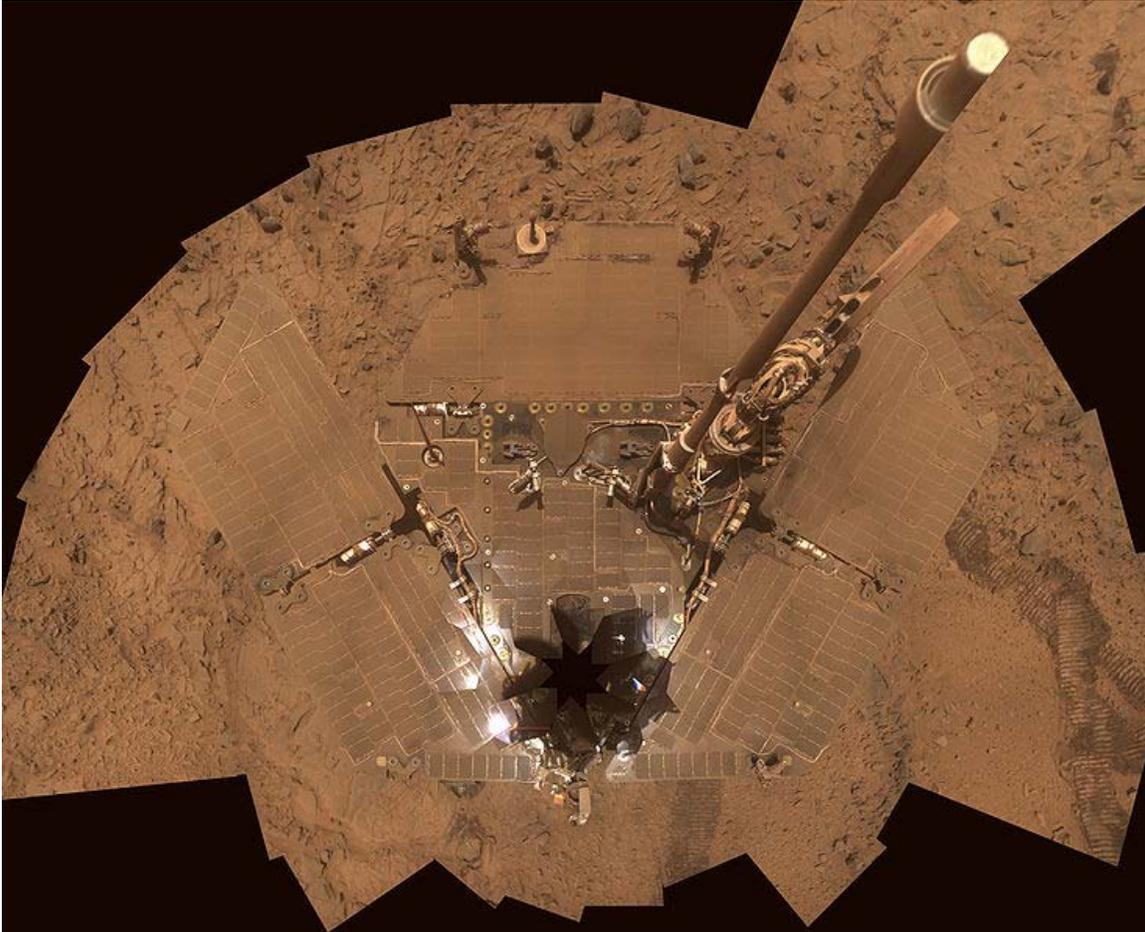
Each rover has six wheels mounted on a rocker-bogie suspension system that ensures wheels remain on the ground while driving over rough terrain. The design reduces the range of motion of the rover body by half, and allows the rover to go over obstacles or through holes that are more than a wheel diameter (250 mm or 10 inches) in size. Each wheel also has cleats, providing grip for climbing in soft sand and scrambling over rocks.

Each wheel has its own motor. The two front and two rear wheels each have individual steering motors. This allows the vehicle to turn in place, a full revolution, and to swerve and curve, making arching turns. The rover is designed to withstand a tilt of 45 degrees in any direction without overturning. However, the rover is programmed through its "fault protection limits" in its hazard avoidance software to avoid exceeding tilts of 30 degrees.

Each rover can spin one of its front wheels in place to grind deep into the terrain. It is to remain motionless while the digging wheel is spinning. The rovers have a top speed on

flat hard ground of 50 mm/s (2 in/s). The average speed is 10 mm/s, because its hazard avoidance software causes it to stop every 10 seconds for 20 seconds to observe and understand the terrain into which it has driven.

Power and electronic systems



Circular projection showing MER-A *Spirit's* solar panels covered in dust in October 2007 on Mars. Unexpected Cleaning events have periodically increased power.

When fully illuminated, the rover triplejunction solar arrays generate about 140 watts for up to four hours per Martian day (sol). The rover needs about 100 watts to drive. Its power system includes two rechargeable lithium ion batteries weighing 7.15 kg (16 pounds) each, that provide energy when the sun is not shining, especially at night. Over time, the batteries will degrade and will not be able to recharge to full capacity.

For comparison, the future Mars Science Laboratory's power system is composed of a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) produced by Boeing. The MMRTG is designed to provide 125W of electrical power at the start of the mission, falling to 100W after 14 years of service. It will be used to power the MSL's many systems and instruments. Solar panels were also considered for the MSL, but RTGs

provide constant power, regardless of the time of day, and thus the versatility to work in dark environments and high latitudes where solar energy is not readily available. The MSL will generate 2.5 kilowatt hours per day, compared to the Mars Exploration Rovers, which can generate about 0.6 kilowatt hours per day.

It was thought that by the end of the 90-sol mission, the capability of the solar arrays to generate power would likely be reduced to about 50 watts. This was due to anticipated dust coverage on the solar arrays, and the change in season. Over three Earth years later, however, the rovers' power supplies hovered between 300 watt-hours and 900 watt-hours per day, depending on dust coverage. Cleaning events (dust removal by wind) have occurred more often than NASA expected, keeping the arrays relatively free of dust and extending the life of the mission. During a 2007 global dust storm on Mars, both rovers experienced some of the lowest power of the mission; *Opportunity* dipped to 128 watt-hours. In November 2008, Spirit had overtaken this low-energy record with a production of 89 watt-hours, due to dust storms in the region of Gusev crater.

The rovers run a VxWorks embedded operating system on a radiation-hardened 20 MHz RAD6000 CPU with 128 MB of DRAM with error detection and correction and 3 MB of EEPROM. Each rover also has 256 MB of flash memory. To survive during the various mission phases, the rover's vital instruments must stay within a temperature of $-40\text{ }^{\circ}\text{C}$ to $+40\text{ }^{\circ}\text{C}$ ($-40\text{ }^{\circ}\text{F}$ to $104\text{ }^{\circ}\text{F}$). At night, the rovers are heated by eight radioisotope heater units (RHU), which each continuously generate 1 W of thermal energy from the decay of radioisotopes, along with electrical heaters that operate only when necessary. A sputtered gold film and a layer of silica aerogel are used for insulation.

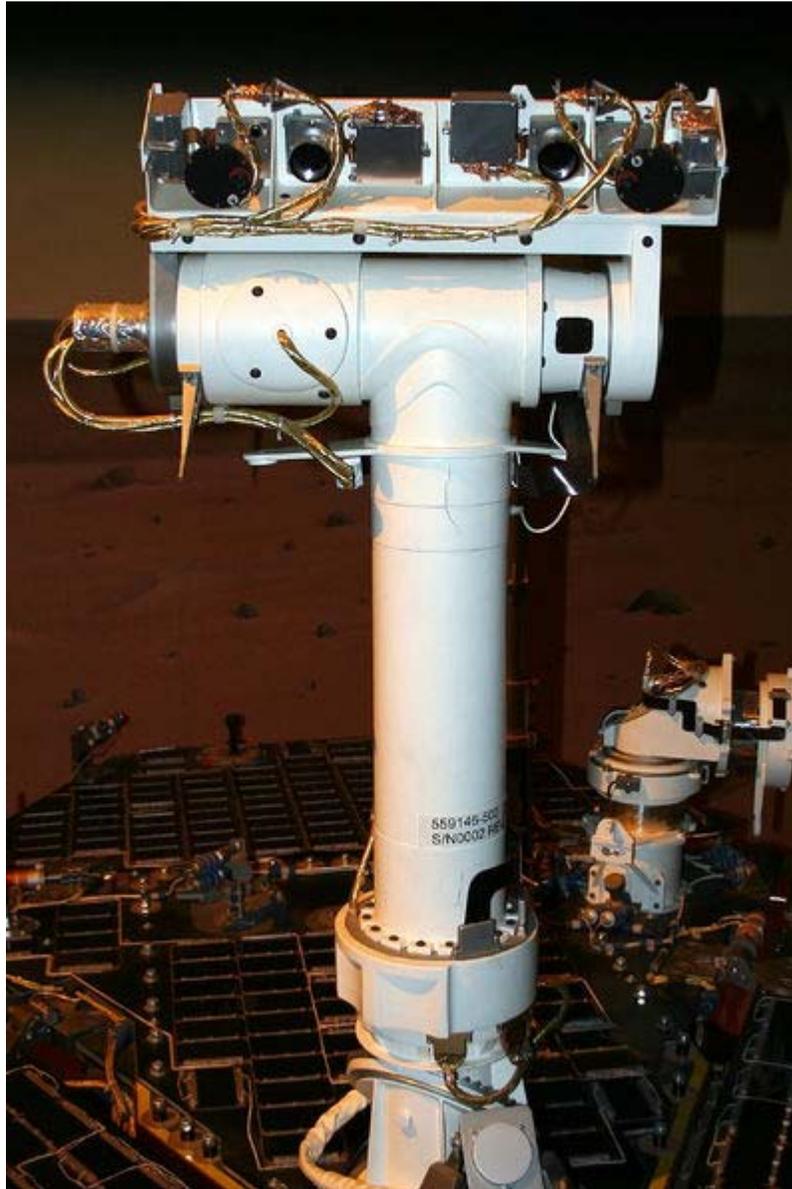
Communication

The rover has a low-gain and a high-gain antenna. The low-gain antenna is omnidirectional, and transmits data at a low rate to Deep Space Network (DSN) antennas on Earth. The high-gain antenna is directional and steerable, and can transmit data to Earth at a higher rate. The rovers also use the low-gain antennas to communicate with spacecraft orbiting Mars, the Mars Odyssey and (before its failure) the Mars Global Surveyor. The orbiters relay data from and to Earth; most data to Earth is relayed through Odyssey. The orbiters are closer to the rovers than the antennas on Earth, and have a view of Earth for much longer than the rovers. The orbiters communicate with the rovers using UHF antennas, which have shorter range than the low and high-gain antennas. One UHF antenna is on the rover, and one is on a petal of the lander to aid in gaining information during the critical landing event.

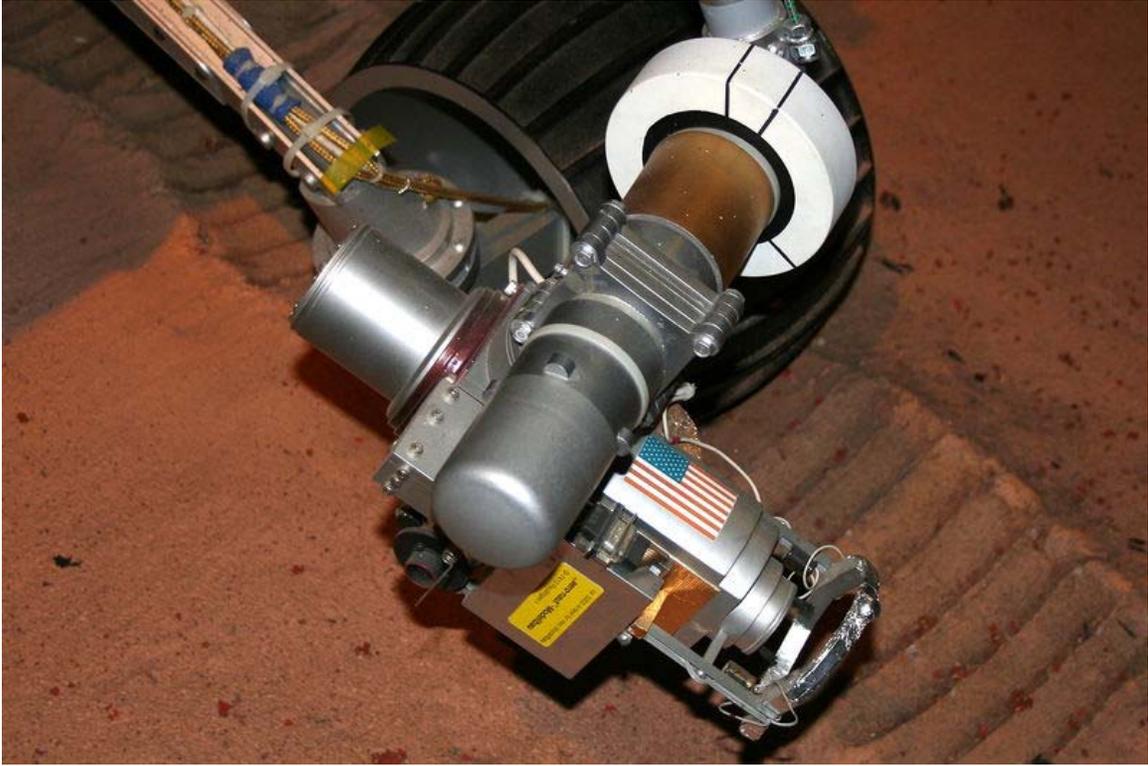
The rovers have a total of 9 cameras, which produce 1024-pixel by 1024-pixel images at 12 bits per pixel, but most navigation camera images and image thumbnails are truncated to 8 bits per pixel to conserve memory and transmission time. All images are then compressed using ICER before being stored and sent to Earth. Navigation, thumbnail, and many other image types are compressed to approximately 0.8 to 1.1 bits/pixel. Lower bit rates (less than 0.5 bit/pixel) are used for certain wavelengths of multi-color panoramic images.

ICER is based on wavelets, and was designed specifically for deep-space applications. It produces progressive compression, both lossless and lossy, and incorporates an error-containment scheme to limit the effects of data loss on the deep-space channel. It outperforms the lossy JPEG image compressor and the lossless Rice compressor used by the Mars Pathfinder mission.

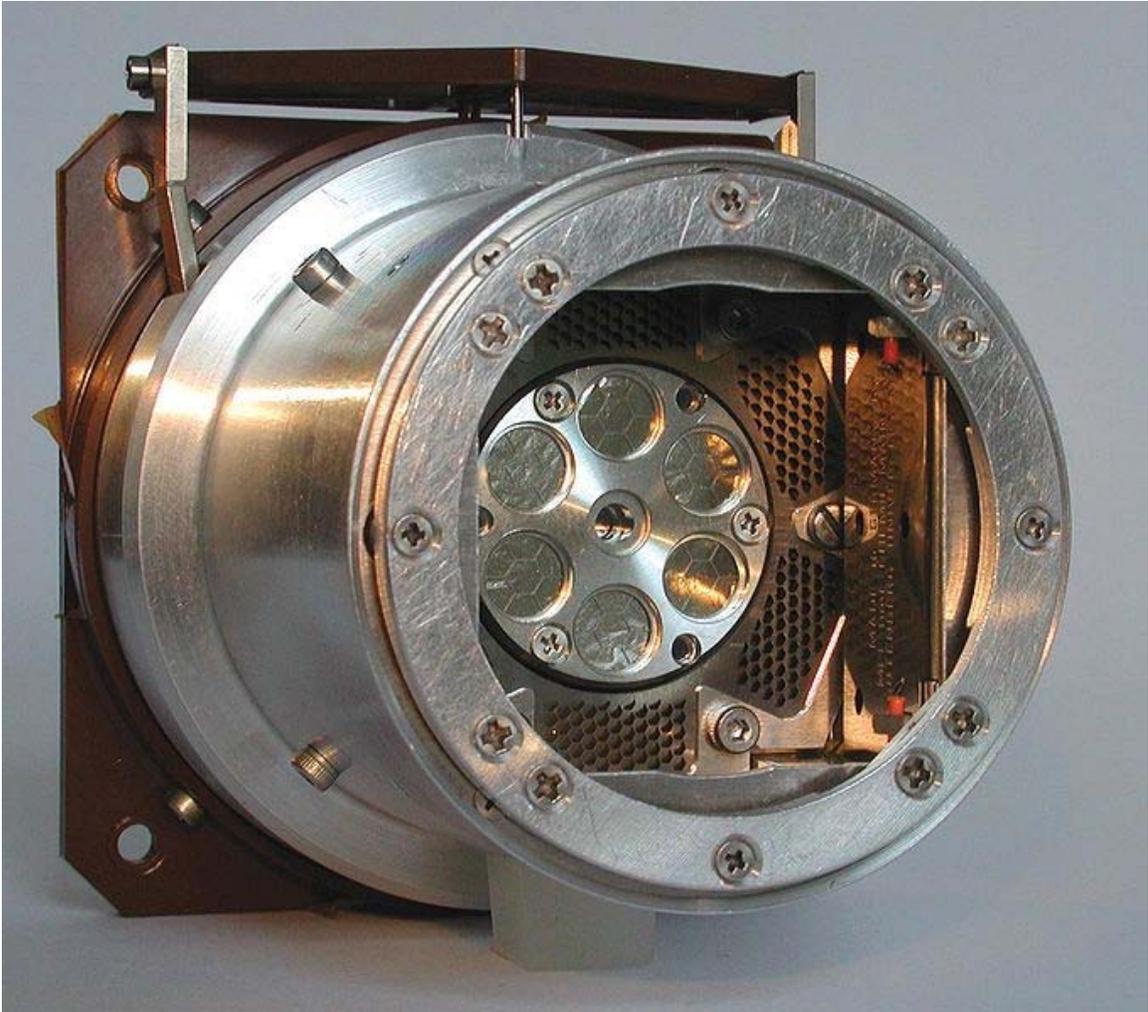
Scientific instrumentation



Panoramic Camera (Pancam)



Rock Abrasion Tool (RAT)



Alpha particle X-Ray Spectrometer (APXS)

The rover has various instruments. Three are mounted on one assembly:

- Panoramic Camera (Pancam), for determining the texture, color, mineralogy, and structure of the local terrain.
- Navigation Camera (Navcam), that has higher field of view but lower resolution and is monochromatic, for navigation and driving.
- A mirror for the Miniature Thermal Emission Spectrometer (Mini-TES), which identifies promising rocks and soils for closer examination, and determines the processes that formed them. It was built by Arizona State University.

The cameras are mounted 1.5 meters high on the Pancam Mast Assembly. One motor turns the assembly horizontally a whole revolution. Another points the cameras vertically, at most straight up or down. A third motor points the Mini-TES, up to 30° above the horizon and 50° below. The assembly was built by Ball Aerospace & Technologies Corp., Boulder, Colorado, as was the High-Gain Antenna Gimbal (HGAG).

Four monochromatic hazard cameras (Hazcams) are mounted on the rover's body, two in front and two behind.

The instrument deployment device (IDD), also called the rover arm, holds the following:

- Mössbauer spectrometer (MB) MIMOS II, developed by Dr. Göstar Klingelhöfer at the Johannes Gutenberg University in Mainz, Germany, is used for close-up investigations of the mineralogy of iron-bearing rocks and soils.
- Alpha Particle X-Ray Spectrometer (APXS), developed by the Max Planck Institute for Chemistry in Mainz, Germany, is used for close-up analysis of the abundances of elements that make up rocks and soils.
- Magnets, for collecting magnetic dust particles, developed by Jens Martin Knudsen's group at the Niels Bohr Institute, Copenhagen. The particles are analyzed by the Mössbauer Spectrometer and X-ray Spectrometer to help determine the ratio of magnetic particles to non-magnetic particles and the composition of magnetic minerals in airborne dust and rocks that have been ground by the Rock Abrasion Tool. There are also magnets on the front of the rover, which are studied extensively by the Mössbauer spectrometer.
- Microscopic Imager (MI) for obtaining close-up, high-resolution images of rocks and soils. Development was led by Ken Herkenhoff's team at the USGS Astrogeology Research Program.
- Rock Abrasion Tool (RAT), developed by Honeybee Robotics, for removing dusty and weathered rock surfaces and exposing fresh material for examination by instruments on-board.

The robotic arm is able to place instruments directly up against rock and soil targets of interest.

Naming of *Spirit* and *Opportunity*

The *Spirit* and *Opportunity* rovers were named through a student essay competition. The winning entry was by Sofi Collis, a third-grade Russian-American student from Arizona.

I used to live in an orphanage. It was dark and cold and lonely. At night, I looked up at the sparkly sky and felt better. I dreamed I could fly there. In America, I can make all my dreams come true. Thank you for the 'Spirit' and the 'Opportunity.'

— Sofi Collis, age 9

Prior to this, during the development and building of the rovers, they were known as MER-1 (*Opportunity*) and MER-2 (*Spirit*). Internally, NASA also uses the mission designations MER-A (*Spirit*) and MER-B (*Opportunity*) based on the order of landing on Mars (Spirit first then Opportunity).

Test rovers



Rover team members simulate *Spirit* in a Martian sandtrap.

The Jet Propulsion Laboratory maintains a pair of rovers at its location in Pasadena for testing and modeling of situations on Mars. One test rover, weighing approximately 180 kilograms (400 lb), is fully instrumented and nearly identical to *Spirit* and *Opportunity*. Another test version is identical in size and drive characteristics but does not include all instruments. It weighs in at 80 kilograms (180 lb), much closer to the weight of *Spirit* and *Opportunity* in the reduced gravity of Mars. These rovers were used in 2009 for a simulation of the incident in which *Spirit* became trapped in soft soil.

SAP

The NASA team uses a software application called *SAP* to view images collected from the rover, and to plan its daily activities. There is a version available to the public called Maestro.

Medical Robots

Robotic surgery

Robotic surgery, computer-assisted surgery, and robot-assisted surgery are terms for various technological developments that currently are developed to support a range of surgical procedures.

Robot-assisted surgery was developed to overcome limitations of minimally invasive surgery, Instead of directly moving the instruments the surgeon uses a computer console to manipulate the instruments attached to multiple robot arms. The computer translates the surgeon's movements, which are then carried out on the patient by the robot. Other features of the robotic system include, for example, an integrated tremor filter and the ability for scaling of movements (changing of the ratio between the extent of movements at the master console to the internal movements of the instruments attached to the robot). The console is located in the same operating room as the patient, but is physically separated from the operative workspace. Since the surgeon does not need to be in the immediate location of the patient while the operation is being performed, it can be possible for specialists to perform remote surgery on patients. Robots can perform surgery without a human surgeon .

History

The world's first surgical robot was the "Arthrobot", which was developed and used for the first time in Vancouver, BC, Canada in 1983. The robot was developed by a team led by Dr. James McEwen and Geof Auchinlek, in collaboration with orthopaedic surgeon, Dr. Brian Day. National geographic produced a movie on robotics which featured the Arthrobot. In related projects at that time, other medical robots were developed, including a robotic arm that performed eye surgery, and another that acted as an operating assistant, and handed the surgeon instruments in response to voice commands.

1985 a robot, the PUMA 560, was used to place a needle for a brain biopsy using CT guidance. In 1988, the PROBOT, developed at Imperial College London, was used to perform prostatic surgery. The ROBODOC from Integrated Surgical Systems was

introduced in 1992 to mill out precise fittings in the femur for hip replacement. Further development of robotic systems was carried out by Intuitive Surgical with the introduction of the da Vinci Surgical System and Computer Motion with the *AESOP* and the ZEUS robotic surgical system. (Intuitive Surgical bought Computer Motion in 2003; ZEUS is no longer being actively marketed.)

The da Vinci Surgical System comprises three components: a surgeon's console, a patient-side robotic cart with 4 arms manipulated by the surgeon (one to control the camera and three to manipulate instruments), and a high-definition 3D vision system. Articulating surgical instruments are mounted on the robotic arms which are introduced into the body through cannulas. The device senses the surgeon's hand movements and translates them electronically into scaled-down micro-movements to manipulate the tiny proprietary instruments. It also detects and filters out any tremors in the surgeon's hand movements, so that they are not duplicated robotically. The camera used in the system provides a true stereoscopic picture transmitted to a surgeon's console. The da Vinci System is FDA cleared for a variety of surgical procedures including surgery for prostate cancer, hysterectomy and mitral valve repair, and is used in more than 800 hospitals in the Americas and Europe. The da Vinci System was used in 48,000 procedures in 2006 and sells for about \$1.2 million. The new da Vinci HD SI released in April, 2009 currently sells for \$1.75 million. The first robotic surgery took place at The Ohio State University Medical Center in Columbus, Ohio under the direction of Dr. Robert E. Michler, Professor and Chief, Cardiothoracic Surgery. <McConnell PI, Schneeberger EW, Michler RE. History and development of robotic cardiac surgery. *Problems in General Surgery* 2003;20:62-72.>

In September 2010, the Eindhoven University of Technology announced the development of the Sofie surgical system, the first surgical robot to employ force feedback.

- In 1997 a reconnection of the fallopian tubes operation was performed successfully in Cleveland using ZEUS.
- In May 1998, Dr. Friedrich-Wilhelm Mohr using the *Da Vinci surgical robot* performed the first robotically assisted heart bypass at the Leipzig Heart Centre in Germany.
- On 2 September 1999, Dr. Randall Wolf and Dr. Robert Michler performed the first robotically assisted heart bypass in the USA at The Ohio State University.
- In October 1999 the world's first surgical robotics *beating heart* coronary artery bypass graft (CABG) was performed in Canada by Dr. Douglas Boyd and Dr. Reiza Rayman using the ZEUS surgical robot.
- In 2001, Prof. Marescaux, while in New York, used the "Zeus" robot to remotely perform gall bladder surgery on a patient who was in Strasbourg, France.
- In September 2001, Dr. Michel Gagner, while in New York, used the Zeus robotic system to remotely perform a cholecystectomy on a woman who was in Strasbourg, France.
- In May 2006 the first AI doctor-conducted unassisted robotic surgery on a 34 year old male to correct heart arrhythmia. The results were rated as better than an above-average human surgeon. The machine had a database of 10,000 similar

operations, and so, in the words of its designers, was "more than qualified to operate on any patient." The designers believe that *robots can replace half of all surgeons within 15 years*.

- In February 2008, Dr. Mohan S. Gundeti of the University of Chicago Comer Children's Hospital performed the first robotic pediatric neurogenic bladder reconstruction. The operation was performed on a 10-year-old girl.
- In January 2009, Dr. Todd Tillmanns reported the results of the largest multi-institutional study on the use of the da-Vinci robotic surgical system in gynecologic oncology and included learning curves for current and new users as a method to assess their acquisition of skills using the device.
- In January 2009, the first all-robotic-assisted kidney transplant was performed at Saint Barnabas Medical Center in Livingston, New Jersey by Dr. Stuart Geffner. The same team performed eight more fully robotic-assisted kidney transplants over the next six months.

Advantages and disadvantages

Major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery. Some major advantages of robotic surgery are precision, miniaturization, smaller incisions, decreased blood loss, less pain, and quicker healing time. Further advantages are articulation beyond normal manipulation and three-dimensional magnification, resulting in improved ergonomics. Robotic techniques are also associated with reduced duration of hospital stays, blood loss, transfusions, and use of pain medication.

With a the cost of the robot at \$1,200,000 dollars and disposable supply costs of \$1,500 per procedure, the cost of the procedure is higher. Additional surgical training is needed to operate the system. Patient surveys indicate they chose the procedure based on expectations of decreased morbidity, improved outcomes, reduced blood loss and less pain. Higher expectations may explain higher rates of dissatisfaction and regret.

The main advantage of this technique is that the incisions are very small and, consequently, patient recovery is quick. In traditional open-heart surgery, the surgeon makes a ten to twelve-inch incision, then accesses the heart by splitting the sternum (breast bone) and spreading open the rib cage. The patient is then placed on a heart-lung machine and the heart is stopped for the length of the surgery. Not only is this a way for bacteria that can cause infections to access the patient's body, it also leads to a painful wound, which takes time to heal.

Because patient recovery after robot-assisted heart surgery is quicker, the hospital stay is shorter. On average patients leave the hospital two to five days earlier than patients who have undergone traditional open-heart surgery and return to work and normal activity 50% more quickly. Reduced recovery times are not only better for the patient, they also reduce the number of staff needed during surgery, nursing care required after surgery, and, therefore, the overall cost of hospital stays.

Compared with other minimally invasive surgery approaches, robot-assisted surgery gives the surgeon better control over the surgical instruments and a better view of the surgical site. In addition, surgeons no longer have to stand throughout the surgery and do not tire as quickly. Naturally occurring hand tremors are filtered out by the robot's computer software. Finally, the surgical robot can continuously be used by rotating surgery teams (Gerhardus 2003). Gerhardus D (2003). Robot-assisted surgery: the future is here. *Journal of Healthcare Management*, Jul/Aug, 242-251. While the use of robotic surgery has become a item in the advertisement of medical services, critics point out that studies that indicate that long-term results are superior to those after laparoscopic surgery are lacking. The robotic system does not come cheap and has a learning curve. Data are absent to show that the increased costs can be justified. In the medical literature, very experienced surgeons tend to publish their results, these, however, may not be representative of surgeons with lesser experience.

The cost of robotic surgical systems lies between \$750,000 and \$1.2 million (as of 2005). Numerous financial feasibility studies have been done to determine whether it is really worth a hospital's while to purchase such a system and opinions differ dramatically. Surgeons report that, although the manufacturers of the systems provide training on this new technology, the learning phase is intensive and surgeons must operate on twelve to eighteen patients before they feel comfortable with the system. During the training phase, minimally invasive operations can take up to twice as long as traditional surgery, which ties up operating room and surgical staff time and keeps patients under anesthesia longer.

Applications

General surgery

In 2007, the University of Illinois at Chicago medical team, lead by Prof. Pier Cristoforo Giulianotti, performed the world's first ever robotic pancreatectomy and also the Midwests fully robotic Whipple surgery. In April 2008, the same team of surgeons performed the world's first fully minimally invasive liver resection for living donor transplantation, removing 60% of the patient's liver, yet allowing him to leave the hospital just a couple of days after the procedure, in very good condition. Furthermore the patient can also leave with less pain than a usual surgery due to the four puncture holes and not a scar by a surgeon .

Cardiothoracic surgery

Robot-assisted MIDCAB and Endoscopic coronary artery bypass (TECAB) surgeries are being performed with the da Vinci system. Mitral valve repairs and replacements have been performed. East Carolina University, Greenville (Dr W. Randolph Chitwood), Saint Joseph's Hospital, Atlanta (Dr Douglas A. Murphy), and Good Samaritan Hospital, Cincinnati (Dr J. Michael Smith) have popularized this procedure and proved its durability with multiple publications. Since the first robotic cardiac procedure performed in the USA in 1999, The Ohio State University, Columbus (Dr. Robert E. Michler, Dr. Juan Crestanello, Dr. Paul Vesco) has performed CABG, mitral valve, esophagectomy,

lung resection, tumor resections, among other robotic assisted procedures and serves as a training site for other surgeons. In 2002, surgeons at the Cleveland Clinic in Florida (Dr. Douglas Boyd and Kenneth Stahl) reported and published their preliminary experience with minimally invasive "hybrid" procedures. These procedures combined robotic revascularization and coronary stenting and further expanded the role of robots in coronary bypass to patients with disease in multiple vessels.

Cardiology and electrophysiology

The Stereotaxis Magnetic Navigation System (MNS) has been developed to increase precision and safety in ablation procedures for arrhythmias and atrial fibrillation while reducing radiation exposure for the patient and physician, and the system utilizes two magnets to remotely steerable catheters. The system allows for automated 3-D mapping of the heart and vasculature, and MNS has also been used in interventional cardiology for guiding stents and leads in PCI and CTO procedures, proven to reduce contrast usage and access tortuous anatomy unreachable by manual navigation. Dr. Andrea Natale has referred to the new Stereotaxis procedures with the magnetic irrigated catheters as "revolutionary."

The Hansen Medical Sensei robotic catheter system uses a remotely operated system of pulleys to navigate a steerable sheath for catheter guidance. It allows precise and more forceful positioning of catheters used for 3-D mapping of the heart and vasculature. The system provides doctors with estimated force feedback information and feasible manipulation within the left atrium of the heart. The Sensei has been associated with mixed acute success rates compared to manual, commensurate with higher procedural complications, longer procedure times but lower fluoroscopy dosage to the patient.

It was estimated that 70 to 90 hospitals in the United States now use minimally invasive surgical robots for heart surgery, and this number is expected to double by mid-2006 (Alt and Worrell 2004). At present, three types of heart surgery are being performed on a routine basis using robotic surgery systems (Kypson and Chitwood 2004). These three surgery types are:

Atrial septal defect repair — the repair of a hole between the two upper chambers of the heart, Mitral valve repair — the repair of the valve that prevents blood from regurgitating back into the upper heart chambers during contractions of the heart, Coronary artery bypass — rerouting of blood supply by bypassing blocked arteries that provide blood to the heart.

As surgeons' experience and robotic technology develop, it is expected that robot-assisted procedures will be applied to additional types of heart surgery.

Alt SJ & Worrell B (2004). More surgeons do minimally invasive heart surgery. Health Care Strategic Management, Apr, 1 & 11-19.

Kypson AP & Chitwood WR Jr. (2004). Robotic applications in cardiac surgery. *International Journal of Advanced Robotic Systems*, 1(2), 87-92.

Gastrointestinal surgery

Multiple types of procedures have been performed with either the *Zeus* or *da Vinci robot* systems, including bariatric surgery.

Gynecology

Robotic surgery in gynecology is one of the fastest growing fields of robotic surgery. This includes the use of the *da Vinci* surgical system in benign gynecology and gynecologic oncology. Robotic surgery can be used to treat fibroids, abnormal periods, endometriosis, ovarian tumors, pelvic prolapse, and female cancers. Using the robotic system, gynecologists can perform hysterectomies, myomectomies, and lymph node biopsies. The need for large abdominal incisions is virtually eliminated.

Robot assisted hysterectomies and cancer staging are being performed using *da Vinci* robotic system. The University of Tennessee, Memphis (Dr. Todd Tillmanns, Dr. Saurabh Kumar), Northwestern University (Dr. Patrick Lowe), Aurora Health Center (Dr. Scott Kamelle), West Virginia University (Dr. Jay Bringman) and The University of Tennessee, Chattanooga (Dr. Donald Chamberlain) have extensively studied the use of robotic surgery and found it to improve morbidity and mortality of patients with gynecologic cancers. They have also for the first time reported robotic surgery learning curves for current and new users as a method to assess acquisition of their skills using the device.

Neurosurgery

Several systems for stereotactic intervention are currently on the market. MD Robotic's NeuroArm is the world's first MRI-compatible surgical robot.

Orthopedics

The ROBODOC system was released in 1992 by Integrated Surgical Systems, Inc. which merged into CUREXO Technology Corporation. Also, The Acrobot Company Ltd. sells the "Acrobot Sculptor", a robot that constrains a bone cutting tool to a pre-defined volume. Another example is the CASPAR robot produced by U.R.S.-Ortho GmbH & Co. KG, which is used for total hip replacement, total knee replacement and anterior cruciate ligament reconstruction.

Pediatrics

Surgical robotics has been used in many types of pediatric surgical procedures including: tracheoesophageal fistula repair, cholecystectomy, nissen fundoplication, morgagni's hernia repair, kasai portoenterostomy, congenital diaphragmatic hernia repair, and others.

On January 17, 2002, surgeons at Children's Hospital of Michigan in Detroit performed the nation's first advanced computer-assisted robot-enhanced surgical procedure at a children's hospital.

The Center for Robotic Surgery at Children's Hospital Boston provides a high level of expertise in pediatric robotic surgery. Specially-trained surgeons use a high-tech robot to perform complex and delicate operations through very small surgical openings. The results are less pain, faster recoveries, shorter hospital stays, smaller scars, and happier patients and families.

In 2001, Children's Hospital Boston was the first pediatric hospital to acquire a surgical robot. Today, surgeons use the technology for many procedures and perform more pediatric robotic surgeries than any other hospital in the world. Children's Hospital physicians have developed a number of new applications to expand the use of the robot, and train surgeons from around the world on its use.

Radiosurgery

The CyberKnife Robotic Radiosurgery System uses image-guidance and computer controlled robotics to treat tumors throughout the body by delivering multiple beams of high-energy radiation to the tumor from virtually any direction.

Urology

Removing the prostate gland for cancer, repair obstructed kidneys, repair bladder abnormalities and remove diseased kidneys. New minimally invasive robotic devices using steerable flexible needles are currently being developed for use in prostate brachytherapy. A few leading urologists in the field of robotic urological surgery are Drs. David Samadi, Ashutosh Tewari, Mani Menon, Peter Schlegel, Mehmood Akhtar, Douglas Scherr, Mohamad W. Salkini, Steven Sukin, and Vipul Patel.

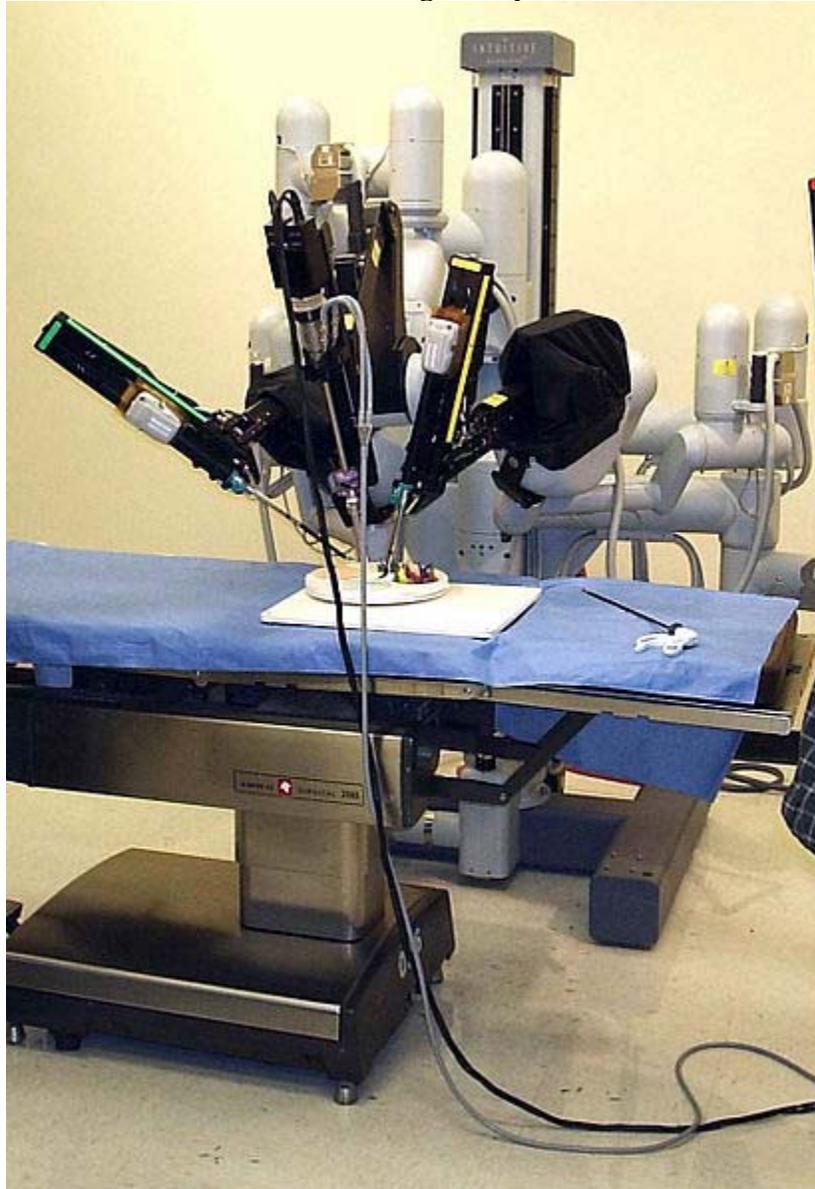
In 2000, the first robot-assisted laparoscopic radical prostatectomy was performed.

Miniature robotics

As scientists seek to improve the versatility and utility of robotics in surgery, some are attempting to miniaturize the robots. For example, the University of Nebraska Medical Center has led a multi-campus effort to provide collaborative research on mini-robotics among surgeons, engineers and computer scientists. There may also be a day and age where nanorobots may be inserted into peoples bloodstreams to act as General Practitioners, or **GPs**; Analysing the problem and sending the information back to the hospital. This could one day remove the need of GPs.

da Vinci Surgical System

Da Vinci Surgical System



The **da Vinci Surgical System** is a robotic surgical system made by Intuitive Surgical and designed to facilitate complex surgery using a minimally invasive approach. The system is controlled by a surgeon from a console. It is commonly used for prostatectomies and increasingly for cardiac valve repair and gynecologic surgical procedures.

Overview

The da Vinci System consists of a surgeon's console that is typically in the same room as the patient and a patient-side cart with four interactive robotic arms controlled from the console. Three of the arms are for tools that hold objects, act as a scalpel, scissors, bovie, or unipolar or bipolar electrocautery instruments. The fourth arm is for an endoscopic camera with two lenses that gives the surgeon full stereoscopic vision from the console. The surgeon sits at the console and looks through two eye holes at a 3-D image of the procedure, meanwhile maneuvering the arms with two foot pedals and two hand controllers. The da Vinci System scales, filters and translates the surgeon's hand movements into more precise micro-movements of the instruments, which operate through small incisions in the body.

According to the manufacturer, the da Vinci System is called "da Vinci" in part "because Leonardo da Vinci invented the first robot", and also because he used anatomical accuracy and three-dimensional details to bring his works to life.

To perform a procedure, the surgeon uses the console's master controls to maneuver the patient-side cart's three or four robotic arms (depending on the model), which secures the instruments and a high-resolution endoscopic camera. The instruments' jointed-wrist design exceeds the natural range of motion of the human hand; motion scaling and tremor reduction further interpret and refine the surgeon's hand movements. The da Vinci System incorporates multiple, redundant safety features designed to minimize opportunities for human error when compared with traditional approaches. At no time is the surgical robot in control or autonomous; it operates on a "Master:Slave" relationship, the surgeon being the "Master" and the robot being the "Slave."

The da Vinci System has been designed to improve upon conventional laparoscopy, in which the surgeon operates while standing, using hand-held, long-shafted instruments, which have no wrists. With conventional laparoscopy, the surgeon must look up and away from the instruments, to a nearby 2D video monitor to see an image of the target anatomy. The surgeon must also rely on his/her patient-side assistant to position the camera correctly. In contrast, the da Vinci System's ergonomic design allows the surgeon to operate from a seated position at the console, with eyes and hands positioned in line with the instruments. To move the instruments or to reposition the camera, the surgeon simply moves his/her hands.

By providing surgeons with superior visualization, enhanced dexterity, greater precision and ergonomic comfort, the da Vinci Surgical System makes it possible for more surgeons to perform minimally invasive procedures involving complex dissection or reconstruction. For the patient, a da Vinci procedure can offer all the potential benefits of a minimally invasive procedure, including less pain, less blood loss and less need for blood transfusions. Moreover, the da Vinci System can enable a shorter hospital stay, a quicker recovery and faster return to normal daily activities.

The robot costs on average \$1.3 million in addition to several hundred thousand dollars of annual maintenance fees. Surgical procedures performed with the robot take longer than traditional ones. Critics have pointed out that hospitals have a hard time recovering

the cost and that most clinical data does not support the claim of improved patient outcomes.

FDA approval

The Food and Drug Administration (FDA) has cleared the da Vinci Surgical System in 2000 for adult and pediatric use in urologic surgical procedures, general laparoscopic surgical procedures, gynecologic laparoscopic surgical procedures, general non-cardiovascular thoracoscopic surgical procedures and thoracoscopically assisted cardiomy procedures. The da Vinci System may also be employed with adjunctive mediastinotomy to perform coronary anastomosis during cardiac revascularization.

Representative clinical uses

The da Vinci System has been successfully used in the following procedures:

- Radical prostatectomy, pyeloplasty, cystectomy, nephrectomy, ureteral reimplantation;
- Hysterectomy, myomectomy and sacrocolpopexy;
- Cholecystectomy, Nissen fundoplication, Heller myotomy, gastric bypass, donor nephrectomy, adrenalectomy, splenectomy and bowel resection;
- Internal mammary artery a blood vessel mobilization and cardiac tissue ablation;
- Mitral valve repair, endoscopic atrial septal defect closure;
- Mammary to left anterior descending coronary artery anastomosis for cardiac revascularization with adjunctive mediastinotomy

Future

Although the general term "robotic surgery" is often used to refer to the technology, this term can give the impression that the robot (the da Vinci System) is performing the surgery. In contrast, the current da Vinci Surgical System cannot—in any manner—run on its own. This is due to the fact it was not designed as an autonomous system and lacks a decision making software, instead it relies on a human operator for all input, however all the functionality—including vision and motor functions—are performed through remote human-computer interaction and thus with the appropriate weak AI software the system could in principle perform partially or completely autonomously. The difficulty with creating an autonomous system of this kind is not trivial, a major obstacle is that surgery per se is not readily formalizable—a requirement for weak AI. The current system is designed to merely seamlessly replicate the movement of the surgeon's hands with the tips of micro-instruments, not to make decisions or move without the surgeon's direct input.

The da Vinci System could also potentially be used to perform truly remote operations. This was, in fact, what the Da Vinci system was originally designed for, though this was abandoned early. The possibility of long distance operations depend on the patient having

access to a da Vinci System and someone to put in the ports, but technically the system could allow a doctor in the United States, for example, to do surgery on a patient in Antarctica. The da Vinci Surgical System can theoretically be used to operate over long distances. According to the manufacturer, this capability, however, is not the primary focus of the company and thus is not available with the current da Vinci Surgical System.

Criticism

While the use of robotic surgery has become an item in the advertisement of medical services, critics point out that studies that indicate that long-term results are superior to those after laparoscopic surgery are lacking. The robotic system does not come cheap and has a learning curve. Data are absent to show that the increased costs can be justified. In the medical literature, very experienced surgeons tend to publish their results, these, however, may not be representative of surgeons with lesser experience.

Pediatric use of robotic technology

Researchers from Children's Hospital Boston developed and perfected the technique for performing robotically-assisted pediatric pyeloplasties, and have recently completed an 18-month study that showed that the same technique is effective for bladder augmentation procedures. Results from research conducted at Children's have also led to advances and refinements in the robotic equipment, making it more suitable for use in pediatric surgery.

The Center for Robotic Surgery's research program is focused on finding safe and innovative applications for robotic technology. Children's Hospital Boston is one of the only pediatric hospitals to perform clinical assessments and outcome analysis - measuring and analyzing the outcomes of robotic surgeries versus open surgeries to ensure the use of the surgical robot is always advantageous to the patient.

A second surgical robot is dedicated exclusively to training surgeons and developing and perfecting new robotic procedures and surgical techniques before they are applied to patients.

Chapter- 4

Aerial Military Robots

Northrop Grumman MQ-8 Fire Scout

MQ-8 Fire Scout



A USN MQ-8B with the BRITE Star II electro-optical/infrared payload at Webster Field, NAS Patuxent River, Maryland

The **Northrop Grumman MQ-8 Fire Scout** is an unmanned autonomous helicopter developed for use by the United States armed forces. Northrop Grumman is developing the Fire Scout to provide reconnaissance, situational awareness, and precision targeting support. The initial **RQ-8A** version was based on the Schweizer 330, while the enhanced **MQ-8B** is derived from the Schweizer 333.

Design and development

RQ-8A

As the US Navy was withdrawing its RQ-2 Pioneers from service, it began to seek a second generation UAV. The Navy requirement specified a vertical takeoff & landing (VTOL) aircraft, with a payload capacity of 90 kilograms (200 pounds), a range of 200 kilometers (125 miles), an endurance on station of three hours at an altitude of 6 kilometers (20,000 ft), and the ability to land on a ship in a 46 km/h (29 mph) breeze. The UAV was to fly 190 hours between maintenance.

There were three finalists in the competition, which was designated "VTOL-UAV" or "VTUAV". Bell, Sikorsky, and a collaboration of Teledyne Ryan and Schweizer Aircraft submitted designs. The Ryan-Schweizer UAV was selected as the winner in the spring of 2000. The **RQ-8A Fire Scout**, as it was named, was a derivative of the Schweizer three-passenger, turbine powered **330SP** helicopter, with a new fuselage, new fuel system, and UAV electronics and sensors.

The initial prototype of the Fire Scout was piloted in initial tests, flying autonomously for the first time in January 2000. The Rolls-Royce 250-C20 turbine engine ran on JP-5 and JP-8 jet fuel, which is nonvolatile and safe for shipboard storage.

The Fire Scout was to be fitted with a sensor ball turret that carries electro-optic and infrared cameras, and a laser range finder. It was to be controlled over a data link derived from the Northrop Grumman RQ-4 Global Hawk UAV, operating over a line of sight to a distance of 280 kilometers (172 miles). The control system was to be fitted onto a ship, or could be carried on a Hummer light vehicle for U.S. Marine service.

MQ-8B

Although progress on the project had been regarded as satisfactory, the Navy decided the Fire Scout didn't meet their needs after all, and cut funding for production in December 2001. However, the development program continued, and Northrop Grumman pitched a range of improved configurations to anyone who was interested. As it turned out, the U.S. Army was very interested, awarding a contract for seven improved "RQ-8B" evaluation machines in late 2003. In 2006, it was redesignated "MQ-8B".

The MQ-8B features four-blade main rotor, in contrast to the larger-diameter three-blade rotor of the RQ-8A, to reduce noise and improve lift capacity and performance. The four-blade rotor had already been evaluated on Fire Scout prototypes. They boost gross takeoff weight by 500 pounds to 3,150 pounds (by 225 kg to 1,430 kg), with payloads of up to 700 pounds (320 kg) for short-range missions.

The MQ-8B is fitted with stub wings as well. The wings will serve both an aerodynamic purpose as well as an armament carriage location, to include weapons such as Hellfire missiles, Viper Strike laser-guided glide weapons, and in particular pods carrying the

"Advanced Precision Kill Weapon System (APKWS)", a laser-guided 70 millimeter (2.75 inch) folding-fin rocket, which the Army sees as ideal for the modern battlefield. The Army is also interested in using the Fire Scout to carry up to 200 pounds (90 kilograms) of emergency supplies to troops in the field.



MQ-8B Fire Scout at the RIAT.

The MQ-8B is being modified to permit rapid swap out of payload configurations. The current sensor configuration of a day/night turret with a laser target designator will of course remain an option. Alternate sensor payloads in consideration include a TSAR with Moving Target Indicator (MTI) capability, a multispectral sensor, a SIGINT module, the Target Acquisition Minefield Detection System (ASTAMIDS), and the Tactical Common Data Link (TCDL). The Army wants the Fire Scout to operate as an element of an integrated ground sensor network as well.

Production of the flight test airframes was initiated in April 2006 at the Northrop Grumman Unmanned Systems production plant in Moss Point, Mississippi. The Navy approved low-rate initial production. First flight of the MQ-8B took place on December 18, 2006 at NAS Patuxent River.

The Army interest revived Navy interest in the program, with the Navy ordering eight **Sea Scout** MQ-8B derivatives for evaluation. In January 2010, the Army terminated its

involvement with the Fire Scout contending that the Shadow UAV could meet the Army's needs.

The MQ-8B compliments the manned aviation detachments onboard Air Capable ships and is deployed along with either an SH-60B HSL/HSM detachment or a SH-60S HSC detachment. With the planned addition of RADAR, AIS, and weapons, the MQ-8B will provide many of the capabilities currently provided by the SH-60B. It will also give the ship and embarked air detachment greater flexibility in meeting mission demands and will free up the manned aircraft for those missions.

Operational history



An RQ-8A prepares for the first autonomous landing aboard the USS Nashville (LPD 13) during sea trials in 2006.

In January 2006, an RQ-8A Fire Scout landed aboard the U.S. Navy warship USS *Nashville* while it was steaming off the coast of Maryland near the Patuxent River. This marked the first time an unmanned helicopter has landed autonomously aboard a moving U.S. Navy ship without a pilot controlling the aircraft. The USS *Nashville*, which is an amphibious transport ship, was maneuvering as fast as 17 mph (27 km/h) in the tests.

The flight test program is underway. Production aircraft will eventually be deployed on the Navy's Littoral Combat Ships. In February 2008, the U.S. Navy announced that they would integrate the MQ-8B Fire Scout VTUAV onto another air-capable ship before it reaches the Littoral Combat Ship (LCS).



An MQ-8B is maintained at Marine Corps Air Station Cherry Point

The Fire Scout is a key enabler for LCS and significantly contributes to its designated warfare mission areas of anti-submarine warfare, surface warfare and mine warfare. The modular nature of the ship to accomplish the designated mission is complemented by the Fire Scout and its modular mission payload capability. However, due to changes in the LCS development schedule, the Navy intends to conduct the Fire Scout Operational Evaluation (OpEval) aboard USS *McInerney* (FFG-8). This will provide the fleet with unmanned aerial system support as soon as possible.

The Fire Scout first embarked aboard the guided-missile frigate USS *McInerney*, an *Oliver Hazard Perry*-class frigate, while in port for operational fit checks and ship integration testing on December 10, 2008. The Fire Scout was slated to deploy aboard USS *McInerney* during its next counter-narcotics trafficking deployment later in 2009.



An RQ-8A Fire Scout takes off at the Webster Field Annex of NAS Patuxent River in 2005.

According to the current schedule, the Navy will conduct Technical Evaluation on the Fire Scout on the FFG-8 in the fall 2008 and Operational Evaluation in the summer 2009. The Fire Scout is to reach Initial Operating Capability soon after the evaluation. The Navy will continue to support LCS Initial Operational Test and Evaluation (IOT&E) efforts in fiscal year 2011.

Recent flight tests took place May 4–8 off the coast of Mayport, Fla. The U.S. Navy Fire Scout completed test flights in areas of shipboard deck motion and wind envelope expansion and landings including the use of the grid and harpoon system. During the five days of testing, the ship/aircraft team compiled 19 flight hours during 12 flights, which included 54 landings, 37 of which were into the NATO standard grid.

In September 2009, the Navy announced the first deployment of the MQ-8B aboard *McInerney*.

On 3 April 2010, an MQ-8 from *McInerney* detected a "go-fast" open speedboat and a support vessel engaged in smuggling cocaine in the Eastern Pacific, allowing the ship to confiscate 60 kg of cocaine and detain a number of suspects.

On 2 August 2010 an MQ-8 became unresponsive to commands during testing and entered restricted airspace around Washington, D.C.

Variants

RQ-8A

RQ-8B

MQ-8B

Operators

 United States

- United States Navy

Specifications (MQ-8B)

Data from Northrop Grumman, Nav Air

General characteristics

- **Crew:** 0
- **Payload:** 600 lbs (272 kg)
- **Length:** 23.95 ft (7.3 m)
- **Rotor diameter:** 27.5 ft (8.4 m)
- **Height:** 9.71 ft (2.9 m)
- **Empty weight:** 2,073 lbs (940.3 kg)
- **Max takeoff weight:** 3,150 lbs (1,430 kg)
- **Powerplant:** 1× Rolls-Royce 250, 313 kw ()

Performance

- **Maximum speed:** 115+ knots
- **Cruise speed:** 110 knots
- **Combat radius:** 110 nmi (203.7 km) plus 5+ hours on station
- **Endurance:** 8 hours
- **Service ceiling:** 20,000 ft (6,100 m)

General Atomics MQ-9 Reaper

MQ-9 Reaper



MQ-9 Reaper above Creech AFB.

The **General Atomics MQ-9 Reaper** (originally the **Predator B**) is an Unmanned Aerial Vehicle (UAV) developed by General Atomics Aeronautical Systems (GA-ASI) for use by the United States Air Force, the United States Navy, the Royal Air Force, and the Italian Air Force. The MQ-9 and other UAVs are referred to as Remotely Piloted Vehicles/Aircraft (RPV/RPA) by the U.S. Air Force to indicate their human ground controllers. The MQ-9 is the first hunter-killer UAV designed for long-endurance, high-altitude surveillance.

The MQ-9 is a larger and more capable aircraft than the earlier MQ-1 Predator, although it can be controlled by the same ground systems used to control MQ-1s. The Reaper has a 950-shaft-horsepower (712 kW) turboprop engine, far more powerful than the Predator's 115 hp (86 kW) piston engine. The increase in power allows the Reaper to carry 15 times more ordnance and cruise at three times the speed of the MQ-1. Although the MQ-9 can fly pre-programmed routes autonomously, the aircraft is always monitored or controlled by aircrew in the Ground Control Station (GCS) and weapons employment is always commanded by the pilot.

In 2008 the New York Air National Guard 174th Fighter Wing began the transition from F-16 piloted planes to MQ-9 Reaper UAVs, which are capable of remote controlled or autonomous flight operations, becoming the first all-UAV attack squadron.

Then U.S. Air Force (USAF) Chief of Staff General T. Michael Moseley said, "We've moved from using UAVs primarily in intelligence, surveillance, and reconnaissance roles before Operation Iraqi Freedom, to a true hunter-killer role with the Reaper." As of 2009 the U.S. Air Force's fleet stands at 195 Predators and 28 Reapers.

Design and development

With the success of the MQ-1 in combat, General Atomics anticipated the Air Force's desire for an upgraded aircraft and, using its own funds, set about redesigning Predator.

Prototype "Predator B"

General Atomics began development of the Reaper with the "Predator B-001", a proof-of-concept aircraft, which first flew on 2 February 2001. The B-001 was powered by an Allied Signal Garrett AiResearch TPE-331-10T turboprop engine with 950 shp (712 kW). It had an airframe that was based on the standard Predator airframe, except that the fuselage was made wider (and longer) and the wings were stretched from 48 feet (14.6 m) to 66 feet (20 m). The B-001 had a speed of 220 kts (390 km/h) and could carry a payload of 750 pounds (340 kilograms) to an altitude of 50,000 feet (15.2 kilometers) with an endurance of 30 hours.

GA refined the design, taking it in two separate directions. The first was with a jet-powered version. The "Predator B-002" was fitted with a Williams FJ44-2A turbofan engine with 10.2 kN (2,300 lbf, 1,040 kgf) thrust. It had payload capacity of 475 pounds (215 kilograms), a ceiling of 60,000 feet (18.3 kilometers) and endurance of 12 hours. The U.S. Air Force ordered two airframes for evaluation, delivered in 2007. The first two airframes delivered with prototypes B-001 and B-002 (now in the USAF museum at Wright-Patterson AFB). B-002 was originally equipped with the FJ-44 engine but it was removed and a TPE-331-10T was installed so that the USAF could take delivery of two aircraft in the same configuration.

The second direction the design took was the "Predator B-003", referred to by GA as the "Altair", which has a new airframe with an 84-foot (25.6 m) wingspan and a takeoff weight of about 7,000 pounds (3,175 kg). Like the Predator B-001, it is powered by a TP-331-10T turboprop. This variant has a payload capacity of 3,000 pounds (1,360 kg), a maximum ceiling of 52,000 feet (15.8 km), and an endurance of 36 hours.

Air Force version



First MQ-9 arrives at Creech AFB, March 2007.

In October 2001, the U.S. Air Force signed a contract with GA to purchase an initial pair of Predator B-003s for evaluation, with follow-up orders for production machines. The first test MQ-9s were delivered to the Air Force in 2002. The name "Altair" did not follow the aircraft into testing, with the Air Force continuing to refer to the system as "Predator B" until it was renamed Reaper ("Altair" instead became the designation for the unarmed NASA version); this is confusing, however, as the manufacturer uses the term to refer to the smaller B-001 prototype.

Operators, stationed at bases such as Creech Air Force Base, near Las Vegas, can hunt for targets and observe terrain using a number of sensors, including a thermal camera. One estimate has the on-board camera able to read a license plate from two miles (3 km) away. An operator's command takes 1.2 seconds to reach the drone via a satellite link. The MQ-9 is fitted with six stores pylons. The inner stores pylons can carry a maximum of 1,500 pounds (680 kilograms) each and allow carriage of external fuel tanks. The mid-wing stores pylons can carry a maximum of 600 pounds (270 kilograms) each, while the outer stores pylons can carry a maximum of 200 pounds (90 kilograms) each. An MQ-9 with two 1,000 pound (450 kilogram) external fuel tanks and a thousand pounds of munitions has an endurance of 42 hours. The Reaper has an endurance of 14 hours when fully loaded with munitions. The MQ-9 carries a variety of weapons including the GBU-12 Paveway II laser-guided bomb, the AGM-114 Hellfire II air-to-ground missiles, the AIM-9 Sidewinder, and recently, the GBU-38 JDAM (Joint Direct Attack Munition).

Tests are underway to allow for the addition of the AIM-92 Stinger air-to-air missile. Air Force believes that the Predator B will give the service an improved "deadly persistence" capability, with the RPV flying over a combat area night and day waiting for a target to present itself. In this role an armed RPV neatly complements piloted strike aircraft. A piloted strike aircraft can be used to drop larger quantities of ordnance on a target while a cheaper RPV can be kept in operation almost continuously, with ground controllers working in shifts, carrying a lighter ordnance load to destroy targets.

By October, 2007 the U.S. Air Force owned nine Reapers, and was expected to decide whether to order full-rate production in 2009. On 18 May 2006, the Federal Aviation Administration (FAA) issued a certificate of authorization that allows the MQ-1 and MQ-9 aircraft to fly in U.S. civilian airspace to search for survivors of disasters. Requests had been made in 2005 for the aircraft to be used in search and rescue operations following Hurricane Katrina but, because there was no FAA authorization in place at the time, the planes were not used.

In September 2007, the MQ-9 deployed into Iraq at Balad, the largest U.S. air base in Iraq. On 28 October 2007 the *Air Force Times* reported an MQ-9 had achieved its first "kill", firing a Hellfire missile against "Afghanistan insurgents in the Deh Rawood region of the mountainous Oruzgan province. The strike was 'successful'," the United States Central Command Air Forces said.



An MQ-9 taking off in Afghanistan

Critics have stated that the USAF's insistence on qualified pilots flying RPVs is a bottleneck to expanding their deployment. Air Force Major General William Rew stated on 5 August 2008, "For the way we fly them right now"—fully integrated into air operations and often flying missions alongside manned aircraft—"we want pilots to fly them." This may be exacerbating losses of Air Force aircraft, in comparison with US Army operations.

The typical MQ-9 system consists of multiple aircraft, ground control station, communications equipment and links, maintenance spares, and military (or contractor) personnel. The crew consists of a pilot and sensor operator. To meet combat requirements, the MQ-9 tailors its capabilities using mission kits of various combinations

of weapons and sensors payloads. The Raytheon AN/AAS-52 multi-spectral targeting sensor suite includes a color/monochrome daylight TV, infrared, and image-intensified TV with laser rangefinder/target designator to designate targets for laser guided munitions. The Synthetic Aperture Radar system enables GBU-38 JDAM targeting, is capable of very fine resolution in both spotlight and strip modes, and has ground moving target indicator capability.

Navy version

General Atomics designed a naval version of the Reaper, named the "Mariner", for the U.S. Navy's Broad Area Maritime Surveillance (BAMS) program requirements. The design would have an increased fuel capacity in order to have an endurance of up to 49 hours. Proposed variations on the ultimate design included one designed for carrier operations with folding wings for carrier storage, shorter and more rugged landing gear, an arresting hook, cut-down or eliminated ventral flight surfaces and six stores pylons with a total load of 3,000 pounds (1,360 kilograms). The Northrop Grumman RQ-4N was announced the BAMS winner.

The US Customs and Border Protection has ordered a "Maritime Variant" of the MQ-9.

NASA version



NASA version Altair



NASA version Ikhana

NASA had initially expressed some interest in a production version of the B-002 turbofan-powered variant, but instead has leased an unarmed version of the Reaper, which carries the GA-ASI company name "Altair". Altair is one of the first 3 "Predator-B" airframes. The other 2 airframes, known as "Predator-B 001" and "Predator-B 002", had a maximum gross weight of 7,500 pounds. Altair differs from these models in that it has an 86-foot (26 m) long wingspan (20 feet greater than early and current MQ-9s). The Altair has enhanced avionics systems to better enable it to fly in FAA-controlled civil airspace and demonstrate "over-the-horizon" command and control capability from a ground station. These aircraft are used by NASA's Earth Science Enterprise as part of the NASA ERAST Program to perform on-location science missions.

In November 2006, NASA's Dryden Flight Research Center obtained an MQ-9 from General Atomics Aeronautical Systems Inc.. The aircraft has been named *Ikhana* and its main goal is the Suborbital Science Program within the Science Mission Directorate. NASA also acquired a ground control station in a mobile trailer. This aircraft was used extensively to survey the Southern California wildfires in 2007. The data were used to deploy firefighters to areas of the highest need.

Homeland Security version



An MQ-9 of the U.S. Customs and Border Protection agency



UAV Operators at Joint Base Balad (LSA Anaconda), Iraq, April 20, 2005

The United States Department of Homeland Security initially ordered one Reaper for border patrol duty, referred to as MQ-9 CBP-101. It began operations 4 October 2005, but on 25 April 2006, this aircraft crashed in the Arizona desert. The NTSB determined (Record Identification: CHI06MA121) that the cause of the crash was most likely a pilot error by the aircraft's ground-based pilot in the use of a checklist. During its operational period, the aircraft flew 959 hours on patrol and had a part in 2,309 arrests. It also contributed to the seizure of four vehicles and 8,267 pounds of marijuana. Because of these successes, a second Reaper, called "CBP-104" (initially referred to as "CBP-102"), was delivered in September 2006, and commenced limited border protection operations on 18 October 2006. The program was further expanded on 16 February 2009, including Canadian border patrols where US officials were concerned about the exploitation of the border by "drug smugglers, migrants and terrorists".

The CBP-101 was equipped with the Lynx SAR, AX-15 payload, ARC-210 radios, and other sensors and communications equipment; CBP-104 was enhanced with Ku band satellite command and control link and MTS-A EO/IR sensors.

The President's FY 2006 Emergency Supplemental budget request added \$45 million for the Reaper program, and the FY 2007 Homeland Security Appropriations bill adds an additional \$20 million. In October 2006, GA-ASI announced a \$33.9 million contract to supply two more Reaper systems by Fall 2007.

U.S. Customs and Border Protection has six operational MQ-9s. One based in North Dakota, at the UAS Operations Center in Grand Forks, four in Arizona, at the UAS Operations Center in Sierra Vista and one based at Fort Drum, N.Y. The aircraft are equipped with GA-ASI's Lynx Synthetic Aperture Radar (Lynx SAR info/web page) and Raytheon's MTS-B ElectroOptical/Infrared sensors.

International versions

Australia

In September 2006, the General Atomics Mariner demonstrator aircraft was operated by the Australian Defence Science and Technology Organisation (DSTO) in an exercise designed to evaluate the aircraft's ability to aid in efforts to stem illegal fishing, drug running and illegal immigration. The Mariner operated from RAAF bases Edinburgh, South Australia and Learmonth, Western Australia in conjunction with a Royal Australian Navy Armidale class patrol boat, the Joint Offshore Protection Command and the Pilbara Regiment.

United Kingdom

On 27 September 2006, the U.S. Congress was notified by the Defense Security Cooperation Agency that the United Kingdom was seeking to purchase a pair of MQ-9 Reapers. They are operated by No. 39 Squadron RAF from Creech Air Force Base, Nevada. A third MQ-9 was in the process of being purchased by the RAF in 2007. On 4 January 2008 it became public that the United Kingdom wanted to purchase a further 10 MQ-9 Reapers, giving the Royal Air Force a fleet of 13 Reapers.

Germany

Germany has made a request to purchase five Reapers and four ground control stations, plus related support material and training. The request, being made through the Foreign Military Sales process, was presented to Congress through the Defense Security Cooperation Agency on 1 August 2008 and is valued at US\$205 million. However, Germany did not go through with this procurement for the time being and decided to lease the IAI Heron offered by IAI and Rheinmetall instead, initially for the duration of one year, representing a stop-gap measure before a long-term decision on a MALE-system is being made.

Italy

On August 1, 2008, Italy submitted a FMS request through the Defense Security Cooperation Agency for four aircraft, four ground stations and five years of maintenance support, all valued at US\$330 million. Italy ordered two more aircraft in November, 2009.

Operational history

US use



MQ-9 Reaper in Afghanistan in 2007

The California Office of Emergency Services requested NASA support for the Esperanza Fire, and in under 24 hours the General Atomics Altair (NASA variant of the Predator B) was launched on a 16 hour mission to map the perimeter of the fire. The Altair had just returned from a test mission a day before the Esperanza Fire started. The fire mapping research is a joint project with NASA and the US Forest Service.

On 25 April 2006, an MQ-9 operated by U.S. Customs and Border Protection crashed near Nogales, Arizona. The pilot, remotely operating the vehicle from Sierra Vista Municipal Airport, reported a momentary lockup of the displays on the primary control console. The pilot switched control to a secondary console, and in doing so inadvertently shut down the vehicle's engine, causing it to descend out of reach of communications and ultimately crash.

On 1 May 2007, the 432d Wing of the United States Air Force was activated to operate MQ-9 Reaper as well as MQ-1 Predator UAVs at Creech Air Force Base, Nevada. The pilots first flew combat missions in Iraq and Afghanistan in the summer of 2007. In October 2007 the USAF was flying operational missions in Afghanistan. As of 6 March 2008, according to USAF Lieutenant General Gary North, the Reaper has attacked 16 targets in Afghanistan using 500 lb (230 kg) bombs and Hellfire missiles. On 4 February

2008 the MQ-9 dropped a bomb on a truck carrying an insurgent mortar and team near Kandahar.

On 17 July 2008, the Air Force began flying Reaper missions within Iraq from Balad Air Base. It was reported on August 11, 2008 that the 174th Fighter Wing of the USAF will consist entirely of Reapers. By March 2009 the U.S. Air Force had 28 operational Reapers.

On 13 September 2009, a MQ-9 was flying a combat mission over Afghanistan when positive control of the aircraft was lost resulting in the drone flying out of control towards the Afghan border with Tajikistan. An F-15E Strike Eagle was sent to destroy it; the Reaper's engine was disabled with an AIM-9 missile. The satellite link with the vehicle was restored immediately after, leaving the operator no option other than to steer it into a mountainside along with its ordnance. It was the first time a US drone was destroyed intentionally by allied forces.

Beginning in September 2009, Reapers were deployed by the Africa Command to The Seychelles for use in Indian Ocean anti-piracy patrols.

As of July 2010, 38 Predators and Reapers have been lost during combat operations in Afghanistan and Iraq, with another 9 crashing during training operations in the U.S.

Non-US use

On 9 November 2007, the UK Ministry of Defence announced that its MQ-9 Reapers had begun operations in Afghanistan against the Taliban. In April 2008, following the crash of one of the UK's two Reapers, British special forces were sent to recover sensitive material from the wreckage before it was blown up to prevent the enemy from obtaining it.

Operators



MQ-9 Reaper operators 2010

Italy

- Aeronautica Militare

Turkey

- Turkish Air Force (Turkey initially ordered four aircraft and three command centers)

United Kingdom

- Royal Air Force
 - No. 39 Squadron RAF

United States

- United States Air Force
 - Air Combat Command
 - 432d Air Expeditionary Wing (Creech Air Force Base, Nevada)
 - 19th Attack Squadron
 - 42d Attack Squadron
 - 53d Wing (Eglin Air Force Base, Florida)
 - 556th Test and Evaluation Squadron (Creech Air Force Base, Nevada)
 - Air Force Special Operations Command
 - 27th Special Operations Wing
 - 33d Special Operations Squadron (Cannon Air Force Base, New Mexico)
 - 58th Special Operations Wing
 - 551st Special Operations Squadron
 - Air National Guard
 - 174th Fighter Wing (Hancock Field, New York)
- U.S. Customs and Border Protection
 - Sierra Vista, Arizona
 - Grand Forks, North Dakota

Specifications



MQ-9 Reaper taxis.

Several minor variations of the RQ-9/MQ-9 exist; these values are indicative.

Sources: USAF Fact Sheet, Globalsecurity.org

General Characteristics

- **Crew:** None
- **Landing Type:** runway
- **Launch Type:** runway
- **Length:** 36 ft (11 m)
- **Wingspan:** 66 ft (20 m)
- **Height:** 12.5 ft (3.6 m)
- **Empty weight:** 4,900 lb (2223 kg)
- **Fuel Capacity:** 4,000 lb (1,800 kg)
- **Max takeoff weight:** 10,500 lb (4760 kg)
- **Power Plant:** Honeywell TPE331-10 turboprop engine, 900 shp (671 kW), with Digital Electronic Engine Control (DEEC)

Performance

- **Maximum speed:** 260 knots (482 km/h, 300 mph)
- **Cruise speed:** 150–170 knots (276–313 km/h, 172–195 mph)
- **Range:** 3,200 nmi (5,926 km, 3,682 mi)
- **Endurance:** 14–28 hours (14 hours fully loaded)
- **Payload:** 3,800 lb (1,700 kg)
 - *Internal:* 800 lb (360 kg)
 - *External:* 3,000 lb (1,400 kg)

- **Service ceiling:** 50,000 ft (15 km)
- **Operational altitude:** 25,000 ft (7.5 km)

Sensors

- AN/APY-8 Lynx II radar
- AN/DAS-1 MTS-B Multi-Spectral Targeting System

Armament

- 7 Hardpoints
 - Up to 1,500 lb (680 kg) on the two inboard weapons stations
 - Up to 750 lb (340 kg) on the two middle stations
 - Up to 150 lb (68 kg) on the outboard stations
 - Center station not used
- Up to 14 AGM-114 Hellfire air to ground missiles can be carried or four Hellfire missiles and two 500 lb (230 kg) GBU-12 Paveway II laser-guided bombs. The 500 lb (230 kg) GBU-38 Joint Direct Attack Munition (JDAM) can also be carried. Testing is underway to support the operation of the AIM-92 Stinger air-to-air missile.

AAI RQ-7 Shadow

RQ-7 Shadow



The **RQ-7 Shadow** unmanned aerial vehicle (UAV) is used by the United States Army and Marine Corps. Launched from a trailer-mounted pneumatic catapult, it is recovered with the aid of arresting gear similar to jets on an aircraft carrier. Its gimbal-mounted, digitally-stabilized, liquid nitrogen-cooled electro-optical/infrared (EO/IR) camera relays video in real time via a C-band line-of-sight data link to the ground control station (GCS). The "R" is the Department of Defense designation for reconnaissance; "Q" means unmanned aircraft system. The "7" refers to it being the seventh of a series of purpose-built unmanned reconnaissance aircraft systems.

The Army's 1st Battalion, 210th Aviation Regiment at Fort Huachuca, AZ trains soldiers, marines, and civilians in the operation and maintenance of the Shadow UAV. The training program consists of mainly civilian instructors.

Description



The RQ-7 in Iraq.

The RQ-7 Shadow 200 unmanned aerial vehicle is of a high-wing, constant chord pusher configuration with a twin-tailboom empennage and an inverted v-tail elerudder. The

aircraft is powered by a 38 bhp AR741-1101 Wankel engine manufactured by UAV Engines Ltd. Onboard electrical systems are powered by a GEC/Plessey 28 volt, direct current, 2,000 watt generator. Currently, the primary payload for the aircraft is the Israeli Aircraft Industries POP300 Plug-in Optical Payload which consists of a forward-looking Infrared camera, a daytime TV camera with a selectable near-infrared filter and a laser pointer. The aircraft has fixed tricycle landing gear. Takeoffs are assisted by a trailer-mounted pneumatic launcher which can accelerate the 375 pound aircraft to 60 knots (110 km/h) in 15 feet (4.6 m). Landings are guided by a Tactical Automatic Landing System developed by the Sierra Nevada Corporation which consists of a ground-based micro-millimeter wavelength radar and a transponder carried on the aircraft. Once on the ground, a tailhook mounted on the aircraft catches an arresting wire connected to two disk brake drums which can stop the aircraft in less than 170 feet (52 m).

The aircraft is part of a larger system which currently uses the M1152-series of HMMWVs for ground transport of all ground and air equipment. The system consists of four aircraft, three of which are transported in the Air Vehicle Transporter (AVT). The fourth is transported in a specially-designed storage container to be used as a spare. The AVT also tows the launcher. The AVT Support Vehicle and trailer contain extra equipment to launch and recover the aircraft, such as the Tactical Automatic Landing System. Maintenance equipment for the aircraft is stored in the Maintenance Section Multifunctional (MSM) vehicle and trailer as well as the M1165 MSM Support Vehicle and its associated trailer. The system also contains two HMMWV-mounted Ground Control Stations (GCS) which control the aircraft in flight. Each GCS has an associated Ground Data Terminal (GDT). The GDT takes commands generated by the GCS and modulates them into radio waves which are received by the aircraft in flight. The GDT also receives video imagery from the payload as well as telemetry from the aircraft and sends them to the GCS. Each GDT is stored for shipping on a trailer which also houses a 10 kW Tactical Quiet Generator which powers its associated GCS. Each trailer is towed by a M1165 GCS Support Vehicle. Each system also contains one Portable Ground Control Station (PGCS) and Portable Ground Data Terminal (PGDT). The PGCS and PGDT are stripped-down versions of the GCS and GDT and are designed to be used as a backup to the two GCSs.

Development

The RQ-7 Shadow is the result of a continued US Army search for an effective battlefield UAV after the cancellation of the RQ-6 Outrider aircraft. AAI Corporation followed up their RQ-2 Pioneer UAV with the similar but refined Shadow 200, and in late 1999 the army selected the Shadow 200 to fill the tactical UAV requirement, redesignating it the RQ-7. The army requirement specified a UAV that used a gasoline engine, could carry an electro-optic/infrared imaging sensor turret, and had a minimum range of 31 miles (50 kilometers) with four hour endurance on station. The Shadow 200 offered at least twice that range, powered by a 38 hp (28.5 kW) rotary engine. The army requirement dictated that it be able to land in an athletic field.

Variants

RQ-7A Shadow

The **RQ-7A** was the initial version of the Shadow 200 UAV developed by AAI. The first low-rate initial-production systems were delivered to the US Army in 2002 with the first full-scale production systems being delivered in September 2003. The RQ-7A was 11 ft 2 in (3.40 m) long and had a wingspan of 12 ft 9 in (3.89 m) with a 327 lb (148 kg) max takeoff weight. The aircraft's endurance ranged between 4 to 5.5 hours depending on mission. The "A" model aircraft also had the AR741-1100 engine which could use either 87 octane automotive gasoline or 100LL aviation fuel. The "A" model also featured IAI's POP200 payload.

RQ-7B Shadow



The RQ-7B leaves its launcher.

Production of Shadow aircraft shifted to a generally improved **RQ-7B** variant in the summer of 2004. The RQ-7B features new wings increased in length to 14 ft (4.3 m). The new wings are not only more aerodynamically efficient, they are "wet" to increase fuel storage up to 44 liters for an endurance of up to 6 hours. The payload capability has been increased to 45 kilograms (100 pounds). After reports from Iraq that engines were failing,

in 2005, the Army's UAV project manager called for the use of 100LL, an aviation fuel, rather than the conventional 87 octane mogas. Avionics systems have been generally improved, and the new wing is designed to accommodate a communications relay package, which allows the aircraft to act as a relay station. This allows commanders or even the aircraft operators themselves to communicate via radio to the troops on ground in locations that would otherwise be "dead" to radio traffic.

Other incremental improvements to the system include replacing the AR741-1100 engine with the AR741-1101 which increases reliability through the use of dual spark plugs as well as limiting the fuel to 100LL. Also, the older POP200 payload was replaced with the newer POP300 system.

The Shadow system surpassed 300,000 flight hours in April 2008. As of July 2007, the Shadow platform accumulated 200,000 flight hours, doubling its previous record of 100,000 hours in 13 months. The Shadow platform has flown over 37,000 sorties in support of operations in Iraq and Afghanistan by US Army and Army National Guard units. The US Marine Corps has completed its replacement of the aging Pioneer with the Shadow.

The Shadow system has also received a special airworthiness certificate (experimental) from the Federal Aviation Administration authorizing operations at Benson Municipal Airport, a general aviation facility in southeastern Arizona. This airworthiness certificate is the first issued by the FAA permitting an unmanned aircraft to operate at a public-use airport that serves general aviation, and the first FAA certificate covering the system's technologically sophisticated automated landing system. This is currently the only FAA certification category available to UAS manufacturers.

In February, 2010, AAI began a fleet update program to improve the Shadow system. The improvements include installing the wiring harnesses and software updates for IAI's POP300D payload which includes a designator for guiding laser-guided bombs. Other improvements in the program will include an electronic fuel injection engine and fuel system to replace the AR741-1101's carbureted engine. The most visible improvement to the system will be a wider wing of 20 feet (6.1 m) in span which is designed to increase fuel capacity and allow for mission endurance of almost 9 hours. The new wings will also include hardpoints for external munitions.

On 19 April 2010 the army issued a "solicitation for sources sought" from defense contractors for a munition for the Shadow system with a deadline for proposals due no later than 10 May 2010. Although no specific munition has been chosen yet, some possible munitions include the General Dynamics 81mm air-dropped guided mortar, as well as the QuickMEDS system for delivering medical supplies to remote and stranded troops.

Preliminary TCDL testing conducted at Dugway Proving Ground was a success. This led to an estimated fielding date of May 2010 for TCDL.

Shadow 600



Romanian AF Shadow 600 during operations in Iraq

AAI has also built a scaled-up Pioneer derivative known as the "Shadow 600". It also resembles a Pioneer, except that the outer panels of the wings are distinctively swept back, and it has a stronger Wankel engine, the UAV EL 801, with 52 hp (39 kW). A number of Shadow 600s are in service in several nations, including Romania.

Operations

Shadow did not see service in the Afghanistan campaign of 2001-2002, but it did fly operational missions during the US Invasion of Iraq in 2003 and the subsequent occupation of that country. The operating conditions in Iraq proved hard on the UAVs, with heat and sand leading to engine failures, resulting in a high-priority effort to find fixes with changes in system technology and operating procedures. Shadow UAVs have since flown more than 100,000 combined hours in support of the Iraq War.

In 2007, the United States Marine Corps began to transition from the RQ-2 Pioneer to the RQ-7 Shadow. VMU-1, VMU-2 and VMU-3 now have their first systems of Shadow and will eventually have 3 systems each. A third UAS unit - VMU-3, was activated on 12 September 2008 in part due to the increased demand for UAS systems in the Marine Corps. Each Shadow system in a VMU is roughly the same as an army Shadow platoon-4 air vehicles and 2 ground control stations.

The navy provided personnel for four Shadow platoons in support of army brigades deployed in Iraq. The first two platoons returned from 6-month tours in Iraq in January and February 2008. The navy personnel went through the army's training program at Fort Huachuca, AZ.

Specifications (200 Family)

General characteristics

- **Length:** 11.2 ft (3.4 m)
- **Wingspan:** 14 ft (4.3 m)
- **Height:** 3.3 ft (1.0 m)
- **Empty weight:** 186 lb (84 kg)
- **Gross weight:** 375 lb (170 kg)
- **Powerplant:** 1 × Wankel UAV Engine 741 used only with Silkolene Synthetic Oil , 38 hp (28 kW)

Performance

- **Maximum speed:** 135 mph; 118 kn (218 km/h)
- **Cruising speed:** 103 mph; 90 kn (166 km/h)
- **Range:** 68 mi (59 nmi; 109 km)
- **Endurance:** 6 h
- **Service ceiling:** 15,000 ft (4,572 m) ELOS (Electronic Line Of Sight)

AeroVironment RQ-14 Dragon Eye

RQ-14 Dragon Eye UAV





A marine checks a DE-903 UAV

The **Dragon Eye Unmanned Aerial Vehicle** is a small reconnaissance UAV developed by the Naval Research Laboratory and the Marine Corps Warfighting Laboratory for use by the U.S. Marine Corps.

It is a tailless design with a rectangular wing and twin props. It is designed to fit into a backpack, with a weight of 2.25 kilograms (5 pounds) and a span of 1.14 meters (3 feet 9 inches). It can be launched by hand or using a store-bought bungee cord. It also uses a break-apart system to increase durability — parts of the plane break apart instead of shattering and can be reattached later or replaced with new parts. It has a GPS-INS-based waypoint navigation system.

One of the interesting features is that the operator monitors Dragon Eye operation through "video goggles" connected to a laptop computer. The control system weighs about 5.4 kilograms (12 pounds).

The Dragon Eye aircraft is used primarily for scouting urban areas, and is especially useful in urban assaults. Its camera, when used with a trained Marine, can be used to spot enemies without alerting them to the UAV's presence.

The production contract for Dragon Eye was awarded to AeroVironment in 2003, and over 1000 aircraft were built before the Marines switched over to another UCAV of AeroVironment (RQ-11 Raven B) for the remainder of the Dragon Eye production contract

The Dragon Eye has been used in post-invasion Iraq, 2003–present.

General characteristics

- Length: 0.9 m (3 ft)
- Wingspan: 1.1 m (3.75 ft)
- Ceiling: 90 to 150 m (300–500 ft)
- Weight: 2.7 kg (5.9 lb)
- Cruising speed: 65 km/h (40 mph)
- Battery Endurance: 1 hour
- Range: 5 km (3.1 mi)
- Transmission Range: 10 km (6.2 mi)
- Endurance: 45–60 minutes

Terrestrial Military Robots

Black Knight (vehicle)

Black knight



The **Black Knight** is a prototype Unmanned Ground Combat Vehicle designed by BAE Systems. Similar in size and appearance to a tank, It is armed with a turret-mounted 30mm gun and a coaxial machine gun. Although the armored vehicle can be controlled from a command center, the Black Knight does feature some autonomous functions in the turret and can also plan a route without hitting obstacles by itself. If necessary, the Black Knight can also be controlled by a Dismounted Control Device, or DCD. Information from the robot is relayed to and viewed by the Commander's Independent Viewer (CIV), or to the DCD in the latter case. Vehicle is fitted with the Caterpillar diesel engine, developing 300 horsepower. The Black Knight uses many automotive components from the Bradley to reduce costs and simplify maintenance. Its high maximum speed allows to keep pace with main battle tanks. The Black Knight can be airlifted by the C-130 transport aircraft. It is an early prototype, which demonstrates advanced robotic technologies. Vehicle is currently being tested and evaluated by the US Army.

Gladiator Tactical Unmanned Ground Vehicle



The **Gladiator Tactical Unmanned Ground Vehicle (TUGV)** is a remotely operated unmanned ground vehicle employed by the United States Marine Corps. It is described as the world's first multipurpose combat robot.

The Gladiator is designed to be able to operate at all times of the day through the use of image intensifying or thermal devices. It is designed to support dismounted units in all environments and terrain and is modular to allow the fitting of mission specific payloads. The main uses for the Gladiator will include direct combat, surveillance, reconnaissance, and personnel obstacle breaching. It is equipped with a Thales SWARM remote weapon station, which can operate a variety of weapons. Most are equipped with a 7.62mm M240 machine gun.

It is built by Lockheed Martin Missiles and Fire Control, with MillenWorks as a subcontractor.

192 Gladiators were expected to be deployed in 2007.

MarkV-A1



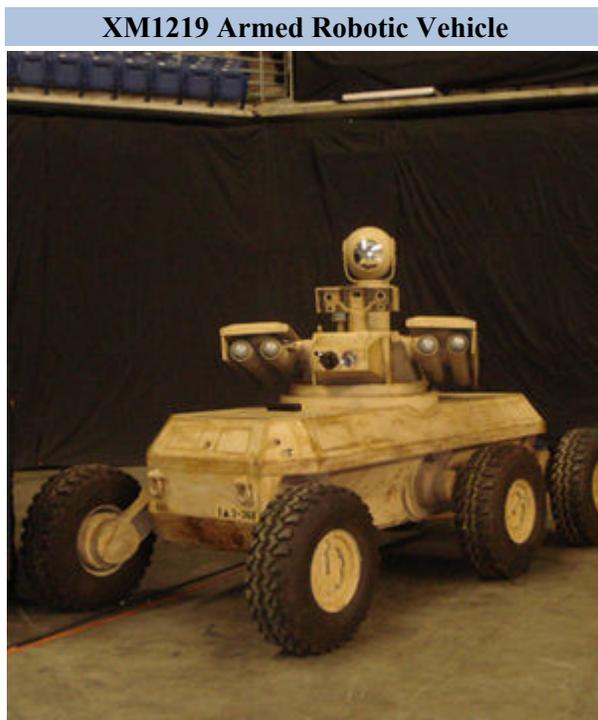
IDF American Andros EOD robot. This particular model is the MarkV-A1

The **MarkV-A1** is a bomb disposal robot designed by Northrop Grumman. It is part of the Remotec ANDROS line, which includes other robotic EODs. MarkV weighs 800 pounds and is about the size of a riding lawn mower. With its manipulator arm fully extended, the robot's height is 8 feet. The tread system is designed to traverse difficult

terrain. The MarkV-A1 can be armed with high pressure water disruptors, for disabling bombs, or if necessary, a shotgun.

In total, the MarkV-A1 has four color video cameras, including a camera mounted on one of the poles protruding from the top of the robot. It also features several microphones, lights, and an array of other sensors.

XM1219 Armed Robotic Vehicle



XM1219 ARV-Assault-Light (ARV-A-L) MULE

Vehicle

Type	Armed Robotic Vehicle
Place of origin	 United States
Service history	
In service	Prototypes in testing
Production history	
Manufacturer	Lockheed Martin Corporation / The Boeing Company
Specifications	
Weight	2.5 short tons (2.3 t)

Primary armament	Line-of-sight gun
Secondary armament	Anti tank weapons
Engine	6x6 in-hub electric motors Diesel-electric
Guidance system	Robotic / command control



The Armed Robotic Vehicle (ARV) variant of the MULE - Photo Courtesy of U.S. Army

The **XM1219 Armed Robotic Vehicle** is a mobility platform based on the MULE Platform. The ARV-A-L MULE Vehicle (XM1219) will feature an integrated weapons and reconnaissance, surveillance, and target acquisition (RSTA) package to support the dismounted infantry's efforts to locate and destroy enemy platforms and positions. The ARV-A-L will support both anti-tank and anti-personnel weapons platforms that will be remotely operated by network linked soldiers.

Design

Mobility

- Transportable inside a C-130 Hercules and CH-47 Chinook.
- Transportable, slung under a UH-60 Black Hawk.
- Climb more than a 1 metre (3 ft 3 in) step.
- Cross a 1 metre (3 ft 3 in) gap.
- Traverse side slopes of 40 percent.
- Ford water obstacles over 0.5 metres (1 ft 8 in).
- Cross obstacles as high as 0.5 metres (1 ft 8 in).

Variants

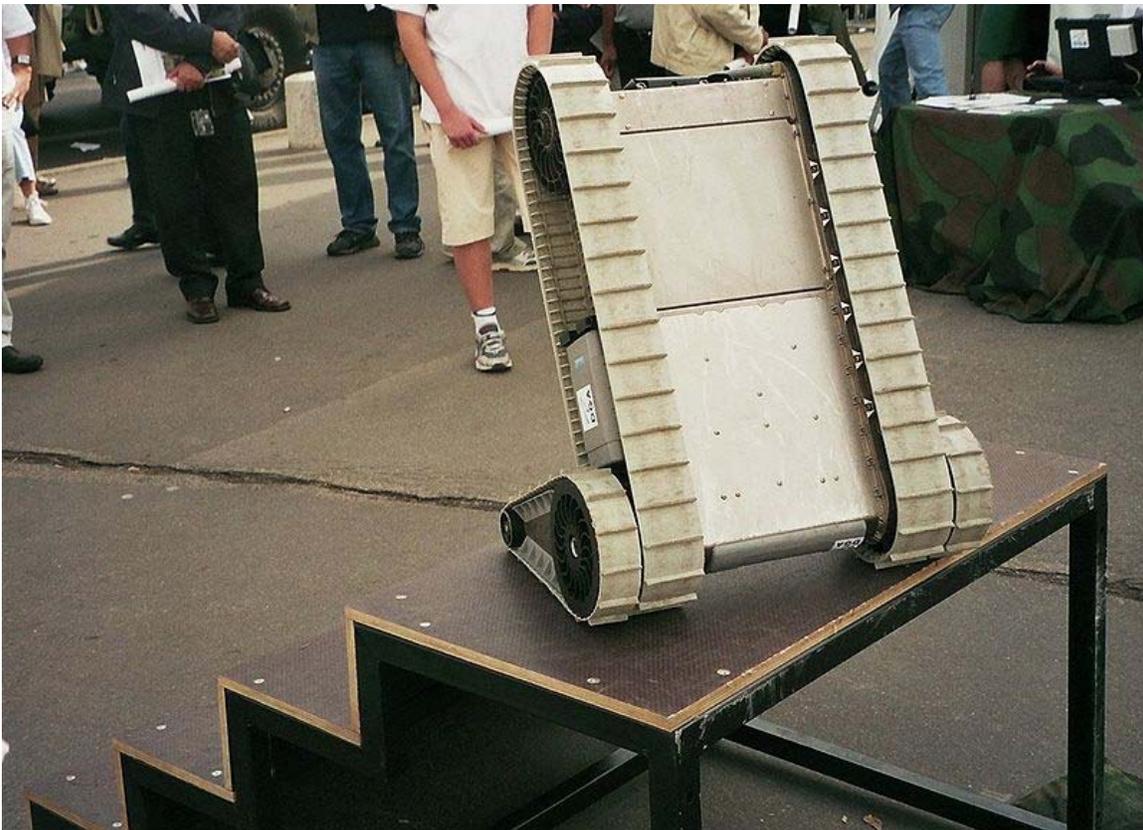
Assault

The only known production variant of this variant is the *Assault Light (ARV-A-L)*.

Reconnaissance, Surveillance and Target Acquisition

The Reconnaissance, Surveillance and Target Acquisition or (RSTA) was likely canceled at some point.

PackBot



PackBot being demonstrated by the French military

PackBot is a series of military robots by iRobot. More than 2000 PackBots are currently on station in Iraq and Afghanistan, with hundreds more on the way.

Current PackBot 510 variants



A U.S. Navy Explosive Ordnance Disposal Technician trains on iRobot's PCC, one of the remote control operation devices used to operate the Packbot.

PackBot 510 is the current base model. It uses a videogame-style hand controller to make it more familiar to young men and women. Configurations include:

- **PackBot 510 with EOD Bomb Disposal Kit** designed for improvised explosive device identification and disposal.
- **PackBot 510 with Fast Tactical Maneuvering Kit** designed for infantry troops tasked with improvised explosive device inspection. This is a lighter weight robot.
- **PackBot 510 with First Responder Kit** designed to help SWAT teams and other first responders with situational awareness.
- **PackBot 510 with HazMat Detection Kit** collects air samples to detect chemical and radiological agents.
- **PackBot 510 with Fido** utilizes the Fido Explosives Detector from ICx Technologies as a payload in order to "sniff" out explosive materials. With the Fido, the PackBot now has the capability of locating explosive devices and subsequently disarming them using on-board robotic capabilities.
- **PackBot 510 with REDOWL Sniper Detection Kit** utilizes the Acoustic Direction Finder from BioMimetic Systems to localize gunshots with azimuth, elevation, and range.

Previous PackBot variants



A U.S. Navy Sailor assigned to an explosive ordnance disposal team holds his M-4 carbine.

- **PackBot Scout** is the basic configuration. It has five payload bays for assignable purposes and can be dropped from a height of six feet (1.83m) onto concrete without being damaged. The Packbot scout version weighs about 40 pounds (18 kg).
- **PackBot Explorer** has a camera head equipped with multiple cameras, laser pointers, audio and other sensors.
- **PackBot EOD** (explosive-ordnance disposal) can be controlled by radio or wired control to handle situations involving potential explosives, thereby reducing the risk of personal injury.

XM1216 Small Unmanned Ground Vehicle

Small Unmanned Ground Vehicle



The **Small Unmanned Ground Vehicle (SUGV)** is a Future Combat Systems specific, man packable (< 30 lbs) version of the iRobot's PackBot.

Description

The XM1216 Small Unmanned Ground Vehicle (SUGV) is a lightweight, man portable Unmanned Ground Vehicle (UGV) capable of conducting military operations in urban

terrain, tunnels, sewers, and caves. The SUGV aids in the performance of manpower-intensive or high-risk functions (i.e. urban Intelligence, Surveillance, and Reconnaissance (ISR) missions, chemical/Toxic Industrial Chemicals (TIC), Toxic Industrial Materials (TIM), reconnaissance, etc.).

Working to minimize Soldiers' exposure directly to hazards, the SUGV's modular design allows multiple payloads to be integrated in a plug-and-play fashion. Weighing less than 30 pounds, it is capable of carrying up to six pounds of payload weight.

The XM1216 can either be remotely manned, or manipulated through use of a Microsoft Xbox 360 gamepad fitted with speciality drivers. This allows full control of the unit, otherwise unavailable through a conventional joystick.

The SUGV is part of Spin Out 1 and has entered evaluation at the Army Evaluation Task Force (AETF). It will be fielded to IBCTs starting in 2011.

Foster-Miller TALON



The SWORDS system allows soldiers to fire small arms weapons by remote control from as far as 1,000 meters away. This example is fitted with an M249 SAW.



Control station

The **Foster-Miller TALON** robot is a small, tracked military robot designed for missions ranging from reconnaissance to combat. Over 3000 TALON robots have been deployed to combat theaters.

Overview

Foster-Miller claims the TALON is one of the fastest robots in production, one that can travel through sand, water, and snow (up to 100 feet deep) as well as climb stairs. The TALON transmits in color, black and white, infrared, and/or night vision to its operator, who may be up to 1,000 m away. It can run off lithium-ion batteries for a maximum of 7 days on standby independently before needing recharging. It has an 8.5 hour battery life at normal operating speeds, 2 standard lead batteries providing 2 hours each and 1 optional Lithium Ion providing an additional 4.5 hours. It can also withstand repeated decontamination allowing it to work for long periods of time in contaminated areas. It was used in Ground Zero after the September 11th attacks working for 45 days with many decontaminations without electronic failure. This led to the further development of the HAZMAT TALON.

It weighs less than 100 lb (45 kg) or 60 lb (27 kg) for the Reconnaissance version. Its cargo bay accommodates a variety of sensor payloads. The robot is controlled through a two-way radio or a Fiber-optic link from a portable or wearable Operator Control Unit (OCU) that provides continuous data and video feedback for precise vehicle positioning.

Regular (IED/EOD) TALON: Carries sensors and a robotic manipulator, which is used by the U.S. Army for explosive ordnance disposal and disarming improvised explosive devices.

Special Operations TALON (SOTAL): Does not have the robotic arm manipulator but carries day/night color cameras and listening devices; lighter due to the absence of the arm, for reconnaissance missions.

SWORDS TALON: For small arms combat and guard roles. Tested in December 2003 in Kuwait prior to deployment in Iraq.

HAZMAT TALON: Uses chemical, gas, temperature, and radiation sensors that are displayed in real time to the user on a hand-held display unit. It is now being tested by the US Armament Research Development and Engineering Center ARDEC.

The robot costs approximately \$60,000 in its standard form. Foster-Miller was subsequently bought out by QinetiQ, a United Kingdom military developer.

SWORDS



Foster-Miller TALON SWORDS units equipped with various weaponry.

SWORDS or the **Special Weapons Observation Reconnaissance Detection System**, is a weaponized version being developed by Foster-Miller for the US Army. The robot is composed of a weapons system mounted on the standard TALON chassis. The current price of one unit is \$230,000; however, Foster-Miller claims that when it enters mass production the price may drop to between \$150,000 and \$180,000. Foster-Miller points out that in comparison, to train a US soldier to a basic level of expertise with BCT and/or AIT would cost \$50,000 to \$100,000. To train them for positions in Armor or Cavalry would cost approximately \$100,000 to \$200,000.

There are a variety of different weapons that can be placed on the SWORDS; M16 rifle, 5.56 mm SAW M249, 7.62 mm M240 machine gun, .50 cal M82 Barrett rifle, a six barreled 40 mm grenade launcher or quad 66 mm M202A1 FLASH incendiary weapon.

SWORDS units have demonstrated the ability to shoot precisely. It is not autonomous, but instead has to be controlled by a soldier using a small console to remotely direct the device and fire its weapons. Foster-Miller are currently at work on a "Game Boy" style controller with virtual-reality goggles for future operators.

In 2007, three SWORDS units were deployed to Iraq. Each unit is armed with a M249 machine gun. This deployment marks the first time that robots are carrying guns into battle; however, their weapons have remained unused as the Army has never given the go-ahead for using them. The Army stopped funding the SWORDS robots after deploying the initial three robots. Foster-Miller is working on a successor: the Modular Advanced Armed Robotic System (MAARS)

Deployment

The Talon has been deployed in military service since 2000 - for example, in Bosnia for the movement of munitions and EOD (explosive ordnance disposal) to get rid of grenades. It was also used in Ground Zero after the September 11th attacks in search and recovery. It is the only robot used in this effort that did not require any major repair. Foster-Miller claims the Talon was used for a classified mission by US Special Forces in the war against the Taliban in Afghanistan as well as in an EOD role. In Iraq its standard role has been performing EOD and IED destruction missions. Its combat SWORDS version is now being used there in a guard role protecting front line buildings from attack. According to Foster-Miller, the robot has performed around 20,000 EOD missions in the conflicts in Iraq and Afghanistan.

MATILDA (Military robot)

Mesa Associate's Tactical Integrated Light-Force Deployment Assembly (MATILDA) is a remote control military robot designed by Mesa Robotics. As with many other contemporary military robot designs, it is small and relatively portable; MATILDA is 30 inches long, 12 inches tall, 21 inches wide, and weighs 61 pounds, (28 kilograms) counting the batteries. Also like other military robots, MATILDA has a modular design. The robot can be configured with cameras, an explosive disrupter unit for disabling bombs, or a manipulator arm. MATILDA is a treaded robot, with a top speed of 3 feet per second. Should a tread be damaged, it can be replaced with a new one within 5 minutes.

Dragon Runner



Dragon Runner is a military robot built for urban combat. At 9 pounds (4 kg) it is light enough to be carried in a Marine's backpack. The original project was funded by the Marine Corps Warfighting Lab in conjunction with Carnegie Mellon University. It was designed at Carnegie Mellon University while the electronics and thermoplastic shell is developed and fabricated by Automatika, Inc.

The robot has four wheels, is 15 inches (38 cm) long, less than a foot wide, and 5 inches (13 cm) in height. The robot is very rugged, and can be thrown over fences, up or down stairwells, from a moving vehicle at 45 miles per hour (70 km/h), or even from a third-

story window. It does not matter how it lands because neither side is the right side up. However, it was not designed to drive up or down stairs on its own. Instead, Dragon Runner was designed so that it could be carried up the stairway.

Use

Dragon Runner is designed for areas that are too dangerous for or inaccessible by human soldiers, particularly urban environments. Dragon Runner's front-mounted, tilting camera provides a video feed that is relayed back to its master controller by a wireless modem. It can save lives by providing soldiers with a view around corners and other obstructions that prevent them from seeing hidden enemies.

Dragon Runner can be operated in three different modes:

- Drive Mode: The robot drives around, transmitting images back to the operator.
- Sentry Mode: Dragon Runner remains stationary, using a microphone and sensors that can detect motion up to 30 feet (9.1 m) away. If it detects something, it will alert the operator.
- Watch Mode: The robot remains motionless and relays images back to the operator.

Modifications include flippers that enable it to climb stairs and treads that can all be snapped on quickly and easily in the field by a soldier with no tools.

In January 2010, under a contract worth £12m with QinetiQ UK, around 100 Dragon Runners were ordered by the British army to improve the ability of bomb disposal experts to find and deactivate improvised explosive devices on the front line in Afghanistan. The first in use were then already proving its worth against the threat of roadside bombs

Crusher (robot)

Crusher

Manufacturer	DARPA
Year of creation	2006
Derived from	Spinner

Crusher is a 13,200-pound (6,000 kg) autonomous off-road Unmanned Ground Combat Vehicle developed by researchers at the Carnegie Mellon University's National Robotics Engineering Center for DARPA. Each of its six wheels is driven by its own electric

motor; the electric motors are powered by battery packs, which are charged by a 78 hp (58-kilowatt) diesel generator. It is a follow up on the previous Spinner vehicle. When fully fuelled, it weighs 14,000 pounds (6,400 kg), and, at that weight, two crushers could be carried by one Lockheed C-130 Hercules aircraft. DARPA's technical name for the crusher is *Unmanned Ground Combat Vehicle and Perceptor Integration System*, and the whole project is known by the acronym UPI, which stands for *Unmanned Ground Combat Vehicle PerceptOR Integration*.

Capabilities

The robot can travel over extreme terrain, such as vertical walls more than 4 feet (1.2 m) high, wooded slopes, and rocky creekbeds. It can turn 180 degrees in place, raise and lower its suspension by 30 inches (76 cm), and lean left or right. The crusher can carry 8,000 pounds (3,600 kg) of combined armor and cargo. According to Stephen Welby, director of DARPA's Tactical Technology Office, "This vehicle can go into places where, if you were following in a Humvee, you'd come out with spinal injuries." The crusher can see enemy troops from over 2 miles (3.2 km) away with its cameras.

Construction

These robots have space frames and skid plates. The space frames, designed by CTC Technologies, have hollow aluminum tubes and titanium connections to improve strength. The high-strength steel skid plates are shock-mounted to protect against heavy blows from tree stumps or boulders. The nose of the crusher vehicle was designed not only to shove aside normal obstacles like small trees and brush, but also to absorb the energy of a major collision.

The crusher has a hybrid engine. This hybrid engine is capable of travelling several miles on one battery charge. The diesel engine then turns on to continue powering the crusher and to recharge the battery module. This diesel engine comes from a diesel Volkswagen Jetta.

Controls

Because they are designed to be autonomous, they have no steering wheel, brake pedal, or any other controls for an internal operator. Instead, operators drive the crusher with the controllers for racing video games. A modified Apple iPhone runs the crusher's self-diagnostics and gives remote updates, and a standard Xbox 360 controller is used to raise and lower the mast, rotate the camera, and fire the weapons.

The crusher can also drive autonomously. By utilizing a few basic GPS coordinates, the crusher can drive to its destination. While it cruises between its waypoints, the crusher continuously evaluates its surroundings to find the fastest and easiest path to its destination. If it finds a boulder more than 6 feet (1.8 m) high or a streambed more than

6 feet (1.8 m) deep, the crusher will find a way around it. Otherwise, it will drive over them or shove them out of the way.

The camera system uses five cameras, of which each is a 1600 by 1200 pixels, single-CCD, Bayer pattern, color camera. These cameras give an overall field of view of 200 degrees horizontally and 30 degrees vertically. The resolution is 40 pixels to the degree, which corresponds to 1.5 minutes of arc per pixel and is over four times the resolution of a normal television set. When running in remote-control mode, the crusher sends images back to the operator, and these images are resized and positioned so the operator sees on his screen what he would see if he were really sitting on top of the crusher.

Currently, the crusher sends data back to an operator via a 0.62 mi (1 kilometre) fiber optic cable. The current cable is 0.063 in (1.6 millimetres) in diameter, including the polyurethane jacket. It can handle sixteen different channels, and six of them are currently in use, five for video transmission and the sixth for gigabit ethernet. The ethernet channel carries the vehicle IMU data, control information, and vehicle audio.

Purpose

The crusher will be used for a number of missions considered highly dangerous for soldiers. For some missions, such as fire support or reconnaissance, driving the robot via remote control would suffice. However, other uses, such as using the crusher for Medevac, as a supply mule, or as a sentry, require that the robot be completely autonomous. John Bares, one of the people on the development team for the crusher, mentions that Medevac would be a good use for the robot because it could go into the battlefield under fire to scoop up fallen soldiers.

Specs

When unloaded, the crusher weighs 13,200 pounds (6,000 kg), and can carry a maximum of 8,000 pounds (3,600 kg) of payload and armor combined. The crusher is 201 inches (510 cm) long, 102 inches (260 cm) wide, and 60 inches (150 cm) high when the ground clearance is set to 16 inches (41 cm). The ground clearance can be dynamically changed from 0 inches (0 cm) up to 30 inches (76 cm), which is more than $\frac{1}{2}$ the 49.5 inches (126 cm) diameter of the wheels. The crusher has zero turning radius because it uses a skid steering system. When pushed to its maximum speed, the crusher can travel at 26 miles per hour (42 km/h), but it can only sustain that for less than seven seconds. Depending upon the traction, the crusher can climb up slopes of more than 40 degrees and travel with more than 30 degrees of slope to the side.

Item	Spec
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Maximum height of step that can be climbed	More than 4 feet (1.2 m)
Maximum width of trench that can be crossed	More than 80 inches (200 cm)
Powertrain	Turbo diesel engine runs a 78 hp (58 kilowatts) generator that powers a battery module with a capacity of 24.9 hp (18.7 kilowatt-hours), which runs six 280 hp (210 kilowatts) traction motors.
Peak torque	40,000 foot-pounds (54,000 N·m)

BigDog



A pair of BigDog robots

BigDog is a dynamically stable quadruped robot created in 2005 by Boston Dynamics with Foster-Miller, the NASA Jet Propulsion Laboratory, and the Harvard University Concord Field Station. BigDog is 3 feet (0.91 m) long, stands 2.5 feet (0.76 m) tall, and

weighs 240 pounds (110 kg), about the size of a small mule. It is capable of traversing difficult terrain at 4 miles per hour (6.4 km/h), carrying 340 pounds (150 kg), and climbing a 35 degree incline. Locomotion is controlled by an onboard computer that receives input from the robot's various sensors. Navigation and balance are also managed by the control system.

History

BigDog is funded by the Defense Advanced Research Projects Agency (DARPA) in the hopes that it will be able to serve as a robotic pack mule to accompany soldiers in terrain too rough for conventional vehicles. Instead of wheels or treads, BigDog uses four legs for movement, allowing it to move across surfaces that would defeat wheels. The legs contain a variety of sensors, including joint position and ground contact. BigDog also features a laser gyroscope and a stereo vision system.

BigDog was featured in episodes of *Web Junk 20* and *Hungry Beast*, and in articles in *New Scientist*, *Popular Science*, *Popular Mechanics*, and *The Wall Street Journal*.

On March 18, 2008, Boston Dynamics released video footage of a new generation of BigDog. The footage shows BigDog's ability to walk on icy terrain and recover its balance when kicked from the side.

Hardware

Big Dog is powered by a two-stroke, one-cylinder, 15-HP go-kart engine operating at over 9,000 RPM. The engine drives a hydraulic pump, which in turn drives the hydraulic leg actuators. Each leg has four actuators (two for the hip joint, and one each for the knee and ankle joints), for a total of 16. Each actuator unit consists of a hydraulic cylinder, servovalve, position sensor, and force sensor.

Onboard computing power is a ruggedized PC/104 board stack with a Pentium 4 class computer running QNX.

Battlefield Extraction-Assist Robot

The **Battlefield Extraction Assist Robot** ("BEAR") is a humanoid robot designed by Vecna Technologies for the US military. Its intended role is to serve as a method for transporting wounded soldiers on the battlefield to safety. BEAR is 6 feet tall and can lift 135 kilograms. Its legs also have wheels and tracks built into them that the robot can switch to by kneeling.

The robot's head is designed to look like that of a teddy bear, to provide reassurance to the wounded soldier it is transporting.

Armored Combat Engineer Robot

The **Armored Combat Engineer Robot (ACER)** is a military robot created by Mesa Robotics. Roughly the size of a small bulldozer and weighing 2.25 tons, ACER is among the larger of the terrestrial military robots. Nonetheless, like many other military robots, it has a modular body, allowing for adjustments for its next mission. ACER is able to reach speeds of 6.3 mph, using treads for movement. Uses for this robot include clearing obstacles, removing explosives, hauling cargo and disabled vehicles, and serving as a platform for various other tasks, such as clearing buildings and disarming landmines.