LASER BEAM POINTING TESTS

C. O. Alley and D. G. Currie

Technical Report #885

(This paper is included in the Surveyor VII Mission Report)

June 1968

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

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Financial support for this work has come from NASA Grant NGR 21-002-109.

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An opportunity to verify the ability of earth stations for directing very narrow laser beams to a specific location on the lunar surface was provided by the detection sensitivity of the Surveyor VII vidicon camera operating in its integration mode. Such tests were of interest primarily because of a planned Apollo lunar surface experiment in which an astronaut will emplace a corner reflector array to provide a fixed point for very precise laser ranging. The successful monitoring of point-to-point earth-moon distances to the expected accuracy of $\pm$ 15 cm would provide: (1) a definitive test of the conjectured slow decrease of the gravitational constant; (2) an experimental study of whether continental drift is occurring now; (3) new knowledge on the physical librations, size and shape, and orbital motions of the moon; and (4) new information on the rotation of the earth (Refs. XI-1 through XI-4). An additional factor in testing narrow laser beam pointing and tracking techniques lies in their potential use in space communications systems.

The idea of using a Surveyor TV camera for such tests occurred to the authors during a discussion on whether an astronaut could see the pulsed ruby laser beam planned for the Apollo laser ranging retro-reflector experiment. Measurements on the wavelength sensitivity of the vidicon surface were conducted in November 1967 at the Jet Propulsion Laboratory (JPL) and indicated a decrease from the peak sensitivity by a factor 1/300 for the ruby laser wavelength of 6943 A, making detection marginal for existing and planned ruby laser systems. However, the availability of argon-ion lasers operating in the blue-green (main wavelengths at 4880 and 5345 A), within the peak of the vidicon sensitivity with average power of a few watts, suggested their use for the tests. The pointing and tracking techniques would be similar to those used with pulsed lasers.

Estimates of the power density on the moon of a 10-W (transmitted) argon-ion laser beam contained within a divergence cone angle (half) of 10 sec of arc yielded a value 2.25 times the power density of a magnitude 0 star, or nearly magnitude -1. The power density would scale directly as the power transmitted and inversely as the square of the beam angle. Experinece with star observations on previous Surveyor missions (p. 15 of Ref. XI-5) indicated that the laser beams could be easily observed if they were directed to illuminate the spacecraft. The diameter of the illuminated area on the moon is about 2 km per arc second of divergence.

A. Laser Transmitting Stations

Six transmitting stations were established; each consisted of an argon-ion laser with a suitable optical system for collimating and aiming the laser beam. All six stations used the technique of directing the laser beam backward through a telescope to reduce the beam divergence. However, each station used a different method for aiming the laser beam. A brief description of each station is given below.

(1) Kitt Peak National Observatory, Tucson, Arizona. The McMath Solar Telescope (60 in., f/60, heliostat configuration) and a 2-W laser were used. The telescope was was used in the normal direction for aiming. The guide beam and the laser beam were separated by a specially constructed, divided-mirror beam splitter placed near the telescope focal plane. A reticle, which was designed for the purpose and which permitted offset guiding from nearby lunar features, and a field lens were placed in the focal plane.

(2) Table Mountain Observatory, Wrightwood, California. The JPL 24-in telescope, utilized at its f/36 Coudé focus, and a 2-W laser were used. A beam splitter with a pinhole was placed in the telescope focal plane to separate the guide beam from the laser beam. A 2.5 magnification microscope with a crosshair reticle was used as a viewing eyepiece.

(3) Wesleyan University, Raytheon Research Laboratory, Waltham, Mass. A 6-in two-mirror coelostat directed the beam from a specially constructed 4-in, f/15 telescope toward the moon; a 60-W laser was used. The guide beam and the laser beam were separated using a clear pellicle beam splitter located ahead of the primary focal plane. The use of an appropriate glass filter over the eyepiece permitted continuous viewing of the crosshair reticle.

(4) Lincoln Laboratories, Lexington, Massachusetts. A beam from a 3.5-W laser collimated with a 3-in. telescope was directed using a special servo driver az-el flat mirror. Guiding was accomplished using a second 3-in telescope, which was boresighted to the first telescope.

(5) Goddard Space Flight Center, Greenbelt, Maryland. An existing mobile laser satellite ranging system was used; the pulsed ruby laser was replaced by a 10-W argon-ion laser. A series of mirrors guided the beam along the rotation axes of the az-el mount through a 5 1/2 in. output aperture. Viewing of the moon was accomplished by an image orthicon television display from a boresighted 16-in. telescope.

(6) Perkin-Elmer Corporation, Norwalk, Conn. A portable 2-W laser was attached at the Cassegrain focus of a 24-in telescope. Aiming was accomplished by the 6-in guide telescope, which was boresighted to the main telescope.

To aid in locating Surveyor VII on the lunar surface, Lunar Orbiter photographs of the region around Tycho and ACIC Lunar Chart LAC 112 were supplied to all stations. The initial estimates of the landing coordinates, as well as the accurate location of Surveyor VII (see Section III of this Report), were communicated with respect to both the Lunar Orbiter photographs and the lunar chart.

1. Lunar Schedule of Tests

The heavy demands on the Surveyor camera resulted in the initial allocation of only one 10-min block of laser observing time on each of four different nights. By combining the laser observations with the planned earthlight polarization observations, it was possible to increase the length of observing periods and to have a second period on Day 020. Time windows were chosen so that stations on both East and West Coasts could be observed simultaneously during control of the spacecraft by the Goldstone Deep Space Tracking Station; the primary constraint was that no station be too close to the terminator. During the window, the laser stations were responsive to the availability of the television camera. Communication was handled by a telephone network connecting all stations with the JPL Space Flight Operations Facility.

The first few days after touchdown were needed for other Surveyor activities and were used for final preparations at the stations. With the exception of the Norwalk and Greenbelt Stations, the first test period was held at 04:30 GMT on Day 014. It was necessary to interrupt the tests during the period near lunar noon because of glare in the camera caused by the proximity of the earth and sun. This time was used to modify techniques at some of the stations on the basis of the first test. Test periods were resumed on Day 019, and continued on Days 020 and 021. This last window was chosen to maximize the probability of observing stations on the East Coast by having them far from the terminator even though, for the West Coast stations, it placed the moon very low in the sky.

During each test period, modes of operation for the stations were prescribed with definite on and off sequences to identify stations that were geographically close together. The aperture and exposure time were varied to produce on the A-scope display approximately one-half the saturation voltage level in the dark part of the earth crescent where laser beams were being transmitted, as this maximized the sensitivity. With this setting, repeated exposures were taken while the stations were directed to follow the above modes.

2. Detection of Laser Beams

Detection was achieved visually during the first observing period on Day 020 for both Tucson and Wrightwood. Suspected laser beam spots with the correct locations, as shown in Fig. XI-1, were observed at the JPL Space Flight Operations Facility. Further confirmation resulted when the earth image was shifted 3 deg within the 6.5-deg narrow field of view, the two spots shifting with it. The on/off sequencing discussed above also served to verify the detection of the beams. Full confirmation was obtained only with the subsequent, detailed study of correlations in projected enlargements from high-quality photographic negatives reproduced from the video tape recordings by kinescope film recorder. A positive print of one of the negatives, enhanced using a high-contrast process, is shown in Fig. XI-2. The spread of the images over several of the video scan lines is caused by aberrations in the optics (electron and visible) of the camera and also in the ground reproducing equipment.

Each of the stations detected was transmitting about 1W, after telescope and atmospheric losses. Wrightwood was systematically scanning about the position of Surveyor VII and was limited by atmospheric "seeing" while Tucson had deliberately spread the beam. The spots appeared with an approximate star magnitude of -1, as originally calculated. Detection of these stations was accomplished again visually with about the same intensity during the second run on Days 020 and 021. The approximate magnitude of the detected beams was determined by comparing pictures of the laser beams with those of Jupiter.

By digitization of the video pictures, it has been possible to increase the sensitivity of detection considerably beyond the visual. It is estimated that by stretching the digitization in regions near station locations, intensities of laser beams directed to illuminate Surveyor VII can be detected with 1/75 the intensity displayed by Tucson and Wrightwood. This technique enabled easy detection of the Tucson beam on Day 019 when high winds and bad seeing conditions had degraded the performance. (Wrightwood was not operating on that day.)

A search for beams from the East Coast stations has been made with the equipment at the University of Maryland developed for visual scan of bubble chamber pictures. No positive results were found. Examination of the stretched digitized printouts has not given positive indication as yet, but the work is continuing with the technique of averaging successive frames for enhancement and looking for correlations at predicted locations. Although local weather conditions and structural obscurations interfered with transmission from East Coast stations (especially in the Boston area), there were periods when contact with Surveyor VII seemed possible.

B. Conclusions

The primary value of these tests lies in the experience gained in a variety of techniques for tracking and pointing laser beams with different types of telescopes. A report on this subject will be prepared by members of this Surveyor Working Group.

The potential value of well collimated laser beams for space communications is emphasized by noting that the 1-W laser beams appeared as bright stars, while the uncollimated light from major cities was not detected.

ACKNOWLEDGMENTS

We wish to thank Mr. Benjamin Milwitzky, Surveyor Program Manager, and Mr. Steve Dwornik, Surveyor Program Scientist, for endorsing the laser pointing test and for providing the support of the National Aeronautics and Space Administration, which made the test possible.

Because of the short time between the initiation and the execution of the laser pointing test, many people and organizations voluntarily participated under adverse conditions and without compensation at each of the six stations. The essential contributions of the following persons are gratefully acknowledged:

Tucson: Dr. James Brault, Staff Astronomer of the Kitt Peak National Observatory, and Professor S. K. Poultney of the University of Maryland, using a Spectra-Physics Laser loaned by the Aerospace Corp.

Wrightwood: Mr. M. S. Shumate, JPL, and Mr. J. W. Young, Table Mountain Observatory, using a laser constructed and loaned by Hughes Research Laboratories.

Waltham: Professor J. E. Faller, Wesleyan University, using a laser from the laboratory of Dr. George De Mars, Raytheon Research Laboratory. Ten undergraduate students from Wesleyan University, led by Mr. D. Burstein, and Mr. M. Hulett assisted Professor Faller.

Lexington: Dr. Robert Kingston and Dr. Hoyt Bostick, Lincoln Laboratories, using a laser loaned by Spacerays, Inc.

Greenbelt: Dr. H. H. Plotkin, Mr. H. Richard, and Mr. W. Carrion of the Optical Systems Branch, GSFC, using an existing laser satellite tracking system incorporating an RCA laser.

Norwalk: Mr. H. Wishnia and Dr. Morley Lipsett of the Perkin-Elmer Corporation, using a Perkin-Elmer laser and Mr. R. Perkin's telescope.

The test would not have been possible without the integration mode of the Surveyor vidicon camera. Work that led to the incorporation of the integration mode into the camera was initiated by Mr. L. H. Allen, JPL, who also performed the vidicon sensitivity measurements at the ruby wavelength and assisted in the overall test operations.

Appreciation is expressed to all members of the Surveyor Project at the Jet Propulsion Laboratory for technical help in the organization and performance of the tests. Special appreciation is extended to the following JPL personnel involved in the television aspects of the mission: Mr. J. Strand, Mr. T. H. Bird, Mr. J. J. Rennilson, Mr. D. L. Smythe, and Mr. C. Chocol; and to Dr. R. Nathan and Mr. E. T. Johnson of the JPL Image Processing Laboratory.

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Fig. XI-1. This photograph of a globe, with the overexposed crescent indicated by cross-hatching, simulates the earth as seen from Surveyor VII at 09:00 GMT on Day 020. The station locations are indicated by black dots, and permit ready identification of the origin of the two laser beams in Fig. XI-2 as Table Mountain Observatory near Los Angeles, California, and Kitt Peak National Observatory, near Tucson, Arizona. Simulations similar to this photograph were prepared in advance by J. J. Rennilson, JPL, for each period of attempted laser detection.

Fig. XI-2. Laser beams with powers of approximately 1 W each appear as starlike images comparable in brightness to Sirius (magnitude, −1.4) in this narrow-angle, f/4, 3-sec exposure of the earth. The crescent of the sun-illuminated earth is distorted because of overexposure. This was one of the first pictures in which the beams were readily visible (Day 020, about 09:05 GMT).