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THIRD QUARTERLY REPORT

DESIGN STUDY
FOR
LUNAR EXPLORATION HAND TOOLS

By Donald S. Crouch

July 1965

Prepared under Contract No. NAS 9-3647 by

MARTIN COMPANY
Baltimore, Maryland 21203

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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ABSTRACT

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The purpose of this report is to present the result of the third three months work performed for the Design Study of Lunar Exploration Hand Tools, under NASA contract NAS 9-3647. Operational and spacesuit interface tests of the first prototype Powered Lunar Geologist Tool were conducted, and design criteria were established for the second model. Additional feasibility tests were conducted for the selection of a range finder surveying instrument which will best meet the early lunar surface exploration requirements. Detail design and fabrication of a sample weighing device, hand lens, and hand-held geologist hammer were commenced.

Author

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SUMMARY

The first prototype model Powered Lunar Geologist Tool was completed during this report period. The basic tool is capable of obtaining geological rock specimens by "chipping" using an axial percussive blow, or by "coring" using a variable energy, rotary-percussion mode. An adjustable energy blow was found desirable for effective chipping or coring where a variety of rock hardnesses may be encountered. Operational and spacesuit interface tests revealed several design areas which will be improved on the second prototype model PLGT:

- Weight of the first model PLGT was reduced from 47.5 to 39.5 pounds by substitution of the HR-21 silver-zinc batteries with the HR-15 type. A further weight reduction to approximately 32 pounds is anticipated for the second model device.
- A redesign of the basic percussion mechanism will be accomplished in order to increase power operating efficiency.
- A relocation of the center of gravity will be accomplished by moving the percussion and battery compartments closer to the upper T-bar handle.

A series of tests were performed to determine the optimum type of rangefinding instrument to be employed with the lunar geological tool kit. This study was limited to lightweight optical instruments, which are considered to be most adaptable for the early lunar missions. Of the instruments evaluated, the coincidence image range finder appears most suitable for use by the astronaut in consideration of handling and rapidity of operation. The alidade-type instrument provides a higher degree of accuracy, but the time required for its use and the fact that a reference stadia rod must be employed reduces the usefulness of the instrument.

Detail design drawings for the PLGT clinometer platform, sample weighing scale, geological hand lens, and a geological sampling hammer were completed. Fabrication of the clinometer platform was completed and fabrication of the other items is currently in progress.

INTRODUCTION

The initial three-month period of this Study consisted of an evaluation of the basic data influencing the design of the geological exploration hand tools. This included the lunar geological and environmental factors, human factors evaluation, and the Apollo LEM interface requirements. As a result of the basic data evaluation a potential design approach was selected for the PLGT and related auxiliary equipment. Preliminary operating parameters were established and detail design study requirements were defined. The results of this phase of the Study were presented in the First Quarterly Report.

The second quarter of the Study consisted of a lunar geological task analysis in order to define in detail the exploration tool requirements. Subsequently, several design approaches were studied and various feasibility tests were conducted in order to evaluate the selected approaches. The results of this phase of the Study were presented in the Second Quarterly Report.

An evaluation of the first prototype model PLGT was conducted during this report period and design criteria established for the second model device to be fabricated during the remainder of the Program. Additional feasibility tests were conducted and detail design drawings for some of the auxiliary geological equipment were completed.

This report includes the work performed from April 26 through July 26, 1965 and was conducted under the auspices of Mr. W. Benckert, Program Manager, and Mr. M. B. Goldman, Manager of Logistic Support, Baltimore Division, Martin Company. Other individuals and their specialty areas, who are contributing to this program include:

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POWERED LUNAR GEOLOGIST TOOL

First Prototype Model

The first prototype model PLGT (Figure 1) was completed during this quarterly report period. This device was fabricated in accordance with the preliminary design criteria established during the feasibility test program. The design criteria was based on spacesuit interface tests for the determination of PLGT envelope, and coring tests for the specification of rotary and rotary impact mechanization requirements.

Basically, the first prototype model PLGT possesses a rotary, rotary-percussion and hammering/chipping capability. The early feasibility tests demonstrated the requirement for a variable energy percussive blow in order to effectively core a wide range of material hardnesses.

Basic rotary power for the PLGT is supplied by fourteen (14) HR-21 Yardney silver-zinc batteries which drive a permanent magnet-type, 28 vdc motor. Percussive energy is supplied by a single lobe cam (rise parallel to rotative axis) which is axially displaced by its cam surface riding in contact with a flange of the percussor shaft. The cam is driven through a single gear reduction (3.9:1) from the motor shaft at 2500 rpm. As the cam rotates the percussor shaft retracts, compresses the impact spring and releases, thus transmitting the spring energy to the percussor shaft and core bit. The single lobe cam provides a percussion frequency of 2500 blows per minute.

The percussor shaft assembly is screw-connected to an adjustable wheel (Figure 2) located between the percussion and battery compartments. Rotation of the wheel causes the percussor assembly and its cam contacting flange to move relative to the stationary axial cam. This results in a variable cam travel which, in turn, permits adjustment of impact energy. A slip clutch is incorporated in the drive train to limit reaction torque to approximately 12 foot-pounds in order to assure that the restraining capability of the astronaut is not exceeded in the 1/6-G environment.

The lower restraint handles illustrated in Figure 2 were originally incorporated to permit sample trimming with a greater degree of controllability. This design feature would allow the lower portion of the PLGT to be mechanically separated from the battery compartment (electrically connected by use of a small jumper cable) and employed as a sample trimming device on a work platform in the vicinity of the LEM spacecraft. However, since it is doubtful that sufficient time will be available to permit meticulous trimming of the lunar surface specimens, the second model PLGT will not incorporate the lower handles. The astronaut will be required to chip or core samples of the correct approximate size at the point of acquisition.

The first prototype model PLGT weighed 47.5 pounds with the HR-21 silver-zinc cells. This was subsequently reduced to 39.5 pounds by employment of HR-15 cells and a lighter battery case. Additional weight saving features will be incorporated on the second prototype model PLGT.

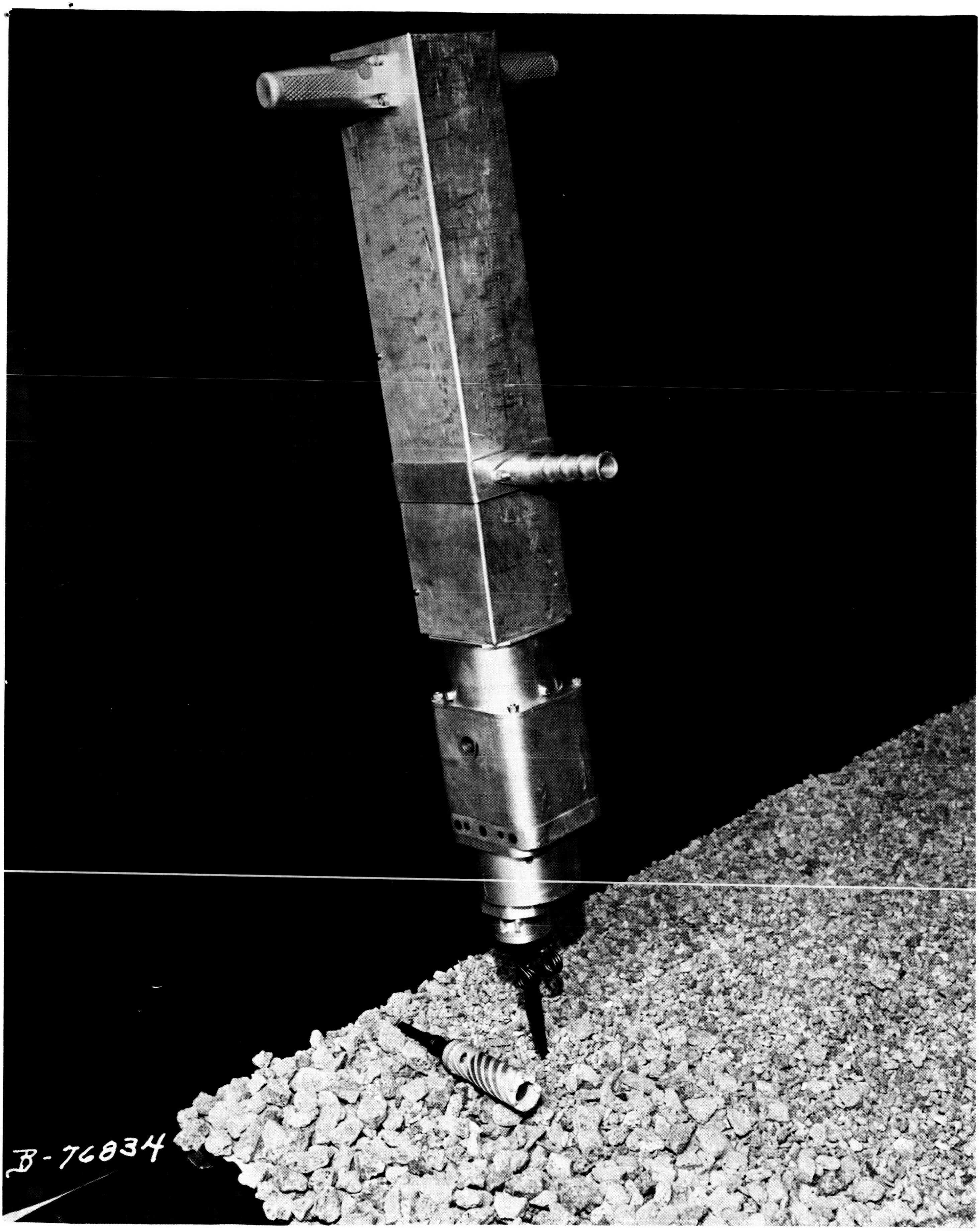


Figure 1. First Prototype Model PLGT

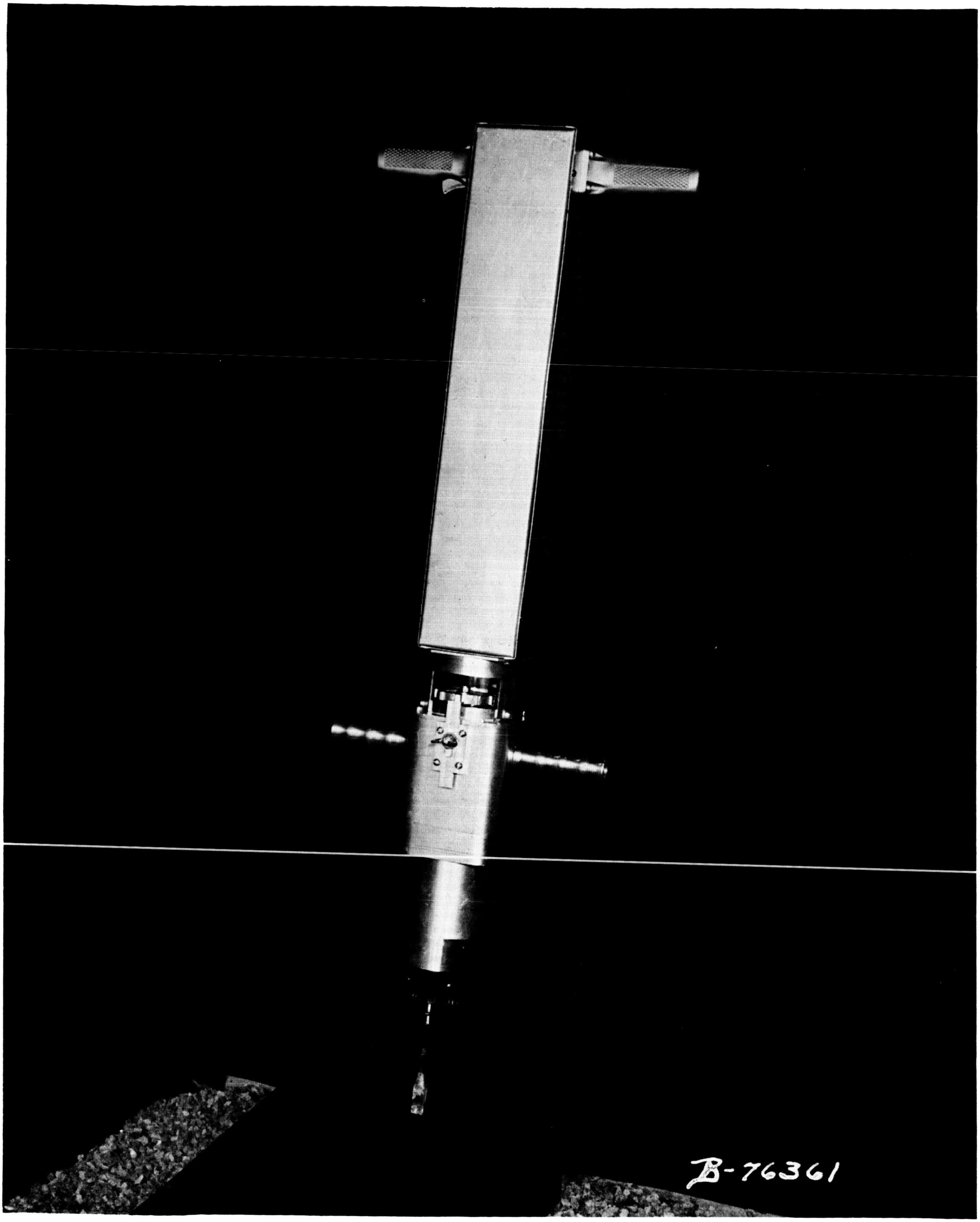


Figure 2. PLGT with Lower Restraint Handles

Operational Test Results

Operational tests of the PLGT in a variety of rock samples (hard, vesicular and porous basalt; obsidian; pumice) revealed that the chipping mode requires the least expenditure of energy per unit volume of specimen. The machine with its current percussion mechanism requires approximately 20 amperes at 26 volts when either chipping or coring. Therefore, the battery would provide approximately 1.5 hours of operating time before recharge was required. The chip samples can be obtained in a relatively short period of time varying from 15-20 seconds depending on the size of the specimens. Larger samples of the harder materials (basalts) can be obtained by chipping a groove into the material and "shaping" the desired specimen until rock fracture occurs.

The coring capability of the PLGT in hard rock material is not as effective as the chipping mode. Penetration rates ranging from 1/4 to 3/4 inches per minute were obtained in the hard and vesicular basalt samples respectively. Coring rates in the porous basalt, obsidian and pumice were significantly higher, but core retention was difficult with the standard type tungsten-carbide bits. The number of core samples (4 inches long by 1 inch diameter) anticipated per battery charge are as follows:

Material	Cores Per Battery Charge
Hard Basalt	4
Vesicular Basalt	14
Granite	4
Obsidian	12
Porous Basalt	20
Pumice	30

Two techniques can be employed for improving core retention: 1) increase core diameter while maintaining the same cutting kerf; or 2) decrease cutting kerf and maintain the same core diameter. The first technique is undesirable because the resulting increase in core bit cutting area will require a corresponding increase in battery power requirements. The second technique is preferred because core retention will improve with a corresponding decrease in power requirement resulting from the reduced core bit cutting area.

The standard tungsten-carbide coring bits (Figure 1) employed during the evaluation tests were approximately 1 inch I.D. by 1.5 inches O.D. (1/4 inch kerf). The Pratt and Whitney Tool Company attempted to fabricate a 1/8 inch kerf bit but was unsuccessful due to failure of the carbide brazing material. The scope of this program cannot permit a thorough study and optimization of the tungsten-carbide bits for this particular application. However, since the efficiency of the core bit is extremely important for the PLGT, an optimization program would be justified.

Coring of soft materials such as pumice can best be accomplished by means of a pure rotary mode using a thin-wall bit instead of the tungsten-carbide. Transport to earth of these "fragile" core samples in the thin-wall core bit used for obtaining the sample should be considered as a means of ensuring core retention. Additional investigation of this technique will continue.

Spacesuit Interface Tests

A series of spacesuit interface tests (Figures 3 and 4) were conducted with the first prototype model PLGT to identify possible problem areas which should be corrected on the subsequent model. The major problem areas include:

1. Weight - Under a 1-G environment, handling of the 39.5 pound PLGT was somewhat difficult. Operation of the PLGT under a 1/6-G condition would present less of a problem, but since the weight of the auxiliary equipment (scale, surveying instrument, clinometers, etc.) must also be considered, a general weight reduction of the entire integrated tool kit is mandatory.

2. Center of Gravity - The first prototype model PLGT center of gravity was located approximately at the transition section between the motor and battery compartment. Since the spacesuit restricts the location of the upper and auxiliary handles to a narrow separation, it is somewhat difficult to operate the PLGT in the rock chipping mode with the extreme location of center of gravity. Therefore, a relocation of components should be accomplished in order to shift the center of gravity upward, preferably between the upper and auxiliary handles.

3. Handle Location - Wrist flexing limitations of the spacesuit dictates that the auxiliary PLGT handle should be relocated at a 45-degree angle with respect to the T-bar handles. Also, it may be desirable to slant the T-bar handles downward for a more efficient interface with the spacesuit during the chipping mode.

4. Percussion Adjustment - Rotation of the percussive energy control wheel was somewhat difficult for the spacesuited operator. A design improvement should be incorporated to correct this problem.

Second Prototype Model PLGT

The rotary and percussion mechanisms for the second prototype model PLGT will be redesigned in order to incorporate various improvements which were deemed mandatory as a result of the first prototype model operational tests. The design changes are primarily oriented toward weight reduction, power operating efficiency and controllability.

The rotary drive system for the second model will be lightened somewhat by the elimination of one reduction gear. A triple reduction spur gear assembly (47/11 x 50/21 x 49/21 = 23.7:1) will be employed to step-down the nominal load operating speed of the motor from 6494 to 274 rpm at the core bit. This is somewhat higher than the first prototype model which incorporated a quadruple reduction spur gear assembly (47/12 x 47/19 x 45/17 x 43/21 = 52:1) with an output speed of approximately 170 rpm. The nominal load operating speed of the first prototype model was higher at 8840 rpm, but possessed a lower torque. The increased core bit speed of the second model is expected to improve coring efficiency.

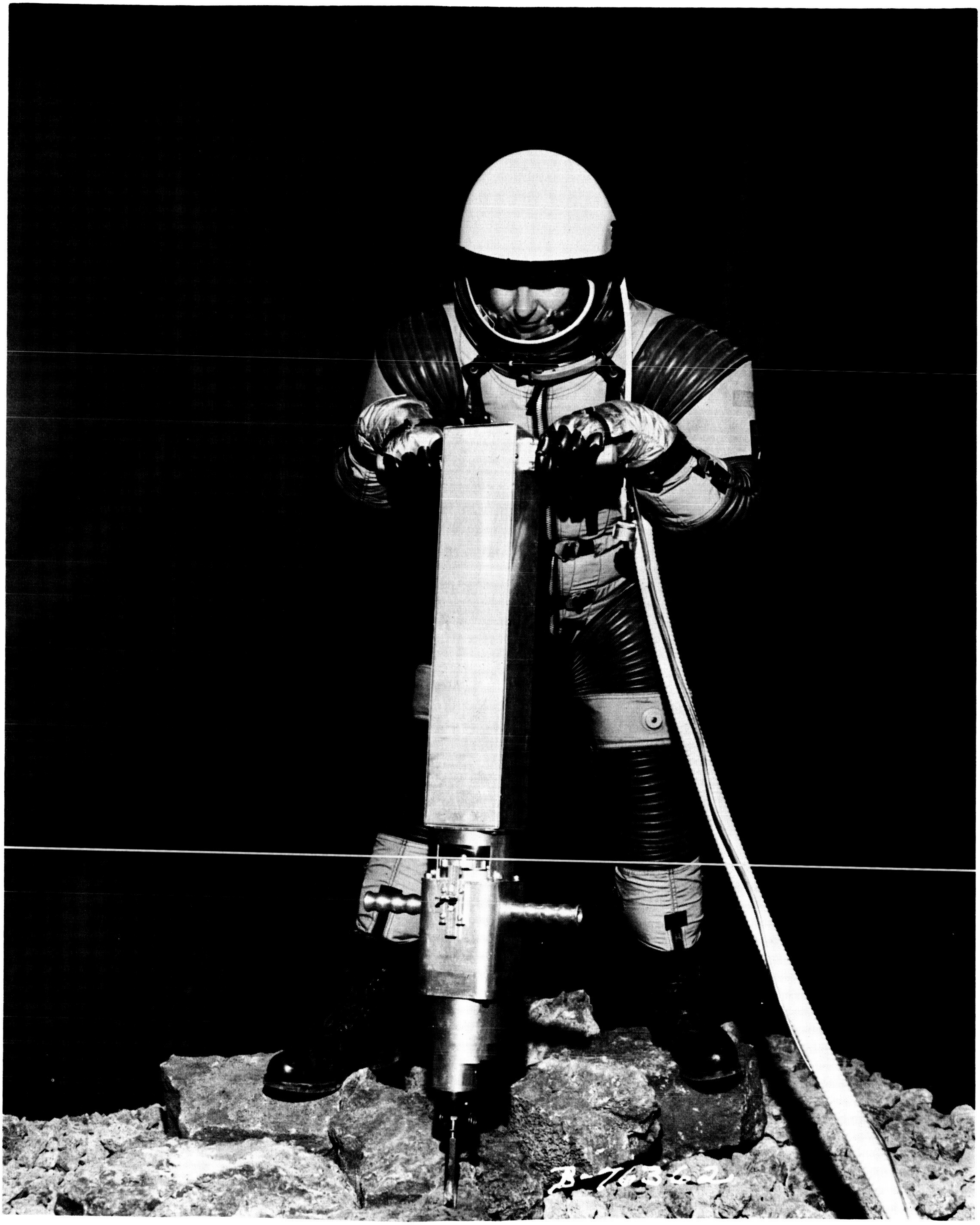


Figure 3. PLGT Rock Coring Spacesuit Interface Tests

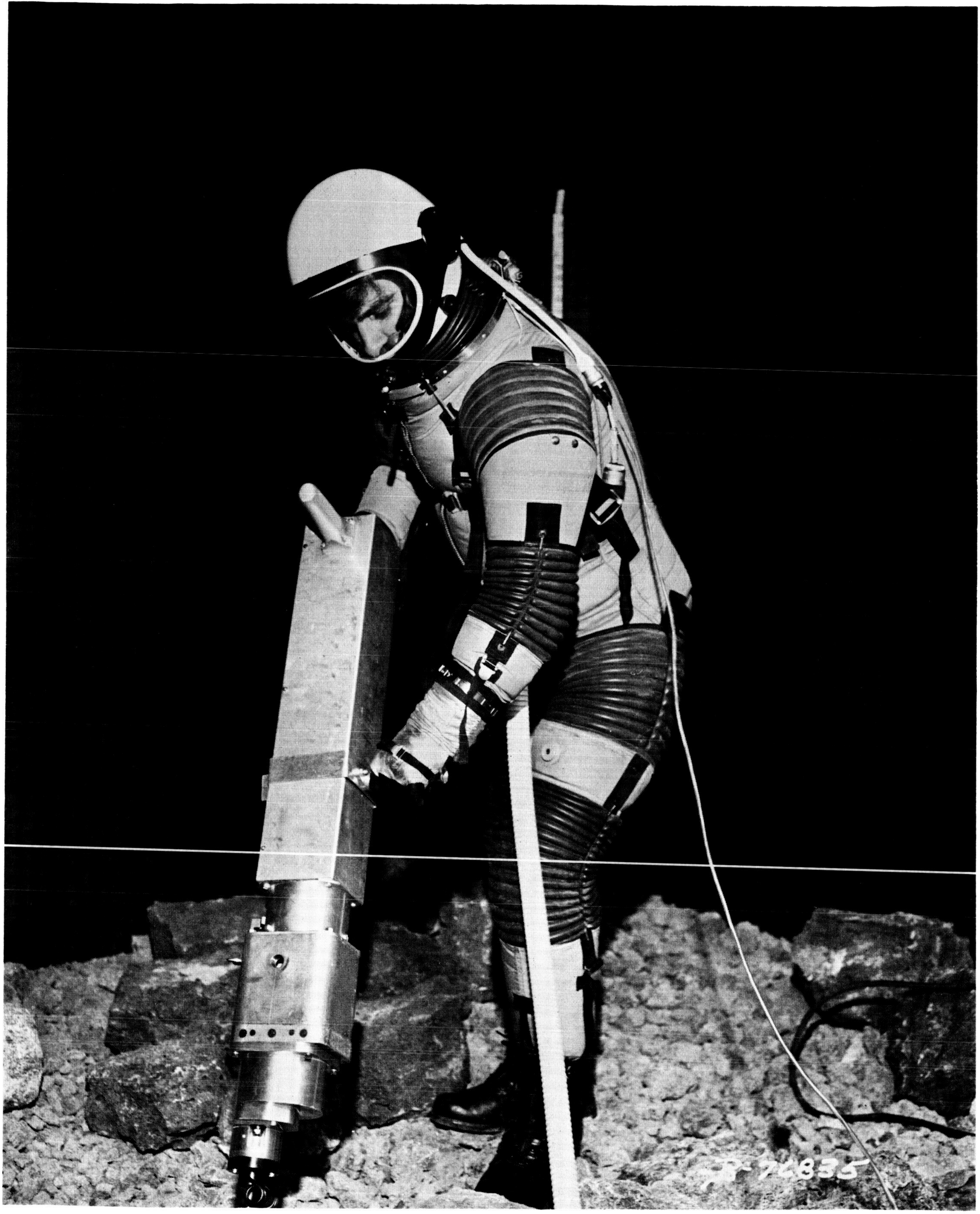


Figure 4. PLGT Rock Chipping Spacesuit Interface Tests

The single lobe cam for the first model PLGT was driven from the first reduction gear. A three-lobe cam will be employed in the second model which will be driven from the 47/11 gear through an additional 87/47 gear for a total reduction of 7.9:1. This will result in an impacting frequency of 2500 blows per minute by the three-lobe cam.

A softer, pre-loaded spring (210 pounds per inch) will be employed in the second model percussion assembly which will operate over a maximum range of 105 to 198 pounds. This will result in an impacting energy adjustable from 0 to 67 inch-pounds. This compares favorably to the "hard" spring (314 pounds per inch) employed in the first model which operated over a range of 5 to 181 pounds. The adjustable impacting energy for this model ranged from 0 to 52 inch-pounds.

The three-lobe cam of the second model PLGT operates similarly to the single lobe cam of the first PLGT. The assembly consists of two three-lobe cams; one is held stationary in the housing and the other is rotated by the 87/47 gear. The rotary cam is spline-driven and is mated axially against the stationary cam by means of the percussion spring. Rotation of the spline-driven cam results in axial movement against the spring, compression and subsequent impact against the striker when the lobe crest is passed.

The stationary cam is screw-connected to a nut located in the housing. The nut is geared to a manually operated wheel located on the outside of the tool housing. When the wheel is rotated, the stationary cam is moved axially to vary the lobe clearance with the rotating cam which, in turn, varies the percussion energy.

The outer envelope (Figure 5) anticipated for the second model PLGT will be modified significantly in order to reduce weight and shift the center of gravity between the T-bar and auxiliary handles. The fourteen (14) HR-15 silver-zinc cells will be packaged in a pressurized container located above the motor and percussor housing. Replacement of the battery pack can be rapidly accomplished if required. Space will be provided around the motor and percussor housing for stowage of core bits, chisel points, hand lens and range finder. The surveying platform and clinometers will telescope out of the small housing located above the battery pack. A sample container bag located below the motor and percussor housing, restrained by the drive shank housing, is currently being considered.

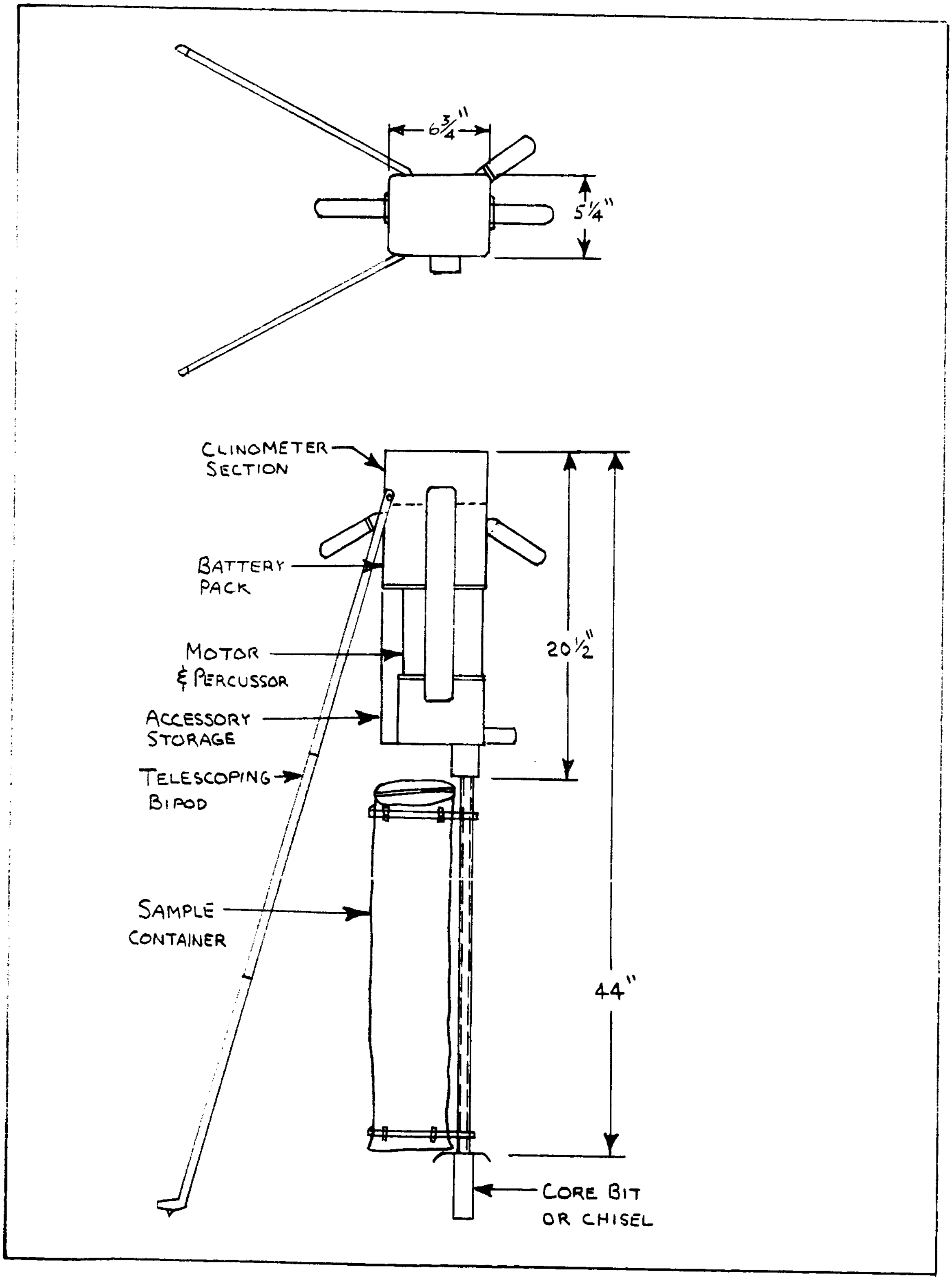


Figure 5. Design Sketch - Second Prototype PLGT

AUXILIARY GEOLOGICAL SAMPLING TOOLS

Geological Sampling Hammer

To further evaluate the capability of an astronaut to obtain lunar surface specimens with the use of a hammer instead of a powered tool, a second hand-held geologist pick was designed and is currently being fabricated. This hammer incorporates various design features which were deemed mandatory as a result of several spacesuit interface tests conducted with the first model (Ref: Second Quarterly Report) sampling tool. These design features (Figure 6) include:

1. Weight - The hammer head weight was increased substantially above that of standard commercial tools. This weight (4.015 pounds) combined with the handle and accessory hardware will total approximately 6.49 pounds.

2. Handle Grip - A new handle grip was designed to more effectively interface with the spacesuit glove. Previous handle designs were based on the use of the tool by both left and right-handed operators. The new design is tailored for a right (or left) handed operator. The rear of the handle is slanted toward the direction of "swing" in order to assure contact of the hammer head with the rock without excessive wrist motion.

3. Hammer Head - The hammer consists of a blunt end for rock fracturing, and a hatchet-type edge which can be rotated parallel or perpendicular to the direction of swing. The hatchet edge was found to be effective for cutting materials such as pumice.

4. Adjustments - The hammer handle is adjustable in length over a range of 18 to 30 inches. In addition, the entire hammer head can be rotated 180-degrees with respect to the handle in order to properly align the desired operating edge with the direction of swing.

A stress analysis was performed in order to ensure that the selected elliptical tubular members would withstand the impact forces applied to the hammer during rock hammering. An impact velocity of 70 mph and force of 1200 pounds was assumed for the analysis which is presented in Appendix A.

Geological Hand Lens

Three achromatic, triplet-type lenses were selected for the geological hand lens. These lenses possess focal lengths of 55.5, 27.0 and 19.9 millimeters respectively, with corresponding magnifications of 4.5, 9.4 and 12.8. A single handle was designed (Figure 7) for mounting the three lenses in the order of decreasing magnification. The large diameter, 4.5 magnification lens permits a relatively wide visual field examination of the rock specimen at low magnification. The lens handle can then be moved relative to the rock sample to facilitate higher magnification inspections with correspondingly smaller fields of vision. The lenses are recessed into the handle to prevent excessive sun glare from the top side.

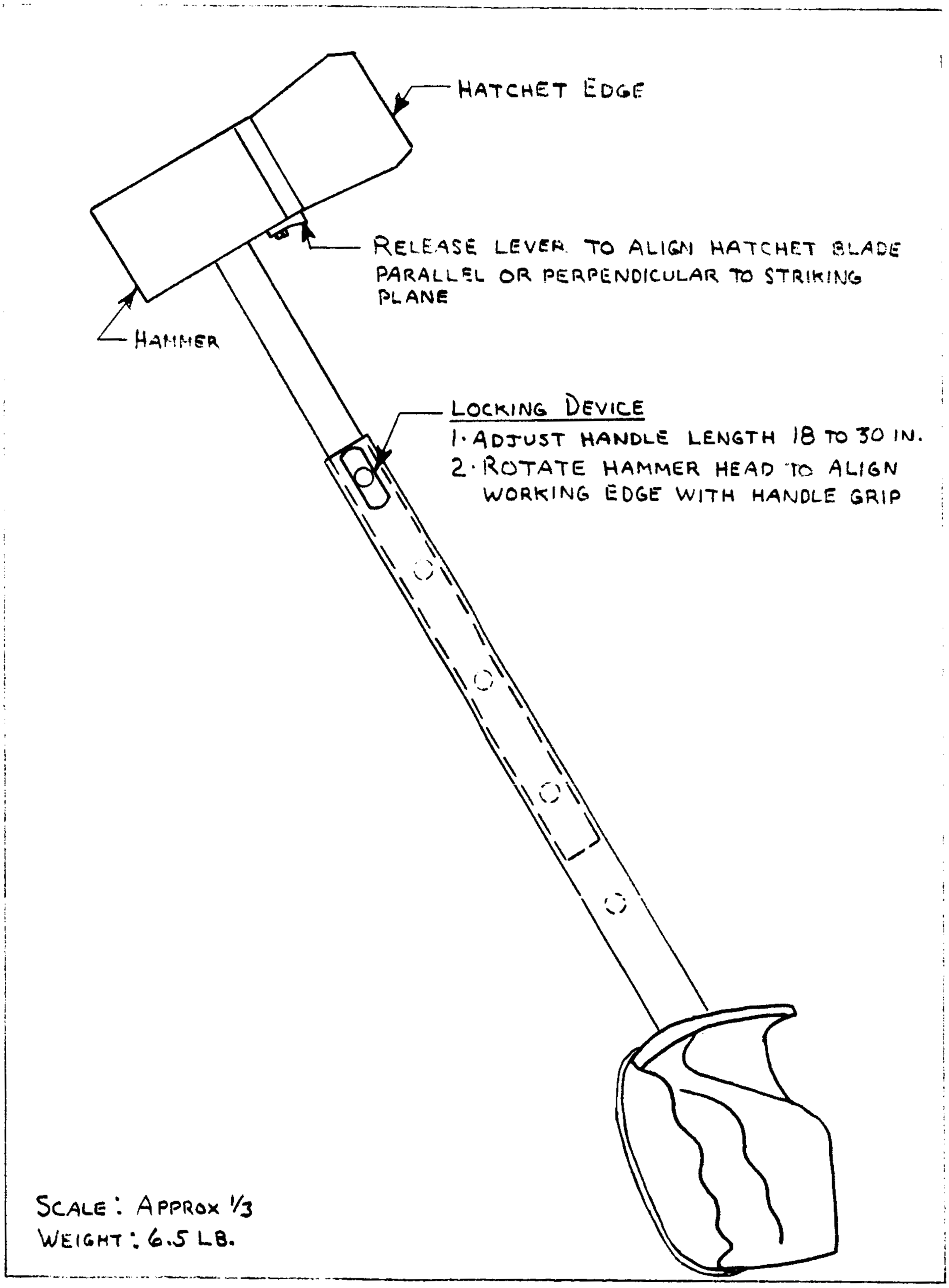


Figure 6. Geological Sampling Hammer

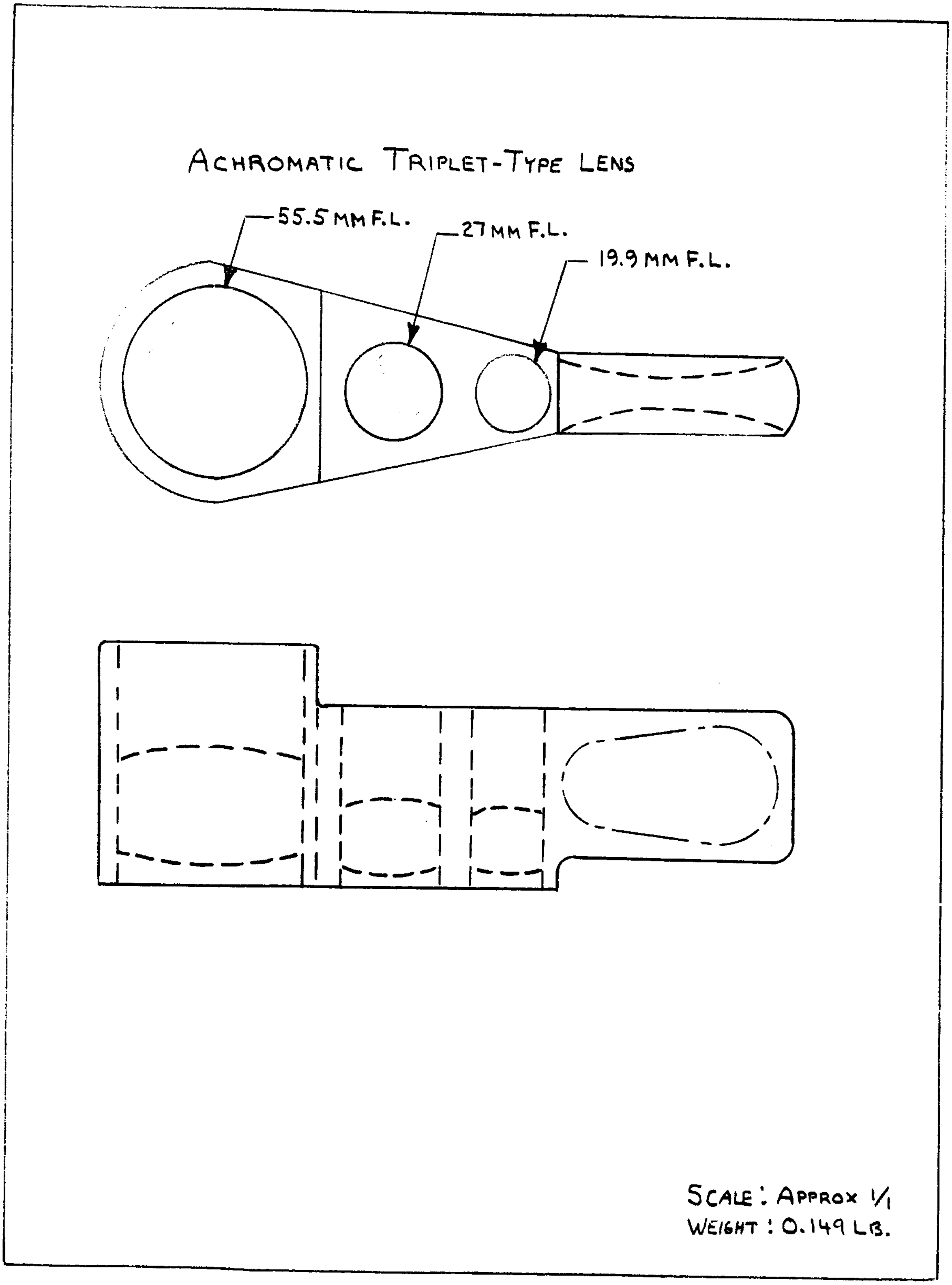


Figure 7. Geological Hand Lens

Sample Weighing Scale

During the period covered by this report, additional effort was placed upon the design of the final sample weighing scale. A preliminary feasibility model was fabricated, tested and described in the previous reporting period. Initially, it was planned to provide an off-center balance-beam device and utilize available items such as the PLGT battery as a counterweight. A series of notches were to be provided in the beam upon which knife edges supporting the unknown and counterweight would rest. The unknown weight and knife edge would then be moved until a balance was obtained. It was proposed that the beam would also be used for the PLGT telescoping section in order to save weight.

During spacesuit interface tests, some handling problems with the feasibility model were noted. A design review indicated several areas of improvement which would be incorporated into the final model. These are:

1. A means must be provided to determine when the balance-beam is level and in a true balanced condition. A pointer-type device was considered adequate.

2. Lifting the knife edge from notch to notch proved to be an undesirable balance technique because the beam required operator restraint while the knife edge and unknown weights were moved. A sliding counterweight approach was considered more appropriate for the final model.

3. The possibility of lunar dust interfering with the free movement of the knife edge prompted consideration of other pivot mechanisms. The use of a dacron cord was deemed appropriate for providing a trouble-free pivot while exhibiting minimum damping.

4. As the weighing system accuracy depends primarily upon the accuracy of the counterweight, it appeared desirable to employ a counter-balance with a more dependable weight characteristic than could be expected from the PLGT battery. Loss of small quantities of electrolyte could introduce small but significant weighing errors. A technique for self-calibration should also be considered.

The final model weighing scale is similar in principle to the feasibility model. Figure 8 illustrates the salient features of the new device. An overall length of 15.6 inches was chosen to facilitate adaptation to the lunar geologist tool kit. The previous concept of integrating the beam with the telescoping section of the PLGT was not implemented because the small weight savings of approximately 0.2 pounds does not justify the additional complexity. The maximum range of weight to be measured remains at 65 pounds. To insure a plus-or-minus 1-pound accuracy and to minimize weighing time, a scale factor of 0.225 inches per pound was chosen. The beam cross section and composition remains similar to the previous model.

Operating on a balanced beam principle, this beam has its fulcrum approximately 1 inch from the end. The unknown weight is placed so that its moment arm is acting downward at 0.500 inch to the left of the fulcrum. The counterweight is moved back and forth to the right of the fulcrum until balance is achieved. A balance condition is determined by alignment of the pointer with the support tape. The pointer is folded down in line with the balance-beam for storage. All pivot points

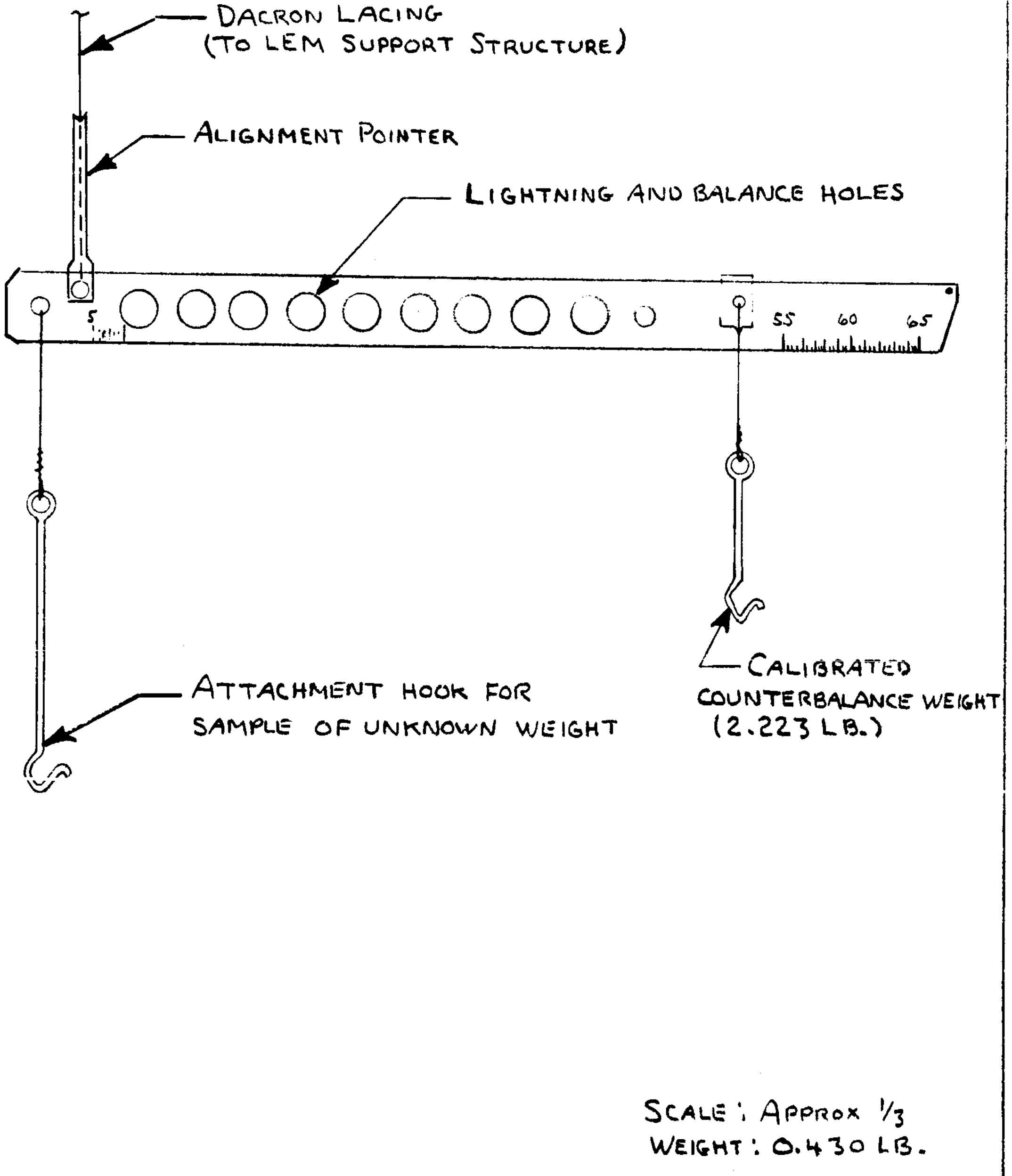


Figure 8. Sample Weighing Scale

are supported by 1/4-inch dacron lacing tape possessing approximately 125 pounds test strength. Attachment points for the dacron tape are teflon which will eliminate abrasion. Dacron was chosen because of its inherent ability to withstand the lunar environment. The weight of the samples is read beneath the slide-bar pointer. Parallax is minimized by sighting through the dacron support for the calibrated weight.

The scale is unique in that it has the ability to determine its own counterweight. This is accomplished by choosing a beam moment of 1.111 inch-pounds. With this moment the counterbalance slide-bar assembly can be removed and suspended to the left of the fulcrum where the lunar samples are normally hung. A small container can be attached to the counterbalance hook which could be filled with lunar material until the beam is balanced. The weight of the counterweight assembly is then given by:

$$\Sigma M_f = 0 = 1.111 - \frac{W_{cb}}{2} \qquad W_{cb} = 2.222 \text{ pounds}$$

The slide-bar is then transferred to its normal position and the scale is calibrated to weigh samples. This self-calibration technique can also be employed to verify the counter-balance system if a pre-weighed tool is used to serve as the counterweight rather than available lunar material.

With this counterweight of 2.222 pounds and a beam moment of 1.111 inch-pounds collectively producing a clockwise moment, the scale calibration points can be determined for various weights as follows:

$$\Sigma M_f = 0 = 2.222\,x + 1.111 - \frac{W_s}{2}$$

where x = Slide-bar distance from fulcrum

W_s = Sample weight

If W_s = 65 pounds,

$$2.222\,x_{65} + 1.111 - \frac{65}{2} = 0$$

$$x_{65} = \frac{32.5 - 1.111}{2.222}$$

$$x_{65} = 14.126 \text{ inches}$$

If W_s = 64 pounds,

$$2.222\,x_{64} + 1.111 - \frac{64}{2} = 0$$

$$x_{64} = \frac{32 - 1.111}{2.222}$$

$$x_{64} = 13.901 \text{ inches}$$

Verification of scale division of .225 inch-pounds is given by $x_{65} - x_{64}$

$$14.126 - 13.901 = .225 \text{ inches}$$

As the scale system is predicated upon an initial beam moment of 1.111 inch-pounds, this must be predicted and can be obtained by again writing moments about the fulcrum considering the various components of the beam and their moment arms individually. A density of 0.1 pounds per cubic inch for aluminum was used. The following table of weights and moment arms applies:

Component	Weight	Arm Length	Moment
Beam, Left	.013 (pounds)	.5 (inches)	- .065 (inch-pounds)
Beam, Right	.185	7.3	+1.33
Left Corner	.0001	1.0	+ .0001
Right Corner	.0026	14.6	- .0380
Restraint Pin	.0016	14.6	+ .0233
Bushing	.0025	.5	- .0012
Hook	.0046	.5	- .0023
Pin Hole	Negligible	--	--
Bushing Hole	.0006	.5	+ .0003
			+1.2472 inch-pounds

This moment is in excess of the desired 1.111 inch-pounds. Therefore, lightening holes must be added. The desired reduction in moment is:

$$1.247 - 1.111 = .136 \text{ inch-pounds}$$

The weight of a 0.688 inch diameter hole is given by:

$$\frac{\pi}{4} \times (.688)^2 \times .125 \times .1 = .00465 \text{ pounds}$$

The total arm required for proper lightening is given by:

$$.136 \div .00465 = 34 \text{ inches}$$

This can be approximately satisfied by placing seven holes one inch apart. An eighth hole is required but would be of smaller diameter. Size would be determined at time of manufacture to reduce accumulated tolerances.

The total weighing system is designed to provide an accuracy of plus-or-minus one pound over the entire usable range of 5 to 65 pounds. The penalty for increasing accuracy beyond plus-or-minus one pound is primarily increased time to adjust the slide-bar for correct balance as a result of increasing balance sensitivity. This particular model is therefore designed to weigh only to the specified tolerance. The design is such, however, that it can be modified so as to provide greater sensitivity and accuracy if required. This is accomplished by reducing the overthrow of the fulcrum from the present 0.1 inch.

Range Finder

During this reporting period significant emphasis was placed upon the evaluation of various apparatus which might be used to provide range information for geological mapping of sample locations. There are two basic types of devices which were considered for this purpose. One is the stadiametric approach whereby knowledge of the height of a landmark such as the LEM permits the range to be determined by measuring the angle subtended by the known object at various distances. The lensless stadiameter discussed in the previous quarterly report is one device which employs this principle. The alidade employs a variation of this approach, requiring the use of a calibrated scale (stadia rod) in order to obtain a high degree of measuring accuracy.

Utilization of an instrument which requires a known reference height has certain disadvantages for lunar use as, initially, the only known reference on the lunar surface is the LEM vehicle. For example, it may be desirable , prior to making an excursion from the LEM, to survey the general "lay of the land" and select a tentative itinerary. Knowing the distance to features of interest could prove highly beneficial in this respect. A coincidence range finder would provide such a capability and is the second type of device considered for use on the lunar surface. It can provide distance information irrespective of the height of the object viewed. The major disadvantage of coincidence range finders is their limited accuracy. Accuracy in this type of range finder is a function of the magnification employed and the base length.

Figure 9 illustrates the anticipated error in percent for a family of coincidence range finders having a variety of base lengths and magnifications. A resolving capability for the human eye of plus-or-minus one minute of arc was assumed for these theoretical performance curves. These curves may appear somewhat pessimistic when compared to manufacturer-stated tolerances of various instruments employing these parameters because a human eye resolving capability of plus-or-minus one-half minute of arc is often optimistically assumed. However, the results of recent Gemini flights have indicated that the resolving capability of the human eye may actually increase under a zero or lower "G" field. If this hypothesis is subsequently substantiated, then the curves of Figure 9 may be overly pessimistic.

A total of five instruments were evaluated during this series of tests:

1. Bell and Howell Model M86F Service Telescope with Range Reticle (Ref. Figure 10) - This instrument incorporates a 2-inch eye relief which may be required with the spacesuit visor limiting the minimum instrument-to-eye distance. This particular reticle scale incorporated ten unequal range marks, and was similar to the previously tested STAPEL. A calibration curve was established for the instrument prior to use.

2. Wild Coincidence Range Finder Model TM 10 (Ref. Figure 11) - This range finder incorporates a base length of 20 inches, and the useful range was quoted to be 100 to 2000 feet. Image magnification included in the device was 6X.

3. Marine Distance Meter, English Manufacture (Ref. Figure 12) - This relatively compact device employs a rotating mirror and split image rather than a reticle. The instrument requires that the image height be known and this known height must be set on an appropriate scale. The operator then rotates the mirror with an adjustment knob until the object split images are aligned above and below each other. The distance is then read on a scale coupled to the adjustment know. This unit employs no magnification.

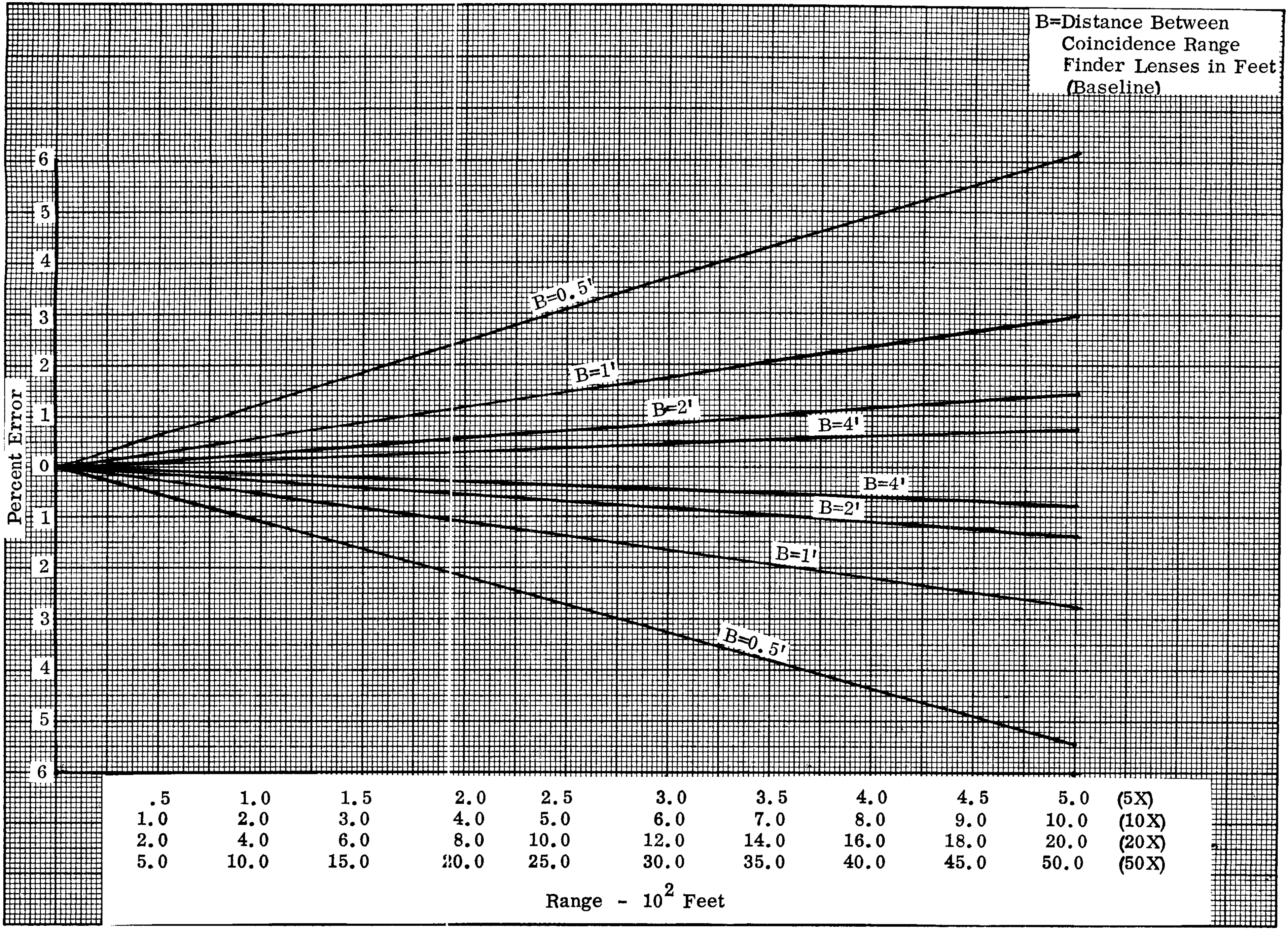


Figure 9. Theoretical Coincidence Range Finder Accuracies

Figure 10. Bell & Howell M 86F Scope

Figure 11. Wild Coincidence Range Finder TM-10

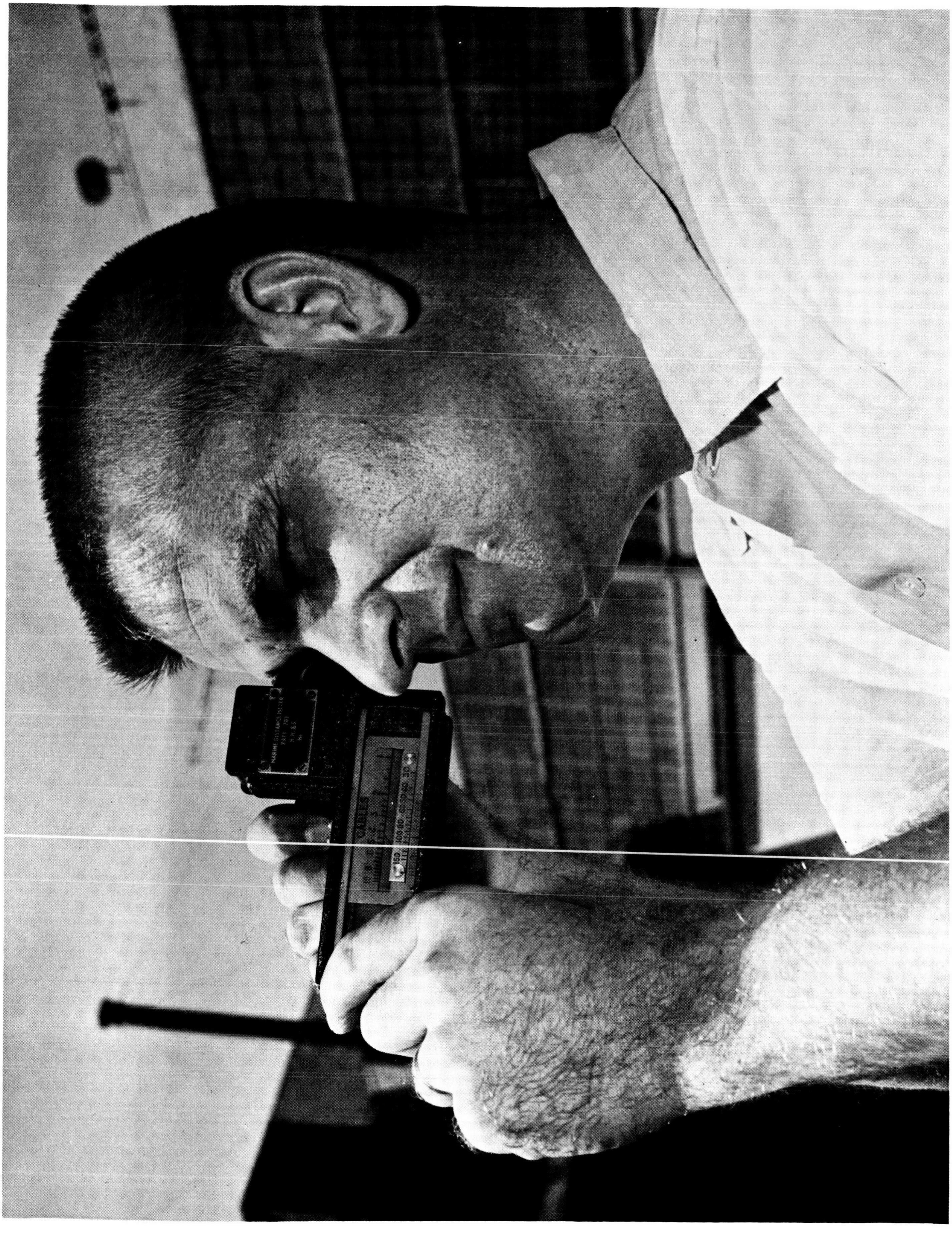


Figure 12. Marine Distance Meter

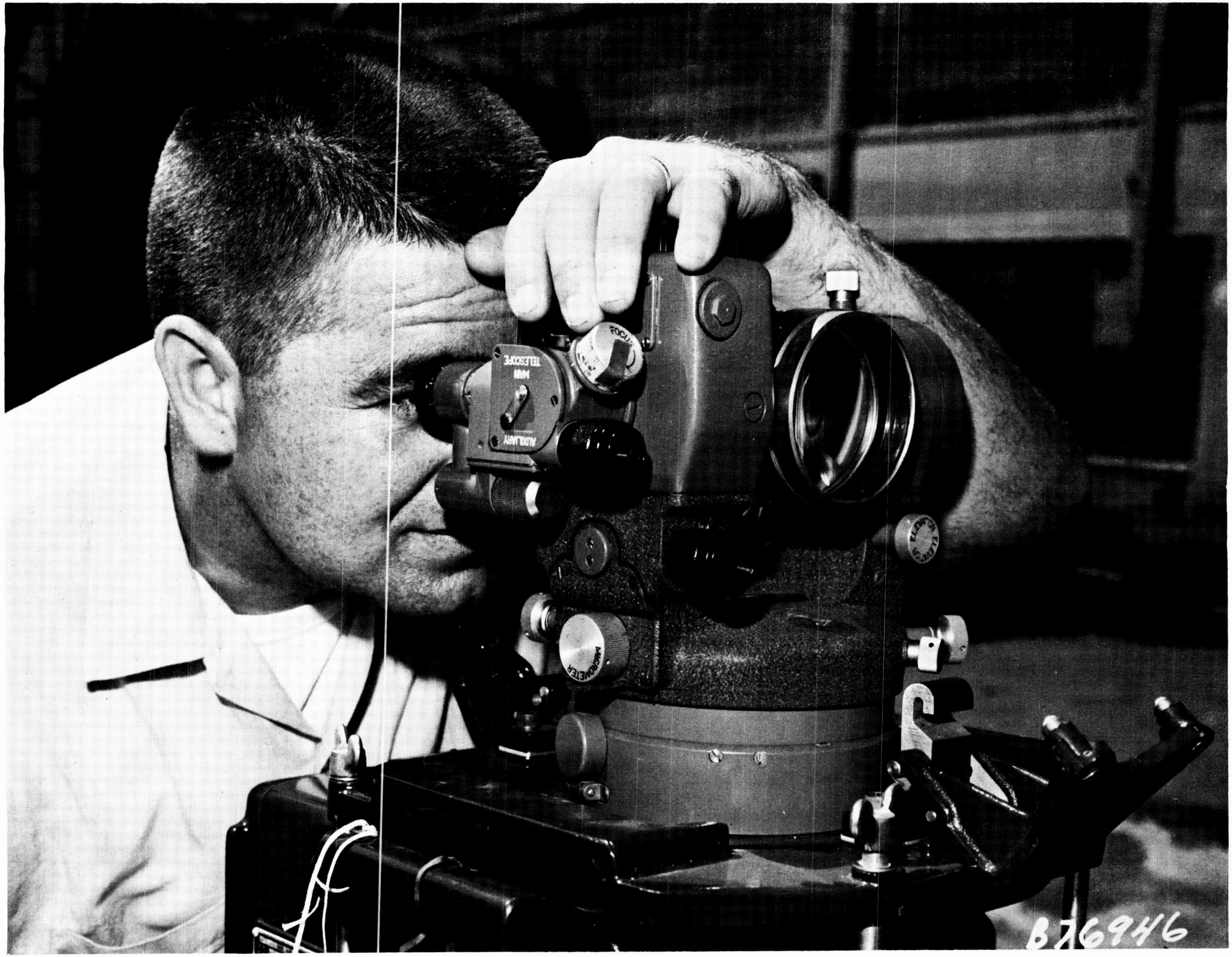


Figure 13. Kern DKM 3 First Order Theodolite

4. Kern DKM 3 First Order Triangulation Theodolite (Ref. Figure 13) - Although this instrument possesses a precise circle reading capability ($\angle 0.5$ second), the unit was used only because of its high telescope magnification of 45X. In using this instrument it was intended to determine how effectively the focus adjustment could be employed as a range determination device. In effect, this could be categorized as a split image rangefinder with the telescope aperture serving as the range finder base. The focus knob was calibrated during testing and the range measurements were interpolated from this calibration. The telescopic aperture of this device was 2.83 inches.

5. K & E Transit - This is a standard survey transit employing a magnification of 16X. A reticle employing stadia markings in the standard ratio of 100:1 was included in the eyepiece.

The test site employed for evaluation of the instruments was measured off by tape in 100-foot increments. At the extreme end of the range a 10-foot survey rod was positioned. All sightings were made on this rod. Two test subjects were employed, each taking three readings with each instrument at each of the ten stations beginning at 100 feet.

The curves shown in Figure 14 depict the average error in feet incurred by the various instruments. For plotting purposes, all errors were assumed to be in the same direction. Specific comments regarding the use of each of the instruments follow:

1. 2X Service Scope - This scope was easy to use in that no adjustments were necessary to obtain a reading. Images were bright and sharp. It was necessary, however, to steady the scope by providing a minimum fixed rest in order to obtain readings. The fact that the reticle in this scope had only ten divisions detracted significantly from its theoretical accuracy. This was especially true at the close ranges where distance between reticle lines was a maximum thereby requiring extensive estimation on the part of the user. Accuracy at 1000 feet was plus-or-minus 50 feet, which coincides with the values theoretically obtainable in this type device.

2. Coincidence Range Finder - This device proved to be the easiest of the group to use and provided the best accuracies at 1000 feet. It was not found necessary to steady this device because any movement of the image in the eyepiece is accompanied by a similar movement of the secondary image thus eliminating relative motion between the images to be brought into coincidence. The relatively low magnification of this device facilitates the addition of eye relief for spacesuit operation if required.

3. Marine Distance Meter - Of all the instruments tested, this meter proved to be the fastest to use at the near and medium ranges. Some difficulty was experienced at 800, 900 and 1000 feet where the lack of magnification and the relatively small aperture resulted in the loss of sharp coincidence adjusting ability.

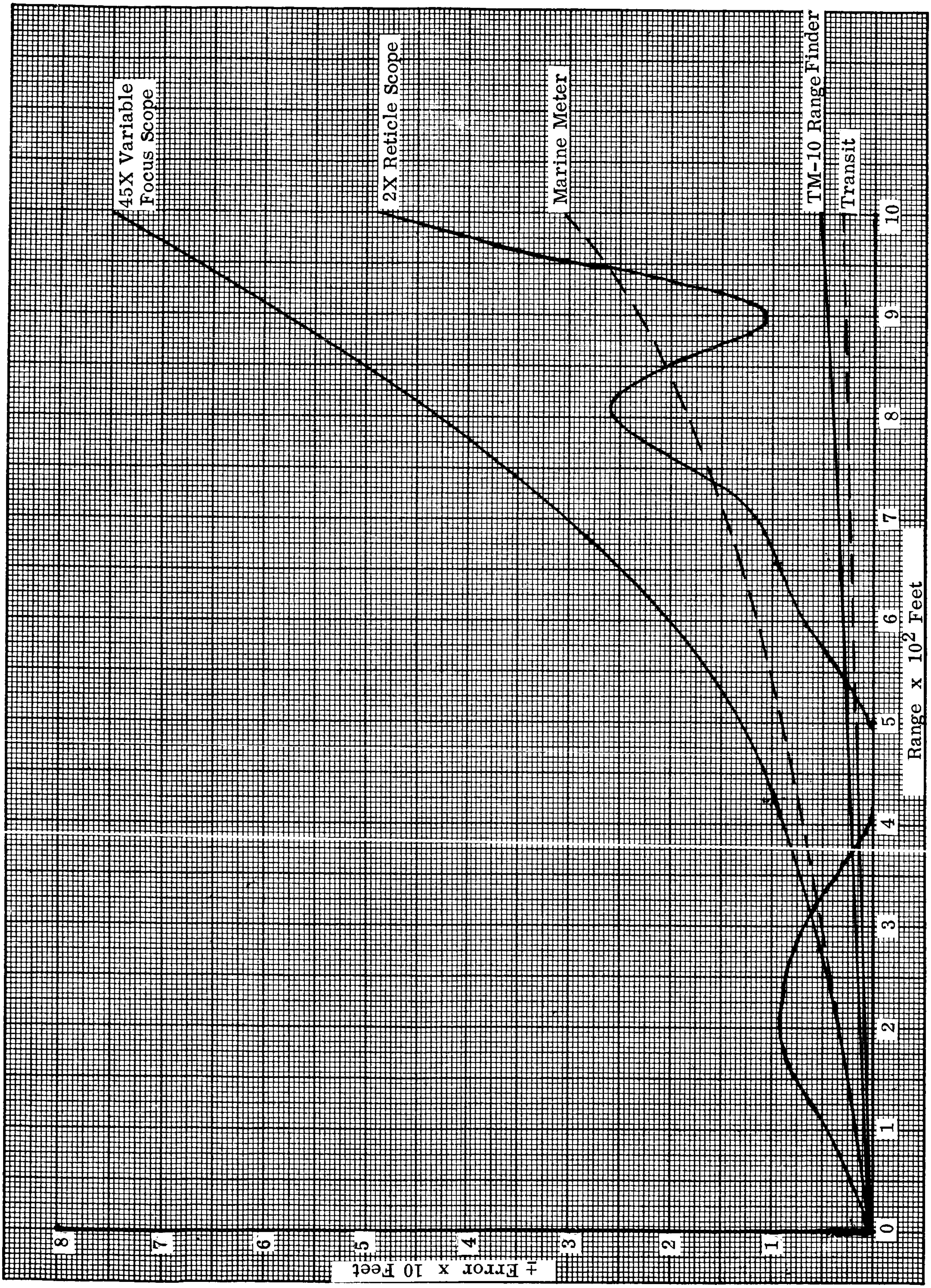


Figure 14. Instrument Measurement Errors

4. Theodolite - Use of the 45X scope on the theodolite for ranging purposes proved feasible but offered limited accuracy which approached 10 percent at 1000 feet. In addition to the limited accuracy, a "k" factor was noted between users. This showed up as a constant displacement between focus knob settings at each station between each user. This can be attributed to differences in eye condition although neither user wears glasses.

5. Transit - At distances up to 500 feet, the transit employing 100:1 stadia markings proved to be the most accurate instrument, although the most difficult to use because of the necessity of taking two readings for each sighting. Vertical alignment was more critical than with the other devices as the stadia markings in the reticle must be perpendicular to the survey rod. The transit could not be used beyond 500 feet because the numerals on the survey rod could not be distinguished at that distance. Numerals were 3/4-inch high. Larger numerals would be required to maintain the usefulness of the transit beyond 500 feet. A considerable amount of vertical jitter was also noted at 400 feet. This implies that the use of this device at 1000 feet will require a more rigid tripod than can be provided by the PLGT.

In summary, it appears that a coincidence-type range finder may best meet the requirements of the early lunar missions. Although the manufacturer-stated accuracy of an alidade-type instrument (plus-or-minus.33 percent) is somewhat higher than the coincidence range finders of comparable size, the ease and rapidity of operation of the coincidence range finder must receive prime consideration. The size and weight (7 pounds) of the Wild TM-10 evaluated during these tests is probably too much of a payload penalty for the plus-or-minus one percent range measurement accuracy. Therefore, additional investigation of lightweight, less accurate coincidence range finders will be conducted during the next report period.

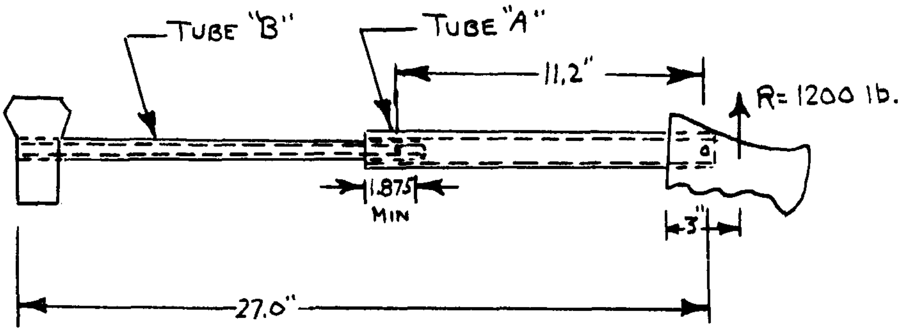
CONCLUSIONS AND RECOMMENDATIONS

Evaluation of the first prototype model PLGT has resulted in the identification of various problem areas which will be corrected in the final prototype model. Primary improvement areas will include weight, mechanism power operating efficiency, center of gravity location, and handle location. One additional problem area beyond the scope of this Program which will ultimately require investigation is the design of a narrow-kerf, tungsten-carbide core bit. Since the operating efficiency of the PLGT is directly dependent upon the efficiency of the core bit, an additional improvement and optimization program is warranted.

Fabrication of the auxiliary geological tools will be completed during the final quarter of the Program. These auxiliary tools will be integrated with the basic PLGT in order to complete the geological tool kit.

Additional study will be conducted to determine an alternative approach for the geological tool kit if the powered capability of the PLGT is deemed unnecessary on the early lunar missions. Most of the auxiliary tools required with the PLGT would also be applicable for the alternative approach.

Appendix A - Geological Sampling Hammer Stress Analysis



1) Calculate load R resulting from nominal swing of arm -

Mass = 7.5/32.2

Velocity = v = 103 ft/sec (70 MPH)

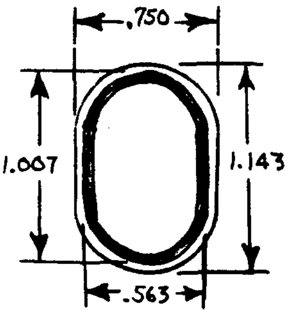
t = Time of Impact = 0.02 sec

$FT = m_1v_1 - m_2v_2$

$F = \frac{mv}{t} = 7.5\ (103)/32.2(.02) = 1200$ lb

Therefore, design load moment in handle = 3 x 1200 = 3600 in/lb.

2) Tube Geometry



Make Tube "A" from 1" O.D. x .065 304 stainless steel (150,000 PSI tensile strength)

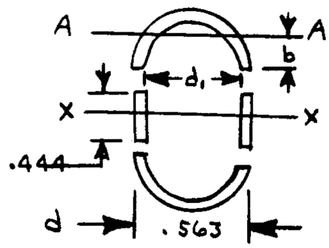
Flatten to 0.750 width

Tube "B" machined as required from 1" O.D. x .188 304 stainless steel.

$$\text{Tension} = \frac{1}{2}\left(\frac{3600}{1.875}\right)\left(\frac{1}{.06}\right)$$

$$= 16000 \text{ PSI}$$

3) Tube "B" Section Properties



$$b = \frac{2}{3\pi}\,\frac{(d^3 - d_1^3)}{(d^2 - d_1^2)}$$

			Diff.
(average wall)	$d = .563$	$- \quad d_1 = .3422$	
	$d^2 = .317$	$- \quad d_1^2 = .1171$	.1999
	$d^3 = .1785$	$- \quad d_1^3 = .0586$	.1199
	$d^4 = .1005$	$- \quad d_1^4 = .01371$	.0868

$$b = \frac{2}{3\pi}\,\frac{.1199}{.1999} = .1272$$

$$Jxx = 2\,Jaa + \frac{bd^3}{12}(2) + \Sigma ax^2$$

Flat $= 1.007 - (.563) = .444$ $\qquad x = .1272 + .222 = .3492$

$$Jaa = \frac{\pi}{128}\,(d^4 - d_1^4) - \frac{4}{72\pi}\,\frac{(d^3 - d_1^3)^2}{d^2 - d_1^2}$$

$$= \frac{\pi}{128}\,(.0868) - \frac{4}{72\pi}\,\frac{(.1199)^2}{(.1999)} = .002132 - .001271$$

$Jaa = .000861$

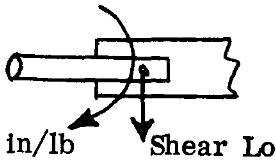
$$\frac{bd^3}{12} = \frac{.1104\,(.444)^3}{12} = .000804$$

$$\Sigma ax^2 = .7854\,(d^2 - d_1^2)\,\left(\overline{\;.444\;}^{\,2}\right) = .0309$$

$Jxx = 2\,(.000861) + 2\,(.000804) + .0309$

$Jxx = .03423$ $\qquad$ Total Area $= .2651$

Tube Joint Load



M = 3600 in/lb   Shear Load = 3600/11.2 = 320 lb.

$$F_b = \frac{Mc}{I} = \frac{3600\ (1.007/2)}{.03423} = 61600 \text{ PSI}$$

$$\frac{\text{Bending Mod of Rupture}}{\text{Ultimate Tensile Stress}} = \frac{F_b}{F_{tu}}$$

$$D/t = \frac{1.054}{.059} = 17.5$$

$$\frac{F_b}{F_{tu}} = 1.2$$

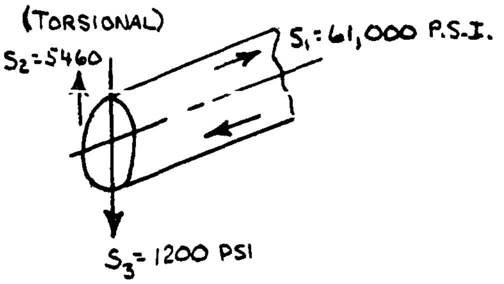
F_b = 1.2 x 150,000 x .6 = 108,000 allowable

$$\text{M.S. (pure bending)} = \frac{108000}{61600} - 1 = 75\%$$

Assume off-center (by 1 inch) - Shear Load Torque = 320 lb.

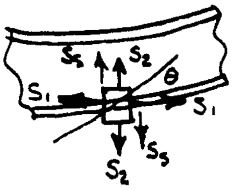
$$\text{Approximate Average } F_s = \frac{T}{2tA} = \frac{(320)}{2\ (.1104)(.2651)} = 5460 \text{ PSI}$$

$$S_3 = \frac{320}{.2651} = 1200$$



Combined Stress - Ref: "Formulas for Stress & Strain" - Roark
Page 91 - Condition 5

Biaxial Stress Combined with Shear



Principle Stresses

$$\Theta = \text{arc tan}\ \frac{2\ S_s}{S_2 - S_1} = \frac{2400}{55140}$$

$$\text{arc tan}\ .0435 \quad \Theta = 6^{o}$$

$$\text{P.S.} = \frac{1}{2}\,(S_1 + S_2) \pm \sqrt{\left(\frac{S_1 - S_2}{2}\right)^{2} + S_s^{\ 2}}$$

$$= 33530 + \left(\overline{27570}^{\,2} + \overline{1200}^{\,2}\right)^{\frac{1}{2}}$$

$$= 61069.8$$

$S_1 = 61600$ PSI

$S_2 = 5460$ PSI

$S_s = 1200$ PSI

Max. Shear Stress:

$$\Theta = \frac{1}{2}\ \text{arc tan}\ \frac{S_1 - S_2}{2\ S_s}$$

$$= \frac{1}{2}\ \text{arc tan}\ \frac{61600 - 5460}{2(1200)} = 23$$

$$\Theta = \text{arc tan}\ 11.5 = 85^{o}\ 2'$$

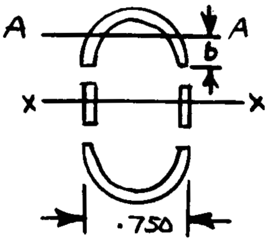
$$\text{Max}\ S_p = \sqrt{\frac{S_1 - S_2}{2} + S_s^{2}} = \left(\frac{55140}{2} + 1440000\right)^{\frac{1}{2}}$$

$$\text{Max}\ S_p = 1211.4$$

$$\text{M.S.} = \frac{108000}{61069.8} - 1 = 75\%$$

$$\text{M.S. (Shear)} = \frac{80000 \times .6}{1211.4} - 1 = 295\%$$

4) Tube "A" Section Properties



$$Jxx = Jaa + \frac{bd^3}{12} + \sum ax^2$$

$$b = \frac{2}{3\pi}\ \frac{(d^3 - d_1^3)}{(d^2 - d_1^2)}$$

			Diff.
$d = .750$	-	$d_1 = .613$	
$d^2 = .5625$	-	$d_1^2 = .3758$	.1867
$d^3 = .4219$	-	$d_1^3 = .23035$	.1915
$d^4 = .31641$	-	$d_1^4 = .1412$	.1752

$$b = \frac{2}{3\pi} \; \frac{.1915}{.1867} = .2175$$

$$\text{Flat} = .3927 = \frac{.1969}{.4144} \; \text{(to A. A.)}$$

$$Jaa = \frac{\pi}{128}\left(d^4 - d_1^4\right) - \frac{4}{72\pi} \; \frac{\left(d^3 - d_1^3\right)^2}{d^2 - d_1^2}$$

$$= \frac{\pi}{128}(.1752) - \frac{4}{72\pi} \; \frac{(.1915)^2}{.1867} = .0043 - .00347 = .00083$$

$$\frac{bd^3}{12} = \frac{.060 \times \overline{.3927}^3}{12} = .000303$$

$$\Sigma ax^2 = .7854\,(.1867)\,(.4144)^2 = .0251$$

$$Jxx = .00083 + 2(.000303) + .0251$$

$$Jxx = .02654$$

$$f = \frac{Mc}{I} = \frac{3600\,(.572)}{.02654} = 77600 \text{ PST}$$

This tube may thus follow the analysis of Tube "B" to show over strength. Optimization by means of tests may save weight in both tubes.