NexStar Alt-Az Alignment Guide

John Carlyle, Yardley, PA, U.S.A.
(with lots of help from Alain Fraysse, Carroll Morgan, and Michael Swanson)
2001 February 22

The NexStar telescopes from Celestron International are capable of very good GoTo accuracy, if some simple steps are followed. This guide attempts to make those steps clear, so that you may enjoy the best possible tour of the heavens with minimum frustration. Please note that these instructions are **only** for Alt-Az use; if you are mounted on a wedge then you will have to follow a different process (that is not covered here).

We would like to make clear at the outset that the two most important steps in this procedure to achieve accurate GoTo operation are (1) making the optical tube assembly (OTA) axis orthogonal (perpendicular) to the azimuth (Az) axis, and (2) accurately centering the alignment stars prior to pushing the Align button. Watch for these two **very** important points in the steps that follow.

Fig. 1. NexStar axis definitions.

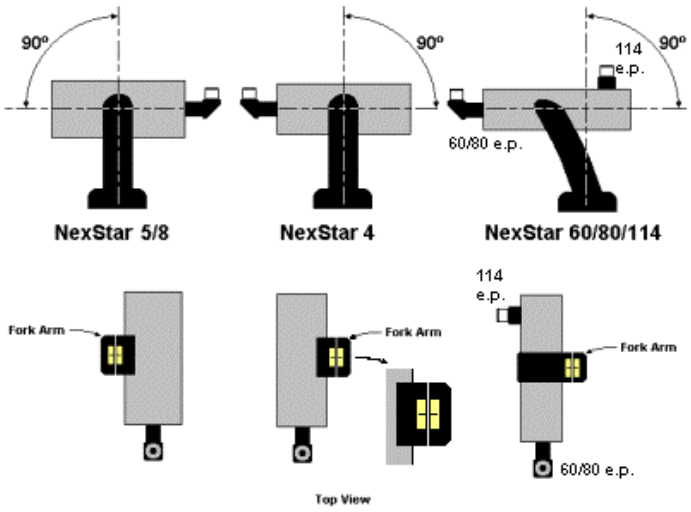

Fig. 2. Proper orthogonal set-up of OTA and Az axes for various models of NexStar telescopes.

Figure 1 defines the three axes of the telescope, while Figure 2 shows precisely what we mean when we say "make the OTA axis orthogonal to the Az axis" for each of the current NexStar telescopes. In Figure 2, note the alignment marks shown in the close-up. The marks are depicted as the small lines on two pieces of yellow tape, one piece on the fork arm, the other on the OTA bracket. Please refer to this close-up when reading the *Marking Zero* section towards the end of this document.

A level is the only tool needed to get accurate alignment. We recommend a short (6 inch) line level, of the sort sold at Home Depot for around $2. This level is designed for masons and has a shallow V-groove on the back, enabling it to work on both flat and curved surfaces.

Movements of the OTA must be done with the hand controller arrow keys. When centering an alignment star, always move the tube so that the star ***as seen in the eyepiece*** moves in the same

direction as a star moves during the final stages of a GoTo — with an upright diagonal in place this is from the lower left quadrant of the field of view, up and to the right. Since this mimics what the NexStar does at the end of its motion when you GoTo a target, it minimizes the backlash in the gears. (Note: if you are not using a diagonal, or it is not placed such that it is going up (away from the focus knob) then the proper approach direction may differ from the "up-and-right" recommended above. But the principle is the same: mimic the scope's own GoTo behavior at the end of its motion.

You should also note that for rates of 6 and below the arrow keys reverse their action on the NexStar 5/8 — at rate 5 an **up** arrow moves the OTA **down**, while at rate 9 an **up** arrow moves the OTA **up** (the left and right arrows do not reverse). And you should note that the view through the finder will show the opposite up and down motion to the eyepiece view. It is believed that Celestron designed the hand controller arrows to work this way so that for rates of 7 through 9 the up and down arrows would correctly control the up and down direction of the finder dot against the sky, while at rates 1 through 6 the up and down arrows would correctly control the direction of motion of the target star as seen through the eyepiece.

And finally, remember that the scope might not behave completely "as if logic prevails". If you find any discrepancies between what we suggest will happen and what your scope actually does, please post a report to the NexStar Group discussion at the following web site:

http://www.groups.yahoo.com/group/nexstar/

Here are the recommended steps for achieving a good alignment:

1. Level the Tripod

This does **not** need to be done if you do a Two-Star Align. However, it **should** be done if you do an Auto-Align, as the first part of a two part process for having the telescope chosen alignment stars show in your eyepiece field of view. If you do not do it, the scope may not point accurately to the alignment stars it has chosen for you.

Start with the plain tripod (before mounting the OTA). On the Celestron N4/5/8 tripod, place the level alternately across the tops of the three Phillips head (cross-slotted) screws on the top surface. On the N60/80/114 tripod, place the level alternately across the tops of the legs, while resting on the flat surface of the mounting "cup". Adjust the legs until the bubble lies between the lines on the glass, no matter which pair of screws the level is on. Now, mount the OTA onto the tripod. (Figure 2 shows the correct relationship between the OTA, the eyepiece, and the arm assembly for those NexStar owners whose scopes have removable OTAs — they can be put in backwards or even upside down.)

2. Zero the Alt

Turn on the power. Select either an Auto-Align or a Two-Star Align (but note that Two-Star Align is only available on the N5/8). You are now starting the first real step of the alignment process (and one of the two most important ones, too!)

The hand controller LCD says to make the OTA "North and level" if you are doing Auto-Align, or if you are doing Two-Star Align it will say "Level the tube". The word "level" is misleading, though. "Level" **really** means "make the OTA axis orthogonal to the Az axis" or, in other words, set the Alt

equal to zero (see Figure 2). Making these two axes of the scope orthogonal is **extremely** important to achieving good GoTo results, and it **must** be done for **both** the Auto-Align and the Two-Star Align processes!

Making the OTA point North for Auto-Align is done as the second part of a two part process for having the telescope chosen alignment stars show in your eyepiece field of view. It is simple if Polaris is visible from your location: use the finder to point to Polaris, then use the arrow keys on the hand controller to center Polaris in the field of view. (At this stage it is good enough to use the 25 mm eyepiece, but later in this procedure a more powerful eyepiece, like a 10 mm, should be used to get better accuracy.) If Polaris is not visible, you can find North with a compass (but do not forget to compensate for the local magnetic declination!)

The next step is to use **only** the up and down arrow keys to move the OTA up or down until Alt equals zero. The most accurate way to accomplish this is to use a permanent mark for the Alt equals zero position on the NexStar OTA mounting arm (made by following the steps in the "Marking Zero" section at the end of this document). However, if you have carefully leveled the tripod by following the directions in Step 1, you can achieve pretty much the same result by using the line level on the top of the OTA. Whether you use an alignment mark or just level the tube, make sure that the final motion of the OTA at the eyepiece end is upwards when approaching either the alignment mark or level, in order to minimize backlash.

At this point, press Enter to conclude either the "North and level" or the "Level the tube" step. Let me emphasize again that care taken now to get the OTA axis orthogonal to the Az axis (as shown in Figure 2) will be amply repaid with better GoTo results later!

3. Auto-Align Tips

You will first be asked to enter the date — be careful that you use the American convention of Month, Day, Year! The time is best entered in Military time, so you don't have to enter the PM up to midnight (note that you'll always have to enter the AM for a morning time, though).

Some people have suggested that you should add about 2 minutes to the exact time, in order for time to be correct when you finish the second star alignment. However, this is not necessary. Although the stars' apparent positions will change during alignment, there's no need to hurry along, nor does one need to set the scope's clock ahead in Auto-Align to compensate for the time it will take to complete the process. The reason for this is that the information retained by the scope after the first alignment fix is to do only with the possible position of the pole: although it compares the RA/Dec and Alt/Az data of the alignment star in order to deduce that information, once done it is no longer interested in the first star. So, when you get around to doing the second fix, no matter how much later, the first-fix information is still valid: since the pole does not move, it will still be exactly where you left it. Thus, entering a time "ahead" is not only unnecessary but is in fact not a good idea, because the more accurate the absolute time the more accurate the NexStar will be in finding fast-moving objects (e.g. the moon or planets) once you're all set up.

Next you enter the Longitude and Latitude. One thing you **must** be aware of is that there is a bug in the NexStar 5/8 software which causes previously saved entries to be corrupted unless you separate them by 4 entry numbers. This means that you can only use locations 1, 5, and 9 (or 0, 4, and 8) to store your Long/Lat values! For some longitudes (apparently the eastern hemisphere), the NexStar

60/80/114/4 software does not store longitude/latitude correctly at all, so if you are having problems when using a stored longitude/latitude you will be forced to enter it each time you use the scope.

After the Longitude/Latitude entry, the scope will slew to an alignment star it chooses for you. If you cannot see the star due to a tree, a building or a cloud, press the Undo key and the scope will choose another one. Also, you should skip any stars that are higher than 70 degrees altitude (as alignment stars high in the sky will lead to GoTo accuracy problems) or stars that are lower than 20 degrees in altitude (to avoid any refraction errors being introduced by the atmosphere). If you are in the northern hemisphere, you might also want to Undo until Polaris is chosen for your first alignment star as this seems to improve alignment (see the discussion in point 4). It does, however, take much of the convenience out of the Auto-Align method.

Since you are doing Auto-Align, please skip the next section, continue with "Center the Stars".

4. **Selecting Stars** (mostly for N5/8 Two-Star Alignment)

When you use Two-Star Alignment you get to choose the stars you will align to from a list of 40 named stars. (Note that you can Undo in Auto-Align and so quasi-choose your own stars.) Be aware that some choices of stars will work better than others! Here are some general guidelines:

First, you should only use stars that are less than 70 degrees in altitude at your location at the time you are doing the alignment (this is because Alt-Az mounts have inherent positioning problems near the Zenith). Also, try to select stars above 20 degrees in altitude, to avoid any refraction errors being introduced by the atmosphere.

Second, you should choose two alignment stars that are about 90 degrees apart (plus or minus about 30 degrees) in azimuth (because this maximizes the difference values for the alignment algorithms, thus producing more accurate results).

The third step is an either/or choice — you can either stay on one side of the meridian (the North-South line that goes through your location), or you can choose symmetrical stars on either side of the meridian. Several things happen when you cross the meridian, like mirror flop and a change in the interaction between balance and gear backlash. It's possible that these factors aggravate mechanical tolerance problems in the scope, and could lead to a loss of centering accuracy — in any event, experience with the NexStar telescopes has shown that very good alignments can be obtained by staying on one side of the meridian. On the other hand, mathematical simulations have shown that if you pick two stars that lie 6 hours apart in Hour Angle and which are symmetrically placed either side of the meridian, you will also achieve good alignment. This alternative needs to be explored more thoroughly, but it looks promising and we encourage NexStar owners to try it and post their results to the NexStar Group.

My recommendation is that your first alignment star be Polaris. For most people in the Northern hemisphere, Polaris is quite visible all the time, and is well below the 70 degree altitude limit. Polaris has the advantage of (almost) not moving across the sky (note that Polaris is 44 arc-minutes from the true North pole), so it won't be moving out of your field of view (FOV) while you are trying to align it. Then, follow the first two principles above to choose your second alignment star. (In the Southern hemisphere you will have a problem with this approach, because Polaris' analog, Sigma Octantis, is not a NexStar alignment star — perhaps the use of symmetrically placed stars on either side of the meridian should be considered here.)

(Note: Meade users apparently have alignment accuracy troubles if they choose pole stars, so you may hear contrary advice from them. Remember that their positioning algorithms are probably different from those used in the NexStar. Polaris does work on the NexStars: in fact, it works very well!)

5. Center the Stars

Whatever type of alignment process you choose, you **must** be sure to approach the alignment stars correctly to minimize gear backlash. What you want to do is to mimic the scope's own GoTo behavior at the end of its motion. To do so, make the star (as viewed in the eyepiece) move up and to the right from the lower left quadrant of the field of view until it is centered in the eyepiece (assuming you're using a diagonal, it's in the upright position, etc.) If you should overshoot the center, simply move the star back down and/or to the left of center, and try again.

To get the best possible alignment you should use a higher-powered eyepiece rather than the 25 mm (or the 40 mm that the N8 is sometimes supplied with). A 10 mm eyepiece works well for this purpose in the N5 (a magnification of 125 times); for the N8 you would need a 16 mm to get the same magnification. (Remember that magnification is the scope focal length divided by the eyepiece focal length — the N5 has a FL of 1250 mm, the N8 a FL of 2030 mm.) A eyepiece with a reticule is even better, of course, as accurate centering of the stars is the second of the two most important alignment steps (orthogonal OTA and Az axes being the first).

Once the first star is centered, you press Enter, then you press Align. For Auto-Align, press Enter again to have the scope choose and slew to the second alignment star. For Two-Star Align, you must select the next star from the list of 40 named stars. After the second star is aligned, the screen on the hand controller will tell you "Alignment Successful". Make sure to turn the power off on the finder at this point, unless you like buying hard to locate finder batteries!

The most common reason to get a "Bad Alignment" message is that you have picked the wrong star. For Auto-Align, you must pick the brightest star in the region of the sky in which the scope is currently pointing: if you've leveled the tripod face, entered the proper time, longitude and latitude it should be inside or at least very close to the FOV. For Two-Star Align, you need to be sure that you have picked the proper star — consult a star map or a planetarium program to be absolutely sure of the names and locations of the alignment stars.

6. How Good does GoTo Get?

There are performance differences between various NexStars, even of the same model (comparing N5s for example). But, if you follow the steps in this guide carefully, you can expect to do a GoTo and have the scope slew to within 7 arc-minutes of the true position of the target. (This is within the center half of the field of view of a 10 mm eyepiece used with an N5.)

We emphasize that you must be careful to make the OTA and Az axes as orthogonal as possible and to accurately center the alignment stars! Modeling has shown that at 45 degrees latitude, making errors of about 0.2 degree in getting the axes orthogonal and making alignment errors of 0.1 of the FOV of the standard N5 25 mm eyepiece when centering the alignment stars (with the first alignment star being Polaris and using a second alignment star at about Az = 90 degree East, Alt = 40 degree), resulted in OTA pointing errors larger than 0.5 of the FOV when going to a star that is located on the meridian at Alt = 65 degrees!

7. Checking your Alignment

Some people recommend that you check your alignment after you receive the "Alignment Successful" message. To do this use the List|Named Star menu function to go back to the first star you aligned on. If it doesn't center properly, then something went wrong with the alignment process. Perhaps you didn't move up and right, perhaps there is something wrong with your backlash settings, or perhaps the balance of the scope is wrong. In any case, you have the choice of starting the alignment process over again, or you can try to tweak the alignment using the third star alignment method.

Use of the Third Star Alignment has had mixed results by various people. If alignment is off badly (i.e., if a GoTo target winds up near the outer edge of the eyepiece field of view consistently), Third Star Alignment doesn't seem to work very well. If a GoTo target is in the middle 25% of the field of view, however, Third Star Alignment helps. In other words, Third Star Alignment tweaks, it doesn't correct gross errors — if you have large GoTo errors, it is best to start the alignment process over from the beginning!

To do a Third Star Alignment, center the desired target (making it move up and right in the eyepiece field of view). Then press Align, use the Up and Down scroll keys (not the arrows) to select which of the two alignment stars to replace (trying to choose the alignment star closest to your present position), and press Enter.

Other Alignment Topics of Interest

Marking Zero — As said above, getting the OTA axis and the Az axis orthogonal is one of the most important steps in achieving accurate GoTos. The best way to accomplish this in the field is to make and use a permanent pair of marks on your telescope. First, take the tripod to a hard level surface, and use a carpenters' level while you adjust the tripod legs until the top surface of the tripod registers level, no matter how you place the level across the tripod top plate. Second, mount the scope and move the OTA (using Figure 2 as a guide for your scope) until the tube is level as determined by a line level (place the line level on the silver part of the tube, not on the ends). Rotate the OTA through 360 degrees of Az, and move the tube up and down until the line level shows that the OTA is level no matter which Az direction it is pointing. At this point scribe two lines (one on the arm and the other on the filler piece between the OTA and the arm) such that the lines point to each other across the joint. (Some people prefer to place pieces of tape across the joint (or use white-out) as a background on which to make the alignment lines.) One person recommended using one line on the filler piece and two lines on the arm, so that with correct alignment the single line was centered between the other two. He claimed that this was easier for him to see using red light. ***However, be careful when marking*****!** Modeling has shown that a 0.2 degree orthogonality error (equivalent to about a 0.25 mm marking error), can yield GoTo errors of up to 1 degree (twice the Moon's diameter!)

Adjusting Backlash — Celestron attempts to compensate electronically to minimize the gear backlash that you experience on the NexStar scopes when you use the positioning arrow keys, and gives you a means for adjusting it. However, they don't give you a good method to tell when it is correct! In a nutshell, the best way to achieve good backlash compensation is to adjust the value (at your most used slew rate, because it is only optimized at one rate) until the scope smoothly reverses direction when you are driving against the backlash and you hit the opposite arrow key. For example,

say that you usually center at rate 5 (this is common because Auto-Align leaves the N5 at this rate). Using an arrow key that moves the target in the eyepiece down or left drives the scope against the backlash. Keeping your eye on the target, release that arrow key, press the opposite arrow key (so the scope will move either up or right), and note what the target does. If the target stops when you release the key that drives the target left, and then the target smoothly and immediately starts moving right when you press the opposite key, your backlash for the Az is set correctly (Alt backlash is set using a target going down followed by going up). Most often, the target will jump or stay stationary for a few seconds when you hit the opposite key — this indicates that the backlash values need adjustment. Values between 15 to 40 seem common for the owners polled. Note that the backlash compensation setting doesn't seem to be active during tracking (as it only is applied when using the arrow keys), so the backlash setting should not affect tracking. However, if you center a star going against the backlash you most definitely **will** affect the alignment!

Checking Balance — Celestron designed the N4/5/8 scopes so that they would be heavy on the corrector plate end. Big, heavy eyepieces (Naglers, Radians) can upset this balance so that the scope is eyepiece end heavy. One sign that balance is a problem is when at the end of a GoTo (while viewing through the eyepiece) you see the target star drop towards 6 o'clock. One solution is easy: wrap a weight (like a wrist weight that runners use) around the corrector plate end of the OTA. The N60/80/114 scopes use a more traditional tube mount that allows you to move the OTA back and forth to achieve balance when mounting heavier eyepieces. For N5/8 owners, a similar solution can be implemented by using a special bracket (originally made by Ray Cooper for the N8 but now also being prototyped for the N5) that permits you to slide the OTA with respect to the Az arm. See this web site for details:

http://www.grcooperjr.com/tnt/

Positioning Error Determination — Occasionally there are problems with the electronics of N5/8 scopes. In one case a hand controller was bad, and caused positioning errors at the end of a GoTo of up to 25 arc-minutes. A replacement hand controller (with the same firmware level) in the exact same scope had position errors of only 2.5 arc-minutes, by contrast. Sometimes, redoing a GoTo gets closer to the correct position. Such performance problems can be diagnosed with the use of a utility program I wrote for PCs called N5EXER, which is available in the Files section of the NexStar Group as *nexstar-exe.zip*. (Another gentleman in the NexStar Group, Matthias Bopp, is writing a similar program for the NexStar 60/80/114 series of scopes — it is also in the Files section.)

Tracking Drift Determination — Some people report that targets drift out of their eyepieces fairly quickly (in a matter of 5 minutes) while others report that targets are still in the field of view after an hour or so. It appears that the NexStar controllers use a different algorithm for tracking than they do for GoTo calculations, and somehow the tracking algorithm is scope sensitive. (One solution for getting around poor tracking when doing visual astronomy is to simply redo the last GoTo; then the scope will place the target back into the FOV.) A figure of merit for tracking drift is that targets should take 35-40 minutes to drift from the center to the edge of a 25 mm eyepiece on an N5 (a rate of about 45 arc-seconds per minute). Tracking performance figures can be diagnosed with the use of the same utility program mentioned above (for PCs) called N5EXER in the eGroup files. I have found that the clock in my N5 is misadjusted: it runs at about 903 arc-seconds per minute rather than the correct sidereal rate of 897.5 arc-seconds per minute. Several members of the NexStar Group

(with Michael Swanson being the principal) have contributed suggestions to develop a simple indoors alignment test that allows you to compare your scope with others who have completed the test. You can download the test and current results at this web site:

http://www.angelfire.com/ns/nexstar/

Alignment Algorithm Details — Celestron does not make engineering data public, so we can only guess exactly how their alignment algorithm is implemented. However, the mathematics behind their algorithm has been worked out by several members of the NexStar Group (principally Alain Fraysse and Carroll Morgan). You can view the details and helpful diagrams at these two web sites:

http://alain.fraysse.free.fr/astro/align/altazal.htm

http://www.cse.unsw.edu.au/~carrollm/n8/

NexStarAlignment Summary

The following points, which are based both upon the mathematics as well as empirical results from using the NexStar telescopes, summarize the more important points of this guide:

1. The critical issues for alignment accuracy are zeroing the Alt, and accurate pointing when you sight the two stars (irrespective of whether Auto-Align or Two-Star Align is selected).
2. Northing and/or leveling the tripod are convenient for Auto-Align purposes, but have little effect on alignment accuracy (see point 1).
3. The time taken for the alignment process (i.e., worries about the earth rotating while you do it) is not critical.
4. When using alignment marks to achieve Alt=0, you should approach mark-alignment from the direction that minimizes backlash errors.
5. Either use alignment stars that lie on the same side of the meridian, or choose symmetrical stars on either side of the meridian.
6. Choose alignment stars whose Alt lies between 20 and 70 degrees, and which are separated by about 90 degrees in Az.
7. The use of Polaris as the first alignment star works well in the NexStar telescope.