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Spacesuits: NASA's Dream — Conservator's Nightmare

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Abstract

Human spaceflight was a pivotal achievement in U.S. history, and the spacesuits used are testimony to the technological advances involved in reaching this goal. Unfortunately, the materials in these suits are deteriorating rapidly, endangering the only records of some stages of the space race technology. Some materials, such as certain neoprene/natural rubber blends, are degrading due to poor manufacturing techniques necessitated by the accelerated pace of the space program. Other materials, such as plasticized PVC tubing, pose a threat to the rest of the artifact. Still others are deteriorating due to conditions to which they were exposed by the National Aeronautics and Space Administration (NASA) testing and use. Present methods of display and storage of these artifacts are not sufficient to delay the degradation process and, in many cases, are accelerating it.

Treatment and storage decisions for these objects are not simple, as the suits contain a variety of materials, including metals, synthetic and natural textiles, synthetic and natural plastics, rubber and adhesives, as well as paints and varnishes; clearly, an interdisciplinary approach to their conservation is needed.

This paper will discuss the results of testing some proposed storage conditions for these materials, which were designed with large collections and low budgets in mind. Recent research on the acceleration of aging in some materials by the conditions encountered in NASA's use and testing of the suits will be reviewed. In addition, treatment considerations, with a focus on the treatments currently used on the suits, will be discussed.

Introduction

Modern materials show up in virtually every museum. However, air and space museums, unlike traditional museums, primarily collect artifacts of relatively recent manufacture. Despite the advances made in materials engineering and processing since the dawn of the space age, there is much to be learned, especially with regard to how such materials will age. Spacesuits are an example of a product of the space age, made of materials that held up to extreme conditions, that are now endangered by very ordinary environments.

It cannot be assumed that new objects and new materials require less care than the more traditional museum objects. At this time, unfortunately, it is suspected that the Smithsonian's National Air and Space Museum (NASM) may be losing some historically significant space artifacts because of a casual approach to modern materials and objects of recent manufacture. Although, for example, Apollo spacesuits worn during the first lunar mission compare in significance to the Wright Flyer, they received far less attention and storage care. It became apparent that storage, display and treatment guidelines were needed if the suits were going to survive for future generations.

Spacesuit Acquisitions*

On March 3, 1967, the National Aeronautics and Space Administration (NASA) and the National Air and Space Museum created an agreement. Called "Agreement between the NASA and the Smithsonian Institution concerning custody and management of NASA historical artifacts," it is registered under NASA Management Instruction 1052.85. The National Air and Space Museum was essentially given first refusal on space hardware and equipment that was retired from active service.

In 1968, the spacesuit worn by Project Mercury astronaut Alan Shepard was acquired by NASM; it was the first spacesuit of the collection. Between 1968 and 1976, many more suits were acquired due to increased activity in human spaceflight programs and the race to the moon. There was no collections rationale or preservation planning for the new space age acquisitions. Many of the suits that were collected by NASM were placed on loan to other museums, and in some instances back to NASA for exhibit in their visitor centers.

Prior to 1975, spacesuits not on exhibit or loan were stored in a warehouse in the Georgetown section of Washington, D.C. They were packed in boxes or suitcases. In 1975 the spacesuits were relocated to the Garber Facility, where they were hung on hangers and placed in tall, cedar-lined cases. It is not known whether the cedar-lined cases were used because they were available, or because the cedar lining was considered to be a preservation measure. At that time, there were no storage buildings with museum quality environmental control at the Garber Facility. Many buildings were unheated.

One of the primary reasons for accepting suits was for exhibit; the spacesuits were treated as exhibit props. Back-up suits and training suits were collected for spare parts. No thought was given to exhibit conditions, such as light levels, temperature and relative humidity, or the length of time suits could be safely exhibited. The suits were stuffed with ill-fitting department store mannequins. Spacesuits were removed from exhibit when they began to "look bad." There were no investigations into why the changes in the suits were made. Some spacesuits were used in demonstrations and were considered to be expendable.

In the absence of a collections rationale, and a collections maintenance program, a rather interesting consensus developed regarding the significance of the various types of suits. Flown suits (suits that were actually worn by astronauts on space missions) were considered to be historically significant and therefore worthy of preservation. Unflown suits (suits worn in training or intended as back-up suits) were much less significant, and were considered to be expendable. The perceived categories of significance provided a convenient excuse for tolerating poor storage conditions and consumptive use, and scavenging for spare parts.

Spacesuit Development**

Long before the space program was a reality, suits were being designed to keep humans alive in low pressure environments. Early achievements were made in the early 1930s, when altitude records were being made and broken by balloonists and pilots. During the 1930s and 1940s, pressure suits were developed for short-term emergency use by jet pilots. None were very mobile when used in low pressure, nor were they comfortable. In the early 1950s the U.S. Air Force set out to fulfill a requirement that a pressure suit be developed for pilots of the B-52 plane. The suit had to be comfortable enough to be used for many hours at a time and flexible enough to allow the pilot sufficient movement for flying. At the same time, the U.S. Navy was developing its own high altitude suit with similar requirements. Thus, in the early 1960s, when John F. Kennedy proclaimed the need for a space program that would eventually put a man on the moon, decades of research on spacesuit development had already been completed.

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* A more complete discussion of the acquisition and treatment philosophies has been given by Baker and McManus elsewhere.[1]

** There are few histories of spacesuit development; the most complete is that of Mallan.[2] Another helpful resource comes in the person of Lillian Kozloski at the Smithsonian Institution.[3]

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The suits for the first missions (Mercury) were modified Navy high-altitude suits with a ventilated undergarment developed by the Air Force. They consisted of a rubberized cloth suit that could be pressurized, an outer garment and a close-fitting helmet. They were very difficult to move in, especially when in use in a vacuum, but this was considered a minor problem, since the Mercury astronauts would complete their missions sitting in their capsules. The suit was mainly an emergency protection from accidental loss of pressure during the mission. The outer layer of the suits was an aluminized cloth, which, it was hoped, would protect the astronaut from radiation and extremes of heat during orbit and especially during atmosphere re-entry (Figure 1).

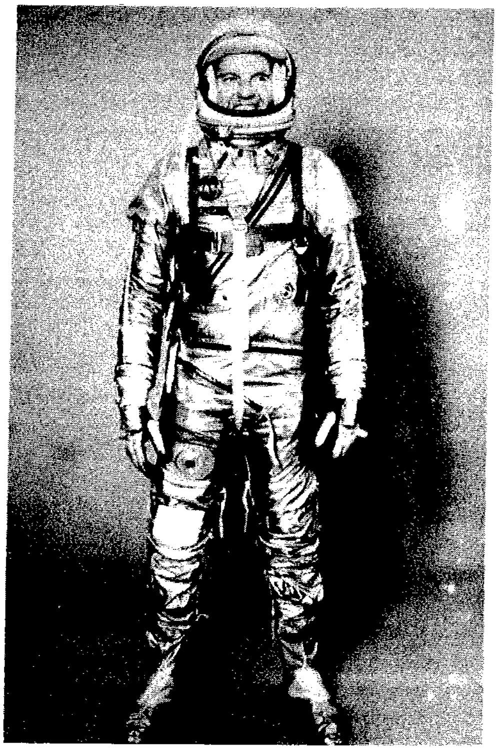

Figure 1 Mercury spacesuit, worn by L. Gordon Cooper. Notice the aluminized cloth exterior and foam padded helmet. Photo courtesy of NASA.

The next set of missions (Gemini) put a new demand on the suits. The astronaut needed to be able to perform work in the spacesuit inside and outside the capsule. Previously, attempts had been made to solve the problem of bending a suit that was inflated, but none of the designed systems were satisfactory. The inflated suits, like balloons, were very difficult to bend, causing near immobility of the astronaut. The solution for the Gemini suits was to use a similar rubber-coated fabric bladder to that used in the Mercury missions, which covered most of the astronaut like a loose wet suit. This bladder was restrained from expanding under pressure by a net (originally Dacron, later Teflon), which decreased the ballooning effect, but was still flexible, allowing bending of the joints. The aluminized outer garment used in Mercury was used only in the prototype Gemini suits; it was replaced by Nylon and Nomex outer layers and aluminized Mylar inner layers. The Gemini suits had increased abrasion resistance and mobility, and could be used for the first spacewalks (Figure 2).

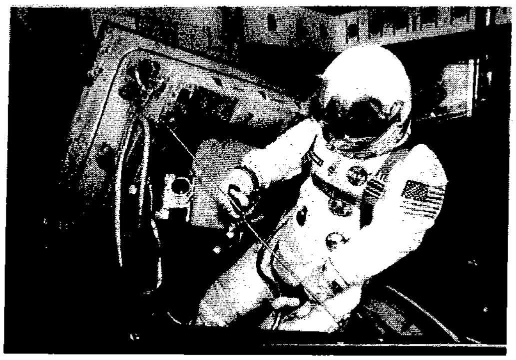

Figure 2 Gemini spacesuit, once worn by Edwin White, now on display in NASM. The outer layer is a facsimile, made by David Clark Company; the original was damaged by exhibit and has been retired. Photo by Virginia Pledger.

The Apollo missions were the culmination of the race to the moon; the suits needed not only to protect the astronaut on the surface of the moon, but also to allow travel far from the capsule or lunar lander. Modifications on the suits included improved helmet design and a liquid coolant garment (LCG) for temperature control. The LCG was a union suit with tubing running throughout; water flowed through the tubes, carrying away excess heat from the astronaut's body. The LCG was a great improvement over the Gemini method, which used air circulation for cooling. The improved helmet design eliminated the close-fitting foam cushion around the head that had been used in Mercury and Gemini helmets; this allowed for more mobility inside the helmet (Figure 3).

Figure 3 Apollo spacesuit.

Shuttle suits had added requirements, which included greater ease of donning and the capacity for reuse. The previous suits were made for one-time use only, and for a particular astronaut. Now, the suits were to be made in generic sizes, with, it was hoped, a long shelf life. The traditional zipper construction was abandoned for teflon seals, which were more flexible and allowed the astronauts to dress themselves and to dress in less time.

The above evolution of suits is a mere outline of all the changes that took place in spacesuits over the course of years. While the changes can be followed by examination of the flown suits, this does not tell the whole story. Many ideas and improvements were tested on prototype suits; some of these changes were adopted for the final suits, others were not. Some suits were of a completely different design, having been part of a contract bid from a new company. A collection of only the suits used on missions does not give a complete story of the inventiveness that went into suit design.

Research is required at this time to gather historic information about the design, construction and testing of spacesuits. Time is of the essence because some of the companies that were involved with spacesuit research and development no longer exist, and researchers who were involved are growing older. Research is also important to the understanding of the deterioration process. That information will enable us to develop better exhibit and storage techniques.

Research on the NASM Suits

The materials in the spacesuits that were showing the most degradation are the soft rubber pieces, such as gloves, boots, linings and gaskets, and the adhesive used to laminate the aluminized fabrics. The rubber parts were softening and flowing, then hardening irreversibly into distorted shapes. The adhesive used in laminating the aluminum to the fabric was becoming very brittle and flaking off, along with the aluminum. Other problems included the poly(vinyl chloride) tubing on the LCGs, which was starting to weep plasticizer; the foam inside the Mercury and Gemini helmets was hardening, and the textiles showed wear spots and discoloration.

The initial work on this project had centered around following the free radical population, in an attempt to determine if there were still reactive sites in the materials. This was a matter of concern since, in the presence of oxygen, free radicals cause oxidation and chain scission, but in the absence of oxygen, free radicals cause crosslinking, as has been discussed in more detail by Schnabel.[4] This information could be important in choosing an oxygen-free storage atmosphere. Electron Spin Resonance (ESR) had been used to show very high populations of free radicals in the glove materials, which were determined to be very stable; most likely they were the result of the antioxidant in the gloves having scavenged the radicals. Since these stable radicals are not likely to be a threat to the suit materials, other causes for their breakdown were investigated.

It was noted in a survey of the suits that many of the unflown suits were in much worse condition than the flown suits. Some of this difference was attributed to the respectful handling of the flown suits by NASA and NASM, yet some of the problems could not be explained by poor handling alone. Some background research showed that extensive artificial aging testing had been conducted on the natural rubber/neoprene blends as well as on the aluminizing adhesive, the results of which predicted that the materials should have fared better than they did, even after storage at high temperatures.

More background research revealed that most of the unflown suits were used in training the astronauts for space; some of this training included wearing the suits in a swimming pool to simulate maneuvering at low gravity. These pools were kept chlorinated; some sources recalled using calcium hypochlorite. (Such pools are still being used for the same purpose by the present manufacturer of space shuttle suits.[5])

Since hypochlorite is a strong oxidizer, it seemed likely that residues from the swimming pool tests could be accelerating the degradation of the spacesuit materials. Since natural rubber seemed to be the suit material that was suffering the most from aging, it was a logical choice for the first material tested. The natural rubber was cast on aluminum foil sheets from solution and allowed to dry. These films could then be monitored by Fourier Transform Infrared Spectroscopy (FTIR), using a microscope attachment in reflectance mode. The dried films were very irregular; they were examined under the microscope and the smoothest areas were chosen. These areas were marked with the tip of a disposable pipette, which coincidentally is the same size as the analysis area of the FTIR-microscope. (In-depth information on the FTIR-microscope theory and methods as they relate to conservation has been given by Baker, von Endt, Hopwood and Erhardt.[6]) With this mark as a guide, the microscope could be set to analyze the exact same spot each time; the spectra taken from such a spot on a given day would overlay perfectly with spectra taken from the same spot one week later.

Several natural rubber/aluminum foil sheets were dipped in simulated pool water, while others were dipped in plain distilled water. The oxidation of the samples was monitored hourly during artificial aging at 60°C, 70°C, 80°C and 90°C for various periods. The FTIR spectra were collected, and the absorbance of the carbonyl band was measured. The spectra showed the greatest difference between pool and distilled water at 90°C and no significant difference at 60°C (Figure 4).

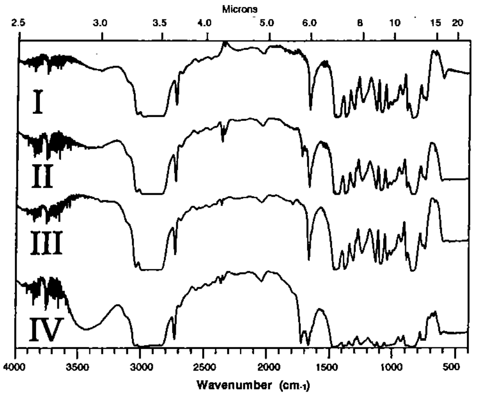

Figure 4 FTIR-microspectra of polyisoprene: (I) dipped in distilled water, unaged; (II) dipped in distilled water, aged at 80°C for 3.5 hours; (III) dipped in pool water, unaged; (IV) dipped in pool water, aged at 80°C for 3.5 hours. Note the peak at 1725 cm^{-1} is equal for the two unaged samples, but is much greater for the pool-dipped aged sample than the distilled-water aged sample, indicating greater oxidation at that point, due to the hypochlorite in the pool water. Also note the growth of the broad peak at around 3400 cm^{-1}, which suggests formation of peroxides.

While this is an interesting phenomenon, if the increased oxidation rate of the rubber chain is not causing a like increase in chain scission, then the mechanical properties of the rubber are unlikely to have been changed by the hypochlorite residue. In other words, the additional oxidation seen by the FTIR could be in the form of stable carbonyls on the rubber chain, and no extra chain scission would actually be happening. Molecular weight determinations would be necessary to monitor the chain scission, as well as any other molecular weight changes, such as crosslinking. These molecular weight changes were monitored by the use of a Size Exclusion Chromatograph (SEC), made up of a multi-angle laser light scattering detector

(MALLS) and ultrastyragel columns. The columns included a linear, mixed bed column, able to separate molecules by molecular size for a range of molecular weights from 500 to 20,000,000. An additional column, useful for low molecular weight molecules, was added to increase the sensitivity on the low end of this range.

The pool-treated and distilled water-treated rubber samples were analyzed by the SEC-MALLS set-up and the results indicated a difference in the molecular weight distribution between the distilled water- and pool-treated rubber samples. Not all of the samples have been analyzed to date, so there are no correlations that can be made with time or temperature, as yet.

Conclusion

These experiments show that exposure to calcium hypochlorite will accelerate the oxidation of rubber, apparently both by decreasing the induction time and increasing the rate of reaction. Ramifications of these findings pose the following questions: Will storage in nitrogen slow or stop this process (or will it favor another reaction, such as crosslinking)? Is there another way to stop it (such as cold storage or chemical treatment)? These areas will be studied in the future. Other future plans include studying some of the other materials that are in trouble, such as neoprene, the nitrile adhesive used in making the aluminized fabric, and the foam inside the helmets.

In summary, NASA has a collection of historically important spacesuits, most of which have not received the best handling in the past. In this collection, a subgroup exists of suits that have not been considered important because they were not used on missions. However, many of them contain intermediate stages of development, which also appeared in the mission suits; considering the amount of records that have been destroyed by NASA and the suit manufacturers, these non-mission suits may be the only record of the course of these developments. Most of these suits have probably been exposed to a strong oxidizer in the form of calcium hypochlorite in addition to the careless handling they received before the recent reappraisal. While this work may have found an answer to why the non-mission suits are deteriorating faster, the need to look for possible ways to stop this deterioration still exists. In addition, work will continue to test storage methods for all the suits not on exhibit; at present, they are housed at low temperature, in the dark, with internal support and an air filtering system. Questions of interest that have come about include the following: Will it be cost-effective to contain the suits in bags with an oxygen-free atmosphere? Can NASM demand proper mannequins (Figure 5) for the entire collection? What restoration, if any, should be allowed of the suits?

These questions apply to the suits on exhibit, as well. Would it be possible to acquire air-tight, oxygen-free, UV-screening, temperature-controlled display cases? While this goal may be unrealistic, NASM is reviewing its loan policy

Figure 5 Virginia Pledger (right) and Lillian Kozloski installing mannequin head in Gemini suit helmet. Virginia Pledger designed and constructed mannequins (under contract for NASM) that fit the new criteria for display of spacesuits as given by Baker and McManus.[1]

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and recalling some of its suits for re-evaluation. The idea is to display the suits for public education of the history they represent without further endangering the only surviving artifacts of the human space race.

An interesting development, as a result of this project, has been the contacts that have been established with companies currently manufacturing spacesuits. We are concerned with the preservation of historic spacesuits while the manufacturers have a desire to extend the useful working life of spacesuits currently in service. Both of us are, for once, very much interested in the same goals; the next generation may, as a result, have more comprehensive and stable documentation of the advances being made in human spaceflight today.

Résumé

Les combinaisons spatiales : un rêve pour la NASA, mais un cauchemar pour les sécialistes de la restauration

Le lancement d'engins spatiaux habités a été un événement marquant de l'histoire des États-Unis, et les combinaisons spatiales que portaient alors les astronautes témoignent des progrès technologiques sur lesquels reposait cette réussite. Néanmoins, les matériaux qui entrent dans la composition de ces combinaisons se détériorent très rapidement, menaçant ainsi l'existence même des seuls objets qui témoignent encore de certaines étapes de la course technologique de l'espace. La dégradation de ces matériaux — des amalgames de caoutchouc naturel et de néoprène, par exemple — s'explique tantôt par la mauvaise qualité des techniques de fabrication auxquelles on a dû, dans la course effrénée du programme spatial, avoir recours. Tantôt, comme dans le cas des tubes de polychlorure de vinyle plastifié, ils constituent une menace pour le reste de l'objet. Et dans d'autres cas encore, ils se détériorent à cause des mauvaises conditions auxquelles ils ont été soumis, lors de leur mise à l'essai ou de leur utilisation, à la National Aeronautics and Space Administration (NASA). Les méthodes qui sont actuellement mises en application pour l'exposition et la mise en réserve de tels objets ne sont pas suffisantes pour retarder la dégradation et, dans nombre de cas, elles l'accélèrent. Or, il n'est par ailleurs pas facile de déterminer le genre de traitement ou le mode de mise en réserve qui leur conviendra le mieux, car ces objets contiennent des matériaux très variés, dont des métaux, des textiles synthétiques et naturels, des plastiques synthétiques et naturels, du caoutchouc, des adhésifs, des peintures et des vernis; et il conviendra donc, de toute évidence, d'adopter une approche multidisciplinaire pour assurer leur conservation. Nous traiterons donc, dans la présente communication, des résultats de l'essai de diverses propositions qui, visant de grandes collections tout en tenant compte d'un budget restreint, définissaient les conditions de mise en réserve de ces matières. Nous passerons ensuite en revue les plus récents travaux de recherche sur le vieillissement accéléré de certaines matières qui serait attribuable aux conditions dans lesquelles elles sont mises à l'essai ou utilisées à la NASA. Enfin, nous traiterons de certaines considérations relatives aux traitements de conservation, en mettant tout particulièrement l'accent sur ceux qui sont actuellement appliqués aux combinaisons spatiales.

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