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Reports of the Department of Geodetic Science

Report No. 105

AN EVALUATION OF THE STELLAR-MOON CAMERA SYSTEM (U)

Final Technical Report

by

S. F. Cushman

June, 1968

Placed by

U. S. Army Engineer Topographic Laboratories

Contract No. DAAE15-67-C-0010
Department of the Army Project No. 4A623501A85201020

OSURF No. 2306

The Ohio State University
Research Foundation
Columbus, Ohio 43212

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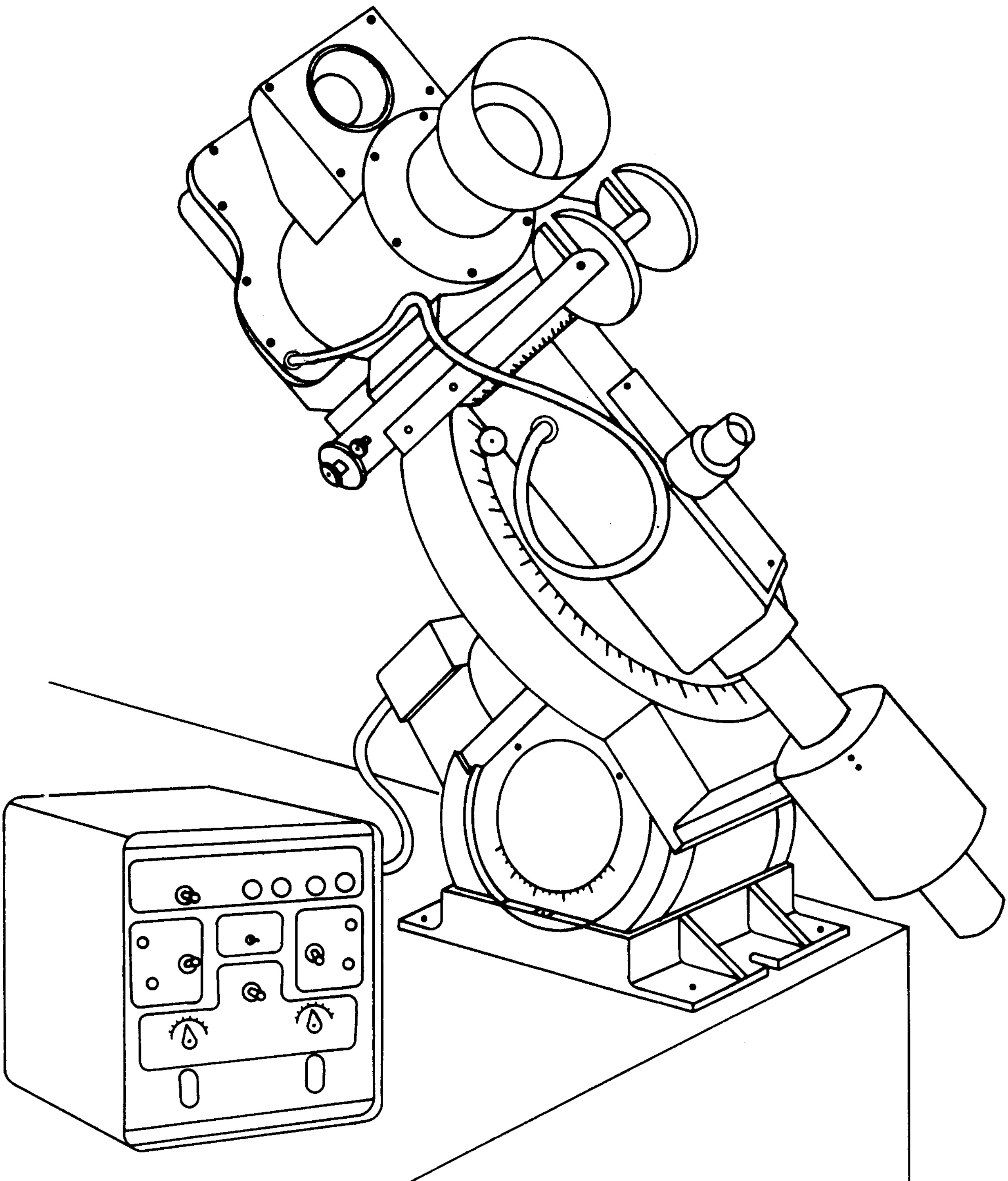

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SUMMARY

This reports the results of tests on the Stellar-Moon Camera and associated equipment under field conditions. Major emphasis was placed on determining sources of error by whatever means necessary, and, within limits, making modifications to equipment or methods to overcome these errors. The tests show that the present form of the camera is not capable of obtaining topocentric coordinates of the moon of sufficient accuracy to warrant further development.

FOREWORD

The test and evaluation of the Stellar Moon Camera System was performed under U. S. Army Engineering Topographic Laboratory (USAETL) Contract No. DAAE15-67-C-0010, The Ohio State University Research Foundation Project No. 2306. The Ohio State University Computer Center provided 33 minutes of I.B.M. 7094 computer time at no charge.

Execution of the contract was under the direction of Mr. Nathan Fishel, USAETL, Research Institute, Contracting Officer's Technical Representative. Personal assistance from many individuals is gratefully acknowledged. William Prescott, North American Rockwell Corp., Columbus; Prof. H. K. Eichhorn-von Wurmb, University of South Florida; Prof. Dr. B. Hallert, Royal Institute of Technology, Sweden; Dr. A. A. Baldini, U. S. Army Engineer Topographic Laboratories; and Professors S. K. Ghosh, D. C. Merchant, I. I. Mueller, and R. H. Rapp, all of the Department of Geodetic Science, The Ohio State University, have provided valuable and willing assistance on both theoretical and practical matters. Administrative assistance was great on the part of Dr. R. L. Cameron from The Ohio State University Research Foundation.

Finally, I am especially grateful for the nonpareil support I received on all aspects of this contract from the Chairman of the Department, Professor U. A. Uotila. Without his help, very little would have been accomplished.

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INTRODUCTION

This report presents the results of test and evaluation of a Stellar-Moon Camera which was originally designed and manufactured by the Autometric Division of Raytheon Corporation. (Design specifications are given in Reference 1.)

Specifically, the purpose of the research was to investigate errors and sources of inaccuracies in the Stellar-Moon Camera system. The system can be used for many purposes, but the project was limited to photography of the moon against a star background. Such photography can provide topocentric coordinates of the moon which can be used in turn to compute geocentric coordinates of the observing station.[2] It is this datum which is desired, and the error analysis was intended to discover if the system could produce geocentric coordinates with an uncertainty small enough to make them useful.

Insofar as possible, sources of inadequacies in the system were to be isolated and if possible corrected, either by design of operating procedures or by limited modifications of the equipment. A known limitation of the system (i.e., total dependency of the concept on clear weather at full moon) was to be investigated also.

The equipment forms a system, of course, and all pieces are interdependent. However, for the purposes of this report four main parts are recognized: the camera, the equatorial mount, the electrical control for the camera, and the timing equipment. Included in the first section will be a discussion of the comparator, since the evaluation of the camera cannot be separated from measurement procedures.

As will be seen, the scope of the investigation has been only a part of that originally planned. Two main reasons for this restriction arose. It was understood originally that the system has been checked out sufficiently to ensure its proper and complete functioning. Such has proved not to be the case. This is not to imply bad faith, for only after the system had been set up in Columbus did the limitations become apparent. Beyond this, facilities for the amount and kind of continuous maintenance required were not available. As a result, by far the major effort was spent on work not at all anticipated in the proposal, to the detriment of the total effort.

Secondly, the amount of delay encountered between orders and deliveries of facilities and equipment was grossly underestimated. The necessary facilities did not exist in Columbus prior to the award of the contract, and agreements made to provide them have been honored in every case. However, the timetable has been extended frequently for the unforseen delays. Partly because of these delays the contract was extended for three months, but even this extension has not been enough to permit completion of as much work as might be desired.

In anticipation of the conclusions, it should be mentioned here that these limitations have not prevented completion of at least the spirit of the investigation. Serious limitations have been discovered and these are enough to make the present system incapable of providing topocentric coordinates of "useful" accuracy.

The camera was designed to some extent with a comment of I. I. Potter in mind.[3] It is ironic that errors of the magnitude referred to are far smaller than the best the present system is capable of.

THE CAMERA

The 290 mm focal length camera is unusual only in having two shutters, each of which can be individually controlled. The lens is an Astro-Berlin Telastan Lens with Equivalent Focal Length of 290.21 mm.[4] The focal plane is defined by a plane-parallel plate, 60 mm in diameter, located on the lens side of the focal plane. The focal plane itself contains an etched reseau, a 4 × 4 cm pattern of lines 1 cm apart.

As originally received, the camera was equipped for use of standard 120 size roll film. A Graflex film holder is mounted in such a manner that film can not be advanced when it is pressed against the plane-parallel plate. The twelve exposures slightly overlap each other; however, the reseau is not obscured.

The objective lens of a finder telescope is mounted above the camera, and is combined with a reflecting prism so that the optical axis of the finder passes through the body of the camera at right angles to the camera axis. This design requires that the camera be mounted on the equatorial base described below in order to use the finder at all. But it also means that there is a large air gap between the base of the camera and the equatorial mount. This is a wholly undesirable situation for field equipment. This air gap has not been sealed since other things were more pressing.

The ultimate accuracy of topocentric coordinates derived from this system can be no better than the metric accuracy of the camera. The two Reports of Test[4,5] indicate that the objective lens, both alone and in conjunction with the plane parallel plate, is of good quality. However, the real test is in actual use; the reduction procedures to be employed would have included internal calibration for at least several plates. To date no plate has been obtained that appears to be of such a quality as to permit calibration.

One characteristic of objective lenses not covered in the Test Reports concerns chromatic distortion. This may be of considerable importance in astrometric work such as the present work should have been.[6] In anticipation of some investigations along these lines, an extension ring was built that would have permitted mounting a coarse objective grating on the camera. Such a grating was actually made by hand and several exposures were taken with it. However, none of these was of sufficient quality to warrant analysis.

Reasons for the low-quality images will be discussed later. Suffice it to say here that no evaluation of the quality of the camera, as such, can be made based on data presented herein.

The plane-parallel plate which defines the focal plane is attached to a rather sturdy mounting ring, referred in the manufacturer's drawings as "Holder, Reseau." This, in turn, is mounted on the camera by means of three pairs of push-pull screws, and it is by means of these screws that focussing of the camera is effected. Tests of the rigidity of this assembly were not made, but it would appear that this could be a serious short-coming if the camera were to be subjected to much moving about. There are no provisions for checking the adjustment, except by the laborious task of examining a series of exposures for best focus.

Another opening in the camera body (i.e., nearly an inch between the "Reseau holder" and the back of the camera body) contributed to instability, since the push-pull screws are rather small diameter (#40, American National Gage), and to collection of dust, especially on the inside of the plane-parallel plate. Larger screws seem advisable, and a small bellows mounted between the camera back and the "Reseau holder" would have sealed this opening completely.

The reseau was made to specifications of the manufacturer of the camera. No tests were planned of the optical qualities alone. The reseau pattern, however, was examined. Coordinates of the grid intersections were provided by the camera manufacturer. These data indicate that (1) the line spacing is slightly more than the 10.010 mm specified as maximum, and (2) perpendicularity has been maintained within the required 1 minute of arc.

There are three possible ways to use the reseau in data treatment, aside from ignoring it. One can use the location of the "Principal Point of Autocollimation" as detailed in Reference 4 as the plate center in computation of the plate constants and measure all image coordinates relative to it, using only the lead screw of the measuring engine to derive coordinates. In employing the grid one can use the coordinates of the grid intersections as given and linearly interpolate between them. The final alternative would be to assume that the grid lines are so straight as to prevent measurement of the deviation and to employ a mathematical equation to define each line. This last proposal seemed sufficiently novel to explore. (See Appendix I for further discussion.) No plates were measured hence no conclusions are drawn.

The measurement of plates was to have been performed on a Mann Type 829C Comparator which was fitted with a specially designed reticle (see Fig. 1). This reticle offers the following features: the two outer circles were slightly larger and smaller than the maximum and minimum images of the moon with the present camera. The radial ticks are marked off in 10° intervals from the major axes and were to assist in locating the terminator. This was in anticipation of attempts to measure plates not taken near full-moon. The major axes were to be used for measurements on the reseau lines. The small concentric circles in the center were for star images and estimation of magnitudes.

It should be pointed out that the two outer circles use nearly all of the field of the microscope of the comparator. This field appears

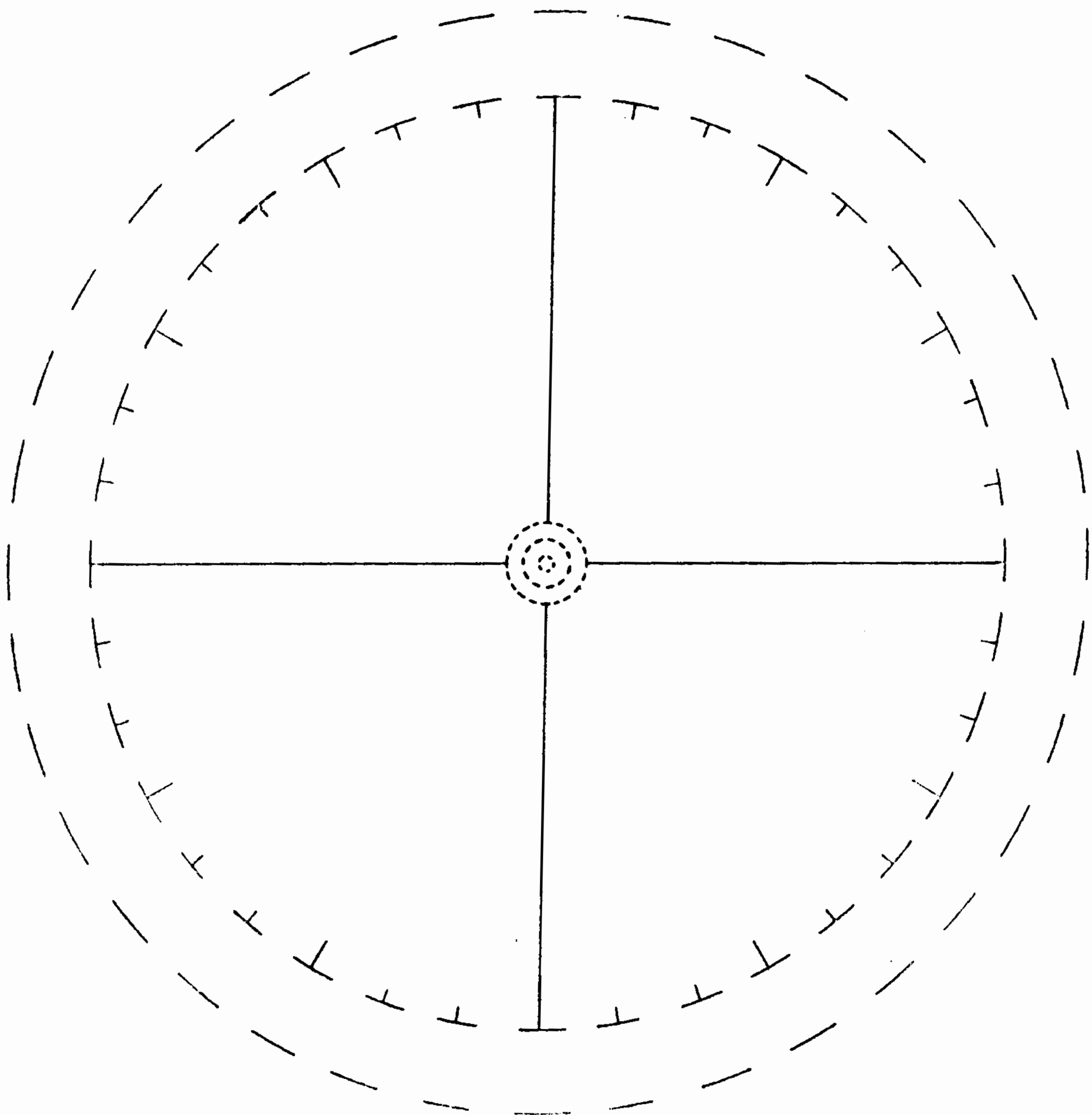


Figure 1 - Sketch of Special Reticle

to be flat beyond the outer circle. Examination of a few (blurred) images of the moon, shows that pointing consistency is comparable to that on stellar images in the same plates.

The problem of measurements has been great. Much time and effort was given to finding a suitable, and available, instrument. When it became clear early in the project that no comparator in the Columbus area could be used, attempts were made to have the measurements performed on a contract basis. This would have been of great advantage to the research effort since it would have made available for research the time that would otherwise have gone into measurements. The problem here was installation of the special reticle. Finally, funds reserved for purchase of a comparator were used for that purpose. However, it has not been possible to obtain a suitable environment for the comparator. Thus not even calibration of the comparator has been performed.

The primary shutter of the camera is of unusual design. It consists of a single blade which rotates on an axis parallel to the camera axis but at a distance of 4.500 inches from it. The shutter blade is suitably counter balanced. Opening and closing is powered by a torsion bar which must be cocked by hand. Coaxial with the shutter is a disc into which notches have been cut so that spring-loaded detents can hold the shutter open or closed. These detents are electrically opened to operate the shutter.

The moon shutter in the center of the field is opened by a solenoid and closed by a spring. It consists of a disk one-half inch in diameter on an arm extending over the useable field and, when opened, clears the field entirely.

Both shutters are timed by photocells. The primary shutter intercepts a light beam at the instant the entire field is cleared by the opening shutter, and in turn clears the beam at the instant the edge of the field is first obscured. For the moon shutter, a slot cut in the counter balance clears the light path to the photocell only at the instant the shutter itself is one diameter from its closed position, that is, the field normally obscured by the moon shutter is entirely clear but the moon shutter is still within the field of the camera. The reaction of the photocell is used to produce a timing pulse in the shutter control circuit.

In order to test the shutter efficiency a beam of collimated light was used as a source. An International Rectifier Corporation photocell, model S1M, was placed behind the focal plane. The output of the photocell was connected directly to the Y-axis of a Heath Company oscilloscope, model IO-14.

As mentioned above, the camera was originally fitted with a roll film back. Soon afterwards a plate holder was designed and built and the later exposures were on $3\frac{1}{4} \times 4\frac{1}{4}$-inch glass plates. The emulsion selected was Tri-X panchromatic, Type B, the selection being based primarily on availibility. The design of the camera back and plate holder is shown in Fig. 2 and 3.

THE EQUATORIAL MOUNT

Tinsley Laboratories, Inc., of Berkeley, California, designed and built the equatorial mount. The sidereal drive is electric, and since the motor is synchronous, it cannot be exact. However, the gear ratio is such as to incur an error of less than one part in one hundred thousand. Slewing in right ascension is accomplished by rotating the sidereal motor. Both the sidereal motor and the slewing motor are switched from the shutter control mechanism.

The declination axis is hollow and forms the path for the finder telescope. The coudé eyepiece is mounted on the north side of the right ascension axis with a first-surface mirror used in place of the traditional coudé prism. This arrangement had the small advantage of permitting field illumination to be mounted quite easily within the housing for the eyepiece. Declination slewing is accomplished by a worm working against a one-toothed gear. Provision for coarse latitude adjustment is gained from a cylinder which forms the lower end of the equatorial mount. One end of the cylinder has a latitude scale engraved on it, and the edges of the cylinder form the clamping surface between the mount and its flat base. The base has foot screws for final adjustments.

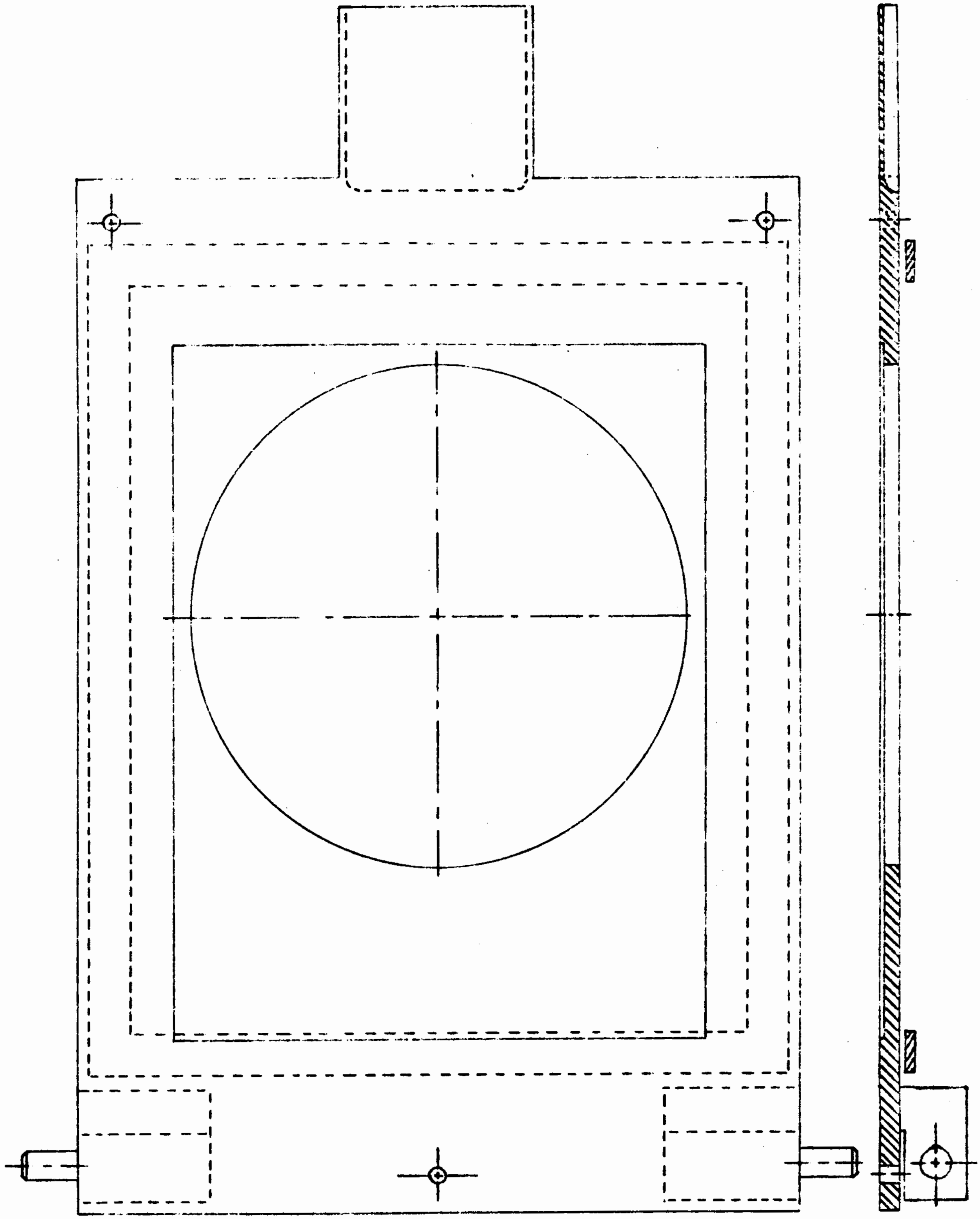
Electrical connections for the camera pass through the mount, with controls for the two right ascension motors joining the cable at the appropriate place. Commutators are used at the right ascension axis so that there is no limit imposed on its motion. The motors themselves are mounted inside the cylinder that forms the latitude axis.

SHUTTER CONTROL UNIT

The electrical circuitry which provides operator control of the shutters and motors is contained in a separate piece which requires connection to 110 V ac. A multiconductor cable then connects to the equatorial mount, and thence to the camera. Timing pulses return through the same cable.

An analysis of the electronic circuiting is not included since the writer is not expert in these matters. Suffice it to say that the following controls are provided:

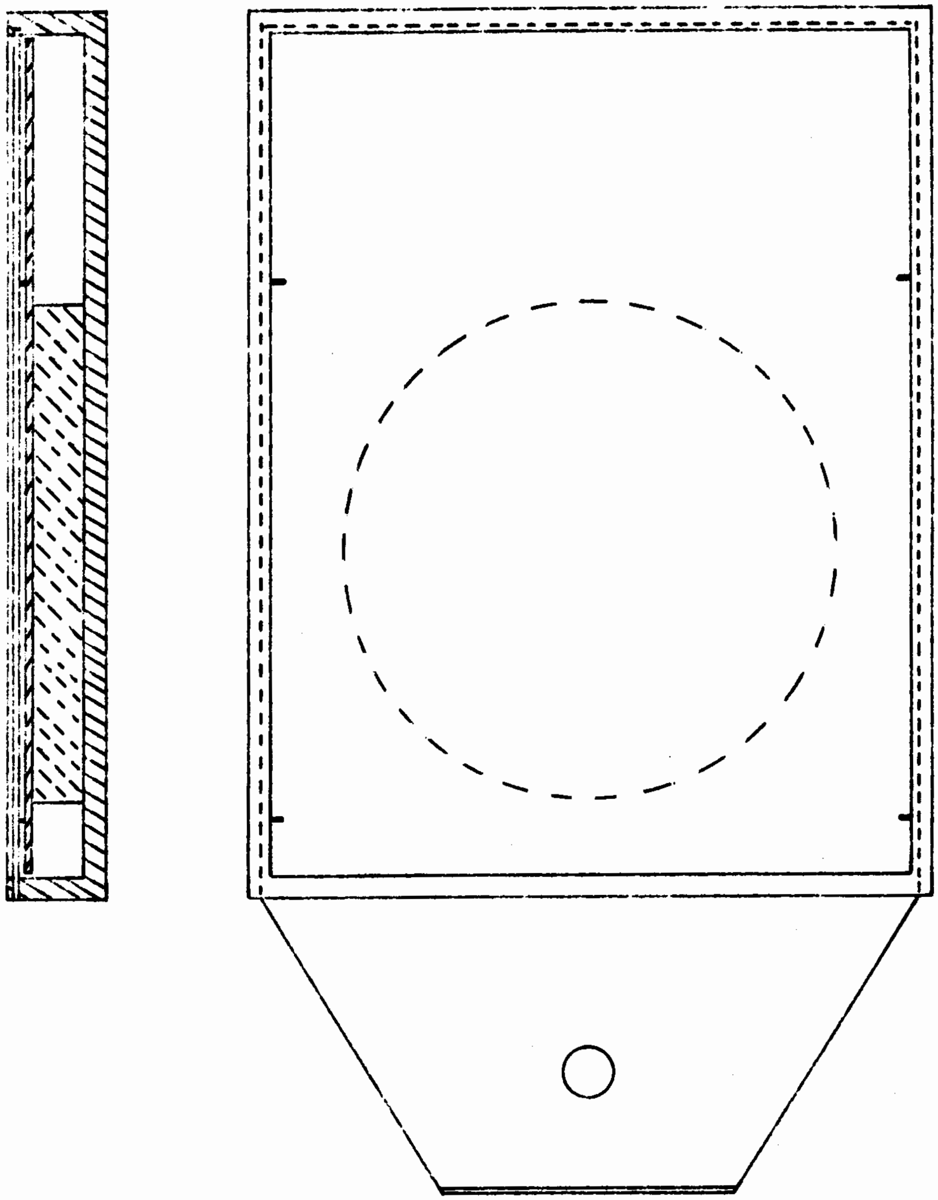
Power - on/off,
Sidereal motor - on/off,
Slewing motor - east/west (this switch has been connected backward),



FULL SCALE

Note 1: Size of indent depends upon the size of the plate holder.
Note 2: Not shown: clips to retain the plate holder.
Note 3: All dimensions are $\pm$ 1/64 inch.

Figure 2 - Plate Holder for USAETL Stellar-Moon Camera



FULL SCALE

Note 1: External dimensions depend on material used.
Note 2: Maximum dimension from bottom of backing plate to emulsion not to exceed 1/4 inch.

Figure 3 - Plate Holder for USAETL Stellar-Moon Camera

Moon shutter - automatic/shut/open,
Moon shutter delays - 1 to 16 sec.,
Moon shutter duration - 25 to 2400 ms, and
Primary shutter - open/close.

The one point of importance is that when the moon shutter is set on automatic, the moon shutter opens after the primary by a time difference determined by the setting of the Moon Shutter Delay control. The moon shutter then remains open for the time set on the Moon Shutter Duration control before it closes automatically. Thus control of the moon shutter can be either automatic or manual, while the primary shutter is wholly manual. The closing of the primary shutter was later modified so that it too was automatic.

Output from the photocells of the shutter mechanism is used to produce a pulsed negative voltage. These pulses are available through a coaxial cable connector for operating timing equipment.

CRYSTAL CLOCK

The clock system is manufactured by Newtek, Inc., and consists of three main parts. The Chronofax is the actual crystal clock, while the Correlator and Power Pack are auxiliary items.

The Chronofax consists of a 3 MHz crystal oscillator in an oven. Dividing circuits reduce this frequency for external outputs to 1 kHz and 1 Hz. Internally, the 1 kHz signal is used as the main timing indication. Counter circuits keep track of this signal and, on command, print out the value of the count in binary coded decimal notation.

The Correlator is used in setting the counting circuits. A cathode ray tube in the Correlator is used to synchronize the 1 Hz signal of the Chronofax to the seconds pulses of a radio time signal, say that of WWV. At exact minutes, the counters of the Chronofax can be synchronized with a 1 Hz signal from the Correlator thereby "setting the clock." Thereafter commands to the Chronofax for print-out result in records of the time of the command in whatever time system was used when the clock was set (e.g., Greenwich Mean Time).

The Power Pack is a slightly misleading name inasmuch as the Chronofax is entirely self-contained for about one day of continuous operation. The batteries for the Chronofax are rechargeable silver-zinc cells and the Power Pack is a "tapered charge" recharger. That is to say, it recharges each of the twenty 2-volt cells individually at a rate which depends on the degree of discharge. There is a sensitive volt meter on this instrument which can be used to monitor the condition of each cell.

These last two components require 110 V ac power for operation.

A radio is, of course, required for obtaining time signals. This project employed both a Zenith Transoceanic, Model 1000D portable, and a National Receiver, Model 100-RC. The latter was used with a half-wave antenna turned to 10 Mhz and beamed toward Fort Collins, Colorado.

TESTS AND RESULTS

The author first used the system at the Engineering Proving Grounds, Fort Belvoir, Va., in August 1966. This occasion was mainly a training exercise prior to transfer of the equipment to Columbus, Ohio

An observatory, designed especially for this equipment, was constructed next to the Geodetic Science Department Observatory on the campus of The Ohio State University. The first months of the contract were devoted to this design work and construction was begun in January 1967. The camera was mounted in late February but modifications to the pillar required removal of the camera and equatorial mount in March. By the middle of April 1967, everything was in working order and the set-up remained almost unchanged until February 1968, when the camera was brought to an indoor laboratory for a final sequency of tests. The observatory was an excellent facility.

Pictures were taken at every full moon from February 1967, to January 1968, inclusive, unless equipment malfunctions or weather prevented. One other sequence of exposure was made in May 1967.

THE CAMERA

The attributes of the camera affecting accuracy include quality of the image produced and the precision of the shutters.

Test exposures for preliminary evaluation of the image were taken on 2/3 May 1967. Some of these exposures were taken with a handmade diffraction grating placed before the objective. Inspection of these plates shows quite clearly a very low quality image. It was not noticed until after another sequence of exposures taken on 23/24 May 1967 that the quality varies as a function of right ascension.

Under the assumption that the reseau is in its proper place, the change in focus can only result from a mislocation of the film back in the Graflex roll film holder. Visual inspection of the situation led to the conclusion that this was the case; however, it could not be definitely established without risking damage to the reseau.

Some simple calculations made concurrently with the field work suggested the advisability of remaking the back of the camera for use with glass plates. The focal length of the camera is equivalent to nearly one second of arc per micron. An ordinary film back cannot be considered stable to within 10μ under the best of circumstances. (See for example, Reference 7, page 260 ff; however, Reference 8, page 482 f is worthy of note.) Uniform changes may be much larger, although these are not a serious problem, being tractable to mathematical compensation. In the size for which the film holder is designed, stable base films are not available except on special order. Thus, since a change is desirable both for stability and better contact with the reseau, conversion to glass plates seemed best. All exposures after May 1967, were made on glass plates.

The first sequences of film exposures were also used to determine exposure times. Since both the film and plates had Tri-X emulsions, it was assumed that exposures should be closely similar. Fogging seems to be equivalent, expecially when the moon is included in the field. It seems that the moon camera has problems quite similar to the coronagraph; light scattering within the camera must be suppressed. It is disturbing to note that star images are easily obtained from dark fields (that is, without the moon) but scarcely at all when the full moon shines into the camera. While at no time were skies at full moon absolutely clear, much of the general fogging on moon plates must be attributed to light scattered by dust within the camera.

The plate holder was designed with the problem of firm contact between reseau and emulsion kept in mind. As a result, the glass plate is pressed against the reseau by a urethane sponge cut slightly smaller than the reseau, and the plate holder is slightly larger than the plate itself. Hence the only forces on the plate at exposure are provided on the emulsion side by the face of the reseau which is in the focal plane, and on the other side by a sponge centered on the reseau. The plate is wholly independent of plate holder since the sponge absorbs any irregularities of adjustment of the camera back.

There are two minor possibilities of maladjustments of the plate; (1) friction between the sharp edge of the plate and the aluminum plate holder, and (2) misorientation of the reseau either from distortion of the push-pull screws or from actual mislocation of the reseau. In trials using an actual plate in the holder, there is no tendency whatsoever for the plate to resist pressure, neither when applied near the edges or corners of the plate, nor symmetrically with respect to the center of the reseau. As for distortion or bending of the push-pull screws holding the reseau in place, there is less tendency for this with the plate holder than with the film holder. Compression of the sponge is a gentle force compared to that of the three springs which hold the camera back against the camera. This camera back is not pulled back by the presence of the plate, that is to say, the sponge provides the only force tending to hold the plate against the reseau.

Examination of the images of the reseau lines on the glass plates indicates that contact is indeed as desired. The images are clear and sharp and of uniform width. There are problems remaining, however, in that the images of stars do not appear sharp. Comparison of the stellar images from the film of 2/3 May with those on any of the glass plates shows that the former are sharp and dense while the latter are softened and very hard to find.

The cause for this lies with the moon shutter. This would have been easy to confirm by exposing a single plate with the moon shutter left open throughout the exposure. Unfortunately the magnitude of the problem was not recognized until after the camera had been taken indoors. Confirmation of a sort lies in comparison of the last two exposures of the film taken on 2/3 May. Frame #11 was taken of the star field centered on β U. Maj., while frame #12 was centered on α Boo. More to the point, the latter frame was designed to show up tracking errors by making multiple exposures under the moon shutter during a lengthy overall exposure. Tracking is manifestly good, but the images are noticeably softer and lens aberrations (resulting from bad focus) are almost not visible.

Thus it appears that the moon shutter is jarring the camera. More direct tests to determine if this is so were performed in August 1967. A plane, first-surface mirror was mounted in various places on the camera. A theodolite with Gaussian eyepiece was then made normal to the mirror by autocollimation procedures. The shutters were activated individually and the motion of the image of the cross hairs observed.

This technique gives graphic evidence of the reaction of the camera assembly to shutter activity. The primary shutter jars the camera noticeably both when it opens and closes. The moon shutter has no effect as it closes but on opening it causes a large jump in the camera position which usually is not fully restored. In short, the main shutter jars the camera but without permanent effect; the moon shutter, on the other hand, is responsible for visible, permanent displacement of the camera axis.

Unfortunately quantitative determinations have not been made. The motion is very rapid. An eyepiece reticle with scales would not greatly help matters since it would tend to confuse the brief image. Practical experience with the theodolite leads to an estimate of perhaps 20 seconds of arc movement of the reflected image of the cross hairs. This means the camera has moved 10 seconds, or the plate about 14μ. This amount should produce a noticeable effect on the photographic image.

Not a single exposure of the moon was obtained in which details of either the limb or the surface are visible. Probably no single cause can be assigned although camera motion has contributed and so has overexposure. Detailed inspection of the plates had to wait on availability of the comparator, hence images considered marginal by preliminary inspection were not discovered to be completely useless until the end of the effort. A problem was recognized to exist in August 1967, but was believed to be caused mostly by overexposure. This problem has to do with timing, however, and will be described later.

The last tests performed on the camera pertained to shutter efficiencies. The experimental equipment has been described previously. The actual setup was such that the circular image of the light bulb produced on the reseau was about 7 mm in diameter. This image was centered over the closed position of the moon shutter. The size compares to the mean lunar image of nearly 3 mm. Both shutters were tested with the same setup.

Figure 4 is a somewhat stylized representation of typical oscilloscope patterns observed. The abscissa represents time; the ordinate, voltage. The actual voltage displayed depends on many things, among which are intensity of light source, lens efficiency, photocell sensitivity and oscilloscope settings. None is significant in the present situation.

Time is significant, however. The sweep of the oscilloscope had been calibrated against the 1 kHz output of the Chronofax which is claimed by the maker to be accurate to $1:10^8$.[9] At frequencies involved in the present tests, the time scale is considered without error. The frequency response of the photocell is essentially flat to about 1 kHz.[10]

The moon shutter was tested first. The sweep of the oscilloscope was triggered, or started, by the switch which opens and closes the shutter manually. The top line is the trace produced by opening the shutter. The length of time until the shutter is fully open has these components: (1) The time necessary to start the shutter moving which is taken up in building the magnetic field of the solenoid which operates the shutter, and overcoming the mechanical inertia of the shutter; (2) The time necessary for the shutter edge to move from its rest position to the edge of the image of the light; and (3) The time for the shutter edge to pass completely across this image. Components (1) and (2) are contained in the horizontal portion of the trace at the far left, while (3) is contained in the rising line. The first two parts are irregular by perhaps 40% but averaged nearly 6 ms. Part (2), of course, would depend upon the location of the lunar image relative to the moon shutter at time of exposure. At other settings of the sweep circuits it was possible to show that the rising portion was 2.8 ms. For the moon this time would be about 1.1 ms.

The second trace represents a typical closing of the moon shutter. Two things are to be noted; the closing is much slower, and a double exposure is a normal part of the operation. At other sweep settings, the closing is seen to take about 8 ms. The delay between exposures is about 30 ms, and the second exposure, which is quite irregular, lasts from 15 to 60 ms.

This double exposure might be considered a partial cause for the lack of resolution in the lunar image. As noted above, however, the closing of the shutter does not cause motion of the camera within limits of the test, which could easily detect image motion of a second of arc. Furthermore, in $0^s.03$, the average motion of the moon relative to the stars is equal to (0.03 sec) $\times$ (120 sec/hr) $\times$ (15"/sec)/(3600 sec/hr) = $0''.015$, or 0.02μ at plate scale.

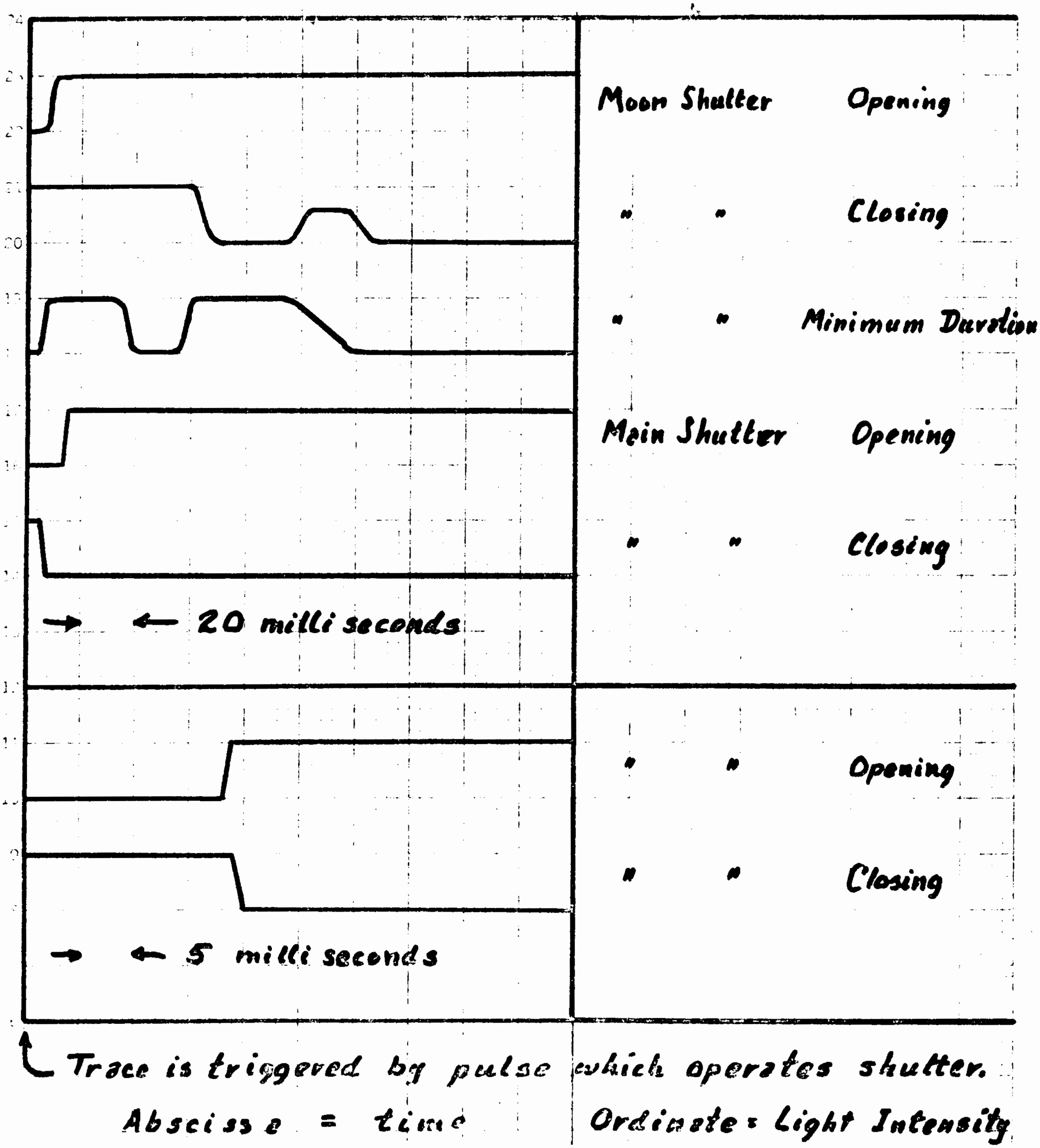


Figure 4 - Typical Light Curves

The third line represents the action of the moon shutters during automatic operation; that is, when synchronized with the primary shutter. Moon Shutter Duration control was fully counterclockwise to obtain minimum possible exposure. Under these circumstances, the second exposure is longer than the first. Were the scale on the shutter control accurate, the exposure should be less than 25 msec, but the total exposure is nearly four times this value.

The last four traces are due to the primary shutter. It can be seen easily that it is highly efficient, and, what is apparent only from watching many cycles of operation, it is quite regular in its functioning. Equipment was not available for producing a full-field light curve, which should be used in a detailed evaluation of this shutter. See page 25 for further discussion, however.

The relationship of timing pulses produced by the shutters to these light curves is discussed on page 19.

THE EQUATORIAL MOUNT

The only real test of an equatorial mount is its ability to hold the camera in the same sidereal direction during exposures. After the camera was set up, Frame #12 of 2/3 May was taken especially to test the tracking. The primary shutter was opened for some 40 minutes, while the moon shutter was opened seven times for ten seconds every five minutes. Two possible effects could be observed; in the main field the star images would be elongated, or in the field of the moon shutter several distinct images would be obtained. Neither of these conditions is present. Visual inspection of the tracking was made again on 17 December 1967 and no change was apparent.

The observatory is exposed and in an area of high winds, though fortunately mostly from one direction. Some trouble was experienced with vibration of the camera by wind. However, reinforcement of the connection between the pillar and the base of the equatorial mount damped most of the vibration, and a slight modification of the observatory permitted use of the roof as an effective wind screen. After these changes the wind caused no apparent difficulties.

SHUTTER CONTROL MECHANISM

The only feature of the control box for the camera which could affect the precision of final results is the synchronization of the timing pulses to mark the shutter positions. Ideally, for each cycle or exposure, the clock should record the following four events: (1) The instant that the primary shutter has fully opened; (2) The instant the moon shutter has opened enough to fully expose the field previously obscured (although it has not yet moved fully out of the main field); (3) The instant the moon shutter reaches the same point as it closes (and hence begins to obscure its field); and (4) The instant the main shutter first begins to obscure the main field. Location of the lights and photocells within the camera mechanism are such as to guarantee the mechanical synchronization of these four events.

Almost always four events are recorded by the Chronofax. However, even before the oscilloscope became available, it was apparent that there were unusual features of the time-recording system. For example, the connection between the control box and the Chronofax must be broken between exposures, otherwise the Chronofax will record the following events: turning the right ascension slew motor on, turning the slew motor off, cocking the main shutter, turning the right ascension motor on, and turning the main power switch on.

It was discovered that no ground connection existed in the chassis of the control, even though one is indicated on the wiring diagram of this item. (It should be noted that this wiring diagram contains numerous errors, some obvious, some discernable only upon comparison to the actual wiring.) Such a ground connection was added since all provisions had been made for it. Some improvement was obvious but extraneous signals could still be registered on the Chronofax.

Examination of the Chronofax records discloses several other items of interest. Some are discussed below, but of interest at this point are the many exposures producing extra time records. Usually it is not difficult to deduce from the record the proper times of the events to be recorded. There are five common errors that appear in the time records: two events, a few milliseconds apart, at the opening of the primary shutter; two events at the opening of the moon shutter; no record of the closing of the moon shutter; two events at the closing of the moon shutter; and two or more events at the closing of the primary shutter.

That extraneous noise generated in the shutter control circuits could trigger the Chronofax was apparent from the first. But the amount of noise generated was not apparent until an oscilloscope was available. Ironically, an oscilloscope had been used to examine the wave form in the early days of the contract. In the laboratories of Newtek, Inc., the camera and its controls were set up for the purpose of ensuring proper "mating" of the Chronofax with the rest of the equipment, since it is necessary to know whether the pulse put out by the shutter control is primarily negative or positive and of what magnitude so the Chronofax can properly respond to it. At that time only the pulse was viewed, and it proved to be of unusual shape, although quite useable.

During the later tests, however, the entire signal was viewed and so the great amount of noise actually generated was seen. Actually it is not possible at present to detect the pulse in the overall noise. This implies an increasing failure of some components in the shutter control, and, worse, it implies that the Chronofax is operating from the noise rather than any real signal. There is no way in the field to determine this. For lack of information provided only by equipment not presently considered part of the Stellar-moon camera system, it is impossible to detect what is causing the Chronofax to record time. To a large measure, this can account for the extra signals listed above. And by hindsight, it is reasonable to suppose that if some switches generate enough noise to trigger the Chronofax, any can, and all probably do. The essence of the problem is simply that the circuitry designed to generate timing pulses on command of the photocells either does so also when stimulated by random electrical signals from other parts of the circuitry or else these random signals themselves are large enough to simulate timing pulses and escape to the Chronofax. The author has insufficient knowledge of transistor technology to differentiate between these possibilities.

But differentiation is unnecessary. In either case, the Chronofax is reacting to the wrong signal entirely and always to one that is early relative to the proper one. Referring to Fig. 4 again, the mechanical design of the moon shutter mechanism is such that the timing pulse should occur at a point slightly after the rising portion of the opening curve and as much before the falling part when the shutter closes. At present, however, examination of the signal from the pulse generating circuit shows only a solid band of noise which begins at the instant either shutter is activated and extends for as much as several tenths of a second afterward. Furthermore, it is very irregular in both magnitude and duration, and may have breaks in the center. The Chronofax is designed to respond to 40 Hz., but probably responds to no more than 30 Hz. This means that only events more than about 35 ms apart can be recorded. A break in the noise that occurs more than that time after the start of the event causing the noise will cause the Chronofax to print a second time record.

More common, however, is a continuous burst of noise, generated, say, by the opening of the moon shutter. The Chronofax responds to the start of this noise, but if the moon shutter is closed before this burst of noise decays, no new signal can be distinguished by the Chronofax so no time is recorded at the closing of the shutter. This information, as mentioned above, became evident only at the end of the effort, and goes a long way toward explaining the problem of over-exposure of the moon. The difficulty in practical use of the camera was not at all in setting the moon shutter for shorter exposures; rather Moon Shutter Duration settings of less than about 0.6 s produced only one time record, and there was no apparent way to determine when this occurred relative to the moon shutter cycle.

The extent to which noise pervades the entire circuit is indicated by the fact that it was unnecessary to change the connection to the trigger circuit of the oscilloscope when testing the two shutters. Control over each shutter is from two separate circuits, but either affects the other.

Transistor circuits being as sensitive as they are to insertion of extraneous electrical influences, including meters and other test instruments, no attempt was made to try to determine the relation between the signal produced by the shutter control and the actual time recorded by the Chronofax. When electrical pulses are to be used for timing, as is the case here, great care is required to ensure response to the proper pulse and only this pulse. Evidently no guarantee of the proper conditions pertain now, if they ever did.

The tests on timing and light curves were ended somewhat prematurely by the total failure of the moon shutter. The shutter control generates the necessary power pulse to activate the shutter, but there is no response by the shutter. Removal of the moon shutter mechanism appears not to be too difficult an operation but replacement of the solenoid, if indeed this is required, could not be performed before the end of the research effort. In addition there is certainly evidence enough already to make modification of this assembly highly desirable, but this should be performed by the maker.

CRYSTAL CLOCK

There are two attributes of the timing system of importance: how accurately does it keep time? and how accurately does it record time? These two questions are related but must be evaluated in different manners.

The first, time-keeping ability, is an inquiry into the constancy, or at least the predictability, of the rate at which the clock changes in relation to some given time system, say UTC. This includes such effects as the accuracy with which the clock can be compared to the given time system and the regularity with which it changes from this system between comparisons. Obviously, if it were possible to use the time system of reference directly there is nothing gained by introducing an intermediate system.

The second question, time-recording ability, is a consideration of what time, according to whatever system the clock is keeping, is actually recorded when the printing mechanism is triggered. This is an internal problem, whereas the other is external.

Time-keeping ability must be measured over long periods of time. The Chronofax was permitted to run for an extended period only once and on that occasion the batteries were completely discharged in much less than 24 hours. With one notable exception, the Power Pack failed every time it was permitted to run unattended. Over short periods of time the comparisons made between the time on the Chronofax and that broadcast by WWV were frequently ambiguous under actual operating conditions.

Time-recording ability is dependent on the circuitry in the Chronofax. In this device silicon rectifiers are used as buffers between the counting circuits and the printing mechanism, controlling which printing fingers are activated to produce the BCD record. According to the manufacturer only 200μs are required for the actual printing. Two questions arise: (1) how rapidly do the silicon rectifiers switch relative to the counting circuits?, and (2) is the 200μs a design value (which is usually less than the actual value)?

No tests have been performed on the timing system to obtain quantitative evaluation. This has resulted partly from the presence of other problems, but mainly from the fact that the Newtek equipment has not functioned reliably at any time. Over the past two decades, the author has spent much time dealing with the problem of recording absolute time (rather than time intervals) to millisecond accuracies, and usually laboratory equipment, such as oscilloscopes and precise frequency generators, has not been available. Based only on this experience, the author is dubious of claims of millisecond accuracy, as opposed to millisecond precision. The Chronofax can produce a time record referred to, say, Greenwich Mean Time as broadcast by WWV to within 5 ms almost certainly, to within 2 ms possibly, but probably not reliably to within 1 ms over a 24-hour period between time comparisons.

There are three main reasons for this opinion. First, there is no accommodation on the Chronofax for the change in frequency of the basic crystal due to aging. For good crystal clocks, this is a necessity since no crystal vibrates indefinitely at the same frequency. Second, there are the questions raised previously regarding response time of the printer. And finally, during the time the Newtek equipment has been available and operating, no synchronization with a radio time signal has been accomplished that left the operator sure of an error less than 2 ms. There is no reason to believe without further proof that there are no other systematic effects within the Chronofax-correlator-radio combination which may introduce even greater errors.

Preliminary results of experience with another Chronofax of slightly modified design owned by the Department of Geodetic Science indicates that the estimates made above are very close to being correct.

DISCUSSION

The specific requirement of this research has been an evaluation of "the accuracy with which the topocentric coordinates of the moon can be determined by the system." This has governed the presentation in the previous parts of the report. However in the Scope of Work also appears the phrase "under field conditions." It is the author's firm convictions that final accuracy of equipment used away from a laboratory depends very largely on factors which can not be expressed quantitatively but are instead quite personal in nature. For this reason, a general discussion of the equipment from the user's stand point is included at this point. It should be understood that the comments are personal and others may disagree. In the final analysis, much of this is a matter of taste.

None of the equipment is easy or convenient to use. Basic complaints are mentioned here with little or no discussion. The controls and switches on all of the Newtek equipment are too small for an operator heavily gloved and jacketed and operating in temperatures well below freezing. Similarly these controls are too close together for operation under conditions of low illumination. The cables for interconnection between the various parts of the Newtek equipment should not be insulated with thermoplastics. The 21-conductor cable from Power Pack to Chronofax, in particular, is so stiff at temperatures below 20°F as to be capable of moving or upsetting the Chronofax.

The Newtek equipment can not be considered field equipment by any test except weight. Mechanical construction is so weak that the slightest jar of exposed metal parts produces at least a bend, occasionally a break. Bolts should never be threaded into thin metal, rather into a real nut, if the bolt must be withdrawn for servicing. The narrow base of the Chronofax is a decided hazard, so much so that usually it was kept hanging up when in use.

There is no advantage gained in using a portable clock such as the Chronofax with equipment as heavy and permanent as the remainder of the Stellar-Moon Camera system. Everything but the Chronofax requires 110 V ac power; the clock should take advantage of this.

Neither is there an advantage to the printed record being in binary coded decimal if the circuitry is not capable of guaranteeing an unambiguous encoding. Many of the printed times include digits that can not be translated from modulus 2 to modulus 10. Unfortunately most of these occur in the decimal second digits so that they can not be interpreted in light of adjacent prints as can similar errors in other digits. During field operations this was generally diagnosed as resulting from low battery power; yet near the end of the effort with virtually new, well charged batteries, the hours and tens of hours were entirely printed; i.e., the time would be something of the order of $(2+1) \times 10 + (8+4+2+1) = 45$ when of course the maximum should be 23. The worst of this problem is that it raises suspicions about other prints as well.

The Equatorial Mount is incredibly awkward in its present application. The latitude axis is grossly unbalanced, and should be redesigned both with this in mind and to make it easier to set and clamp. The right ascension axis is large enough for a 30 cm refracting telescope weighing many times as much as the camera and having tremendous moment arms to overcome. If electrical slewing motion is used, anti-backlash gears are a necessity. The clamp for this axis is impossible although not as bad as that for the declination axis. Motion clamps should be quick, smoothly operating, positive, so that there is no question as to which way they should be turned, and insensitive to temperature effects. Flexible shafts should never be used in such mechanisms.

Friction in both axis makes counterbalancing difficult. Finer adjustment for the right ascension counterbalance would have been helpful. A counterbalance for the declination axis was added by improvization, but was not wholly satisfactory, since no fine adjustments were possible. The counterbalance weights were borrowed from a 30 cm Cassegrain telescope on loan from the U. S. Army Map Service to the Department of Geodetic Science.

The gear trains for sidereal drive are heavy enough for the camera but not so for the equatorial mount. The innermost gear was stripped during initial assembly in Columbus, and required considerable work for repairs. Electrical slewing motions should always have anti-backlash gears. The declination slew is adequate but stiff.

The white color of the camera is an advantage in dim light. The face, at least, of the shutter mechanism should be the same color. The right ascension slewing motor switch should be located on the equatorial mount. The shutter switch should either be quite different or far away from the power switches.

Little thought must have been given to delay/duration times on the moon shutter. Symmetry between moon and star exposures is highly desirable, but is not possible except manually; then the moon exposure is not controllable. Exposures on the moon must be short enough to prevent the image from blurring because of motion relative to the stars (this is even more a problem if satellites are to photographed). If image motion is to be kept an order of magnitude less than the smallest unit of measurement, then the 0.1μ maximum motion allowable is equivalent to an exposure on the moon of no more than 143 ms, much less than what is now possible with good time recording.

The camera is both the strength and the limitation of the system. There is no doubt it is convenient in use. Cocking is simple and sure. The electrical shutter control guarantees no interference from the operator at the critical time of exposure. Plate handling is simple and straightforward; to be sure, the film back originally mounted was convenient enough.

But it would seem that no real thought was given to the uses to which this camera might be put after it was constructed. This contract has been concerned with its use in lunar photography, but the proposal was made that it could also be used for satellite photography. In the following discussion the moon can be considered a limiting case since any satellite available at present moves much faster than the moon.

Consider first the problem of star photography. The only requirement placed on the photograph is that it present a good representation of the position of the star. To this end the camera is made to track the apparent motion of the stars. The stars move relatively to each other almost not at all, hence time is not a problem. Knowledge of time to a second at mid exposure is more than adequate. Thus a dark slide or a dust cap is good enough to start and stop the exposure of the star field. However, introducing a mechanical shutter runs the risk of moving the camera in reaction to its own motion. This motion will be systematic, although it may depend also on things other than the mechanics of the shutter, such as the orientation of the camera on its mount. If blurring of the image results, even though slight, positions determined from the image will be in error in nonrandom ways.

Suppose, however, that a rapid opening and closing of the shutter is necessary for other, fast-moving objects. Both shutters of the Stellar-Moon Camera are essentially focal plane shutters. While the primary shutter is close to the lens, that it is still a focal plane shutter can be seen from Plate No. 13 in which apparently the primary shutter was not cocked. Focal plane shutters are generally moving slits. The distortion in image shape introduced by a focal plane shutter to an extended, moving object are covered, for example, in Reference 7, page 150 ff. A similar analysis for an oscillatory shutter would be somewhat more complex. With regard to the present camera, some numbers were discussed previously. Limiting allowable image motion to 0.2μ (one-fifth least reading in measurement) means limiting exposures to 0.3 s with the moon as the target. Satellites would obviously impose even tighter restrictions.

With the present equipment, changes in procedure (see Appendix III) are not very helpful. One possibility is the following: (1) open moon shutter electrically, (2) open primary shutter, (3) immediately close moon shutter, (4) close primary shutter at normal end of field exposure. This procedure seems to offer the only chance of avoiding some of the difficulties but has the disadvantage of offering little control over the length of the moon exposure.

Changes in the equipment seem the only solution. Here the possibilities are endless, of course, and only a few are discussed. Perhaps the simplest is to redesign the electrical circuitry with the above procedure in mind. Thus the operator might operate one switch to perform the four steps in the sequence described above. This has the disadvantage of a nonsymmetric exposure (a condition pertaining at present since the field exposure is somewhat more than twice the maximum Moon Shutter

Delay). Actually such asymmetry may be a disadvantage only from the standpoint of aesthetics, but there is the very real possibility remaining that any shutter which moves during the exposure can introduce system atic motions to the camera. And it must be recalled that the present moon shutter does produce a double exposure.

It seems preferable, therefore, that any mechanical changes include redesign of the shutters as well. The wealth of experience gained in the past few years in the design and manufacture of complex, high-speed, rotating shutters could perhaps be employed here. A redesigned shutter implies a different control mechanism as well.

This leads directly to the question of the value of coordinates of the topocenter. Is it worth modifying the camera? Presently, it seems likely that the ultimate accuracy claimed for satellite triangulation methods of one tenth of a second of arc is reasonable; if not at present, it certainly can be in the very near future. The Stellar-Moon Camera cannot equal this. Increasing the focal length of the camera can increase positional accuracy but then the maximum exposure on the moon must be divided by the same factor used to obtain the increased focal length. A factor of 10, for example, implies about $0\overset{''}{.}07/\mu$ plate scale, but a maximum moon exposure of 30 ms which begins to be very difficult to obtain with an occulting disk. It is interesting to note in this connection that the plate scale is only now approaching the order of magnitude of the error mentioned by Potter (see Introduction).

There is another possibility, namely, the use of the Stellar-Moon Camera for determination of coordinates at sites where (1) maximum accuracy is not necessary, and (2) the difficulty of bringing a larger system to the site is not economical. At this point the question becomes slightly modified, since, at least in theory, the geocentric coordinates can be determined by correcting astronomic coordinates for deflection of the vertical, which in turn can be derived from knowledge of the geoid. Thus the question really is, can the Stellar-Moon Camera give better results than corrected astronomic coordinates?

(There is no question here of ease; astronomic coordinates can be observed far more easily than can the Stellar-Moon Camera be set up. The assumption is made here that fully trained personnel and completely adequate logistic support is available to both systems.)

Astronomic coordinates are normally published with a probable error in the order of one-tenth of a second of arc. This, however, is a measure of internal consistency rather than overall accuracy, so a more reasonable figure for an "estimated standard deviation" (rather than probable error) is perhaps $0\overset{''}{.}3$. At present, in areas of best gravity coverage (North America, for example) it seems possible to compute the gravimetric deflection of the vertical to approximately the same accuracy. Thus any derived coordinate could be said to have an "estimated standard deviation" of about one-half second of arc. [This figure should not be taken out of context of the discussion which follows in the next paragraph.] At the opposite extreme, the gravimetric deflection of the vertical can be estimated in a remote area (a South Pacific island, for example) with an "estimated standard deviation" of at least 10 times the figure above and maybe as much as 30 times. It contributes virtually all of the uncertainty in a derived coordinate, hence such a position has an "estimated standard deviation" of from 3" to 10".

These figures must be considered with the following kept clearly in mind. At high latitudes, determination of astronomic latitude becomes difficult; determination of longitude becomes very uncertain indeed. Thus the figures in the preceding paragraph cannot serve in polar areas. For convenience, and with no lack of rigor, the figures are to considered the radius of a circle about the observation site, that is, a sort of circular error. For a rough size, the usual approximation $1'' \approx 30$ m. may be used.

The coordinates so derived are strictly "geocentric geodetic", that is, they would be geodetic coordinates relative to an ellipsoid concentric to the center of mass of the earth. The ellipsoidal parameters would be determined by the gravity formula used in computing the gravimetric deflections. Errors in the deflections come not only from uncertainties in the topocentric gravity field but also from possible systematic effects from the unsurveyed areas of the gravity field of the earth.

To evaluate the possible accuracy of the Stellar-Moon Camera, the assumption must be made that clear plates of the moon against a star background can be obtained with essentially the same equipment as on hand. If these plates were measured, it seems highly unlikely that instantaneous topocentric coordinates of the moon (right ascension and declination) can be obtained with an accuracy of better than 1". To obtain this figure the following line of reasoning was used. One μ is the limit of measuring and if other sources of error are included (image motion on small plates, pointing errors on stars, measurement errors), this figure may be taken as the standard error of unit weight. From the plate scale this is equated to $0''.7$. With an average star field of 10 reference stars (probably too large) the fraction of the standard error of unit weight in the center of the field, where the image of the moon will be, which can be maintained will be approximately 0.6.[11] The ratio of the variances of measured positions of a star and the moon are taken to be 1:4. Hence $0.7 \times 0.6\sqrt{4} = 0''.8$.

By the use of Eqs.(6) of Reference 2 (page 44),

$$x_o \sin G' + y_o \cos G' = \sigma \cos \delta \sin (\alpha' - \alpha)$$

and

$$x_o \cos G' - y_o \sin G' - z_o \operatorname{ctn} \delta' = \sigma \cos \delta \cos (\alpha' - \alpha) - \sigma \sin \delta \operatorname{ctn} \delta' \quad ,$$

a direct solution may be made for the geocentric cartesian coordinates of the observation station. However, to estimate the accuracy of the geocentric coordinates, a solution for the latitude and longitude is desired. At local geocentric transit, conditions are optimized for the determination of latitude. From the triangle consisting of the centers of the earth and moon and the observation station, the sum of the angles is

$$180° = (\phi' - \delta) + (\delta - \delta') + \arcsin \frac{\sigma}{\rho} \sin (\delta - \delta')$$

or

$$\phi' = 180° + \delta' - \arcsin \frac{\sigma}{\rho} \sin (\delta - \delta') \quad ,$$

in which the notation follows that of Reference 2. From this, simple differentiation gives

$$\frac{\partial \phi'}{\partial \delta'} = 1 + \frac{\sigma \cos (\delta - \delta')}{\sqrt{\rho^2 - \sigma^2 \sin^2 (\delta - \delta')}} \quad .$$

For the purposes of evaluation, $\sigma/\rho = 60.3$, (Ref. 12, p. 107) the latitude of the station is almost exactly 40° N, and the optimum declination of the moon is 29° S. Using these values, the error in the geocentric latitude is 176 times the error in the observed geocentric latitude; that is, if $d\delta' = 0\overset{''}{.}8$, then $d\phi' \approx \pm 141''$ or better than two minutes of arc. In this computation the geocentric radius, among other things, is assumed to be known exactly.

For the longitude there is a slight improvement. The first of Eqs. (6) of Reference 2 can be solved for the longitude:

$$\lambda' = \arcsin \frac{\sigma \cos \sigma \sin (\alpha' - \alpha)}{\rho \cos \phi'} - G' \quad ,$$

again with his notation, and again by differentiation,

$$\frac{\partial\lambda'}{\partial\alpha'} = \frac{\sigma \cos \delta \cos (\alpha' - \alpha)}{\sqrt{\rho^2 \cos^2 \phi' - \sigma^2 \cos^2 \delta \sin^2 (\alpha' - \alpha)}} .$$

Optimum conditions pertain when $\alpha' - \alpha$ is a maximum (that is, when the moon is at an hour angle of $\pm 6^h$) and also when it is at its extreme declination. Thus to evaluate the above $\delta = 29°$, $\sin (\alpha' - \alpha) \approx \rho \cos \phi'/\sigma$. From these data the error in the longitude is 94 times the error in the observed topocentric right ascension; or if $d\alpha' = \pm 0\overset{''}{.}8$, then $d\lambda' \approx 75''$. Here the geocentric latitude is considered known without error.

What can be concluded from these necessarily rough figures? Since not all sources of error have been considered, the above values can only increase with a more detailed analysis. Suppose 100 observations are made; these values can be considered to decrease by roughly an order of magnitude, to ± 14" and ± 8", respectively. These figures approach the accuracies of the corresponding determinations by astro-gravimetric methods. Integrated solutions for the cartesian coordinates by least squares may improve things somewhat. The fact is, however, that the parallax of the moon is so slight that its use for the determination of positions on earth is fraught with difficulties much too large for the present system. This does not preclude using the Baldini theory for the World Geocentric Geodetic System which is independent of the parallax of the moon and provides higher accuracies.

CONCLUSIONS

(1) The moon shutter and, to a lesser extent, the primary shutter jar the Stellar-Moon Camera enough to prevent the formation of sharp images.

(2) The Shutter Control Unit of the Stellar-Moon Camera is so electrically noisy as to prevent reliable timing of any of the shutter positions.

(3) The Stellar-Moon Camera system, even with remaining faults corrected, cannot provide geocentric coordinates as accurately or as easily as, say, the astrogravimetric method. The very recent improvements in gravimetric data are considered available for use.

(4) Statement (3) above, may not apply to the Baldini Theory.

APPENDIX I

ANALYSIS OF THE RESEAU

A brief analysis of the reseau was performed under the assumption that in making the grid lines, a mathematically straight line was actually scribed, and that deviations of the intersections from this line result from the uncertainties of the measurement. For this purpose, the given reseau coordinates were subjected to a least squares solution, one for each grid line. From the coefficients of the straight line, the grid coordinates were computed.

The printed output consists of the results in the following order:

x (1,1) obs.	x (1,2) obs.	. . .
x (1,1) comp.	x (1,2) comp.	
y (1,1) obs.	y (1,2) obs.	. . .
y (1,1) comp.	y (1,2) comp.	
. . .	. . .	

At the bottom are the coefficients of the ten straight lines involved. These data presented in the following order:

m (x_1)	b (x_1)	m (y_1)	b (y_1)
m (x_2)	b (x_2)	m (y_2)	b (y_2)
. . .		. . .	

in which the equation is $y = mx + b$. Note that the equations of the grid lines are referred to the axes of the measuring engine used in determining grid intersection coordinates.

The intended procedure was to compute the reseau coordinates of the star from the comparator coordinates (as produced by the plate measurement) of the grid lines and the star image. Thus the measured y-interval within one square of the reseau would be used to compute the x-coordinate of the star in the coordinate system of the reseau, and vice versa.

This method would have been compared to other data reduction systems before any selection of a preferred method was made.

```
1001 FORMAT(9F8.3)
1002 FORMAT(5F14.4)
1003 FORMAT(///(5X,E16.8,5X,E16.8,10X,E16.8,5X,E16.8))
1004 FORMAT( 1H )
     DIMENSIONGRID(5,5,2),EX(5,2),WHY(5,2),CGRID(5,5,2)
     READ(5,1001)GRID
     DO10I=1,5
     SUMX=0.
     SUMY=0.
     SUMX2=0.
     SUMXY=0.
     DO11J=1,5
     SUMX=SUMX+GRID(I,J,1)
     SUMY=SUMY+GRID(I,J,2)
     SUMX2=SUMX2+GRID(I,J,1)**2
     SUMXY=SUMXY+GRID(I,J,1)*GRID(I,J,2)
  11 CONTINUE
     DET=(5.0*SUMX2-SUMX**2)
     WHY(I,1)=(5.0*SUMXY-SUMX*SUMY)/DET
     WHY(I,2)=(SUMX2*SUMY-SUMX*SUMXY)/DET
  10 CONTINUE
     DO20J=1,5
     SUMX=0.
     SUMY=0.
     SUMY2=0.
     SUMXY=0.
     DO21I=1,5
     SUMX=SUMX+GRID(I,J,1)
     SUMY=SUMY+GRID(I,J,2)
     SUMY2=SUMY2+GRID(I,J,2)**2
     SUMXY=SUMXY+GRID(I,J,1)*GRID(I,J,2)
  21 CONTINUE
     DET=(5.0*SUMY2-SUMY**2)
     EX(J,1)=(5.0*SUMXY-SUMX*SUMY)/DET
     EX(J,2)=(SUMY2*SUMX-SUMY*SUMXY)/DET
  20 CONTINUE
     DO30I=1,5
     DO31J=1,5
     CGRID(J,I,1)=EX(I,1)*GRID(J,I,2)+EX(I,2)
     CGRID(J,I,2)=WHY(J,1)*GRID(J,I,1)+WHY(J,2)
  31 CONTINUE
  30 CONTINUE
     DO41I=1,5
     DO40K=1,2
     WRITE(6,1002)(GRID(I,J,K),J=1,5)
     WRITE(6,1002)(CGRID(I,J,K),J=1,5)
     WRITE(6,1004)
  40 CONTINUE
     WRITE(6,1004)
  41 CONTINUE
     WRITE(6,1003)(EX(I,1),EX(I,2),WHY(I,1),WHY(I,2),I=1,5)
     STOP
     END
```

$DATA

-20.0450	-10.0250	-0.0040	10.0160	20.0360
-20.0454	-10.0252	-0.0040	10.0158	20.0366
20.0420	20.0420	20.0420	20.0420	20.0430
20.0418	20.0420	20.0422	20.0424	20.0426
-20.0430	-10.0230	-0.0010	10.0190	20.0400
-20.0429	-10.0227	-0.0015	10.0186	20.0393
10.0210	10.0220	10.0220	10.0220	10.0230
10.0212	10.0216	10.0220	10.0224	10.0228
-20.0410	-10.0200	0.	10.0200	20.0420
-20.0404	-10.0202	0.0010	10.0214	20.0420
0.0010	0.	0.	0.	0.0010
0.0004	0.0004	0.0004	0.0004	0.0004
-20.0380	-10.0180	0.0040	10.0250	20.0450
-20.0379	-10.0177	0.0035	10.0242	20.0447
-10.0210	-10.0210	-10.0210	-10.0200	-10.0190
-10.0214	-10.0209	-10.0204	-10.0199	-10.0194
-20.0350	-10.0150	0.0060	10.0270	20.0470
-20.0354	-10.0152	0.0060	10.0270	20.0474
-20.0410	-20.0400	-20.0410	-20.0410	-20.0390
-20.0410	-20.0407	-20.0404	-20.0401	-20.0398

-0.24947541E-03	-0.20040400E 02	0.19968400E-04	0.20042199E 02
-0.24948245E-03	-0.10020200E 02	0.39916275E-04	0.10022000E 02
-0.24947809E-03	0.10000998E-02	0.59770899E-09	0.40000000E-03
-0.27941582E-03	0.10021400E 02	0.49893978E-04	-0.10020400E 02
-0.26945788E-03	0.20042000E 02	0.29928622E-04	-0.20040400E 02

APPENDIX II

BACKGROUND TO THE MEASUREMENT FACILITY

Equipment of several University departments, of a branch of the State government, and of several local firms were considered by the writer for use in measurements to be made on the present contract. All were found unsuitable for one or more reasons. At one time just after the contract had been signed, it appeared likely the measurements could be made on a new stereocomparator to be purchased by the Department. However, by this time the decision had been made to try measurements with the special reticle and this instrument could not be operated with a reticle other than the basic design.

Much time was also spent in investigating the possibility of performing the measurements under contract to another organization. This had one distinct advantage; namely, the time spent in measuring would, in effect, become so much time added to that of the effort on the part of the principal investigator. This too proved impractical for the simple reason that the cost of modifying an existing instrument to take the new reticle plus the contract costs for measurement nearly equalled the purchase price of a comparator with the new reticle installed.

Thus in April 1967, a purchase order, duly approved, was issued for a new monocomparator with the reticle of special design. Delivery was promised within 90 days, and in July the instrument arrived in Columbus.

Prior to signing the contract, the University was notified of the possibility it would be called upon to provide suitable space for such a measuring device. When the order for the comparator was written reminders were made that now the actual need had arisen. When no action had been taken by the University, the Department of Geodetic Science kindly made space available and after some difficulty with funds had been cleared up, the work order for modification to the space was written in September.

Work began in mid-December and occupancy was in the second week of January. Trouble was immediately experienced with the temperature control. After several weeks of attempting to get the temperature within reason it was discovered the air conditioning system is such that in winter it can only heat, in summer, only cool. Since the temperature was too high to begin with and could only be increased (until summer), all thought of measurement was abandoned since new thermal controls could not be ordered, much less installed, within the three weeks then remaining in the active part of the contract. Instead the comparator was used to examine all photographs taken. An informal effort was also made to determine how consistently pointings could be made on the lunar image, but no conclusions were drawn.

The complaint has been made that the comparator should not have been unpacked with only six weeks left in the contract. However, it is not the intent or meaning of the contract or principal investigator to purchase an expensive item of precision equipment merely to leave it uncrated if there is any hope at all of getting useful information. Such useful information was definitely obtained, although by no means as much as was hoped for, even as late as January 1968.

APPENDIX III

FIELD PROCEDURES

Since the film back can be used simply by remounting it, the following procedural routine is included as being suitable to ensure proper sequencing of connections and operations.

1. Turn Power Switch ON
2. Turn Sidereal Drive Switch ON
3. Cock primary shutter
4. Open backing plate
5. Load film
6. Advance film to stop
7. Close backing plate
8. Set f-stop if necessary
9. Aim camera at moon
10. Set Moon Shutter Delay control
11. Set Moon Shutter Duration control
12. Set Moon Shutter switch to AUTO
13. Plug in timing cable between Control Unit and Chronofax
14. Expose frame
15. Disconnect timing cable at Chronofax
16. Cock primary shutter
17. Open backing plate
18. Repeat steps 6 through 18 as necessary to make as many exposures as desired or to use up entire film
19. Roll out remainder of film
20. Remove film
21. Close backing plate
22. Relax primary shutter
23. Turn Sidereal Drive Switch OFF
24. Turn Power Switch OFF

For use with glass plates, the procedure is very similar but is given here in detail to avoid confusion.

1. Turn Power Switch ON
2. Turn Sidereal Drive Switch ON
3. Cock primary shutter
4. Open backing plate
5. Remove reseau cover
6. Load plate holder (A dark bag, or "portable darkroom," was used)

7. Mount plate holder on camera
8. Withdraw dark slide
9. Close backing plate
10. Set f-stop, if necessary
11. Aim camera
12. Set Moon Shutter Delay Control
13. Set Moon Shutter Duration Control
14. Set Moon Shutter Switch to AUTO
15. Plug in Timing Cable between Control Unit and Chronofax
16. Expose frame
17. Disconnect timing cable at Chronofax
18. Cock primary shutter
19. Open backing plate
20. Insert dark slide
21. Remove plate holder
22. Remove exposed plate
23. Repeat steps 6 through 23 as necessary for complete sequence of exposures.
24. Mount reseau cover
25. Close backing plate
26. Relax primary shutter
27. Turn Sidereal Drive Switch OFF
28. Turn Power Switch OFF

Some comments regarding the exposure of the plate seem desirable. As originally designed, the primary shutter was controlled entirely manually; that is to say, each of the four positions of this shutter (RELAXED, COCKED, OPEN, CLOSED) was produced by individual manipulations by the operator. For some reason, closing this shutter at the appropriate time was difficult to remember; automating this one step seemed desirable on two counts; (1) it removed one operation, and (2) it made field exposures more uniform.

The primary shutter control now operates in the following fashion:

For normal exposures, the switch is pushed to OPEN for at least two full seconds, and then released. This one operation performs three functions; i.e., (1) the primary shutter is opened immediately, (2) the moon shutter timing sequence is started, and (3) a synchronous motor is started. This motor has a 60 rpm shaft and near the end of the first rotation, a cam on the motor shaft activates the switch to close the primary shutter, and then, in turn, shuts off the motor itself.

The primary shutter can be opened by tapping the switch towards OPEN. It cannot be closed except by starting the motor and allowing it to make its full cycle. The moon shutter can be opened and closed manually at any time regardless of the condition of the primary shutter.

In making these modifications, the switch provided by the manufacturer was rebuilt, and the synchronous motor added. These modifications, as in fact all made during this research effort, are wholly reversible.

The change has not been entirely successful. The cam seems to be slightly temperature sensitive, although adjustment is easily made. The duration of the field exposure, at present about 55 seconds, can be changed but not easily. But it does work and does relieve the operator of watching the clock during exposures.

Some similar provision, perhaps more sophisticated, should be included in any redesign of the Control Unit.

In loading the plate holder, the plate is put in along one long side first. Then each corner is held by one finger as the other side is forced against the pressure of the sponge and under the two retainers of the plate holder. Once the plate is in place, it is checked to make sure it moves freely, marked with a pencil for plate number and date of exposure, and covered by the dark slide.

Removal starts by depressing a long side to the bottom of the holder. The other side pops out from beneath the retainers. Finger prints in the corners of the plate only will not damage the field of interest.

The sequence in which plates were taken is derived mainly from Reference 2. To the end of providing convenient data for field use, a computer program was designed to print the approximate topocentric coordinates at even hours before and after transit of the moon. Required for the program were data copied directly from the American Ephemeris and Nautical Almanac for the hour (or day, depending on the tabulation interval) nearest local transit time. A listing of the source program statement listing, together with one nonlibrary subroutine, and a typical page of output follows. The equations on which the computations are based are taken from the same paper. The source program language is IBM FORTRAN IV.

```
 101 FORMAT(I1)
 102 FORMAT(2F2.0,F5.3,F6.3,F3.0,F2.0,F4.2,F7.2,F2.0,F5.3,F6.3,3F2.0,F5
    1.3)
 103 FORMAT(1H ,3I3,3X,3I3,3X,3I3,3X,3I3)
 104 FORMAT(1H0,4X,2HUT,9X,3HLST,10X,2HRA,9X,3HDEC)
     DIMENSIONALPHA(11),DELTA(11),THETA(11),CLOCK(11),SIGMA(11),IO(12)
     READ(5,101)N
   5 READ(5,102)RAH,RAM,RAS,DRA,DD,DM,DS,DDEC,PM,PS,DP,ETO,GSTOH,GSTOM,
    1GSTOS
     WRITE(6,104)
     DRA=DRA*0.727221E-04
C    TSEC/TSEC TO RAD/TSEC
     ALPHA(6)=TIME(RAH,RAM,RAS)
     THETA(6)=TIME(GSTOH,GSTOM,GSTOS)+0.26251617*(ETO-0.01)-1.4493105
C    THETA=GSTO(RADS)+1.0027*RADS/HR*UT-LONG(RADS)
     FACT=(ALPHA(6)-THETA(6))/(0.26251617-DRA)
     CLOCK(6)=ETO-0.01+FACT
C    TRANSIT TIME IN U.T. HOURS
     ALPHA(6)=ALPHA(6)+DRA*FACT
     THETA(6)=THETA(6)+0.26251617*FACT
     DDEC=0.48481368E-05*DDEC
     DELTA(6)=ARC(DD,DM,DS)+DDEC*FACT
     DO1I=1,11
     IF(I.EQ.6)GOTO1
     TEMP=I-6
     CLOCK(I)=CLOCK(6)+TEMP
     ALPHA(I)=ALPHA(6)+TEMP*DRA
     DELTA(I)=DELTA(6)+TEMP*DDEC
     THETA(I)=THETA(6)+TEMP*0.26251617
   1 CONTINUE
C    UT, LST, AND GEOCENTRIC RA AND DEC
     TEMP=12.
     IF(ETO.LT.12.)TEMP=0.
     FACT=(CLOCK(6)-TEMP)/12.
     DP=DP*0.48481368E-05
     PM=ARC(0.,PM,PS)+FACT*DP
     SIGMA(6)=1./SIN(PM)
C    LUNAR DISTANCE AT TRANSIT
     DP=DP/12.
C    CONVERT DELTA PARALLAX TO HOURLY RATE
     DO2I=1,11
     IF(I.EQ.6)GOTO2
     TEMP=I-6
     SIGMA(I)=1./SIN(PM+TEMP*DP)
   2 CONTINUE
C    LUNAR DISTANCES
     DO3I=1,11
     TEMP=ALPHA(I)-THETA(I)-1.4493105
     SING=SIN(TEMP)
     COSG=COS(TEMP)
     DENOM=SIGMA(I)*COS(DELTA(I))-0.09295789*COSG+0.76140677*SING
     TEMP=ATAN((0.09295789*SING+0.76140677*COSG)/DENOM)
     DELTA(I)=ATAN(COS(TEMP)*(SIGMA(I)*SIN(DELTA(I))-0.63945982)/DENOM)
     ALPHA(I)=ALPHA(I)+TEMP
   3 CONTINUE
```

```
C      X=0.09295789,Y=0.76140677,Z=0.63945982 AT GS OBS.
C      TOPOCENTRIC RA AND DEC
       DO4I=1,11
       IF(ALPHA(I).LT.0.)ALPHA(I)=ALPHA(I)+6.2831853
       IF(ALPHA(I).GE.6.2831853)ALPHA(I)=ALPHA(I)-6.2831853
       IF(THETA(I).LT.0.)THETA(I)=THETA(I)+6.2831853
       IF(THETA(I).GE.6.2831853)THETA(I)=THETA(I)-6.2831853
       IF(CLOCK(I).LT.0.)CLOCK(I)=CLOCK(I)+24.
       IF(CLOCK(I).GE.24.)CLOCK(I)=CLOCK(I)-24.
       IO(1)=CLOCK(I)
       CLOCK(I)=(CLOCK(I)-FLOAT(IO(1)))*60.
       IO(2)=CLOCK(I)
       IO(3)=(CLOCK(I)-FLOAT(IO(2)))*60.+0.5
       IO(4)=THETA(I)/0.26179939
       THETA(I)=THETA(I)-0.26179939*FLOAT(IO(4))
       IO(5)=THETA(I)/0.43633231E-02
       IO(6)=(THETA(I)-0.43633231E-02*FLOAT(IO(5)))/0.727221E-04+0.5
       IO(7)=ALPHA(I)/0.26179939
       ALPHA(I)=ALPHA(I)-0.26179939*FLOAT(IO(7))
       IO(8)=ALPHA(I)/0.43633231E-02
       IO(9)=(ALPHA(I)-0.43633231E-02*FLOAT(IO(8)))/0.727221E-04+0.5
       IO(10)=DELTA(I)/0.17453293E-01
       IF(DELTA(I).LT.0.)DELTA(I)=ABS(DELTA(I))
       DELTA(I)=DELTA(I)-0.17453293E-01*ABS(FLOAT(IO(10)))
       IO(11)=DELTA(I)/0.29088822E-03
       IO(12)=(DELTA(I)-0.29088822E-03*FLOAT(IO(11)))/0.48481368E-05+0.5
       WRITE(6,103)(IO(J),J=1,12)
     4 CONTINUE
       N=N-1
       IF(N.GT.0)GOTO5
       STOP
       END
```

```
  FUNCTIONTIME(A,B,C)
  A=A*15.
  B=B*15.
  C=C*15.
  ENTRYARC(A,B,C)
  FACT=1.
  IF(.NOT.(A.LT.0.))GOTO1
  A=-A
  FACT=-FACT
1 TIME=(A*0.17453293E-01+B*0.29088822E-03+C*0.48481368E-05)*FACT
  RETURN
  END
```

45

FEB 13

UT	LST	RA	DEC
23 58 32	3 54 47	8 47 9	22 41 47
0 58 32	4 54 56	8 49 7	22 35 26
1 58 32	5 55 6	8 50 54	22 28 29
2 58 32	6 55 16	8 52 33	22 20 43
3 58 32	7 55 26	8 54 6	22 11 60
4 58 32	8 55 36	8 55 36	22 2 12
5 58 32	9 55 46	8 57 6	21 51 19
6 58 32	10 55 56	8 58 39	21 39 26
7 58 32	11 56 5	9 0 18	21 26 39
8 58 32	12 56 15	9 2 6	21 13 10
9 58 32	13 56 25	9 4 4	20 59 13

FEB 14

Full Moon

14 Feb 0h43 UT

UT	LST	RA	DEC
0 50 31	4 50 51	9 43 36	18 1 45
1 50 31	5 51 1	9 45 29	17 51 40
2 50 31	6 51 10	9 47 12	17 41 5
3 50 31	7 51 20	9 48 46	17 29 48
4 50 31	8 51 30	9 50 15	17 17 45
5 50 31	9 51 40	9 51 40	17 4 49
6 50 31	10 51 50	9 53 5	16 51 3
7 50 31	11 51 60	9 54 34	16 36 28
8 50 31	12 52 10	9 56 9	16 21 13
9 50 31	13 52 19	9 57 52	16 5 27
10 50 31	14 52 29	9 59 46	15 49 20

FEB 15

UT	LST	RA	DEC
1 40 22	5 44 46	10 37 51	12 14 28
2 40 22	6 44 56	10 39 40	12 1 13
3 40 22	7 45 6	10 41 19	11 47 36
4 40 22	8 45 16	10 42 50	11 33 29
5 40 22	9 45 26	10 44 14	11 18 48
6 40 22	10 45 36	10 45 36	11 3 33
7 40 22	11 45 46	10 46 57	10 47 43
8 40 22	12 45 55	10 48 22	10 31 23
9 40 22	13 46 5	10 49 53	10 14 39
10 40 22	14 46 15	10 51 32	9 57 36
11 40 22	15 46 25	10 53 21	9 40 23

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13. ABSTRACT

This reports the results of tests on the Stellar-Moon Camera and associated equipment under field conditions. Major emphasis was placed on determining sources of error by whatever means necessary, and, within limits, making modifications to equipment or methods to overcome these errors. The tests show that the present form of the camera is not capable of obtaining topocentric coordinates of the moon of sufficient accuracy to warrant further development.

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