International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:13, No:11, 2019

Construction of Large Scale UAVs Using Homebuilt Composite Techniques

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Abstract**—**The unmanned aerial system (UAS) industry is growing at a rapid pace. This growth has increased the demand for low cost, custom made and high strength unmanned aerial vehicles (UAV). The area of most growth is in the area of 25 kg to 200 kg vehicles. Vehicles this size are beyond the size and scope of simple wood and fabric designs commonly found in hobbyist aircraft. These high end vehicles require stronger materials to complete their mission. Traditional aircraft construction materials such as aluminum are difficult to use without machining or advanced computer controlled tooling. However, by using general aviation composite aircraft homebuilding techniques and materials, a large scale UAV can be constructed cheaply and easily. Furthermore, these techniques could be used to easily manufacture cost made composite shapes and airfoils that would be cost prohibitive when using metals. These homebuilt aircraft techniques are being demonstrated by the researchers in the construction of a 75 kg aircraft.

Keywords**—**Composite aircraft, homebuilding, unmanned aerial system, unmanned aerial vehicles.

I. Introduction

STRUCTURAL composite materials, such as fiberglass impregnated with an epoxy resin system, have played a major role in aircraft design and construction since the 1960s. The Windecker Eagle was the first all fiberglass aircraft to receive Federal Aviation Administration (FAA) certification certification in 1969, but was ultimately abandoned due to the high cost of manufacturing and certification [2]. Closely following the revolutionary Eagle composite aircraft was the Varieze, which was the work of famed composite aircraft designer Burt Rutan. Rutan was a pioneer in the early years of homebuilt composites and he founded the Rutan Aircraft Factory Inc. The company eventually sold more than 1,200 kits for homebuilt aircraft [3].

Many other aircraft designs using composites kits followed throughout the 1980s and 1990. These composite kits were cost efficient to build, performed well, and were aesthetically pleasing to homebuilt aircraft enthusiasts [4]. The homebuilt aircraft industry flourished in the mid-1990s with over 1000 aircraft constructed using homebuilt kits appearing in the General Aviation scene [5].

Within aviation, composite materials are expected to surpass conventional aluminum as the primary structural material for aircraft in the foreseeable future. In contrast to aluminum structures, composite materials provide greater strength, lower density, and considerably higher fatigue resistance. Composite materials can be conveniently laid-up into complex forms and can achieve quicker and more aerodynamic contours with fewer parts needed for fabrication. This provides a great incentive for achieving aircraft structural member design for a lower cost than conventional aluminum structures. Due to these benefits, automobile manufacturers, such as Toyota and Honda, have transcended their industry boundaries and are working toward manufacturing composite aircraft for future release [6].

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II. Composite Construction for UAV Applications

Structural composite materials are expected to find many uses in UAVs over the next decade. It is estimated that over 200 UAV models currently in the market are composed of composite materials [1]. Although glass fiber composites were used in many applications over the years, the industry is shifting to carbon fiber-reinforced polymer material in lightweight composite UAV airframes. Current composite UAV applications span four major areas of application, many of which are for military use. These include target drones, radar decoys, information/surveillance/reconnaissance, and unmanned combat vehicles. However, there are UAV applications for civil use, including condition monitoring for crop yield, traffic monitoring, police surveillance, and information relay and transmission [7].

III. Fiberglass and Foam Construction

Composite foam and fiberglass construction techniques have been around since the days of Burt Rutan in the 1970s. The Rutan Aircraft Factory, Inc. published a book for homebuilt composite aircraft enthusiasts in 1983 entitled “Moldless Composite Homebuilt Sandwich Aircraft Construction”. The book provides a general overview of the materials, tools, and techniques necessary to fabricate traditional homebuilt aircraft kits, such as the Varieze and the Long-EZ [8]. These same techniques can be used to develop a composite UAV, which can be erected at home with relatively cheap tools. Although these processes are decades old, they are still being used for composite aircraft construction today [9]. For detailed videos on composite layup techniques, the Experimental Aircraft Association (EAA) offers a wide range of How-To videos regarding work with fiberglass and foam composites.

IV. Fiberglass

The materials used to create an all composite UAV are the same as the materials used in earlier proven composite aircraft designs [10]. The basic material used in many of Rutan's earlier designs is the fiberglass cloth. Although there is a wide variety of fiberglass cloth materials on the market, the homebuilder of the aircraft must be diligent in selecting the appropriate aviation grade cloth that can handle the expected performance requirements of the aircraft to be built.

There are two types of fiberglass cloth orientations used in the construction of aviation grade composite [4]. The first fiberglass orientation is bidirectional cloth, designated BID. As shown in Fig. 1, this type of cloth is woven with half of the fibers oriented in parallel and the other half perpendicular to the selvage edge of a fiberglass roll. BID fiberglass is laid at a 45° and has both shear and torsion capabilities. BID can be placed relatively easy into difficult contoured shapes.

Fig. 1 Bidirectional fiberglass

Conversely, unidirectional fiberglass, designated UND, is placed in areas where the stress, or load, occurs in only one direction. Often, unidirectional fiberglass will be chosen for wing skins. Multiple layers of fiberglass are generally placed for strength and rigidity of a composite aircraft component, and each layer is called a ply [4].

When working with fiberglass, it is imperative that the builder keeps the fiberglass away from any other materials used in making the composite structures. This includes keeping it free from the aerospace grade Styrofoam particles the builder will encounter while cutting the Styrofoam into the desired airfoil shape. It is especially important to keep it away from the resins used during the curing process. When transitioning from mixing epoxy resin to cutting and working with untainted fiberglass, the builder must change gloves to ensure that the epoxy resin mixture does not contact the fiberglass. This will cause the fiberglass to improperly cure and will ruin the fiberglass [4]

V. Epoxy Systems

There are several epoxy systems on the market that fit a variety of needs. Many homebuilders still use the original epoxy system pioneered by Rutan. This epoxy system, designated the Rutan Aircraft Factory system, was used during development of the VariEze aircraft. However, early epoxy systems were harmful to the skin and, as a result, many homebuilders abandoned their projects before they came to fruition. Consequently, a newer epoxy system, called Safe-T-Poxy, was introduced in 1980 [8]. Safe-T-Proxy is a safer, relatively non-toxic alternative to the traditional epoxy systems. The Safe-T-Poxy system has a low water absorption rate, which prevents moisture in the air from being absorbed in the epoxy and makes it tacky during the cure process [4].

The epoxy systems work by combining resin and a hardener in predetermined quantities, called a mixing ratio. As the builder mixes these two parts together, a chemical reaction takes place. This reaction creates heat that speeds up the hardening process. It is critical to mix these parts in small batches, generally not more than 100 grams at a time. Attempting to mix these components in larger batches will cause an exothermic reaction that will greatly reduce the pot life or the amount of time it takes for the components to mix and become hard. Once the mixture is hard, it is useless and must be thrown out [4].

The epoxy system, Fig. 2, used to construct the fiberglass layers over the Styrofoam core, is certified by the German Federal Aviation Administration for use with aramid, carbon and glass fibers for high static and dynamic loads. The manufacturer of the two part system is Hexion Specialty Chemicals. All manufacturer's instructions and recommendations should be followed when using the products because of their chance to cause minor irritation to epidermal tissue [11].

Fig. 2 MGS Laminating Resin and Hardener

The system consists of a laminating resin (MGS L 335) and its corresponding hardeners. For the purpose of homebuilt UAV applications, there are two suitable hardeners, each providing a different pot life when mixed with the laminating resin. The range of thorough impregnation of the glass fibers depends on a variety of environmental conditions, including but not limited to ambient temperature and ambient humidity. Mixing the laminating resin with the MGS Hardener H335 will result in a fast gel life. Conversely, mixing the laminating resin with the MGS H340 will have a much slower gel life. The laminating resin and the hardener have a mixture ratio of 100 parts by weight resin to 38 parts by weight hardener. Considering that the hardeners share the same mixing ratio, they can be mixed among themselves in any ratio, however this will affect the gel time by a factor of the mixing ratio of the hardeners [11].

Glass microballoons may be added to the epoxy mixture to achieve the desired viscosity of the mixture. It is important to note that the different hardeners have different densities and viscosities, and these factors must be understood before attempting to mix the hardeners. The mixture of laminating resin and desired hardener will create heat, so it is highly recommended that the two parts are mixed in small batches with the appropriate ratios by weight. Mixtures in excess of approximately six ounces have been found to produce an undesirable thermal runaway situation that produces excess heat and significantly reduces the gel life of the mixture [11].

VI. Wing Core Construction

The core of the composite structure is made of a low density aerospace Styrofoam. This material, Fig. 3, is blue and has high compressive strength. It acts as a mold during the wet layup process that shapes the fiberglass during impregnation with the epoxy resin system. The Styrofoam can be cut using a hot wire saw, which may be constructed relatively easily using few materials. The hot wire saw used by Rutan can be created using a wooden beam, approximately 4 feet wide, with two stainless steel rods fixed perpendicularly to the wood on each end. The span between the rods is connected by a .032" stainless steel wire. Using a direct current power source, the positive and negative ends are individually connected to the rods. The current causes the wire to heat up due to the internal resistance of the electrons moving through the wire [4]. This hot wire is used to cut the Styrofoam core [8].

Fig. 3 Aerospace grade Styrofoam

It is easy for a builder to follow a template when cutting the Styrofoam core. The template will represent the airfoil desired for the aircraft, and can be made from aluminum or anything that is rigid enough to maintain its shape, but smooth enough to glide over when tracing it with the hot wire cutter. Two identical templates are needed for this process [4]. The template is numerically marked at regular intervals and is pinned into the Styrofoam block to hold it in place during the cutting process. Two people are needed to cut the foam core using the hot wire cutter. The two people will trace the shape of the airfoil, using the numbers on the template as a cadence for speed to ensure that both sides of the cutter are at an equal pace to smoothly cut through the foam core. The finished product, Fig. 4, will be a foam core section of the wing, and this process will be repeated multiple times to achieve the desired wingspan [4].

Fig. 4 Complete wing core with fiberglass skin

A benefit of using a hotwire cut foam core is that a UAV designer can quickly build a series of wings using different airfoils. An experienced builder could cut a 2 meter wing from a solid block of styrofoam in less than an hour. The builder could then apply epoxy coated fiberglass to the core in a few hours resulting in a fully cured, aerodynamic wing in the following day. Fig. 5 shows a three core wing section with fiberglass skin. Also, a computer controlled mill could be used to cut the foam into complex shapes. Several low cost commercially available machines exist. Due to the ease of the application of fiberglass and epoxy onto the foam, the designer is able to quickly create aerodynamic surfaces or shapes that would be difficult to build from aluminum.

Fig. 5 Three core wing section

VII. Repairability and Modification

Once the UAV structure is complete, composites are easy to repair and modify as compared to their aluminum counterparts. For example, if a wing is found to be lacking sufficient lift, an extension could be added with minimal effort by simply cutting a new wing core and applying the correct layers of fiberglass. This extension could be bonded to the wingtip of the UAV. For an aluminum wing, the metal would need to be cut, bent, and riveted in order to achieve the same result. Furthermore, aluminum is limited by the bend radius of the metal. This could result in a decrease of the amount of airfoil choices by the designer. If the composite structure is damaged, a simple scarf patch to the skin could be made. Once cured, sanded, and painted, the repair would be indistinguishable from the original structure.

VIII. CONCLUSION

Homebuilt aircraft construction techniques are tried and true techniques that have been used for decades. Using the guidance of Burt Rutan, any builder can create a large scale composite UAV efficiently and for a very low cost. The final product is a durable, lightweight UAV capable of being powered by a small piston engine and controlled by a series of servos for proper flight control deflection. With some basic knowledge and skills, a variety of aircraft designs can be manufactured to meet the specific needs of any UAV application. These composite structures are easy to repair in the event of damage. In addition, the structures are easily modified in the event of a design change of alteration after the vehicle is complete.

IX. FUTURE WORK

In order validate the cost savings and easy of workability of composite materials in UAV construction, the researchers are currently constructing a 4 m wingspan, 3 m fuselage, 75 kg UAV. They are using the techniques described in this document. The UAV, Fig. 5, is being built by a team of graduate and undergraduate students.

Fig. 5 Large scale UAS under construction

Due to the ease of manufacture, the UAV from initial design to first flight is planned to be 12 months. The current schedule is on track to finish on time and on budget. The researchers estimate that if the aircraft was built from aluminum, it would take double the time to complete. Results from this ongoing project will be published in another academic paper.

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