# 15 COMPLETE TELESCOPE

## 15.1 INTRODUCTION

The problems encountered in the design of a complete telescope are well suited to illustrate how the individual design of objective, erecting system, and eyepiece must be fitted into the overall solution. If the limits on space, vibration, method of support, and other factors permit or demand it, a lens type erecting system, rather than a prism system, may be employed. The basic concepts of this type were discussed in Section 7.5.3. The refinement of the lens design is patterned after the techniques described for the objective and eyepiece. However, the designer is usually faced with restrictions on space and other considerations which require that he fold the light path. Let us therefore consider such a case.

## 15.2 THE DESIGN PROBLEM

Suppose the following specifications are established for a telescope:

| | | |
|---|---|---|
| (1) | Magnifying Power | 10 X |
| (2) | Apparent Field of View | 30° (half angle) |
| (3) | Exit Pupil Diameter | 0.5 cm. |
| (4) | Minimum Eye Relief | 2.0 cm. |

(5) Line of sight to be displaced a minimum of one inch in a plane at 45 degrees to the observer's vertical and to his right. (This is actually a conclusion drawn from more complex requirements but will serve to establish the need for a displaced line of sight.)

## 15.3 PRELIMINARY CONSIDERATIONS

15.3.1 Prism type. From requirement (5) above and from Section 13.10.2 we can easily see that a Porro prism system will offer a ready solution to displacement and erection if we have $A \geqq 0.7$ inch (approx.)

15.3.2 The eyepiece.

15.3.2.1 From Section 14 we can also quickly determine that it will be necessary to use an eyepiece of the Erfle type, since, from requirement (2), the apparent field must be 30°.

15.3.2.2 We now must determine the focal length of the eyepiece. One can say almost without qualification that the longer the focal length of the eyepiece, the better the image quality of the system. Usually, however, this means the telescope will become large, expensive, and cumbersome. Most commercial applications call for a small compact system. There is, however, a lower limit to the focal length of the eyepiece, since there is a minimum eye relief which can be used with comfort by the observer. The data on the Erfle eyepiece (Section 14.9) showed that the eye relief is around 0.8 of the focal length. Therefore in order to meet requirement (4) it will be necessary to have an eyepiece focal length of at least 2.5 cm.

15.3.3 Preliminary summary. We have now established the following design parameters.

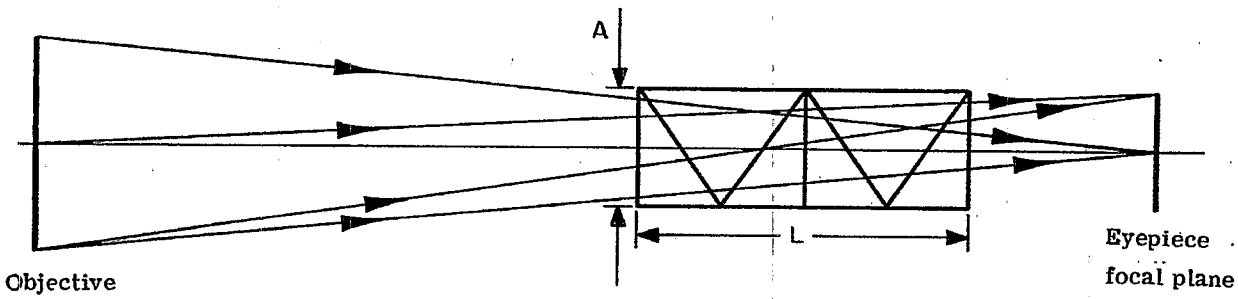
| | | | |
|---|---|---|---|
| (1) Objective: | (a) | Focal length, $f_o$ | 25 cm. |
| | (b) | Diameter | 5.0 cm. |
| | (c) | $f$-number | 5.0 |
| | (d) | Field of view (half angle) | 3° (approx.) |
| (2) Eyepiece: | (a) | Type | Erfle |
| | (b) | Focal length, $f_e$ | 2.5 cm. (min) |
| | (c) | Eye relief | 2.0 cm. (min) |
| | (d) | Field of view (half angle) | 30° |

(3) Erecting System: (a) Type Porro Prism System

(b) Aperture 1.8 cm. (min.)

15.4 DESIGN REFINEMENT

15.4.1 The Porro erecting system. The next step in the design is to determine the size of prisms needed to erect the image. The prism length is determined by drawing a thin lens telescope system and using a tunnel diagram for the prisms. In order to keep the prism small, as much as 50% vignetting is allowed at the edge of the field. The glass type selected for the prisms is of importance. It must have a high transmission with relatively low dispersion, and the index of refraction must be high enough to insure total reflection for all the rays. A glass frequently used in prisms is type number 573574. The drawing shown in Figure 15.1 shows the layout of the prism system used in this sample problem. The prism aperture is 2.9 cm and the total thickness of the prism is 11.6 cm.




L' = Reduced prism length = 4 A/n = 7.3767 cm.
A = Aperture diameter of prisms.
n = Index of refraction of prisms.

Figure 15.1 - Diagram illustrating positioning of Porro prism system in telescope. The prisms are shown "reduced".

15.4.2 The objective.

15.4.2.1 The objective design is started by consulting Table 11.3 for a thin lens solution. In this example the following solution (case No. 14) was used:

Lens (a) 517645

(b) 689309

15.4.2.2 From the curvatures given in the table, it is possible to draw up the lens and assign the proper thicknesses. Figure 15.2 shows a scale drawing of the thin lens solution (curvatures) with proper thickness added. Then, with the thicknesses and the prism added, the third order aberrations are computed to compensate for the eye piece.

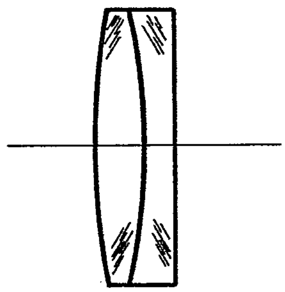


Figure 15.2 - Scale drawing of the objective.

15.4.3 The eyepiece

15.4.3.1 The preliminary eyepiece may be scaled from the Erfle shown in Section 14.9. The astigmatism and lateral color will probably have to be adjusted to match the objective and prisms. They may be controlled either by changing the curve on the cemented surfaces or by changing the glass in the eyepiece. The astigmatism and lateral color are corrected in the eyepiece, and then the total coma and spherical aberrations are corrected in the objective. Very little can be done about the distortion introduced by the eyepiece. It is closely connected to the astigmatism, so once the astigmatism is corrected to the desired value, the distortion is determined. Distortion is really not a very objectionable aberration in a viewing telescope.

15.4.3.2 The lateral color is made more positive by finding glasses with reduced dispersion for the positive elements. If the index difference between the positive and negative lenses of the cemented doublets is reduced, it is possible to make the cemented curves shorter in radius (thereby adding positive lateral color) without introducing high order positive astigmatism.

15.4.3.3 In correcting the astigmatism in the eyepiece, it is necessary to ray trace for every change. The reason for this is that near the edge of the field the astigmatism is dominated by higher than third order aberrations.

15.4.4 Objective readjustment. After the astigmatism and the lateral color have been corrected to match those of the objective and the prisms, it is necessary to readjust the objective to correct for the axial color, spherical aberration and coma of the complete telescope.

15.5 THE COMPLETED DESIGN.

The completed telescope system, shown in Table 15.1, represents a solution to the design problem. The aberration curves are shown in Figures 15.4, 15.5, and 15.6. Figure 15.4 is a plot of the angular aberrations in D light for skew fans of rays at three obliquities. Figure 15.5 is a similar plot for meridional fans of rays. Figure 15.6 contains field curves, a plot of distortion, and lateral color curves. In all three figures, the dashed curve represents the third order. This telescope was corrected by an expert designer. It represents excellent correction, so it may be used as a guide on what to expect from such a telescope. Note in Figure 15.6 how the final T and S curves are adjusted. At the edge of the field they are split by 3.7 diopters. The mid-focus is inside the paraxial focus by 0.8 diopter. This means if the eyepiece is focused in by 0.8 diopters, the image quality will essentially be free of astigmatism out to 20°. These aberrations may appear to be very large but they are typical and are not as objectional as it may seem. A telescope is used for acute vision primarily close to the axis (within ±12° apparent field). The observer seldom uses the telescope in a fixed position and rolls his line of sight around to observe objects near the edge of the field. The edge of the field is usually used to notice motion. If anything of interest does appear in the edge of the field, the observer can train the telescope to center it in the field. When an observer has his eyes to the telescope he wants all the field of view he can have. It is much better to have a picture blurred at the edges than none at all. For this reason a telescope should always be designed for as wide a field as possible, even if the astigmatism and distortion may become large. The limit should be set by the size of the instrument and the cost, rather than by the image quality. As the field is increased beyond the 30° half angle of the Erfle, the size of the instrument grows rapidly, for the prisms and eyepiece must be enlarged. In wide angle telescopes it is also desirable to maintain as large an exit pupil as possible. The reason for this is that the iris of the observer's eye is not located at the center of rotation of the eye. With the iris located at the exit pupil there is a tendency for the iris to rotate out of the exit pupil when viewing objects near the edge of the field. This is demonstrated in Figure 15.3. It is true that the observer may move his eye but in a binocular instrument this is not possible for both eyes.

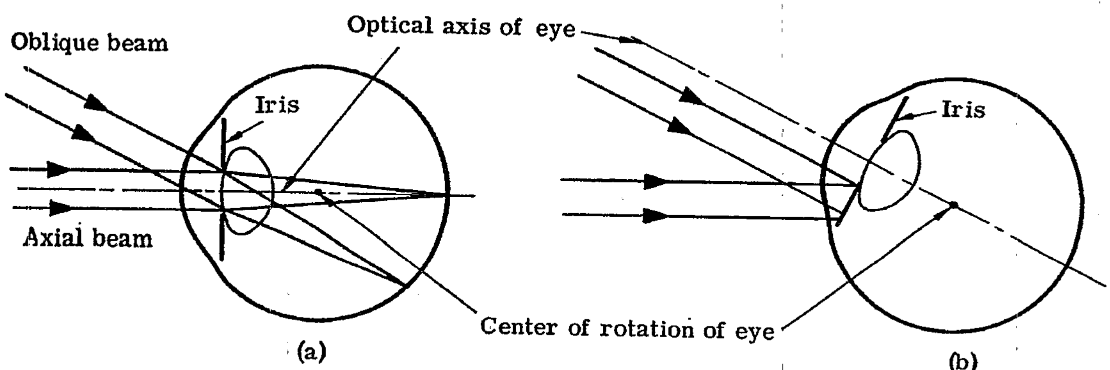



Figure 15.3 - Diagram (a) illustrating the eye viewing an axial image. Diagram (b) illustrating the eye rotated to view an oblique image and losing the entire beam.

| c | t | n | ν |
|---|---|---|---|
| 0.07080 | | | |
| | 0.80 | 1.517 | 64.5 |
| -0.06874 | | | |
| | 0.05 | 1.00 | |
| -0.07165 | | | |
| | 0.40 | 1.689 | 30.9 |
| -0.02413 | | | |
| | 15.00 | 1.00 | |
| 0.0000 | | | |
| | 11.60 | 1.5725 | 57.4 |
| 0.0000 | | | |
| | 3.0186 | 1.00 | |
| -0.21670 | | | |
| | 0.254 | 1.649 | 33.8 |
| 0.35000 | | | |
| | 1.8796 | 1.620 | 55.5 |
| -0.25000 | | | |
| | 0.1015 | 1.00 | |
| 0.15350 | | | |
| | 0.8840 | 1.620 | 55.5 |
| -0.10000 | | | |
| | 0.1015 | 1.00 | |
| 0.35000 | | | |
| | 1.2294 | 1.517 | 64.5 |
| -0.27500 | | | |
| | 0.12190 | 1.617 | 36.6 |
| 0.00000 | | | |

Table 15.1 - Specification for 10 X telescope.

15.5.1 Eyepiece and objective checks. In the preliminary design it is advisable to correct the eyepiece and objective as separate units. Usually designers trace parallel rays into the eyepiece from the eyeside towards the focal plane, and trace parallel rays through the objective to the focal plane. The transverse image errors are then made to match at the intermediate focal plane. After it appears that the two match reasonably well they should be put together and studied as a complete telescope. It is advisable to insert a dummy reference surface at the internal focal plane so that when the rays are traced through the entire system it will be possible to note the image errors on the image plane.

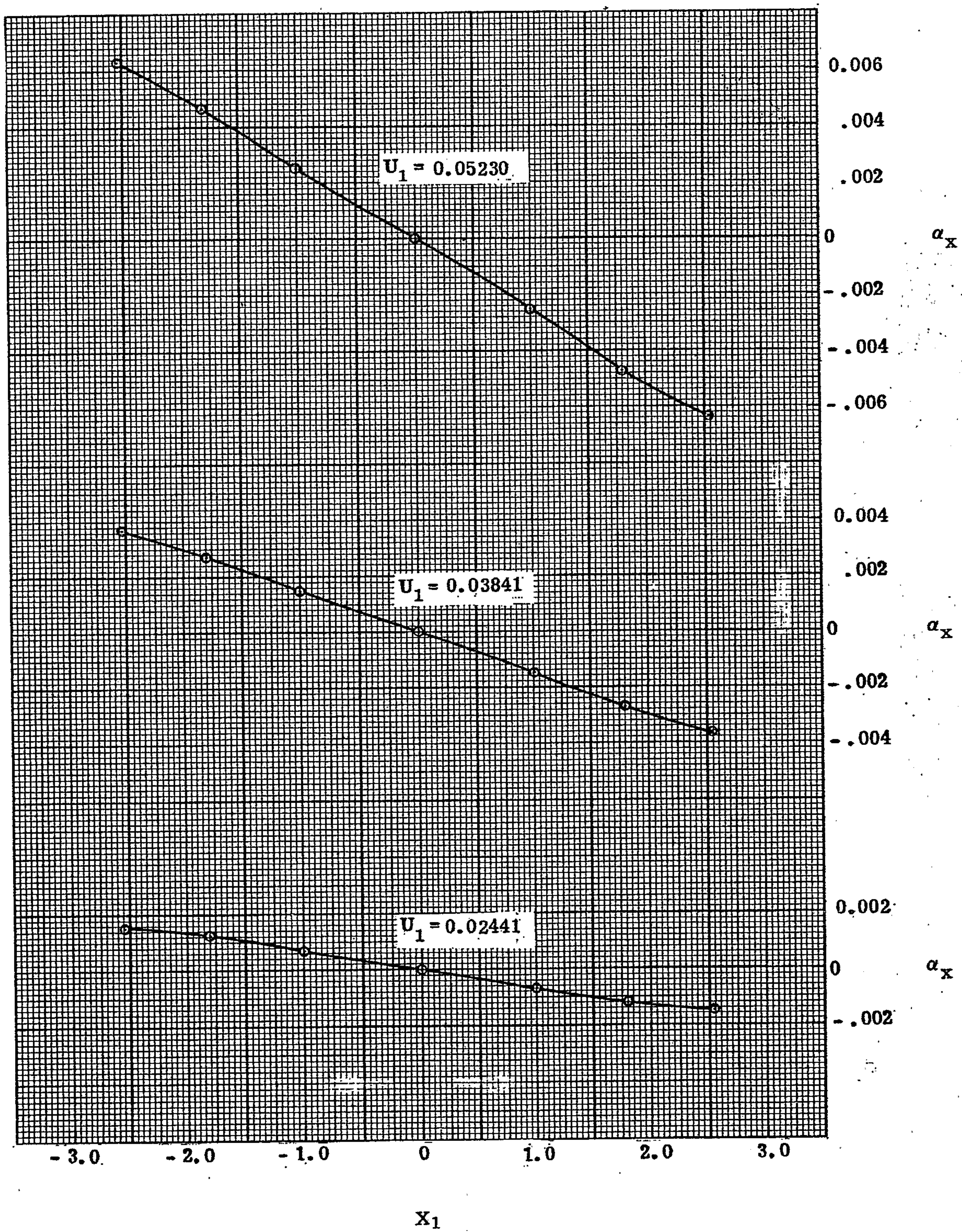



Figure 15.4 - Skew rays.

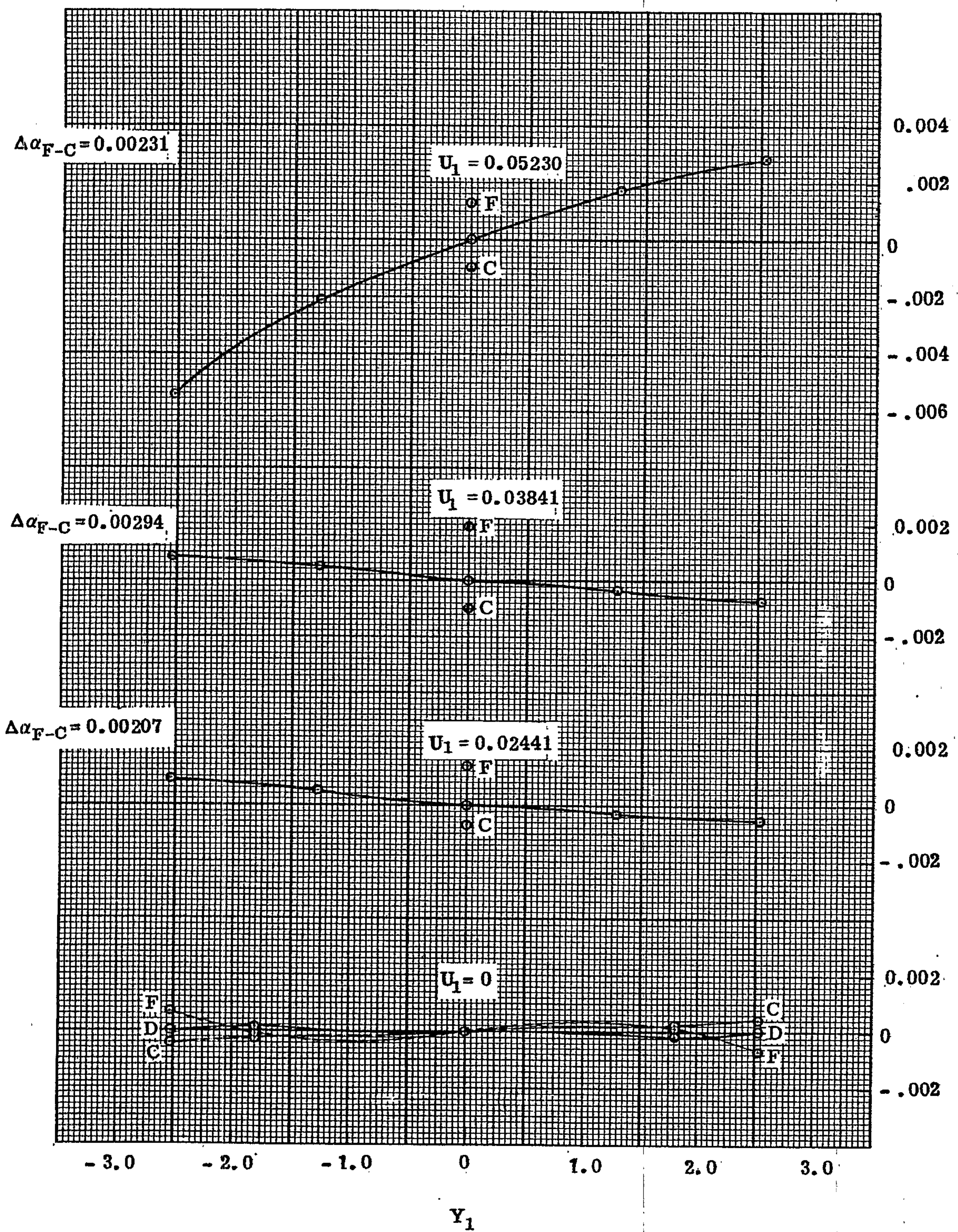



Figure 15.5 - Tangential rays.

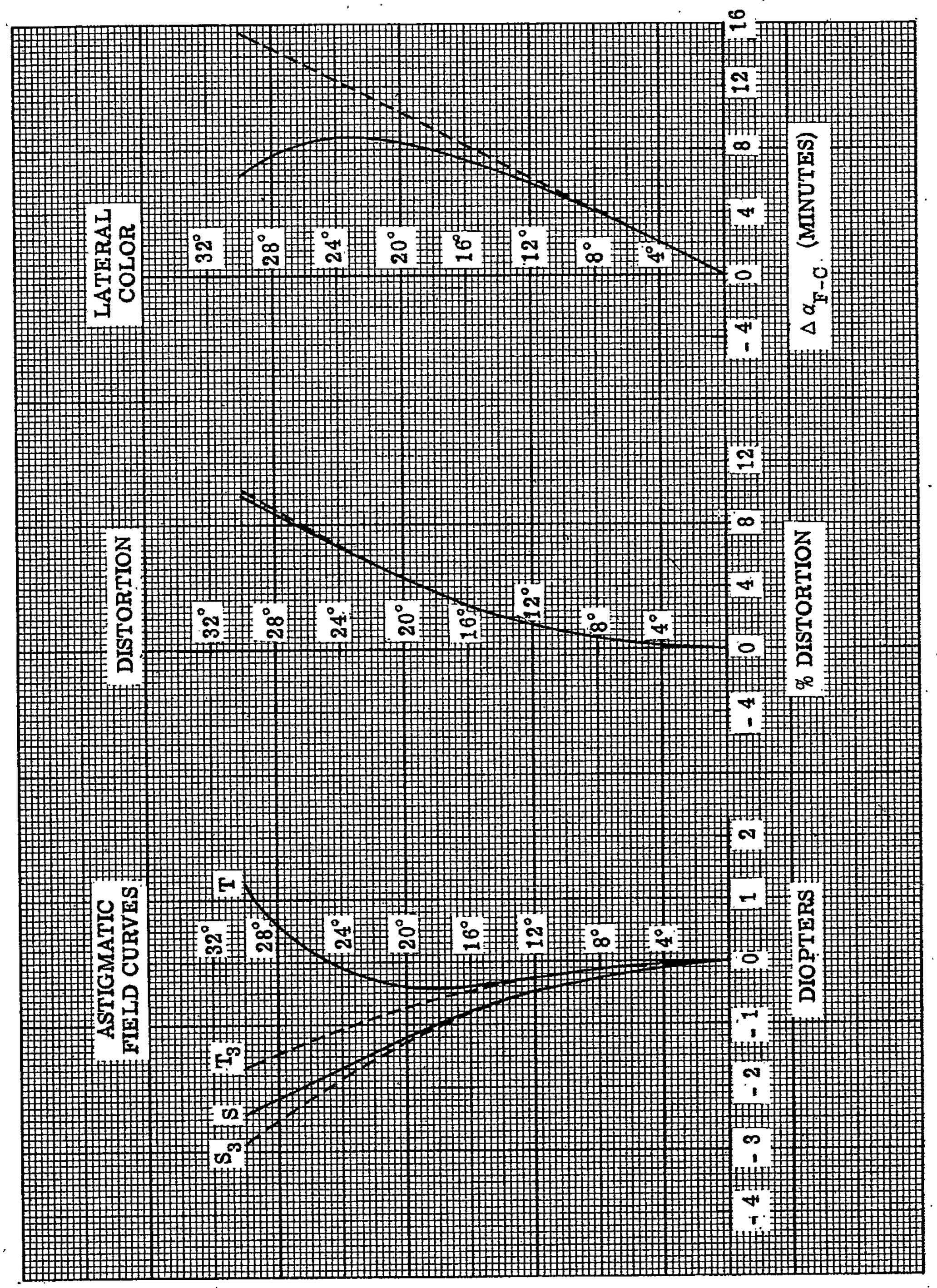



Figure 15.6 - Astigmatic field curves, distortion, and lateral color.