

This paper is an outgrowth of a seminar given at the 1992 meeting of the Optical Laboratories Association in Dallas, Texas. Originally the topic was to be 'Minus Aspheric Lenses'. The scope was expanded to discuss plus aspheric lenses, as the design methods used in both situations are similar.

Design Considerations for Aspheric Single Vision Ophthalmic Lenses

Richard B. Whitney, American Optical Corporation

Aspherical surface has a constant curvature. If one were to take a brass gauge of matching curvature to a spherical surface, complete contact with the gauge and surface would occur. Uniform contact would be evident as this gauge is moved in any direction along the curve being examined.

An aspheric surface is, by definition, any surface which is not a sphere. Such surfaces have a non-uniform or variable curvature. As a gauge is moved away from the centre of the asphere, gaps between this gauge and surface become evident. It is not possible to

produce a matching gauge that could have continuous contact as it is moved in all directions about an aspheric lens surface.

The most common aspheric surface used in ophthalmic lenses is the toric surface. It is frequently used to correct vision resulting from defects of the eye itself. A toric surface is non-spherical and therefore aspheric. This is not the type of aspheric intended for discussion here, however. The type of aspheric surface that will be discussed is utilised typically for two reasons:

- (1) to control off-axis optical errors;
- (2) to reduce lens thickness and improve cosmetic appearance.

In an aspheric single vision ophthalmic lens, a commonly employed family

of aspheric surfaces are those of a 'conic section'. Some of the more commonly thought of conic sections are circles, ellipses and parabolas. As one might gather from the name, conic sections result from taking a cross section of a cone. The resulting shape is dependent upon the angle at which the dissecting plane intersects this cone. In attempting to visualise the general shape of surfaces suited for plus and minus aspheric lenses, it is helpful to examine how a conic section might be utilised:

Plus lens aspheric surface

The steepest point(s) of curvature on the ellipse shown in Fig 1a is where the major axis intersects the figure. As the curve moves away from this point of intersection, the curve becomes flatter. Taking a section from this ellipse and rotating about this axis, a three-dimensional surface results. By selecting a section of this ellipse and adding a rear spherical curve to this figure, a plus aspheric lens can be visualised.

Minus lens aspheric surface

Turning our examination to the flattest point(s) of curvature on the elliptical surface (where the minor axis intersection occurs), a similar three-dimensional figure can be made by rotating the surface about this axis. Again, by

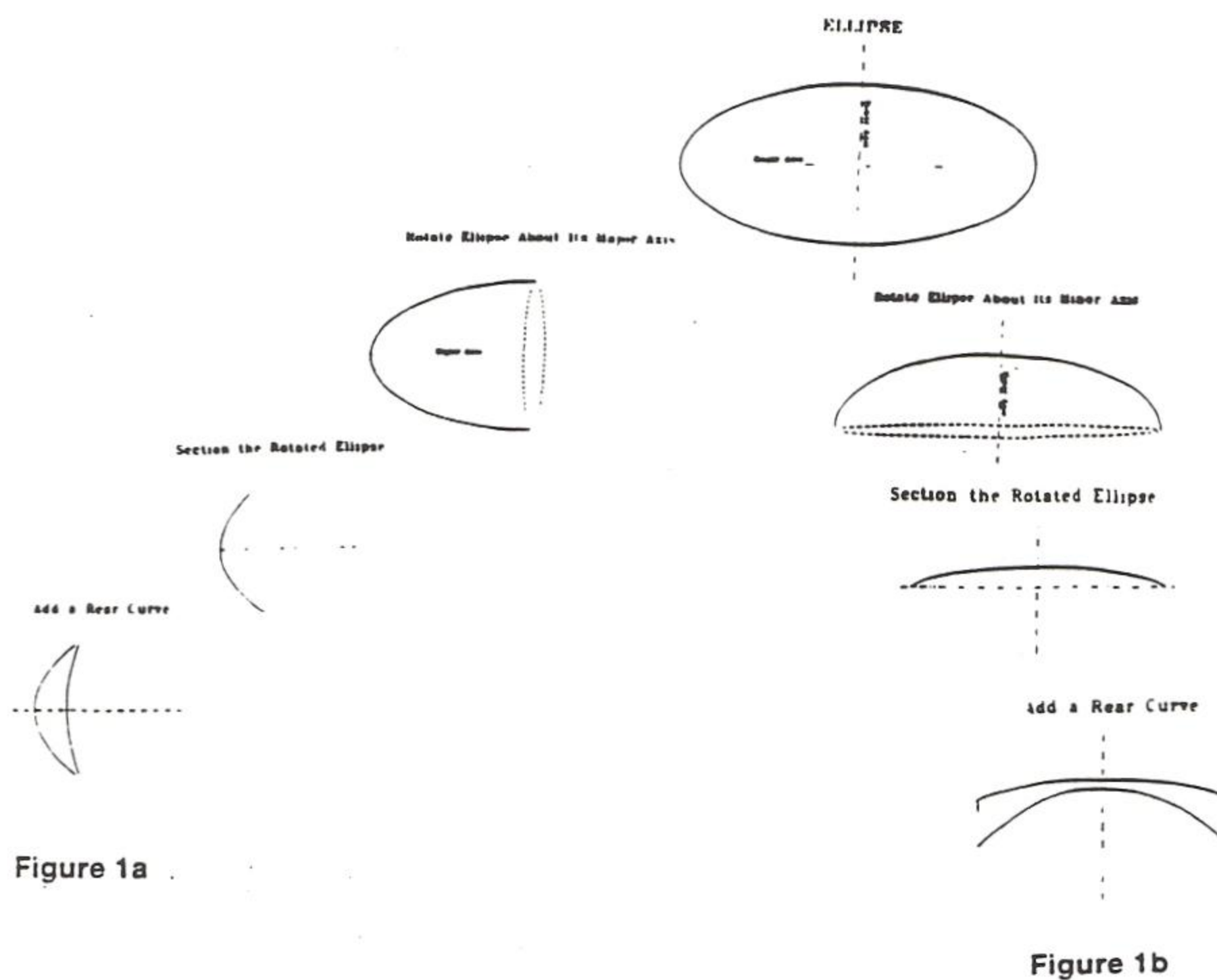


Figure 1a

Figure 1b

selecting the appropriate section of this aspheric and adding a steeper back curve, a lens of negative back vertex power results.

As a general rule, aspheric surfaces used in most ophthalmic lenses flatten

as one moves away from the centre of the aspheric surface for plus lenses. In the case of minus lenses, just the opposite occurs; for these lenses the curvature steepens away from the design centre.

The image of the pole will now appear out of focus, while its crossarms remain in sharp focus (Fig 2a). In such a case, where the vertical image is blurred, tangential power error has been introduced. When a flattened base curve is chosen, this power error is likely to become significantly worse. Additionally, this image is also degraded when lateral chromatic aberration (see below) is present. Tangential power error and lateral chromatic aberration error are additive. By controlling the degree of tangential power error present, the sum of these errors is minimised.

Why are aspheric surfaces used in ophthalmic single vision lenses?

The cosmetic trend in ophthalmic lenses in recent years has been to provide thinner lenses than had been produced in the past. This need has resulted in the increased popularity of higher index materials, as well as lenses employing aspheric surfaces. When higher index materials are substituted for lesser index materials for a given lens power, the difference between front and back curvatures are lessened due to the increased light bending power of the material.

Thinner lenses may also be achieved by choosing base curves that are flatter than traditional designs of the past. It is possible to choose a front curve that is significantly flatter and still maintain the same on-axis power of the lens. With the proper selection of a flattened rear curve, a lens of identical back vertex axial power can be made. *The flatter the lens, the thinner the resulting centre or edge thickness of that lens.* The properties of such lenses, as the eye rotates away from optical centre (to a point off-axis), become vastly different.

As the eye rotates away from the optical axis of this flattened spherical surface lens, off-axis errors are introduced; these errors are likely to be significantly worse than the steeper 'best form' sphere design. Lens flattening can provide more dramatic thickness and bulge (protrusion from the frame) reductions for plus lenses than for like minus powered examples, since their front curves are steeper to begin with.

It is serendipitous that aspheric surface geometries (if properly chosen by the designer) are beneficial in that they simultaneously:

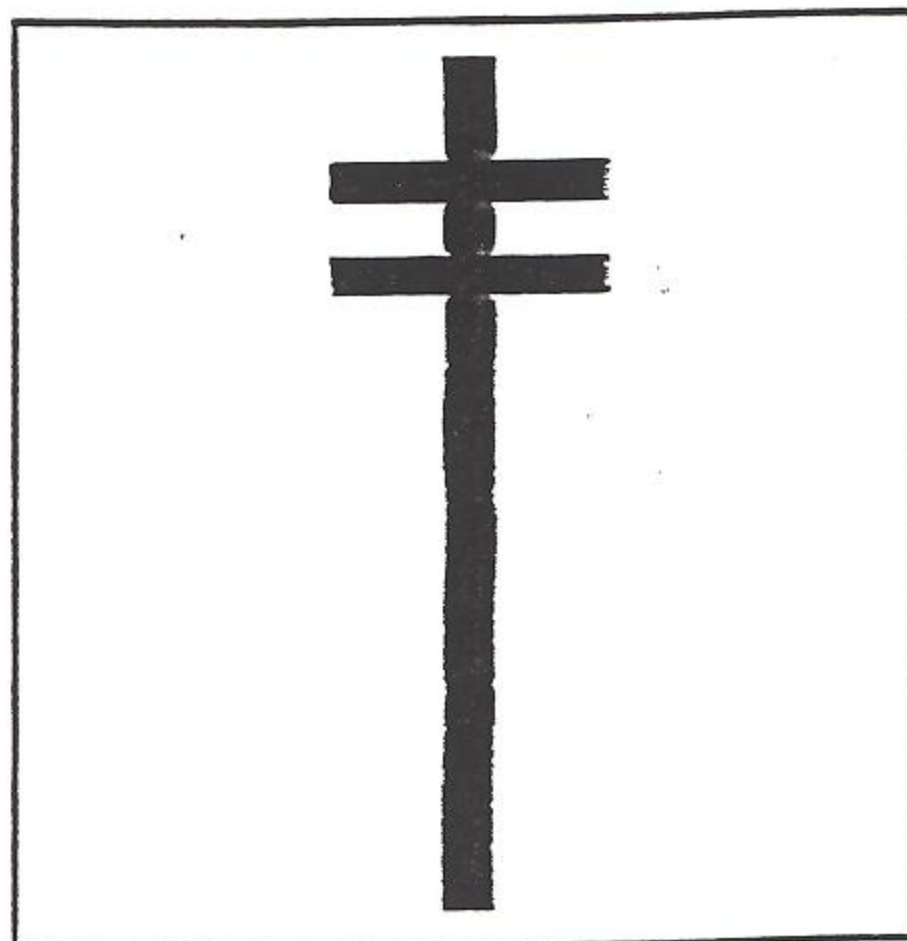
- aid in the reduction of off-axis optical errors resulting from the flatter base curve choice.

- provide increased thickness reductions as compared with designs using spherical surfaces.

Off-axis ophthalmic lens errors

To understand the nature of errors that result when the eye rotates away from the optical centre of a lens, it is helpful to visualise what happens to the image of a telephone pole when viewed in such a manner. Imagine that you are wearing single vision lenses. When looking through the optical centre of the lens, the pole and its crossarms appear in perfect focus. Instead of turning your head to look directly at that image, you chose to rotate your eye laterally off-axis to view the same telephone pole.

Tangential power error



Tangential blur for the horizontally rotated eye

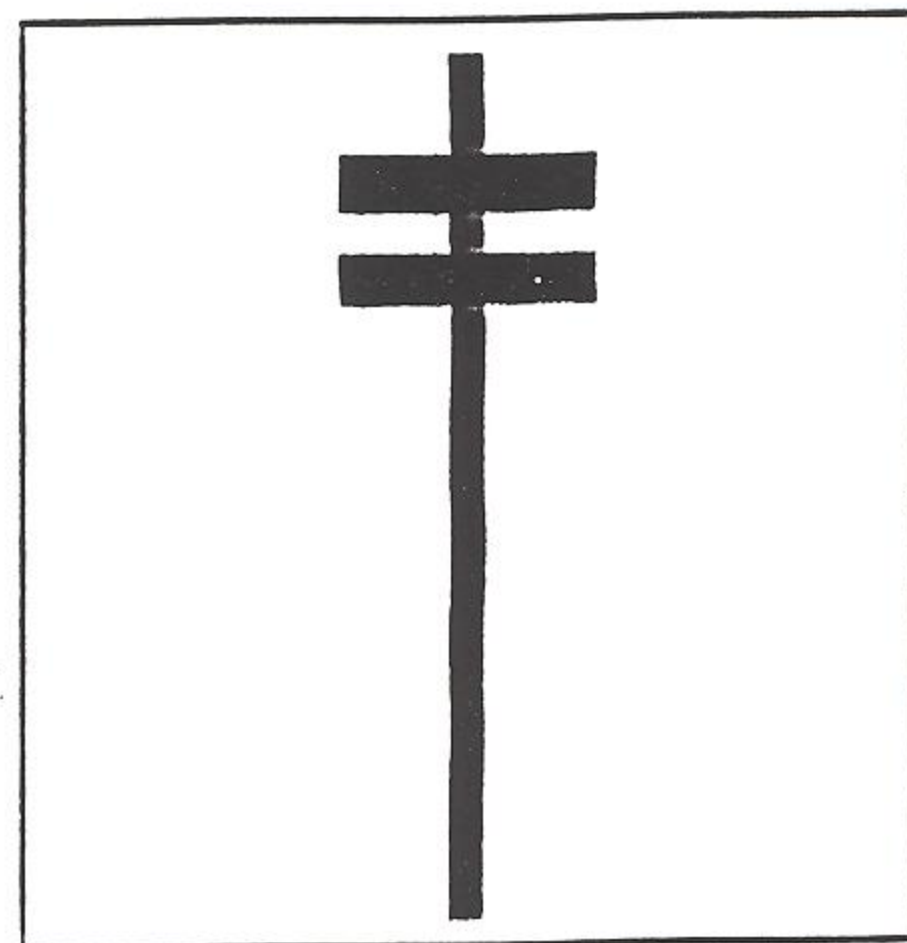
Fig. 2a

Sagittal power error

Viewing the same pole when the eye is rotated laterally, sagittal power error is present if the image of the crossarms of the pole is degraded (Fig 2b). The illustration showing the blurred crossarms demonstrates how sagittal power error affects the image. In this case, the pole is in focus and tangential power error is not evident.

Astigmatic power error

If the telephone pole and its crossarms are not simultaneously in focus, sagittal and/or tangential power errors may exist. The difference between them is the astigmatic power error. As the eye rotates off-axis, differences between



Sagittal blur for the horizontally rotated eye

Fig. 2b

power errors result; as such, astigmatic power error is present.

Mean oblique power error

It is possible that an off-axis image of our telephone pole may be equally out of focus for both the crossarms and vertical pole when viewed off-axis. In such a case, there is no astigmatic power error. Rather, the tangential and sagittal power errors are equal but not zero. The arithmetic mean of the tangential and sagittal power errors is defined as the mean oblique power error; it is present for this situation where the entire image is equally out of focus (zero astigmatic error).

Lateral chromatic aberration

Another important off-axis error which affects visual acuity is lateral chromatic aberration. The presence of such an error results in a degradation of the same image that is degraded with the presence of tangential power error. If significant enough, the wearer may be aware of a rainbow effect resulting from the lateral chromatic error. This error is a function of two variables:

Lateral Colour = Prism/Abbé Value

As the eye rotates away from optical centre, prism is introduced for a given viewing angle. As the viewing angle increases, so does the resulting off-axis prism. Since the Abbé value of a lens material inversely contributes to the lateral colour error, it is desirable to select a material with as large an Abbé as possible. For conventional plastic ($n=1.498$) the Abbé value is 58, whereas higher index 1.6 plastics have typical values in the low to mid 30s.

Attached is a comparative graph of the lateral colour error for a +3.00 and -3.00 lens (Fig 3). This graph depicts what would happen to the lateral colour error for a lens index of 1.60 if it were possible to vary the Abbé value between 30 and 58. The horizontal line at 0.125 diopters lateral colour, depicts the level above which the presence of such an error might be detected by the wearer. In the case where the Abbé is in the 30s, the errors for both the plus and minus lenses are above the detectable threshold. As the Abbé value increases, the colour error decreases quickly (in a non-linear manner). For identical off-axis

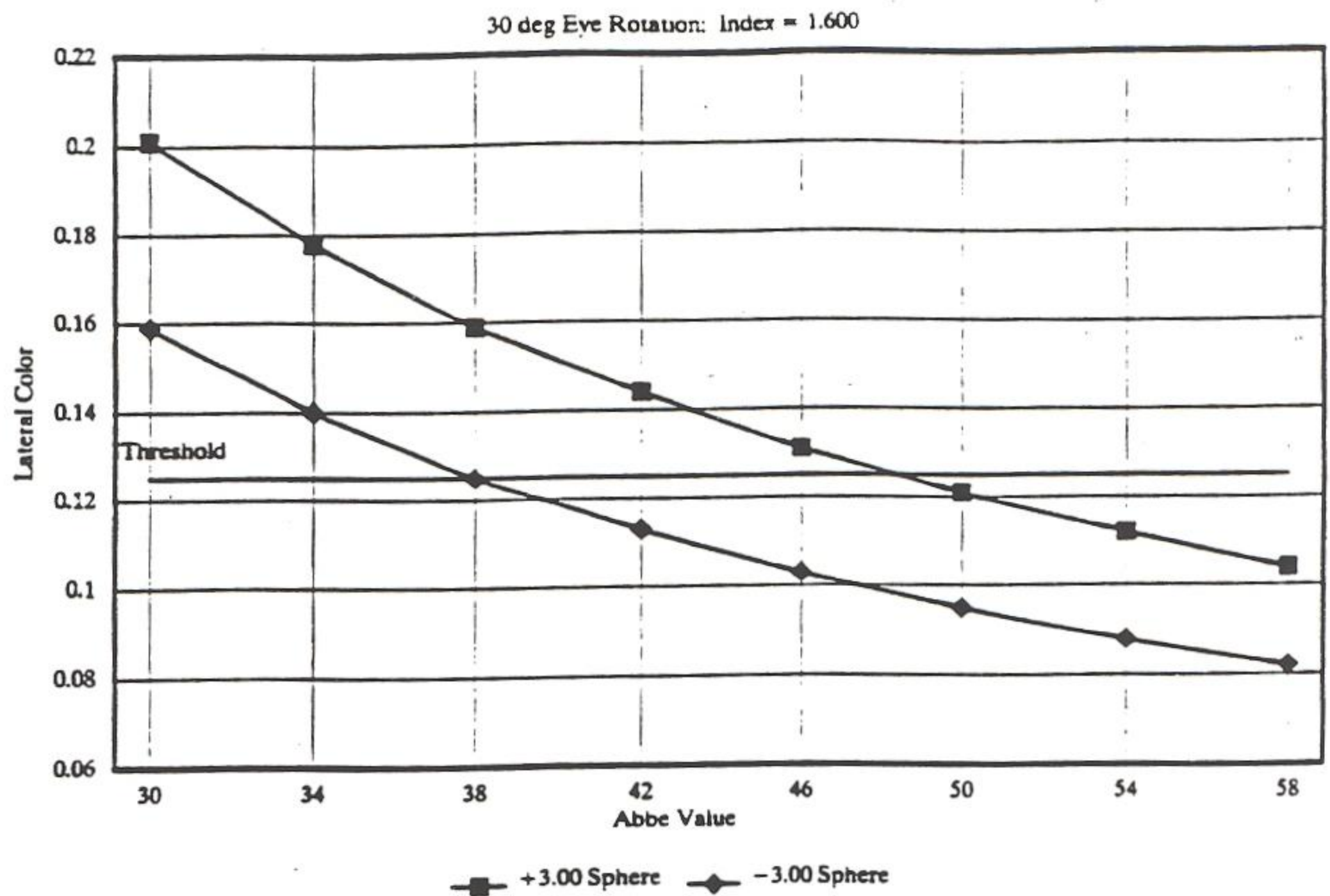


Fig. 3: Comparison of lateral colour for +3.00 and -3.00 spheres

angles of view, a plus lens has greater lateral colour error than a similar powered minus lens of the same material; this is because the amount of prism (when viewing off-axis) is greater for the plus lens case.

Distortion

The previous errors discussed are acuity related - that is, they have an effect on the sharpness of the image through the lens. Distortion affects the shape of the image, not its clarity. While numerical values can be assigned to these errors as well, the validity of comparing errors is obscured by the ability that the brain has in dealing with distortion. The brain can mask a stationary distorted image quite effectively, as long as the distortion is smoothly changing and is not abrupt in nature.

As a general rule, a flattened spherical surface design increases the amount of distortion through the lens. Introducing typical aspheric curvatures on this flattened design helps to decrease this distortion, but does not improve upon the steeper spherical case.

In judging how much distortion is present for the wearer, the 'magnifier' demonstration is commonly used to promote the optical advantages of a particular aspheric design. Such a demonstration shows a grid pattern as seen in transmission, where the lens is held near the grid and used as a magnifier. While impressive to the consumer,

such a test has no validity in demonstrating the actual as-worn optical performance of an ophthalmic lens. Flattened base curves result in improved magnifiers (whether or not they have been aspherised). A bi-convex magnifier will perform well as a magnifier, but provides terrible off-axis optical performance should it be worn as an ophthalmic lens.

Considerations in plus aspheric ophthalmic lens design

Most have come to accept (although perhaps not fully understand the reasoning behind) the fact that aspheric surfaces permit the designer to select non-traditional base curves for plus lenses. For aspheric ophthalmic lens designs, base curves that are significantly flatter than traditional spherical surface designs are typically chosen. In aspheric lens design, surface curvatures are often flattened several diopters.

A primary reason for using an aspheric surface is to restore the off-axis optical performance (worsened from flattening) to that of the steeper spherical surface design. Unless aspheric surfaces are employed to counteract the errors introduced by the flatter base curve choice, significant and

bothersome off-axis errors are the result. Some aspheric surfaces used also further reduce the lens thickness of the flattened sphere.

Figures 4a and 4b are bar charts of the off-axis power errors which result for an aspheric and flattened spherical surface of like base curves. The bars represent tangential power errors (Fig 4a) and astigmatism (Fig 4b) for eye rotation angles between 0 and 40 deg. The aspheric example shown is American Optical Corporation's Aspherlite design (diagonal striped bar). The bars labelled flat sphere represent the errors which would have resulted had the lens been flattened to the Aspherlite base curve without employing any aspherisation.

If optical performance is not considered, flatter and thinner lenses could be fabricated by selecting flatter spherical base curves and ignoring optical performance. Some 'semi-aspheric' designs take this approach, as their central curve is a sphere (with the off-axis errors of a flattened sphere for critical angles of view).

Aspheric designs permit much more dramatic base curve flattening than can result from simply the selection of a higher index material. Identical base curves can be chosen for normal and high index plus lenses with no significant cosmetic differences being detected. High index materials can aid in reducing a plus lens thickness in these cases, but similar front curvatures would render their appearance to be virtually the same.

The only restriction preventing plus lenses of differing indices from utilising the same convex curves would be limitations with regard to the back curve of such a lens. If there is a lower practical limit to the choice of such a rear curve (reflections, eyelash clearance, generator tool curve), a restriction as to the possible degree of flatness is reached for a given material and power.

Summarised below are factors which affect the thickness and bulbous appearance of a plus aspheric ophthalmic lens (for a common diameter and lens power):

- Base curve selection.
- Index of refraction of lens material.
- Nature of the aspheric curve employed.

Minus aspheric ophthalmic lens design considerations

In the case of a minus powered ophthalmic lens, it is the *edge* thickness which becomes desirable to minimise. The same three factors contributing to plus lens centre thicknesses discussed previously,

Fig 4a: + 5D optical comparison
ASPHERLITE vs. Same Base Curve Sphere

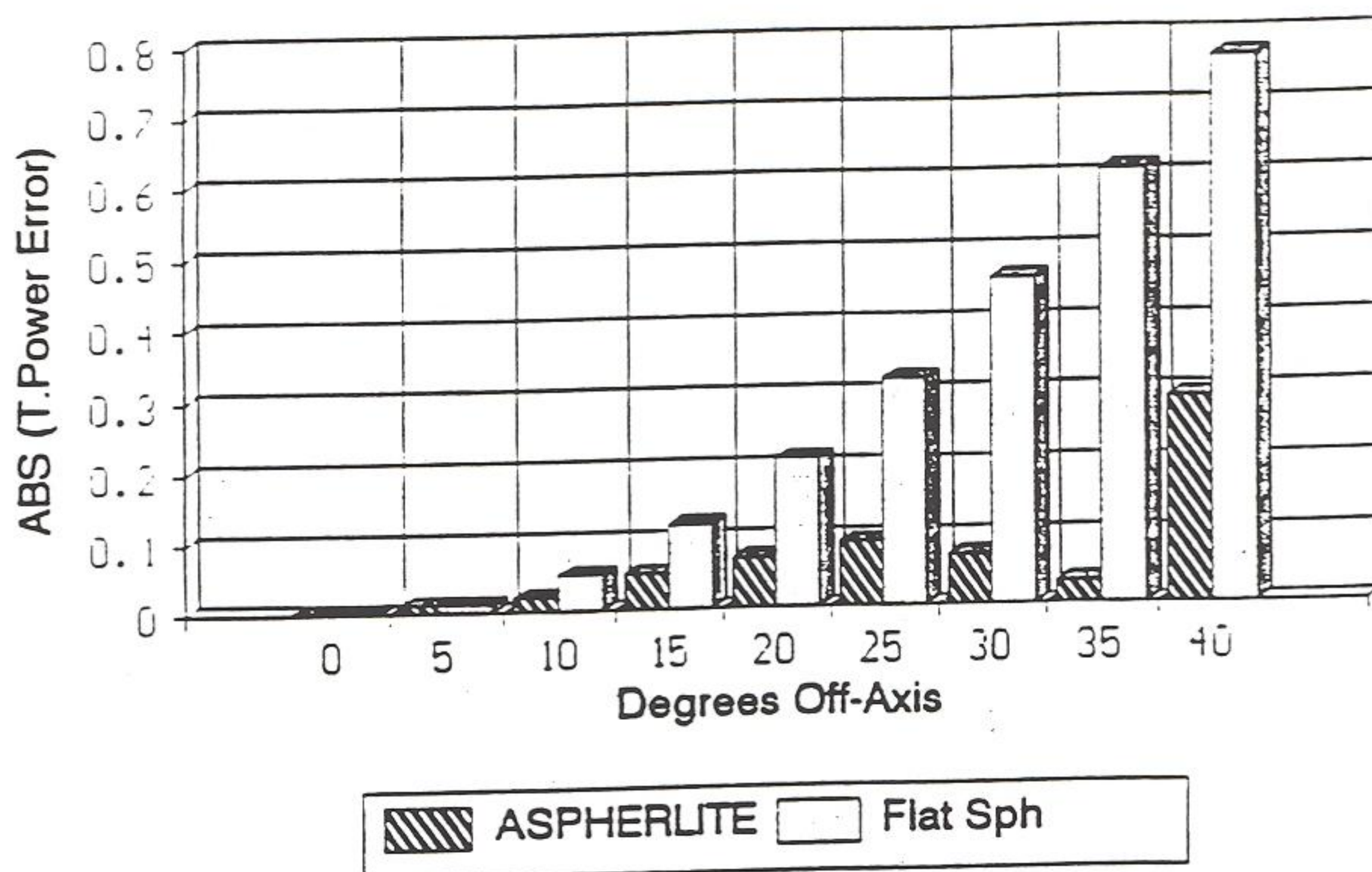
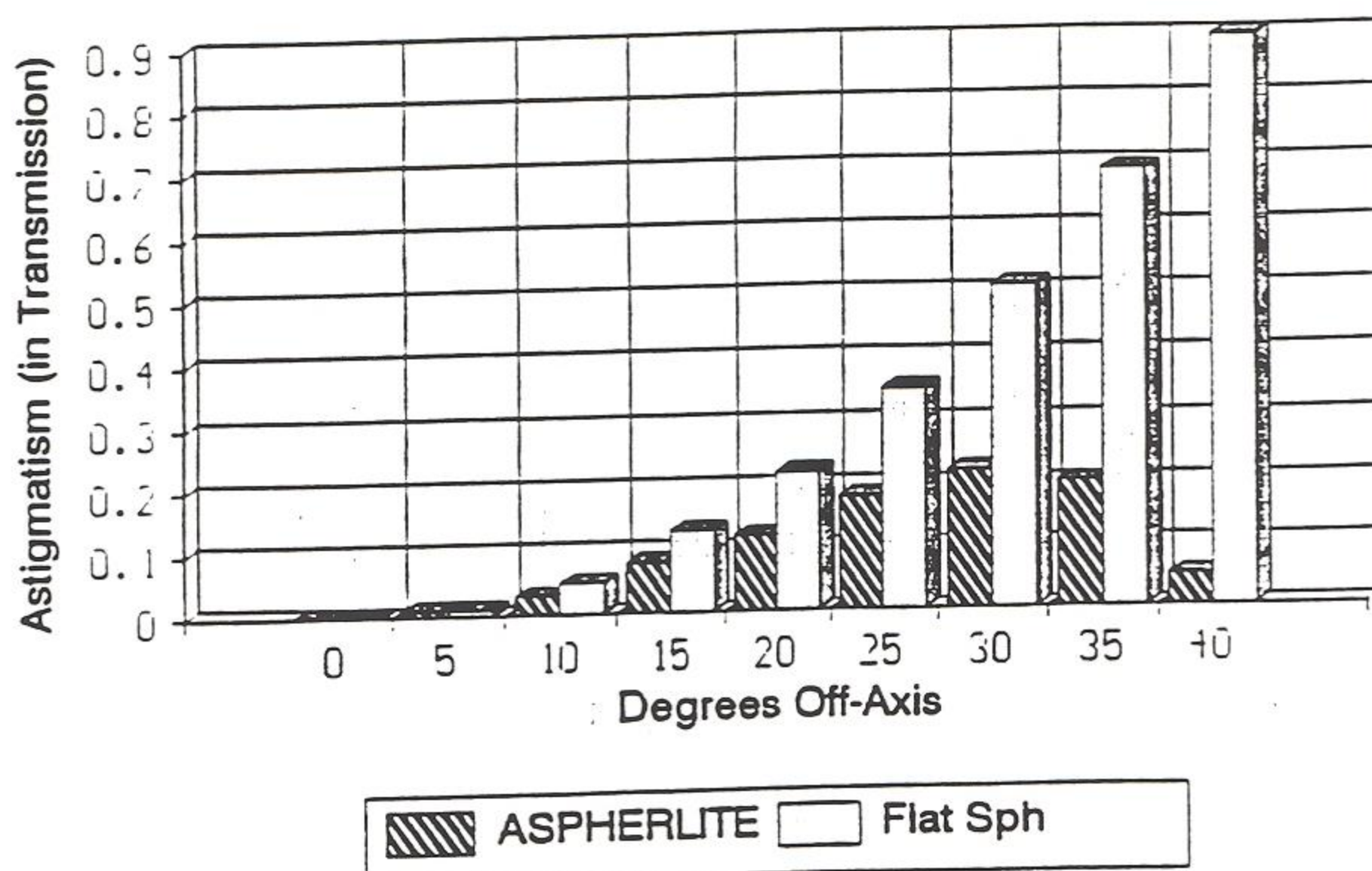


Fig 4b: +5.0D optical comparison
ASPHERLITE vs. Same Base Curve Sphere



also affect the edge thickness reductions achieved for minus aspheric lens designs.

A fourth factor, centre thickness, is typically also varied when comparing spherical surface vs aspheric minus lens

designs. By decreasing the centre thickness of a minus lens, the edge thickness will be reduced by the same amount. For plus lenses, comparative figures are calculated usually with common minimum edge thicknesses. For minus lens comparisons, however, common centre thicknesses may not always be used, thus adding a further variable when comparing lens designs.

Coatings and process variations have an effect on a materials impact strength

In the United States, manufacturers must demonstrate that product complies with the FDA impact regulation. In order to assure compliance with this regulation, it is generally recommended that conventional plastic ($n=1.498$) not be surfaced or cast to a centre thickness of less than 2.0mm. Coatings and process variations have an effect on a material's impact strength; such a thickness choice supplies an adequate margin of safety in recognition of this fact. With new higher index materials, thicknesses below 2.0mm often are recommended.

While less obvious to many, the selection of flattened base curves from steeper spherical surface designs aid in the reduction of the edge thickness of a minus lens. By combining this flatter base curve with an aspheric surface, beneficial results can be achieved.

Figure 5 shows three different cross sectional scale drawings of a -4.50 diopter lens. The lens on the left is that of a non-aspheric ADC ($n=1.498$) design. For a 70mm diameter and a centre thickness of 2.2mm, the resulting edge thickness for the curves shown is 8.8mm. The lens shown on the right is to American Optical Corporation's Aspherlite design ($n=1.498$) of the same power. The edge thickness has been reduced from 8.8mm to 7.9mm without varying either the material index or centre thickness. If one were to produce the same edge thickness reduction by varying only the material index of the lens, a refractive index of 1.567 would be required!

Selecting spherical base curves that depart significantly from the best form sphere design results in significant degradation of off-axis optical performance unless aspheric surfaces are employed. This is as true for minus lenses as it is for the plus lenses.

Off-axis tangential power errors (Fig 6a) and astigmatism (Fig 6b) are shown for aspheric and flattened sphere designs of like central curvatures. Again, the improvement in reducing the degree of off axis astigmatism in the aspheric design is apparent.

Fig 5

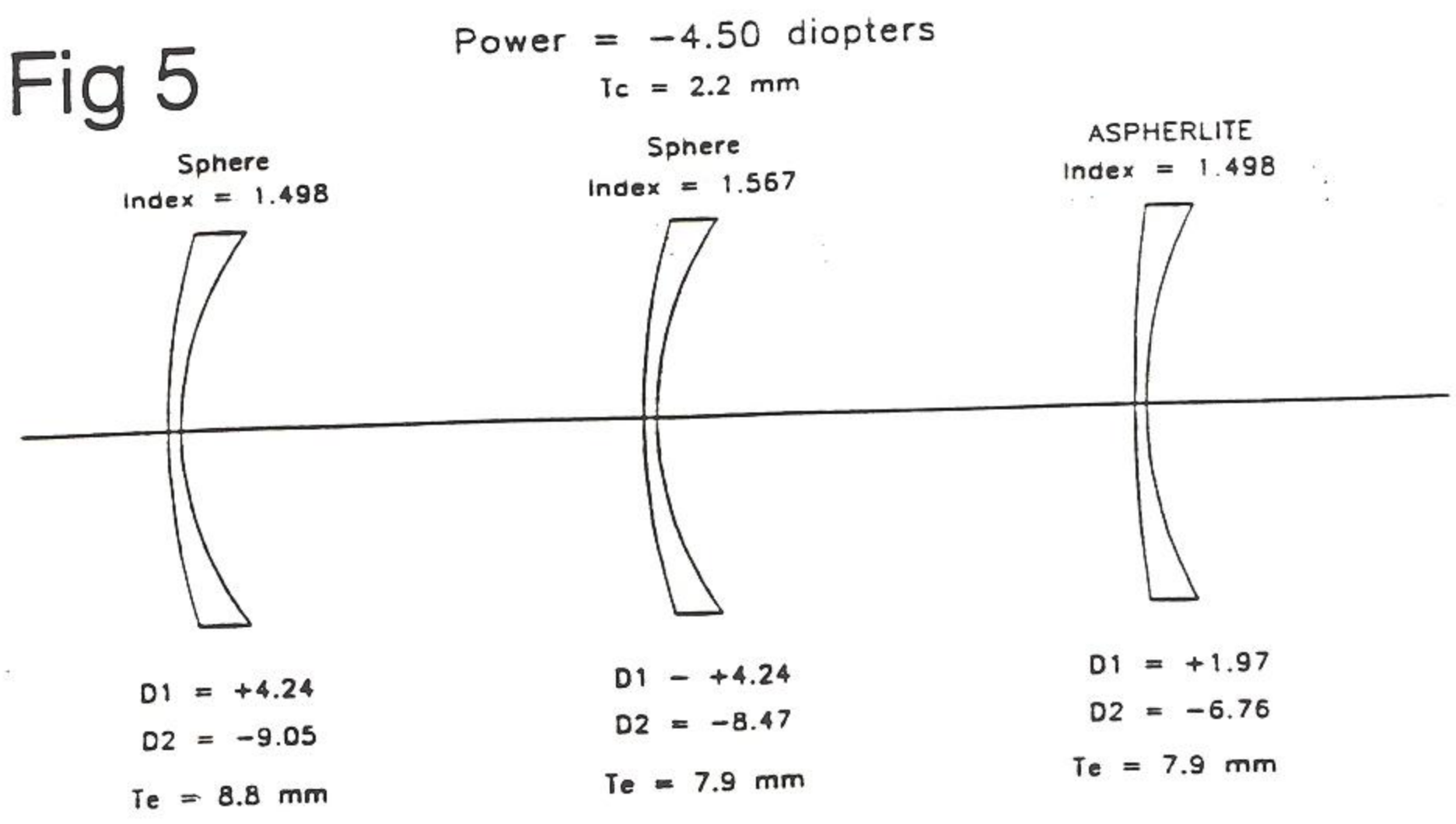


Fig 6a: -5.0D optical comparison ASPHERLITE vs. Same Base Curve Sphere

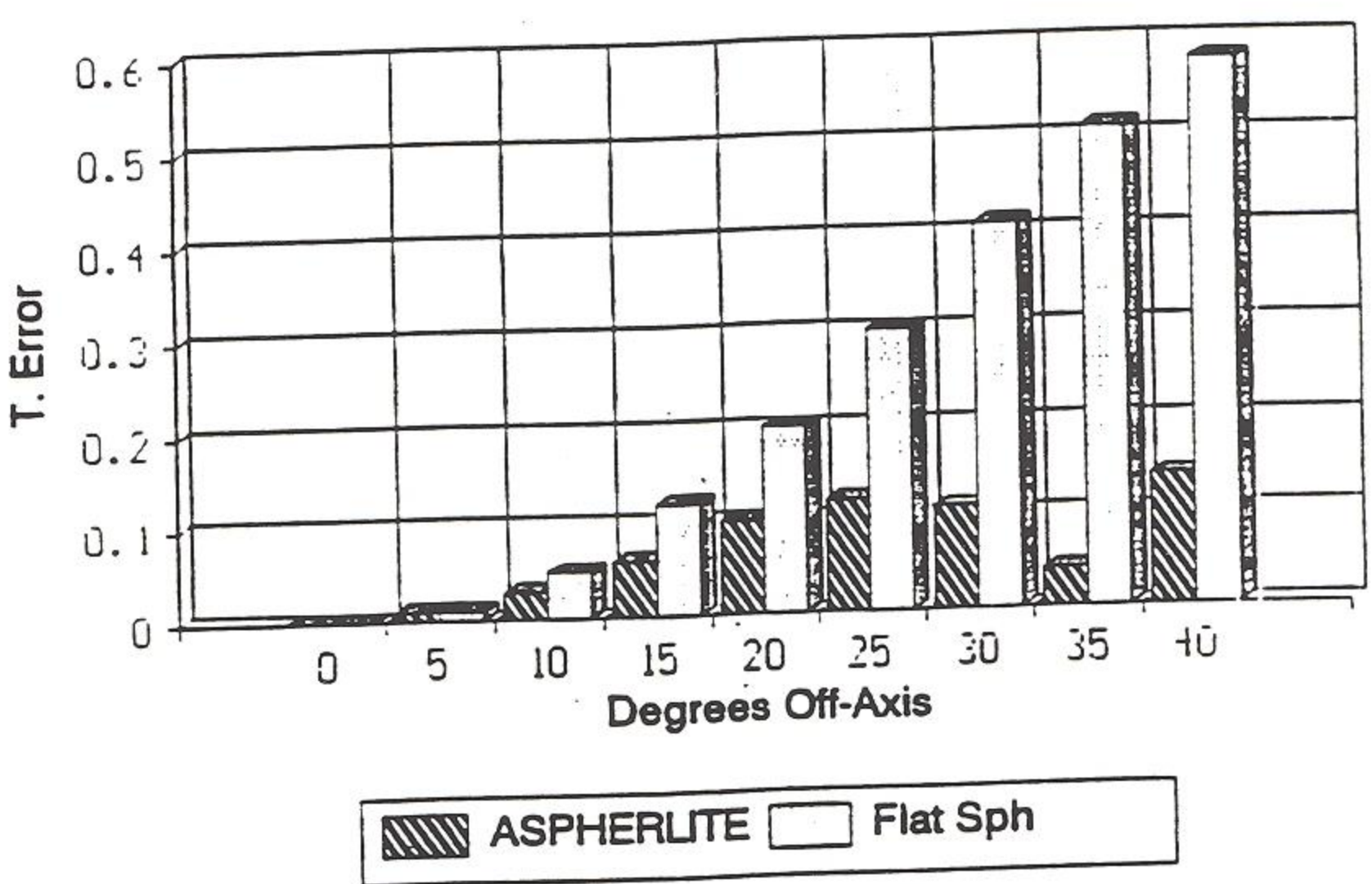


Fig 6b: -5.0D optical comparison ASPHERLITE vs. Same Base Curve Sphere

