From design towards manufacturing of winglets with integrated VHF antenna

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Abstract. This paper shows the technical aspects and the progress of manufacturing a winglet concept with integrated VHF antenna.

1 INTRODUCTION

Reducing fuel burn emissions is one of the most important aims in aircraft design nowadays. One possibility for reducing the aerodynamic drag of airplanes is to reduce the number of protruding parts as antennas. One possible design concept is to move the antenna within the winglet and to integrate the transceiver of electromagnetic radiation into the aerodynamically optimized structure [1]. The challenge of this goal is to build the VHF antenna with its wavelength defined size into a winglet. The winglet designed in ACASIAS is for a small transport aircraft of the type Evektor EV55. This small size makes the integration in the small installation space a demanding task. This construction method shown here can also be easily used on larger aircraft. Another challenge of the design process is that the winglet must be certifiable, maintainable, and repairable at the final stage for all systems and structure.

2 WINGLET DESIGN

Neither a high-quality winglet nor a VHF antenna is a revolutionary new idea. In aviation, however, assemblies are usually separated according to their function. Functional integration is unusual. In this chapter the structural design and the necessary boundary conditions will be discussed.

Several aspects of the winglet design have to be considered. First of all, it should apply the aerodynamically optimized shape for reducing the vortex drag at the tip of the wing, as well as it should fulfill the structural need for inducing aerodynamic forces and moments to the wing, remain stable in the event of bird strikes, and it should resist lightning strikes. The integrated antenna should be able to transmit VHF (very high frequency) radio communication to and from other air or ground stations.

Therefore, it is inevitable that the signals from the integrated antenna within the CFRP structure (Carbon Fiber Reinforced Plastic) are erased by a GFRP (Glass Fiber Reinforced Structure) "window" inside the winglet. CFRP does not allow electromagnetic radiation to pass through. The boundary conditions for an antenna is summarized in [2] and [3].

Figure1: Cross-section of scarfed GFRP "window" (flare) of the winglet

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The notch antenna design itself was delivered by IMST, which is responsible for this topic. The production of the antenna itself is done by TRACKWISE, who create a thin, flexible PCB (Printed Circuit Board) which can be integrated within the winglet. The electromagnetic design is given in [4].

The position of the notch fiberglass antenna and "window" is very important for the reception and transmission of high frequency data.

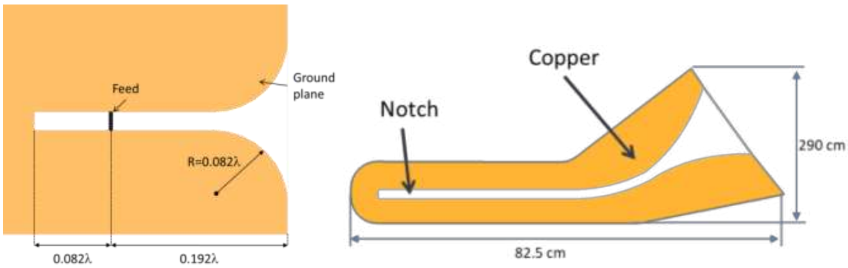

Figure2: Notch antenna. Left: Basic structure, Right: final geometry

2.1 Aerodynamic optimization

As mentioned, the Evektor EV55 is used for the EU project ACASIAS for the design. This aircraft was examined and optimized by VZLU under the aerodynamic conditions of the flight envelope. The core of the optimization is the reduction of drag and the reduction of the number of attachments promoting drag. Two Evektor EV55 aircrafts are flying at the time of this study.

The optimization strategy is based on the Design of Experiment (DoE). The Response Surface Method (RSM) is also used. More detailed descriptions can be found in [5]. The optimization resulted in a winglet shape with the highest reduction of induced drag. The result is the yellow winglet shorn in Figure 3.

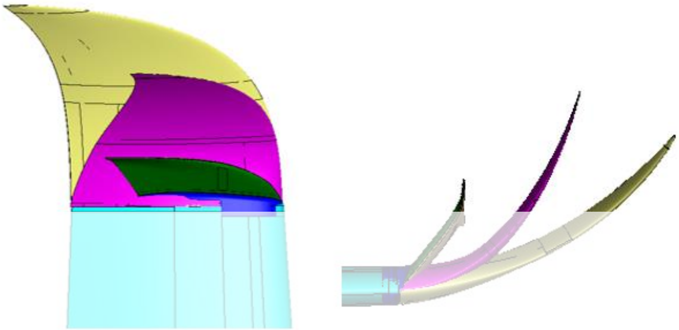

Figure 3: Stages of Optimization
(green = original, magenta = 1st optimization, yellow = 2nd optimization)

2.2 Structure simulation

With this aerodynamic design, structural investigations can follow. The dimensions of the winglet make it necessary that (as is usual in large wing constructions) a spar passes through the structure perpendicular to the plane of the wing in the area of the largest profile thickness. This beam absorbs a large portion of the load but reduces the installation area for the antenna. Therefore, the opening of the antenna is rotated so that the rear opening of the antenna terminates within the trailing edge of the winglet. The monolithic trailing edge in GFRP is a basic requirement for the functionality of the antenna. The beam, in the front area of the antenna, also limits the mounting position of the PCB sheet. With these boundary conditions, the antenna window (hereinafter referred to as “flare”) can be positioned.

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The structure of the design concept was used to create a model for structural analysis. Before the structural investigation can be performed, the antenna notch must be positioned.

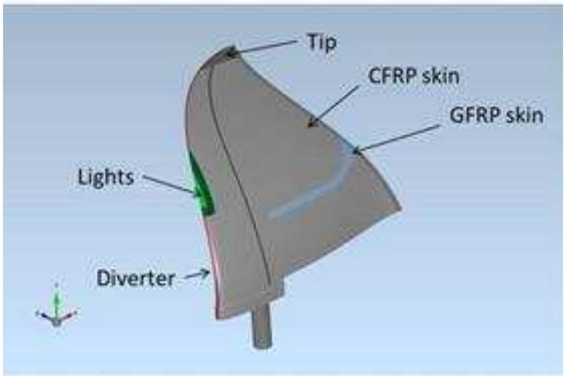

Figure: 4: Structure of winglet with notch antenna and the “flare” window

The stress on the winglet is calculated using the pressure distribution. In fact, the ultimate load factor must be taken into account. The winglet itself is made out of CFRP with a scarfed GFRP flare with dielectric properties for VHF antenna operation. The core of the winglet consists of a spar and a structural foam. The critical load case was considered by VZLU and EVEKTOR for an AoA of 17°. INVENT placed the pressure field (delivered by VZLU) on the structural model of the winglet. The ultimate load as a safety factor for individual parts were determined as followed:

- x 2.25 for composite parts
- x 1.5 for metallic components

The pressure distribution was also multiplied by this safety factor, as well as the acceleration due to gravity. The pressure distribution was projected onto the wetted winglet surface. The first structural model was based on a CFRP material thickness of 2.5mm, which corresponds to a plybook of 10 layers for the outer skin. The first estimation of material and thickness provided a total weight of 11.5kg.

The first iterations with the 11.5kg model showed that the winglet is far stronger than required. This led to weight optimization. In several successive steps, the influence of the reduction in material thickness and density was determined under the specific load. The structurally optimized winglet is a design with a lightweight foam core. The spar thickness is reduced. The material thickness of the outer skin was also reduced from 2.5mm to 1.7mm (corresponding to 7 layers). 2mm CFRP is applied only in the winglet root area. The final weight is around 8.5kg.

In the following the maximum principal stress of the upper side (left) and the lower side (right) of the winglet is shown. On the bottom side you can see the scarfed GFRP window, which has little influence on the strength of the winglet skins.

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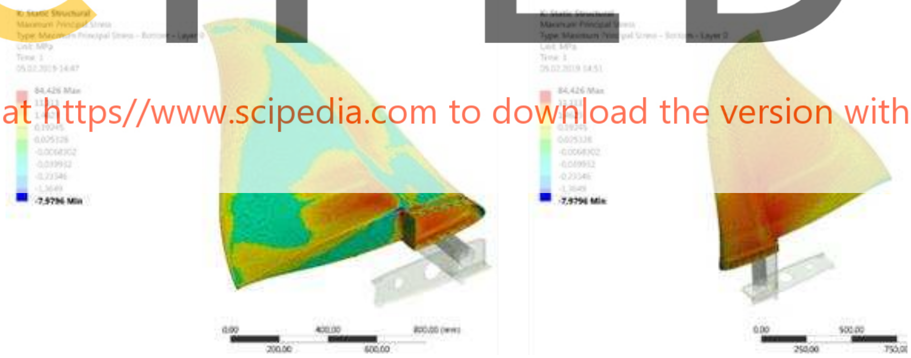


Figure 5: Maximum principal stress in logarithmic scale (Left: top side, Right: bottom side)

Within the optimization process the structure model could be further refined. For the calculation an Inverse Reserve Factor (IRF) with Tsai-Wu failure criteria was used. If the value of the IRF is less than one, there is no damage to the fiber composite structure.

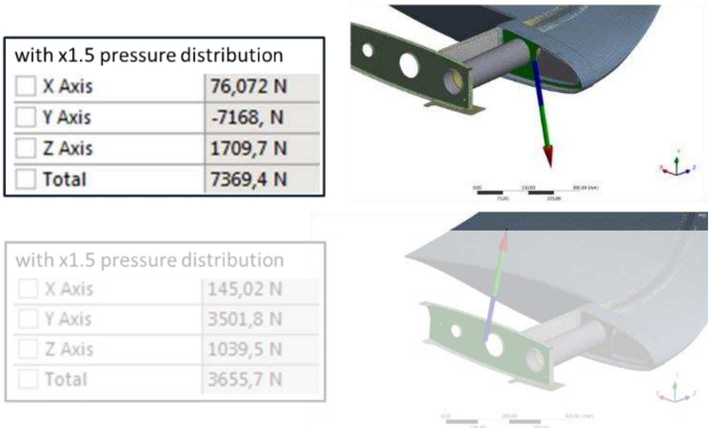
The resulting IRF composite is 0.29 (usual: IRF = 1 = Failure). According to ultimate load.

$$\boldsymbol{IRF}/(\textbf{ultimate load}) = \mathbf{1}/(\mathbf{2.25}) = 0.57$$

is below IRF=1. Therefore, the winglet structure is safe.

The support reaction that are transferred into the wing was also calculated. For EVEKTOR these values are essential for the design of the wing itself. These values were delivered for re-dimensioning the wing spars and stringers.

Bird strike is also considered. The highest risk of a bird strike is the displacement of the trailing edge inwards towards the aileron. In the event of a bird strike, the winglet must not block the aileron. For cruising speed of 400 km/h and a bird weight of 2 kg the reaction force on the wing via the impact energy and the impulse were calculated. The calculation of this force applied to the outermost part of the structure results in a displacement of the trailing edge of 4mm. This displacement does not affect the aileron



with x1.5 pressure distribution

☐ X Axis	76,072 N
☐ Y Axis	-7168, N
☐ Z Axis	1709,7 N
☐ Total	7369,4 N

with x1.5 pressure distribution

☐ X Axis	145,02 N
☐ Y Axis	3501,8 N
☐ Z Axis	1039,5 N
☐ Total	3655,7 N

Figure 6: Resulting forces and moments on the joints between winglet and wing

4 TECHNICAL ISSUE ON THE WAY TO THE WINGLET

4.1 The scarfed shape GFRP window

The winglet is mainly made from CFRP. As mentioned, one characteristic of carbon fiber is shielding electromagnetic radiation. In addition, the outer layer of a winglet must be covered with a copper fabric in order to prevent lightning strike damage. Such a copper mesh also has a negative effect on the electromagnetic permeability. The antenna is constructed with a monolithic trailing edge in GFRP. This is necessary so that the antenna has the most suitable potential and thus the most optimum radiation of the radio signal.

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In order to give the winglet composite structure, the necessary strength for the antenna in the area of the electromagnetically acceptable window, this area must be scarfed. This means that the size of the glass fiber cut-outs increases towards the inside of the winglet. Correspondingly, the opening of the carbon fabric becomes larger towards the inside. The resulting overlap creates a firm bond between the CFRP and the GFRP. This surface optimizes the emission of the electromagnetic radiation of the winglets and minimizes the surface without lightning protection on the outside.

Before a complete winglet is built, several panels were built for the technical realization of such a layer construction. In accordance with the shape of the winglet, INVENT built a specimen to provide information about the production process and thus the final structure of the winglet. The shafting was realized. A curved shape with the winglet radius and flat panels were sent to IMST for further investigations

4.2 Mold construction

The entire winglet is produced in one cycle and this has to be considered within the design process of the molds. This one cycle process production means cost-effective manufacturing, but requires a little more planning. At first, all necessary semi-finished products are prepared. The molds are wetted with a special varnish in order to release the winglet after production.

The skin layers are laid in the molds covered with a pre-impregnated resin system. A foam block milled to contour is then placed on the already prepared lower shell. This foam block also serves as a support to form the spar within the winglet. Both molds are then pressed together and cured at higher temperature by integrated heating pads.

The mold construction must be set with such precision so that the separation planes can release the winglet from the tooling negative forms after the curing of the resin. For this reason, we work with four molds. One heatable top and bottom and additionally two unheated side molds, which form the end rib facing towards the aircraft.

At first, the original forms are milled as positive (i.e. with the original contour). The negative tooling molds are then made from this positive. After preparing the milled master tooling foam, the heater mats are brought to the contour using a vacuum injection process. The necessary stability of the negative mold is then provided by applying prepreg and a specially knitted fabric (comparable to sandwich construction). Various tests must be carried out within these steps in order to document the functionality of the self-heating tools.

The geometry and the number of molds must be selected so that the molds can be separated after curing. For example, there must be no undercuts in the molded parts.

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Figure 7: Left: the construction of molds and wing, Right: sepeartion area and the four mold elements for finals production process of winglet

4.3 Heated molds

In the ACASIAS project we are also aiming for self-heated mold production. For this purpose, it is necessary to produce special type of molds. INVENT strives for a heatable mold with specially defined heating surfaces that cure the material of the winglet at the required temperature. In this special case, we have to heat the mold up to 125°C.

INVENT pursues two strategies for heating the molds for the winglet. At first is the possibility of placing fabric embroidered with heating wires as a layer in the negative mold. This mat is then embedded in the fiber composite. The advantage of this manufacturing process is that the heating mat can be prefabricated exactly to the geometry needed of the produced component. The other possibility is to use a special layer of CFRP, which is connected with wiring. The internal resistance of the CFRP causes this layer to heat up. With this variant, however, the effort required for assembly is somewhat higher. The heatable surface is divided into as many large rectangular surfaces as possible. These individual surfaces must then be electrically insulated from each other using GFRP. However, the winglet has a simplified triangular shape. Various geometries were taken into consideration for optimizing several divisions of a small number of independent heating areas . These are shown in the picture. In order to save heating surface three rectangular heating surfaces are favored. In the following picture these are outlined green.

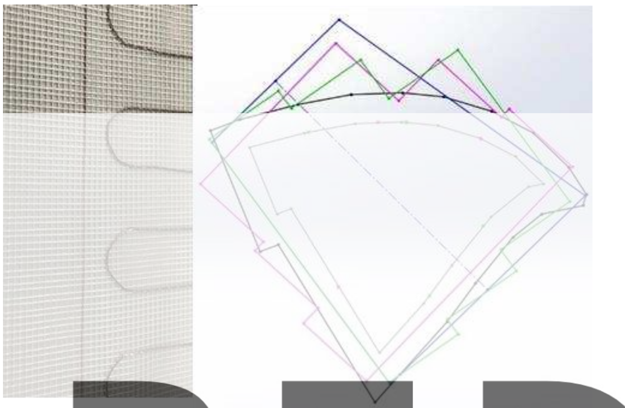

Figure 8: Left: Carrier fabric with embedded and embroidered heating filament, Right: Three possible designs for a heating field with different geometry

The structure of the heating surfaces is built up in an infusion process. This means that the top layer in the molds is a dry basalt layer, which serves as electrical insulation. This is followed by the heating layer with special carbon fabric, which is electrically connected at the edges with a wire mesh. A layer of fabric is applied on top of this for electrical insulation. This provides a molding tool that makes it possible to produce a component outside an autoclave or oven.

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5 MAINTENANCE AND REPAIR

Maintenance and repair are a major focus for attention. The winglet presented here will be optimized for a smaller twin-engine 12-seater cruise aircraft. Due to the size of the aircraft, the construction volume of the winglet is very small compared to the winglet size on a large aircraft (CS-25). Due to the small construction volume and the special scarf shape GFRP flare, special repair measures are necessary.

The largest damage potential for the winglet would be: Lightning strike, collision damage, bird strike and electrically unusable/malfunction/damage antenna

For the first three types of damage, it can be assumed that the winglet would become aerodynamically and structurally unusable. This would result in a very costly repair and release to service. If the fiber composite in the area of the antenna is defective, there are different possibilities of repair. It would be possible to cut out and insert dry, large-area, prefabricated elements with the GFRP window in case of damage in the antenna area. The scarfed flare is the biggest challenge in the production of such a patch. The ideal solution would be to replace the winglet. In the size segment of the aircraft class presented here (CS23), a new production might be cheaper than a repair.

For the repair of an electrically unusable antenna, the installation and handling space is not sufficient for the isolated repair of the antenna. Handhole covers would mean a considerable loss of the aerodynamic quality of the winglet for an aircraft of this size. One way to repair the antenna within the winglet would be to use position lights and ACL (Anti Collision Light) for opening the antenna mounting surface from the front of the winglet. For the best possibility of maintenance for the antenna would be a mounting, in which the flexible material could be slid into the final position.

The focus for the endurance tests should be a program for the durability of the solder joint for the antenna. The antenna is produced by TRACKWISE. There, the solder joints could also be made of flexible material and integrated into the manufacturing process of the antenna. The worst case for an electrical failure would be a cable break close to an edge near the wing root or a hidden cable break. These faults should be tested in a fatigue strength test and should lead separately to a special repair instruction.

For larger aircraft there are more possibilities to position the antenna with regard for a cheaper repair of the antenna itself. Unfortunately, the construction of the antenna depends on the fact that the flare must have a glass fiber edge at the end. Nevertheless, it would be possible to reach the antenna through an opening of the Leading Edge (through the holder of the position lights) by means of a special spar geometry in large aircraft.

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Figure 9: Two different winglets with position lights and openings for possible antenna replacement (from internet picture research [10] and [11])

6 CONCLUSION AND OUTLOOK

The first results of the integration of a VHF notch antenna in an aircraft winglet have been presented. The antenna measured performance complies with the requirements in terms of bandwidth. The next steps include the measurement of the radiation patterns, and the adaption of the structure to the real, conformal winglet geometry.

Lightning protection will also be investigated in this context. Since the winglet is the component predestined for lightning strikes, this issue will be investigated further more. Especially with regard to the electrical components inside the winglet, it is necessary to discuss the rules and regulation for the certification and for increasing the TRLs.

13 ACKNOWLEDGEMENTS

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