THE American Surveyor

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National Treasures

Along Came a Spider

From crosshairs to clothing—a fascinating look at the versatility of spider silk.

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Along Came a Spider—Spinning Silk For Cross-Hairs

The Search for Cross-Hairs for Scientific Instrumentation, Part 1

Spider silk has been used for centuries by various civilizations and for a variety of purposes because of its strength and other remarkable characteristics. In more recent times new uses for it have been found in the support of science.

Spiders use their silk for various purposes. Some male spiders deposit sperm onto a web and offer it to a female's genital opening; eggs are wrapped in a cocoon and offspring are held by a silk lifeline; cobwebs of spider silk serve to snare a spider's food. Fossil evidence found in rocks in the New York area reveals that spiders already were actively spinning silk some 380 million years ago.

Through the ages, spider silk has been used in several early societies for various purposes. The ancient Greeks used cobwebs to staunch bleeding wounds. Later, doctors in the nineteenth century also studied treatment with cobwebs for the same purpose. It was not until a century later, however, that it was learned why treatment with cobwebs was successful–because spiders coated their silk with antiseptic agents that served as anticoagulants. Indigenous people of the Pacific world, Asia and Australia have used spider webbing for woven water-shedding gear, kites, nets and fishing lines and for personal ornamentation. Fish nets, headgear and bags are fashioned from spider silk by natives of New Guinea. Australian aborigines used the silk of a giant tropical spider for fishing lines to attract small fish. They rubbed parts of the spider's body onto the silk, and when they bit the spider tidbits, the fish became caught in the sticky silk. [1]

With the evolution by the eighteenth century of a range of optical instruments developed for measurement and for observation, there was an immediate need for precision of calibration, and so began a constant search for material that was suitable for making the required cross-hairs. The extensive variety of materials that were tested ranged from textile thread, silk, and human hair, to wire of silver and platinum among yet others, but none were suitable. Generally, each of them proved to be too thick so that it obscured part of the image that was to be observed and measured.

Then, because it is 40 times finer than human hair, a potential solution of spider silk was suggested. Some of the spider filaments that were tested were too fragile and often broke, or they were too elastic and sagged due to vibrations. Yet again, some were liable to change during variations in temperature and humidity. It was a frustrating endeavor, but the search doggedly continued over many years for a suitable filament.

Mass production of spider silk has often been attempted but always proved to be elusive because of the cannibalistic ways of spiders. They tend to eat each other when brought together in silk-making colonies, and their silk is difficult to work with because it hardens on contact with air. [2]

Gascoigne Credits the All Disposer

Among the earliest known pioneers to have found spider silk of interest was the young amateur astronomer William

Spider trap made by inventor George H. Ketteringham. Images courtesy *Ketteringham Collection, National Museum of American History, Smithsonian Institution.* Note: More information on George Ketteringham will appear in Part II of this article, in the May 2005 issue.)

>> By Silvio A. Bedini

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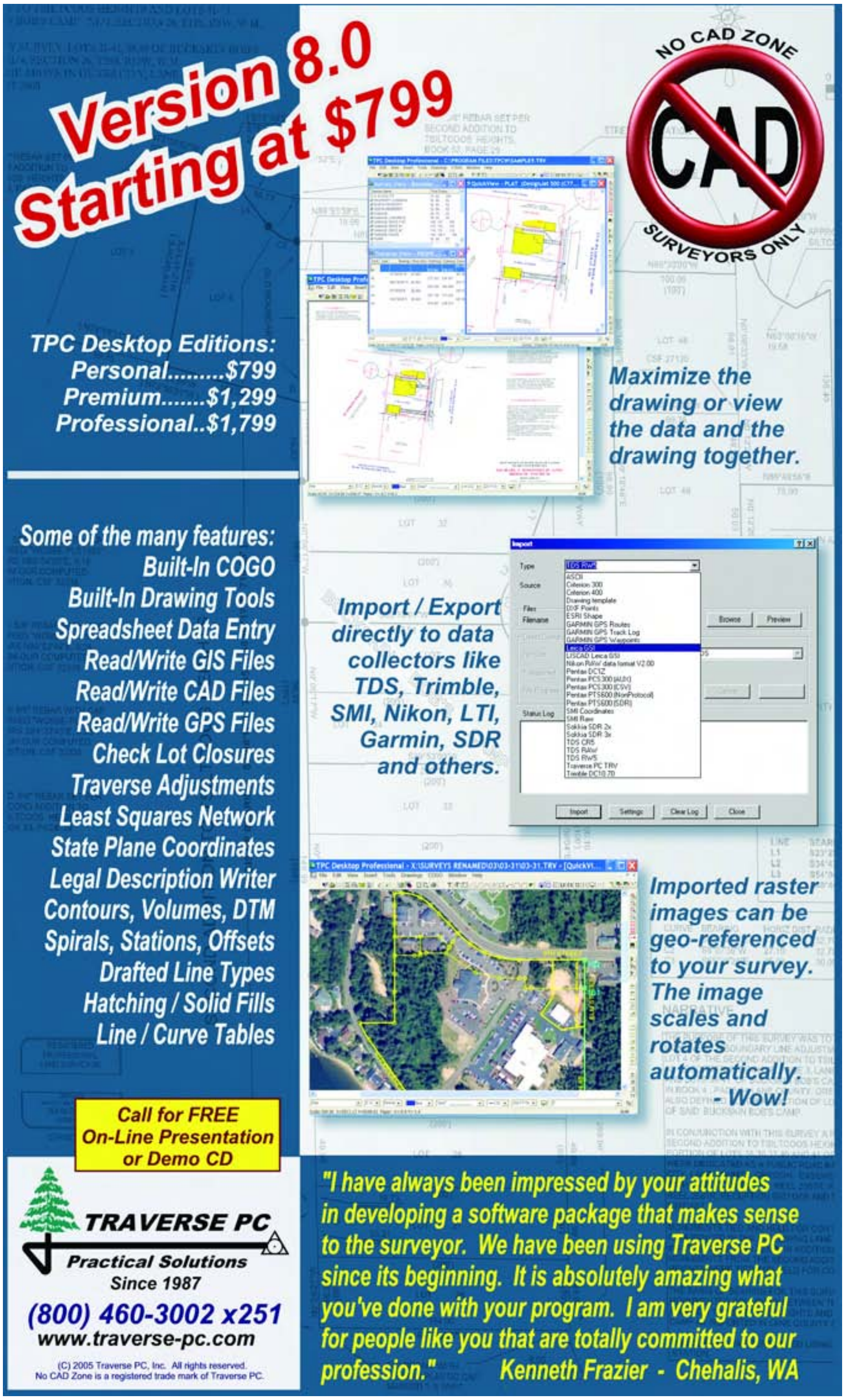
Along Came a Spider

Gascoigne (1621-1644) of Middleton near Leeds, England. A member of a small local band of amateur astronomers, history records that one day in about 1639, when he went to take up his telescope where he had left it overnight, he discovered that a spider had spun a web inside his telescope tube. This led him to devise the first astronomical micrometer. As he wrote at that time to his friend, the mathematician William Oughtred (1575-1660), *"This is an admirable secret which, as all other things, appeared when it pleased the All Disposer, at whose direction a spider's line drawn in an open case could first give me by its perfect apparition, when I was with two convexes trying experiments about the sun, the unexpected knowledge."*



Undoubtedly he had become aware of the advantages of spider silk and although he may have attempted to apply it to his telescope, presumably he abandoned it because of the difficulty in mounting the tiny filament. [3]

Shortly thereafter (c. 1638--) in a letter to Samuel Crabtree, who was another member of the group of local amateur astronomers, Gascoigne wrote, *"If the night be so dark that the hair, or the pointers of the scale not to be seen, I place a candle in a lanthorn, so as to cast light sufficient into the glass, which I find very helpful when the moon appeareth not, or it is otherwise not light enough."* [4]

Later in that year Crabtree informed fellow member Jeremiah Horrocks of a visit he had made to Gascoigne, where he had seen *"a large telescope, amplified and adorned with new inventions,"* by means of which the owner could *"take the diameters of the sun or moon, or any small angle of the heavens or upon the earth, most exactly through the glass to a second."* [5]

Two years later Gascoigne described his micrometer invention in several letters to his friend, Crabtree, but said little in his correspondence about the mounting of his telescope. It is known that it had consisted of two tubes, the outer one oblong in section and containing the micrometer fittings. The ocular was a single equi-biconvex lens. Gascoigne commented on the regrettable absence of skilled artisans in metals in his district and criticized the poor quality of the work he obtained from his joiner. Nonetheless, he managed to construct several graduated instruments to fit a Galilean telescope from *"Londin best sale glasses"* and to apply telescopic sights to his quadrant and sextant. Several measurements of the diameters of the moon and planets, together with other observations, were made before his death but are no longer available. Information about his work was limited to the small circle of fellow astronomers, all of whom died before or during the English Civil Wars.

Gascoigne was killed in the battle of Marston Moor on July 2, 1643, and shortly thereafter some of his astronomical instruments were rescued and brought to Richard Towneley (1629-1707). In 1667 Towneley wrote about the micrometer to the Royal Society of London, and arranged to have several of the micrometers made to Gascoigne's specifications; in 1670 his friend Sir Jonas Moore presented one to John Flamsteed. Towneley used the micrometer to measure the movement of Jupiter's satellites, a work passed on to Newton by Flamsteed. [6]

At approximately the same period the Marquis Carlo Malvasia (1616-1693) was seeking a filament having sufficient strength and thinness for a micrometer he developed and described in 1662 in his *Ephemerides.* He experimented with fine silver wires arranged at right angles to each other to form a network of small squares that he placed at the focus of his telescope. He determined the mutual distances of the intersecting wires by counting by means of a pendulum clock, the number of seconds required by an equatorial star to pass from web to web, while the telescope was so adjusted that the star ran parallel to the wires at right angles to those under investigation.[7]

Spider Silk Clothing

When in 1709 when the French naturalist Rene-Antoine Ferchault de Reaumur (1683-1757) was asked by the French government to find uses for spider silk, he demonstrated that spider silk was usable for fabrics in the same manner as the silk of the silkworm. He proceeded to diligently collect the material from egg sacs of spiders, then had a large number of egg sacs washed, boiled and cleansed of all extraneous matter, after which they were allowed to dry out. The sacs were carded with fine combs and worked into slender thread of a pleasing gray color. Two or more pairs of stockings and gloves were made from this natural silk and were presented to the French *Academie Royale des Sciences*. This accomplishment proved to be so sensational that in the following year the Academie commissioned Reamur to investigate the possibility of extensive utilization of spider silk. After a thorough study, however, the eminent entomologist regretfully concluded that there was little likelihood that such spider silk as was available in Europe could become a profitable industry. This is the selfsame Reaumur who after studying wasps' nests suggested that, like the wasps, men could make paper from wood.

Later in the century another man in France, Bon de Saint-Hilaire, attempted to cultivate spiders but discovered that unlike silkworms, spiders could not be reared in close quarters. Nonetheless, the French appear to have persisted in this endeavor to domesticate the spider. A Frenchman named Chachot is said to have managed to harness a spider to a machine that operated tiny bobbins that revolved constantly. As the spider spun the spider silk it was wound as fast as the spider produced it. The end of the silk thread was caught as it came from the spider's body and fastened firmly to a bobbin. Then, as the machine was gently activated, the spider pulled in the opposite direction to escape, but not with sufficient force to break the thread, and seemingly enjoying the process, the spider maintained just sufficient tension to keep the silk in constant motion, eventually producing sufficient spider silk to make into as fabric.

An interesting display at a French Colonial Exhibition held at Marseilles in 1907 was a silk-like product derived from a large spider native to

Madagascar, and which was expected to be manufactured in future as a substitute for silk. A French Jesuit, M. Camboue, installed a testing plant at Tananarivo on the eastern coast of Madagascar *"in which spiders are reared in order to be artificially deprived of their webs. Each spider will yield 150 to 600 meters of silk thread at a time, and will die after being emptied five or six times a month."* So much for French endeavor.[8] It was not until the mid-eighteenth century that the first successful experiments with spider's silk for making cross hairs for scientific instruments were recorded, in the work of Felice Fontana (1730-1805). A physiologist at the court of the Grand Duke of Tuscany, Fontana was born at Pomarolo (Trento) on April 15, 1730. He studied theology, philosophy and physics at Verona, Padua, and Bologna. He organized a museum of physiology and natural history in Florence for the Grand Duke and by decree of November 7, 1766, he was nominated professor at Pisa and then became director of the Cabinet of Physics in the Pitti Palace in Florence. From 1775 until his death on March 19, 1805, he served as director of the Museum of Physics and Natural History he had founded.

In 1755, while attempting to add cross-hairs to the lens of a leveling instrument, Fontana succeeded in attaching the silk from a spider's web for the purpose. The instrument in question appears to have been a level having a micrometer and two telescopes, a lead thread in a level of brass with glasses, on a the brass base having movement for correction. The instrument devised by Fontana probably was constructed for him in the Museum's workshop. Presumably it was found to be satisfactory by many and seems to have been immediately modified to make it adaptable for some *piede* already existing. Although Fontana's instrument was recorded in his time in a catalogue of the royal cabinet of physics and natural history, his discovery did not become known elsewhere until almost a century later.[9]

Rittenhouse and Ellicott

It was some three decades later that an experiment was made in the United States to make cross-hairs with spider silk. The Philadelphia instrument maker David Rittenhouse (1732-1796) attempted to make the cross-hairs of his astronomical instruments from spider silk, the first known to do so in the New World. He described his experience to the Reverend John Ewing (1732-1802), the first Provost of the University of Pennsylvania, in a letter that was read before the members of the American Philosophical Society and then published in 1786 in the Society's *Transactions.*

It was in a postscript that Rittenhouse wrote, *"The great improvement of object glasses by Dollond has enabled us to apply eye glasses of so short a focus that it is difficult to find any substance proper for the cross hairs of fixed instruments. For some years past I have used a single filament of silk, without knowing that the same was made use of by the European astronomers, as I have lately found it is by Mr. Hirschel. But this substance, though far better than*

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wires or hairs of any kind, is still much too coarse for some observations. A single filament of silk with totally obscure a small star, and that for several seconds of time, if the star be near the pole. I have lately with no small difficulty placed the thread of a spider in some of my instruments, it has a beautiful effect, it is not one tenth of the size of the thread of a silkworm, and is rounder and more evenly of a thickness. I have hitherto found no inconvenience from the use of it, and believe it will be lasting, it being more than four months since I first put it in my transit telescope, and it continues fully extended, and free from knots or particles of dust." [10]

Spider silk could be taken directly from the living spider and used to replace damaged cross hairs, or taken from the inner silk padding of the egg sac. Rittenhouse did not identify the species of spider from which he obtained his silk, but the species most common in the Philadelphia area in the eighteenth century were several species of *Araneus, Neoscona, Metepeira, Eustala* and other genera of the family *Araneidae*, any of which could have been used by Rittenhouse. He probably preferred the large *argiopas (Argioe aurantia)* and (*Argioe trifasciata*), however, that were always present in large numbers and capable of producing large egg sacs. [11]

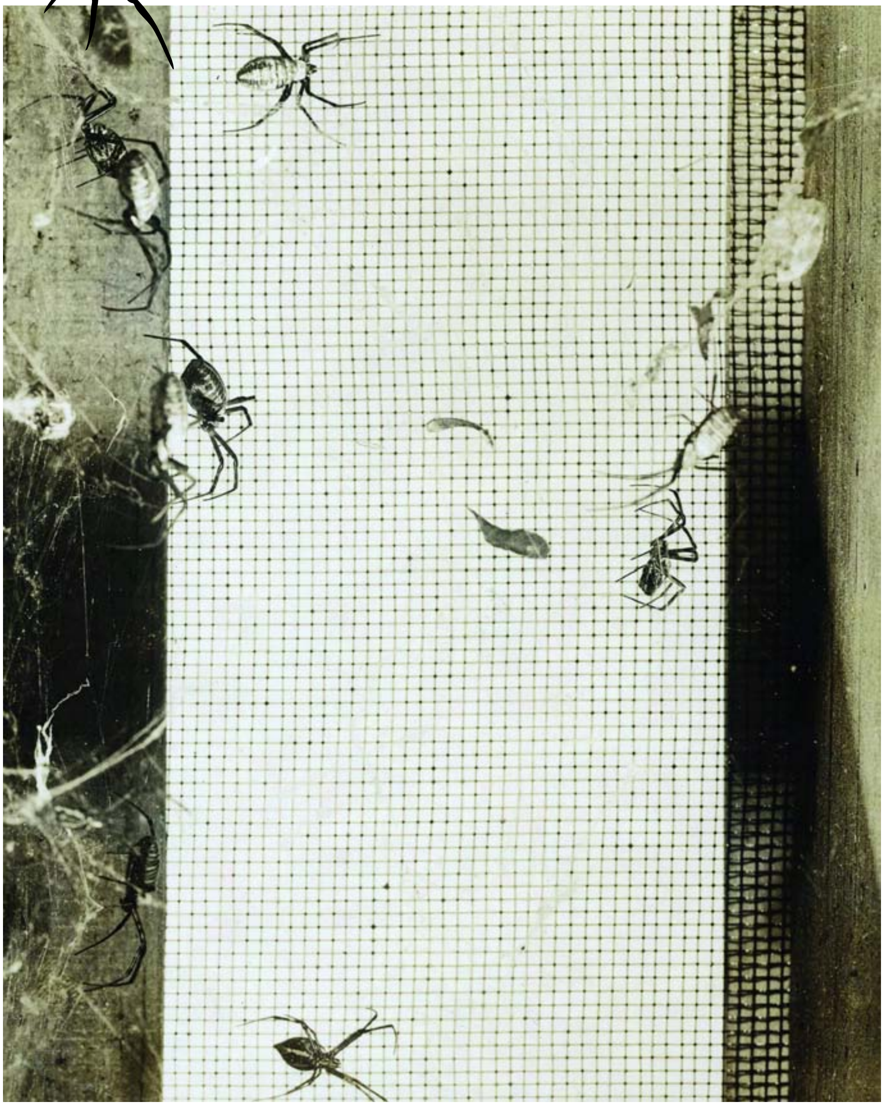
The next effort to use spider silk to be recorded was made some sixteen years later by the surveyor Andrew Ellicott (1754-1820), who also experimented with the use of spider silk for his instruments. In 1802 when he became secretary of the Pennsylvania Land Office at Lancaster, Pennsylvania, because he lacked fixed instruments for his astronomical observations, he constructed his own transit and equal altitude instrument. For the cross-hairs, he successfully utilized spider silk. As he informed Thomas Jefferson in May 1802, *"I expect to get my transit instrument set up in three, or four weeks, by which I shall be able to increase the number and value of my observations.... I have with great difficulty, and patience, placed a reticule of spider's web (the first ever executed), in the focus of this instrument! And intend accommodating my Telescope with a diaphragm, to observe the eclipses of Jupiter's satellites...this precaution appears necessary, and is strongly recommended by De LaLande in a late work."* Ellicott presumably succeeded, and did not make further reference to this in subsequent letters. [12]

Further Studies in England

Edward Troughton, in the forefront of nineteenth century English makers of mathematics instruments, was the first in England to apply spider silk in surveying and astronomical instruments. Other English makers soon followed his lead as the use of micrometers with spider silk with large aperture objectives on equatorial telescopes and transit instruments brought about increased precision. Troughton acknowledged that prior use of spider silk for cross-hairs had been achieved by Rittenhouse. [13]

In 1782 Sir William Herschel (1728-1822), the first astronomer to measure position angles, wrote, *"I have in vain attempted to find lines sufficiently thin to extend them across the centres of the stars, so that their thickness might be neglected. The single threads of the silk-worm, with such lenses as I use, are so much magnified that their diameter is more than that of many of the stars."* [14]

The problem of finding or developing a thread of sufficient fineness for micrometers for astronomical observa-



tion continued, and many materials were tested. On February 18, 1813, Dr. William Hyde Wollaston (1766-1828), secretary of the Royal Society of London, in a paper he read before the members, discussed *"A method of drawing extremely fine Wire."* He proposed fine platinum wires prepared by surrounding a platinum wire with a cylinder of silver, and drawing out the cylinder with its platinum axis into a fine wire. The surrounding silver was then dissolved by nitric acid, and remaining was a platinum wire of considerable fineness. Experience was soon to prove the superiority of spider web. [15]

A decade later Sir John Frederick William Herschel (1792-1871) in a seven-foot equatorial instrument he used for the observations which he made between 1821 and 1823 of the apparent distances and positions of 380 double and triple stars, had the telescope furnished with a micrometer made by Edward Troughton. *"The telescope is furnished with a micrometer, the work of Troughton,"* he wrote, *"similar in all respects to that of the five feet just described, with the exception of a peculiar apparatus carrying an additional moveable cross wire, for a purpose not connected with the present paper. *The wires employed in these micrometers, are spider's lines of extreme tenuity, and were inserted by Mr. Simms."* [16]

In 1824 on their five-foot focus equatorial telescope John Herschel and Sir Edwin South, used a Troughton micrometer and measured position angles to the remarkable degree of accuracy of 1" of arc. [17]

Eventually the unusual properties of spider silk became more widely recognized, and it was realized that it had the strength of steel and that its thinness made it workable. It also has the ability to stretch to 40 percent of its normal length, yet retaining great resiliency to shorten back. Furthermore, it could withstand low temperatures. Although spider silk is a soluble fluid in the aqueous environment of a spider's abdomen, it becomes an insoluble solid after it exits the spider's body. Recognizing some of these qualities, by the early nineteenth century the British attempted to collect and make use of spider silk for various commercial purposes. The problem they immediately encountered was the necessity to immobilize the spiders. In 1830 the Society of Arts presented a silver medal to the inventor Daniel Rolt for a device consisting of a spool attached to an engine to harvest the spider silk. This invention reportedly wound 18,000 feet of silk from two dozen spiders in two hours. Whatever use was made of the silk was not reported. [18]

During the War Between the States in the United States, a Civil War surgeon named Burt G. Wilder (1841-1925) attempted to solve the problem of extracting spider silk in quantity. He constructed a device resembling the stocks used in colonial New England to hold criminals. The stocks held the spiders still while Wilder gently drew the silk from them. He successfully extracted 150 yards from one especially cooperative arachnid, then calculated that it would require 5000 spiders to retrieve sufficient material to make one dress. Wilder published a series of papers between 1866 and 1873 describing his efforts in the *Proceedings of the American Association for the Advancement of Science*, in the *Proceedings of the Boston Society of Natural History,* and in the *Atlantic Monthly.* [19]

(To be continued in the May 2005 issue. A complete list of references for the footnotes in Parts I and II of this article can be found on our website at *www.theamericansurveyor.com*)

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