REPORT ON DECEMBER 1969 PERFORMANCE AND CALIBRATION TRIP TO THE LUNAR LASER RANGING STATION AT McDONALD OBSERVATORY

S. K. Poultney

Technical Report #70-075

January 1970

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

FACILITY FORM 602

70-28791 (ACCESSION NUMBER)	(THRU)
25 (PAGES)	1 (CODE)
CR-110208 (NASA CR OR TMX OR AD NUMBER)	16 (CATEGORY)

REPORT ON DECEMBER 1969 PERFORMANCE AND CALIBRATION TRIP TO THE LUNAR LASER RANGING STATION AT McDONALD OBSERVATORY

S. K. Poultney

Technical Report # 70-075

January 1970

Work supported by NASA Grant NGR 21-002-109

University of Maryland

Department of Physics and Astronomy

College Park, Maryland

Abstract

Performance of the detector package, Korad laser, receiver efficiency, and other portions of the McDonald Observatory Laser Ranging Station during December 1969 is reported upon. A summary of START and STOP LINE delay calibration is also included.

Table of Contents

Page

1. Quantum Efficiency Measurements (RCA 31000 F)

The quantum efficiency of PMT-1 (#08132) was measured by the procedure described in Maryland Technical Report #958 and inferred to be 6.6(± 1.8)%at 6943 Å. At the same time, the replacement for PMT-3 (#08029) was found to be 7.3(± 1.8)%. RCA quoted a value of 7.1% for the PMT-3 replacement.

The former PMT-3 (#08010) was returned to RCA where it was found to have a quantum efficiency at 6943 Å of 4.4 %. Since this PMT had not been used at McDonald, no degradation of the photocathode is expected and therefore the original quantum efficiency quotes may well be reduced by 16%, although RCA was prone to believe their reference thermopile had aged. The RCA measurement of #08010 also indicates that a systematic error was made in my September measurements which were #08010 (2.4%) and #08132 (4.7%). The behavior of the quantum efficiency of #08132 at 6943 Å throughout its operating period can then be described as

Date	QE	Place
June 1	8.9%	RCA
Sept 7	8.6%	McDonald
Dec 2	6.6%	McDonald

Measurements were also made by RCA on the severely degraded PMT-2 (#08028) that was returned for warranty action. These measurements indicated that the quantum efficiency at 6328 Å dropped from 9% to 2%

and the quantum efficiency at 6943 Å dropped from 7% to 0.7%. This latter behavior indicates that a measured degradation at 6328 Å may indicate a more severe degradation at 6943 Å. In such a case, the PMT in question should be returned to Maryland for measurement at 6943 Å.

2. Single Photoelectron Level and Dark Current

The single photoelectron level of PMT-1 was checked by both methods described in Maryland Tech Reports #957 and #958. Both methods indicated that the operating HV of 3400 volts placed the PMT well up on the plateau and no degradation of discriminator levels had occurred. In fact, an HV of 3300 volts could be used. This 100 volt decrease would change the stop-line calibration by about +0.6 nsec.

A change in the connection of the necessary PMT electrostatic shield was made in that the connection to negative HV was made directly to the Ortec 270 base by means of a quick disconnect line. Typical dark currents on December 3 were 51 KHZ at room temperature and 60 KHZ on December 14. The reader is reminded that exposure to fluorescent light can cause a temporary increase in the dark current. The electrostatic shield is still not an optimum one. One recently fabricated at Maryland consisted of Cufoil so that the HV lead could be soldered directly to the foil. The lead was then brought to the Ortec 270 tie-point by means of an HV lead passing through the Teflon PMT base. The HV lead was soldered directly to the tie-point. One final improvement would be a shield configured so as to shield the photocathode (e.g. Ortec 270 Instruction Manual). It was also noted that the detector package needs continued care to prevent light leaks. A light leak of about 5 KHZ is now present with full lights on and no cloth cover.

The efficiency of the magnetic shield was called into question because of its effect on the dark current; although the light leak may imitate the effect. On December 15, a low dark current was noted (e.g. 38 KHz) at room temperature. The reduction was traced to the magnetic shield which was not properly placed around the PMT. The reader will recall that extensive tests of magnetic shielding and PMT orientation were done prior to acquisition. These tests should now be repeated since either the Korad laser or faulty shield may have made the previous tests no longer useful.

PMT-3 (#08029) was later evaluated at Maryland and found to have a single photoelectron level at an operating HV of 3100 volts when the Ortec 270 Discriminator was adjusted as described in its instruction manual.

Now that a less dead-line-oriented approach can be taken with the equipment, one should consider thermoelectric cooling to reduce PMT dark current. A smaller diameter PMT would also help, but the present discriminator electronics requires the use of 31000 Type PMTs; at least one of which will have a smaller photocathode. The author is presently studying the pulse height spectrum of detected single photoelectrons in the 31000F/270 combination. If the dynamic range required for nanosecond single photoelectron timing is less than 100:1 (as it now appears), one could choose to use an Ortec 453 Constant Fraction Timing Discriminator (dynamic range 20:1) in conjunction with a smaller diameter RCA PMT (e.g. 8644). A fast amplifier may also be necessary. RCA is now developing a whole series of PMTs with different photocathodes, different photocathode sizes, and different multiplier chains. The best one for Lunar Ranging will only be determined once each of these PMTs is evaluated for quantum efficiency, gain, dark current, and timing jitter.

3. Detector Package Components

A. Re-Positioning of Perkin-Elmer Filter

The need to reposition the Perkin-Elmer Filter in the detector package was pointed out in Maryland Technical Report #957. The Perkin-Elmer filter should be placed between the spatial filter and the PMT. The repositioning requires a relocation of the solenoid and terminal strip inside the detector package. While time-consuming, this change is relatively easy and straight-forward. Complete detector package drawings can be found in Maryland Technical Report 957A.

B. Up-grading of Spatial Filter Components

The optical components used in the spatial filter are described in Technical Report #957. Although measured to be adequate, they were purchased in haste. Each element should be looked at closely for replacement and/or improved coatings. The second lens in the spatial filter can be used to change the spot size on the PMT photocathode.

C. Optimization of Perkin-Elmer Filter Transmission

It has become obvious through trial and error that the Perkin-Elmer filter transmission is difficult to optimize during a star measurement. One might better use the moon itself. Use of a steady laboratory source is indicated (e.g. the HP photo-emitter) as long as the f/number of the beam is large enough. The laboratory source could well be mounted at the focus of the GSFC auxiliary alignment device. One of the Davidson autocollimators may also be tried. It would also be nice to have an external control on the screw adjustment of transmission of the filter.

4. Air Shutter Solenoid

The wiring details and air shutter solenoid driving circuits are included as Figure 11 in Maryland Technical Report #957B. The solenoid is an a.c. solenoid. A change was made in September to d.c. operation. This change overheats the solenoid and could lead to solenoid destruction. The circuit in Figure 11 should be reinstated. Periodic lubrication of the shutter blade with Molykote is essential.

5. Spectra of Korad Laser

The spectra of the Korad laser was obtained with the help of E. Barker, W. Williams, B. Bopp, and W. Van Citters in the manner described in Technical Report #957. Plates taken on December 2 indicate that the laser output consisted of strong lines at 6943 Å and 6943.6 Å and medium lines at 6942.9 Å and 6943.9 Å when the laser was operated at the recommended temperature of 68° F and at the normal repetition rate of 15 per minute. The plate was exposed on the 20th and 40th shots. All lines looked broad (about 0.1 Å). The 0.7 Å Perkin Elmer filter was set at 44° C which corresponds to a center wavelength of 6943 Å. The Perkin Elmer filter thus passed only about one-half of the lunar return. It was first thought that the Filter/Laser Wavelength Matching Monitor indicated that only one-third was passed during the October-December period, but the monitor may not have been kept in alignment. Thus the accepted return most probably degraded to the value found on December 2 rather than being that low for the entire period.

When the mismatch was discovered, the Korad procedure for KLMS alignment was followed. The KLMS is the sub-cavity which controls the laser axial-mode structure. The KLMS was out of alignment and so explained the multi-wavelength operation of the laser. The KLMS was re-aligned and more laser spectra taken. Spectra of December 7 indicate that the laser output consisted of a strong line at 6943.1 and a weak line at 6943.5. Measurements were made at operating temperature on the 20th and 40th shots. These spectra indicated that the lunar return was being completely accepted by the Perkin Elmer filter. The filter temperature might well be raised to 45°C to better center it on the laser output.

The spectral behavior of the Korad laser was not checked on its arrival at McDonald; probably because it had been recently tested at Korad with favorable results as reported in their "Final Test Data" report to GSFC on August 29, 1969.

6. Beam Divergence of Korad Laser

Beam divergence photographs of the Korad laser were taken by J. Mullendore and W. Williams on October 15 in the manner described in Technical Report #957. Although the negatives never arrived in the author's hands, the positives indicated a beam divergence of 2 milliradians full angle full energy. The Spacerays laser was 2.4 milliradians on the same basis. Korad quoted 1.3 milliradians at the factory on the basis of the more exact analysis possible when negatives are available. The beam divergence measurements should be repeated as soon as practicable.

A continuous monitor of laser beam-divergence can be accomplished by using a partially-transmitting mirror as the sample mirror in the GSFC optics box. The transmitted beam can then be focused down by an auxiliary lens in the same manner as is now done for beam divergence photographs. A divergence smaller than a certain value can be monitored if an appropriate aperture and detector are placed in the focal plane of the auxiliary lens. An added Sample-and-Hold amplifier in the Astroverter would record the result on magnetic tape. Normalization can be attained by careful monitor of laser output energy and occasional removals of the limiting aperture.

7. Uniformity of Laser Output Pulse Shape and Amplitude

Photographs of pulse shape and pulse energy monitors recorded by W. Williams were reviewed. Under normal conditions, the laser output is raised to about 5 joule and a lunar run taken. The data indicate that the pulse shape remains the same; that the peak amplitude changes by ± 8%, and that the energy changes ±7% under these normal conditions. These variations correspond to a dynamic range of about 1:1.14 and indicate that leading-edge pulse discrimination (Ortec 417) in the timing system start-line can be done to a precision of better than 1 nsec. substitution of a constant fraction timing discriminator (e.g. Ortec 453) would allow sub-nanosecond timing over a much larger dynamic range. However, such a substitution at present is no panacea since one would like to know more about the laser pulse behavior. Equipment is on hand to automatically record the pulse shape and such a study should be begun using the Tektronix 519 and acquisition camera. Pulse energy could be entered on magnetic tape by means of another Sample-and-Hold amplifier in the Astroverter.

8. Laser Control Electronics and Epoch of Laser Firing

Technical Report #70-049 describes how the Spacerays laser was made to emit its output pulse within microseconds of a known seconds marker by pre-firing the flash-lamp and then firing the Pockel cell on the seconds pulse. Arrangements had been made with GSFC and Korad by the author to operate the Korad laser in a similar manner. However, these arrangements were not carried out during installation at McDonald; probably because the operator would no longer have any control over the laser output. The Korad laser is fired by pre-firing the flash-lamp only. The laser pulse is emitted a millisecond or so later under control of Korad circuitry (and the laser operator). The jitter of this laser pulse about the seconds pulse has not yet been measured. However, it has been noted that the operator may, during a run, change the epoch of laser firing up to a millisecond. This change occurred only once, but the danger is clear. One must either use the original control scheme or measure the epoch with the present control scheme. Use of the original scheme really requires that the laser operator have control over the pre-firing time of the flash-lamp through the computer which is easily done. An actual measurement of the epoch is to be preferred on basic principles and could be done either by an additional TPHC/A-to-D link similar to the Start and Stop Verniers of the ranging electronics or by using the present Monsanto counter in its Time Interval Mode. The external circuitry for this application of the Monsanto counter is being developed by D. Ditmar and R. Gonzales.

9. Filter/Laser Wavelength Matching Monitor

Each time the HeNe reference beam is moved, the GSFC sample mirror must be re-adjusted to allow the sample beam to remain normal to the Perkin Elmer Filter. It is advised that the GSFC sample mirror be re-mounted so that it is more easily adjustable (e.g. a two-screw, flat spring holder). One of the Davidson auto-collimators can be used to position the GSFC mirror after the PE filter is aligned.

At the times that the 3 Å spectral filter is used, the sample path should be blocked to avoid the unnecessary and higher light level at the PMT photocathode.

Normalization of the wavelength matching monitor can be accomplished by removing the Perkin-Elmer filter during a laser run and noting the increase in monitor signal. This method will work only when no flash-lamp stray-light is present. Recording of the monitor signal on magnetic tape can be accomplished by using an additional Sample-and-Hold amplifier in the Astroverter.

10. Star Measurements

The star measurements described in Technical Report #957 and advocated again in Technical Report #957B were repeated in December. Table I includes these measurements as well as some others, taken by McDonald personnel during the last quarter. The format is the same as for Table II of Technical Report #957. The correction factors used to obtain the Adj. Rate in Table I were found as described in detail in Technical Report #957B. Not much information is available on the conditions of the measurements because of lack of access to McDonald records. The extreme disparity between the rates after December 18 and those before December 18 are attributed to extremely poor seeing. Lunar rates were about that expected and so that neither atmospheric absorption nor receiver misalignment was the cause.

It is suggested that a lunar run should be called off if seeing is worse than 6" or atmospheric transmission is worse than 50%.

Table I.: Star Photometry Record

Date	Config.	Star	Obs Rate	Corr Fact	Adj Rate	Remarks
22 Sept	.7A,6",PMT 1	A LYR	75 KHZ	1 x 4/1	300 KHZ	
18 Oct	.7A,6",PMT 1	A LYR	75 KHZ	1 x 4/1	300 KHZ	
5 Dec	.7A,6",PMT 1	A VIR	10 KHZ	1 x 4/0.4	100 KHZ	within minutes
5 Dec	.7A,9",PMT 1	A VIR	16-20 KHZ	1 x 4/0.4	160-200 KHZ	
5 Dec	.7a,9",PMT 1	A LYR	50 KHZ	1 x 4/1	200 KHZ	within minutes
5 Dec	.7A,6",PMT 1	A LYR	35 KHZ	1 x 4/1	140 KHZ	
5 Dec	.7A,12",PMT 1	A LYR	50-60 KHZ	1 x 4/1	200-240 KHZ	
10 Dec	.7A,9",PMT 1	A ORI	300 KHZ	1 x 4/2.4	500 KHZ	JVM
10 Dec	.7A,?,PMT 1	A BOO	190 KHZ	1 x 4/2.7	280 KHZ	JVM
10 Dec	.7A,?,PMT 1	A VIR	35 KHZ	1 x 4/0.4	350 KHZ	JVM
15 Dec	.7A,6",PMT 1	A PSA	28 KHZ	1 x 4/0.4	280 KHZ	
18 Dec	.7A,6",PMT 1	A TAU	24-33 KHZ	1 x 4/1.5	64-88 KHZ	
19 Dec	.7A,6",PMT 1	A ARI	6 KHZ	1 x 4/0.36	67 KHZ	
20 Dec	.7A,6",PMT 1	A ARI	7 KHZ	1 x 4/0.36	78 KHZ	
21 Dec	.7A,6",PMT 1	A TAU	60 KHZ	1 x 4/1.5	160 KHZ	
23 Dec	.3Å,3",PMT 1	A AUR	160 KHZ	1 x 1/1.7	94 KHZ	bad seeing 8"

Note: Best A LYR rate seen with 0.7 Å,6",PMT 1 was 580 KHZ

11. Sulser 2.5c Maintenance

The maintenance for the Sulser 2.5c and its various battery packs as well as for the Astrodata Time Code Generator and its battery packs should be done as described in their instruction manuals. The campaign to achieve the claimed Sulser 2.5c behavior continues. The shorting out of the external varactor control and power line isolation did not improve the Sulser 2.5c behavior all the way to that expected. The varactor control, by the way, will allow the later addition of a Rubidium Frequency Standard (e.g. Tracor 304D) and a comparator (e.g. Tracor 538) to constitute a Rubidium clock. The cost would be an additional $7300 compared to a new price for a Rubidium clock (Tracor) of $19,000. However, we do not feel that a Rubidium clock is necessary for the Laser Ranging experiment at McDonald. Moreover, one on loan from the Naval Observatory has not impressed us by its behavior over the last several months. D. Currie has watched the behavior of both very closely and will report on such in a supplement to Technical Report 70-021. This report will be the basis of any warranty action with Sulser.

The Sulser 2.5c has thrice had its regenerative divider chains supplying 1 MHZ and 100 KHZ go off. The 1 MHZ outage is especially serious since it drives the Time Code Generator. Twice the outages can be traced to physical shock. The third time is due to either temperature shock or to a power line failure when both of its battery packs were low. Corrective external action consists of further isolating the Sulser 2.5c from the room temperature (e.g. by a styrofoam case or another oven) and making sure that the batteries are always charged. However, such shocks probably would not cause outages if the regenerative divider chains are correctly tuned. Sulser (i.e. Jim Underwood 213-670-5544) has advised retuning the chains as follows:

1. Refer to Schematic Diagram 569000 in the instruction manual.
2. Take Sulser out of rack and remove cannister. Expose the silk-screened circuit boards.
3. Look at 5 MHZ on collector (blue sleeve) of Q-18 with oscilloscope. Adjust transformer T5 for maximum signal using slug with spin-tite, hex lock nut.
4. Go to pin 1 of T6. Use a general lab. supply (0-24v, 1 to 2a) in place of Sulser 5P. Adjust T6 for maximum amplitude and minimum modulations at 24 v. Repeat for T7 as T6 and T7 interact.
5. Reduce d.c. voltage and repeat T6 and T7 adjustments. One should reach 15 volts and probably 10 to 12 volts before the dividers remain off. In this manner, the sensitivity of the Sulser 2.5c to environment shocks can be reduced. One must, however, make provisions for keeping time while the Sulser 2.5c is down.

12. Potentiometer for Astroverter Checks

Proper functioning of the Astroverter A-to-D converter can be checked by replacing one of the TPHC outputs with a stable d.c. voltage. Variation of this stable voltage in a known way will then indicate how the Astroverter is working. Varying the voltage in a known way can be done easily if one can reliably measure the stable d.c. voltage. A reliable measurement can be made using the Electro-Nite 2784 Potentiometer lent to McDonald Observatory by the University of Maryland. Auxiliary equipment includes a 12 volt storage battery, the Keithly microvoltmeter, and the Epply 100 standard cell. The latter item is also on loan to McDonald. The connections to the 2784 Potentiometer are made under the removable cover on its top. The storage battery is connected to + and - Bat. The microvoltmeter is connected to + and - Galv. The standard cell is connected to SC. The unknown is connected to + and - Emf. Next, the 2784 Potentiometer is made direct reading by comparison of the storage battery to the standard cell. Then the unknown emf. is measured. Instruction manuals came with the 2784 Potentiometer. Further information can be obtained by calling Mr. Prouty at 205-NE7-0600.

With the system calibration method now in use, continued use of the 2784 Potentiometer will not be needed at McDonald after final acceptance of the Astroverter from Astrodata.

13. Summary of Start-Stop Delay Calibration

A. Philosophy of Calibration

Our goal is to have an automatic calibration procedure for the individual verniers, the time interval between verniers, and the start-stop line delays whose results are entered on magnetic tape before and after each lunar ranging run along with the rest of the system calibration data. Ideally, one would like to combine the time-interval-between-verniers calibration with the start/stop-line calibration by providing a subnanosecond light pulse at the beginning and end of a known interval to the respective start/stop detectors. It is not efficient to calibrate the verniers by changing the known interval so these are calibrated separately as described in University of Maryland Technical Report #70-049.

At present, the start-line detector is a KD1 photodiode as was used during acquisition. This device is very stable, has a very fast rise-time ($\sim$0.2 n.sec.), and puts out 10v signals into 50 ohms without amplification. However, it is quite insensitive to light signals that can be expected from any sub-nanosecond photo-emitter other than a laser. Thus the ideal calibration method cannot be used unless the start-line detector is changed. Two alternatives are obvious. First, one might use a PMT (e.g. RCA-8644) with enough gain to detect the calibration photo-emitter pulse. The amount of laser pick-off energy must then be reduced to give the same size output from the PMT. The sub-nanosecond photo-smitter pulse can then be attenuated so as to yield a single photoelectron pulse in the stop-line PMT. Second, the laser light fed back to the stop-line PMT in the filter/laser wavelength matching monitor can be used to start the timing circuits in place of either KD1 or a separate start-PMT. Here great care is needed to ensure that the start signal contains a number of photoelectrons so that an additional statistical jitter due to laser pulse-width is not added, but that the Ortec 270 discriminator is not out of its dynamic range. The present sample level is about 100 photoelectrons,but the method has not yet been tried due mainly to large amounts of noise from the laser at the start-time. There is also some fear that even these light levels may degrade the photocathode at the present PMT gain. If the start PMT gain is not decreased in some manner at the start, the high dark currents will add an additional statistical uncertainty in the calibration unless a start gate is added.

When the same photo-emitter is used to calibrate start and stop lines, its unknown delay in emission cancels out.

B. Present Calibration

Although not ideal, the present calibration method is adequate. In addition to the disadvantage of using the KD1, there is no triggerable subnanosecond photo-emitter now available although C. Steggerda is developing one. The method of calibrating the verniers as well as the method of calibrating the time interval meter in conjunction with the verniers by means of NIM pulses at the verniers is described in Technical Report #70-049. All that remains of the electrical calibration is to measure the start and stop line delays to the vernier inputs. Work at Maryland has shown that a Tektronix 109 nanosecond pulse generator used with an HP 5082-4400 photo-emitting diode and with the RCA 31000F (#08029), Ortec 270, and Ortec 437A indicates that the combination operates at the single photoelectron level with a timing uncertainty of less than 1.2 n.sec. Work at Maryland has also shown that the PMT-3/Ortec 270 delay (plus emitter delay) is 48 n.sec. at 3400 HV, 50 n.sec. at 3200 HV, and 52 n.sec. at 3000 HV. A systematic error may remain in these delays because the vernier trigger levels were not known.

At McDonald the Tektronix 109 pulser was used to measure all cable delays and to imitate the KD1 output pulse. All delays were referenced to the Steggerda calibrated cables (*i.e.* the green ones) and the small differences were measured by a Tektronix 454 or the start vernier in conjunction with the K program. The KD1 cable from KD1 output to Ortec 417 had a delay of 80 n.sec. The delay from KD1 output to TPHC input was 93 n.sec. found with an electrical pulse imitating the KD1 pulse and the Ortec 417 at a typical level. The typical level is that for a pulse amplitude much greater than the trigger level. For example, the Ortec 417 is now at a level of 1 volt and the pulse amplitude is ~3 volts. A check of Ortec 417 trigger stability was made with the laser firing as usual for a run. The trigger stability was good to better than a nanosecond. The delay in the KD1 is one nanosecond as estimated from its length.

The stop line delays were calibrated first by pulsing the photo-emitter with the 109 pulser and looking at the differential delay from the green cables with the start vernier in conjunction with the P program. PMT-1 and 270-3 were used at 3200 HV on December 14-16. In spite of the jitter of the former photo-emitter, the delay from PMT photocathode to Ortec 403A output was 145 n.sec. using the first observed stops. The light travel distance has been subtracted, but the delay in photo-emission of the former diode is not yet known. An oscilloscope picture corroborates this 145 n.sec. value. A separate measure of PMT cable to 403A output yielded 89 n.sec. which, when combined with a PMT/220 delay of 50 n.sec. at 3200 HV and an additional cable in the detector package (~ 2 n.sec.), again corroborates the above value although it is less accurate due to pulse level and uncertainty as to TPHC trigger. The total stop delay from photocathode to detected TPHC input is obtained by adding the 145 n.sec. to the 403A/TPHC connecting cable which, if not changed, was earlier found to be 2 n.sec. for a total stop line delay of 147 n.sec.

In summary, the start line delay excluding KD1 delay was found to be 93 n.sec. and the stop line delay including photo-emitter delay was found to be 147 n.sec.. Thus, a total of 54 n.sec. must be subtracted from an observed range in addition to light path and other corrections (e.g. the Steggerda time interval calibration correction). The light path will be reported in my full calibration report. The omissions and uncertainties in this 54 n.sec. electrical delay correction to the observed lunar range are clearly stated above. The uncertainties can be removed by repeating the whole calibration at McDonald. The omissions are more difficult to deal with. One expects a nanosecond or two delay in the KD1 and C. Steggerda has some indication that the photo-emission delay may be as much as 10 n.sec. One can measure the KD1 delay by starting the KD1 (and TPHC) with the laser pulse and looking at the ensemble of PMT stop delays produced by the laser sampling provision. A noise gate may be needed. The photo-emission delay should eventually cancel itself out when the methods of A. are used. Until then, a method of doubling the delay as suggested by Silverberg can be used. It is obvious that the present method is long and involved (although adequate). Work is now in progress to achieve the methods discussed in A. which hold out promise of reaching the goal of the automatic calibration of lunar ranging.