The Really, Really Basics of Laser Rangefinder/Clinometer Tree Height Measurements

By Edward Frank – January 12, 2010

Many of us have been measuring tree heights for a long time. We have subconsciously incorporated subtle details of the process into our routine. We have filed away much of what we have learned as obvious. There are steps we go through without even thinking about the mechanics of what we are doing. On the surface of everything, the process seems simple and it is if you know what you are doing. Essentially we measure the straight-line distance to the top of a tree using a laser rangefinder. Then we measure the angle to the top of the tree with a clinometer. The height above eye level is calculated using a pocket calculator to be the trigonometric sine of the clinometer reading x the distance measured to the top of the tree. The same process is used to measure how far the base of the tree extends vertically above or below eye level. Then the number for the height of the base of the tree above or below eye level is added or subtracted from the number for the top of the tree to get the total height of the tree. If we able to show someone in person how to measure a tree, we can do a fairly adequate job of it. But for people just learning the techniques on their own, it isn't as straight forward and trying to explain the process through emails, through online chats, or even through an article is a much more hit or miss proposition. This is not only because of the math involved, but because of the variability in the shapes of the trees and the obstacles to seeing their tops and base from a common vantage point. Actual field situations add levels of complexity to tree measuring beyond that of the theoretical models taught in forestry courses.

What does tree height mean?

Tree height is the vertical distance between the base of the tree and the highest point on the tree. It is not the same as the length of the trunk. If a tree is leaning, the trunk length may be greater than the height of the tree.

How do we know what we know about tree height measurement?

There are several different sources of the knowledge we embody as an individual and as a group. 1) Background knowledge. Each of us has unique set personal experiences in our lives that we bring to the process of measurement. For example I had been using a clinometer for years, had been involved in cave surveys with tape-compass-clinometer, and had done surveying with transits, plane tables, and total stations. I brought that knowledge with me when I started tree measuring. 2) Information we have read. Most of us had read something about the measurement process and instrumentation before we jumped into tree measuring. 3) Knowledge we have been taught. If we have the luxury we can have someone walk us through the entire tree measurement process. 4) Knowledge we have observed. We learn by watching others measure trees even if they are not explaining everything they are doing. We see how someone scans through a tree top, how they approach finding a large tree, and the order of how things are done. 5) Knowledge we have discovered through doing. We learn how to do things with practice and experimentation. We teach ourselves many of the details of what we are doing. The goal of this article is go over as many of these smaller details and processes, to go over what seems obvious, and to create a document that better addresses the needs of someone trying to teach themselves to measure trees without the in person guidance of an experienced measurer.

Clinometer Basics

A clinometer or an inclinometer measures the vertical component of angle between your eye and whatever you are targeting. It is basically a weighted wheel that pivots in the center and is mounted in a sighting case. It is a purely mechanical device. The wheel mount liquid filled to assure that it can spin freely but still dampen the shaking ad sloshing. . There are two brands of clinometer that are used by most tree measurers. The first option is a Suunto and the second is a Brunton.

Figure 1: The Suunto PM-5 has dual scales – one reads in degrees, the other in slope percentage. For tree measuring a clinometer that measures in degrees is required.

Figure 2: This is a Brunton Clinomaster and it works essentially just like the Suunto PM-5 clinometer.

The Suunto Company has a user's guide on their website, explaining how to use the instrument to measure trees. Don't use their instructions. They are based upon the idea of a measuring tree height from a base distance and the percentage slope scale. This is called a tangent based methodology and it will not give you accurate tree heights, except in the uncommon situation where the top of the tree is located vertically over the base and clearly visible to the measurer. Getting an accurate result is the point of measuring the tree in the first place. Advanced use of a clinometer and a tape measure to avoid the pitfalls of the simplified approach described by user guides accompanying the purchase of clinometers requires math beyond what beginners often are willing to tolerate. Some of the more esoteric math applications to basic tree measuring with a tape and clinometer are presented by Robert Leverett (2010b) in the Bulleting of the Eastern Native Tree Society. Suunto's user's guide actually does give a nice description of the mechanics of sighting a target with a clinometer:

> "Readings are usually taken with the right eye. Owing to differences in the keenness of the sight of the eyes and because of personal preferences the use of the left eye is sometimes easier. It is of prime importance that both eyes are kept open. The supporting hand must not obstruct the vision of the other eye. The instrument is held before the reading eye so that the scale can be read through the optics, and the round side-window faces to the left. The instrument is aimed at the object by raising or lowering it until the hairline is sighted against the point to be measured. At the same time the position of the hair line against the scale gives the reading. Owing to an optical illusion the hair line (crosshair) seems to continue outside the frame and is thus easily observed against the terrain or the object. The left-hand scale gives the slope angle in degrees from the horizontal plane at eye level. The right-hand scale gives the height of the point of sight from the same horizontal eye level, and it is expressed in per cent of the horizontal distance."

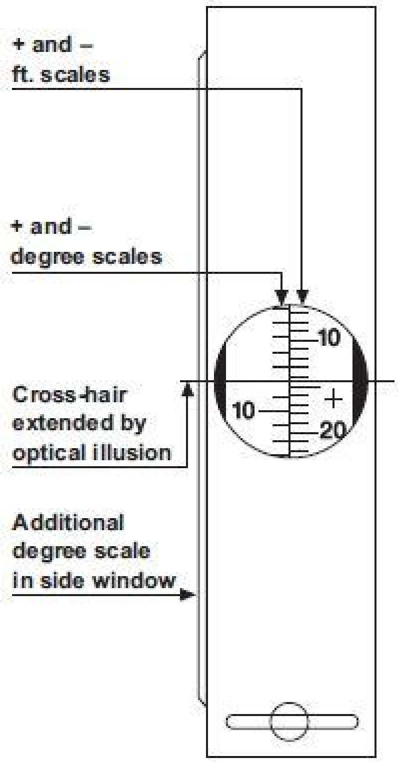

Figure 3: Using the Suunto clinometer

Sighting summary. 1) Hold the instrument in your right hand with the dial facing to the left, 2) Look through the viewing port with both eyes open, 3) The black line will look like it extends beyond the frame of the instrument. Line up the optical illusion of the black line with the object you are measuring, 4) Read the number of degrees on the left hand scale.

Reading the clinometer. Read the degree scale on the left side of the instrument. The clinometer has marking ticks every 1 degree. When using the instrument a goal is to try to estimate the angle to the nearest one-tenth of a degree. Chances are that the person using it will not be able to hold it still enough to measure to that degree of accuracy, but it is a goal to shoot for. With practice users are able to hold the instrument steadier and will be able to better refine the angle estimates.

The degree scale. The readings for the angles to the top and base of the tree must be made using the degree scale on the left. If the user can't remember whether to use the scale on the right, or the scale on the left, you can look at the reading on the dial to figure out which one is the correct scale to use. If the instrument is held level, both scales will read 0. Now tilt it half way between horizontal and vertical. This is a 45 degree angle. The degree scale will read 45, while the percent scale will read 100. On the percentage scale that means at that angle, the change in horizontal distance is the same as the change in vertical distance. Point the instrument straight up. This is a right angle, or is 90 degrees from horizontal. The degree scale will read 90, but there will not be any numbers on the percentage scale because the vertical component along that line is changing infinitely faster than the horizontal distance.

Reducing shake. There are several methods that can be tried to help hold the instrument still. Shaking is the enemy. One method is to brace the hand holding the instrument tightly against your forehead. The elbow can be braced against your chest. Holding your breath while reading help keep the instrument steady. Each individual needs to simply practice and find out what works best for him.

Using the clinometer. When I use the clinometer I keep my eye on the target, and while doing that I raise the clinometer to my eye and take a reading. Without taking my eye off the target, I drop the clinometer back down, jiggle it a little, and then raise it back up to my eye. The readings should be the same. If they are widely different repeat the process until you figure out what is wrong. The dropping it back down and jiggling it step assures that the clinometer is not sticking. It also gives you a second chance to check the reading to make sure you read the correct number off the dial and correctly interpreted the scale.

Sticking clinometer. Some clinometers have been reported to stick occasionally when used. While looking through the dial move the clinometer up and down slightly to see if the dial is moving freely. If you think the clinometer is sticking follow the procedure outlined above. Lower the clinometer back down, shake it slightly, and take another reading. If it has stuck the mild shaking should free it. Once it is free, recheck the readings again to make sure you have the correct numbers.

Bubbles in the clinometer. Older instruments will sometimes have bubbles in the liquid cushioning the dial. The Suunto website recommends sending the instrument back to the seller for repair. I have two clinometers and one has a large bubble. There does not appear to be any difference in the accuracy between the instruments. I would not worry about bubbles unless it appears that they are causing the dial to stick and not turn freely.

Is my 0 degree reading really level? These are precision instruments and if they are not reading exactly level, they should be really close. You can test to see if the instrument **is** reading exactly level with the help of another person or some creativity on your part.

Sight with the clinometer from a marked point on a tree or pole toward another distant object. Have an assistant mark the point on that distant object that the clinometer or instrument says is level. Move to that spot and sight back to your original position. If it is perfectly accurate the back-sight will be right on the point you shot from originally. If it is reading high, then the angle it is off will be under-reading by

> arc tan [(0.5 x error)/distance] = reading error in degrees,
>
> where distance in the above formula is the distance between the two targets and error is the distance on the original pole or tree between the original mark and where the sighting from the second target falls on the original pole or tree.

If it is pointing lower than the starting point, then it is reading high. The calculations are the same. In this way you can tell at least if the original level line is actually level or not (Frank 2005). In trigonometry arc tan is the inverse of the tangent function. On most calculators it is a second level function marked as tan^{-1} on the keypad. What this means is that instead of using the tangent function to calculate a height from and angle and distance, the height and distance are being used to calculate an angle. Stated another way, the tangent returns the ratio of the opposite side to the adjacent side for the included angle, and the arc tangent returns the included angle from the ratio.

Even if the instrument is off by a few tenths of a degree, this does not substantially affect the accuracy of the readings when employing the sine method that will be described later in detail. John Eicholz wrote (Nov 10, 2003):

> "I think I can prove mathematically that the error in tree height that results from each degree of clinometer error is approximately between 1.75% and 1.9% of the horizontal distance to the trunk... Because the factor: (1/cos(@))*(Sin(@)-sin(@+e)) is nearly a constant! Its range is a smooth progression from 1.74% at 0 degrees to 1.9% at 80 degrees. I think I'm always within +/- 0.4 degrees with my Suunto. This translates to +/-0.8 feet per segment on a 100 foot baseline, or +/-1.6 feet overall."

Basically what that means is that the error added or subtracted by a misreading clinometer is essentially cancelled out by an error in the same direction at the base of the tree, when using the sine method. When using the tangent method any errors in the calibration of the clinometer do not cancel out and are incorporated as an error in the final height calculation.

Can't see the dial. In dim light it may be difficult to read the numbers on the degree dial. A flashlight can be used to light the dial from the side. The instrument is completely mechanical and using a light will not affect the reading.

Laser Rangefinder

The second instrument needed to measure trees is a laser rangefinder. A laser rangefinder is a device which uses a laser beam to determine the distance to an object. The laser rangefinder sends a laser pulse in a narrow beam towards the object and measuring the time taken by the pulse to be reflected off the target and returned to the sender. Some laser rangefinders work better than others, have more repeatable readings, have narrower laser beams, are less affected by target color and reflectivity, and better deal with brush along the laser path. If you have a laser rangefinder, try it out and see how well it works for measuring trees. If you are going to buy one, here are some recommendations.

Figure 4: Nikon Prostaff Laser 440 laser rangefinder.

The best overall laser rangefinder in the under $500 range is the Nikon Prostaff Laser 440. This particular model is no longer being made, but can often be purchased used on eBay for less than $100.

The Nikon 440 has been replaced by the Nikon 550 but the newer model does not work as well as the 440 for measuring tree heights. It has a wider beam path; therefore it is harder to shoot through small gaps in the tree canopy and forest in general. The Nikon 550 can be found new for around $190 - $200 range.

A third option is a Nikon Forestry 550 laser rangefinder/hypsometer. This model combines the functions of both the laser rangefinder and the clinometer in a single instrument. In addition it will make the correct calculations of the vertical distance between any two points automatically. So you can point it at the top of the tree and point it at the base of the tree, and it will generate a tree height. This all-in-one instrument costs around $350 dollars from most outdoor suppliers.

Figure 5: Nikon Forestry 550 laser rangefinder/hypsometer.

Finally there are more expensive laser rangefinders with built in electronic clinometers such as the TruPulse 200 and TruPulse 360 http://www.lasertech.com/TruPulse-Laser-Rangefinder.aspx. In a post to the ENTS Discussion list Robert Leverett (2010) says: "I am very fond of both TruPulses (200 and 360). Their lasers and tilt sensors are very accurate under controlled conditions [My TruPulse 360 laser averages within +/- 0.25 feet of tape measured distance as a long run average on targets that are clearly visible and with no intervening clutter.] , but alas, the lasers do not shoot through clutter very well the way my old Prostaff 440 does. The implications for Ents are clear. If you must view targets through clutter as we frequently do when measuring forest-grown trees, you are not going to be a happy camper with the TruPulses - especially considering that they are quite pricey." Another problem with the TruPulse series is that the built in height calculation routine is based upon the flawed tangent baseline distance/inclination method rather than the Sin Top/Sin Bottom calculations used in the ENTS methodology. The Sin Top/Sine Bottom method can be used with the TruPulse, but it must be completed in two separate steps, one for the top triangle, and one for the bottom triangle, rather than using the built in height function.

For someone just starting out measuring trees I would recommend purchasing a used Nikon 440 from eBay and a clinometer. The Nikon Prostaff 440 has the best overall characteristics of any of the laser rangefinder models; the narrower beam is a big plus for this model. A Suunto clinometer or Brunton clinometer can also be purchased used from eBay or new from a variety of suppliers. If purchasing one of these clinometers make sure it looks like the ones in the photos above, and be sure it has a degree scale or it is effectively useless.

At first glance it might seem a better idea to purchase a Forestry 550 rangefinder/hypsometer rather than two separate instruments and I would recommend one over the basic rangefinder 550. But, even though the Forestry 550 has some things going for it, when compared to the Prostaff 440, the better option is to purchase a used Prostaff 440 and a clinometer. The major problem with the Forestry 550 rangefinder/hypsometer is that it has a wider laser beam dispersion than the Prostaff 440 and does not work as well as the 440 when shooting through tight openings or where there are intervening brush or branches. The other concern is that if you are just learning how to use the instruments and you are making mistakes with the measurements, it will be less obvious. There is a tendency to just shoot the height of a tree, write down the measurement and move on to the next. Perhaps you are actually hitting a forward leaning branch, or hitting a branch on another tree, maybe you are hitting an intervening branch rather than the one you are trying to measure. If you are writing down each reading of angle and distance taken with the Prostaff 440 and the clinometer, you will be more likely to catch these types of errors than you will if you just write the heights down. If you do decide to purchase a Nikon Forestry 550 rangefinder/hypsometer you should still write down each of the individual measurements that went into the height the instrument has calculated. All of these measures are displayed on the digital display on side window of the Forestry 550. In addition to error checking there are other types of analysis that can be done with these values.

Nikon Prostaff 440 laser rangefinder. I will use the Nikon Prostaff 440 as the base example for this type of instrument. First off the rangefinder is relatively small in size. The documents giving the specifications for this and the other Nikon rangefinders and instructions on its usage should come with it, or they can be downloaded from the Nikon website:

Nikon Laser 440 / ProStaff Laser 440 / Nikon Team REALTREE LASER 440
http://www.nikonusa.com/pdf/sportoptics/rangefinders/Laser440_0927.pdf

Nikon Laser 550, PS, TR http://www.nikonusa.com/pdf/sportoptics/Laser550PSTR(186K)3E.pdf

Nikon Laser 550A S / Forestry 550
http://www.nikonusa.com/pdf/sportoptics/rangefinders/Laser550.pdf

The 440 rangefinder can be set to read in either yards or meters. In the United States we are culturally programmed to use feet and yards and the instrument is generally used in the yards mode. It will read to the nearest ½ yard/ ½ meter at distances under 100 yards/meters, and to the nearest yard/meter at distances over 100 yards/meters. There are ways to get greater accuracy out of the instrument with calibration tables, and click-over points. Calibration of your rangefinder is discussed later in this document. The target of the instrument is viewed through an 8x magnification optical system. The readings and other information is shown on an internal LED display.

State of the Internal Display

1. [—¦—] — Reticle (aiming system)
   Use to take aim at the target. Position the target at the center of the reticle.
2. [88.8] — Distance/measurement status display
   Digitally indicates measured distance in meters/yards. Also indicates measuring status such as "Measurement in progress", "Measurement unsuccessful" or "Unable to measure".
   Display of results: (≥100m/yards) e.g. 234m = [234m]

   Display of results: (<100m/yards) e.g. 76.5yards = [76.5YD]
   [-] — Now measuring
   [- - -] — Fail to measure or cannot measure distance
3. [m] — Indicates distance being measured in meters.
4. [YD] — Indicates distance being measured in yards.
5. [battery] — Indicates battery condition.
   (See "Changing Batteries")

Although the LCD was produced using the most advanced technology, it is impossible to eliminate dust completely. When using this product, the LCD is magnified by high magnification of the eyepiece lens and dust may appear as a defect. It will not, however, affect measurement accuracy.

Figure 5: Excerpt from the Nikon 440 rangefinder manual showing internal display features.

The rangefinder uses a single Lithium CR2 battery that fits into a compartment in the bottom of the instrument.

Figure 6: Bottom side of the Nikon Prostaff Laser 440 rangefinder.

The compartment can easily be opened in the field using a quarter or other coin as a screwdriver. Be careful not to lose the o-ring that seals the compartment.   The battery fits in with button side (+) inward. The instrument has low power consumption and automatically shuts itself off after a few seconds of inactivity, so the battery doesn't need to be changed very often. Still it is a good idea to carry an extra battery into the field with you as it would be a disaster to drive to a site and hike deep back into the woods only to find that the battery was dead in the rangefinder.

I experienced a problem with the reading becoming intermittent and not working in general. I thought at first this was because the battery was getting low, but instead it was a poor connection on the inside. The positive terminal had become bent down and was not making good contact.   I was able to pull up slightly on the contact with a car key to fix the problem, and I was back in business.

On the top of the rangefinder are two buttons. The button in the back is the MODE used to change the mode from meters to yards. The internal display will show which mode the instrument is currently using. The second button from the back is the POWER button. Depressing this button will activate the rangefinder and let you measure the distances. Holding the button down will allow you to scan across various targets and display the distances to each of these targets. After releasing the button the last reading will be displayed for a few seconds.

Calibrating your laser rangefinder. The rangefinder comes from the factory designed to read to the nearest ½ yard or yard depending on the distance. Actually the rangefinder can do much better than that if care is taken. Part of this process is calibrating the laser rangefinder. Will Blozan (2004, 2008) writes:

> "The laser measurement accuracies listed in their respective specifications essentially is a statement that the actual distance will be within so much of the distance displayed. The precision of the instrument is actually much higher. Before you use a new laser, it must be calibrated. To do this, stretch out a long measuring tape flat on the ground. Have an assistant stand at various locations on the tape with a reflective target. Place yourself in a position so the eyepiece of the laser is over the "0" mark on the tape. Alternatively, you can do this by yourself by affixing the "0" end to a reflective target and walking down the tape, shooting back at the target and noting your position at click-over. Shoot a known distance; say to 40 yards (or meters). Have the assistant move the target closer or away from you until you get to the "click-over", or inflection point of the laser for 40 yards (or meters). Make note where the target is in relation to the tape. Do this calibration over a wide range of distances to see the variation and correction factor to use (if needed). For example, if the laser reads 40 yards at a distance of 40.6

yards based on the measuring tape, then you would use that figure when your laser gives the click-over reading for 40 yards. By calibrating your laser, you can actually be mere inches off in the distance measuring part of the tree height."

That is basically it. You point the rangefinder at the target, push the power button, or hold the button down scan around and look for the target, and read the distance from the LCD display. The next step is to get down to the business of measuring trees.

Measuring Trees with a Laser Rangefinder and Clinometer

The Eastern Native Tree Society methodology for measuring trees (ENTS Method) involves the use of three instruments: a laser rangefinder, a clinometer, and a scientific calculator. Only four numbers are needed to complete the tree height calculation, and no tape is necessary, nor is direct contact with the tree. The readings are 1) the distance to the top of the tree measured using the laser rangefinder, 2) the angle to the top of the tree measured with the clinometer, 3) the distance to the base of the tree measured with the laser rangefinder, and 4) the angle to the base of the tree measured with the clinometer. The calculations involve some basic trigonometry as illustrated in the Figure 7 below, but these calculations can easily be done on any scientific calculator.

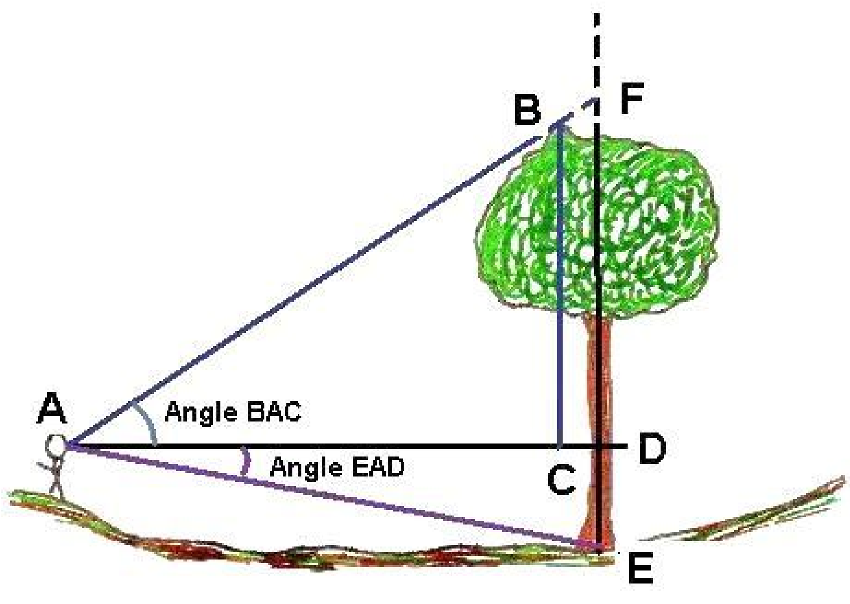

Figure 7: Diagram of basic ENTS laser rangefinder/clinometer tree height measurement trigonometry.

In this example the top of the tree being measured is above eye level and the base of the tree being measured is below eye level. This is the most common situation encountered in the field and therefore was chosen for the initial explanation. The other two situations are those where both the top of the tree and the base of the tree are above eye level, and where both the top of the tree and base of the tree are located below eye level. These last two cases will be discussed later in this explanation.

In Figure 7, point B represents the high point of the crown of the tree. Point A is the point from which the measurement is taken. The distance between point A and point B is marked as a blue line (AB) and can be measured using the laser rangefinder. The pink line between point A and point D represents a line on the horizontal, level plane (AD) extending from the measurers eye level through the tree. This angle (BAC) represents the slope of the line AB above horizontal. This angle can be measured directly with the clinometer with the angle from point A to point B simply being read from the clinometer dial. In the Figure 7 diagram point C is a point on the horizontal plane directly below the top of the tree. Think of it as an imaginary plumb bob hanging from the top of the tree down to a horizontal plane at the measurer's eye level. The same process is used to measure the triangle formed by the base of the tree. The measurements are made from the same spot with point A representing the position of the measurer, point E representing the base of the tree, and point D representing a point directly above the base of the tree on the horizontal plane at the measurer's eye level. Point F represents the erroneous height that would be generated if a tangent based height measurement would have been used.

Now for the math. Essentially when you are measuring a tree using our laser rangefinder/ clinometer methods, you are creating a pair of giant triangles each with one square corner. In the upper triangle, the angle between the line BC (the plumb bob) and the horizontal line (AC) is 90 degree and forms one corner of a right triangle. Similarly, point D is directly above point E, and the line ED is perpendicular to horizontal line (AC). This forms the 90 degree corner of the right triangle in the lower measurement. Since the sum of the angles of a plain triangle equals 180 degrees, if one angle equals 90 degrees, the other two must add up to 90 degrees, and each individually must be less than 90. In geometry, angles less than 90 degrees are called acute angles, and the acute angles of a right triangle are called complements of one another. How does all this math terminology help us? A useful property of a right triangle is that for every pair of complementary angles there are unique ratios between the lengths of the sides of the triangle. These ratios are the same no matter how large or small the triangle. If you know one of the complementary, corner angles, in addition the square corner, and the length of one of the sides, you can calculate the length of the other two sides. This is the basis for right angle trigonometry. While many people shy away from basic math, the procedures needed to measure tree heights using laser and clinometer are surprisingly easy, and practice makes perfect.

For the top triangle, with the clinometer you are measuring this second angle (BAC) and with the rangefinder you are measuring the length of side (AC). Therefore you can calculate both the height of the top above eye level (BC), and how far the top is displaced horizontally from your position (AC). The height above horizontal (BC) is equal to sin(angle BAC) x distance AB. The horizontal displacement distance (AC) is equal to the cos(angle BAC) x distance AB.

The measurement calculations for the basal triangle work the same way. With the clinometer you are measuring this second angle (EAD) and with the rangefinder you are measuring the length of side (AE). Therefore you can calculate both the height of the base below eye level (DE), and how far the top is displaced horizontally from your position (AD). The height below horizontal (DE) is equal to sin(angle EAD) x distance AE. The horizontal displacement distance (AD) is equal to the cos(angle EAD) x distance AE. The specifics of punching the measured numbers into the calculator are discussed later in this article.

Looking at the diagram in Figure 7, you can see that the top of the tree extends above the horizontal plane through the measurer's eye for a height of BC. The tree extends down at its base below the horizontal plane a distance of DE. To get the total height these values should be added together. The total height of the tree is the distance BC + distance DE.

Height = sin(BAC) x distance(AB) – sin(EAD) x distance(AE)

Having just indicated that we add distances BC and DE, why do we show a subtraction sign in the above formula? Strictly speaking, in the proper mathematical terms, the height of the bottom triangle should always be subtracted from the height of the top triangle. Specifically, the angle EAD is negative in the clinometer. Therefore the sin of this angle will be negative, and the distance DE will be a negative distance. The height would be BC – DE, with DE being negative. Subtracting a negative is the same as adding the positive equivalent of the height of DE to BC.

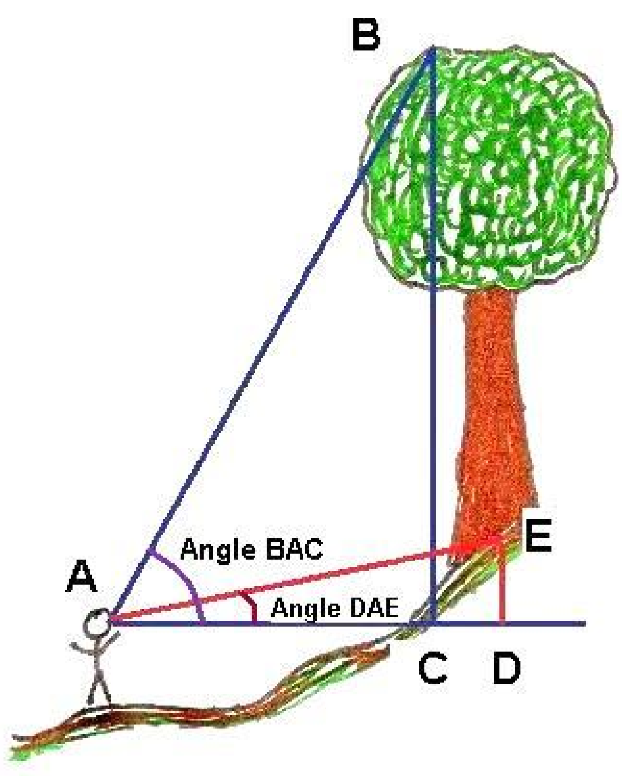

Figure 8: Situation where both the base of the tree and the top of the tree are above eye level.

If both the top of the tree and the base of the tree are above eye level, two right triangles can still be constructed, only both will extend above the horizontal plane at eye level. There will be a distance to go up to reach the top from the horizontal plane, and there will be a distance to go up to reach the base of the tree. The difference between these two values is the height of the tree. Think of this like a set of shelves. If one shelf is 3 feet above the floor, ad a second shelf is four feet above the floor, the height difference between them is 4 feet – 3 feet = 1 foot.

If both the top of the tree and the base of the tree are below eye level, a rare occurrence when measuring, then the top of the tree will be below the horizontal plane by a certain distance, and the bottom of the tree will be an even greater distance below the horizontal plane of the eyes. The difference between the two values is the top distance minus the bottom distance. Since both are negative this is equivalent to treating both these values as positive and subtracting the smaller value from the larger. Think of it as if you are standing atop a cliff. There is one ledge 20 feet down and a second 40 feet down. The distance between the ledges is 40 feet – 20 feet = 20 feet.

The line formed by AB in the diagram is the longest side of that right triangle and is located opposite the right angle itself. This side is called the hypotenuse of the triangle. The same can be said of side AE and the lower right triangle. AE is the hypotenuse of the lower triangle. These values are being measured directly using the laser rangefinder, therefore any lean of the tree or any sloping ground between the measurer's position and the tree are irrelevant to the calculation. The calculations of the vertical distance or height are dependant only on the position of the point being measured relative to a horizontal plane at eye level. The relative positions of the base of the tree and the top of the tree are not a factor in determining these vertical distances. The top triangle and the bottom triangle are independent and only share the same eye-level horizontal plane that forms is the base of the top triangle and the top of the lower triangle.

Why use the laser rangefinder techniques over other techniques?

If, as I wrote above, when you know one of the comer angles, in addition the square corner, and the length of one of the sides, you can calculate the length of the other two sides, would it not be easier to just tape the distance from the measurer (point A) and the tree, and the angle to the top, and make the calculations that way? That is what is done with the standard forestry techniques based upon a distance from the tree and clinometer angle. In this tangent based method the height formula is:

Height = tangent(angle) x distance from base

There are problems with this methodology. The first problem is that is the top of the tree is rarely directly over the base; therefore you are not really forming a right triangle. So how does that affect the height measurement? An analysis of over 1800 trees found that on average the top was offset from the base by 13 feet. Conifers tended to have offsets less than that average and broad canopied hardwoods tended to have higher offsets. If you were measuring a tree and looking upward at an angle of 64 degrees, given an average offset of 13 feet in your direction, the height of the tree would be overestimated by 26.6 feet! This type of error will be present in all of the readings using the tangent method, except in the unusual cases where the highest point of the tree actually is located directly above the base of the tree. Again except in this unusual case the result is not repeatable as a different height reading would be obtained depending on the direction and position from which the measurement was taken.

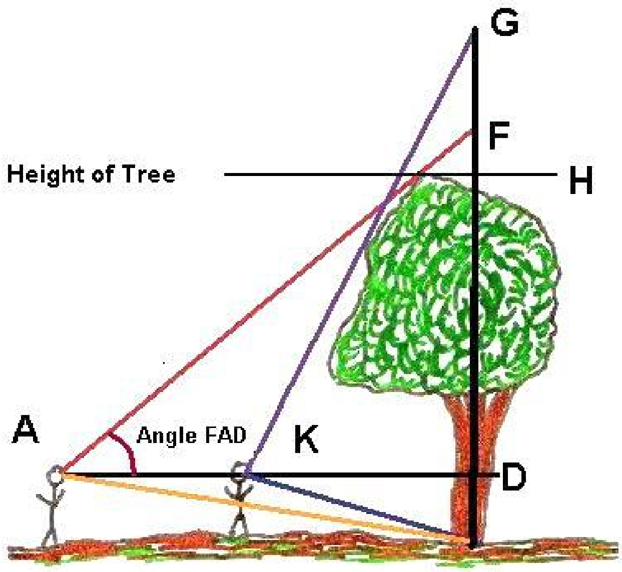

Figure 9: This diagram shows some of the potential errors when using a tangent based height measurement.

In the example in Figure 9 a tangent height measurement was used to calculate tree height. The actual height of the tree is from the base to point H. The exaggerated top of the tree marked as point F represents the projected height of the tree calculated using a tangent base method: Height = tan(FAD) x distance (AD). The error is present because the highest point of the tree is not directly over the base of the tree. Using the ENTS methodology with the laser rangefinder/clinometer, it does not matter if the top is directly over the base or not. Any such offset will not affect the accuracy of the height measurement at all.

Suppose instead of finding the top of the tree, you misidentified an outward leaning branch as what only appeared to be the highest point of the tree. Then the chances are the height measurements will be even further off. In Figure 9 the even more exaggerated top of the tree marked as point G and represents the height generated if a forward leaning branch was misidentified as the top of the tree from point K. When using the laser rangefinder in the ENTS method, you are scanning the top of the tree and getting immediate measurement feedback on all of the points you are hitting. This enormously increases your chances of finding the actual top of the tree and obvious misidentification of the top of the tree can be quickly weeded out. Using the ENTS method, even If the top is misidentified the value calculated is simply the height to that misidentified top rather than to the exaggerated projection of height to an imaginary top located directly over the base of the tree as would be obtained using the tangent method.

There are other systematic and implementation problems that can lead to additional measurement errors in the standard forestry tangent based techniques and in the simple stick method (not discussed), but the bottom line is that height errors often occur in the ranges of tens of feet and typically exaggerate the height of the trees being measured. The height errors in tree measured using the ENTS method are typically are less than a foot from those confirmed by tree climbs and tape drops.

These inconsistent results when using the tangent method, with an unknown and variable amount of error in the calculated height of every tree are not good enough for use in any type of scientific investigation and really should not be acceptable for inclusion on champion tree lists.

Blozan (2004, 2008) writes: **"**Getting an accurate tree height is the nemesis of many potential tree hunters, and the leading source of point errors on champion tree lists. Although the techniques are very simple, employing them accurately is another story... Tree heights are typically remotely obtained using a clinometer or transit for angles and a measuring tape or infrared laser rangefinder for distance. By using simple trigonometry and laws of similar triangles and right triangles, the true height of a tree can be easily obtained. In all cases, the height obtained is the *vertical distance* between the top and base, *not trunk length*... The ENTS method requires the use of a laser rangefinder, a clinometer, and a basic calculator. This low-cost method has the advantage of being the quickest, simplest, and most accurate. A clinometer and a laser rangefinder is a relatively minor expense (<$300) and easily justified by the speed, accuracy, and foremost, the REPEATABILITY of your results! "

Getting Started

I am sure anyone reading this has an idea of a site they want to explore or some trees they want to measure or they would not be considering buying a clinometer and rangefinder. There are other posts on the ENTS BBS or the ENTS website talking about locations of old forests or big trees. There are dozens of links on the internet that deal with old growth forests. So finding a place to start measuring should not be a problem. The first trees I measured with my shiny new instruments when they arrived were trees in the lot around my house.

Once you decide where you want to measure, get out there and start measuring. Beforehand, I print out a map of the site or air photos and fold it up and put it in my camera bag. In the field I carry my rangefinder, my clinometer, and my camera all on straps around my neck. I carry my measuring tape, my calculator (and lately a second calculator), extra batteries, my field book, pencils, and the like in a camera bag over my shoulder. I turn on my GPS unit when I arrive at the site and stick it in my pocket. Then head off into the woods. There isn't really a system to this exploration, especially for a new site. I start walking down a path, then head off into the woods at the first prospect of a big tree. People on these types of trips get cricks in their neck from looking upward and tend to stumble over rocks and limbs on the ground as they look upward.

What trees should you measure once you get out in the woods? Different people have different ideas and preferences of the trees they choose to measure. Some people concentrate on just finding the tallest trees, others my visit a particular patch of forest to measure a specific species of tree as part of a larger project. I like to measure as many different species of trees as I can find to better document that section of the forest. I measure the tall trees as well, but that is not my sole purpose. Often what trees you measure will also be dependent on what you find. If you are measuring with other people their choice of what to measure will also influence your choices. On more than one trip I have found myself primarily measuring the shorter trees to characterize the site diversity while my companions focus on finding the tallest specimens of the tallest species. One worthwhile goal for a site is to measure the tallest specimen of at least ten species on a site to enable the calculation of a Rucker Height Index.

Tree identification. If you are not good at tree identification take a good guide, like Peterson's Field Guide to North American Trees, with you in the field. Carry it in a plastic ziplock bag and stick it in your field bag. If you can't correctly identify the tree you are measuring then the measurements are not very useful. If you do find yourself in a situation where you can't identify the species, take photos of the leaves, the bark, the buds, branch patterns, fruits, nuts, or seeds, blossoms, and anything else you think might help in identifying the species, note the location, the type of terrain, associated species, and look it up or ask others for help when you return from the trip. If your companions are better at tree identification than you are, ask them for tips that help them identify the species with which you are unfamiliar.

Scouting the canopy. Explore the heights of trees with your rangefinder as you walk around. A few numbers to keep in your head as you explore. Any tree top at an angle of 80 degrees or higher will be a height of 98% or more of the laser reading, any treetop at an angle of 64 degrees will have a height of 90% of the laser reading. Any treetop at an angle of 45 degrees will have a height of 71% of the laser reading. So with a bit of practice you can rough out in your head the heights of the trees you come across in your scouting of an area and see if they warrant a more precise measurement.

Figure 10: The Boogerman Pine in the Great Smoky Mountains National Park has a nested top. The arrow points at the actual tallest point on the tree (photo by Will Blozan)

Finding the highest point. Finding the top of the tree while scanning the tree with the rangefinder is the primary art form of tree measuring. I am still working on it. Experts in the process like Will Blozan, Bob Leverett, Dale Luthringer, and others can whip out a tall measurement and be done while I am still looking. Once you find a tree deserving a more detailed measurement it is time to get down to business. Walk around the tree trying to locate the top. Often the tallest part of the tree will be lit slightly differently or the leaves will look slightly smaller than those on branches that are closer. Use the laser to explore the crown by holding the button down and scanning across the crown of the tree. Look for the highest point; look for the crown through windows between forward reaching limb. Look through pockets or holes in the canopy. Look among the tops of nested crowns. Try to find little windows to shoot up through the canopy closer to the tree and try to find tree tops farther back into the mass of the tree. A general rule of thumb two potential tops that are at a similar vertical angle, the tallest point will be the one farthest away. You can use the rangefinder to give you immediate feedback on distances to the points you are scanning. This enables you distinguish between the actual top of the tree and those that only appear to be the tallest. The highest point of the tree may be well below what on first appearance looks to be the tallest point of the tree.

You also need to be sure you are actually reading reflections from the branch you are looking at rather than an intervening branch. Scanning back and forth helps you decide if you really are hitting the branch you are pointing at. If you are unsure what you are hitting in the top of the tree, point the laser beam at the sky behind the target. Slowly move the sight towards the target until you get a hit. The laser will not read anything at all when it doesn't reflect off something. Look for wider openings to get a better shot free from any intervening branches. Walk around the tree and look for shots from different angles. Look for different high points. All are not visible from the same position.

Measurement distance. Good distance from which to measure the height of a tree is at a distance at about equal to the height of the tree. If you are closer the actual top may be hidden by branches pointing in your direction. However, at farther distances errors in the clinometer reading have a bigger effect on the height numbers. But that aside, you need to measure from where you can get a good shot of the top and bottom no matter what distance you are from the tree. For example, on level ground when dealing with a broad-crowned tree, the measurer often needs to be much farther back in order to see the actual top of the tree. So, the shape and architecture of the tree determine how far back the measurement should be taken. Walk around until you find multiple places where you can see both the top and bottom and measure the tree height from each place. Look for shots from different angles. Look for different high points. All are not visible from the same position. Using this laser rangefinder/clinometer technique, it is virtually impossible to overestimate the height of the tree (unless the laser shoots long - which can be determined when by the laser calibration process.) So, if you do not mess up the clinometer reading, and there is no reason why you should, the highest top you find from any of these locations is the best measurement of the height of the tree.

Shooting Straight Up. Shooting straight up s a viable option for measuring tree heights where the crown architecture will allow it. The Nikon 440 rangefinder is calibrated to measure to ½ yard to 1 yard increments. A person standing at the base of the tree can shoot upward and add the height of his eye level or that of the click-over point for the laser, above the base to that reading and get a height for the tree. With careful exploration of the canopy and good lines of sight the measurements can come close to those obtained from the standard rangefinder/clinometer techniques. Will Blozan (2004, 2008) notes:

> "I use this technique to help determine if more careful searching is needed or to find the highest leader for more detailed measurements. Since a straight line leaning 11 degrees off vertical is still over 98% of vertical length, this technique gives you a full 40' circle of exploration on a 100' tree from one spot. Figures obtained by shooting *straight* up are seldom less than one foot different than the two triangle ENTS technique (often listed as *SIN+SIN*) described above. All you need to do is find the inflection or click-over point and sight the level point on the trunk and add it to the laser reading. "

One difficulty with shooting straight up is that view of the actual top of the tree may be obstructed. Branches themselves may obscure the top. It may be impossible to hit the tip of a branch that is rising vertically. When dealing with dense conifers and fully leaved hardwoods it may be difficult to impossible to locate the tree top and measure this way because of the foliage. In the winter with leaves off, or even during early leaf out in the spring, it is possible to use this shooting straight up method on most hardwoods. But even then some species, like birches and beeches, are nearly impossible to measure any time of year because of the extremely fine twigging that prevents an unobstructed view of the tree top. In these situations the best you can say that these trees are "not-less-than" the measured height. In a closed canopy, dense forest it may be difficult to find a place to see the top of the tree from any distance and the height value obtained by shooting straight upward may yield the tallest you can measure under those conditions.

With the above caveats in mind, shooting straight upward is a useful exploration technique and can serve as a double-check of the measurements made from farther away. From a point near the trunk and scan upward into crown of the tree find the highest point visible from this vantage. If someone measuring the tree height from a distance using the standard ENTS sin top/sin bottom methodology is not equaling or exceeding that height, they are not hitting the top of the tree from their vantage point.

Where is the base of the tree? The definition used here is "the base of the tree is where the projection of the pith (center) of the tree intersects the existing supporting surface upon which the tree is growing. (Frank 2005a). Trees often sprout and begin their life on nurse logs. These logs eventually decay and the initial sprouting point may be a foot, or in the case of some of the giant western trees 10's of feet above the existing ground surface. Over time these exposed tap roots grow bark and become virtually indistinguishable from other portions of the trunk. This definition avoids the necessity to make those distinctions. In cases where the ground has been eroded to a lower elevation by this definition any exposed root above the ground surface directly beneath the center of the tree would be included in the tree height. Trees growing on the side of a cliff would still have their base at the cliff side as that position would be the intersection of the pith of the tree with the supporting growth surface. Roots that extend down the side of the rock face would not be considered toward the total tree height, just as exposed roots extending down a hillside are not considered toward tree height. Trees growing as epiphytes on other trees would have their base defined as where their pith intersected the supporting surface, in this case the branch or trunk, upon which it is growing. In Olympic National Park, WA in the summer of 2005I saw a large red cedar upon which two tree sized western hemlocks were growing, The largest epiphytic hemlock was likely 50 feet high and a foot or more in diameter and was perched on a notch of the cedar 20 feet above the ground - so this is a real-life consideration. There are trees that grow from spreading roots or from braches that have touched the ground and sprouted. The base of these trees would be the point at which their new trunk emerges from the supporting surface. Trees growing in swamps or marshes would have their base measured from the bottom of the water pool in which they were growing.

Shooting the Base of the Tree. Hitting the base of the tree with the laser rangefinder can be more difficult than getting a reflection from the top. Often the base of the tree is obscured by brush, or just beyond sight below a bank, or you can't tell if you are really hitting the base of the tree or not. What defines the base of a tree? Colby Rucker stated this simply (Aug 11, 2002), "All height measurements start from the same place - "where the acorn sprouted." The application of the principle is where the trouble begins, but I do believe that any interpretations of the tree base should be true to this concept. Trees will sprout virtually anywhere and the physical landscape changes over periods of time. In many cases with trees on level or slightly sloping ground where little alteration of the ground surface has taken place, the base of the tree can be determined fairly easily. In cases where trees are on sloping surface with debris accumulation and soil erosion, where the trees are sprouting from the side of a rock outcrop, where trees are growing on nurse logs, where trees are growing in a swamp or marsh, and where trees are growing as epiphytes on other trees, the determination is more complex.

When shooting the distance to the base of the tree the target should be the edge of the trunk rather than the front side of the trunk. The base of the tree is often obscured by brush and it may be difficult to shoot through the brush the laser to get a good distances. There are several things that can be done.

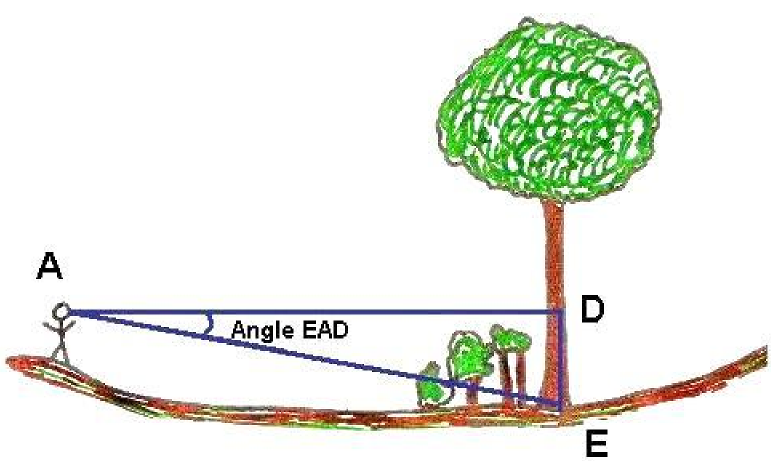

Figure 11: The base of the tree is blocked by shrubs.

This situation is illustrated in Figure 11. In this example the base of the tree, point E, is blocked by shrubs from being targeted directly by the laser rangefinder from point A. If the angle is relatively shallow, and you can see the base of the tree, measure that angle with the clinometer. Then measure the horizontal distance to the trunk (AD) at eye level. The length of the base below eye level can then be calculated to be tangent (base angle) x horizontal distance to the trunk. This will only work if the tree is not leaning and the angle is relatively shallow or the errors associated with the tangent method will assert themselves.

If the laser has a filtering mode you can try to set the filter on rain, or distant object and hopefully this will allow the laser to ignore the clutter created by the brush in front of the tree. If you are unsure if you are hitting the base or the brush shoot to an unobstructed portion of the trunk close to the base. If the distances are similar, then you are likely hitting the base rather than the brush. Another option to try is to place a piece of reflective material such as a piece of white paper or an actual reflector on the trunk which will provide a stronger laser bounce.

Another approach and one I have used is to solicit the help of another measurer. This second person can hold a reflector or an object in a position near the base of tree where I can hit it with the laser. Sometimes it works to just shoot to the top of that person's head. I have even made a pole reflector where I attached a bicycle reflector to the end of a 10 foot PVC pole and used it to measure the base of several trees in high brush. The measurement process works as described above, only the position of the reflector or target is substituted for the base of the tree. Then when the calculations are made the height of the reflector or target above the base of the tree is simply added to the heights derived from the top and bottom triangles.

What about my own height? It doesn't matter how tall you are. Both the top angle and distance and the basal angle and distance are shot from your eye level. Your height is already incorporated into the measured values.

What if it is getting dark? If you can't see the clinometer you can use a small flashlight. It is simply mechanical and the presence of metal or current will not affect the reading. The laser rangefinder does not use ambient light to determine distance it measures reflected laser light and can be used in total darkness. The problem is that you can't read the LCD display if the target is dark. If you are sure you are hitting the target, release the power button and quickly turn the rangefinder to a lighter background. The last reading collected will persist for a few seconds and can then be read. Really at this point you can no longer scan the trees and you can't be sure you are hitting the point you are aiming at. If you can't illuminate the target with a flashlight well enough to read the display, you are pretty much done for the night.

Crown offset. You can measure the horizontal distance to the base of the tree or from the top of the tree as well as the height. These values will enable you to see how far the top of the tree is offset from the base in the direction of the measurer. The actual offset will be greater than this value if the offset direction is not directly toward the measurer. This can also be used to get an idea if the top measured is actually the top of the tree or a forward leaning branch. In an analysis of 1800 tree measurements it was found that the average offset in the direction of the observer was 8.3 feet, or an average actual offset of the tree top from the base of 13 feet (Frank 2005b, Eicholz 2005). Conifers averaged less offset, while broad topped hardwoods averaged a higher offset. Some of the offsets for broad topped trees were as much as 30 to 40 feet, but most were less than 20 feet even for hardwoods. The calculation is simple. In the notation used for the diagram in Figure 7 the formula is: [cos(angle BAC) x distance(AB)]- [cos(angle EAD) x distance (AE)] = offset of top from base in direction of the measurer. The horizontal distance of the top from the measurer is the cosine(angle to the top) x distance to the top. The horizontal distance from the measurer to the base of the tree is cosine(angle to the base) x distance to the base. The relative offset is the difference between the two values.

Measuring From Two Different Points

Tree heights can be measured additively from two different points if the top of the tree and the base can't both be seen from a single position. Shoot them from the best locations and reference the triangles to a common point easily seen from both sites, i.e. lowest branch, a burl, or bend in the trunk. First shoot the top and calculate the height above your position. Then shoot to the distinctive point on the tree and note its height. The difference between the two is the height of the tree above the distinctive point. Then from a second location, from where you can see the base and the distinctive point, calculate the height above the base to the distinctive point as if it were the top of the tree. Then add the height from the first measurement to this second height to get the total height of the tree. Creating two triangles from the two (or more) locations allows you to measure tree heights that could not be measured using other methods.

If at all possible you can make things enormously easier on yourself by finding a place to shoot where you can see both the top and bottom of the tree from one spot. Avoid the burl and branch steps if at all possible. Walk around until you find places where you can see both the top and bottom and measure from each place.

Other Acceptable Measurement Methods

Are there other acceptable methods of measuring tree heights besides a laser rangefinder and clinometer? Yes, there are a number of methods that will generate heights that are accurate enough for inclusion in the ENTS data set. Tree climbing and a tape drop is one acceptable method. Generally a climber will climb ropes attached to a tree into the canopy and then work their way to near the top of the tree. For the last few feet of the tree a pole is usually used to reach the very top. Then a tape is lowered by the climber and the distance from the base of the pole to the ground is measured. Adding the length of the pole to the taped distance yields the height of the tree. This process provides a physical measurement of the tree and has been used to confirm the heights obtained using the laser rangefinder/clinometer method. More details on tape drops can be found in Blozan (1998).

Figure 12: Will Blozan doing a tape drop measurement of the Seneca Hemlock, Cook Forest, PA in 1997. (photo by E. F. Frank)

A second acceptable method is using a measuring pole to measure shorter trees and shrubs. Again this is a physical measurement of the tree and provides excellent accuracy. Of course the longer the pole, the more unwieldy it becomes to use. An article on the ENTS website by Colby Rucker (2003) discusses the pole method in more detail.

Professional surveying techniques with a transit or total station can yield good results if the top of the tree is distinctive and easily visible. The drawback is that the time it takes to set up the instruments limits their usage in field settings where each tree is typically measured from multiple places to assure the actual top of the tree has been found.

Calculations of Height

As discussed above, only four numbers are needed to complete most tree height calculations and no tape is necessary, nor is direct contact with the tree. Many otherwise intelligent people have an aversion to math. One of the difficulties is that people typically teaching or explaining math are those to whom the math comes easily. Points that are intuitively obvious to math people to the point they do not even think about it are not clear to others. Steps like punching a formula into a calculator has been a sticking point to some people. Most calculators use a pretty basic input format. Most basic scientific calculators input data as described below. However, some calculators require input entry in a different format than described. If you have one of these calculators you should read the instructions for data entry that came with the calculator to determine how to enter the measurement data or look up that information on the internet.

Figure 13: This is a scientific calculator, meaning one that does trigonometric functions. It cost $1 at Dollar Tree. It is always a good idea to take an extra calculator into the field with you in your field pack. On an occasion where my calculator died, it severely limited my ability to contribute data to the effort on that day.

If, for example, these are the four measurements that have been taken: Angle to the tree top = 47, distance to the top = 35 yards, angle to the base = -7, and distance to base = 23 yards, write these numbers down in your field book.

How to calculate tree height:
1) First punch in the top angle [47],
2) press the sin button on the calculator [In this case the number that appears will be 0.73135],
3] press the multiplication key [X],
4) type in the distance to the top in yards [35],
5) press the multiplication key [X],
6) type in the number 3 [3 feet per yard],
7) press the = sign. This will give you the height of the top above your eye-level. [76.8]
8) Write this number down; it is the height of the tree top above eye level.

Next calculate the "height" of the base of the tree, using the same steps.
9) First punch in the base angle [7], Ignore at this step whether the number is positive or negative.
10) press the sin button on the calculator [In this case the number that appears will be 0.1219],
11] press the multiplication key [X],
12) type in the distance to the base in yards [23],
13) press the multiplication key [X],
14) type in the number 3 [3 feet per yard], this gives you 69 feet 15) press the = sign. This will give you the height of the top above your eye-level. [8.4]
16) Write this number down, it is the height of the base of the tree above or below eye level.

In almost every case the top of the tree will be above eye level, so it will be a positive number.

17) If the base of the tree is below eye level [negative angle], add the two numbers [from steps 8 and 16] together to get the height of the tree.
18) If the base of the tree is above eye level, subtract the base height [step 16] from the top height [step 8] to obtain the height of the tree.

If you think about it, it makes sense. If you know the top of the tree is so many feet above eye level, then if the base is below eye level, you must add the two together to get the height of the tree. If the base is above eye level, then the tree starts out at some point above eye level and that base height must be subtracted from the height of the top above eye level.

In the method above, I said to ignore when doing the basic number calculations whether or not the base angle was positive or not. If you calculate the sin x distance of a negative angle you will get a negative number. In a rigorous mathematical sense, if you do use the sign + or - for the base height, you subtract the base height from the top height. If the base angle is positive, then like the list above [18] you subtract the base height for the top height to get a true height of the tree. If the angle is negative, then you are subtracting a negative height from the top height. Subtracting a negative number is the same as adding the two heights together with both being considered positive as listed in step 17 above.

If you are using a calculator with the odd RPN notation, or are programming it with a formula that requires you enter whether the top angle and base angle are each positive or negative in a single long function with both trigonometric, and arithmetic functions, then you probably don't need the calculator discussion above anyway.

In summary, do the top calculation and write it down. Do the bottom calculation, and write it down. If both the top and base of the tree are above you subtract the two of values to get a distance between them. If the top is above you and the base is below you add them together to get the distance between them.

Beyond the height measurements

If you are out measuring tree heights, there are additional measurements you should be making at the same time. A girth should be measured for every tree for which a height is measured. The girth of a tree is measured by wrapping a measuring tape around the trunk at a height of 4.5 feet above the base of the tree. Special situations such as low branches, burls, multiple trunks will further complicate this girth measurement process. A third measurement that should be taken, at least for notably large trees, is crown spread. This is an average measurement of the breadth of the trees crown. More detailed explanation of the processes of measuring girth and crown spread are included in the Tree Measuring Guidelines of the Eastern Native Society (Blozan 2004, 2008). I personally like to get a GPS reading of latitude and longitude at the base of every tree for which I measure a height. This enables the tree location to be plotted on Google Maps and for the location information to be precisely linked with the physical measurement data in the ENTS Tree database currently being developed by Mitch Galehouse. As mentioned previously, it is worthwhile to measure the height of the tallest specimens you can locate of at least ten different species of trees from a site in order to generate a Rucker Height Index. Similar indices can be made for girth and crown spread but are compiled less frequently. Photographs of the trees and of the site, and written site descriptions always add to the value of the raw measurement data. The posting of trip report summaries on the ENTS BBS http://www.ents-bbs.org is encouraged.

Now you are well on your way to becoming a tree measuring expert, all you need now is practice.

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