# LCROSS Description

Mission Overview

LCROSS launched as a secondary payload with Lunar Reconnaissance Orbiter (LRO) on June 18, 2009 5:32 Eastern Time. After trans-lunar injection, LRO separated and performed its mission. The LCROSS Shepherding Spacecraft (SSC) remained attached to the spent Atlas upper stage, called the Centaur. Over 112 days, the Shepherding Spacecraft adjusted the Centaur’s course to bring it to an impact within the Cabeus Crater near the South Pole of the moon.

LCROSS used the Centaur as a 2300 kg kinetic impactor with more than 200 times the energy of the Lunar Prospector (LP) impact to excavate more than 250 metric tons of lunar regolith. The resulting ejecta cloud was observed from a number of Lunar-orbital and Earth-based assets, and the LCROSS spacecraft. After releasing the Centaur, the SSC flew toward the impact plume, sending real-time data to characterize the morphology, evolution and composition of the plume with a suite of cameras and spectrometers. The SSC then became a 700kg impactor itself, providing a second opportunity to study the nature of the Lunar Regolith.  
  
Mission Objectives

The scientific objectives of the Lunar Crater Observation and Sensing Satellite (LCROSS) were to:   
 \* Confirm the presence or absence of water ice in a permanently shadowed region on the moon.   
 \* Identify the cause of the hydrogen signatures detected at the lunar poles.   
 \* Determine the amount of water, if present, in the lunar regolith or soil.   
 \* Determine the composition of the regolith in one of the moon’s permanently shadowed craters.   
  
Mission Phases

LCROSS and LRO launched on June 18, 2009 at 21:32 UTC aboard an Atlas V launch vehicle in the 401 configuration (4-meter fairing, no solid rocket boosters, single-engine Centaur). After achieving low-Earth orbit, the Centaur performed a 23 minute coast, and then re-ignited to perform the trans-lunar injection (TLI) burn for both LCROSS and LRO.

Three minutes after TLI, the Centaur separated from LRO and then maneuvered to increase separation to avoid contaminating LRO. To minimize the residual propellant species aboard the Centaur at lunar impact (potential contaminants of water measurements), the Centaur next performed a sequence of propellant depletion maneuvers with both cryogenic and hydrazine-based reaction control systems. During these depletion maneuvers, the Centaur powered the SSC up and pointed its solar array at the sun. After the maneuvers were finished, the Centaur ceded attitude control to the SSC and shut down.  
   
Transfer Phase [6/18/2009 - 6/23/2009]  
The transfer phase covered the period from TLI to lunar swingby. This phase contained the QUICKLOOK and STARFIELD data collection periods. Both periods were used to confirm instrument function and pointing prior to the lunar swingby.  
   
Lunar Swingby [6/23/2009]  
The lunar swingby was a gravity assist maneuver that placed LCROSS in a steeply-inclined, nearly circular orbit around Earth at approximately lunar distance. Called a Lunar Gravity Assist Lunar Return Orbit (LGALRO), this trajectory returned LCROSS to the moon again after three orbits.

Just after closest approach to the moon, the instruments were pointed at the surface and turned on to gather calibration data. The instruments were swept across the surface, pausing three times at targets on the surface with distinctive spectral characteristics. Finally, the instruments were swept back and forth across the limb. This limb-crossing data was used to confirm instrument pointing to within 0.1 degree.  
   
Cruise Phase  
Cruise phase activities included trajectory correction maneuvers and additional periods of payload data collection observing the Earth and Moon.

Several “Cold Side Bake” activities were also performed to reduce ice in the Centaur insulation that remained since launch. During these maneuvers, the SSC and Centaur were turned to place cold side of the spacecraft, which was normally in darkness, in sunlight. Sublimating ice embedded in the insulation generated enough thrust to be detectible in Doppler measurements. If left in place, this ice could potentially have contaminated observations of the Centaur’s impact.

On the second half of the second Earth orbit, LCROSS experienced a major propellant loss stemming from a short-lived Inertial Reference Unit (IRU) glitch. This was discovered immediately before the third Cold Side Bake event. With the mission in jeopardy, LCROSS declared an emergency and transitioned to maximum DSN coverage to enable full-time monitoring. Over the following two weeks, the flight team developed strategies to prevent another glitch and to minimize propellant usage during planned maneuvers. With operational and software protections in place, the LCROSS project returned to a nominal operational posture on Day 78, albeit with a significantly smaller propellant margin.

The deadline for final selection of the Centaur target crater was 30 days prior to impact. This late date allowed the Team to use early data from LRO to improve the targeting decision. During the final two weeks of cruise, the Science Team twice refined the target location within the crater.  
   
Separation  
Centaur separation was performed successfully 9 hours 40 minutes prior to Centaur impact and, with the substantial change of mass properties, was accompanied by a transition to a completely new set of attitude control modes tuned for post-separation conditions. One minute following separation, the SSC flipped 180 degrees to point the payload at the receding Centaur. These observations are contained in the SEPARATION data collection period. Forty minutes after separation, the SSC performed the Braking Burn, a delta-v maneuver used to produce a 600 km separation between the Centaur and the SSC at the moment of Centaur impact.  
   
Impact  
Approximately one hour prior to centaur impact, the spacecraft was turned to point the instruments at the predicted impact location. Fifty minutes of calibration data are contained in the PREIMPACT data collection. Five minutes of data are contained in the IMPACT data collection, starting one minute prior to Centaur impact.

The Centaur impacted the moon at 11:31:19.51 UTC on 10/9/2009 at -84.68 deg latitude, -48.69 deg longitude, Mean Earth frame.

The SSC impacted the surface at 11:35:34 UTC.   
  
Earth-based Observations

The LCROSS project provided funding for four investigators to record Earth-based observations of the LCROSS impact using various observatory facilities, and to archive their data in the PDS. Many other Earth-based facilities also observed the impact. The four LCROSS-sponsored observers were:  
(1) Dr. Marc Buie, Southwest Research Institute in Boulder, CO, using the PHOTDOC and PHOTGJON cameras on the Magdalena Ridge Observatory 2.4-m telescope, Socorro, NM  
(2) Dr. Nancy Chanover, New Mexico State University, using the Agile camera on the Astrophysical Research Consortium 3.5-meter telescope at the Apache Point Observatory, Sunspot, NM  
(3) Dr. Faith Vilas, University of Arizona, using the CCD47 and CLIO cameras at the MMT Observatory, Tucson, AZ  
(4) Dr. Eliot Young, Southwest Research Institute in Boulder, CO, using three facilities: the Gemini North telescope at the Mauna Kea Observatory on the island of Hawaii; the SPEX spectrograph and imager on the 3.0-meter Infrared Telescope Facility (IRTF) at the Mauna Kea Observatory; and the Near Infrared Spectrograph (NIRSPEC) on the 10-meter Keck II telescope, Keck Observatory, Kamuela, Hawaii.   
  
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