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Using a CPC edge to model a compound parabolic concentrator

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Syntax:

EDGE

```
CPC X x a a'
      Y y a a'
      Z z a a'
```

Option

X, Y, or Z

x, y, or z

a, a'

Description

Specifies the axis of symmetry

Location along the coordinate axis

Half width of the apertures

A compound parabolic concentrator, or CPC, is a reflector formed by rotating a tilted off-axis section of a parabola about an axis. Figure (1) illustrates the geometry. The large aperture on the left that collects the light has a half width of a . The small exit aperture has a half width of a' . The slope of the parabola section is parallel to the sweep axis (X, Y, or Z) at the large aperture. The focus of the parabola section is located at the edge of the small aperture. Rays that enter the CPC parallel to the parabola axis come to focus at the edge of the small aperture.

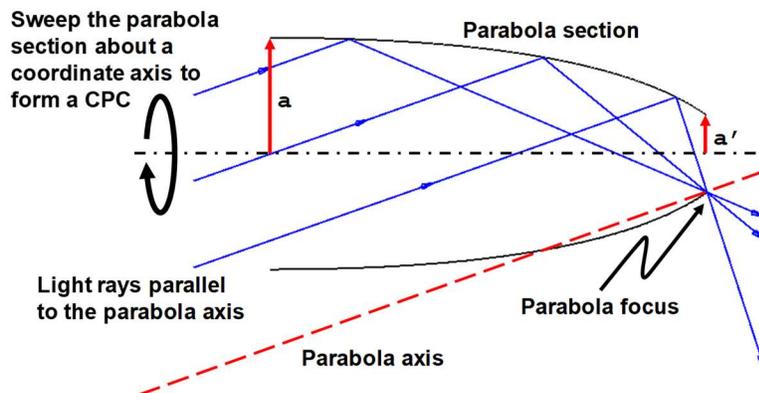
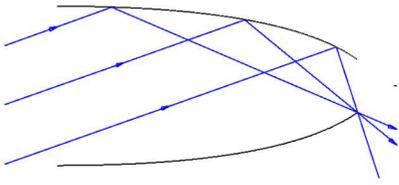


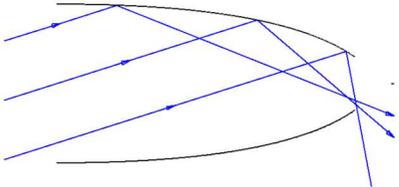
Figure (1): Illustration of how a CPC is generated by sweeping a tilted parabolic section about an axis.

CPCs are used to concentrate light into a small circular area. The angle between the parabola axis and the reflector axis may be called the *acceptance angle*. Any in-plane ray with an angle that is less than the acceptance angle will pass through the small aperture. Any in-plane ray entering at an angle larger than the acceptance angle will be rejected. That is, the ray will reflect multiple times until it comes back out the large aperture. This is illustrated by ray traces in Figure (2). It so happens that almost any skew ray will also pass through the small aperture if its off-axis angle is less than the acceptance angle. Because of this the CPC is an almost ideal concentrator. Almost all light passing through the large aperture that is within the acceptance angle is concentrated within the small aperture.

Ray angles at the acceptance angle



Ray angles less than the acceptance angle



Ray angles greater than the acceptance angle

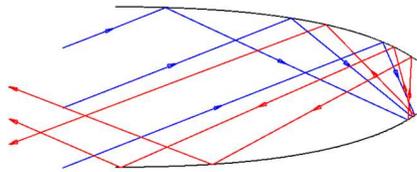


Figure (2): Ray traces that show how light at an angle that is less than the acceptance angle passes through the small aperture of the CPC, while light with an angle greater than the acceptance angle is reflected back out of the CPC (red rays).

Equations for the dimensions of the CPC are given by Welford and Winston.¹ Let a be the half width of the large entrance aperture, and a' be the half width of the small exit aperture. The acceptance angle θ_i is given by

$$a' = a \sin \theta_i . \tag{1}$$

The focal length of the parabola section is

$$f = a'(1 + \sin \theta_i) . \tag{2}$$

¹ W.T. Welford and R. Winston, *High Collection Nonimaging Optics* (Academic Press, New York, 1989), p. 57.

The length of the CPC is

$$L = \frac{(a + a')}{\tan \theta_i}. \quad (3)$$

We note the geometry of the CPC is fully determined by the half widths of the entrance and exit apertures a and a' .

To construct a CPC in ASAP we use the CPC edge. Here is an example where the entrance aperture half width a is three times the exit aperture a' .

EDGE

```
CPC Z 0 37.5 12.5
```

```
SWEEP AXIS 360, 0 0 1, 0 0 0
```

```
OBJECT 'MYCPC'
```

```
INTERFACE 0.9
```

RETURN

The axis of this CPC is parallel to the global z axis. The entrance aperture is at $z=0$ and has a half width of 37.5. The exit aperture has a half width of 12.5, and ASAP sets its location on the z axis using Equation (3). The **SWEEP AXIS** command tells ASAP to rotate the CPC edge about the z axis (defined by the axis vector $0\ 0\ 1$ which passes through the point $0\ 0\ 0$) by 360 degrees to generate the three-dimensional CPC shape. This is followed by the **OBJECT** command, which tells ASAP to make an object out the swept edge and assign the object the name **MYCPC**. The **INTERFACE** command assigns a reflectance of 0.9 to the CPC. The **RETURN** command tells ASAP we are done defining the object. Figure (3) shows a three-dimensional rendering of our CPC that is created by a **PLOT FACETS 15 15** command followed by a **\$VIEW** command.

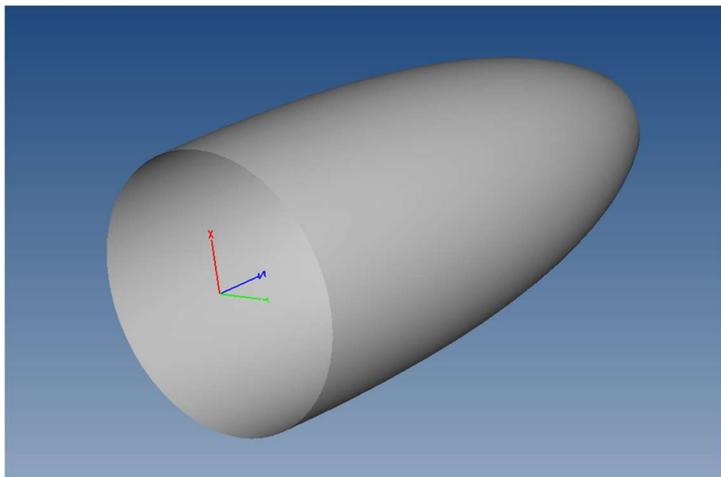


Figure (3): Rendering of the example CPC.

The coordinates of the points that define the CPC edge may be seen by issuing a **PRINT EDGE n** command, where **n** is the number of the edge. The output from this command for the edge in our example is shown in Figure (4), where we note that the length of the CPC, from Equation (4), is given by the *z* coordinate of the third point.

```

CURVEDG  1: Pts=3 (CPC      ) X  0.00000      Y  0.00000      Z  0.00000
      1 segments of degree  2
      1 total with      1 breaks
Sweep angle & direc/posit  360.000      0.00000      0.00000      1.00000
                                0.00000      0.00000      0.00000

This entity used by objects      1
Points and Connection Factors:
      x      y      z      q      x      y      z      q
37.5000  0.0000  0.0000  2.00000  37.5000  0.0000  106.0660  1.00000
12.5000  0.0000  141.4213  0.00000

```

Length of the CPC

Figure (4): Output from a **PRINT EDGE** command for our example.

We note that the plane of this edge, created with a *Z* axis entry, is in the *z-x* plane. If we had used an axis entry of *X* the edge would be in the *x-y* plane, and if we had used an entry of *Y* the edge would be in the *y-z* plane.

It is also possible to create an ideal trough concentrator from a CPC edge. To do this we change the **SWEEP** command from **SWEEP AXIS** (sweep about an axis) to **SWEEP DIR** (sweep along a direction). Here is an example that creates a trough concentrator with a length of 1000. Note that two edges are needed. One for the top half of the CPC and one for the bottom half. Figure (5) is a rendering of the trough concentrator.

```

EDGE
CPC Z 0 37.5 12.5
  ROTATE Z 90 0 0
  SWEEP DIR 1000, 1 0 0
  SHIFT -500 0 0
OBJECT 'CPC.TOP'
INTERFACE .9
REDEFINE COLOR 4
RETURN

```

```

EDGE
CPC Z 0 37.5 12.5
  ROTATE Z -90 0 0
  SWEEP DIR 1000, 1 0 0
  SHIFT -500 0 0
OBJECT 'CPC.BOTTOM'
INTERFACE .9
REDEFINE COLOR 4
RETURN

```

```
WINDOW Y Z  
PLOT FAC 15 15  
$VIEW
```

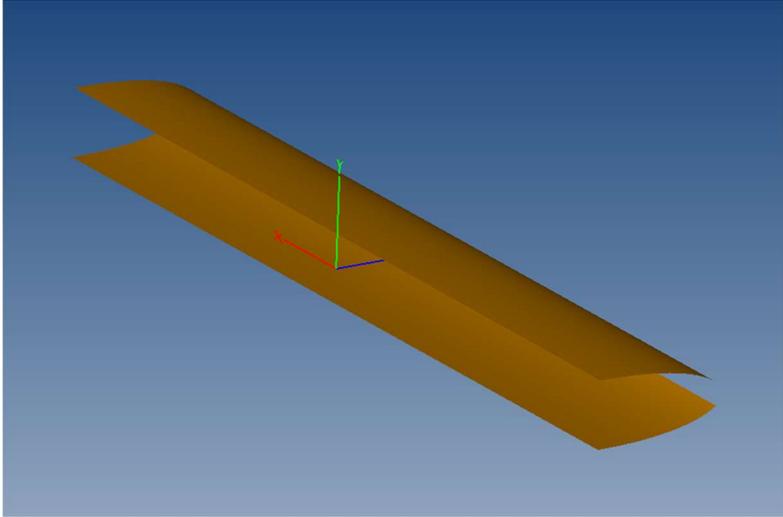


Figure (5): Rendering of a trough concentrator built from two CPC edges.