Along Came a Spider—Spinning Silk For Cross-Hairs

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

Ancient Greeks used spider web to close wounds, Australian aborigines used spider silk to fashion fishing lines, and natives of New Guinea used it to weave fishing nets and bags. In modern times it has proven its value for making cross-hairs for scientific instruments.

In his published study of American spiders, Willis J. Gertsch of the Department of Insects and Spiders of the American Museum of Natural History in New York, wrote that even prior to World War I spider silk was being used very extensively for cross-hairs and sighting marks in a great variety of engineering, laboratory and fire-control instruments. There was nothing superior to spider silk, he claimed, for transits, levels, theodolites, astronomical telescopes and many other optical devices. There was a slackening in the use of this material after World War I, however, because the finest threads were useless for cross-hairs due to their fragility and difficulty of installation. It was the "dragline" fiber that was most often used, but their jointed fibers first must be separated so that the primary line remains a single uniform thread.[20]

The use of spider silk for scientific instruments came into its own again by the beginning of World War II. Although a spider's web lasts only one or two days, after which the build up of atmospheric dust ruins the filament's tackiness making it difficult to trap prey, the durability of spider web filaments could be measured in years, when sealed or encapsulated for the cross-hairs in gun sights and telescopes. Filaments continued to be used for this purpose until the 1960s.

An undated announcement from London during the war years entitled "Progress Traps Spiders' Webs" reported that "*spiders have entered the thousands of the unemployed in Britain, because their job in a Northern England optical equipment factory had been taken over by a machine. The spiders, of the genus Epeira diademata, had been vital to the Vickers instrument firm in York for years.*" The article stated, "*The spiders' webs were used to produce fine markings and sight lines on instruments such as telescopes and*

>> By Silvio A. Bedini

surveyors theodolites." Now spider silk was superseded by a newly-developed electronic etching system that proved to be easier to use and just as accurate.

"It is remarkable, the spiders' webs could be accurate to within just over a ten thousandth of an inch," commented George Key, age 63, a foreman at the Vickers factory. "I have worked here for 48 years and the firm was using spiders long before then. They were essential to the work. But now we have no use for them." He told how at the end of August every year the factory apprentices went out to a nearby common and in the early morning mist they crawled on hands and knees seeking the *epeira*. Over a period of two weeks they would find as many as 200 females, recognized by a white cross on their backs. After spinning their webs at the factory, the spiders were returned to the common and set free. The webs, with up to 40 feet of thread, were sufficient for the year's needs. Where once they were able to find scores of the spiders, later there were fewer gorse bushes, however, so that the spiders became scarcer and only about a dozen were found during their spider hunt.[21]

All images in this article show spider silk equipment from the Ketteringham Collection, National Museum of American History, Smithsonian Institution. Shown here, Ketteringham's alcohol lamp, aligning frame, and forceps.

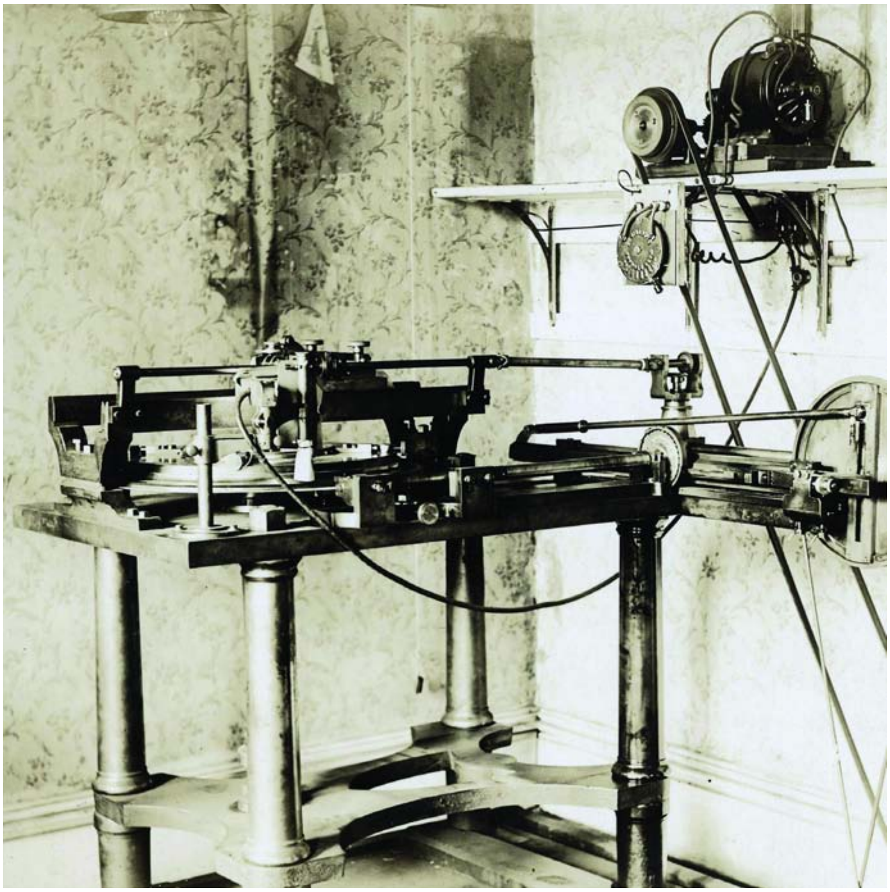
In England during the war, the web of the gray spider that generally was to be found in gardens on dahlia plants also was being used for making cross-hairs for bomb sights of aircraft.

In a wartime BBC broadcast, Frank Elliott described how spiders having a cross on their backs were selected and brought back to the factory where bomb sights were made, and there they were fed. When they needed another graticule, they put a spider to a frame having two prongs like a tuning fork and then someone breathed upon the spider, which made the spider jump off the frame and throw a life line. One end of the thread stuck to the frame and the frame was wound round and round so that the thread coiled around the prongs with the spider dangling beneath.

Before being put to work, the spiders first were starved for about twenty-four hours, because when starved they produced a more even thread. A section of spider silk that was even throughout was selected and it was laid upon the frame over a metal diaphragm, adding a tiny spot of wax on the end of the thread to secure it to one edge. Then the thread was carefully stretched and tacked down with wax on the opposite side to make a graticule. After having served their purpose, the spiders then were brought back to the moors to recuperate and breed. If a particularly fine thread was required, it was split by brushing the thread up and down with a fine sable brush. The strands were unraveled and those not desired were brushed off leaving one in position on the frame, ready to use.[22]

Of the numerous war industries that developed in the United States following the bombing of Pearl Harbor, among the most unusual were the tiny "defense plants" scattered throughout the country. These were maintained by private individuals who cultivated spiders for the express purpose of producing spider silk for the war effort. Among these productive sources of spider silk was one developed by the late George Ketteringham of Cleveland, Ohio. Born at Nen Terrace, Crowland, Lincolnshire in England on February 11, 1877, he left England with his family, arriving in Cleveland in 1881. There he attended public school then enrolled in the Manual Training Course at West High School from which he graduated in June 1894. In 1896 his father arranged for him to be apprenticed to the prominent young optical instrument maker in Ohio, John Christian Ulmer (1863-1950). There Ketteringham became proficient in the manufacture and repair of surveying and other precision instruments, and in time he also achieved recognition as an inventor. Among his accomplishments in this area was the design and construction of the apparatus used in making the first blood transfusion, by Dr. George Washington Crile (1864-1943), founder of the Cleveland Clinic.

During World War I Ketteringham worked on the development and perfection of the periscope with which the Ulmer company was involved. In the early years of World War II Ketteringham was employed by the Brush Development Company as a member of the team under contract to Western Electric that developed the underwater detector to locate enemy submarines. There also during the war years he utilized spider silk for making cross-hairs for periscopes, telescopes, microscopes surveying instruments and bomber sights for airplanes. Every year as late August turned into September, Ketteringham would search through his garden seeking large garden spiders. Years of study had shown him that these black spiders with orange spots produced the finest strong silk for making cross-hairs. When neighbors informed him of the presence of spiders, he collected them in a handmade cage. He then would position the threads, which were less than a thousandth of an inch in diameter, on metal rings that his employer J.C. Ulmer Co., would use to make cross-hairs. Ketteringham frequently gave presentations about his work to local groups and to schools. He died on December 29, 1954.[23]



Ketteringham spider silk equipment

Among the most highly publicized of the wartime "spider ranches" of World War II was that of Mrs. Nan Songer of Yucaipa, California, who acquired considerable national press describing her endeavors during the war years. In 1939 she had learned from a member on the staff of the American Museum of Natural History in New York that the U.S. National Bureau of Standards was anxiously seeking information concerning sources for spider silk because there was a market for it, from the Bureau itself as well as from contractors making implements for war for the government.

From her childhood Mrs. Sponger had been familiar with insects, and upon learning of the need, she began to collect live black widows and other spiders in answer to the demand. Armed with glass jars, she ventured out and combed the sagebrush and live oak covering the foothills behind Yucaipa and collected a wide variety of spiders that lived there. Sometimes she was fortunate enough to find sacs of spider eggs that she also brought home and placed in glass containers. When the spiderlings hatched, she fed them their natural diet of crickets and gnats. It was not long before spiders of all ages were spinning away, in one of the front rooms of her small farmhouse, producing spider silk for bombsights and optical instruments of high altitude bombers. The spider silk being produced proved to be particularly useful for this purpose because it had been discovered that in addition to its other desirable qualities, spider silk withstood extremes of temperature better than any other known material.

Most of the spiders Mrs. Sponder used she not only recruited locally but also had obtained from contacts all over the country who sent spiders to her. When a San Bernardino newspaper printed a notice describing her work and noted that she was seeking black widow spiders, the local postal office was deluged with shipments of the spiders from donors who were unaware that there was a federal law against shipment of poisonous insects! Upon learning of her work, the U.S. Bureau of Standards called upon her for assistance in providing spider silk for their use, and their first order was for silk that was 1/10,000 of an inch in diameter or smaller.[24]

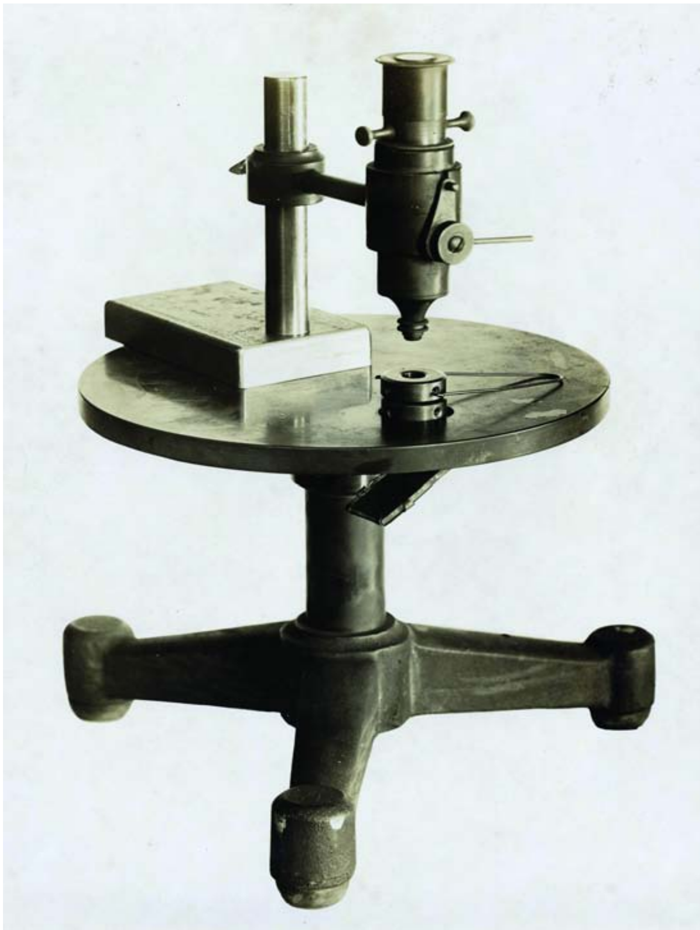
Mrs. Sponder learned to extract the spider silk by a process called "silking." The only specifications she had received from the Bureau of Standards was that the silk must be one ten thousandth of an inch in diameter, a requirement that took her almost two years to achieve. If a spider lives out its life span without suffering injuries, probably it can produce about one thousand feet of silk during its existence. She learned that spiders had more than one gland from which they secreted the fluid that formed the silk, and that they could change from one gland to another to produce different sizes and types of silk. The most difficult part of the task was to split the silk into two or three threads by means of a dissecting forceps. In her experience, the four varieties of spider that were the best producers were the Banded and Golden Garden Spiders, the deadly Black Widow and the Lynx, a bright green spider found in sagebrush.

As the volume of her work orders increased, Mrs. Sponder did as many other California employers did at that time, and appealed to the Mexican government for "workers." Soon thereafter some 250 spiders from Mexico were added to her work force. They arrived in a battered canvas-covered suitcase accompanied by a warning that "it is not to be removed from the immediate premises." At the time spider silk sold for twenty dollars per hundred feet.[25]

In July 1942 an article in *Popular Aviation* stated *"An adequate supply of spider silk vitally needed for the cross-bars of bomb sights, gun sights, telescopes and microscopes, is assured the United States through the development of a 'spider ranch' at Fredericktown, Ohio. There, harnessed in a contraption which prevents them from snipping the silk with their hind legs, more than 200 spiders of the Golden Garden Miranda aurentia breed are 'in production' for Uncle Sam's war program.*" The "spider ranch" was operated on the farm of Emil Albright near Fredericktown, who became involved in the endeavor in about 1937. The project had been some-what inadvertently initiated by his brother, John G. Albright, who was Associate Professor of Physics of the Case School of Applied Sciences (now Case Institute of Technology) in Cleveland. It began that whenever the school's telescopes and other optical instruments became out of order, Professor Albright would be called upon to repair them. During his visits to his brother on the farm he would go out to the field with a forked stick to reel in some spider web to bring back to the school for making cross-hairs. Several Case graduate students who were associated with the firm of Warner & Swasey, manufacturers of precision instruments in Cleveland, also asked Professor Albright to provide them with spider silk for their work. In time, as orders became too numerous for the Professor, he suggested that Emil take over the collecting of the spider silk, while he would continue to process the orders and handle the bookkeeping. In a letter in 1942, Albright, wrote, "*. . .we have a farm on which there is a patch of blackberry bushes down along the creek, in a sheltered spot. Among these blackberry bushes the golden garden spider (Miranda aurentia) thrive without any special attention from us. We take the silk direct from the female spider by a process which we have developed.*"

Emil Albright would work on his spider silk reeling during the latter part of August, September and October until frost, a season during which the spiders were most liberal with their output. When he went out to tend his cows or on other farm chores, he customarily took with him a lidded glass jar in which he would catch a spider and bring it back to his work room. Others responsible for repairing microscopes and telescopes who came to the farm also went out in the autumn months to collect cocoons; these were filled not with eggs, but with minute spiders, that would live through the winter and serve as a live-in source for spider silk.

A reel designed by Warner & Swasey resulted in producing the silk in a cleaner and neater manner. Thereafter Albright made his reels in the same design, on each of which 50 feet or more of silk was wound. The silk that emerged from the spider's pouch was wound on reels, about 100 feet to a reel, and was sold at $9 a reel through the Central Scientific Company of Chicago. In September 1940, Hollywood scientific film makers came to Albright's farm and produced several educational films of his operation.



Ketteringham microscope for fixing spider silk in an instrument

Although Professor Albright later moved away when he became head of the department of physics of Rhode Island State College, the brothers continued to work together, and one of their clients was the U.S. Bureau of Standards. Subsequently Emil's son, Albert A. Albright, took over the operation, packaging the spider silk in cartons with printed labels identifying "*SPIDER SILK For Optical Instruments Grown and Produced by Albert A. Albright.*" His shipments were accompanied by a pamphlet describing the history of the use of spider silk with instructions for installing it for cross-hairs.[26]

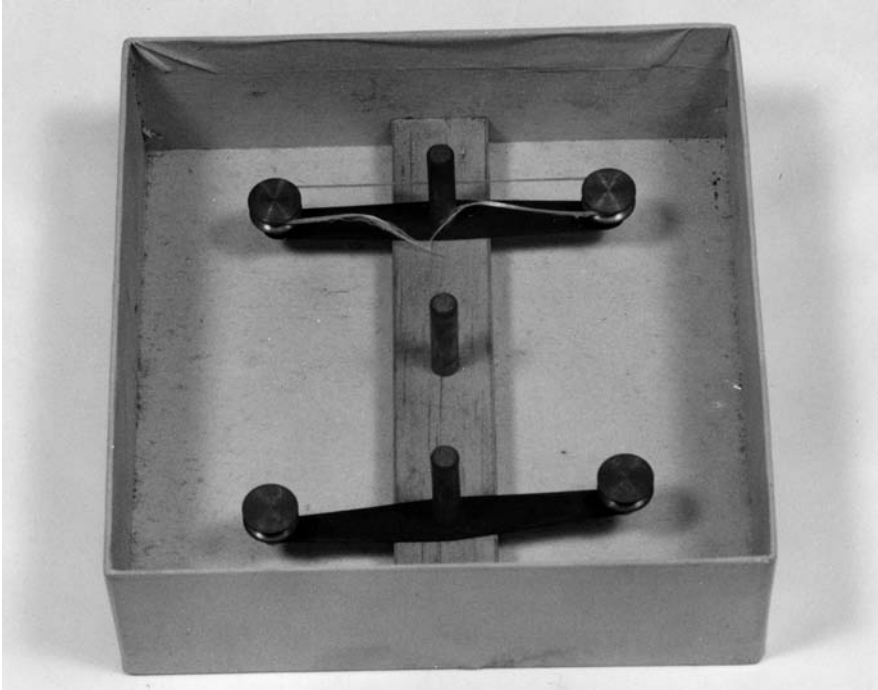
As was readily apparent, there was substantial variance among makers of scientific instruments in their preferences of the spiders that in their estimation produced the finest silk. C.L. Berger & Sons of Boston stated they used only *"fibers found next to the eggs of spiders on account of their fineness and darker color."* At first they utilized the web drawn *"from the cocoons of the small black wood spider"* which was commonly found about their shop premises. In 1900 Professor J. B. Davis of the University of Michigan began supplying them with cocoons of a species native to Michigan, which presumably was better suited to their needs.[27]

In more modern times special equipment was developed for the various steps in the process of preparing and using spider silk for making cross-hairs in instruments. The Boston firm of Buff & Buff used a "Diaphragm Ruling Apparatus" to cut the infinitesimal grooves which held the silk to a precision of 1/50,000 inch, enabling the construction of diaphragms having horizontal and vertical lines so close that they remained in perfect focus. As noted in their catalogue, *"One of the most essential points in a good micrometer is that all the webs shall be so nearly in the same plane as to be well in focus together under the highest powers used, yet absolutely free from 'fiddling.'"* Illustrated was a microscope used for fixing spider silk in a micrometer, demonstrating how the microscope could be pivoted around a diaphragm to enable the operator to have a magnified view of each individual groove.[28]

A number of firms making precision instruments requiring cross-hairs developed facilities for raising their own spiders and milking them to produce spider silk, while other firms purchased their supply from sources developed specifically for this purpose. The firm of Keuffel & Esser Co. in Hoboken, New Jersey reported *"we have always purchased Spiders from people who capture them locally and have found that the web from these Spiders produce satisfactory cross-hairs."* In 1889 the selfsame firm of K & E had hired Mary Pfeiffer, a girl of fourteen, who appears to have been among the earliest to engage in full time work collecting spiders for silk to be used in scientific instruments. She was still employed in this endeavor in 1941, collecting an average of more than 2000 feet of spider silk each year, obtained from spiders of only two species, the common garden variety *Epeira diademata and Zilla atrica* which she found in pig styes in nearby Secaucus, New Jersey.[29]

In 1972 John Webster Brown of St. Petersburg, Florida became worried that he might have to go out of business due to the loss of his black widow spider named "Mac," that had fallen prey to a hungry cricket. A stockbroker's representative, he worked part time making cross-hairs for surveying instruments. After weeks of searching failed to bring to light a single black widow spider in his vicinity, an article reporting his loss appeared in the local press, and suddenly he was inundated with telephone and mail offers of black widow spiders, addressed simply to "The Spider Man."[30]

Charles M. Dilger, service manager of North American Survey Supply Company in Philadelphia, which sells and repairs surveying instruments and also sells spider silk, stated in an interview in 1984 that the silk of black widow spiders was the finest for making cross-hairs. *"Their web provides the best combination of strength and thinness. If a Black Widow can't be found, we will turn to a Brown Barn or Golden Garden spider."* He added that in his firm they separated the strands and used only one



Double silk reel

for a cross-hair. *"In installing a thread of the silk it is placed and then weights are added at both ends. It is then blown upon, and the moisture of the breath will cause the weights to stretch the silk tight. He finds black widow spiders in the woods in a rotting tree stump or under a log."*[31]

Within the past decade and more, a specific type of spider silk that has become popular to use for making cross-hairs is "dragline silk"–the thread that spiders use to create the scaffolding of their webs, and the thread from which they hang. It is one of the toughest materials that is known, both strong and extensible; it can stretch by 40% of its length and absorb a hundred times as much energy without breaking as steel. The dragline silk from the golden orb weaver *Nephila clavipes* is reported to have been especially successful.

Today spider silk is attracting the attention of a wide range of researchers. Geneticists, materials scientists and protein biochemists are among those at work understanding and replicating the unusual properties of spider silk, working out the precise chemical structures of silk proteins. Spider silks have been named according to their macroscopic functions, such as "bridgeline silk" that consists of the first strand on which an entire web is constructed. "Trapline silk" extends from the web's center and vibrates to inform the spider that a prey has made contact. "Dragline silk" makes up the spokes of the web and always extends from the spider to the web. The "dragline silk" of the golden orb weaver, *Nephila clavipes*, a species that is found from Florida to southern Brazil, has been the focus of much research and is known to consist of two types of major ampullate proteins. Orb-weaving spiders form about one-fourth of all spider species and their genes that are responsible for producing dragline silk have remained essentially unchanged through 125 million years of evolution, according to Dr. Randy Lewis, professor of molecular biology at the University of Wyoming at Laramie. Also engaged is spider silk research is Dr. Lynn Jelinski, professor of engineering at Cornell University in Ithaca, New York.[32]

In 2002 a team combined of scientists from the U.S. Army and a Canadian biotech company finally solved the mystery of how to make spider silk without spiders. The research was developed by Nexia Biotechnologies based in Montreal and by the U.S. Army Soldier and Biological Chemical Command. They extracted silk-making genes from two orb-weaving spiders and implanted them in cells from a cow's udder and a hamster's kidney. The cultured cells secreted a water-soluble protein "soup" that was squeezed through a syringe-like aperture to create a crystalline silk filament like the fiber a spider used to rappel from the ceiling or to make the spokes of its web.

In order to produce the protein in sufficiently large batches, the genes have been implanted in the eggs of nanny goats in order that female offspring will secrete the protein in their udders, stated Dr. Jeffrey Turner, geneticist and president and chief executive of Nexia, so that all one has to do is milk the goats. Since then the daughters of the original pair have become pregnant with their own offspring and the enlarged herd is expected to produce useable quantities of spider silk yard.[33]

Turner explained that spider silk had evolved through 400 million years and that it had the strength of at least five times stronger by weight than steel, with considerable toughness and elasticity. This is a combination of properties not matched by any known synthetic fiber. He added that strands of spider silk, only 3 microns thick, are triple the toughness of DuPont's bulletproof Kevlar and it is claimed that a woven cable as thick as one's thumb is capable of bearing the weight of a jumbo jet. Among the uses anticipated for the silk are artificial ligaments, featherweight ballistic vests, and medical sutures. Turner stated that Nexias's aim is to strengthen the man-made silk sufficiently to make it useful for body armor. It already has sufficient strength to be used for making soluble sutures for delicate surgery or as biodegradable fishing line.[34]

The manufacture of large proteins was a challenge that the Canadian scientists overcame by using a shortened version of one of the two genes for "dragline silk" and inserted it into hamster and bovine cells, both of which are capable of releasing high quantities of proteins. After a quantity of the silk proteins had been manufactured and collected, the material was sent to microbiologist Dr. Steven Arcidiacono of the U.S. Army Soldier Biological Chemical Command in Natick, Massachusetts.

Prepared cross-hairs from Ketteringham collection

Researchers there had developed a "spinning" technique, by means of which the proteins were placed in a syringe and squeezed through a tiny tube which forced the proteins into the shape of a silk fiber, about 10 to 40 microns in diameter.[35]

In a military facility described as a mothballed Air Force base in Plattsburgh, New York and housed within a concrete bunker protected from intruders by security guards and razor wire, are two Nigerian dwarf goats highly prized by the U.S. military named Millie and Muscade. Born early in 2001, their 70,000 gene chromosomes have been manipulated to include a gene from the orb weaver that weaves the world's toughest material. By injecting the orb weaver gene into the father of Millie and Muscade, Nexia bred female goats whose mammary glands are capable of producing the complex proteins of which spider silk consists. The spider's silk is being "grown" inside the mammary glands of Millie and Muscade. Their milk has the appearance and taste of the real thing but once the proteins are filtered and purified into a fine white powder, they can be spun into tough thread.

Turner's inspiration came in 1992, while teaching at McGill University in Montreal. There he learned that scientists had isolated three spider genes that code for silk proteins. *"It was a purely serendipitous find,"* he stated. *"The silk gland of spiders and the milk gland of goats are almost identical, and teats equal spinnerets."*

With two million dollars in venture capital, in the next year he founded Nexia, beginning with mouse embryos and graduated to goats because their large mammary glands were known to be better milk machines. The Nigerian dwarf goats proved to be the perfect candidates since they began breeding and lactating at just 13 weeks. Nexia quickly expanded the herd by flying 130 goats from New Zealand to its installation at Plattsburgh. Although spider silk was two years away, Nexia's recent public offering raised $27 million. Turner's goats may run dry if the spider silk hits it big, so the question arises, what will be next in expansion plans?[36]

(A complete list of references for the footnotes in this article can be found on our website at www.theamericansurveyor.com. Special thanks to Steven Turner, Museum Specialist with the National Museum of American History, Smithsonian Institution, for his assistance in obtaining the Ketteringham Collection photographs.)

Silvio Bedini is a Historian Emeritus of the Smithsonian Institution. He is the author of more than 300 articles and monographs published in scholarly periodicals, and is presently completing his 23rd book.

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