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THE MIRROR CALIPER, A NEW OPTICAL DENDROMETER

Abstract.-Five years of field tests have proved that the mirror caliper-a hand-held, nonmagnifying, optical caliper-is a practical instrument for use in taking upper-stem measurements (diameter outside bark) at any point on a standing tree. Parallel lines-of-sight produce direct-reading measurements within a range of 3.5 to 16.0 inches. Accurate readings can be taken in approximately 30 seconds.

During the past few years, most specialists in forest inventory have retired their gaff-type tree climbers and tree-climbing ladders in favor of optical dendrometers that make it possible to measure diameters in the upper stems of distant trees while standing safely on the ground. The early, unsuccessful attempts to develop a suitable dendrometer and the subsequent achievements in recent years were described by Grosenbaugh,[1] who classified all optical dendrometers as being either optical forks, optical calipers, or short-base range-finders.

The mirror caliper is a hand-held optical caliper used to measure diameter outside bark at any point on the main stem, forks, or limbs of standing trees (fig. 1). It is constructed by mounting two strips of first-surface mirror in parallel so that they face one another on an irregular, somewhat parallelogram-shaped body. A sliding scale with a peephole in one end is mounted on the body between the two mirrors.

Two parallel lines-of-sight are generated by sighting through the peephole and looking simultaneously into and over the front mirror (fig. 2). A reflected image of the tree's bole appearing in the front mirror is offset to the left, and a direct reading of diameters to the nearest tenth-inch is made at the point a perfect split-image is obtained. The width between the parailel lines-of-sight is varied by the angle at which the direct line-of-sight strikes the front mirror, making it possible to measure a range of diameters without repositioning the scale. Diameters are read directly from the mirror-corrected scale immediately below the reflected tree image in the front mirror. The user can therefore make a rapid series of measurements up the tree without removing his eye from the peephole.

Because parallel lines-of-sight are used, distance from the caliper to the point being measured need not be a consideration. Any error attributable to mirror alignment, however, will increase in direct proportion to the line-of-sight distance. There are two, other, equally important reasons for keeping measurement distances to a minimum: the unaided human eye cannot clearly distinguish slight deviations in image alignment at distances over 50 feet, and image clarity breaks down at distances of 100 or more feet.

A general-purpose caliper designed for direct readings of diameters ranging from 3.5 to 16.0 inches can be used to measure

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[1]Grosenbaugh, L. R. Optical dendrometers for out-of-reach diameters: A conspectus and some new theory. Soc. Amer. Forest. Forest Sci. Monogr. 4, 47 pp. 1963.

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diameters from 16.0 to 32.0 inches by bisecting the tree's bole with the prism attachment on the front, measuring the half-diameter, and then doubling the diameter measurement. Trees over 32.0 inches can be measured by using the prism attachment as an optical fork and then measuring line-of-sight distance with the mirror caliper functioning as a variable-base rangefinder.

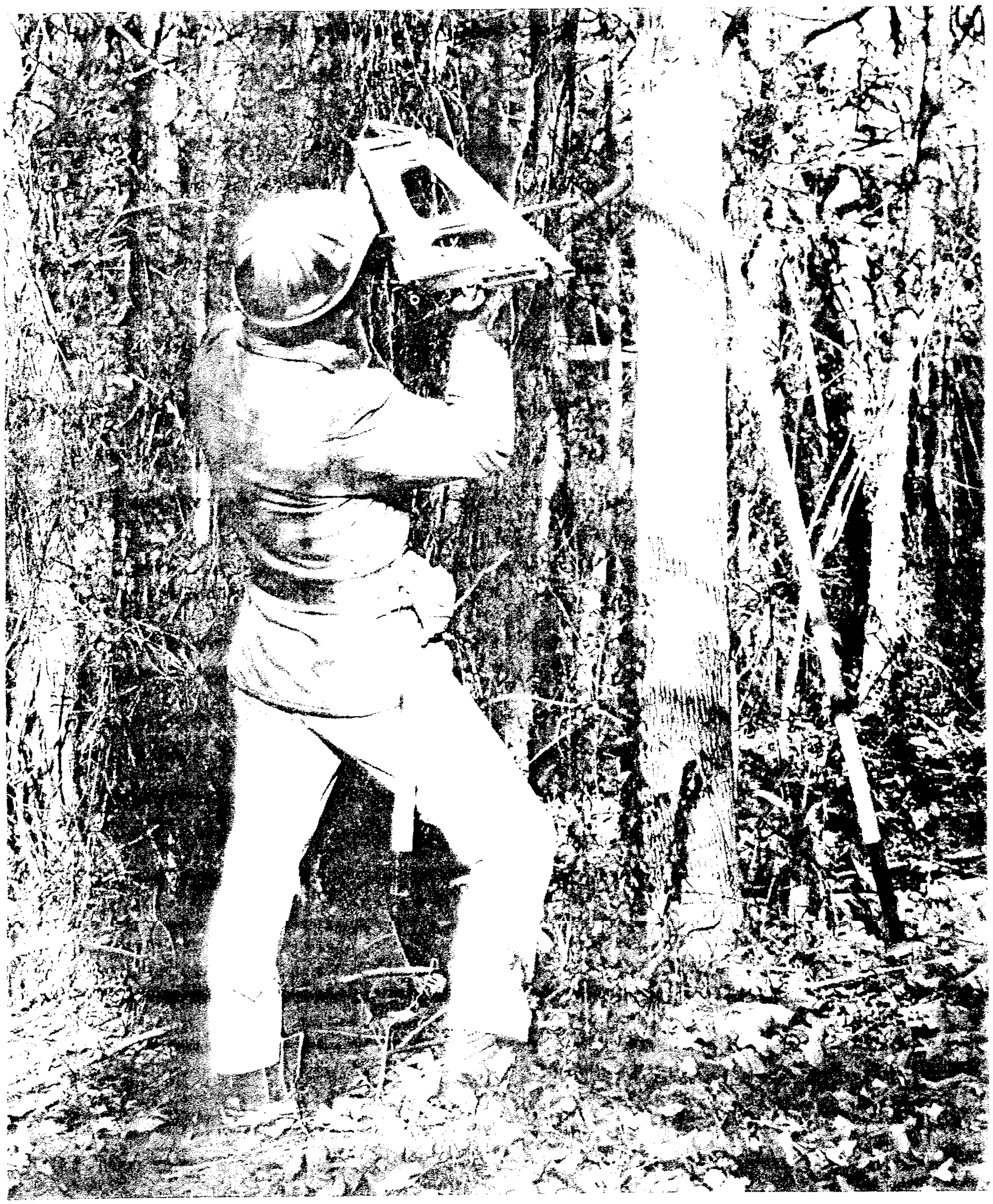

Figure I.-Measuring upper-stem diameter with the mirror caliper.

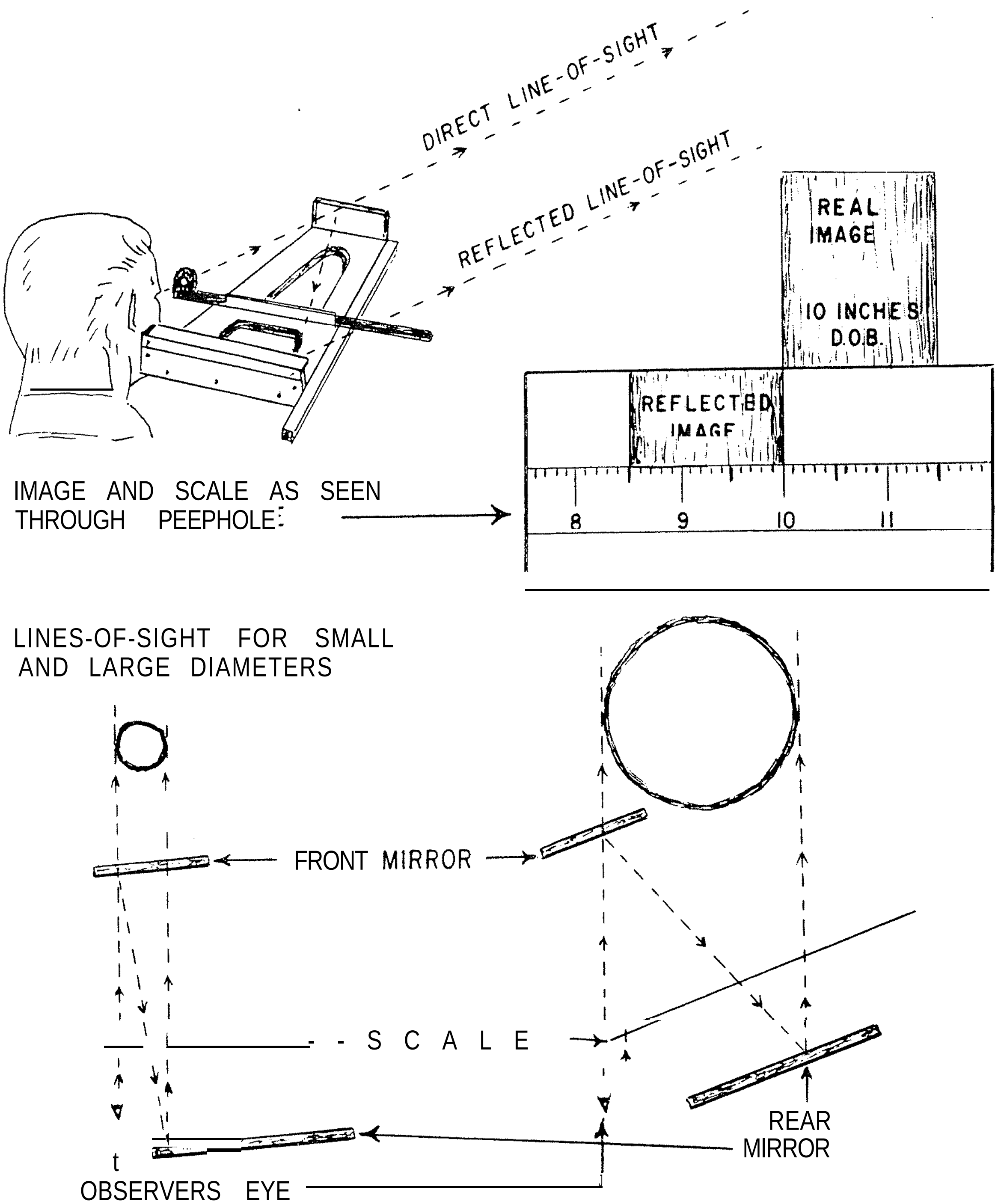

Figure L-Operating principle of the mirror caliper.

MIRROR CALIPER APPLICATIONS

1. *Location of a specific minimum diameter of the upper stem.* -The mirror caliper can be used when a specific minimum top diameter, such as 4.0, 7.0, or 9.0 inches, must be located before a merchantable length can be measured.

2. *Measurement of merchantable top diameter.*-The caliper can be used when the diameter at the upper limit of merchantability serves as an independent variable in volume prediction equations. The point to be measured may occur at any point on the tree's bole.

3. *Determination of form factors.*-The mirror caliper can be employed to measure diameter outside bark at the appropriate point on the stem when form class, form point, form quotient, or other form-factor volume equations are used.

4. *Determination of standing-tree volume with sectional aluminum poles.* -The measurer can select each measurement point on the tree by breaking the stem into a series of sections or logs. Sectional aluminum poles, described by McClure,[2] are extended along the tree bole for length control. Each section is then documented separately and assigned product, grade, and cull classifications. Section volumes are computed by mathematical formulae and summed to obtain tree volumes by product and grade. Fork and limb volume can be measured and identified as separate material classes if total tree volume is desired.

5. *Determination of standing-tree volume with a hypsometer.*—The general objective in this method of tree measurement is similar to application 4, except that the hypsometer attachment is used in place of sectional poles to measure heights to the various points of measurement.

6. *Direct determination of tree volume by accumulation.*-The total merchantable volume in a standing tree can be determined in a matter of minutes in terms of cubic feet, board feet, cords, or other units of volume or value by the selection of an appropriately graduated scale. Scales are prepared by calculating volumes corresponding to either midpoint or scaling diameters with appropriate selection of section lengths best suited to the level of accuracy desired.

According to Grosenbaugh,[3] "No optical dendrometer without magnification can achieve the precision needed for research. No optical dendrometer without coincident or superposed alignment can achieve the speed and accuracy needed for practical forest inventory. Hence, only magnifying, coincident dendrometers have enough potential to warrant developmental effort." This evaluation would be totally acceptable if all tree measurement applications were limited to making a few, very exacting measurements on a relatively small number of sample trees under nearly ideal field conditions. However, there are many forest inventory applications which require inexpensive measurements of many trees under far less than ideal field conditions. In a broad-scale forest inventory, such as the nationwide Forest Survey, an alternate set of criteria for a practical optical dendrometer is needed.

Magnification in an optical dendrometer may be a luxury rather than a necessity when the measurer is dealing with smaller trees such as those typically encountered in the eastern United States. In this area, the average line-of-sight distance from the instrument to the point of measurement may be less than 50 feet, and the more critical measurements in the lower portion of the stem are measured from only a few feet away. In tests with a penta-prism caliper[4] with and without magnification, Robbins and Young[5] found no significant gains attributable to limited magnification.

To be practical in general field use, an optical dendrometer must be reasonably accurate and have enough precision to meet realistic goals of measurement. Because a tree's bark is typically rough and ragged, image alignment is essentially an approximation. The fact that bark thickness in the upper stem is estimated or predicted rather than measured tends to further discount the need for fine precision in measurements of outside bark. Attempting to micrometer a diameter outside bark is generally unrealistic and overly ambitious when an estimate of diameter inside bark is the real objective. The latter objective places a premium on reasonable accuracy rather than precision. Accuracy tests, such as those conducted by Robbins and Young, consistently indicate that average differences between the mirror caliper and conventional calipers are well within the tolerances required for most upper-stem measurements.

With a good field instrument, the measurer should be able to take direct readings, and

[2] McClure, Joe P. Sectional aluminum poles improve length measurements in standing trees. Southeast. Forest Exp. Sta., U.S.D.A. Forest Serv. Res. Note SE-98, 4 pp. 1968.

[3] Grosenbaugh, op. *cit.*, p. 27.

[4] Wheeler, P. R. Penta-prism calipers for upper-stem diameter measurements. J. Forest. 60: 877-878. 1962.

[5] Robbins, Wallace C., and Young, Harold E. An evaluation of the McClure and Wheeler optical calipers. Forest. Chron. 44(4): 16-18. 1968.

individual measurements should require only a few seconds. Robbins and Young confirmed that a single measurement could be taken with the mirror caliper in approximately 30 seconds. The instrument should be compact, highly portable, and should remain in adjustment when exposed to the unavoidable abuse encountered under rough field conditions. Mirror calipers used daily by Forest Survey crews usually remain in adjustment for weeks at a time, and all necessary adjustments can be made in the field.

An optical dendrometer should not require a measured base distance or necessitate excessive clearing of saplings, limbs, or brush. This is a particularly important consideration when the measurer is working on permanent sample plots in which the understory must not be disturbed. Only those optical dendrometers classed as optical calipers have the unique capability of measuring upper-stem diameters without a base distance or line-of-sight distance. A mirror caliper can therefore be used to measure upper-stem diameters even though the lower portion of the bole is totally obscured.

An optical dendrometer should be simple to operate and have good light-transmission properties through its optical system. Vague imagery can become a serious source of measurement error when the measurer is working under poor light conditions. The mirror caliper reflects an indirect image from two first-surface mirrors, each of which has light-transmission capabilities of approximately 94 percent for all visible light striking the mirror surface at 22.5". These excellent light-transmission properties in the caliper eliminate the need for a light booster or supplemental light source.

Optical dendrometers that are currently available vary considerably in versatility. Instruments that require extensive use of prepared tables or computer calculations to convert instrument readings into usable diameter measurements, such as the Barr and Stroud dendrometer, are very impractical for locating the point at which a specified diameter occurs on the stem. In comparison, the mirror caliper is equally efficient in locating predetermined diameters and in measuring selected points on a tree.

One of the most serious limitations to all optical calipers is that the instrument's physical size is directly proportionate to the largest diameter it is designed to measure. A specially designed series of wedge prisms are attached to the mirror caliper to extend the range of diameter measurements without any significant increase in caliper size, shape, or weight. The measurement of larger diameters involves the combination of characteristics of the optical caliper and the principle of optical forks, as is implied by the use of wedge prisms.

Additional features incorporated in the design of the mirror caliper include interchangeable scales graduated in inches, centimeters, cross-sectional area, and in units of volume for direct tree-volume accumulation. A clinometer is conveniently attached to the caliper for height measurement, and an accumulation device is mounted on the rear of the caliper to aid in summing tree-section volumes for direct tree-volume determination. The user can easily measure horizontally oriented limbs as well as vertical stems simply by holding the caliper in a vertical orientation.

Forest Survey crews in the Southeast and North Central States have extensively tested different models of this optical caliper during the past 5 years under a wide variety of field conditions. Over 16,000 individual sample trees representing over 150,000 individual readings have been measured with the caliper in the Southeast alone. Specially prepared folding models calibrated in centimeters have been used with good results in South American rain forests, and approximately 90 units are now in use throughout the United States and Canada. Response from many users of the mirror caliper indicates that it has proven to be a versatile and practical field instrument.

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