

INFLATABLE AND RIGIDIZABLE WINGS FOR UNMANNED AERIAL VEHICLES

David Cadogan^{*†}, William Graham^{*‡}, Tim Smith^{*§}

Abstract

Recent shifts in tactical defense operations have led to a need for improved capabilities in Unmanned Aerial Vehicles (UAVs). Several vehicle types such as the Predator are currently operational, and numerous smaller specialized vehicles are under development. Many of the vehicles under development require the ability to stow their wings and control surfaces into very small volumes to permit gun launch or packaging into aircraft mounted aerial drop assemblies. One technology that has shown promise in achieving this goal is the inflatable wing.

Inflatable wings have been demonstrated in many applications over the past five decades, including aircraft, UAVs, airships, and missile stabilization surfaces. Recent advancements in high strength fibers and rigidizable materials have enabled higher performance designs for modern application. The inclusion of “smart materials” has provided the opportunity to impart a multi-functional capability to inflatable wings. Such materials include electronic-textiles, which provide the potential for the integration of numerous functions directly into the structure of the wing such as shape modification for control and morphing, power generation and storage, antennas, and sensing.

Past, present, and future developments of inflatable and rigidizable wing structures for use on UAVs, airships, and other applications are presented. Patents exist and are pending for information discussed in this paper.

Introduction

Inflatable wings have been in existence for decades and have found application in manned aircraft, UAVs, munitions control surfaces, and Lighter Than Air (LTA) vehicles such as aerostats. Recent system design challenges have ushered advances in the areas of materials, manufacturing, and configuration that have

advanced this technology into a practical form for near term application (Figure 1). Maturation of the materials used in inflatable structures such as space suits and Mars landing craft impact attenuation airbags, has led to an improved understanding of high strength fibers and laminates that are now used in high performance inflatable wings [1]. Fabrics with high strength to weight ratios such as Kevlar, Vectran, and PBO, have enabled inflatable wing designs that possess a high packing efficiency.



Figure 1. Inflatable UAV Wing (ILC)

Inflatable wings can be packed into volumes more than ten times smaller than their deployed volume without damaging the structural integrity of the wing materials. Deployment can occur on the ground or in flight, in a very short duration on the order of fractions of a second to a few seconds, depending on the size of the wing and the type of inflation system used.

The strength and stiffness of the inflatable wing are dictated by the type of material used, the cross-section design of the wing, and the internal pressure. It is desirable to reduce the internal pressure to as low a value as possible to reduce the mass of the inflation system and structure, and reduce leakage rates. The preferred approach uses a design that is comprised of a series of fabric spars that run roughly perpendicular to the aircraft body, and are attached to an upper and lower fabric restraining layer. This approach results in a cross sectional design that possesses a high moment

^{*} ILC Dover, Inc., Frederica, DE

[†] Associate Fellow AIAA

[‡] Member AIAA

[§] 2nd AIAA “Unmanned Unlimited” Systems, San Diego, CA, Sept. 2003 AIAA 2003-6630

of inertia. The surface of the resultant inflated structure has a “bumpy” appearance, as inflatable structures approximate the shape of a cylinder or sphere upon inflation. A skin can be added to the surface of the structure to provide a smooth aerodynamic surface. Through appropriate design of the fabric patterns that make up the inflatable wing, a variety of wing shapes can be manufactured, including wings that possess camber.

One of the more notable features of an inflatable wing is its durability. The materials are robust and can be packed and deployed numerous times in test or reuse with minimal degradation in performance. The use of an inflatable reduces the likelihood of damage in shipping, handling, flight, and landing, through the impact resiliency of the materials, and the natural impact absorption capabilities of an inflatable structure. As a result, there is less of a need for highly skilled support personnel in the field. A related property of inflatable wing design is the ability of the wing to recover shape in flight if the load limit is exceeded and the wing buckles.

Another technology that can be used to create an inflatable wing with a high packing efficiency and improved performance is rigidization. Rigidization is the action by which a flexible inflatable structure is converted into a rigid composite structure. Once a wing or other surface is “rigidized”, it no longer relies on inflation pressure to maintain its shape. This technology has been most recently applied to deployable space structures such as antennas, solar arrays, and solar sails [2]. Several mechanisms exist by which to rigidize a structure, including thermal-chemical reactions, UV-chemical reactions, and inflation gas-chemical reactions.

The most notable advantage of a rigidizable structure, is the increased stiffness that results compared to a structure supported by inflation pressure alone. Stiffness increases of an order of magnitude or more can be achieved over comparable inflatable only structures. This will allow for the evolution of thinner airfoils and improved aerodynamic performance compared to a conventional inflatable wing. A further advantage of a rigidizable wing is the elimination of inflation gas dependence to maintain the shape of the structure after deployment. Inflation gas is required only to initially deploy the structure.

Inflatable aerodynamic surfaces have been considered for use in several military UAVs [3,4,5]. These include the Loitering Electronic Warfare Killer (LEWK) (Figure 2), the US Navy Forward Air Support Munition

(FASM), the US Army Quicklook, and the Small Unmanned Aerial Vehicle (SUAV).



Figure 2. LEWK Prototype Vehicle (SAIC)

Background

Inflatable wing technology has been used in aircraft applications since the 1950's. Many concepts have been proposed since the 1930's [6], and numerous incarnations are flying today, some are mentioned in this paper. Goodyear Aerospace designed and manufactured several prototype aircraft using inflatable components during the 1950's [7]. The GA-33 Inflatoplane had capabilities comparable to a J3 Cub (Figure 3).



Figure 3. The GA-33 Goodyear Inflatoplane (1956)

The airplane was maneuvered into position like a wheelbarrow on its own wheel and inflated within 5 minutes to ~25 psi. It used a two-cycle 40 horsepower Nelson engine that was hand started. Its wing span was 22 feet and had a length of 19 feet 7 inches. The airplane held 20 gallons of fuel and carried a maximum weight of 240 lbs. Its range was 390 miles with an endurance of 6.5 hours. Its cruise speed was 60 mph. The inflatoplane could be dropped by container behind enemy lines as a means of rescuing downed pilots. It was ideally suited for both land and water use. A total of twelve Inflatoplanes were built. Development, testing, and evaluation of the inflatable airplane continued through 1972 and the project was finally terminated in 1973.

The 2 place GA-466 Inflatoplane was also designed by the Goodyear Company in the 1950s (Figure 4). The airplane was inflated to ~25 psi in about 6 minutes. This aircraft used a 60 horsepower McCulloch 4318 engine that was hand started. Its wing span was 28 feet and had a length of 19 feet 2 inches. The airplane held 18 gallons of fuel and had a gross weight of 740 pounds. The range of this airplane was 275 miles with an endurance of 5.4 hours. Its cruise speed was 55 mph, stall speed was 43 mph, and had a maximum speed of 70 mph.



Figure 4. The GA-466 Goodyear Inflatoplane

ILC Dover employed inflatable wing technology in the 1970s with the invention of the Apterion unmanned aerial vehicle (Figure 5). This small vehicle was able to be stored in a small volume for ease in portability, and launched from any remote location. This aircraft had a 5.1 ft wingspan, and a 0.5 hp engine. The entire craft weighed 7 lbs. Elevons were used for flight control.

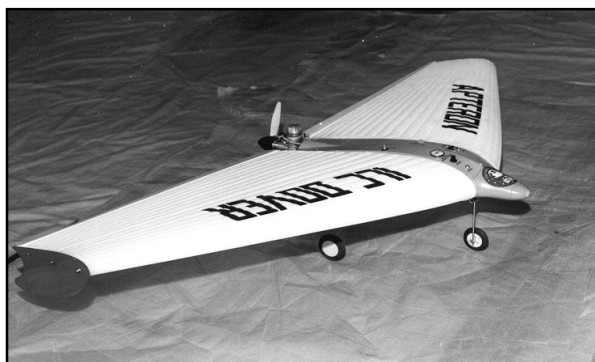


Figure 5. The ILC Dover Apterion

Inflatable wing/fin technology has also been demonstrated for several decades on lighter than air (LTA) vehicles that use tail-fin assemblies for stability and control (Figure 6). These vehicles range in size from 15 ft long advertising vehicles to 595,000 ft³ aerostats [8]. The fins are symmetrical airfoils based on

the NACA 0018 geometry. Aerostats are tethered to the ground during operation and are used to carry an airborne radar platform for border surveillance. They can fly in winds of 60 kts, with gusts up to 90 kts. The fins are constructed from a multi-ply fabric that provides gas retention and a structural layer to react aerodynamic loading. The envelopes are constructed from a flexible composite material using thermal and radio frequency sealing techniques.



Figure 6. 420,000ft³ aerostat

Inflatable fins of similar design have been tested in deployable munitions stabilization applications. One such program was the Weapons Integration and Design Technology program (WIDT) for the Air Force Research Laboratory, Eglin AFB, Florida (Figure 7). In this program, various technologies including inflatable fins were developed for creating a compact vehicle package with a reduced radar signature for external weapons carriage. The inflatable stabilization fin prototypes were designed for use with 250 lb and 500 lb bombs, deployed at altitudes of 300 to 25,000 ft and at speeds up to Mach 1.2. Inflation occurred in under 150 milli-seconds using a CO₂ gas generator. The inflation pressure was 200 psi.

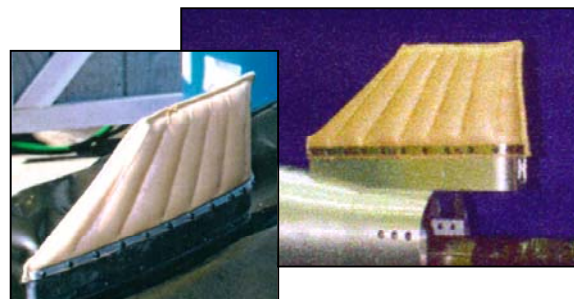


Figure 7. WIDT Munitions Fin

Inflatable Wing Development

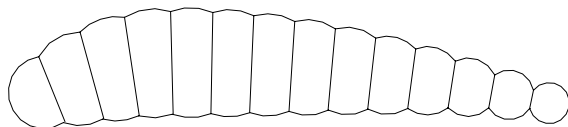
Inflatable wings constructed by ILC are typically comprised of a gas retaining bladder and a structural restraint that reacts inflation and aerodynamic loads

(Figure 8). Several methodologies have been used in the past, including inflated tubes of various diameters covered by a tensioned skin and sometimes supported underneath by a foam [9, 10, 11]. However, this paper focuses on a highly efficient multi-spar approach, which provides several advantages over tubular approaches.

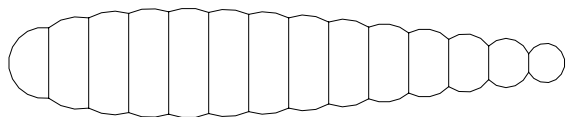


Figure 8. Inflatable Wing Restraint

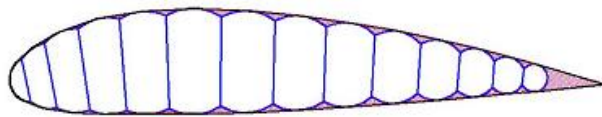
In the multi-spar approach, wing stiffness is dictated by internal pressure and the modulus of elasticity of the restraint material, and can be elevated through the use of higher strength and modulus materials that can withstand higher internal pressures. The cross-section of this type of airfoil reveals that the geometry of the wing is defined by a series of intersecting cylinders (Figure 9).



NACA 8318 with even spar distribution



NACA 0018 Symmetrical with even spar distribution



NACA 4318 with distributed spars & skin

Figure 9. Inflatable Wing Cross-Sections

The exterior of the wing has a “bumpy” appearance, but can be covered with a skin to improve aerodynamics (Figure 10). The volume difference between the inflated shape and the ideal airfoil shape is minimal,

and if filled with a compressible spacer material, would have little impact on the packing volume of the wing. Minimizing spacer material also limits the potential for adverse shape effects due to compression set of this material during packing and storage.



Figure 10. Inflatable Wing with Skin in Wind Tunnel

Inflatable wings can be made tapered, swept, or altered in planform through appropriate patterning of the restraint. Similarly, with careful patterning, the airfoil can be made to have camber. Fiber positioning is used in the design of the external restraint and internal spars to control elongation and therefore dimensional accuracy of the construction. The use of internal spars to separate the upper and lower external restraints yields a wing that optimizes the cross-sectional moment of inertia of the wing by maximizing internal pressurized area. This yields the lowest possible internal pressure required for the wing which in-turn yields lower potential for leakage, lower inflation system mass, and a lower packed volume.

Inflatable Wing Materials - The restraints are manufactured from high modulus fibers such as Kevlar, Vectran, or PBO. The fibers are selected based on the storage and performance requirements of the vehicle (Tables 1 & 2). Packing characteristics also play a large part in the selection of fibers. Some fibers, such as PBO, are sensitive to compression failure experienced in bending, which significantly degrades strength and stiffness, and are less desirable. PBO also degrades when exposed to various wavelengths of light, reducing its tenacity. However, even with these factors, PBO still retains a large percentage of its strength and stiffness to make it competitive for various applications.

Vectran has been used by ILC in numerous aerospace applications including the Mars Pathfinder and MER impact attenuation airbags [1]. Notable properties of this fiber include excellent resistance to degradation from handling and packing, as well as an increase in strength in cold environments. Kevlar is another high strength fiber that is slightly lower in cost and available

in a wide range of weaves. To date, inflatable wings have been manufactured from Vectran and Kevlar.

Material	Specific Gravity	Cost	Yarn Tenacity	Tensile Strength	Tensile Modulus	Strain to Failure
	g/cm ³	\$/lb	g/den	x 10 ³ psi	x 10 ⁶ psi	%
SPECTRA/DYNEEMA						
- Dyneema	0.97	23	40	507	16	3.5
- 900 UHMW PE	0.97	23		375	17	3.5
- 1000 UHMW PE	0.97	29	32	435	25	2.7
VECTRAN						
- HS	1.41	22-90	23	412	9.4	3.3
- M	1.4	15	9	161	7.6	2
PBO						
- AS	1.54	110	42	840	26	3.5
- HM	1.56	110	42	840	39	2.5
KEVLAR						
- 49 Aramid Fiber	1.46	25	23	420	9.8	2.5
- 29 Aramid Fiber	1.46	15-40	23	420	12	3.6
- 68 Aramid Fiber	1.46	15-40		420	25-26	
- 149 Aramid Fiber	1.55	25	18	340	21	1.45
TECHNORA						
- T-240	1.45	15-30	28	414	15.8	4.4
FIBERGLASS						
- S-Glass	2.49	5.5	21	665	13.5	5.7
- E-Glass	2.6	0.85	15.1	500	12.4	4.8
GRAPHITE/CARBON						
- H.S. Pan	1.7-1.8	20	21.3	410-580	33-36	2-2.5
- UHS Pan	1.7-1.8	20	31.3	590-830	38-42	1.8
- HM Pan/Pitch	1.8-2.0	20	14.2	250-500	50-80	0.4
- UHM Pitch	2.0-2.2	20	11.9	300-360	90-130	0.3

Table 1. High Performance Fiber Physical Properties

Numerous materials are available and suitable for the design and construction of the internal bladder. Material selection is typically driven by flex cracking and modulus at cold temperature, manufacturing process, resistance to gas permeation, and resistance to developing pinholes when folded or flexed. Polyurethane is often used, but specialized polyurethane compounds and laminates, such as Armorflex™, are also applicable. The materials used in the construction of the inflatable wings have low dielectric constant and are therefore low observable from a radar perspective.

PROPERTY	POLYESTER	KEVLAR	SPECTRA	VECTRAN
Tenacity (g/d)	8.3	22	30	23
Modulus (g/d)	80	458	1400	525
Shrinkage @ 350°F, %	1.6	Minimal	Decomposes @ 296°F	Minimal
Resistance to Flex Cracking	Excellent	Poor	Excellent	Good
UV Degradation	Good	Poor	Good	Poor
Hydrolytic Stability	Good	Excellent	Excellent	Excellent
Oxidation Resistance	Good	Excellent	Excellent	Excellent
Coating Adhesion	Excellent	Good	Poor	Excellent
Creep Under Load	Good	Excellent	Poor	Excellent
Abrasion Resistance	Fair	Poor	Excellent	Good
Elongation @ Break	16.3	3.6	3.5	3.3
Density	1.38	1.44	0.97	1.4

Table 2. Fiber Characteristics

Packaging & Deployment - Several folding techniques can be used to package the inflatable wings for deployment. Random, z-folding, rolling, and combinations are usually considered. Deployment rate and effects on flight dynamics are leading criteria in the selection of the method. Inflatable wings can pack into volumes more than ten times smaller than their deployed volume. A well packed structure can exceed packing efficiencies (package volume to material volume) of 60%.

Deployment synchronicity is improved as the rates of deployment are increased. Some control can also be achieved through specific packing patterns and control of the inflation path. This approach can also be used to build stiffness of the wing from the root during deployment, to eliminate the potential for wing fold-back. Regardless of the path they take during deployment, inflatable wings always achieve their final shape because of their robust nature. An example of a wing with a 10:1 deployed to packed volume can be seen in Figure 11.



Figure 11. Packed Inflatable Wing

System Analysis - There are several benefits and drawbacks to the use of inflatable wings that must be considered by the user prior to selection of a technology. The greatest advantage that inflatables provide over conventional structures is in packaging. This is usually at the core of a decision to consider inflatable structures for wings. Some higher order benefits and drawbacks of inflatable vs conventionally constructed (metal or composite) wings include the following:

Benefits:

- High packing efficiency (low packed volume)
- High G deployable
- Robust / simple / reliable (no moving parts)

- Low cost
- Long storage life
- Recoverable / durable / reusable
- Can be morphed or shape modified for control
- Can recover shape if buckling occurs in flight (gust load)
- Inflatable structures dampen vibrations well

Drawbacks:

- Potential for leakage / ballistic penetration
- Thicker airfoil required for high stiffness – less efficient aerodynamically
- Aspect ratio limited for high wing loading
- Inflation system mass burden
- Need for make-up gas (thermal/altitude excursions)

This list is not inclusive but is representative of the aspects of the technology for consideration.

Many of these drawbacks can be addressed by applying a materials technology known as “rigidization”. In this approach, a flexible material is packed and deployed as in the case of the inflatable wing, but then undergoes a change in properties and becomes rigid, no longer requiring the support of inflation gas to maintain its geometry. This approach will be discussed in the next section.

Inflation Systems - Inflation systems can be configured from several well understood technologies such as bottled compressed gas, chemical gas generators, feed lines from engine compressors, etc. DC electric blowers are used in aerostats and are very efficient sources of inflation gas in these low pressure systems. Inflation system selection will depend on several criteria focused on mission requirements such as deployment time, thermal and altitude gradients after deployment, and the need for a pressurization maintenance source for long duration missions.

Integrated Technologies – There are a number of technologies that are maturing rapidly that can expand the inflatable wing’s performance, several of which are being studied for application. The collapsible and deformable nature of a textile assembly makes an inflatable wing an attractive platform upon which to apply wing morphing techniques. Actuators can be applied strategically to alter the shape, size and cross section of the inflatable wing for various flight regimes. This approach has the potential to be extremely mass effective in comparison to mechanical technologies, especially if electronic textiles can be applied. Electronic textiles, or E-textiles, are an emerging class of materials that combine electrical components directly into textile materials, such as the restraint in this case [12]. These materials can be made to perform various

functions such as changing shape via constriction, producing power, acting as sensors or embedded antennas, or as microcircuits.

E-textiles are being developed for use in inflatable wing structures as control mechanisms. Through deformation of the wing geometry, a simple method of control can be obtained that reduces part count and complexity of wing systems. Control of this nature also provides a smooth transition at the trailing edge of the wing, thus reducing aerodynamic disturbances of mechanical systems. This is accomplished through constriction or deformation of various components within the inflatable wing structure, especially the aft third of the airfoil, where loading and cross-sectional stiffness are lower and can be more easily maneuvered. Examples of how Nastic cells, a biomimetic style of actuation system noted in plants, are shown in Figure 12. Through inflation of these small tubes, foreshortening the selected area can locally alter the shape of the wing. Deformation of this nature is desirable for long duration camber change, but may be too low in frequency response to be used as a control mechanism.

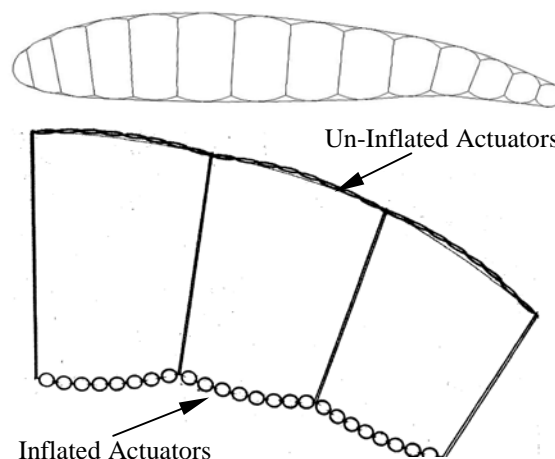


Figure 12. Nastic Cells for Morphing Inflatable Wings

The most promising method of morphing wing shapes for control purposes focuses on the use of piezoelectric materials. Several approaches of application of these materials to inflatable wings are currently under development. Two different types, Thunder and Macro-Fiber Composite (MFC) actuators produced by FACE International and Smart Material Inc. respectively, are being applied to the surface of wings for test. These can be applied in a localized or a global format. Figure 13 shows one method of altering the shape of the wing that is currently in test. Flattening of the bumps in the inflatable wing extends the surface run length and thus deforms the shape of the wing.

Excitation can occur rapidly thus allowing the technique to be used for control applications via local morphing.

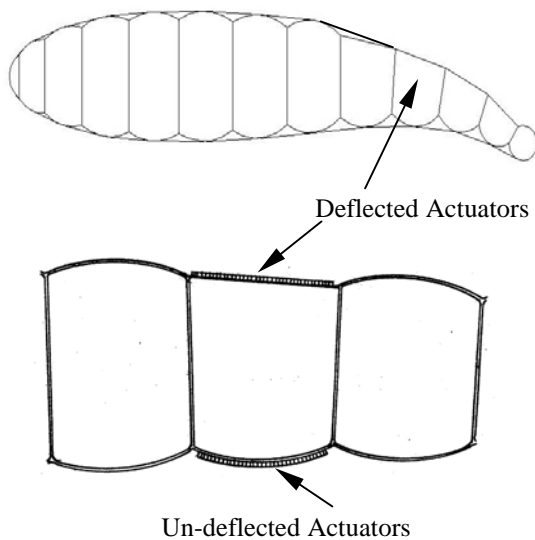


Figure 13. Piezoelectric Actuators for Morphing Inflatable Wings

Rigidizable Wing Development

A number of potential drawbacks have been identified and discussed with regard to inflatable wings. ILC has developed a technique for addressing these issues and creating an inflatable wing that can be packaged into a small volume, yet provide the same structural properties of a conventional composite or metal wing. This method of transformation is known as “rigidization” and is currently being patented for this application. Rigidization is a process by which a flexible material is altered physically by an external controlling influence and becomes a solid composite structure [13, 14, 15, 16]. Numerous mechanisms are available, but the most promising appear to be Ultra-Violet (UV), and Inflation Gas Reaction rigidization. UV Rigidization uses UV radiation to cause a chemical reaction (cure) in a matrix resin, and Inflation Gas Reaction resin uses an inflation gas that is loaded with a curative agent that reacts with a benign matrix resin in the structure. Once the wing is made rigid, within seconds to minutes depending on resin chemistry, the wing no longer requires inflation to provide structural stability.

The most practical in the near term for wing structures appears to be UV-chemical exposure. In this case, a reinforcement fabric is coated with an uncured polymer that chemically hardens when exposed to Ultra-Violet light to form a composite structure. The UV source can be the sun or from internal sources such as LEDs. Timing of the rigidization event is controlled by the resin chemistry, and can be on the order of tens of

seconds if required. The wavelength at which the material rigidizes can be shifted to accommodate manufacturing and field use needs if required, or to cure at various rates under specified conditions. Resin cure is accelerated under elevated thermal conditions and may require an integrated method of heating the wings during cure if very cold environments are encountered. The reinforcement fabric can be one of several materials normally used in composite structures, but glass or quartz is normally preferred for ease of UV transmission. Distributed reinforcements of higher performance fibers such as carbon can be used if required to further optimize structural efficiency. For brevity the UV system only will be discussed.

The motivation for this work is to provide an inflatable wing with properties that approach that of a fixed rigid wing made from metal or composite materials. A majority of the benefits of inflatable wings still exist, however, some of the drawbacks can now be addressed. This provides some advantages in several areas including the following:

- Reduced puncture/leakage vulnerability
- Stiffer than an inflatable wing (higher load factor)
- Thinner, Higher Aspect Ratio Wing = Less Drag, improved aerodynamics
- No gas leakage / make-up gas mass or complexity
- Longer flight duration via efficient wing design
- Smaller, Lighter Deployment System
- Minimal inflation pressure required (3-5 psid)

There are many benefits of this approach that lead to the potential for some high performance UAV systems. However, there is still one limitation to this approach, which must be considered. The time duration of the cure of the composite and the design of the thin, potentially high aspect ratio inflatable wings, require that the wings not be “loaded” during rigidization. In other words, the UAV will probably have to be deployed and rigidized while suspended from a parachute. The parachute and possibly the inflation system can then be jettisoned prior to the flight component of the mission. If the wings were to be aerodynamically loaded, they would have to rely on the design of the inflatable structure and thus have a thicker cross-section and be inflated with a high-pressure inflation source.

Inflatable rigidizable wing components are currently being designed and fabricated in a university space grant consortium flight experiment program. In this effort the University of Kentucky is structuring a high altitude balloon drop test for a UAV with inflatable rigidizable wings supplied by ILC. The wings will be

inflated and rigidized during ascent (from 60,000 to 80,000 ft), and then the aircraft will be dropped from an altitude of approximately 80,000 ft. Photography and location transponders will be used to monitor the deployment and flight characteristics of the wings. In this case the sun's radiant energy will be used to rigidize the wings.

Several subsections of the wing were fabricated and tested to verify manufacturing techniques and structural properties of the rigidized component. The completed wing shown in Figure 14 is the test model of the inflatable rigidizable wing, manufactured from a fiberglass/UV epoxy laminate.

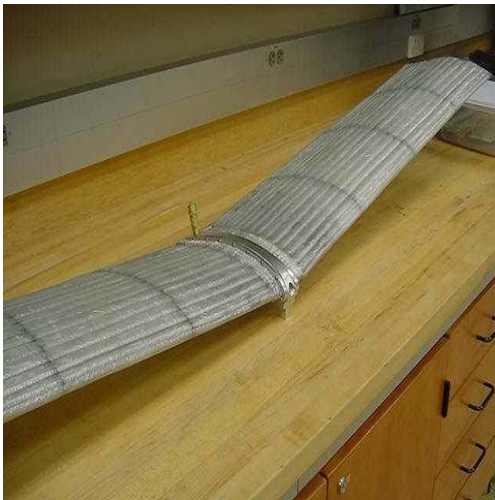


Figure 14. UV Rigidized Wing

The test unit was evaluated for structural stiffness and manufacturing process accuracy. Information derived from the sub-component tests was used in the development of the rigidizable wing section. This is a prototype of the wing that was successfully flown in the BIG BLUE balloon flight experiment in May of 2003 [17]. The wing is a 16 spar symmetrical airfoil based on a based on an E398 airfoil with a chord of 12 in, and a half span of 36 in. The airfoil is designed to support a 10.4 lb vehicle with a 2G wing-loading, and has a factor of safety of > 2.0 over ultimate.

Summary and Conclusions

Significant advancements have been made with respect to deployable inflatable wings over the past few years, which have made them both attractive and viable for UAV application and design integration. Advances in rigidization technologies that yield high stiffness deployable wings, multi-functional structures, and morphing technologies, have expanded the utility of the technology. Applicability of these technologies to various classes of UAVs is evident (compact carriage and gun launch, as well as extra-planetary research).

The technology is also scalable to accommodate the needs of high altitude airships, munitions systems, and similar applications.

Acknowledgment

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References

- [1] Cadogan D., Sandy C., Grahne M., Development and Evaluation of the Mars Pathfinder Inflatable Airbag Landing System, 49th International Astronautical Congress, 1998.
- [2] Cadogan D., Grahne M., Mikulas M., Inflatable Space Structures: A New Paradigm for Space Structure Design, 49th International Astronautical Congress, 1998.
- [3] Palmer, M., LEWK Joins SAIC's Growing Flock, SAIC Spectrum Newsletter, Fall 2001.
- [4] Palmer, M., Forward Air Support Marine (FASM) Briefing, Reconnaissance & Surveillance Operation (RSO) Website (<http://rso.saigtuc.com/>).
- [5] Small UAV Program Website, NAVAIR, 2003, (<http://uav.navair.navy.mil/smuav/>).
- [6] McDaniel, United States Patent Office, Patent Number 1,905,298, 1933.
- [7] Jerry Jay's Wing and a Prayer Page - <http://www.geocities.com/Athens/Ithaca/1397/>.
- [8] ILC Dover Inc. Aerostat Development - <http://www.ilcdover.com/Aerostats/aero.htm>.
- [9] Priddy, United States Patent Office, Patent Number 1,905,298, 1933.
- [10] Sebrell, United States Patent Office, Patent Number 1,905,298, 1933.
- [11] Haggard, United States Patent Office, Patent Number 1,905,298, 1933.

[12] Cadogan, D.P., Shook, L. S., Manufacturing and Performance Assessments of Several Applications of Electrotiles and Large Area Circuits, Materials Research Society, Boston MA, 2002.

[13] Cohee, D. et. Al., Method of Making Three Dimensional Articles From Rigidizable Plastic Composites. United States Patent Office, Patent Number 5,651,848, 1997.

[14] Allred, R., Scarborough, S., Cadogan, D, McElroy, P., UV Rigidizable Isogrid Structures, 43rd AIAA/ASME/ASCE/AHS/ASC SDM Conference, Denver, CO, 2002.

[15] Lin, J.K., Sapna, G.H., Cadogan, D.P., Scarborough, S.E., "Inflatable Rigidizable Isogrid Boom Development," AIAA-2002-1297, 43rd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit AIAA Gossamer Spacecraft Forum, Denver, CO: April 22-25, 2002.

[16] Cadogan, D.P., and Scarborough S. E.. "Rigidizable Materials for Use in Gossamer Space Inflatable Structures," AIAA-2001-1417, 42nd AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit AIAA Gossamer Spacecraft Forum, Seattle, WA: April 16-19, 2001.

[17] University of Kentucky Collge of Engineering
B.I.G. B.L.U.E. project -
<http://www.engr.uky.edu/bigblue/home.htm>.