Effect of Side and Central Obstruction For Circular Aperture on Image Intensity of Optical System Using Triangular Object

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Abstract:

In this research , the effect of obstructed circular aperture from the sides by line or by hyperbola has been studied to the specific values of the obstruction (0.25,0.5,0.75) on the image of triangular object by studying triangular spread function of triangular object for ideal optical system or contains focus error (W_{20}= 0.5λ, 1λ) or spherical aberration (W_{40} =1λ) or astigmatism aberration (W_{22}=1λ) with rotation angle(ϕ=0),the results have been compared with the circular aperture and obstructed circular aperture centrally in same values of side obstruction.

The results showed that increasing the side obstruction in the ideal system leads to increase depth of focus of the image while the increasing ratio of central obstruction leads to increase the resolution power of the optical system، as for when there are focus error or aberrations in the optical system, the side obstruction is working to increase the intensity in the formed image and reduce the effect of aberrations on the distribution of intensity at plane of the image, while the central obstruction lead to distortion the formed image by the triangle.

The side obstruction gave good results for the distribution intensity of image and increase the side obstruction lead to increment image clarity, so the value of side obstruction (0.75) better than the other cases selected in the search, so that using the aperture obstructed by line better than using aperture obstructed by a hyperbola as given the preference in values of intensity of the formed image.

تأثير الإعاقة الجانبية والمركزية للفتحة الدائرية على شدة الصورة لنظام بصري باستخدام جسم مثلث

الخلاصة:

تم في هذا البحث دراسة تأثير الفتحة الدائرية المعاقة من الجوانب بخط أو بقطع زائد لقيم محددة من الحجب (0.25,0.5,0.75)على صورة جسم مثلث وذلك بدراسة دالة الانتشار المثلث لنظام بصري محدد بالحيود أو يحتوي على خطأ بؤري مقداره (W_{20}=0.5λ,1λ) أو زيغ كروي(W_{40}=1λ) أو زيغ اللابؤرية (W_{22}=1λ) بزاوية دوران (ϕ=0)، وقد تم مقارنة النتائج مع الفتحة الدائرية و الفتحة الدائرية المعاقة مركزياً بنفس قيم الحجب الجانبي.

بينت النتائج إن زيادة الإعاقة الجانبية في النظام المثالي تؤدي إلى زيادة العمق البؤري للصورة بينما تؤدي زيادة نسبة الإعاقة المركزية إلى زيادة قدرة التحليل للنظام البصري،أما عند وجود خطأ بؤري أو زيوغ في النظام البصري فان الفتحة المعاقة من الجوانب تعمل على زيادة الشدة في الصورة المتكونة وتقلل من تأثير الزيوغ على توزيع الشدة في مستوى الصورة ، بينما تؤدي الإعاقة المركزية إلى تشويه الصورة المتكونة للجسم المثلث.

إن الإعاقة الجانبية أعطت نتائج جيدة لتوزيع الشدة للصورة وان زيادة الإعاقة الجانبية تؤدي إلى زيادة وضوح الصورة، لذلك فان قيمة الإعاقة الجانبية (0.75) أفضل من باقي الحالات المختارة في البحث ، وان استخدام فتحة دائرية معاقة من الجوانب بخط أفضل من استخدام فتحة دائرية معاقة من الجوانب بقطع زائد لما أعطته تلك الإعاقة من أفضلية بقيم الشدة للصورة المتكونة.

1. Introduction:

The diffraction is the major phenomenon limiting the resolving power of the system, For example, consider imaging of a distant star through a telescope, because of the distance of the star, the image should form on the focal plane, ideally as a point, as a result, the image consists of a central maximum in radiance surrounded by other optimal (secondary maxima or minima) which may be mistaken for other sources, for the same reason, a second and weaker star nearby may be missed altogether [1].

An imaging system is said to be diffraction-limited if a diverging spherical wave emanating from a point-source object is converted by the system into a new wave again perfectly spherical, that converges towards an ideal point in the image plane, where the location of that ideal image point is related to the location of the original object point through a simple scaling factor (the magnification) , a factor that must be the same for all points in the image field of interest if the system is to be ideal. For any real imaging system, this property will be satisfied, at best, over only finite regions of the object and image planes, if the object of interest is confined to the region for which this property holds, then the system may be regarded as being diffraction-limited. The two-point resolution criterion has long been used as a quality factor for optical systems, particularly in astronomical applications where it has a very real practical significance, according to the so-called Rayleigh criterion of resolution, two incoherent point sources are "barely resolvedly by a diffraction-limited system with a circular pupil when the center of the Airy intensity pattern generated by one point source falls exactly on the first zero of the Airy pattern generated by the second" [2].

The optical systems use real optical elements with machining and material deficiencies, it may not be possible to mathematically model these and other imperfections present in an optical system. Furthermore, the paraxial approximation which lies at the core of the matrix formulation of the preceding section may not be fully satisfied during the actual use of an optical system. Deviations from the paraxial approximation lead to geometrical aberrations (spherical aberration, coma, astigmatism, etc.), which degrade the quality of the image formed by an optical system, these deviations, at least in principle, can be handled mathematically, in addition, the effects of chromatic aberration and other aberrations are usually minimized by replacing a single lens by a suitable combination of lenses or by optimizing the radii of curvatures of the lenses (lens bending). Furthermore, diffraction of light puts a fundamental limit to the sharpness of optical images. Notwithstanding the fundamental role of diffraction in image formation, particularly in determining the resolving capability of optical systems, it is still useful to describe image formation by optical instruments within the paraxial approximation [3].

The point object is perfect object for testing optical system ,thus the point object has very small radius, therefore using this object is limited when studying the distribution intensity of image for optical systems contain aberrations, because of the aberrations cause complex secondary peaks ,therefore extended objects have been used in this case , because the distinct illumination of this objects such as (line, edge, triangle, etc.) which have wide applications in optical systems[4].

Many researchers studied and discussed the effect of aperture shape on intensity image for different objects, the researchers M.Fernandes and M.Dela Cruz [5] compared between the analytical and numerical fourier-bessel form for diffraction pattern of circle and square apertures, James E. Harvey and Christ Ftaclas[6] discussed the effect of annular aperture on image quality of optical telescope, Tingyu Zhao and Feihong Yu[7] studied the point spread function (PSF) of wave front coding system with a rectangular pupil theoretically and numerically compare with cubic phase wave front coding system with a circular pupil, Al-jizany[8] studied the effect of motion factor on triangular object with circular and annular apertures for optical system has many kinds of aberrations and conclude that the annular aperture better than circle in resolving power and lessening the depth of focus ,also J.N.Maggo et.al. [9]evaluated the optical transfer function for rectangular aperture using uniform and non-uniform illumination for triangular object .

2.Theoretical model:

Diffraction on a circular aperture is present on all optical devices and instruments with circular symmetry.

A perfect lens transforms a plane wave front into a converging spherical wave, any deviations from this ideal behavior can be described by introducing a complex Pupil function, both amplitude and phase aberrations can be presented in a lens, but it is latter that usually play the dominant role, the amplitude aberrations are typically limited to some apodization towards the edge of the pupil[10].

The used object is triangular which can derive its function from the pupil function technique,the triangular is an extended uniform Object, it is consider composed of a set of linear sources parallel and compact. The intensity in an image of triangular object can be found through the use of convolution integration, which is a mathematical process enables us to find intensity to the image of a particular object using the spread function[10],where the convolute complex amplitude in an image of line object with the complex amplitude of triangular to get the complex amplitude of triangular object after taking the integration convolution, i.e.:

$$T(z') = \int_{-\infty}^{\infty} T(z) \cdot L(z'-z)dz ......(1)$$

Where T (z '): is the distribution of image intensity of the triangular object ,T (z) : represents the function of triangular object, L (z'-z) : the line spread function resulting from a line source located within the triangular on the axis z which is defined as follows [8]:

In this research the diffraction-limited system or include aberrations was studied for triangular spread function (TSF) to triangular object have half width of base (L=4) and demonstrated the effect of side obstruction of circular aperture by line and by hyperbola in comparison with circular aperture and annular aperture which studied in previous research [8] for many value of obstruction .

$$L(z'-z) = \int_{y}\int_{x}\int_{x1} \begin{bmatrix} f(x,y) \cdot f(x_1,y) \cdot \\ e^{i(z'-z)x} \cdot e^{-i(z'-z)x_1} \end{bmatrix} dx_1 dxdy ....(2)$$

substitute the value of L (z'-z) from equation (2) in (1) we obtain :

$$T(z') = \int_{-\infty}^{\infty}\int_{y}\int_{x}\int_{x_1} \begin{bmatrix} T(z) \cdot f(x,y) \\ \cdot f^*(x_1,y) \cdot \\ e^{i(z'-z)x} \cdot e^{-i(z'-z)x_1} \end{bmatrix} dx_1 dxdydz ....(3)$$

Where f (x, y) : is a function of the pupil, which can be written as follows[8,11]:

$$f(x,y) = \tau(x,y) \cdot e^{ikW(x,y)} ....(4)$$

k: wave number which equal to (2π/λ), λ:is the wavelength of light used, $\tau(x,y)$: representing the distribution of true amplitude at the pupil and termed the transparency of the pupil, its value equal to one for a uniform aperture.

other term of the equation is aberrations polynomial which represents spherical and astigmatism aberrations [11,12]:

$$\left.\begin{aligned} W(x',y') &= w_{20}(x^2+y^2) + w_{40}(x^2+y^2)^2 + \\ W &= W_{22}(x^2\sin^2\phi + y^2\cos^2\phi + xy\sin 2\phi) \end{aligned}\right\} ......(5)$$

re-arrange equation(3) :

$$T(z') = \int_{-\infty}^{\infty}\int_{y}\int_{x}\int_{x_1} \begin{bmatrix} T(z) \cdot f(x,y) \cdot \\ f^*(x_1,y) \cdot e^{iz'x} \\ \cdot e^{-iz'x} \cdot e^{-iz'x_1} \cdot e^{izx_1} \end{bmatrix} dx_1 dxdydz ....(6)$$

or :

$$T(z') = \int_{y}\int_{x}\int_{x_1} \begin{bmatrix} f(x,y) \cdot f^*(x_1,y) \cdot \\ e^{iz'(x-x_1)} dx_1 dxdy \end{bmatrix} . \int_{-\infty}^{\infty} T(z) \cdot e^{-iz(x-x_1)} dz ....(7)$$

The implicit integration in the last equation represents the spectrum intensity of the triangular object which can be found by inverse Fourier transform [8,9]:

$$\int_{-\infty}^{\infty} T(z)\cdot e^{iz(x-x_1)}dz = \frac{1}{\pi(x-x_1)^2 L}\cdot \tan\left[(x-x_1)\frac{L}{2}\right]\cdot \sin[(x-x_1)L] \quad \ldots\ldots(8)$$

Where L: represents the half width of base triangular object, substitution the spectrum intensity of the triangular object from equation (8) in equation (7) results :

$$T(z') = N\iiint_{y\,x\,x_1}\left[\begin{array}{l} f(x,y)\cdot f^*(x_1,y)\cdot \\ e^{iz'(x-x_1)}.\tan\left[(x-x_1)\frac{L}{2}\right] \\ \cdot\frac{\sin[(x-x_1)L]}{\pi(x-x_1)^2 L}\end{array}\right]dx_1dxdy \quad \ldots\ldots(9)$$

simplify the equation to becomes[8]:

$$T(z') = \frac{LN}{2\pi}\iiint_{y\,x\,x_1}\left[\begin{array}{l}\left\{\frac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot \\ f(x,y)\cdot f^*(x_1,y)\cdot \\ e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy \quad \ldots\ldots\ldots(10)$$

Where N: is a normalization constant is calculated from (T(0) = 1) for the diffraction limited system,this constant depends on (L).

The intensity distribution of the diffraction pattern is affected mainly the shape and size of the used aperture, so the qualification of system and the quality of their performance depends on the appropriate choice of the used aperture shape to ensure the best image .

The limits of integration for triangular spread function were given by the limits of aperture which used in optical system, in this study the following apertures were selected:

2.1. Circular aperture :

The common use of the circular aperture in optical devices have given preference in terms of comparison with the other apertures, the limits of equation (10) determine through the aperture with a circular pupil with area (π) and a radius (1) as shown in (figure 1-a) (the area of circle aperture is same in all cases) as follows :

$$T(z') = \frac{LN}{2\pi}\int_{-1}^{1}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\begin{array}{l}\left\{\frac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2 \\ .f(x,y)\cdot \\ f^*(x_1,y).e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy \quad \ldots\ldots.(11)$$

2.2.Central obstruction circular aperture (annular aperture) :

Annular aperture (figure 1-b) is a considerable practical importance and usually encountered when using control stop in the optical system with circular aperture, we input new term (e) which represent the ratio between radius of circle aperture and radius of obstructed aperture or :

$$e = \frac{r}{R}$$

$$\because R = 1 \Rightarrow e = r$$

Equation of (TSF) for annular aperture results from subtraction TSF of obstructed region from same function of circle aperture so:

$$T(z')=\frac{LN}{2\pi}\left[\begin{array}{l}\int_{-1}^{1}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\begin{array}{l}\left\{\dfrac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\\ \cdot f(x,y)\cdot f^*(x_1,y)\\ \cdot e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy-\\ \int_{-e}^{e}\int_{-\sqrt{e^2-y^2}}^{\sqrt{e^2-y^2}}\int_{-\sqrt{e^2-y^2}}^{\sqrt{e^2-y^2}}\left[\begin{array}{l}\left\{\dfrac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\\ \cdot f(x,y)\cdot\\ f^*(x_1,y)\cdot e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy\end{array}\right] \text{.....(12)}$$

2.3. Side obstruction circular aperture by line :

To find (TSF) for circular aperture obstructed by lines at sides as shown in (figure 1-c) we divide this aperture into three regions (1,2,3) and derive the equation of intensity for each region then collect all equations to result the equation of intensity for circular aperture obstructed by side, the TSF results from intensity function of this regions, so must find the intersection points of circle and lines which can be obtained as following :

Equation of circle is :

$$y^2+x^2=R^2$$
$$\because R=1\Rightarrow$$
$$\therefore x=\sqrt{1-y^2}\text{......(13)}$$

Equation of lines are:

$$x=c,x=-c\text{....(14)}$$

Where (c): is the distance from the circumference to point at axis represent the line.

From eq.(13) & eq.(14) we get :

$$c^2=1-y^2\Rightarrow$$
$$y=\pm\sqrt{1-c^2}$$

Then intersection points are :

$$(c,\sqrt{1-c^2}),(c,-\sqrt{1-c^2}),(-c,\sqrt{1-c^2}),(-c,-\sqrt{1-c^2})$$

,thus the equation of (TSF) becomes

$$T(z')=\frac{LN}{2\pi}\left[\begin{array}{l}\int_{-\sqrt{1-c^2}}^{\sqrt{1-c^2}}\int_{-c}^{c}\int_{-c}^{c}\left[\begin{array}{l}\left\{\dfrac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot\\ f(x,y)\cdot\\ f^*(x_1,y)\cdot e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy+\\ \int_{\sqrt{1-c^2}}^{1}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\begin{array}{l}\left\{\dfrac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot\\ f(x,y)\cdot\\ f^*(x_1,y)\cdot e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy+\\ \int_{-1}^{-\sqrt{1-c^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\begin{array}{l}\left\{\dfrac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot\\ f(x,y)\cdot\\ f^*(x_1,y)\cdot e^{iz'(x-x_1)}\end{array}\right]dx_1dxdy\end{array}\right] \text{.....(15)}$$

2.4. Side obstruction circular aperture by hyperbola:

Triangular spread function for circular aperture obstructed by hyperbola from sides as shown in (figure 1-d) can be found by dividing this aperture into three regions and found intersection points of circle and hyperbola curve, then :

Equation of hyperbola is:

$$\frac{x^2}{a^2}-\frac{y^2}{b^2}=1 \Rightarrow x=a\sqrt{1+\frac{y^2}{b^2}} \text{.......(16)}$$

Subtract eq.(16) from eq.(13) we obtain :

$$\sqrt{1-y^2}=a\sqrt{1+\frac{y^2}{b^2}} \Rightarrow 1-y^2=a^2+\frac{a^2}{b^2}y^2 \Rightarrow$$

$$y=\pm\sqrt{\frac{1-a^2}{\left(\frac{a^2}{b^2}+1\right)}} \text{............(17)}$$

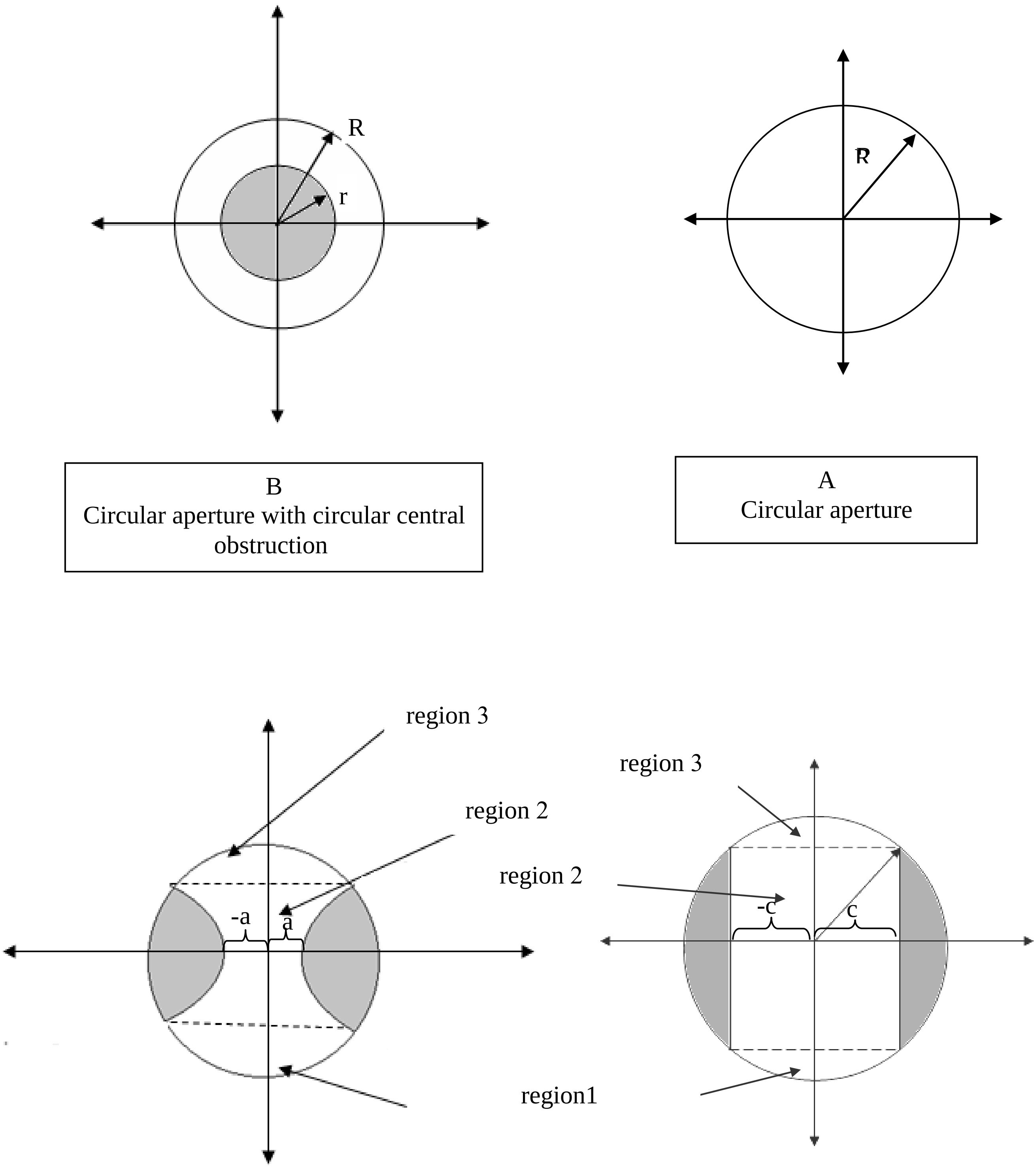
,

Where (a): represent the distance from center point to tip of hyperbola (which represent also value of obstruction),

(b):represent the value determine in vertical height of hyperbola curve(which taken (b=4) as constant in research).

From eq.(17) and eq.(16) and eq.(13) TSF can be written as following:

$$T(z')=\frac{LN}{2\pi}\left[\begin{array}{l}
\displaystyle\int_{-\sqrt{\frac{1-a^2}{\left(\frac{a^2}{b^2}+1\right)}}}^{\sqrt{\frac{1-a^2}{\left(\frac{a^2}{b^2}+1\right)}}}\int_{-a\sqrt{1+\frac{y^2}{b^2}}}^{a\sqrt{1+\frac{y^2}{b^2}}}\int_{-a\sqrt{1+\frac{y^2}{b^2}}}^{a\sqrt{1+\frac{y^2}{b^2}}}\left[\left\{\frac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot f(x,y)\cdot f^*(x_1,y)\cdot e^{iz'(x-x_1)}\right]dx_1dxdy+\\
\displaystyle\int_{\sqrt{\frac{1-a^2}{\left(\frac{a^2}{b^2}+1\right)}}}^{1}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\left\{\frac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot f(x,y)\cdot f^*(x_1,y)\cdot e^{iz'(x-x_1)}\right]dx_1dxdy+\\
\displaystyle\int_{-1}^{-\sqrt{\frac{1-a^2}{\left(\frac{a^2}{b^2}+1\right)}}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}}\left[\left\{\frac{\sin\left[(x-x_1)\frac{L}{2}\right]}{(x-x_1)\frac{L}{2}}\right\}^2\cdot f(x,y)\cdot f^*(x_1,y)\cdot e^{iz'(x-x_1)}\right]dx_1dxdy
\end{array}\right] \text{.....(18)}$$



B
Circular aperture with circular central obstruction

A
Circular aperture

D
Circular aperture with side obstruction by hyperbola

C
Circular aperture with side obstruction by line

Figure (1) shape of apertures

3.Results and Discussion :

The triangular spread function has been solved by using the program (MathCAD) for ideal optical system or contain focus error (W_{20}=0.5λ,1λ) or contain spherical aberration (W_{40}=1λ) or astigmatism aberration (W_{22}=1λ) with rotation angle(ϕ=0).

The results of circular and annular apertures have been calculated in the previous research[8],the previous results were computed using numerical method ,in this research evaluate results using mathematical programming, the previous and present results (numerical and mathematical solution) are agreement at the common cases.

The figures (2,3,4) show the effect of (annular, side obstruction by line, side obstruction by hyperbola) circular apertures respectively, on intensity distribution of triangular image for ideal optical system, the results show that increase in ratio of central obstruction lead to decrease in half width of curves, this is work to increase the resolution power of optical system because the obstruction lead to decrease the flux of passing light therefore the area under curve to become less than circular aperture, while the effect of sides obstruction (by line or hyperbola) leads to increase in half width of curves because centering the enter light through aperture, this is work to decrease the resolution power of systems, but the depth of focus is increased in optical systems whenever an increase in side obstruction accrued.

The figures (5,6,7) indicate the effect of focus error (W_{20}=0.5λ) in optical system for (annular, side obstruction by line, side obstruction by hyperbola) circular apertures respectively. The effect of focus error leads to degeneration of the intensity in central peak to (0.67531) for circular aperture.

The ratio of central obstruction leads to decrease in the value of central intensity whenever an increase in obstruction occurs as shown in table (1),because deviation of light at focus therefore any central obstruction effect on intensity of image, so, this aperture is not useful in systems that contain focus error, while the increase in sides obstruction lead to increase in the value of normalization of central intensity of the triangular image of aperture obstructed by line which are shown clearly in table (2) and for aperture obstructed by side hyperbola in table (3) .

When the system contain focus error (W_{20}=1λ) and spherical aberrations (W_{40}=1λ) as shown in figures (8,9,10), for (annular, side obstruction by line, side obstruction by hyperbola) circular apertures respectively, the value of normalization intensity became (0.46012) when the spherical aberration and focus error were found in system using circular aperture.

The increase of obstruction ratio of annular aperture work to decrease the value of central intensity of triangular image as show in table (1), the effect of spherical aberration and focus error lead to unsharp and lower intensity at focus point, in addition to effect of obstruction quantity which work to lessening central light intensity entering through aperture.

The effect of side obstruction (by line or hyperbola), lead to an increase in values of normalization central intensity of image whenever an increase in side obstruction occurs as indicated in tables (2,3) for side line and side hyperbola obstruction respectively, because of the side obstruction work to entering light at center of aperture and don't allow light to pass at edges which lead to make the intensity of image more centering and decrease effect of aberration in system .

The figures (11,12,13) show us effect of astigmatism aberration (w_{22}=1) with rotation angle (ϕ=0) and existence focus error (w_{20}=1) for (annular, side obstruction by line, side obstruction by hyperbola) apertures respectively.

The effect of focus error and astigmatism aberration lead to make the image unformed, and when using annular aperture the image be more unformed because the appearance of central intensity far from center of system axis ,in addition to the central obstruction lead to a decrease in the value of intensity (table 1).

The side obscuration work to minimize the effect of astigmatism aberration ,so the intensity rise to (0.976, 0.97456) when obstruction by line and hyperbola at the highest obstruction (c=a=0.75) respectively , as show in tables (2,3) .

Table (1) central intensity of triangular image for annular aperture with different states of aberrations

state	circular	annular		
When $z^\backslash=0$	e=0	e=0.25	e=0.5	e=0.75
$w_{20}=0,w_{40}=0,w_{22}=0$	1	1	1	1
$w_{20}=0.5,w_{40}=0,w_{22}=0$	0.67531	0.66723	0.61417	0.4940
$w_{20}=1,w_{40}=1,w_{22}=0,\phi=0$	0.46012	0.44683	0.37392	0.32627
$w_{20}=1,w_{40}=0,w_{22}=1, \phi=0$	0.23079	0.21175	0.09764	0.04154

Table (2) central intensity of triangular image for aperture obstructed by side line with different states of aberrations

state	circular	side obstruction by line		
When $z^\backslash=0$	c=1	c=0.75	c=0.5	c=0.25
$w_{20}=0,w_{40}=0, w_{22}=0$	1	1	1	1
$w_{20}=0.5,w_{40}=0,w_{22}=0$	0.67531	0.81673	0.95219	0.99666
$w_{20}=1,w_{40}=1,w_{22}=0, \phi=0$	0.46012	0.52512	0.81927	0.98668
$w_{20}=1,w_{40}=0,w_{22}=1, \phi=0$	0.23079	0.33499	0.72203	0.976

Table (3) central intensity of triangular image for aperture obstructed by side hyperbola with different states of aberrations

state	circular	Side obstruction by hyperbola		
When $z\backslash=0$	a=1	a=0.75	a=0.5	a=0.25
w20=0,w40=0, w22=0	1	1	1	1
w20=0.5,w40=0,w22=0	0.67531	0.81443	0.95081	0.99653
w20=1,w40=1,w22=0, ϕ=0	0.46012	0.52328	0.8145	0.98616
w20=1,w40=0,w22=1, ϕ=0	0.23079	0.33184	0.71349	0.97456

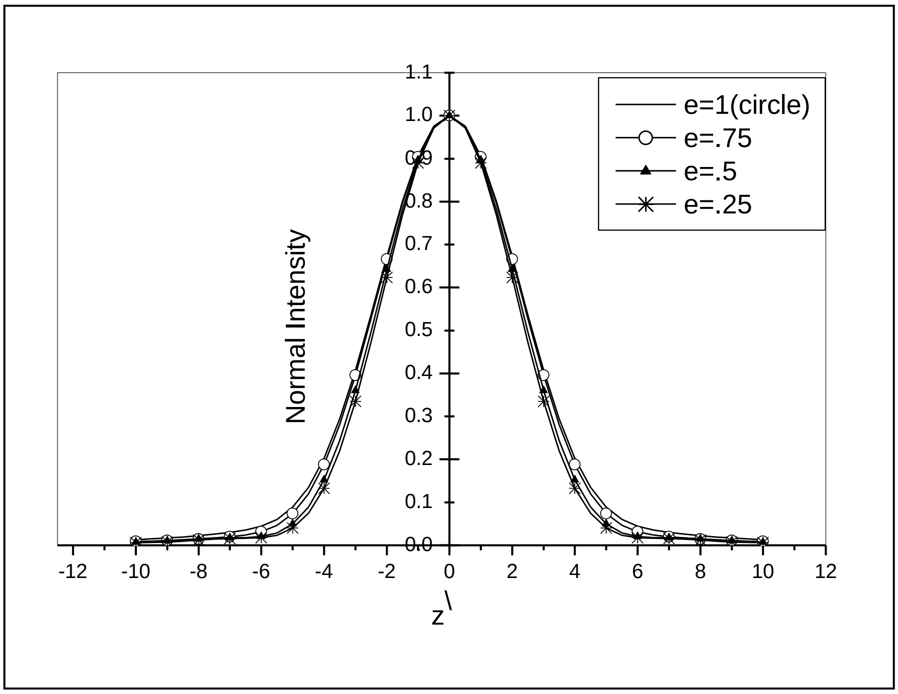


Figure (2)
Intensity distribution of triangular object image for ideal optical system having different values of central obstruction

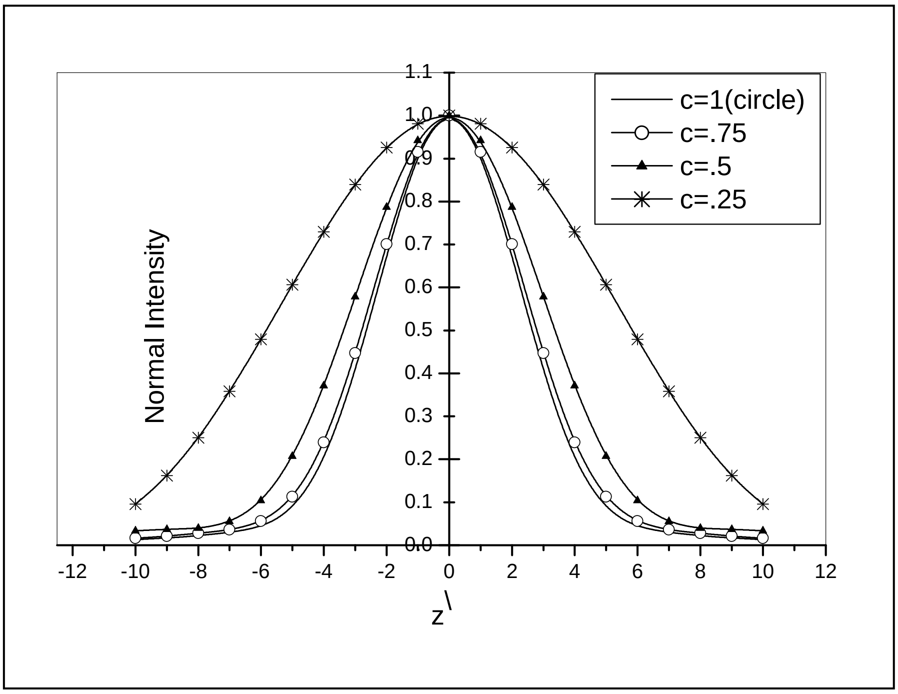


Figure (3)
Intensity distribution of triangular object image for optical ideal system having different values of side obstruction by line

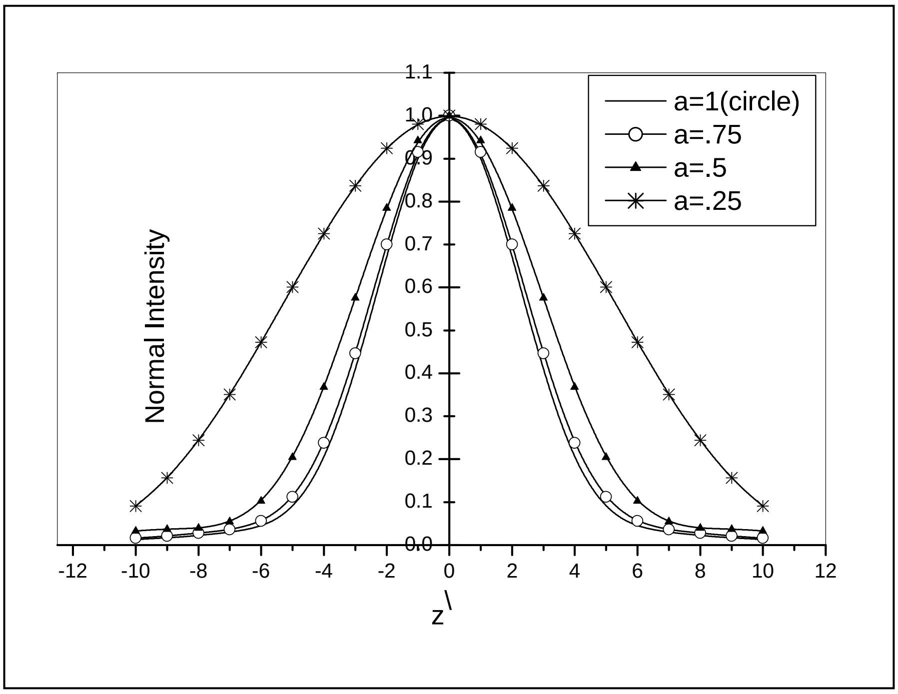


Figure (4)
Intensity distribution of triangular object image for optical ideal system having different values of side obstruction by hyperbola

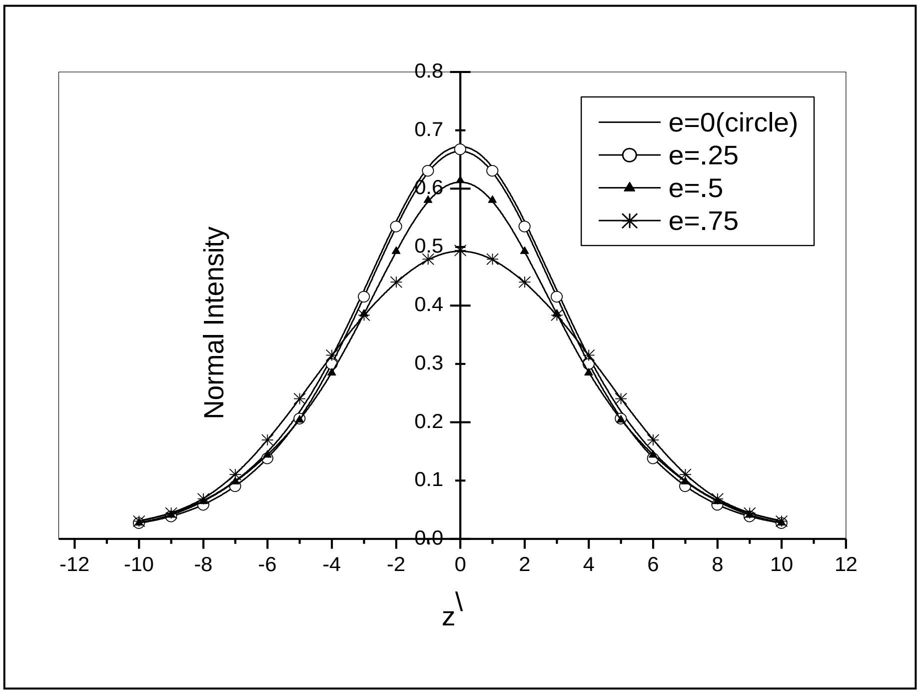


Figure (5)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=0.5) with different values of central obstruction

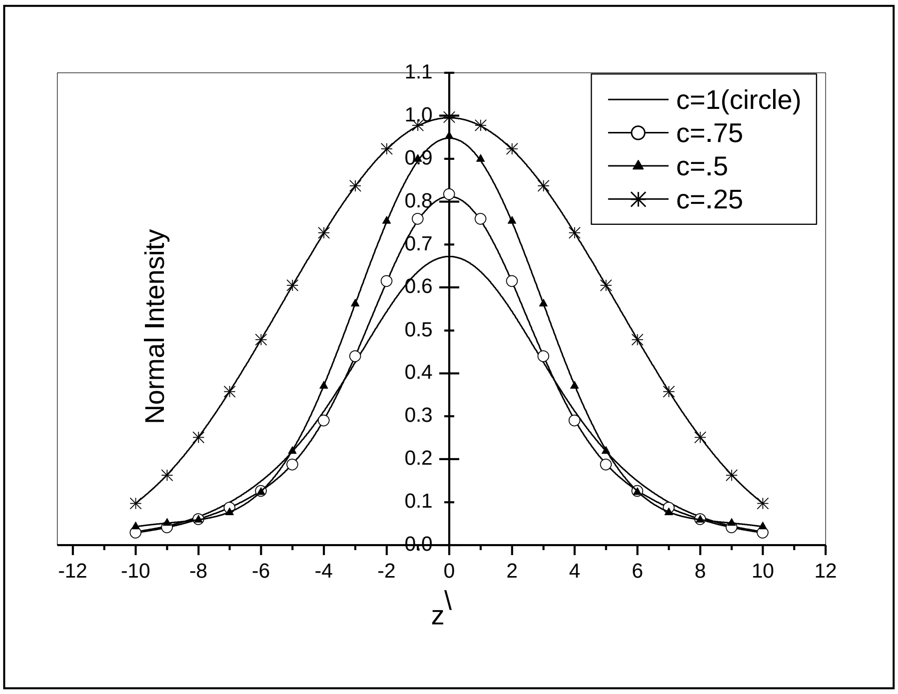


Figure (6)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=0.5) with different values of side obstruction by line

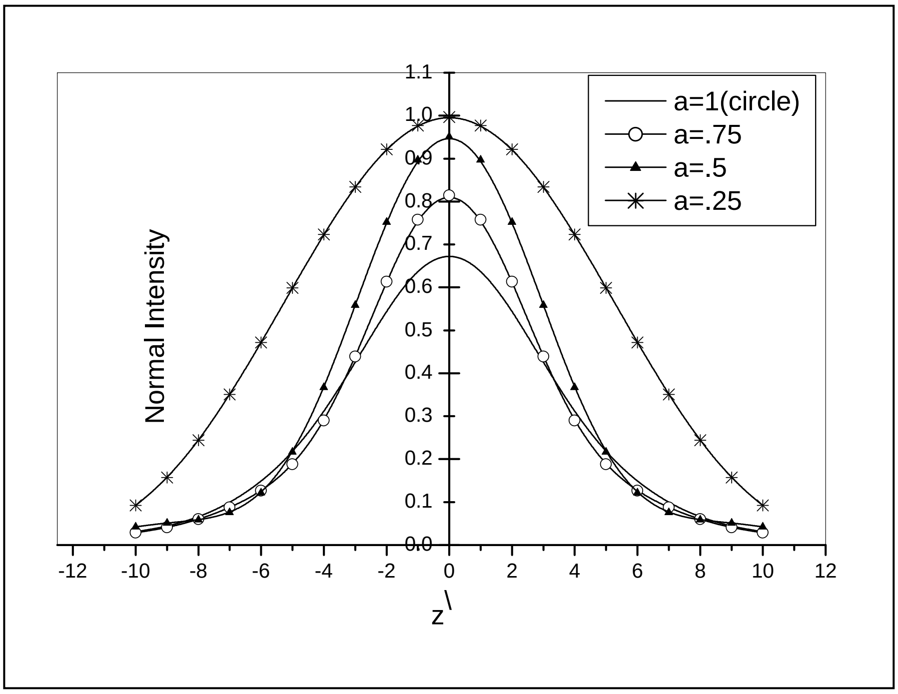


Figure (7)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=0.5) with different values of side obstruction by hyperbola

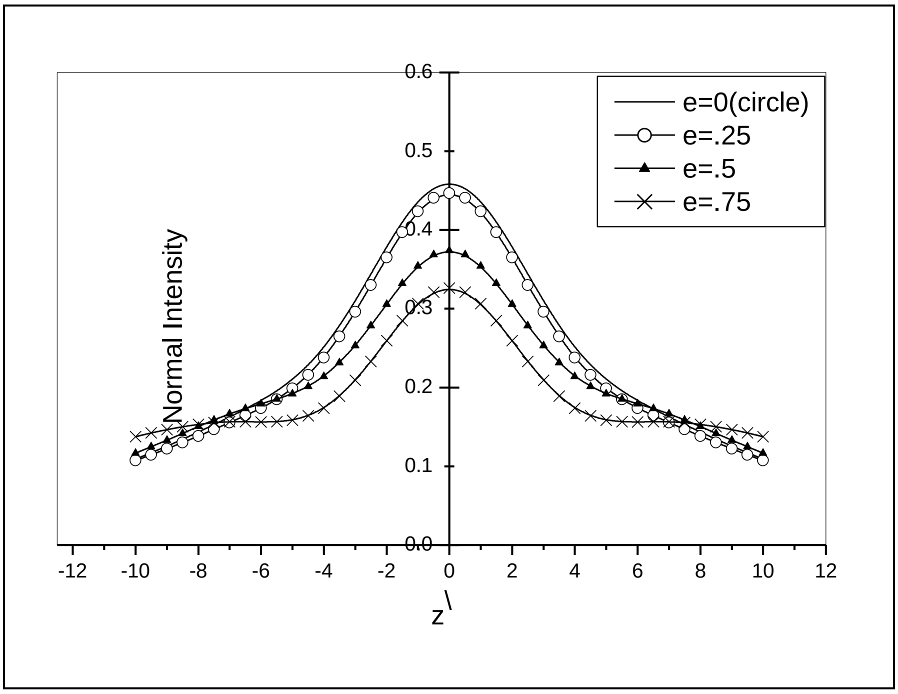


Figure (8)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and spherical aberration (w_{40}=1) with different values of central obstruction

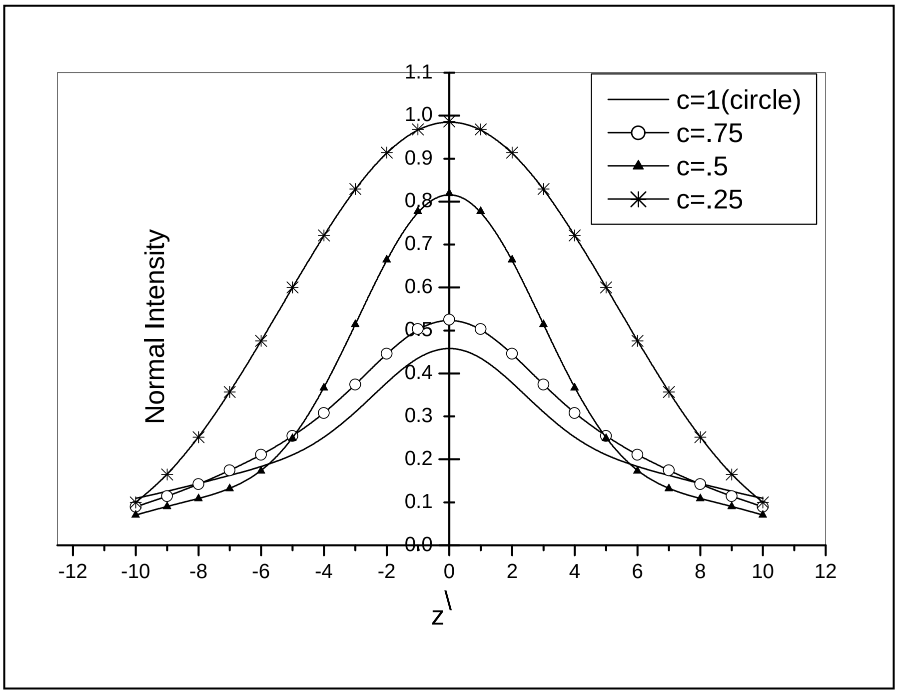


Figure (9)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and spherical aberration (w_{40}=1)with different values of side obstruction by line

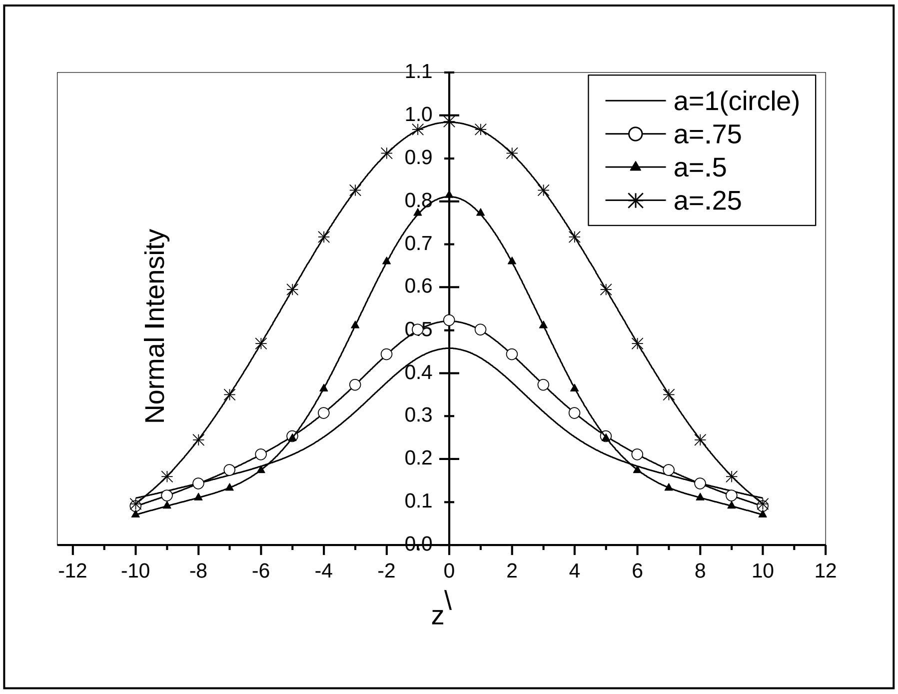


Figure (10)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and spherical aberration (w_{40}=1) with different values of side obstruction by hyperbola

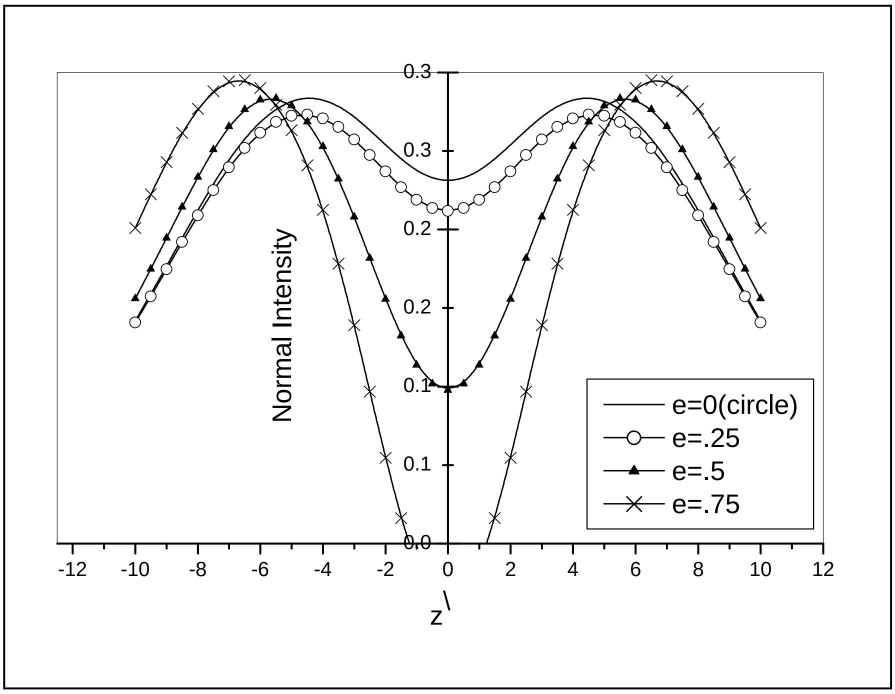


Figure (11)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and astigmatism aberration (w_{22}=1) with rotation angle (ϕ=0) for different values of central obstruction

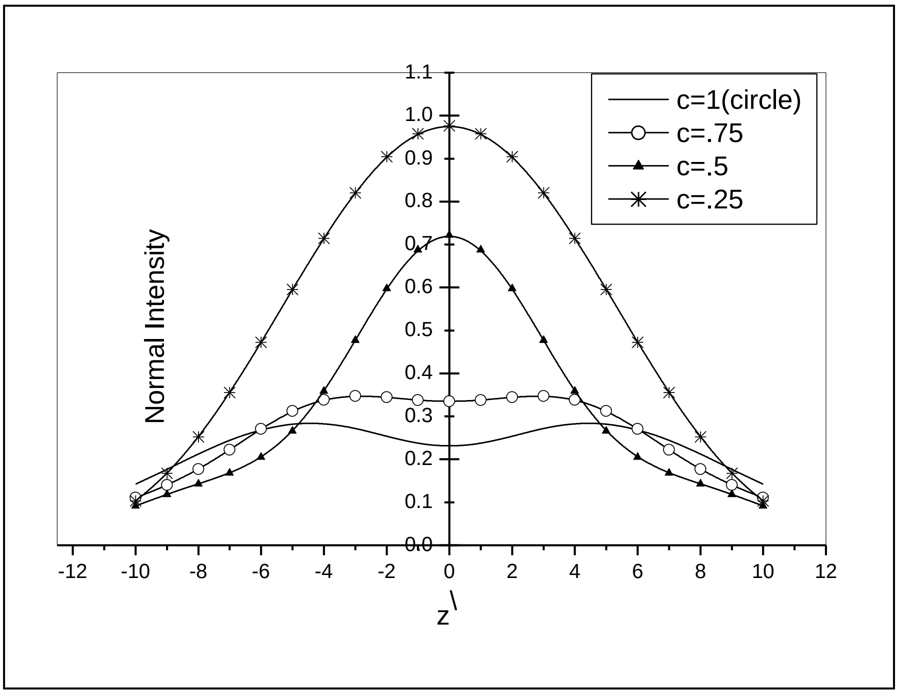


Figure (12)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and Astigmatism aberration (w_{22}=1) with rotation angle (ϕ=0) for different values of side obstruction by line

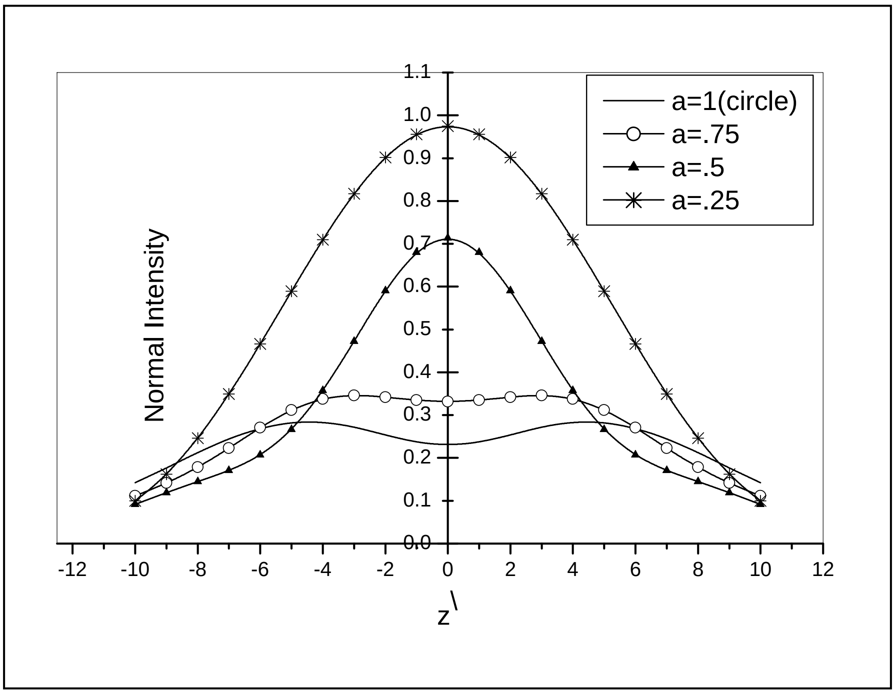


Figure (13)
Intensity distribution of triangular object image for optical system contain focus error (w_{20}=1) and Astigmatism aberration (w_{22}=1) with rotation angle (ϕ=0) for different values of side obstruction by hyperbola

4. Conclusions:

1- Using annular aperture in ideal optical system lead to an increase in resolution power, while using side obstruction circular aperture lead to an increase in depth of focus .

2- When the optical system contains focus error, or aberrations, using side obstruction circular aperture lead to an increase in intensity of the image, while annular aperture work to decrease the intensity and the image will be unshaped, therefore using side obstruction circular aperture is the better than annular aperture or circular aperture in the systems contain aberrations .

3- An increase in side obstruction cause an increase in intensity value of the image distribution, therefore case of obstruction (0.75) better than other cases.

4- The side obstruction circular aperture by line better than side obstruction circular aperture by hyperbola in values of image intensity at all cases.

5. References:

[1] Okan K. Ersoy ,"Diffraction Fourier Optics and Imaging", John Wiley & Sons, Inc., New Jersey,USA, 2007.

[2] Joseph W. Goodman, "Introduction to Fourier Optics",the McGRAW-HILL companies,ink., second edition, USA, 1996.

[3] K. K. Sharma ,"optics Principles and Applications" Elsevier Inc.,UK,2006.

[4]Hanaa M. I. Alanbari,"the quality of optical image for alens having different apertures", M.Sc. thesis, Almustansirya University, Iraq,1989.

[5] M.Fernandes guasti,M.Dela cruz Heredia, "diffraction pattern of Circle / square aperture ", Journal of modern optics,Vol.40,No.6,P.1073-1080,1993.

[6] James E. Harvey and Christ Ftaclas," Diffraction effects of telescope secondary mirror spiders on various image-quality criteria', applied optics ,Vol. 34, No. 28,P. 6337- 6349 ,1995.

[7]Tingyu Zhao,Feihong Yu,"Point spread function analysis of a cubic phase wave front coding system with a circular pupil", Optical Society of America, Optics Express ,Vol. 20, No. 3, P. 2408- 2419, 2012.

[8] A. B. Al-jizany,"studying and evaluation of image intensity and aberrations effectiveness for trianguarobject', M.Sc. thesis University of Baghdad, Iraq ,2001.

[9] J.N.Maggo,K.N.chapro,G.S.Bhatnagar,"Correspondence images of truncated triangular object formed by an apodized slit aperture ", optica Acta , Vol.20 , No.12 , P.995-998,1973.

[10] K.D. Möller," Optics " ,Springer-Verlag, New York USA,2003.

[11] Born ,M.,Wolf,E. ," principle of optics ", 6th edition ,New York , USA, 1984.

[12]David Voelz, "Computational fourier optics", Tutorial Texts in Optical Engineering,Vol. TT89, Bellingham, Washington USA,2011.