Amateur Telescope Making

Stephen F. Tonkin (Ed.)

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We dedicate this book, with humility, to the memory of the late Tom Waineo. Tom epitomised the most laudable qualities of the amateur telescope maker, giving selflessly of his time and using his extensive experience and wisdom in order to help others. We hope that our efforts will help to keep Tom's star shining.

Contents

Introduction

Over the last few decades the range of mass-produced equipment available to amateur astronomers has increased in both extent and capability, and decreased in real-term cost. Obvious examples of the enhanced capability of amateur equipment lie in CCD cameras and computer-controlled mounts. The CCD is said to increase the light-gathering power of a telescope by a factor of about a hundred; that is, it is possible to take images with an 8 in (20 cm) instrument that would previously have required an 80 in (2 m) telescope using photographic emulsion. Of course, the resolving power of the 8 in is not also increased! Computer control enables simplified finding of faint objects and, coupled with a CCD, can automatically guide the telescope during imaging. Where then, in this context, is the place for amateur telescope making (ATMing) and the basement tinkerer, the person Albert Ingalls referred to, in his *Amateur Telescope Making* trilogy, as the TN - the Telescope Nut?

Quite simply, the opportunities for TNs - who are now better known as ATMs (amateur telescope makers) - have also increased correspondingly, and their craft has developed far beyond what can legitimately be termed "basement tinkering". Richard Berry's *CCD Camera Cookbook* has resulted in the construction and use of hundreds of home-made CCD cameras, at a cost well below that of the commercially available instruments. As Al Kelly demonstrates (Chapter 14), making a *Cookbook* CCD is, while time-consuming, not a particularly difficult task, and the resulting images easily rival those taken with the mass-produced products. Similarly, the innovations of Mel Bartels and others (Chapter 10) have extended computer control to the most common ATM telescope, the Dobsonian-mounted Newtonian, again at a much-reduced cost compared with commercial offerings.

While cost reduction has always been one of the driving forces behind ATM, it is neither the only one nor the most powerful. However, there are still among us those who aim to make good astronomical kit at a shoestring cost, and there are several such examples in the first section of this book. You should understand that the costs are cut not by sacrificing optical quality, but usually by adapting free or low-cost items that were intended for another purpose. While we don't eschew good craftsmanship, we stand by the principle (or is it merely an excuse?) that telescopes are primarily for looking *through*, not looking *at*. As long as the telescope holds the optical components rigidly in collimation while excluding stray light from the eyepiece, and the mount is as steady as the Rock of Gibraltar, while permitting smooth movement about two axes of rotation, all else is optional.

More often, the ATMing impulse is a response to mass production. One of the consequences of this mass production is standardisation, as witnessed by the ubiquitous 8 in (20 cm) Schmidt-Cassegrain telescopes. If you want something non-standard, you are often left with two choices: either to forgo the cost advantage of mass production by having a one-off instrument specially made, or to make the instrument yourself. The section "Specialised Telescopes" shows how some ATMs have met this need. This is the realm where much innovation takes place, and some ATMs have found their developments to be so popular that they have gone into commercial production.

Another powerful stimulus to ATMing lies in human nature - some of us are inveterate tinkerers. If we buy a telescope, within days we find we have invalidated the warranty. A few days (or, in some severe cases, hours) later, the first modification is made and within a month or so the instrument bears little relation to the original product. Our workshops usually contain several telescopes, mostly in various states of dismantlement, and we are known in astronomical circles as people who spend more time tinkering with telescopes than actually using them. This ailment is probably incurable, but its cravings are certainly satisfied by ATMing!

Whatever the impulse that attracted you to this book, you will find a number of ways that it differs from most other books on the subject. The most obvious of these is that each chapter is written by someone who has, to some extent, become an expert in the realm his chapter covers and who has, in most cases, spent considerable time helping others to attain a similar level of expertise. Each contributor is someone with a proven ability to make equipment that works effectively, and many have devised creative ways of using common artefacts - this inventiveness will inspire you to do likewise. He is also someone who is willing to help you further, should the need arise. To this end, the publishers have dedicated a World Wide Web site to this book, via which you can contact any of the contributors to the book.

This linking to a web site also enables the book to be kept up to date. In particular, software is continuously under development, but the latest versions may be obtained on the web.

The multi-contributor nature of the book is a microcosm of another aspect of ATMing: that of mutual aid. Most ATMs are eager to share the experiential fruits of their work with others, and many of the international group of contributors to this book "met" on the Internet via the ATM Mailing List, which was established purely to facilitate this sharing. Many of us have had the privilege of being advised, via this medium, by experts in their field. Those of us who began our ATMing with no tutor but a book will appreciate the value of a resource that can be questioned when the need arises; the ATM Mailing List is just such a resource and is an excellent forum for sounding out any ideas that this book may inspire.

Another difference is that optical work is not specifically covered. There are several reasons for this. It requires an entire book to itself, and there are already several excellent publications on the subject available. While it is true that optical work is a craft that can be learned, there are relatively few excellent amateur opticians - like any other craft, it takes time and practice to achieve excellence. Consequently many, but by no means all, first amateur mirrors are of inferior quality and, unless you have a specific desire to develop the necessary skills, it often makes good sense to purchase optical components from a reputable source. There usually is little financial saving, if any, to be made by making a small primary mirror, although the skills so gained will prepare you for those specialised tasks where there are significant savings are to be made. Obviously, most specialised instruments require specialised optical components, and for these you may have no choice but to make them yourself. If this is the case, it is advisable to learn your skills on a "standard" mirror, such as a 6 in (15 cm) f/8 or an 8 in (20 cm) f/7, before attempting the specialised optical surfaces.

Whether you decide to buy your optics or to make them yourself, it is essential to learn to test them. It is unfortunate but true that not all mass-produced optical components are of the quality that the maker claims for them, and it makes excellent sense to be able to evaluate them for yourself. In any case, you will need to test your finished telescope, whatever the source of the optical components.

The Bibliography lists several excellent books on optical design, work and testing.

In any book of this nature that has an international body of contributors, it is inevitable that there will be a "confusion" of units of measurement. Even in countries that still use non-metric measures, focal lengths, particularly of eyepieces, are usually expressed in millimetres. The style I have adopted is that the author's chosen system of units is given first, followed by an appropriate "translation", where this is possible, when the measurement is first used. I have attempted to render these as translations into standard sizes where this is appropriate. For example, $^{3}/4$ in is almost exactly 19 mm, but the nearest metric equivalent to $^{3}/4$ in thick plywood is 18 mm thick. There are some instances where a sensible translation is not helpful, usually in relation to screw threads. For example, a tripod bush for a camera has a $^{1}/4$ in UNG ($^{1}/4$ in 20 tpi) thread - there is no metric equivalent. In these instances, I have not given equivalents.

Finally, although detailed instructions are provided for many of the projects in this book, a hallmark of ATMing is creativity. Each project will perform well if it is made as the author made it, but most are capable of adaptation and development to your specific needs or to the materials you have available. Although the projects vary greatly in simplicity/difficulty of construction, most will fall within the capability of an ATM with a moderately well-equipped workshop and reasonable workshop skills. Whether you use this book as a manual or as a source of ideas that you will develop to meet your own particular requirements, I hope you will find it as stimulating to read and use as I have found it to compile.

Stephen Tonkin April, 1998

Part I

Shoestring Telescopes

Chapter 1

A 6-inch f/5 Telescope

Steven Lee

This project is typical of those suitable for someone who has a collection of leftovers from previous projects. Steven Lee raided his junk box to construct this very portable 6 in f/5 instrument for an additional outlay of about A$30. He has designed a slide focuser in order to minimise the secondary obstruction. As with all shoestring projects, the main skill required is that of finding and adapting the components - the construction itself is simple.

A low-power, wide-field telescope provides spectacular views of the heavens - the Milky Way, a bright comet or an eclipse are perfect targets. Such a telescope is an ideal second telescope to complement the high-power views of a larger instrument. It is also the right size for the junior astronomers of the family, or just for taking on holidays when you don't have room for a larger one. My telescope was made quite quickly and almost entirely from spare bits and pieces - its total cost was about $30. This is mainly because I have a large and well-filled junk box brought about by many years of telescope making - most people couldn't build it quite this cheaply. I tried to make it as simple as possible and yet be innovative in its design where I thought I could improve on standard parts.

Optics

Most people wrongly attribute wide fields of view in a telescope to having a fast focal ratio. This is not really true, but does work if you take the simple example of the same eyepiece used in telescopes of the same diameter but different focal ratios. To achieve the same wide field in a telescope of higher focal ratio, you just use a longer focal length eyepiece. In practice, the faster the focal ratio the worse the aberrations, and the better the eyepiece must be in order to cope with the faster beam; this is why the view through a slower focal ratio telescope is usually better than with a fast one. The traditional RFT (richest field telescope) is a 6 in (150 mm) f/4, but an f/5 mirror yields considerably better images for little extra inconvenience. The real benefit in the slightly slower focal ratio is not so much the lower aberrations of the mirror, but the improved performance of the eyepiece. The tube does have to be one mirror diameter longer in an f/5, but the improved image quality is well worth it. Many years ago I made a 6 in f/4 as my second telescope and its performance was fine, but this f/5 configuration is definitely better. With the same eyepiece the field of view is slightly smaller (1.7° versus 2.1°) but the quality of the field is noticeably improved. The tube is no more awkward to use and I can see no reason to use the faster focal ratio, especially with such a small telescope. In fact I would recommend never making any telescope for visual use faster than f/5 for the above reasons.

How to Calculate the Field of View for any Telescope and Eyepiece

Given f_{tel} - the telescope focal length,

$f_{eyepiece}$ - the focal length of the eyepiece, and

$fov_{eyepiece}$ - the apparent field-of-view of the eyepiece

(usually stated by the manufscturer):
First calculate the magnification on the combination by:

magnification = $f_{tel} \div f_{eyepiece}$

and then the desired field:

true field-of-view = $fov_{eyepiece} \div$ magnification

As an example, a 6 in f/8 telescope has a focal length of approximately 1200 mm, while a 6 in f/5 telescope is 760 mm. A 25 mm eyepiece used in each telescope will yield magnifications of 48× and 30× respectively. If that eyepiece has an apparent field of 50°, then it will give a 1°
f/8 telescope will give 30× and a 1.6° field.

I made the 6 in f/5 paraboloidal mirror on the obverse of a standard Pyrex blank which had just been used as the tool to make a friend's mirror. I used a piece of 12 mm (^{1}/2 in) plywood as my tool, cut round with a jigsaw and coated with varnish to seal it against warping, then covered in ceramic tiles for the working surface. The mirror and tool were then ground together using standard techniques. It was polished on polishing pads stuck to the tiles and finally figured on a pitch lap on the same piece of plywood (once the tiles had been removed). I had to rush to make this mirror because I could get it aluminised (free!) if it was ready by a particular time - which was less than a week after I decided to make it. I spent several days grinding the curve, while polishing it took another 2. Figuring lasted approximately 5 minutes (in two sessions) which brought the surface accuracy to about ^{1}/4 wave - good enough for the low powers intended for this telescope.

The secondary mirror was one from my junk box, left over from a long-forgotten project. It has a small chip on one edge, but it doesn't matter for this telescope as it is well out of the on-axis field. It is a 38 mm (l^1/2 in) minor-axis mirror - larger than is necessary -but as I had it on hand, I used it. A 34 mm (l^1/3 in) one is the ideal mirror for this instrument.

The Tube

Fibreglass tubes are strong yet light, and totally maintenance-free - the perfect combination for a good telescope. My tube is home-made, which saves cost at the expense of a messy and smelly few days. It was originally built for the f/4 mirror I made long ago *(c.* 1973). That mirror was sold when I moved (something I regretted and was the reason for making this telescope), although I still had the tube. Of course I had to extend it because of the longer focal length mirror, but the technique came back easily to hand despite the intervening years. I had the necessary materials on hand for another project and was using this as practice. It took only a few hours of sanding, filling and more sanding to add the extra 6 in (15 cm) and smooth out the join, although it was necessarily spread over a few days. One of the advantages of this type of tube is that the colour permeates the whole job and so scratches are never seen - a boon if the telescope is mistreated or suffers when in transit. However, I couldn't match the colouring that had originally been used and so I was forced to simply paint the outside of the tube, which I did in a dark blue.

Any telescope tube should extend sufficiently far in front of the eyepiece holder to stop stray light from getting directly to the eyepiece, and to shade the area opposite the eyepiece from direct illumination. This is a failing in many telescopes and results in lower contrast images because of the extraneous light flooding the focus. The tube I made is 18 cm (7 in) inside diameter and 85 cm ($33^1/2$ in) long, giving good shielding for the eyepiece. Finally, the tube is lined with black flock paper to make it really non-reflective. This produces a far darker finish compared with the more usual coating of black paint, with any internal reflections absorbed in the fibres of the material. Black velvet is even better, but would have cost more than I paid for the whole telescope! Besides, I had some left over from other projects and this project was intended to use up leftover bits.

The Focuser and Secondary Holder

Getting the focuser right is very important in small telescopes - not only must it satisfy all the usual requirements for a focuser (strong, light and smooth movement), but it needs to have a very low profile in order to minimise the size of the diagonal required to illuminate the field. I have always believed that a lateral-sliding focuser is the best way to achieve this, but I'd never made one, believing that they required exacting machining in order to work properly. After a lot of thought I constructed one that didn't require any machining. While it isn't perfect, it works well enough and is made almost entirely from scrap parts.

I can adjust the position of the focal surface relative to the tube over a 40 mm range, from being level to the tube surface to 40 mm above. This is a perfectly adequate range for visual use and all my eyepieces come into focus somewhere within these extremes. Because the eyepiece I intend to use most on this telescope - an old 20 mm Erfle - comes to focus with the focal surface close to the tube, it needs only a 34 mm minor-axis mirror (22% obstruction) to yield a 12 mm ($^{1}/2$ in) fully illuminated field (almost 1°) and only 0.2 magnitude loss at the edge of the field. This is excellent performance and very difficult to achieve with normal up-down focusers.

The heart of a slide focuser is the slide. Instead of precision rails and ball bearings, mine is made from the discarded rails of a computer printout binder. In the old days of computers, you used to file printouts of programs (on paper 15 in (38 cm) wide) into special binders. They had cardboard covers (later plastic - just like Kydex - good for top ends) and plastic spikes which went through the end sprocket holes of the paper to restrain them. The spikes were tucked under little bits of metal which slid on metal rails. (If you don't know what I'm describing, you'll just have to take my word that these things were extremely common around computers 10 years or more ago.) Anyway, I had already cannibalised the covers of these binders for the top end of my ball-scope and I was looking at the rails wondering if they should be thrown out or put in my ever-growing junk box when I thought "rails ... slide-focuser ... hmm". And here it is (Figures 1.1 and 1.2, *overleaf).*

The sliders and rails are anodised steel, so are well protected and strong. The rails were cut to 17 cm ($6^{1}/2$ in) in length, and they are kept at the right distance apart by two cross-members of 10 mm ($^{3}/8$ in) wide, 2 mm ($^{1}/16$ in) aluminium. Holes through these two pieces are used to bolt it to the tube. Longitudinal pieces of 1 mm ($^{1}/32$ in) aluminium bent into a right angle add extra stability and allow a mounting point for the driving mechanism. The moving part is a plate of 2 mm thick aluminium approximately 70 mm ($2^{3}/4$ in) wide and 100 mm (4 in) long. A $1^{1}/4$ in (31.8 mm) hole is at one end of the plate, with an aluminium tube over it to hold the eyepieces. Normally, such a tube would need to be machined, but I had one in my junk box from a previous project. Motion is provided by a rack-and-pinion drive from (you guessed it) my junk box. My father made this for me for my very first telescope - a $4^{1}/4$ in (108 mm) f/12 Newtonian - which was decommissioned some years ago. The pinion gear rides on a chrome-plated steel shaft removed from a floppy disc drive, which in turn rides in brass blocks which simply have suitable holes drilled in them. The hand knob is from another

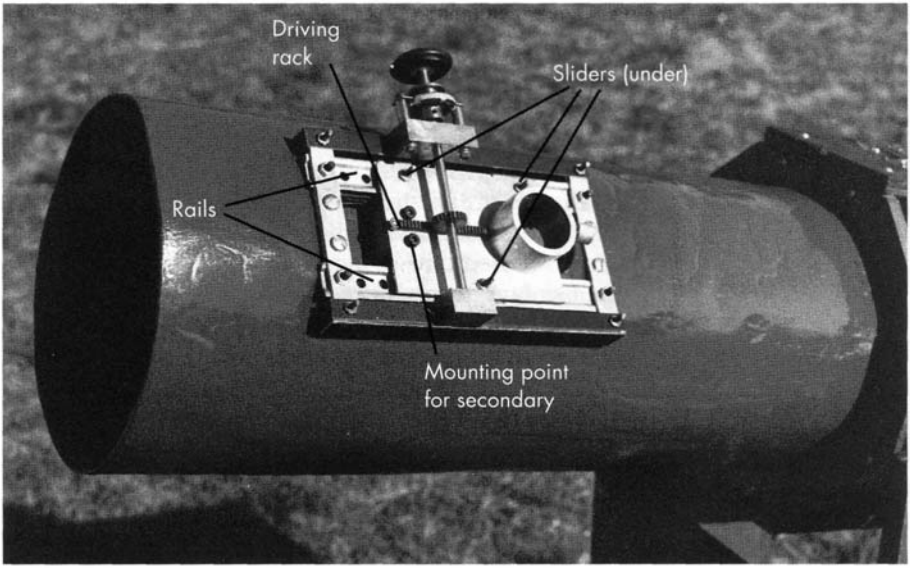

Figure 1.1 Slide focuser

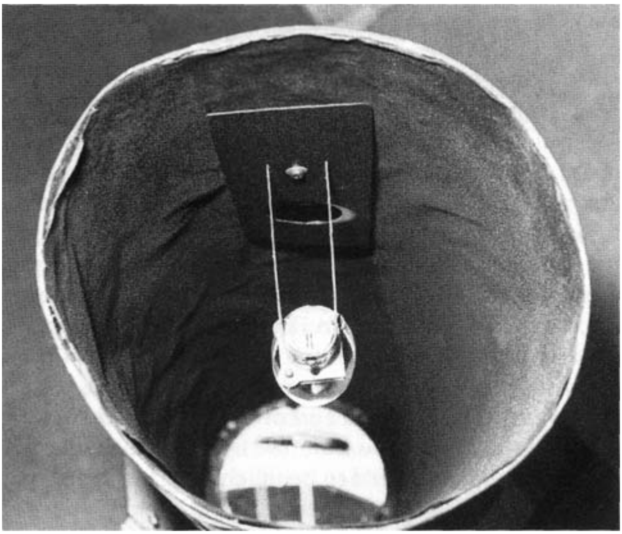

Figure 1.2 The secondary mounting, showing the moving plate and the flock-paper lining.

focuser which was removed when fitting a motor drive and placed in a junk box to await re-use. (The shaft end of the knob was used as a coupling between the focuser and encoder on my 20 cm (8 in) f/4.5 Newtonian imaging telescope - nothing wasted here!) There is one other important feature in this mechanism which makes it a delight to use - a 6:1 reducer. This is a commercial part, sold to amateur radio builders as a reducer for a radio tuning knob; current price is of the order A$20 (but I had one in my junk box from a previous abandoned project). It is gearless, the reduction being done by friction-coupled balls turning between the input and output shafts. The addition of this mechanism turns the focuser from an ordinary one into an exceptionally nice one.

The secondary mirror must be attached to the moving plate and positioned so that its centre (optical, rather than geometrical) is directly under the eyepiece holder. I use a U-shaped piece of 1 mm thick aluminium about 20 mm ($^3/4$ in) wide to link the plate to the secondary holder. A suitably sized block of aluminium on the plate keeps it at the right spacing, while the bottom of the U wraps around a 20 mm-diameter aluminium tube (a cut-off portion of one of the truss tubes on the ball-scope in Chapter 8). A single screw and nut holds the two together and allows for rotation of the secondary should it be necessary. Slots in the top of the U allow for positioning the secondary mirror accurately under the eyepiece. Mounted on the same block on the plate is a piece of plastic used to shield the secondary from light getting through the slot in the tube in which the focuser slides.

Getting back to the secondary holder, the end of the tube has a small, flat 2 mm aluminium plate glued to it through which three collimation screws are located. The secondary mirror is attached with silicon sealant to another 20 mm tube cut at 45°. The other end of this tube also has an aluminium plate glued to it through which the other end of the collimation bolts go. The spring-tensioned collimation bolts are arranged not at the "standard" 120° spacing, but rather so that adjustments occur at right angles (up-down and left-right as seen through the focuser). One screw acts as a pivot and is only touched if the whole assembly needs to be moved towards or away from the primary mirror; only the other two are used when collimating.

The Primary Mirror Cell

The primary mirror cell (Figure 1.3, *overleaf)* is one 4 mm ($^3/16$ in) thick aluminium plate, the mirror resting

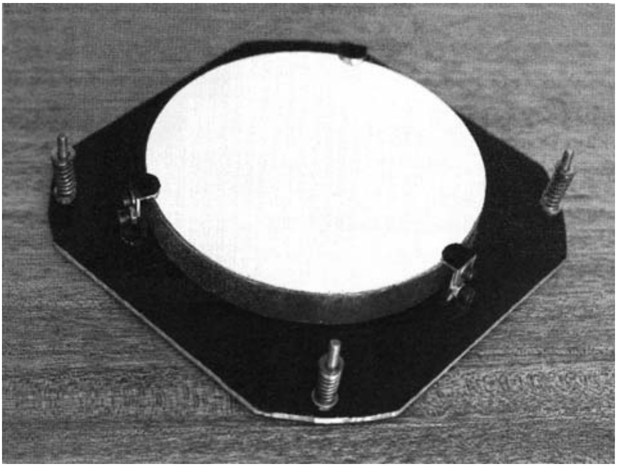

Figure 1.3 Primary cell with the collimating bolts in a right-angle configuration for easier collimation

on a three-point support and held laterally by three posts attached to the plate. Through each post is a bolt (with locknut) to securely position the mirror. The collimation bolts are on the outside of the tube and move the plate relative to the tube. Figure 1.4 shows two of the bolts and the attachment points on the outside of the tube. They are easily accessible while looking through the eyepiece, a boon for easy collimation. I made the primary cell adjustments operate in the same way as I did for the secondary mirror cell. Up-down, left-right adjustments are far superior to the traditional triaxial method and I don't understand why people still insist on making them.

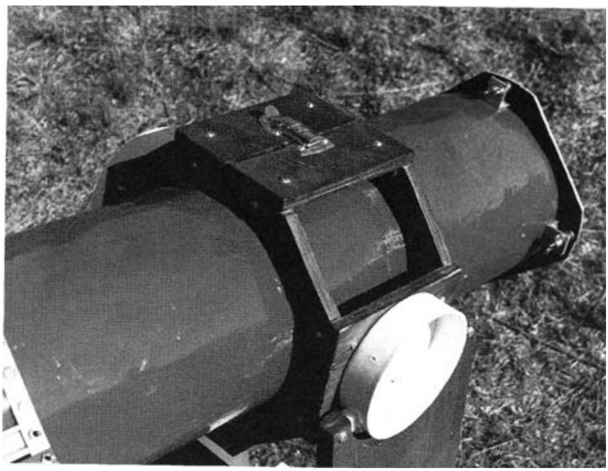

Figure 1.4
Mounting cradle and altitude trunnions. The primary cell and two of its collimation bolts are shown on the right-hand end of the tube.