Pre-Launch Testing of NGSLR Ranging to LRO

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Abstract. *A comprehensive test program for NASA's Next Generation Satellite Laser Ranging (NGSLR) system is being conducted as the development phase nears completion. A subset of those tests pertaining specifically to tracking the Lunar Reconnaissance Orbiter (LRO) spacecraft fall into three functional categories, namely, (1) the telescope must track LRO, (2) LRO must be scheduled as the highest priority target, and (3) NGSLR software is correctly modified for LRO. This document describes the subtest of LRO-related tests and focuses on three examples to demonstrate testing procedures. The LRO testing program has been successfully completed and NGSLR is prepared for operational tracking once the spacecraft is lunar orbit and is ready to receive laser pulses from Earth stations.*

1. Introduction

NGSLR will be used for one-way ranging to LRO with the goal of providing an improved lunar gravity field and a precise spacecraft orbit. Data from the Lunar Orbiter Laser Altimeter (LOLA) instrument can then be referenced to the orbit to facilitate high accuracy surface mapping.

NGSLR has a 28 Hz, 50 milli-Joule laser for tracking LRO, in addition to the 2000 Hz eye-safe laser for Earth orbiting satellites. The laser ranging telescope is mounted on the high gain antenna which normally points toward the Earth. A fiber optic bundle carries light from the ranging telescope to the LOLA receiver. Meanwhile, the telescope for altimetry points to nadir, and thus the receiver can be used for altimetry and ranging. The 28 Hz LOLA duty cycle has separate time windows for receiving lunar reflected pulses from its own laser and Earth pulses. Thus, one testing criteria is that NGSLR pulses will arrive at LRO during the 8 milli-second Earth window.

The overall testing program for NGSLR has 137 elements including 19 that pertain specifically to tracking LRO. Each of the 19 LRO tests falls into to one of three functional categories described in section 2 and each includes a set of criteria for success. Testing procedures involve operating the NGSLR system, running test scenarios, and comparing logged data with expected results. Interplanetary calculations make use of SPICE software, ephemeris kernels and clock files. Simulation is being used in order to complete the test program before the spacecraft is launched.

The following tests will be described in some detail. In section 3, the arrival time of laser pulses during the Earth window will be demonstrated using SPICE calculations. Section 4 illustrates the results of manually controlling the laser fire offset and frequency. Finally, in section 5 correct and accurate telescope pointing will be validated using photographic images of the Moon taken through the NGSLR telescope.

2. Functional Test Categories

There are three levels of requirements recognized in the overall testing plan for NGSLR. The highest one is identified as mission level or level 1, and the requirement to track LRO is number 8 of all the NGSLR mission requirements. Thus, the test numbers in this document all begin with '8' in conformance with the general testing plan.

Proceeding directly from the LRO mission requirement are the following functional level requirements, also known as level 2: 8.1, the telescope must track the LRO spacecraft; 8.2, LRO must be scheduled as the highest priority target; and 8.3, NGSLR software is correctly modified for LRO.

Testing level requirements, level 3, follow from the functional requirements listed above. The hierarchy from mission through test requirements is shown below.

8. Lunar Reconnaissance Orbiter Requirements
- 8.1 The telescope must track the LRO spacecraft
  - 8.1.1 The telescope commanded pointing is correct
  - 8.1.2 The telescope actual pointing is correct
- 8.2 LRO must be scheduled as the highest priority target
  - 8.2.1 When the Moon is above 20 degrees LRO is scheduled
  - 8.2.2 LRO is scheduled as the highest priority target
- 8.3 NGSLR software is correctly modified for LRO
  - 8.3.1 Laser pulses hit the LR receiver in the LOLA Earth window
  - 8.3.2 The software functions correctly when no returns are received
  - 8.3.3 No satellite search takes place
  - 8.3.4 Biases are not applied automatically
  - 8.3.5 LRO is the sole target and it is tracked whenever scheduled
  - 8.3.6 Manual control of laser fire including offset and frequency
  - 8.3.7 All fires are recorded
  - 8.3.8 Output data is in ITDF format
  - 8.3.9 The LRO-LR web site is displayed to the operator
  - 8.3.10 SCLK data can be input
  - 8.3.11 Laser parameters are automatically switched
  - 8.3.12 Go/NoGo restrictions are correctly processed
  - 8.3.13 The time of the laser fire is correct
  - 8.3.14 Signal processing parameters are correct for LRO
  - 8.3.15 The percentage of laser fires missing is acceptable

The following sections illustrate the procedures and results for tests 8.3.13, 8.3.6 and 8.1.2.

3. The Time of the Laser Fire is Correct (Test 8.3.13)

For this test the laser fire times from a log file were used as input to a SPICE program that used an SCLK file to compute their arrival time in the LOLA duty cycle. This cycle, illustrated in Figure 1, shows that the Earth window opens near the start of the cycle and ends approximately 9 milliseconds later.

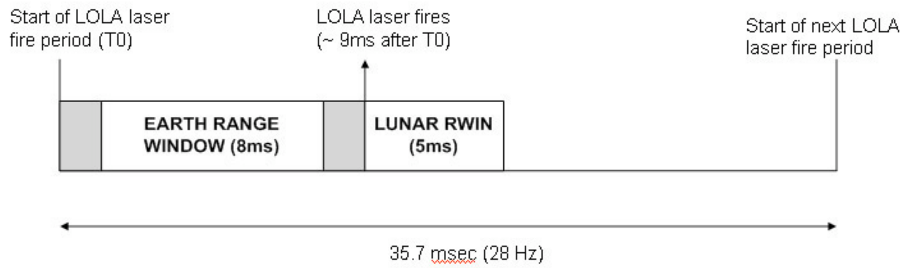


Figure 1. The LOLA duty cycle showing the location of the Earth Range Window.

The data portion of an SCLK file is shown below where the columns represent ticks of the spacecraft clock, ET seconds elapsed since the epoch of J2000, and the ratio of the rates of the spacecraft clock and ET, respectively.

SCLK01_COEFFICIENTS_85 = (
0.0000000000000E+00 3.1579264184000E+07 1.0000000010000E+00
1.5485503275008E+13 2.6786929218400E+08 1.0000000010000E+00)

Procedures:
1. Capture laser fire time.
2. Compare with off-line calculation.
3. Verify SCLK data usage.

Results
1. Captured fire times in two log files.
2. In Figure 2 and statistics below form the comparison.
3. Statistics: 99% of pulses arrive at 5.0 +/- 0.1 msec

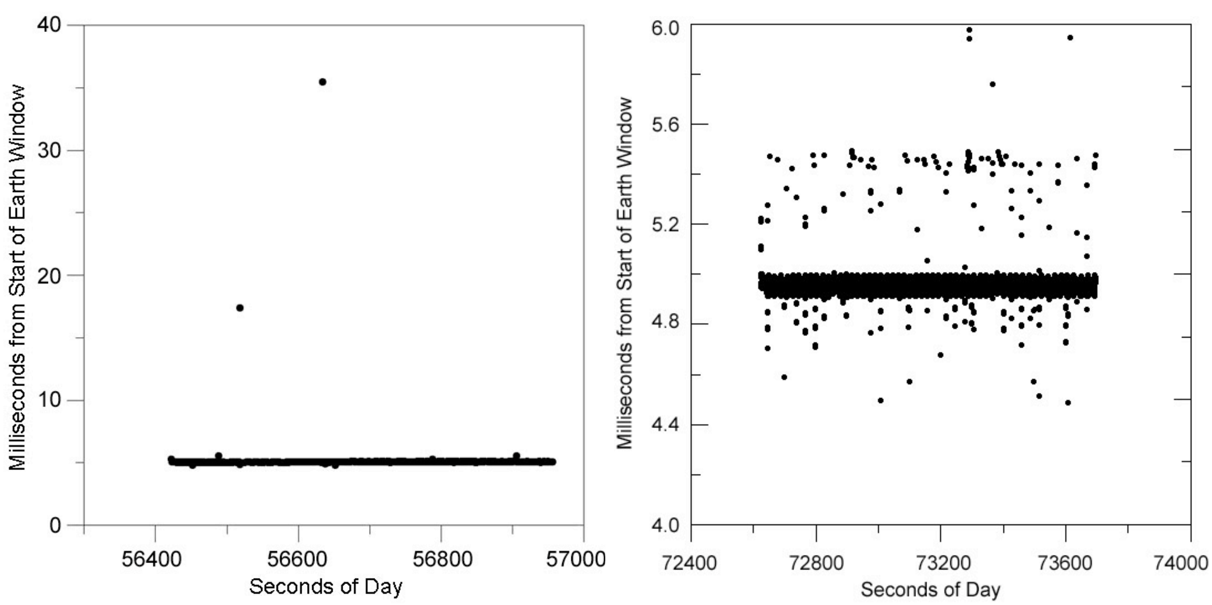


Figure 2. Two data sets of arrival times of pulses in the LOLA duty cycle.

4. Manual Control of Laser Fire Including Offset and Frequency (Test 8.3.6)

Offsets can be commanded from +35.7 milliseconds to minus that same magnitude and the frequency can be changed from +100 microseconds per second to minus that magnitude. The test is to analyze fire times when offset and frequency changes occurred and to compare commanded and measured values.

Procedures:
1. Identify the LRO pass.
2. Manually adjust the laser fire offset and frequency (both separately and together) and record those adjustments.
3. Verify that the log and message files recorded the manual offset and frequency adjustments.

Results:
1. Ran a simulated track of LRO on 2006 August 21 at 18:50.
2. Commanded a comprehensive set of frequency and offset changes.
3. Shown in Figure 3 on the left are offset of +2, 0 and -2 milliseconds versus time. On the right are the intervals between fires during a frequency change versus time.

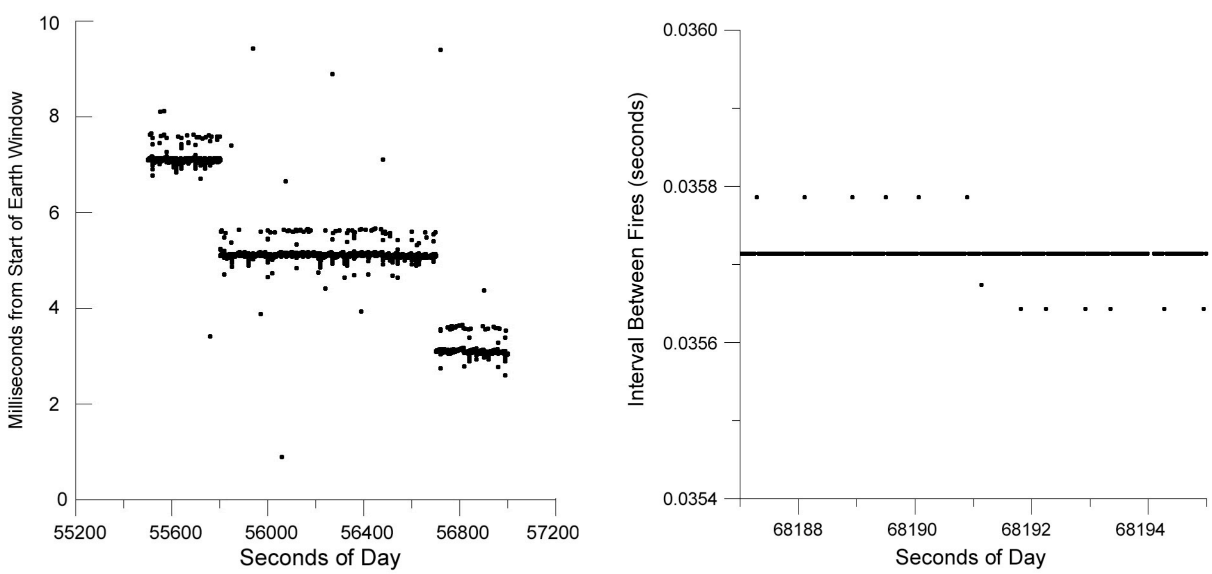


Figure 3. Left – arrival times of pulses. Right – interval between fires.

5. The Telescope Actual Pointing is Correct (Test 8.1.2)

In this test the pointing of the NGSLR telescope was verified using images of the Moon captured during a simulated LRO track.

Procedures:
1. Request Flight Dynamics Facility for dummy LRO pass including STK output
2. Run the pass and image the Moon with the star camera
3. Compute actual pointing based on identification of lunar craters
4. Record the differences in the sense 'actual minus STK'
5. Compute the statistics of the difference

Results:
Steps 1 and 2 were completed as specified.
Steps 3 and 4 are illustrated in Figures 4 and 5, and were augmented by a comparison of 'actual minus SPICE'.
Step 5. The statistics measured in arc seconds are in Table 1.

Table 1. Pointing differences of NGSLR versus STK and SPICE

Comparison	Root-mean-square Difference	Largest Difference
NGSLR versus STK	3.2	5
NGSLR versus SPICE	2.4	4

Intermediate results from Steps 3 and 4 are described below.

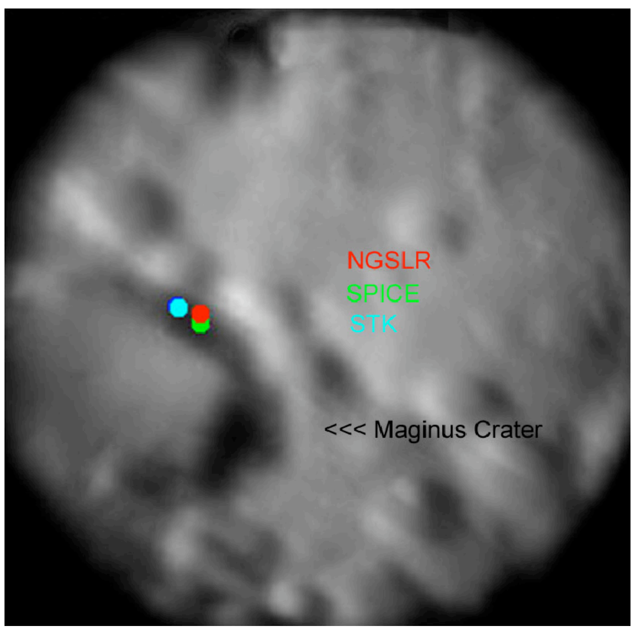
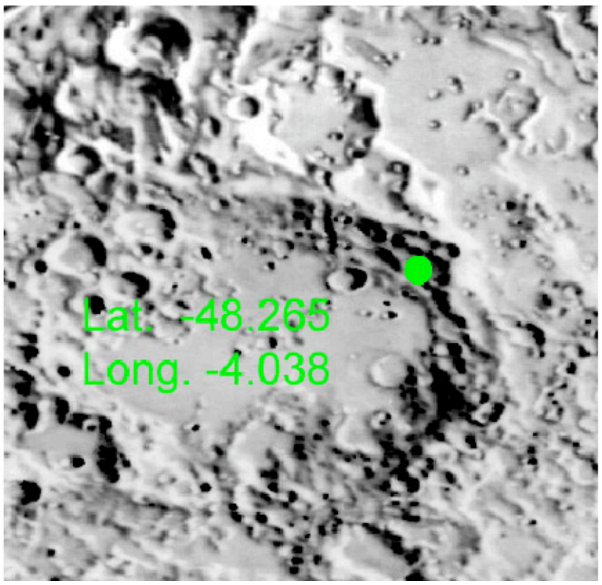


Figure 4. This image of a portion of the Moon was captured with the NGSLR star camera. The red dot indicates the location of the telescope pointing. Identification of lunar features, such as the crater Maginus in this case, and auxiliary information allowed the SPICE and STK positions to be superposed on the images as well.

SPICE coordinates were computed in a separate program. The main SPICE kernels were (1) NGSLR position from custom generated kernel, (2) Earth and Moon positions from DE421, (3) LRO position from a special orbit kernel obtained from FDF, and (4) the Lunar 'Mean Earth' reference frame. The SPICE point-ahead correction, XCN+S, was used. This corresponds to the transmission case computed with a converged Newtonian light time correction and stellar aberration applied.

The resulting lunar coordinates were then plotted on a USGS airbrushed shaded relief map that had been warped to correspond with the Unified Lunar Coordinate Network, ULCN2005. The sample image in Figure 5 (left) shows the plotted location of coordinates computed from the SPICE program. This location was then transposed to the NGSLR image of the Moon.



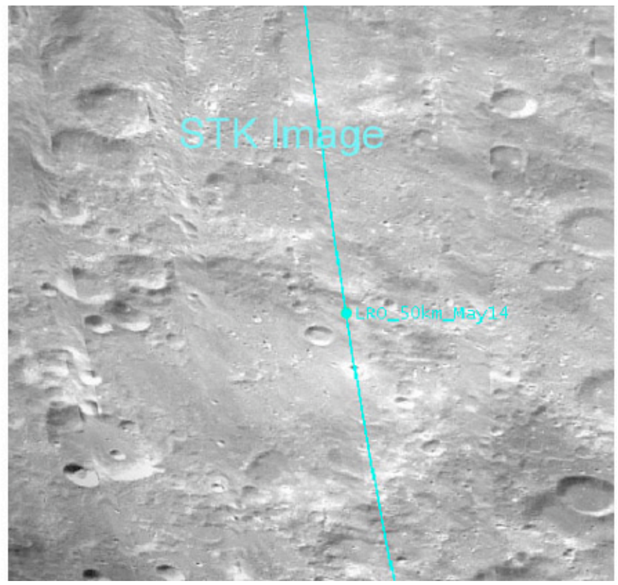


Figure 5. SPICE (left) and STK (right) coordinates plotted.

Finally, STK positions were transposed straight from images generated by the STK program. STK images indicate the position of LRO directly, as shown in Figure 5 (right).