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Material Challenges for Lighter-Than-Air Systems in High Altitude Applications

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Lighter-than-air applications at high altitudes (stratosphere) impose significant challenges for the system flexible materials. The materials must be lightweight and strong, capable of containing lifting gas, maintaining flexibility at low temperature, have excellent damage resistance, and provide a good balance between airframe weight and system safety factors. The material must also be designed to resist the harsh stratospheric environment, high ozone concentration, intense UV, and extremely low temperatures. In addition, the material must have specific thermal radiation properties, which govern the system thermal performance. This paper will discuss in detail, the challenges, material characteristics (as they apply to LTA vehicles), progress that has been made, and the work that still lies ahead.

I. Introduction

IN recent years, there has been increased interest in high altitude, lighter-than-air (LTA) systems operating above 65,000 feet. The chosen altitude is due to many factors, including it is above the jet stream, severe weather, and the FAA air traffic layer. The windspeed is generally low, and the line-of-sight to the horizon is approximately 320-nm. The LTA systems have applications in telecommunications relay, weather forecasting, and surveillance. The military is especially interested in the role of LTA systems in missile defense and homeland defense efforts. It appears the threats to LTA platforms are very low. In addition, once on station, the LTA system provides long endurance continuous/persistent support. The benefits include:

1) persistent 24/7 capability
2) low cost, rapid reconstitution of capabilities
3) multi-mission, exchangeable/repairable/upgradeable payloads
4) long duration aloft (≥ 1 year)
5) low inherent detectability, observability
6) relocatability
7) improves performance of nearly all sensors

There are two basic types of LTA systems: either tethered (aerostat) or un-tethered (airship). An un-tethered high altitude airship is an unmanned, powered, free flying vehicle. Lift is provided by a combination of aerodynamics and lifting gas, such as helium or hydrogen that is contained in the envelope. The combination of photovoltaic and advanced energy storage systems delivers the necessary power to perform the airship mission. In contrast, the tethered high altitude aerostat is operated from a fixed location. Lift is provided solely by a lifting gas such as helium or hydrogen which is contained in the envelope. The tether provides a structural link to the mooring system, power for the aerostat and payload, and secure command and communications. The tethered high altitude aerostat is very power efficient, requiring no power for station keeping or altitude control. It is also easily recoverable for payload maintenance. The goal of both the un-tethered airship and the tethered aerostat is to remain on station for a year or more while supporting a sizable payload. The challenges for high altitude LTA systems include:

1) strong light weight LTA material
2) efficient pressurization system
3) attitude and altitude control (airship)
4) icing and lightning
5) on board power generation for long duration missions (airship)
6) light weight propulsion units (airship)

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7) light weight tether (aerostat)

Development of material suitable for high altitude LTA applications presents many challenges to the material designer. The strength-to-weight ratio significantly affects LTA system size and/or altitude. The challenge is to develop a very lightweight yet strong material that is capable of containing lifting gas and resistant to the environment. The stratosphere extends from approximately 17 km to 50 km above the Earth's surface. The stratosphere is also called the "ozone layer" because 90% of the earth's ozone is concentrated in this region. At this altitude, the nominal temperature is -70ºF which can cause the material to become brittle with a resultant loss of flexibility. The high ozone concentration and intense UV radiation can also deteriorate LTA material, resulting in a loss of strength and permeability. This paper will discuss the major flexible material design considerations, progress made, and challenges that still lie ahead.

II. LTA Material System

A typical LTA system uses a "balloon-within-a-balloon" concept. There is an outer balloon (or hull) and one or more internal balloons (or ballonets). The lifting gas is typically contained in the external envelope and air is contained in the internal ballonet(s). During ascent, the lifting gas in the hull is allowed to expand while air in the ballonet(s) is allowed to escape, thus maintaining a nearly constant internal pressure and hull shape. During descent, the situation is reversed, the lifting gas is contracting, and air must be forced back into the ballonets to maintain the pressure and hull shape. The two most significant materials used in an LTA system are the hull (external skin) and ballonet (internal barrier) materials.

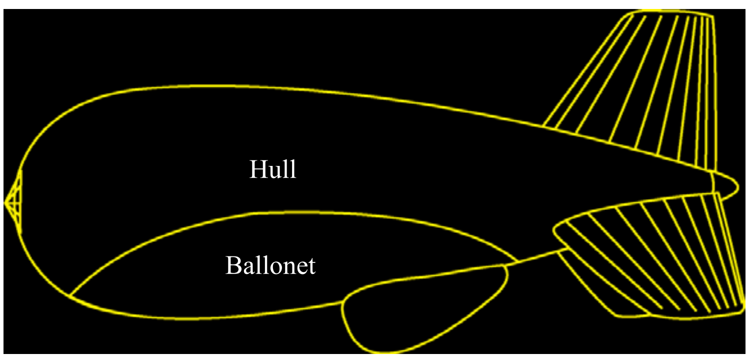

Figure 1. "Balloon-Within-A-Balloon" Design

III. Hull Material Challenges

The hull or envelope material is the outer membrane and provides structural strength for the system and acts as the primary barrier between the outside air and lifting gas. For high altitude LTA applications, the hull material must exhibit low gas permeability, high environmental resistance, high strength-to-weight ratio, and excellent tear resistance. A low gas transmission rate through the hull material is required to minimize lift loss and maximize on station time. Excellent environmental resistance protects the system from environmental degradation, which ultimately leads to a longer system life and low system maintenance. The hull material must also be lightweight to minimize balloon size and weight, while exhibiting sufficient strength to overcome aerodynamic stresses and the pressure differential acting on the hull. Furthermore, high tear resistance is also necessary to maximize damage tolerance and prevent catastrophic tear propagation. In addition, the material must be designed to minimize vehicle thermal changes. The considerations in the design of a hull material are shown in Table 1.

Typical hull material is a multi-layer flexible laminate, see Figure 2. The material generally consists of components, which permit tailoring of the various material properties to optimize the resulting balance between tensile strength, service life, weight, gas retention, and flexibility.

Table 1. High Altitude LTA Hull Material Design Considerations

Requirements	Criteria
Structural	Pressure load, Safety factor • Tensile and shear strength • Tear resistance • Weight
System	Service life, On-station time • Environmental resistance (UV, ozone, temperature, etc.) • Lifting gas permeability
Material Performance	Flexing, Blocking, Inter-layer bonding
Material Producibility	Repeatable process control (consistency) Yield percentage
Envelope Manufacturability	Bondability Handling Joint strength
Thermal Control	Solar absorptivity, α Infrared emissivity, ε

A. Strength layer

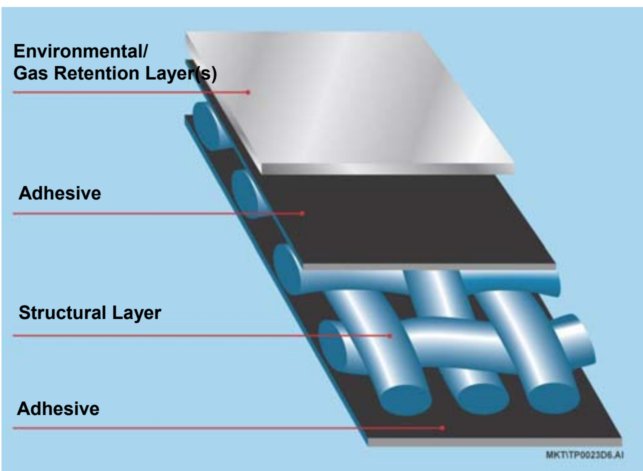

Figure 2. Typical Hull Material Layout

The typical LTA hull material strength layer is woven fabric, either single or multi layer. The most challenging aspect in designing the strength layer is the identification of a structural fiber. With the development of synthetic fibers, the textiles used in the LTA industry have undergone many changes. Synthetic fibers provide the highest strength-to-weight ratios, and scientists continue to work on design and development of new synthetic polymers and fibers. Figure 3 shows the history of modern textile fiber development.

Nylon and polyester fiber are synthetic fibers that were commercialized in the 1940's and 1950's. They are so-called technical or industrial fibers. The maximum strengths of commercial nylon and polyester fiber approach 10 g/den, with break extension of more than 10%. The combination of moderately high strength and moderately high extension gives a very high energy to break or work of rupture. Nylon and polyester fiber have broad range applications including clothing, furnishings, and the industrial textile market[1]. However, the high strength-to-weight ratio, low creep, low moisture regain, and improved hydrolysis resistance makes polyester fiber a good choice for LTA applications. Almost all current LTA hull materials are made from a high tenacity polyester fiber composite. The performance and characteristics of polyester fiber are well understood and technical data are readily available. The high performance fibers became available in the late twentieth century. High performance fibers are defined as high-modulus (over 300 g/den) and high tenacity (over 20 g/den). The strongest commercially available fibers are Zylon® and Spectra®. Other high performance fibers include Vectran® and Kevlar®. M5® fiber is a new fiber in development. It is a "designer" fiber that is targeted to be used both as a ballistic fabric and a composites material – a dual-use status that previously has not been successfully achieved by any polymer fiber. It has experimental tenacity performance similar to Zylon® and improvements are expected. Currently, M5® is moving from the R & D phase to the pilot plant. It is estimated that limited fiber samples will be available for test and evaluation in 2006. High performance fibers are attracting considerable attention in the LTA industry. However, concerns such as stress concentration due to low extension, creep characteristics (for Spectra®), moisture and UV resistance (for Zylon®) remain for these fibers. Another important consideration is that most high performance fibers are developed for special rather than for commercial applications. This means that the cost for high performance fiber is much higher, resulting in limited availability, research, and technical information. Table 2 compares several high performance fibers with high tenacity polyester (KoSa®).

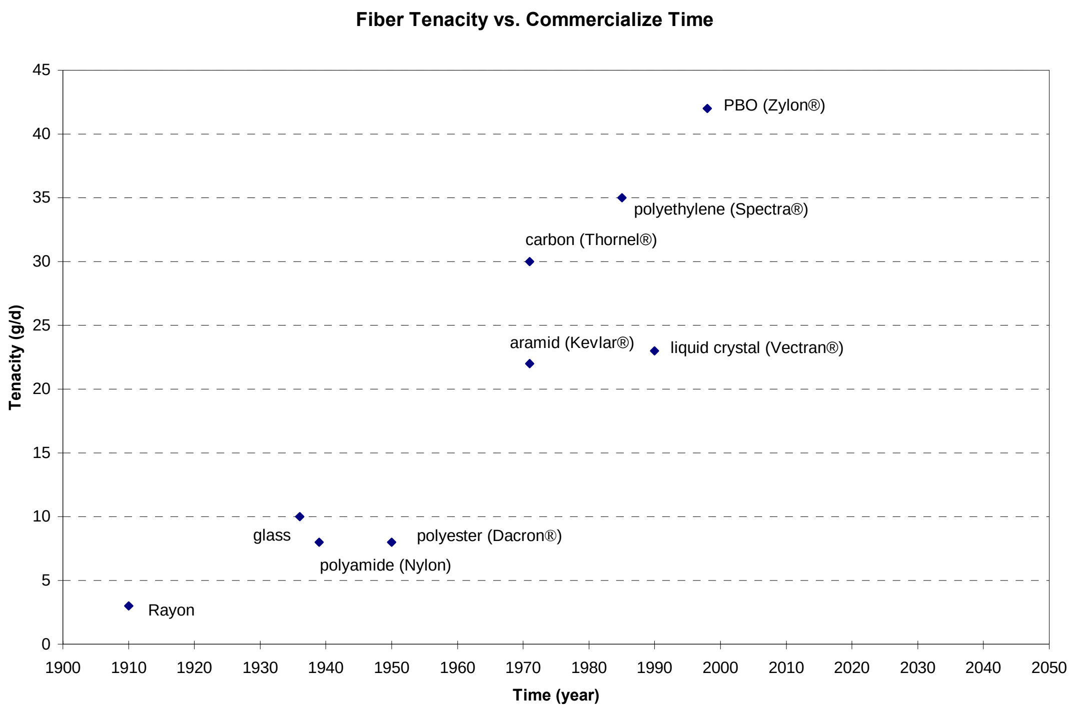

Figure 3. Textile Fiber Development History

Several lab scale and trial composite samples have been made to understand the behavior of high performance fiber composites for LTA applications. A light weight flexible Vectran® based trial material for a high altitude application was produced and evaluated with promising results. A Vectran® based hull laminate was also produced and used in a prototype heavy lift spherical balloon system, see Figure 4. This material, when compared to polyester based material, demonstrated much higher strength/weight ratio and excellent tear resistance. Figure 5 compares estimated material strength vs. weight for several strength members.

In addition to new fiber/polymer development, researchers have been experimenting with blends of different yarns to improve the overall performance. A hybrid fabric takes advantage of the fact that the loss of strength due to one factor, flex for instance, is not usually accompanied by a loss of modulus. However, the information about hybrid fabrics is very limited and in most cases, the work is conducted for special applications.

B. Material Fabric Weave

Another challenge in material development is to efficiently translate as much of the theoretical yarn strength into the finished material. Almost all medium strength hull material uses single layer woven fabric as the structural layer. The weave pattern design, weaving process and other textile technologies significantly affect the finished fabric properties. The key factor affecting this is load sharing between the yarns. This is more critical for high modulus fibers which have very low elongation.

Plain weave is a basic simple interlaced weave pattern that allows many variations. A plain weave scrim can be woven with various yarn sizes and counts (number of yarns in the warp and fill directions) to modify the tensile strength and openness of the finished scrim. A common variation of plain weave is the basket weave and "rip stop" which improves the tear resistance. Weft insertion warp knit is warp/weft yarn laid on each other and knitted together. This pattern is not actually a woven structure and because the warp and weft yarns are not interlaced, the fabric is also called a "no-crimp" structure. This structure exhibits a much improved tear resistance when compared to a woven structure. A multi-layer fabric can be made when a very high strength material or a multi-axial material is needed. The layers can be bonded by adhesive or knitted together to give the desired properties. Compared to single layer fabric, the multi-layer fabric is thicker, stiffer, stronger, and heavier. Recently, a multi-layer, multi-axial Teflon® laminate was successfully developed for an inflatable military application. Tensile strength for this material exceeded 2000 lb/in in four directions (warp, fill, and both 45° axes). New weaving machinery and technologies continue to be developed for the textile industry. Multilayer weave, 3-D braiding, and Jacquard weaving technologies provide opportunities to improve the fabric producibility, strength efficiency, and overall performance.

Figure 4. Vectran® Based Hull Laminate Used in a Prototype Heavy Lift Balloon

Table 2. Compare High Performance Fibers

MATERIAL		**STRENGTH, g/d**	**PROs**	**CONs**
M5®	PIPD	> 40	Strong, good compressive properties, excellent weatherability	Limited technical data and not commercially available
Zylon®	PBO	42	Strong	Low flex resistance, poor UV, visible light, and moisture resistance
Spectra®	PE	25-40	Strong, flexible, and good weatherability	Low melting point, poor creep resistance, and difficult to bond
Thornel®	Carbon	30	Strong, high temperature resistance, excellent weatherability	Stiff , low flex resistance, processing difficulty (weave), and very low stretch
Vectran®	LCP	23	Good overall properties and excellent cut resistance	Not as strong as Spectra® or Zylon®, poor UV Resistance
Kevlar®	Aramid	22	Strength comparable to Vectran®	Poor folding and abrasion resistance
Kosa®	PET	7-9	Tough, durable, inexpensive, fully evaluated LTA fiber	low strength

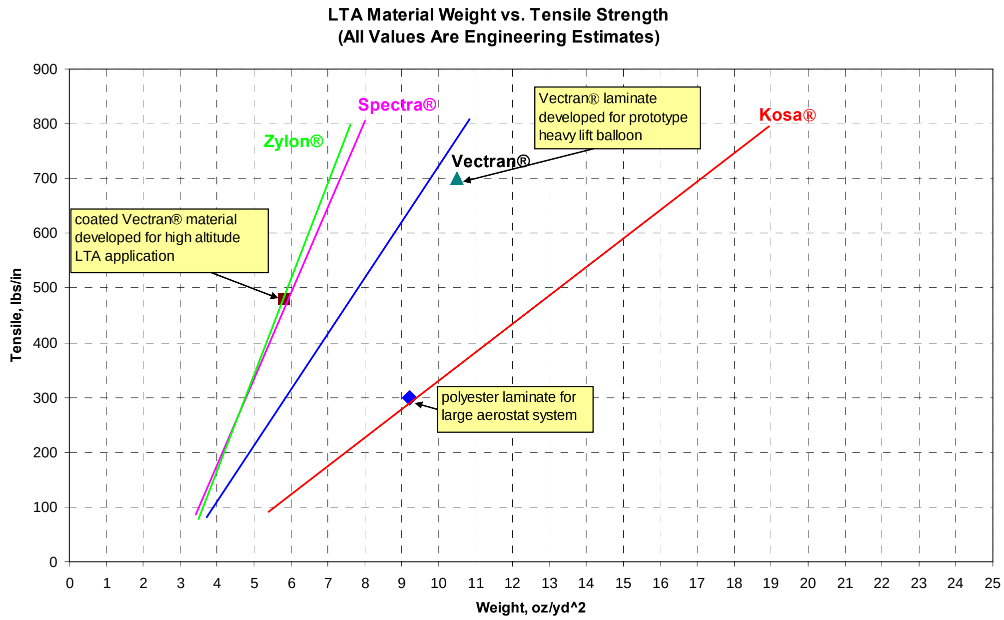

Figure 5. Theoretical Weight vs. Strength for Laminated LTA Material

C. Environmental/gas holding layer

A coating or film is necessary to provide weatherability and gas retention characteristics. The material chosen for this layer(s) must also have good shear stiffness, bondability, and thermal reflective/emissive properties. Table 3 summarizes candidate environmental/gas holding layer polymeric materials.

Floropolymer, Tedlar® film, has been used for most large LTA hull material applications. Tedlar® has excellent resistance to solar degradation. Pigmented Tedlar® film offers the highest level of UV protection which means the strength member underneath will not be exposed to high-energy, destructive light. Tedlar® also has non-staining properties, chemical and graffiti resistance, toughness, flexibility over a wide temperature range (-72 to 107 ºC), and good gas containment properties.

DuPont FEP fluorocarbon film offers excellent optical properties and outstanding weather resistance. Teflon® film can be heat-sealed, thermoformed, welded, metallized, and laminated to many other materials. The low permeability to gases, and low temperature toughness (service temperature range from -240 to 205 ºC) make Teflon® film a good candidate for high altitude LTA applications.

Polyurethane coating on textiles gives a wide range of properties to meet diverse end uses like apparel, artificial leather, fuel and water storage tanks, inflatable rafts, containment liners, etc. Polyurethane is available in many formulations and possesses an excellent balance of properties. It has outstanding overall toughness, high tensile strength, tear strength, abrasion resistance requiring much less coating weight, low temperature flexibility, fair gas permeability, good handling properties, crease resistance, and good weatherability and ozone resistance. Thermoplastic polyurethane can be heat sealed, adhesively bonded, and laminated to other substrates.

Silicone rubber has the best low temperature flexibility of all polymeric materials. However, its high gas permeability, low toughness, and low abrasion resistance are problematic.

Plasticized polyvinyl chloride (PVC) is commonly used in commercially coated fabrics. It has good low temperature flexibility, exhibits good weathering (5 years) and ozone resistance, is heat sealable, and inexpensive.

Low density polyethylene (LDPE) is a very flexible and heat sealable polymer. It is normally coextruded with other films to improve its gas permeation. It is reported in the literature that a lightweight LDPE/Mylar®/polyester fabric laminate has been used in a superpressure balloon application[2].

Vinylidene chloride/vinyl chloride copolymers (Saran®) are excellent barrier materials and extensively used in packaging applications. However, they are not recommended for use in a composite LTA fabric because of their poor flex life, especially at low temperatures.

Triton Oxygen Resistant (TOR) polymers may be a candidate for the protective film layer of high altitude LTA systems. TOR polymers are currently being tested in low earth orbit by NASA and appear to have potential as weather resistant films or coatings in harsh environments. Preliminary data indicates these thermoplastic polymers have a high resistance to degradation from atomic oxygen, ozone and ultra-violet radiation. TOR polymers have the unique ability to form an outer oxidized layer that will protect against abrasion and will reform if surface damage occurs that does not penetrate completely through the material.

Multi-layer films are more likely to achieve the necessary properties. New machinery and technologies, like co-extrusion, make it possible to eliminate the adhesive between multiple layers, thus reducing weight while maintaining other critical properties, such as adhesion, weatherability and gas retention. Other approaches, like polymer blending, can combine characteristics typically achieved from multiple layers into a single film. It is also reported that polymers containing inorganic additives and inorganic surface coating (plasma) may significantly reduce gas permeability. These new technologies are currently being used or experimented with in the packaging industry.

LTA system diurnal temperature changes impose significant challenges for vehicle altitude control, power consumption, as well as for the envelope and ballonet materials. The material surface properties significantly influence system thermal control. A low solar absorptivity with a high infrared emissivity (low α / ε ratio) is desirable to minimize system temperature excursions. A white non-metallic surface is good, but a transparent non-metallic surface with a shiny metallic backing is better. Table 4 compares several material combinations, white Tedlar®, silvered Teflon®, quartz over silver, and a lab coupon produced for a high altitude LTA system study. As shown in Table 4, the metallic finished lab coupon demonstrated excellent thermal control parameters.

Table 3. Candidate Environmental/Gas Holding Polymeric Materials

Material	Permeability	Weatherability	Flex Fatigue	Adhesion to Fabric/Film	Heat Sealability
PVF (Tedlar®)	Good	Excellent	Good	Poor	No
PTFE (Teflon®)	Good	Excellent	Good	Poor	Yes (> 500 °F)
Polyurethane	Fair	Good	Excellent	Excellent	Yes
Silicone Rubber	Poor	Excellent	Excellent	Poor	No
PVC	Fair	Good	Good	Excellent	Yes
Low Density Polyethylene	Fair	Fair	Excellent	Poor	Yes
PVDC (Saran®)	Excellent	Poor	Fair	Fair	Yes
Nylon	Excellent	Poor	Excellent	Fair	Yes
Polyester (Mylar®)	Good	Fair	Fair	Fair	No

Table 4. Material Surface Thermal Properties

	α	ε	α/ε
White Tedlar®	0.3	0.85	0.35
Silvered Teflon®	0.08	0.6	0.13
Quartz over Silver	0.077	0.79	0.10
LTA hull coupon	0.07	0.75	0.09

D. Adhesive layer (s)

Adhesive is often used in multilayer composite material to bond the various components together. A thin adhesive layer(s) is critical to minimize material weight. Flexibility and good bondability to each component (to prevent delamination) are essential requirements for the adhesive. The intermediate adhesive layers can be either thermoset or thermoplastic. However, if welding technology is used, the inner layer must be thermoplastic.

The adhesive properties are mainly controlled by the bulk properties of the polymer selected. Various formulating agents, like plasticizers and fillers, are used to modify the base polymer. In addition to the adhesive, substrate surface properties, treatments, and application processes also significantly affect the finished material weight, flexibility, bond strength and other physical properties. Selecting the adhesive, the substrate surface treatment, and the proper application technique are key parameters in achieving a well engineered material.

E. Joint Challenges

Joining technology is as critical as development of the base material. Since the base material carries the loads, the seam must be able to transfer these loads from one piece of base material to another, which creates tensile and shear forces on the seam. As a result, it is important that the tensile properties of the finished seam be equal to or greater than the strength of the base material itself to ensure the integrity of the entire envelope structure and maximum structural efficiency.

Butt and lap joints, as shown in Figure 6, are typically used for LTA construction. The lap joint is a simpler design, but has the restriction that the material must be structurally bondable on both sides.

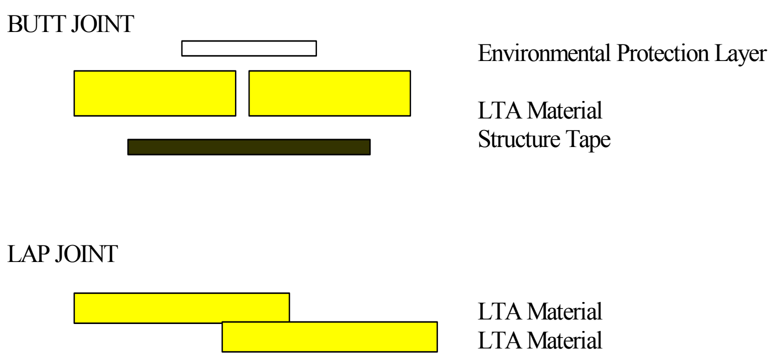

Figure 6. Typical Joint Design

Once the type of seam is identified, there are several joining techniques to consider for fabrication of the LTA envelope:

1) Ultrasonic welders produce a continuous or static weld in thermoplastic materials. The continuous feed machines draw the material into the machine through a feed mechanism and series of rollers that subjects the material to ultrasonic vibrations that heats the material while under pressure.
2) RF welders are typically configured to produce both static and "semi-continuous" welds in thermoplastic materials.
3) Thermal welders produce a seal in thermoplastic materials using an external heat source and pressure. There are three primary variations of the thermal welder, impulse, hot wedge and hot air. All are available in both static and traveling configurations.
4) Mechanical bonding includes sewing with gas seal tape, fasteners, etc.
5) Adhesive bonding is applying a structural adhesive such as polyurethane, epoxy, acrylic, etc., to the bonding surfaces with or without pressure to produce a joint.

In general, joining medium strength materials (up to 700 lb/in) using a thermal technique (impulse welder) has been very successful. However, joining much stronger material has proven to be very challenging. Wider structural tape and/or double tapes (tape on both sides of the material) have been tried with some success. Design and development of a seaming system (seam design and seaming technology), remains as a major challenge for high strength LTA material.

In addition to the strength requirement, the low temperature environment and thermal cycling impose significant issues for joint integrity and durability. The joint must be able to absorb stresses and have high fracture energy at the service temperature. One major factor is the adhesive polymer bulk properties. Glass transition temperature, Tg, is a very useful physical property measurement that reflects the behavior of polymers in the adhesive. Molecular freedom influences the behavior of the polymer. At low temperatures the polymers exist as solids in which the molecular segments vibrate rather gently and independently. As the temperature of the polymer is increased, a point is reached at which the molecule suddenly becomes more flexible and mobile. The temperature required to cause this increase in molecular freedom is known as the glass transition temperature, Tg. The Tg signifies a transition of the polymer from a glassy to a rubbery state. Flexibility, toughness and solvent penetration increase at temperatures above the Tg, while tensile strength and elastic modulus decrease. Therefore, the relationship between the Tg and the service temperature is a critical consideration in predicting the performance requirements of polymer materials[3].

Polymers with low transition temperatures are more resistant to low temperature. Several adhesives are considered good candidates for low temperature application.

1) Polyurethane has the best low temperature properties of all commercially available adhesives. Some grades of polyurethane offer outstanding cryogenic properties. Polyurethane adhesives are easily processed and bond well to many substrates.
2) Silicone adhesives retain excellent properties over a wide temperature range from approximately 250 ºC down to the cryogenic range. In general, silicone elastomer joints are superior where peel is the primary loading rather than for tensile or lap shear properties.
3) Rubber based adhesives demonstrate useful properties at low temperatures. Included in this group are butyl, neoprene, and polysulfide rubbers. Those adhesives normally retain their flexibility between -50 and 60 ºC.
4) Modified epoxies are often selected for low temperature applications whenever urethane and silicone adhesives are not suitable.
5) Pressure sensitive acrylic adhesives are used primarily for packaging and label applications and are excellent down to approximately -50 ºC. Thermosetting acrylic resins are generally considered excellent structural adhesives at temperatures down to -40 ºC

Another important factor is the effect of thermal cycling and resulting internal stresses on the joint interface. Difference coefficients of thermal expansion and thermal conductivity between the adhesive and adherend can result in residual stress. Trapped gases or volatiles evolved during bonding are other opportunities for stress concentration in bonded joints. These internal stresses are magnified under low temperatures, and could lead to bond rupture[4].

IV. Ballonet Material Challenges

Ballonet material is another important component of a Lighter-Than-Air system. The ballonet is an internal barrier that separates the air and helium compartments inside of the hull. The ballonet allows the lifting gas in the hull to expand and contract during altitude and temperature changes and is continually flexed as it is inflated and deflated. Because the ballonet is required to inflate/deflate during operation, the ballonet must remain flexible throughout the most extreme temperature conditions the system will experience. The ballonet material must also be lightweight, have good abrasion resistance, and exhibit low gas permeability to minimize lifting gas loss and purity decay.

A. Material challenges

Flexible film and fabric supported materials have been used as ballonet material in LTA systems. A flexible film, such as polyurethane, PVC, polyethylene, or multi-layer film can be used since the ballonet is not generally subject to continuous load. However, under any flight condition that puts the ballonet membrane under stress, the film will stretch to relieve the stress. If the stress is below the yield point of the film, the film will fully recover when the load is removed. A reinforced material, such as a coated lightweight woven material is more commonly used. Coated fabric generally has improved strength and better handleability. The coating is applied to both sides of the fabric to provide the air/helium retention, abrasion resistance, and bondability. For large ballonets, both film and coated fabric may be used in combination. The coated fabric is used as the ballonet "skirt material" to join the main body of the ballonet to the hull. This skirt material is intended to support the ballonet body weight and resist the attachment forces while an unsupported flexible film is used for the main ballonet body material to provide better flexibility and save weight.

Desirable properties for high altitude LTA ballonet material include low temperature flexibility, low gas permeability, minimal weight, good bondability, abrasion resistance, and ozone resistance, etc. Low temperature flexibility is considered the most important parameter. The most promising polymeric materials were found to be polyolefin, polyurethane, ethylene propylene diene monomer (EPDM) rubber, and silicone rubber. Table 5 compares these polymeric materials along with some other materials used in LTA industry. Some candidate ballonet materials were developed and evaluated for high altitude LTA application. Polyurethane is a good polymeric material for moderately low temperature ballonet applications. It has been successfully used for years by the LTA industry. This material exhibits excellent material properties above approximately -20°C, including excellent flexibility, good abrasion resistance, and fair helium/air permeability, with minimal coating thicknesses. However, the low temperature flexibility is not satisfactory. Silicone rubber exhibits the best low temperature flexibility of all the candidate polymeric materials. Unfortunately, however, silicone rubber has the worst gas permeability of all the candidate polymeric materials. Considerably more work needs to be done to improve the permeability of silicone rubber. Investigation of multi-layer structures, gas barrier additives, plasma coating, and polymer blending are approaches that may improve the material performance.

Table 5. Candidate Ballonet Polymeric Materials

Polymeric Materials		Specific Gravity	Low Temperature Flexibility	Ozone Resistance	Heat Sealable	Permeability[5] (cm^3.mm)/(m^2.day.atm)		
						O_2	N_2	He
polyvinyl fluoride	PVF	1.4	poor	excellent	no	1.2	0.1	59
fluorinated ethylene-propylene copolymer	FEP	2.2	good	excellent	yes	40	125	
polyester	PET	1.4	poor	poor	no	2.4	0.39	67
ethylene vinyl alcohol copolymer	EVOH	1.1-1.2	poor	good	yes	0.02	0.003	9
polyester rubber		1.17-1.25	fair	fair	yes		147	1356
polyurethane rubber	PU	1.05-1.3	fair	good	yes	141-1067	35-297	687-2340
low density polyethylene	LDPE	0.91-0.94	good	good	yes	102-188		
ethylene-propylene rubbers	EPDM	0.96-1.05	good	good	no		553	1410
silicone rubber		1.1-1.16	excellent	excellent	no	19685	17280	19050

B. Evaluation challenges

Beyond the material challenges, establishing requirements and estimating service life and flex life present additional challenges to the material designer. Currently there are no published models that simulate ballonet movement and no suitable test standard for flex and service life evaluation. The LTA industry has been using ASTM D 6182 (Flexibility and Adhesion of Finish on Leather) for material comparison. This test is mainly used by the artificial leather industry to evaluate resistance to cracking, delamination, and discoloration of the finish when subjected to repeated flexing. The sample size is fairly small, 45 by 70 mm, and the specimen is repeatedly flexed through the center line, see Figure 7. To evaluate the material flex life at low temperature, the test fixture can be placed in a low temperature environmental chamber, see Figure 8, and the specimen movement can be observed through the observation window. Based on years of field experience and data from this test, some correlation has been established for low altitude LTA systems. However, no correlation has been established for extreme low temperature high altitude LTA systems. Establishment of a material flex life requirement, development of a flex test fixture, procedure, and standard in parallel with material development are necessary steps to ensure high altitude LTA system success.

V. Conclusion

LTA systems operating in the stratosphere impose significant challenges to the system hull and ballonet flexible materials. The main challenges for hull material are the strength member and seam design/technology. Development or identification of a strong light yarn (fiber) that is suitable for the stratospheric environment is the first key step. High performance fibers such as, Vectran®, Spectra®, Zylon® and M5® are attractive candidates. These fibers have the potential to save significant system weight, which reduces system size and/or increases payload weight. However, concerns such as stress concentration, creep, fatigue, moisture and UV resistance remain for these fibers.

The second key step is the design of a "structurally efficient joint" for these high strength materials. An efficient joint which is equal to or stronger than the base material is as critical as the envelope material itself. Joint design, adhesive selection, and seaming technology are major factors affecting joint strength. Furthermore, joint performance under extreme low temperature and thermal cycling will need further investigation.

The main challenges for the ballonet material are the low temperature flex life and establishment of flex life/service life requirements. Silicone rubber exhibits the best low temperature flex life but also is the most permeable polymeric material. Further modification or composite design will be necessary before silicone is successfully used as a ballonet material. In addition, development of a model to simulate ballonet movement, establishment of flex life and service life requirements, development of a flex machine and test specification must also be accomplished in parallel to ensure high altitude LTA system success.

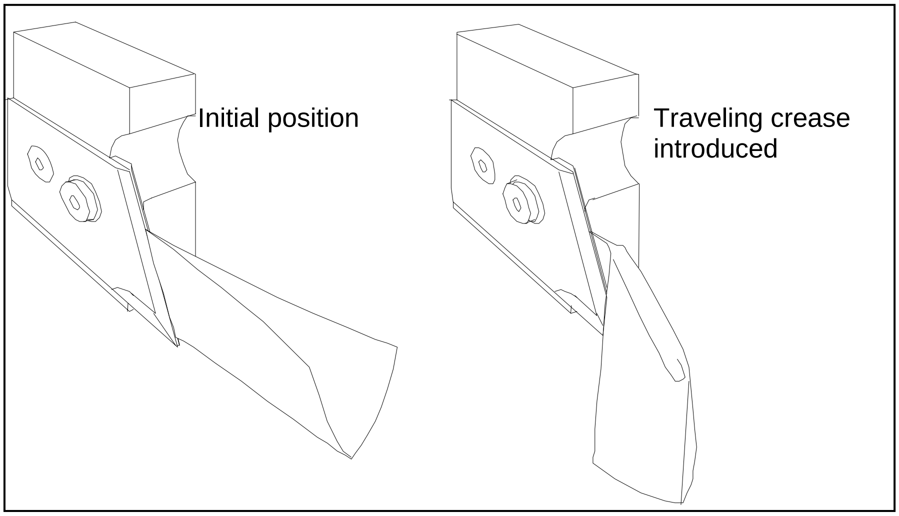

Figure 7. Specimen Set Up of ASTM D 6182 Bally Flexometer

Figure 8. Bally Flexometer in a Cold Chamber

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