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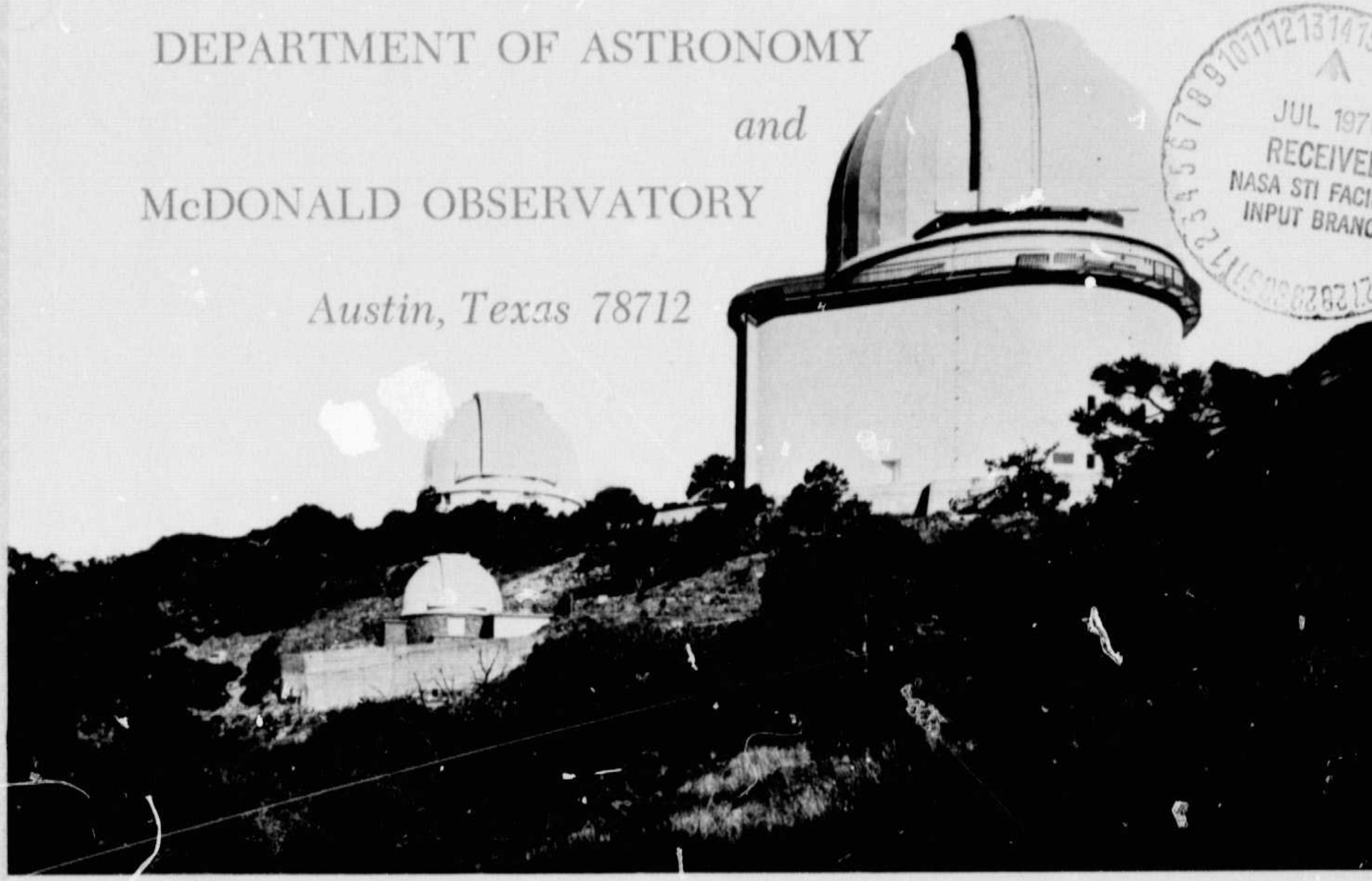
DEPARTMENT OF ASTRONOMY

and

McDONALD OBSERVATORY

Austin, Texas 78712



REPORT ON THE
LUNAR RANGING
at
McDONALD OBSERVATORY
FOR THE PERIOD
1 FEBRUARY 1976 to 31 MAY 1976*

by
C. S. PALM
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Research Memorandum #76-004

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* This work is supported by NASA Grant NGR 44-012-165.

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ABSTRACT

The four spring lunations produced 105 acquisitions, including the 2000th range measurement made at McDonald Observatory. Statistics were normal for the spring months. Laser and electronics problems are noted. The Loran-C station delay was corrected. Preliminary "doubles" data is sh[illegible]. New magnetic tape data formats are presented. R & D efforts include a new laser modification design.

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I. SUMMARY OF OPERATIONS

RANGING STATISTICS

Table I shows a summary of the McDonald Observatory lunar ranging statistics for four lunations occurring between 1 February 1976 and 31 May 1976. The average signal level of 0.037 photoelectrons per laser shot, the 77% success rate and the 105 successful ranges compare favorably with the same spring-month lunations of 1974 and 1975. The average number of monthly ranges was 26 during this triannual reporting period as compared to a 31-range monthly average over the past 13 months of operation. The dominant factor in limiting the number of ranging attempts was the weather. High winds, clouds and poor seeing conditions were prevalent. Only 125 range attempts were conducted under "clear" conditions for the spring lunations as compared with 205 attempts under "clear" conditions during the winter lunations.

Figure 1 shows an updated histogram of successful range measurements made at McDonald Observatory since September 1970. It should be noted that the April lunation produced the 2000th lunar range measurement made at McDonald since September 1970.

As usual, a more detailed description of the daily operation is given in the McDonald Lunar Laser Operations Log which is presented as Appendix A. The system calibration data is explained and presented in Appendix B.

OPERATIONS NOTES

Operations for this reporting period were relatively uneventful as far as failures were concerned. There were no major failures, but a number of minor systems problems arose on occasion.

TABLE I

RANGING STATISTICS

Lunar Site*	Attempts	Ranges	Shots Fired	Returns	Signal Level
0	21	15	4412	123	.028 p.e./shot
1	0	0	0	0	--------------
2	11	5	2521	39	.015 p.e./shot
3	87	74	15794	702	.044 p.e./shot
4	17	11	3431	91	.027 p.e./shot
total	136	105	26158	955	.037 p.e./shot

Success Rate = 77%

*Reflector Sites: 0 = Apollo 11
1 = Luna 17
2 = Apollo 14
3 = Apollo 15
4 = Luna 21

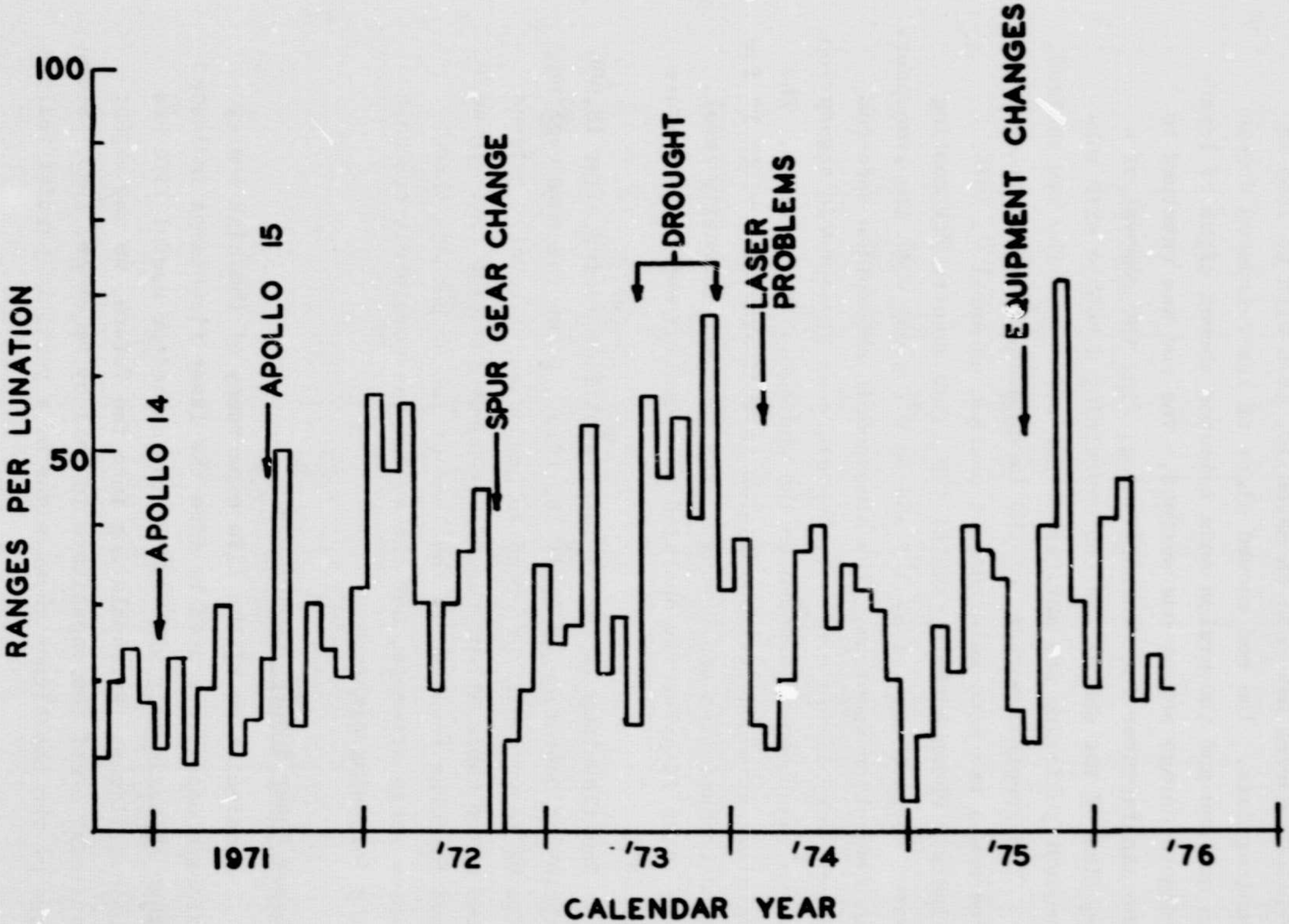

FIGURE 1: LUNAR RANGES AT McDONALD OBSERVATORY

Laser:

The laser oscillator rod and the laser mode selector were replaced during new moon on March 30, 1976, with no loss in ranging data. The rod showed signs of laser-induced damage on one end and the etalon mode selector showed signs of laser-induced damage across one surface. The rod was returned to the manufacturer for reconditioning, i.e. the removal of a portion of the end of the rod containing a bubble with subsequent polishing and antireflection coating of the new surface.

The spectral output of the laser using a new oscillator rod and a new mode selector was checked on April 7, 1976. Figure 2 shows a photograph of the laser spectra for cooling water temperatures of 54.5°F and 62.0°F along with the atmospheric absorption spectrum. The atmospheric absorption spectrum showed very little contrast, therefore an atmospheric absorption curve[1] has been superposed on the photograph for clarity. The relative atmospheric transmission is indicated as "~100% T" for good transmission and "~50% T" for the half intensity level. The laser is presently operated at a cooling water temperature of 56°F.

The flashlamp in the #3 laser amplifier failed after 18,000 cycles of operation on April 18, 1976. Later the same evening, the #2 laser amplifier arced to ground and literally severed the power cable at the underfloor power junction box. These two failures resulted in the loss of two or perhaps three laser range attempts, but the system was completely operable the following night.

Laser Power Supply, Capacitors:

A calculation of the life expectancy of the high energy storage capacitors used to fire the laser flashlamps indicated that approximately 55%- 60% of the capacitor useful life has been utilized. Extrapolating into the future, we may expect at least one of the capacitors to fail by December, 1980. Since one of the capacitors shows signs of a possible partial failure

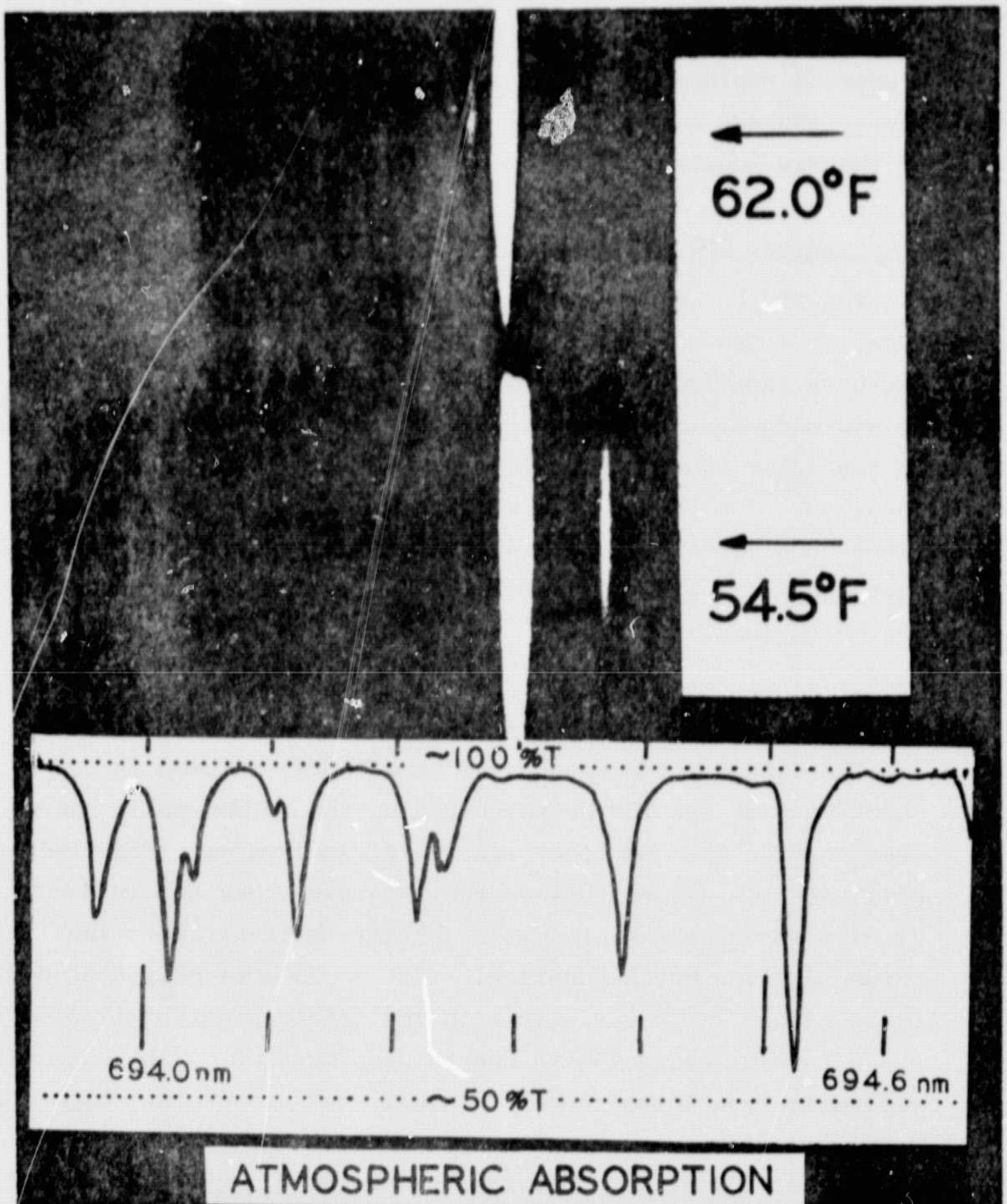

FIGURE 2: LASER SPECTRA

in the form of a slightly bulged casing, it was decided to procure a replacement as soon as possible. The spare high energy storage capacitor was received during the latter part of the May lunation.

Electronics, TDC 100:

The TDC 100 timer (see RM #75-009, June-Oct., 1975) showed signs of a few eighths of a nanosecond jitter during the February lunation. This would tend to show up as a spreading or widening of the laser pulse data and a corresponding spread in the lunar range residuals calculated during the February lunation. The TDC 100 was adjusted by J. Wiant to give ± 1/8 nanosecond jitter on the start and stop pulses. The timer has been operating at this jitter level since the first part of the March lunation.

Electronics, T140 Discriminator:

The T140 discriminator (see RM #75-009) is used in conjunction with the 100 Hz pulse train, the 20 MHz pulse sharpener and the TDC 100 timer in the timing system. The T140 unit had transistors fail on two separate occasions in March. It also showed signs of jitter and intermittent operation throughout the March lunation. Jitter in this component shows up as rather large variations in the feedback calibration data and a loss of ranging data due to displacement of the calculated residuals from actual lunar returns. Failure of the component results in a complete lack of calibration data and calculated residuals. J. Wiant repaired the unit on March 25, 1976 and no obvious problems with the T140's operation have been detected since that date.

Start Diode:

The start diode (see MR #75-009) is normally operated in a photoconductive mode with a 67.5 VDC reverse bias applied via a dry cell battery. Near the beginning of the April lunation one of the leads became disconnected, presumably causing the photodiode to operate in a photovoltaic mode. The lower signal level to the start diode discriminator was offset by operating the 453 discriminator at a lower minimum threshold level. The threshold was not lowered enough to incur premature triggering of the discriminator by Pockels cell spark gap noise and no significant effect on the operation of the system was noticed until late in the lunation when the flip mirror refused to operate with a three joule pulse being emitted by the laser. The "NO LASER" response on the teletype focused attention on the start diode circuit; the problem was identified and promptly cured.

Loran-C Station Delay:

William Klepczynski and Carl Lukac of the U.S. Naval Observatory checked the accuracy of the McDonald clock using a portable, cesium atomic clock after completion of the May lunation. It was found that the total propagation and instrument delay associated with the Loran-C receiver used at McDonald was in error by 28 microseconds. The total McDonald station delay used previously was 74698 microseconds; the corrected station delay as determined by comparison with the visiting atomic clock was 74670 microseconds. The change in the total station delay is presumably associated with the Loran-C receiver components. This was the first clock check performed since the Loran-C receiver was sent to the factory for repairs during the March-April, April-May lunations of 1975. A 28 microsecond offset error in the absolute time reference should cause a negligibly small error in the range measurements made at McDonald.

Comments:

A few range attempts were cancelled for TV autoguider tests and several more attempts were cancelled due to telescope scheduling conflicts with other projects, principally nova observations, occultations, and lengthy interferometer runs.

The McDonald laser ranging station,as a whole, seems to be operating as well as ever. This statement has some credibility despite the fact that the March, April and May lunations produced the fewest number of acquisitions of any three-month period in over a year. Even though the March lunation yielded only 17 successful range attempts, it was accomplished with "clear" sky conditions on only 14 of the range attempts. This is a better acquisition-to-clear-sky ratio than the record month of October, 1975. The February lunation produced one range with 12 returns in only 31 laser shots. That performance rivals the best ranging performances that have ever come out of the McDonald station.

To date, no statistics have been given on the effectiveness of the doubles counter (tag on a double photoelectron event) installed in September, 1975. The double photoelectron events have not been studied in any great detail, but Table II presents the total number of double photoelectron events per lunation since October, 1975. A few of the events were not correlated with the lunar residual and were presumably "noise doubles", however most of the events were within the lunar residual spread and may be considered "lunar range doubles". The most impressive "doubles" range came on February 8, 1976 when 12 returns came from 62 laser shots with three double photoelectron events coinciding with the lunar residual.

TABLE II

DOUBLE PHOTOELECTON EVENTS
PER LUNATION

Lunation	"Doubles" Events
October, 1975	24
November, 1975	15
December, 1975	19
January, 1976	25
February, 1976	38
March, 1976	9
April, 1976	15
May, 1976	18

II. DATA REDUCTION NOTES

RANGING DATA FORMAT CHANGE

Starting with magnetic tape reference MCD 89, 4 March 1976, the ranging data laser shot format changes from a 14 word per shot to a 20 word per shot description. The additional words allow the data reducer to obtain parameters from the magnetic data tape that were previously given to him on computer cards. The old ranging data format may be found in a previous report, RM-#75-009. The new format is shown in Table III.

LORAN-C DATA RECORD

Starting with magnetic tape reference MCD 89, 4 March 1976, the Loran-C versus the crystal clock readings are lifted one at a time from the housekeeping records, grouped together and written as a separate large record. Henceforth, clock epoch and frequency information are available to the data reducer directly from the magnetic data tape. The Loran-C data format is shown in Table IV.

MAGNETIC TAPE RECORD TYPES

As a matter of convenience for the reader, a summary of the magnetic tape record types used throughout the ranging program from 25 August 1971 to the present date is presented in Table V.

TABLE III

RANGING DATA LASER SHOT FORMAT

Legend: 0 = Always 0

1 = Always 1

X = 0 or 1

N = Shot Number

Word No.	Bit Description	Symbol	Word	Form
20(N-1)+1	0000 00XX XXXX XXXX	Day1	Day,UTC	BCD
2	00XX XXXX 0XXX XXXX	HM1	Hour, Minute, UTC	BCD
3	0000 0000 0XXX XXXX	SEC1	Second	BCD
4	XXXX XXXX XXXX XXXX	RA2	Middle Adj. Range	BCD
5	XXXX XXXX XXXX XXXX	RA3	Least Adj. Range	BCD
6	XXXX XXXX XXXX XXXX	CRT3	Calc. Range .1 Nano	BCD
7	0XXXXXXXXXXXXXXX	RES2	Range Resid .1 Nano	BIN
8	0XXXXXXXXXXXXXXX	R111	K	BIN
9	0XXXXXXXXXXXXXXX	R110	Eighth Nano	BIN
10	0XXXXXXXXXXXXXXX	R121	Laser to 10MS	BIN
11	0XXXXXXXXXXXXXXX	R120	Eighth Nano	BIN
12	0XXX XXXX XXXX XXXX	SEC2	10 MS Time	BCD
13	XXXXXXXXXXXXXXXX	R211	K Prime, Tag 3	BIN
14	0XXXXXXXXXXXXXXX	R210	Eighth Nano	BIN
15	0XXXXXXXXXXXXXXX	R221	PMT to 10 MS	BIN
16	0XXXXXXXXXXXXXXX	R220	Eighth Nano	BIN
17	0XXX XXXX XXXX XXXX	SEC3	10 MS Time	BCD
18	0XXXXXXXXXXXXXXX	R231	PMT to Second 10 MS	BIN
19	0XXXXXXXXXXXXXXX	R230	Eighth Nano	BIN
20	0000 0000 0000 0000		Spare	

TDC Format: The least SIG bit of the most SIG word equals 2^{15}.

SEC2, SEC3 contain 10SEC, SEC, 100MS, 10MS BCD.

This format starts with magnetic tape #MCD 89, Day 64, 4 March 1976.

TABLE IV

LORAN-C DATA FORMAT

Legend: 0 = Always 0
1 = Always 1
X = 0 or 1

Word No.	Bit Description	Symbol	Word	Form
1	1111 1111 1111 1111	-1	-1, Flag	BIN
2	0XXX XXXX XXXX XXXX		Remaining # Words	BIN
3	0000 0000 0000 0011	3	Record Type 3	BIN
4	0000 0001 XXXX XXXX	0176	McDonald site/year	BCD
5	0000 00XX XXXX XXXX	Day	Day,UTC	BCD
6	00XX XXXX 0XX0 0000	HM	Hour, Minute, UTC	BCD
7	0000000000000010	MLD1	McD Loran Delay MSW	BIN
8	0XXXXXXXXXXXXXXX	MLD0	McD Loran Delay LSW	BIN
9	0000000000000000		Spare	
10	0000000000000000		Spare	
11	0000 00XX XXXX XXXX	Day	Day, UTC	BCD
12	00XX XXXX 0XX0 0000	HM	Hour, Minute, UTC	BCD
13	000000XXXXXXXXXX	LC1	Loran Compare MSW	BIN
14	000000XXXXXXXXXX	LC2	Loran compare LSW	BIN
15	0000000000000000		Spare	
16		Day		
17		HM		
18		LC1		
19		LC2		
20			Spare	
		etc.		

Maximum record length, 1010 words
Mimimum record length, 15 words

TABLE V

RECORD TYPES

Record #	Effective Period	Record Type, Comments
0	25 Aug 71 - 29 Jun 75 MCD 34 - MCD 80	Ranging Data, Verniers
1	25 Aug 71 - 29 Jun 75 MCD 34 - MCD 80	Calibration Data, Verniers
2	17 Jul 75 - 25 Feb 76 MCD 81 - MCD 88	Ranging Data, TDC-100 AKPP in place of DR1 (1)
3	4 Mar 76 - MCD 89 -	Loran-C Data
4	25 Aug 71 - MCD 34 -	Housekeeping Data
	25 Aug 71 - 29 Jun 75 MCD 34 - MCD 80	Channels 3-7 Information
	4 Mar 76 - MCD 89 -	Loran Delay to McDonald at Mt Locke
5	25 Aug 71 - MCD 34 -	Operations Log
6	25 Aug 71 - MCD 34 -	Comments
7	25 Aug 71 - MCD 34 -	Hand Typed Ranging Data
8	4 Mar 76 - MCD 89 -	Ranging Data, TDC-100, 20w/shot

(1) See MCD 81 Addendum for peculiarities on MCD 81.

LASER PULSE WIDTH

The laser pulse feedback calibration gives the single shot uncertainty associated with the laser pulse. The measure of the single shot uncertainty is obtained by plotting the K calibration data (the relative delay between the photodiode start of the TDC 100 and the photomultiplier stop of the TDC 100) for a given night and then estimating the spread of the K calibration data. The pulse width is then reflected in the calibration data presented in column B of Appendix B.

Over the past year or so, there has been a gradual increase in the apparent width of the laser pulse. In June, 1975 the typical pulse width was $\pm$ 1.7 to $\pm$ 2.4 nanoseconds; in May, 1976 the pulse width was typically $\pm$ 2.9 to $\pm$ 4.2 nanoseconds. There are three basic reasons for an apparent increase in the laser pulse width as published in these triannual reports: an actual increase in the laser pulse duration, jitter in the electronic components measuring the laser pulse width, and an error in the estimation of the pulse width from the calibration data. Brief comments on each of these three areas are in order.

An actual increase in the laser pulse duration is readily checked by photographing the pulse shape as it appears on the Tektronix 519 oscilloscope after being detected by the Korad laser pulse monitoring photodiode. A large number of photographs gives a good indication of the stability and shape of the average pulse over the course of one night of ranging. This has been done on occasion to stay abreast of the laser performance on a real time basis. The February and March lunations showed signs of multi-mode lasing when observed via the photographs. The actual pulse length was greater than 5 nanoseconds full width at the half maximum points (FWHM) with nanosecond sub-structure discernable in the pulse shape. For the most part, this problem was cured after the new oscillator rod and mode selector were installed. The laser pulse shape during the April and May lunations was relatively free of multi-mode structure and showed a reasonably constant pulse width of 3.0 to 4.5 nanoseconds FWHM.

The estimation of the laser pulse width from the calibration data is presently performed manually rather than being a computer-calculated value. Even though the method of estimating the pulse width has been consistent throughout the past year, it is felt that the pulse width calculation should be entirely a computer-calculated value. This change will be initiated as soon as time allows.

Jitter in the electronic components of the McDonald timing system has been reported in numerous, previous reports. At the present time, we feel that we may have a jitter problem but further investigation is require before a definitive statement can be made on the subject. The primary evidence pointing toward a jitter problem is the fact that certain range residuals show a statistical dispersion of ± 2 nanoseconds which is consistent with the photographed laser pulse shape, while the calibration data corresponding to those range residuals show a statistical dispersion of ± 3.5 nanoseconds which is consistent with the overall calibration data estimates of the laser pulse shape. A case which illustrates this type of behavior is range data from May 22, the 11:00 range on reflector number 3. Further comments on the electronic jitter problem will be made in the next triannual report.

SUSPECTED BIAS ERROR

The calculation of the system calibration constant requires a knowledge of "K prime", the difference between the start and stop paths which is internal to the timing electronics. This constant was measured to be 15.375 nanoseconds in October 1975. Since we did not anticipate any secular changes in this area, the constant was not monitored regularly. When checked in March 1976, it was found to have drifted to 16.8 nanoseconds due to a misalignment of the TDC 100. For the March, 1976 lunation and later the data can be corrected for the drift in K' because the data format change (page 10) allows daily monitoring of this parameter. Unfortunately, the data between October and March may be biased by unrecoverable drifts in the K' constant. We would guess that the range measurements may be as much as 1.4 nanoseconds too low in February 1976 with progressively smaller errors as far back as the November lunation in 1975.

III. R & D EFFORTS

TELESCOPE FLEXURE MODEL

The effort to improve the telescope pointing via a spherical harmonics flexure model has moved forward nicely from a computer programming point of view, but has suffered from an application pont of view due to unpredictable movements of the primary mirror in the 2.7-meter telescope at McDonald Observatory. A set of 201 observed positions in the ranges -3^h to $+4.5^h$ (hour angle) and -30^o to $+70^o$ declination have resulted in absolute position errors of 11.55 arc seconds for one standard deviation. The telescope pointing problems surfaced in May, 1976 when primary mirror movement was found to be responsible for pointing errors as great as 60 arc seconds in a 700 - 900 arc second drive. The 2.7-meter primary has since been secured with a considerable improvement in the absolute pointing accuracy. The flexure observations will likely be continued after the primary mirror of the 2.7 meter telescope is aluminized in late July, 1976.

LASER UPGRADE: PULSE SHAPING

Components have been ordered to modify the laser oscillator cavity and perform pre-amplifier shaping on the Pulse Transmission Mode (PTM) pulse. Details of the laser modification will be given in a later report after the new system has been successfully installed and is fully operational. Only a cursory description of the modification is given here.

The laser oscillator cavity will be lengthened enough to accomodate an additional Pockels cell and a small beam splitter. The oscillator cavity will still be "formed" by applying a voltage pulse to one of the Pockels cells. A fraction of the oscillator cavity energy will be diverted by a beam splitter to a laser triggered spark gap (LTSG) .

The LTSG will be adjusted to switch a high voltage to the second Pockels cell when the oscillator energy build-up reaches a predetermined level. The second Pockels cell will dump the energy in the cavity in a conventional PTM manner and then clip the trailing edge of the pulse after being turned off by a reflected voltage pulse. External to the oscillator cavity , a dye cell with a saturable absorber will sharpen the leading edge of the emitted laser pulse before it enters the laser amplifiers. The operational gain expected from this modification is two-fold. The pulse clipping and dye cell leading edge shaping should reduce the pulse width to 1-1.5 nanoseconds with a 300 - 500 picosecond risetime on the leading edge. The laser triggered spark gap should act as an internal power regulator to stabilize the laser output to a constant energy output. Thus, it is expected that the modification will produce a shorter, more stable laser pulse.

Preliminary tests with a static dye cell located between the laser oscillator cavity and the first amplifier have indicated that cryptocyanine in methanol will indeed shape the leading edge of the laser pulse. The present PTM pulse showed a 40% increase in the leading dege slope (Δpower/Δtime), a 22% improvement in the leading edge risetime, and a 20% decrease in the pulse width when the dye was near an optimum concentration.

AIRCRAFT SPOTTER

The automatic aircraft spotter system appears to be too expensive to have manufactured by an outside concern. Most of the cost estimates have been in the $15,000 - $18,000 range with at least one system priced at $40,000. Preliminary calculations for an "in house" aricraft spotter design show that an aircraft spotter- laser interrupt system could detect an aircraft at 30 miles distance from the observatory during night time operation. Calculations on the daylight performance have not been completed yet. The cost estimate on the "in house" aircraft spotter is approximately $1500.

TV AUTOGUIDER

The Reticon autoguider uses two different computers in guiding the telescope. The Varian computer in the laser room reads the angle of the bright limb imaged on the 32 x 32 diode array in the Reticon camera. After the Varian determines the limb angle and hence the location on the limb, the information is fed into the IBM 1800 computer where lunar libration corrections are made. The corrected lunar limb position is then used as a reference for computer driving to any other site on the lunar surface.

At the present time, the autoguider system lacks the computer link which allows the Varian to communicate with the 1800. Therefore, a test of the entire system has not been completed. However, Varian limb angle determination repeatability and 1800 limb-to-crater and crater-to-limb drive accuracy have been tested with encouraging results. Without being finely tuned, the Varian has demonstrated the capability of making lunar limb angle determinations with a repeatability of $\pm 0.2^{\circ}$. When the Varian determinations were manually fed into the 1800 computer, moderate telescope drives of several hundred arc seconds were accurate and repeatable to within 1-2 arcseconds. The Varian limb measurements were improved by the addition of a transfer lens between the laser room focal plane and the Reticon photodiode array. The Reticon now sees five arc seconds per diode instead of the previous 1.85 arc seconds per diode. The increased field of view apparently helps to smooth over the local variations in the limb appearance produced by lunar mountain ranges near the limb.

An actual lunar reflector acquisition was not acheived during the "manual data transfer" tests because of poor weather conditions and the long-drive pointing inaccuracies associated with the 2.7 meter primary mirror movement problems.

APPENDIX A

The McDonald Lunar Laser Operations Log

from

1 February 1976 to 31 May 1976

STATION LOG FEB. 1976

DATE	DAY	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb.		19:30			Cloudy		cancelled clds.
4	035	22:30			"		
		01:30			"		
Feb.		20:30			Cloudy		cancelled clds.
Feb. 5	036	23:30			"		
	037	01:30			"		
Feb.	037	21:00			clear	8-10	cancelled seeing contrast
Feb. 6		23:00	233/0	10/0	"	4-5	
			143/4	10/4	clear	"	
	038	02:00	226/4	9/4	"	5-6	
Feb.	038	21:15	287/4	8/4	clear	5	bad-seeing, contrast
Feb. 7	039	00:15	95/4	12/4	clear	3	
			97/3	9/3	"		
			182/0	11/0	"		
	039	03:15	283/4	0/4	clear	4-5	
Feb. 8	039	22:10	94/3	10/3	light cir-		
					urs	3-4	bad contrast
	040	00:30	62/3	12/3	lgt. cirrus	3	
			113/0	10/0	"	"	
			37/2	0/2	"	"	no computer drive N-S
	040	03:40	99/3	0/3	med. cir-	4	
					rus		stopped by clouds
Feb. 9	040	23:00	162/3	8/3	ptly. cldy	4	
	041	02:00			cloudy		cancelled seeing
	041	04:30			"		" "
Feb.	042	00:00			"		cancelled
Feb. 10		03:15	73/3	10/3	clear	3-4	
			145/0	5/0	"	4	
		06:00			cloudy	6-8	cancelled clds. seeing
Feb. 11	043	00:30	342/3	12/3	clear	3	supervisor guiding
	043	03:00	134/3	10/3	"	3-4	" "
Feb. 12			181/0	6/0	clear	3	
	043	06:30	101/3	10/3	"		
			240/2	0/2	"		

STATION LOG FEB. 1976

DATE	DAY	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb. 12	044	01:30			cloudy		cancelled
	044	04:40	31/3	12/3	light cir-		
					rus	2	
			136/0	10/0	"	"	
			191/2	10/2	"	"	
		07:30	85/3	9/3	clear	3	
Feb. 13	045	02:30			clds.		cancelled
		05:30			"		"
		08:30			ptly cldy		
						6-8	cancelled seeing
Feb. 14	046	03:30	46/3	9/3	clear	3	
			335/0	5/0	clear	"	
Feb. 15	046	06:00	54/3	12/3	clear	"	
			263/2	9/2	"	"	
Feb. 15		09:00	156/3	10/3	"	"	
Feb. 15	047	04:30	136/3	10/3	clear	4	
Feb. 16		07:30	247/3	9/3	"	5-7	wind 20-30 mph
Feb. 16		10:30					
Feb. 16	048	05:30			cldy		cancelled
Feb. 17		08:30	204/3	9/3	clear	4-6	stopped by seeing
Feb. 17		11:00	238/3	6/3	"	5-7	stopped by wind 40mph (W)
Feb. 18	049	06:30	143/3	15/3	clear	3-4	wind 20mph
		09:30	115/3	10/3	"	3-4	
			287/0	10/0	"	"	
			183/2	0/2	"	"	
		12:30	285/3	7/3	"	5-7	image motion
Feb. 19	050	07:30	139/3	10/3	clear	3	" "
			142/0	11/0	"	"	" "
	050	10:30	217/3	11/3	"	4	" "
			334/2	0/2	"	"	" "
Feb. 19	050	13:30	121/3	11/3	clear	3-4	
Feb. 20	051	08:00	67/3	10/3	clear	4	image motion
	051	11:00	71/3	12/3	"	5-7	" "
			207/0	8/0			
			143/4	6/4			

STATION LOG FEB. 1976

DATE	DAY	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb. 20	051	13:30			clear & windy		cancelled high winds
Feb. 21	052	09:00			clear	6-7	cancelled bad seeing
		12:00			"	8	" " "
		15:00			"	"	" " "
Feb. 22	053	10:00	240/3	6/3	"	5-6	
		12:50	146/3	8/3	"	5	
		15:30			"	5-6	poor contrast, bad-seeing cancelled
Feb. 23	054	11:00	94/3	10/3	"	4-5	
			190/4	0/4	"	"	
		14:30	319/3	7/3	clear	4-5	poor contrast
		16:30			"	5-7	cancelled seeing contrast
Feb. 24	055	12:00			cldy		cancelled, cloudy
		14:00			"		" "
		16:00			"		" "
Feb. 25	056	12:00			"		" "
		14:00			"		" "
		16:00			"		" "

ATTEMPTS	SUCCESSFUL MEASUREMENTS
10/0	10/0
0/1	0/1
6/2	2/2
30/3	29/3
7/4	5/4

STATION LOG MARCH 1976

DATE	DAY (GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Mar. 4	064	19:00			clear	7-9	cancelled seeing contrast
	064	22:00			"	"	"
Mar. 5	065	20:00			cloudy		cancelled
	065	23:00			"		"
	066	02:00			"		"
Mar. 6	066	20:30			cloudy		cancelled
	066	23:30			"		"
	067	[illegible]:30			clear	6-8	"
Mar. 7	067	21:00			ptly.cldy.	6-7	poor contrast
	068	00:00			" "	"	" "
	068	02:00	271/4	0/4	hazy	5	
Mar. 8	068	22:00			cloudy		cancelled
	069	00:00			cloudy		cancelled
	069	04:00	240/3	0/3	hazy	4	
Mar. 9	069	23:00			clear	6-8	cancelled seeing
	070	02:00	90/3	11/3	"	3	
			270/0	0/0			
	070	05:00			cloudy		cancelled
Mar.10	070	23:30			cloudy		cancelled
	071	02:30			"		"
	071	05:30			"		"
Mar.11	072	00:30			wind		cancelled wind 45-55 mph
		03:30	65/3	11/3	clear	3-5	wind 25 mph
			237/0	0/0	"	"	
Mar.12		06:30	288/3	6/3	cirrus	4-6	

STATION LOG MARCH 1976

DATE	DAY(GMT)	TIME	NO.OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Mar.12	073	01:30			clouds		cancelled
		04:30			"		"
Mar.13	073	07:30			"		"
Mar.13	074	02:00			heavy cirrus	4-5	cancelled
		05:00			" "		"
		08:00			" "		"
Mar.14	075	02:30	224/3	4/3	cirrus	3-4	
		05:30	212/3	10/3	"	"	stopped by cirrus
		08:30	235/3	11/3	"	"	
Mar.15	076	04:00			hazy	5-8	cancelled seeing
		07:00			"	7-9	" "
		10:00			"	8=10	" "
Mar.16	077	05:00	144/3	10/3	light haze	3-4	
		07:15			cloudy		cancelled
		10:15			"		"
Mar.18	078	06:30	120/3	11/3	light haze	2-3	
		09:30	178/3	9/3	" "	3	
			151/0	8/0	" "	3	
		12:30	236/2	0/2	cloudy	3	cancelled
Mar.19	079	07:00	196/3	11/3	light haze	2-3	tried new beam
		10:00	139/3	9/3	clear	3	splitters
			95/0	9/0	"		
			240/2	4/2	"		
		13:00	97/3	0/3	heavy cirrus	3	
Mar.20	080	08:30			clear,windy		very windy,cancel.
		12:30			cloudy,windy		" " "

STATION LOG MARCH 1976

DATE	DAY(GMT)	TIME	NO.OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Mar.21	081	09:00			clear	8-10	cancel.,bad seeing
		13:00			cloudy		" ,cloudy
Mar.22	082	09:30			cloudy		cancelled
		13:00	236/3	6/3	light cirrus	3-4	
			190/4	3/4	" "	"	
		15:00			cloudy		cancelled
Mar.23	083	11:30			cirrus	5-7	cancelled
		14:30			clds.		"
Mar.24	084	13:00	326/3	9/3	clear	4	First 230 shots with 60° water temp. 2 returns lowered H_2O to 53° got 7 returns in 100 shots
	084	15:45	326/3	0/3	clear	4	poor contrast
Mar.25	085	13:00					cancel.,electronic problems
		16:00					" " "
		18:00					" " "
Mar.26	086	13:30			windy		cancel.,wind 60mph
		16:30			"		" "
		19:00			"		" "
Mar.27	087	14:00			cloudy		cancelled
		16:00			"		"
		18:00			"		"
				Attempts	Success		
				4/0	2/0		
				0/1	0/1		
				2/2	1/2		
				16/3	13/3		
				2/4	1/4		

STATION LOG APRIL 1976

DATE	DAY (GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
April 1	92	22:50					Start tape MCD 90
April 2	93	18:00			cloudy		cancelled
		21:00			"		"
	94	00:00			"		"
April 3	94	18:45			cloudy		cancelled
		21:45			"		
	95	00:45			"		
April 4	95	19:30			Cloudy		cancelled
		22:30			Rain		"
	96	01:30			"		"
April 5	96	20:30			Cloudy		Cancelled
		23:30			"		"
	97	02:30			"		"
April 6	97	21:30			cloudy		cancelled
	98	00:30			cloudy		"
		03:30			ptly cldy	4	detector pkg alignment problem
April 7	98	22:30			clear	4-5	cancelled occulta-tion
	99	01:30			clear	2	" "
		04:30	234/3	2?/3	cirrus	4-5	
April 8	99	23:30			cloudy		cancelled
	100	02:30			"		"
		05:30			"		"

STATION LOG APRIL 1976

DATE	DAY(GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
April 9	101	00:00			cloudy		cancelled
		03:00			"		"
April 10		06:00			"		"
	102	01:00	126/3	11/3	clear	3	Hooray
		04:00	288/0	?6/0	ptly cldy	4	
April 11		07:00			cldy		cancelled
	103	01:30			cldy		"
		04:30			"		"
April 12		07:30			"		"
	104	02:30	200/3	9/3	Hazy	3-5	
		05:30	326/3	7/3	slight hz	4-7	
April 13		08:30	242/3	9/3	clear	4-5	
			226/0	0/0	"	"	
	105	03:30			cloudy		cancelled
April 14		06:30	192/3	9/3	clear	2-3	
			274/2	0/2			
		09:30	278/3	7/3	clear	4	
	106	04:30			cloudy		
April 15		07:30			Hazy	4-5	cancelled
		10:30			"	5-6	"
	107	05:30			clear	8-10	cancelled
April 16		08:30			clear	8-10	cancelled
		11:30			"	5-7	"
April 17	108	06:30			Hazy	15-20	cancelled seeing
		09:30			"	10-15	" "
		12:00			"	15-20	" "

STATION LOG APRIL 1976

DATE	DAY(GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
April 18	109	07:30			cirrus	7-10	cancelled seeing
		10:30	42/3	2?/3	clear	3-4	blew #3amp flash lamp
		13:00	92/3	10/3	clear	3-4	broke wire
			27/0	0/0	"		connector #2 amp head
April 19	110	08:30	211/3	11/3	cirrus	4-5	
		11:30	86/3	9/3	clear	4-5	
			285/0	7/0	"	"	
		14:30	109/3	9/3	"	"	
April 20	111	09:30	112/3	10/3	clear	4-5	
		12:00	131/3	9/3	"	"	
			189/4	6/4	"	"	
		15:00	154/3	10/3	"	"	
April 21	112	10:00	115/3	10/3	clear	4	
		13:00	185/3	7/3	"	"	
			295/4	0/4	"	"	
		15:00	218/3	10/3	"	"	Pockels voltage: 82-8.5KV
			79/4	0/4	"	"	
April 22	113	11:00	89/3	11/3	"	3	
			239/2	9/2	"	"	
			203/4	0/4	"	"	
		13:00	287/3	9/3	"	"	
		15:00			"	"	cancelled, interferometer run
April 23	114	12:00			cloudy		cancelled
		14:00			"		"
		15:30			"		"

STATION LOG APRIL 1976

DATE	DAY (GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
April 24	115	12:30	274/3	4/3	clear	3-4	
		14:30	309/3	2?/3	clear, hzy	4	poor contrast electronics
		16:30			clear, hzy		cancelled, poor contrast
April 25	116	13:00			clear	5-6	cancelled seeing-contrast
		15:30			"	"	
		17:30					cancelled JPL INT.
April 26	117	14:53					Stop MCD 90

Attempts	Successful measurements
4/0	2/0
2/2	1/2
22/3	19/3
4/4	1/4

STATION LOG MAY 1976

DATE	DAY(GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
May 2	123	18:08	start	tape	MCD 91		
	123	18:30			clear	4-6	cancelled seeing contrast
		21:30					" "
		23:00					" "
May 3	124	20:00			clouds		cancelled clouds
		23:00					" "
	125	02:00					" "
May 4	125	20:30			clouds		cancelled
		23:30			clouds		"
	126	02:30			clouds		"
May 5	126	21:00			clouds		cancelled
		23:30	211/4	10/4	ptly cldy	4-5	
			451/3	8/3	ptly cldy	4-5	
	127	03:00	241/4	10/4	clear	4	image motion
			227/3	0/3	clear	4	" "
May 6	127	22:00	271/3	6/3	ptly cldy	5-6	poor contrast
			312/4	6/4	ptly cldy	5-6	poor contrast
	128	01:00	187/3	8/3	cirrus lt.	4	
			73/4	11/4	cirrus lt.	4	
	128	03:30	263/0	0/0	clouds		cancelled clds.
May 7	128	22:30			cloudy		increased delay cable by about 1 nano sec.
	129	01:30			cloudy		cancelled clds.
	129	04:00			cloudy		cancelled f=0.2
May 8	129	23:30			cloudy		cancelled
	130	02:30			cloudy		cancelled
	130	05:30			cloudy		cancelled

STATION LOG MAY 1976

DATE	DAY(GMT)	TIME	NO.OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
May 9	131	00:20	204/3	0/3	ptly cldy	5	
		03:30	203/3	13/3	clear	3	
		06:30	282/3	0/3	clear	4	
May 10	132	01:30	78/3	10/3	clear	3	
		04:30	97/3	10/3	cirrus	3	
			317/0	7/0	cirrus	3	
		07:30	280/3	9/3	lt.to heavy cirrus	3	
May 11	133	02:00			cloudy		cancelled
		05:00			cloudy		cancelled
		08:00			cloudy		cancelled
May 12	134	03:00			cloudy		cancelled
		06:00			cloudy		cancelled
		09:00			cloudy		cancelled
May 13	135	04:00			clear	3-6	bad seeing,grass fire to south
		07:00	290/3	0/3	clear	3-4	
		10:00			clear		cancelled nova
May 14	136	05:00			clear.	4	cancelled for auto guider tests
		07:45	241/3	8/3	clear	3	
		11:00			clear		cancelled nova
May 16	137	07:00	190/3	10/3	clear	4	
			292/0	0/0			cancelled
		11:30			cldy		cancelled
							1 run canc. inter.
May 17	138	07:30			cldy		cancelled
		11:30			cldy		cancelled
							1 run canc. inter.

STATION LOG MAY 1976

DATE	DAY (GMT)	TIME	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
May 18	139	08:00			cldy		cancelled clds. fog
		12:00			cldy		cancelled clds. fog
		14:30			cldy		cancelled clds. fog
May 19	140	09:00			cldy		cancelled
		12:00			cldy		cancelled
		15:00			cldy		cancelled
May 20	141	10:00			cldy		cancelled
		12:30			cldy		cancelled
		15:00			cldy		cancelled
May 21	142	10:30			cldy		cancelled
		13:30			cldy		cancelled
		16:30			ptly cldy	4-5	poor contrast
May 22	143	11:00	189/3	9/3	clear	2-3	
			284/2	7/2			
		13:00	141/3	13/3	clear	3	
		15:00	170/3	10/3	clear	3	
May 23	144	11:30			clear	3	cancel. for reticon occultation test
			242/3	7/3	clear	3	
		15:15	232/3	8/3	clear	3-4	poor contrast
May 24	145	12:00					cancel.for occultat.
		14:30	373/3	0/3	ptly.cldy	4-5	
		17:30					cancel.seeing contr.
May 25	146	13:00			cldy		cancelled
		15:00			cldy		cancelled
		17:00			cldy		cancelled
May 26	147	13:30			clear		cancel.poor contrast
		15:30			clear		cancel.poor contrast
		17:30			clear		cancel.poor contrast

STATION LOG MAY 1976

DATE	DAY (GMT)	TIME	NO.OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
May 28	149	14:57					McD ended

Attempts	Successful measurements
3/0	1/0
1/2	1/2
19/3	13/3
4/4	4/4

APPENDIX B

The Lunar Laser Calibration Data

from

1 February 1976 to 31 May 1976

APPENDIX B

SYSTEM CALIBRATION DATA

The following pages contain the calibration constants for the triannual period covered by the present report. The categories A-D are explained below.

A. This column contains the uncorrected calibration constant for the entire lunar laser ranging system as measured by the light emitting diode. Due to differing cable lenths for the calibration system, this number is not exactly the magnitude of the actual system calibration value. It is , however, an accurate measure of the relative shift in the calibration value on a day-to-day basis.

B. This column shows the single shot uncertainty as keyed to the following code: (all values are in nanoseconds) A = ±0.4, B = ±0.5, C = ±0.6, D = ±0.7, E = ± 0.8, F = ±1.0, G = ±1.2, H = ±1.4, I = ±1.7, J = ±2.0, K = ± 2.4, L = ±2.9, M = ±3.5, N = ±4.2. The absence of a letter will indicate the single shot uncertainty of J.

C. This column gives the arithmetic mean of the feedback calibration return through the entire lunar ranging system as recorded by the system teletype during the actual ranging.

D. This column shows the value of ELCOR which has been determined by subtracting K' and adding 13.9 nanoseconds to the average in Column C. The units have been changed to tenths of nanoseconds and a minus sign added to coincide with how this additive constant appears on the preliminary data cards. Letters A, B, C, D follow the corrected calibration, where: (all values are in picoseconds) A = ± 200, B = ± 400, C = ± 600, D = ± 1000, and E = ± 1000 - 1500.

CALIB. FEB. 1976

31000f V=2900 Disc.=5.0 Int.=5 G=2.0 F=0.4	A	B	C	D
36	69.9	-	-	-
37	65.6	-	-	-
38	67.0	N	82.2A	-807A
39	66.4	M	81.4A	-799A
40	66.0	M	81.6B	-801B
41	66.8	M	82.0C	-805C
42	66.3	L	82.4C	-809C
43	-	M	81.7A	-802A
44	67.6	M	81.6A	-801A
45	67.0	-	-	-
46	66.7	M	82.2A	-807A
47	66.8	M	81.6B	-801B
48	66.4	L	81.7B	-802B
49	65.6	L	81.1A	-796A
50	66.3	M	82.1A	806A
51	67.5	M	81.7B	-802B
52	67.7	-	-	-
53	66.9	N	82.5B	-806C
54	66.5	N	81.7A	-802A

(assumes K' = 15.4 nsec)

CALIB. MARCH 1976

31000F V=2900 Disc=5.0 Int.=5 G=2.0 f=0.4	A	B	C	D
068	567.6	M	83.0A	-815A
069	567.1	L	83.6B	-821B
070	566.7	L	83.0A	-815A
071	566.8	-	-	-
072	567.4	L	82.8A	-813A
073	566.0	-	-	-
074	567.5	-	-	-
075	567.3	M	83.0A	-815A
076	566.7	-	-	-
077	566.9	M	83.8B	-823A
078	567.2	N	82.1A	-806A
079	566.2	L	81.5A	-800A
080	-	-	-	-
081	567.2	-	-	-
082	566.3	M	83.6A	-821A
083	567.1	-	-	-
084	567.2	K	82.2A	-807A

(assumes K' = 15.4 nsec)

CALIB. APRIL 1976

31000f V=2900 Disc.=5.0 Int.=5 G=2.0 f=0.4	A	B	C	D
96	66.9	-	-	-
97	67.1	-	-	-
98	67.6	-	-	-
99	65.7	N	80.9B	-794B
100	67.0	-	-	-
101	67.1	-	-	-
102	68.5	M	82.3B	-808B
103	67.4	-	-	-
104	66.9	M	82.1A	-804A
105	67.0	M	82.3A	-808A
106	-	-	-	-
107	66.9	-	-	-
108	67.1	-	-	-
109	67.4	M	82.0B	-805B
110	67.0	M	82.8A	-813A
111	66.3	L	82.4A	-809A
112	-	L	82.5A	-810A
113	63.7	M	82.9A	-814A
114	-	-	-	-
115	67.4	N	82.5A	-810A
116	67.2	-	-	-

(assumes K' = 15.4 nsec)

CALIB. MAY 1976

31000f V=2900 Disc.=5.0 Int.=5 G=2.0 f=0.4	A	B	C	D
124	66.8	-	-	-
125	66.1	-	-	-
126	65.9	-	-	-
127	66.3	M	85.3A	-838A
128	66.4	M	85.4A	-839A
f changed from 0.4 to 0.2 also increasdd delay cable by 1 nsec.				
129	67.8	-	-	-
130	67.2	-	-	-
131	67.6	M	84.5A	-830A
132	67.4	L	84.5A	-830A
133	67.6	-	-	-
134	67.0	-	-	-
135	66.6	K	84.6B	-831B
136	66.7	M	84.9B	-834B
137	67.0	N	86.2A	-847A
138	66.7	-	-	-
139	67.4	-	-	-
140	66.8	-	-	-
141	68.1	-	-	-
142	66.8	-	-	-
143	66.1	M	85.4A	-839A
144	67.0	K	85.7A	-842A
145	66.6	K	82.8B	-803B

(assumes K' = 15.4 nsec)

REFERENCES

1. Photometric Atlas of the Solar Spectrum, Sterrewacht „Sonnenborgh" Utrecht, reference 20.6, 114a.