

CONSTRUCTION OUTLINES OF THE UTRECHT OPEN SOLAR TELESCOPE

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ABSTRACT

The geometric configurations of an open telescope construction which combines maximum stiffness with minimum area exposed to the wind, are given.

1. INTRODUCTION

We present an asymmetric triangular form of telescope and fork which fit together in a logical way. This configuration leads to more stiffness in less volume than a symmetric fork construction offers. Further advantages are the easy access and interchangeability of the secondary optics, and the low shadow area on the primary mirror.

Point of departure for the further telescope mount is a polar mount as stiff as possible. An alt-azimuth mount can be constructed on the same principles slightly stiffer, but has the complication, that the rotation velocities of the two axes have to be regulated for following an object. We preferred to avoid this complication for the removable telescope with a primary mirror of 45 cm diameter. The direction of the polar axis can be adapted to the geographic latitude with minor modifications in the telescope mount.

The presented geometric configuration of an open telescope may be well extended to telescopes of large aperture, for example with a primary mirror of 2 m diameter. The configuration offers good prospects for high resolution work because of the low internal seeing combined with the low disturbance of the local environment, for solar astrometry because of the mechanical stability, and for polarisation measurements because of the optical axial symmetric configuration up to the polarisation encoder. The configuration is also suitable for stellar work because nearly the complete sky will be accessible. This offers the possibility to make high resolution spectra of the sun and stars with the same spectrograph. This paper emphasizes the outlines of the mechanical design. A discussion of the potential advantages of a large-aperture telescope based on the open configuration was given by Hammerschlag and Rutten (1978).

An integrating addition to the telescope is a transparent tower, which elevates the telescope above the air layer of forced convection near the ground without a disturbance of the air mass around the telescope by the tower itself. A description of the tower is found in

Hammerschlag (1973). The construction of this tower is finished (Hammerschlag and Zwaan, 1975). Interferometric methods for recording the deflections of the tower by wind were developed (Hammerschlag, 1975). The interferometric measurements proved the stability of the tower (Hammerschlag, 1977). A brief description of the tower and the interferometric measurements is given in this volume (Hammerschlag, 1980). It is not only a summary of the other references, but gives also additional results and ideas. The height of the tower for the 45 cm instrument is 15 m. A higher tower fits organically to a larger instrument, for instance a height of 50 m to a telescope with primary mirror of 2 m diameter.

The paper consists only of figures with explanatory captions. This unusual form is chosen, because the essence of the mechanical design can only be shown in schematic drawings.

A summary of the applied principles, which lead to stiff constructions, is given in an appendix.

FIG. 1.- Optical configuration

Examples of polarisation encoders PE are revolving polarisers or retardation plates or electro optical devices. It is also possible, that the polarisation encoder splits the light in two orthogonally polarised beams, for instance right and left circularly polarised. Two images are transported side by side behind the polarisation encoder. The telescope is suitable for polarisation measurements because the primary mirror PM and lens L1 are used axially. The mirrors M1, M2 and the possible mirrors for a coudé-focus have no influence since they are located behind the polarisation encoder.

The mechanical structure permits a larger primary mirror, see figures 3 to 6 and 10. In case the telescope works well with the existing 45 cm parabolic mirror, we would like to replace this mirror by a larger one. We think about a spherical mirror. The secondary optics should compensate the spherical aberration. Figure 25 shows a possible configuration.

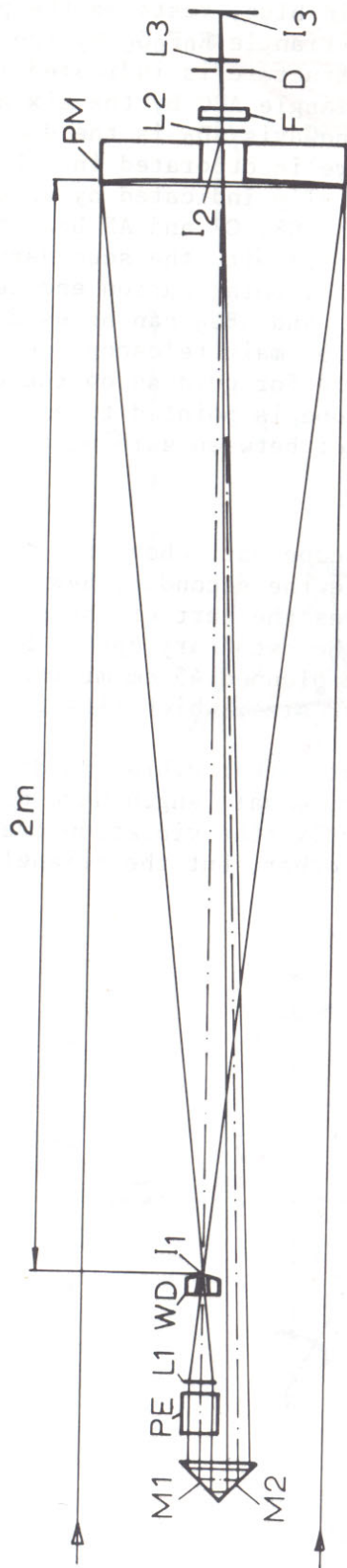


FIG. 1.- Optical configuration

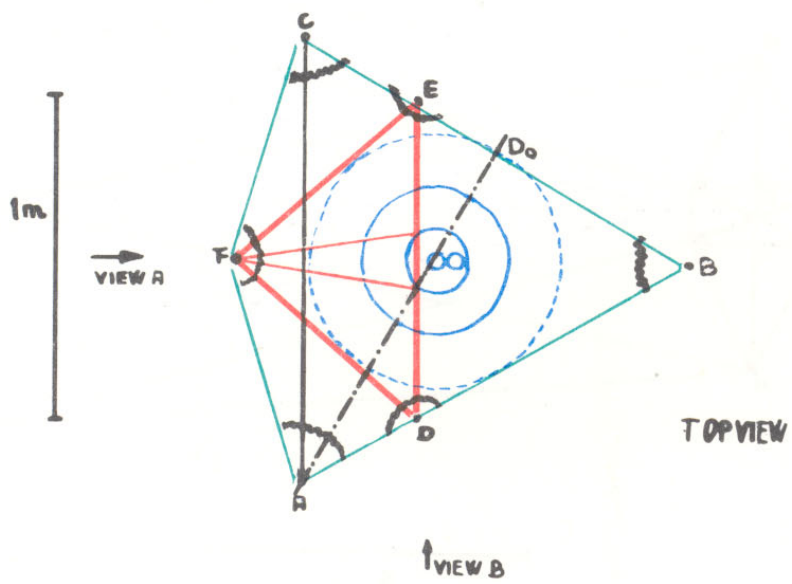
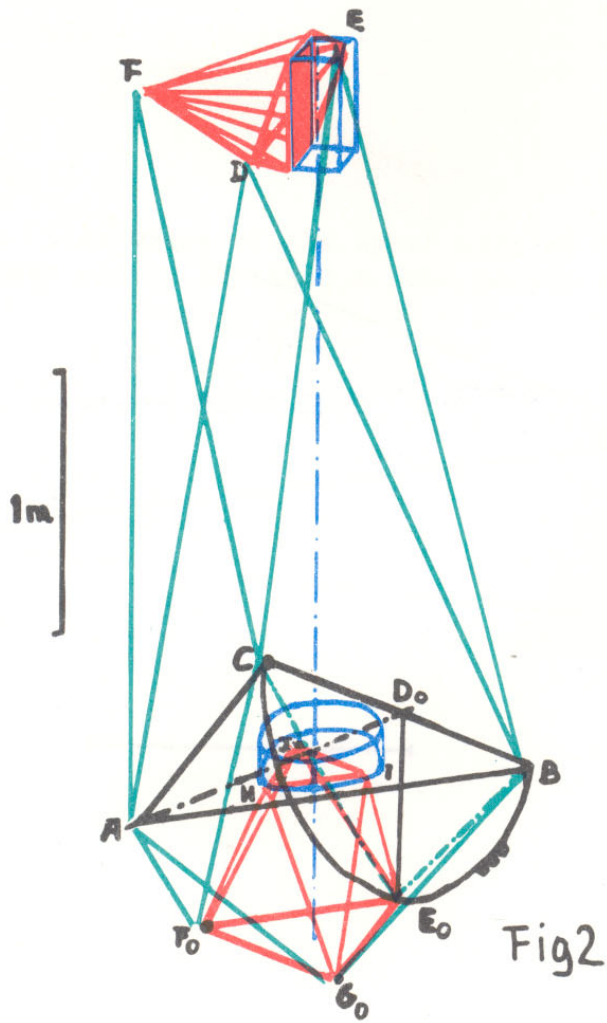
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|-----------------------|---|
| PM = primary mirror | D = diaphragm against the sky light |
| WD = cooled diaphragm | L2 forms an image of L1 in the plane of D |
| L1 = (objective) lens | PE = location for polarisation encoder |
| L2 = field lens | F = location for spectral filter, etc. |
| L3 = (ocular) lens | I ₁ = primary image |
| M1 } flat mirrors or | I ₂ = image near field lens |
| M2 } prism | I ₃ = final image |

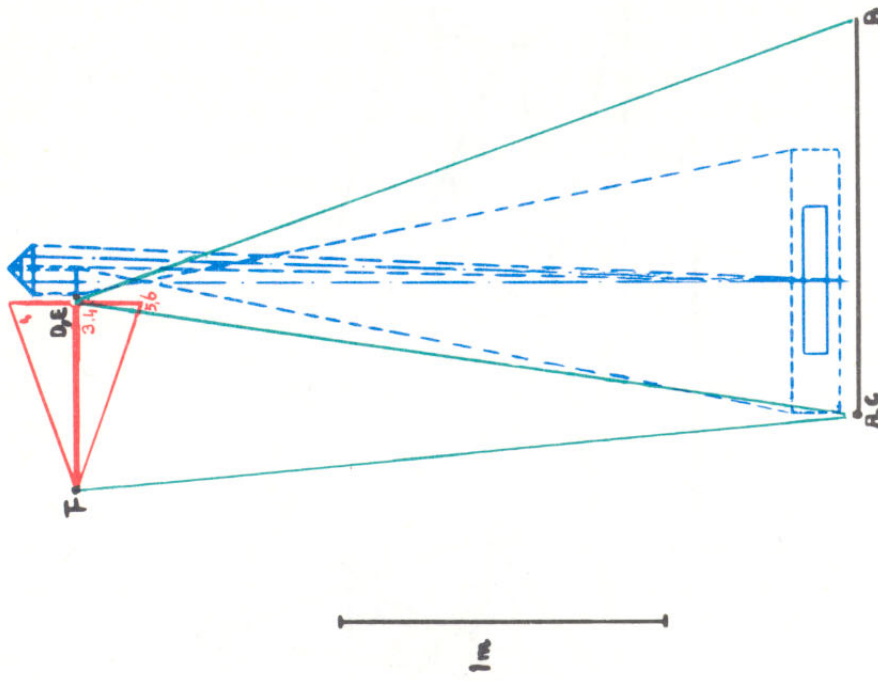
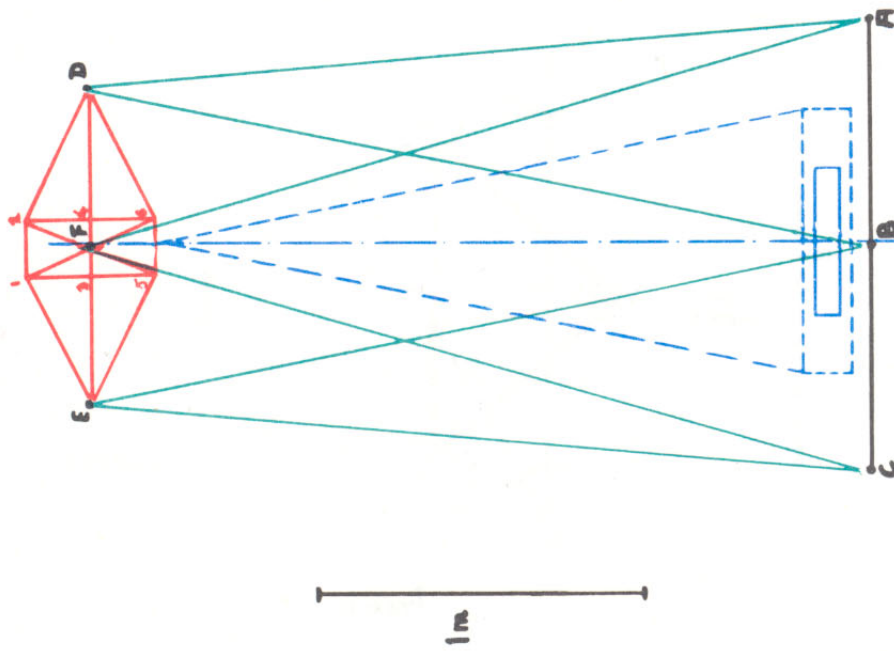
FIG. 2.— Pseudo perspective drawing of the telescope. The primary mirror and its support, indicated in blue, rests on the points H, I and J, which are connected to the triangle $E_0F_0G_0$ by the six bars HF_0 , HG_0 , IG_0 , IE_0 , JE_0 and JF_0 . This structure is indicated in red. The triangle $E_0F_0G_0$ is fixed to the triangle ABC by the six green bars E_0B , E_0C , F_0C , F_0A , G_0A and G_0B . The axis AD_0 is the declination axis. The dash-dotted bars E_0B and E_0C are incorporated in the declination gear wheel BE_0C , which is schematically indicated by three teeth.

The six green tubes AD, BD, BE, CE, CF and AF bear the red top triangle DEF, which holds the blue box with the secondary optics consisting of cooled diaphragm, lens L1, polarisation encoder and mirrors M1 and M2. The triangles BCE_0 , CAF_0 and ABG_0 can be used for attachment of guiding telescopes, since the main telescope sees only a part of the sun and offers no possibility for guiding on the opposite rims of the solar disk. The main telescope is pointed to a certain point of the solar disk by setting the offset between guiding telescope and main telescope.

FIG. 3.— Topview of the telescope part above the triangle ABC. The two small blue circles indicate the secondary beams. The circle around these two small circles gives the part of the primary beam, which is occulted by a screen on the secondary optics box. The large full circle is the boundary of the planned 45 cm mirror. The dashed circle indicates the maximum mirror size, which fits in the mechanical structure.

The black waving lines indicate, that vibration dampers are planned between the tubes. Tubes of equal length have different diameter, but equal sections. Consequently, the vibration frequencies are different and the tubes damp each other, but the triangle stiffness is equal.





FIGS. 4 and 5.— Side views of the upper part of the telescope.
The box with secondary optics is fixed to the points 1 to 6.

FIG. 6.— Bottom view of the telescope part below the triangle ABC. The planned 45 cm mirror is indicated in full blue line. The dashed blue circle indicates the maximum mirror size.

FIG. 7.— Side views of the lower part of the telescope. The mirror support is schematically indicated by blue lines between the mirror contour and the points H, I and J.

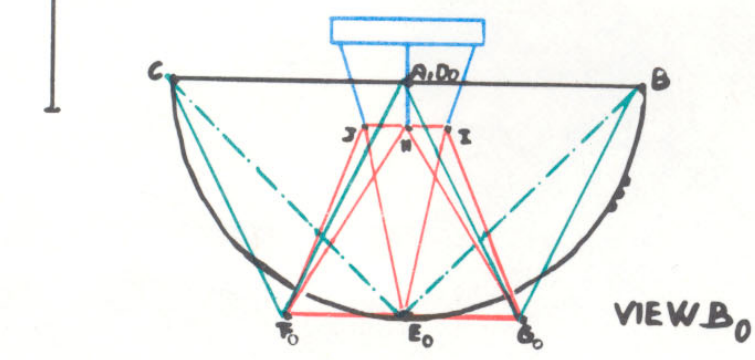
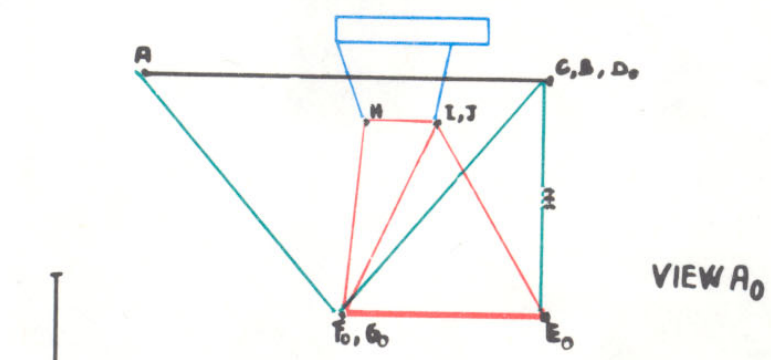
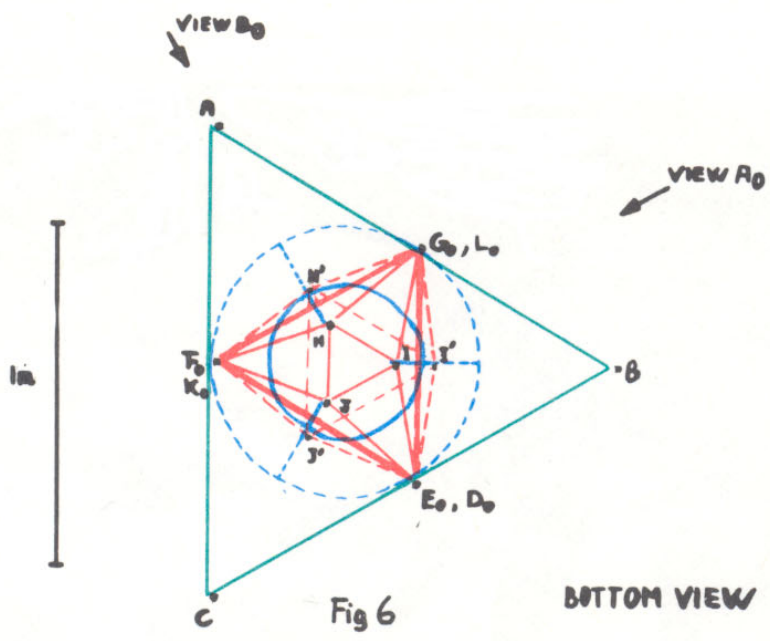


Fig 7

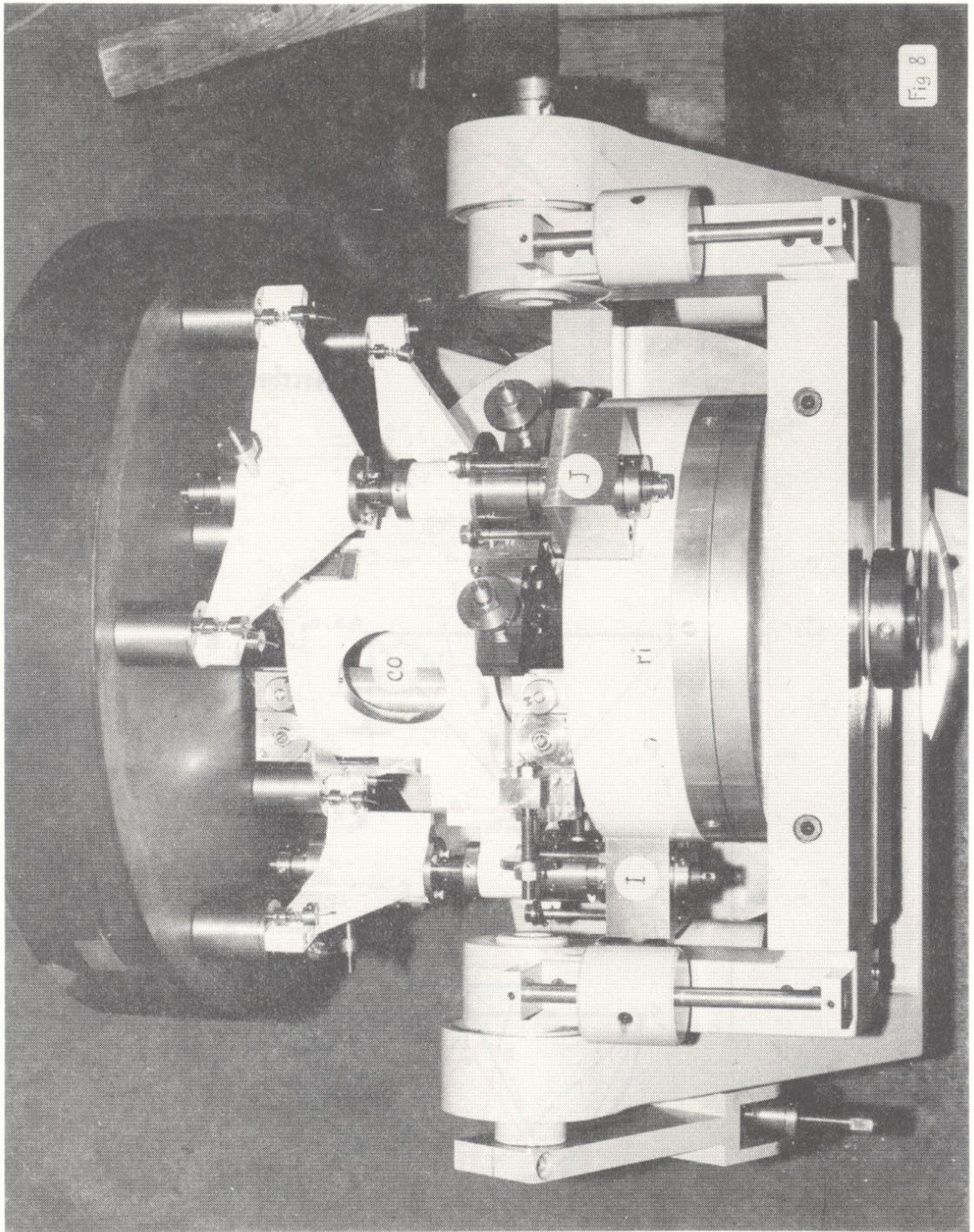
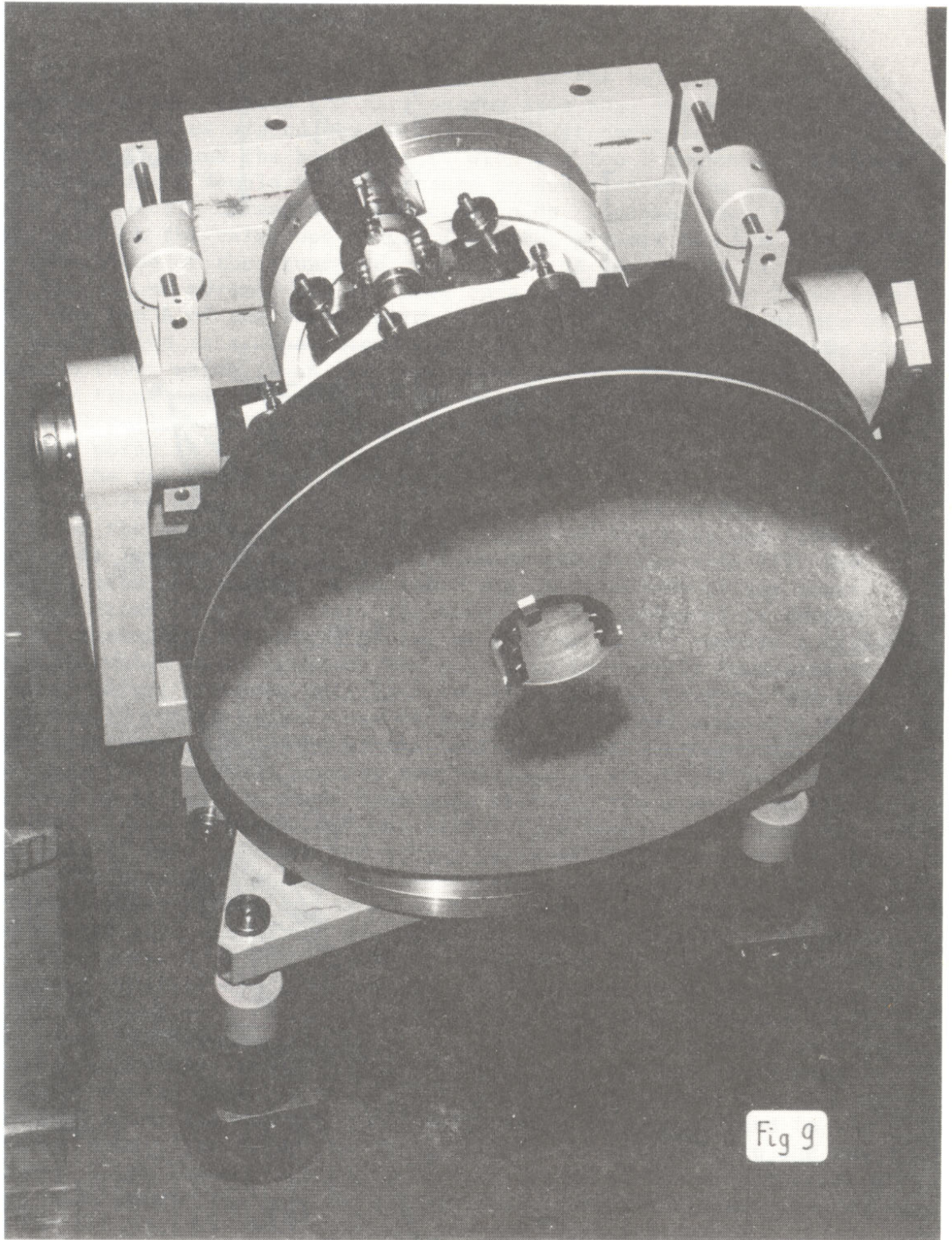


FIG. 8.— The real mirror support in a test mount. The mirror support rests with three "feet" on the points H, I and J. Two of these feet are visible in the figure and are indicated by I and J. Also a ring indicated by ri hangs on the feet H, I and J. Auxiliary equipment, like cameras and filters, is attached to this ring. In the figure the mirror support is fixed to the test mount by this ring. Stiff connection bars between the feet H, I and J are inside the ring. The hole indicated by co permits the passage of a coudé beam along the declination axis to D_0 .

FIG. 9.— The mirror is radially supported inside the central hole.



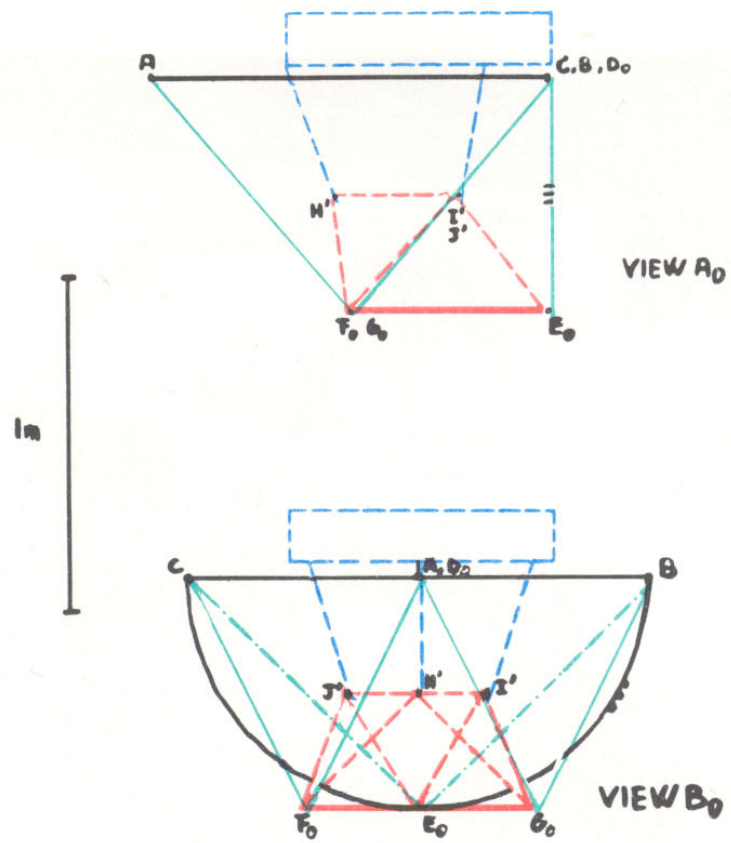


Fig 10

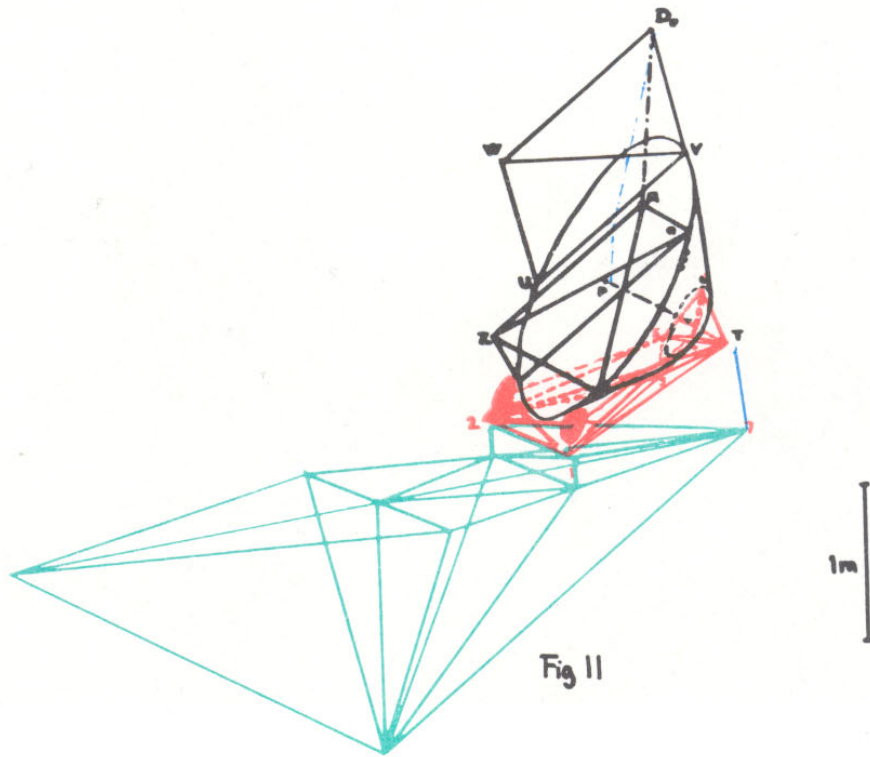


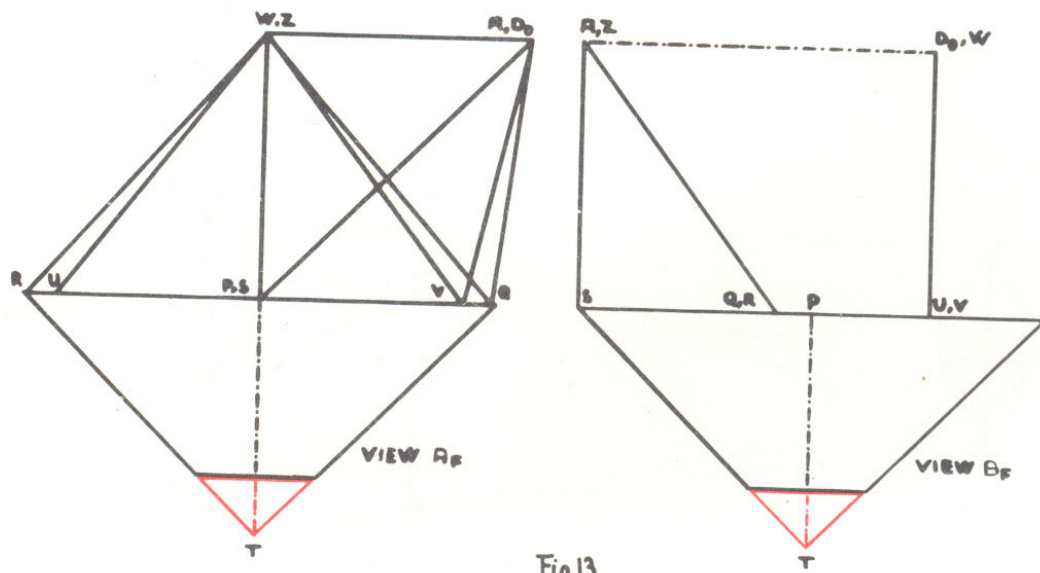
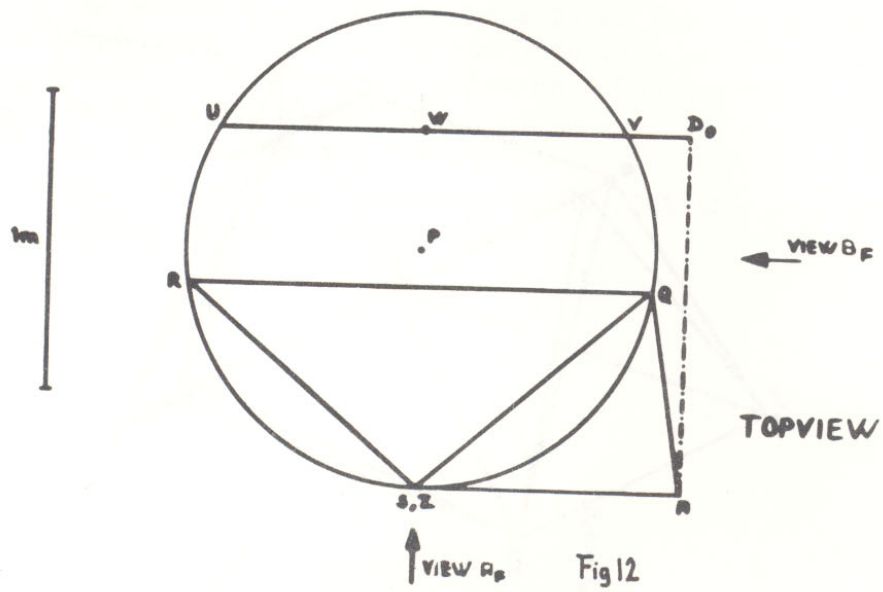
FIG. 10.— Side views of the lower part of the telescope with maximum mirror size. Replacement of the mirror by a larger one changes the 6 bars between triangle HIJ and triangle EFG_0 . The rest of the construction remains the same.

FIG. 11.— Pseudo perspective drawing of the telescope mount. The telescope rotates around the declination axis AD_0 . The black part in the figure rotates around the hour axis PT. It consists of a truncated cone centered round the hour axis PT with the top T downwards and base plane upwards. A double pyramid stands on one side of the base plane and a flat double triangle on the other side. Together they form a fork in which the telescope hangs. The first pyramid has its base on the base plane of the truncated cone. Z is the top of the first pyramid. The second pyramid has its base on a side plane of the first pyramid. The top A of the second pyramid is one of the bearing points of the declination axis. The second bearing point rests on the top D_0 of triangle VWD_0 , which is on its turn supported by triangle UVW.

The truncated cone rests on two rollers in the base plane and a spherical roller bearing under preload with its virtual self aligning rotation point in T. The two rollers and the spherical roller bearing rest in the red frame work construction, which will be explained in figure 18. The direction of the hour axis is adapted to the polar height of the observation site by the length of the blue bar from point T to 7. The red construction rotates around the axis 1-2. The pedestal with oblique top plane 1-2-7 and the platform of the tower are both drawn in green lines. The height of the pedestal is chosen for 55° maximum polar height. Polar heights up to 90° require a higher pedestal, which is no problem. The hour axis is movable downwards to 0° polar height (equator position) for all pedestal heights. The pedestal should not be higher than necessary, if maximum stability and consequently minimum height of the telescope mount is required. The flat construction $UVWD_0$ permits easy passage of the coudé beam through the bearing in D_0 . The coudé beam goes from D_0 , via a point on the line UV, to the hour axis PT (the dashed blue line), goes along the hour axis PT and it leaves the moving parts of the telescope through one of the triangles of the red construction. The coudé beam can be reflected under the telescope mount to the remaining free part of the platform or downward to the ground for very large auxiliary equipment. The coudé beam has a small diameter compared to the primary beam. Consequently, the use of prisms and/or multi-layer mirrors with very high reflection coefficients is possible for the reflections in the coudé beam. This removes the problem of the light loss, which could be present with 6 ordinary mirrors. It is advisable to put the coudé beam in evacuated tubes, which is no problem because of the small diameter of the coudé beam. The drive for the declination axis is mounted in the plane of $UVWD_0$. The drive for the hour axis is combined with the two rollers, which support the cone. The base plane of the cone carries a large gear wheel. The axes of the two rollers bear the pinion gears, one for the preload and the second for the regulated motion.

FIG. 12.— Top view of the fork construction on the base plane of the cone.

FIG. 13.— Side views of the fork.



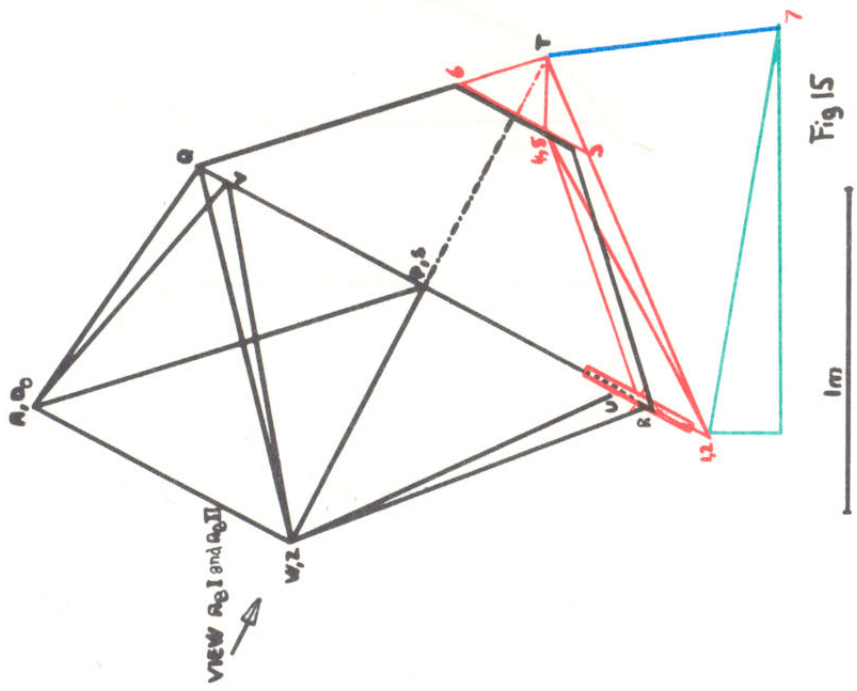
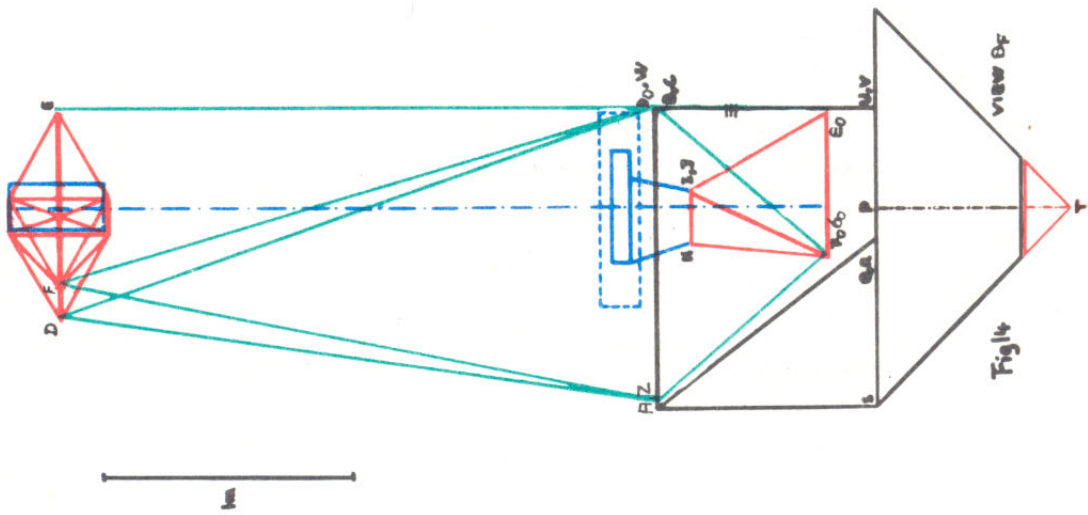


FIG. 14.— The telescope hanging in the fork. The top D_0 of the flat fork-leg UVD_0W gets stiffness in the direction of the declination axis from the other fork-leg via the telescope. The telescope hangs in tapered roller bearings under preload.

FIG. 15.— Side view of the telescope mount with the hour axis 28° from the horizon (for instance on La Palma).

FIG. 16.— View A_B I shows the structures in and in front of the base plane of the cone.

FIG. 17.— View A_B II shows the structures behind the base plane of the cone. The triangle 4-5-6 is fastened to the spherical roller bearing, which is indicated by the circle through the points 4, 5 and 6. The pyramid 4-5-6-T is supported by two pyramids 1-3-T-4 and 2-3-T-5.

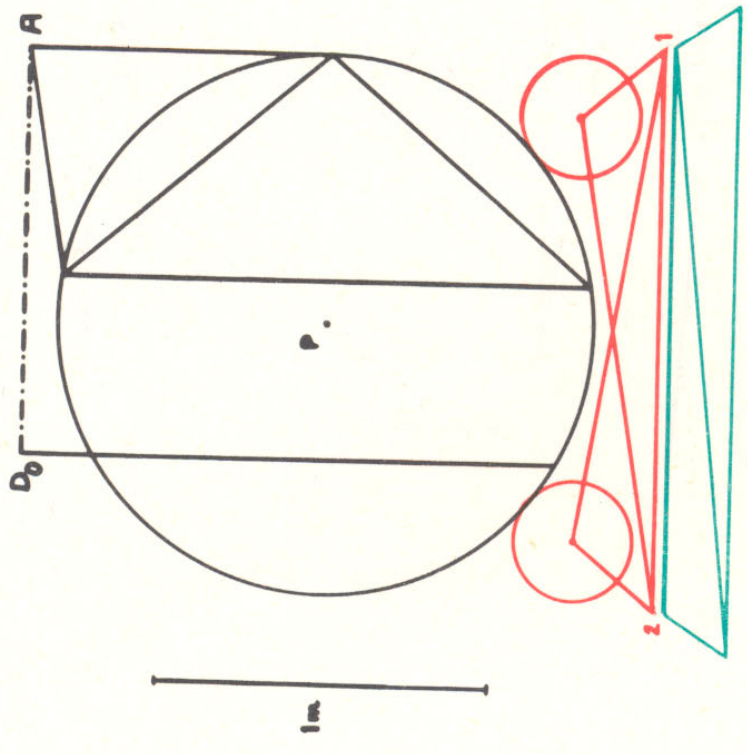
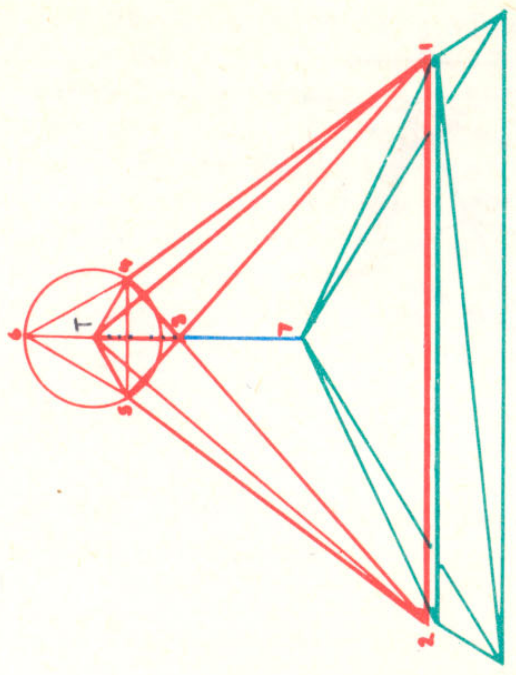


Fig 16



VIEW A_B II



Fig 17

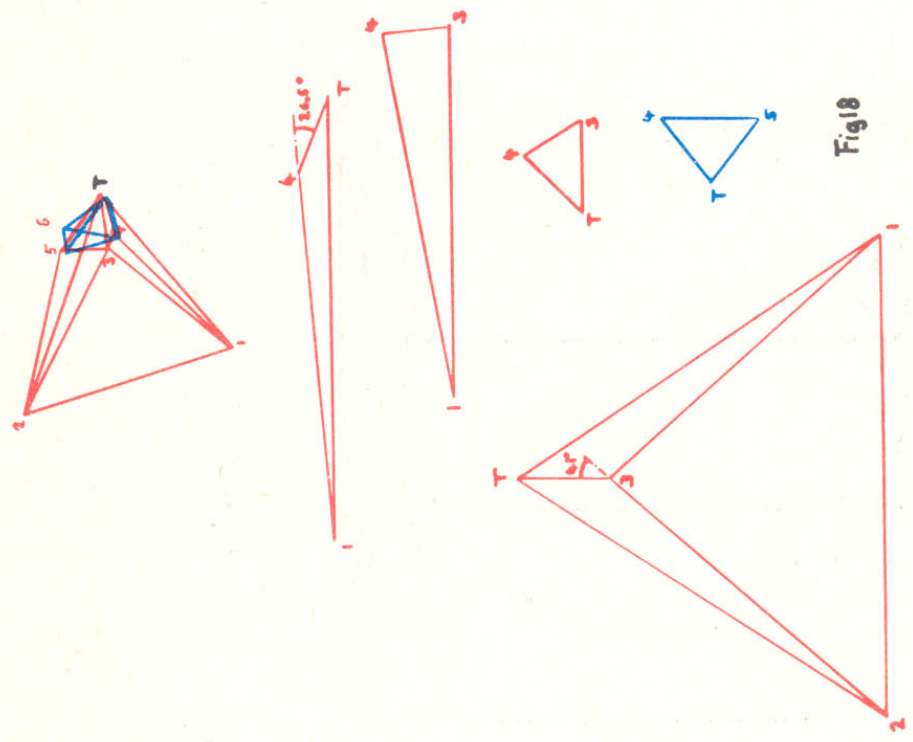
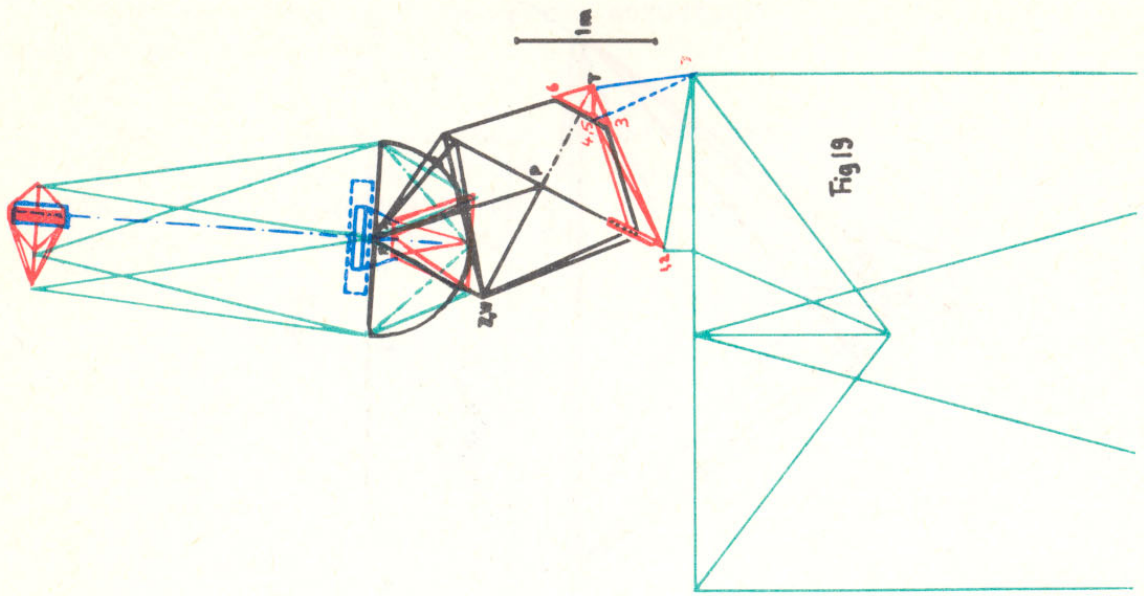
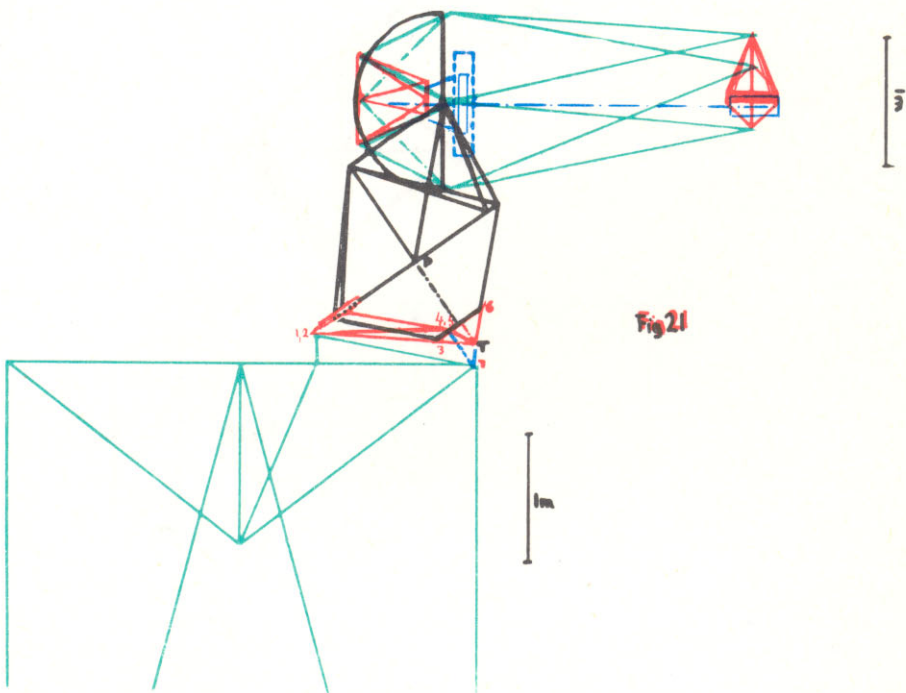
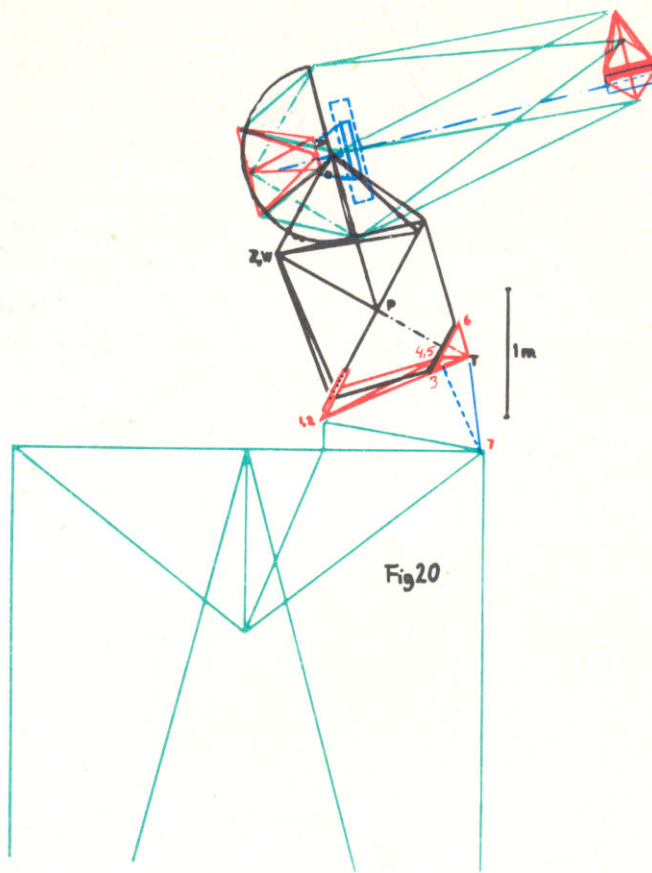


FIG. 18.— A pseudo perspective view of the support of the pyramid 4-5-6-T by the pyramids 1-3-T-4 and 2-3-T-5 is shown on top of the figure. For clarity, the pyramid 4-5-6-T is drawn in blue. The rest of the figure shows the sides of the pyramids with true angles. Angle 4 of triangle 1-T-4 is somewhat large to obtain maximum stiffness. However, there is no need for extreme stiffness of point 4 because the self aligning rotation point of the spherical roller bearing is in T. A small deviation of point 4 gives no displacement of the cone. The same holds for point 5. In addition it is possible to place bars from the points 4 and 5 to point 7, which gives points 4 and 5 the same high stiffness as point T. In figure 19 these bars are indicated with a dashed blue line.

FIG. 19.— Side view of complete telescope on tower platform for 28° latitude, midday midsummer position.

FIG. 20.— We plan to use the telescope for stellar work too. We made the fork such, that at 28° latitude (La Palma) we can see objects downwards to 15° above the horizon in the equator direction (South for the Northern hemisphere). The figure illustrates this position. In the other compass directions (North, East and West for the Northern hemisphere) the complete sky will be accessible.

FIG. 21.— The telescope mount adjusted for 55° latitude. Now, the whole sky till the horizon is accessible. The figure illustrates horizon position in equator direction.



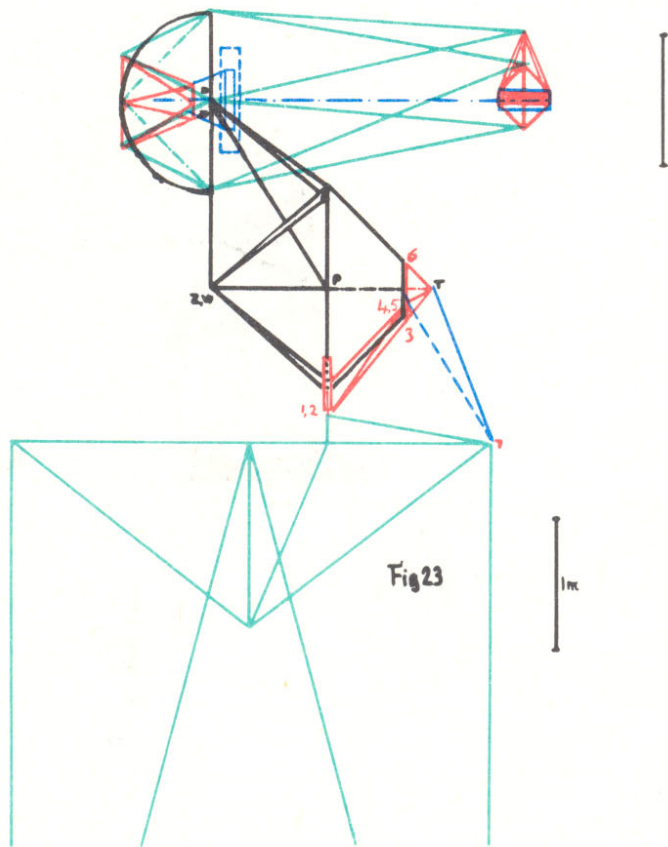
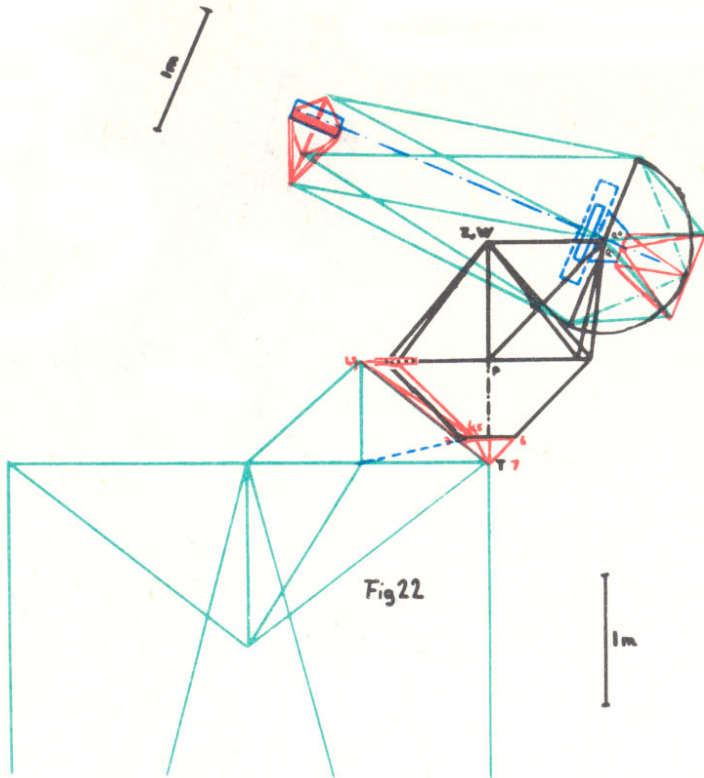


FIG. 22.— A higher pedestal is required for higher latitudes than 55° . The figure shows the extreme of 90° latitude, the pole. The telescope is drawn in the position of solar observation in midsummer. Rollers under spring load inside a raised rim on the base plane of the cone and between the outside rollers, prevent, that the movable part of the telescope mount could fall downwards. The asymmetric fork is not necessary if the telescope is intended only for polar work; the declination axis could be located through ZW and the second pyramid and triangle to AD_0 can be omitted.

FIG. 23.— The same telescope concept is usable for stellar work on the equator. In order to reach objects near the horizon the fork should be somewhat more asymmetric than is chosen for our telescope. The figure shows the extreme case, where in all directions the horizon is accessible. The figure illustrates that also for this extreme requirement a stiff fork construction is possible.

FIG. 24.— The truncated cone centered round the hour axis PT, see figure 11, has the duty to transport forces from the points Q, R, S, U and V to the three points of the circle on the truncated side of the cone, which lie opposite the points 4, 5 and 6. The position of the three points changes as the truncated cone rotates around the hour axis PT relative to the points 4, 5 and 6. Consequently, a truncated cone consisting of only thin walls is not stiff enough. The upper part of the figure shows the cross section, which is theoretically required for stiff connection of any point of the QRSUV circle to two of the three points opposite the points 4, 5 and 6 for arbitrary rotational position of the truncated cone. The inner boundary of the cross section is a hyperboloid of revolution. The lower part of the figure shows the cross section of a practical implementation of the truncated cone. The part of the cone near the points Q, R, S, U and V can be open, which means arms to the points Q, R, S, U and V. Air can circulate inside the cone, which benefits a homogeneous temperature. The plane of QRSUV should be sufficiently closed because the forces of the rollers attach to changing points. Some holes for air circulation are allowed.

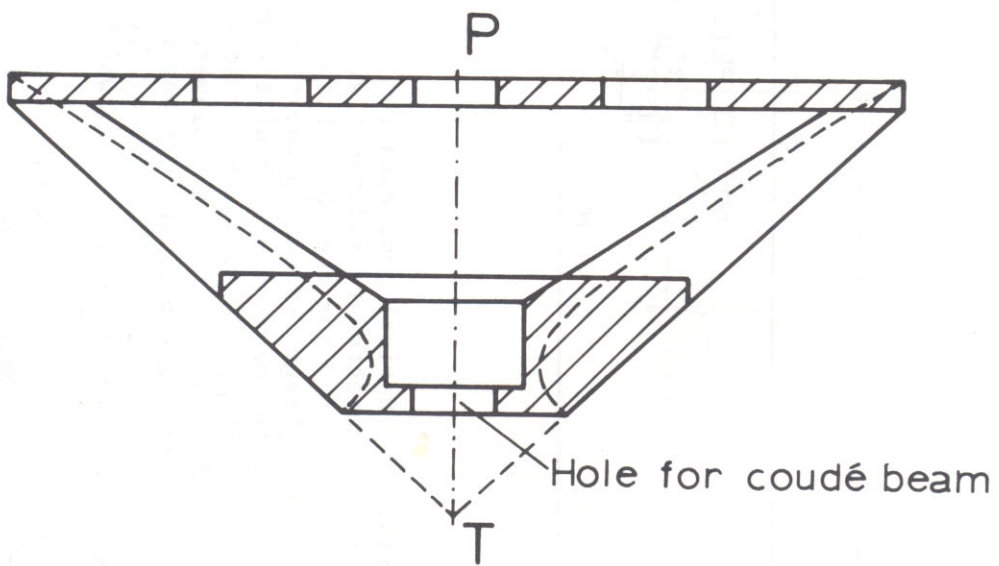
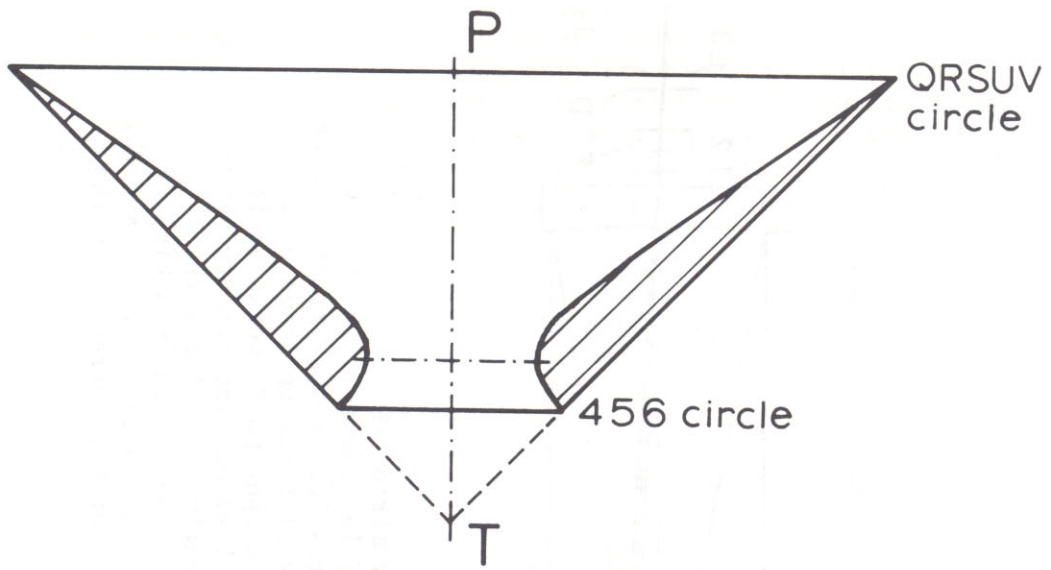


FIG. 24

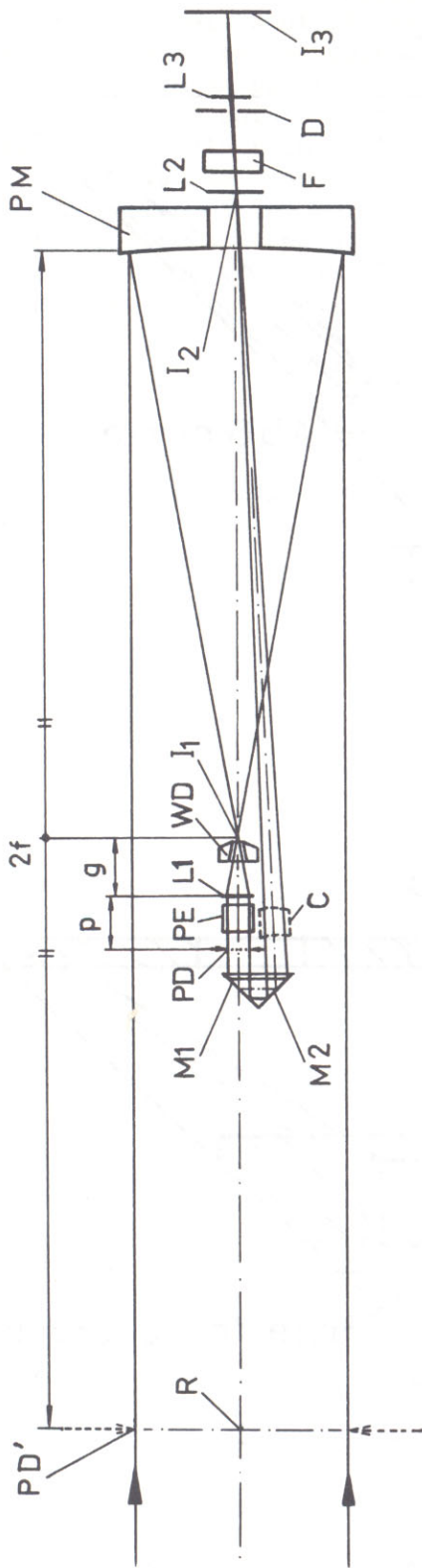


FIG. 25.— Optical configuration with spherical primary mirror PM. The optical elements are indicated with the same symbols as in figure 1. The following elements are added for the correction of the spherical aberration of the primary mirror: PD : diaphragm, placed in the plane, in which the lens L1 forms an image of the center of curvature R of the primary mirror. The diaphragm PD works as if a diaphragm PD' would be present in front of the telescope. The primary mirror has a somewhat larger diameter than PD'. Consequently, PD defines the entrance pupil. In this way we have the telescope transformed in a kind of concentric Schmidt camera. The corrector plate is placed in the diaphragm PD. C : Maksutov like corrector, which may be used instead of the corrector in the diaphragm PD.

Calculation of distance p:

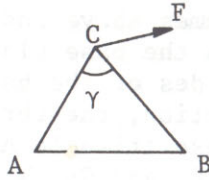
f = focal length of PM (2 m) ; f_1 = focal length of L1

$g \approx f_1$ from which follows $p \approx (f - f_1) f_1 / f$

APPENDIX : Some principles for stiff constructions

A1. Everywhere are triangles.

A and B are fixed points. C is a point loaded by a force F which can take any direction, see figure A1.



We want to connect C to the points A and B in a stiff way. An efficient way to use the material is to put it in straight connections CA and CB. In this way we get a triangle with top angle γ . The stiffness (this is force per unit deflection) of point C is roughly proportional to $\sin^2\gamma$. The angle γ must be larger than a minimum value θ and

FIG. A1.— Loaded triangle

smaller than $\pi-\theta$. The value of θ depends on the required stiffness and the available material (the modulus of elasticity of the material and the mass of the material, which you are prepared to put in the construction). $\theta = 30^\circ$ seems to be a reasonable limit for optical telescopes exposed to wind.

It follows from the requirement $\theta \leq \gamma \leq \pi-\theta$ that C can be fastened in a stiff way only in a limited area. C is only allowed in the shaded area in figure A2. There are two circles through A and B with radius $AB / 2 \cos\theta$. The allowed area is the area inside the two circles, which is not inside both circles.

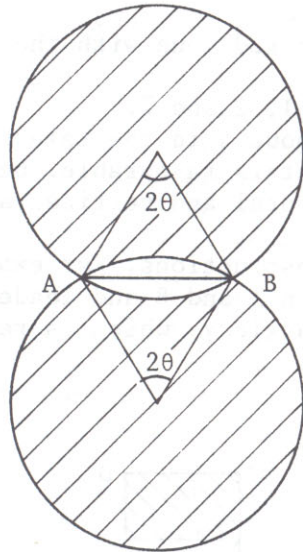


FIG. A2.— The allowed area for C

Now suppose that C is in the forbidden area, for instance near the straight connection line AB, see figure A3. An additional point D inside the allowed area can help us to fasten C to A and B in a stiff way. Simply connect D to A and B, and C to D and A or B (or to both A and B).

If we look at the telescope construction in figure 2, we see

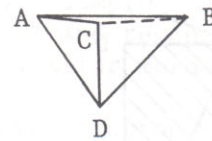


FIG. A3.— Stiff connection of C to A and B with the help of D

that point D_0 is fastened to B and C with the help of E_0 . Also, the points H, I and J of the mirror support are nearly in the plane of A, B and C. The stiff connection between HIJ and ABC is made with the help of the points E_0 , F_0 and G_0 . Here the same principle is applied but now in the three dimensional case. The circles in figure A2 are

rotated around the axis AB for the three dimensional case. A point C fastened to only two fixed points A and B can move over a circle in a plane perpendicular to AB. A base of three fixed points becomes necessary. A pyramid is formed by the connections of a point with the three base points. Not only the top angles of the faces of the pyramid, but also the angles between the faces must be not too small and not near π . The allowed area becomes roughly two sphere like volumes above and under the base triangle. The spheres are dented towards the base plane and have prickles towards the base points. Unequal sides of the base triangle deform the sphere. In the telescope construction, the three pyramids from the points E_0 , F_0 and G_0 towards the base triangle ABC are combined to a single body by interconnecting E_0 , F_0 and G_0 . Now one beam of each pyramid can be omitted and still a stiff body remains.

The construction with the help of the additional point D in figure A3 works also for points C outside the circles in figure A2. Points C far away from the base AB can be reached by adding repeatedly points D. A framework of piled triangles is built towards C. However, for larger distances this will not give a stiff construction any more. A broadening of the fixed base is necessary. One should look at the ratio between the distance $(CA+CB)/2$ and the base length AB if more than two triangles are piled.

The telescope shows at several places a base from where piles of triangles are built. The critical bases are connected with the rotation axes:

Declination axis: base is A, D_0 and the point of the gear wheel BE_0C , which is in touch with the pinion of the drive.

Hour axis: the points of contact of the truncated cone with the two rollers and the spherical roller bearing.

The adaption to the polar height: the points 1, 2 and 7.

The maximum ratios of distance to base are about 4 in the telescope. It is at this point, that an alt-azimuth mount is favourable, because it is easier to make broad bases for a horizontal and vertical axis than for oblique axes.

Triangles are also present in closed constructions. For example, figure A4 shows a beam ABCD, which is fixed in A and B and loaded in C. The stiffness depends on the maximum top angle γ , which is reach-

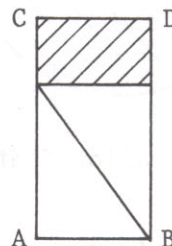
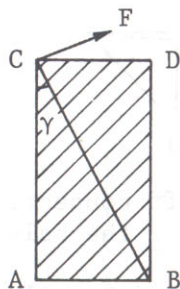


FIG. A4.— Beam stiffness and inscribed triangle

FIG. A5.— Partly closed construction

able with a triangle inside the beam. If the load only applies in C, bars from C to A and B give the same stiffness with less material. In case forces apply everywhere on the line CD a lighter construction can be made with a partly closed construction, as shown in figure A5.

The bars of an open construction are not stiff against forces perpendicular to the bars and outside the corner points. Wind gives this kind of forces. The internal damping of metal constructions is very low. Resonant vibrations can easily occur. Wind has two drivers for resonant vibrations: the wind gusts and vortex oscillations in case of constant or slowly changing wind speed. The resonance gives a larger deformation of the bars than expected from the wind pressure. In this way the vibrations of the bars can affect the positions of the corner points in spite of the insensitivity of the corner point positions to the bending of individual bars.

The energy in wind gusts decreases rapidly with increasing frequency for frequencies higher than 1 Hz. Consequently, a remedy for resonance vibrations is thicker bars. The higher moment of inertia of the bar cross section raises the resonance frequency. Application of tubes or profile steel raises the resonance frequency more without increasing weight. However, the area exposed to the wind increases also, which can affect the deformation of the total construction. The best compromise depends on the individual case.

Short connections between close corner points also increase the resonance frequencies. We get a "fine mesh" framework. The wind force on a fine mesh framework is larger than on a coarse mesh framework. Concerning the wind force the fine mesh framework is more comparable to the closed construction, but the advantage of good mixing and less heating of the air remains. If we look at the telescope and tower, we can qualify the 8 legs of the tower (Hammerschlag, 1980) and the 6 tubes between triangle ABC and triangle DEF of the telescope (see figure 2) as coarse mesh framework. The tower platform and the other parts of the telescope are more fine mesh frameworks.

We will try to suppress the vibrations in the coarse mesh frameworks by damping, if it turns out to be necessary. It is difficult to increase the internal damping of connection beams, because application of damping material in loaded parts would decrease the stiffness. Damping material can be added to beams, for example tubes can be filled with damping material like sand. But the increase of weight decreases the resonance frequency. In figure 3 a damping method is explained, which does not decrease the stiffness and resonance frequency. It is a solution with geometric elements. A similar method can be applied to the legs of the tower.

The bending of individual beams can cause rotations of the corner points. These rotations do not change the position of bodies, which are fastened to three or more corner points. The distances between the corner points should not be much smaller than the distances between the base points of the framework. It is not advisable to fasten a small body like a small optical component to a single corner point, if a rotation of this component is not allowed. We give an example. In principle it is possible, that the secondary beam is reflected by M1 (see figure 1) to a mirror near corner point D (see figure 2). The

mirror near D reflects the light downwards to an instrument next to the primary mirror. The mirror near D will make too large rotations. The same problem of rotations can arise, if a small body is attached to three (or more) corner points of a framework with direct beams to a much broader base. The small body should be fastened in the center part of a secondary framework, which is on its turn fastened to the primary framework, which rests on the broad base. Figure 2 shows how this principle is applied for the box with the secondary optics. In conclusion, a small body should be connected to a broad base by framework which becomes broader in steps. The breadth of the base is determined by the requirement, that the base should not be much smaller than the largest distance between the telescope components, as we have seen before in the discussion of the pile of triangles.

A2. An optical beam prevents the straight connection of points.

We want to bring force F from point A to B . The logical way is a straight bar from A to B . Suppose there is an optical beam O , which is crossed by such a bar, see figure A6. We do not want a bar through the optical beam. Figure A7 shows frameworks around the optical beam, which bring the force from A to B . The solutions b and c are for the case that A and B are near the limb of the optical beam.

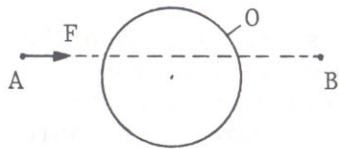


FIG. A6.— Optical beam crossed by bar

Suppose there is a reason, that we can not go with a framework beam above the optical beam, for instance the optical beam is sometimes turned upwards. Figure A8 shows the framework, which brings force F

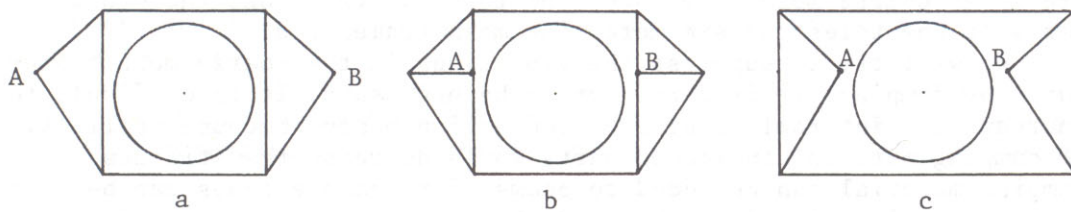


FIG. A7.— Frameworks around the optical beam

from A to B with two bars on the same side of the optical beam. Addition of the dashed bar makes the framework stiff in all directions. A fork construction is found. The triangles should satisfy the requirement, that the angles of loaded corner points are larger than θ ($=30^\circ$) and smaller than $\pi-\theta$. The angles with the sign \times have to satisfy this requirement for the transportation of the force F from A to B . In addition the angles with the sign $+$ have to satisfy the requirement if the framework is used as fork, which is fastened to the fixed base CD and bears loads of arbitrary directions in the points A and B . We see, that a certain width of space around the optical beam is needed for a stiff fork construction. A massive fork construction, which fits close-

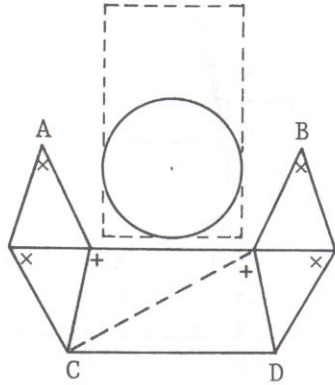


FIG. A8.— Fork

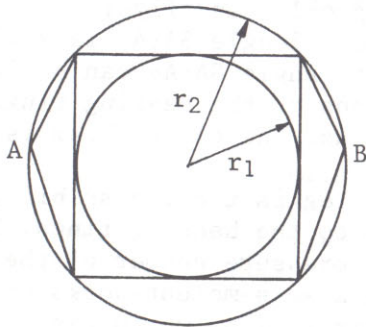


FIG. A9.— Minimum width of a stiff ring

ly around the optical beam is heavy and not stiff. The use of space around the beam leads to lighter and stiffer constructions.

Now we look at the problem of many points around an optical beam, which we want to connect in a stiff way. A ring around the optical beam is an apparent solution. The question arises, what is the minimum width of the ring, which gives stiffness comparable to direct connection of the points with beams through the optical beam. Figure A9 shows, that the framework of figure A7a or b just fits inside a ring with radius r_2 , which is $\sqrt{2}$ times the radius r_1 of the optical beam. In this way, a force can be transmitted between each arbitrary pair of points on the ring. It follows, that rings of width larger than $(\sqrt{2} - 1)r_1$ will satisfy the stiffness requirement. If only a few points on the ring need a stiff connection, a framework will give a lighter construction than a complete ring. For example, the construction, which holds the secondary mirror in a Cassegrain telescope can be a framework. A bearing with an optical beam through its center has a ring, where many points are used. An example is found

where the coudé beam goes through the bearing in D_0 of the declination axis, see figure 11. The situation is more complex where the coudé beam goes through the bearing of the hour axis, because also axial forces load this bearing, see figure 24.

Instead of an optical beam another element can prevent the straight connection of points. An example is found in the bearing of the declination axis in point A. In figure 14 the bearing is drawn as a point. In reality the bearing consists of two rings with rolling elements in between. One ring is fastened to the telescope. The beams from B, C, D, F, F_0 and G_0 go straight to the center of a disk fastened to the ring. The second bearing ring should be fastened to the top of the fork pyramid AQSZ. We can provide the second ring with a disk from the fork side and try to go from Q, S and Z to the center of the disk.

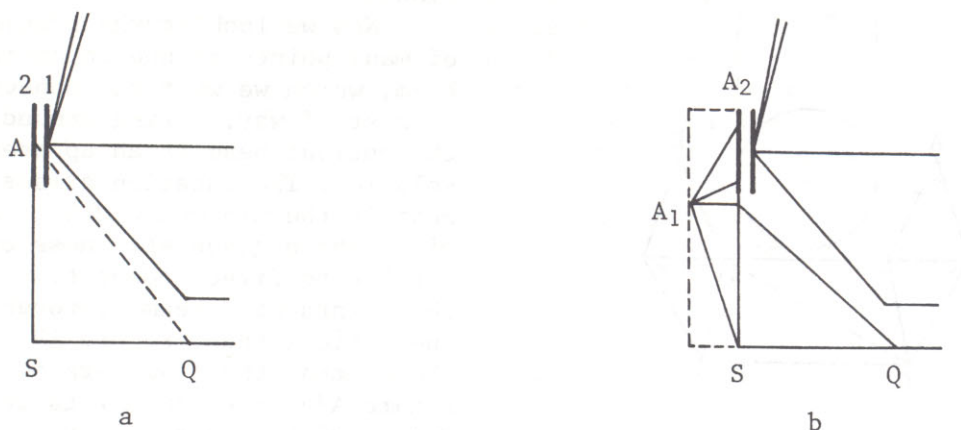


FIG. A10.— Bearing ring 1 is in the way of beam QA (a)
 Solution with framework in triangle SA_1A_2 (b)

However, this is not possible from Q, because the first bearing ring is in the way. Figure A10a illustrates the problem and figure A10b gives the solution. The framework inside the triangle SA_1A_2 is a kind of secondary fork leg inside the fork. The triangle SA_1A_2 can be incorporated in a closed beam, if the dimensions of the bearing rings are small compared to the telescope dimensions. The closed beam is indicated by a dashed line in figure A10b.

A second reason for the secondary fork leg is the impossibility of coinciding centers of the disks fastened to the bearing rings. The center of the first disk is situated in the pressure center of the bearing. Consequently, not only a force but also a moment works on the second disk. The secondary fork leg forms a base, which can carry this moment without large deformations.

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