14 EYEPIECES

14.1 GENERAL PRINCIPLES

14.1.1 Basic functions. The functions of the eyepiece were briefly described in Section 7.3. Let us now examine these more closely. The eyepiece in a visual instrument has three basic functions:

(1) It must, with the objective, form a good image of the object being viewed.

(2) It must serve as a magnifier if the instrument has a reticle.

(3) It must be designed so that the observer's eye can be placed in the exit pupil. Hence the exit pupil must be located at least 10 to 12 mm away from the last glass surface, this being the nearest the normal eye can approach the eyepiece surface with comfort.

14.1.2 Design considerations. Eyepieces should be designed to have a large apparent field of view (total field about 30° to 60°). Otherwise the viewer has the impression of looking down a tunnel towards a small opening. A large field of view necessitates bending the chief ray through an angle of $\alpha + \beta$, where α is the angle subtending one half the true field (field of view in object space), and β is the angle subtending one half the apparent field (field of view in image space). The chief ray must be bent with small spherical aberration so that the observer's eye may have a definite position in which to be located. Thus, one must design for a very large aperture lens with the aperture stop completely removed. Eyepieces are therefore very difficult to design. Very little can be done to improve the existing designs appreciably, nor is this a particularly fruitful area for a designer to spend time on. A more practical approach is to use or modify one of the existing designs. In the following paragraphs, several representative eyepieces are described which represent quite accurately the state of art in this field.

14.2 METHOD OF DESCRIPTION

14.2.1 General. In order to describe representative eyepieces on a comparative basis, the examples shown were designed for use with a ten power (10X or MP = 10) telescope. All eyepieces were designed to have a focal length of 2.54 cm and an exit pupil diameter of 5 mm. For each design a figure shows the shape of the lenses, and the location of the field stop and exit pupil. The eyepiece is shown with the exit pupil to the left and the objective is assumed to lie to the right. The reason for this representation is that it is generally easier to design a system with the object at infinity instead of the image at infinity. Hence eyepieces, as well as telescope objectives, are designed with the incident light assumed parallel. Similarly, microscope objectives as well as photographic objectives, are designed from long to short conjugate. The exit pupil is located by tracing a paraxial chief ray from the center of the objective (entrance pupil) back through the eyepiece. The exit pupil point is the intersection of the optical axis and this chief ray after it emerges from the system.

14.2.2 Descriptive details. In addition to the drawing, the following information is included.

(1) A table of curvatures, thickness, indices of refraction, ν-number, ΣP, and γ. This number, γ, is the ratio of the radius of the Petzval surface to the focal length of the eyepiece, and is used to estimate the field curvature in a complete telescope system. See Equation 11-(3).

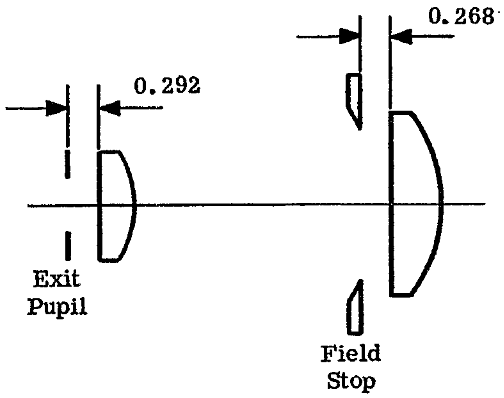
(2) Aberration curves in the focal plane of the eyepiece for parallel bundles of rays entering the eyepiece through the exit pupil. The curves are plotted in the same way as they were in Figures 8.7 and 8.8(b). The meridional fan and skew fan are shown on the same graph.

(3) The field curves, the distortion, and the lateral color. The first two are similar to the curves in Figures 8.10 and 8.9.

(4) A brief statement about each eyepiece.

14.3 THE HUYGENIAN EYEPIECE

14.3.1 Design data. Table 14.1 and Figures 14.1 through 14.3 present the design data and aberration curves for this eyepiece.



Scale - 1.35 to 1

Figure 14.1 - Huygenian eyepiece. Distances in cm.

c	t	Glass Type
0		
	0.3	517645
-0.9519		
	2.31	Air (n = 1)
0		
	0.45	517645
-0.6732		
$\Sigma P = -0.5538$		
$\gamma = 0.711$		

Table 14.1-Lens constants for the Huygenian eyepiece. Lengths in cm.

14.3.2 Use and characteristics. This eyepiece may be used where the apparent field of view is small (about ± 15°). It is commonly used in microscopes and small-field telescopes. The entire eyepiece is well corrected for lateral color. But because the field stop is located between the two lenses, and hence the field stop is viewed with the eyelens alone, its image will not be color free. Therefore, the Huygenian eyepiece is not recommended for use with a reticle in the field stop except in the special applications described in Section 23.3.5.2. It main virtue is its low cost. However, the eye relief (usually about 3 mm) afforded by this eyepiece is extremely short.

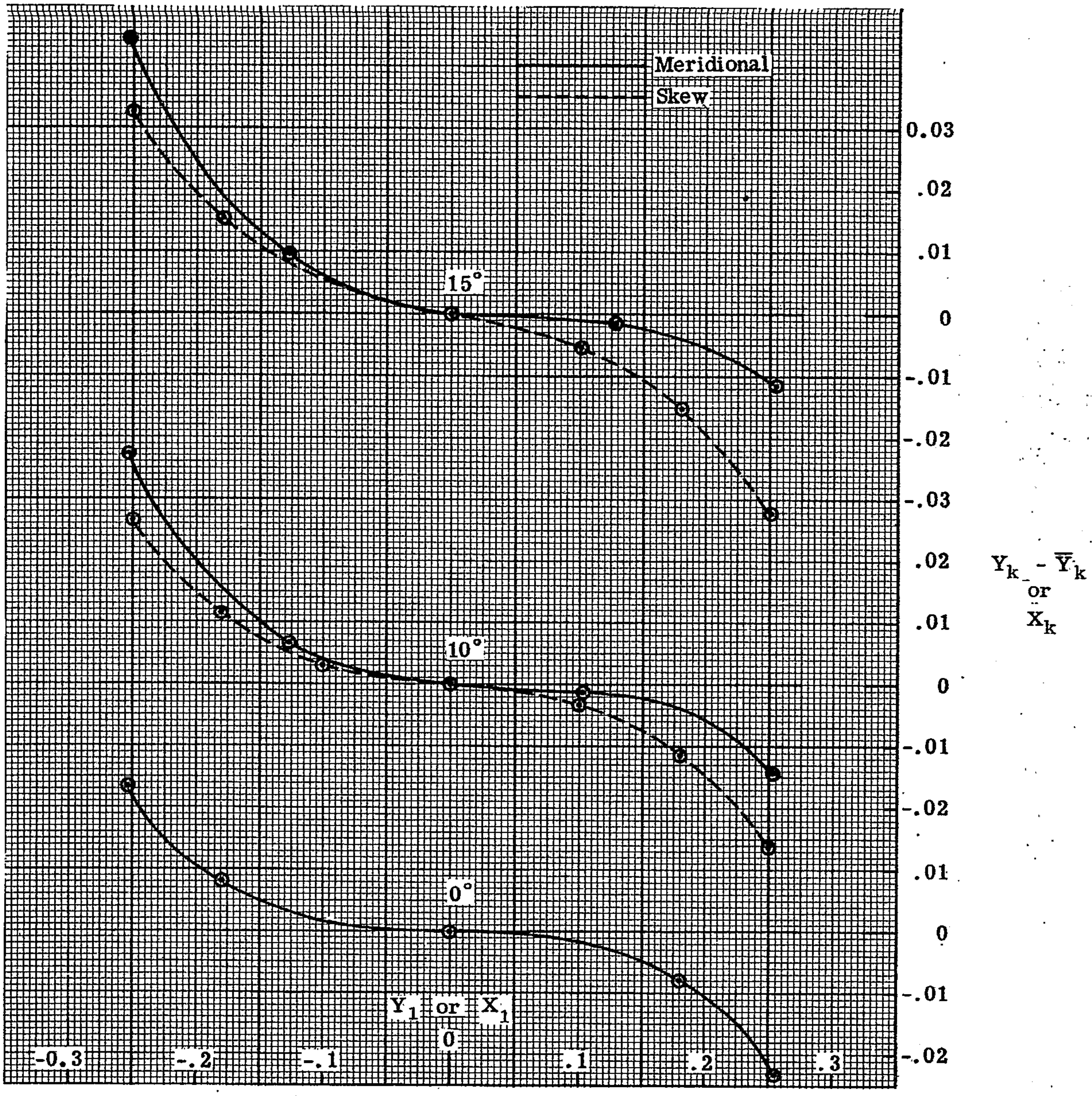


Figure 14.2- Meridional and skew fans for the Huygenian eyepiece.

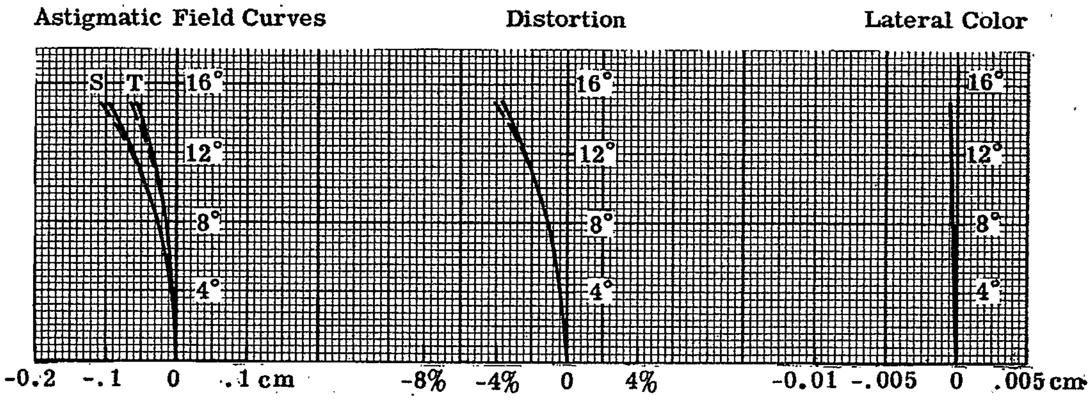
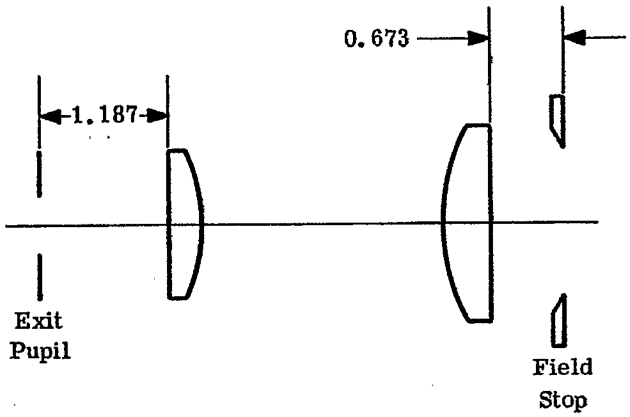


Figure 14.3 - Field, distortion, and lateral color curves for the Huygenian eyepiece.

14.4 THE RAMSDEN EYEPIECE

14.4.1 Design data. Table 14.2 and Figures 14.4 through 14.6 present the design data and aberration curves for this eyepiece.



Scale - 1.35 to 1

Figure 14.4 - Ramsden eyepiece. Distances in cm.

c	t	Glass Type
0		
	0.297	517645
-0.5712		
	2.116	Air (n = 1)
0.5077		
	0.424	517645
0		
	0.6733	
$\Sigma P = -0.3677$		
$\gamma = 1.07$		

Table 14.2 - Lens constants for the Ramsden eyepiece. Lengths in cm.

14.4.2 Use and characteristics. This eyepiece has a smaller field curve and is better corrected for the field stop plane than is the Huygenian. However, the lateral color is not corrected at all. At 15°, the lateral color is -0.007 cm which subtends an arc of 0.9 of a minute. This is well within tolerance, but if the field were extended beyond 15°, the color would become quite noticeable. The Ramsden is used in place of the Huygenian when cross hairs or reticles must be viewed. Like the Huygenian, its chief asset is its low cost. Its eye relief is still short (about 12 mm), but better than that of the Huygenian.

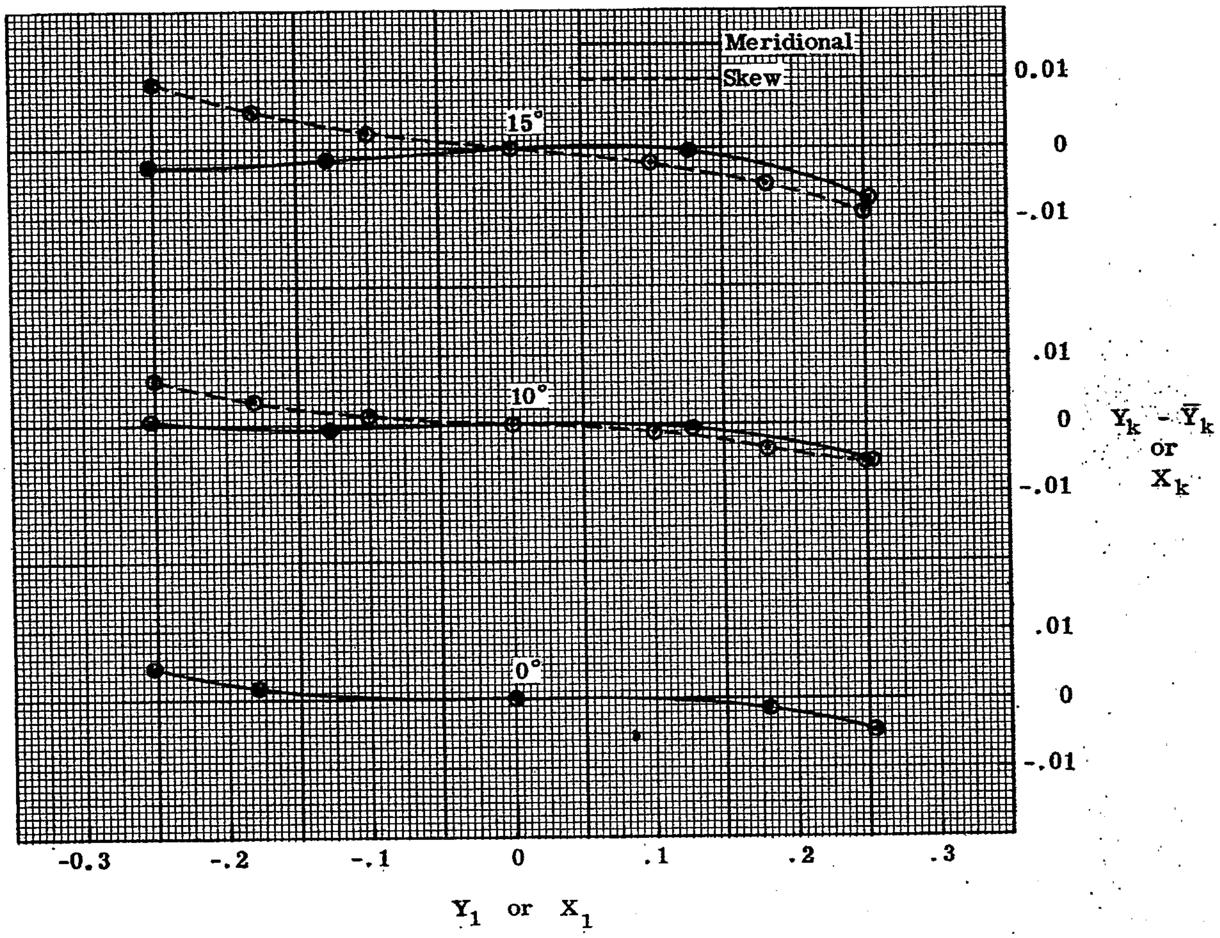


Figure 14.5- Meridional and skew fans for the Ramsden eyepiece.

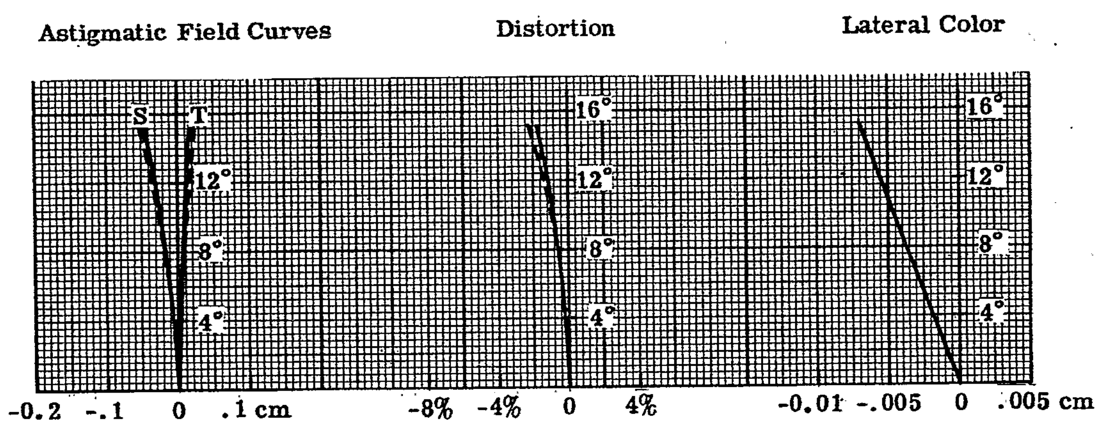
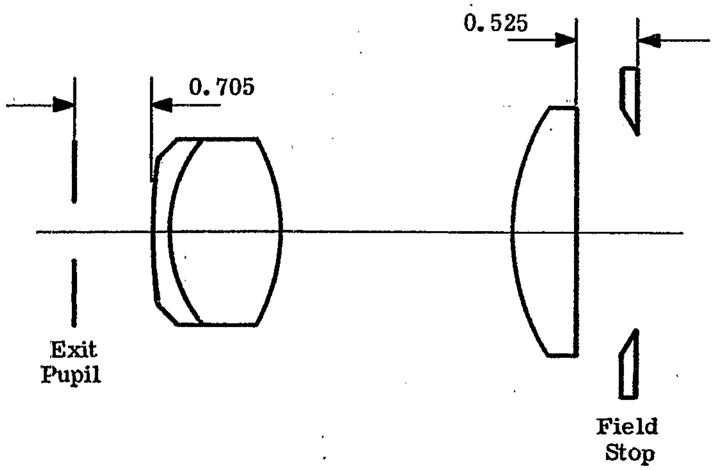


Figure 14.6- Field, distortion, and lateral color curves for the Ramsden eyepiece.

14.5 THE KELLNER EYEPIECE

14.5.1 Design data. Table 14.3 and Figures 14.7 through 14.9 present the design data and aberration curves for this eyepiece.



Scale - 1.35 to 1

Figure 14.7 - Kellner eyepiece. Distances in cm.

c	t	Glass Type
0.1039		
	0.159	617366
0.7393		
	0.995	541599
-0.5525		
	2.089	Air (n = 1)
0.4699		
	0.577	541599
0		
	0.5251	
$\Sigma P = -0.3760$		
$\gamma = 1.047$		

Table 14.3 - Lens constants for the Kellner eyepiece. Lengths in cm.

14.5.2 Use and characteristics. The Kellner eyepiece is partially corrected for lateral color and is used out to 20° half angle. It is probably the most common eyepiece used in moderately wide field telescopic systems. The eye relief (about 7 mm) is intermediate between the Huygenian and as the Ramsden eyepieces.

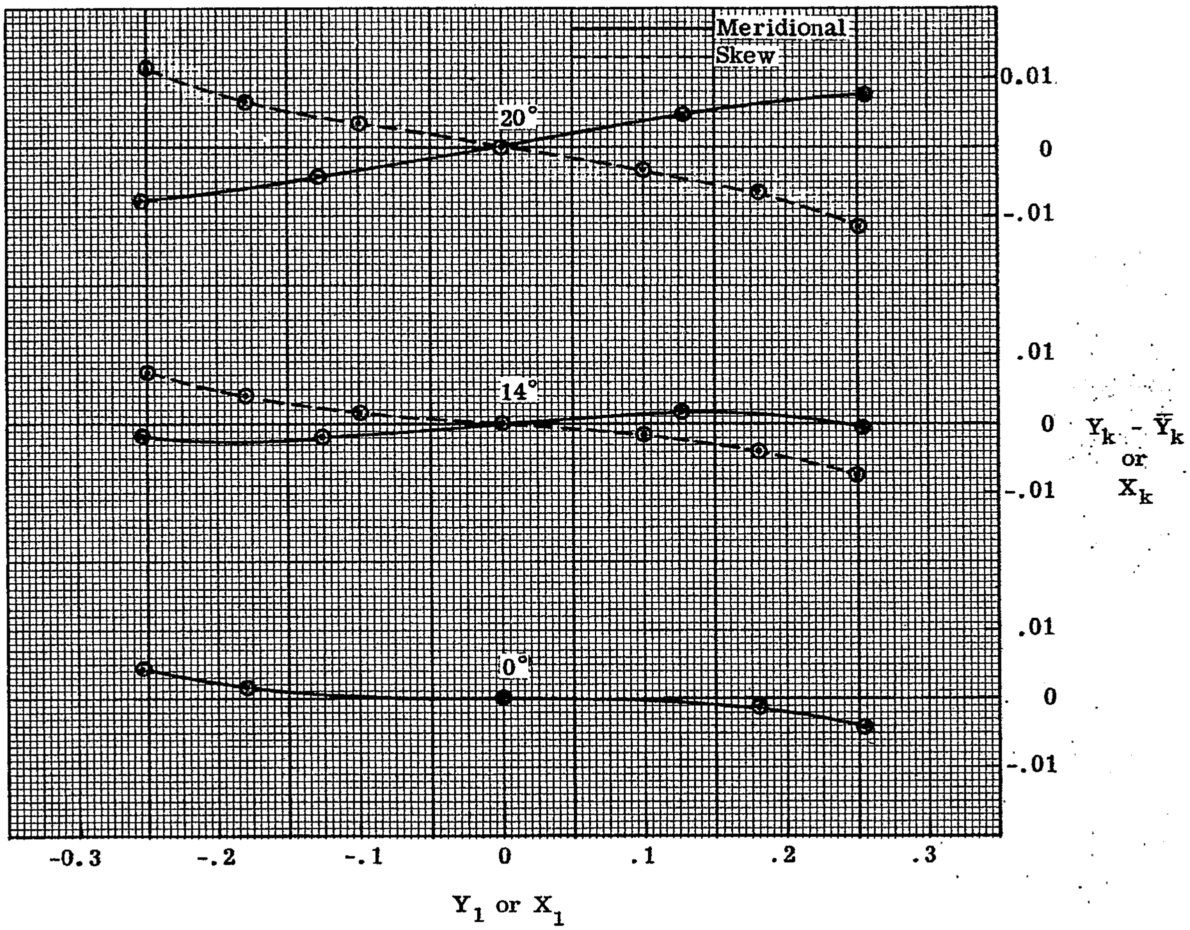


Figure 14.8- Meridional and skew fans for the Kellner eyepiece.

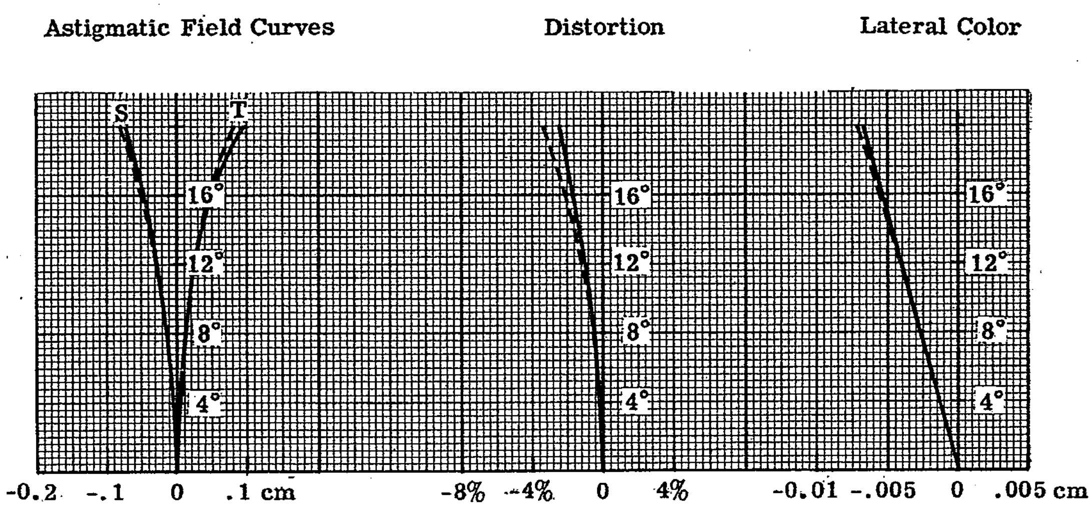


Figure 14.9- Field, distortion, and lateral color curves for the Kellner eyepiece.

14.6 THE ORTHOSCOPIC EYEPIECE

14.6.1 Design data. Table 14.4 and Figures 14.10 through 14.12 present the design data and aberration curves for this eyepiece.

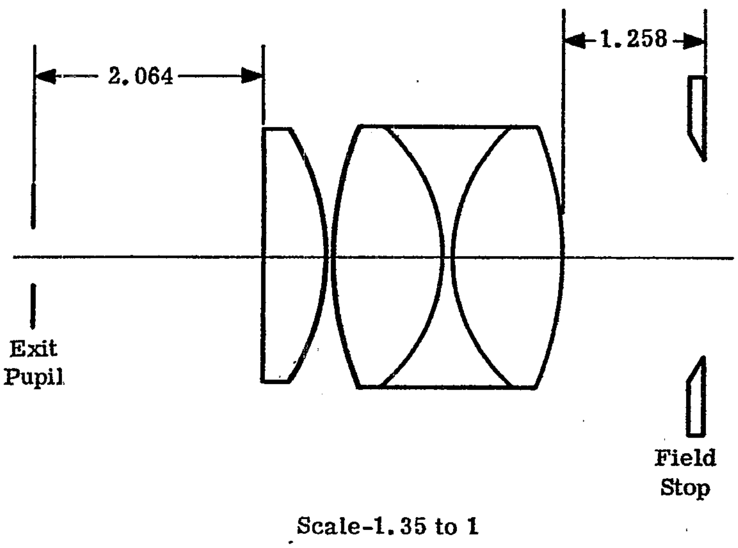


Figure 14.10- Orthoscopic eyepiece. Distances in cm.

c	t	Glass Type
0		
	0.582	573574
-0.4398		
	0.0276	Air (n = 1)
0.3089		
	0.9921	513605
-0.6281		
	0.1012	617366
0.6281		
	0.9921	513605
-0.3089		
	1.258	
$\Sigma P = -0.3158$		
$\gamma = 1.25$		

Table 14.4- Lens constants for the orthoscopic eyepiece. Lengths in cm.

14.6.2 Use and characteristics. The orthoscopic eyepiece has several advantages: (a) the γ is larger than for the two previous examples, hence the Petzval curvature is smaller; (b) the lateral color is very well corrected; and (c) it has a long eye relief (about 20 mm). However the T field has a tendency to fly backward rapidly. In more expensive instruments this eyepiece is used instead of the Kellner, sometimes as far out as 25° half angle.

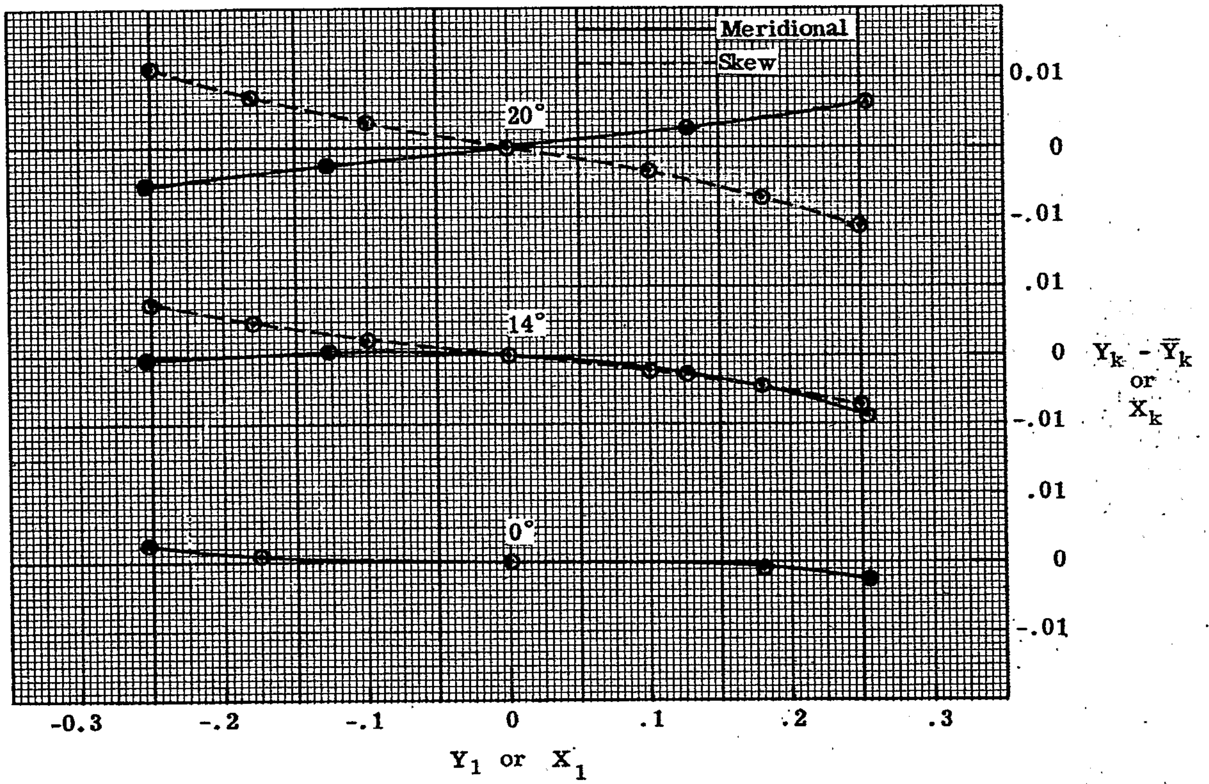


Figure 14.11- Meridional and skew fans for the orthoscopic eyepiece.

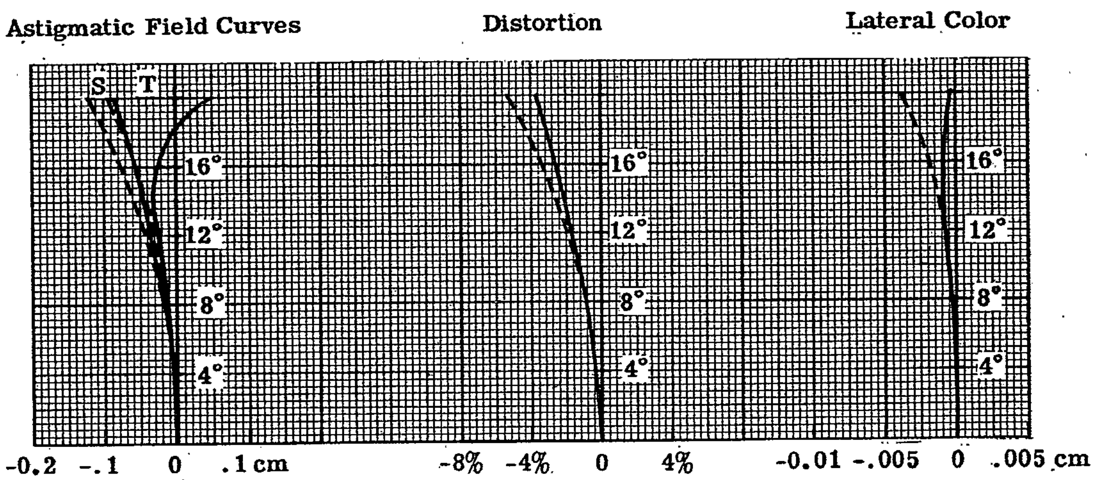
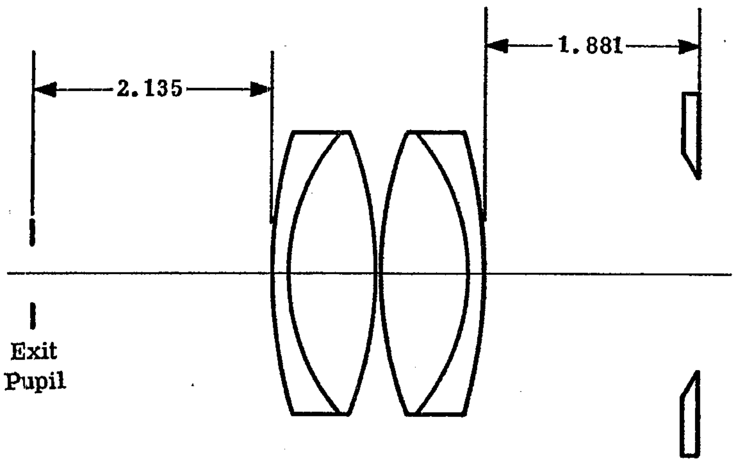


Figure 14.12 - Field, distortion, and lateral color curves for the orthoscopic eyepiece.

14.7 SYMMETRICAL (PLÖSSL) EYEPIECE

14.7.1 Design data. Table 14.5 and Figures 14.13 through 14.15 present the design data and aberration curves for this eyepiece.



Scale-1.35 to 1

Figure 14.13 - Symmetrical (Plössl) eyepiece. Distances in cm.

c	t	Glass Type
0.2135		
	0.1478	649338
0.4868		
	0.8026	517645
-0.2708		
	0.0051	Air (n = 1)
0.2708		
	0.8026	517645
-0.4868		
	0.1478	649338
-0.2135		
	1.881	
$\Sigma P = -0.3013$		
$\gamma = 1.307$		

Table 14.5 - Lens constants for the Plössl eyepiece. Lengths in cm.

14.7.2 Use and characteristics. This eyepiece, like the orthoscopic, has a long eye relief (about 20 mm) and is well corrected for lateral color. This lens, which has an overall imagery better than that of the orthoscopic, is sometimes used out as far as 25°.

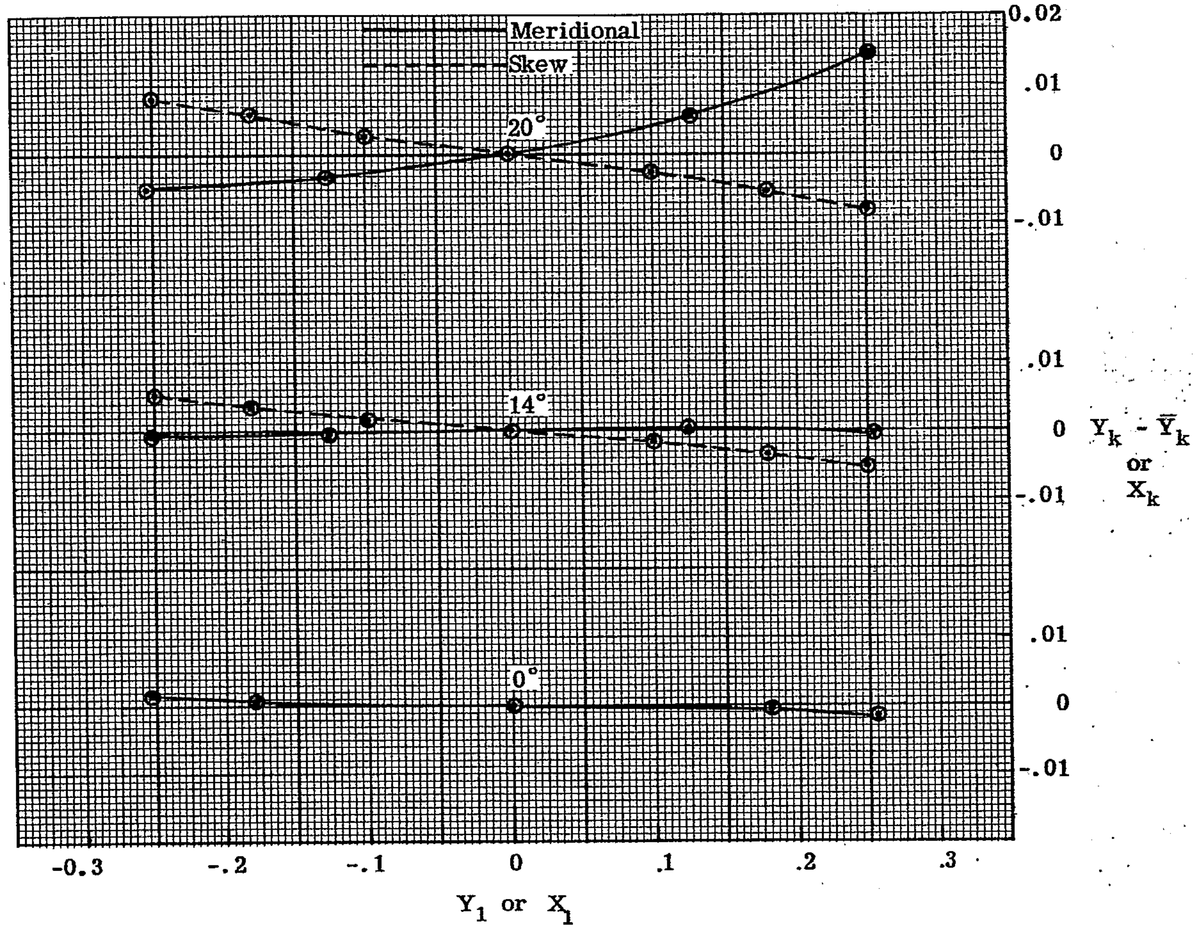


Figure 14.14 - Meridional and skew fans for the symmetrical eyepiece.

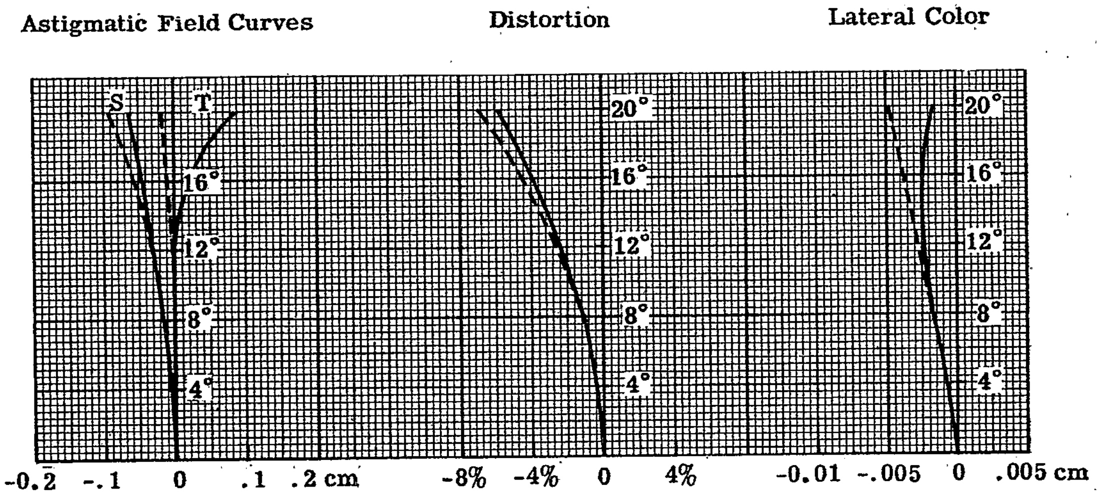
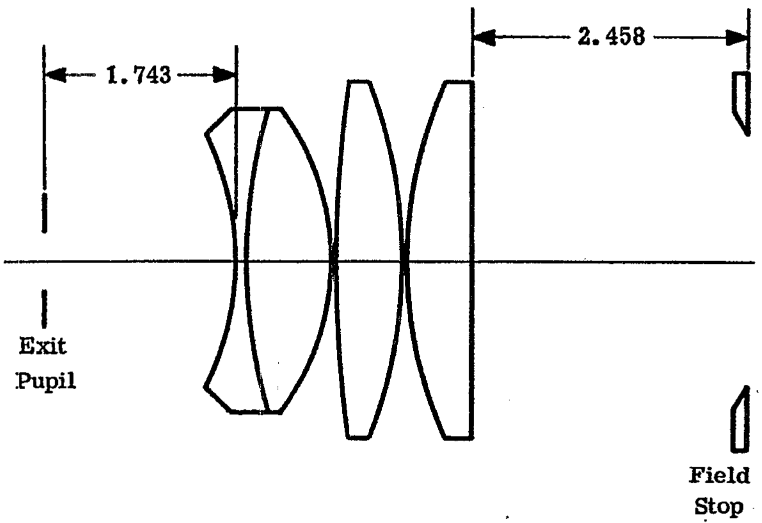


Figure 14.15-Field, distortion, and lateral color curves for the symmetrical eyepiece.

14.8 THE BERTHELE EYEPIECE

14.8.1 Design data. Table 14.6 and Figures 14.16 through 14.18 present the design data and aberration curves for this eyepiece.



Scale- 1.35 to 1

Figure 14.16 - Berthele eyepiece. Distances in cm.

c	t	Glass Type
-0.3774		
	0.08	689309
0.2000		
	0.8	620603
-0.4238		
	0.02	Air (n = 1)
0.0714		
	0.60	620603
-0.2107		
	0.02	Air (n = 1)
0.2452		
	0.60	620603
0		
	2.458	
$\Sigma P = -0.2050$		
$\gamma = 1.920$		

Table 14.6 - Lens constants for the Berthele eyepiece. Lengths in cm.

14.8.2 Use and characteristics. The design aim in this eyepiece is to reduce ΣP, the field curvature. This is accomplished at the expense of lateral color, which is not well corrected.

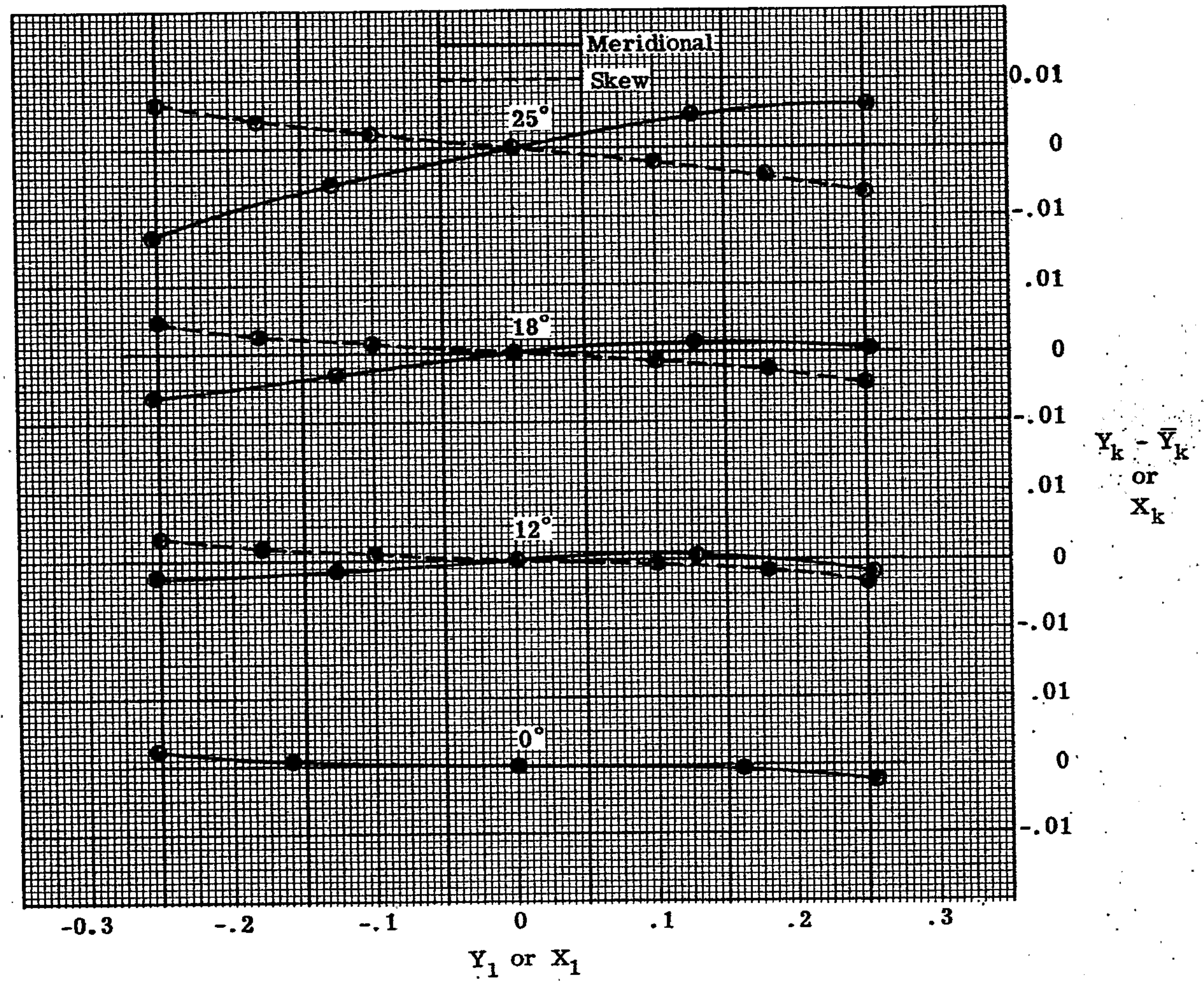


Figure 14.17 - Meridional and skew fans for the Berthele eyepiece.

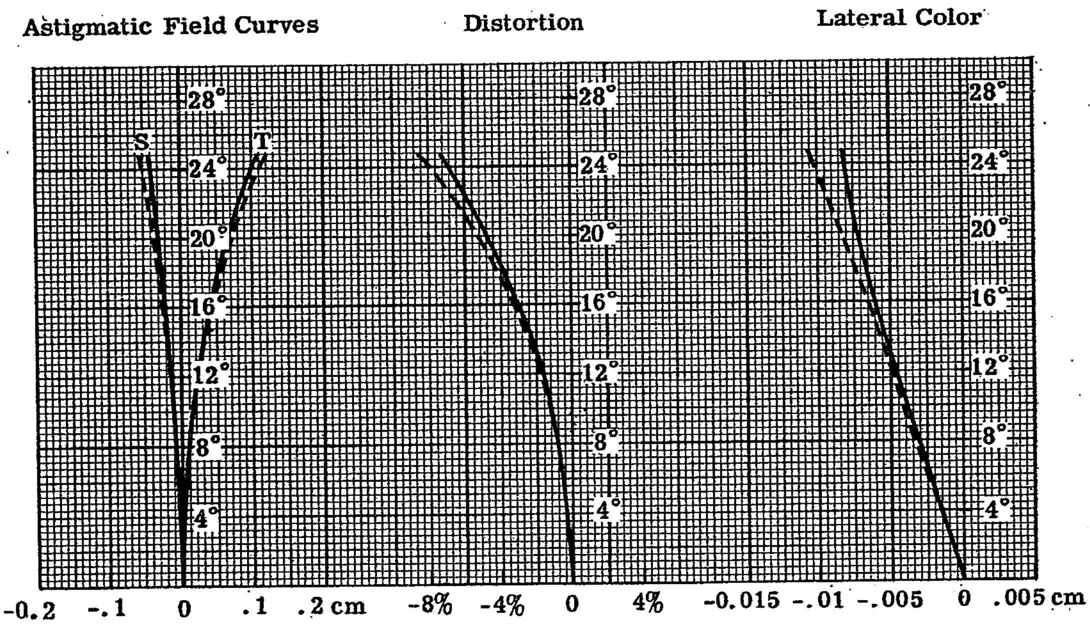
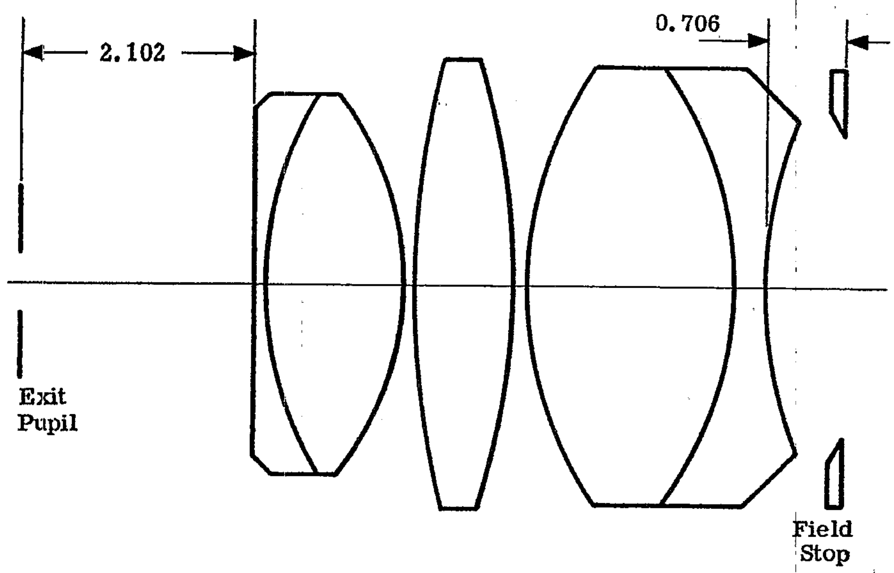


Figure 14.18 - Field, distortion, and lateral color curves for the Berthele eyepiece.

14.9 THE ERFLE EYEPIECE

14.9.1 Design data. Table 14.7 and Figures 14.19 through 14.21 present the design data and aberration curves for this eyepiece.



Scale - 1.35 to 1

Figure 14.19 - Erfle eyepiece. Distances in cm.

c	t	Glass Type
0		
	0.1219	617366
0.2912		
	1.229	517645
-0.3490		
	0.1015	Air(n= 1)
0.1125		
	0.8840	617549
-0.1437		
	0.1015	Air(n=1)
0.2537		
	1.880	611588
-0.2912		
	0.2540	649338
0.2144		
	0.7062	
ΣP = -0.2125		
γ = 1.853		

Table 14.7 - Lens constants for the Erfle eyepiece. Lengths in cm.

14.9.2 Use and characteristics. This is a widely used eyepiece which may be designed to cover a half field of 30°. The tangential field curves are controlled fairly well out this far. The lateral color can be corrected better than shown, but one must remember that the eyepiece is used with an objective and prism system. The prisms tend to compensate for the residual lateral color shown here. This is one of the most commonly used wide angle eyepieces. The lateral color is fairly large in the version described, so that sometimes it is designed with an achromatic center lens. The Petzval curvature of the lens is fairly small, but it can be further diminished by reducing the distance between the focal plane and the first surface of the eyepiece. The fallacy with this solution is that any dust on this surface comes sharply into focus. The Petzval curvature can also be reduced by introducing more thickness on the negative lens closest to the exit pupil and by making the surface concave instead of plane. This alternative cuts down on the eye relief.

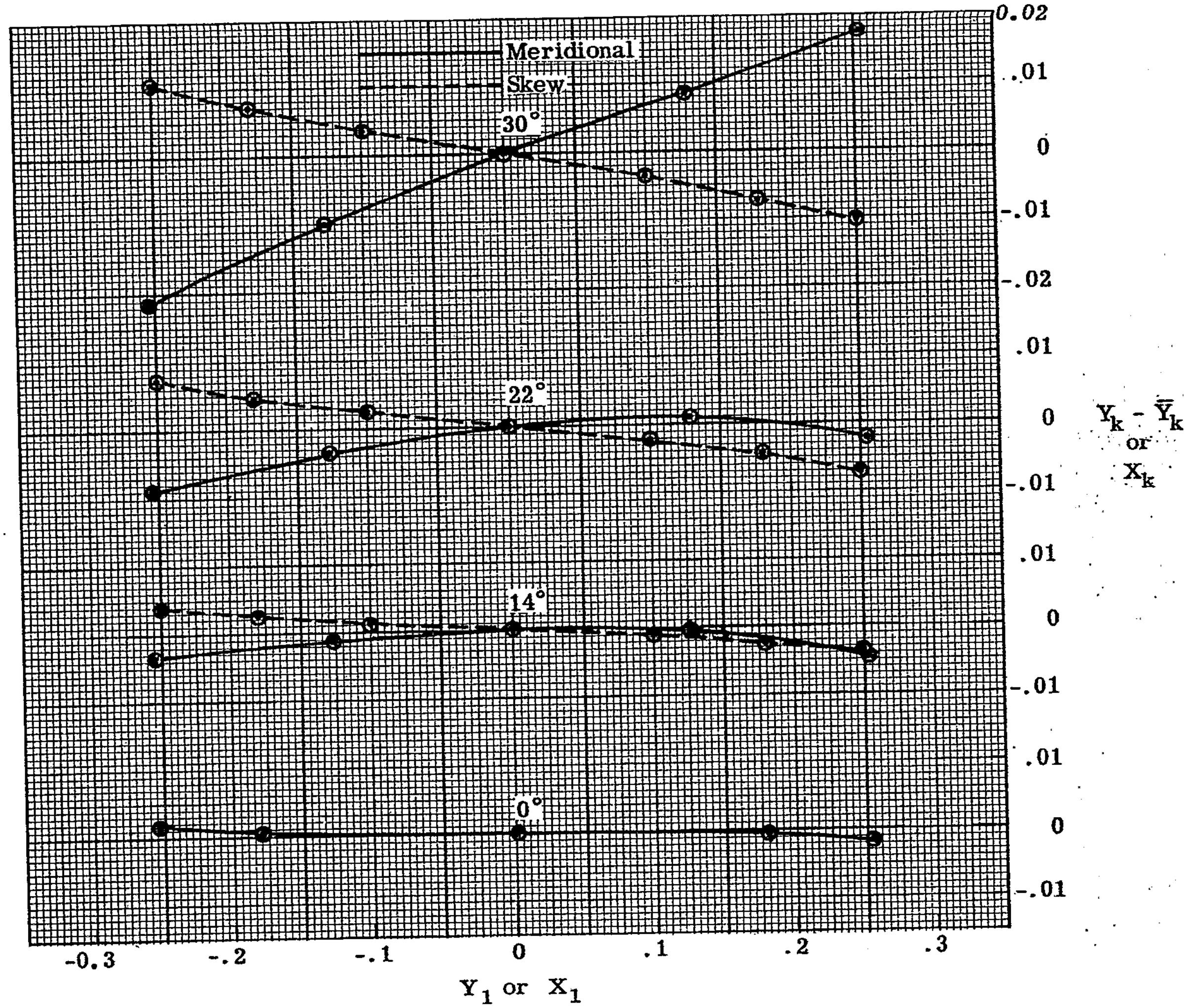


Figure 14.20 - Meridional and skew fans for the Erfle eyepiece.

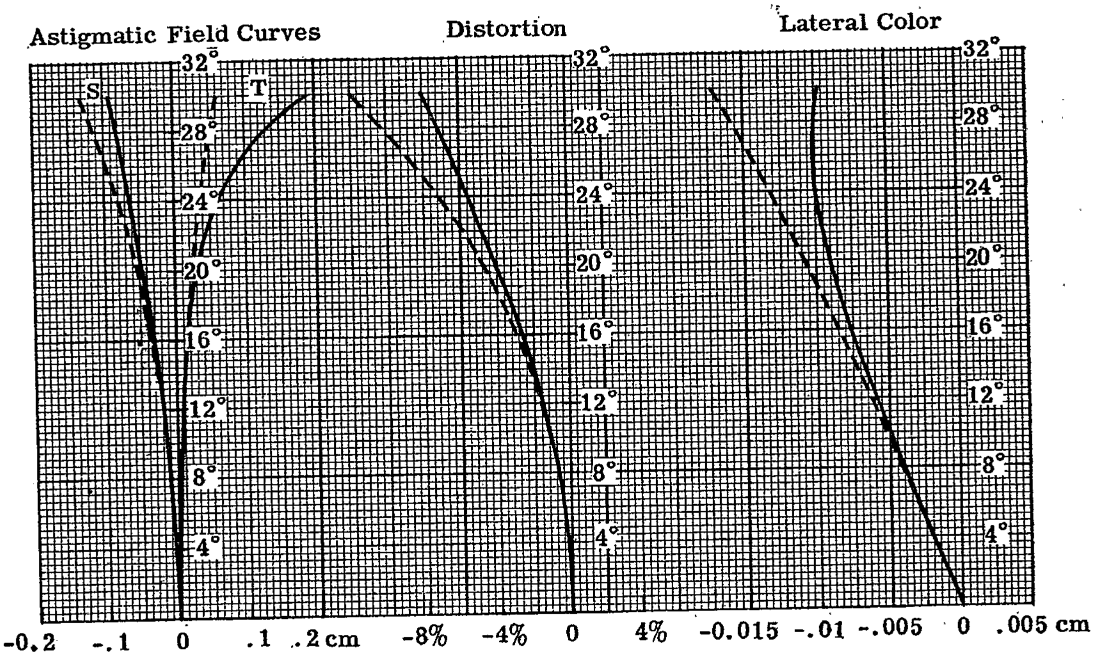


Figure 14.21 - Field, distortion, and lateral color curves for the Erfle eyepiece.

14.10 THE MODIFIED ERFLE EYEPIECE

14.10.1 Design data. Table 14.8 and Figures 14.22 through 14.24 present the design data and aberration curves for this eyepiece.

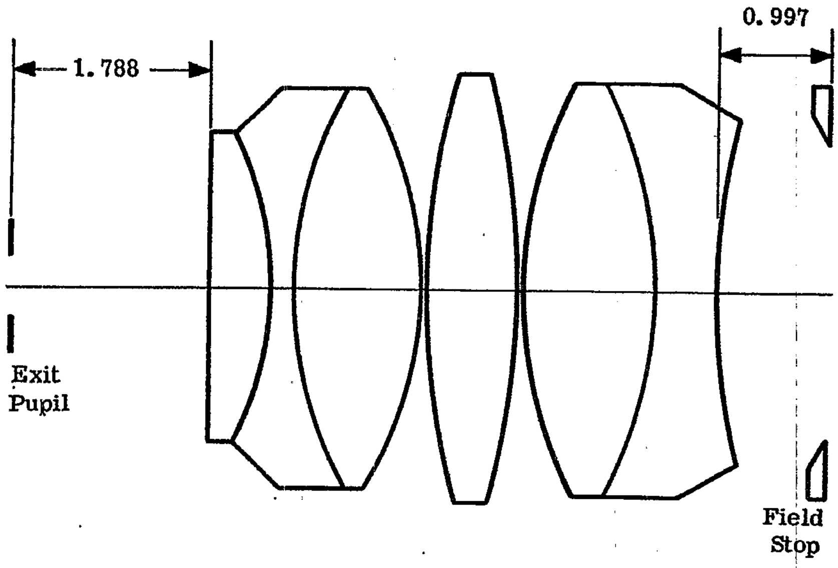


Figure 14.22 - Modified Erfle eyepiece. Distances in cm.

c	t	Glass Type
0		
	0.55	638555
-0.310		
	0.180	649338
0.275		
	1.15	638556
-0.275		
	0.05	Air(n= 1)
0.123		
	0.80	638555
-0.130		
	0.05	Air(n= 1)
0.234		
	1.20	638555
-0.234		
	0.54	720293
0.159		
	0.9973	
$\Sigma P = -0.221$		
$\gamma = 1.78$		

Table 14.8 - Lens constants for the modified Erfle eyepiece. Lengths in cm.

14.10.2 Use and characteristics. This eyepiece is an improvement on the Erfle eyepiece. The lateral color is better and the tangential and sagittal fields are not as widely split. It still has a good eye relief. The distortion is large but for telescopes this is not too objectionable because the field stop is round. Hence the corners of the field, which suffer from large distortion, are missing.

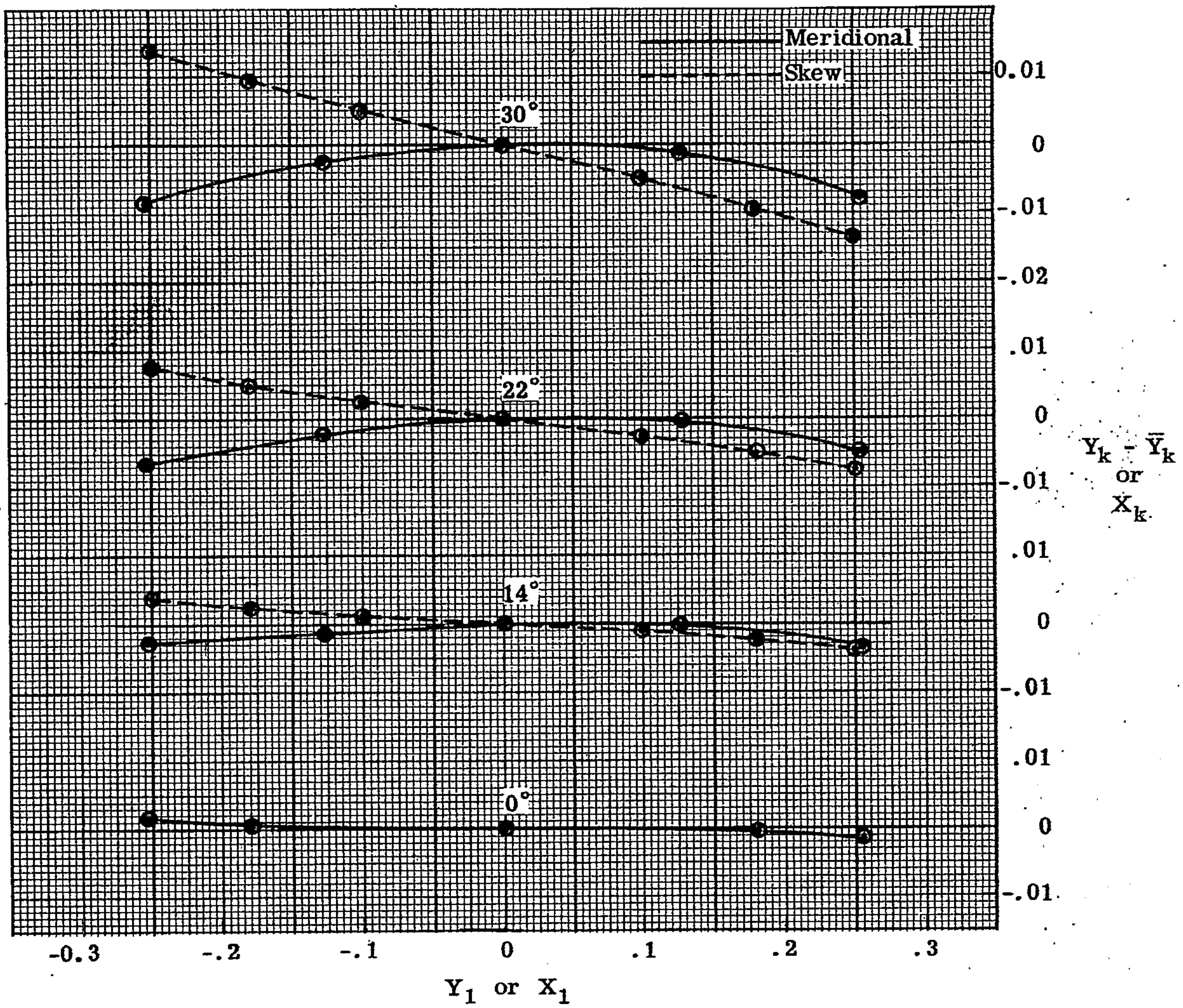


Figure 14.23 - Meridional and skew fans for the modified Erfle eyepiece.

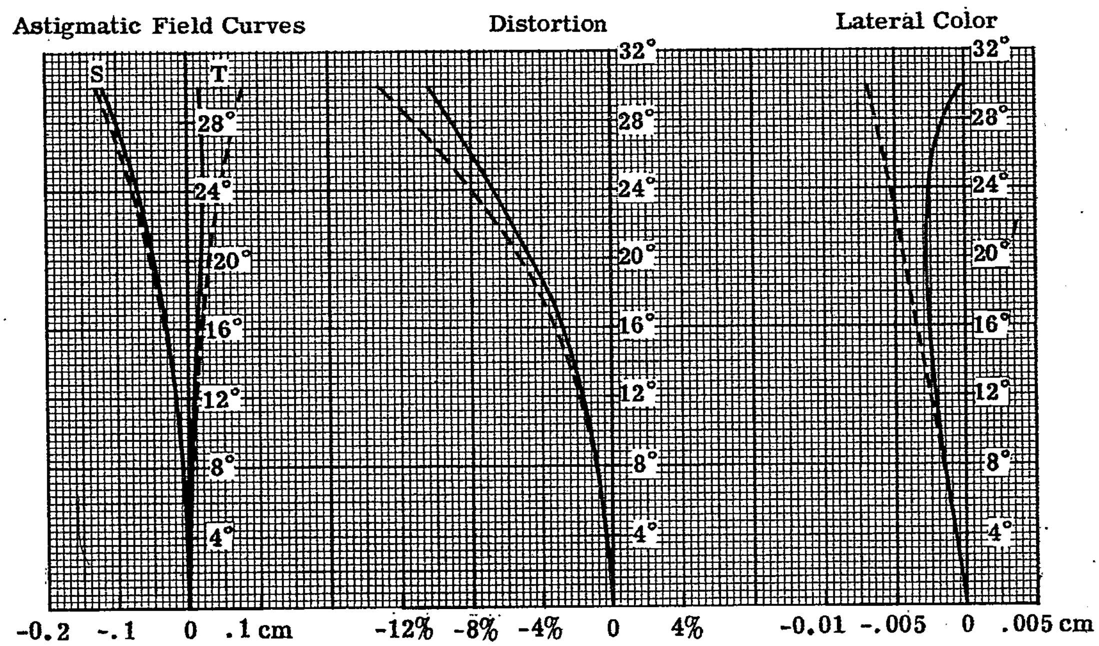
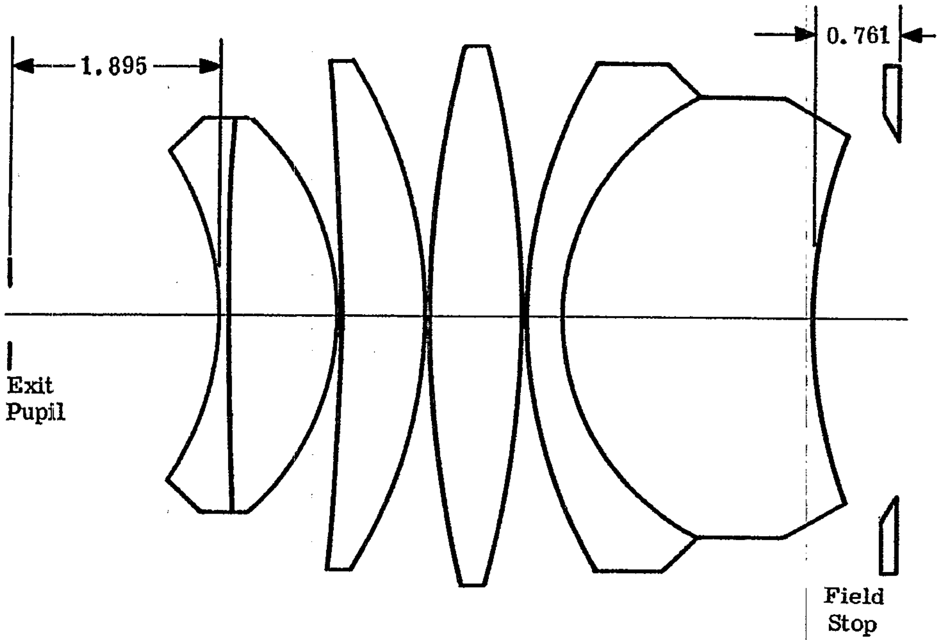


Figure 14.24 - Field, distortion, and lateral color curves for the modified Erfle eyepiece.

14.11 THE WILD EYEPIECE

14.11.1 Design data. Table 14.9 and Figures 14.25 through 14.27 present the design data and aberration curves for this eyepiece.



Scale - 1.35 to 1

Figure 14.25- Wild eyepiece. Distances in cm.

c	t	Glass Type
-0.3636		
	0.10	689309
0.04		
	0.95	620603
-0.4000		
	0.01	Air(n=1)
-0.0200		
	0.80	620603
-0.2243		
	0.01	Air(n=1)
0.1025		
	0.85	620603
-0.1025		
	0.01	Air(n=1)
0.2171		
	0.35	649338
0.4400		
	2.25	573425
0.2170		
	0.761	

$\Sigma P = -0.1538$
$\gamma = 2.56$

Table 14.9-Lens constants for the Wild eyepiece. Lengths in cm.

14.11.2 Use and characteristics. This rather complex eyepiece is interesting because the Petzval curvature is so small. The tangential field is also well under control out as far as 36°. The Petzval curvature is kept small by using strongly curved surfaces as the outside surfaces of the lens. If this is done the glass used for the element nearest the field stop must be free of bubbles; otherwise they will be seen since they are so close to the focal plane.

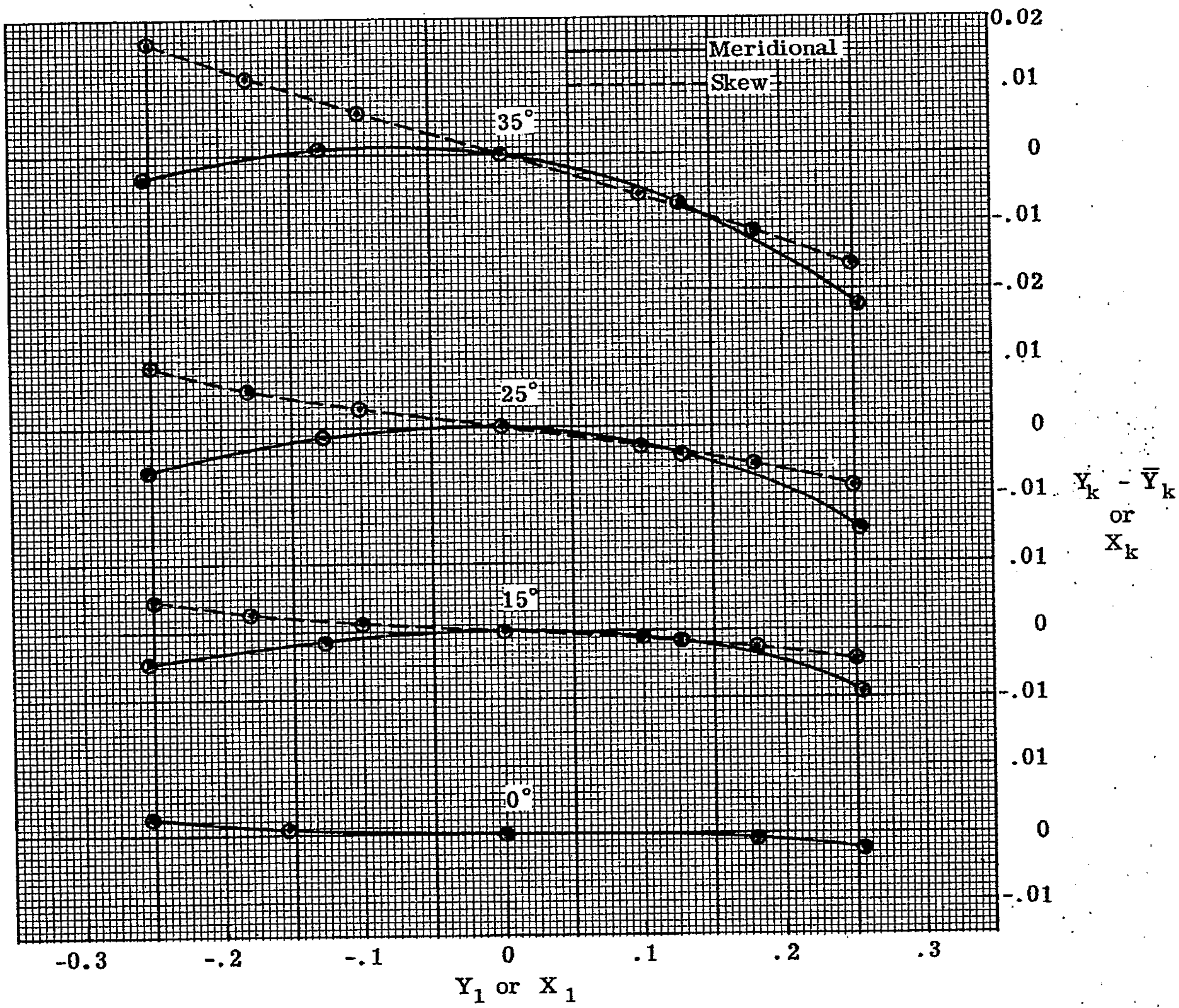


Figure 14.26- Meridional and skew fans for the Wild eyepiece.

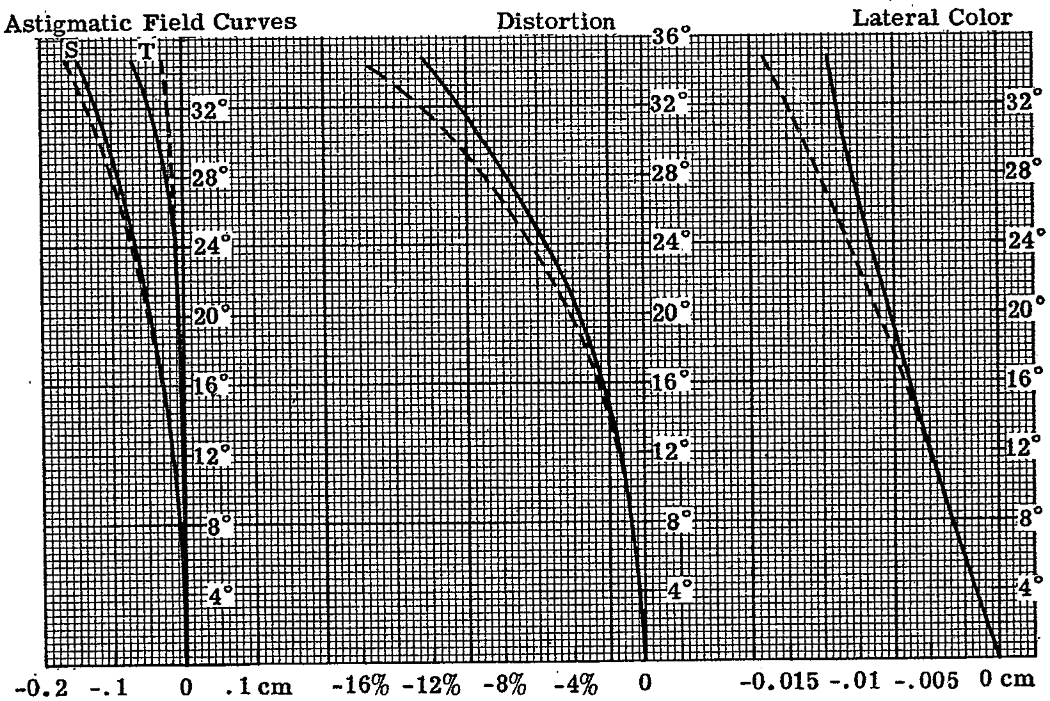


Figure 14.27- Field, distortion, and lateral color curves for the Wild eyepiece.

14.12 SUMMARY

The eyepieces shown in the previous sections are merely representative of types. When they are used in differing applications slight modifications should be made to correct the aberrations of the system. In Section 15 a telescope with prism system is designed to show how the eyepiece is adjusted to fit the particular problem.