Designing and Optimizing a Dobsonian Telescope

Andrew Valentini[1]

[1]Carthage College, Kenosha, Wisconsin

December 2023

Abstract:

In this project, I intend to design a Dobsonian telescope and optimize its performance with a constraint placed on its primary mirror. The Dobsonian telescope is a traditional Newtonian reflecting telescope that was popularized in the early 1960s due to its high performance with respect to its relatively low cost. The Dobsonian telescope was initially designed by John Dobson with the intention of making high-quality telescopes for amateur astronomy and the general public more affordable. Since it is one of the most commonly-used telescopes today, analyzing its optical properties and performance will, in addition to informing the reader of the general operations of a reflecting telescope, give the reader a better understanding for how a Dobsonian telescope works, which properties can be altered to optimize the telescope's performance and how to minimize its defects, which will result in the ability to make a more informed decision about a potential construction or purchase of one of these telescopes.

Introduction

A Dobsonian telescope, a version of the Newtonian reflector, is easily identifiable by its large, tube-like shape. Due to its large aperture, it is designed to operate as a "light bucket"; to collect a large cross-sectional area of light and focus this upon the eye. This collection of light is carried out by the large primary mirror that sits at the telescope's base and reflects incoming light onto a secondary mirror, which is found above the primary mirror. The light that's reflected onto the secondary mirror is then met by a focusing lens before it meets the observer's eye to ensure the light appears to come from a very far distance to accommodate for our eye's resolution abilities. A basic diagram of a Dobsonian telescope is given below:

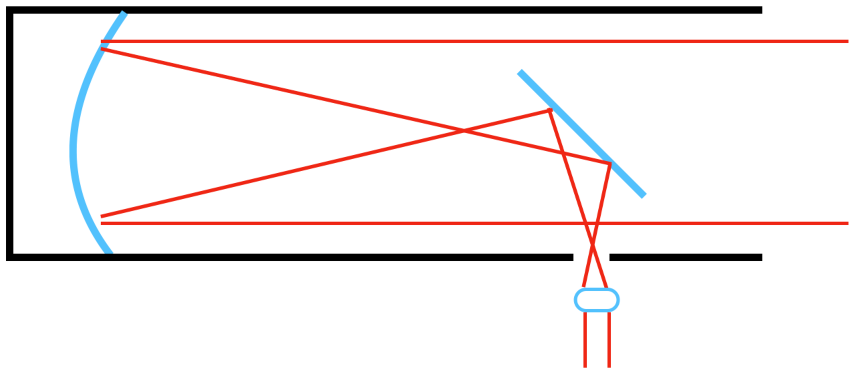

Figure 1: The basic design of a Dobsonian telescope. The primary mirror is the one at the bottom of the telescope and the secondary mirror is the one angled at a 45° to the primary mirror. A lens outside of the tubular body of the telescope is used to focus the exiting light on the way to the observer's eye.

One of the best selling Dobsonian telescopes available on a popular website that sells observing equipment relevant to amateur astronomers, Orion, is called the Orion Skyquest XT10 Classic Dobsonian. As is typical for Dobsonians, the name of the XT10 comes from the diameter of the primary mirror, in inches, meaning that this telescope's tube is ten inches wide. Because Dobsonians are typically defined by how large this primary mirror is, in this project, I choose to limit my design of the Dobsonian to the size and focal length of the XT10's primary mirror, given in the manual [2]. I will first analyze the basic optics of the general Dobsonian telescope and, given the constraint of the primary mirror, I will then quantitatively describe the telescope and attempt to design the most optimal optical system for astronomical viewing.

The Basic Optics of a Dobsonian

Valid to be applied to both mirrors and lenses, the thin lens equation is given as:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \tag{1}$$

where f is the focal length of the mirror or lens, d_o is the distance of the object from it, and d_i is the distance at which the lens or mirror projects the light from the original object out to [1]. Since the distance from the object whose light is being collected by the primary mirror of the Dobsonian is extremely far away with respect to the telescope, we assume that $d_o \to \infty$, making $1/d_o \to 0$. This assumption alters Eq. (1) to be of the following form for the primary mirror:

$$f_p = d_{i,p} \tag{2}$$

Where the p subscript is used to indicate that this describes the primary mirror of the Dobsonian.

Carrying out the same analysis for the secondary mirror of the Dobsonian, we again use Eq. (1) where $d_{o,s} = d_{i,p}$ since the "object" that the secondary mirror sees is the image created by the primary mirror. Since I am constraining this Dobsonian by the focal length and mirror size of the primary mirror, I will set $d_{o,s} = f_p$ by Eq. (2), leaving:

$$\frac{1}{f_s} = \frac{1}{f_p} - \frac{1}{d_{i,2}} \implies d_{i,2} = \frac{1}{\frac{1}{f_p} - \frac{1}{f_s}} \tag{3}$$

Before analyzing the lens that the light enters before making contact with the observer's eye, the optical abilities of the human eye must first be considered. Because our eyes ideally focus objects that are far distances away from us, light coming from those distance objects effectively travels in parallel rays. To replicate this effect, telescopes and most other optical systems are designed to make the light that strikes the eye parallel so that it can be focused. Because of this, we assume that the image distance that the Dobsonian's lens creates will be $d_l \to \infty$. This assumption combined with the fact that the object "seen" by the lens will be the image created by the secondary mirror converts Eq. (1) for the lens of the Dobsonian to be of the form:

$$f_l = d_{i,2} \implies f_l = \frac{1}{\frac{1}{f_p} - \frac{1}{f_s}} \tag{4}$$

The focal length of the primary mirror is given as 1200 mm and, since we want to bring the light into focus, I will assume that the focal length of the secondary mirror approaches infinity, making the $1/f_s \to 0$ and $f_l = f_p$, meaning that the focal length for the focusing lens that's used in the telescope will be taken to also be $f_l = 1200$ mm.

Another optical property that is important to consider in this analysis is magnification power of the telescope. To determine the magnification power of this telescope, the angle that a beam of light entering the telescope must be compared to the angle of the beam that exits the telescope on the way to the observer's eye. If the telescope has a high magnification power, a small initial angle would be increased. To determine this, I first send a beam into the telescope with an angle of .286°. I find the angle leaving the telescope to be around 3° (using the telescope simulation I describe in the following sections) which means that the magnification power of this telescope is $3/.286 = 10.47$x. This means that an object seen by the telescope is magnified by nearly 10.5 times by the time it reaches the observer's eye.

Another optical property to consider for the telescope is the focal ratio, often called the f-number, which is the focal length of a mirror or lens divided by its aperture, or the area [1]. It is given in [2] that the focal ratio is $f/4.7$ for the primary mirror, which makes sense because it also gives the focal length of the primary mirror to be 1200 mm and its mirror diameter to be 254 mm. The focal ratio describes a "speed" of the telescope and it should be noted that focal ratio values within the $f/4 - f/5$ range are ideal for wide field observing and deep space photography.

Initial Dobsonian Design

As detailed in the previous section, I have constrained the design of this telescope by the properties given for the primary mirror in [2]. This results in $f_p = f_l = 1200$ mm from Eq. (4), and the diameter of the primary mirror being set at 254 cm. I additionally assume that the diameter of the secondary mirror to be 8 cm and its focal length to approach infinity. It should be noted that, because $f_p = d_{i,p} = 1200$ mm, I am beginning this analysis with the secondary mirror placed 120 cm above the primary mirror. These constraints and assumptions allow me to simulate an initial design of the Dobsonian telescope, which results in the image shown below:

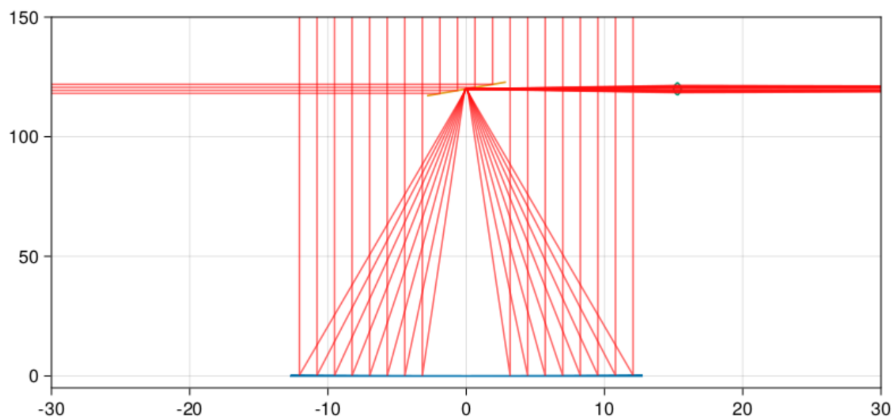

Figure 2: Initial design of the Dobsonian telescope. Axis units are in centimeters.

In this design, the horizontal displacement of the lens from the telescope tube (the tube of the telescope would be built around the outer edge of the mirror so it's assumed to exist after the mirror ends in this diagram) was arbitrary. Since the secondary mirror is placed at a distance of 120 cm away from the primary mirror and oriented 45° to its plane with a radius of 4 cm that was arbitrarily chosen, the minimum height possible of the telescope can be determined by determining how much additional height of must be added to the tube to account for the secondary mirror (you obviously wouldn't want a telescope to have half of its mirror sticking out of its end). This results in a minimum height of the telescope of around 122.8 cm, which is 4.02 feet. The manual for the XT10 telescope lists the tube height at 3.93 feet so our placement of the secondary mirror does not currently agree with that of the real XT10 telescope.

To analyze the performance of this telescope and the effectiveness of the assumptions we made in this initial design, a screen can be placed to the right of the telescope to receive any of the light leaving the lens. The following aberration plot displays the angle of the beams incident on the surface of the screen to graphically display one aspect of how I will define one major aspect of the telescope's performance:

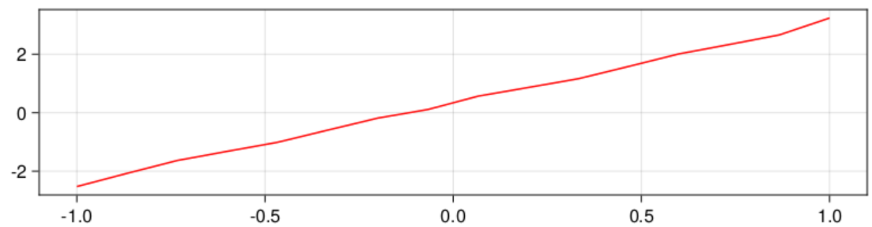

Figure 3: Angles of beams incident on the screen's surface. The ideal telescope would have all light ray angles parallel to each other as they enter the observer's eye.

Because our eyes best focus on object that is infinitely far away, the best design of the Dobsonian will be the one that minimizes these angles being displayed. In the most ideal scenario, the beams of light travelling out of the lens would be perfectly parallel. From Fig. (3), it's shown that the beams of light that would enter an observer's eye are not perfectly parallel in the current iteration of the Dobsonian telescope but its performance is still acceptable at this point since the angles present are so small. Because the horizontal placement of the lens was arbitrarily chosen, I will discuss how Fig. (3) may be optimized in the next section.

Improved Design

Since the horizontal displacement of the lens and the size of the secondary mirror used to create Fig. (2) were arbitrarily chosen in the initial design, I will now attempt to optimize the telescope's design by changing these assumptions. In decreasing the radius of the secondary mirror and making the overall height of the Dobsonian smaller, I will additionally attempt to more accurately model the XT10.

To first make my Dobsonian design match the conditions of the XT10, I shrank the secondary mirror's radius down to 1.5 cm and moved the mirror down to a vertical height of 118 cm above the primary mirror. Again considering that the secondary mirror is oriented at a 45° angle, this makes the total height of my Dobsonian to be 3.87 feet which more closely matches the height of the XT10 at 3.93 feet. With the radius of the secondary mirror decreased, this also means that less light entering the Dobsonian will be deflected by the secondary mirror on its journey down to the base of the telescope, which increases the amount of light that will make it to the observer's eye.

With these modifications made to the secondary mirror, I now consider the placement of the lens. To optimize its horizontal displacement (intending to decrease the angles that the beams of light strike the screen at), I use a slider to run the horizontal position of the lens over a range of values and look for the value that minimizes the line shown in Fig. (3). In doing this, I find the optimal horizontal placement of the lens to be 2.3 cm from the edge of the Dobsonian.

To display these optimized conditions, I repeat Fig. (2) and Fig. (3) below:

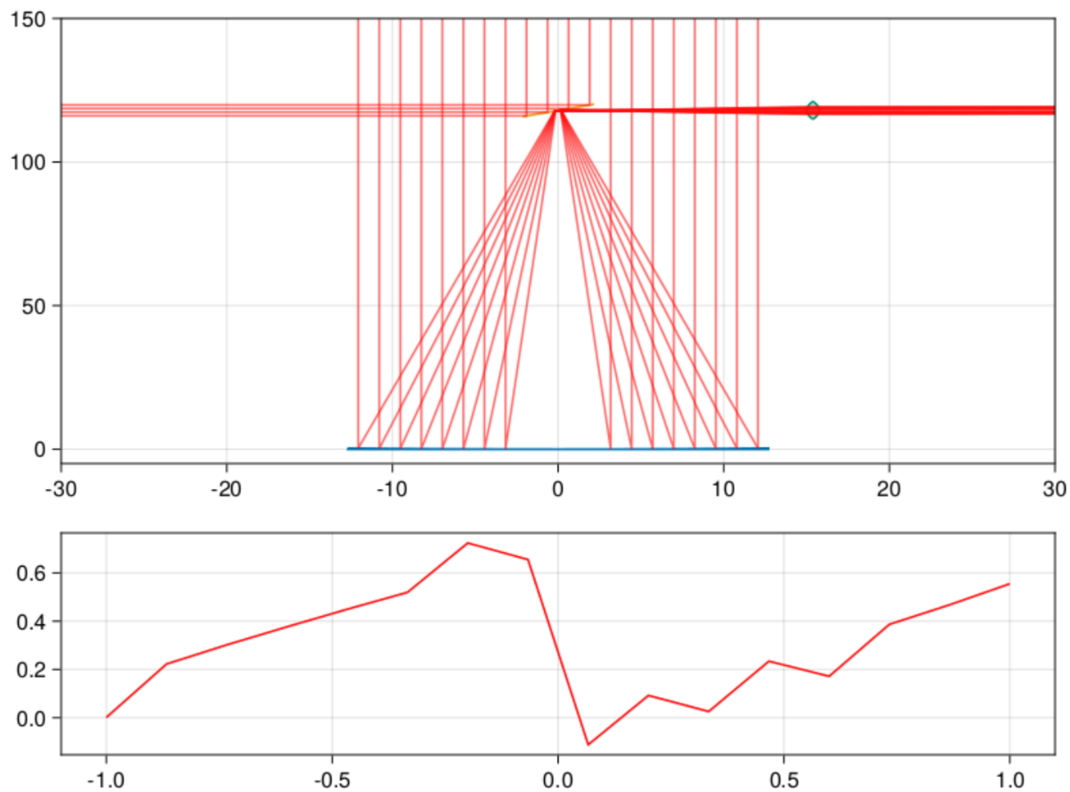

Figure 4: The optimized design of my Dobsonian telescope along with its aberration plot

Visually comparing the telescope's design in Fig. (4) to the initial design in Fig. (2), it's clear that no substantial changes have been made to the telescope itself but in comparing the second half of Fig. (4) to Fig. (3), it's clear that this new design has decreased the unwanted aberration in our initial design with our slight modifications.

For clarity, this improved design of the Dobsonian kept the primary mirror's radius at 12.7 cm and its focal length at 1200 mm while moving the secondary mirror to a vertical height of 118 cm and decreasing its radius to 3 cm. The lens has been moved to a horizontal displacement of 15 cm, which is 2.3 cm away from the right edge of the Dobsonian.

Conclusions and Future Work

In this report, a simple Dobsonian telescope was simulated with constraints provided by a real telescope currently being sold. The initial design of the simulated telescope was not ideal and did not match the height of the real telescope given in [2] so the design was then optimized to more closely model the real telescope. The final design appears to be the most optimal given the constraints placed by the primary mirror. Because the diameter of the primary mirror is the defining feature of a Dobsonian telescope, if one wanted to improve upon this exact design, the diameter of the primary mirror would have to be held constant. To investigate an even more optimal design while keeping the diameter of the primary mirror unchanged, altering the focal length of the primary mirror and the corresponding properties of the secondary mirror and lens may be fruitful.

Because of the relative simplicity of the Dobsonian telescope, one could use this report as a guide to constructing their own Dobsonian or just use the concepts learned to make a more informed decision when purchasing one of them from a professional provider.

References

[1] Eugene Hecht. *Optics*. San Francisco, CA: Addison Wesley, 2002.

[2] *Orion Skyquest Classic Dobsonians*. Orion Telescopes and Binoculars. Watsonville, CA, 2020.