PRELIMINARY STUDY OF A NEW UAV CONCEPT: THE VARIABLE GEOMETRY VEHICLE

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Abstract

Since 1989 the military scene has substantially changed: there are many nimble and dynamic threats as opposed to the former deployment of each state army.

Therefore, this leads to the need of permanent surveillance and monitoring of large areas associated with the capability of a fast combat reaction and this demand is usually performed by deploying both surveillance and ground attack aircrafts. Fighter employment increases the mission costs, because of their poor flight endurance, so it is necessary to use many aircraft; moreover, these vehicles are requested to have a very low radar and infrared signature..

On the other hand, surveillance aircraft usually have a very limited attack capability, so there is a dead time between the detection of a threat and the action, with a consequent tactical inefficiency.

This paper shows a preliminary analysis referred to an unmanned vehicle with a variable geometry configuration, named VGV (Variable Geometry Vehicle), that aims at matching the high endurance capability of surveillance aircrafts with the high performances and survivability of fighter-ground attack aircrafts. The performance analysis of an open and a closed configuration has been undertaken and a conceptual study has been afforded in order to find a mechanical solution to move the outer portion of the wing and inserting it into the trailing edge of the fixed part in order to change the geometry of the aircraft in flight.

The proposed design solution is innovative because it matches two different configurations in a unique aircraft.

A new unmanned system concept is proposed, with a variable wing geometry which can move from a typical surveillance configuration to a combat one.

1 Introduction

Air vehicles are currently designed for single missions such as reconnaissance or attack. The vehicle geometry for current aircraft for specific missions is dictated by the primary mission segment and is non-optimal for other mission segments and roles.

Wings are fully extended to generate lift for low-power takeoff, or to permit aircraft to loiter; when fully retracted, wing configuration yields high-speed capability and increased agility.

The ability to change wing shape and vehicle geometry, substantially while in flight, would allow a single vehicle to perform missions that are beyond current capabilities or to perform multiple mission tasks; the ability to morph and become a shape-changer combines optimal performance into a single system with low turning radius, long endurance, increased payload, and high speed—tasks that cannot be efficiently combined today.

A morphing aircraft can be defined as an aircraft that changes configuration to maximize its performance at radically different flight conditions. These configuration changes can take place in any part of the aircraft, e.g. fuselage, wing, engine, and tail. Wing morphing is naturally the most important aspect of aircraft morphing as it dictates the aircraft performance in a given flight condition and has been studied by the aircraft designers since the beginning of the flight, progressing from the design of control surfaces to the variable-sweep wing.

Many studies investigate the use of optimal search techniques to demonstrate the benefits of different forms of geometric changes of a morphing aircraft. Designers of morphing aircraft face the challenges of determining what sorts of geometric changes will most benefit the overall mission performance of the aircraft.

The study proposed in [1] discusses a method to design a family of non-morphing aircraft to help identify the nature and magnitude of the most beneficial in-flight geometric changes. The problem formulation has been posed as a multi-objective optimization problem and the solution approach is based on a two-branch tournament Genetic Algorithm.

Recent research efforts are focusing on even more dramatic configuration changes. The Morphing Aircraft Structures (MAS) Program initiated by the Defense Advanced Research Projects Agency (DARPA) envisions a morphing aircraft that had the ability to perform either a 200% change in aspect ratio, a 50% change in wing area, a 5 degree change in wing twist, or a 20 degree change in wing sweep [2].

A critical aspect of the development of a morphing aircraft is determining the appropriate mission requirements for such an aircraft. In [3] a method is proposed for determining these requirements: a scenario based evaluation model compares different operational fleet architectures, such as a fleet of morphing aircraft versus a fleet of multiple types of aircraft.

The most distinguishable advantage of a morphing Unmanned Combat Air Vehicle (UCAV) is its ability to adapt to the dissimilar phases of reconnaissance missions, involving subsonic loiter and supersonic dash. Effective UCAV configurations are necessarily unconventional, leading to atypical design issues that arise early in the design phases of such an aircraft. As a result, traditional design methods that rely solely on historical data and legacy codes are not viable options. In [4] a physics-based design approach is described where Response Surface Methodology (RSM) is utilized to effectively bring the physics-based knowledge to the early design stages as well as to allow for the exploration of the design space through a parametric design study. As a first step geometric models are generated in accordance with a Design of Experiments (DoE) using Rapid Aircraft Modeler (RAM). The aircraft design is then optimized using the RSE's (Response Surface Equation) to minimize overall drag.

The possibility of varying mission objectives and functions under many flights revolutionizes the costs of building and operating aircraft enabling aircraft to be more efficient and operate under a wide range of varying flight conditions. However there might never be a single solution for a morphing aircraft. The suitability of a type of morphing technology that is integrated into an aircraft will depend on size, range and flight performance envelope. Paper [5] shows how to organize and summarize the many varying projects, concepts, and technologies of morphing aircraft.

The recent developments in the field of smart materials have spurred research in the field of morphing wings where those materials can be used. NASA's own Aircraft Morphing prominent project focuses on shape-memory alloys and other smart technology to create shape alterations in the wing. In [6] benefits of shape morphing, key features of the design and a wind tunnel testing to develop morphing UAVs are presented. Further studies, that present technology maturation tests included full-scale subcomponent and integrated models, are sown in [7]: these tests demonstrated concept feasibility using static loads and cyclic tests and an articulated large-scale half span wind tunnel model that validated morphing system operation under realistic flight loads.

Such wing geometry and configuration changes can be conceptually achieved in a variety of ways - folding, hiding, telescoping, expanding, and contracting a wing, coupling and decoupling multiple wing segments. This type of design might be incorporated to enhance various operational capabilities of the aircraft, reduce the aircraft's required takeoff gross weight, and/or enable an aircraft to fly a design mission that a fixed geometry wing aircraft could not.

2 Mission Requirement

Typical aircraft missions are composed of segments, each segment having specific requirements in terms of altitude, speed, payload and endurance. Usually, the design of a new aircraft has to find a trade off solution between the different segments that are typical for the aircraft mission.
For the new UAV concept proposed in this paper, the mission requirement is more critical than usual. The dimensioning mission is an *active surveillance* mission (Figure 1).

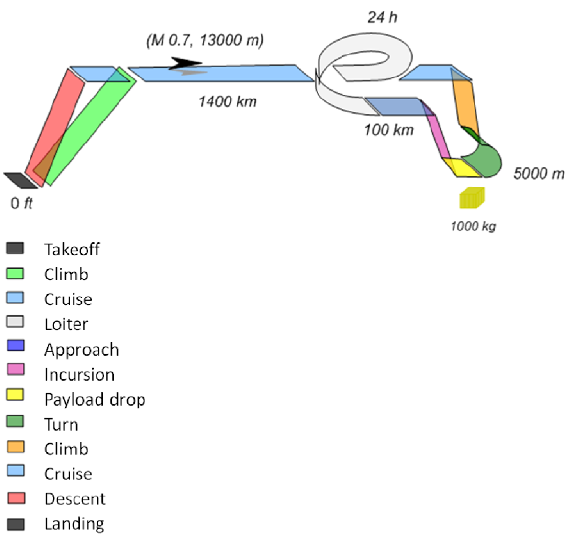

Figure 1 - Mission requirement: active surveillance.

It is comprised of twelve segments: take-off, climb, cruise, loiter, approach, incursion, payload drop, turn, climb, cruise, descent and landing. In figure 1 the lengths of main mission segments are indicated. A further requirement is stealthness.
The Variable Geometry Vehicle (VGV) study draws on a previous preliminary study [8] of an all-wing Combat MALE UAV designed to fulfill the mission requirement described above.

3 VGV modelling

The VGV is a vehicle able to fly in two different configurations. We will refer to the first configuration as "open", having high aspect ratio and wing span values; it is designed to fulfill the requirements of the *surveillance* segments of the mission. The second configuration is obtained from the open one by reducing wing span in order to reach a "closed" configuration, similar to diamond, to perform *active* segments of the mission.
This paper focuses on the design of a mechanical device able to move the outer part of the wing and inserting it into the trailing edge of the fixed part, in order to change the geometry of the aircraft during the flight.
The variable geometry configuration involves a substantial variation of geometric and aerodynamic parameters.
Figure 2 shows the open configuration.

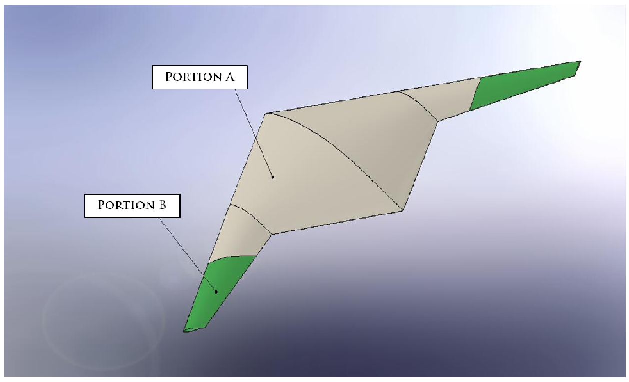

Figure 2 – VGV in open configuration, portion A is fixed while portion B can rotate around a pin.

It is an all-wing aircraft drawing on the Combat MALE design. The wing is divided in two portions, the inner one called portion A and the outer one portion B. Portion A is fixed while portion B can rotate around a pin in order to allow portion B to be partially inserted into the trailing edge of portion A. When the rotation is completed the closed configuration is obtained (Figure 3).

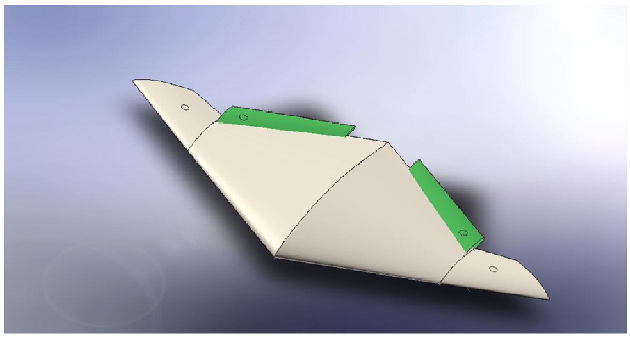

Figure 3 - VGV in closed configuration.

Although the insertion of the portion B into the portion A is necessary for the purpose of obtaining an acceptable airfoil, it is one of the main issues faced in this paper. The parts highlighted in red and blue in figure 4 have to be opened.

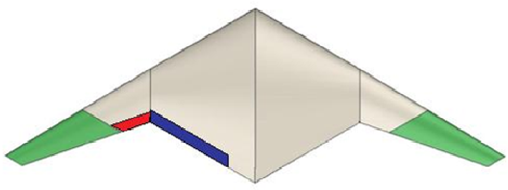

Figure 4 - Parts highlighted in red and blue have to be opened.

We consider to open the fix airfoil in correspondence of the point in which the fix airfoil thickness and the moving airfoil maximum thickness are the same.
In the portion A the skin is made of two separate panels; one panel is mounted on a support that can move on a guide rail in order to allow it to slide under the other panel (Figure 5).
The guide rail shape is modelled in a proper way so as to define the correct movement of the panel (Figure 6).

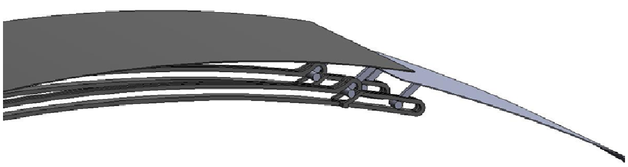

Figure 5 - The rear panel is mounted on a guide rail that allows it to slide under the front panel.

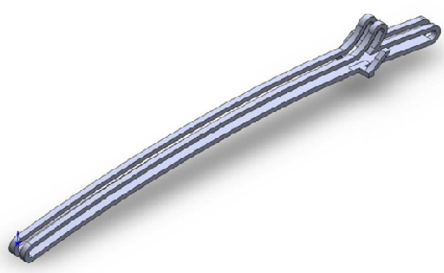

Figure 6 - Guide rail.

Analysing the closed configuration (Figure 7) we can identify two significant sections: in section I the chord of portion B is maximum whereas the chord of portion A is minimum; on the other side in section II the chord of portion B is minimum while the chord of portion A is maximum. Since the portion B has to be inserted into the portion A, section I is the most critical.

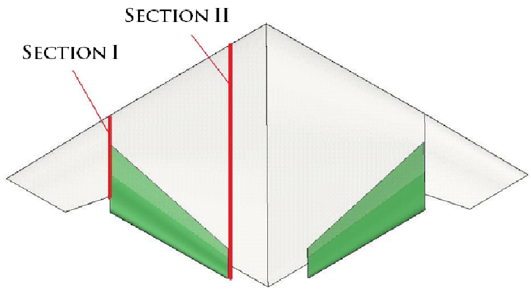

Figure 7 – Two significant sections are identified. Section I is the most critical.

In that section portion B airfoil has the following characteristics:

- chord = 1.545 m;
- maximum thickness = 0.185 m at 0.695 m from the leading edge (55% of the chord).

Therefore, the part of airfoil that has to be inserted into the portion A is 0.849 m long.
In section I portion A airfoil has the following characteristics:

- chord = 1.839 m;
- thickness = 0.185 m at 1.247 m from the leading edge (67% of the chord).

Figure 8 refers to section I in closed configuration.

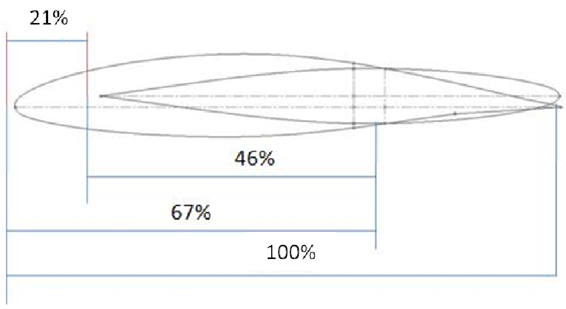

Figure 8 - Section I in closed configuration: only 21% of the chord is empty.

It is possible to notice that only 21% of the chord is empty. This is not acceptable because there would not be as much space as necessary to hold the structure. We assume that in each section the minimum value of free chord has to be 50%.
Figure 9 shows the percentage of free chord along the wing span from section I to section II.

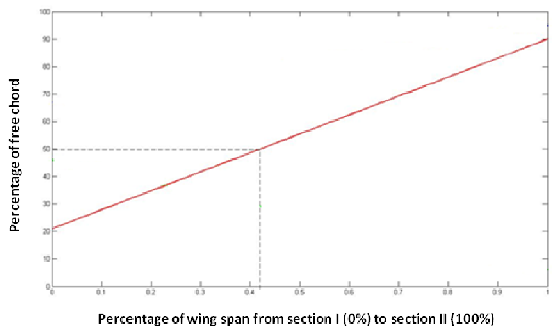

Figure 9 - Percentage of free chord variation along the wing span from section I to section II in the closed configuration.

It is possible to observe that the condition mentioned above (the minimum value of free chord has to be 50%) is verified from 42% to 100% along the wing span between section I and section II.
Sections between 0% and 42 % will adopt a specific solution, opening the panels in correspondence of the trailing edge of portion B in order to hold the wing structure. The device adopted is similar to the one used to open the panels in portion A.
The device that allows the rotation of portion B is showed in figure 10 and 11, both in the open configuration and in the closed configuration.

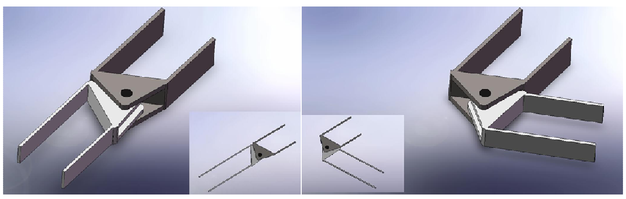

Figure 10 - Device that allows portion B to rotate.

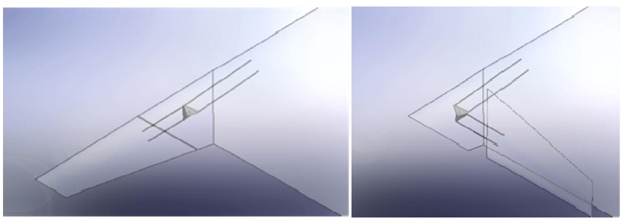

Figure 11 - Rotation of portion B

The aerodynamics of the resultant profile in the closed configuration is critical because the leading edge of portion B has to work as a trailing edge. Moreover there are some cusps in the airfoil. Therefore, separation of the boundary layer can occur.

We suppose to exploit smart materials technology in order to solve this problem. The introduction of components, made of two way SMA (Shape Memory Alloy) both in the leading edge of portion B and in the junction area between portion A and portion B, allows to modify the airfoil shape in order to reduce the separation of the boundary layer.

4 Results

Performance analysis of the new UAV concept is achieved comparing the open configuration with the closed one with the aim of studying the effect produced by the geometry variation on mission performances.
Most significant results of the analysis are listed below. Subscript "(O)" refers to open configuration whereas subscript "(C)" refers to closed configuration.

Moment of inertia around roll axis I_x:

$$\frac{\Delta I}{I_{x(O)}} = \frac{I_{x(O)} - I_{x(C)}}{I_{x(O)}} = 23\%$$

Roll acceleration $\dot{\rho}$:

$$\frac{\Delta \dot{\rho}}{\dot{\rho}_{(O)}} = \frac{\dot{\rho}_{(C)} - \dot{\rho}_{(O)}}{\dot{\rho}_{(O)}} = 30\%$$

Range X_{max}:

$$\frac{\Delta X_{\max}}{X_{\max(C)}} = \frac{X_{\max(O)} - X_{\max(C)}}{X_{\max(C)}} = 16\%$$

Endurance t_{max}:

$$\frac{\Delta t_{\max}}{t_{\max(C)}} = \frac{t_{\max(O)} - t_{\max(C)}}{t_{\max(C)}} = 55\%$$

Stall speed V_{st}:

$$\frac{\Delta V_{st}}{V_{st(O)}} = \frac{V_{st(C)} - V_{st(O)}}{V_{st(O)}} = 6\%$$

Gust sensitivity S_g:

$$\frac{\Delta S_g}{S_{g(C)}} = \frac{S_{g(O)} - S_{g(C)}}{S_{g(C)}} = 14\%$$

The analysis performed shows that the variations of main performance parameters are considerable.

We can observe that, as supposed, closed configuration is more manoeuvrable and less sensitive to gust than open configuration. On the other side, open configuration has a higher endurance and range than the closed one, fitting the surveillance requirements very well.

Conclusion

In this paper a new unmanned system concept is proposed, with a variable wing geometry which can move from a typical surveillance configuration to a combat one.

The first preliminary study is evident for the advantages that VGV could produce performing an active surveillance mission.

The transition from a configuration to another is a critical control problem not covered in this paper.

The leading edge working as a trailing edge in the closed configuration is one of the most critical issue. In order to solve it, innovative solutions such as smart materials have been slightly investigated.

Further developments will address in-deep investigation about smart materials as well as control systems.

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