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# INDIRECT 3D PRINTING OF AN INFLATABLE WING FOR SMALL UAVS REINFORCED WITH 3D HEXAGONAL DIAMOND STRUCTURES

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**ABSTRACT**: Small UAVs provide beyond-line-of-sight situational awareness to frontline troops and minimize unnecessary loss of lives. Small UAVs are carried into the field and launched manually. Inflatable wing is a potential way to increase the packing efficiency of small UAVs and reduce the load on troops. A new inflatable wing design is described in this article which addresses some of the problems encountered in existing designs. The new design can reduce weight and complexity while increasing aerodynamic performance. An indirect 3D printing method to fabricate the new wing was tested and a 3D hexagonal diamond structure was produced.

Keywords: Unmanned aerial vehicles, inflatable wing, indirect 3D printing, lattice structure.

## INTRODUCTION

The purpose of this article is to describe a new small UAV wing design that is inflatable and possesses a lattice structure network inside which helps the wing conforms to the desired shape of the aerofoil and also carrys part of the load that is exerted on the wing during flight.

An UAV (unmanned aerial vehicle) is an aircraft that operates autonomously or remotely by operators. UAVs can be classified according to their range and attitude. In the United States, a tier system is used. The first tier, Tier N/A, represents small UAVs like Wasp Block III. Subsequent Tiers represent UAVs of higher range, speed and attitude. The new wing design described herein is produced for small UAVs that is carried by their operators into the field and launched from a tube.

The main purpose of UAVs is to minimize unnecessary loss of lives. For example, UAVs can take over reconnaissance duties over hostile airspace and armed UAVs can even carry out strikes against targets to eliminate them after spotting them. For small UAVs, their usefulness lies in their ability to be deployed quickly in the field and navigated through tight spaces at the street level. Crucially, they can provide beyond-line-of-sight situational awareness to alert their users to potential ambushes in their path or help spot approaching enemies.

Portability of small UAVs can greatly reduce the load carried by military forces since they form part of the payload and essential equipment that accompany these troops into their operations. The ability to stave their wings or even the entire aircraft into a small package is one possible way to improve their portability. One technology that may be able to fulfill this objective is inflatable wings.

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## LITERATURE REVIEW

As the UAV of interest was designed to be launched from a tube, the deployment of the wing will occur immediately after launch and preferably takes at most one second to complete. The wing is expected to be light and strong since the small UAV has limited power. The strength and stiffness of the inflatable wing will be maximized by controlling the material used to fabricate the wing, the profile of the wing, and the internal pressure.

An internal pressure of 52 to 138 kPa will be used. A low pressure is preferred although stiffness will be compromised but it will be easier to prevent or minimize leakage. Previous inflatable wing designs operated with pressures exceeding 1000 kPa and consequently, the thickness of the skin of the wings and other associated accessories, like seals and gaskets, have to be overengineered. With a low pressure design, the capacity and thus weight of the inflation system can also be reduced as compared with a high pressure one.

Although low pressure will be used, high stiffness is still achievable by selecting a wing profile with a high sectional moment of inertia. The wing profile selected is NACA 2412.

The entire prototype will be made of silicon rubber which is available from Polytek. The product, PlatSil 71-35, has a tensile strength of 4.38 MPa which is one of the highest among similar products.

One of the more widely used approaches in inflatable wing design is to connect a series of fabric cylindrical tubes together as the spars of the wing as described in Cadogan et al. (2003). The cylindrical tubes divide the entire wing into spanwise baffles which are filled with an inflatable urethane bladder having numerous long finger-like sections that extends from a centralized manifold. During inflation, pressurized gas such as nitrogen or carbon dioxide is released into the urethane bladder which causes the entire structure to expand and assume the shape of an aerofoil. This design is not perfect and newer variants have been proposed to address some of the problems encountered.

One of the problems arises due to the use of cylindrical tubes as the resultant shape is marred by a ribbed surface that deviates from the original wing profile. To restore the surface to a smooth one, a layer of crushable foam, at the expense of more weight and reduced packing efficiency, is sometimes added. A second problem arises due to the permeability of the urethane bladder which allows small amount of pressurized gas to leak out causing the wing to gradually lose its strength and stiffness, the problem is exuberated if micro-punctures exist in the bladder due to wear and tear. A solution is to replace the leaked amount with make-up gas using a constant pressure inflation system. Another solution is to use a rigidizable material as the wing material so that once inflated, the wing can retain its initial shape without further pressurization as described in Allred et al. (2004). A suitable rigidizable material is UV curable resins which become rigid once exposed to UV light.

Another method to produce inflatable wings was described by Alioto et al. (2009). The core of the wing is cut from open cell foam and covered with PVC fabric. The foam core supplies the tensile strength necessary for the wing to remain in its desired profile after inflation while also allowing the profile to stay smooth. A prototype was produced but the pressurization process caused the PVC membrane to delaminate from the foam core causing the wing to lose its shape.

## METHODOLOGY

The new wing design proposed in this article seeks to address all the problems encountered in previous designs. The inflatable wing will be fabricated integrally with a lattice structure as reinforcement using a flexible impermeable material silicon rubber. The lattice structure serves two purposes, the first is to provide the inflatable wing its shape and the second is to absorb a portion of the load exerted on the wing. The new wing design is shown in Figure 1.

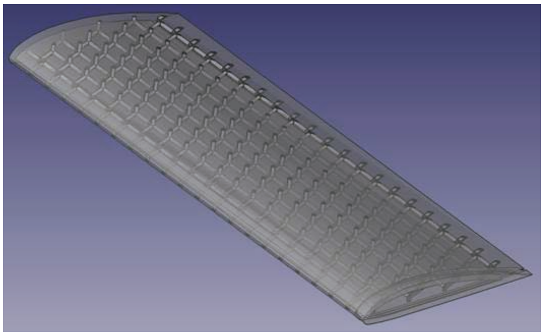

Figure 1. Inflatable wing based on NACA 2412 with lattice structure.

Owing to the need to produce the new wing design in one-piece, 3D printing was first considered and a 50 mm segment of the wing was produced. The system chosen was the Objet 350 3D printer while the material selected was a rubber-like material called Objet TangoGray FLX950. Difficulties were encountered during fabrication and they prevented the entire wing segment from being produced. Namely, it was found that support material cannot be completely removed during post-processing as the complex geometry of the design prevented the solvent from reaching them. Despite the setback, the suitability of the manufacturing process and material selected were evaluated based on the physical model produced. It was found that the physical model is more flimsy than expected perhaps due to the layer-by-layer construction. When the model was gently twisted by hand, delamination between the layers could be readily observed. This led to the conclusion that another manufacturing method was needed.

To circumvent the limitations of 3D printing and its materials, an indirect 3D printing method was proposed. 3D printing was used to create a sacrificial thermoplastic mold for the room temperature vulcanizing (RTV) casting of the wing in silicon rubber. The advantage of this method over direct 3D printing is that the final product is a monolithic part instead of being an amalgam of many different layers representing the part. There will be no layer boundaries in the final part and this is especially advantageous to mission critical parts that cannot tolerate defects in the bonding of separate layers and materials that do not bond well. This method also opens up the choice of material that can be considered for the part. For instant, the number of polymeric materials that can be used for direct 3D printing is limited by the manufacturing process. For FDM and SLS, only thermoplastics can be used as the processes involve melting. For stereolithography which works by radical initiated polymerization, only photo-reactive resins can be used.

Indirect 3D printing has been used to fabricate intricate collagen scaffolds with internal channels with widths of 135 µm according to Sachlos et al. (2003) using Model Marker II (Solidscape). Other indirect 3D printing methods include Mold Shape Deposition Manufacturing (Mold SDM) which produces wax molds for the casting of alumina, silicon nitride, polyurethane, epoxy and silicon parts Cooper et al. (1999). Ceramic lattice structures were produced by combining 3D printing of polymer inks with replication in Ortona el al. (2012).

Figure 2 summaries the process of fabricating a silicon rubber part using the proposed method. The process begun with the generation of a CAD model of the required silicon part using a commercial CAD software Solidworks. The model was then converted using the original part as cavity within a solid part to form a mold. The mold was manufactured with a 3D printer, 3Z Studio, from Solidscape. 3Z Studio is an ink-jet printing system using two printheads to deliver a build material and a support material separately. The system works by melting both the build material and support material and ejecting them from the printheads by piezoelectric actuation. Upon leaving the printheads, the molten materials cool and solidify upon impacting the build platform or an earlier layer that was deposited. Individual layers are built through the accumulation of multiple droplets. The support material 3Z support is a low-melting point wax based material and can be easily removed by submerging finished parts in a solvent Bioact maintained at 50 to 55 °C. For the prototype wing, due to the presence of a complex network of lattices, the effect of the solvent alone is not sufficient to completely remove the support material. Therefore, the temperature of the solvent was raised above the melting point of the support material to 72.5 °C and combined with continuous stirring. Once all the support material was completely removed leaving only the build material, the molds were washed in clean water, air-dried and stored. The casting process involves injecting silicon rubber into a mold through the sprue using a syringe. After curing, the mold was placed in an oven and heated at above the melting point of the build material of 120 °C to melt the build material. As silicon rubber has a melting point much higher than 120 °C, the desired part will not be adversely affected by the heating process.

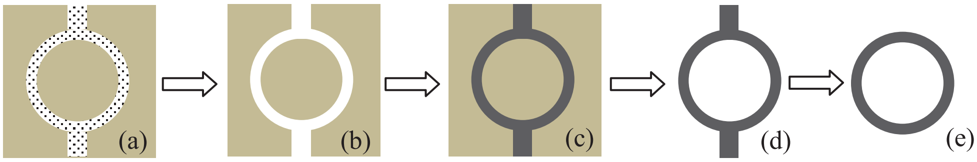

Figure 2. Schematic representation of the process. (a) 3D printed mold created using the negative image of the original part. Grey areas represent build material while dotted areas represent support material. (b) Support material was removed by submerging in a suitable solvent. (c) Silicon rubber was injected into the mold with a syringe for casting. (d) Mold is melted in a oven at 120 °C to reveal the desired part. (e) The sprue, runner and gate attached to the silicon part were removed during post-processing.

## RESULTS

A 3D hexagonal diamond structure has been successfully cast using the proposed method as shown in Figure 3.

Figure 3. 3D hexagonal diamond structure produced with indirect 3D printing.

## CONCLUSION

A new inflatable wing design for small UAVs was proposed in this article. The design seeks to address some of the problems encountered in existing inflatable wing designs. The interior of the wing houses a lattice structure to increase the stiffness of the wing and helps regulate the shape of the wing. To build such a part, an indirect 3D printing method was used. A mold was created using 3D printing and silicon rubber was cast in it. So far, a 3D hexagonal diamond structure was successfully fabricated.

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