Wresting the Secrets of the Skies – Making a School Telescope

A craftsman's account of a complex design process that led to a remarkable range of new technological understandings and new aesthetic experiences

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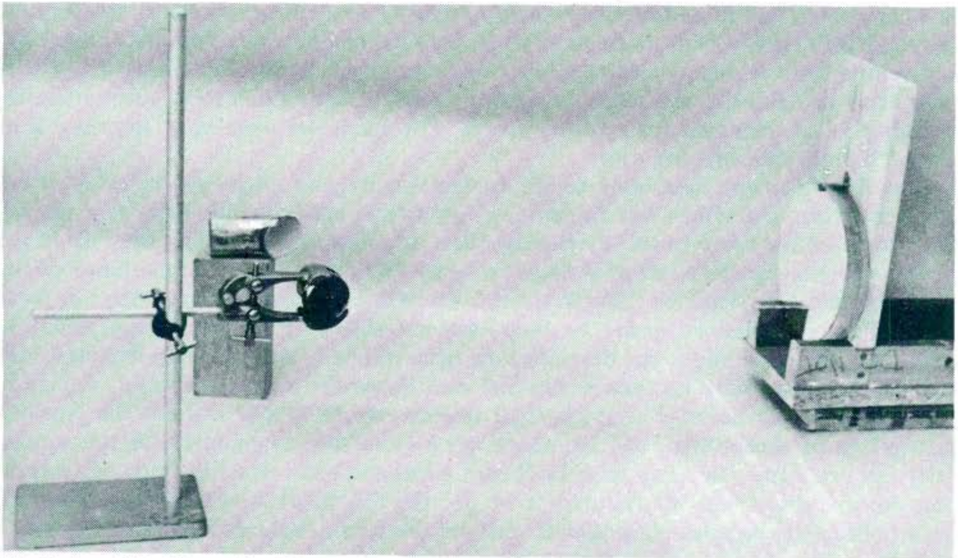
Ever since my son and I saw the moons of Jupiter through a "home–made" telescope, of lenses and cardboard tubes, eighteen or so years ago, the desire to see more of the solar system persisted with me. Sporadic forays to the library to read up on telescopes kept alive the urge to make an instrument which my craftsman's knowledge told me would be a fascinating enterprise in new techniques. I was deterred for all those years by the immediate demands upon my time, and my other interests, and not least by having an hour or so with an enthusiast making a 6 inch Newtonian reflector. I realized the amount of work involved in making the parabolic mirror alone.

Somewhere in one of the works on telescope making I have read, it is said that a famous group of amateur telescope makers were so fascinated by the techniques involved in their hobby, that those techniques took precedence over the astronomical observations they did with their superb products. This thought has haunted me somewhat throughout my venture into telescope making which was determined, firstly, by sensing that " it is later than you think", and secondly, that the rings of Saturn will soon, astronomically speaking, be at their best for small telescopes. The maximum opening of rings is due in early 1980. So you still have time!

The first telescope, according to the romantic story, was discovered in 1608 by the children of the Dutchman Jan Lippershey, a spectacle maker, whilst they were playing with some of his spare lenses. By holding them at appropriate distances they could see birds nesting under the eaves of a distant steeple. The father saw the importance of the discovery and developed his " magic tubes". The story says that the knowledge of these first refractor telescopes spread to Italy, where Galileo, with his searching, scientific mind, saw the possibilities and developed the ideas of fixed lenses. He experimented with them in lead tubes, until he became the first man to see the moons of Jupiter, and study the craters of the moon. The intellectual freedom we all enjoy, without the crushing restrictions of superstition, and ignorance, grew from such beginnings. But the simple telescope we made years ago, with cardboard tubes and balsa wood lens holders, was far superior to those of the innovators, for we had the benefit of three centuries of modern glass polishing techniques. Nevertheless such are the laws of light and lenses that Galileo, and us, with our simple convex and concave lenses, were troubled by chromatic aberration. ("An awful thing to have in your telescope", murmured a colleague orientated towards iconoclasm, in a chosen moment, when I was in full spate with a captive audience.) In lens making this inherent defect can only be eradicated by elaborate techniques, and different expensive glasses, ground and polished into complex radii.

If this was the only solution to astronomical observation, then this branch of science and technology would be a closed book to the amateur, for few of us would venture into this field. But, thanks to our own Newton, the parabolic mirror was scientifically deduced, and the deflecting flat introduced to bring the light rays to a magnifying eye piece at the side of the tube. This arrangement, shown in the first illustration, has stood the test of time. From his first efforts with his small metal mirror of an inch or so in diameter to the giant 200 inch diameter at Mount Palomar, with the observer actually sitting inside the tube, the basics are the same – concave mirror of parabolic form, small diagonal flat, and magnifying eye–piece. Everything with all the multitudinous variations follow these basic elements for all accessories, ingenious or simple, designed or contrived, are to hold the optic parts in their determined place, and allow them to follow the moving object in the sky. An added advantage is that Newtonian mirror telescopes give a colour free image. No chromatic aberration to terrify my colleague! Newtonian telescopes have been further developed by experts, and amateurs, into variations of the original system, to such an extent that the present catadioptric systems only incorporate part of Newton's original concept. But for the beginner, the original concept of the reflector telescope is still the easiest way, and for the writer, one of the most fascinating, if infuriating and exhausting, craft experiences of his life. But that first observation of the moon, through my first reflector, with the rays of Tycho showing distinctly, the unexpected but beautiful crescent of Venus, and mighty Jupiter with, alas, only one



The Basics of the Newtonian Telescope.

1 On right, the accurately polished parabolic mirror. (On testing stand)
2 An elliptical flat (1 is to V 2) to deflect at 45 degrees the returned rays from the mirror to the magnifying eyepiece.
3 In front left, the eyepiece. Magnification is determined by dividing focal length of mirror by focal length of eyepiece.

noticeable moon on that memorable evening made it worth all the effort. Newton allow me the temerity to salute your name!

It may be wondered by the reader how such an individualistic prelude as the above can have much educational value in a school. This can be explained by the characteristics of the techniques of telescope making, with the primary purpose of developing a new school technology in the technical department, and assisting a school astronomical society to flourish. It is not necessary of course to make anything towards the finished telescope. Complete telescopes can be brought, or as sometimes happens, given by a benefactor. Or the telescope can be assembled from individual parts, selected to match other components, by someone knowledgeable in the subject. Or one can follow the advice of suppliers who advertise in the Journal of the British Astronomical Association, which is generally available in the local Reference Library. Or you can make some of the parts, purchase others to match, and assemble in the school workshop. We at Holland Park are doing the latter. As the most important part of a reflector is the concave mirror, and as it demands individual concentration, I decided to start upon this first. I had no practical experience in making the highly polished spherical curve and then deepening it into a parabolic curve, but I had read reams of descriptions and instructions on the processes, for unfortunately I knew of no one to instruct me.

This has certainly proved the hard way, but once started on the grinding of the first 6 inch diameter + 7 parabolic mirror I found myself planning the next one! So far I have made three mirrors, and, with the full co–operation of the technical staff, made up two into telescope form and tried them out. The making of the mirrors and the diagonal flats offered opportunities to innovate, experiment and adapt whatever was to hand. Frequently the staff, even at the height of their ribald banter made helpful suggestions and gave practical assistance. Much interest was aroused in the pupils, parents on Open Day, visitors and staff, and, when the mechanical parts are finally completed, the school astronomical society should benefit. The optical parts of a telescope decide the quality of the instrument but it is not practical, in an article of this length, to give detailed account of the project, when it is pointed out that William F.A. Ellison (b. 1864 d. 1937) wrote the first informative account of making a Newtonian telescope and this booklet, by present standards, has been included in the first volume of *Amateur Telescope Making.* Ellison's work occupies about 80 pages of the 500 or so pages of Volume 1 all closely printed and meticulously detailed. Volumes II and Volume III are much more advanced, for the appeal of telescope making has spread widely, and lends itself to experiment throughout the scientific, and technological, world. It has also made the telescope makers into writers, for we, who are interested, want to know how the other fellow did it. So a general account of our telescopes is all that can be done for we, like others, have only had guidance from the text books.

If two discs of glass are rubbed across their diameters, with a cutting compound such as carborundum and water between then, so that the top disc, which will become the mirror, is pushed beyond the edge of the bottom disc, known as the tool, the mirror will become concave and the tool convex, If we keep turning the top disc and keep stepping around the bottom disc, so that we present different diameters of top and bottom to each other, a spherical concave surface will be produced. A long stroke with No. 80

carborundum will hog out the centre comparatively quickly, say about three hours. But it leaves deep scratches and pits in both surfaces. We continue until the mirror is a spherical curve and the depth established according to the simple formul $S = \frac{r2}{2R}$

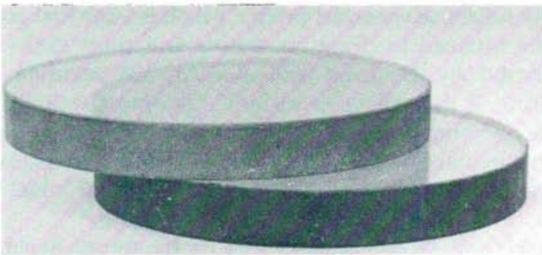
Depth of Mirror (sagitta)	=	S
Radius of Mirror	=	r
Radius of Curvature of Mirror	=	R

As all polishing is the process of removing scratches left by the previous cutting medium, we continue by using less coarse and finer cutting compounds, Nos. 120 – 220 – 320 – 400 and 600 carborundum, and the fine finishing emeries, until we have arrived at the even, whitish, grey surface which is essential before polishing commences. All glass workers are conditioned to the avoidance of pits and scratches. But despite all my care to wash away the previous wets of coarser grade carborundum, some rogue grains, I swear, took on animate form, deliberately hid away, jumped out without being observed and let me unsuspectingly break them down into the fine–ground surface. The inward singing of satisfaction I heard, as I passed on to each finer grade, was, in restrospect, nothing but the siren voices of separate grains of a coarse nature which had assumed an incubus spirit. The surprising number of scratches and blemishes showed up when the mirror was aluminized, after many hours of polishing, with cerium oxide and rouge, on pitch. My deflation was complete when I was jocularly told by one of the staff on the optical works, where I took the mirror for aluminizing, that I would not get a job there, if that was the best I could do!

Fortunately an advanced technology came to my aid, for I particularly wanted to make an unblemished, accurately parabolized mirror. I made a visit to H.N. Irving & Son, Scientific Instrument Makers, 258 Kingston Road, Teddington, TW11 7JQ to discuss tubes, eye–pieces and accessories for the telescope when he showed me a large mirror he had made to order. The surface was so dazzlingly smooth and reflective, that near–perfection is not too exaggerated a compliment. I cannot imagine that its performance fell short of its surface smoothness. How did he do it, when I explained my disappointing result? He now generates the curve with a diamond tipped tool in a machine, grinds out the fine spiral tool marks with fine compounds, as standard practice everywhere, polishes the surface with rouge on pitch.

So impressed was I about the new possibilities opening to me in mirror making, that I ordered two discs of Pyrex glass, which is eminently suitable because of its low expansion factor, and the discs to be generated to the agreed curvature. These duly arrived and I set to work upon the first, a 8¾ inch diameter Pyrex mould with its generated f7 curvature. Examination of the diamond tool marks on the glass disc, and the fine grade powders delivered with it, gave rise to some trepidation of the prospect of reaching the desired surface. My qualms and fears were allayed, when, after only one hour or so of careful grinding, the spiral marks had disappeared. Another session with my finishing emeries completed the grinding process to my satisfaction.

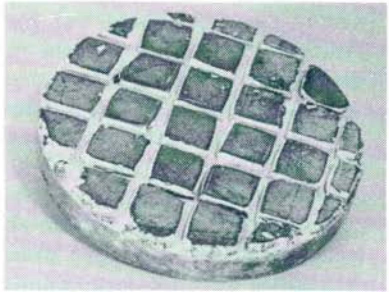
Polishing as before was the next operation. I have read that Newton himself polished his speculum metal on hard pitch using putty powder (tin oxide) ground pumice and,



Two Discs of Glass before Grinding

The top disc becomes the mirror and the bottom disc, the tool.

The amount of overhang of the mirror determines the depth of the concavity.



Pitch Block

The convex tool is coated with beeswax, covered with pitch and made into "squares." It is pressed into the shape of the mirror and polished into (a) spherical form (b) parabolic form.

At Holland Park we made up a former, in wood, of long troughs 1 inch wide and 3/8 inch deep. Paper backing, from perspex sheets with its high gloss surface, pressed into the troughs allowed the cold pitch to be turned out into convenient strips, without troublesome adhesion. Extreme caution must be observed to avoid any fire risk and it still defiles!

may be, whiting. Our cerium oxide and rouge (ferric oxide) are infinitely better, easy to obtain and their polishing qualities on the mirror gave me the sweet satisfaction of hearing the expert aluminizer of mirrors at the optical works, laughingly agree it was passable by their standards. From the rags of deflation, to the riches of elation, in two generations of mirror making!

The polishing process on the pitch block, shown in the photograph, has to be pursued with care and understanding. Pitch is a solid material which can flow under pressure, and it is this quality that makes it valuable to the lens maker. (No indignant letters, please, from the purists to prove conclusively that pitch, whether it be Swedish, Burgundy, Canadian or merely the local road works department, is not a solid but a super cooled liquid or ...): It has been cherished for centuries because of its glass polishing qualities. This flow–under–pressure quality can also make it the most infuriating, intractable material when one is in a hurry to finish the job. It flows with warmth and gravity – it can be too soft in summer or in an over–heated room – it can be too hard when cold and actually can make sleeks and marks on the hard glass surface – it can be unreasonable and unco–operative, but when you have cajoled it, and pressed it, and coaxed it into shape, it can work delightfully. Instinctively you feel that every push-pull stroke is aiding you in your quest to wrest the secrets of the skies from their earth–bound limitations. But never swear at it, for at times I suspect it is in league with those few rogue grains which have a perverse nature!

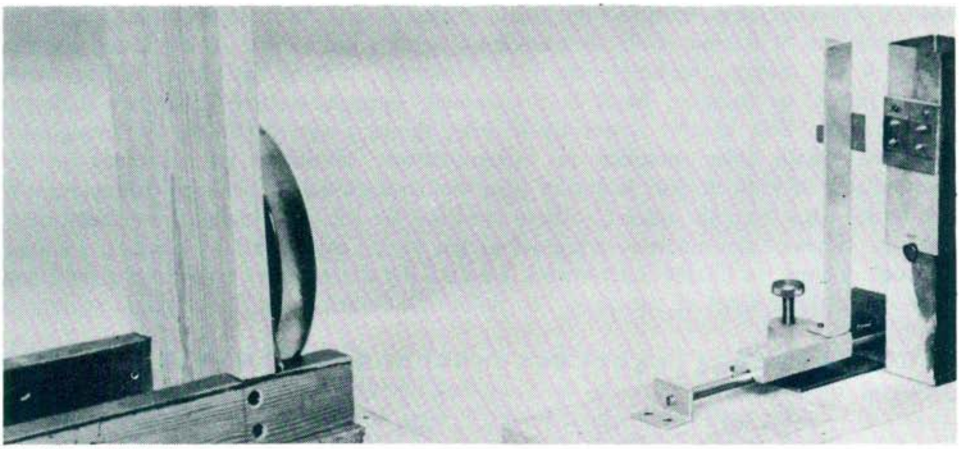
Long periods of pressing the tool, under weights, upon the pitch, with net curtain between to make extra facets, is an essential part of the process. The curtain must be well soaped to avoid adhesion. You must always press your well – rouged mirror directly onto the pitch, to gain the final essential contact, before each session of polishing. I learned this from a hard–to–bear experience, for uneven contact between mirror and pitch

mitigates against producing the highly reflective spherical surface which is your first goal. This spherical curvature can only be attained by frequent testing and short spells of corrective polishing. The tests, devised by Foucault and Ronchi, are accurate to millionths of an inch on the curvature of the reflective surface. Like most techniques precision is only comparative. Hence we obtain mirrors accurate to one or more light waves, or when we have achieved some mastery of our techniques, including a propensity for self–deception, some smaller part of a light wave, the average length of which is 0.000022 inch.

Because I am now confident in the interpretation of what I see on the testing bench, I mainly use the Ronchi test for the attainment of the concave spherical surface. The Foucault test, which Ronchi used but with the introduction of his grating, is shown and described herewith. I believe that if the Ronchi test does not indicate a spherical surface do not proceed until this is achieved. A quick glance at the Ronchi grating, both inside and outside the focus, is sufficient to send you back for another short spell on the well pressed pitch block, or to leave your mirror there under a suitable weight whilst you consider your next process – parabolizing.

So much has been written about this important process, in the past, that it is said telescope makers are often disheartened before they start. My experience was that the difficulties were not insurmountable but time consuming, exhausting, conducive to self deception and finally exhilarating. Given that I had not cheated myself in the data collected, and that the Head of Mathematics was not bribed to verify my findings, I had parabolized my second mirror to within 25% ± of mathematical perfection. I faithfully followed the detailed description of graph–analysis on pages 257–261 "A.T.M." Volume I and pages 123–127 in *Hand–book of Telescope Making* by N.E. Howard. This is good for an amateur and gives an acceptable standard of observational accuracy. When questioned by visitors, influenced by my spiel, I murmur self deprecatingly, that it is accurate to a part of a light wave! (If anyone should be so churlish as to disprove that studied throw–away remark, I will plaintively ask why make me a liar for a light wave or two?)

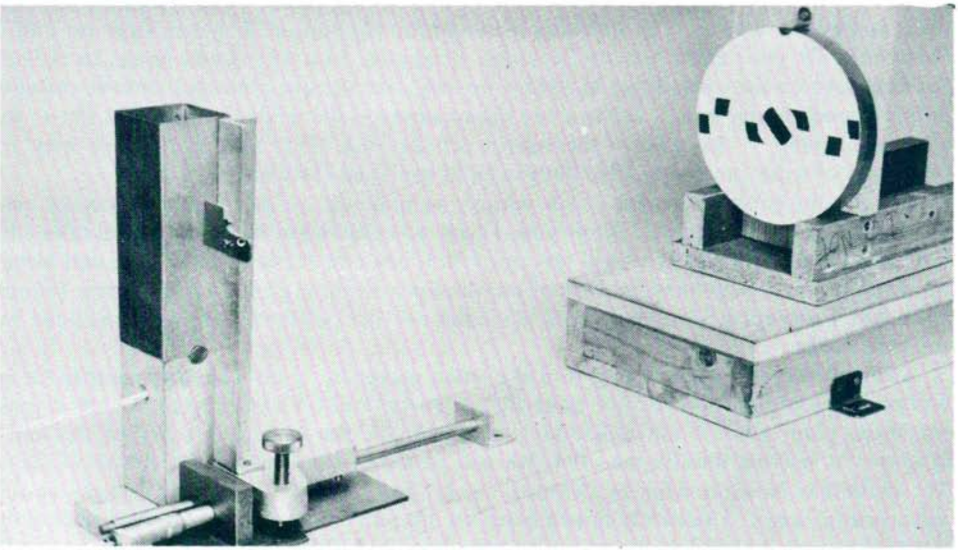
The spherical surface we have obtained cannot focus light rays to a single point focus. Only a parabolic surface can do that. Fortunately the difference between the sphere and the parabola, on our size of mirror, is so small that polishing selectively on pitch, and measuring by the Foucault light test, to dimensions predetermined by the formula r2, brings it well within the capacity of the amateur. Foucault's name will live as long as reflector telescopes are made and used. It is worth noting that the astounding contributions to 20th century optical astronomy have been made by giant reflectors, which have out–paced the refractors, primarily because of production restrictions on the latter. Other tests for the paraboloid have been devised but none are used as frequently as Foucault's. His contribution to the practice of testing curved surfaces is almost breathtaking in its simplicity, and of incalculable value to the mirror–maker. Before Foucault's test was publicly described in 1859, mirrors could only be tested on a star. Now we test on a bench in a darkened room. The mirror is placed upright on a stand, a light, encased and shielded, is projected through a pin–hole, or a slit about 0.25 inch high and 0.0015 inch wide. This slit can be tested for accuracy with feeler gauges. When the



The Foucault Test

The light, from inside the tin plate box, is projected through the adjustable slit onto the mirror on its stand. The light rays are reflected back to the tester's eye behind the knife edge.The knurled-headed bolt controls the entrance, and exit, of the knife edge into the reflected beam. The consequent "dough nut" shadows on the mirror are analysed. Focal length can be determined precisely when the mirror blackens instantaneously.

Simpler arrangements of razor blades on wood, and moved in and out of the reflection by hand, are also satisfactory.



The Mirror Under Test with the Couder Screen.

The zones, cut on the same radii each side of centre, give us four small areas for testing the parabolic curve. When opposite zones darken instantaneously the focal length of that zone is determined. Comparison with measurements calculated by the formula r2/R, and related to the focal lenth of the centre of the mirror, tells us when we have reached our desired degree of accuracy.

light is projected correctly it fills the mirror brilliantly and the reflection back, a little out of direct line of the pin–hole, is intercepted with a knife edge. At the exact point of focus of the mirror, the knife edge instantaneously darkens the mirror totally. When either inside, or outside, focus is intercepted, opposite vertical halves are darkened progressively. The mirror, under these tests, shows a varied pattern of "doughnut" shadows, which after practice in interpretation, determine the accuracy of the parabolizing of your mirror. Accuracy is further determined by checking the distances of the knife–edge from the mirror – these positions are pre–determined by calculation of separate zones of the mirror – a feature of the testing introduced by Couder. We used, without qualms, an English micrometer, adapted for the purpose by removing the frame as the Metric system is usurping the hallowed eminence of the English system in engineering.

The combination of long and short strokes on the pitch block, as well as varied pressures on different zones – so well descibed in *How to Make a Telescope* by Jean Texeseau – along with the frequent Foucault tests, eventually leads to the standards of accuracy where, as a hag–ridden amateur, you say, "enough is enough".

The mirror can then be silvered, with the easy workshop method developed by Brashear, but this has given way to aluminizing by the professional vacuum evaporation method. The latter metallic surface does not tarnish easily, as does the silvered surface, so renewal is only required every few years, whilst the silvering must be repeated every six months, but, as some compensation for this, it can be done cheaply at home.

Now your self–inflicted torment could be over if you consider that you have reached your apogee of accuracy in finishing a mirror,for aluminized diagonal flats are easily obtainable. Or you could use the accepted alternative of a 45 degree prism to deflect the light rays to the magnifying eye-piece. In any case the eye-piece will almost certainly be purchased complete and all the other components – the spider to hold the flat – the eye-piece holder – the tube – the mirror cell and the stand with accessories may be purchased or made, and assembled with familiar tools and familiar techniques.

But if your personal demon drives you on, as mine did to me, you will attempt, and succeed, in making a diagonal.. Mark you, I have not stipulated how long it will take, nor how many pieces of glass you will test and reject, nor how many mistakes you will make. So learn from my first mistake. Do not use the thick window glass such as in large framed windows. I suspect it is modern float glass and not the polished plate recommended by the text books.

After my experience in trying to make small diagonals, from what appeared to be an unlimited supply of broken, raw material on the premises, I earnestly urge you to look for thick plate glass. I am deliberately sparing you the horror – story of the early attempts at making the diagonal flat. We will pass over the frustrations, the blind alleys, the persistent Newton rings or "fringes" under test, and the craftsman's anger at the unsuccessful work. I suddenly remembered an old mirror, discarded on a shelf and partly unsilvered with age, which proved to be over 5/16 inch thick. By then I was a practised hand at cutting thick glass with a wheel cutter, and had 100% success at reducing the old mirror to the small rectangles required for testing for flatness. The less the number, and the straighter the Newton rings -- fringes – show under a light test, the flatter is the surface.

The old silver was dissolved with acid and the pieces tested for flatness by the universal method of 1 + 2: 1 + 3: 2 + 3. After the equation and substitution, I found three, or four pieces, showing only two, or less, fringes. Further elimination, and work on a pitch block, gave me two which were below one fringe set against the straight edge.

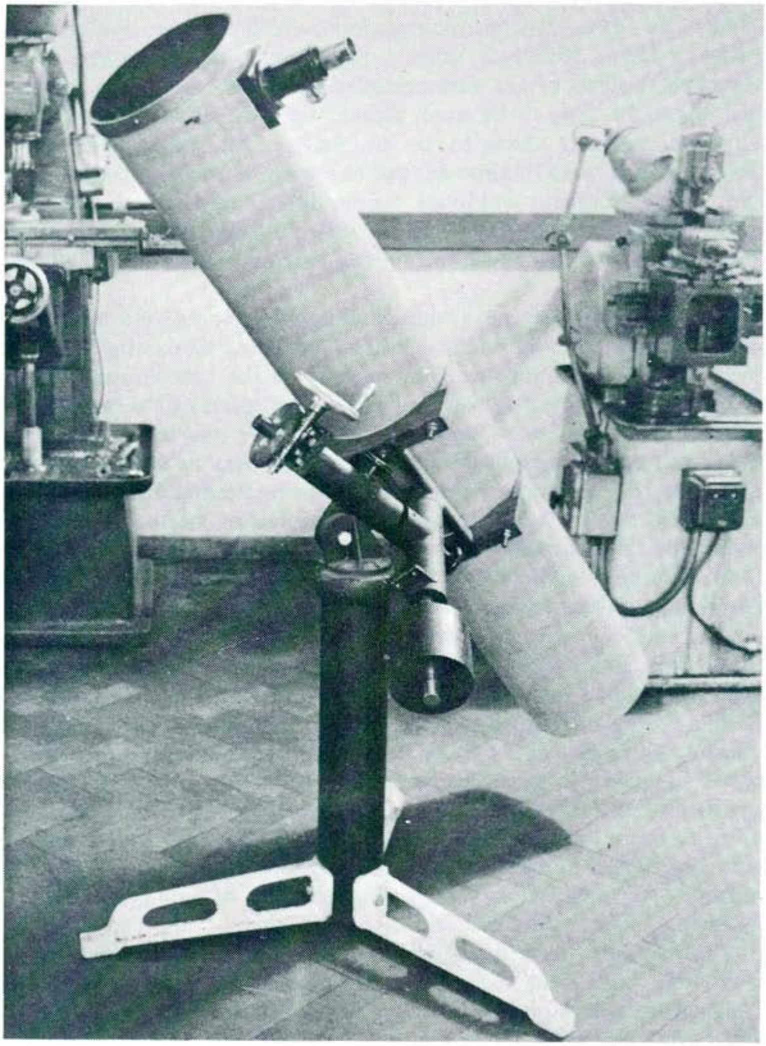
As a matter of interest, an article in the December 1972 issue of the Journal of the B.A.A., describes an apparatus for the testing of glass flat surfaces, such as I adapted from sketches in Howards *Handbook,* and also from Selby's article, page 124 A.T.M. Volume I. I also found that a six–tube–light printing machine, which produces dye line prints, was satisfactory. Also a Heath Robinson affair I rigged up, with only a one–tube–light, worked well enough, instead of the recommended neon indicator lamp and condenser lens. I decided upon the flats to be used, ground them to an elliptical shape on our lapidary equipment and sent them to be aluminized. All testing gives way to the pragmatic test of "does it work?" Mine do. But to see my younger colleagues shake their irreverent heads in mock despair, and to see the pupils smilingly looking upon the antics of the old man, was only another part of the cross I had to bear. But from then on we had no trouble for we used the tools, techniques, machines and materials in which we were skilled.

The first rigged–up telescope was a success, although it underlined the bug–bear of the whole aspect of observational work – instability. Those momentary periods, when your sky object was in view were rare, in relation to the time impatiently spent in capturing and retaining the object in the eye–piece. The speed of the moon across your line of vision was surprising, when you were particularly wishing to examine a well defined crater, or as I tried one night, to see how far the telescope would resolve the rays of Tycho. This you will note was my first break away from the awe–struck viewer, revelling in the product of his work, to the deliberate Lunar observer, setting himself a study to the limits of his instrument. It is because of these limits that men have searched often, and produced, bigger and better telescopes, which have extended the Universe far beyond the knowledge of the astronomers of the past.

This is not the end, by any standards, of telescope making for school purposes. Nothing has been said about the aligning, and collimating, of the optics, nor about the need for a small refraction telescope finder, nor about the relative merits of eye pieces, nor about the actual simple measure – merits for the Foucault test, nor about the many other improvements you can make. I make no apologies for concentrating mainly on the production of the optics for I found this part almost totally absorbing. It was an entirely new handicraft to me, and one which embraced knowledge, skill, techniques and science. The technical department colleagues were entirely co–operative and, I believe, have gained from the experience. Some of their serious suggestions, when I was in difficulties, were almost inspired, for they analysed the problems calmly, offered practical advice, and without arm–twisting, made up the specialized requirements.

Many of the pupils only showed a passing interest. All those who probed into the techniques must have benefited. The groups of children and parents, who asked and listened to explanations when the first telescope was exhibited on Open Day, leads me to think that observing, providing it is not too cold outside, has attractions, if the instrument is not too small.

But why make a telescope for use outside, when we can read more of the wonders of astronomy discovered by the optical giants in huge observatories and from the radio antennae covering acres of ground? Because, like Everest, it is there! No photograph of the skies has thrilled me, as did the first view through that now laughable telescope we made. I have a fanciful thought that, aeons hence, when the Pole Star yields its pride of place to another star, because of the inexorable path our parent Sun, and its captive



The First Telescope made at Holland Park.

family, takes around our Milky Way, someone, somewhere on this comparatively infinitesimal speck of matter will look up, marvel, work and sweat to make a mirror as did Newton. He will make this mirror because he must, although all the then known information of the skies, could roll on a screen at the touch of a switch. He may be hesitant in explaining the reason which coerces him but which has, he thinks, a similar effect as that symphony has – you know – that one the research student discovered in the archives of ancient music – oh yes – Beethoven's Fifth.

The following books have all been of value in the making of our telescopes and will be used further, if and when, we pursue our more ambitious plans.

Amateur Telescope Making Books I–II–III
Albert G. Ingalls (Editor)
Scientific American Inc. New York.

Handbook for Telescope Making
N.E.Howard
Faber and Faber
24 Russell Square, London.

How to Make A Telescope
Jean Texereau
Interscience Publishers Inc.
New York.

I enjoyed reading some years ago:

Making Your Own Telescope
Allyn Thompson
Sky Publishing Company
Cambride 38
Massachusetts.

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