REPORT ON LUNAR RANGING AT McDONALD OBSERVATORY
FOR THE PERIOD
FEBRUARY 16 TO APRIL 15, 1970

Douglas G. Currie

TECHNICAL REPORT NO. 70-106

April 1970

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

REPORT ON LUNAR RANGING AT McDONALD OBSERVATORY

FOR THE PERIOD

FEBRUARY 16 TO APRIL 15, 1970

Douglas G. Currie

TECHNICAL REPORT NO. 70-106

April 1970

UNIVERSITY OF MARYLAND

Department of Physics and Astronomy

College Park, Maryland

ABSTRACT

This report describes the lunar ranging activities at McDonald Observatory and the associated activities at the University of Maryland for the two-month period February 16, 1970 to April 15, 1970.

During this period numerous acquisitons were obtained. A major problem was discovered and remedied. As a result, a continuing high rate of acquisition producing good data is anticipated.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

APPENDICES

GENERAL DISCUSSION

One of the major goals for the reporting period covered by Technical Report No. 70-090, i.e., the improvement of the system's efficiency, has been realized. The progress toward the several others has been significant. The regular use of the final overall calibration system is not yet complete but should be by the next reporting period. An additional significant step during this period was the discovery of range prediction anomalies in the range tapes for the 620I.

In March, during discussions at McDonald concerning anomalous surface returns, the accuracy of the range tapes came under suspicion. Subsequent hand calculation by B. W. Bopp verified that the predicted ranges on the tapes were quantized in units of 32 nanoseconds. Further checking by J. D. Mulholland and J. D. Rayner indicated that the tapes which were generated by a program written at the University of Maryland, but run on the Jet Propulsion Laboratory computer, were quantized while the tapes that had been generated on the Maryland computer did not have this problem. The trouble was traced to a change in the JPL Fortran compiler. The new compiler caused a five-bit truncation in the range information tape (see Appendix III). Corrected tapes were sent to McDonald from JPL beginning April 7, 1970.

In addition to the 32 nanoseconds quantizations, an error of 1,000 to 2,000 nanoseconds was also discovered. At present this is considered to arise from the use of nonstandard libration parameters in the cards sent from JPL to Maryland to check Mc Donald data. Because of these offsets which appeared between the range prediction received at Maryland from JPL and the ranges printed by the Varian 620I at McDonald have been explained, the procedure to verify the tapes at McDonald has been terminated.

A preliminary analysis of the drift of some of the April data indicates that it could be explained by an error of about 40 meters in longitude or 80 meters in latitude. Analysis by W. M. Kaula and J. D. Mulholland indicates that the coordinates of McDonald should be adjusted by the following:

50 meters north

200 meters west

40 meters out

In the quest of testing old data for good returns, we find that during a period in which the residual range has changed by over 100 nanoseconds, the ambiguity of old quantized range predictions introduces a large problem in the data reduction. Tapes with corrected ranges have been requested from JPL but these will not be available for several months. In the meantime, some differential corrections will be done at Maryland as time and personnel permit.

The review of this old data has turned out particularly important since there appear to be other unknown effects in the system. While the current data is showing a high precision with the range quantization removed, the impetus for this search, i.e., data from day, 15 December 1969 was

NOT during the interval of range quantization. Thus there appears to be other difficulties which were operational during this time, but not at present. It is hoped that the identification of earlier acquisitions will, in addition to providing additional data, provide some insight into how the system was operating during October, November, and December. The effect does not appear to be jitter or drift (see Appendix IV), and is no longer present.

With the new tapes and with some recent fortuitous weather, we have been getting ranges with a high degree of reproducibility. In particular, recent observations were obtained on the following dates: April 12, 13, 14, and 15. Thus, the system seems to be operating at present in rather satisfactory fashion concerning the ability to acquire the array.

SPECIFIC ITEMS

Range Data Transfer

Range data in the form of daily hand logs, magnetic tape, and punched cards is flowing smoothly to Maryland. Progress is being made in the implementation of the second phase of data transfer (see TR No. 70-090, Appendix 3, p. 17).

Magnetic tapes have been received for the period Day 350-69 to Day 90-70. The first two were original tapes and were readable on the 1108 at Maryland while one was a copy made at McDonald. An apparent bug in the tape copy program resulted in that tape being unreadable. The original tape has been received and is completely readable. Upon the completion of the tape copy program, copies of each tape will also be sent to JPL. All previous data on the Korad operation which is available at Maryland has or will be sent to JPL. The format for the Varian output and the raw data cards are in Appendix 5. The Varian tape output format is contained in TR No. 70-064, Appendix II, of J. D. Rayner's software report.

The completion and flow of the daily operating logs from McDonald is on a sound regular basis. Most likely, the logs will go through one more evolutionary stage before a final form is chosen.

Automatic Computer Logging

During the March visit of Dr. Currie and Mr. Mullendore, preliminary work was done on the automatic computer logging system. This system (a combination of new hardware and software) will eventually write directly on the data tape such information comparisons between the VLF receiver, the Rubidium clock, and others with the Master clock, seeing measurements, etc. The system is being tested section by section to assure that it will not affect the present reading of range data. The installation of the first part is expected during the next report period. Data has been taken using a preliminary form of the automatic computer logging program and this data is presently being analyzed at the University of Maryland.

Programming

Several changes were made in the main data analysis program resulting in several versions adaptable to different requirements. The calculated residual ranges are now sorted and printed in order with returns falling within 5 nsecs flagged with an asterisk, and those within 35 nsecs with a dollar sign. The projected range can optionally be calculated from polynomial coefficients read from cards and thus correct the erroneous results caused by truncation of the projected range on range tape. The raw data can now be punched on cards to avoid continual rereading of the data tapes.

Appendix VI has reproduction of a computer page showing processed data for Day 75.

Data on Clock.

Work is continuing on the analysis of the day-to-day clock data. As was explained in TR No. 70-090, daily clock information is sent from McDonald Observatory to the University of Maryland. This data is constantly being woven into a picture of clock performance. A clear understanding of the rather numerous idiosyncrasies of this system is emerging that will soon allow conclusions as well as predictions to be made.

Seeing Problems.

The seeing problem is still under attack. During the telescope down time in late February, foam insulation was added to some of the inside of the tube. Higher speed fans were also installed in March in an effort to get more cooling air through the tube while no observations are in progress. In addition, warmer outside temperatures reduce the dome cooling problems. The seeing problem in general is improving. A graph of overall seeing for this report period is in Appendix VII.

Epoch Determination.

A new system has been installed to measure automatically and precisely the relation between the time at which laser fires power as determined by the output of the Korad photodiode and the 1 second pulse. This is measured by a modified time to pulse height converter that compares the photodiode output with the 1 second pulse of the master clock.

This time difference is converted into a voltage which is automatically read by the computer and put upon magnetic tape in conjunction with the range data. This procedure has been tested and, upon successful reading of the output on the magnetic tape, will be started as a normal procedure.

Guiding.

The new reticles have not yet arrived at McDonald; however, clever manipulation of old reticles by B. W. Bopp has allowed continuing operation.

The program (MRS) written by W. Van Citters to log the telescope position vs time, has been used successfully several times. This data will be correlated with reflector returns as time and personnel permit. It is expected that new MRS data will be taken during each computer guided run. It is hoped that some data can also be taken under visual guiding conditions. This data will be used to obtain information on the pointing accuracy which is available when the site is in the dark and guiding must be come by the computer.

Calibration.

The design of the light pulser has been completed and a prototype has been built and tested. The packaging and exact placement within the laser detector package has not yet been finalized. On their recent trip to McDonald Observatory, S. K. Poultney and J. V. Mullendore installed and tested an 8644 photomultiplier. This will be employed with the light pulser when it is placed in use.

Calibration measurements were also made using the 8644 vs the photodiode startline.

The calibration procedure outlined in TR No. 70-090, Appendix 8, has been made independently by Dr. Silverberg and Dr. Poultney. The method is successful and there is good agreement between the independent measurements. The calibration for the current period remains at -130 nsecs.

Quantum Efficiency Measurements.*

All PMTs will henceforth be referred to on the basis of their RCA serial number.

PMT 08029 is now in use because it has a slightly higher quantum efficiency (7.1%) than PMT 08132 which had been used since last July and a somewhat higher gain for a given high voltage.

A study of quantum efficiency enhancement with the RCA 31000E (flat, clear window version of the 31000F) has been completed and is included as Appendix VIII. For convenience, the study was done at 6328 Å. A maximum enhancement of 60 percent was found for PMT 06306.

Single Photoelectron Level and Dark Current.

PMT 08029 is now being used with Ortec 220 discriminator #69. The discriminator tested at the University of Maryland (#91) failed soon after installation in January. The reasons for failure are unclear. The STOP

---

* The following 6 pages have been excerpted from TR No. 70-099 by Dr. S. K. Poultney.

LINE delay calibrations give a record of relative single photoelectron counting efficiency as a function of PMT high voltage in addition to delay calibration. From the calibration records in Technical Report No. 70-100, the combination of PMT 08029 and Disc 69 yield good relative single photoelectron counting efficiency over the range of 3000 to 3300 volts.

Part of the trouble with Disc 91 was light noise which leaked from the HV-ON lamp in the base through the shield-wire hole in the tube socket to the PMT chamber. The leak was serious because the magnetic shield, which previously had served also as a light shield for such a leak, had been removed. The neon lamp in Ortec 270 bases should be replaced with a 50KΩ resistor upon receipt from the factory.

Detector Package Components.

Several new 101mm lenses have been purchased for evaluation of spherical aberration at Maryland using a uniphase, constant amplitude 6328 Å wavefront, precision pinholes, and PMT. The present 101mm lens in the spatial filter allows 94 percent of the light of a 20mm beam to pass through a 100μ diameter pinhole when the pinhole is adjusted at the circle of least confusion. The reader will recall that the pinhole usually used in the spatial filter at McDonald is 400μ or 6 seconds. One of the new lenses allows 93 percent of the light through a 50μ pinhole and will probably be installed at McDonald. Smaller pinholes are now required due to the higher receiver efficiency recently attained.

McDonald Observatory personnel have built and installed a permanent adjustable mount for the Perkin-Elmer filter.

A mount for the HP light emitting diode was fabricated by J. V. Mullendore out of the old mount for the Perkin-Elmer filter. The diode mount holds the diode centered and about 4" from the PMT face.

E. C. Silverberg and S. K. Poultney are discussing a further means of reducing lunar background by employing a prism to reject the lunar background of the wrong polarization and to bend the correctly-polarized signal to an enhancement device on the 31000E as discussed in Appendix VIII.

Uniformity of Laser Output Pulse Shape and Amplitude.

The amplitude of the electrical pulse from the Korad photo diode reported in Technical Report No. 70-087 was 8 volts into 50Ω at the TEK 519 when the laser was operated at 3-3/4 joules. The Ortec 417 was set at 3.0. Concern was expressed that a change in the amplitude with time would cause a systematic error in the observed lunar range, and an interim method was proposed to minimize that amplitude change.

On 2 April, the peak amplitude was +4.8 volts into 50Ω at the TEK 519 when the laser was operated at the new operation level of three joules. The Ortec 417 discriminator was still at 3.0 which means a minimum amplitude of +2.7 volts for triggering. Instructions were left with the laser operator to keep the laser output peak amplitude at 4.8 volts (4.4 to 5.2 volts seemed attainable) no matter at what level the laser was operated. A set of neutral density filters was provided which would allow a 0.1 to 10 range in steps of ND 0.1 when used with the existing ND 1.0. The set consisted of ND 0.1, ND 0.1, ND 0.2, ND 0.2, and ND 0.4.

Filter/Laser Wavelength Matching Monitor.

E. C. Silverberg re-instituted the use of the monitor during the last month. The present "on-the-floor" alignment allows the adjustment of the sample mirror that was not possible with the previous alignment method. The operating level is about 20 millivolts with the same attenuation factors as reported in Technical Report No. 957 and is consistent with previous levels at higher output energies.

Laser Control Electronics and Epoch of Laser Firing.

During the March trip of D. G. Currie and J. V. Mullendore, the additional TPHC / A-to-D link was installed using the second stop vernier as TPHC. The TPHC maximum range was an unmodified 80 μsec. On 2 April, a larger capacitor was added to the X100 multiplier to make it a X1000 multiplier. The modified TPHC was calibrated in a manner similar to the calibration of the start-stop verniers using the TDG, but at larger time intervals. The TPHC was found to be non-linear, but could be easily used in the region ±200 μsec about a mean laser epoch time. Appendix X summarizes the semi-automatic calibration procedure and how to enter the numbers on magnetic tape.

Star Measurements, Receiver Efficiency, and Lunar Background Rates.

A. Star Measurements.

Star measurements for the period of 28 December to 27 March, taken from the McDonald Operations Log, are here recorded in Table I (Appendix IX). The format is the same as is in Technical Report No. 957 and Technical

Report No. 70-075. The filter and star adjustments are done as outlined previously. E. C. Silverberg has pointed out that there may be a systematic error in the star adjustments due to the definition of the Arizona UBVRI photometry system. The measurements for the last few days of March are consistent with the best measurements of last summer and fall. The extremely high rates on 13 March for good seeing conditions are due to sky background near the sun. Note how subtraction of a reasonable 800 KHZ adjusted rate for A AQL (TR No. 957) yields an increase close to the ratio of pinhole areas.

B. Receiver Efficiency.

From a peak value on about 13 March, the receiver efficiency had dropped back to levels typical of last summer by 27 March. These levels, though, are significantly higher than those for most of December and January. Assuming an adjusted rate of 900 KHZ (neglecting anomalous readings of 13 December), one finds a receiver efficiency of 0.5 percent (a new high). PMT 08029 has a quantum efficiency of 7.1 percent and so the transmission of telescope and injection optics is 19 percent if total PMT counting efficiency is also 7.1 percent. The telescope efficiency is now within a factor of two of that expected. The receiver efficiency had dropped back to about 0.25 percent by the end of March.

C. Lunar Background Rates.

Lunar background rates are recorded as a matter of course on the Log Sheets for each day, whereas star measurements are only taken sporadically. Mary Flaherty at the University of Maryland is keeping a graph of adjusted lunar rates as a function of lunar phase to see if one can check receiver efficiency for any given ranging run during a lunar cycle. The lunar rate is adjusted for the 3 Å, 400μ, PMT 1 configuration and is included for reference as Table II (Appendix IX) to update Technical Report No. 957. Recent adjusted rates of 1.4 MHZ at full moon were observed on 23 March. This peak rises sharply from 450 KHZ on 14 March (1st quarter) and falls sharply to 450 KHZ on 25 March. Previous measurements at full moon were 1040 KHZ on 23 December and 125 KHZ on 29 July. On 29 July, star readings were a factor of four low and on 23 December they were a factor of eight too low. Previous measurements at 1st quarter were 475 KHZ on 16 December and 200 KHZ on 20 August and on 22 July. Star readings were low by a factor of about 2 on 20 August and by about 2.8 on 16 December. The many inconsistencies in these readings are apparent. It is impossible to trace the history of these inconsistencies and so explain why the best star rates are about the same over the whole span whereas the lunar rates appear to be higher recently by a factor of two or three. The readings of 23 December are particularly strange. There is also a question of whether the base star rate for 23 March 1970 is 860 or 480 KHZ. The peak lunar rate expected was calculated in Technical Report No. 957 and is equal to an adjusted 1 MHZ which is not inconsistent with recently observed rates. A high lunar rate on 23 March is not inconsistent with the 7 March solar eclipse. However, the expected 25 September peak was not observed due to lack of data.

Table III (Appendix IX) gives adjusted star and lunar rates for observation dates closest to full moon. The angle listed is the difference between the sun's Selenographic longitude and the earth's Selenographic longitude taken from The American Ephemeris and Nautical Almanac.

Whatever the reason for the inconsistencies between star rates and lunar rates, the fact remains that the unadjusted bright moon rate is about 300 KHZ. This high background makes on-the-spot verification of acquisition difficult and begins to waste returns due to noise turn-off of the stop vernier. A better lens has been sent to McDonald so that the spatial filter pinhole can be decreased to 200μ (or even 100μ) with confidence. The background should be decreased by the square of the ratio of pinhole diameters. A further background reduction scheme using a polarizer is being considered since the lunar signal return is expected to be polarized the same as the laser output.*

Old Laser Firing Data and Emergency Procedures.

Effort is being made to organize and log all old laser firing and return data. In addition, old clock and epoch history is being compiled. Preliminary work is being done to establish emergency procedures for loss of important equipment at McDonald, such as the crystal clock, VLF recorder, etc. This is being done in order that a well defined smooth transition can be made in operations during the period when certain critical equpment is not functioning.

---

* End of excerpt from TR No. 70-099 by Dr. SK. K. Poultney.

Laser Counter.

In the continuing effort to keep running logs and cross-checks on equipment and data, we have designed and installed a laser shot counter. This device will allow accurate records to be kept on ruby rods as well as cross-correlation with firing data.

Telescope Work.

On February 19, 1970, work began on correcting the damage to the 107" primary mirror (see Technical Report No. 70-090, p. 8). This work was under the direction of Mr. Davidson of Davidson Optronics (the original company who ground the mirror); Mr. John Floyd, Chief Engineer, Astronomy Department, University of Texas; and Mr. Maurice Marin, Resident Observer at McDonald Observatory. The work consisted of relieving the area around the bullet holes and hammer blows of strain, and filling the holes with an appropriate material. The reported loss in reflecting area is about 1.5%. After the work described above was accomplished, the primary mirror, along with the several other mirrors of the 107" telescope, was re-aluminized. The telescope was reassembled and then aligned by Mr. Marin by a new and more thorough technique. The initial usage of the telescope indicates that it has an improved transmission efficiency, while the improved alignment technique has apparently eliminated many old problems. A similar determination of the present efficiency indicates a significant decrease which implies the initial speed of the oxidation process. The present efficiency numbers are similar to the efficiency numbers of the past summer.

New Corner Cubes.

With the installation of the Korad laser, a new problem developed due to the interaction of the laser and the corner cubes, the corner cubes are used for guiding and aligning, and are mounted on the telescope secondary spider. It would seem that these cubes and the laser formed a giant 30'+ lasing system that fired normal mode prior to the pocket cell firing in the laser. The prelase destroyed the proper short pulse firing of the laser. Remote acting-corner covers were installed to cover the corner after alignment and during firing. This, however, prevented the person doing the guiding from seeing the corner return during the firing of the ruby laser. This meant that a continual check of the co-alignment of the site and ruby direction were not available. This could be particularly difficult if the alignment of the telescope were such to permit significant field rotation between checks of the reticle alignment. To prevent this problem, one and one-half inch flight type corner reflectors have been obtained from Perkin-Elmer. These have been aluminized at the Goddard Space Flight Center. Their pattern is being tested at the University of Maryland at present and they will be sent to McDonald Observatory shortly. Dielectric filters will be used in front of the corners to permit a high transmission for the helium-neon alignment laser, while reducing the transmission at the ruby wave length to a level below that at which pre-lasing will take place.

Equipment Failures.

During the period of the report, the following equipment difficulties occurred:

February 16 - Photo tube base.
February 17 - Laser.
February 18 - Laser.
March 13 - 14 - Telescope.
March 15 - Laser chiller.
March 16 - Range tape not readable.
March 17 - Laser.
March 26 - Laser cooling.

In many cases the failure resulted in the loss of only one run. Laser problems should be reduced to near zero frequency, due to the several optical improvements and the reduction in laser energy to three joules. It also appears that photo tube base problems should be nearly eliminated. Two additional failures that were recorded but caused no lost runs were attributed to the laser capacitor bank fuse failure.

Personnel.

It is anticipated that before the end of the next bi-monthly period, Texas will lose two of the key graduate student personnel who have been on the project for some time -- Mr. B. W. Bopp and Mr. Wayne Van Citters. Mr. Bopp has been primarily concerned with guiding and predictions of lunar parameters which affect the laser operations Mr. Van Citters has been responsible for the operation of 620I laser computer as well as the IBM 1800 telexcope computer. It is hoped that these people can be partially replaced by a new fulltime Texas employee. Several are now under consideration. A significant portion of the remaining time of these two key people will be devoted to clearing up old problems and a complete documentation of their work. We would also like to take this opportunity to thank Messrs. Bopp and Van Citters for their valuable contributions to the experiment.

APPENDIX I

MARCH AND APRIL 1970 MONTHLY REPORTS FROM McDONALD OBSERVATORY

THE UNIVERSITY OF TEXAS
McDONALD OBSERVATORY AT MOUNT LOCKE

FORT DAVIS, TEXAS 79734

Post Office Box 1337
Telephone: (915) 426-3263

March 7, 1970

Lure Team Members

Subject: Monthly Report

Gentlemen:

While I had hoped to report the acquisition of a fair amount of laser data this month, I am sorry to say that a number of uncontrollable circumstances have prevented that. As you undoubtedly know, the main primary of the 107" telescope was damaged earlier in the month by a distraught employee. The damage resulted in the permanent loss of about 1.5% of the surface area of the instrument. It also necessitated a major operation preparatory to realuminizing. This resulted in the loss of nearly two weeks of laser ranging at a time when we are virtually starved for data. This loss of telescope time was even worsened by the fact that we had an abnormally large number of equipment failures during the week which remained to do ranging. Thus, I must warn you, this report is written in rather bleak tones. In as much as any comments I could make now will probably be much augmented by oral discussions during the March meeting, I will include only a short summary of the month's activities.

1. Log Sheets: Per usual, I have included a log sheet of the ranging activities last month. During the week available we had 25 possible periods in which to range. Eight of these were lost due to poor weather and seeing, nine due to equipment breakdowns and one due to an observing conflict. This left seven tries at the moon, none of which produced a standout acquisition. (The noise rate was quite high during this period making it hard to pick out the corner in the real time printouts.) There were a number of statistical anomalies present in the printouts, but these may not produce any data unless the range uncertainty can be made significantly less than 6 microseconds.

2. Difficulties During February: Aside from the difficulties with the telescope, the only other thing which characterized February was the difficulty with equipment breakdowns. We had serious breakdowns with both a PMT base and the laser. Unfortunately,

our spare PMT base was already at the factory for repair and I did not realize the seriousness of the difficulty early enough to get a replacement from Maryland. While these bases may be the state of the art in timing accuracy, they are not as reliable as we could hope. More than once they have caused difficulty during a laser run. After the experience we had last month, I am stocking quite a few more spares than we had before.

By comparison, the trouble with the laser was quite straightforward. We did lose a little time due to this breakdown but it involved simply the normal wear of an expendable component. Once we were able to zero in on the blown part the laser returned to normal operation.

In general, the laser has continued to operate quite reliably and with a minimum of servicing. Korad Engineers have been very good in helping us on a number of rough spots. We were somewhat disappointed that our second ruby rod only lasted 4000 shots. This may have been due to an alignment difficulty, however, which is now corrected. The original flashlamps are still operating with no sign of wear. Our major difficulty regarding the laser is keeping the glass circularizing prism in front of the last ruby. We are only averaging about 1000 shots per crown glass prism. I would greatly appreciate any knowledgeable suggestions regarding a more durable substance.

3. Improvements in February: During the month we tried to take as much advantage as possible of the down time to further improve the system. In the short week which we had to operate we were able to see some improvements in a number of aspects. One of these was the improved time keeping. The clock is now set and checked by Loran C measurements. While the process is not yet semi-automated, as Dr. Currie would hope, it is none-the-less fairly accurate and up to the job at hand. We were, as a consequence, able to improve the epoch for all the previous acquisitions by calibrating the WWV delay from Fort Collins, Colorado.

During the month I switched to a more sensitive PMT, found a little vignetting which had previously been missed, eliminated another optical surface and ended up with an optical efficiency of over .4%. If you will recall my previous comments on this subject, this was more than I had thought possible only one month ago. With fresh aluminum coatings on the telescope and all dielectric mirrors in the detector package, I now hope we can do much better. Unless there is something that has escaped us, it now seems possible to squeeze almost a one percent efficiency out of this receiver.

Many people, including myself, are now putting considerable time into curing the 107" seeing. This will involve both changes in operating technique as well as modifications to the dome. We

Lure Team Members
Page 3
March 7, 1970

will block the circulation between the laser room and the dome and run the laser room as close to ambient temperatures as possible (above freezing). In addition, the telescope tube will probably be totally insulated. Due to the repairs on the 107" mirror however, we really did not have time to get much data on the effectiveness of our ideas. I can only say that had we been operating as normal we would have had three runs of exceptional seeing in which to make acquisition.

The one field in which I had hoped to make progress, but which keeps being pushed aside, is the idea of a systematic daily calibration. Dr. Poultney calibrated the system to about a nanosec. in February. So far I have simply taken him at his word. A continual calibration scheme is sorely needed and I will get it installed as soon as possible. In spite of not having a permanent hookup, I was able to check out the system at various temperatures. I've deduced that there is no detectable temperature coefficient in our range data (to 50 psec).

4. Future Plans: The future work plans involve mainly a polishing of our techniques and a calibration study. Most of the major difficulties which I saw in January are now either taken care of or are nearly out of the way. If we can get a fair break with the weather and keep the breakdowns to a minimum we certainly should be able to get an acceptable acquisition rate. Telescope scheduling is now in our favor. Long periods of coudé operation are planned for March, April and June. Throughout, we are scheduled for three operations a day. Thus, at least as far as telescope time, the situation is quite bright. Hopefully, there will be no repeat of last month's difficulties.

Yours truly,

Eric C. Silverberg

Eric C. Silverberg
Project Scientist

ECS/maw
cc: H. J. Smith
C. E. Jenkins
D. S. Evans
C. D. Laughlin
S. Poultney

THE UNIVERSITY OF TEXAS
McDONALD OBSERVATORY AT MOUNT LOCKE

FORT DAVIS, TEXAS 79734

Post Office Box 1337
Telephone: (915) 426-3263

April 9, 1970

The LURE Team

Re: MONTHLY REPORT

Gentlemen:

The month of March was considerably more successful in the operation of the laser experiment than the two that preceded it. We were able to keep the equipment operating fairly consistantly and succeeded in acquiring the corner reflector on more than one occasion. The only real difficulty was the lack of good weather conditions in which to fire the laser. In spite of the latter, however, the month probably had a greater impact on the experiment than any since August. I can best explain by recapitulating the month's events.

Following the meeting of the coinvestigators, we had a couple of unsuccessful runs bracketted by the final stages of telescope alignments. On the night of March 14th, the system appeared to be peaked in performance higher than at any time before. The receiver efficiency (mostly as a result of the re-aluminizing) was up to about .8%. The electronics and optics had received a thorough check. The seeing was exceptionally good. It was very discouraging, therefore, when we failed to see a detectable signal after 400 shots. As a result the McDonald crew and Dr. Currie sat down and began to question some of the heretofore unquestioned aspects of the experiment. The next day, as a result of that conference, Mr. Bopp discovered that the magnetic tapes which set our range gate had a jitter of 32 nanoseconds about the correct range. (This was explained more fully in the April 1st memo by Dr. Mulholland). While the magnetic tapes do not in any way affect the accuracy of our measured ranges, they are incorporated into the programs which express that range in the form of a residual from the Mulholland ephemeris. This residual is how we recognise whether or not we are hitting the corner reflector. With a jitter of 32 nanoseconds it meant that we needed a very high signal to detect the presence of the corner. In fact, under average conditions we were practically shooting blind. This jitter caused the corner to show up more than once as an "anomalous surface return" such as mentioned at the last meeting. We can only feel fortunate that any data we did take is completely recoverable by reprocessing with the correct range tapes. Dr. Currie will be in a better position to comment on the results of that reprocessing when it is completed.

As luck would have it, had we not found the error in the magnetic tapes during the day of March 14th we certainly would have that night. Again the conditions were spectecularly good. This time, however, the signal was strong enough to stand out despite the 32 nanosec range jitter. We noticed the corner reflector about 2 hours west of the meridian in the first 100 shots. At the time we could immediately see that the corner was drifting rather fast relative to the Mulholland epheremis. We extended our observation period, therefore, and followed the corner with 50 shot bursts every 15 minutes for 2 hours. We hoped that the data would be valuable in determining the accuracy of McDonald coordinates. It also was quite valuable in another manner. During the best run of 50 shots we had 1" seeing, .7% receiver efficiency and were putting 3 joules per shot into the telescope. We received 13 returns. This most certainly indicates that the corner reflector has not degraded very much during the past 8 months. It also showed us that the parameters which we were using at the time (filter temperature, alignment, range gate, etc.) were very nearly optimum. Thus, in 24 hours we not only found out why the corner has been so hard to locate but succeeded in locating it anyway. All in all it was a fairly good day for lunar ranging.

The rest of that week we had reasonable weather (although none even comparing with March 15th) and fired about 1300 shots. This resulted in one more definite acquisition and 2 more probable acquisitions. The following 10 days however, the conditions were uniformly poor and we were only able to get one "possible" data point. That brought us up to new moon. We're now spending most of our time overhauling the laser so that we can expect it to run another 4000 shots. Our next operation starts on April 10. We have a new set of data tapes on hand to rid ourselves of the jitter problem. They should not only improve our technique, but will allow me to be able to more definitely state the number of acquisitions in each monthly report.

Partly as a result of the coinvestigators meeting we have concentrated more this month on improving the performance of the optical train. One big step was the re-aluminizing. This raised our optical efficiency about 200% and undoubtedly contributed to the acquisition of March 15. It so affected our full moon noise rate, however, that we have got to try some different filtering techniques or improve the range prediction tapes by a factor of two. Acting on comments during the meeting we have installed adjustable or dynamic mounts on the .7Å filter, the He-Ne beam splitter, the diverging lens and the feedback loop that checks the ruby/filter wavelength matching. Although the 1.5" corners have not yet arrived, we have also arranged that a ruby return is visible on every shot from the 4" corners. The upstairs guiding system is now in the active planning stages.

In order to get a better lifetime from the rubies we have lowered the average laser energy to 3 joules. This seemed to be justified by the performance of the system. We were able to run the entire month without losing a single "in the beam" component or even having to make a major re-alignment of the optics. I think it is important to avoid breakdowns so that you are always able to fire the system during those few good moments each week when you expect to make acquisitions. The only way we can be sure of that is to be very conservative with things like laser energy, equipment changes and new techniques. Since damage to the circularizing prisms is not a problem at these energies, we have held off trying to A.R. coat them.

When I went to install the bin system to interogate a wider range gate for returns, it was found to be incompatible with the present software. I still have hopes, however, that it will be operating in parallel with the present system soon. Certainly some of the urgency for that modification was lessened when the Mulholland ephemeris only missed by about 300 nanoseconds on the recognizable acquisitions in April.

The operation this month is summed up in a few statements. First, we think we know why we were having so much difficulty hitting the corner regularly. Secondly, the acquisition of March 15 shows that, at least on that night, the corner and the ground system was operating close to specification. And thirdly, the system ran quite well for the entire month but the weather was quite poor. As of a month ago, I was beginning to make up contigency plans for some drastic steps if we did not hit the corner soon. In light of the recent developments, however, I think the best course is to stand pat and simply try for a month of "routine" operation.

Yours truly,

Eric C. Silverberg
Project Scientist
Lunar Ranging Experiment

ECS/maw
cc: A. T. Strickland
S. Poultney
H. J. Smith
C. E. Jenkins
D. S. Evans
C. D. Laughlin
D. N. Dittmar

APPENDIX II

FEBRUARY - APRIL 1970 LASER FIRING HISTORY

LASER FIRING HISTORY

1970

Date	Time (CST)	Number of Shots	Results	Weather	Seeing	Comments
Feb 15	6 & 9 PM	-	-	Cloudy	-	-
	12 midnite	-	-	Clear after front moved through.	10^{π}	Impossible seeing.
Feb 16	7 PM & 1 AM	-	-	Clear	-	Again PMT base trouble.
Feb 17	9 PM	60	None	Clear, 12°C	$2\text{-}3^{\pi}$	Computer blew.
	11:30 PM	250	Uncertain	Clear, 11°C	2^{π}	Laser quit at 250.
Feb 18	9:30 PM	200	Uncertain	Clear, 16°C	4^{π}	Laser at only 3 joules.
	11:30 PM	0	0	-	-	Working on laser.
	2 AM	0	0	Windy	10^{π}	-
Feb 19 to Mar 4	Worked on damaged primary as well as re-aluminizing. Also overhauled the laser.					
Mar 5-10	New moon; Cassegrain run.					
Mar 11-12	Telescope alignment.					
Mar 13	3 PM	180	None	Clear	$4\text{-}5^{\pi}$ Image Motion	Optical efficiency up to ∿.8%.
	6 PM	350	None	Clear	$\sim 6^{\pi}$	(Optical efficiency up to ∿.8%.)
	No last run. Work on telescope.					

1970

Date	Time (CST)	Number of Shots	Results	Weather	Seeing	Comments
Mar 14	4 PM	Work on telescope alignment.				
	7 PM	250	?	Clear	3″	-
	8 PM	160	?	Clear	<2″	-
Mar 15	4 & 9 PM	Work on laser water leaks and alignment.				
	10 PM	350	~40 returns	Clear	1-2″	Followed drift in corner return distance for 2 hours.
Mar 16	6 PM	-	-	Cloudy	-	-
	9 PM & 12 midnite	Dropped, no range tapes.		-	5″	-
Mar 17	7 & 10 PM	Blew flashlamp on laser.		-	-	-
	12:30 AM	320	Probable acquisition.	Clear, high winds.	3-4″ with some image motion	-
Mar 18	8 PM	100	Probable acquisition	Hazy	3″	-
	9 PM & 2 AM	-	-	Cloudy	-	-
Mar 19-20	-	-	-	Snowing; completely socked in.	-	Got retro-return from corner reflect working.

1970

Date	Time	Number of Shots	Results	Weather	Seeing	Comments
Mar 21	9:30 PM	100	None	Clear	5^{π}	-
	11 PM & 2 AM	-	-	Clear	-	Seeing too poor to run.
Mar 22	10 PM	-	-	Dropped for poor seeing.		
	1 AM	200	Acquisition	Clear - windy.	$3\text{-}4^{\pi}$	Moon noise ∿300 KHz.
	3:30 AM	200	Maybe	" "	"	" " "
Mar 23	11 PM	150	Maybe	Hazy	$2\text{-}3^{\pi}$	-
	12 Midnite & 4 AM	-	-	Thick cirrus	-	-
Mar 24	11:30 PM	150	None	Clear	3^{π}	Guiding trouble.
	12 Midnite & 3 AM	No runs due to gale force winds.				
Mar 25	11:40 PM	200	?	Clear	4^{π}	-
Mar 26	No runs due to laser chiller repairs and poor seeing.					

1970

Date	Time	Number of Shots	Results	Weather	Seeing	Comments
Mar 27	1:30 AM	_	_	Clear	$>10^{\pi}$	Run cancelled.
	4:40 AM	100	Maybe	Clear	$\sim 5^{\pi}$	Rough guiding.
	7 AM	0	-	-	-	Contrast too low to guide.
Mar 28	2 & 5 AM	-	-	Cloudy	-	-
	8 AM	-	-	Clear	$\sim 7^{\pi}$	Couldn't guide; sky too bright.
Mar 29	3 AM	200	None	Clear	$\sim 4^{\pi}$	Computer guiding.
	6 AM	-	-	Cloudy	-	-
Mar 30	4 & 7 AM	_	_	Clear	-	Lost due to telescope.
	10 AM	_	_	Clear	-	No contrast to guide.
Apr 1 - 9	New moon. Work on system.					
Apr 10	2 PM	-	-	Cloudy	-	-
	5 PM	-	-	Cloudy	-	-
	6 PM	200	-	Clear	2-3π	Computer guide good. RA load trouble.

1970

Date	Time	Number of Shots	Results	Weather	Seeing	Comments
April 11	3 PM	-	-	Cloudy	-	-
	6 PM	280	-	Clear	-	Moltke visible. Ritter and Sabine not.
	9 PM	-	-	Cloudy	-	-
April 12	4 PM	90	-	-	>5π	Image motion.
	7 PM	300	-	-	<1π	
	10	-	-	-	∿1π	Guided dead on Moltke, Some image motion.
April 13	5 PM	-	-	-	3-5π	
	11 PM	230	-	-	3-6π	Erratic laser.
April 14	5 PM	180	-	-	4-5π	Unstable but fair reticle fit.
	8 PM	150	-	-	2-3π	Fair reticle fit guided on Moltke.
	12 M	120	-	-	2-3π	Lot of bad tape records.
April 15	6 PM	200	-	-	3-4π	
	9 PM	150	-	-	1-2π	

APPENDIX III

PREDICTION DISCREPANCIES

JET PROPULSION LABORATORY California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103

Ref. No. 391.13-190

1970 April 1

MEMORANDUM

TO: Doug Currie

FROM: Derral Mulholland

SUBJECT: Prediction Discrepancies

Since your telephone call of 1970 March 15, I have spent quite a lot of time examining possible causes for the range discrepancy noted then and the other problems discovered subsequently. I have now done everything possible, except examination of the tapes that have not yet returned from Texas. I find the following:

Re 32 nsec "quantization" of predictions on recent drive tapes:

This problem has been isolated and corrected. When the new laser was being installed last fall, John Rayner sent me a generalized revision of the range tape writing program, in which he had removed two apparently redundant instructions. If the UNIVAC system did what the UNIVAC manual claims, they would indeed be redundant. Not so, however; the result was a truncation of the range prediction from 35 to 27 bits. The 27th bit represents 32 nsec. I have revised Rayner's program accordingly.

Re "jitter" between data on range tape and prediction listing:

These discrepancies, which I observed after fixing the quantization problem, run in the range from -2 to +6 nsec (listing minus tape). They arise from a combination of two causes. A ± 4 nsec randon component exsists as an error in the printed listing, due to the same UNIVAC system error noted above. This affects only the formatting of the number for printing, not the prediction in any way. I have programmed around the system error, so that this print error has been corrected. The additional 2 nsec appears to arise from a programming error in Rayner's tape writing program. He evaluates the Chebyshev polynomial and then subtracts 2 nsec for no reason apparent to me. Unless you object, I shall delete this subtraction on range tapes beginning 1970 April 22.

Telephone 354-4321 Twx 213-449-2451

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

Re microsecond discrepancies between Varian and prediction listing:

You and Eric have both commented upon discrepancies of this magnitude during February. I have examined and compared prediction listings, data input to mag tapes on hand, and data read from those tapes. I find no discrepancies other than those resolved above, judging from numerous points selected at random. One cannot say for certain until I have the February tapes back for examination, but, based on my investigation to date, it appears that the problem is in the Varian rather than the tapes.

Re unreadable range tape:

Discussion with Eric leads me to suspect that the tape may be at the wrong bit density. This cannot be checked reliably except by applying a chemical that makes the bit structure visible, after which the tape may not be used. Such a test will be made when I receive the tape, but only after the data have been examined. This has been done with a tape on hand (one that I had planned to send to Eric); that tape was ok. Tape densities on the UNIVAC are set by the system software according to card input requests. It is conceivable that a card reader failure could cause an incorrect density. We can institute procedures that will provide some safeguard against this, but there is no way to be absolutely sure about the density. Modern tape drives provide no means for a physical indication of the density at which they are set.

* * *

I have sent a new tape for 1970 April 7-21 to Eric; it has been thoroughly tested. I know that it contains data that are 2 nsec short of the polynomials. I know that it is readable. I know (in this case) that it is 556 bpi. I can do no more until I have examined the tapes being returned from Texas.

DM:bm

cc: LURE Team Members
E. Silverberg
J. Lieske

APPENDIX IV

ANOMALOUS SURFACE RETURN ON DAY 350

UNIVERSITY OF MARYLAND

Department of Physics and Astronomy

INTRAMURAL

To: C. O. Alley, S. K. Poultney, J. M. Mullendore

From: D. G. Currie

Subject: Anomalous surface return on day 350

Date: February 9, 1970

On the day 350 one of the runs is analyzed to demonstrate the anomolous surface return which appeared during that observation. The analysis is expressed in terms of the return obtained in certain time intervals about the apparent time of the array.

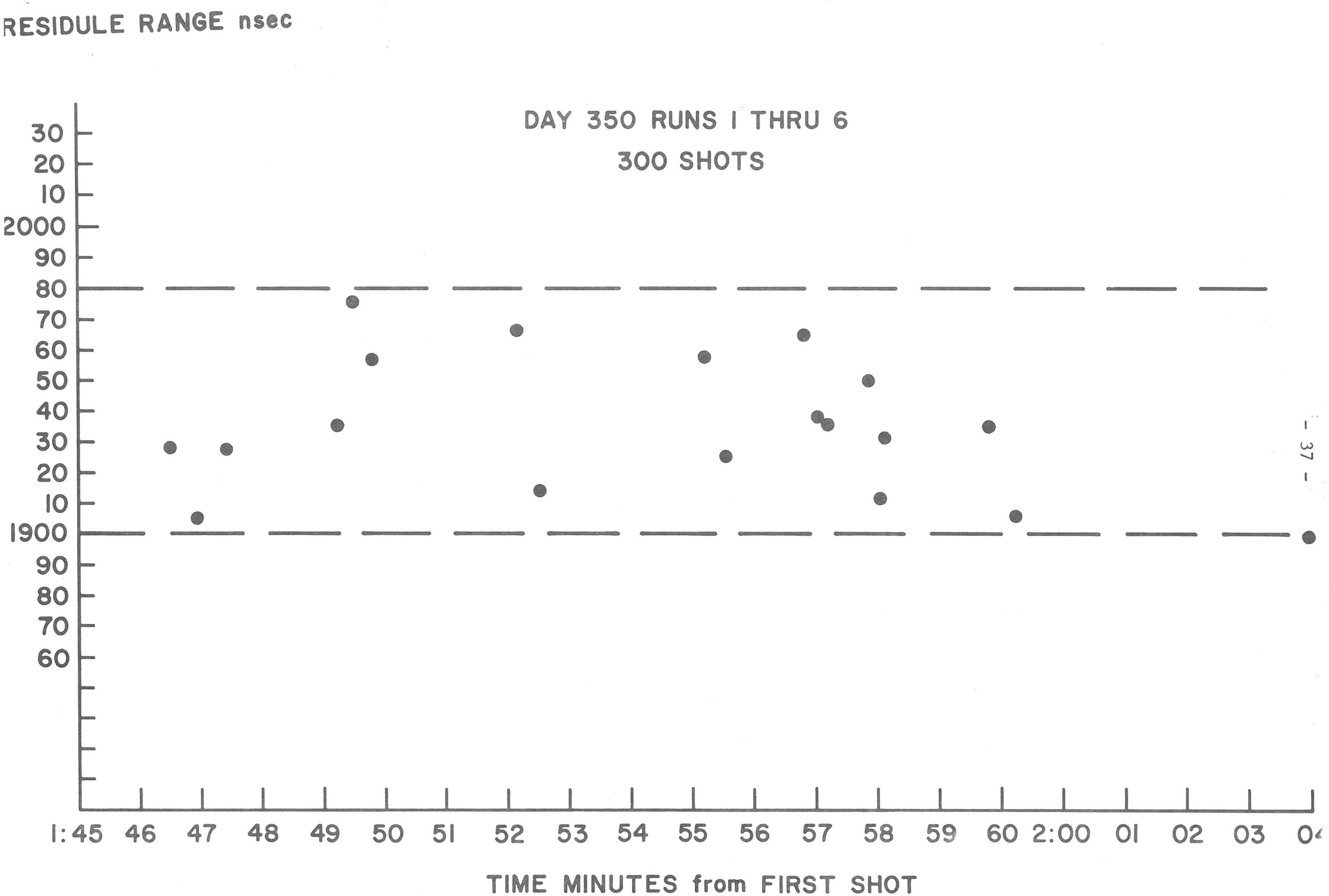
Time Interval	No. of Returns	Rate of Returns	Enhancement
$0<\tau<5$	8	0.400	55.0
$5<\tau<15$	9	0.225	31.0
$15<\tau<75$	4	0.0167	2.3
$75<\tau<500$	17	0.0063	0.9
$500<\infty$	----	0.0073	1.0

The first column is in nanoseconds, the second column is the number of returns in the total interval, and the last column is in units of photoelectrons/nanoseconds. The last line is the entry obtained by the measurement of the total count of dark current plus moon rate. The last two lines agree in the third column to within the statistical error of the fourth line. Thus, asymtotically, the two different approaches give the same result.

This return appears to be above that for any reasonable model which might explain a high surface return. It could imply a jitter in the measurement of the range, however, at this time does not seem to be any such proglem.

The remaining runs of this observation, as well as other observations, should be analyzed in the same fashion.

clt


RESIDULE RANGE nsec
DAY 350 RUNS 1 THRU 6
300 SHOTS
30
20
10
2000
90
80
70
60
50
40
30
20
10
1900
90
80
70
60
1:45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 2:00 01 02 03 04
TIME MINUTES from FIRST SHOT

APPENDIX V

COMPUTER FORMAT

February 11, 1970

Dr. Derral Mulholland
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Dear Derral:

Following is a brief description of the Varian teletype output format.

The first line gives the time of run initiation. For example: TIME = 030:15:56 means day 30, hour 15, minute 56. The second line gives the constant which subtracted from the predicted range before it is sent to the gate generator. Thus: DELTA = 0000003000 means that the return gate is opened 3μsec. before the predicted return time.

Following these two heading lines are the actual return data, one shot per line. For the purpose of this discussion take the sample line: :48 2536113928 3809.4. The :48 represents the second on which the laser was fired. This will be expanded to include the minute, ie. 56:48. The second number (2536113928) is the delay for the return gate in nanoseconds. The third number (3809.4) is the time from the return gate until the return pulse. The round trip time is thus the sum of these two numbers (2536113928 + 3809.4 = 2536117737.4) is the round trip time. Since the printed predicted range is the ephemeris range minus DELTA, the true residual range is the printed residual (3809.4) minus DELTA (3809.4 - 3000 = 9.4 ns). NO LASER implies that no start pulse was received while NO RETURN implies that no return pulse was detected.

There are three other possible print outs relating to tape errors. REDUNDANCY and SHORT REC. refer to reading errors and result in a gap of one minute in the measurements. They will usually cause SYNC. ERROR to be printed which reflects this fact.

I hope this information will allow you to interpret the print out. If not, please contact me and I will verbally expand it.

Sincerely,

D. G. Currie John Rayner

DGC, JR:clt

The range cards are produced by the sequence

```
WRITE(DOUT,1) DAY,HR,MIN,SEC,EPOCH,PREDICTED_RANGE,RESID_RANGE,LHA,DEC,EL
1    FORMAT('RANGEb'4I3,F7.6,1X,I10,2X,F8.1,3(2X,F6.3))
```

The raw data cards result from

```
     WRITE(DOUT,2) DAY,HR,MIN,SEC,RA,RB,(AV(I),AVN(I),I=1,3))
2    FORMAT('DATAbb',4I3,I12,I9,3(I5,I2))
```

Where

RA=(predicted range from range tape) - DELTA

RB=time interval meter reading (units of 50 nsec)

AV(I)=initial vernier

AVN(1)=0

AV(2)=final vernier

AVN(2)=1

AV(3)=epoch vernier

AVN(3)=2

Each run is headed by a delta card.

```
     WRITE(DOUT,3) DELTA
3    FORMAT('DELTAb',I10)
```

These are mixed with coefficient cards of the JPL format for each day.

APPENDIX VI

PROCESSED DATA FROM DAY 75

PROCESSED DATA FROM DAY 75

SHOT NO.	RANGE		
41	-1928.0		
33	-1869.5		
40	-1753.4		
18	-1490.9		
13	-829.0		
27	-629.8		
38	-375.5		
14	-320.5		
5	-261.0		
43	183.6		$
23	212.7	*	$
24	213.0	*	$
22	213.8	*	$
31	214.1	*	$
21	215.0	*	$
9	215.4	*	$
7	215.7	*	$
11	215.7	*	$
39	215.9	*	$
20	217.6	*	$
25	219.1	*	$
42	230.7		$
44	454.6		
32	709.9		
45	824.6		
35	1988.6		
34	2842.3		
37	2958.9		
46	3353.2		
4	4320.3		
12	4377.3		

Range = Difference from Mulholland prediction.

---

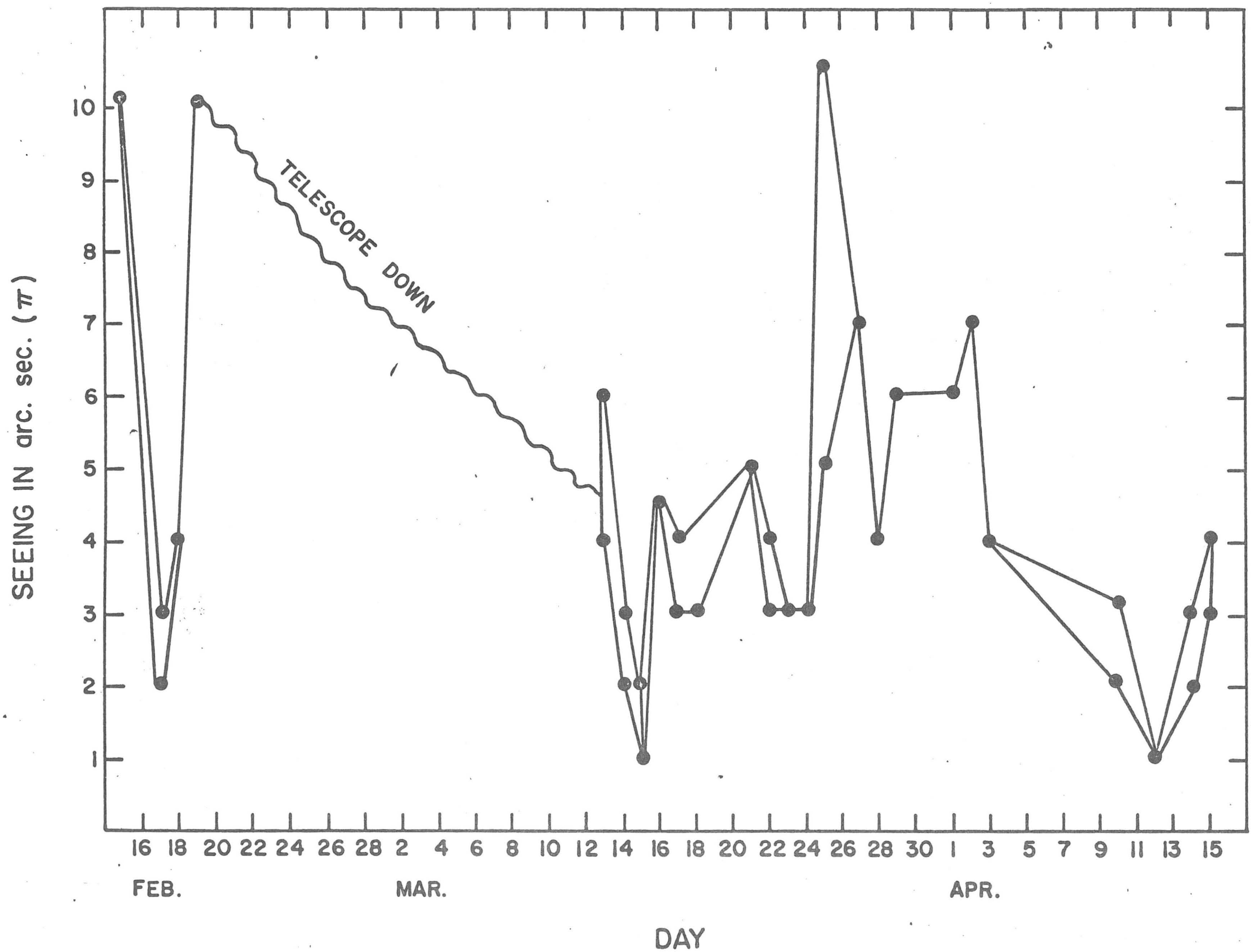
* Indicates successive points within 5 nsecs.

$ Indicates successive points within 30 nsecs.

APPENDIX VII

GRAPH OF SEEING DATA

FEBRUARY - APRIL 1970


SEEING IN arc. sec. (π)
10
9
8
7
6
5
4
3
2
1
TELESCOPE DOWN
16 18 20 22 24 26 28 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15
FEB.
MAR.
APR.
DAY

APPENDIX VIII

PHOTOCATHODE QUANTUM EFFICIENCY ENHANCEMENT OF THE RCA 31000E PHOTOMULTIPLIER AT 6328 Å

PHOTOCATHODE QUANTUM EFFICIENCY ENHANCEMENT OF THE RCA 31000E PHOTOMULTIPLIER AT 6328 Å

R. Lakes and S. K. Poultney
Department of Physics and Astronomy
University of Maryland
College Park, Maryland
20742

The RCA 31000E (or F) photomultiplier has a combination of features which makes it preferred for fast timing and efficient detection at the single photoelectron level such as in the Lunar Ranging Experiment.[1] Typical RCA 31000E (or F) quantum efficiencies are quite good; about 6.6% at 6943 Å and 9% at 6328 Å as measured on seven different tubes. A low-level light signal such as in the Lunar Ranging Experiment makes a high quantum efficiency in the red highly desirable. Quantum efficiency enhancements up to factors of 4 or 5 have been measured at these wavelengths using other photomultipliers in conjunction with special optical devices.[2] Several of the enhancement methods currently employed[2] were therefore tried on the RCA 31000E. The RCA 31000F has a window with a curved outside surface and a diffuse finish and shows only about a 10% enhancement when the tube is tilted with respect to the incident beam. No other attempt was made to enhance the RCA 31000F although it would be possible to add a suitable device in optical contact with the outside surface if tests with the RCA 31000F proved favorable. The RCA 31000E has a window with a flat outside surface and a curved inside surface. The window is clear.

Measurements of the quantum efficiency were made using the photomultiplier as a diode with 300 volts anode potential. Light from a Spectra Physics 130B HeNe laser suitably attenuated by calibrated neutral density filters (ND 2.0 to ND 3.0) was directed to the photocathode. The amount of light was calibrated using an Eppley thermopile as a primary standard and a Spectra Physics 401 Power Meter as a secondary standard. A Bausch and Lomb 33-86-25-02 Monochromator was used to obtain head-on quantum efficiencies only at wavelengths other than 6328 Å. A Keithley 150B Microvolt Ammeter was used to measure the cathode current. Enhanced quantum efficiencies at 6328 Å are stated with respect to head-on measurements (i.e. $R/N)^2$ at photocathode center. The photocathode was first studied for non-uniformities with a head-on beam. The quantum efficiency rose 5 to 10% at a radius of 5mm from the center and 20 to 30% at a radius of 10mm. The larger value just happened to be the place on the photocathode where the enhancement devices were placed. Next, a large 45°-90°-45° prism was placed with its long side in optical contact with the photocathode so as to obtain a single bounce of the HeNe beam from the photocathode at the point 10mm from the center. A second similar prism with one side silvered was used to get a double bounce. Finally, a smaller 45°-90°-45° prism was used to try to obtain multiple bounces. Visual inspection allowed optimization of the number of bounces. The last enhancement attempt was not particularly successful due to the curved inner surface of the photocathode. The results of the measurements are given in Table I for both polarizations. Also included are measurements for 45° incidence at photocathode center.

Typical head-on quantum efficiencies at 6328 Å are 9% for the 31000E. The results of the measurements shown in Table I indicate quantum efficiency enhancements with the RCA 31000E (and F) are quite poor compared with the experience with other photomultipliers. A maximum enhancement of 60% was achieved. (A larger enhancement was noticed when the beam hit the white inside of the tube envelope, but attempts to trap the light in the photocathode-first dynode space were not successful.) However, the high head-on quantum efficiency of the 31000E places its enhanced quantum efficiency within a factor of two of the best enhanced quantum efficiency obtained with an S-20 photocathode at this wavelength.[2] It is possible that both the high head-on quantum efficiency and low enhancement ratio of the C31000E are due to its thicker photocathode which does appear less-transparent to the eye than do typical S-20's. The observed enhancement, although modest, will raise the level of the return signal in the Lunar Ranging Experiment and increase the role of the RCA 31000E (or F) in the success of that experiment.

TABLE I. QUANTUM EFFICIENCY ENHANCEMENT OF THE RCA 31000E AT 6328 Å USING CURRENT OPTICAL METHODS.[2]

Enhancements (R/N) are quoted relative to central, head-on measurements. Polarizations (P) are either perpendicular to the plane of incidence (I) or parallel to it.

Beam and Optical Configuration	R/N
Head-on, center	1.0
Head-on, prism location	1.3
Single Bounce Prism, P⊥I	1.0
Single Bounce Prism, P∥I	1.4
Double Bounce Prism, P⊥I	1.1
Double Bounce Prism, P∥I	1.6
Multiple Bounce Prism, P⊥I	1.4
Multiple Bounce Prism, P∥I	1.4
Beam 45°, center, P⊥I	0.9
Beam 45°, center, P∥I	1.1

APPENDIX IX

STAR AND MOON RATES

TABLE I. STAR PHOTOMETRY RECORD

Date	Configuration	Star	Obs. Rate	Corr. Factor*	Adj. Rate	Remarks (Seeing)
28 Dec	3Å,400μ,PMT1	A LEO	6 to 10 KHZ	1 x 1/0.3	20 to 30 KHZ	>10"
31 Dec	3Å,600μ,PMT1	A BOO	210 KHZ	1 x 1/2.7	28 KHZ	8-10"
26 Jan	.7Å,400μ,PMT1	A VIR	19 KHZ	1 x 4/0.4	190 KHZ	4"
28 Jan	.7Å,400μ,PMT1	A VIR	24 KHZ	1 x 4/0.4	240 KHZ	3-6"
13 Mar	.7Å,200μ,PMT3	A AQL	25-29 KHZ	1 x 4/0.45	240 KHZ	} 3-6" SKY 60 KHZ 2PM local time
	.7Å,400μ,PMT3	A ORI	UNC 490 KHZ	1 x 4/2.4		
13 Mar	.7Å,400μ,PMT3	A AQL	UNC 150 KHZ	1 x 4/0.45		} 4-5" SKY 220 KHZ
	.7Å,600μ,PMT3	A AQL	100 KHZ	1 x 4/0.45	890 KHZ	
13 Mar	.7Å,200μ,PMT3	A ORI	200 KHZ	1 x 4/2.4	333 KHZ	} 2-4" 7PM local time
	.7Å,400μ,PMT3	A ORI	340 KHZ	1 x 4/2.4	566 KHZ	
	.7Å,800μ,PMT3	A ORI	515 KHZ	1 x 4/2.4	860 KHZ	
14 Mar	.7Å,400μ,PMT3	A ORI	390 KHZ	1 x 4/2.4	650 KHZ	3"
15 Mar	.7Å,400μ,PMT3	A ORI	415 KHZ	1 x 4/2.4	691 KHZ	1-2"
18 Mar	.7Å,400μ,PMT3	B GEM	95 KHZ	1 x 4/0.73	520 KHZ	∿3"
	.7Å,open,PMT3	B GEM	101 KHZ	1 x 4/0.73	550 KHZ	
21 Mar	.7Å,400μ,PMT3	A ORI	330 KHZ	1 x 4/2.4	550 KHZ	∿5"
22 Mar	.7Å,400μ,PMT3	A ORI	250 KHZ	1 x 4/2.4	416 KHZ	2-3"
24 Mar	.7Å, ? ,PMT3	B LEO	18 KHZ	1 x 4/0.15	480 KHZ	3"
27 Mar	.7Å,400μ,PMT3	A BOO	294 KHZ	1 x 4/2.7	435 KHZ	Poor

* NOTE: PMT3 (08029) assumed equal to PMT1 (08132) until in situ comparison with light diode can be made.

TABLE II. LUNAR BACKGROUND MEASUREMENTS IN THE VICINITY OF SITE 2

Date	Configuration	Peak Obs. Rate	Corr. Factor	Adj. Rate	Remarks
15 Nov	.7Å, 400μ, PMT1	14 KHZ	4 x 1	56 KHZ	Scattered clouds
15 Dec	.7Å, 400μ, PMT1	28 KHZ	(4 x 1)	112 KHZ	
16 Dec	.7Å, 400μ, PMT1	120 KHZ	4 x (1)	480 KHZ	Clear sky
19 Dec	.7Å, 400μ, PMT1	60 KHZ	4 x 1	240 KHZ	
20 Dec	.7Å, 400μ, PMT1	86 KHZ	4 x 1	344 KHZ	Scattered ci
21 Dec	.7Å, 400μ, PMT1	114 KHZ	4 x 1	456 KHZ	High ci
23 Dec	3Å, 200μ, PMT1	260 KHZ	1 x 4	1040 KHZ	
31 Dec	3Å, 400μ, PMT1	455 KHZ	1 x 1	455 KHZ	
25 Jan	.7Å, 400μ, PMT1	66 KHZ	4 x 1	264 KHZ	
26 Jan	.7Å, 400μ, PMT1	86 KHZ	4 x 1	344 KHZ	Cloudy
27 Jan	.7Å, 400μ, PMT1	70 KHZ	4 x 1	280 KHZ	Ci
28 Jan	.7Å, 400μ, PMT1	100 KHZ	4 x 1	400 KHZ	High, light ci
30 Jan	3Å, 400μ, PMT1	58 KHZ	1 x 1	58 KHZ	
30 Jan	.7Å, 600μ, PMT1	78 KHZ	4 x 4/9	160 KHZ	
12 Feb	.7Å, 400μ, PMT3	28 KHZ	4 x 1	112 KHZ	
13 Feb	.7Å, 400μ, PMT3	85 KHZ	4 x 1	340 KHZ	Light ci
14 Feb	.7Å, 400μ, PMT3	100 KHZ	4 x 1	400 KHZ	Windy
17 Feb	.7Å, 400μ, PMT3	150 KHZ	4 x 1	600 KHZ	
18 Feb	.7Å, 400μ, PMT3	130 KHZ	4 x 1	520 KHZ	

(Continued)

Table II (Continued)

Date	Configuration	Peak Obs. Rate	Corr. Factor	Adj. Rate	Remarks
13 Mar	.7Å, 400μ, PMT3	102 KHZ	4 x 1	408 KHZ	Cloud wisps
14 Mar	.7Å, 400μ, PMT3	115 KHZ	4 x 1	460 KHZ	
15 Mar	.7Å, 400μ, PMT3	88 KHZ	4 x 1	352 KHZ	
17 Mar	.7Å, 400μ, PMT3	85 KHZ	4 x 1	340 KHZ	
18 Mar	.7Å, 400μ, PMT3	130 KHZ	4 x 1	520 KHZ	
21 Mar	.7Å, 400μ, PMT3	300 KHZ	4 x 1	1200 KHZ	
22 Mar	.7Å, 400μ, PMT3	350 KHZ	4 x 1	1400 KHZ	
24 Mar	.7Å, 400μ, PMT3	180 KHZ	4 x 1	720 KHZ	
	.7Å, 200μ, PMT3	60 KHZ	4 x 4	960 KHZ	
	.7Å, 400μ, PMT3	104 KHZ	4 x 1	416 KHZ	
27 Mar	.7Å, 400μ, PMT3	30 KHZ	4 x 1	120 KHZ	
29 Mar	.7Å, 400μ, PMT3	2 KHZ	4 x 1	8 KHZ	

TABLE III. ADJUSTED LUNAR AND STAR RATES AT FULL MOON

Full Moon	Earth's Selenographic		Sun's Selenographic			Peak	Normalized	Rate
Date - Time	Longitude	Latitude	Longitude	Latitude	Star Rate	Lunar Rate	Lunar Rate	Remarks
1969								
29 Jul - 0246	+1.94°	+4.78°	+1.82°	+1.11°	185 KHZ	120 KHZ	470 KHZ	29 Jul
27 Aug - 1033	+3.66°	+1.98°	+5.68°	+0.44°	-	360 KHZ	-	24 Aug
25 Sep - 2022	+4.71°	-1.40°	+5.05°	-0.35°	300 KHZ	-	-	
25 Oct - 0845	+4.92°	-4.45°	+5.08°	-1.08°	300 KHZ	-	-	18 Oct
23 Nov - 2354	+4.31°	-6.31°	+4.30°	-1.52°	-	-	-	
23 Dec - 1736	+2.76°	-6.27°	+2.82°	-1.52°	94 KHZ	1040 KHZ	8000 KHZ(?)	Bad seeing
1970								
22 Jan - 1256	+0.41°	-4.37°	+0.29°	-1.07°	210 KHZ	264 KHZ	900 KHZ	25 Jan
21 Feb - 0819	-2.20°	-1.16°	-2.22°	-0.30°	-	520 KHZ	-	18 Feb
23 Mar - 0153	-4.31°	+2.25°	-4.27°	+0.53°	480 KHZ	1400 KHZ	1400 KHZ	22 Mar
21 Apr - 1622	-5.26°	+5.08°	-5.23°	+1.20°				

Normalized lunar rates are normalized to a star count of 720 KHZ before February 1970 and to 480 KHZ after 20 March 1970.

APPENDIX X

CALIBRATION PROCEDURES

LASER FIRING EPOCH VERNIER CALIBRATIONS WITH TDG

1. Trigger TDG by computer. Use START vernier (#0).

2. Start vernier with TDG start and stop vernier with TDG stop using equal length cables.

3. Address calibration data by K6 after raising Sense Switch 3 to store data. Press 6 five times for each TDG delay. (One does well to check numbers obtained from K with Switch 3 down before entering on tape.)

4. Set TDG from 50 μsec to 800 μsec in 50 μsec steps.

START/STOP VERNIER CALIBRATIONS WITH TDG

1. Trigger TDG by computer. Use start vernier (#0).

2. Start vernier with TDG start and stop vernier with TDG stop using equal length cables.

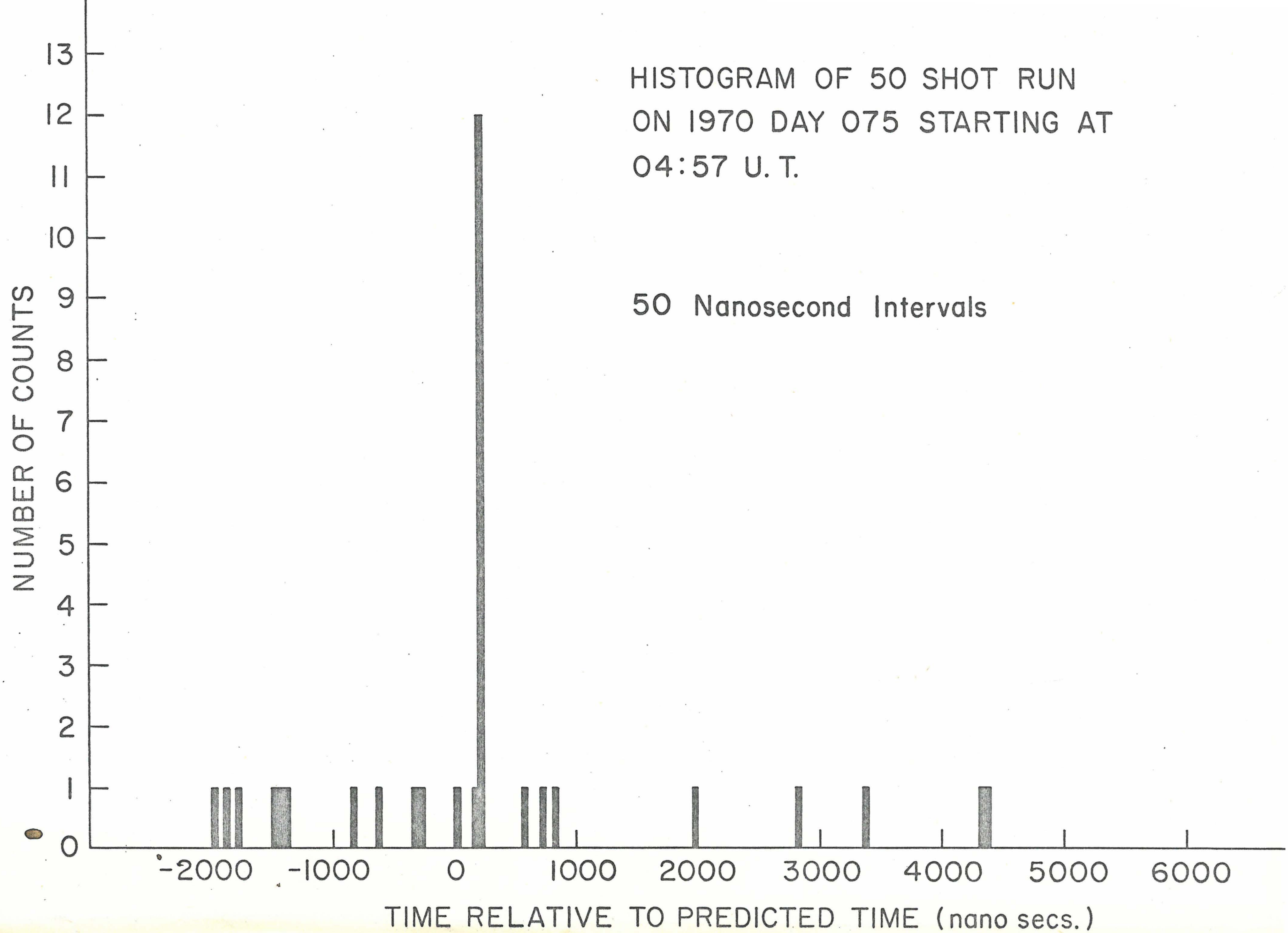
3. Address calibration data by K 1 after raising Sense Switch 3 to store data. Press 1 five times for each TDG delay.

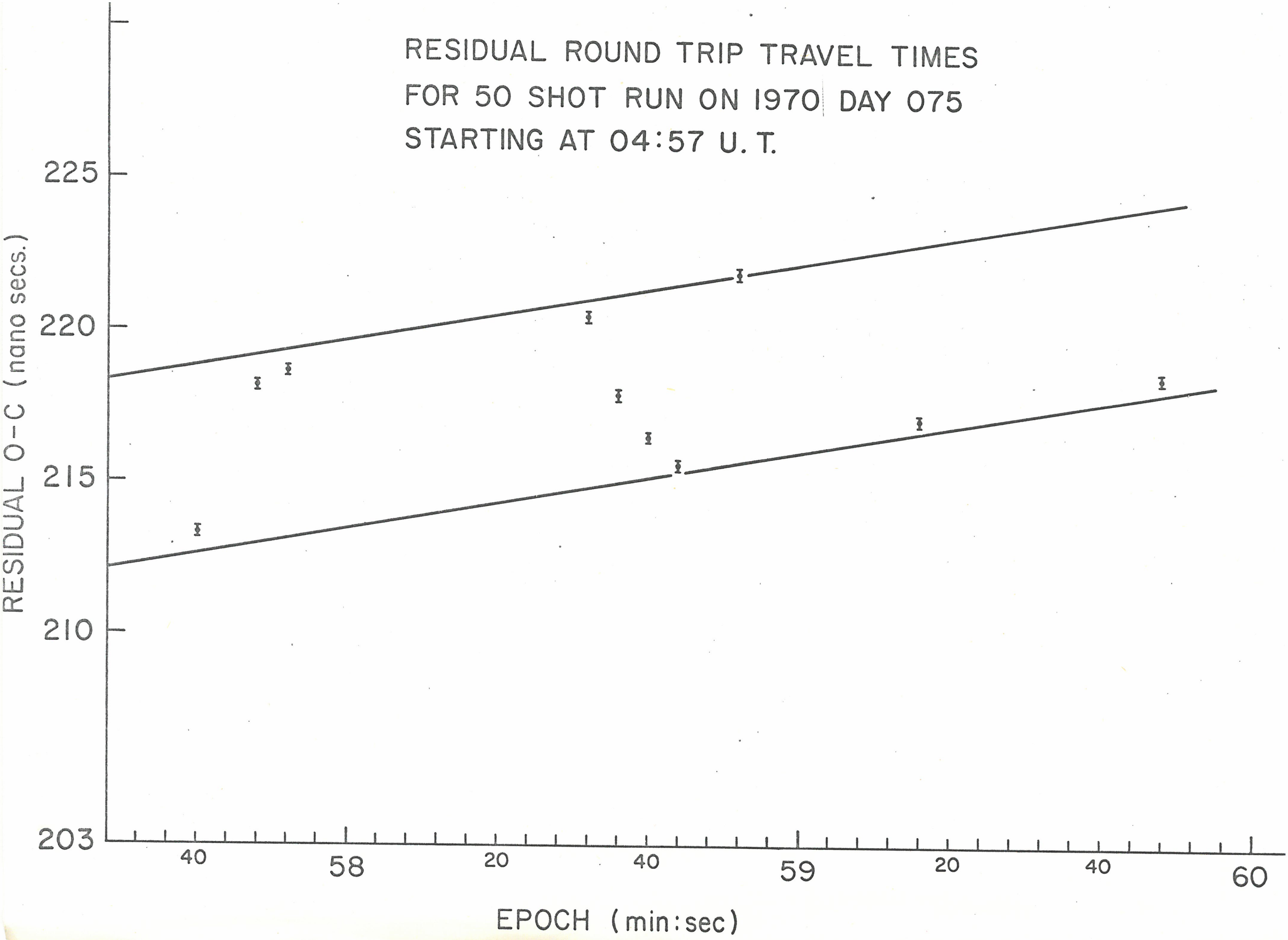
4. Set TDG from 10 nsec to 200 nsec in 10 nsec steps.

5. Repeat for each vernier. The computer labels each internal to program.

TABLE OF CONTENTS OF TECHNICAL REPORT NO. 70-100:

CALIBRATION PROCEDURES FOR THE LUNAR RANGING STATION AT McDONALD OBSERVATORY


HISTOGRAM OF 50 SHOT RUN
ON 1970 DAY 075 STARTING AT
04:57 U.T.
50 Nanosecond Intervals
NUMBER OF COUNTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
-2000
-1000
0
1000
2000
3000
4000
5000
6000
TIME RELATIVE TO PREDICTED TIME (nano secs.)


RESIDUAL ROUND TRIP TRAVEL TIMES
FOR 50 SHOT RUN ON 1970 DAY 075
STARTING AT 04:57 U. T.
RESIDUAL O-C (nano secs.)
225
220
215
210
203
40
58
20
40
59
20
40
60
EPOCH (min:sec)

41	-1928.0		
33	-1869.5		
4[illegible]	-1753.4		
18	-1490.9		
13	-829.0		
27	-629.0		
3[illegible]	-375.5		
14	-320.5		
5	-261.0		
43	183.6		$
23	212.7	*	$
24	213.0	*	$
22	213.8	*	$
31	214.1	*	$
21	215.0	*	$
9	215.4	*	$
7	215.7	*	$
11	215.7	*	$
39	215.9	*	$
20	217.6	*	$
25	219.1	*	$
42	230.7		$
44	454.6		
32	709.9		
45	824.6		
35	1988.6		
34	2842.3		
37	2958.9		
46	3353.2		
4	4320.3		
12	4377.3		

SORT OF OBSERVATION

1	3	-3941.5	
2	23	-3896.0	
2	12	-3781.9	
1	8	-3668.0	
1	16	-3629.8	
2	7	-3494.4	
2	25	-3419.5	
2	11	-3338.5	
2	8	-3223.2	
2	21	-3075.2	
1	14	-2971.9	
1	10	-2886.7	
2	6	-2798.8	
1	13	-2782.7	
1	2	-2493.7	
2	17	-2475.7	
1	19	-2160.3	
4	26	-1990.4	
3	6	-1934.8	D
4	19	-1933.0	D
4	25	-1815.8	
1	22	-1762.0	
1	20	-1728.2	
1	9	-1722.1	
6	6	-1562.5	D
3	20	-1559.7	DT
4	9	-1556.5	D
5	17	-1539.6	
5	13	-1531.5	
1	7	-1514.6	D
3	7	-1511.2	D
6	10	-1473.2	
1	11	-1452.0	
1	18	-1387.7	D
2	2	-1383.6	D
1	4	-1166.6	
1	6	-1124.2	
6	23	-1096.9	
3	1	-1080.2	
3	2	-1047.5	
1	5	-1020.2	
2	13	-908.7	
4	7	-895.7	
6	8	-805.3	
6	11	-747.7	
4	16	-694.3	
3	18	-574.0	
4	23	-438.4	
2	9	-395.6	
4	8	-386.7	
4	2	-328.8	
3	3	-293.2	
2	16	-212.3	
5	8	-154.8	
1	17	-39.7	
6	5	-27.1	
6	25	11.9	
4	28	121.8	
3	17	128.8	D
3	12	132.2	DT
3	15	134.6	DTQ
1	1	139.0	DTQ
1	12	139.9	DTQ
1	21	140.4	DTQ
2	4	141.8	DTQ
2	14	141.8	DTQ
2	26	143.0	DTQ
2	15	143.5	DTQ
4	13	147.6	DTQ
6	19	147.9	DTQ
4	14	147.9	DTQ
4	4	148.1	DTQ
4	3	148.4	DTQ
4	12	148.7	DTQ
4	5	149.0	DTQ
2	10	149.9	DTQ
4	11	149.9	DTQ
4	17	150.1	DTQ
3	11	150.9	DTQ
4	10	152.0	DTQ
5	5	152.4	DTQ
5	2	152.9	DTQ
4	24	153.5	DTQ
5	7	154.2	DTQ
4	15	154.6	DTQ
6	13	156.3	DTQ
6	21	156.5	DTQ
6	22	156.9	DTQ
3	23	160.5	D
4	27	168.9	D
3	19	173.1	D
5	15	201.6	D
5	9	202.0	D
5	4	224.8	
5	1	337.2	
6	16	371.8	
4	29	392.8	
6	7	445.7	
5	19	500.4	
3	22	531.3	
6	9	595.3	
1	15	607.8	
6	17	617.1	
4	18	646.4	
3	13	691.3	
4	30	762.8	
2	1	955.4	
2	18	1014.9	
3	5	1090.0	
2	5	1182.8	
2	22	1375.2	
5	3	1446.7	
2	19	1611.1	
6	12	1653.7	
5	16	1683.3	
5	11	1890.3	
3	14	1904.1	
4	21	1925.7	
6	24	2080.2	
5	6	2160.6	
5	10	2281.8	
2	3	2310.4	
2	24	2502.1	
5	18	2519.8	
3	10	2773.9	D
4	20	2778.8	D
6	3	2856.6	
4	22	2896.0	
2	20	3123.4	
4	31	3291.9	
3	16	3332.0	
6	18	3642.2	
3	21	3683.3	
3	4	3837.7	
6	14	3871.8	
5	14	4074.6	
3	9	4150.3	
3	8	4208.5	
4	1	4252.5	
4	6	4310.6	
6	1	4546.7	
5	12	5057.4	
6	2	5078.0	
6	15	5207.5	
6	20	5298.5	
6	4	5323.3	