Preface

I have three primary motivations for writing this book. The first began with a simple observation: a large majority of amateur-owned portable Newtonian reflectors, both commercial and home-built, that purported to be "truss" telescopes, actually contain no trusses. On the one hand, I found this surprising since trusses have been well-understood for over a hundred years. As college freshmen, aspiring engineers learn the importance of placing loads at the ends of straight struts joined together as triangles. Trusses are employed wherever designers want to make efficient use of materials to create stiff, strong structures such as bridges and roof frames. Almost 20 years ago, Roy Diffrient[1] applied these design principles to the four trusses in common eight-strut telescopes to generate the basic equation describing their lateral deflection.

On the other hand, unlike most bridges, large portable telescopes must be disassembled for transport. Their trusses should assemble easily and quickly. No doubt this is one of the reasons that the upper ends of each pair of struts of many telescopes do not meet. If the upper ends of each strut pair do not meet, no triangle (*i.e.,* no truss) is formed. This does not necessarily mean that structure stiffness is insufficient. It does mean that the equation for calculating truss deflection is invalid. So, deflection of the structure cannot be easily predicted — it must be measured. Consequently, I devote an entire chapter to measuring deflections of structures simulating a variety of common truss configurations and strut connection practices. This chapter makes it possible, for the first time, for the telescope builder to estimate why, and how much, stiffness is sacrificed by various designs. I believe Chapter 7 is one of the most important in the book.

Roy Diffrient's equation should predict the lateral deflection of a telescope structure using four true trusses. But the telescope designer also may need to predict deflections due to other loads the structure is subjected to, and/or, need to predict deflections of structures using a different truss system. For example, a structure with as few as three trusses (six struts) can accomplish the same tasks as one with four trusses. In the past, it appeared

[1] "Flexure of a Serrurier Truss", Roy Diffrient, *Sky and Telescope*, February, 1994. (Note that the name Serrurier used in the title is an inaccurate term for the simple truss system described in the article and commonly used in most large, portable amateur telescopes. The Serrurier Truss consists of two truss systems, each extending in opposite directions from the central pivot axis.)

that few amateur builders dared deviate from the established norm. However, today the number of telescopes using only three trusses (with strut pairs of equal or unequal length) is growing. Yet, I know of no published equations that address these needs. Consequently, Chapter 6 also provides a set of equations that predict deflections of four-truss structures subjected to various types of loads, and deflections of three-truss structures whose configuration, and lengths and composition of individual struts, vary.

My second motivation for writing this book is to promote building one's own telescope. The recommendation arises from my experiences building telescopes for myself and for others. I have a hereditary neuromuscular condition that was diagnosed in my 30s. Although I was active in a variety of sports for much of my early life, by age 40 I had to abandon them as progressive weakness limited my physical capabilities. Today, at 58, I can barely lift my arms over my head. With some effort, I can use both arms to lift something like 10 pounds to chest level. Climbing stairs or a ladder is impossible. I can stand for a few minutes, or walk with a cane maybe 20 yards, before needing to rest. Most of the time, I ride around on a power wheelchair.

To a large extent, amateur astronomy has filled the void created by having to abandon my past athletic activities. I am an avid observer, having logged observations of 10,000 unique objects. Most of them are faint galaxies that can only be seen from remote, dark sites with moderate to large aperture telescopes. In order to sustain my level of observing, the telescope must satisfy a set of critical needs. In addition to having sufficient aperture, it must be easy for me to transport and set up, light enough that I can load it into my vehicle (almost any telescope with sufficient aperture is too difficult to lift), the eyepiece height must be low enough that I can access most of the sky while seated in an adjustable-height chair (my wheelchair has a power seat elevator), and the location of focuser and finders must be ergonomic to minimize fatigue. No commercial telescopes meet all of my needs.

Based on a variety of assumptions, I cautiously started out building lightweight telescopes with apertures of 12½ inches. However, like most deep-sky observers, I suffer from aperture fever. Despite my growing weakness each year, the aperture of my personal telescopes has grown. My most recent creation is a 24-inch $f/3.3$ that still meets all of my stringent needs. Many people are surprised to see me finding objects quickly while seated comfortably at the eyepiece of my larger telescopes, but particularly when using the 24-inch. Clearly the rewards from building a custom telescope can be great.

Able-bodied observers who can lift 100 pounds, climb a ladder, or stand for hours may question the benefit of building a custom telescope. Based on my discussions with others, many find the benefits worthwhile.

Even something as simple as placing the focuser and finders close to one another on a preferred side can increase efficiency, comfort, and enjoyment. Selecting a mirror with a custom focal length can mean the difference between using a ladder or stepstool, standing on the ground, or being seated comfortably in a chair. Minimizing fatigue allows anyone to see more detail, and observe longer on successive nights during multi-day star parties. Finally, everyone has physical limits. Often one can build a custom telescope with a significantly larger optic than a commercially-available one of similar weight and/or size.

My third motivation for writing this book is to help reduce the real and perceived barriers to building one's own telescope. One may not possess the necessary knowledge, equipment, or self-confidence. I recommend beginning with a review of *The Dobsonian Telescope*[2]. It provides an excellent description of how to build classic large, four-truss portable reflectors. With few modifications, one can expect a telescope built using its guidelines to perform well.

Those wanting to deviate from proven designs can benefit, as I did, from applying the principles of product development. A simplified overview of the product development process is described in Chapter 1, and it serves as a framework for the organization of the book. Simplified versions of some best practices are described throughout. Chapter 2 is devoted primarily to one of the essential steps of successful product development - defining clear goals. This step may be one of the most challenging for less-experienced observers. Don't rush to order parts and begin construction. Take the time to observe through a variety of existing telescopes, particularly those having designs you may wish to emulate. Note the methods of construction of telescopes whose performance and ergonomics you find satisfactory, and those you do not. Take pictures and quantify your impressions by measuring and recording weights and dimensions. Volunteer to help the owner assemble and/or disassemble the structure.

Developing products requires knowledge of basic materials properties and understanding of the impact of potential modifications. Chapters 3, 4, and 5 provide those aspects of materials science and engineering that are most relevant to building any type of portable Newtonian. As mentioned previously, Chapters 6 and 7 are specific to the class of portable telescopes that use trusses. The greater the deviation from existing designs, the greater the need to predict and confirm anticipated performance. Throughout the book, I emphasize the importance of making prototypes and making decisions based on data. Most people should be capable of duplicating the simpler tests.

[2] *The Dobsonian Telescope* David Kriege and Richard Berry, Willmann-Bell, Inc., 1997.

Each of the last two chapters (8 and 9) serves two purposes. First, each illustrates the use of the product development process: setting clear goals, selecting the design, and constructing the final telescope. Even though the goals are similar, the telescope in each chapter represents a different outcome. Many variations are possible depending on individual priorities and preferences. Consequently, I expect few people will make exact duplicates. Second, most of each chapter is devoted to describing, in detail, specific construction steps. In many cases, construction is more time-consuming than for classic designs. The details may provide some fresh ideas to more experienced builders, and should reduce the reluctance of the less experienced to consider more ambitious designs.

From across the observing field, these examples may appear to be classic truss designs. This is no coincidence. There are good reasons why the classic design has endured for so long. I believe that many of its elements will satisfy a majority of observers' goals. Also, like the classic truss telescope, for the most part, construction of the two examples drew upon similar readily-available materials. However, each example has been tailored to fit a set of well-defined goals. Some design elements are subtle, increasing ease of transport and assembly, and viewing comfort. The most important difference cannot be seen at all. The heaviest subassemblies of each of the two examples weigh 35–40% less than those of most commercial reflectors with the same aperture. Applying engineering principles covered in this book was essential to achieving weight reduction while maintaining, and in some cases simultaneously improving, performance.

For those without formal technical training, some of the book's content may appear intimidating. Don't let it be. On the one hand, the book is meant to serve as a reference for those who want to apply the quantitative equations. On the other hand, I've worked with many people who possessed no engineering background. Merely grasping the design principles enabled them to successfully create personal telescopes tailored to their needs.

By far the greatest concerns I've encountered with those considering building a telescope center on necessary equipment and prior woodworking experience. I routinely invite people to visit my "shop" to discuss their goals. The face-to-face conversations not only help me clarify their goals and suggest alternative solutions, they also allow me to demonstrate just how modest my equipment is.

In my experience, the quality of the finished telescope is nearly independent of the cost of the tools used to make it. My short list of essential power equipment includes router, hand drill, and table saw. Even the table saw could be considered optional. Straight cuts can be done using a router or circular saw guided by a straight edge clamped to a sturdy table. Beyond these, my list of highly desirable power tools includes belt sander and drill press. I use these regularly to shape and sand wooden parts and to drill straight holes. I built all of my telescopes using a Sears Craftsman 10-inch table saw that I acquired 25 years ago. It is a basic table-top model with a 1 HP motor. To reduce cost, I purchased it used. Similar, and even less expensive, table saws are available from a variety of manufacturers today. Unless the tool is defective, even the least expensive table saw should be capable of making sufficiently straight and accurate cuts.

I also own a palm sander, miter saw, and biscuit joiner. These tools are definitely optional and used less frequently. The palm sander shortens sanding time of large, flat surfaces. It is relatively easy to set up the miter saw to cut multiple sections of aluminum tubing to the same length, and to cut stock at angles other than 90°. But such cuts usually can be done with a table saw or other tools, albeit less conveniently. The biscuit joiner is just one of many ways of joining wood panels.

I highly recommend owning a good plunge router. In my opinion, it is the single most useful power tool for this type of work. Although some high-end models cost as much as $500, good performers can be purchased for less than half that amount. Similar to table saws, more expensive models usually have more powerful motors, intended for more demanding users, and additional features. Years ago, I bought the least expensive router I could find — a fixed-base 1½ HP Sears Craftsman — for much less than $100. If this is the type of router you already own, by all means use it. I built several telescopes with it. However, after many years of moderately heavy use, it did fail. For the past few years I've used a variable-speed Porter-Cable plunge router with a 2¼ HP motor. To reduce cost, I also bought it used.

More expensive routers usually have interchangeable collets, allowing one to select bits with shaft diameters of ¼ inch or ½ inch. This feature is useful, but not essential. Many woodworkers prefer using bits with larger shafts, but I've always used those with ¼-inch shafts. The smaller bits are considerably less expensive. At the time of this writing, a couple of manufacturers began offering smaller (*i.e.*, their "compact") routers with plunge bases. Since performance in small, light weight packages is very important to me, I took advantage of a sale and bought a Dewalt 1.25 HP router with fixed and plunge bases for $145, including shipping. I am eager to try it out on my next project.

The most expensive power tool I own is a combination mill/drill manufactured by Jet. It basically is a drill press equipped with heavy-duty spindle bearings to handle the lateral loads encountered when milling, and a work surface that allows coarse X-Y positioning of the work piece. Although it is one the least expensive mill/drills available, it cost more than all of my other power tools combined. I think most people would find a conventional shop drill press more useful and considerably less expensive. The mill/drill was not necessary to build any of my telescopes, but it did prove convenient when fabricating some of the small aluminum parts.

If you own no power tools, even limiting purchases of basic, inexpensive equipment to several hundred dollars may seem unjustified for one telescope project. Seek out friends who own such equipment. Alternatively, some woodworking shops offer classes and access to their equipment for a fee. For example, close to me is The Sawdust Shop in Sunnyvale, CA. With a similar format, TechShop in Menlo Park, CA provides members access to a much wider selection of tools and equipment (allowing one to shape metal, wood, and plastic). Check local listings to see if such facilities are located near you.

In addition to tools, one needs work space. Most people do not have a dedicated workshop. This is true of me as well. I build all my telescopes in the garage. When not in use, tools are stored out of the way. For example, my table saw is mounted on wheels, allowing it to be rolled into a corner after use. A fellow telescope-builder I know has no garage. Instead, he keeps his tools and materials in a rented temporary storage unit near his home. When working on a project, he sets up his contractor-style table saw on sawhorses just outside the roll-up door. When routing, a piece of plywood placed over the sawhorses serves as the work bench.

When discussing telescope construction in Chapters 8 and 9, I assume the reader has access to and experience using typical shop tools mentioned above. Most construction steps highlight techniques that I found to work well building past telescopes, using the basic tools I already own and readily-available materials. However, I also wanted to demonstrate that telescope design need not be restricted by one's existing tools and capabilities. Vendors possess a variety of fabrication equipment. Smaller shops often specialize in providing prototyping services and are happy to work on an interesting, small project. For example, I paid rather modest amounts for a local metal-working shop to weld and water-jet selected parts.

I believe the difference between a good- and a great-looking telescope is most dependent on the patience and care of the builder. Even the most inexperienced builder can acquire the necessary skills with instruction and practice. If unfamiliar with power tools, take the time to learn how to use them safely and correctly. Always work with sharp tooling. Before each project, I have my saw blades sharpened and purchase replacements for a couple of the most-used router bits.

Perhaps more than anything else, the look of the final product depends on proper preparation of the surface and application of the finish. Professionals usually spray on coatings in a controlled environment (spray booth). I do not own spray equipment or have the space to set up a spray booth. I apply most finishes by hand. Following manufacturers' application instructions is a good place to start, but I usually find them inadequate. Applying finish largely is an art. Practice your technique on test pieces until you are satisfied with the results.

Unfortunately, even in a book of this length, I was unable to include more information on a variety of topics. For example, I would have liked to include discussions of mirror cell and baffle design, fabrication, and testing, and to include design rules and construction details for all the telescope types mentioned in Chapter 5. I hope to be able to do so at a later date. For the time being, Chapters 8 and 9 discuss the design and construction of mirror cells with six and eighteen points of support. Those cells should satisfy the requirements of most applications.