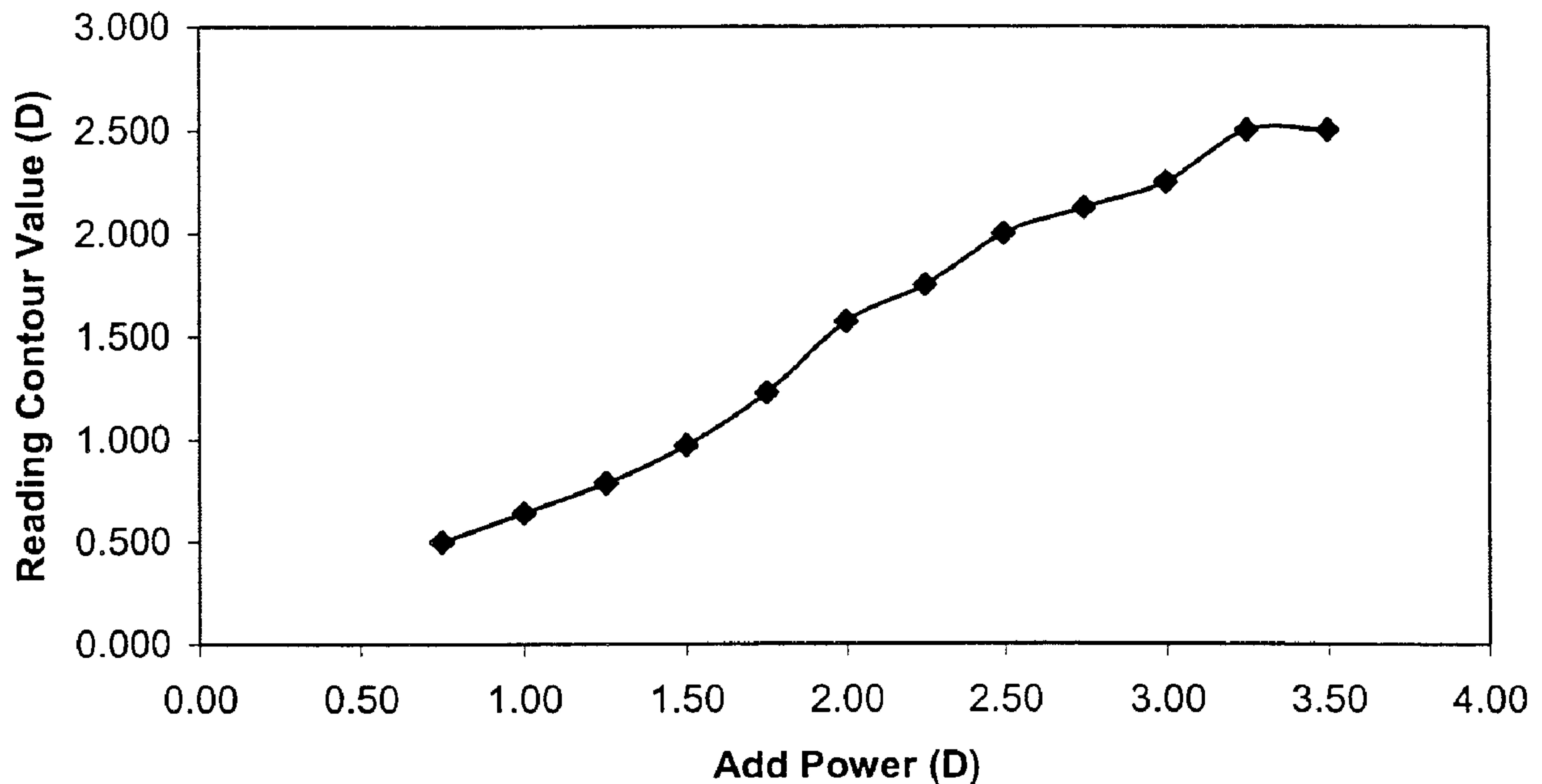




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A progressive ophthalmic lens element including a lens surface having an upper viewing zone having a surface power corresponding to distance vision, a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone, the corridor and lower viewing zone exhibiting a power progression profile having at least two segments the slopes of which related at least in part to the prescribed addition power and/or the depth of focus of the wearer.



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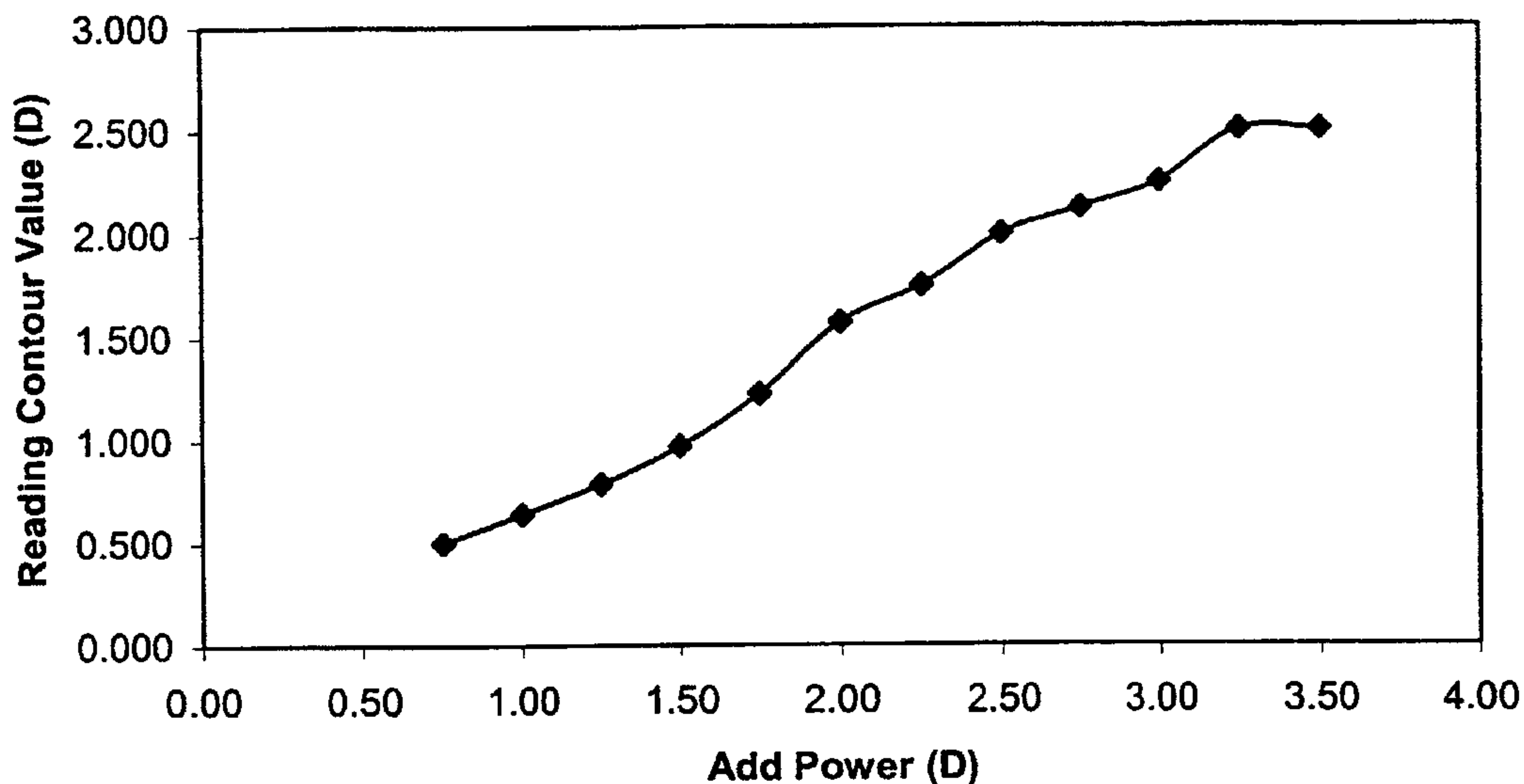
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(54) Title: PROGRESSIVE LENS



(57) Abstract: A progressive ophthalmic lens element including a lens surface having an upper viewing zone having a surface power corresponding to distance vision, a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone, the corridor and lower viewing zone exhibiting a power progression profile having at least two segments the slopes of which related at least in part to the prescribed addition power and/or the depth of focus of the wearer.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## PROGRESSIVE LENS

The present invention relates to a progressive ophthalmic lens and in particular to a progressive ophthalmic lens exhibiting reduced sensitivity to fitting errors, improved functionality and ease of adaptation, designed to more closely  
5 follow the natural eye movements of the wearer and taking into account wearer sensitivity to blur, and to a process for producing such lenses.

Numerous progressive lenses are known in the prior art. Progressive lenses have heretofore been designed on the basis that they have distance, near and intermediate viewing zones. The intermediate zone joins the near and  
10 distance zones in a cosmetically acceptable way, in the sense that no discontinuities in the lens should be visible to people observing the lens of the wearer. The design of the intermediate zone is based on a line called the "eye path" along which the optical power of the lens increases more or less uniformly.

Prior art progressive lenses do not address the depth of field factor, which  
15 defines wearer sensitivity to blur. They also did not attempt to tailor the blur gradients to wearer preferences.

A further disadvantage of prior art progressive lenses is that they are difficult to fit. Such lenses must be fitted to a carefully measured pupillary height relative to the lower frame edge, and to a carefully measured pupillary distance  
20 relative to the nasal frame edge. Errors of as little as 1 or 2 mm in either measurement can cause significant reduction in lens utility.

It would be a significant advance in the art if a progressive ophthalmic lens could be designed with reduced sensitivity to horizontal fitting errors (such as errors in pupillary distance measurement of the wearer) and vertical fitting height  
25 errors ascribed to frame and face conformation measurement errors. This would make such lenses more similar in ease of fitting to single vision reading lenses.

It would be a further significant advance in the art if the progressive lens could more closely relate to the requirements of the individual wearer and to the

natural eye movements of a wearer in performing distance, intermediate and near tasks.

Accordingly, it is an object of the present invention to overcome, or at least alleviate, one or more of the difficulties and deficiencies related to the prior art.

5 These and other objects and features of the present invention will be clear from the following disclosure.

Accordingly, in a first aspect of the present invention, there is provided a progressive ophthalmic lens element including a lens surface having

10 an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

15 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

20 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments the slopes of which being related at least in part to the prescribed addition power and/or the depth of focus of the wearer.

It will be understood that the present invention permits the progressive lens design to be tailored to improve functionality and/or ease of adaptation, depending on the wearer's prescription.

25 It will be understood that the ophthalmic lens element according to the present invention may form one of a series of lens elements. The lens element series may be of the type described in International patent application PCT/EP97/00105, to applicants, the entire disclosure of which is incorporated herein by reference.

The present invention accordingly relates to a progressive ophthalmic lens series exhibiting improved functionality and ease of adaptation, as it takes into account factors including one or more of the following: wearers' sensitivity to blur, natural eye movements, preferences for the blur gradients across the boundaries  
5 of the peripheral zones. These factors may be dependent on the wearer's prescription.

Accordingly, in a further aspect of the present invention, there is provided a series of progressive ophthalmic lens elements, each lens element including a lens surface having

10 an upper viewing zone having a surface power to achieve a refracting power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

15 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including a corridor of relatively low surface astigmatism;

the progressive ophthalmic lens series including

20 a first set of lens elements having at least one base curve suitable for use in providing a range of distance prescriptions for myopes, emmetropes or hyperopes, each lens element within a set differing in prescribed addition power and including a progressive design, the corridor and lower viewing zone exhibiting a power progression profile having at least two segments the slopes of which are related to the prescribed addition power and/or depth of focus of the wearer;

each lens element within a set

25 having an addition power of from approximately 0.75 D to 1.50 D, exhibiting a relatively shallow power progression in the first segment and a relatively steep power progression in the second segment; and

30 having an addition power of from approximately 1.75 D to 3.00 D, exhibiting a relatively steep power progression in the first segment and a relatively shallow power progression in the second segment.

The ophthalmic lens element, at low addition powers, for example from

approximately 0.75 D to 1.50 D, where accommodation reserve is relatively high, may exhibit a relatively shallow power progression within the upper part of the corridor; and a relatively steep power progression from the lower part of the corridor to the near measurement point (NMP). This makes a functionally better  
5 progressive lens for those wearers that do not have much need for addition power when viewing objects at intermediate distances. They have sufficient amount of accommodation to be able to view most objects at intermediate distances through the distance zone of the lens.

The ophthalmic lens element, at high addition powers, for example from  
10 approximately 1.75 D to 3.00 D, may exhibit a relatively steep power progression within the upper part of the corridor; and a relatively shallow power progression from the lower part of the corridor to the near vision measurement point.

It will be understood that the provision of, for example, a relatively steep power progression within the upper part corridor of the ophthalmic lens element  
15 provides an increased level of freedom in lens design within the lower or near viewing zone, thus permitting an improvement in optical quality within the zone. This is very important for high add wearers that are likely to lead a more sedentary lifestyle and have high demands on the near vision performance of their spectacles.

20 It will be further understood that the ophthalmic lens element according to this aspect of the present invention exhibits a power progression profile which is divided into at least two segments. The slopes of the segments are related to the addition power, accommodation reserve, and the depth of focus of the wearer.

The two segments may exhibit a length ratio, for example, of approximately  
25 2:1): fitting cross (FC) to the "highest reading point" (HRP) and the tail between the HRP and the full addition power at the near vision measurement point (NMP).

The first segment may be characterised by a steep rise of power making the effective length of the corridor very short, for example approximately 11 mm, for addition powers up to approximately 2.50 D and increasing slightly with

increased addition power thereabove, while in the second segment the profile of the power progression is considerably shallower. For example the effective corridor length increases up to approximately 13 mm for addition powers above 3.0 D.

5 By the term "corridor", we mean an area of the intermediate zone of varying power bounded by nasal and temporal contours of tolerable aberration for foveal vision.

By the term "highest reading point" we mean the highest point along the eye path where the wearer can read normal size text at the 40 cm reading  
10 distance without perceiving the blur. This is equal to the nominal prescribed add minus the effective depth of focus for near vision which is around 0.50 D for a broad range of addition powers.

The corridor has a "corridor length" (L), which corresponds to the length of the segment of the visual fixation locus which extends from the vertical height of  
15 the fitting cross (FC) to the vertical height of the near vision measurement point. For example, in a typical lens element according to the present invention, the power progression begins at the fitting cross (FC) height.

By the term "effective corridor length" as used herein we mean the length from the "fitting cross" (FC) to the highest reading point (HRP) on the lens surface.

20 By the term "lens element", we mean all forms of individual refractive optical bodies employed in the ophthalmic arts, including, but not limited to, lenses, lens wafers and semi-finished lens blanks requiring further finishing to a particular patient's prescription. Also included are formers used in the manufacture of progressive glass lenses and moulds for the casting of progressive lenses in  
25 polymeric material such as the material sold under the trade designation CR39.

By the term "astigmatism or surface astigmatism", we mean a measure of the degree to which the curvature of the lens varies among intersecting planes which are normal to the surface of the lens at a point on the surface.



The distribution of surface astigmatism and/or surface power may be varied proximate the peripheries of the upper (distance) and/or lower (near) viewing zones.

5 In a preferred form, the lens element may exhibit a modified distribution of peripheral astigmatism. The distribution of peripheral astigmatism may for example exhibit a shift away from the distance-peripheral boundary.

Preferably the distribution of surface astigmatism and/or ray traced RMS power error exhibits a relatively low gradient proximate the distance periphery and a relatively high gradient proximate the near periphery.

10 This modification may, for example, both reduce sensitivity to horizontal fitting errors and make the lens easier to adapt to, as the transition between the distance and intermediate peripheral zone is less perceptible. It may also permit a greater smoothing of the prism gradients over large areas of the peripheral zones lessening the uncomfortable swimming sensation that can be induced by a  
15 progressive lens.

Such a modification may provide the lower (near) viewing zone with relatively high blur gradients. Whilst this might appear to be disadvantageous, it may occur at a position on the lens surface which is close to the lower periphery of the lens that is rarely used by the wearer. So, this is an acceptable trade-off in  
20 designing a more functional progressive lens.

This modification in peripheral blur distribution can be quantified by examining the ratio of the maximum rate of change of the ray traced RMS power error along vertical lines horizontally offset from the Fitting Cross (FC) a specified distance, for example equal to 15 mm on the lens surface, to the maximum  
25 horizontal rate of change of the RMS power error at the level of the near vision measurement point (NMP). In a preferred form, this ratio may be less than approximately 0.60 and may preferably vary from approximately 0.40 to 0.60.

In a preferred aspect of the present invention, the location of the corridor of

the ophthalmic lens element may be dictated at least in part by the visual fixation locus;

the visual fixation locus being inset generally horizontally nasally below the fitting cross (FC) of the lens element.

5 The degree of inset may vary along the eyepath profile relative to up to three reference points therealong. The first one is the 0.5 D local addition power (LAP) point, which represents the depth of focus limited distance vision point. The degree of the horizontal 0.5 D LAP inset may decrease with increasing addition power.

10 By the term "Local Addition Power" as used herein we mean the surface power offset at a specific point along the eye path line with reference to the power at the distance measurement point.

The second reference point along the eye path is the "highest reading point" (HRP). The second reference point may exhibit a generally constant inset  
15 corresponding to the reading distance of approximately 40 cm.

The third reference point is the "near measurement point" (NMP). The third reference point may exhibit a constant 2 mm inset for addition powers up to 2.50 D and then may increase gradually with increases in addition power, e.g. up to 2.8 mm for the 3.50 D addition power. The increased horizontal inset at high  
20 addition powers is due to the shortened reading distance for the high add wearers, thus allowing such wearers to benefit from an increased magnification of the image.

By the term "visual fixation locus", as used herein, we mean the set of points which are the intersection of the lens surface and the patient's line of sight  
25 as he or she fixates on objects in the median plane. The term does not signify a required, continuous eye movement path. Rather, the visual fixation locus indicates the set of points corresponding to variously positioned objects in the median plane. As will be explained in detail below, the visual fixation locus takes into account the fact that the wearer may or may not use the accommodative

reserve for a particular fixation. As a result, points at different locations in the visual fixation locus are provided having a power sufficient for comfortable use at the appropriate object distances.

The progressive ophthalmic lens element, in a preferred form, may exhibit a  
5 multi-segmented power progression profile.

Accordingly, in a preferred aspect of the present invention, there is provided a progressive ophthalmic lens element including a lens surface having  
an upper viewing zone having a surface power corresponding to distance vision,  
10 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and  
an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including  
15 a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone;  
the corridor and lower viewing zone exhibiting a multi-segmented power progression profile.

20 By the term "multi-segmented power progression profile", we mean that the profile exhibits three or more distinct segments.

Applicants have found that by fixing the position of the highest reading point to that corresponding to the wearer's natural eye rotation for reading, the ophthalmic lens element provides improved comfort to the wearer and thus  
25 achieves greater acceptance by the wearer.

The power progression may include a first segment from the fitting cross (FC) to the 0.5 D LAP point.

The fitting cross (FC) is generally located at  $(0, y_{FC})$  with the local addition

power (LAP) of 0.0 +0.125 D, -0.125 D. The value of  $y_{FC}$  may vary, for example, from approximately 2 mm to 6 mm above the geometric centre of the lens element.

0.50 D LAP point of the eye path may exhibit an inset which is a function of the addition power ranging for example from 2.0 mm for 1.00 D addition (and lower) to 0.5 mm for 2.5 D additions and higher.

The power progression may include a second segment from the 0.5 D LAP to the highest reading point (HRP), located at (2,  $y_{FC}-11$ ) for adds up to 2.50 D, sliding down to (2,  $y_{FC}-13$ ) for the 3.00 D add and staying constant for the higher addition values.

The power progression profile may include a third segment from the HRP to the near measurement point (NMP), located at approximately (x,  $y_{FC}-16$ ). The slope of the power progression within the third segment varies from steeper than in the second segment for low addition powers through generally equal to that within the second segment at mid addition powers to relatively shallower at higher addition powers.

The power progression may include a fourth segment from the NMP to the Maximum Addition Power (MAP) point, at approximately (x,  $y_{FC}-18.5$ ). The MAP point has an addition power approximately 0.125 D above the nominal addition power of the lower (near) viewing zone, for lenses having adds up to a 2.50 D.

By the term "Maximum Add Power" (MAP) as used herein we mean the nominal addition power plus 0.125 D.

The MAP should be located at  $y \approx y_{FC}-18.5$ , with a nominal x coordinate of 2 mm for addition powers less than or equal to 2.50 D, and at an inset determined by the reciprocal of the addition power for addition powers higher than 2.50 D. A preferred implementation is to adjust the x coordinate to be equal to the point at which the chief ray from the near object point intersects the lens surface.

The eyepath below the MAP may generally be vertical.

In a still further preferred form, the value of the Reading Contour for low to medium addition powers,  $P_r$  may in turn vary with addition power.

By the term "Reading Contour" as used herein, we mean the contour of the mean local addition power equal to the nominal addition power less 0.50 (minimum value 0.50 D) for adds up to 2.00 D. The contour should preferably be symmetric about the vertical meridian passing through the HRP. For higher additions the value of the Reading Contour varies such that the difference between the power at the NMP and the HRP gradually increases from 0.5 D for a 2.25 D addition power up to 1.00 D for the 3.50 D addition power.

In a preferred form the relationship between the Reading Contour, defined as the mean addition power at the highest reading point (HRP) and the nominal addition power,  $A$ , may be given by the following formula:

$$P_r = A - \alpha (2.5 - A)$$

15 where  $\alpha = \exp\left[-\frac{(A - 2.5)^2}{1.575}\right]$

Add Power	Alpha	Reading Power
0.75	0.143	0.500
1.00	0.240	0.641
1.25	0.371	0.786
1.50	0.530	0.970
1.75	0.700	1.225
2.00	0.853	1.573

The relationships between the Reading Contour Value and addition power and Alpha and addition power are illustrated in Figures 1 and 2 below.

The relationship applies up to addition powers of approximately 2.00 D, above which the variation of  $P_r$  is as described earlier in this section.

In a preferred form, the progressive ophthalmic lens element, exhibiting a multi-segmented power progression profile, may again form part of a lens element series as described above.

Accordingly, in a preferred aspect, there is provided a series of progressive  
5 ophthalmic lens elements, each lens element including a lens surface having  
an upper viewing zone having a surface power to achieve a refracting  
power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper  
viewing zone to achieve a refracting power corresponding to near vision; and  
10 an intermediate zone extending across the lens element having a surface  
power varying from that of the upper viewing zone to that of the lower viewing  
zone and including a corridor of relatively low surface astigmatism;

the progressive ophthalmic lens series including  
a first set of lens elements having at least one base curve suitable for use  
15 in providing a range of distance prescriptions for myopes, emmetropes or  
hyperopes, each lens element within a set differing in prescribed addition power  
and including a progressive design,

the corridor and lower viewing zone exhibiting a multi-segmented power  
progression profile;

20 wherein the power progression of each lens element within a set includes a  
first segment from the fitting cross (FC) to the 0.5 D Local Addition Power (LAP)  
point;

the fitting cross (FC) being located at  $(0, y_{FC})$  wherein the value of  $y_{FC}$   
varies from approximately 2 mm to 6 mm above the geometric centre of the lens  
25 element; and

the 0.5 D LAP point exhibiting an inset which is a function of the addition  
power ranging from approximately 2.0 mm for addition powers of 1.00 D and  
below, to approximately 0.5 mm for addition powers of approximately 2.50 D and  
above;

30 a second segment from the 0.50 D LAP point to the HRP;

the position of the HRP being located at  $(2, y_{FC} - 11)$  for addition powers up  
to 2.50 D and ranging to  $(2, y_{FC} - 13)$  for addition powers of approximately 3.00 D

and above;

a third segment from the HRP to near vision measurement point (NMP), located at approximately  $(x, y_{FC} - 16)$ ;

wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D;

the slope of the power progression within the third segment varying from steeper than in the second segment for low addition power through generally equal to that within the second segment at medium addition powers, to relatively shallow at high addition powers.

Preferably, the power progression includes a fourth segment from the NMP to the maximum addition power (MAP) point, at approximately  $(x, y_{FC} - 18.5)$ ;

wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D.

More preferably, the value of the Reading Contour  $P_r$ , varies with addition power as described above.

The optical lens element according to the present invention may further include a relatively wide upper viewing zone with relatively low surface astigmatism. At high addition powers the upper viewing zone may exhibit slightly increased surface astigmatism.

In a preferred aspect of the present invention, the optical lens element may be designed to at least partially compensate for optical aberrations, generated, for example, by pantoscopic tilt in the as worn position and/or offset or wrap to suit the styling of the frame.

Accordingly, in a further preferred aspect of the present invention, there is provided a progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance

vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface  
5 power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression  
profile having at least two segments, the slopes of which are related at least  
10 in part to the prescribed addition power and/or depth of focus of the wearer;  
and

a lens base surface bearing a surface correction(s) to at least partially adjust for an observed optical aberration(s) within the upper viewing zone due to obliquity of incoming rays crossing the lens surface.

15 The progressive ophthalmic lens element according to this aspect may again form part of a lens element series as described above.

The optical aberration may be generated by astigmatism and by power errors. One measure combining these two kinds of errors is the RMS power error. Therefore, an optimisation merit function based on the RMS power error can  
20 effectively minimise both kinds of errors leading to wider viewing zones and an increased acceptance of the lens element by the wearer.

The optical aberration may be introduced by pantoscopic tilt and/or wrap of the lens element in an "as worn" configuration.

In a particular preferred embodiment of the present invention, the optical  
25 lens element may include a surface having a generally aspheric component that is asymmetric in the vertical (Y) and/or horizontal (X) direction.

It will be recognised that the asymmetry in the vertical direction may compensate for off-axis aberrations including aberrations introduced by pantoscopic tilt, in the upper (distance) viewing zone.



Where a lens element surface exhibits asymmetry in both the X and Y directions, off axis aberrations may be improved over substantially the entire surface of the lens element.

The asymmetry in the horizontal direction may compensate for aberrations  
5 introduced by cosmetic or safety wrap of the lens element in the "as worn" configuration.

Accordingly, in a further aspect of the present invention, there is provided  
a progressive ophthalmic lens element including  
a lens base surface having an upper viewing zone having a surface power  
10 corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper  
viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface  
power varying from that of the upper viewing zone to that of the lower viewing  
15 zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression  
profile exhibiting at least two segments, the slopes of which are related at  
least in part to the accommodation reserve and/or the depth of focus of the  
20 wearer; and

a lens base surface bearing a surface correction to at least partially  
adjust for an observed optical aberration(s) within the upper viewing zone  
due to obliquity of the incoming rays;

the lens surface correction being described by a polynomial asymmetric  
25 along the vertical (Y) and/or horizontal (X) meridian; and whose coefficients are  
chosen to minimise a merit function constructed of the sum of a selected optical  
aberration(s) within the upper and/or lower viewing zone.

The optical aberration(s) may include a power error.

The lens surface so formed thus bears an optical correction required to  
30 improve the optical performance within the upper and/or lower viewing zone.

## Optical Aberrations

We may define a number of measures of the lens optical aberrations, such as

$$\begin{aligned}
 \text{mean power error (mpe)} &= \frac{\varepsilon_{11} + \varepsilon_{22}}{2} \\
 \text{astigmatic (cyl) error} &= \left( (\varepsilon_{11} - \varepsilon_{22})^2 + 4\varepsilon_{12}^2 \right)^{1/2} \\
 \text{RMS power error} &= \left( \frac{\varepsilon_{11}^2 + 2\varepsilon_{12}^2 + \varepsilon_{22}^2}{2} \right)^{1/2} \\
 &= \left( (\text{mpe})^2 + \frac{1}{4}(\text{cyl error})^2 \right)^{1/2}
 \end{aligned}$$

where  $\varepsilon$  is the focal error matrix and may be written

$$\varepsilon = \begin{pmatrix} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{pmatrix}$$

where  $\varepsilon_{12} = \varepsilon_{21}$  by the choice of the orthonormal basis set.

Merit functions which may be applied depending on the specific application of the optimised lens include

$$\begin{aligned}
 M_1 &= \sum_{\theta} (\text{RMS blur})_{\theta}^2 \\
 M_2 &= \sum_{\theta} \left( (\text{mpe})^2 + (\text{cyl error})^2 \right)_{\theta} \\
 M_3 &= \sum_{\theta} \left( \frac{1}{16}(\text{mpe})^2 + (\text{cyl error})^2 \right)_{\theta} \\
 M_4 &= \sum_{\theta} \left( (\text{mpe})^2 + \frac{1}{16}(\text{cyl error})^2 \right)_{\theta}
 \end{aligned}$$

where summations are over a number of sample eye rotations  $\theta$ .

In a still further embodiment, a term may be included in the merit function that represents the cosmetics of the lens. For example, instead of using  $M$  alone, a modified merit function may be defined by

$$M^* = M + \eta_{\theta} \lambda^2 \left( \frac{V}{\pi r^2} \right)^2$$

where  $\eta_{\theta}$  denotes the number of sample eye rotations  $\theta$  considered in  $M$ ,  $r$  is a specified lens radius, and  $V$  is the lens volume out to the radius  $r$ . The factor  $\lambda$  is seen to be a weighting on the average lens thickness.

## 5 Mathematical Description of Lens Surface

In a still further aspect of the present invention, there is provided a method of designing a progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance  
10 vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing  
15 zone and including

a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

the corridor and lower viewing zone exhibiting a power progression profile  
20 having at least two segments, the slopes of which are related at least in part to the prescribed addition power and/or the depth of focus of the wearer;

the lens base surface bearing a surface correction(s) to at least partially adjust for an observed optical aberration(s) within the upper viewing zone;

which method includes

25 selecting a base surface function for the lens surface in the form of an  $n$ 'th order asymmetric polynomial:

$$z = \sum_{k=0,1,2,\dots}^n \sum_{j=0,1,2,\dots}^k C_{k-j,j} x^{k-j} y^j;$$

In its general form, the polynomial has all the even and odd powers of both

$x$  and  $y$  up to the powers of  $n$  and  $k$  respectively. In the designs without wrap or offset, the base curve has no odd powers of  $x$  and the odd powers of  $y$  may be limited to 1 and 3. All other terms of odd power in the above example may be set to zero.

5           The method according to the present invention may further include selecting a merit function relating to at least one optical aberration characteristic of the lens to be minimised;

          computing the coefficients of the asymmetric polynomial surface function that minimise the said merit function within the upper viewing zone of the  
10 ophthalmic lens element;

          replacing the coefficients for a spherical base curve in the original design with the computed coefficients to obtain a new optically optimised design; and

          fabricating an ophthalmic lens element having a lens surface shaped according to said modified surface function.

15           The optimisation function may be selected from one of the optimisation functions referred to above.

          In a further aspect of the present invention, the method may further include

          selecting a modified merit function relating at least one optical aberration  
20 characteristic and at least one lens cosmetic characteristic to a merit figure.

          The purpose of the modified merit function may be, for example to reduce the lens thickness, for example towards the periphery of the lens. The modified merit function may be of the type described above.

          The ophthalmic lens element may be formulated from any suitable material.  
25 A polymeric material may be used. The polymeric material may be of any suitable type. The polymeric material may include a thermoplastic or thermoset material. A material of the diallyl glycol carbonate type, for example CR-39 (PPG Industries) may be used.

The polymeric article may be formed from cross-linkable polymeric casting compositions, for example as described in Applicants' United States Patent 4,912,155, Australian Patent Applications 50581/93, 50582/93, 81216/87, 74160/91 and European Patent 5 Specification 453159A2.

The polymeric material may include a dye, preferably a photochromic dye, which may, for example, be added to the monomer formulation used to produce the polymeric material.

10 The ophthalmic lens element according to the present invention may further include standard additional coatings to the front or back surface, including electrochromic coatings.

The front lens surface may include an anti-reflective (AR) coating, for example of the type described in United States Patent 5,704,692 to Applicants.  
15

The front lens surface may include an abrasion resistant coating. e.g. of the type described in United States Patent 4,954,591 to Applicants.

20 The front and back surfaces may further include one or more additions conventionally used in casting compositions such as inhibitors, dyes including thermochromic and photochromic dyes, e.g. as described above, polarising agents, UV stabilisers and materials capable of modifying refractive index.

The present invention will now be more fully described with reference to the accompanying figures and examples. It should be understood, however, that the 25 description following is illustrative only and should not be taken in any way as a restriction on the generality of the invention described above.

In the figures:

Figure 1 is a graph illustrating the relationship between the reading contour value and addition power.

Figure 2 is a graph illustrating the relationship between the coefficient alpha  
5 ( $\alpha$ ) and addition power for the low to medium addition powers.

Figures 3a and 3b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 0.75 dioptre (D) nominal addition power.

Figures 4a and 4b illustrate the location of the visual fixation locus and the  
10 corresponding power progression profile for an ophthalmic lens element according to the present invention having 1.00 dioptre (D) nominal addition power.

Figures 5a and 5b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 1.25 dioptre (D) nominal addition power.

Figures 6a and 6b illustrate the location of the visual fixation locus and the  
15 corresponding power progression profile for an ophthalmic lens element according to the present invention having 1.50 dioptre (D) nominal addition power.

Figures 7a and 7b illustrate the location of the visual fixation locus and the  
20 corresponding power progression profile for an ophthalmic lens element according to the present invention having 1.75 dioptre (D) nominal addition power.

Figures 8a and 8b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 2.00 dioptre (D) nominal addition power.

Figures 9a and 9b illustrate the location of the visual fixation locus and the  
25 corresponding power progression profile for an ophthalmic lens element according

to the present invention having 2.25 dioptre (D) nominal addition power.

Figures 10a and 10b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 2.50 dioptre (D) nominal addition power.

5        Figures 11a and 11b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 2.75 dioptre (D) nominal addition power.

10        Figures 12a and 12b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 3.00 dioptre (D) nominal addition power.

Figures 13a and 13b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 3.25 dioptre (D) nominal addition power.

15        Figures 14a and 14b illustrate the location of the visual fixation locus and the corresponding power progression profile for an ophthalmic lens element according to the present invention having 3.50 dioptre (D) nominal addition power.

The scale of the following Figures 15, 16, 18 and 19 is indicated by the circles appearing therein, the diameter of which is 60 mm.

20        Figure 15a illustrates a contour plot of surface astigmatism of an optical lens element according to the present invention, which has a 6.0 D base surface, where the surface is an asymmetric asphere.

Figure 15b illustrates a contour plot of surface mean power of the optical lens element according to Figure 15a.

25        Ray tracing has been carried out with the model lens in the material with refractive index of 1.499 having the front surface as shown in Figures 15(a) and

15(b), a spherical back surface of 3.44 D, zero prism at the prism reference point and centre thickness of 2 mm; located in the front of the eye at a 27 mm back vertex distance from the centre of rotation of the eye and tilted pantoscopically by 7 degs. The assumed object field of the ray trace has a vertically varying distance starting at infinity (the dioptric distance of 0.00 D) for all rays crossing the front lens surface at elevations above the FC, through a linearly decreasing object distance below the FC up to the NMP, where the object distance was 0.4 m (2.5 D), and staying constant along each ray at 0.4 m for elevations below the NMP. In calculating the mean power error of the ray traced image as perceived by the wearer it has been assumed that the wearer has up to 0.5 D of reserve accommodation enabling him/her to cancel the negative mean power errors up to that magnitude in the lower part of the lens.

Figure 16a illustrates a contour plot of ray traced optical astigmatism of an optical lens element having a spherical distance prescription of 2.5 D and a basic surface design as illustrated in Figure 15.

Figure 16b illustrates a contour plot of ray traced RMS power error of an optical lens element having a spherical distance prescription of 2.5 D and a basic surface design as illustrated in Figure 15. The distribution of RMS power error illustrated in Figure 16b exhibits a relatively low gradient proximate the distance-periphery and a relatively high gradient proximate the near-periphery of the lens design.

Figure 17 illustrates a combined graph of the variation in mean surface power and surface astigmatism with vertical distance along the optical lens element mapped in Figure 15.

Figure 18a illustrates a contour plot of surface astigmatism of an optical lens element according to the present invention, which has a 5.0 D spherical base curve.

Figure 18b illustrates a contour plot of surface mean power of the optical lens element according to Figure 18a.



Figure 19a illustrates a contour plot of ray traced optical astigmatism of an optical lens element having a spherical distance power prescription of 0.0 D and a basic surface design as illustrated in Figure 18.

Figure 19b illustrates a contour plot of ray traced RMS power error of an optical lens element having a spherical distance prescription of 0.0 D and a basic surface design as illustrated in Figure 18. The distribution of RMS power error illustrated in Figure 19b exhibits a relatively low gradient proximate the distance periphery and a relatively high gradient proximate the near periphery of the lens design.

Figure 20 illustrates a combined graph of the variation in mean surface power and surface astigmatism with vertical distance along the optical lens element mapped in Figure 18.

It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

It will also be understood that the term "comprises" (or its grammatical variants) as used in this specification is equivalent to the term "includes" and should not be taken as excluding the presence of other elements or features.

## CLAIMS

1. A progressive ophthalmic lens element including a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

5 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

10 a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which being related at least in part to a prescribed addition power and a depth of focus of a wearer.

2. A progressive ophthalmic lens element including a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

20 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

25 a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which being related at least in part to a depth of focus of a wearer.

3. A progressive ophthalmic lens element according to Claim 1, wherein the lens element has an addition power from approximately 0.75 D to 1.50 D and exhibits a relatively shallow power progression within the upper part of the corridor; and

5 a relatively steep power progression from the lower part of the corridor to a near vision measurement point (NMP).

4. A progressive ophthalmic lens element according to Claim 3, wherein the power progression profile includes a first segment within the upper part of the corridor from a fitting cross (FC) to a highest reading point (HRP) and a second  
10 segment within the lower part of the corridor from a highest reading point to the near vision measurement point (NMP).

5. A progressive ophthalmic lens element according to Claim 1, wherein the lens element has an addition power of from approximately 1.75 D to 3.00 D and exhibits a relatively steep power progression within the upper part of the  
15 corridor; and

a relatively shallow power progression from the lower part of the corridor to a near vision measurement point.

6. A progressive ophthalmic lens element according to Claim 5, wherein the power progression profile includes a first segment within the upper part of the  
20 corridor from a fitting cross (FC) to a highest reading point (HRP) and a second segment within the lower part of the corridor from highest reading point to the near vision measurement point (NMP).

7. A progressive ophthalmic lens element according to Claim 6, wherein the relatively steep power progression in the first segment is such that an effective  
25 corridor length is very short.

8. A progressive ophthalmic lens element according to Claim 7, wherein the effective corridor length is approximately 11 mm, for addition powers up to approximately 2.50 D and increasing with increased addition power thereabove up to approximately 13 mm for addition powers above 3.0 D.

9. A progressive ophthalmic lens element according to Claim 1, wherein a  
30 distribution of surface astigmatism and ray traced RMS power error exhibits a

relatively low gradient proximate the distance periphery and a relatively high gradient proximate the near periphery.

10. A progressive ophthalmic lens element according to Claim 1, wherein a distribution of surface astigmatism exhibits a relatively low gradient proximate the distance periphery and a relatively high gradient proximate the near periphery.

11. A progressive ophthalmic lens element according to Claim 1, wherein ray traced RMS power error exhibits a relatively low gradient proximate the distance periphery and a relatively high gradient proximate the near periphery.

12. A progressive ophthalmic lens element according to Claim 9, wherein a ratio of maximum rate of change of the ray traced RMS power error along the vertical lines offset 15 mm from a fitting cross (FC) to a maximum horizontal rate of change of the RMS power error at the level of a near vision measurement point (NMP) is less than approximately 0.60.

13. A progressive ophthalmic lens element according to Claim 1, wherein the location of the corridor is dictated at least in part by a visual fixation locus; the visual fixation locus being inset generally horizontally nasally below a fitting cross of the lens element.

14. A progressive ophthalmic lens element according to Claim 13, wherein the degree of inset varies along the eyepath profile relative to up to three reference points therealong.

15. A progressive ophthalmic lens element according to Claim 14, wherein, at a 0.5 D local addition power point (LAP) the degree of horizontal inset decreases with increasing addition power.

16. A progressive ophthalmic lens element according to Claim 15, wherein, at a highest reading point (HRP) the inset is generally constant and corresponds to that of a reading distance of approximately 40 cm.

17. A progressive ophthalmic lens element according to Claim 16, wherein the horizontal inset at the NMP is a generally constant 2 mm up to addition powers of approximately 2.50 D, and then increases gradually with increasing addition power, up to a value of approximately 2.8 mm for a 3.50 D addition power.

18. A progressive ophthalmic lens element according to claim 1,

wherein the corridor and lower viewing zone exhibit a multi-segmented power progression profile.

19. A progressive ophthalmic lens element according to Claim 18, wherein the power progression includes a first segment from a fitting cross (FC) to a 0.5 D  
5 Local Addition Power (LAP) point;

the fitting cross (FC) being located at  $(0, y_{FC})$  wherein the value of  $y_{FC}$  varies from approximately 2 mm to 6 mm above the geometric centre of the lens element; and

10 the 0.5 D LAP point exhibiting an inset which is a function of the addition power ranging from approximately 2.0 mm for addition powers of 1.00 D and below, to approximately 0.5 mm for addition powers of approximately 2.50 D and above.

20. A progressive ophthalmic lens element according to Claim 19, including a second segment from the 0.50 D LAP point to a highest reading point (HRP);

15 the position of the HRP being located at  $(2, y_{FC} - 11)$  for addition powers up to 2.50 D and ranging to  $(2, y_{FC} - 13)$  for addition powers of approximately 3.00 D and above.

21. A progressive ophthalmic lens element according to Claim 20, wherein the power progression profile includes a third segment from the HRP to a near  
20 vision measurement point (NMP), located at approximately  $(x, y_{FC} - 16)$ ;

wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D;

25 the slope of the power progression within the third segment varying from steeper than in the second segment for low addition powers through generally equal to that within the second segment at medium addition powers, to relatively shallow at high addition powers.

22. A progressive ophthalmic lens element according to Claim 21, wherein the x coordinate is adjusted to be equal to the point at which a chief ray from a near  
30 object point intersects the lens surface.

23. A progressive ophthalmic lens element according to Claim 21, wherein the power progression includes a fourth segment from the NMP to a maximum addition power (MAP) point, at approximately  $(x, y_{FC} - 18.5)$ ;

5 wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D.

24. A progressive ophthalmic lens element according to Claim 23, wherein the x coordinate is adjusted to be equal to the point at which a chief ray from a near object point intersects the lens surface.

10 25. A progressive ophthalmic lens element according to Claim 18, wherein a value of the Reading Contour for low to medium addition powers,  $P_r$ , varies with addition power.

26. A progressive ophthalmic lens element according to Claim 25, wherein a relationship between the value of the Reading Contour, defined as the mean  
15 addition power at a highest reading point (HRP) and the nominal addition power,  $A$ , is given by the formula

$$P_r = A - \alpha (2.5 - A)$$

$$\text{where } \alpha = \exp \left[ -\frac{(A - 2.5)^2}{1.575} \right]$$

up to addition powers of 2.00 D.

20 27. A progressive ophthalmic lens element according to Claim 26 wherein, for addition powers above 2.00 D, the value of the Reading Contour varies such that the difference between the power at a NMP and the HRP gradually increases from 0.5 D for a 2.25 D to 2.50 D addition powers up to 1.00 D for a 3.50 D addition power.

25 28. A progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a prescribed addition power and a depth of focus of a wearer; and

a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays crossing the lens surface.

29. A progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a depth of focus of a wearer; and

a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays crossing the lens surface.

30. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt and wrap of the lens element in an "as worn" configuration;

5 the lens base surface having a generally aspheric component that is asymmetric in a vertical (y) and a horizontal (x) direction.

31. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt and wrap of the lens element in an "as worn" configuration;

10 the lens base surface having a generally aspheric component that is asymmetric in a vertical (y) direction.

32. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt and wrap of the lens element in an "as worn" configuration;

15 the lens base surface having a generally aspheric component that is asymmetric in a horizontal (x) direction.

33. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt of the lens element in the "as worn" configuration; and

20 the lens base surface has a generally aspheric component that is asymmetric in a vertical (y) and a horizontal (x) direction.

34. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt of the lens element in an "as worn" configuration; and

25 the lens base surface has a generally aspheric component that is asymmetric in a vertical (y) direction.

35. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by pantoscopic tilt of the lens element in an "as worn" configuration; and

30 the lens base surface has a generally aspheric component that is asymmetric in a horizontal (x) direction.



36. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by wrap of the lens element in an "as worn" configuration; and

5 the lens base surface has a generally aspheric component that is asymmetric in a vertical (y) and a horizontal (x) direction.

37. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by wrap of the lens element in the "as worn" configuration; and

10 the lens base surface has a generally aspheric component that is asymmetric in a vertical (y) direction.

38. A progressive ophthalmic lens element according to Claim 28, wherein the optical aberration is introduced by wrap of the lens element in the "as worn" configuration; and

15 the lens base surface has a generally aspheric component that is asymmetric in a horizontal (x) direction.

39. A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

20 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

25 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a prescribed addition power and a depth of focus of a wearer; and

30 a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a vertical (y) and a horizontal (x) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

40. A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to prescribed addition power and a depth of focus of a wearer; and

a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a vertical (y) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

41. A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

5 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a prescribed addition power and a depth of focus of a wearer; and

10 a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a horizontal (x) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

15 42. A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

20 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

25 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a depth of focus of a wearer; and

a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a vertical (y) and a horizontal (x) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

43. A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a depth of focus of a wearer and

a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a vertical (y) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

44 A progressive ophthalmic lens element including

a lens surface having an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

a corridor of relatively low surface astigmatism;

5 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to the depth of focus of a wearer; and

10 a lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone due to obliquity of incoming rays;

the lens base surface correction being described by a polynomial asymmetric along a horizontal (x) meridian; and whose coefficients are chosen to minimise a merit function constructed of the sum of a selected optical aberration within the upper, lower or upper and lower viewing zones.

15 45. A method of designing a progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance vision,

20 a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

25 a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a prescribed addition power and a depth of focus of a wearer;

the lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone;

which method includes

5 selecting a base surface function for the lens surface in the form of an n'th order asymmetric polynomial:

$$z = \sum_{k=0,1,2,\dots}^n \sum_{j=0,1,2,\dots}^k C_{k-j,j} x^{k-j} y^j$$

wherein:

10  $x, y, z$  are Cartesian coordinates of the lens surface where  $z$  represents the height of the surface;

$C_{k-j,j}$  are coefficients to the polynomial that are solved for in the optical optimisation problem;

$n$  is the highest power of the polynomial used to describe the surface.

15 46. A method of designing a progressive ophthalmic lens element including a first lens surface having

an upper viewing zone having a surface power corresponding to distance vision,

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

20 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including

25 a corridor of relatively low surface astigmatism; the corridor exhibiting a power progression from that of the upper viewing zone to that of the threshold of the lower viewing zone,

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a depth of focus of a wearer;

the lens base surface bearing a surface correction to at least partially adjust for an observed optical aberration within the upper viewing zone;

which method includes

5 selecting a base surface function for the lens surface in the form of an n'th order asymmetric polynomial:

$$z = \sum_{k=0,1,2,\dots}^n \sum_{j=0,1,2,\dots}^k C_{k-j,j} x^{k-j} y^j$$

wherein:

x, y, z are Cartesian coordinates of the lens surface where z represents the height of the surface;

10  $C_{k-j,j}$  are coefficients to the polynomial that are solved for in the optical optimisation problem;

n is the highest power of the polynomial used to describe the surface.

47. A method according to Claims 45 or 46, further including selecting a merit function relating to at least one optical aberration characteristic of the lens to be minimised;

15

computing the coefficients of the asymmetric polynomial surface function that minimise the said merit function within the upper viewing zone of the ophthalmic lens element;

20 replacing the coefficients for a spherical base curve in an original design with the computed coefficients to obtain a new optically optimised design; and

fabricating the ophthalmic lens element having a lens surface shaped according to said modified merit function.

48. A method according to Claim 47, further including selecting a modified merit function relating at least one optical aberration characteristic and at least one lens cosmetic characteristic to a merit figure.

25

49. A series of progressive ophthalmic lens elements, each lens element including a lens surface having

an upper viewing zone having a surface power to achieve a refracting power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

5 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including a corridor of relatively low surface astigmatism;

the progressive ophthalmic lens series including

10 a first set of lens elements having at least one base curve suitable for use in providing a range of distance prescriptions for myopes, emmetropes or hyperopes, each lens element within a set differing in prescribed addition power and including a progressive design,

15 the corridor and lower viewing zone exhibiting a power progression profile having at least two segments the slopes of which are related to a prescribed addition power and a depth of focus of a wearer;

the lens elements within a set exhibiting a relatively shallow power progression in the first segment and a relatively steep power progression in the second segment for an addition power of from approximately 0.75 D to 1.50 D; and

20 exhibiting a relatively steep power progression in the first segment and a relatively shallow power progression in the second segment for an addition power of from approximately 1.75 D to 3.00 D.

50. A series of progressive ophthalmic lens elements each lens element including a lens surface having

25 an upper viewing zone having a surface power to achieve a refracting power corresponding to distance vision;

a lower viewing zone having a greater surface power than the upper viewing zone to achieve a refracting power corresponding to near vision; and

30 an intermediate zone extending across the lens element having a surface power varying from that of the upper viewing zone to that of the lower viewing zone and including a corridor of relatively low surface astigmatism;



the progressive ophthalmic lens series including

a first set of lens elements having at least one base curve suitable for use in providing a range of distance prescriptions for myopes, emmetropes or hyperopes, each lens element within a set differing in prescribed addition power and including  
5 a progressive design,

the corridor and lower viewing zone exhibiting a power progression profile having at least two segments, the slopes of which are related at least in part to a depth of focus of a wearer;

the lens elements within a set exhibiting a relatively shallow power  
10 progression in the first segment and a relatively steep power progression in the second segment for an addition power of from approximately 0.75 D to 1.50 D; and

exhibiting a relatively steep power progression in the first segment and a relatively shallow power progression in the second segment for an addition power of from approximately 1.75 D to 3.00 D.

15 51. A lens element series according to Claims 49 or 50, wherein the location of the corridor in each lens element within a set is dictated at least in part by a visual fixation locus; the visual fixation locus being inset generally horizontally nasally below a fitting cross of the lens element; the degree of inset varying along an eyepath profile relative to up to three reference points therealong.

20 52. A lens element series according to Claim 51, wherein at 0.5 D local addition power point (LAP) the degree of horizontal inset decreases with increasing addition power;

at a highest reading point (HRP) the inset is generally constant and corresponds to that of a reading distance of approximately 40 cm;

25 at a near measurement point the horizontal inset is a generally constant 2 mm up to addition powers of approximately 2.50 D, and then increases gradually with increasing addition power, up to a value of approximately 2.8 mm for a 3.50 D addition power.

30 53. A series of progressive ophthalmic lens elements according to Claim 49,

wherein the corridor and lower viewing zone exhibit a multi-segmented power progression profile; and

wherein the power progression of each lens element within a set includes the first segment from the fitting cross (FC) to the 0.5 D Local Addition Power (LAP) point;

the fitting cross (FC) being located at  $(0, y_{FC})$  wherein the value of  $y_{FC}$  varies from approximately 2 mm to 6 mm above the geometric centre of the lens element; and

the 0.5 D LAP point exhibiting an inset which is a function of the addition power ranging from approximately 2.0 mm for addition powers of 1.00 D and below, to approximately 0.5 mm for addition powers of approximately 2.50 D and above;

the second segment from the 0.50 D LAP point to a HRP;

a position of the HRP being located at  $(2, y_{FC} - 11)$  for addition powers up to 2.50 D and ranging to  $(2, y_{FC} - 13)$  for addition powers of approximately 3.00 D and above;

a third segment from the HRP to near vision measurement point (NMP), located at approximately  $(x, y_{FC} - 16)$ ;

wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D;

the slope of the power progression within the third segment varying from steeper than in the second segment for low addition power through generally equal to that within the second segment at medium addition powers, to relatively shallow at high addition powers.

54. A progressive ophthalmic lens element series according to Claim 52, wherein the power progression includes a fourth segment from the NMP to a maximum addition power (MAP) point, at approximately  $(x, y_{FC} - 18.5)$ ;

wherein the x coordinate is approximately 2 mm for addition powers less than or equal to approximately 2.50 D, and is inset by an amount determined by the reciprocal of the addition power for addition powers greater than 2.50 D.

55. A progressive ophthalmic lens element series according to Claim 53, wherein a value of the Reading Contour  $P_r$  varies with addition power.

56. A progressive ophthalmic lens element series according to Claim 52, wherein a relationship between a value of the Reading Contour and addition power is given by the formula

$$P_r = A - \alpha (2.5 - A)$$

$$\text{where } \alpha = \exp \left[ -\frac{(A - 2.5)^2}{1.575} \right]$$

up to addition powers of 2.00 D.

57. A progressive ophthalmic lens element series according to Claim 54, wherein, for addition powers above 2.00 D, a Reading Contour varies such that the difference between the power of the NMP and the HRP gradually increases up to 1.00 D for a 3.50 D addition power.

FIGURE 1

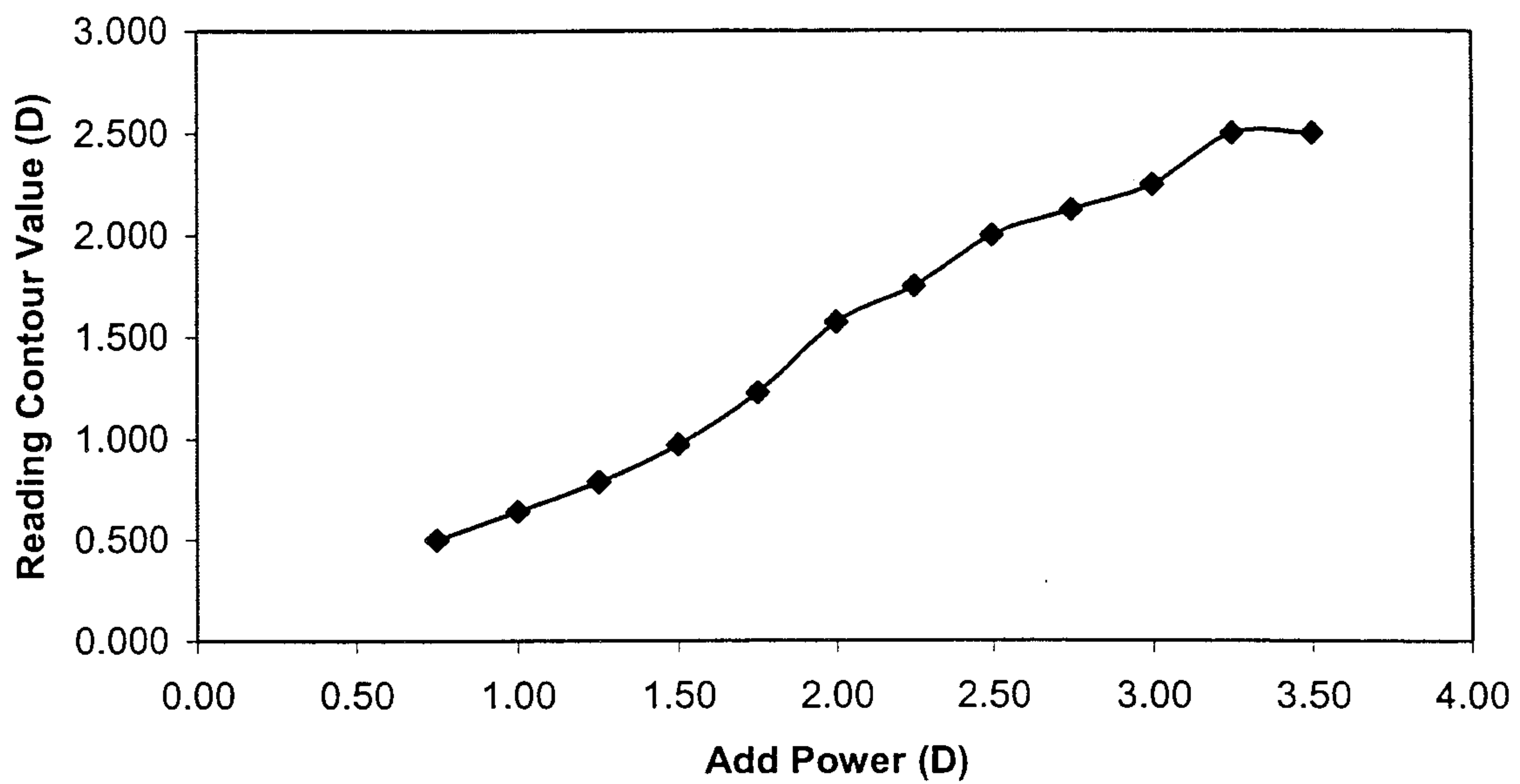
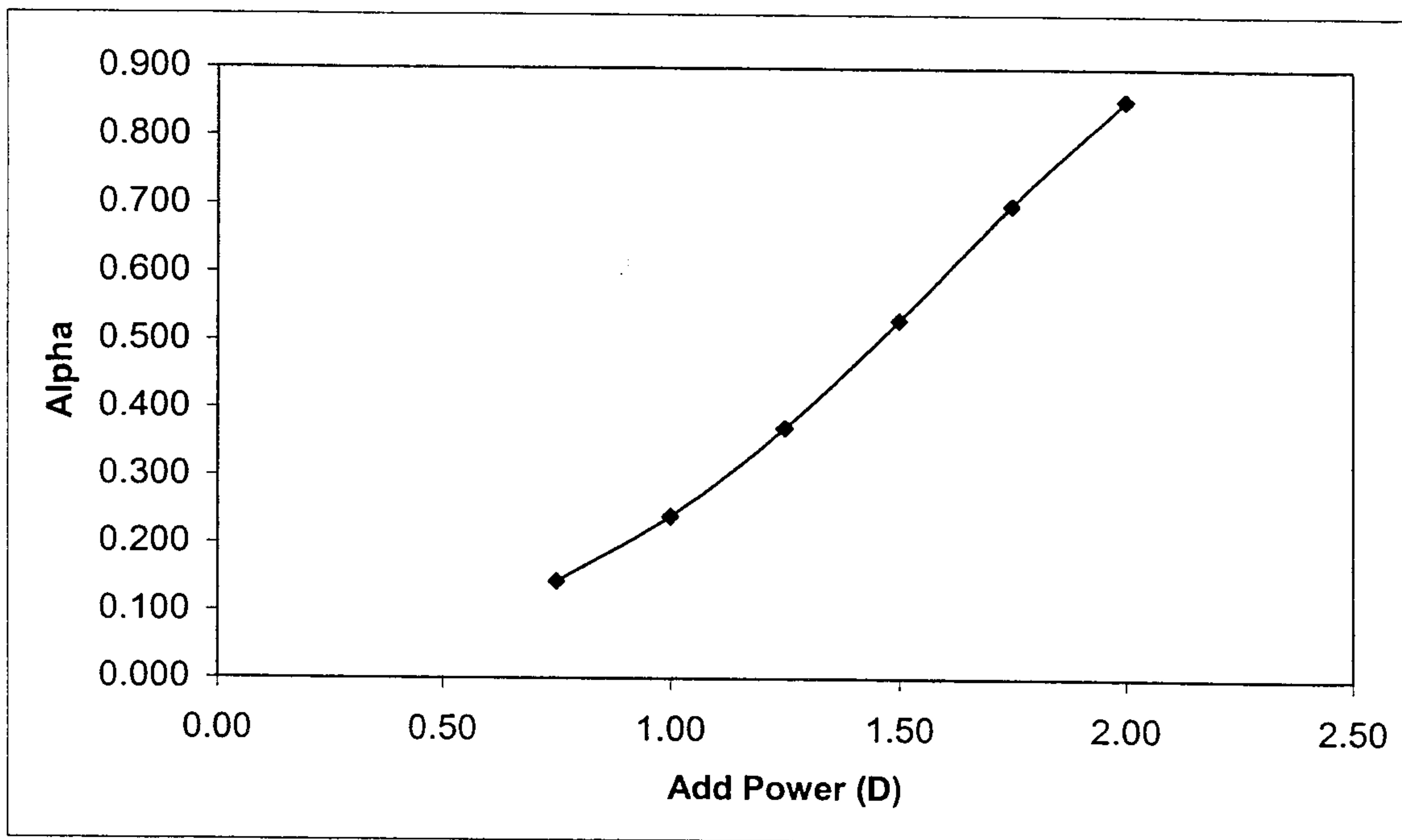
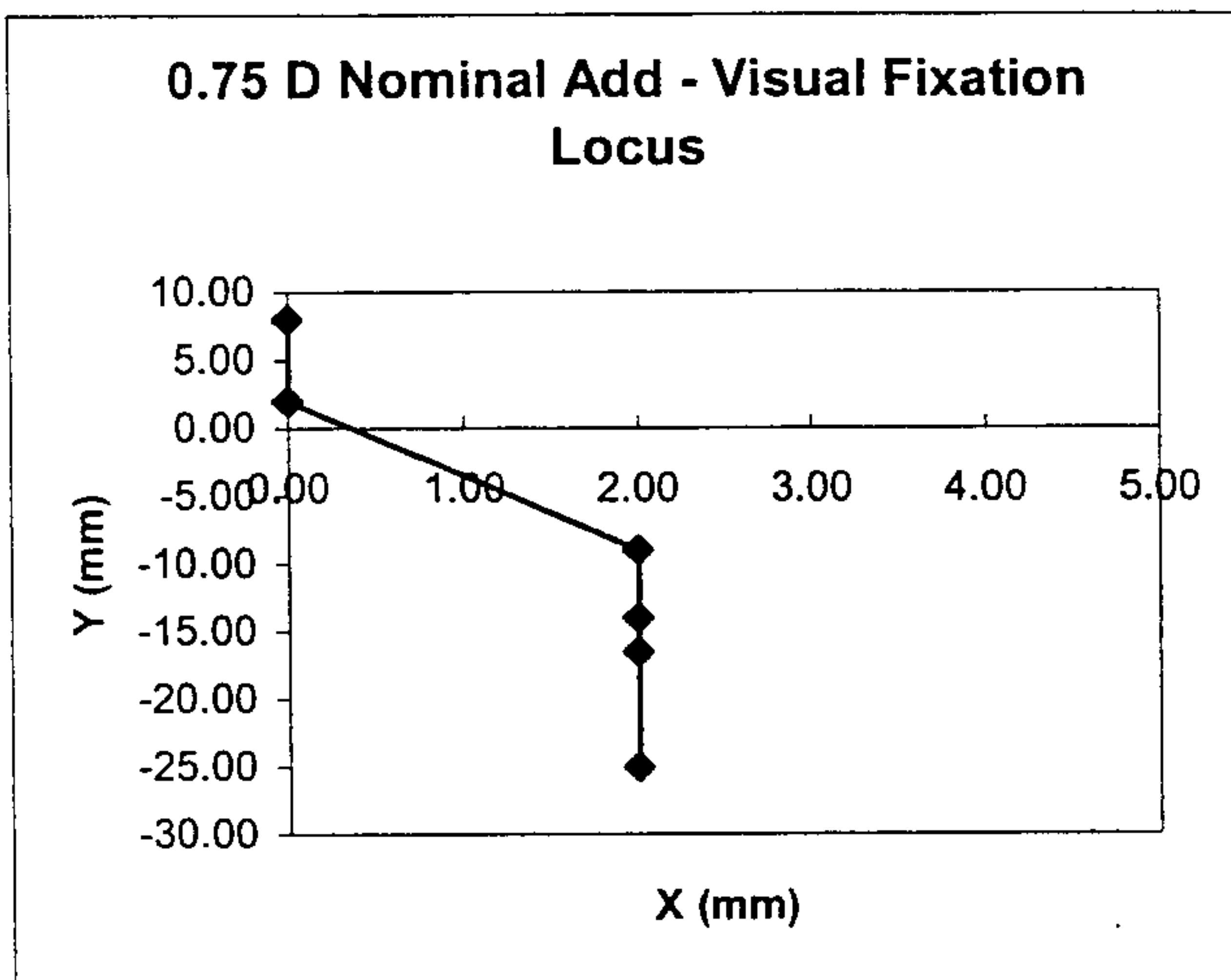


FIGURE 2



**FIGURE 3A**



**FIGURE 3B**

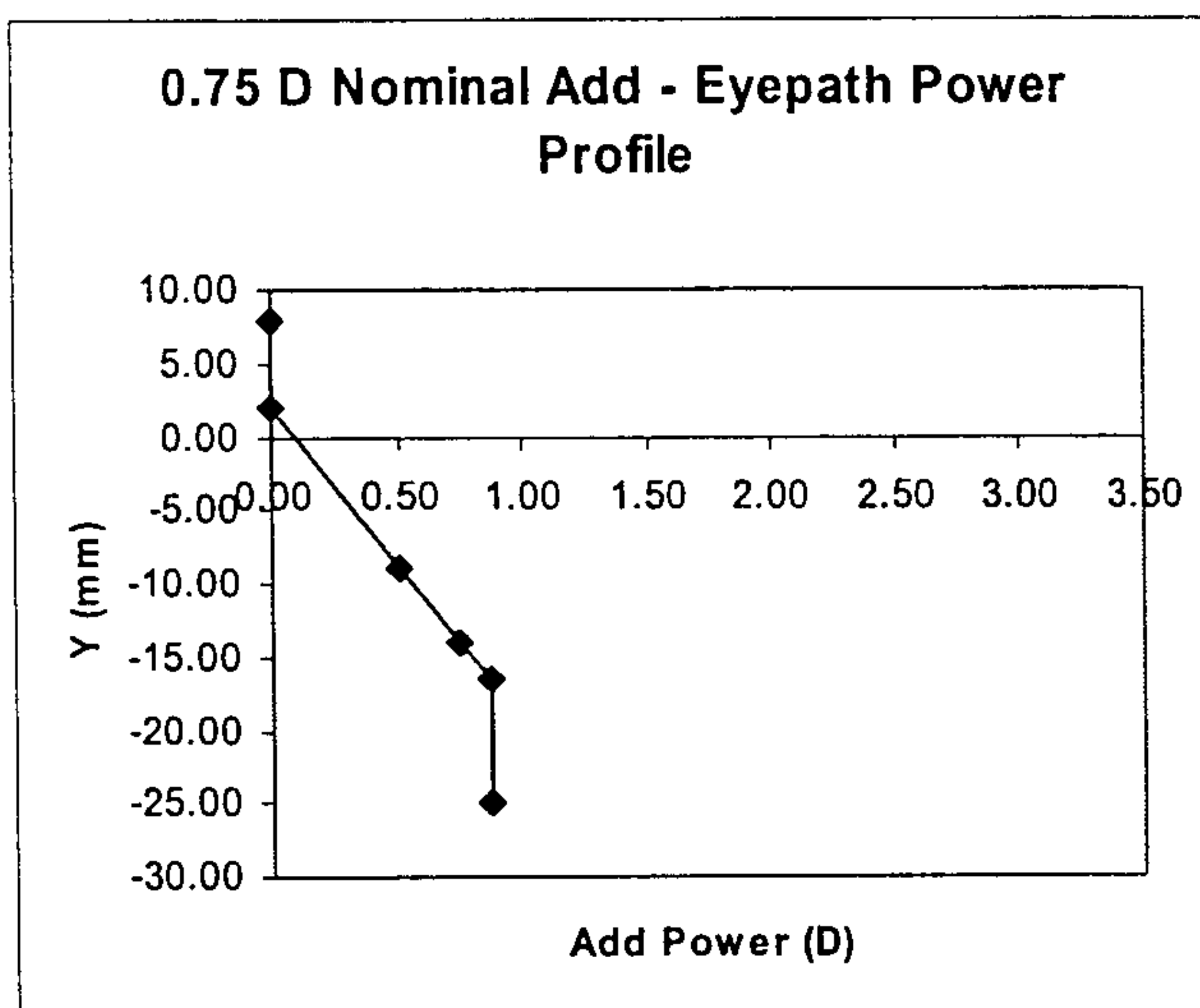


FIGURE 4A

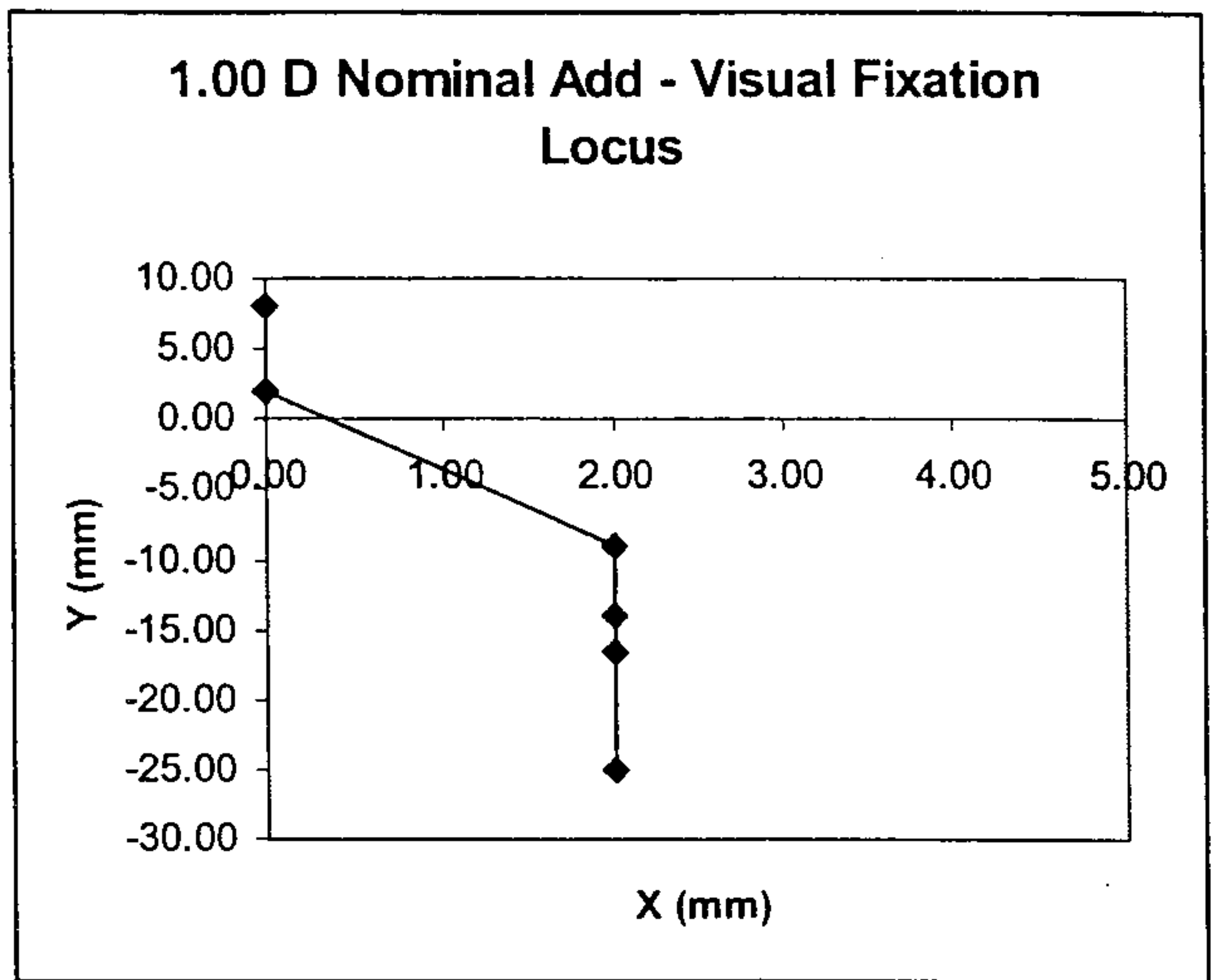


FIGURE 4B

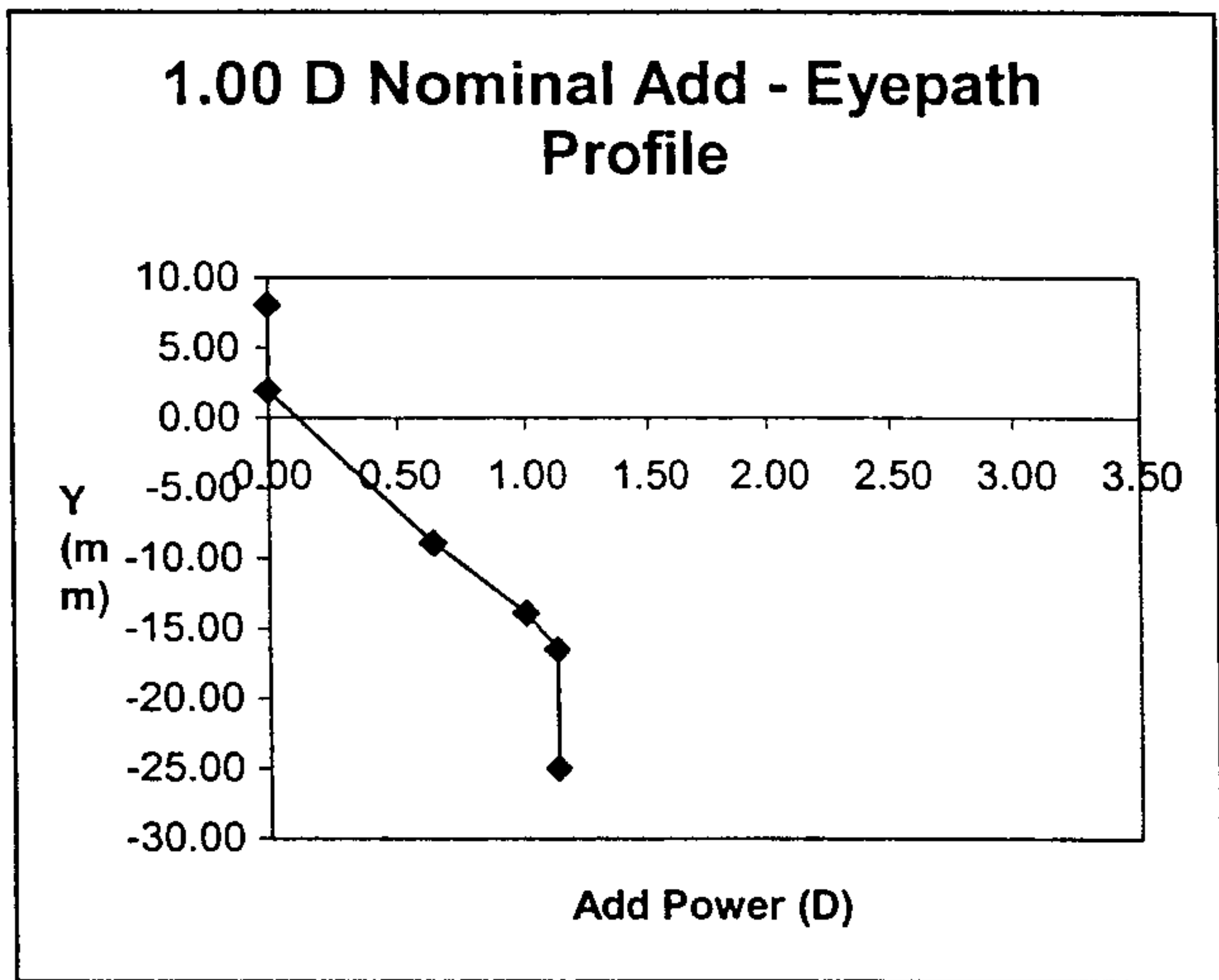


FIGURE 5A

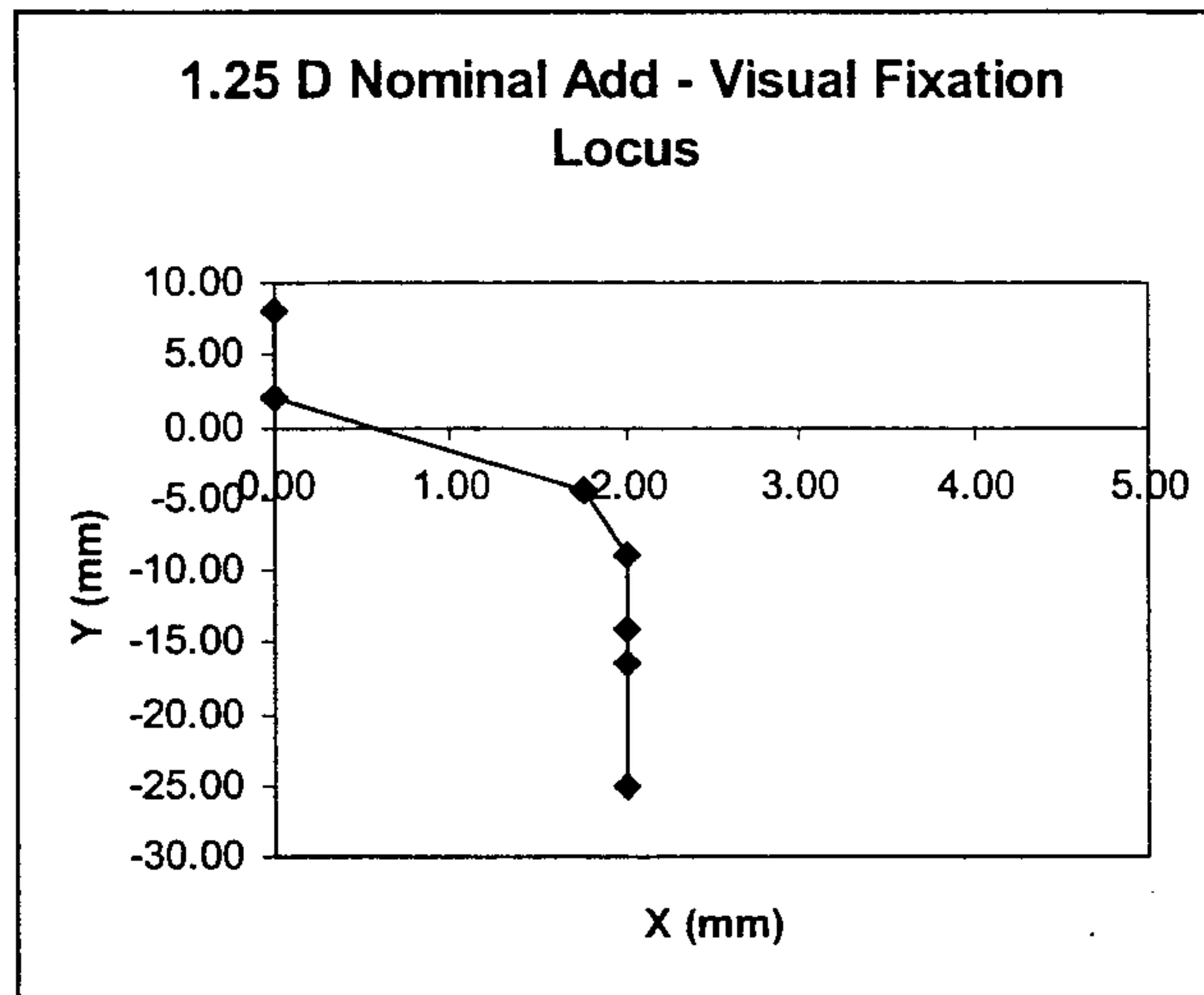


FIGURE 5B

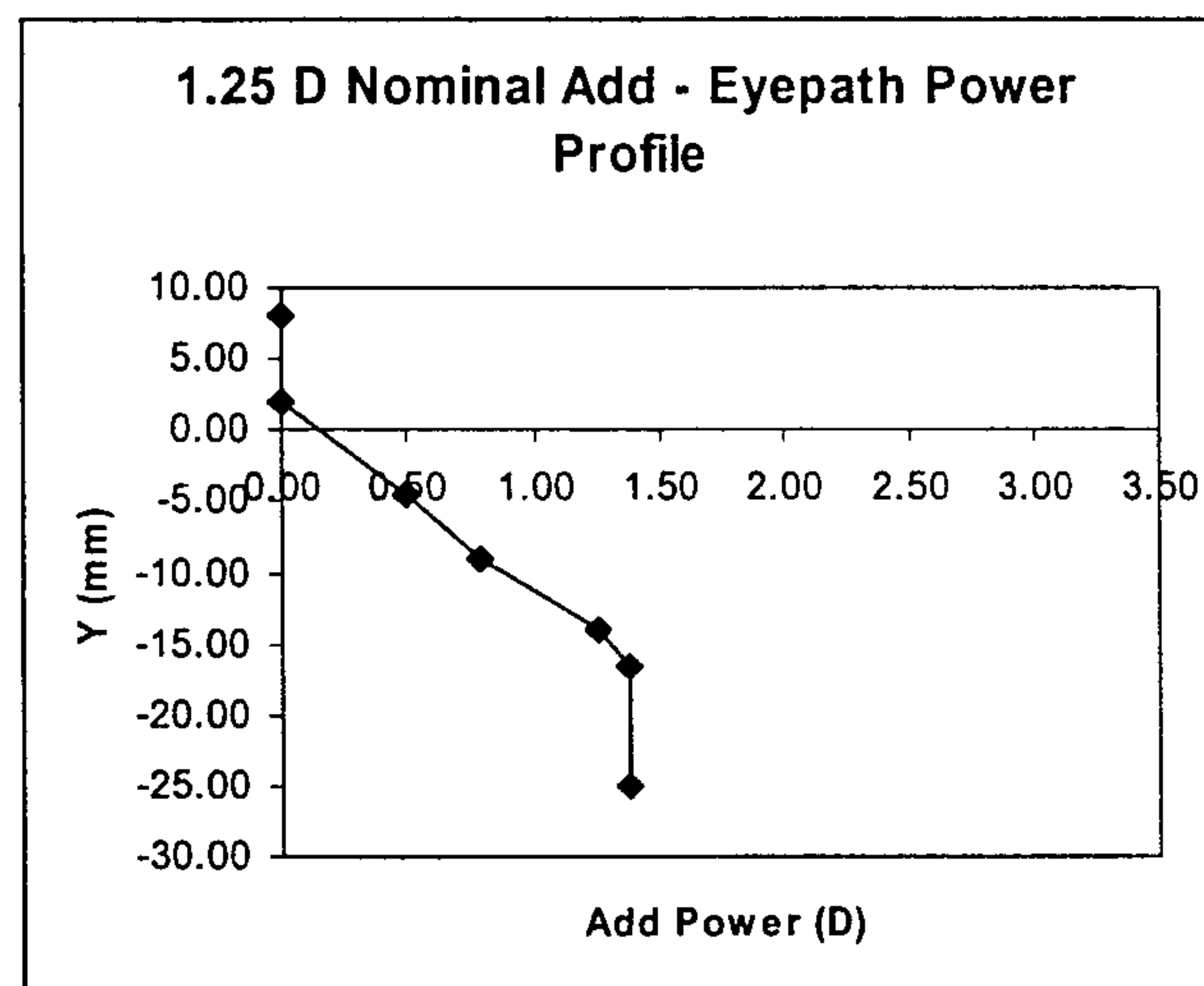




FIGURE 6A

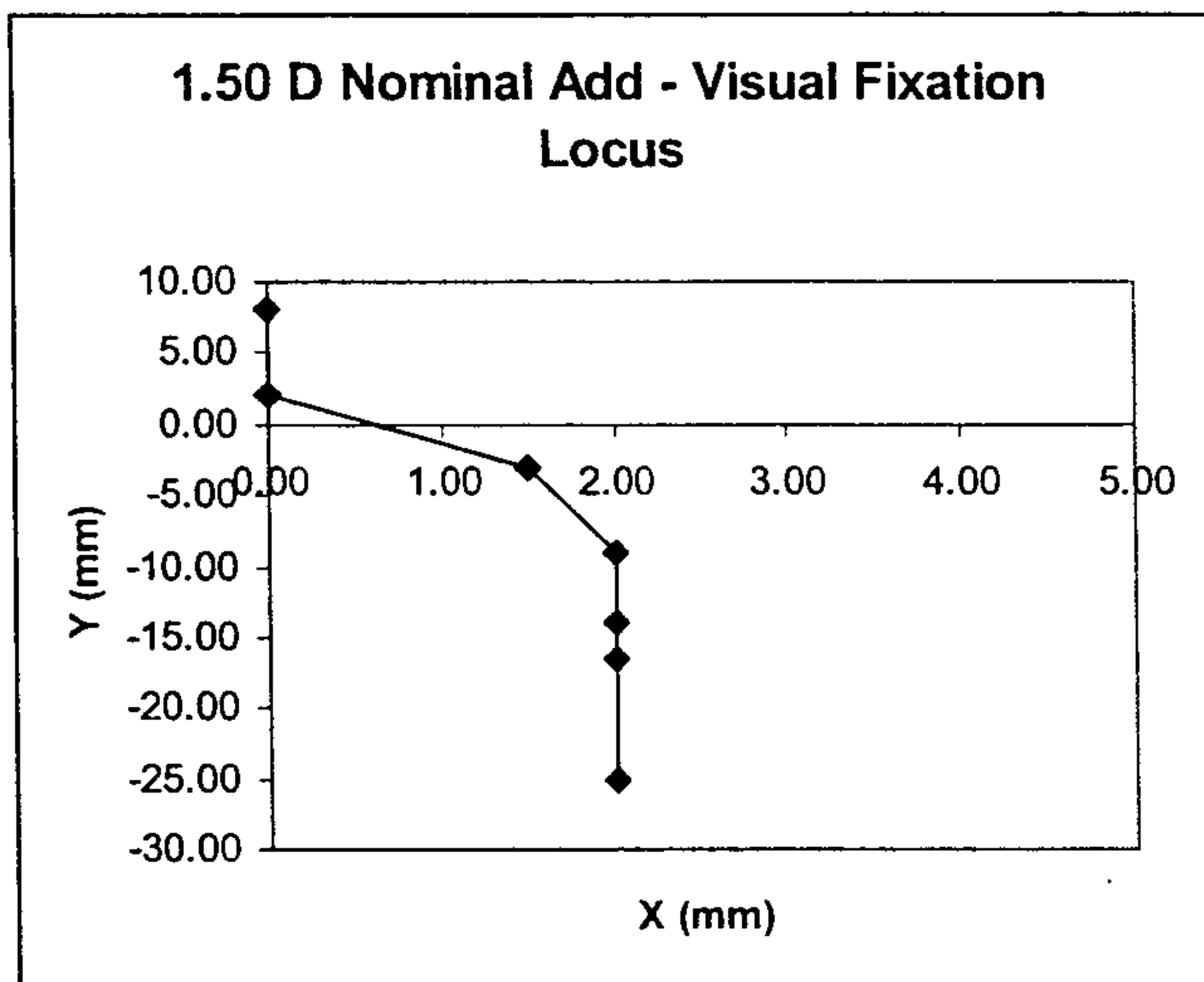


FIGURE 6B

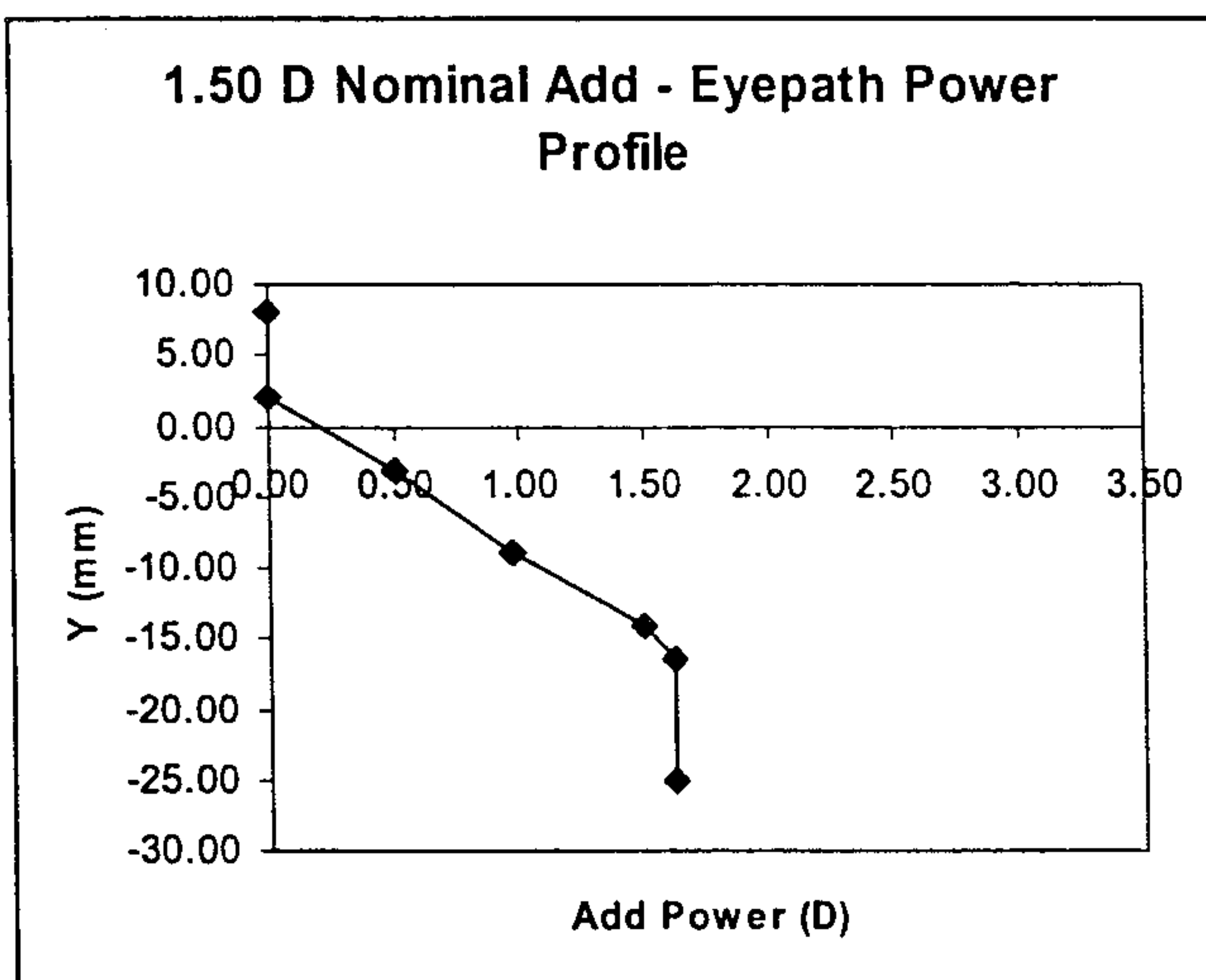


FIGURE 7A

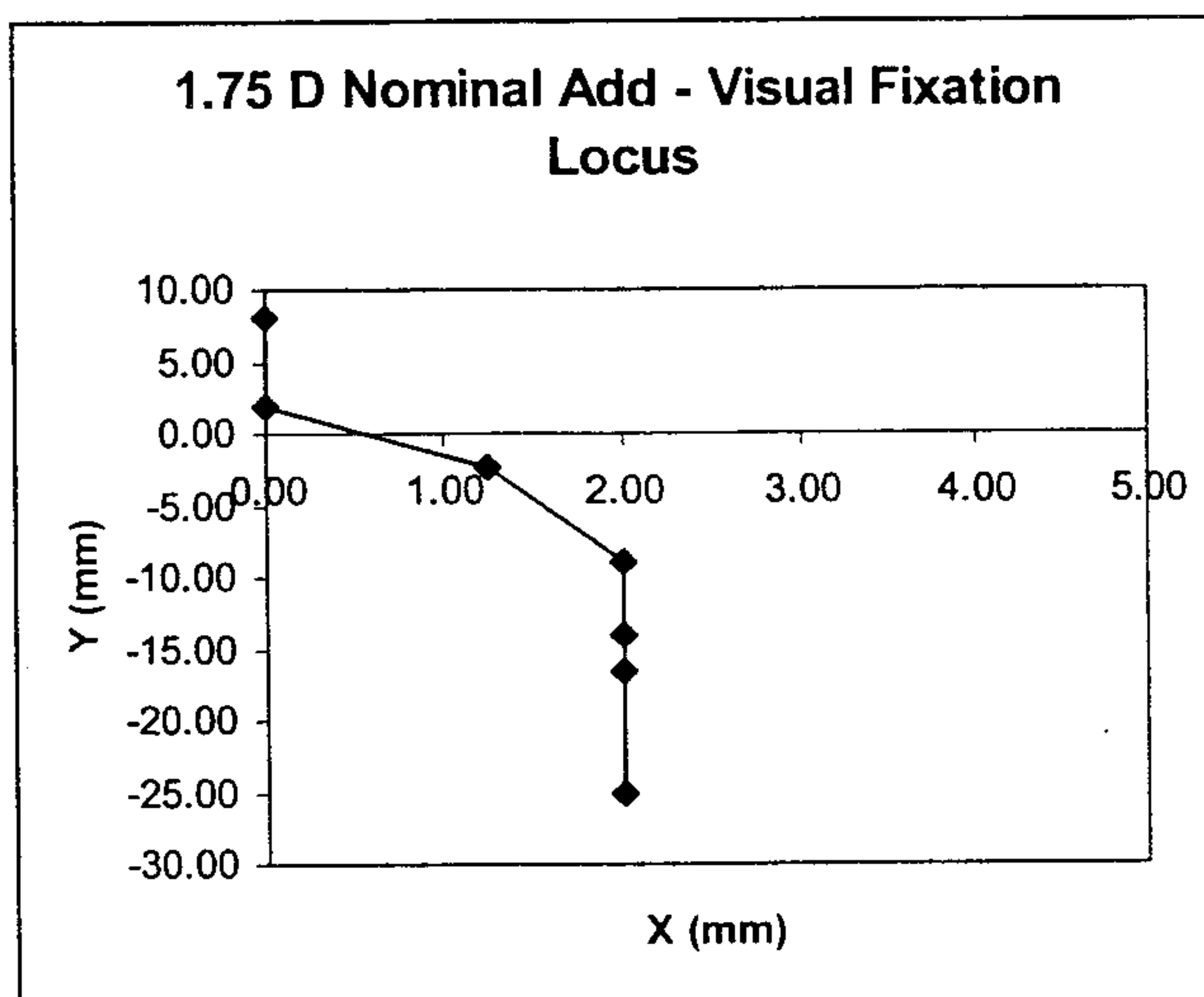


FIGURE 7B

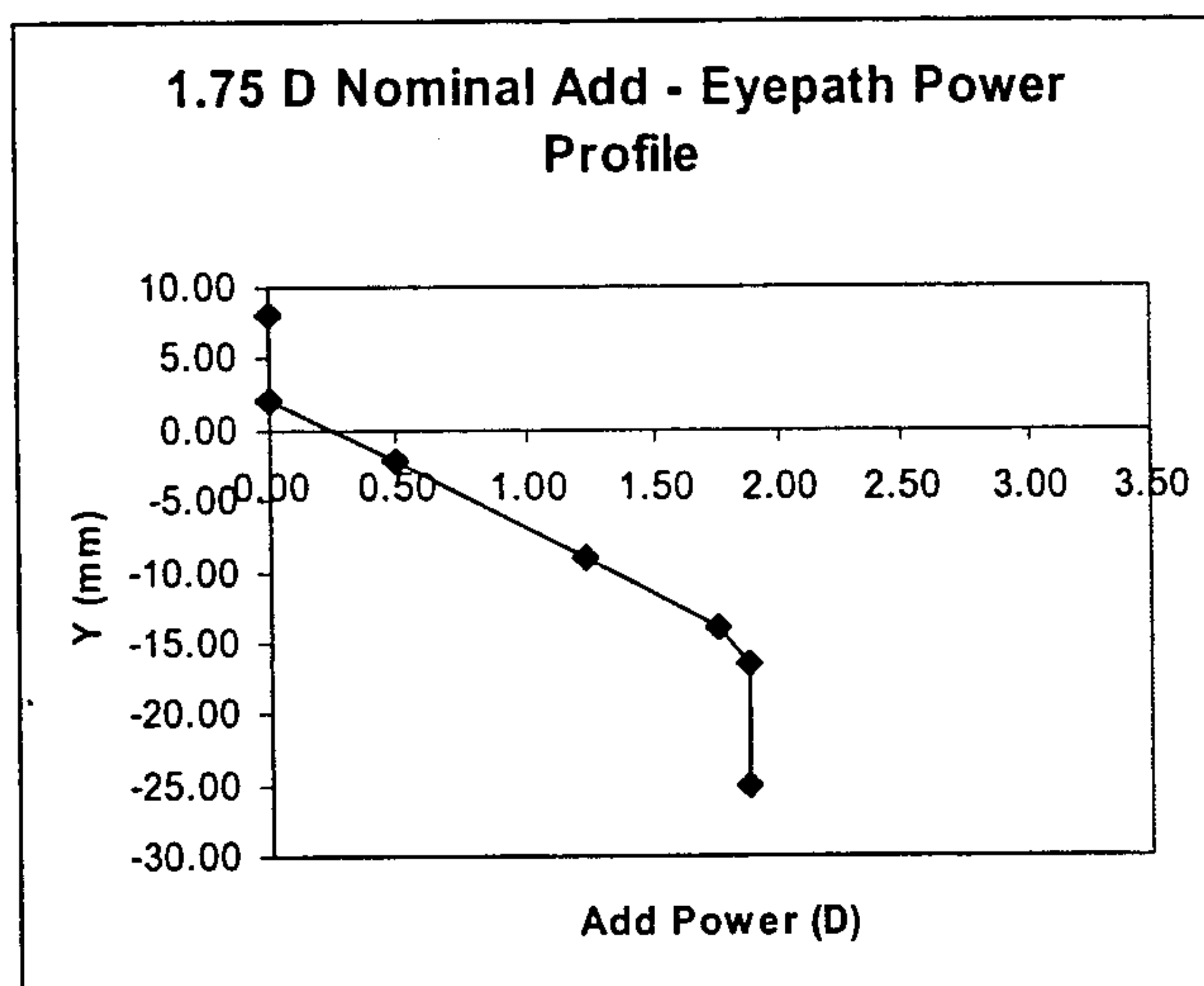


FIGURE 8A

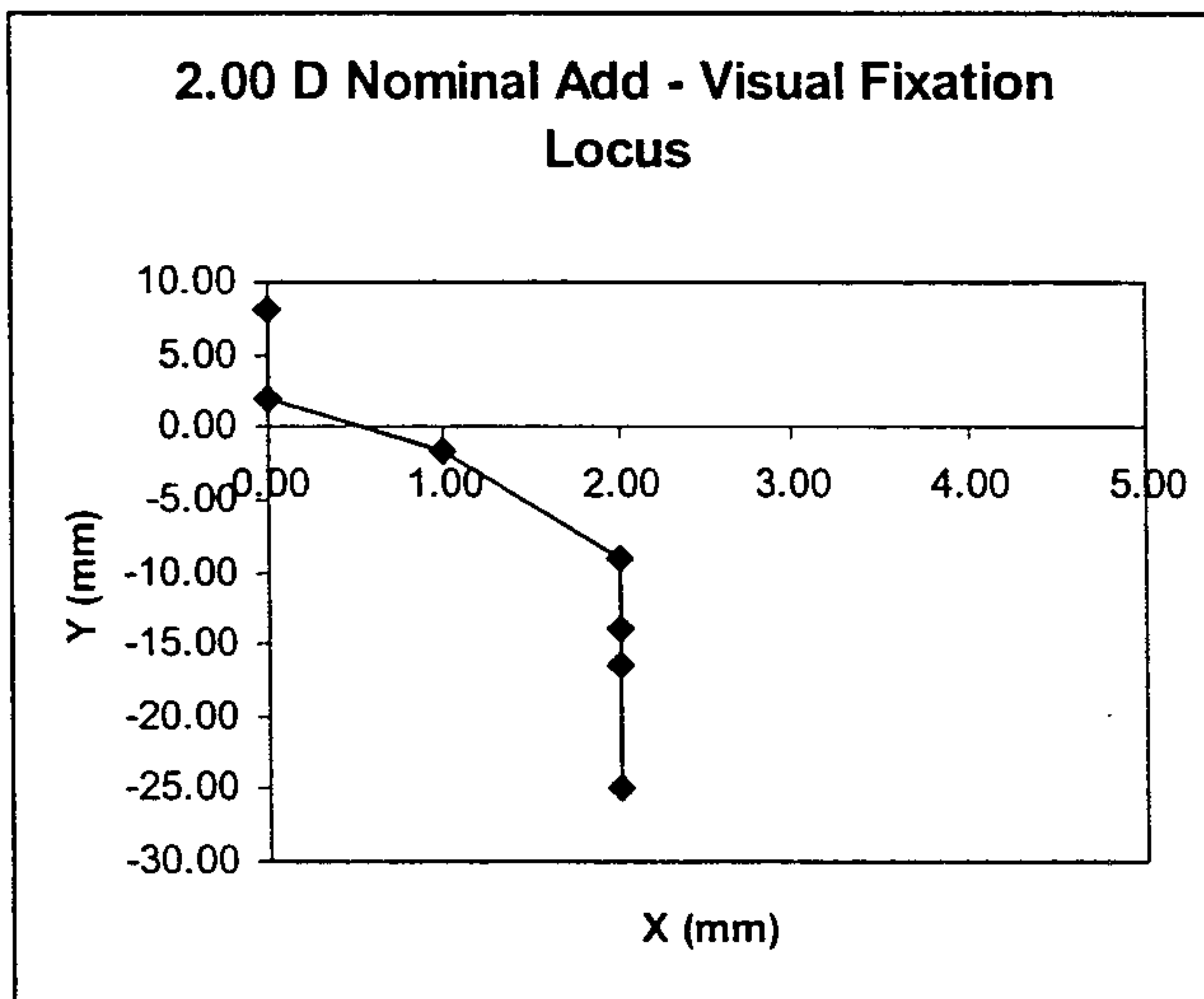


FIGURE 8B

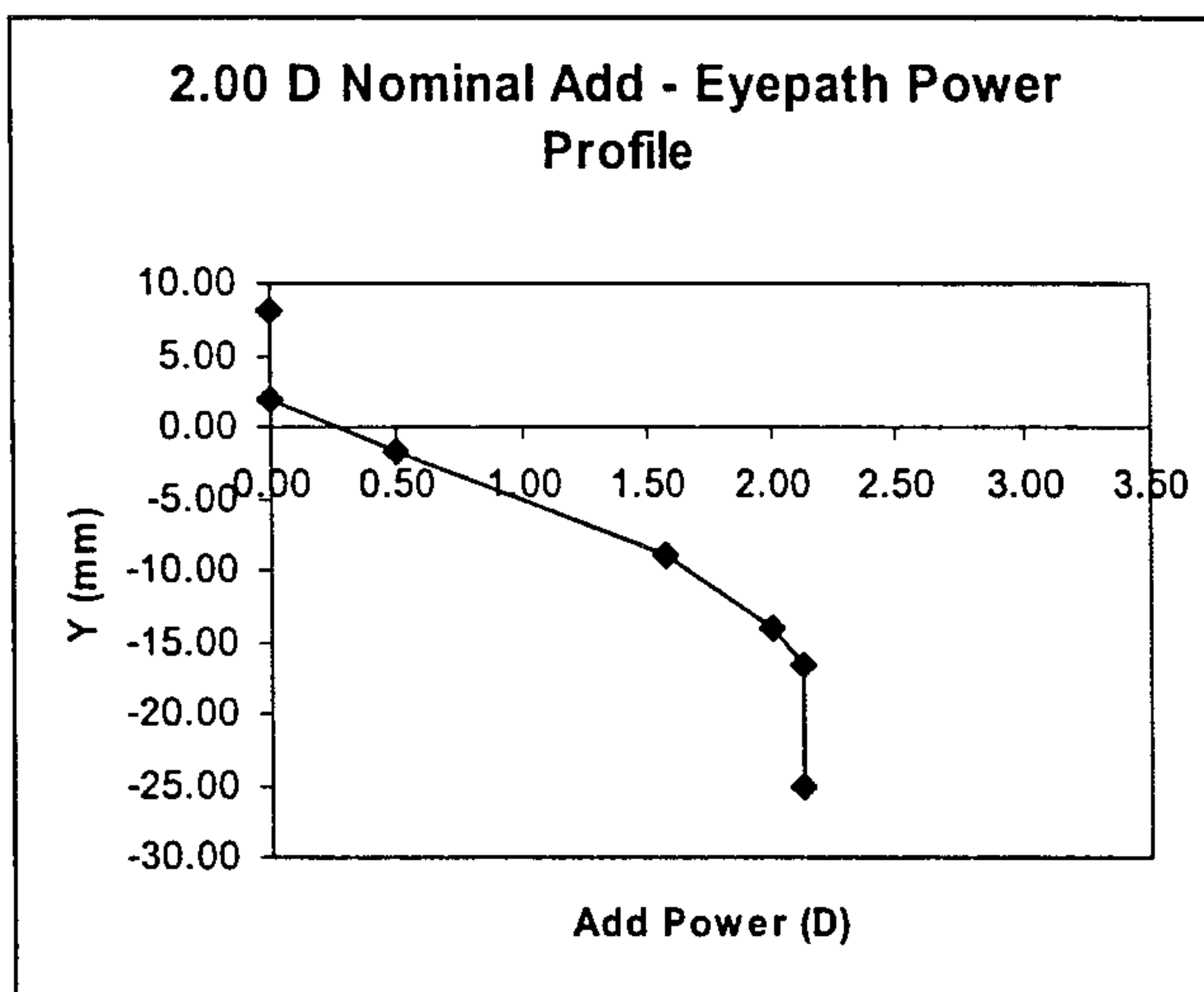


FIGURE 9A

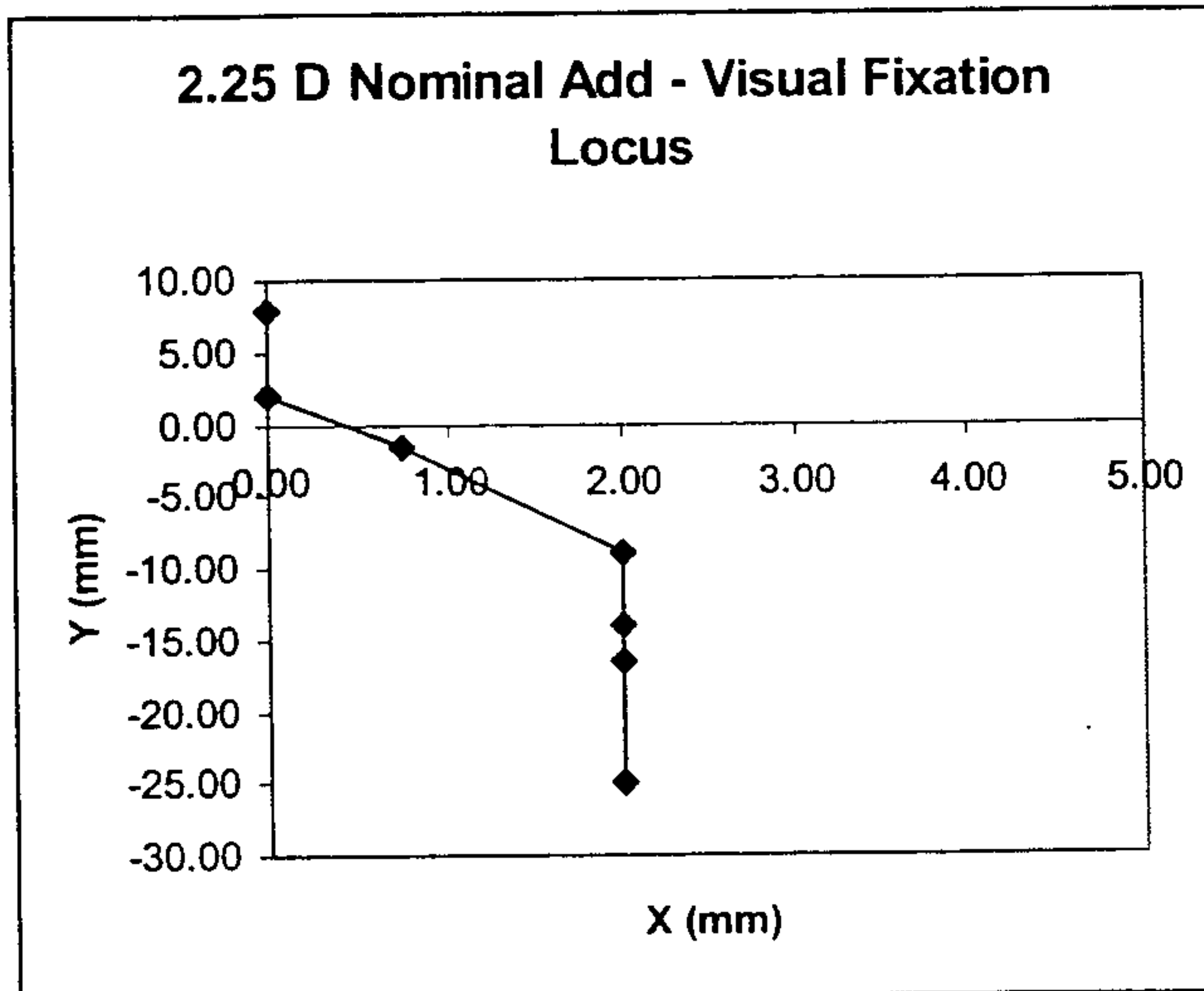


FIGURE 9B

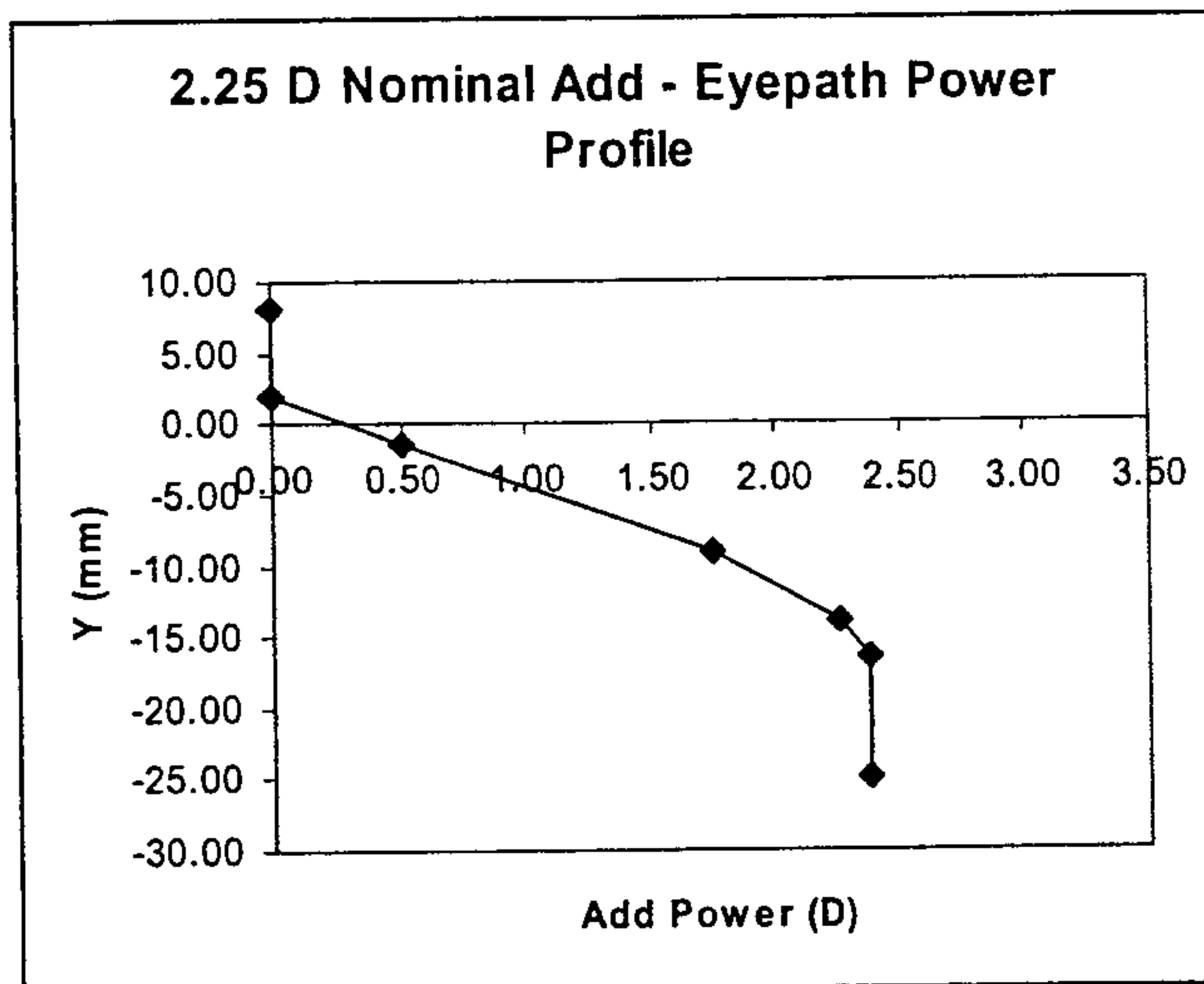


FIGURE 10A

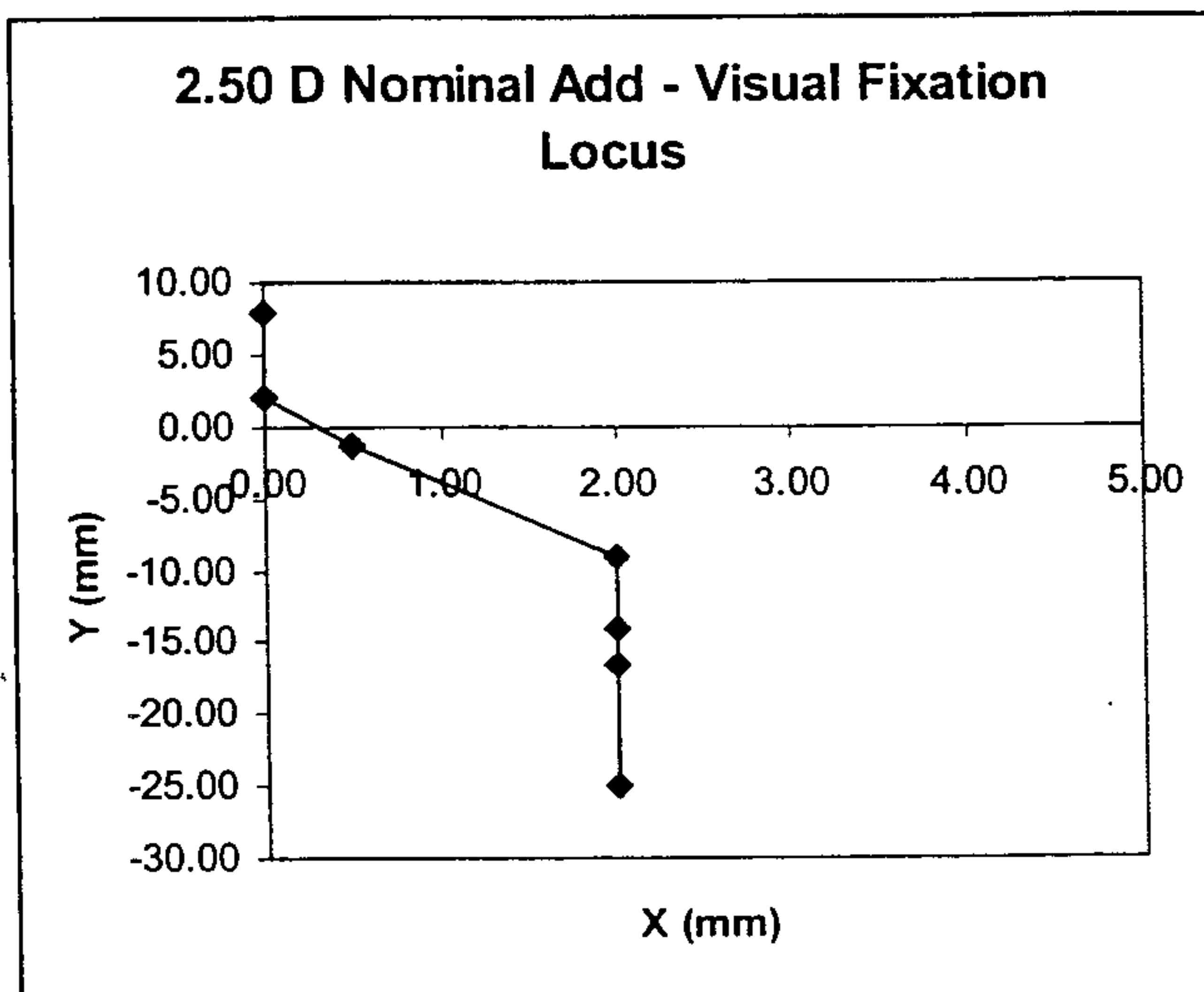
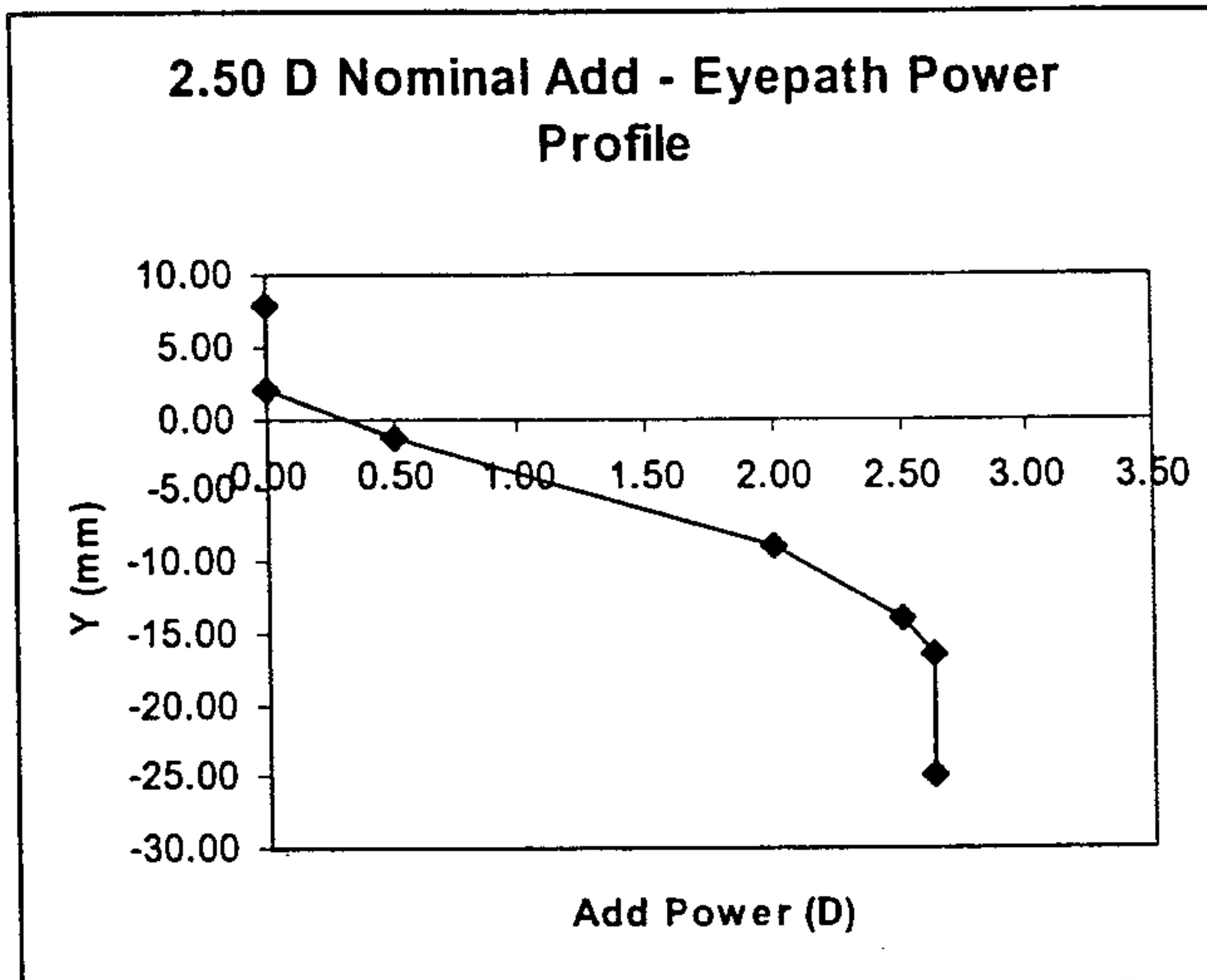
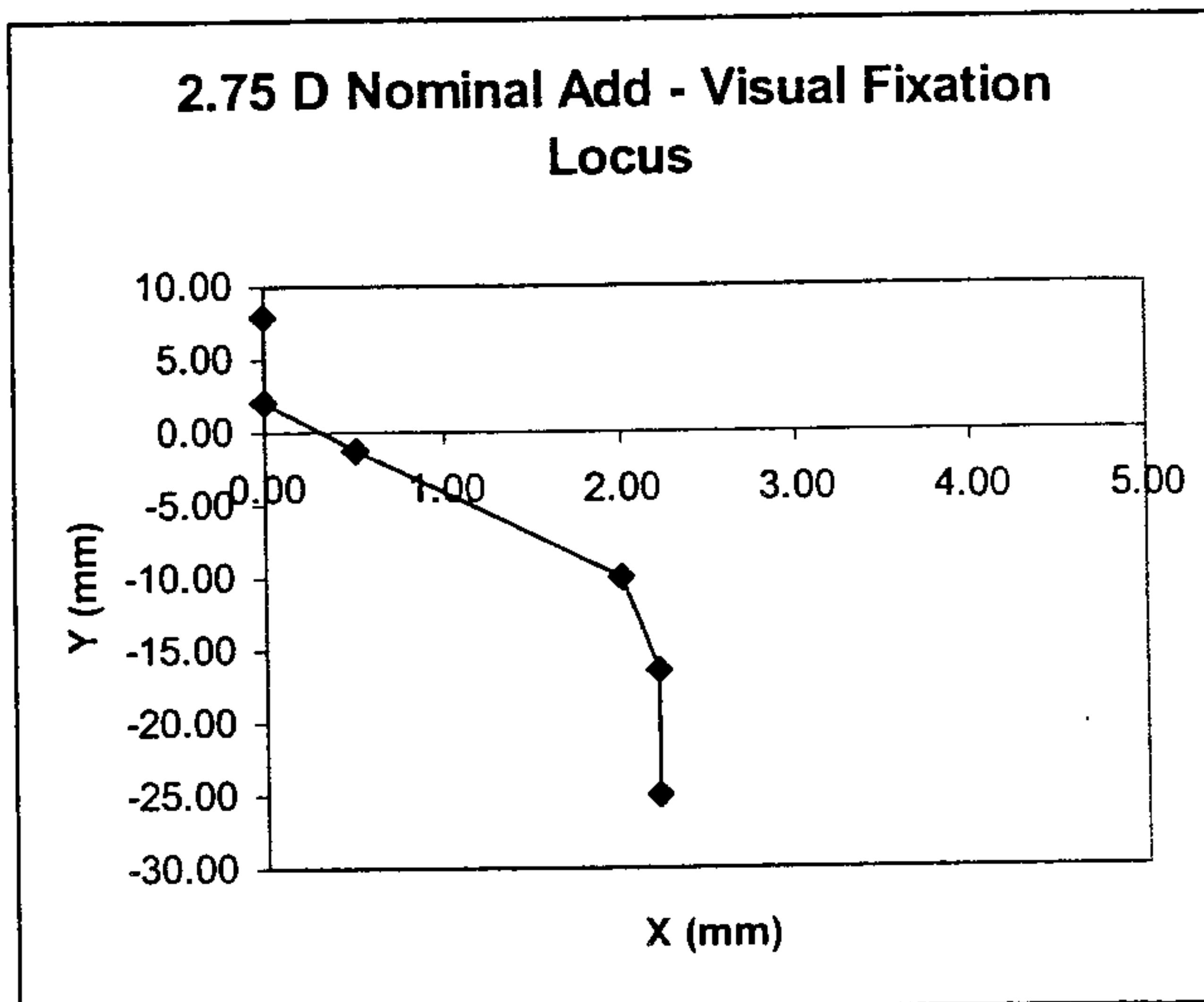


FIGURE 10B



**FIGURE 11A**



**FIGURE 11B**

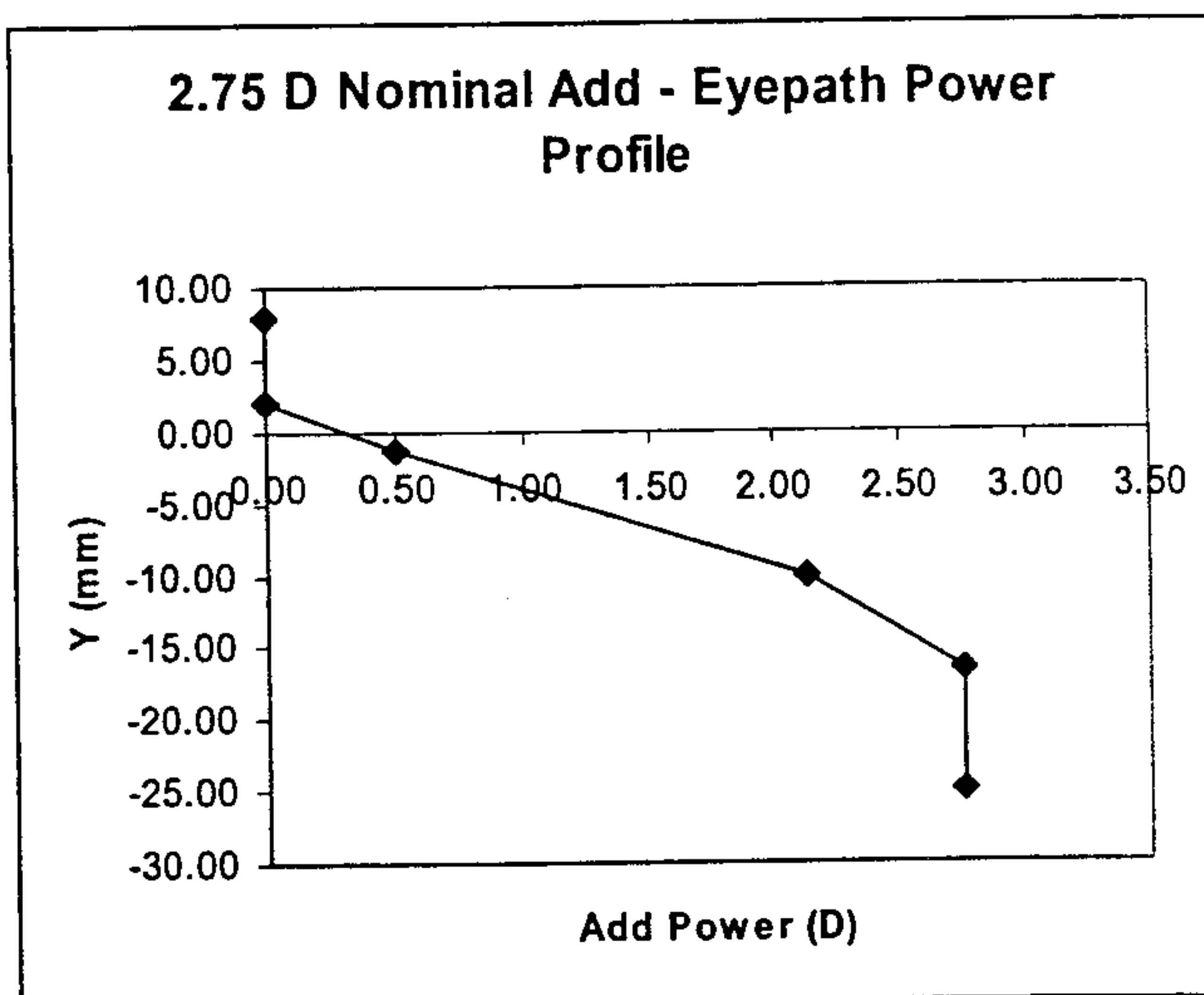


FIGURE 12A

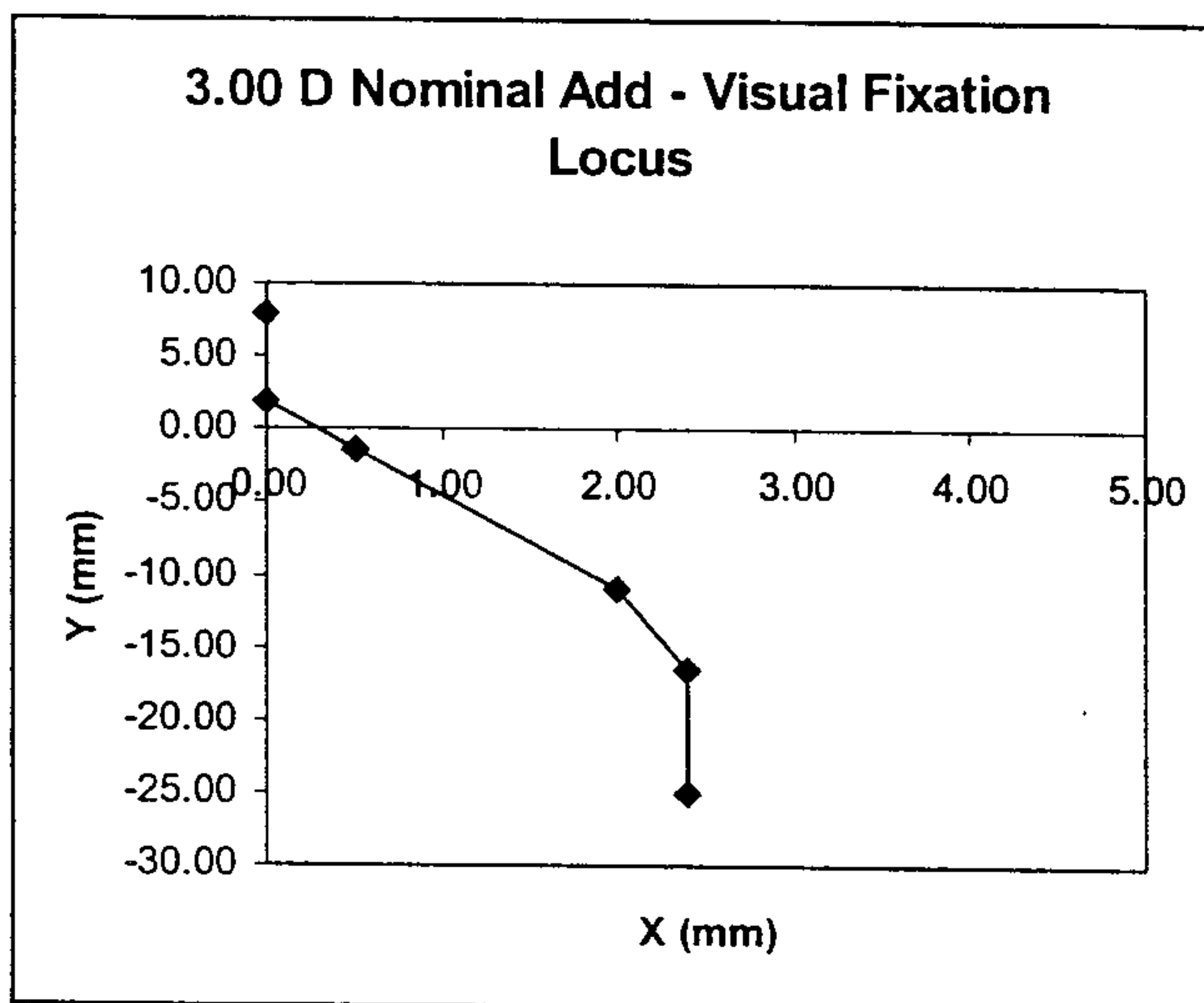
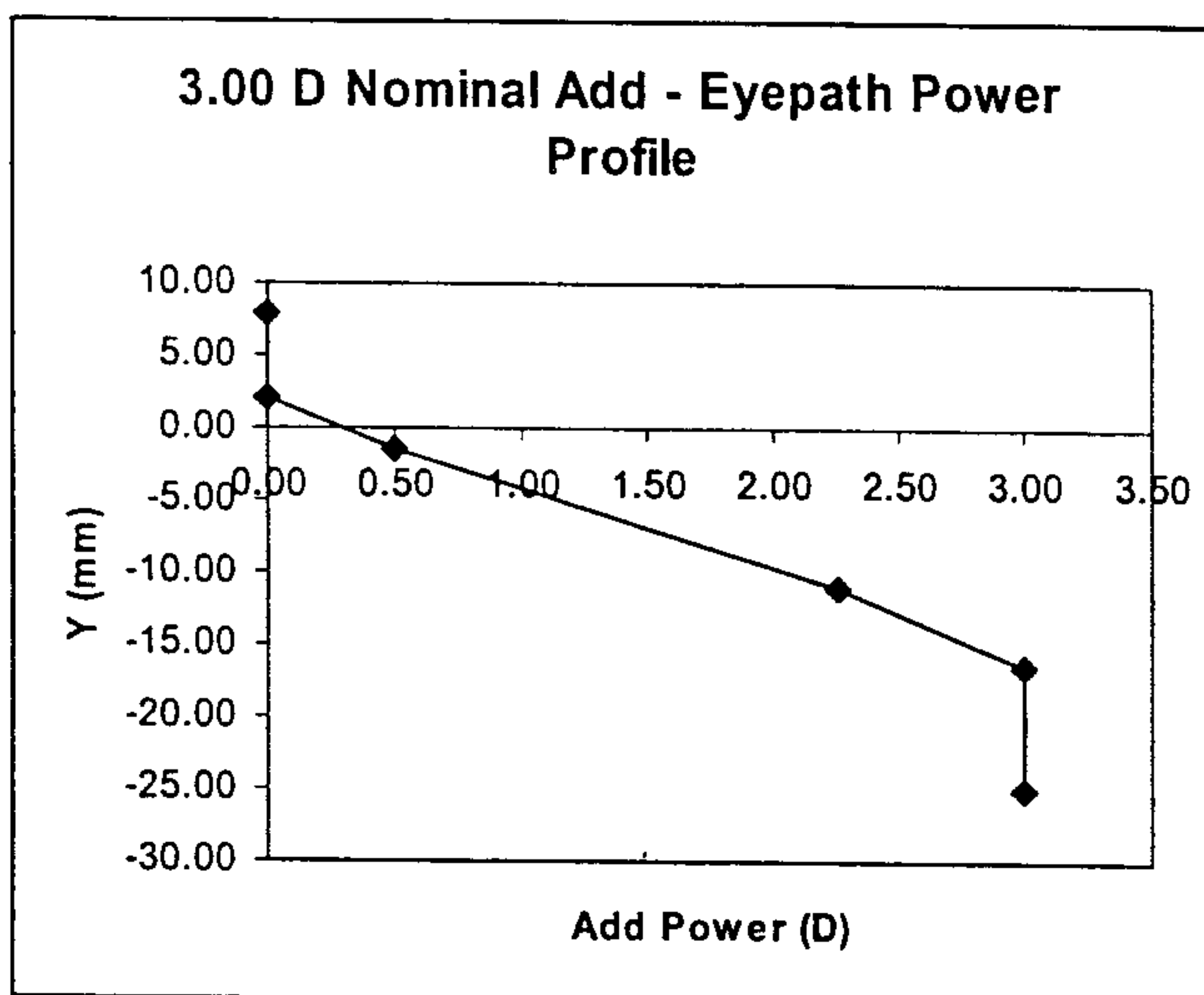
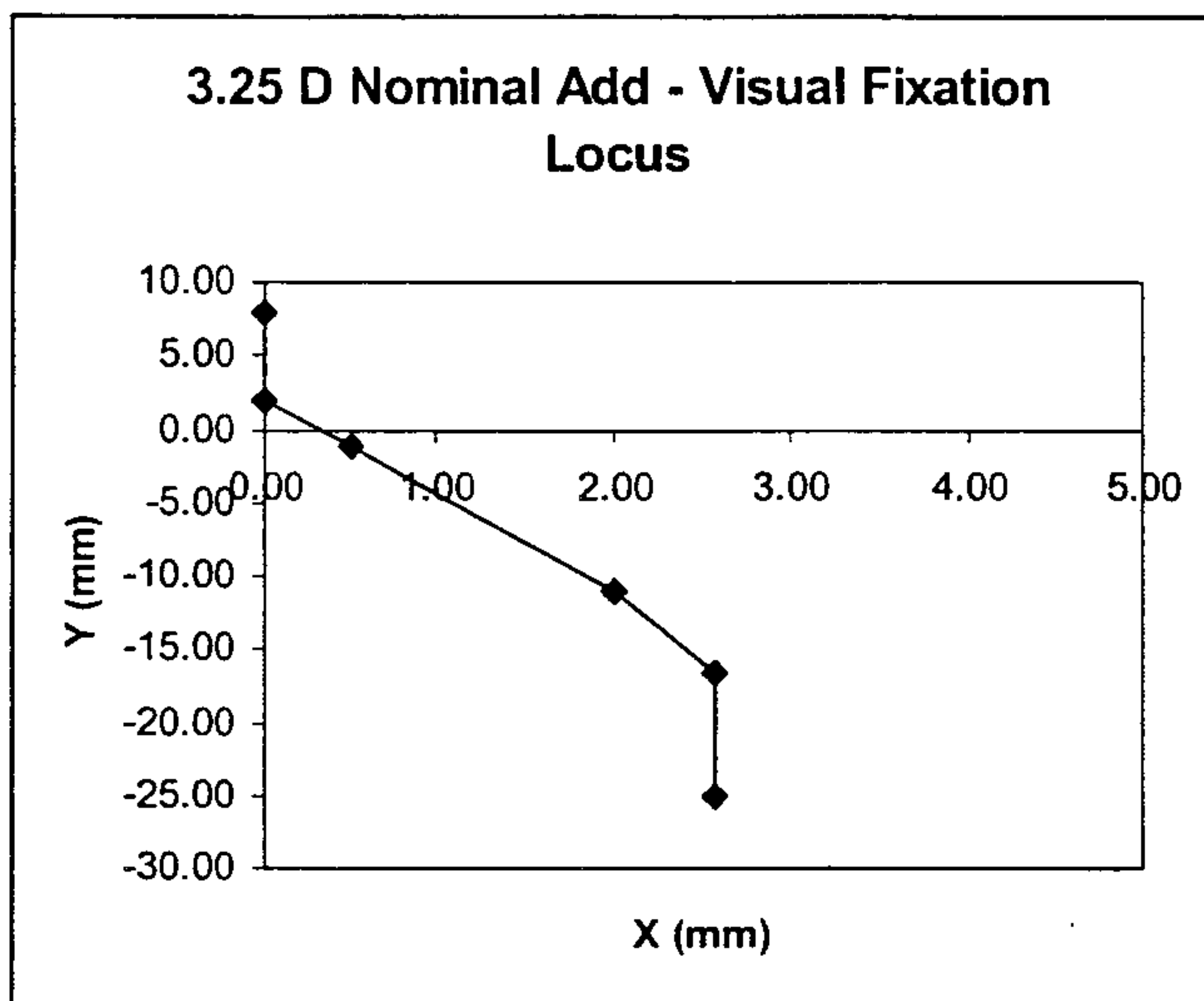


FIGURE 12B



**FIGURE 13A**



**FIGURE 13B**

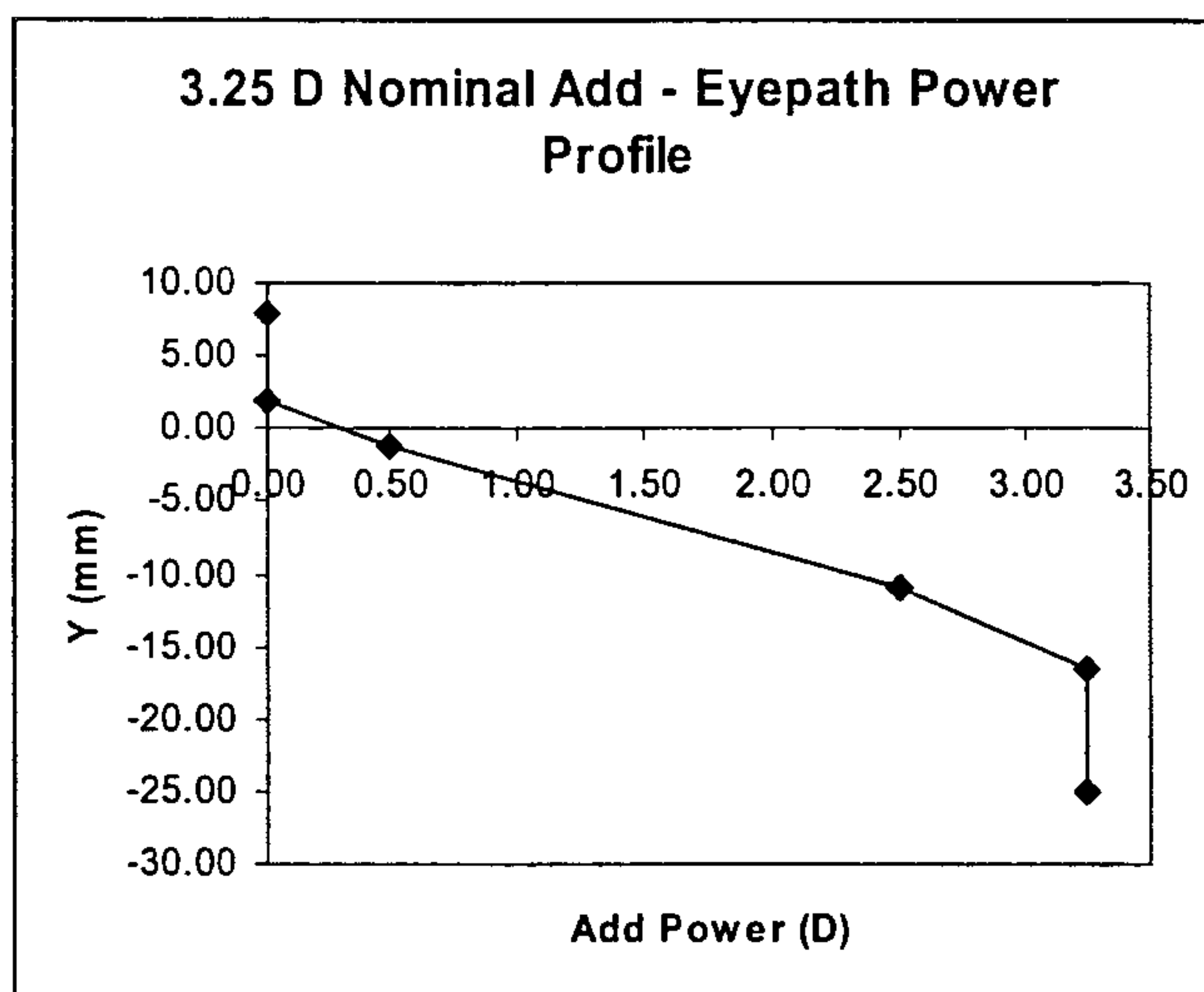




FIGURE 14A

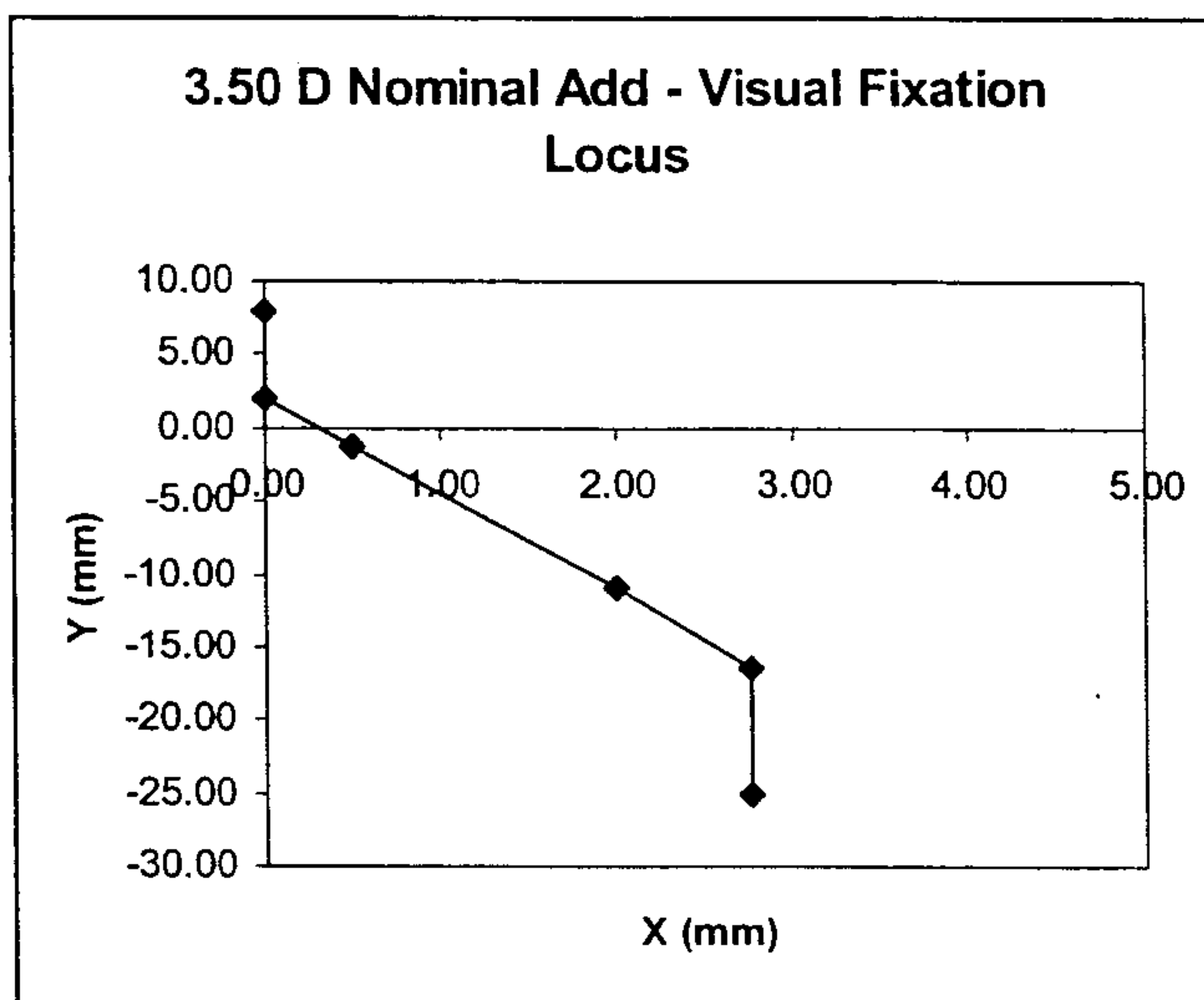
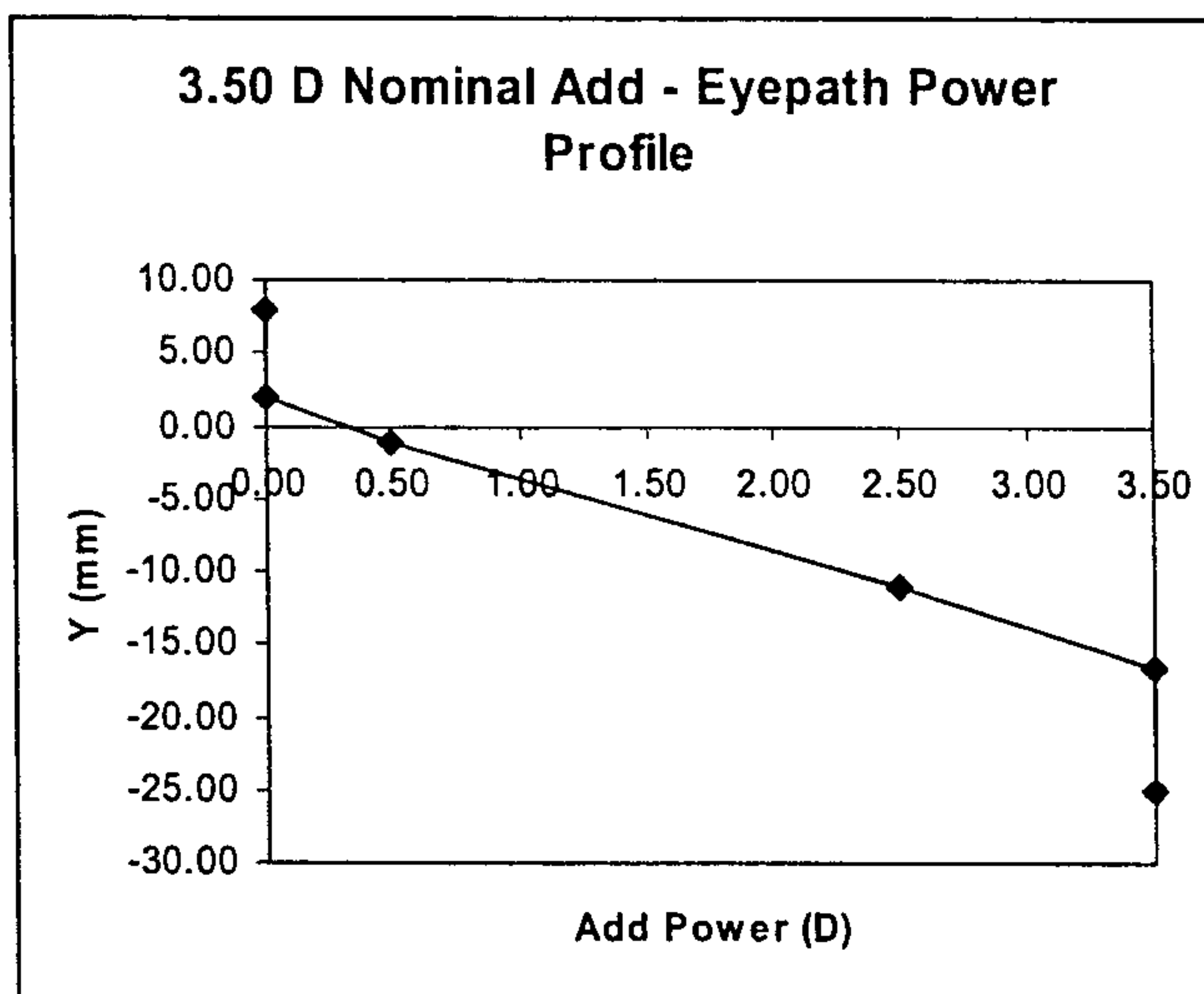
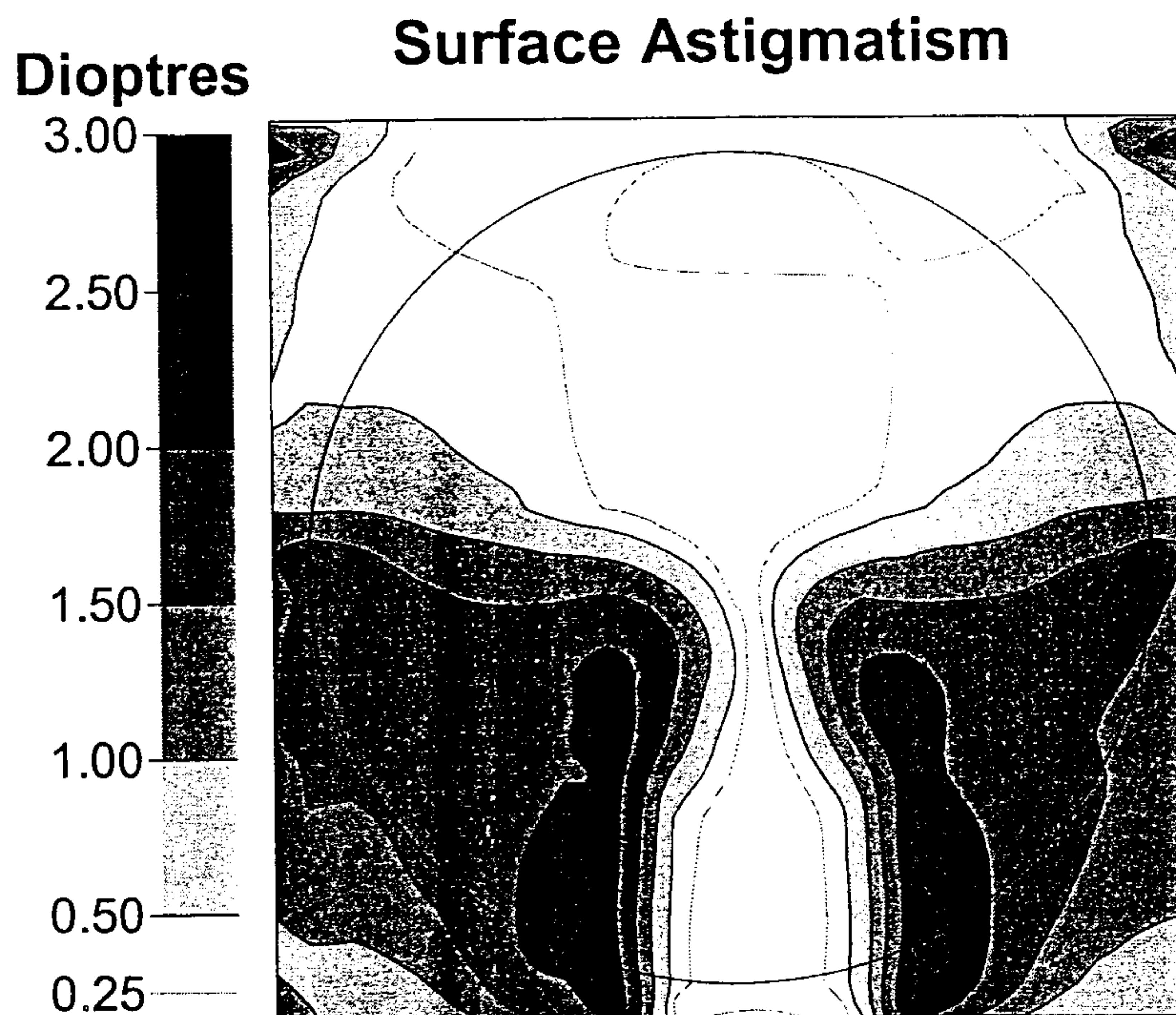


FIGURE 14B



**FIGURE 15A**



**FIGURE 15B**

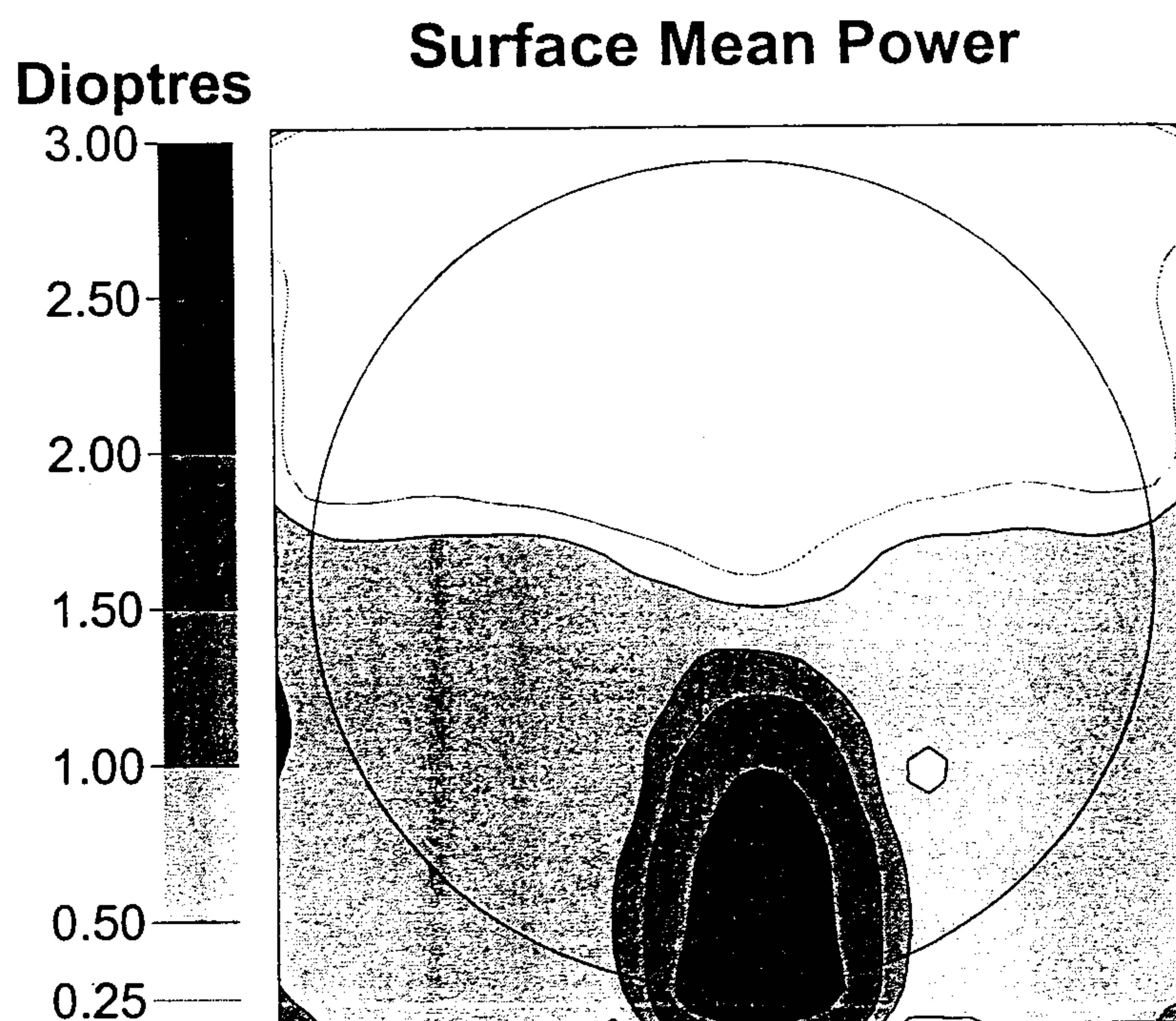


FIGURE 16A

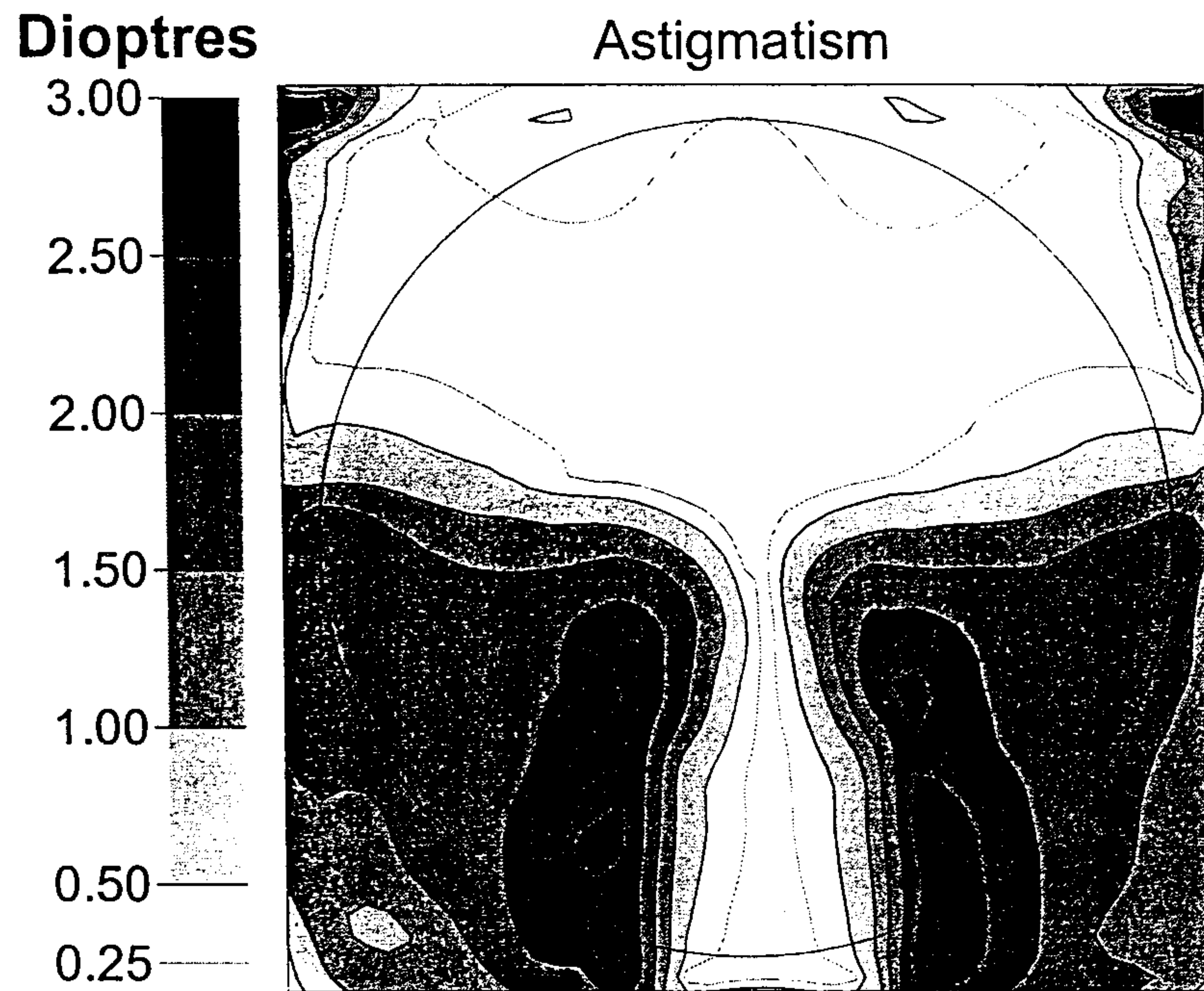


FIGURE 16B

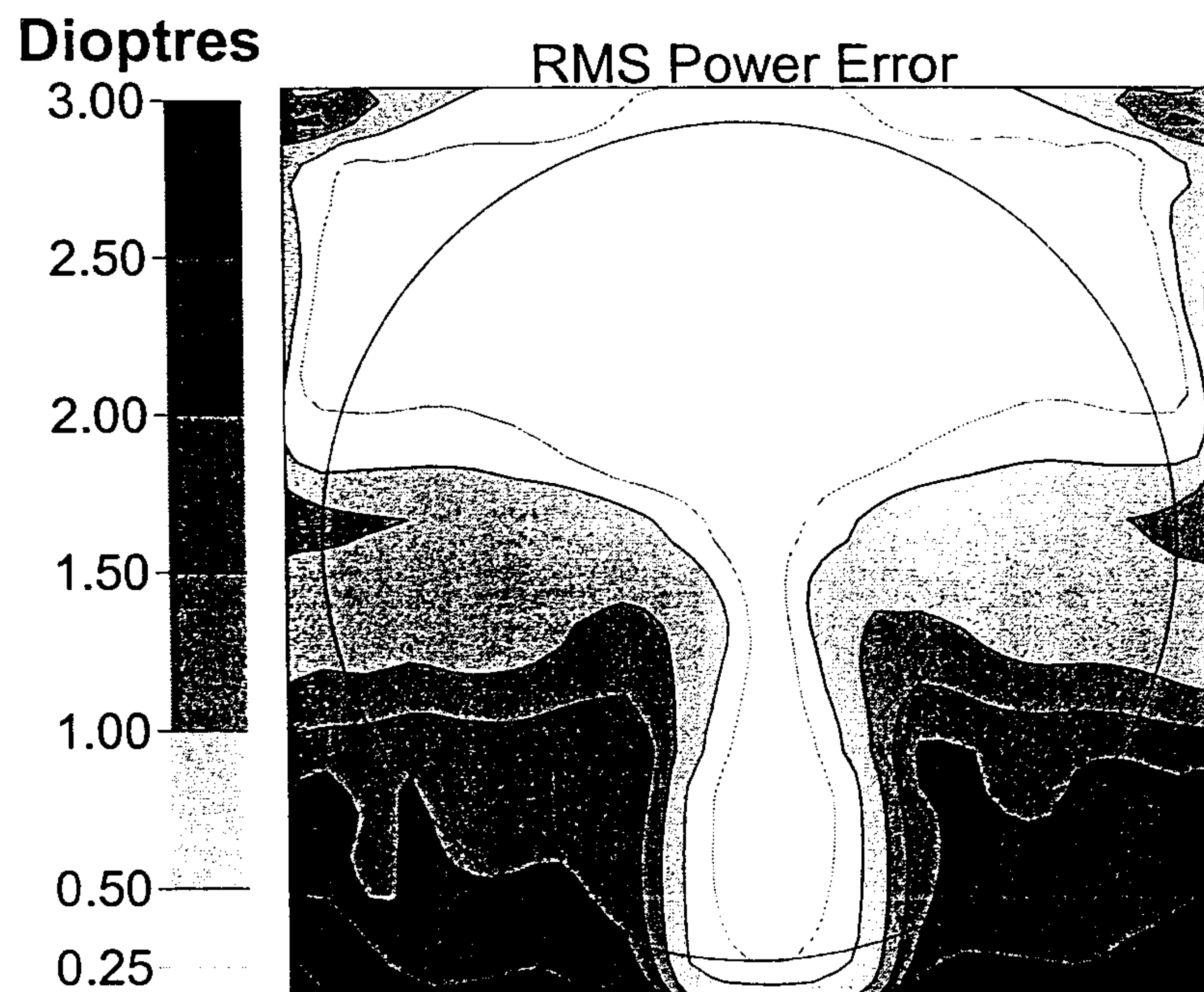


FIGURE 17

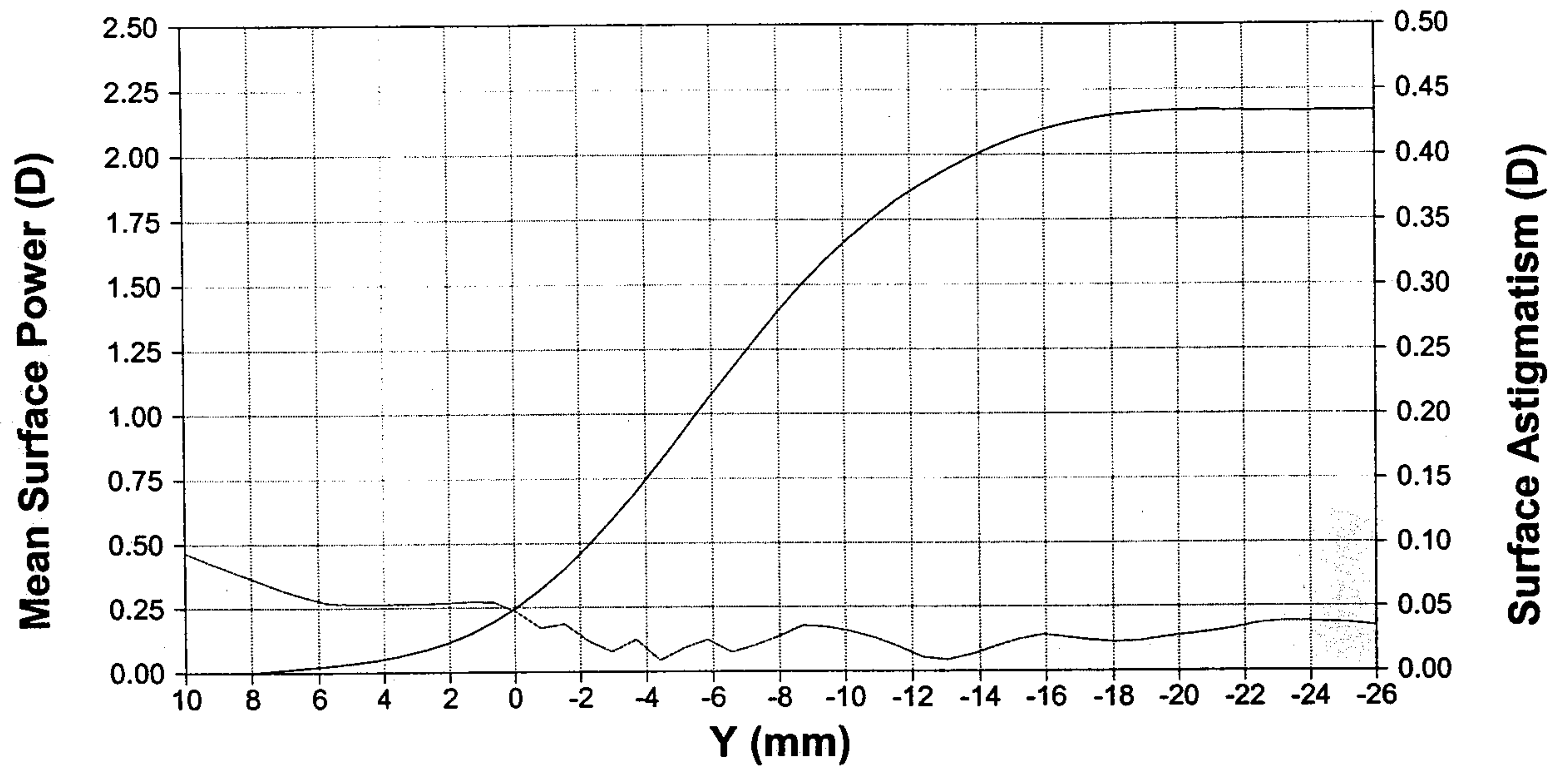


FIGURE 18A

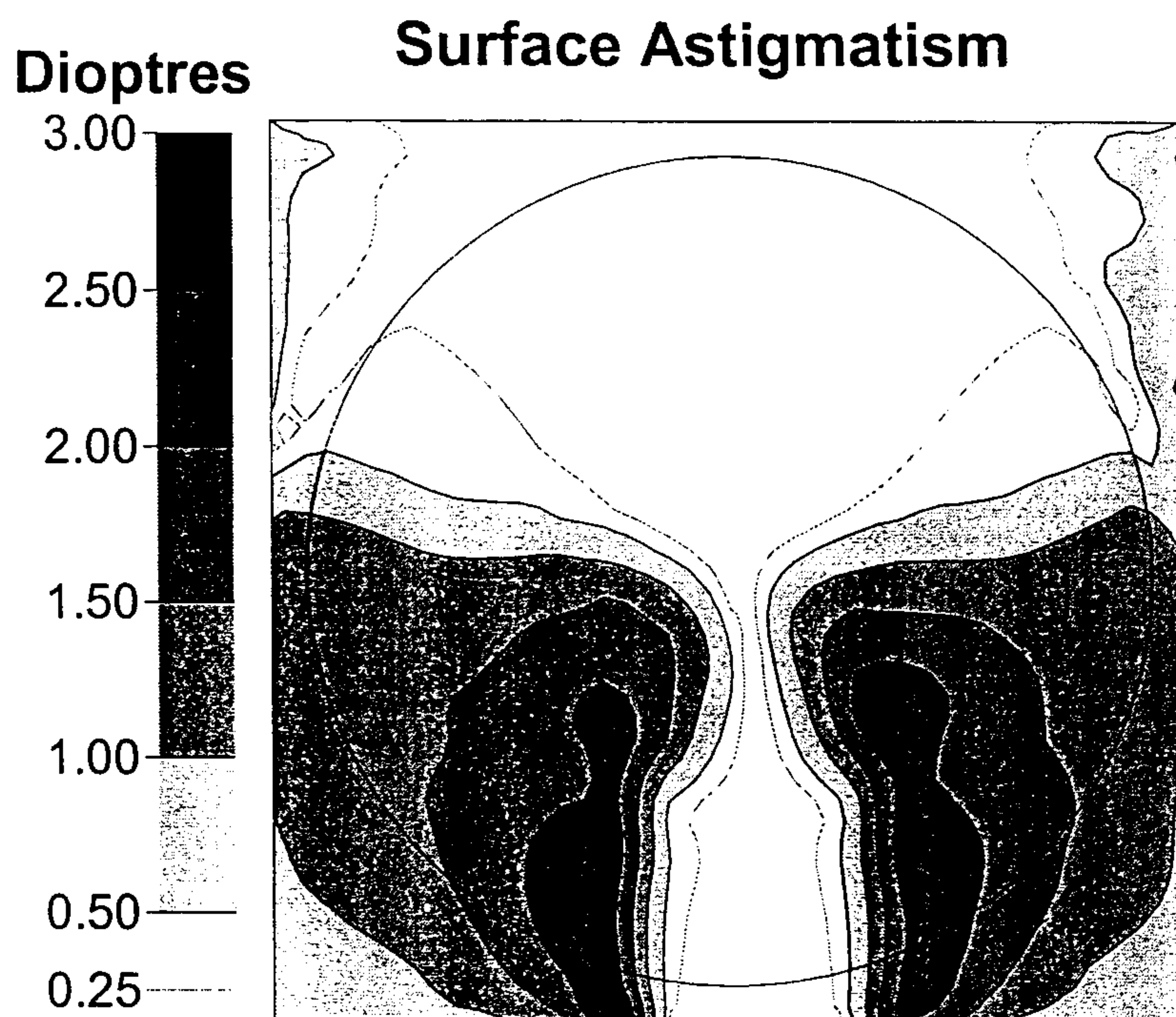


FIGURE 18B

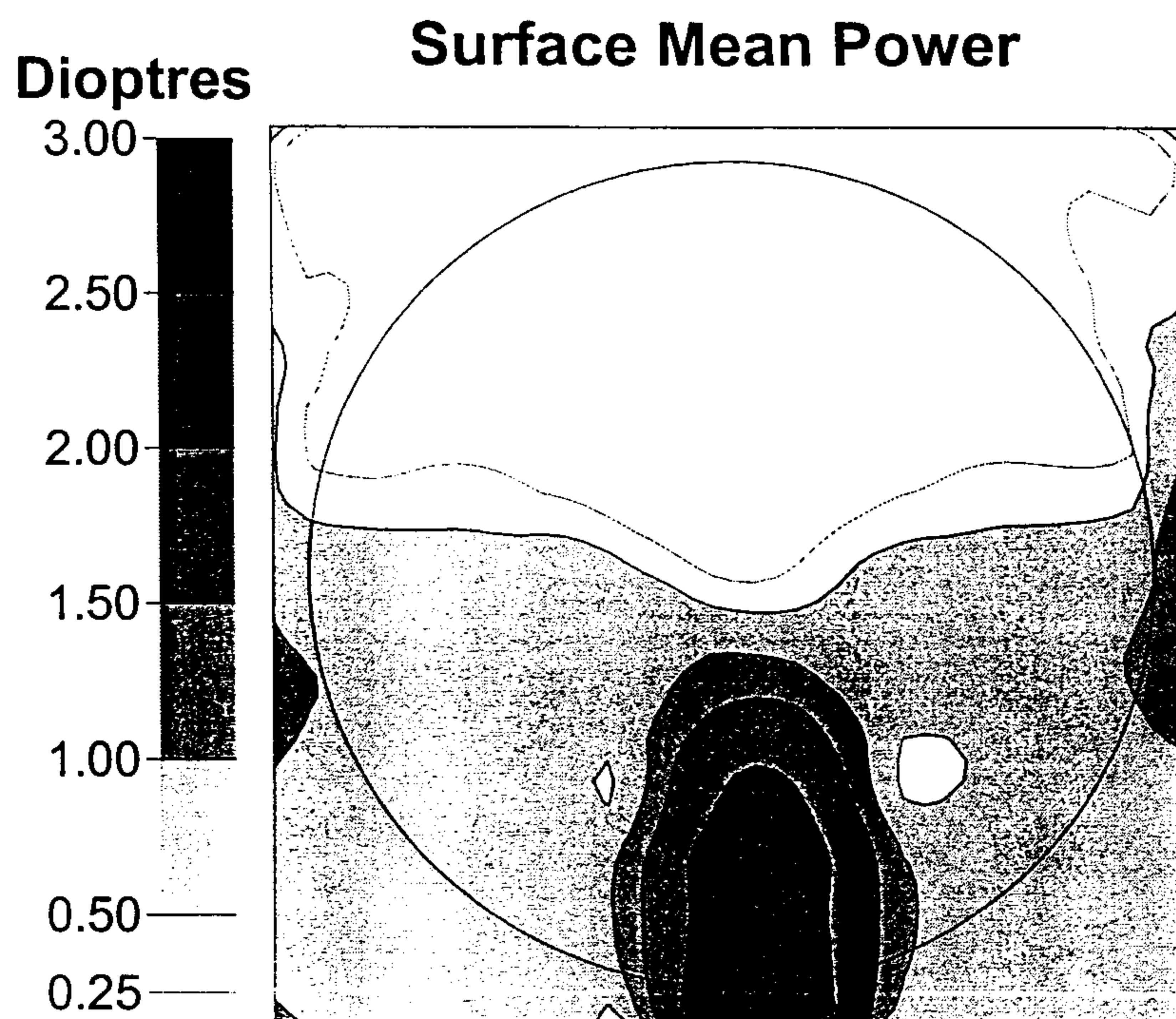


FIGURE 19A

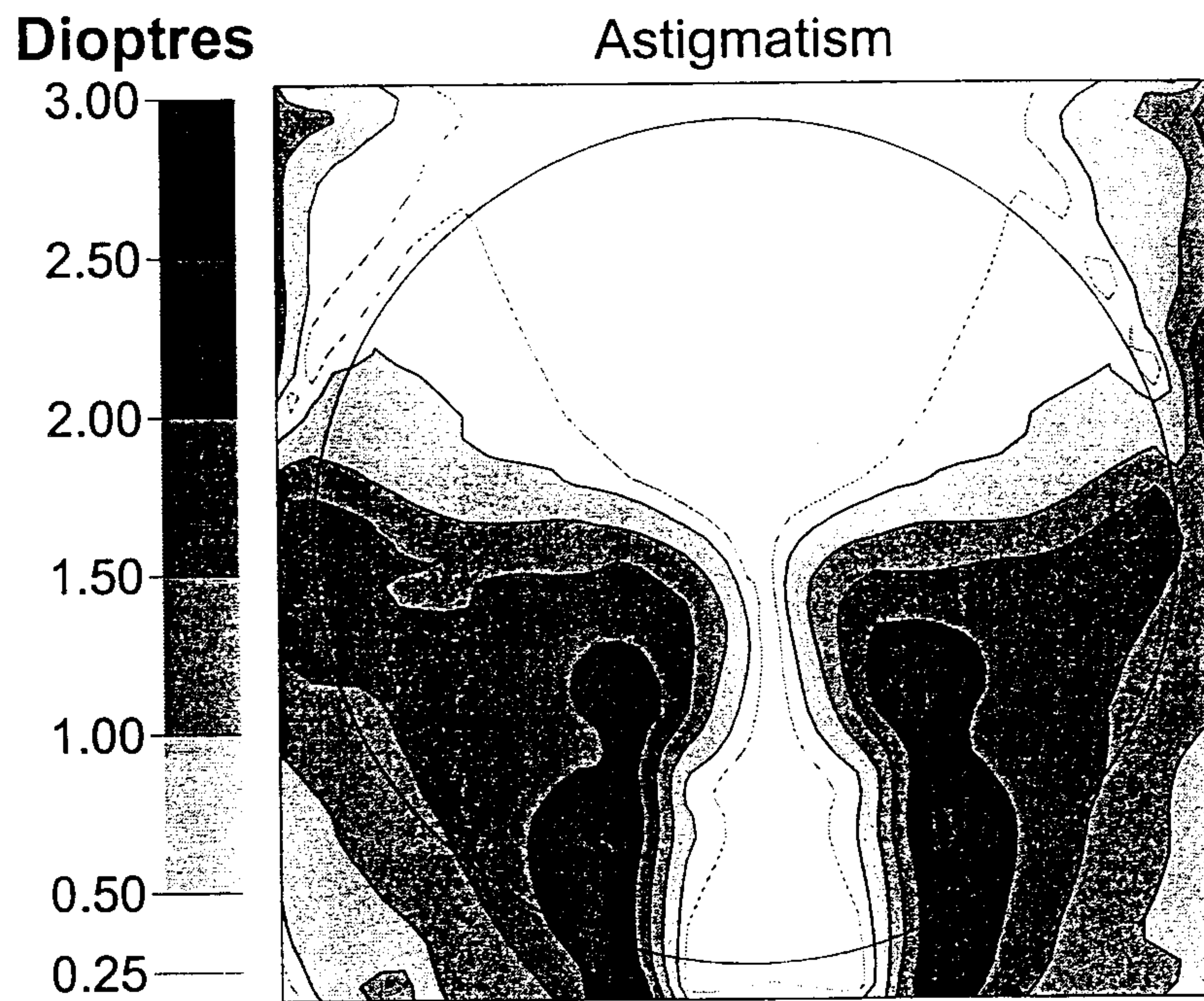


FIGURE 19B

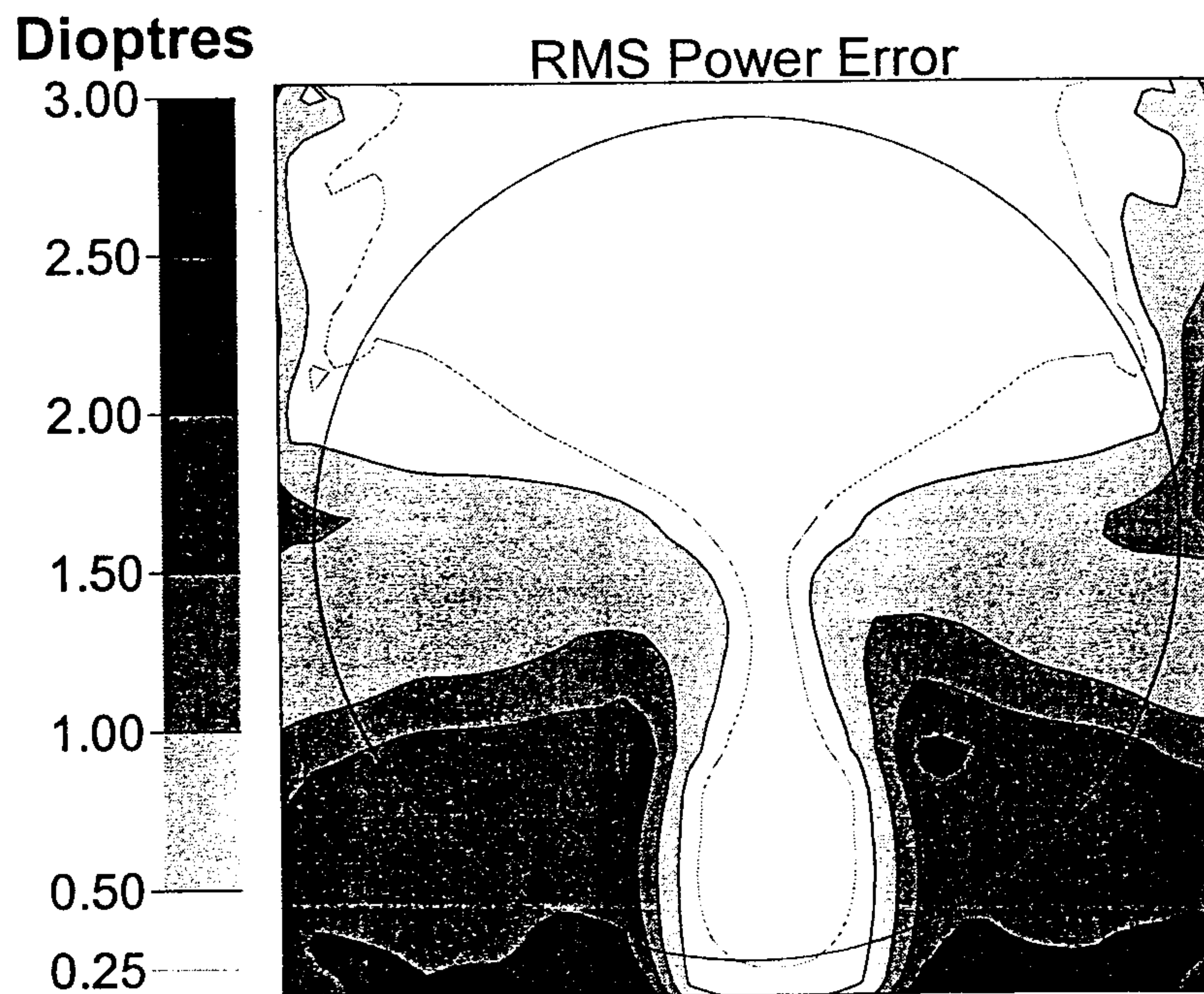


FIGURE 20

