AOS Application Note:
Specifying the Geometry of Off-Axis Parabolic Mirrors

Aperture Optical Sciences

INTRODUCTION

The growing need for advanced reflective optics operating over a broad bandwidth has motivated the development of off-axis parabolas with higher imaging performance then ever before. Specifying imaging and wavefront performance over a broad range of spatial frequencies is essential for enabling the highest levels of performance. As system level requirements have advanced, the way we specify OAPs must also change. Within recent years everything about OAP's has evolved including tolerances for quality and performance, manufacturing methods, testing methods, thin film coatings and alignment technologies. AOS continues to re-engineer the Off-Axis Parabola to meet the needs of tomorrow's applications. These topics are explored in a series of new application notes from Aperture Optical Sciences Inc. This paper provides instruction on how to define the key geometric features of Off-Axis Parabolic Mirrors (OAPs) and describes the concept of axial offsets as a function of off-axis angle.

Key Terms: Parent Focal Length, Segment Focal Length, Off-Axis Angle, Off-Axis Distance

GEOMETRY & DESIGN

The nomenclature for off-axis parabolas varies between manufacturers so it is useful to define the fundamental elements of off-axis parabola geometry for this discussion. These are the off-axis angle (OAA), off-axis distance (OAD), and focal length (f_s, f_p). The general form of these features and relationships are illustrated in Figure 1.

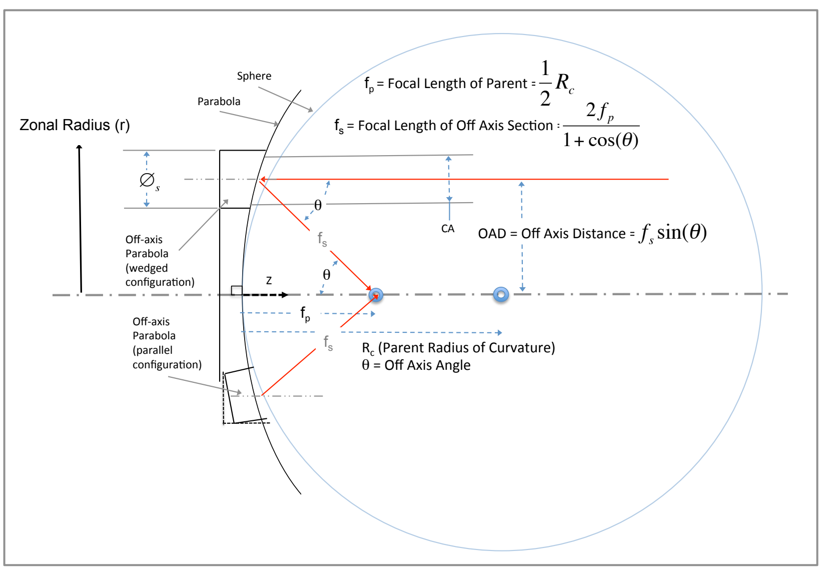

Figure 1: OAP Geometry

Focal Length: Every OAP has two consequential focal lengths - the parent or vertex focal length and the focal length of the off-axis section. The parent focal length "f_p" is measured from the vertex (a virtual dimension for an off-axis parabola) and the focus. f_p is exactly one half of the Radius of Curvature. The focal length of the off-axis section (f_s) is measured from the center of the projected entrance pupil to the focus. This dimension is sometimes called the effective focal length however we recommend not using this term to avoid confusion with the commonly held definition of the effective focal length ("EFL") of a lens. We believe the term Sectional or Segment Focal Length (f_s) is more descriptive.

The segment focal length and parent focal length are related by the off-axis angle (θ) using Equation 1 below:

$$f_s = \frac{2f_p}{1+\cos\theta} \qquad \textit{Equation 1}$$

Off-Axis Distance: The OAD is the unique location of zonal radius corresponding to the location of the geometric center of the parabola. *(note that Zonal Radius (r) is defined as the distance to any point on the OAP as measured radially from the parent axis.)* The OAD is sometimes defined as measured from the parent axis to the nearest edge of the OAP. *We recommend against this practice, as this quantity cannot be as accurately measured.* The virtual location of the absolute edge of the OAP surface is impossible to mechanically locate with a measurement probe due to chamfered edges, and the edge of the optics is subject to errors in wedge and perpendicularity. The geometric center of the optic however can always be determined with sufficient sampling of the edge or based on a conveniently placed datum flat located on the edge of the OAP. This enables location of the geometric center (and axial center – having calculated its axial offset) and thus the OAD to within a few microns or better with a coordinate measuring machine.

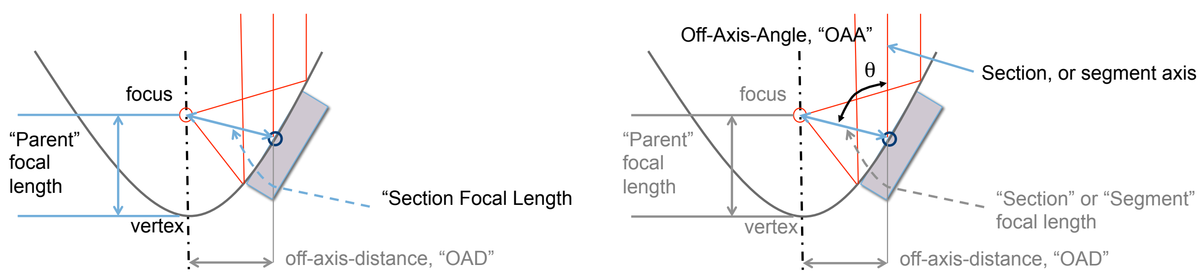

Figure 2a, b: Graphical Depiction of the Off-Axis Distance and Off-Axis Angle

Off-Axis Angle (OAA): The off-axis angle is the angle subtended between a ray parallel to the parent axis at the off-axis distance and the reflected ray of the OAP surface to the focus. Note that this is not the same as the angle of incidence. The angle of incidence varies as a function of zonal radius, however, the nominal angle of incidence will be equal to one half of the OAA. The angle of incidence tends to be of lesser importance when defining an off-axis parabola except when specifying the performance of thin film coatings. Equation 2 relates the OAD, OAA and sectional focal length:

$$OAD = f_s \sin\theta \qquad \textit{Equation 2}$$

Projected vs. Normal Geometry: An important concept to clarify in these definitions is that of "Projected" vs. "Surface Normal" space convention. Nearly every geometric drawing of an optical component is defined relative to a set of datums generally traceable to the optics' surface normal. These include the radius of curvature to incident angle, and clear aperture. However, OAP dimensions for purposes of alignment to an optical axis are determined by the way the incident or reflected light projects onto the surface. The nature of off-axis association to an optic axis often leads to an off-centered clear aperture whereby the optic axis and optic center of rotation no longer align. This concept is important because key dimensions like off-axis distance, focal length and off-axis angle must either be defined relative to the centerline axis of the incident beam *or* of the optic's center of rotation (or geometric center as defined by a diameter or edge). There is no universal convention for this. At AOS, we generally define these dimensions based on the optical axis because this is how our customers use our optics. We then relate these dimensions to the geometry of the component and clarify the association on the design drawing. The difference between the projected entrance pupil center and the physical center of the optic can be large depending on the angle and focal length of the OAP. This "offset" is illustrated in figure 3 below. We define the basis for the definitions and the values of offsets, when appropriate, on each drawing we make. Understanding the convention adopted is essential for accurate alignment.

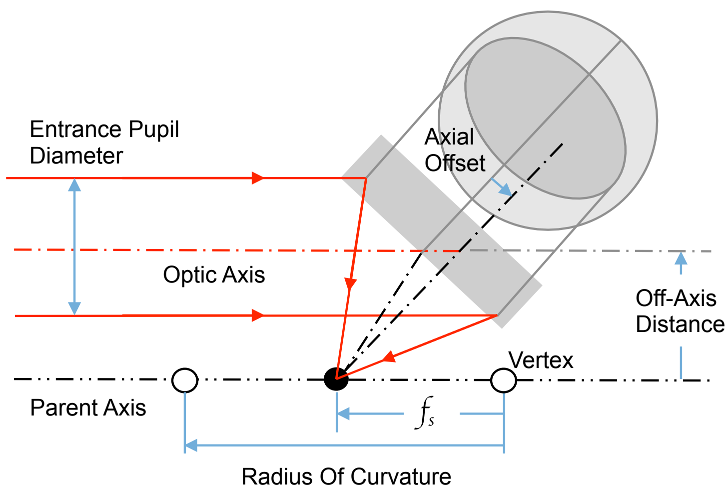

figure 2: Off-Axis Distance and Axial Offset

These key geometric quantities will allow first order definition of OAPs for most applications, however, ensuring agreement between design intent and actual performance requires that these quantities be measurable to within the tolerances needed for optimized performance. The next application note in this series will explore tolerances and metrology of these quantities.

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