JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

*Volume 3, Issue 4, Winter2004*

# GIANT VEHICLES

Magdi A. Said
Goddard Space Flight Center
Wallops Island, VA 23337

Willi W. Schur
Physical Science Laboratory
New Mexico State University
Field Engineering Office: GSFC-WFF
Wallops Island, VA 23337

Amit Gupta, Gary N. Mock, Abdelfattah M. Seyam*, and Thomas Theyson
College of Textiles
NC State University
Raleigh, NC 27695-8301

## Abstract

*Science and technology development from balloon-borne telescopes and experiments is a rich return on a relatively modest involvement of NASA resources. For the past three decades, the development of increasingly competitive and complex science payloads and observational programs from high altitude balloon-borne platforms has yielded significant scientific discoveries. The success and capabilities of scientific balloons are closely related to advancements in the textile and plastic industries. This paper will present an overview of scientific balloons as a viable and economical platform for transporting large telescopes and scientific instruments to the upper atmosphere to conduct scientific missions. Additionally, the paper sheds the light on the problems associated with UV degradation of high performance textile components that are used to support the payload of the balloon and proposes future research to reduce/eliminate Ultra Violet (UV) degradation in order to conduct long-term scientific missions.*

*Keywords: Scientific Balloon, Payload, High Performance Fibers, UV Resistant, Tendon, Gore*

* Communicating Author

## INTRODUCTION

Scientific balloons are very large structures capable of carrying scientific payloads of up to 3,600 kg to an altitude of 35 km. A relational aspect of the NASA standard size 39 million cubic feet zero pressure balloon and the Washington Monument is shown in Figure 1 for both, launch and float configurations. That figure also demonstrates the fact that the volume of the lifting gas at float altitude is about 200 to 300 times that of the gas volume at launch altitude. Figure 2 shows a stratospheric balloon during launch operations.

Many scientific experiments involving outer space and upper atmosphere observations can be conducted from air buoyant platforms in the upper atmosphere, the scientific balloons, rather than from orbiting space probes and satellites. Most notable missions that use these large platforms are: (1) the epochal flight of the BOOMERANG experiment (and then MAXIMA) to measure the angular distribution of extremely subtle variations in the temperature of the cosmic microwave background (CMB) radiation as mapped on the sky enabled the first, and most convincing, evidence for the growth of primordial structure in the universe; (2) cosmic ray experiments from balloons have probed the isotopic composition of matter produced (e.g. supernova remnants) where cosmic recycling is occurring; (3) the near-environs of black holes have been imaged in hard x-rays for the first time with balloon-borne telescopes of novel design which pave the way for future higher sensitivity studies (and surveys) of these regions of cosmic extremes.

Generally, floating large payloads on a balloon platform costs significantly less than boosting such payloads into orbit. Most experimenters, however, require constant altitude for taking measurements. While this altitude keeping requirement does not pose any difficulties in the polar regions where during the summer season the balloon has 24 hours exposure to the sun, at mid-latitude, diurnal variations in the thermal radiation environment cause significant changes in the state of the lifting gas. Unconstrained, the lifting gas in the balloon expands during daytime and contracts during nighttime. If that is allowed to happen, then the balloon undergoes large altitude excursions over the diurnal cycle.

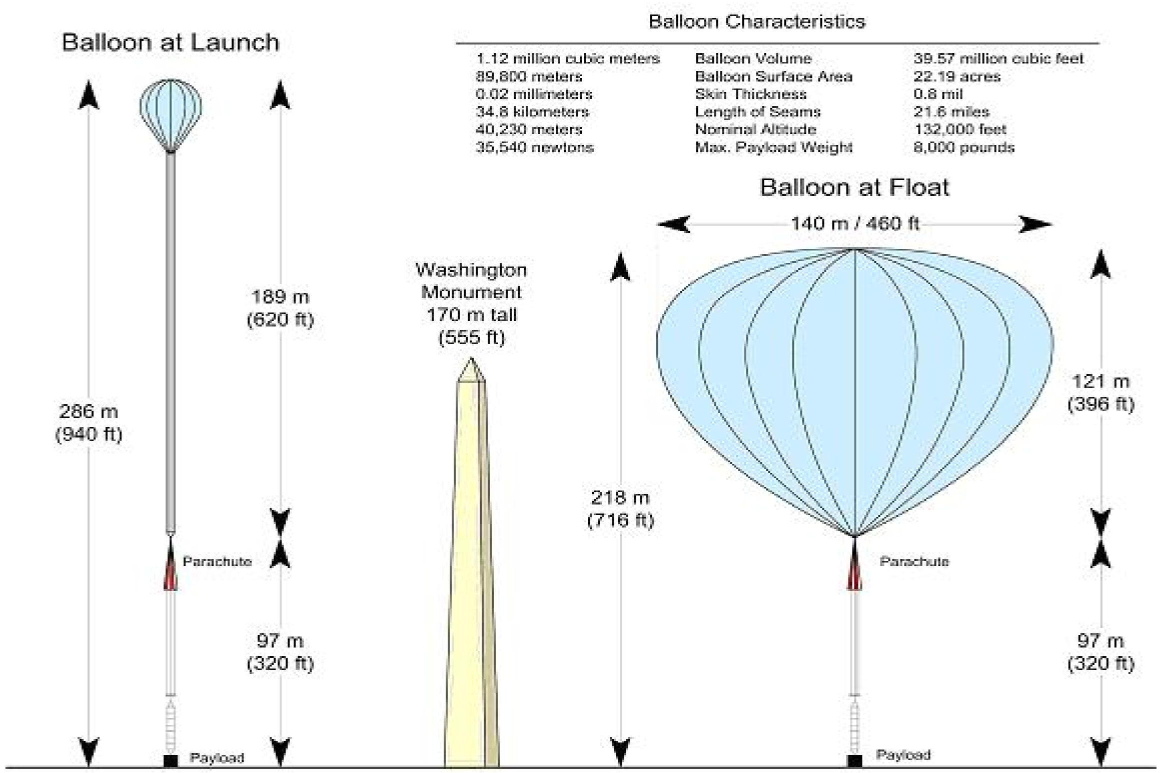



**Figure 1 Balloon characteristics**

**Figure 2 Zero Pressure Balloon in Launch Configuration**

There are two options that all but eliminate these altitude excursions during the mission. One is to carry ballast and corresponding excess lifting gas and allow the gas to vent as the temperature in the lifting gas rises with the rising sun (Figure 3 shows this type of balloon at float altitude with the vent ducts extending to below the nadir of the balloon), and then to drop ballast during night time when the lifting gas cools and contracts. This is the way all large-payload-capacity scientific balloons to date operate. Limitations on the amount of ballast that can be carried limits the duration of mid-latitude flights from one to three diurnal cycles. These are short duration flights. The other option is to contain the lifting gas in a quasi-fixed volume. In that case, the gas pressure in the lifting gas rises with the temperature in the gas, hence the differential pressure on the envelope rises and the restraining force required of the pneumatic envelope exceeds many-fold the restraining force required of a similar size venting balloon (commonly called zero pressure balloon). The pressurized balloon (commonly called super-pressure balloon) could in principle float indefinitely at almost constant altitude if gas leakage could be completely eliminated.

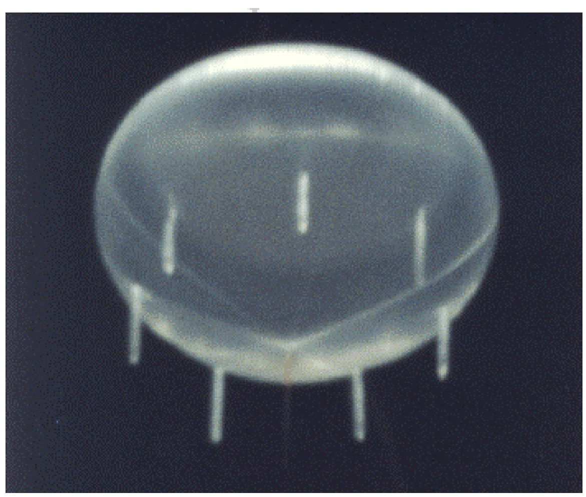


**Figure 3 Zero Pressure Balloon at Float Altitude**

## BALLOON DESIGN CONSIDERATIONS

### Standard Zero Pressure Balloon

In the zero-pressure balloon the maximum apex pressure rises with the linear size of the balloon. In addition, current zero pressure balloons are constructed in a manner that requires the skin to participate in the global load carrying function. These two aspects combine so that the film strength requirement in current zero-pressure balloons rises quadratically with the linear size of the balloon. The payload forces are introduced at the nadir, picked up by the load tapes, and transmitted into the pneumatic envelope via the load tapes that are heat sealed to the gore seams. These load tapes are anchored to the nadir fitting at the bottom of the balloon and the apex fitting at the top. The apex fitting is usually a plate with sufficient real estate to accommodate some instrumentation and a pressure valve. The load carrying elements of the load tapes are polyester strands that are embedded in a polyethylene sheath. Typically, the fabrication of the load tapes creates some wavy-ness in these strands, about up to 3%, so that load uptake by the strength fibers requires significant straining in the balloon skin. The design shape of these balloons, the so-called natural shape, is derived from the assumption of zero hoop-stress in the film in the fully inflated state at float altitude. The construction of these balloons, however, prevents realization of this design assumption. Zero-pressure balloons have been flown with up to 4,000 kg to altitudes of about 37 km. The fully inflated shape of these balloons resembles the shape of an onion.



### Spherical Balloons and Fabrication Challenges

Current scientific super pressure balloons are made of polyester film, which is significantly stronger than the polyethylene (PE) film that is used in the zero pressure balloons. However, with the customary design, it only allows for the construction of relatively small balloons that carry significantly smaller payloads to much lower altitudes than are achieved by zero-pressure balloons. Payloads for these super-pressure balloons ranged from about 50 kg to 100 kg. The design of these balloons is a sphere made of polyester gores that are butted and taped at the gore seams. Payload introduction into the pneumatic envelope is via a load skirt, a conical arrangement of straps that are anchored to the balloon skin at the tangent intercept of the cone and the meridional seam tapes. The load introduction detail, the “bear-paw patch”, is a stress raiser. It introduces in its vicinity a structural “hot spot”. Very exacting, hence expensive, construction techniques are required to fabricate a spherical balloon lest randomly distributed additional stress raisers due to manufacturing imperfections will occur on the pneumatic envelope.

### Development of Pumpkin Shape Super-Pressure Balloon

High strength, high stiffness, low weight fibers (high structural efficiency fibers) enable a different design scheme for stratospheric super-pressure balloons, one which has been contemplated in the late 1960s and reported on in 1970 [1], and re-examined in the succeeding decades [2,3], but essentially shelved until 1998 when proposed for the Ultra-Long-Duration Balloon (ULDB) project, and analytically demonstrated as technologically feasible for large scale balloons by Schur [4]. This is the so-called pumpkin Shape balloon (Figure 4).

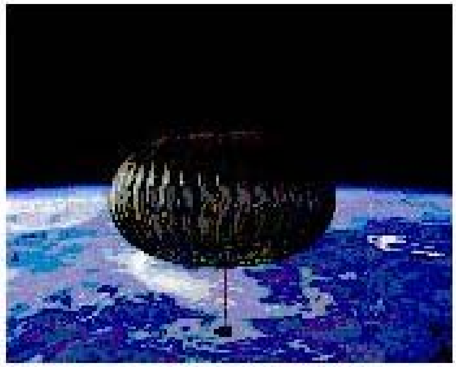


**Figure 4 Lobed ULDB, Pumpkin Balloon Shape Model of 48 Gores**

High structural efficiency fibers enable a significant leap in capability for scientific stratospheric balloons. Their high strength and high stiffness relative to their mass allows them to be used as the primary pressure confining structural element for the lifting gas. These high strength fibers are twisted into yarns, which are then braided into ropes. These ropes are the load tendons. The skin of the pneumatic envelope can be relegated to the role of gas barrier and to local pressure load transfer to the primary structural elements, the load tendons. In this design scheme, the strength requirement for the skin grows linearly with a local parameter, the bulge radius, while in the spherical balloon the strength requirement for the skin grows with the radius of the sphere. That is, in the pumpkin shape balloon, the skin strength requirement, and hence the areal density of the balloon skin, is independent of balloon size. There are several additional advantages to the design scheme of the pumpkin shape balloon. Single orientation materials can be made significantly stronger than sheet or bulk material. The heterogeneous structure of the pumpkin balloon is also significantly more tolerant to fabrication imperfections than the spherical design, allowing designs with nominally smaller factors of safety than would be used for spherical designs. There are no structural "hot spots" in the design; the stress resultants in the tendons are nearly uniform. By suitably balancing the structural stiffness of the film and the tendons and structural lack of fit between the tendons and the gore seams, the film stress resultants can be made uniform. This results in a structurally efficient design in which the strength of each structural element is nearly uniformly exhausted. This is quite different from the spherical design where the load introduction detail introduces a structural "hot spot" that dominates the skin strength requirement. Similarly to the current zero pressure designs for stratospheric balloons, the tendons are anchored on the top plate and a bottom plate. The latter plate supports the attachment to the flight train assembly, which in turn holds the suspended payload.



The ULDB is still in its development phase. There are a number of technological hurdles to be overcome. Three of these involve the opportunity for undesired and dangerous stable equilibrium states at full inflation and pressurization to occur. These are states at which the stress resultants in the film envelope significantly exceed the predicted (design) stress resultants for the symmetrically deployed configuration. Similar problems arise in other compliant structures particularly when, during the evolution to full deployment, control of the deployment path is given up, and the system proceeds on its path autonomously under the influence of environmental force systems that can only be bounded by estimates but not fully predicted. Good designs do not exhibit this problem. The difficulty here is in knowing which design features constitute a good design. The three aspects that need to be resolved are: 1) there must exist a robustly stable, cyclically symmetric equilibrium state at full inflation and pressurization, and, if in addition, other stable equilibrium exist, then 2) design features must ensure that even under the influence of environmental perturbation the inflation path will always autonomously lead to the desired equilibrium, and 3) deflation and re-inflation and re-pressurization due to the diurnal cycle will not cause the balloon to depart into one of the undesired equilibria. NASA sponsored analytical and empirical investigations are currently underway to gain sufficient understanding and to establish guidelines and design thresholds, which will lead consistently to well-designed pumpkin shape super-pressure balloons.

Other technological questions that are as yet not fully answered relate to the high structural efficiency load tendons.

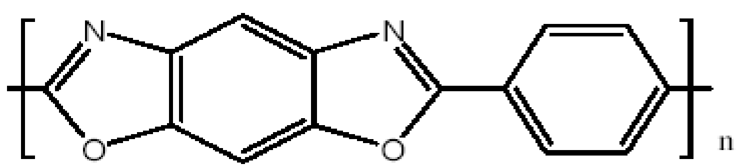
**The Role of Tendons to ULDB Success**

Along with the development of a design for the new balloon, a number of technical issues have been addressed including new construction techniques, balloon film optimization and load tendon development. In the proposed design of the super pressure balloon, the ultimate size of the balloon is limited by the performance characteristics of the tendons of braided yarns. The skin carries the pressure load to adjacent tendons within the total structure. Hence the tendons need to be structurally efficient (strong) and lightweight. Therefore, it is advantageous to construct the tendons out of the highest strength to weight ratio fibers available. After reviewing several commercially available high performance fibers, four fibers were identified. These are Zylon PBO fiber supplied by Toyobo Ltd. of Japan, Kevlar aramid fiber supplied by Dupont, Spectra ultra high molecular weight polyethylene supplied by Honeywell, and Vectran supplied by Celanese Acetate LLC.

**High Strength Fibers**

**Zylon (PBO)**

Zylon is a new high-performance fiber developed by Toyobo Co. Ltd. Zylon consists of rigid-rod chain molecules of poly (p-phenylene-2, 6-benzobisoxazole) or PBO [5]. The chemical structure of PBO is shown below [6]:



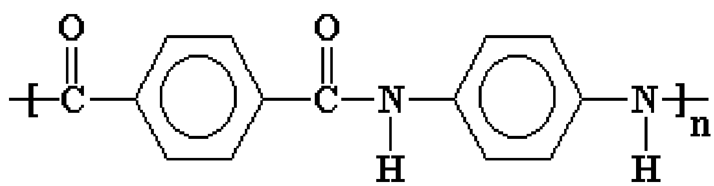

PBO has strength and modulus almost double that of a p-aramid fiber. Zylon shows 100°C higher decomposition temperature than p-aramid fiber [7]. The limiting oxygen index (LOI) is 68, which is the highest among organic super fibers. There are two types of fibers, AS (as spun) and HM (high modulus). HM is especially different from AS in modulus and moisture regain. Properties of Zylon AS and HM fibers are depicted in Table 1.

**Table 1 Properties of Zylon fiber [7]**

| Properties | ZYLON AS | ZYLON HM |
|---|---|---|
| Filament dtex | 1.7 | 1.7 |
| Density ($g/cm^3$) | 1.54 | 1.56 |
| Tensile strength (cN/dtex) | 37 | 37 |
| Tensile modulus (cN/dtex) | 1,150 | 1,720 |
| Elongation at break (%) | 3.5 | 2.5 |
| Moisture regain (%) | 2.0 | 0.6 |
| Decomposition temp. ($^0C$) | 650 | 650 |
| LOI | 68 | 68 |

**Kevlar**

Kevlar aramid fiber is based on poly (*p*-phenylene terephthalamide) (PPT-T). PPT-T can be prepared by the low-temperature polycondensation of *p*-phenylene diamine (PPD) and terephthaloyl chloride (TCL) in a dilalkyl amide solvent [7]. Kevlar has the following structure [8]:



Kevlar was introduced by DuPont in the 1970s and is supplied by DuPont Textile Fibers. It was the first organic fiber with sufficient tensile strength and modulus to be used in advanced composites. Originally developed as a replacement for steel in radial tires, Kevlar is now used in a wide range of applications [9].

The rod form of the Para-aramid molecules and the extrusion process make Kevlar fibers anisotropic (they are stronger and stiffer in the axial direction than in the transverse direction). In comparison, graphite fibers are also anisotropic, while glass fibers are isotropic. The aramid ring gives Kevlar thermal stability, while the Para-structure gives it high strength and modulus [7].

Today, there are many grades of Kevlar available: Kevlar yarns for tire, Kevlar 29 (all-purpose yarn), Kevlar 49 (high modulus yarn), Kevlar 68 (moderate modulus yarn) and Kevlar 149 (ultra-high modulus yarn). The first two have similar tensile properties while the rest have higher tensile modulus and a higher degree of crystalline orientation. Table 2 shows the differences in material properties among the different grades of Kevlar fibers.

**Table 2 Properties of different grades of Kevlar fibers [7]**

| Kevlar Grade | Density, g/cm$^3$ | Tensile modulus, g/denier | Tensile Strength, g/denier | Tensile Elongation, % |
|---|---|---|---|---|
| 29 | 1.44 | 970.27 | 42.1 | 4.0 |
| 49 | 1.44 | 1531.39 | 42.1-47.9 | 2.8 |
| 149 | 1.47 | 2174.34 | 39.746 | 2.0 |

Kevlar is a very crystalline polymer, where the phenyl rings of adjacent chains stack on top of each other very easily and neatly, which makes the polymer even more crystalline, and the fibers even stronger. Overall, Kevlar is an outstanding high-strength, high-modulus fiber. Its tenacity (strength per linear unit density) is greater than all conventional fibers. Its strength is relatively insensitive to temperatures up to $T_g$ (~280 $^0$C) and is dimensionally stable.

### UV Light Stability of Kevlar

Since Kevlar is self-screening, its light stability depends on the thickness of the exposed textile structure. Very thin Kevlar 49 fabric, if exposed directly to very high intensity sunlight for an extended period, will loose about half its tensile strength [7]. In thicker items, such as the 13 mm (half-inch) diameter rope, the majority of yarns are protected by the outer layer and strength loss is minimized (Table 3).

**Table 3 Strength of 13 mm rope from Kevlar 49 in terms of exposure period to Florida Sun [7]**

| Product | Break Load | Strength Retained (%) |
|---|---|---|
| Unexposed | 14,400 lb (64,100 N) | ---- |
| 6 months | 13,000 lb (58,000 N) | 90 |
| 12 months | 11,600 lb (51,600 N) | 81 |
| 18 months | 9,950 lb (44,300 N) | 69 |
| 24 months | 9,940 lb (44,200 N) | 69 |



### Spectra

Spectra is a high-strength, lightweight, extended-chain polyethylene fiber supplied by Honeywell Specialty Fibers and has the highest strength to weight ratio of any man-made fiber [10]. It is prepared by the gel-spinning process, in which the polymer is dissolved in a solvent (10% polymer + 90% solvent), which results in a gel. This gel is then stretched 1,000 times and thereby all the folded polyethylene chains are straightened and oriented along one axis. After that the solvent is removed, allowing the chains to come close to one another resulting in ultra-high orientation and close packing [11]. The high tenacity of Spectra fiber makes it eight to ten times stronger than steel and 40 percent stronger than aramid fiber [7]. The properties of Spectra 900 and 1000 are listed in Table 4.

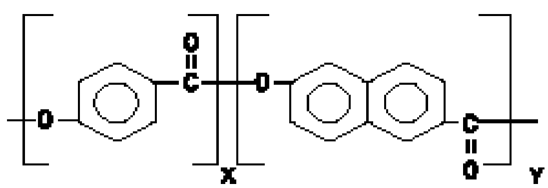
Spectra 1000 fiber, the second in a series of Spectra fibers, was developed to meet the needs for increased performance. It is available in a multitude of deniers for use in a wide range of applications [10]. Spectra 1000 fiber has 15%– 20% higher tenacity than that of Spectra fiber 900 (Table 4).

**Table 4 Properties of Spectra 900 and 1000 fibers [10]**

| Properties | Spectra 900 [4800 denier] | Spectra 1000 [1300 denier] |
|---|---|---|
| Tensile strength (g/d) | 25.5 | 35 |
| Tensile modulus (g/d) | 785 | 1150 |
| Elongation (%) | 3.9 | 3.4 |
| Density (g/cm$^3$) | 0.97 | 0.97 |
| Filaments | 480 | 240 |
| Denier per filament | 10 | 5.4 |

**Vectran**

Vectran fiber comes under the class of aromatic polyesters and is a polyester-polyarylate fiber. The chemical formula for the Vectran fiber is shown below [12]:



This fiber is based on the HBA/HNA copolyesters where HBA stands for *p*-hydroxybenzoic acid and HNA stands for *p*-hydroxynapthoic acid. The actual monomers are *p*-acetoxybenzoic acid and 2-acetoxy-6-napthoic acid. The polymer is prepared by the melt polymerization at approximately 250-280$^0$ C for about 4 hrs [7].

Vectran is a high-performance thermoplastic multifilament yarn spun from Vectra liquid crystal polymer (LCP). Currently, Vectran is the only commercially available melt spun LCP fiber. The presence of three aromatic rings in one single repeat unit makes the polymer chain highly rigid and a perfectly linear rod-like molecule and, hence, Vectra comes under the category of Liquid Crystalline Polymers (LCPs) [12] in which case the molecules position themselves into randomly oriented domains. The polymer exhibits anisotropic behavior in the melt state, thus the term "liquid crystal polymer." Upon extrusion of the molten polymer through small spinneret holes, the molecular domains align parallel to each other along the fiber axis. The process is schematically [12] shown in Figure 5. The highly oriented and packed chain molecular structure of Vectran fiber gives rise to excellent mechanical properties.



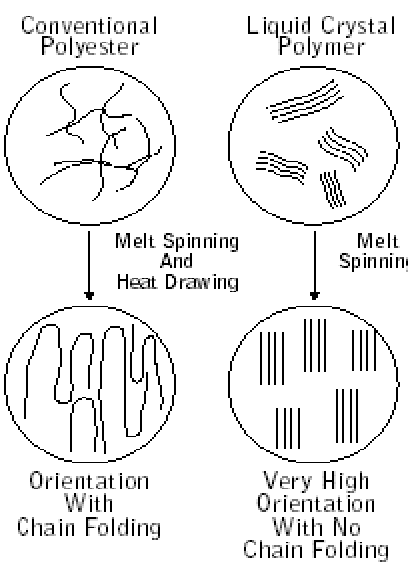



**Figure 5 Schematic of Molecular Chain Structure of Vectran Fiber**

*Image courtesy of Vectran Fiber*

## Properties of Vectran Fiber

Vectran fiber exhibits exceptional strength and rigidity. It is five times stronger than steel and ten times stronger than aluminum. Vectran fibers possess unique properties. These are high strength and modulus, excellent creep resistance, high abrasion resistance, excellent flex/fold characteristics, minimal moisture absorption, excellent chemical resistance, low coefficient of thermal expansion (CTE), high dielectric strength, outstanding cut resistance, excellent retention properties at high/low temperatures, outstanding vibration damping characteristics, and high impact resistance and good shock absorbency. Some typical values are shown in Table 5.

**Table 5 Properties of 1,500 denier/300 filament yarns from Vectran HS and M fibers [12]**

| Properties | Vectran HS | Vectran M |
|---|---|---|
| Tensile strength* (g/denier) | 23 | 9 |
| Tensile modulus* (g/denier) | 525 | 425 |
| Elongation at break* (%) | 3.30 | 2.00 |
| Melting point ($^0$C) | 330 | 276 |
| Moisture regain (%) | < 0.1 | < 0.1 |
| Density (g/cm$^3$) | 1.4 | 1.4 |
| Chemical resistance | Hydrolytically stable. Resistant to organic solvents<br>Stable to acids (< 90% conc.). Stable to bases (< 30% conc.) | |
| * ASTM D885, 10 in. gauge length, 10% strain rate, 2.5 tpi twist<br><br>Vectran HS is the high strength reinforcement fiber and Vectran M is a high performance matrix fiber. | | |

## The Need for Improved Tendon

PBO and the other high strength fibers are subject to ageing mechanisms that significantly degrade the fiber strength. Environmental conditions that promote degradation, degradation rates, interaction between the degradation mechanisms, all must be well understood to implement measures that delay/eliminate damage and to assess the damage that is accumulated during fabrication, storage, and service life exposure. Scrupulous accounting of exposure conditions and exposure times must be implemented from fiber drawing to decommissioning of the service product, and must be supplemented by testing at least up to the end of manufacture of the service product. That this has not been done, at least not been done consistently, has been recently brought to the attention of the public by newspaper articles and news broadcasts [13,14,15,16] about not so bullet proof vests that underperformed at less than half the guaranteed service life.

As a structural material there is little industrial experience with PBO fibers in general and PBO ropes in particular. Reliable use for critical strength components requires that a guaranteed minimum strength threshold can be established that takes all degradation effects into account. Such a strength threshold is used by the designer to qualify the design. In the case of a well-designed pumpkin-shape super-pressure balloon, the tendon is nearly uniformly loaded over its entire length. For the ULDB pumpkin shape super-pressure balloon with expectations of at most one failure in a fleet of 100 balloons, this means that at most one substandard strength location per 4,500,000 m of rope is allowed. (Currently, ULDB has 290 tendons that are each about 160 m in length.) And this must be guaranteed with an acceptable high level of confidence. Any acceptance testing is performed well before the end of service life. Therefore reliable predictive rules for projection of end of service life strength from a known earlier state must be available, exposure during storage, transportation, and in service conditions must be conservatively estimated and actual exposure must be scrupulously tracked.

**Fiber Protection to Improve Performance**

The critical issue to be addressed is: "Can a lightweight, flexible coating be developed to protect the fibers from UV degradation?" The objective would be to design a coating, which can be applied to the surface of the fiber and would provide a high level of protection against the negative impact of UV exposure for a 100-day period. The coating should be non-migrating and possess a high level of coverage uniformity so as to minimize the potential of damage to unprotected areas on the tendon. Along with protecting the fiber, some attention has to be paid to secondary performance issues including:

Will the coating be stable under the near space conditions to which the fiber will be exposed?

Will the coating impact the frictional behavior of the fibers (fiber/metal and fiber/fiber friction)?

To what extent is the surface coating susceptible to abrasion damage?

Does the coating process impact any other critical fiber performance property?

The aim is to stabilize the high strength fibers without creating other problems that slow down the development of the program.



**Anti UV Treatments**

Different approaches have been chosen for making the fibers UV resistant:

1. Self polymerizing: This includes finishes with suitable chemical structure to allow their application from a water base, and then dried and cured at a temperature range of $120\text{-}130^0$ C. This should form a thin layer with high UV absorption. The chemistry of such finishes would not allow interaction with the fiber. Approximately 80% by weight of the added chemical will be an active UV absorber. This chemical can be applied to any substrate and will not encapsulate the entire bundle; rather it will encapsulate individual filaments when applied to a yarn. The total add-on should be about 1%-2%.

2. Diffusion Application: This type of finish is similar in action to disperse dyes in polyester. Surface-applied UV absorbers would diffuse into the fiber structure. This technique is used in the automotive industry to achieve higher light fastness.

3. Polymer filled with 30-40% UV absorber: - This is silicone or acrylate filled with UV absorber.

4. Combination of dyeing and surface application.

The application technique used for tire cord treatment technology, which benefits from low penetration with the yarn bundle, could be employed in order to keep stiffness low and retain reasonable abrasion resistance.

Another approach comes from the cosmetics industry and sunscreen development. Use of high-load, small particle size ZnO in the sub micron range results in a clear coating without light scattering. A reactive silicone/acrylate binder system to hold the particles in place is needed.

It is also suggested that a fluorescing agent be incorporated into finishes to judge the application quality in terms of finish application uniformity around and along filaments since the cost of failure is high; therefore a reasonable effort should be made to ensure quality. This should help establishing a quality control procedure since non-uniform finish applications on the yarn/filaments may lead to spots that are vulnerable to UV- a matter that may cause weak spots and failure of the yarn and, hence, the braided cords.

**Solving One of the Technological Hurdles, Introducing Another**

The current ULDB concept uses a nominally 38 μm thick linear low density tri-laminate PE film. Polyethylene balloon film is a preferred pneumatic envelope material for stratospheric balloons because it remains ductile down to the lowest temperatures encountered in the stratosphere. Its low cost and heat sealing characteristics, which is a relatively fast and cheap process makes it highly desirable for these giant structures. Current performance specifications would be satisfied with a 290-gore balloon. Should it turn out that the need for robust deployment of the balloon into the design configuration at float places an upper threshold on the design that is less than 290 gores, then one possible alternative is using a lightweight composite textile structure that is made impervious to the lifting gas by impregnation with a suitable matrix material. One small test balloon with 134 gores and a fabric film composite has been flown. The skin of that test balloon was a composite made of polyester fabric as a load carrier, laminated with adhesive to two layers of film. These films, a polyester film and a polyethylene film serve to improve the stability and barrier properties of the structure. Much of the weight and costs of that composite that made it unattractive for ULDB were associated with the adhesive and the two film layers. The fabric of that test balloon was more than twice as strong as the PE film of the current ULDB design scheme. The hurdles to overcome for the impregnated fabric is making it impermeable to helium and finding reliable ways for gore seam construction.



**CONCLUSION**

The Balloon Program Office (BPO) provides support for scientific investigations sponsored by the NASA Office of Space Science. The BPO has entered a new phase of research to develop an Ultra Long Duration Balloon (ULDB) that will lift payloads of up to 3,600 kg to altitudes of up to 40 km. The flight duration is targeted to ranges between 30 to 100 days. Attaining these target durations requires the development of a super-pressure balloon design. The use of textile structures have already been established in these missions in the form of either the PE film in the ULDB or the high strength fibers in the load tendons. To improve the mission performance, new lightweight textile structures with protective UV treatment need to be developed. NASA and NC State University College of Textiles are undertaking a research program to address these issues. Our next publications will deal with understanding the mechanism of UV degradation of high performance fibers and identifying finishes and methods of finishes applications that will reduce/eliminate such degradation.

**REFERENCES**

1. Justin H. Smalley "Development of the E-Balloon", National Center for Atmospheric Research, Boulder Colorado, June 1970.
2. M. Rougeron, "Up To Date CNES Balloon Studies", Centre Special de Toulouse, ca. 1978.
3. N. Yajima, “A New Design And Fabrication Approach For Pressurized Balloon”, COSPAR 1998.

4. Willi W. Schur, “Analysis Of Load Tape Constrained Pneumatic Envelopes,” 40th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference and Exhibit, St. Louis, MO, April 1999

5. www.toyobo.co.jp/e/seihin/kc/pbo/

6. http://www.mat.usp.ac.jp/polymer-composite/30th-yamashita.pdf

7. Yang, H. H., “Aromatic High Strength Fibers,” New York, J. Wiley, c1989.

8. http://www.psrc.usm.edu/macrog/aramid.htm

9. www.dupont.com/kevlar

10. www.spectrafiber.com

11. Kent. A. James (Editor), “Riegel’s Handbook Of Industrial Chemistry,” 10th ed., Kluwer Academic/Plenum Publishers, New York 2003.

12. www.vectranfiber.com

13. Dallas Morning News, TX, Oct. 22, 2003

14. Fox News, Oct. 20, 2003

15. Pittsburgh Post Gazette, PA, Oct. 18, 2003

16. Montana Forum, MT, Oct. 1, 2003