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Design and Construction of Rifle Telescopes

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ABSTRACT. Two approaches have been made to construct a rifle telescope using different objectives. Following a third-order analysis the results of ray tracing through several examples are presented. The total length of the telescope is 233 mm, whereas the eye-relief is 93 mm. For the whole system, at a field angle 2.5°, the percentage distortion is 0.3%. Tables of design parameters for aplanatic telescopic systems with angular magnification $\gamma = 5$ are presented.

Viewing efficiency in telescopes, defined as the ratio of the limiting resolvable detail when test objects were viewed with the naked eye and with the aid of a telescope, was estimated by Osipova (1981). The calculation was made on the basis of an estimate of the apparent contrast at different distances up to 7 km. An aplanatic telescopic system consisting of two lenses was presented by Miks (1982), considering the existence of monochromatic and polychromatic effects, respectively. The relations derived from the theory enable calculation of the lenses, the distance between them and the refractive indices of the glasses. A table of design parameters for aplanatic telescopic systems with an angular mangification $\gamma = 2$ was published. Stavroudis (1967, 1969) applied the concept of a modular approach to the design of optical system. A lens design can be assembled from a class of objects called modules each having the property that third order spherical aberration and third order astigmatism are identically zero. Stavroudis and Mercado (1975) studied the coupling of two modules with the preservation of their properties. The "hard way" coupling occurs when two modules are brought together so that the two main focii coincide; the two first pupil planes also coincide

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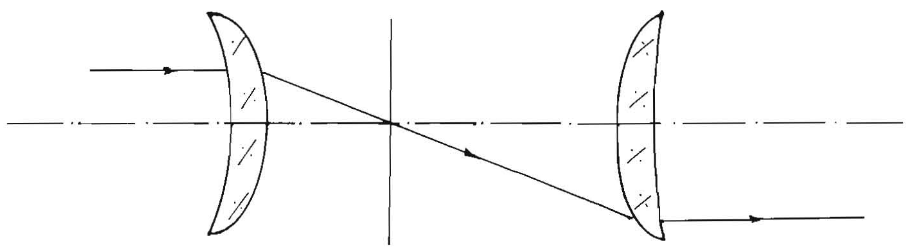
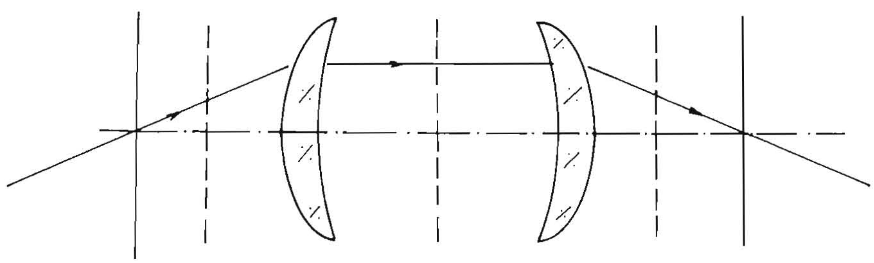
as in the afocal systems such as shown in Fig. 1. In an "easy way" coupling, the two second pupils are made to coincide and the resulting system has a pair of finite conjugate planes for which third order spherical aberration and astigmatism are zero for any choice of values of two powers.



(a)



(b)

Fig. 1. Hard way and easy way couplings of modules

This paper deals with the design and construction of the rifle telescope. The design is based on the paraxial and finite ray tracing technique given by Hopkins (Conrady 1957). Moreover, the easy way of coupling of modules (Stavroudis and Mercado 1975) is applied in the construction to achieve the minimum aberrations. A suitable change in the various parameters (*e.g.* curvature of the surfaces, their separation, lens central thickness, type of glass *etc.*) is made to keep all aberrations within tolerance.

Specifications of the Rifle Telescope Design

The aim of this work is to design a rifle telescope within certain military specifications *e.g.* maximum range 1300 m and magnification from 3 to 5 times.

The target is assumed to be illuminated by daylight; consequently a suitable field of view ranges from 2° to 5°. In order to match the pupil of the human eye, the exit pupil should be 6 to 10 mm in diameter. In the gun under consideration the eye-relief has to be in the range from 80 to 100 mm and the total length of the telescope from 210 to 240 mm. To increase its resolving power the objective aperture should be 30.00 mm in diameter *i.e.* f/4.

Construction of the Telescope

Two rifle telescopes were designed. In constructing the first rifle telescope, a specially designed doublet objective, a unit mangification Gaussian doublets erector (Ghobashy *et al.* 1986) and modified triplet eyepiece with E.F.L. 30 mm were used. Seven trials were carried out to get a good telescope within the desired tolerance. The system is adjusted paraxially in which the objective and erector are used as one module coupling in the easy way with the triplet eyepiece as the second module.

For the whole system $\Sigma SI^* = 0.0001434$, $\Sigma SII^* = -0.00312$, $\Sigma SIII^* = -0.015050$, $\Sigma SIV^* = 0.077237$, $\Sigma SV^* = -0.322841$, $\Sigma C_L^* = 0.002011$ mm, $\Sigma C_T^* = -0.022148$, $\delta\ell' = 0.158098$ mm, coma = 0.060311 mm, $\Sigma(d-D)\,\delta n = -0.000879$ mm. The total magnification is 5.07 and the eye relief 93.71 mm. It is noted that all these results are acceptable except C_T^* which can be reduced by using a different type of glass having the same refractive index but with different V number. The glass type DBC 569631 was used instead of MBC 569561 for the second doublet of the erector and all of the eyepiece. For this system $\Sigma C_L^* = -0.00076$ mm, $\Sigma C_T^* = -0.009312$ mm and $\Sigma(d-D)\,\delta n = -0.001867$ mm. The percentage distortion of the whole system for a U_{pr} of 1.25° is −1.17754% and this is acceptable. The final sagittal and tangential curvature of the field with respect to a reference plane placed at the paraxial position ($\Delta'S$ and $\Delta'T$), are calculated at the paraxial focal plane between the erector and eyepiece for different angles, as shown in Table 1. They are calculated from the sagittal and tangential fan ray tracing.

For the whole system (extreme difference of focus) tan U'_m is calculated for different angles from Figs. 2 and 3. It is equal to 0.009325 at an angle of 1.25°, and this is an acceptable value since the tolerance is 0.01. So the acceptance field of view of the telescope will be 2.50°. The telescope may be considered short as compared with an astronomical one in which no glare stops will be used. The aperture stop is the mount of the first lens of the objective. The field stop is placed at the image plane near the eyepiece, *i.e.* at a distance 26.694 mm from the last surface of the erector as shown in Fig. 4. Its diameter is chosen to cut out the defective marginal rays so the field stop is used to admit a greater field than the accepted field of view. The accepted field is 2.50°, the field stop is used to limit

3.50° field. Accordingly its diameter is 9.308 mm. From principal ray tracing the half-field angle is 1.75°. All the parameters of the telescope are shown in Table 2 and Fig. 4.

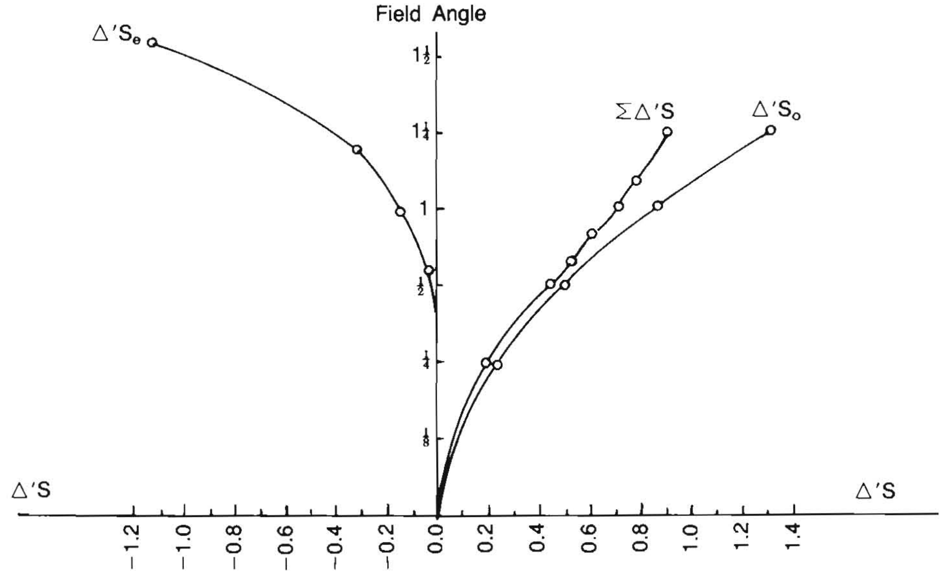


Fig. 2. Δ'S for objective and erector eyepiece and for the whole system against the field angle

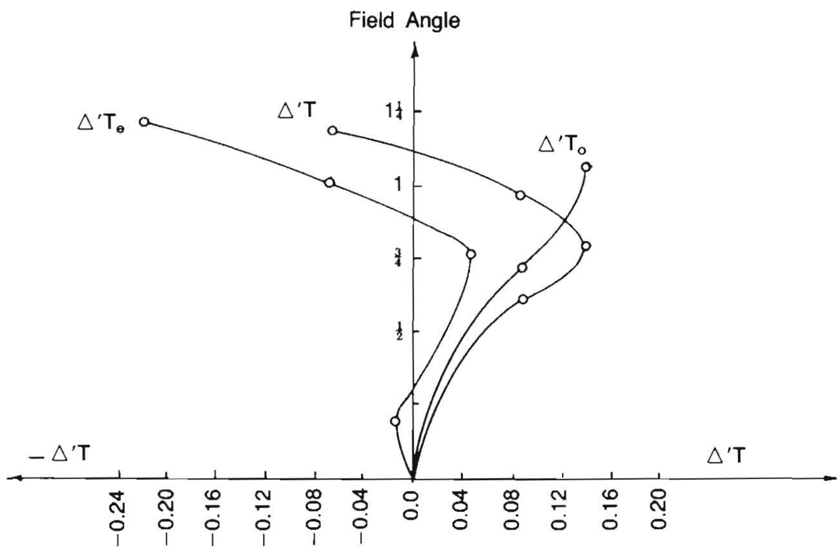


Fig. 3. $\Delta'T_o$, $\Delta'T_e$ and $\Sigma\,\Delta'T$ against the field angle

In constructing the second rifle telescope, the previously designed triplet objective is used in addition to a unit magnification Gaussian doublets erector and triplet eyepiece with f = 30.0 mm (Ghopbashy *et al.*, 1986). The separation d_3 of the eyepiece was reduced to 11.0 mm to improve the aberrations while C_5 was changed to 0.0238784 mm^{-1} to correct the E.F.L. Three trials were carried out to construct this telescope. The aberrations for objective, erector, eyepiece and the whole system are shown in Table 3. The eye-relief is equal to 94.963 mm.

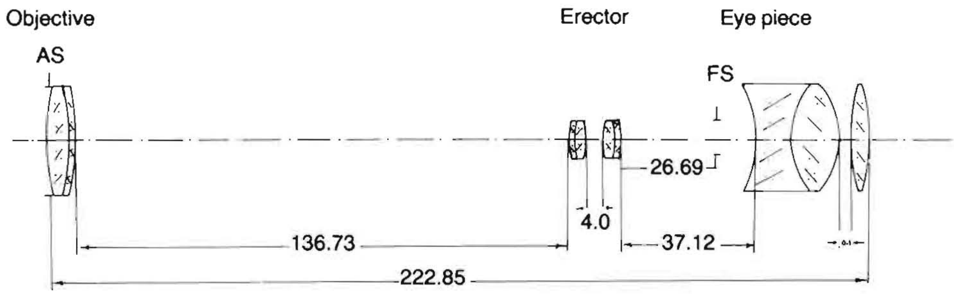


Fig. 4. The optical layout of the first telescope

It may be noted that as the E.F.L. of the erector increases, $\triangle$'S, $\triangle$'T, ΣSIII* and the eye-relief are improved but the whole length of the telescope will increase. In Table 4, 5 and, $\triangle$'S and $\triangle$'T for objective and erector, eyepiece and the whole system are shown.

For an angle 1.25°, the extreme difference of focus can be found from Figs. 5 and 6; *i.e.* tan U'_n = 0.00605999. Therefore the accepted field of view is about 4.0°. The percentage distortion for the whole system, for a semifield angle of 1.25° is 0.308% which is an acceptable value. All the results are acceptable except ΣC^*_L and ΣC^*_T which can be controlled by changing the type of glass. When type DBC 569631 is used as a crown glass for erector and eyepiece, the following results for the whole system are found to be, $\Sigma C^*_L = -0.000288$ mm, $\Sigma C^*_T = -0.000032$ mm and $\Sigma(d-D)\,\delta n = -0.001488$ mm. These results are acceptable.

A field stop will limit the field angle to 4.0°. It will be placed 12.16 mm away from the last surface of the eyepiece as shown in Fig. 7, with a diameter of 8.38 mm. All the parameters of the second telescope are shown in Table 7.

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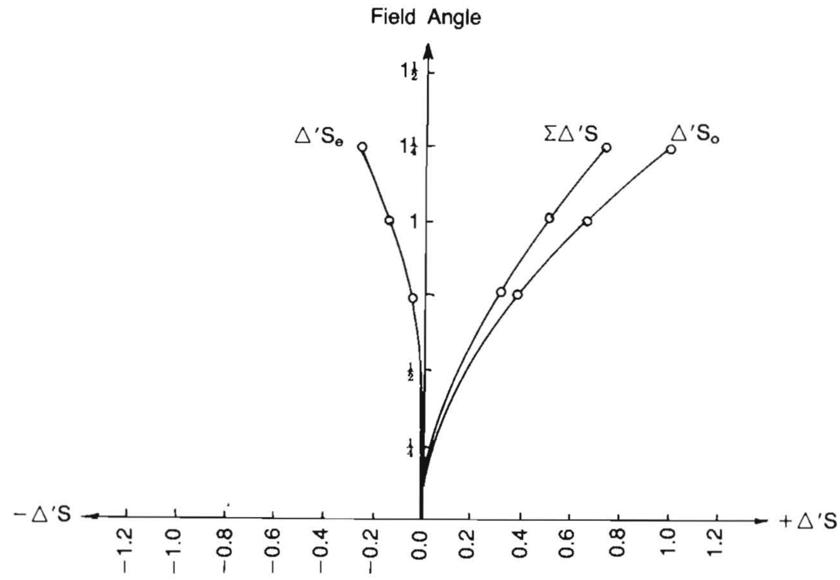

Fig. 5. $\Delta'S_o$, $\Delta'S_e$ and $\Sigma\ \Delta'S$ against the field angle

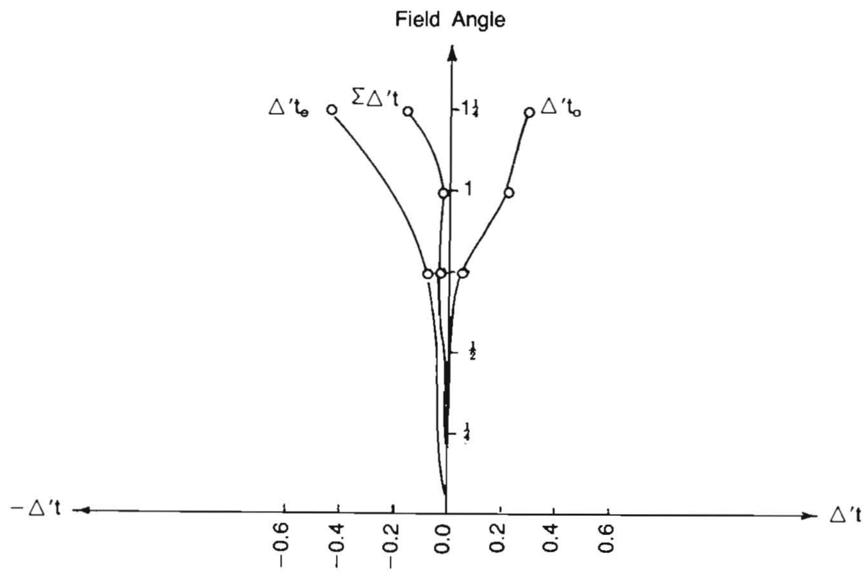

Fig. 6. $\Delta'T_o$, $\Delta'T_e$ and $\Sigma\ \Delta'T$ against the field angle

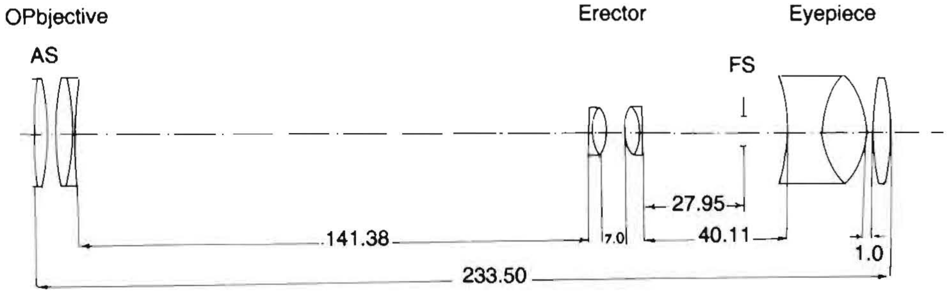

Fig. 7. The optical layout of the second telescope

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Table 1. The relation between sagittal △'S and tangential △'T curvature of the field at the paraxial focal plane between the erector and eyepiece, for different angles

Angle	**0.50°**	**0.75°**	**0.00°**	**0.25°**
△'S	0.22071	0.487448	0.85957	1.317579
△'T	0.047922	0.094331	0.13805	0.127049

Table 2. The parameters of the first telescope

No.	**Curvature mm^{-1}**	**Separation (mm)**	**Refractive index (for d line)**	**V-value (for d line) λ = 587.5 nm**
1	0.0107			
		6.00	1.56883	56.13
2	−0.0215			
		2.00	1.69895	30.07
3	−0.007323			
		136.7334	1.00	—
4	0.02519			
		1.00	1.69895	30.07
5	0.0966			
		3.00	1.56883	56.13
6	−0.0625			
		4.00	1.00	—
7	−0.0625			
		3.00	1.56873	63.08
8	0.0966			
		1.00	1.69895	30.07
9	−0.025193			
		37.1205	1.00	—
10	−0.029208			
		10.00	1.69895	30.07
11	0.045333			
		13.00	1.56873	63.08
12	−0.045333			
		1.00	1.00	—
13	0.017333			
		5.00	1.56873	63.08
14	−0.017333			

Table 3. The aberrations for objective, erector, eyepiece and the whole system

Item	Objective and erector	Eyepiece	The Whole system
ΣSI^*	−0.00759	−0.000808	−0.006785
ΣSII^*	−0.010142	−0.008898	−0.001244
$\Sigma SIII^*$	−0.053360	−0.067118	−0.013758
ΣSIV^*	−0.060654	−0.016969	−0.077623
ΣSV^*	−0.507418	0.334971	−0.172447
ΣC_L^*	−0.002082	0.002810	−0.004892
ΣC_T^*	−0.000148	−0.018825	−0.018974
$\delta\ell'$	−0.058763	−0.047939	−0.010824
Coma	−0.006100	−0.010296	0.004196
$\Sigma(d-D)\delta n$	−0.000341	−0.001337	0.000995

Table 4. The percentage distortion, $\Delta'S$ and $\Delta'T$ for objective and erector at different angles

angle	0.75°	1.00°	1.25°
D_{pr}	28.124725	28.25736	28.42803
D_s	27.754301	27.606228	27.421274
$\Delta'_s = D_{pr} - D_s$	0.3704242	0.651132	1.00676
D_T	28.087248	28.047212	28.13549
$\Delta'_T = D_{pr} - D_T$	0.037477	0.210148	0.29254
$h_{paraxial}$	—	2.094462	2.618239
h_{finite}	—	2.134414	2.695679
Percentage distortion	—	−1.9074%	−2.9577%

Table 5. The percentage distortion, $\Delta'S$ and $\Delta'T$ for eyepiece at different angles

angle	0.75°	1.00°	1.25°
D_{pr}	12.132783	12.108981	12.077524
D_s	12.201779	12.255699	12.364124
$\Delta'_s = D_{pr} - D_s$	−0.068996	−0.146718	−0.2866
D_T	12.225787	12.322032	12.532907
$\Delta'_T = D_{pr} - D_T$	−0.093004	−0.213051	−0.455383
$h_{paraxial}$	—	2.0944783	2.6246908
h_{finite}	—	2.117977	2.668634
Percentage distortion	—	−1.1227%	−1.67422%

Table 6. The results of $\triangle'S$ and $\triangle'T$ for the whole system at different angles

angle	0.75°	1.00°	1.25°
$\triangle'_s$	0.301428	0.504414	0.720156
$\triangle'_T$	−0.055527	−0.002903	−0.162842

Table 7. The parameters of the second telescope

No.	Curvature mm^{-1}	Separation (mm)	Refractive index (for d line)	V-value (for d line)
1	0.00534			
		3.00	1.56883	56.13
2	0.00534			
		1.00	1.00	—
3	0.0104			
		4.00	1.56883	56.13
4	−0.0104			
		2.00	1.69895	30.07
5	0.00344			
		141.3862	1.00	—
6	0.020938			
		1.00	1.6985	30.07
7	0.0805			
		3.00	1.56873	63.08
8	−0.052			
		7.00	1.00	—
9	0.052			
		3.00	1.56873	63.08
10	−0.0805			
		1.00	1.69895	30.07
11	−0.020938			
		40.1185	1.00	—
12	−0.023878			
		10.00	1.69895	30.07
13	0.045333			
		11.00	1.56873	63.08
14	−0.045333			
		1.00	1.00	—
15	0.017333			
		5.00	1.56873	63.08
16	−0.017333			

تصميم وتكوين تليسكوب قنصي

توفيق الدسوقي و م. غباشي[1] و م. س. الطوخي

قسم الطبيعة ـ كلية العلوم ـ جامعة عين شمس ـ القاهرة ـ مصر

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