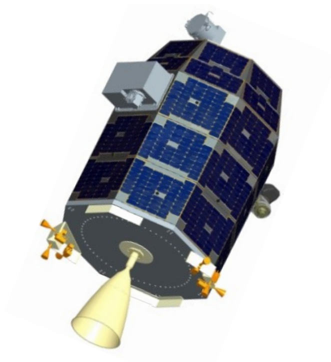

Lunar Atmosphere and Dust Environment Explorer

(LADEE)

LADEE PDS Mission Description

May 13th, 2014

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California

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Page three of this document contains the approved routed release of this document.

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REVISION HISTORY			
Rev.	**Description of Change**	**Author(s)**	**Effective Date**
1.0	Initial draft	G. Delory	Nov 1, 2012
1.1	Resolved several TBDs	G. Delory	Nov 29, 2012
1.2	Updated TOC and prepared for conversion to PDF	G. Delory	March 21, 2012
NC	Baseline	G. Delory	March 21, 2012
1.3	Edited mission objective #2 as per PDS peer review results	G. Delory	April 4, 2013
1.4	Updated mission timeline and orbit plots to reflect as-flown data	G. Delory	May 6, 2014
1.5	Incorporate comments from DAWG team. Release for second PDS peer review	G. Delory	May 13, 2014

CONFIGURATION MANAGEMENT PLAN

This document is an LADEE Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the LADEE Project Manager. Proposed changes shall be submitted to the LADEE CM office along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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1 INTRODUCTION

National Research Council decadal surveys and the “Scientific Context for Exploration of the Moon” (SCEM) report have identified studies of the pristine state of the lunar atmosphere and dust environment as among the leading priorities for future lunar science missions. The Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission was created in March 2008 to address these goals.

The LADEE program will determine the composition of the lunar atmosphere and investigate the processes that control its distribution and variability, including sources, sinks, and surface interactions. LADEE will also address the longstanding mystery of whether dust is present in the lunar exosphere, and reveal the processes that contribute to its sources and variability. These investigations are relevant to a broader understanding of surface boundary exospheres and dust processes throughout the solar system, address questions regarding the origin and evolution of lunar volatiles, and have potential implications for future exploration activities.

The LADEE mission employed a high-heritage science instrument payload, including a neutral mass spectrometer, an ultraviolet spectrometer, and an in-situ dust sensor. In addition to these science instruments, LADEE carried a laser communications system technology demonstration. The purpose of this document is to describe the main relevant aspects of the LADEE mission for users accessing LADEE data through the Planetary Data System (PDS).

2 MISSION OBJECTIVES

The top-level programmatic and science requirements for the LADEE project are designed to accomplish the following mission objectives:

1. Determine the composition of the lunar atmosphere and investigate the processes that control its distribution and variability, including sources, sinks, and surface interactions.
2. Characterize the lunar exospheric dust environment and measure spatial and temporal variability and impacts on the lunar atmosphere
3. Demonstrate the Lunar Laser Communications Demonstration (LLCD)
4. Create a low-cost reusable spacecraft architecture that can meet the needs of certain planetary science missions
5. Demonstrate the capability of the Minotaur V as a launch vehicle for planetary missions

Based on the overall science goals outlined in objectives 1 and 2 above, the LADEE mission was designed meet the specific baseline science requirements outlined in Table 2-1.

Table 2-1: LADEE Baseline Science Requirements

	Science Requirement
1	Measure the relevant spatial and temporal variations of Ar, He, Na, and K. The temporal scales covered shall range from 12 hours to 1 month. The spatial scales covered shall be as follows: Ar, within ±20° of the terminator regions of the Moon; He, sufficient coverage to resolve variations from noon to midnight; K, Na, sufficient coverage to resolve variations over the lunar dayside.
2	Detect or establish new limits for selected other species for which previous detections have been attempted. These shall include the following from the family of exogenic/volatile species (CH_4, O, OH, H_2O, CO, S), and the following from the family of endogenic (regolith-derived refractory) species (Si, Al, Mg, Ca, Ti, Fe).
3	Perform a survey for the presence of other species beyond those listed above, or positive ambient ions of these species and other atoms or compounds, within a mass range of 2-150 Da and a sensitivity of several particles/cc.
4	Detect or set new limits for the spatial and size distribution of atmospheric dust over an altitude range from 3 km up to 50 km, with a height resolution of 3 km, at a minimum detectable density of 10^{-4} grains/cc, for grains from 100 nanometer to at least 1 micrometer in radius. These observations shall be conducted at the temporal and spatial scales for Ar as outlined in the first science requirement above.

3 MISSION DESCRIPTION

3.1 Mission Overview

LADEE was launched on September 7th, 2013 03:27 UTC, from the Wallops Island Flight Facility (WFF) on a Minotaur V launch vehicle (LV). The LV inserted LADEE into an Earth-centered phasing orbit followed by a direct lunar transfer. At lunar arrival, LADEE was inserted into a retrograde equatorial orbit at an inclination of 157°, at which point a commissioning/checkout phase was conducted, followed by the science phase. The total mission duration was 223 days, including 100 days dedicated to nominal science operations and a 48 day extended science mission. The mission was decommissioned by impact into the Moon on April 18th, 2014. The LADEE science mission was designed to fulfill the science requirements in Table 2-1. The science payload consisted of three instruments: a Neutral Mass Spectrometer (NMS), an Ultraviolet/Visible Spectrometer (UVS), and the Lunar Dust Experiment (LDEX). A separate articulated laser assembly comprised the LLCD. Data from the NMS, UVS, and LDEX instruments were processed and submitted to the PDS for access by the scientific community and the public. The LADEE project and spacecraft were managed by the NASA Ames Research Center (ARC), with the instrument payload and science operations center managed by the NASA Goddard Space Flight Center (GSFC).

3.2 Spacecraft

The LADEE spacecraft bus design was derived from the Modular Common Spacecraft Bus (MCSB or "common bus") architecture developed by ARC from 2006-2008. The spacecraft was 3-axis stabilized, and pointed the instruments in various directions, including ram (in the direction of the spacecraft velocity), limb, occultation, or other viewing directions as needed. The remaining major spacecraft systems included a bi-propellant propulsion section, body-mounted solar arrays, several medium-gain and omni-directional antennas, and star trackers. The LLCD system utilized a laser mounted on an articulated boom. The NMS was mounted to the spacecraft body while UVS and LDEX resided on the upper deck. The basic spacecraft and instrument configuration is shown in Figure 1.

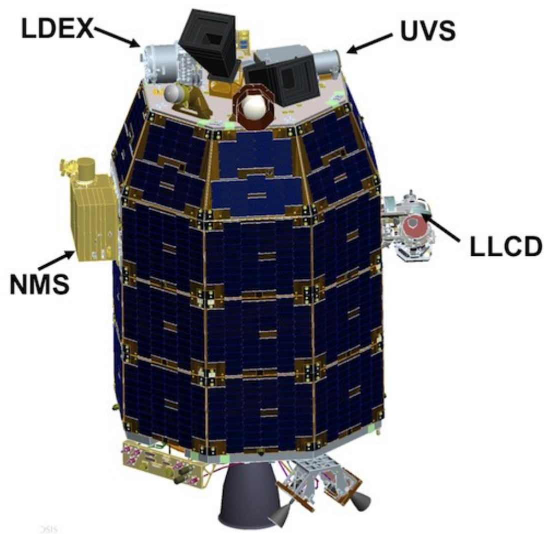

Figure 3-1: The LADEE Spacecraft and Instrument Locations

3.3 Instrument Payload

3.3.1 Neutral Mass Spectrometer

The LADEE NMS measured the mass distribution of neutral species over a mass-to-charge (*m/z*) range between 2-150. NMS drew its design from similar mass spectrometers developed at GSFC for the MSL/SAM, Cassini Orbiter, CONTOUR, and MAVEN missions. At low altitudes, NMS was capable of measuring the abundance of gases such as Ar and CH_4, which may indicate internal geophysical processes at the Moon. Measurements of He are used to understand the importance of the solar wind in the generation and dynamics of the helium exosphere. NMS was also designed to detect refractory elements in the exosphere (Si, Al, Mg, Ca, Ti, Fe), as well as Na and K, which may be indicative of more energetic processes acting on the lunar surface such as sputtering and impact vaporization. In terms of volatiles, NMS could detect H_2O, OH and CO. There was also an ion-detection mode. Ultimate sensitivity for detection of most species was in the few/cc range.

3.3.2 Ultraviolet/Visible Spectometer

The UVS instrument was a next-generation, high-reliability version of the LCROSS UV-Vis spectrometer, spanning 250-800 nm wavelength, with high (<1 nm) spectral resolution. UVS was designed to be used in both limb and occultation mode. In limb mode, UVS searched for resonant scattering emissions from exospheric species as well as scattering of sunlight from lunar dust. In occultation mode, UVS searched for scattering of sunlight by dust using a separate solar viewing optic. UVS could detect volatiles such as OH, K, Li, Ba, and Na, as well as more refractory elements such as Al, Ca, Si, Ti, and Mg. UVS could also detect water (H_2O) in several of its positively ionized states

3.3.3 Lunar Dust Experiment

LDEX sensed dust impacts in situ, using an impact vaporization and charge detection assembly. Dust particle impacts on a large hemi-spherical target create electron and ion pairs. The latter are focused and accelerated in an electric field and detected at a micro-channel plate. The LDEX design heritage included instruments aboard the HEOS 2, Ulysses, Galileo and Cassini missions. It was designed to operate at the relatively low LADEE orbital speed of 1.6 km/s and altitudes of 50 km and below, and was sensitive to a particle size range of between 100 nm and 5 µm.

4 MISSION PHASES

The LADEE mission profile consisted of the following major phases: launch, ascent, activation & checkout, phasing orbits, lunar transfer, lunar orbit acquisition, commissioning, nominal science operations, extended science, and lunar impact. These phases, along with dates and durations for each, are summarized in Table 4-1

Table 4-1: LADEE Mission Phases (all times UTC)

Mission Phase	Entry	Exit	Duration	Description
Launch & Ascent	LV lift-off 9/7/2013 03:27	LADEE separation from 5th stage 9/7/2013 03:51	24 min	Launch from Wallops Flight Facility Achieve phasing orbit insertion De-spin 5th stage
Activation & Checkout	LADEE separation from 5th stage 9/7/2013 03:51	Completion of initial checkout procedure 09/08/2013 00:50	21 hrs	S/C acquisition of Safe Mode attitude Ground station acquisition and initial orbit determination Transition to fine pointing mode
Phasing Orbit	Completion of initial checkout procedure 09/08/2013 00:50	Earth perigee #3 10/01/2013 10:55	23 days 10 hrs	Execute 3 phasing loops Spacecraft commissioning and bake-out Instrument aliveness checks
Lunar Transfer	Earth perigee #3 10/01/2013 10:55	One day prior to LOI-1 10/5/2013 10:57	4 days 2 hrs	Final targeting for LOI
Lunar Orbit Acquisition	One day prior to LOI- 10/05/2013 10:57	End of LOI-3 Burn 10/13/2013 03:36:57	7 days 17 hrs	Series of three LOI maneuvers. Achieve goal of 250 km staging orbit.
Commissioning	End of LOI-3 Burn 10/13/2013 03:36:57	End of OLM-4 Burn 11/21/2014 04:53:20	39 days 1 hr	Instrument checkout & commencement of LLCD operations. Instrument science checkout during last 10 days
Science	End of OLM-4 Burn 11/21/2014 04:53:20	100 days in prime Science configuration 3/1/2014 04:53:20	100 days	Nominal operation of UVS, NMS, and LDEX instruments on a duty-cycled basis. 15 OMMs to maintain orbit.
Extended Science	100 days in Science configuration 3/1/2014 04:53:20	Lunar impact 04/18/2014 04:31:45	47 days 23.5 hrs	Science measurements obtained until lowest possible altitude.

4.1 Launch

Launch occurred on September 7th, 2013 at 03:51 UTC, from WFF on a Minotaur V launch vehicle. The ascent phase lasted 24 minutes at which point LADEE separated from the last (5th) stage of the vehicle. This was followed by a day of spacecraft activation and checkout in a low-Earth orbit, culminating in a maneuver to increase the LADEE apogee into the Earth-centered phasing loop orbits.

4.2 Phasing Loops

After ascent, LADEE was inserted into Earth-centric phasing loop orbits on September 7th, 2013, ranging in period from 6 to 10 days each. LADEE executed a total of three phasing orbits over a period of almost 24 days prior to a maneuver placing LADEE into a trans-lunar trajectory (Figure 4-1.)

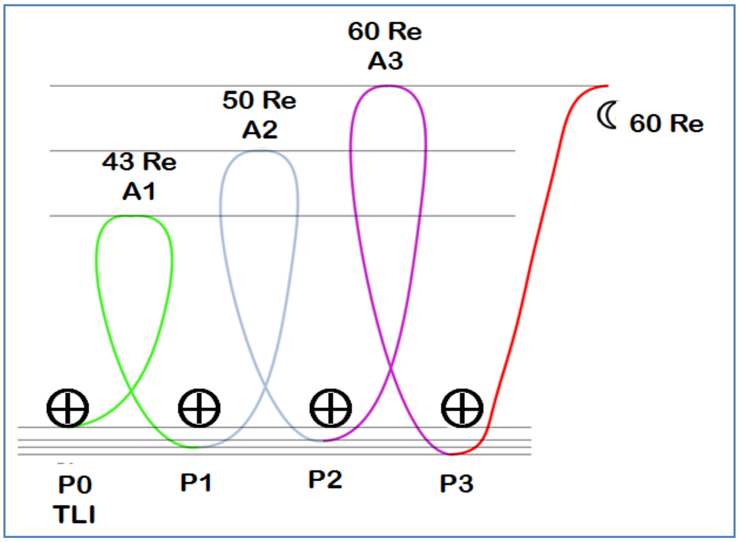

Figure 4-1: LADEE phasing loops (approximate periods of 6, 8, and 10 days, respectively)

4.3 Lunar Transfer & Acquisition

Initiation of the trans-lunar trajectory began on October 5th, 2013 at 10:57 UTC. The trans-lunar trajectory phase ended with the lunar orbit acquisition phase, which commenced with the first lunar orbit insertion (LOI-1) burn that captured LADEE into lunar orbit. Two subsequent LOI maneuvers sequentially lowered the lunar orbit from the arrival hyperbola to a 250 km circular orbit as shown in Figure 4-2. During this phase LADEE approached the Moon from the left (white line) in the figure shown, and was captured into a 24 hour orbit with a 155,786 km apoapsis where the spacecraft remained for 3 revolutions lasting 3 days. LOI-2 lowered the orbit down to a 4 hour orbit with a 2,184 km apoapsis. Finally, LOI-3 lowered the orbit down to a 250 km × 250 km lunar commissioning orbit on November 21st, 2013 at 04:53 UTC.

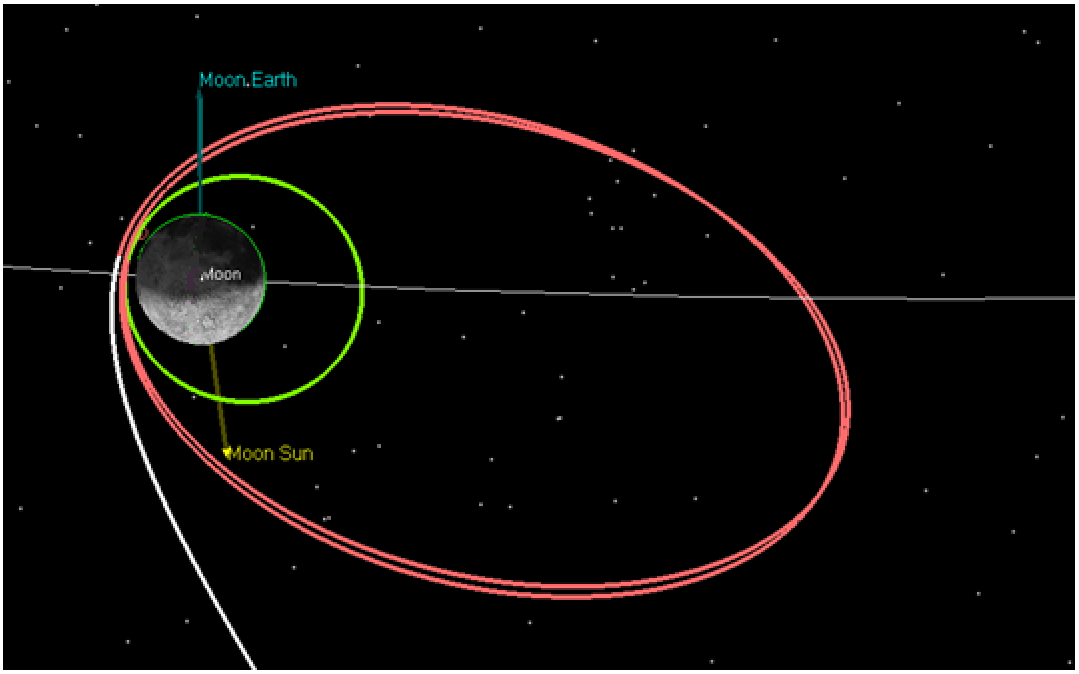

Figure 4-2: LOI phase of the LADEE mission. Last phasing loop (white), LOI-1 orbits (orange), LOI-2 orbits (green), and LOI-3 transition to the commissioning orbit (darker green semi-circle on the upper half of the Moon)

4.4 Commissioning Phase

During the commissioning phase the LLCD technology demonstration and basic checkout of the science payload was completed. The prime operational phase of the LLCD was conducted during the first 30 days while LADEE was in the 250 km circular orbit at 157° inclination. During this time, science payload activation and initial checkout was also initiated. During the last 10 days of the commissioning period, the LADEE periapsis was lowered to 50 km while science payload checkout activities continued, and the first measurements of the lunar exosphere and dust properties were performed. The commissioning phase ended on November 21st, 2013, when LADEE was maneuvered into the science orbit. Figure 4-3 shows the orbit altitudes (perigee and apogee altitudes) as a function of mission phase from the commissioning phase through impact.

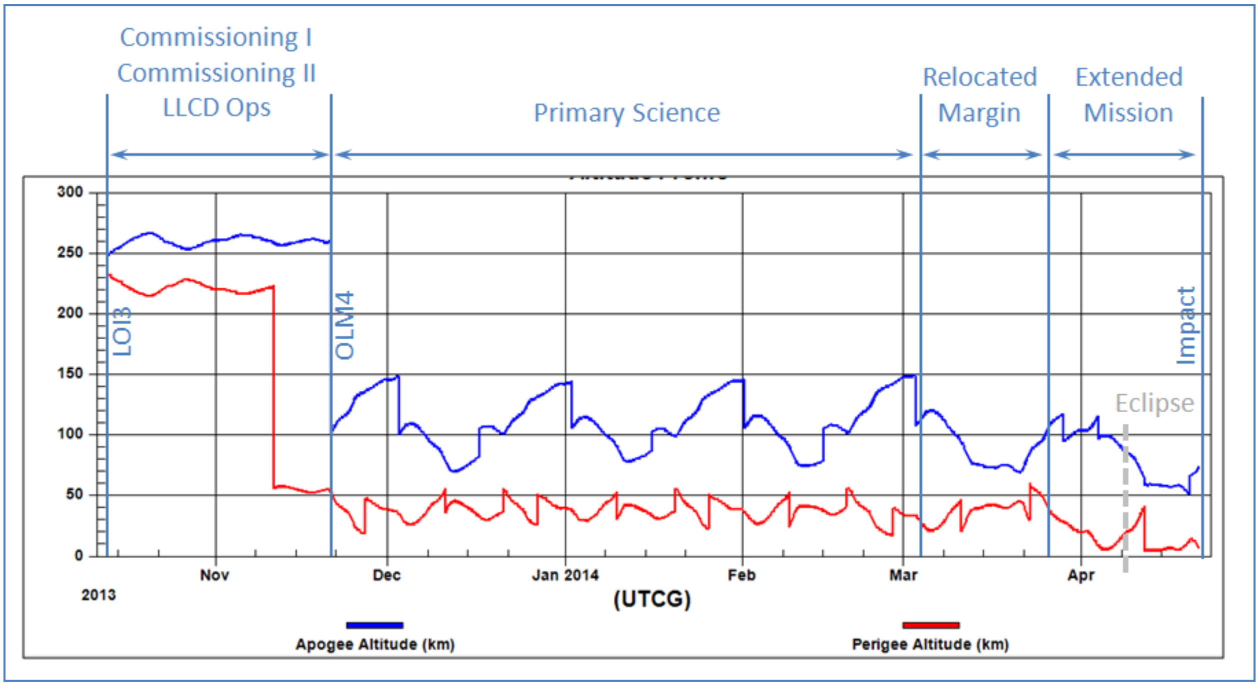

Figure 4-3: LADEE orbit altitude profile throughout the commissioning, science, and extended science mission phases. Note the extended science phase covered the relocated margin + extended mission intervals.

4.5 Science Phase

The science phase began on November 21st, 2013 at 04:53 UTC and lasted 100 days. Orbit Maintenance Maneuvers (OMMs) were used during this period to keep the periapsis altitude at or below 50 km and the apoapsis altitude below 150 km to the extent possible. The orbit design with OMMs during the science phase is shown in Figure 4-3. OMMs were designed to maintain the periapsis over the lunar sunrise terminator whenever possible.

4.6 Extended Science Phase

The extended science phase began on March 1st, 04:53 UTC. During this time the orbit periapsis was allowed to decrease in order to achieve low-altitude science observations. An eclipse period was encountered on April 15th, which precluded science activities starting on April 14th, 22:00 UTC. Science observations resumed on April 15th, 16:53 UTC and continued through the end of the extended science phase on April 18th, 2014.

4.7 Impact

The planned impact of LADEE into the Moon occurred on April 18, 2014 at 04:31:47 UTC at 11.840 deg latitude and −93.252 deg longitude (Moon-centered Mean Earth coordinates).

Appendix A

Acronyms

ARC	Ames Research Center
GSFC	Goddard Space Flight Center
LADEE	Lunar Atmosphere and Dust Environment Explorer
LDEX	Lunar Dust Experiment
LLCD	Lunar Laser Communications Demonstration
LOI	Lunar Orbit Insertion
LV	Launch Vehicle
MCSB	Modular Common Spacecraft Bus
NASA	National Aeronautics and Space Administration
NMS	Neutral Mass Spectrometer
OMM	Orbital Maintenance Maneuver
PDS	Planetary Data System
S/C	Spacecraft
UVS	Ultraviolet/Visible Spectrometer
UTC	Coordinated Universal Time
WFF	Wallops Flight Facility