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Preliminary Design Process for an Adaptive Winglet

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***Abstract*— In the framework of Clean Sky 2 Airgreen 2 GRA ITD project, this paper deals with the design process of a morphing winglet for a regional aircraft. By improving A/C aerodynamic efficiency in off-design flight conditions, the morphing winglet is expected to operate during long (cruise) and short (climb and descent) mission phases to reduce aircraft drag and optimize lift distribution, while providing augmented roll and yaw control capability. The mechanical system is designed to face different flight situations by a proper action on the movable parts represented by two independent and asynchronous control surfaces with variable camber and differential settings. A set of suitable electromechanical actuators are integrated within the limited space inside the winglet loft-line, capable of holding prescribed deflections for long time operations. Such a solution mitigates the risks associated with critical failure cases (jamming, loss of WL control) with beneficial impacts on A/C safety. Numerical details on the system architecture and ability to cope with the typical mission loads profiles are given, along with a description of the conceptual analysis and the expected system performance according to a suitable metric.**

***Index Terms*— morphing winglet, camber morphing, tab-like morphing, aerodynamic optimization**

I. Introduction

Aircraft winglets are a proven way to reduce drag, save fuel, cut CO_2 and NO_X emissions, and reduce community noise. Blended winglets have been present in aviation since late 1970s with the invention of Richard Whitcomb from NASA. They are nowadays offered as standard equipment on new aircraft designs and are also available as retrofit installations on existing commercial airplanes to increase aircraft range capability along with reducing fuel consumption. Conventional winglets are static aerodynamic devices with an optimised shape for wing drag reduction. On the other hand, they introduce significant loads into the main wing structure that may namely diminish the aerodynamic optimization margins. These additional loads may result in a heavier design of the wing box and an overall re-engineering of the interfaces to host the winglet surface.

The idea of an adaptive winglet has been successfully investigated in the recent past through theoretical studies and small scale experiments. Adaptive winglets, where the geometry can be adjusted to the changing flow conditions, has the potential to improve the aerodynamic performance during climb and high-speed off-design conditions by providing adapted wing lift distribution throughout the A/C flight envelope. Additionally, they can significantly reduce aerodynamic loads at critical flight points (active load alleviation) having a variable trailing edge control. Several patents have been produced by the major aircraft manufacturers as Airbus, Boeing and McDonnell Douglas focusing on changing the winglet shape to achieve minimal drag at multiple flight points [1]-[2]. The Boeing patent [3] also includes a control surface but the winglet is just planar. Others focused on drag reduction at multiple flight points, and investigating roll control as well. Static load alleviation has been investigated as well using an all-moveable winglet [4]. Among the many prototypes of morphing winglets found in the literature, the adaptive winglet with active trailing edge (WATE), developed in the framework of the SARISTU project, is probably one of the most advanced examples [6]. A full-scale CFRP adaptive winglet device, including conformal skin, stringers and four ribs, was designed, manufactured and tested into a

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wind tunnel, with very promising results. An active flap actuated by an EMA and attached to the winglet's rear spar by a fail-safe connection (5 single hinges) was commanded through a pure feedforward control with no adaptation. In addition, a morphing skin covered the region between the fixed and movable part ensuring a smooth morphing shape. However, such a design choice resulted in additional actuation power to deform the morphing material under operative loads. Furthermore, a C-shape cut-out was necessary to avoid excessive membrane deformation at the winglet trailing edge, significantly reducing the expected aerodynamic benefits. Although the growing interest shown from aviation industry, there is still a big step towards bringing the adaptive winglet concept to a real flight application. Adaptive systems are perceived to be particularly difficult to certify because they adapt aircraft functions and change its configuration whilst in operation in response to the experienced time varying operating environment. Such new capabilities can only be realized if the associated design complies with the current certification standards. An acceptable safety related design methodology and more automated methods for manufacturing, assembly and integration of the subcomponents are only some of the most urgent issues to be addressed for certifying these new devices within the context of industry standards.

In this paper, the conceptual design of a morphing winglet is investigated. A variable trailing-edge camber concept is explored that adjusts the winglet geometry to the changing flight conditions to gain optimum performance. Finally, a trade-off aeroelastic assessment is carried out in order to estimate the winglet mass threshold that will cause the system flutter. The innovation in winglet design relies on new-generation morphing trailing edges. The variable camber of the winglet is achieved by incorporating a morphing architecture into the trailing edge. In addition, discrete morphing deflections can be used to redistribute the span-wise aerodynamic loading in order to reduce the induced drag. This alternative approach can also be employed in structural load alleviation context to reduce the wing weight or increase aircraft performance.

The preliminary design is proposed taking into account the EASA CS25 certification aspects for integration into a regional aircraft. In order to assess the overall system benefit, manufacturing, operation and maintenance requirements are taken into account since the preliminary design stages. The potential failure modes are assessed and a fault tree analysis is proposed to identify the key drivers for the system architecture design.

II. Morphing Winglet Design Drivers

Depending on the time-scale of deployment, three different aircraft functions may be typically associated with a morphing device:

- Very Slow morphing (order of minutes): for instance, Lift (and Drag) control during long mission segments (mainly cruise) to compensate aircraft weight reduction due to the fuel consumption.
- Slow morphing (order of seconds): for instance, lift distribution control to maximize L/D during short off-design mission segments (mainly climbing and turning operations).
- Fast morphing (less than a second): for instance, wing loads alleviation by reducing gusts-induced RBM peaks on aircraft wing.

For some last-generation aircraft, as B787 and A350, some novel aircraft functions, like differential flap setting, are already ensured by innovative flap actuation system concepts. Distributed actuation enables decentralized load control along the wing span, which is particularly suited for active lift distribution control for induced drag reduction. More, tailored control systems and inherent positioning sensors contribute to guarantee this functionality. Aircraft wing design is a compromise between many competing factors and constraints and accounts for aerodynamic and structural constraints through a multi-objective optimization. Different flight cases including high speed and high lift conditions are then considered, having a different impact on wing structure and aerodynamic performance, as shown in Fig. 1.

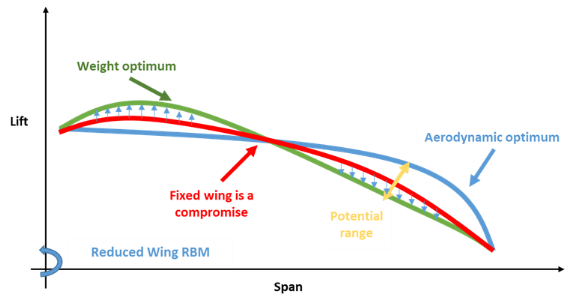


Figure 1. Impact of aircraft load control devices on spanwise wing lift.

The winglet design is generally devoted to optimum cruise performance. It is thus optimized for a pre-defined nominal cruise condition where the aircraft is expected to spend most time and consumes the majority of fuel. However, the aircraft remains close to this operating point only for a limited time of flight. Climb and descent, for instance, have to be considered as off-design cases, leading to some penalty with respect to the optimal aerodynamic performance. In addition, the high lift conditions limit the winglet optimization for cruise. Thus, drag reduction in off-design flight points (such as take-off, climb, descent, off-design cruise) is one of the beneficial effect potentially delivered by a morphing winglet. In order to validate such drag benefits, quasi-static analyses at different deflections and various flight points are then necessary.

However, although these benefits may be remarkable for long-range aircraft, it remains doubtful how they may impact on the regional aviation market. For regional aircraft, the typical mission may range between 300-500 nautical miles, limiting the margin of morphing deployment. This means that a morphing winglet may represent a favourable innovation only if it delivers wing aerodynamic benefits in both cruise and climb conditions and such benefits are higher than those ensured by a passive (fixed) winglet design, coming up from a more standard multi-objective optimization of different design cases.

In principle, as shown in Figure 2. for a nominal regional aircraft mission, active positive deflections can minimize drag in off-design conditions at the expense of the root bending moment (RBM) margins of the passive winglet counterpart, whose structure is traditionally sized for the worst load cases and flight conditions. On the other hand, active negative deflections can alleviate the RBM increase due to the enlarged winglet dimensions or to the aerodynamics gusts. Both individual and mixed conditions are then considered as design flight cases.

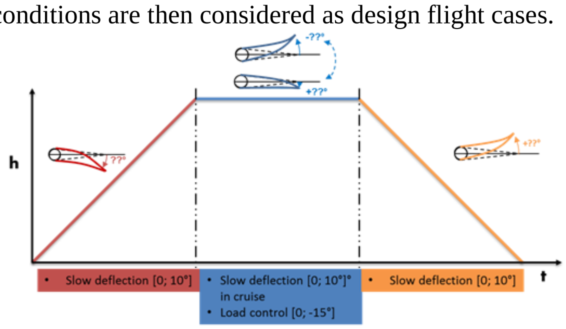


Figure 2. Typical regional aircraft mission using a morphing winglet

However, with respect to medium/long range aircraft, the adaptive winglet is less efficacious if deployed during cruise to compensate the A/C weight reduction due to the fuel consumption. Due to the limited A/C design mission, the A/C weight is expected to remain almost stable (it decreases less than 1%), and the aircraft flies most efficiently throughout the cruise phase.

In the literature, the design of a morphing device can be separated into a series of key decisions that the designer must make, as shown in Fig. 3. The design flow generally involves:

- the morphing layout approach (kinematics-based or optimization-based),
- the finite element representation of the design space (continuum, discrete, or hybrid),
- the optimization algorithm (gradient-based or stochastic).

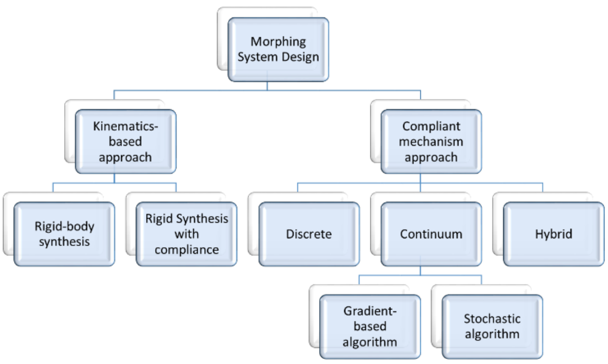


Figure 3. System Design Decision Tree

Conventional hinged mechanisms are surely the simplest and most effective way to realize morphing systems. A kinematic-based approach aims at defining the rigid-body mechanisms and, hence, the associated hinges by considering kinematic equations only. This design strategy, however, determines discontinuities over the wing's surface resulting in earlier airflow separation and, consequently, drag increase. The compliant mechanism synthesis technique, instead, considers energy storage characteristics in the flexible segments in addition to the rigid-body kinematic equations. As both kinematic equations and static force equations are then considered, this is also referred to as kinetostatic synthesis. On the other hand, compliant mechanisms are increasingly emerging as an effective way to design morphing devices through carefully arranged flexible structures supporting and driving a smooth skin. A compliant system is a kind of one-piece flexible structure, which can transfer motion and power through its own elastic deformation. Compared to rigid-body mechanisms, they do not have the characteristic problems of mechanisms, such as friction, need for lubrication, noise and recoiling, thereby achieving smooth shape changing thanks to its joint-free nature. On the other hand, they may suffer from fatigue problems. Nevertheless, compliant architectures hold high potential for use in morphing applications given the benefits over conventional sliding/pinned/rigid-link mechanisms, as, among the others, easier assembly and the elimination of backlash [5]. The use of the topology optimization approach as applied to the design of compliant mechanisms can be traced back to work by Bendsoe and Sigmund [22]-[23]. As for the general topology optimization approach, the compliant mechanism design domain is defined by external loads, boundary conditions, and desired responses and the resulting material is systematically "distributed" (added or removed) throughout the domain in a manner that minimizes (or maximizes) the defined objective function within a prescribed set of design constraints. This results in the effective and efficient use of material within the part.

For a given morphing layout, the next decision regards the finite element discretization of the design space. This could be either discrete, such as that used in truss and frame topology optimization in order to drastically reduce the computational time of the optimization routine at the cost of resolution and design freedom, or continuum which offers the potential for a more refined representation of topology. A hybrid representation might be able to balance the speed of the discrete representation with the resolution of the continuum method. The final step to be made when considering the design decision tree in Fig. 3. is whether to solve the chosen formulation with a gradient-based optimization algorithm or stochastic search optimization algorithm (such as genetic algorithms). It is worth mentioning that stochastic methods can be computationally expensive in high dimension spaces such as those of continuum topology optimization.

III. Certification Aspects

The adaptive Winglet is a “safety critical” aircraft control surface. Past investigations have demonstrated that loss of the adaptive winglet control can be classified as catastrophic for aircraft [6]. Thus, the probability of its occurrence must be below the threshold value of $<10^{-9}$ per flight hour for safety reasons, as written in paragraph CS 25.1309. The design of a morphing winglet design shall follow a standard safety-critical system design approach, starting from a Functional Safety Analysis (FSA). A failure hazard assessment (FHA) is then needed in order to derive the design prerequisites for the system architecture on the one hand as well as for the control system on the other. Once such qualitative safety classification is made for each functional failure. By using empirical values and experience for subsystem failure rates, an overall system may be iteratively designed using fault tree analysis (FTA). For systems related to structural load alleviation/control functions, the safety classification and relevant safety figures are also a driver for structural sizing. In fact, the recommended safety factor (SF) increases with the probability of being in failure condition, as shown in Fig. 4.

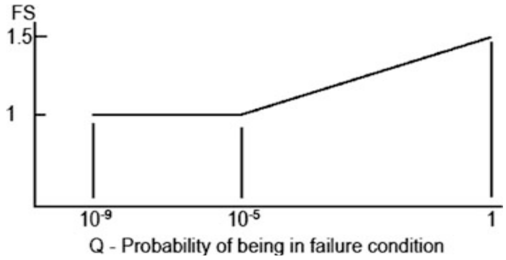


Figure 4. Computation of the safety factor (FS)

Although a failure condition related to degraded performance of an adaptive winglet may be classified as MIN due to the minor safety repercussions on the aircraft occupants, a fault tree is always recommended for such systems in order to be able to compute the ultimate load for jam in the worst-case load position. An example of a fault tree applicable to a morphing winglet is reported in [5].

In order to verify that the preliminary system architecture meets symmetrical/unsymmetrical loads due to failures, the following assumptions are also proposed:

- For active failures, the Mean Flight Time is 2 hours;
- For hidden (Latent/ Passive/ Dormant) failures, the Safety checks interval is 20000 hours (requirement for maintenance activity);
- For equipment never inspected, the Safety checks interval is 60000 hours (standard for A/C life time)

In addition, a load (static or dynamic) alleviation system requires a dual command and monitoring lane with own control unit (ECU) to guarantee an adequate redundancy. In addition, an acceptable number of linear variable displacement transducers (LVDTs) mounted to the actuator ball screw and angular sensors are needed to favour the operational reliability.

IV. Aerodynamic Design

The aerodynamic design was performed using the optimization chain described in Fig. 5. The process consists of the optimization tool GAW, the aerodynamic solver Xavl and a post-processor. GAW is based on the Pareto dominance [7]. More details may be found in [8]. Xavl is a 2.5D code which couples an inviscid 3D VLM solution with viscous 2D analyses performed in a series of wing spanwise sections. The coupling is obtained by using the equivalent mean-line approach. The use of a low-order aerodynamic solver makes possible to perform the full optimization reducing the overall computational costs.

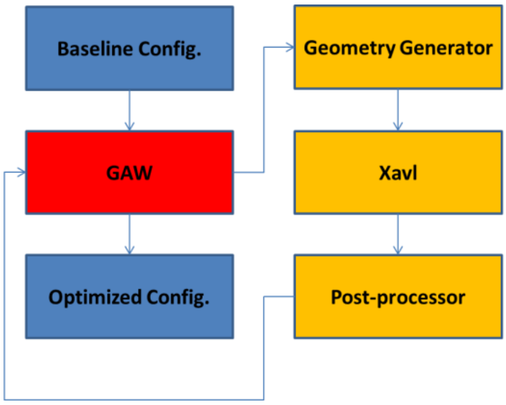


Figure 5. Flow of the aerodynamic optimization tool

The winglet was designed, starting from an existing baseline configuration, in order to maximize the aerodynamic efficiency in three different design points, cruise, climb and climb in one engine out condition. The optimization was performed by taking into account both the geometrical and structural constraints. The main goal was to enhance the winglet aerodynamic performance, in particular the LoD in off-design conditions, and the wing root bending moment (with a safety factor) at the wing box sizing loads. The winglet geometry was parametrized using 5-design section, Fig. 6. In each station, the sweep angle, the twist angle, the chord extension and the cant angle were optimized. Moreover, it was possible to change the spanwise distance between the five sections, and so to modify the overall winglet height.

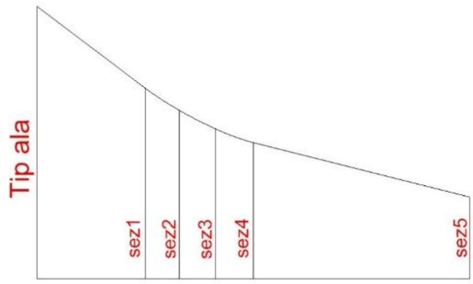


Figure 6. Winglet parametrization

Analytically functions were used for the clean airfoil shape modification. The airfoil shape was defined as:

$$y(x) = y_0(x) + \sum_{i=1}^{n} w_i f_i(x) \tag{1}$$

where y0(x) is the initial geometry, fi(x) i=1..n is the modification function set, and wi are the design variables. The generated aeroshape is depicted in Fig. 7.

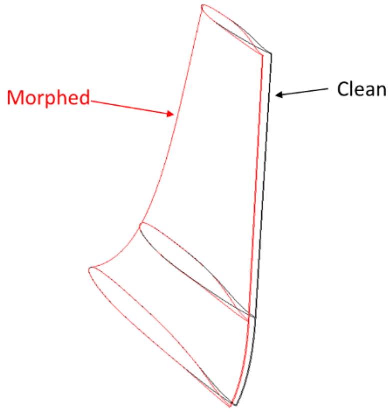


Figure 7. Morphing Winglet Aeroshape

V. Structural Design

A. Winglet Box

A realistic estimate of the effect of a winglet device equipped with an adaptive trailing edge on the design loads envelope of an aircraft wing is studied in [9]. In Fig. 8. , the 2.5-g design dive speed manoeuvre loads (bending moment along the wing span), are compared for three deformation states corresponding to positive and negative deflections. Loads with ±15° deflection are depicted as a ratio of the undeformed condition, i.e. passive winglet. The −15° (up) state shows the potential for reducing loads, particularly in the outer wing. The +15° (down) state, on the other hand, shows significant load increase in the event of jam of the electromechanical actuator. The critical load cases and bending moment distribution sizing the TP90 aircraft wing box, developed in Clean Sky1 (GRA ITD) were the baseline conditions for the conceptual design of the morphing winglet. A set of static, quasi-static and dynamic analyses at various flight points and different winglet deflections and safety critical conditions were considered as additional design load cases. The confined space inside the winglet loft-line represented a significant challenge for the integration of the morphing system actuators and the associated kinematics and a dual-lane control. With respect to the original aeroshape, the winglet section was also modified during the optimization phase so that the hinge moment did not exceed an initial guess value of 100 N*m and both wing geometrical and structural constraints were met. The volume inside the winglet was maximized to accommodate suitable electromechanical actuators with a minimum associated drag penalty. The resulting loft-line of the winglet is shown in Fig. 9. , whereas a preliminary sketch of the winglet structural box is depicted in Fig. 10. In order to withstand the actuation forces, a winglet box made of two spars (rear spar and a front spar) extruded from the root section to the wing tip airfoil, was also envisaged. The structural sizing considered not only the aerodynamic loads but also the interface ones arising from the deployment of the morphing part through the actuators interfaces.

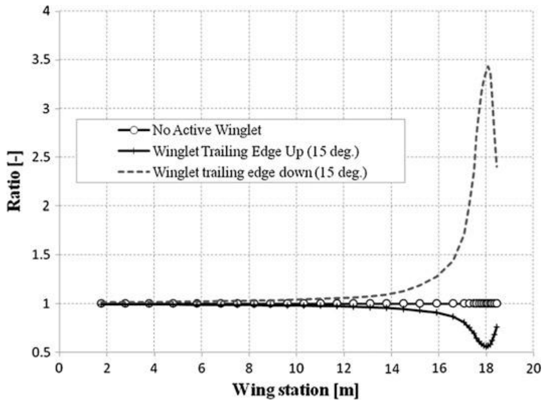


Figure 8. Comparison of wing bending moments (rigid dive manoeuver) [9]

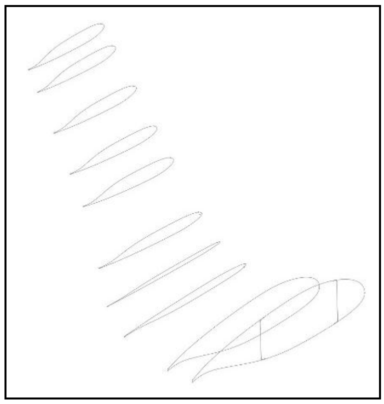


Figure 9. Winglet loft-line distribution

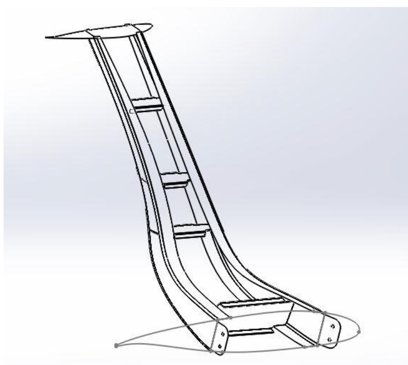


Figure 10. Baseline winglet structural architecture

B. Actuation System: Tab-like Mechanism

The safety-driven design of a fault tolerant morphing winglet concept suitable for the next generation regional aircraft was enabled by two individual (asynchronous) control surfaces (upper and lower) aimed at performing variable camber and differential tab settings depending on the actual flight conditions. A sketch of the two electro-

mechanical actuators housed inside the winglet along with the relative ECUs have been described in [10].
A major potential advantage of this architecture is the ability to move the individual surface either synchronously or independently to different angles (twist). LoD improvements are achieved by separately controlling the downward deflections of the control surfaces in climb and cruise conditions. Varying the angles b/w inner and outer winglet may lead to further aerodynamic benefits. On the structural side, the wing bending and torsion control is accomplished by acting on a single surface through tailored upward/downward deflections.

Furthermore, such a configuration may improve the lateral control in one engine inoperative (OEI) failures and mitigate the safety risks associated with critical failure cases, such as jamming of one EMA and the partial loss of the winglet control. However, mechanical lockers are needed to hold prescribed deflections for long time operations (e.g. temperature rise), to alleviate EMA power consumption, interface loads and reaction forces. A dedicated control system shall avoid the inadvertent deployment of the surfaces.

Although electro-hydraulic actuators guided by conventional feed-forward control logics are nowadays the preferred choice for high lift movable devices, the morphing winglet was equipped with electromechanical actuation (EMA). Despite their energy efficiency, particularly suitable for secondary control surfaces, there are still some concerns related to the proposed application. In fact, the reliability and safety requirements requested to hazardous operations are very stringent and involve specific needs in terms of failsafe protection in the event of emergency shut-down, diagnostics and maintenance, which may be hardly met by the state-of-the-art electromechanical based actuation concepts. Also, symmetric actuation on both wings is a paramount for safe flight and is usually ensured by coupling the surface actuators to a torque shaft system. For the morphing winglet application, a distributed actuation concept was also considered. Nevertheless, assuming that in principle a flight-worthy actuator of similar size, weight, and power can be designed, two off-the-shelf EMA are selected to power the morphing surface. Within the limited space inside the winglet, the kinematic design challenge of delivering the necessary power with the limited actuation force is currently under investigation. Fig. 11 shows two actuation options, i.e linear and rotary actuation, combined with the mechanism hinges, underlining how to take advantage of the given geometry. Such actuation layout is aimed at driving the morphing ribs of the winglet trailing edge individually. In order to withstand the operational loads, the achievable lever arm needs to be maximized, given that the hinge line has to be a straight line to allow the rotary movement and has to stay inside the winglet aero-shape. In addition, the actuators are assumed to be supported by the front spar and are located inside the winglet's main box where the biggest volume is available.

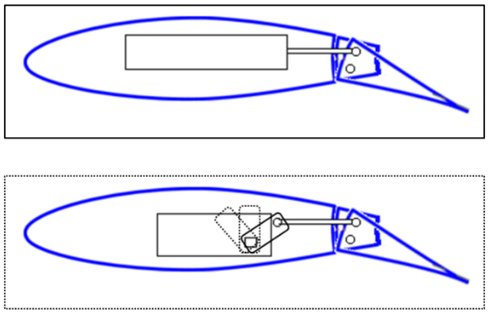
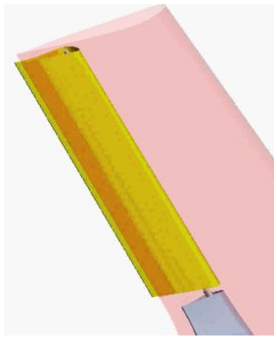
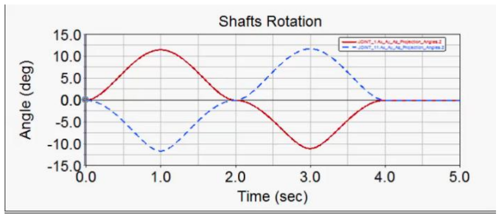


Figure 11. Concept of the tab-like actuation system

The capability of the structure to enable morphing through smooth rigid-body kinematic of the embedded mechanisms was assessed through multi-body simulations. As shown in Fig. 12. , the winglet upper and lower surfaces have been considered as rigid movable tab which deflect in the range between + 12 ° and – 12 ° in opposite direction.



(a)



(b)

Figure 12. Multi-body winglet model (a), deflection angle (b)

C. Rigid-body Morphing Mechanism

The morphing trailing edge device enables the shape transition of the winglet airfoil from the reference (baseline) shape to the target ones during aircraft flight in order to enhance aerodynamic efficiency and alleviate loads. The rigid-bodies morphing design concept was already demonstrated in past projects, such as SARISTU [11]-[17] and CRIAQ [18]-[21]. Such concept was further enhanced following the targets envisaged in the proposed application. Each rib (Fig. 13.) was assumed to be segmented into four consecutive blocks (B0,B1,B2,B3) connected to each other by means of hinges located on the airfoil camber line (A,B,C). Block B0 is rigidly connected to the rest of the wing box, while all the other blocks are free to rotate around the hinges on the camber line, thus physically turning the camber line into an articulated chain of consecutive segments. Linking rod elements (L1, L2) -hinged to not adjacent blocks- force the camber line segments to rotate according to specific gear ratios.

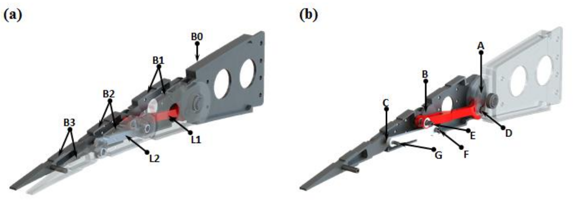


Figure 13. Morphing rib architecture: (a) blocks and links, (b) hinges

These elements make each rib equivalent to a single-DOF mechanism: if the rotation of any of the blocks is prevented, no change in shape can be obtained; on the other hand, if an actuator moves any of the blocks, all the other blocks follow the movement accordingly. The rib mechanism uses a three segment polygonal line to approximate the camber of the airfoil and to morph it into the desired configuration while keeping approximately unchanged the airfoil thickness distribution. An inverse kinematic problem was addressed to properly define the positions of all the hinges of the mechanism; the positions of the hinges along the camber line (both in un-morphed and morphed configurations) represented the input data of the problem, they were fixed by imposing equal chordwise extensions for the blocks B1,B2,B3; the positions of the links (i.e. of the hinges D,E,F,G) were considered as the unknown variables to be determined. In the next Fig. 14. , it is shown the adaptive rib movement from the morphed up configuration to the morphed down.

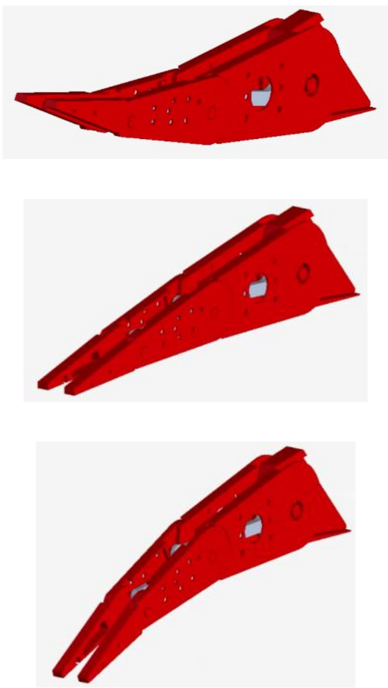
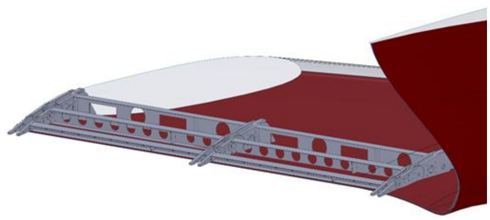


Figure 14. Morphing rib mechanism: (a) morphing up, (b) baseline, (c) morphing down

The preliminary layout is shown in Fig. 15. (a). The ribs' kinematics was transferred to the overall structure by means of a multi-box arrangement characterized by a single-cell configuration delimited along the span by homologue blocks belonging to consecutive ribs. A sketch of the winglet morphing upper surface incorporating the adaptive kinematics is shown in Fig. 15. (b). Such an architecture, derived from a pure kinematic-based approach, aimed at replicating through a structural mechanism the rigid morphing aeroshape ensuring the optimal aerodynamic performance. After that, a topology optimization was launched by taking into account both the aerodynamic loads and intrinsic structural properties of the mechanical system.

(a)



(b)

Figure 15. Morphing trailing edge box (a) and its integration on the upper winglet (b)

D. Structural Optimization

Given the morphing layout, the purpose of topology optimization was to find the optimal light-weight structural architecture preserving the target shape during system operation under aerodynamic loads. Topology optimization has proven to represent an effective tool in the conceptual phase of aerospace structures design enabling weight savings and maximization of structural performances [23]-[24]. Here the SIMP approach, a popular finite element based material distribution method proposed by Bendsoe in 1989, [25] is used to optimize the whole structure of a morphing winglet trailing edge with support and load conditions expected in its operative environment. The volume of the structure to be optimized was created by extruding the ribs profile along the skin surface, as shown in Fig. 16. The final design volume was defined by subtracting to the initial volume some non-design areas needed to preserve the nodes where loads and BC are applied. Non-design areas were also used around the hinge to preserve the rigid elements that connect the three parts of the morphing winglet trailing edge. In order to obtain accurate results from the optimization process, the volume of the structure was discretized with a rather fine mesh consisting of 2346749 solid elements (both tetrahedral and hexahedral). The topology optimization was carried out using the commercial software Altair Optistruct. The objective function to be minimized is the global compliance with a constraint on the total mass of the winglet of 700g. Optimization converged to a feasible design after 56 iterations. Results are shown in Fig. 17. for a relative element density threshold of 0.3, whereas the stress distribution over the mechanism link is shown in Fig. 18.

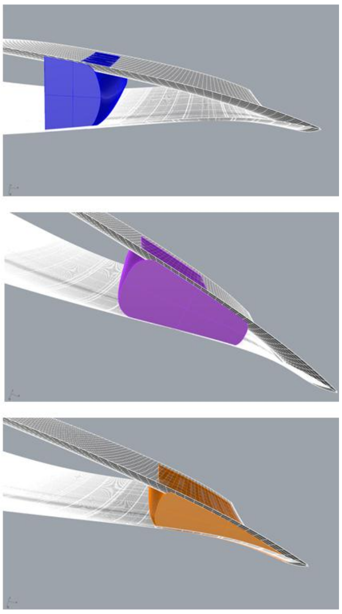


Figure 16. Initial design volumes of the morphing mechanism to be optimized

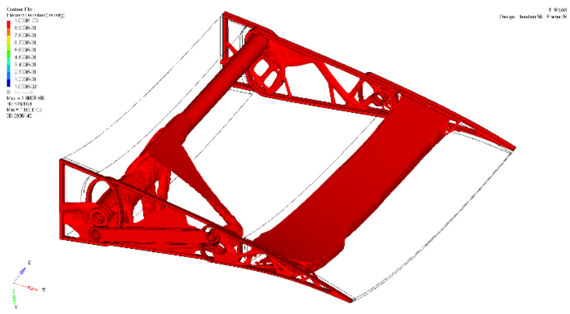


Figure 17. Topology optimization results

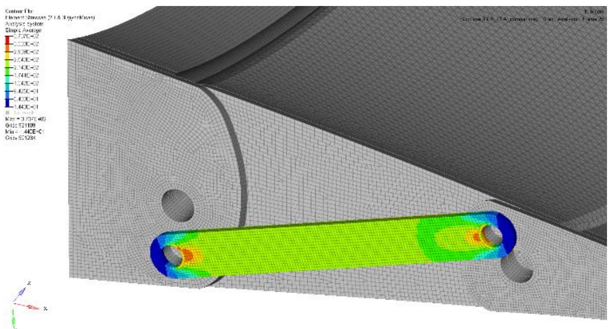


Figure 18. Stress distribution over the mechanism link.

VI. Aeroelastic Issues

Impacts induced by the morphing winglet on aircraft aeroelastic stability were estimated since the preliminary design stage in order to avoid the maturation of inadequate structural configurations.. In absence of more refined data on morphing winglet structure, the stiffness and inertial distributions of a typical (conventional) arrangement were assumed. Since morphing capabilities are usually accompanied by mass increase, trade-off flutter analyses were carried out while considering positive variations of the winglet mass distribution with respect to its assumed value; limitations for the overall mass of the morphing device were then found on the basis of the obtained flutter trends.

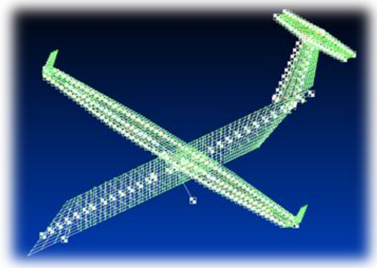


Figure 19. Aeroelastic Model of the reference aircraft

A stick-beam equivalent model (Fig. 19.) was used for the evaluation of wing bending and torsion frequencies in correspondence of each considered winglet mass and free-free aircraft condition. The range 15 Kg -100Kg. was explored for the overall mass of the winglet.
Bending/torsion flutter speed was then conservatively estimated referring to the Molyneux equation ([26]); both symmetric and antisymmetric coupling mechanisms were considered (Fig. 20).

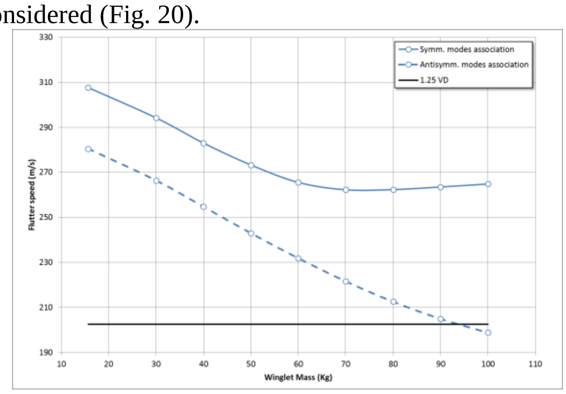


Figure 20. Flutter Speed diagram with various winglet mass

The diagram of Fig. 20 shows that the flutter due to coalescence of anti-symmetric wing bending and torsion modes is more sensitive to winglet mass increase; it follows that in order to assure aircraft flutter clearance (at least with reference to wing bending/torsion binary flutter) the overall mass of the morphing winglet should not exceed the value of 90 Kg.

VII. Conclusions

Following the successful experiences gained in SARISTU, where an adaptive trailing edge device was developed for medium to large size commercial aircraft, some conceptual ideas and the preliminary design of an adaptive winglet have been investigated. Such a system has the potential to reduce the induced drag more than a conventional fixed winglet. A fault tolerant concept based on two individual (asynchronous) control surfaces (upper and lower) was investigated with the purpose to achieve variable camber and differential tab settings. Focus was given to the kinematic design of the morphing surfaces through multi-body simulations to validate the double shaft concept, the integration of the finger-like morphing rib architecture into the structure and the aeroelastic computation of the flutter speed with different winglet mass values.

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