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Forensic Botany: Trichome Evidence

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ABSTRACT: Stellate trichomes (epidermal, star-shaped plant hairs) recovered from the stored wreckage of an aircraft's engine were used as a basis for arguing that faulty engine design led to the plane's crash near Ruidoso, New Mexico. Light and scanning electron microscope analyses of the trichomes recovered from the engine wreckage and other associated debris, when compared with trichome samples taken from the nightshade (Solanaceae) and cotton (Malvaceae) families about the storage site and elsewhere, provided positive identification of the trichome source. These data, when interpreted in relation to basic ecological and plant life cycle information, confirmed that the trichome presence was the result of post-crash rather than pre-crash events.

KEYWORDS: forensic science, December 1989 Ruidoso NM plane crash, forensic botany, trichomes, aircraft accident, Malvaceae, Solanaceae, *Sphaeralcea, Solanum*

The suit, Fish vs. Beech Aircraft Corporation (1), from which this report is drawn, was based on a premise that included the following elements: a twin-engine Beechcraft, flying in December snow squalls above the mountains near Ruidoso, New Mexico, drew plant materials, specifically stellate trichomes, i.e., star-shaped epidermal hairs, into tubes of the air compressor system of at least one of the two turboprop engines, where despite the great internal air pressure, the trichomes lodged, in mass, causing the engine to shut down and the plane to crash.

In evaluating the reasonableness of the foregoing premise, as it relates to trichomes, three issues required resolution. The first was to identify the trichomes recovered from the aircraft's engines. The second was to determine the source of the trichomes. The third was to evaluate the assumptions that presumably were made in order to give the trichomes such a profound role in the plane's crash. Consideration of these issues, which constitutes the main body of this report, is predicated on having a basic understanding of the nature of plant trichomes and of the general ecology of the region east of Ruidoso, New Mexico, an area of Lincoln County that encompasses both the crash site east of Hulbert Spring and the Sierra Blanca Regional Airport where the aircraft's wreckage was stored.

Materials and Methods

The trichomes and associated materials that were the focus of contention in Fish vs. Beech Aircraft Corporation were obtained from within and about the storage yard of the Sierra Blanca Regional Airport (Fig. 1), which lies on the Fort Stanton Mesa some 3 km south of Fort Stanton and 23 km northeast of Ruidoso, New Mexico.

The Sierra Blanca site provided samples of four kinds. First were the samples taken from within various air compressor and fuel lines of the engines of the Beechcraft's wreckage, including that labeled the "B2" elbow, a fitting from the air compressor system (Fig(s). 2 and 3). These samples were composed of stellate trichomes, plant cells, an amorphous gummy substance, and, in some instances, pollen and/or insect remains. Second were the samples obtained from tubes and fittings of non-aircraft equipment, which were held in the storage yard with the Beechcraft's wreckage. The composition of these samples consisted of the same kinds of items as those taken from the Beechcraft's engine components. Third were the samples of soil debris adhering to the outside of the Beechcraft's engines. They contained a variety of manufactured microelements, apparently from the Beechcraft's wreckage, soil particles, and occasionally stellate trichomes felted into masses. The fourth sample was not physical, but rather a census of the plant species occurring in and about the storage yard. It included an inventory of common plant species made by one of us (Lee) and other observations and collections subsequently made by him and others at the site.

In addition to materials collected at the Sierra Blanca site, authenticated specimens of the plant genera *Solanum* and *Sphaeralcea,* held in the herbaria of the L. H. Bailey Hortorium, Cornell University, Ithaca, New York, and the Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, Connecticut, provided samples of trichomes against which those taken from about the storage area were compared.

Selections made from the samples taken at the Sierra Blanca

FIG. 1—*Storage yard at the Sierra Blanca Regional Airport.* Sphaeralcea coccinea *occurs with other plant species in the foreground and about the fenced storage yard.*

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site and from herbarium specimens were examined in February and April, 1992, at the SEAL Laboratories, Los Angeles, California, using a dissecting microscope and a compound light microscope. From these selections, a subset of materials was chosen for analysis with a scanning electron microscope (SEM), also at the SEAL facility. Other selections were used in a sequence of experiments, again at the SEAL facility, designed to determine the temperatures at which trichomes would char. Supportive examinations of herbarium materials were also undertaken at Cornell University and the University of Connecticut, with the latter also the site of one series of SEM-based studies.

Floristic and ecological understanding of the Sierra Blanca Regional Airport and the actual crash site, which lies about 19 km east of the Airport and about 1.5 km east of Hulbert Spring, were confirmed through a visit to both sites on May 19 and 20, 1992, from Lee's studies cited above, from standard floristic and weed references (2–4), and from access to an unpublished list of plant species noted at the crash site by Dr. Randall J. Bayer, University of Alberta, Edmonton, Alberta, who was serving as a consultant to the plaintiffs.

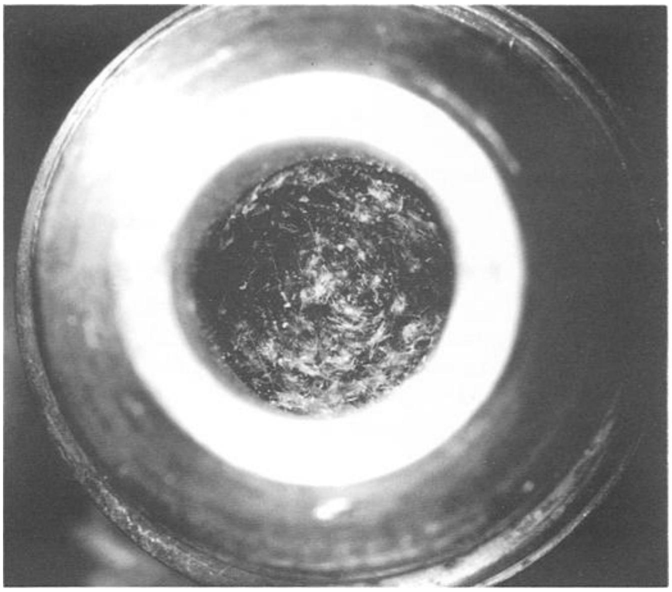

FIG. 2—*Elbow (B2) from the Beechcraft's engine air compressor system, viewed from above, showing the mass of stellate trichomes imbedded in an amorphous matrix within the orifice.*

Ecological Setting and Relevant Plant Species

The Sierra Blanca Regional Airport and the Hulbert Spring crash site are situated in central New Mexico, bordered to the west by Sierra Blanca, a peak of some 3,658 m elevation, and to the north and northeast by the Capitan Mountains, where El Capitan reaches 3,073 m elevation. Below the mountains the land is a high plain, generally in excess of 1,830 m elevation, cut by deep canyons and arroyos. This region is characterized by cool winters with a mean minimum temperature below freezing and warm summers with a mean maximum temperature of about 30°C. The average frost free period is about 160 days. Precipitation is about 350 mm annually, with most rainfall occurring from June through September in convectional, often highly localized storms. Vegetational response parallels this pattern, with dormancy through the winter months, followed by a modest burst of late spring growth and flowering. Summer growth and flowering reflect, in part, the variations in the water availability, a phenomena which also influences diminishing vegetational activity in the fall.

The vegetation about the airport and the crash site is of mixed affinities—many elements are westward extensions of the Great Plains flora; other elements have a southerly, Chihuahuan Desert relationship; whereas still others are typical floristic elements of the Great Basin and Rocky Mountains. Adding complexity are a number of weedy, introduced species, such as the yellow sweet clover, *Melilotus officinalis* (Linnaeus) Pallas, the Russian thistle, *Salsola iberica* Sennen, and the summer cypress or kochia, *Kochia scoparia* (Linnaeus) Schrader., all of which are of Eurasian origin. The Great Plains influence is evident in such grasses as blue grama, *Bouteloua gracilis* (Kunth) Griffiths, hairy grama, *Bouteloua hirsuta* Lagasca, and creeping muhly, *Muhlenbergia repens* (Presl) Hitchcock., and various forbs, including the silverleaf nightshade, *Solanum elaeagnifolium* Cavanilles, and the prairie or scarlet globe mallow, *Sphaeralcea coccinea* (Pursh) Rydberg (Fig. 4). The latter two species are focal points of this trichome-based study, as is the widespread, weedy, narrowleaf globe mallow, *Sphaeralcea angustifolia* (Cavanilles) G. Don. Among common western elements are the pinyon pine, *Pinus edulis* Engelmann, and the one-seeded juniper, *Juniperus monosperma* (Englemann) Sargent.

Observations made during the May visit to the Sierra Blanca Regional Airport revealed young shoots of the perennial *Solanum elaeagnifolium* both within the fenced storage yard and the vegetation adjacent to it. Of greater significance, at least in retrospect, was the abundance of the *Sphaeralcea coccinea* throughout the area surrounding the storage site. This low-growing perennial had just begun its blooming period and was made obvious by its magenta-orange corollas. *Sphaeralcea angustifolia,* notable in its erect, wandlike branches, while not present about the storage area, was relatively common along the road edges about 0.3 km to the east, where it occurs in disturbed soil interspersed with *S. coccinea.*

The appearance of *Sphaeralcea* in vicinity of the storage area may well be attributed to the fact that the plants, which experience has shown are palatable to livestock and often heavily grazed, were protected by fencing from livestock. In contrast, the crash site is unprotected from livestock and lies within an area that is grazed. Here the state of vegetation was comparable to that found

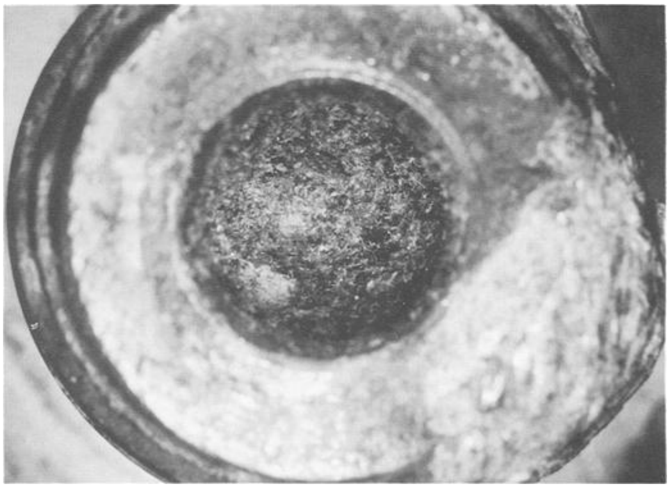

FIG. 3—*Fitting (23A) from the Beechcraft's engine fuel line, viewed from above, showing the mass of stellate trichomes and an amorphous matrix within the orifice, and melted aluminum residue at the face (lower right).*

in grazed areas in the vicinity of the storage area, with no evidence of either *S. coccinea* or *S. angustifolia.*

A third species of *Sphaeralcea, S. leptophylla* (A. Gray) Rydberg, which has been recorded from Fort Stanton region (2), was not observed, nor were any of the other five widely distributed species of the genus that have been attributed to Lincoln County, New Mexico (3).

Trichomes as Characters and Evidence

Defined narrowly, plant trichomes are outgrowths of the epidermis. In the more general sense, however, the term trichome also encompasses emergences, which are of both epidermal and subepidermal origin. The distinction is difficult to make without anatomical study and is not of concern in this paper.

Trichomes, considered through the plant kingdom as a whole, are of remarkably diverse morphology and structure (5). They may be unicellular or multicellular, unbranched or branched, scalelike to dendritic, or secretory or non-secretory, among other character expressions. The intrinsic features of trichomes, as well as variation in their form and distribution on individual plants, add to seemingly infinite variety. Yet, in this variety there is evident and consistent patterning, which may be exploited in a systematic way. Particular trichome types, for example, may characterize a given plant family or group of families, a genus or group of genera, or a species or group of species. When distinctive and constant, trichomes can be diagnostic and characteristic of a taxon (taxa, plural., a word used for any taxonomic group or entity) at most levels of classification.

Stellate trichomes, which are of interest in this study and which serve to demonstrate the usefulness and limitations of trichomes as evidence, are those with rays or arms that radiate from a central point. This kind of trichome is found in some 80 plant families and not unexpectedly encompasses many variants on the common theme (5). The rays, for example, vary in number, orientation, length, and degree of fineness, among other characters, and the trichome itself may range from sessile, i.e., with the rays seemingly arising from the surface bearing them, to stalked or stipitate, i.e., with the point of radiation borne above the surface.

FIG. 4—Sphaeralcea coccinea, *flowering branch. From a plant growing in proximity to the storage yard of the Sierra Blanca Regional Airport.*

The plant family Malvaceae, to which *Sphaeralcea* belongs, is among those families characterized by stellate trichomes. On this basis alone, it can be distinguished as a family from all those lacking such trichomes. Furthermore, among families with stellate trichomes, the Malvaceae can be distinguished from some by the character of the trichomes themselves. For example, while the stellate trichomes of Malvaceae are composed of many cells, those of the family Brassicaceae (Mustard Family) are remarkable in being composed of a single branching cell, the complexity of which is well illustrated in the genus *Lesquerella* (6). In still other instances, the general form and structure of malvaceous trichomes are duplicated in taxa of other families and in such cases are not of a definitive nature. This fact alone serves to emphasize that although the identification of the taxon to which a particular type of stellate trichome belongs ultimately depends on the characteristics of the trichome, itself, placing the trichome in a broader context also has relevance in determining its identity. Broader context is found in knowledge of the phylogenetic relationships of taxa, the diversity and variation of trichomes in relation to other morphological characters, and the eco-geographical distributions of relevant taxa.

A truly comprehensive survey of trichomes in the Malvaceae has not been published; however, studies dealing with ontogeny, structure, and classification have appeared (7,8) and a number of generic monographs have considered trichome types and their relationships within genera (9–11). These publications provide a reasonable understanding of trichomes in the family. Similarly, the trichomes of *Sphaeralcea,* a genus that includes about 50 species in North and South America (12,13), have not been fully catalogued, but their character and variation patterns are adequately understood (12) and are in accord with those observed in other malvaceous genera.

The two species of *Sphaeralcea* that have been placed in the immediate vicinity of the Sierra Blanca Regional Airport, i.e., *S. coccinea* and *S. angustifolia,* can be consistently distinguished from each other by differences in their stellate trichomes. In *S. coccinea* the rays of the trichomes are joined only at the base and are borne in a flat whorl, extending outward from a raised, rounded, somewhat fluted central protuberance (Fig. 5). Figures 6 and 7 show two expressions of this central protuberance, with that of Fig. 7 showing extreme reduction. In contrast, the rays of the trichomes of *S. angustifolia* are borne in a star burst fashion, ranging from horizontal to perpendicular to the surface on which the trichome is borne (Fig. 8). There is no defined central protuberance. The third species of *Sphaeralcea, S. leptophylla,* which has been reported in the general region of the airport (2), bears scale-like trichomes. In this species the rays form a flat whorl, but unlike *S. coccinea,* they are united, with rare exceptions, one-fourth or more of their length, to create more or less fringed scales.

The remaining species whose trichomes are of issue in this case, *Solanum elaeagnifolium,* is distinctive in its trichomes, relative to the three species of *Sphaeralcea.* In *Solanum eleaegnifolium* the stellate trichomes consist of a ring of rays in a flat whorl, surmounted at the center by a single erect ray (Fig. 9). This condition

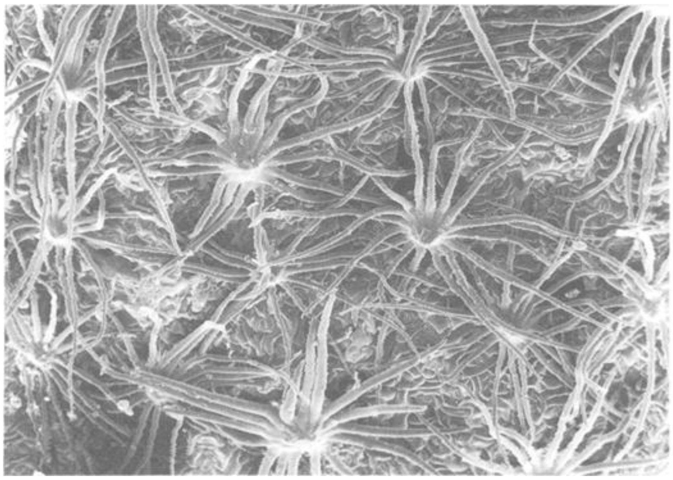

FIG. 5—*Scanning electron micrograph of trichomes from an upper leaf surface of* Sphaeralcea coccinea *(From Bates and Blanchard 2292 BH) (SEAL 4011).*

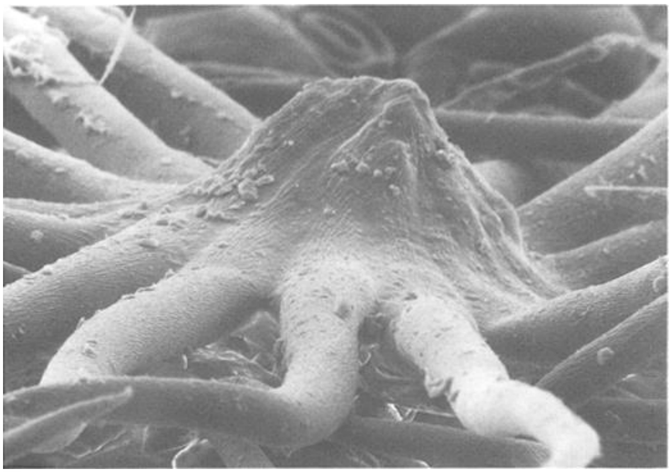

FIG. 6—*Scanning electron micrograph of the central region of a trichome of* Sphaeralcea coccinea *(From Bates and Blanchard 2292 BH) (SEAL 4012).*

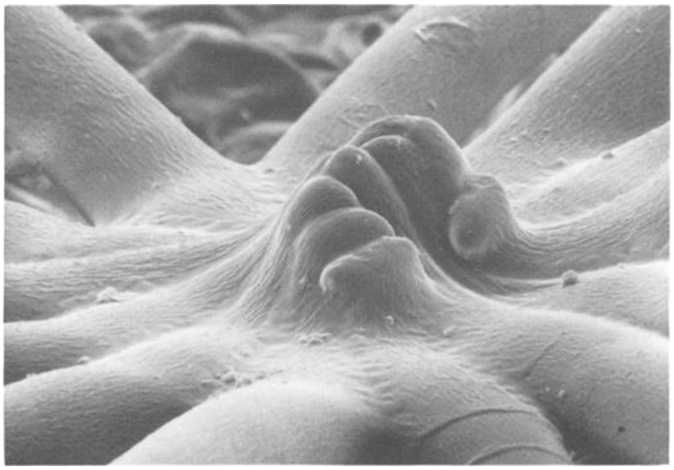

FIG. 7—*Scanning electron micrograph of the central region of a trichome of* Sphaeralcea coccinea *(From Bates and Blanchard 2296 BH) (SEAL 4022).*

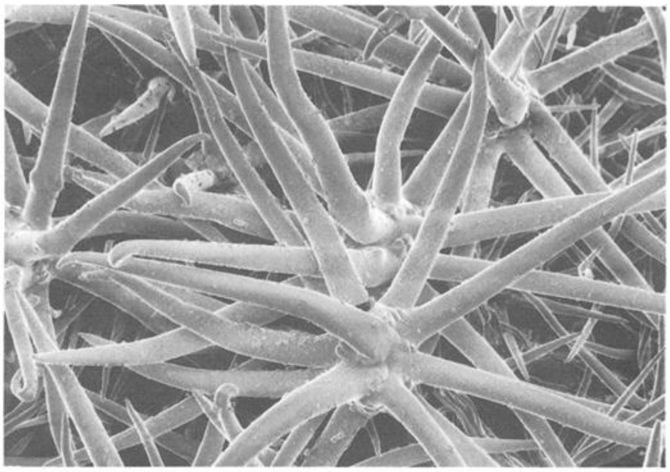

FIG. 8—*Scanning electron micrograph of trichomes of* Sphaeralcea angustifolia *obtained from plants growing to the east of the storage area of the Sierra Blanca Regional Airport (SEAL 3172).*

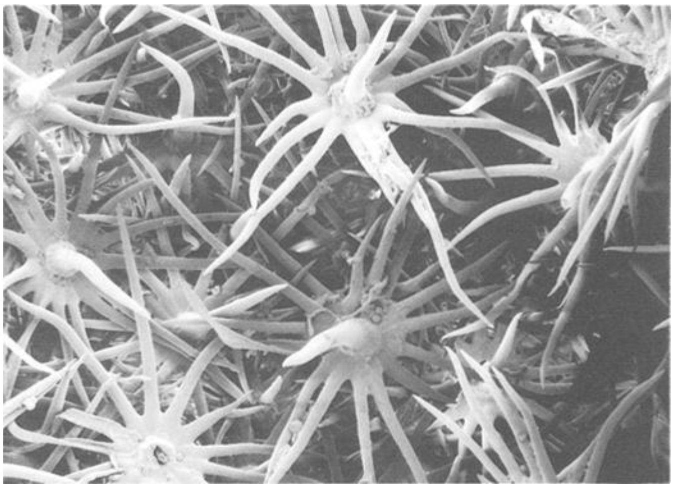

FIG. 9—*Scanning electron micrograph of trichomes of* Solanum elaeagnifolium *obtained from plants growing in proximity to the storage area of the Sierra Blanca Regional Airport (SEAL 3176).*

is known as porrect and is commonly found in the family Solanaceae (14).

Results

The pieces of evidence relevant to this case were brought together in February of 1992 at the SEAL Laboratories where with others of the defense's and the plaintiff's legal and expert entourage, two of us (Bates and Lee) viewed an array of tubes, fittings, and debris, which had been gathered from the storage yard at the Sierra Blanca Regional Airport. This evidence is considered here in two contexts: First are the samples of soil and debris adhering to the outside of the wreckage of the Beechcraft's engines; and second are the samples obtained from within various air compressor and fuel lines of the engines and from tubes and fitting of non-aircraft equipment.

External Deposits

Samples adhering to the external surfaces of the turboprop engines, where the engines were in contact with the ground, contained a mix of soil and a variety of microelements, including bits of metal and mineral fibers, which may have come from the engines themselves. Within one of these samples (22C), a felted mass of stellate trichomes was found (Fig. 10).

The massed hairs included no other plant tissues, i.e., they occurred as amalgamations of single stellate trichomes, which were contaminated with fine soil particles. Scanning electron microscope comparisons of these massed hairs with those taken from collections of *Solanum elaeagnifolium* made at the storage site (Fig. 9) demonstrated that the massed hairs were identical to those of that species.

Internal Deposits

Although the deposits of materials within a number of tubes and fittings were ultimately examined, initial and primary focus was on those from a turboprop air compressor fitting, which was designated as the B2 elbow. Visible below the male opening of the B2 elbow was a mass of mixed texture (Fig. 2) that initially was determined by the plaintiff's experts to include stellate trichomes, perhaps of the family Malvaceae or of the Solanaceae—a conclusion reinforced by the finding of masses of similar composition in other tubes and fittings. Because the mass in the B2 elbow was thought to be directly implicated in the crash, it had remained in place until the February meeting, when under controlled conditions, it was removed and the fragments were divided between the plaintiff's and the defense's attorneys.

The examined fragments removed from the B2 elbow consisted variously of three kinds of plant material. One fragment was composed of pollen, the character of which is considered by Lewis (15) and Graham (16), and an insect part, the identity of which, as a member of the bee genus *Ashmeadiella*, is reported on by Eickwort and Rozen (17). The remaining fragments consisted of stellate trichomes and cellular tissue that were imbedded, more or less, in what initially was described as an amorphous substance, but later was identified as a "sugary nectar" (18) (Fig. 11).

The stellate trichomes extracted from the B2 elbow are distinctive in two principal characters: 1) the rays are largely borne in a single radiating plane, although occasionally they may seem to form two somewhat superposed whorls, and 2) the rays come together centrally to form a rounded, more or less fluted central protuberance (Fig. 12). Variation seen in the number of arms, their length, and relative coarseness is consistent with variation recorded elsewhere in the Malvaceae (9). For example, the trichomes on the lower surface of the leaf are larger, possess a greater number of rays, and are distributed more densely than those on the upper leaf surface.

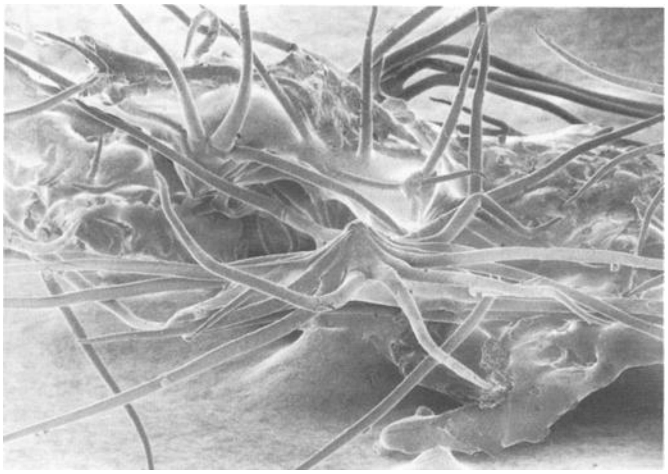

FIG. 11—*Scanning electron micrograph of trichomes of* Sphaeralcea coccinea *mixed with cellular material and an amorphous matrix recovered from the elbow (B2) of the Beechcraft's air compressor system (SEAL 3228).*

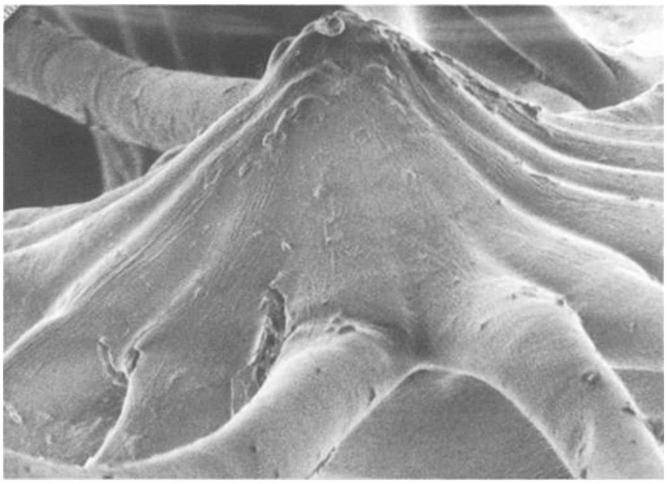

FIG. 12—*Scanning electron micrograph of the central region of a trichome of* Sphaeralcea coccinea *recovered from the elbow (B2) of the Beechcraft's air compressor line (SEAL 3229).*

FIG. 10—*Scanning electron micrograph of trichomes of* Solanum elaeagnifolium *recovered from an external surface of one of the Beechcraft's engines (22C) (SEAL 3256).*

Once characterized, the trichomes found in the B2 elbow were compared with those taken from herbarium samples of *Sphaeralcea coccinea* and *S. angustifolia*, some of which had been collected in the general region of the Sierra Blanca Regional Airport and the Hulbert Spring crash site, and which were available for analysis prior to the May visits to the Airport and crash sites. In this comparison, using dissecting, light, and scanning electron microscopes, the trichomes of the B2 elbow matched those of the *S. coccinea*, as shown in Fig(s). 5 and 6. There was no evidence of the trichomes of *S. angustifolia*, or of any other species, including *Solanum elaeagnifolium.*

Among the other fitting and tubes from which samples of trichomes and their associated matrix were recovered, two were notable. One was a fuel line from one of the Beechcraft's engines, labeled "23A" (Fig. 3); the other was a tube from a heater, which was in the storage yard but was not from the Beechcraft, labeled "H-CP". In both 23A (Fig(s). 3, 13, and 14) and H-CP (Fig(s). 15 and 16), as in all other tubes examined, the samples were of the same basic composition as those of the B2 elbow, and the trichomes matched those of *S. coccinea.*

Lastly, noting that several of the aircraft's fittings, including 23A, showed residue of melted aluminum, indicating temperatures in excess of 593°C at the time of the crash, trichomes of *S. coccinea* were heated to temperatures of 93°C, 204°C, and 315°C for periods of one-half hour. At the highest temperature, the trichomes became distorted, charred, and brittle, indicating that they could not have survived the temperatures of the crash, if they had been present prior to it.

Discussion and Conclusions

The trichomes of *Solanum elaeagnifolium* recovered from the debris adhering to the external parts of the Beechcraft's engine were of passing interest, but proved not to occur in the B2 elbow or in any tube or fitting recovered from the storage site. Rather, it was concluded that these trichomes collected on and in the surface layers of the ground as the tissues which bore them senesced and disintegrated over time. With rainfall and subsequent puddling they adhered to the external engine parts together with soil and other debris, as might be expected if dried, fragmented plant materials had simply washed together and had massed against the engine and in depressions in the earth about it. These events occurred during the summer or fall of 1991 after the engines had been placed in airport storage in May of that year.

The presence of stellate trichomes of *Sphaeralcea coccinea* in lines of both the air compressor system and the fuel system of the Beechcraft's engines and in items unrelated to the aircraft, as well as a demonstration that the trichomes could not have survived the heat present at the time of the crash, are sufficient in themselves to negate the premise that airborne trichomes were cause of the crash. In other words, simple awareness of the varied occurrence of the trichomes and of their vulnerability to heat confirmed that

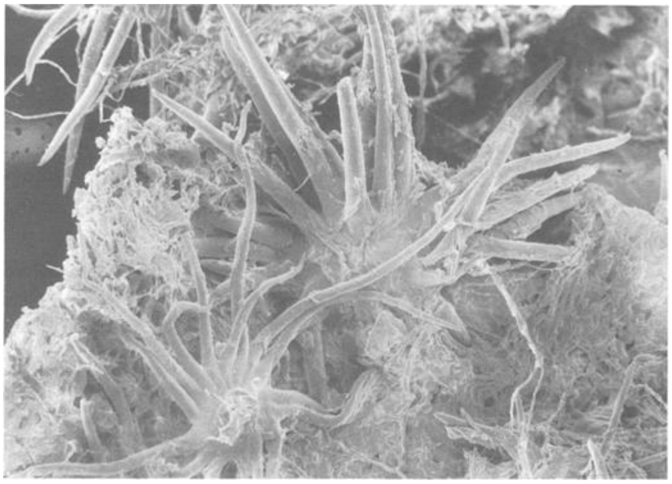

FIG. 13—*Scanning electron micrograph of trichomes of* Sphaeralcea coccinea *mixed with cellular material recovered from the fitting (23A) of the Beechcraft's fuel line (SEAL 4087).*

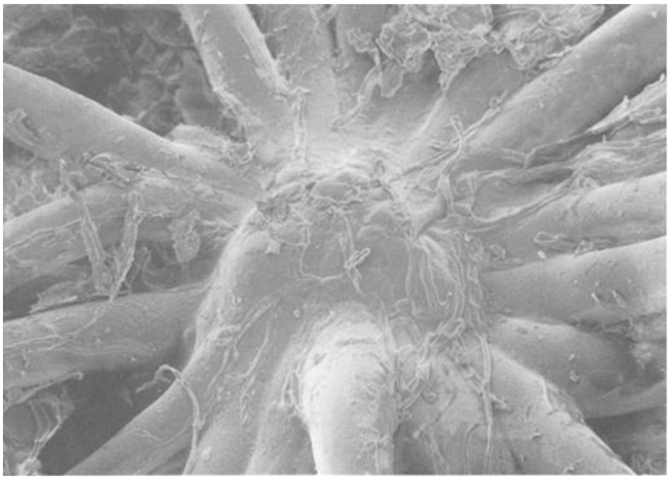

FIG. 14—*Scanning electron micrograph of the central region of a trichome of* Sphaeralcea coccinea *recovered from the fitting (23A) the Beechcraft's fuel line (SEAL 4088).*

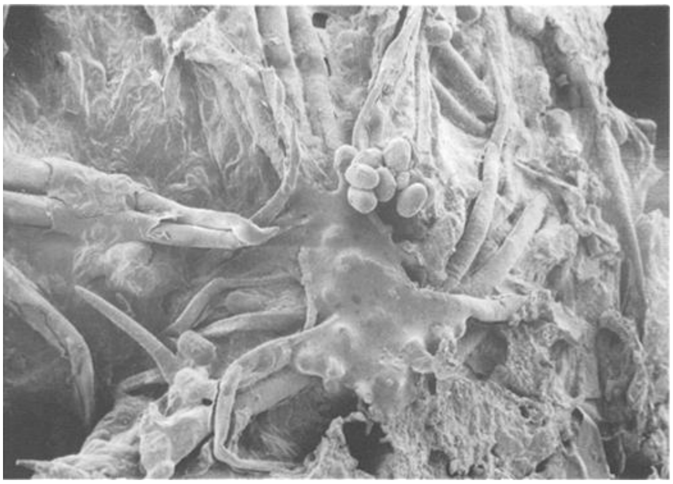

FIG. 15—*Scanning electron micrograph of trichomes of* Sphaeralcea coccinea *mixed with cellular material, an amorphous matrix, and pollen of* Melilotus officinalis *recovered from a non-aircraft heater tube (H-CP) (SEAL 4091).*

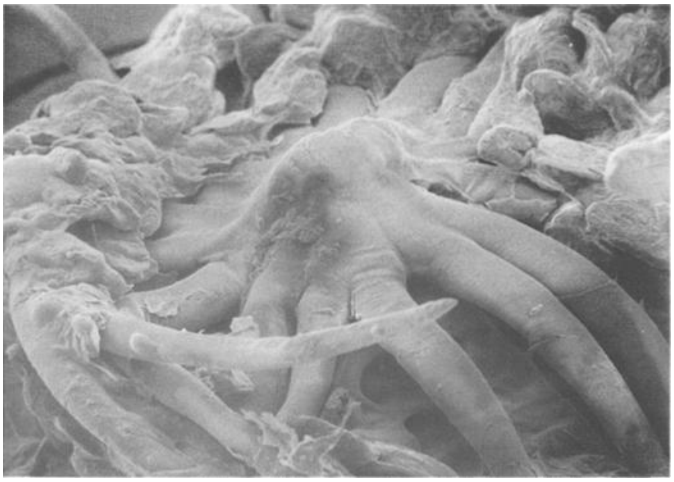

FIG. 16—*Scanning electron micrograph of the central region of a trichome of* Sphaeralcea coccinea *recovered from a non-aircraft heater tube (H-CP)(SEAL 4094).*

the trichomes owed their presence to post-crash events. There is simply no plausible way that airborne trichomes could have entered and lodged in the engine's air compressor lines and the fuel lines at the same time, or have been drawn into stored, non-aircraft equipment in the same manner.

All other evidence evaluated during the course of the investigation confirms the conclusion and provides a full explanation of the presence of plant trichomes in the B2 elbow and elsewhere—both in the Beechcraft's engine and in the non-aircraft equipment. The presence of trichomes with associated cellular materials, sugary nectar, and, in some instances, pollen from different species and immature bees, in various tubes and fittings, resulted from the nest building activities of bees, active during the late spring and summer, when the relevant plants were in leaf and in flower. Arguments specific to this point have been developed for the presence of pollen (15,16), bees (17) and sugary nectar (18).

The trichomes, themselves, were determined to be of a single type. They matched those of *Sphaeralcea coccinea,* a species which occurs commonly in the vicinity of the Sierra Blanca Regional Airport storage yard. It was assumed that all the cellular material associated with the trichomes was also from *S. coccinea,* but even if it was not, it logically may be attributed to the bee nest building explanation.

When placed in the broader ecological context of the region about the Sierra Blanca Regional Airport and the Hulbert Spring crash site, the evidence contradicts the premise that airborne trichomes were ultimately responsible for the crash of the aircraft. While common in protected areas about the Airport, *Sphaeralcea coccinea* is not common through the flora as a whole. The assumption that trichomes of this species could either accumulate or become airborne in sufficient quantities to present a hazard is indefensible. But even if such trichomes could become airborne, the collective presence of cellular matter, pollen, sugary nectar, and developing bees in various tubes and fitting make such an explanation impossible without assuming the airborne nature of each of these elements in uniform, massive fashion to the exclusion of all other biotic elements. Such assumptions become even more fanciful if events are placed in December when the vegetation and associated insect life of the region are dormant.

The evidence, however it is evaluated, whether directly on the characters of the trichomes themselves or in the context in which they exist, is unequivocal. The trichomes owe the presence to post-crash, not pre-crash events.

Acknowledgment

We wish to thank the personnel of SEAL Laboratories for their help in making the SEM micrographs.

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