NASA TECHNICAL NOTE

NASA TN D-3003

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PRELIMINARY CONSIDERATIONS OF OPTICAL TELESCOPES FOR LUNAR SURFACE USE

by Ernest H. Wells

George C. Marshall Space Flight Center
Huntsville, Ala.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1965

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SUMMARY

One prime objective of the exploration of space should be to obtain pictures of the planets, multiple stars, selected galaxies, and nebulae in the ultraviolet and infrared ranges, since this is not possible on earth to the desired degree of perfection.

This report discusses the various types of telescopes and the advantages of each. The relationship between mirror size and its capability is given, and it is shown how the resolution on Mars decreases with mirror sizes up to 200 inches.

A 21-inch porthole folded-optics telescope is considered to be a practical and reasonable size for an early lunar mission. A preliminary design has been worked out and is presented in this report.

This design was chosen to provide the maximum spectral coverage in ultraviolet and infrared. This design will give a 50 percent decrease in resolution over current earth-based instruments and powers up to 1050 are possible. The complete package should not exceed 300 pounds (168 Kg).

INTRODUCTION

The moon offers multiple advantages for an astronomical outpost or full observatory. Obviously, a full observatory equipped with a massive telescope cannot be built on the moon in the immediate future, but every opportunity should be taken to evaluate astronomical equipment for use on the lunar surface.

The nearly ideal optical environment of the moon affords an unlimited window to the whole electromagnetic spectrum. The lack of atmospheric absorption, scattering and aberration, and the physical environment with its low gravity, stability, and slow motion enables even small telescopes of one-third to one meter diameter to produce unexcelled quality of results for their sizes, and may excel all instruments on earth for definition. Such optical instruments would not be an unreasonable burden, payload-wise, and their use in lunar shelters offers wide avenues for basic astronomical research.

Shelters are necessary to protect the scientific crews and to provide a base for sustained operations. The telescope optics have to be protected against high velocity abrasion, ideally with a dome, but a small covering shelter or a set of covers could suffice for initial experiments. If optical instruments are to be left on the lunar surface for very long periods of time (viz. between missions), some type of shelter is considered imperative. Smaller sizes could be left in the personnel shelter, but larger sizes (much over one-half meter) should have their own protection due to the difficulty of storing and removing from the main shelter.

Sir Isaac Newton introduced a new basic optical principle when he built the first reflecting telescope (Figure 1). With a concave mirror less than 2 inches (50 mm) in diameter, mounted in the bottom end of a tube about 1 meter long, reflecting light to a small diagonal mirror near the eyepiece, and sturdily mounted, his telescope showed great promise. This basic design is used in all the world's largest telescopes today, because a reflecting mirror provides more nearly perfect color rendition than a lens and can be made in much larger sizes.

About 200 years ago, two Englishmen developed the achromatic lens, consisting of one element of crown glass and another one of flint glass. Hall proved the feasibility for such a lens, and Dollond manufactured it. It is capable of excellent performance, and is widely used in optical instruments and small telescopes. The Yerkes telescope has the largest achromatic lens (1 m in dia.) and the Mount Palomar telescope has the largest mirror (5 m in dia.). Refractor telescopes are much longer than reflectors of the same diameter and cut off most of the IR and UV spectrum. For these reasons, they are not considered in this report. The rarely used Herschel type is also omitted.

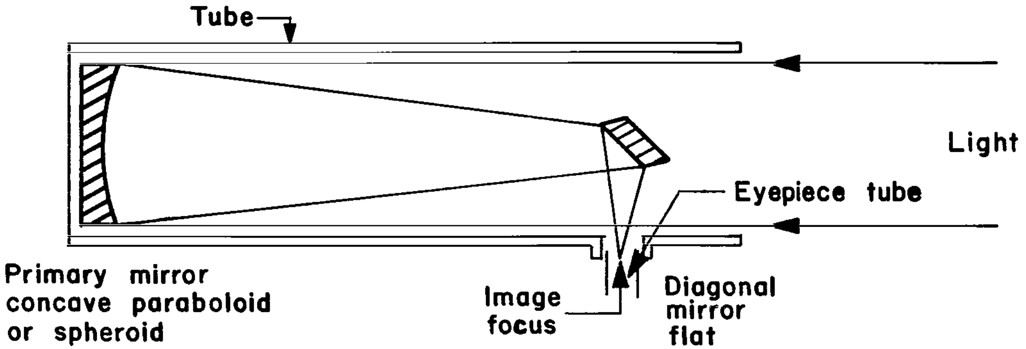
ASTRONOMICAL REFLECTING TELESCOPES

For prime focal photography, power and focal length are related:

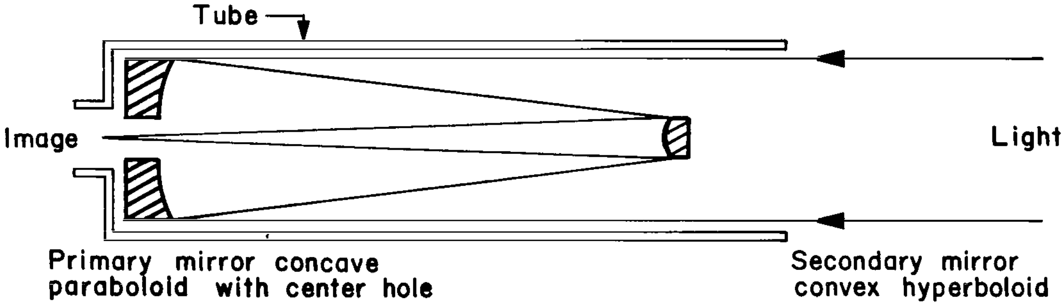
$$p = kf_o$$

where p is the power (linear magnification of image); f_o is the focal length of the objective (either actual or effective); and k is the constant of proportionality.

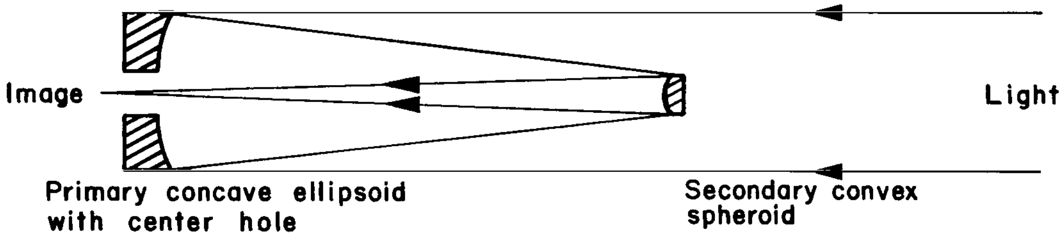
The preceding equation shows that the size of the mirror is not theoretically involved in the power of a telescope. In practice, this is not true due to known limits of resolution. The commonly quoted limit beyond which magnification fails to help reveal hidden detail is 50-power per inch (2 power per mm). As an example, a telescope mirror of 10 inches (25.4 cm) diameter would be usable up to 500 power. Beyond this power, the image would appear proportionally larger (and dimmer), but no



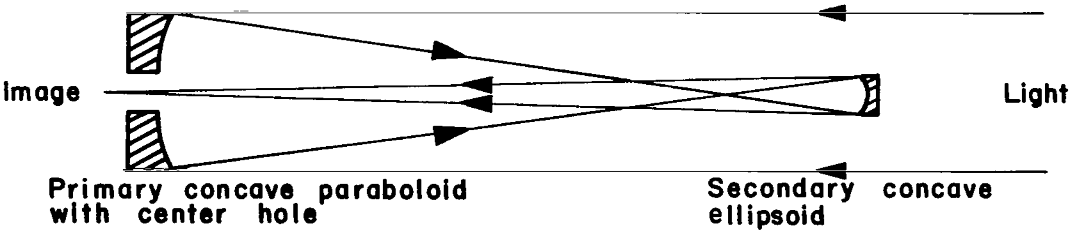
NEWTONIAN



CASSEGRAIN



DALL KIRKHAM



GREGORIAN

FIG. 1 - REFLECTOR TELESCOPES

more detail would have been added. At powers lower than this (for example, 100X), the image would contain much more detail than could be extracted from such a small area, resulting in a need for magnification.

As stated, the above is the maximum usable value and does not generally hold when a telescope is in actual use on earth. In practice, a 10-inch telescope may be best used at 100X for certain atmospheric conditions while 500X may be used to advantage only on a night of excellent visibility.

When a telescope is used visually, another factor is present. Eyepieces are used and the power can be changed over a wide range by changing to different focal length eyepieces. The basic telescope power therefore becomes:

$$\text{power} = -\frac{f_o\,(\text{eff})}{f_e}$$

where f_o (eff) is the effective objective focal length; f_e is the eyepiece focal length (the minus sign indicates an inverted image).

For example, a telescope which magnifies 50 times with a 1-inch (25 mm) focal length eyepiece will magnify 100 times with a 1/2-inch (12.5-mm)* eyepiece. The basic power of a telescope is usually determined by the use of a 1-inch eyepiece. This probably relates directly to man's eye, which is approximately a 1-inch focal length system. The 50 power instrument in the example would therefore be 50 inches (127 cm) in focal length (actual or effective).

Other developments include the folded optical principle, the first of which was invented by Cassegrain. This form has been modified into the Gregorian type (Figure 1) and other forms including the Schmidt camera (Figure 2).

The Cassegrain type has a concave objective mirror which collects parallel rays of light from the stars and concentrates it into a cone reflected in front of the mirror (Figure 1). Before this light focusses to a point, it is intercepted by a smaller convex mirror which spreads out the cone and reflects it back down the tube (usually through a hole in the center of the primary mirror). The desired images are obtained at the focus of the secondary where eyepieces, film, a photometer, or other accessories are used for research. The prime advantage of the Cassegrain type is that a very long effective focal length (f_{eff}) can be obtained in a short physical length (tube).

On a Cassegrain system (Figure 3), the effective focal length is:

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* Dimensions used with eyepieces denote focal lengths, not diameters.

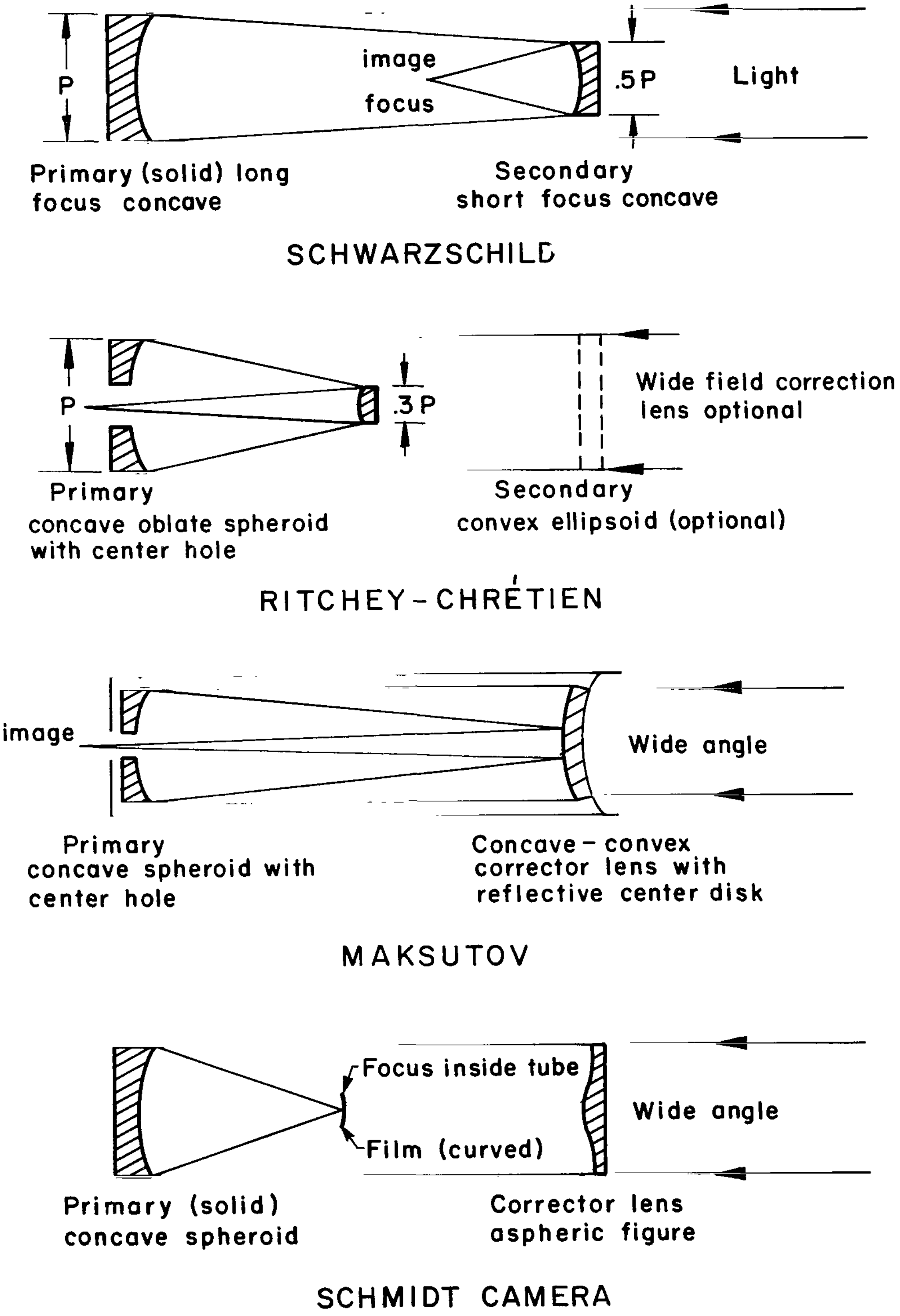


FIG. 2 - REFLECTOR TELESCOPES AND CAMERAS (NEWER TYPES)

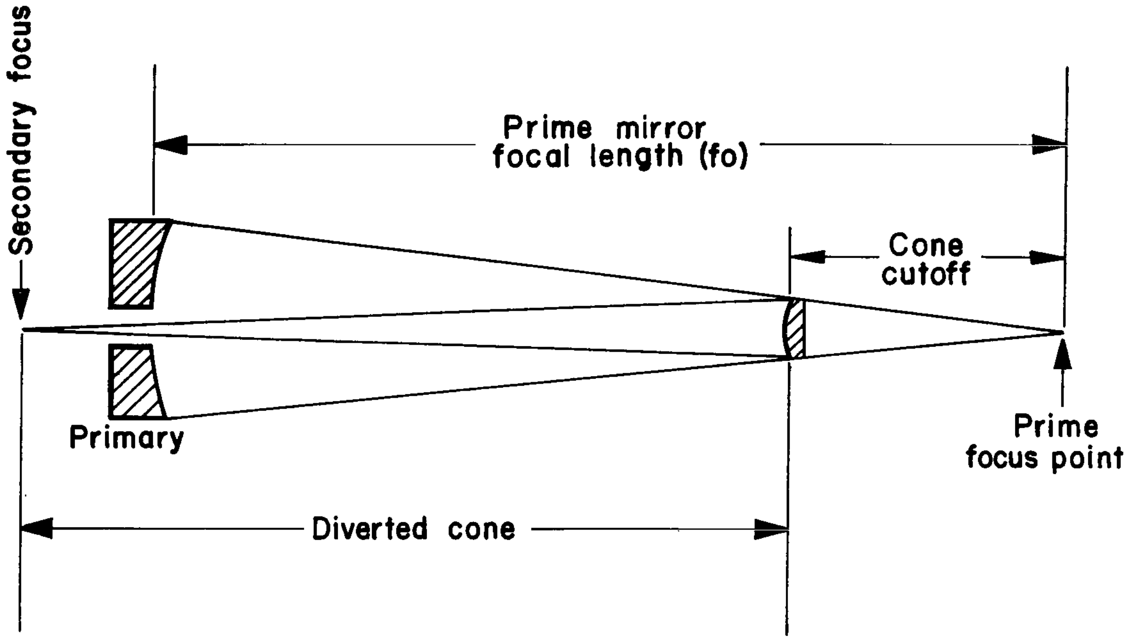


FIGURE 3. CASSEGRAIN OPTICAL RELATIONSHIPS

$$fl_{cg} = f_o (D_{si}/D_{cd})^{**}$$

where

f_o = focal length of the prime mirror

D_{si} = the length of the light path from the secondary to its image

D_{cd} = the length of the original light cone diverted by the secondary

A very high multiplication factor can be obtained by the proper choice of mirror focal lengths and sizes. The convex secondary mirror should not be more than one-third the diameter of the primary for good optical efficiency.

The major factors involved in choosing the size of the secondary are the size and focal length of the prime mirror, the "tradeoff" between tube length and optical efficiency, and the required magnification. The folded optical principle enables a designer to achieve a good compromise in mirror size, tube length, and long effective focal length.

Other types of folded optical systems (Figures 1 & 2) include the Gregorian, the Dahl Kirkham, the Schwarzschild, and the basic Ritchey-Chrétien.

The Gregorian requires a longer tube, but can be designed for higher powers. The secondary mirror is concave and is located on the optical axis past the prime focus. The concave secondary is easier to correct and figure, optically, than the convex Cassegrainian secondary.

The Dahl Kirkham (Figure 1) uses a spherically figured secondary instead of the hyperbolic one required for the Cassegrain system. The spherical secondary is much simpler to make. The primary has an ellipsoidal figure.

The Schwarzschild (Figure 2) uses a slightly concave secondary mirror approximately half the diameter of the primary which blocks 25 percent of the light. It is free from coma and spherical aberration, and has an effective speed of f/3, but requires a longer than normal tube. It has a flat 2° image field, but the focal plane is inside the tube and modification would have to be made for direct viewing [1].

The Ritchey-Chrétien (Figure 2) [1] requires a slightly oblate spheroidal primary with an elliptical convex secondary. The secondary is approximately three-tenths that of the primary diameter. It is free of coma, but the image field is curved.

** All numbers are taken as positive values.

The telescope can be built with less length than the prime mirror focal length. For best results, it requires a correction lens to widen the field of coverage and properly belongs under the heading of catadioptric types.

Catadioptric Types

Catadioptric is a term applied to optical systems using both mirrors and lenses [2, 3]. Obviously, the eyepiece lens is not included in this definition, because every reflecting telescope would then qualify. For mirrors of very short focal length (f/1 to f/2.5), enough image distortion results from the steep curvature to require some form of correction. A large lens in front of the primary mirror is generally used.

Bernhard Schmidt, in 1930, was the first to use a spherical mirror with a full aperture aspherical corrector lens for a very highly efficient camera (Figure 2). Many variations of this arrangement have been designed, some with speeds of f/1 or better. Visual use is not practical [4] due to curvature of field and image inaccessibility.

One form, related to the Schmidt, is the Maksutov-Bouwers telescope [5] or camera (Figure 2). In 1940 these two independent inventors, one in Russia and one in Holland, found that a single, spherical, concave-convex lens could be used to provide adequate spherical aberration [6] correction for short focus spherical mirrors. An additional advantage is that the lens can be placed relatively near the primary mirror, making the telescope quite short and compact. This design appears to be the optimum overall compromise where tube length and weight are of utmost importance. Since it does employ a lens, it would be less suitable for IR and UV than a Cassegrain, but it should be possible to make the corrector lens of quartz for UV use, although this is not known to have been done. A 12 1/2-inch (32 cm) telescope could be built with a length of approximately 3 feet (1 m). Such a telescope would approach one-third second of arc resolution.

For wide field photography, a super-Schmidt has been designed. The whole assembly is almost spherical and can be built to optical speeds of f/.67. It covers a very wide field but is very complex optically [7]. It is unlikely that such an instrument would be justified on the moon at an early date.

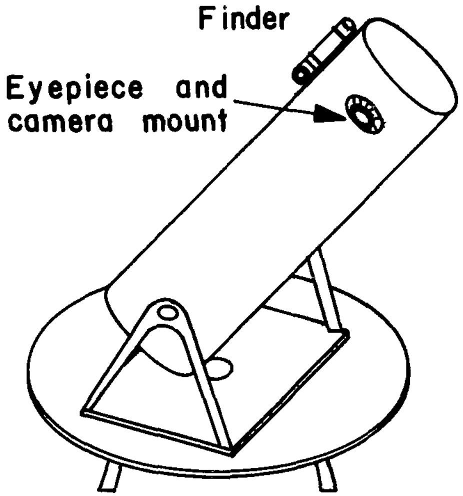
Mounting Considerations

On earth, a telescope is usually mounted either in a yoke providing altitude and azimuth movements, or in an equatorial mount in which one axis (polar) is parallel to the earth's rotational axis, and the other axis (declination) is at right angles. Since the polar axis of the earth is changing slowly enough to be considered constant in space over the lifetime of any telescope mount, the equatorial mount is used for perhaps 99 percent of the installations. The advantage of this type of mount lies in its ability to track stars by rotating only one axis (polar) of the mount. By powering this axis with a motor geared down to one revolution per (sidereal) day (23 hours, 56 minutes, 4.1 seconds), almost perfect tracking is attained. The only serious trouble is caused by atmospheric refraction at different altitude angles. Even this can be partially compensated for automatically, but for a long exposure photograph, small corrections must be frequently made by an astronomer so that the image will not be blurred.

Using an equatorial mount should solve the tracking problem to a very satisfactory degree for a lunar-based observatory. The moon's axis of rotation is not perfectly space-fixed due to its peculiar motions. Nutations of the moon [8] move its axis direction in a very complicated manner. Basically, the tracking on the moon can be resolved by considering the lunar motion as $\omega + \Delta\omega$. The basic motion of the moon ω would be its mean sidereal rotational velocity, and $\Delta\omega$ represents all the deviations from this mean. $\Delta\omega$ will then be a correction to be applied during use only and may be effected by hand control (for visual work), or by star tracker-controlled servo drive for long-term photography or other type research. A basic equatorial mount would be used, oriented to the mean lunar north. A motor drive for the polar axis at one revolution each 27 d, 7 h, 43 m 11.5 sec would take care of the ω requirement for star fields. Actually, a standard telescope drive (for earth) with a 27 1/3 to 1 reduction ratio should be entirely satisfactory for the initial instrument. For visual use and relatively fast photography (exposures of a few seconds of stars), no corrections would normally be necessary for $\Delta\omega$ after the desired object has been centered in the field of view. For longer exposures, a very precise drive is necessary. For planets, asteroids, comets, or earth tracking, constant $\Delta\omega$ corrections would be necessary. Since the telescope drive will be torquing a mass at a very low constant rate of motion, no acceleration is involved and the size motor required on the moon may be the same as on earth. Apparently, no weight reduction can be assumed for the drive mechanism.

Telescope Usability

Many possibilities exist relative to the use of a lunar-based telescope. Many of the factors involved will depend on other considerations, or even policy. If the telescope can be mounted outside the shelter (Figs. 4 & 5), or even in a secondary nonpressurized shading shelter, the mounting could be simplified. If it is to be used only while the astronaut is inside the prime shelter, its use may be somewhat restricted due to the impracticability of having a dome with a slit or of rotating the shelter as a whole.



Simple newtonian telescope mounted on a low two pivot mount to reduce the weight and size. The telescope should be as large as practical but must be used outside the shelter on the lunar surface.

FIGURE 4. LUNAR SURFACE TELESCOPE CONCEPT NO. 1

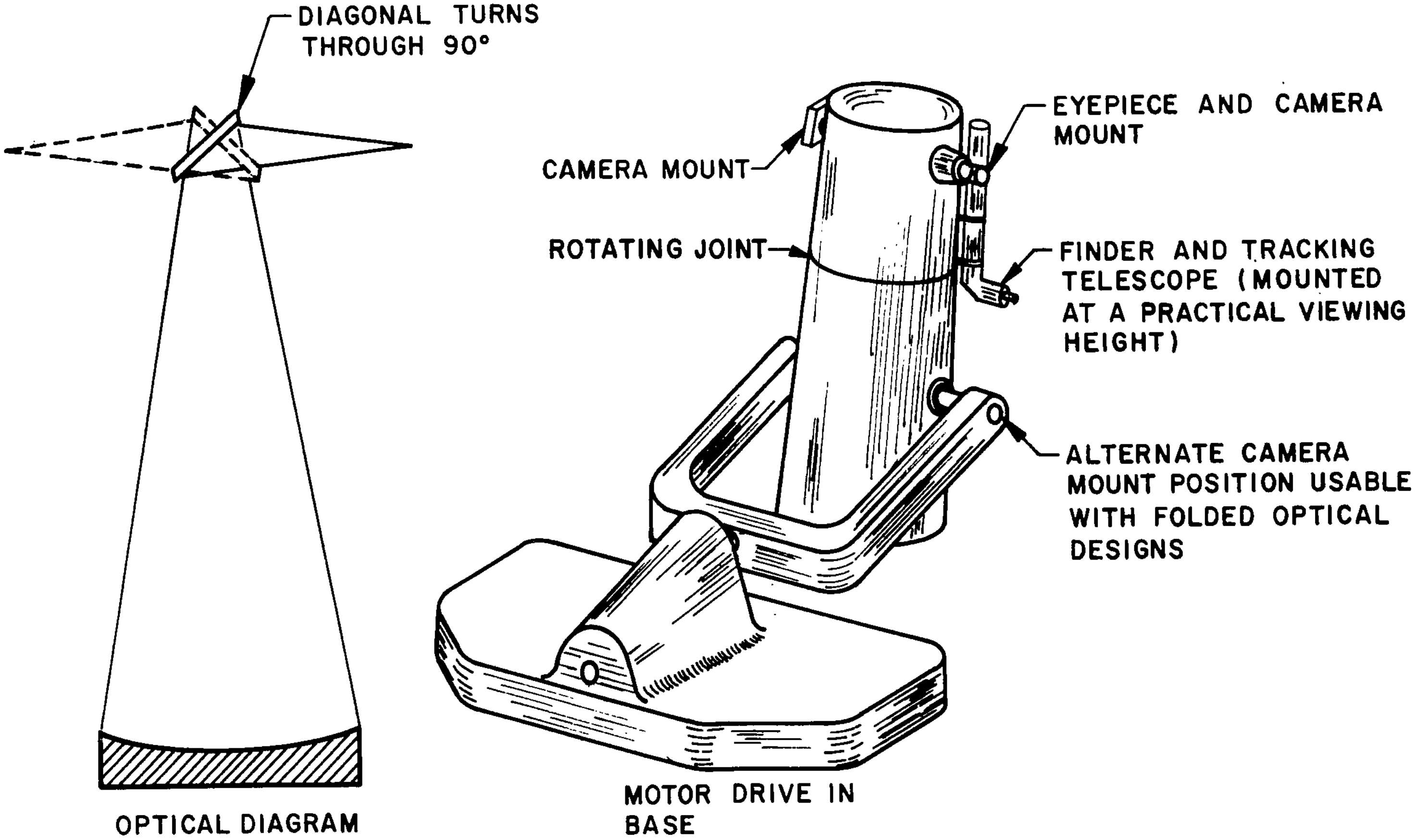


FIGURE 5. LUNAR SURFACE CONCEPT NO. 2 (FORK-MOUNTED NEWTONIAN)

One obvious advantage would be to have the telescope mounted outside the shelter but attached to it (Figure 6) and the viewing and photography done from both inside and outside. This would not be too difficult if it were permissible to have the astronaut carry the telescope outside and attach it to prepared mounting plates around the portholes. The eyepiece image would be projected into the shelter and the telescope would swing at least 30° horizontally, giving 60° coverage at each port. A prearranged viewing schedule would be made up so that all objects in view of each mount would be examined before moving the instrument to another view port. It appears that this method would give the required flexibility and offer the advantage of safer viewing conditions. All ultraviolet and infrared photography would be done outside by turning the diagonal so that the image is projected out the other side of the tube at either the Cassengrainian or Newtonian focus where the camera is mounted. Moving the telescope to another porthole could be accomplished while the astronaut was normally outside for other reasons. It also simplifies the astronomical operation since viewing eyepieces, filters, etc., would remain in the shelter. One astronaut could find the desired objects while inside the shelter so that the astronaut outside could photograph them or the photography could be accomplished by remote camera controls. This arrangement would require a coudé focus arrangement which is not too difficult to provide. It would simplify the mounting problems but the advantage of an equatorial mount would have to be sacrificed. A Cassegrainian type telescope would be preferable. It could be designed so as to also be usable outside on a separate mount (covering the whole sky) for direct photographs in the infrared-ultraviolet regions (Figures 7 & 8). A dome as shown could be used.

A fixed telescope could be mounted vertically through the roof of the shelter (Figure 9). Over this would be a plane mirror mounted on two axes so that it can tilt in all directions. By reflecting light into the telescope, a large part of the sky up to about 40° from any horizontal direction could be covered. The only part that would not be seen would be a cone of approximately 50° from the vertical. This might not be serious since, due to the rotation of the moon, stars are moving into and out of this cone constantly. When the telescope is used, it should first be used for those areas in which the stars would soon be invisible — the parts of the sky entering the cone and those about to set. Viewing to the lunar horizon would be practical since there is no atmospheric refraction with which to contend. An equatorial axis could be achieved for one mirror axis by mounting the telescope at right angles to the north-south lunar axis. If the mirror pivots on a line parallel to the lunar axis, it could thus give the advantage of equatorial movement. Another axis at right angles to the first and extending east and west would be used to tilt to other views.

For this arrangement, a Maksutov would be desirable. The front lens would form the vacuum interface, and the flat mirror would be mounted on top of the shelter and operated manually or electrically from the inside. When used for tracking, the mirror would be driven at half the normal rate.

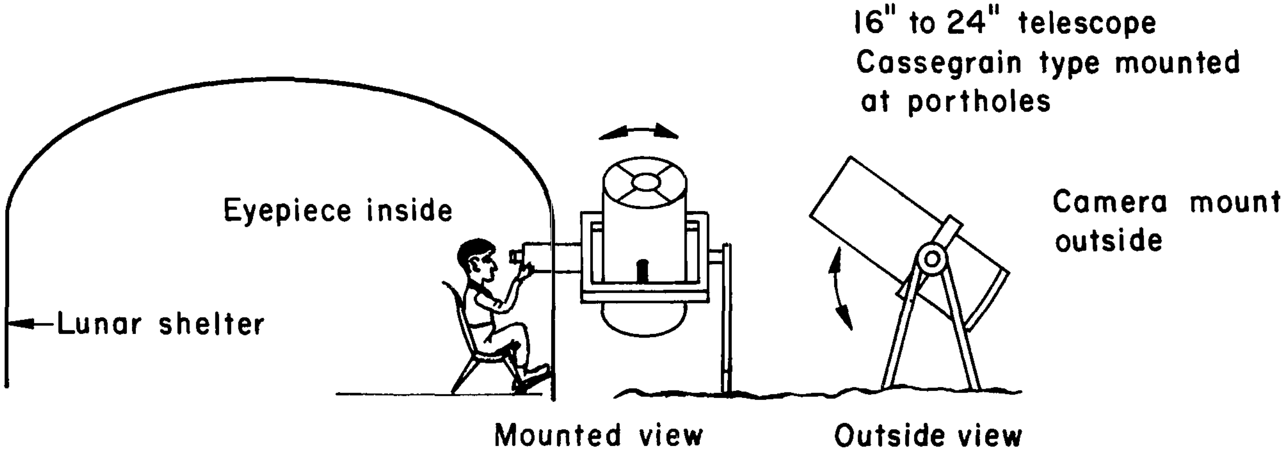


FIGURE 6. SHELTER TELESCOPE CONCEPT NO. 1

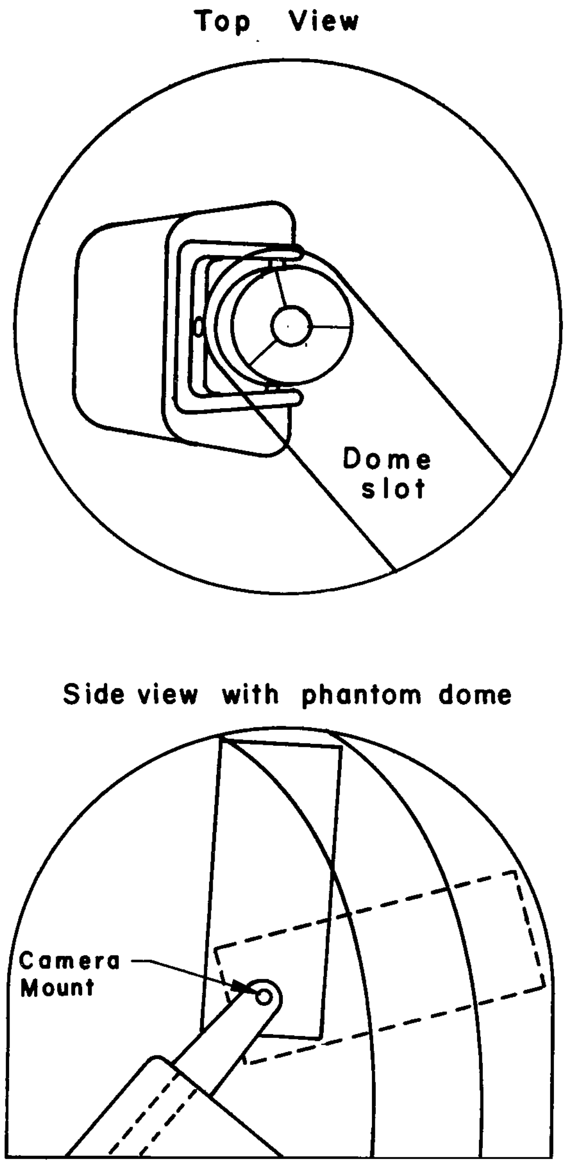


FIGURE 7. OBSERVATORY FOR MIDDLE LATITUDES WITH YOKE MOUNT*

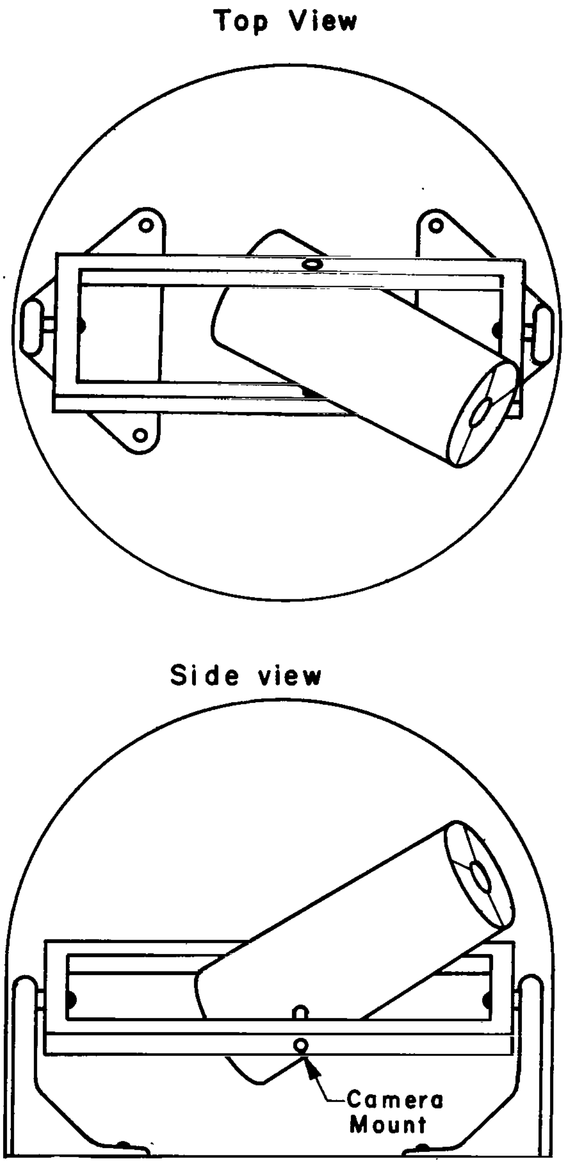


FIGURE 8. OBSERVATORY FOR EQUATORIAL LATITUDES WITH CLOSED YOKE MOUNT*

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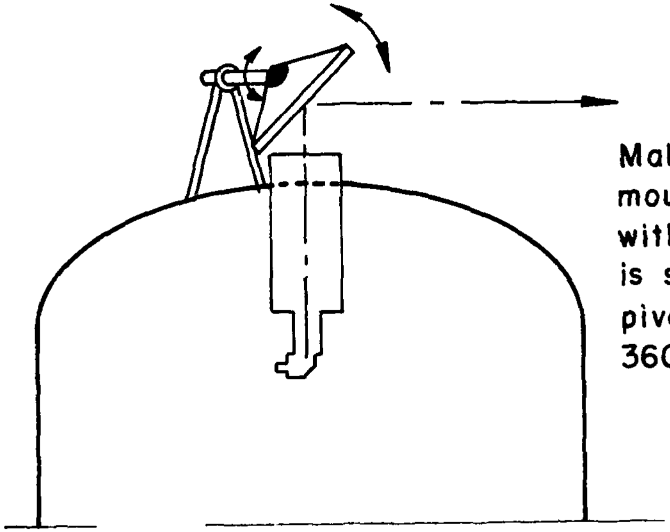
*Minimum Dome Designs for Lunar Surface Telescopes (Supplemental Unpressurized Domes to Afford Shade and Impact Protection)



Maksutov or Cassegrain telescope mounted vertically in top of shelter with tilting mirror above. Telescope is stationary. The mirror could be pivoted vertically from above to give 360° view

FIGURE 9. SHELTER TELESCOPE CONCEPT NO. 2

The telescope could be mounted on the equatorial (lunar rotation) axis and a flat mirror used as described above. However, this is not the best arrangement, because of the limited coverage attainable. The mirror would probably not be able to reflect a good image much past the vertical, and the shelter would block much of the opposite view.

The telescope could be mounted at other angles, such as 45° or directly toward north (Figure 10). Although this would give a better arrangement for observing the planets for an observatory at lunar equatorial latitudes, it would not be an equatorial mount unless the installation was at the lunar latitude corresponding to the polar telescope axis tilt.

These arrangements simplify the telescope mount, but make it necessary to supply a flat optical front-surfaced mirror, 1.4 times the telescope diameter. Also, since the light must pass through a lens to seal the air in, the usefulness of the arrangement for ultraviolet and infrared would be largely lost. Only reflecting surfaces can preserve the true image in these regions. Finding the desired celestial objects would be difficult with the reflecting systems.

An alternative would be a mount for use on the lunar surface. In this case, the telescope could be mounted on a low base containing the axes and motor drive (Figures 4, 5, 7, 8, 11 and 12. A Newtonian design would offer many advantages for a small telescope of 12 inches diameter (305 cm), or less, with the eyepiece on the top of the tube (about eye level). The end of the tube containing the eyepiece could revolve so that best use could be realized at all angles (Figure 5). The simplified optics would provide high optical efficiency and the "spikes" normally seen in such an instrument could be eliminated by using a disk of optical plate glass to support the diagonal. For infrared and ultraviolet photography, the use of this glass would be disadvantageous.

A low center of gravity, high stability, equatorial mount would be very practical for lunar surface use. Two mounts (cradle and fork designs) are shown in Figures 11 and 12. Motors could be built in for driving the polar axis. These mounts would be heavier than the porthole mount, but could be taken to the moon on a later mission to remount the porthole telescope for efficient use. Note that these mounts require minimum dome diameters.

As previously suggested, the telescope could be a Maksutov on a motor-driven equatorial mount. This type would probably not offer any more advantages than the Newtonian, because the mount would have to be higher for astronaut use, making it more susceptible to vibration and tipping. In addition, the optical efficiency and color rendition would not be quite as good. A choice between the two may not be easy to make unless IR and UV studies prove to be important, and further studies are indicated. For either type, if used on the lunar surface, the eyepieces should be turret-mounted to reduce the possibility of loss or breakage.

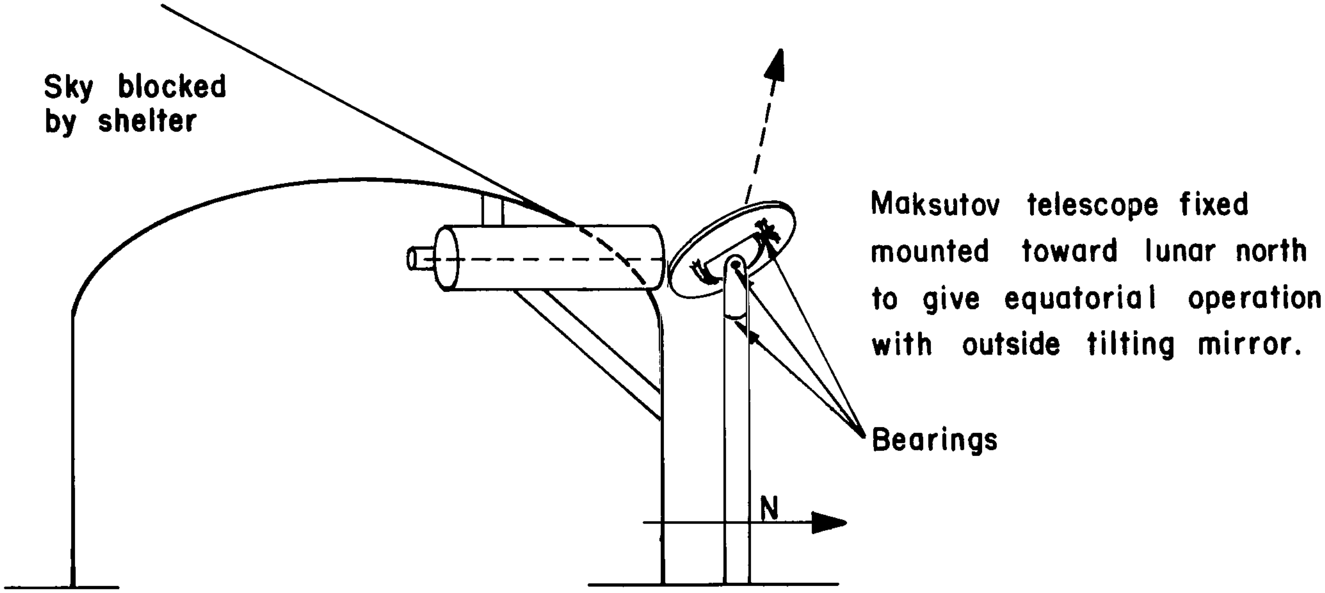


FIG. 10 - SHELTER TELESCOPE CONCEPT NO. 3

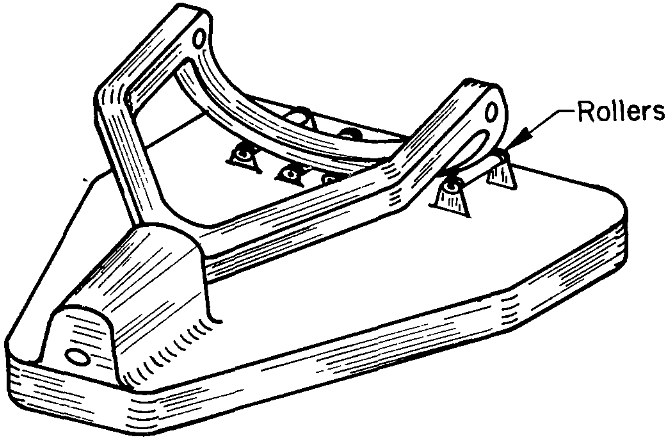


FIGURE 11. CRADLE MOUNT

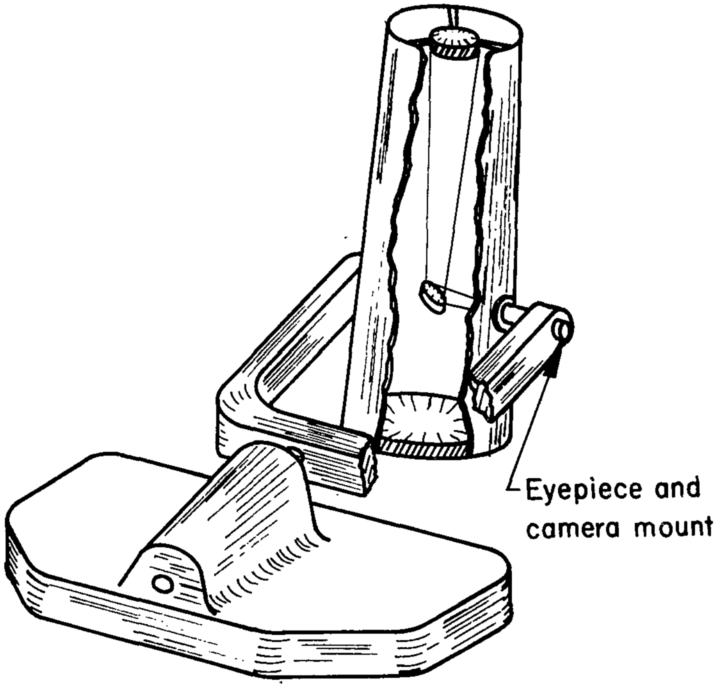


FIGURE 12. FORK MOUNT

These mounts are ideal for compact designs. By careful mechanical design, the center of gravity could be kept very low and the weight could be optimized. The cradle type could probably be made sturdier than the fork type for the same weight, but the individual rollers would be less desirable since they would probably get dirty and erratic in operation. The fork mount would have to be driven on the polar axis but the cradle type could be driven through one or more rollers or the polar axis. Both mounts meet the requirements for a minimal diameter dome.

Some factors that bear upon the choice between the Newtonian and the Maksutov are offered. The Newtonian is simple, "fool-proof," and not so critical relative to exact optical alignment. It could be used to photograph objects in the infrared and ultraviolet. It could even be assembled at the site, if desired. The proposed design would have a very low center of gravity and high stability. It could be built similar to an amateur's Newtonian in which a metal "spider" supports the secondary diagonal mirror, and thereby save weight. The covering glass disk, proposed above to replace the spider, would help to protect the primary mirror from high velocity particles, dust, and dirt which could fall down the tube. On the other hand, these particles would damage the disk. The extra weight of the glass might be an advantage in counterweighting the tube, since the main mirror at the bottom would be quite heavy. The moment of the tube itself might not be large enough to effect a balance without using a heavy tube or a weight on the top. Further design can answer these problems. The Maksutov is a highly efficient, very compact instrument but is very delicate and could be destroyed if dropped. Small parts could be carried as spares, but not the large parts (e. g., primary mirror and lens). The mount would have to provide for comfortable eyepiece viewing and photography, and even with a seated astronaut-operator, could be approximately 1 1/2 meters high. A well-designed, rigid mount supporting a heavy telescope could be assembled at the desired location by the astronaut.

Parts and Materials

Eyepieces (Table I) are usually 1 1/4 inches (32 mm) in diameter, and 1 inch (25 mm) to 3 inches (76 mm) in length. They have almost negligible weight and at least one of several types should be included. Part of the astronaut's duty could be to evaluate the relative advantages of various eyepieces for direct viewing in space.

Using a telescope while wearing a face shield has many disadvantages, among which are the limitations it places on the optics. The face shield would have to be free from color and distortion, preferably flat, and should be made of perfect optical glass. Since it causes a separation between the eye and the telescope eyepiece, symmetrical eyepieces are preferable, because they provide the maximum eye relief required in gun scopes. They are best adapted for low-power application, since the eye relief apparently decreases with high power. The characteristics of some eyepieces are given in Table I. If inside operation is provided, many types of eyepieces can be used. For wide fields of view, either orthoscopic or Erfle types are preferred.

Mirrors must be made of the best materials known. Full advantage must be taken of recent research in this area (including the OAO) Corning Glass Works has developed a material called Pyroceram. It has been claimed that zero coefficient glass is possible [9]. Recent work has indicated the advantages of using metal mirrors. The OAO mirror is made of 5200 B beryllium with a .006-inch (.0152-mm) Kanigen overcoating. It is

TABLE I

Eyepiece Types and Powers for 21-Inch Lunar Telescope

Focal Length		Type	Power	Field of View		
Inches	mm			Eyepiece	Telescope	Arcseconds
4	102	1**	88	30°	.342°	
4	102	2**	88	30°	.342°	
4	102	3**	88	45°	.512°	
4	102	4**	88	65°	.74°	
3	76	1	117	30°	.256°	
3	76	3	117	45°	.385°	
3	76	4	117	65°	.552°	
2	51	4	175	65°	.372°	
1.5	37	4	234	65°	.277°	
1	25.4	4	355	65°	.183°	(660)*
1	25.4	5**	355	30°	.085°	(306)
.8	18.7	4	438	65°	.148°	(532)
.8	18.7	5	438	30°	.068	(286)
.6	15.2	4	582	65°	.11°	(396)
.6	15.2	5	582	30°	.052°	(188)
.5	12.5	5	710	30°	.042°	(152)
.4	10.2	5	876	30°	.0343	(124)
.3	7.6	5	1050	30°	.0286	(104)
.28	7.2	5	1250	30°	.024	(80)
.25	6.4	5	1400	30°	.021	(77)

* Reference: Tools of the Astronomer P 65-67

Eyepiece Type**	Optics	Field of View	Notes
1. Hastings Triplett		30°	Field of view not available, 30° field assumed
2. Achromatic Symmetrical		30°	
3. Kellner		45°	May be used with a reticle
4. Erfle		65°	Various arrangements high quality, excellent performance
5. Orthoscopic		30°	Best type for high powers because of the wider field

necessary to provide an excellent mirror with the lowest possible temperature coefficient or one that will quickly adjust to the extreme lunar temperature variations. Mirrors can be ribbed on the back to reduce the weight. The relationship between mirror (objective) size and its capability is given in Table II.

Telescope tubes could be made of a nonmentallic material, probably plastic. It must be very stable and capable of protecting the optical components to the highest degree. It should be as light weight as practical. If a protecting dome is provided, it may be possible to eliminate the tube and use only a skeleton frame, but good shading against stray light for daylight use would be necessary.

The drive motor should be a synchronous alternating current unit driven by an oscillator, although when the large number of corrections which must be included in the $\Delta\omega$ term are considered, a series direct current motor [10] using a rheostat speed control may be suitable for visual work, even on solar system objects, if the voltage is constant.

One prime objective should be to obtain pictures of the planets and selected galaxies, multiple stars, and nebulae in the ultraviolet and infrared ranges since this is not possible on earth to the desired degree of perfection. The best filters should be chosen for this work. Other filters should be provided to observe in various colors.

Several photographs of the planets should be made of the highest practical powers to obtain detail not now known. The powers used should be chosen by viewing through the telescope with various eyepieces. Eyepiece projection techniques would be used to increase the photographic image size. This is especially suitable for image intensifier work and some of this should be done.

Telescope Size

Even though a telescope as small as 8 inches (20.3 cm) will give the astronaut almost unexcelled views of celestial objects, it seems entirely justifiable to carry as large a telescope as is reasonably possible. The size can be determined by knowing the power and resolution desired, the resolution being inversely proportional to the diameter. From many sources and much experience in astronomy, a practical photographic limit of one-third second of arc has been found for earth telescopes. This is because of atmospheric turbulence, absorption, and scattering of light. The resolution limit (from Dawes' studies) is:

$$\text{Resolution} = \frac{4.56}{D} \text{ seconds of arc,}$$

TABLE II

Mirror Sizes and Capabilities

Mirror Diam.	Resolution	Maximum Power for Theoretical Resolution*	Resolution on Mars **	
Inches	in Arcseconds	Power	Miles	Km
4.56	1.0	228	175	282
9.12	.5	456	88	142
13.68	.33	684	58	93
16.0	.29	800	51	81.7
20.0	.228	1000	40	64
24.0	.19	1200	33.2	53.2
30.0	.151	1500	26.4	42.3
36.0	.13	1800	22.6	36.3
40.0	.114	2000	19.9	32
45.6	.10	2280	17.5	28
60.0	.076	3000	13.2	21.2
70.0	.065	3500	11.4	18.3
80.0	.057	4000	10	16.9
90.0	.051	4500	8.9	14.3
100.0	.046	5000	8.1	13.1
120.0	.038	6000	6.7	10.8
140.0	.033	7000	5.8	9.3
160.0	.028	8000	4.9	7.85
200.0	.0228	10,000	3.4	5.45

* This is the maximum power theoretically capable of yielding usable resolution

**Based on Mars at the near approach to earth 36,000,000 miles (57,800,000 Km) where D is the objective diameter in inches, or

$$\text{Resolution} = \frac{11.58}{D'} \quad ,$$

where D' is the objective diameter in centimeters.

This shows that the theoretical diameter required to resolve to one-third second is 13.68 inches (34.7 cm). In space, the theoretical resolution is attainable. On the moon, with the proper power, a 14-inch (35.4 cm) telescope should reveal as much detail of the planets as any telescope on earth can normally photograph. Going just to the earth limit is good; but it would be a real achievement to exceed this, so an even larger mirror should be considered, such as between 14 and 30 inches (35.4 and 76.2 cm). If the shelter porthole method of mounting is used, most of the weight of a mount can be eliminated, leaving most of the allowable weight for the telescope (optics and tube). It seems that a 16-inch (41.6 cm), or so, might be allowable, giving .29-arcseconds resolution and 800 power with full definition, with higher powers up to possibly 1000 usable on distant planets and satellites. For resolutions and powers of larger mirrors, refer to Table II.

Mirrors are usually made of pyrex and have approximately a 6 to 1 diameter-to-thickness ratio. By molding a ribbed design into the back, this ratio and weight can be decreased. The coefficient of expansion of pyrex glass is 25 to 30 x 10^{-7} per °C. Clear fused quartz has excellent temperature stability with a coefficient of 49 x 10^{-8} per °C, and is considered the ultimate material by some opticians. Its density is 2.21. Metal mirrors are entirely practical and can be made much thinner and therefore lighter than glass for the same size.

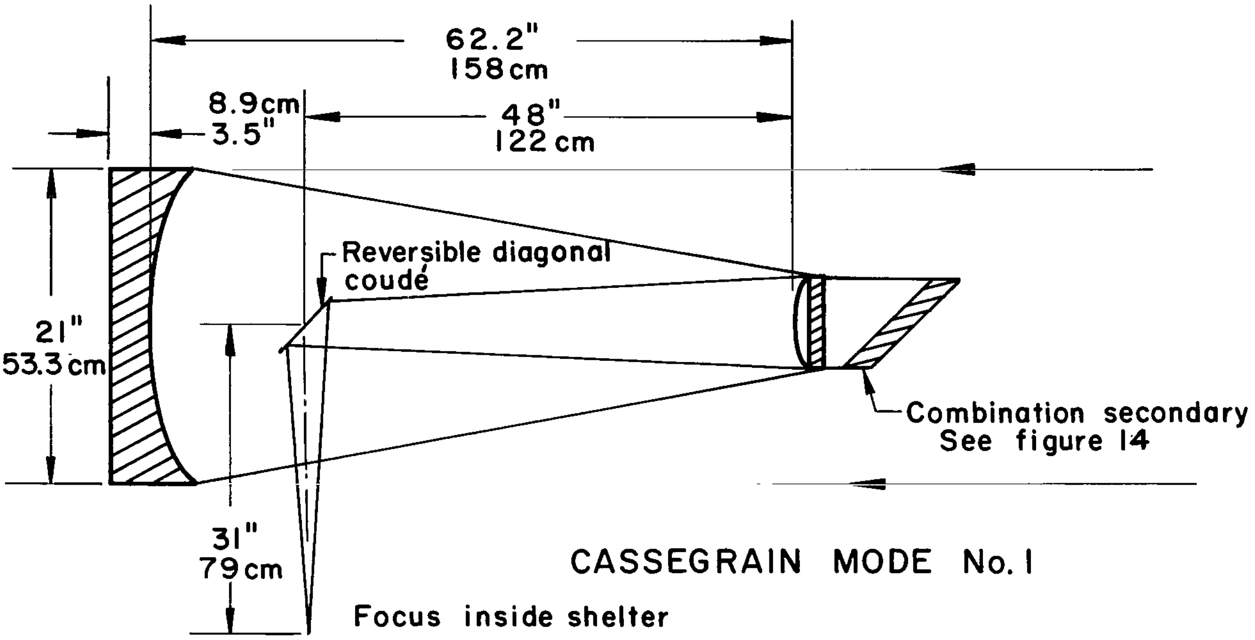
Minimal Dome Designs

Although the first telescope on the moon will probably not be used with a dome, it is most probable that later missions will allow this. For lunar use, the dome and telescope must be designed for optimum efficiency and utility. The dome would shade and protect the telescope optics and the astronaut from impacts, heat, and cold. A yoke or fork mount is very advantageous as the center of revolution of the telescope axes always remains at a fixed point. This allows the maximum length telescope to be used with any particular dome. If a yoke is designed for a dome and a telescope is mounted so that it rotates about the center of the dome, no waste space is left. The telescope top will have only to clear the dome by a reasonable amount. A study of Figures 7 and 8 shows this very clearly. The telescope should also be designed to ensure that its center of gravity coincides with its pivot in the yoke. The yoke mount is most convenient for middle latitudes, and becomes somewhat awkward at the equator and the poles. If the pivot point is higher than 1 to 1 1/2 m, the design shown in Figure 5 is very practical since the eyepiece and camera remain at a convenient height for all viewing angles. For low pivot mounts, a Newtonian would be preferable (Figures 6 and 12). For objects too high for eyepiece use, a camera is attached, and the tracking telescope is used to center the object while photographing. The tracking telescope can be mounted at any convenient height above the ground. A flip mirror can be used at lower altitudes (see optical diagram) to permit photography on the other side as soon as an object has been located through the eyepiece.

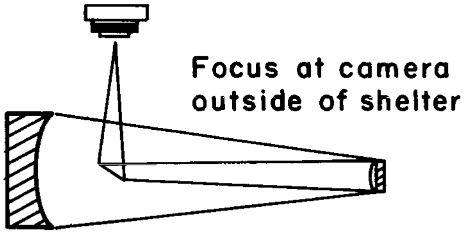
A counterweighted German equatorial mount would require a larger dome for the same telescope, since the two rotation axes do not intersect over the mount but to one side. The counterweight is also added on one side providing a questionable increase in stability for this additional mass.

A 21-INCH LUNAR TELESCOPE CONCEPT

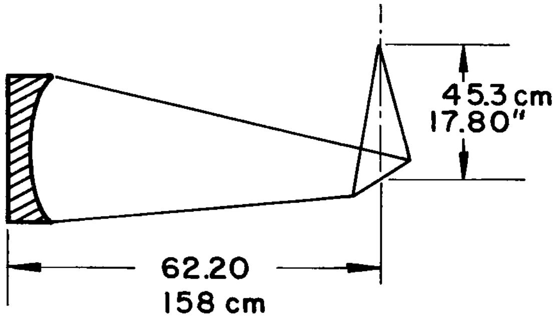
A 21-inch (53.2 cm) porthole folded optics telescope is considered to be a practical and reasonable size for an early lunar mission. A preliminary design has been worked out (Figures 13 and 14, and Tables I and III). This design will give a 50 percent decrease in resolution over current earth-based instruments and will allow high powers (up to 1050) to be used as desired. This design was chosen to provide the maximum spectral coverage in ultraviolet and infrared. An innovation could permit photography at the Newtonian prime focus by the use of a combination mount for the Cassegrainian/Newtonian secondaries, Figure 14. Using an internal correcting lens or stopping down the system to f/6 would eliminate much of the coma at prime (Newtonian) focus. A 13.3-inch (34-cm) diaphragm could be provided. The secondaries of this design have not been sized for correct field coverage. A reversing coudé diagonal flat is also provided for projecting the image to either side of the tube. This telescope could be mounted for porthole use, as shown in Figure 6, for the first mission. On a later mission, an equatorial mount, a Schmidt corrector lens, and possibly a dome, could be supplied to provide a complete observatory on the moon. Figure 5, 7, 8, 11, and 12 depict the ideas possible for mounting and remounting. The complete Schmidt system would provide an excellent wide field photographic telescope. The f/3.8 17-inch Schmidt at Cambridge England covers a 5° field [11]. Two lenses could be provided to cover spectral ranges well into the IR and UV if justifiable for wide field studies.



CASSEGRAIN MODE No. 1



CASSEGRAIN MODE No. 2
Same dimensions as mode no. 1 but diagonal reversed



NEWTONIAN FOCUS MODE No. 3

FIG. 13 - OPERATING MODES FOR 21-INCH LUNAR TELESCOPE

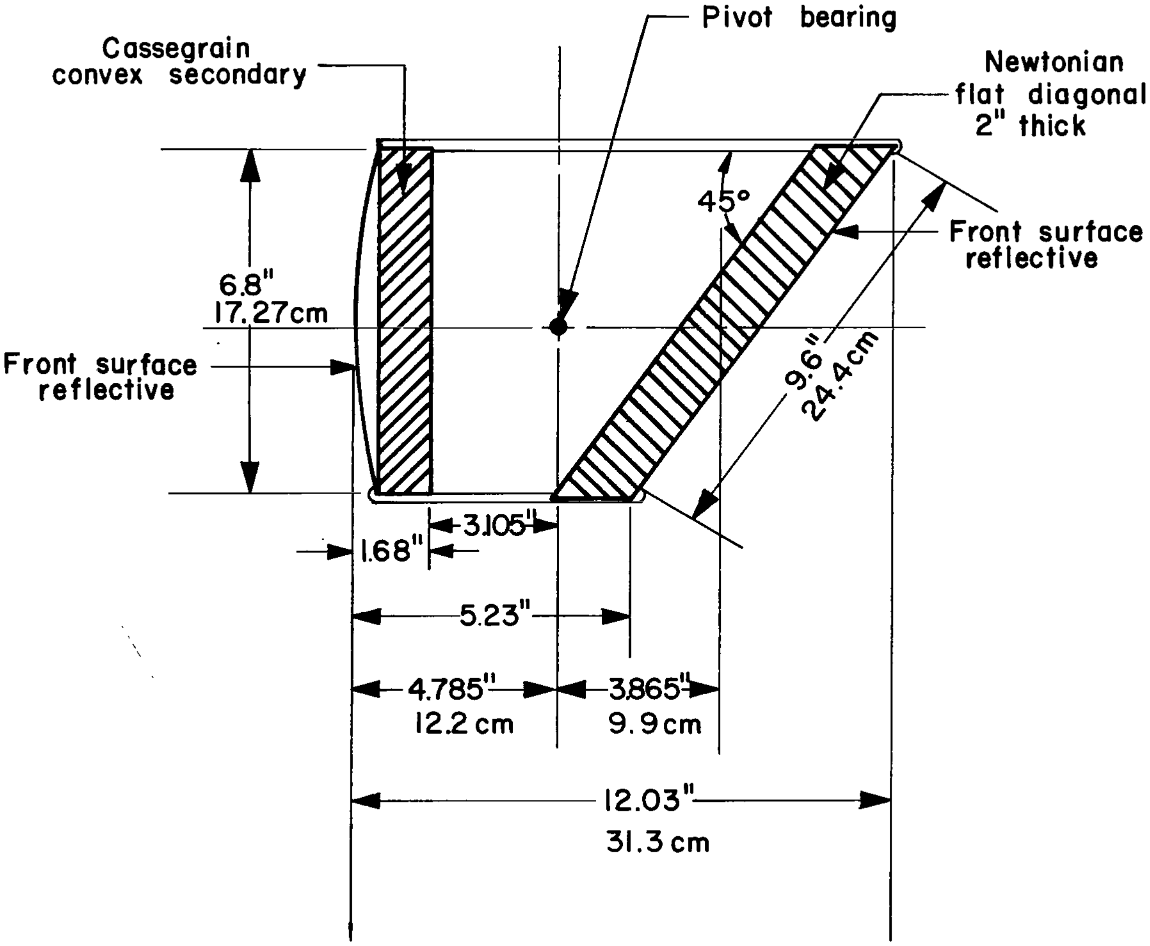


FIGURE 14. COMBINATION CASSEGRAINIAN-NEWTONIAN SECONDARY OPTICAL ARRANGEMENT FOR 21-INCH LUNAR TELESCOPE CONCEPT

TABLE III

Specifications For 21-Inch Lunar Telescope
(preliminary)

Type: Combination Newtonian/Cassegrain

Primary:
- Diameter: 21" (52-2 cm)
- Focal ratio: f/3. 8
- Focal length: 80" (203 cm)
- Thickness: if pyrex, 3. 5" (8. 9 cm)
- Thickness: if metal, to be determined
- Surface figure: Concave paraboloid
- Accuracy: 1/50 wave, visual range

Secondary No. 1, Cassegrain
- Diameter: 6. 8" (17. 2 cm)
- Surface: Convex hyperboloid front surface reflective

Secondary No. 2, Newtonian
- Diameter: 6. 8" (17. 2 cm)
- Surface: Flat to 1/50 wavelength front surface reflective

The component maximum weights are estimated as follows:

COMPONENT	WEIGHT	
	Lbs.	kg
Objective Mirror	125	56.8
Secondary Combination	12	5.4
Tube and Hardware	150	68.2
Accessories	13	5.9
	300	136.3

With metal optics, this could probably be reduced to 250 lbs (114 kg) or less. Electrical power required for motor drive, etc., would be about 15 W.

George C. Marshall Space Flight Center,
National Aeronautics and Space Administration,
Huntsville, Alabama, June 4, 1965

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3/18/75

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