

Tree Measuring Guidelines of the Eastern Native Tree Society

Prepared by Will Blozan, ENTS President, October 2004

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Introduction

The Eastern Native Tree Society is a diverse, non-profit group of ecologists, educators, naturalists, and world-renowned canopy researchers dedicated to a better understanding our Eastern forests. Accuracy is the premise of our mission, and ENTS has developed research techniques unmatched by any other institution. There are three key measurements made to characterize the size of a tree: 1) Height; 2) Girth; and 3) Crown Spread. The next steps beyond taking these basic size measurements is calculation of the wood volume of the tree, and mapping of the structure of the tree itself in three dimensions. The final consideration included in this basic guidelines are the concepts of Tree Dimension Index, which relates the size of a particular tree to the largest known for the species, and the Rucker Height Index which is the numerical average of the tallest individual of each of the ten tallest species on a site. This RHI provides a useful characterization of the overall composite maximum heights of the tree species found on a site.

The most significant difference between ENTS measured trees and those measured via conventional forestry methods is a much higher standard of accuracy. In fact, the "ENTS method" of laser-based tree height measurements is so accurate that it is being employed in height growth monitoring projects by several universities and premier forest ecologists. Perhaps the most important value of the ENTS method is that it is *repeatable*, a basic premise of any scientific project. Users of the method, with a few minutes of training, can produce measured results within 1% or less of a seasoned ENTS researcher. Seasoned ENTS researchers can measure a tree from the ground to within inches of a direct tape drop. This process takes but a few minutes for most trees.

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Tree Height Measurement

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, which will be dealt with later in this section. 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*. Leaning trees and hardwoods have longer trunk and branch systems than indicated by vertical height, but is beyond the scope of my efforts or champion tree lists to measure.

Case-in-point

The giant Sag Branch Tuliptree in the Smokies has an immense crown over 100 feet across. The tree has probably 20 “tops” in the crown that are less than 10 feet different in height, the shortest 159’ above the ground. How do you find out which is the tallest? Lots and lots of exploration! An ENTS research climb of the tree revealed a “nested” top that was nearly impossible to see from the ground. A tape drop and laser measurement found that top to be just a hair under 169’ above the ground, and less than 2 feet taller than the five other tops previously measured.

In standard forestry methods only a clinometer is used. At a set distance from the tree, the angle (A) to the top is measured. Using a simple formula $\tan(A) \times \text{distance to base} = \text{height of the tree}$. This method requires the use of a series of untenable assumptions. One of the flaws of this tangent method is the assumption that the top sprig of a tree is directly over the base. Preliminary analysis of a set of 1500+ measurements indicates that the top is on average offset more than 13 feet from the base of the tree. This value is even higher for broad canopy deciduous trees. Shooting at a reasonably steep angle this will result in height measurements exaggerating the tree height by upwards of tens of feet. There are a number of electronic instruments on the market that measure tree heights using a built-in laser rangefinder, clinometer, and auto-calculating routines. Unfortunately, the vast majority of these instruments employ the same flawed tangent calculation methodology which still assumes the tree top is directly over the base. So even though the instrumentation is technologically advanced, the height results will still on average provide a height with a built in error of feet to tens of feet. Sources of error are discussed in more detail later in this document.

The ENTS Method Laser Technique

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,

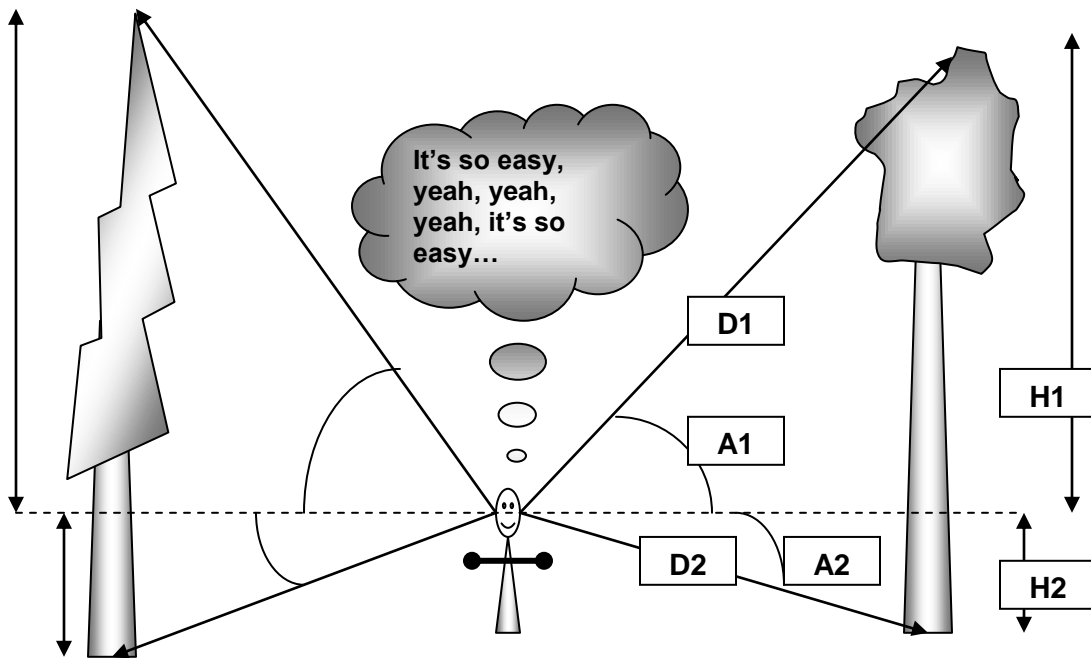
the REPEATABILITY of your results! It is certainly cheaper than the all-in-one measurement instruments that use the erroneous tangent calculations to determine heights.

The laser rangefinder is a device that sends out a pulse of infrared laser light. This light reflects off a target and bounces back to the laser unit. A clock inside times the bounce and calculates the distance based on elapsed time. Since the laser requires a return bounce, this method has the distinct advantage of automatically measuring a physical part of the tree, as opposed to an extrapolation of a part of the tree via cross-triangulation or conventional methods.

Only four numbers are needed to complete the tree height calculation, and no tape is necessary, nor is direct contact with the tree. This last bonus can be useful for trees across a river, road, a mean dog lair or other obstacle. When searching for champions, a quick height reading will tell you if further exploration and contact with the tree, the dog or its owner are necessary. Since the hypotenuse of the triangle is the baseline and it is measured from a physical part of the tree *any lean or slope correction is irrelevant*. You are simply creating two right triangles to an imaginary (but fully real) level plane (eye-level or tripod, etc.) that is the base of the top triangle and the top of the lower triangle.

Use the laser to explore the crown looking for the highest point. “Skate” the laser over the surface of the crown and in “nested” pockets and places you may not expect a high part to be. The highest point may be well below what appears to be the tallest part. Look for the farthest distance first, then the highest angles with far readings. Once you become familiar with a species and its architecture, you will know how to narrow your search down. A general rule of thumb is that at a similar vertical angle, the tallest point will be the one farthest away. A laser rangefinder gives you instant feedback on the distances to different points in the crown and enables you to identify the true top from many similar looking options.

Figure 1: The “ENTS Method”



Total tree height= $H1+H2$, where $H1= [\sin(A1)*D1]$ and $H2= [\sin(A2)*D2]$

Measuring From Two Different Points

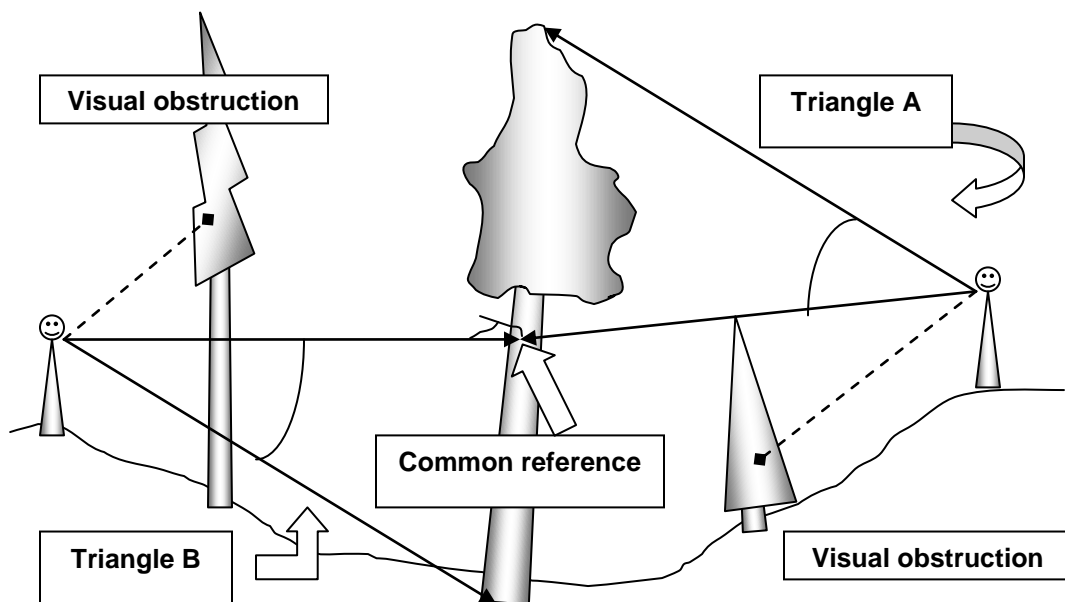
Tree heights can be measured additively from two different points if the top of the tree and the base can't both be seen from a single position. Shoot them from the best locations and reference the triangles to a common point easily seen from both sites, i.e. lowest branch, a burl, or bend in the trunk. 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.

Laser Calibration

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.

Figure 2. Using a reference point to create triangles from two positions

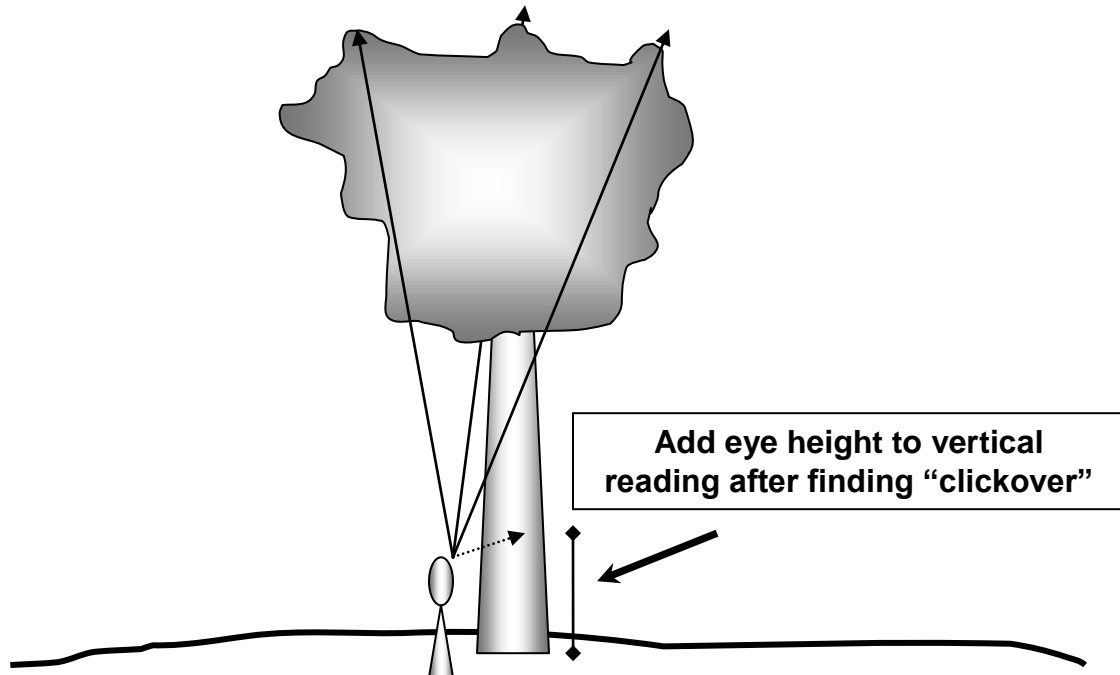


Shooting Straight Up

The laser is calibrated in 0.5-1 yard increments, and shooting straight up seems to be a logical way to at least rough-out a tree's height. This is true, and shooting straight up is in fact a fully legitimate and appropriate method to measure a tree that has a crown conducive to it. Dense conifers and fully leaved hardwoods are impossible to measure this way, but hardwoods in winter are typically fine. Some trees, such as oaks and sycamore are easy to measure by this method during early leaf-out. Careful exploration of the canopy is necessary to find the highest point. Figures obtained from straight-up shots are usually recorded as “NLT”- “not-less-than”. 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. See Figure 9 below:

Figure 3: Exploring the crown by shooting straight up



Measurement Accuracy

The ENTS website has a table of trees that appeared on various state and national champion lists that upon re-measurement using ENTS laser/sin techniques were found to have dramatic height errors.

http://www.nativetreesociety.org/measure/mismeasured_trees.htm

A similar comparison of tree heights measured from the ground using ENTS laser/sin techniques and the actual heights of the tree determined by later tree climbs and tape drops demonstrates the remarkable accuracy of the ENTS methodology. The list includes all trees that were measured by these dual criteria from 2000 until the list was compiled in 2005.

http://www.nativetreesociety.org/measure/measured_trees.htm

Girth

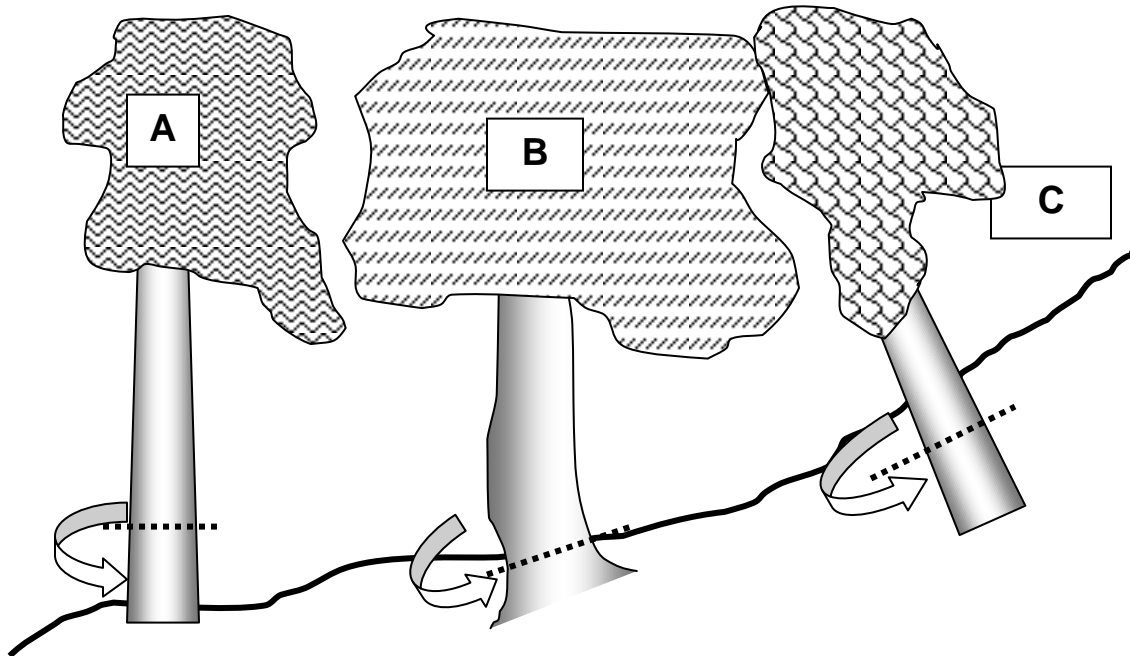
Girth is a dimension taken at a point 4.5 feet (BH) above average soil level (A). This measurement is called *circumference at breast height* (CBH). If a burl or other atypical growth formation is encountered at this point the least distorted girth below this point is used (B); otherwise above *BH*. When a tree is growing on a slope the girth is taken at a point that is the average of the highest point and the lowest point the tree trunk appears to contact the soil (Mid-slope-C). This mid-slope rule is used to follow the *American Forests* guidelines for measuring champion trees. In *all cases* the girth is taken *perpendicular to the axis of the trunk at BH, not parallel to the soil*. Measured girth is the best approximation of size, since it is a real number, not a calculation based on fictional premises. Even girth has its limitations, as a sinewy or contorted trunk will have lots of hollows and ridges that are not accounted for in the measurement.

Diameters calculated from such trees, or measured with a diameter tape, will be overstated (diameter= CBH/ 3.142). For volume measurements, “footprint” maps must be obtained to calculate the “functional” diameter and girth. The functional diameter is always smaller than the calculated diameter. For this reason the actual measurement of girth should be recorded. For some types of calculations girth must be converted to an approximate radius or diameter with the assumption of circularity, but there is no reason to introduce these assumptions into the raw dataset.

Case-in-point

A huge black cherry I found several years ago had a very burly base. At BH, the tree was 24' around, and the narrowest point below was 31' around. I chose to measure the tree at the lowest undistorted part of the trunk, where at 8' above the ground it was nearly 19' in girth.

Figure 4. Girth measurement locations



When most people ask how big a tree is they want to know the diameter, not the girth. Diameter is useful to calculate since it is an attribute readily understood by most people. It also seems to be one of the most overstated dimensions other than height, with many “5-6 foot diameter” trees being closer to 3-4 feet in actual diameter. Lack of an accurate reference is often to blame, as is in the case of overstated heights.

Why is Girth measured at 4.5 feet? This 4.5 foot value is a measurement grandfathered from decades of forestry measurements. It was developed because of the simplicity and ease of measurement. There is no one “ideal” height at which to measure girth. Tree trunks flare outward at their base. In some trees this flare extends only a short distance up the trunk, while in others it may extend thirty feet up the tree. Ideally the girth would be measured every few feet along the length of the trunk to characterize the shape of the entire trunk. This is what is done in trunk volume modeling. Since the height at which girth is measured is essentially arbitrary, then the best point to measure is at one which is the simplest and easiest to measure, therefore the old forestry standard is still used. Using a consistent height for girth measurement allows rough comparisons to be made between different trees, even if not ideal in all cases.

Multitrunk Trees

I use a “pith test” to define what a multitrunk tree is. If the tree has more than one pith at ground level it is a multiple-stemmed tree. Note I did not say 4.5 feet *above* the ground. This is because the 4.5 foot height is a forestry standard and is an arbitrary and convenient place for most people to measure a tree. Some trees, like flowering dogwood or rhododendrons, may branch well below 4.5 feet

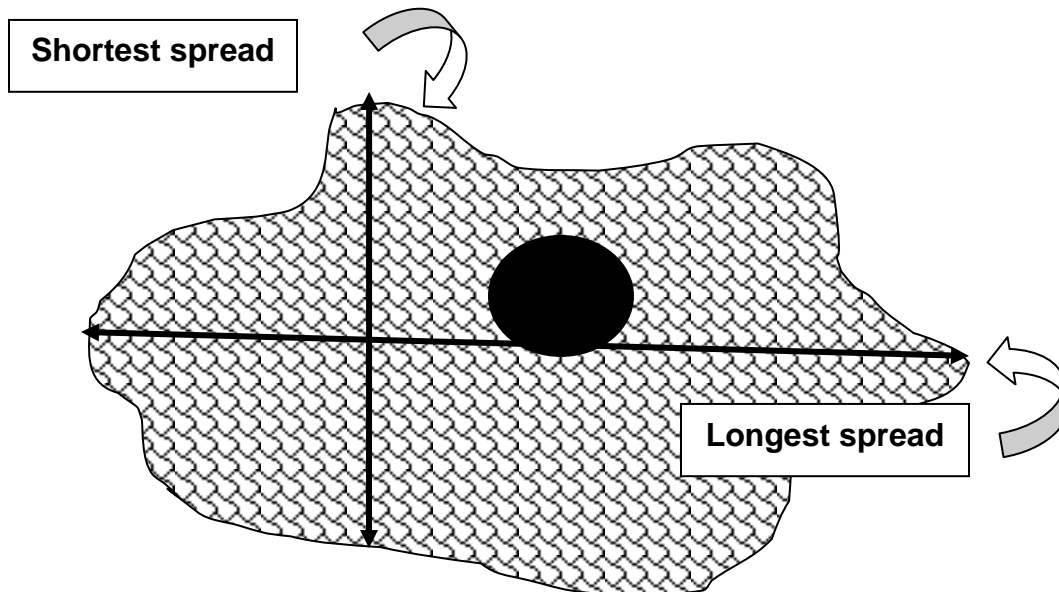
but have a single pith at ground level. In the case of such trees, I would measure the narrowest point below the lowest fork. More detailed discussions of how to measure multitrunk trees and trees with other odd forms is presented on the ENTS website.

For champion tree listings Measure the attributes of the target stem only. Do not include the crowns or heights of the other sprouts. To me, the entire point of a champion tree list and the ENTS research is to assess the capabilities of the eastern species. The best way to assess this is to study individual stems or trees of the species. By focusing on individuals we can accurately assess the potential and find benchmarks for restoration efforts or whatever the goal may be. To me, a champion tree is one that represents the best development of an individual, and therefore I do not include multi-stemmed trees in my research or nominations. Many will argue that a clump of sprouts fused into a huge trunk that originates from one root system is a single tree. I would agree, but it is not a single stem and thus does not represent the potential of an individual.

Average crown spread

Average crown spread is obtained by measuring the longest and shortest extent of the crown and averaging the figures. Crown spread is taken independent of trunk position. I measure to the tips of the limbs, not to “notches” in the crown shape. Try for a ninety-degree difference in measuring location.

Figure 5. Measuring crown spread



$$\text{Average crown spread} = (\text{longest} + \text{shortest}) / 2$$

When measuring crown spread on steep slopes (>15 degrees), it is important to correct the slope distance to horizontal distance to avoid exaggeration. This can easily be accomplished by taking the COSINE function of the angle of the slope in degrees and multiplying it by the slope distance.

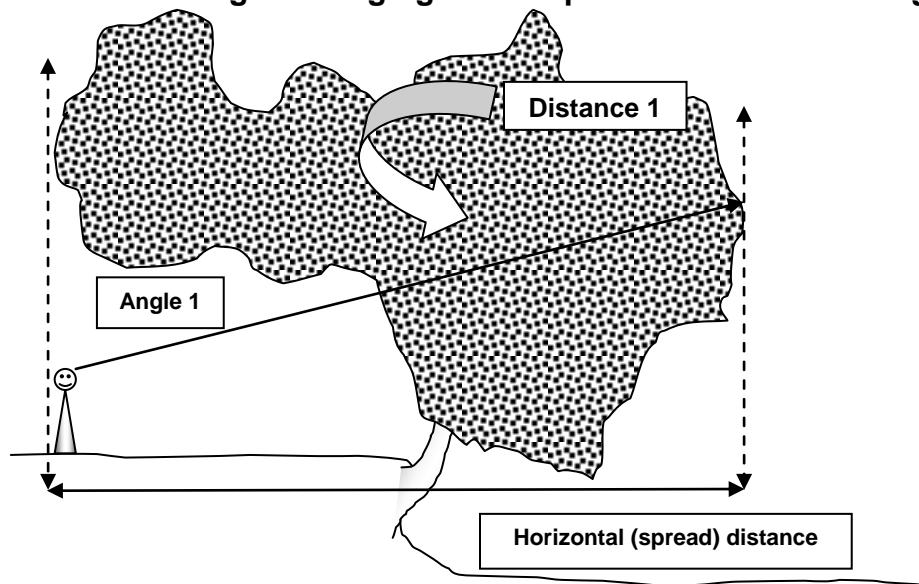
Another method is the “Spoke Method”. Four or more measurements are taken from the midpoint of the trunk to the outer extremities of the crown. These are averaged and the result is the average crown spread. This is the preferred method of canopy researchers and is probably the most accurate, and can be used to quantify crown area. On large trees it can be accomplished quickly with a laser rangefinder. The increased accuracy is largely overkill for champion tree registers, and slope correction can get tedious to say the least!

$$2 \text{ (SUM/n)} = \text{Average crown spread}$$

Lasered crown spreads

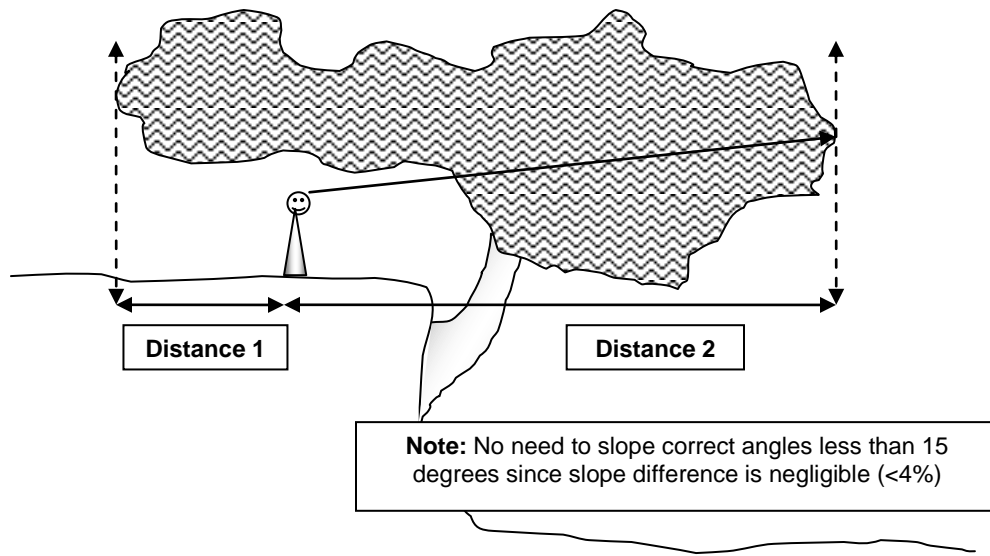
The use of a laser rangefinder can really speed things up when measuring crown spread. The laser can also be used to measure crown spread on tree canopies over an obstacle such as those described below. As in measuring tree height, several points on the tree can be “explored” to find the furthest point. Simply use the formula described below in Figure 3. In the illustration below, the observer is directly under the opposing crown edge, but multiple triangles can be used or combined with ground-based measurements as in figure 3b.

Figure 6a. Measuring challenging crown spreads with a laser rangefinder



$$\text{Crown spread} = \text{Distance 1} * \text{COS (A1)}$$

Figure 6b.



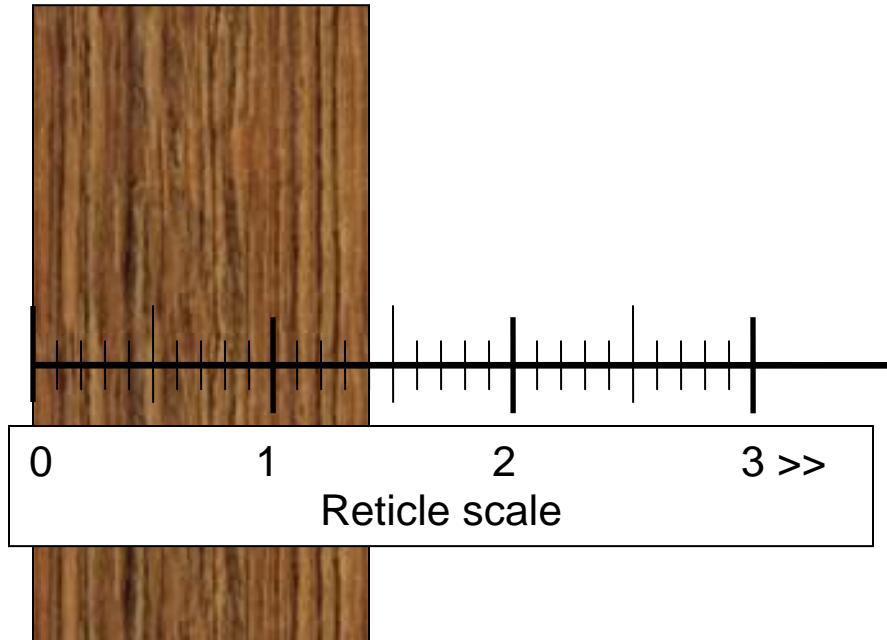
$$\text{Spread} = D1 + D2$$

Tree volume measurements

Volume measurements can be achieved via ground-based or aerial methods. Ground-based measurements are obtained by the use of a reticled monocular, laser rangefinder, and a clinometer. Aerial measurements are direct tape measures obtained by a climber in the tree.

Ground-based Volume Measurements

A reticled monocular is used to accurately measure diameters from great distances. The distance from the measured section of trunk multiplied by the reticle reading and divided by an optical factor results in the diameter of the target. Lasered distances were estimated to the nearest 1/10th whole unit (meters or yards) by finding "click-over" to the next unit relative to the rear of the monocular. The monocular coupled with a clinometer for heights and section lengths allowed for a volume determination to be made without climbing the tree (see below).



As illustrated in the above diagram, the scale is oriented by fine adjustments of the tripod to line up with- and perpendicular to- the edge of the trunk at the “0” point on the scale. The optical intercept of the opposite side is read against the scale and estimated to the nearest 1/100th unit. The section of tree above is recorded as intercepting 1.41 on the reticle scale. To calculate the diameter the following formula would be used:

$$\text{Diameter} = (\text{Reticle scale}) \times (\text{distance to target}) \div (\text{optical factor}^*)$$

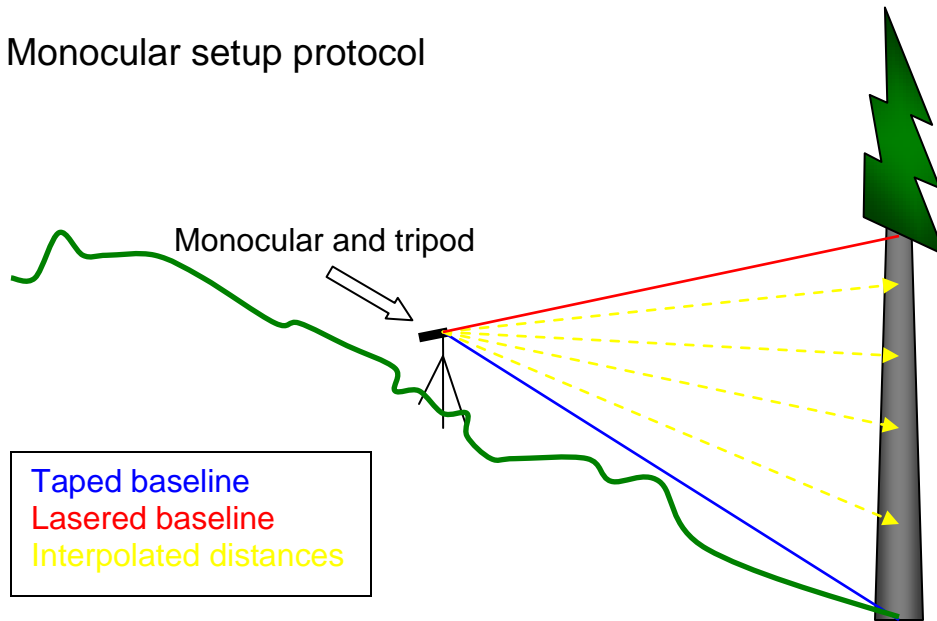
If the section above were 27.4 m (90 ft) away the diameter would be:

$$\text{Diameter} = (1.41) \times (27.4) \div 75; \text{ which is } 0.52 \text{ m (1.69 ft)}$$

(*Note: the optical factor is supplied by the manufacturer, and specific to the monocular model.)

Trees with limited visibility of the trunk that obscured accurate laser bounces can be measured by using a single baseline measurement to the base of the tree and a single lasered distance to the highest portion of the trunk (or top) that was clearly visible. This allows for measuring a portion of the trunk visible to the monocular but not directly measurable by the laser due to beam obstructions. After a point is located with a good view of the entire tree a tripod is set up with the monocular attached. The baseline distance to the *center* (side) of the base of the tree (or a measured distance up the trunk if obscured by underbrush) is measured and the distance to the *centerline* (side) of the highest visible point of the trunk (or top) is measured with the rangefinder. See diagram below.

Monocular setup protocol



This procedure creates a triangle encompassing the measurable portion of the trunk, with vertices at the observer's eye and the bottom and top of the measurable section of trunk. The position of- and distances to- desired measured points along the trunk could then be interpolated based on the clinometer angle.

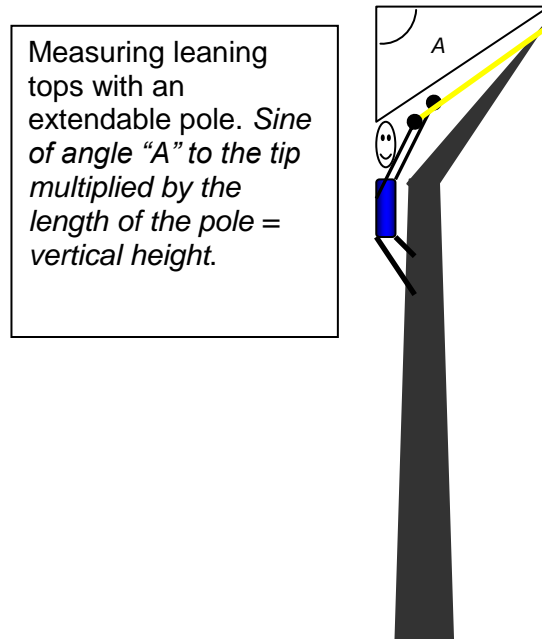
If the tree appears to deviate significantly (± 0.6 m; 2.0 ft) from a straight bole the distance to the midpoint of the trunk is measured for every sighting. Widths of the measured sections are then calculated and the height of the measurement points and lengths of the resulting sections calculated by the angles obtained from the clinometer.

Aerial Volume Measurements- Main Trunk

Aerial trunk measurements are directly obtained by a tree climber. All points of measurement are referenced for height above ground to a fixed tape in the tree which was initiated at the highest point and terminated at midslope. If the top of the tree was not safely reachable a pole or stick was used to assist in terminating the tape at the appropriate point (see diagram below). The climber accesses the top of the tree and drops a weighted throw line straight to the ground. If the top was offset the drop was moved laterally towards the main trunk so the reference tape would be along the trunk when possible. A measuring (reference) tape is then attached via a small carabineer to the dropped throw line and pulled up to the top, following the vertical path of the weight's descent. The tape is affixed to the trunk via several thumbtacks and the exact position relative to the top noted. A measuring tape with the first 3.0 m (10 ft) removed worked well. The end of the tape is terminated in a loop to facilitate attaching it to the dropped throw line. Thus, the tape is generally set 3.0 m (10 ft) below the absolute top. All other points measured in the tree are referenced to this tape and the total tree height is

measured to the midslope position of the trunk at ground level. (See volume calculations below.)

Heavily leaning tops that defied direct access by the climber are measured using the *sine* of the angle of a pole extended from the climber to the highest point. The vertical distance is used to determine where to set the tape for subsequent trunk measurements.



Measurement intervals are subjectively chosen based on changes in trunk taper. An area where a change in profile is observed (in or out) is measured with a diameter tape perpendicular to the bole axis. Clear sections of trunk were selected so as to not include branch collars, burls, etc. Typically, around fifteen measurements are taken on single-trunked trees in addition to those obtained for the base (see below). Generally, measurements are no more than 3.0 m (10 ft) apart.

Reiterations

Trunk reiterations are measured and added to the final trunk volume. Reiterations are identified by an upturned branch that had gained apical dominance and formed an additional branch supporting trunk. Reiteration lengths are terminated at the point of trunk contact. No attempt are generally made to account for the often oval shape of the reiteration base.

Bifurcations

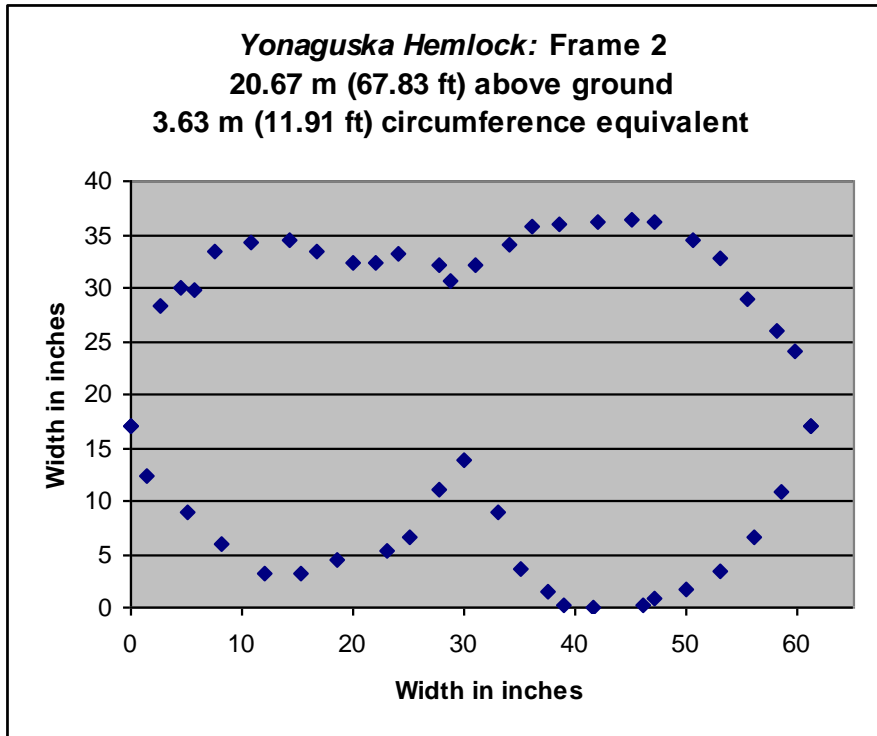
A bifurcation is defined as a split or fork in the trunk that formed two or more often similarly sized ascending trunks. Bifurcations often formed an irregularly shaped fused section that cannot be accurately measured with a tape. All

bifurcation lengths are terminated at estimated pith origination from the main stem.

Frame mapping

Significantly large (>75 cm; 2.5 ft diameter) fused sections are measured with the ENTS frame mapping technique. With two climbers, each on opposite sides of the tree, an area of fusion is selected to be measured. Two, ~2.0 m (~6 ft) poles were connected by a thin rope threaded through opposite ends so they are adjustable (we used non-stretch arborist throw line and garden stakes). The poles are temporarily tensioned and the distance between the ends measured. Adjustments are made until they were parallel and perpendicular to the axis of the trunk. The slight tension between the poles holds them steady against the trunk. Tents stakes wedged in the bark can also used to level and steady the frame.

The climbers sight across the poles and agree on a “0” point from which to begin measurements. The “0” point is the “point of contact” at one end of the frame where a retracting steel carpenter’s tape is stretched across at 90 degrees to the poles. The “0” point is marked on both sides as the common reference. This reference is the “0” on the X axis for each pole, and the tape is used to measure in to the trunk across the entire intercept with the pole. Thus, the trunk profile is plotted as the distance from the X axis reference point and the distance in to the trunk as the Y axis. Points where the tree contacted the pole are recorded as whatever the X distance is and a “0” for the Y. Measurements are made at changes in the trunk profile and to the nearest .32 cm (.125 in). Graphing of the coordinate data illustrates the cross-sectional representation of the fused trunk. See example below.



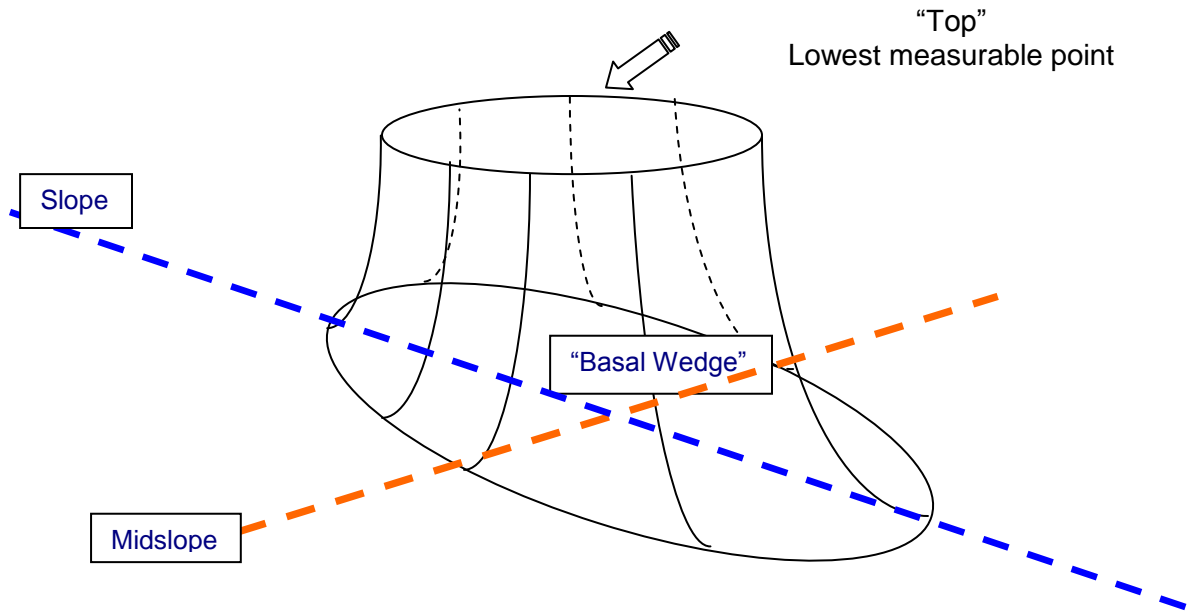
The data is then entered into a trapezoidal area function in an Excel™ spreadsheet and converted into cross sectional area so as to calculate the equivalent circumference to use in the volume formula.

Volume calculations

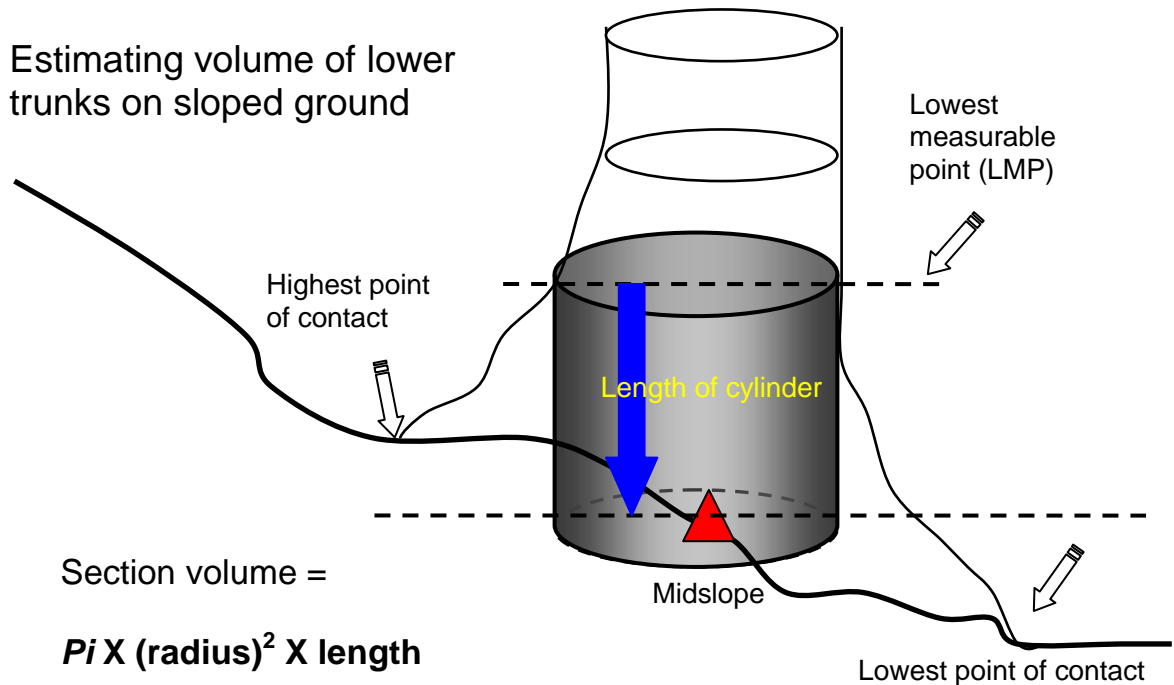
Cumulative trunk volume is calculated by adding the measured sections of the tree together. The formula for the frustum of a cone is used for all trunk and reiteration sections.

$$\text{Volume} = H \cdot \pi / 3 \cdot (r_1^2 + r_2^2 + r_1 \cdot r_2)$$

H is the height of the frustum and r_1 and r_2 are the radii of the top and bottom of the frustum. The aerial or ground-based measurements are added to a basal section that is measured in more detail than those above due to a typically less columnar trunk profile. For practical purposes, the wedge of wood below high side ground formed by a tree growing on a slope is dealt with in the following way: the midslope point is carefully established by using clinometers to transpose the highest side of the ground contact (below duff) against the lowest side. The elevation positioned in-between was considered the base of the tree (midslope) and is used in both the basal volume calculations and the absolute height determination.



The lowest measurable point (LMP) above root flare is taken as the lowest trunk measurement, even if several feet above the midslope point. The LMP is then extended down to midslope as a column.



This technique, though crude, should satisfactorily approximate the volume of the flared and fissured section (fissures are not illustrated above). In cases where the trunk is extremely incised, a section higher up the trunk can be chosen (and thus smaller) to represent the basal column. In most cases detailed footprint maps are very time consuming and generally will not result in significant gains in accuracy

relative to the rest of the tree. However they can be done where deemed appropriate.

Formula for a Frustum of an Ellipse

Not all trees are perfectly circular in cross-section. One option that can be considered is to use the formula for the frustum of an ellipse for sections of the trunk that are significantly out of round.

Let D1 = major axis of upper ellipse of the frustum

D2 = minor axis of upper ellipse of the frustum

D3 = major axis of lower ellipse of the frustum

D4 = minor axis of lower ellipse of the frustum

H = height of frustum

V = volume of frustum

PI = 3.141593

$$V = (H*PI)/12*[D1*D2 + D3*D4 + SQRT(D1D2D3D4)]$$

Note that this formula is a little more involved than the equivalent for a circle. In terms of the above definitions, the conical frustum based on a circular cross-sectional area yields the more familiar formula:

$$V = (H*PI)/12*[D1^2 + D3^2 + D1*D3]$$

Canopy Mapping

Detailed three dimensional mapping of the trunk and major branches of trees can be done for significant specimens. The methodology used to map the Middleton Oak and the Sag Branch Tuliptree was developed by Dr. Van Pelt. It is outlined in a chapter of the book: *Forest Canopies, Second Edition* by Margaret D.

Lowman and H. Bruce Rinker, 2004, 544 pp. Chapter 3: Quantifying and Visualizing Canopy Structure in Tall Forests: Methods and a Case Study 49-72. Robert Van Pelt, Stephen C. Sillett, and Nalini M. Nadkarni. A LTI Criterion 400 Laser Survey instrument was used to map the tree canopies. It is essentially a device that includes a laser-rangefinder, clinometer, and a compass. The LTI Criterion 400 uses an infrared semi-conductor laser diode for slope distance measurement. A vertical tilt-sensing encoder provides vertical inclination, while a fluxgate electronic compass measures magnetic azimuth, completing the data required to establish a point's three-dimensional location in space. It was used to map the position of every branch point in the canopy down to a certain size and also the positions of various reiterations, breaks, kinks, or any other eccentricities in the tree. This is usually done from a set position or a series

of positions within the tree. Sketches and photographs are used to facilitate the process. Trees were climbed and the architecture mapped in accordance with criterion previously established. This involves mapping the location of the main stem and all reiterated trunks, in addition to all branches that originate from trunks. Each mapped trunk and branch was measured for basal diameter, length, azimuth, Climbers measure specific circumferences and detail other features within the tree. In addition a footprint map of the base of the tree is made to calculate the exact volume of the basal section of the tree. More details of these procedures can be found also in the book "Forest Giants of the Pacific Northwest." The data is processed in Excel to generate a volume calculation. Graphing functions can be used to create a 3-dimensional figure of the tree data. Dr. Van Pelt also uses an Excel macro to rotate the image so that it can be viewed from different angles. In the cases of the Middleton Live Oak and Sag Branch Tulip each of the trees were mapped from a single set station from within the canopy of each tree.

Tree Dimension Index

The Eastern Native Tree Society has proposed the use of an index with which to compare relative sizes of trees, both within the same species and against others. The index, named the Tree Dimension Index (TDI) is highly adaptable and can be tailored to reflect the attributes of an individual tree and how they compare relative to the largest known specimen. The premise is that the specific dimensions of the tree are given a value (percentage) that reflects its relative rank against the maximum known for the same dimension. For example, the tallest known eastern hemlock would get a value of 100 for height since it represents 100% of the maximum value known for the species. A shorter tree that was 75% of the maximum known height would get a value of 75 for its height. Likewise, the values of diameter and volume would be determined by the relative value when ranked against the known maxima. With three ranked attributes the maximum TDI value would theoretically be 300. However, this would represent one tree exhibiting all three maxima- an unlikely possibility. However, the apparent size of a tree can be realized by ranking the cumulative values against the theoretical maximum. A tree scaling close to 300 would suggest that it was nearly the largest specimen theoretically possible based on currently known maxima.

Rucker Height Index

The Rucker Height Index is the numerical average of the tallest individual of each of the ten tallest species on a site. It provides a numerical evaluation of both maximum height and diversity of the dominant species. High index values are the result of many factors, including climate, topography, soils, and a lack of disturbance. While the most extensive sites benefit from a greater variety of

habitat and more individual trees, some exceptional sites are quite small. The Rucker Height Index is essentially a foreshortened version of a complete profile of all the species found on a particular site.

The Rucker Site Index or Rucker Index has a numerous merits that make it a useful measurement when comparing various tall tree sites.

1) The formula is straight forward, unambiguous, and easy to apply. The measurement is simply the average height of the tallest examples of the ten tallest species found at each site. Anyone who can add ten numbers and then divide by ten can calculate the figure.

2) The index can be applied to forests in any area with any make-up of trees. One of the biggest problems faced when comparing different areas is that the same tree species are not found in all areas to be compared. The index is not species dependent. It does reflect to some degree the species included, because all tree species do not reach the same height, but none-the-less the formula will produce a useful concrete number.

3) The index requires a fairly diverse mix of trees in order to generate a high index value. This means in order to achieve a high index rating that the forest patch being evaluated must not be primarily dominated by a single species, but be reflective of a more complete and by inference a more intact forest ecosystem. This has some drawbacks however. Robert Van Pelt, author of "Forest Giants of the Pacific Coast" writes in a post dated October 29, 2002, "The low diversity of trees in some Western forests quickly reduces the Index to below 200. Humboldt Redwoods SP, for example, has the world's tallest tree, and 86 trees over 350'. Due to the overwhelming dominance by redwood, the Index drops below 200 after only six species are included!"

4) To get a sufficient diversity of trees of great height requires a fairly large plot of forest. This limits sites with a very small area and few trees generally from having a high index. The value in this, as I see it, is small sites with only a couple of spectacular trees, or only a single big tree do not falsely appear from the index value alone to be the equal of larger sites with larger numbers of trees.

Some common questions and answers

What can I do if...

- ***I can see the base but can't get a laser bounce?***

Shoot the distance level on the trunk, and use the TANGENT of the angle to the base instead of SINE. This is only useful on shallow angles and non-leaning trunks.

- ***I am not sure I am getting a bounce off a certain part of the tree?***

Fire the beam into the sky behind the target. Slowly move the sight towards the target until you get a hit. The laser will not read anything when it "misses".

- ***I can see the top and/or base but the laser bounces are from branches of other trees?***

If practical, back up from the tree far enough that you can put the laser into a filtering mode, such as "rain". This will allow it to ignore the clutter under a certain yardage and give the reading to the tree only. Use a reflector on the base.

- ***I can almost get a laser return through underbrush, or the distance seems short?***

First, verify the distance's plausibility by shooting an unobscured portion of the trunk close to the base. Place a reflective material, (white paper, bicycle reflector) on the trunk to get a strong laser bounce. Reflectors are excellent!

- ***I have an excellent shot just beside the trunk, but not on it?***

Have an assistant stand or hold a reflective object perpendicular to the center of the trunk, and level with the base or a known height relative to the trunk.

Some more helpful laser advantages

When measuring from a level, common substrate as in a boardwalk in a swamp, a canoe, a field or an observation deck, one base height can be determined and the rest of the tree heights shot at will and added to it. You can measure as many trees as you can see from one point, useful for "exploiting" good vistas from a trail or other prime vantage point in the forest.

Conclusion

It is the inaccurate figures and resulting false claims that concern us as much, if not more than, the inability to put an accurately measured tree on any champion tree register. The types of measurement errors discussed here are exceedingly common, and equally overlooked. Many ancient forest trees certainly exceed the false heights of some of the open-grown trees that have been incorrectly

measured. This is significant in the sense that it does not give justice to the accurately measured trees and their measurers, but the inaccurate numbers misrepresent the true nature of the species and confound conservation efforts.

Of the several champion trees nominated by other tree hunters that I have remeasured, only three even came close to the true height of the tree. In all other cases, the error on the height alone added enough points to exclude a challenger from co-champion status. Some trees have had height errors exceeding 35 *percent* of true height, which in some cases added dozens of points. The height errors were due to the application of inaccurate techniques and unverified assumptions. In *all* cases the trees were leaning or had a wide spreading crown.

Advantages of the ENTS method:

- a) Greater accuracy and Repeatability;
- b) Ease of measurement;
- c) Less expensive instruments;
- d) Ability to explore the crown for the correct top.

For more information, please visit the ENTS website:

<http://www.nativetreesociety.org>

Appendix A: Sources of Error in Other Techniques

Huh? News Flash! The top of a tree is never directly over the base. This assumption is the fatal flaw of conventional forestry height measuring techniques. We all have been taught to measure out 100 feet from the base of the tree, take an angle reading with a clinometer and multiply the result by 100 to get the tree height. Some forestry clinometers are calibrated in “chains” (66’), and work similarly. These techniques do work, but only on trees that have ALL of the following conditions satisfied:

Case-in-point

In a training session in Congaree Swamp National Park, I had the trainees use a chain based (66’) height system on the current National Champion loblolly pine. I lasered the tree, climbed it and dropped a tape, and we compared results. The laser was 4 inches different than the tape drop and the chain-based figures were up to 30 feet *higher* than the actual height! The tree had a definite lean and a rounded crown with an obscured top that, even two chains away, could not be seen clearly.

- The highest point of the tree is directly over the base of the tree
- The highest point of the tree is clearly visible
- The tree is growing on level ground
- The tree does not lean

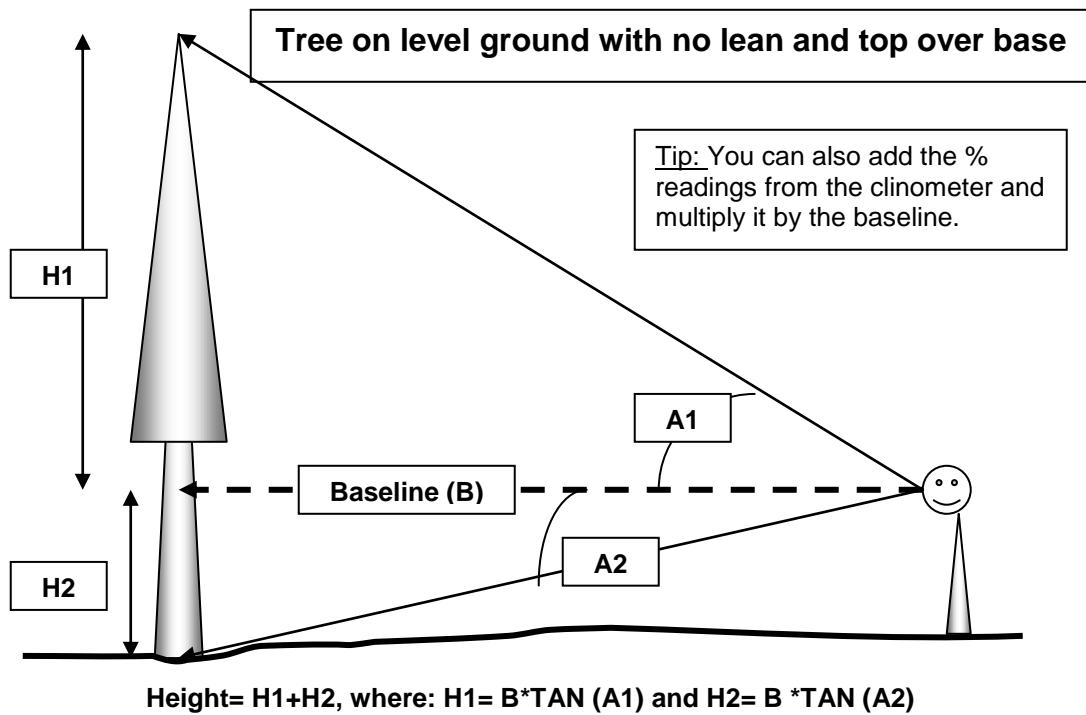
How often does this happen? Not very often! Aside from perhaps a Norway spruce growing in a level parking lot, most trees do not ordinarily satisfy all of the above conditions. Older trees and trees in old-growth forests do not typically grow straight or have a well-defined top when viewed from our limiting terrestrial level. I have climbed many tall conifers and performed tape drops (vertical) from the highest point to the ground. The tape has *never* come down on the base. Ten feet

or more is a common displacement from vertical on large conifers. Hardwoods can be much more. In fact, live oaks and other wide spreading trees can have tops more than 40 feet off the base. Consider the photo below of the Middleton Oak in Charleston, SC.



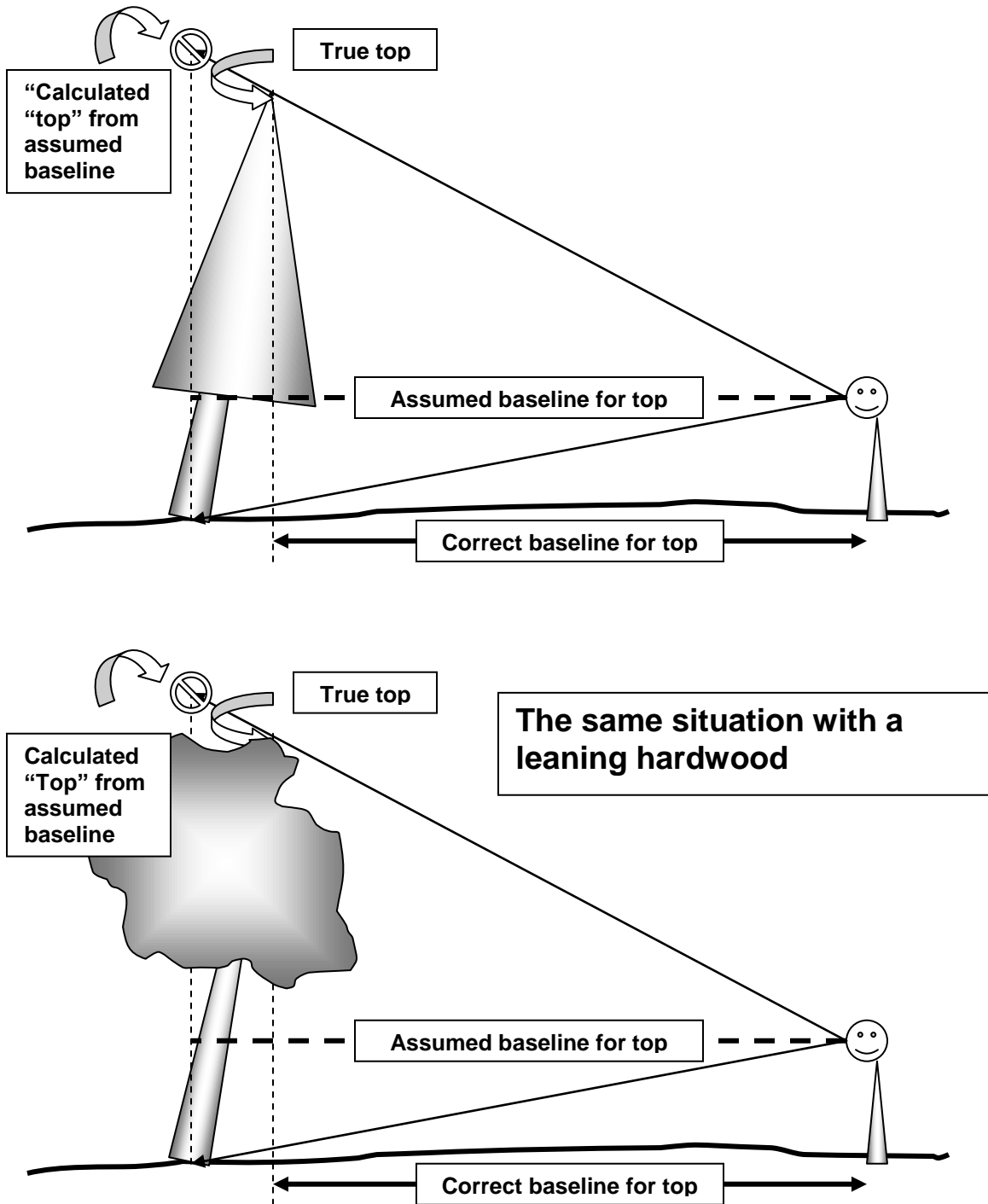
Where do you begin? Is what appears to be the highest point really the tallest part of the tree? A huge tree like the Middleton Oak is a challenge to measure, and lots of time will be spent chasing false leads and finding nested tops. For example, the highest point of the tree above is actually a small triangle shape “peeking” though the window of sky formed under what appears to be the highest part in the photo. It is fully 35 feet off the base and on the other side of the tree!

Figure 7. General formulas and techniques for measuring tree height



Ideal parameters rarely occur in nature, and situations critical to accuracy are often overlooked or not considered, thus making many claims of tree height inaccurate and unacceptable. See the figures below for an illustration of common sources of tree height errors

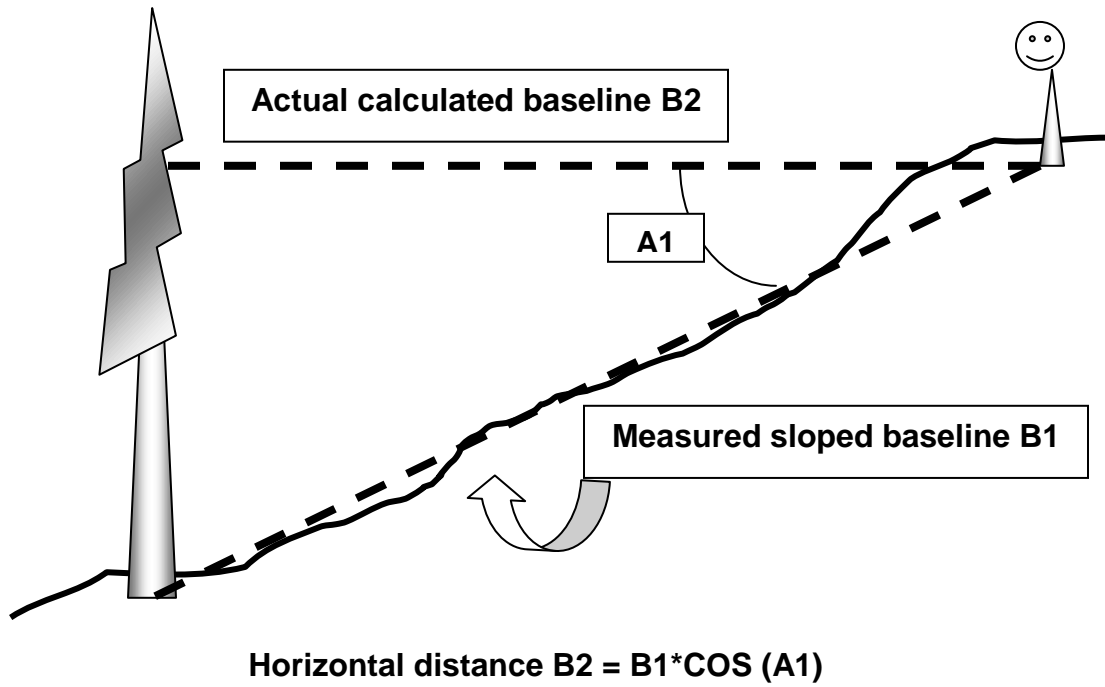
Figure 8. Common sources of height errors on leaning trees



In Figure 8, the tops are leaning towards the observer, and it is necessary to cross-triangulate the actual top projection to the soil (the point directly under the highest point). From this point a separate baseline for the top measurement is taken, otherwise the height will be exaggerated (or underestimated on a tree leaning away from the observer). Without correcting for the lean and the true top location, even small trees can yield enough error (i.e. point spread) to keep co-champions away (6 points).

The slope distance of a line between the observer and the tree (B1) is longer than the same horizontal distance (B2) between the same points. Since conventional height calculations are based on the *horizontal* distance between the observer and the tree, the distance must be corrected to the horizontal equivalent. This is very easy, and even easier to forget to do!

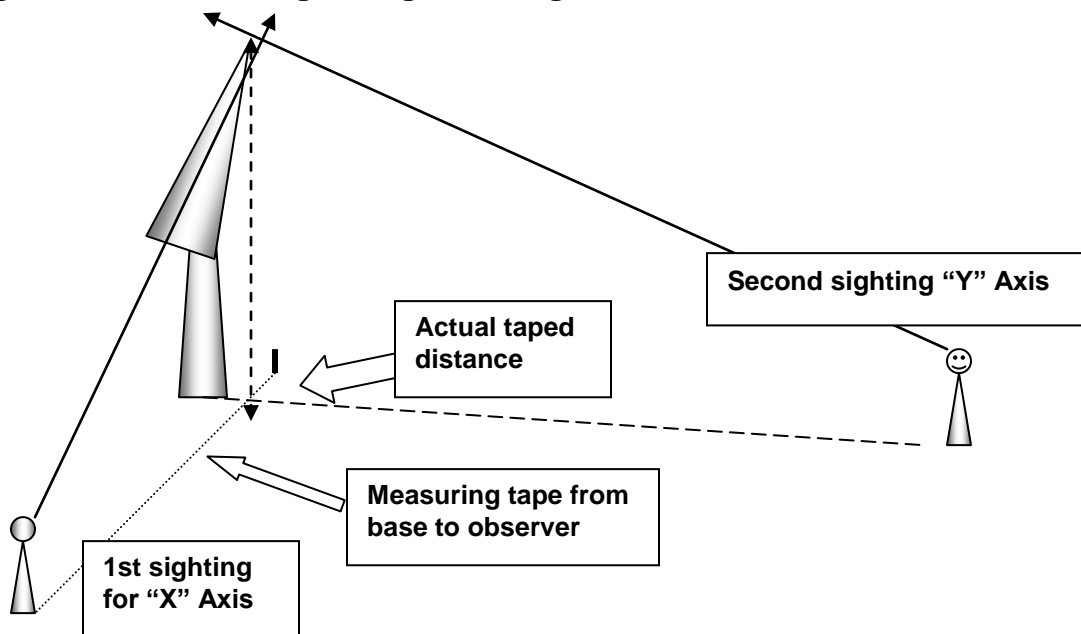
Figure 9. Correcting the baseline for trees growing on a slope



Appendix B: Cross-Triangulation

Cross-triangulation is essentially the process to map a point on the tree (the top) in three dimensions. Once we know where the top is, we can then properly measure its position relative to the ground (height). In a two dimensional photo like the one above, there is no way of knowing for sure which part of the tree is far back and which is closest. In cross-triangulation, you pick a target point. Dangling your clinometer (or plumb-bob) by the lanyard, you transpose the point to the ground (a helper is useful). Mark this point with a stick or other object. Go ahead and measure the angle to the top while you are there. This is the point in one dimension that the top intersects the ground, and is in a sense the “X” axis. Then, observing the same point with your eyes, go 90 degrees to either side and transpose the top to the ground again. This is the “Y” position on the “X” axis that the top resides. Move the stick to that position, staying 90 degrees (perpendicular) to the line of sight. It is often helpful to lay the measuring tape out on the first sighting so that you can more easily find the 90 degree mark, and when you move the stick to the “Y” position you can modify the distance and calculate the height. The stick’s position is the adjusted baseline.

Figure 10. Cross-triangulating a leaning tree



On some trees this is a very difficult and time intensive procedure to accomplish, and if you are going to measure a lot of trees or trees in a forested setting, I encourage you to skip this method, buy a laser rangefinder and go to the section on page 11 on the ENTS Method. Regardless, cross-triangulation is good to know, as it illustrates the fallacy and pitfalls of conventional techniques, and when your laser battery dies or you forget your equipment, you can fall back on it. When properly applied, the results of cross-triangulation are extremely accurate. Its biggest drawback is TIME!

Side note: I must point out that within the Eastern Native Tree Society and many universities cross-triangulation techniques are no longer being used. This is because once you get familiar with using a laser rangefinder; you basically can't imagine doing it any other way. The technique is so accurate, quick, and foolproof that its introduction into scientific canopy studies was a "no-brainer". Height growth of mere inches can be ascertained with the techniques described after this section on conventional forestry methods.

Cross-triangulation summary

All of the above situations (i.e. a leaning tree *and* leaning ground) can compound themselves into massive height errors. Such compounded errors can be highly significant on small trees as well as on trees that don't appear to be leaning much. Naturally, the observer can often position themselves in such a way as to minimize the potential for having to correct for compounding errors. Such tactics include selecting a sighting position perpendicular to the lean and sighting from a point level with the base. Here is an example of a calculation you may need to use to avoid compounding errors:

$$H1 = [\text{TAN}(A1)] * [B1 * (\text{COS } a1)] \text{ +/- } H2 = [\text{TAN}(A2) * B2 * (\text{COS } a2)]$$

H1= Height above eye

H2= Height below eye

A1= Angle to top

a1= Slope angle of baseline for top

A2= Angle to base from observer

a2= Slope angle of baseline for base

B1= Sloped baseline distance for top

B2= Sloped baseline distance to base

NOTE: Absolutely none of the challenges associated with cross-triangulations are an issue when using the ENTS laser method.