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# Aspects Regarding the Integration of Flexible Wing Concept in Small Unmanned Aerial Vehicles

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**Abstract.** Unmanned Aerial Vehicles have seen a rapid development due to increased miniaturisation of technology, and their multiple usages in both military and civilian fields, thus making the UAV business very profitable. Although the UAVs are high enabling capabilities, they are still single-role (one flight, one mission). The capabilities of an aerial drone are induced by its payload capacity and the quality of on-board sensors. The types and performances of the on-board sensors vary in accordance with the mission requirements. The present paper is reviewing the Flexible Wing concept with the stated intent to give a stabilizing model for the morphing UAVs.

**Keywords:** morphing, UAV, flexibility, micro-pilot, close-loop system

## 1. Introduction in the concept of flexibility

The concept of flexibility or morphing generally defines an aircraft whose shape is changing during the flight in order to optimize its performance. The changes of the aircraft's shape include but are not limited to span, area, camber, cord, thickness profile, aspect ratio, and planform. The morphing can be used as an element of control by the variable shape aircraft to change the dynamic flight. In the past the aircraft have adopted different techniques for adapting their shape depending on the desired flight characteristics.

## 2. Review of current concepts of morphing

Wright developed the idea to change the airplane's aerodynamic features by modifying the shape of the wings. Other method is a variable dihedral angle for aircraft's stability with the change of span wing. The morphing technology is not limited to crew-operated aircraft, developing a new generation of UAVs that in conjunction with the advanced technology materials has led to renewed interest for radical configurations of morphing. The current research is dedicated to various wing shapes, by way of variable span, camber and 3D structural. The current types of morphing are the following:

***a. 1D Change***

That is the one-dimensional change of span wing (Fig. 1). The form of the wing can be split during the flight to comply with different missions, by large variation in span size in a limited section of the wing. In addition, differential span change between wingtips can generate a roll moment, potentially replacing ailerons on the aircraft.

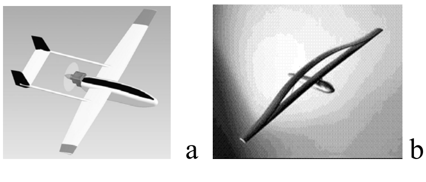

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Fig. 1: Change span of UAV  a) one-dimensional change (1D)  b) Morphing by DARPA

### *b. Concept of Morphing Buckle-Wing*

The UAV (3D morphing, Fig. 1b) has the capacity to change the configuration of its wings from a single one in two wings glued to the extremities.

### *c. Complex Morphing Wing Concept Generation*

These are aircraft with wings that have the capacity to change the shape of the planform during the flight with a 200% aspect ratio, a 50 % wing area, and with 20° the wing sweep. The concept of morphing by DARPA was further developed in the Phase II program called MAS (Morphing Aircraft Structures). The ‘wing folding’ concept developed by Lockheed Martin allows variations on the span, aspect ratio cord’s angle and effective sweep angle (Fig. 2).

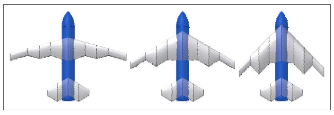


Fig. 2: Morphing by Lockheed Martin MAS and NextGen Aeronautics

### *d. Total Morphing concepts for UAV*

The aircraft with the total morphing are flying vehicles that change their shape in order to accomplish the stated mission without the use of conventional control surfaces or seams for flight control (Fig. 3). The aircraft built with morphing technology promise the distinct advantages of being able to fly many types of missions, to perform radically new manoeuvres not possible with conventional control surfaces, to be more fuel efficient, and to provide a reduced radar signature. The key concept is full integration of the control shape of wing structure with a truly intelligent structure. The design of these vehicles must take full account of the aerodynamic loads and must carefully consider the power requirements for shaping control to ensure an overall performance benefit.

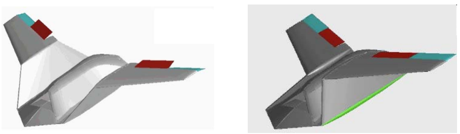


Fig. 3: Change planform-Lockheed Martin fold wing concept

The experiment about the aircraft with adaptive surface (APVE) is a design of the University of Virginia. The UAV has a telescopic morphing structure in the wings, tail and fuselage. This project was done to assess the benefits obtained in the NextGen Aeronautics Inc. project, since the results had not been available (Fig. 4).

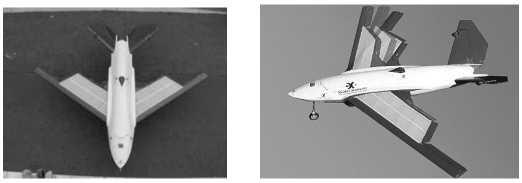


Fig. 4: Morphing concept, N-MAS, horizontal bi-dimensional (2D) morphing

In Fig. 5, a variable sweep / variable root chord concept was developed by NextGen Aeronautics that enabled direct variations in root chord length and sweep angle, thus indirectly varying the planform area and aspect ratio. MFX-2 is capable of autonomous metamorphosis during the flight to adjust the wing in 10 seconds, thus allowing a varied angle for optimisation at different schemes of flying.

Fig. 5: NextGen Aeronautics MFX-2

### *e. Multi-axial Winglets*

The multi-axial winglets are attached wings able to perceptibly change their angle (Fig. 6). They do not replace conventional surface control, but their use would improve the flight substantially. The next step in this research is to test a model with multi-axial winglets to replace all conventional control surfaces.

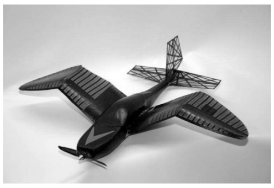


Fig. 6: Multi-axial winglets

### *f. Vertical Bi-dimensional Morphing*

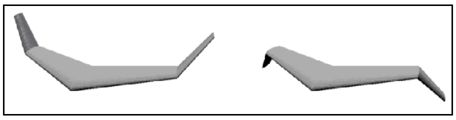
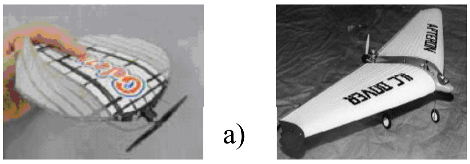


Fig. 7: Vertical bi-dimensional (2D) morphing

It worth mentioning that morphing changed the system of constants over time, therefore introducing new inertial terms in the dynamic of flight. The UAV with multiple degrees of freedom for translation and rotation must properly account for inertia to a high level of accuracy in order to mould the dynamics of flight.

### *g. Flexible Flying Wing concepts*

The University of Florida made a research about deformable wings with the capacity to transform continuously. These wings are very complex and could be used for UAVs (Fig. 8a). The flexible wing allows complex forms and is more stable than the stiff ones, particularly in turbulent weather conditions. The manual control of the wing shape is impossible, thus making necessary the software and hardware to control them.



a) b)

Fig. 8: a) Flexible wing concept b) ILC Dover 'The Apteron' UAV

### **Case of Flexible Wing (Inflatable Wing)**

This wing inflates during flight (University of Kentucky) and it is reinforced under the action of UVs during the ascension made with the help of a balloon. Researchers from Dover had a similar approach (Fig. 8b and 9), with wings powered by piezoelectric means. The wing is inflated and deflated, according to the needs of control during the flight and is able to change shape tips, such as NACA profiles (NACA 8318 and 0018).

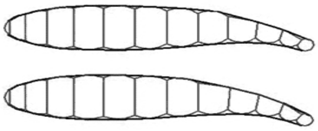


Fig. 9: Inflatable wings

Another interesting morphing UAV concept comes from 1950, involving the idea of inflating and deflating wing for storage and transport. The idea came from the auto casings produced by GoodYear which created "Inflatoplane", a plane for rescuing the pilots dropped-in behind the enemy lines. GoodYear had continued to produce these planes for two decades, until the idea was adapted by the ILC Dover for a UAV called "Apteron" (Fig. 8b).

### *g. Morphing solutions for Rotary Wings*

The blades of the RW aircraft have also been modified by increasing the length through centrifugal forces (Fig.10), based on the methods developed by State University of Penn. This would be ideal for a vehicle which needs the available power to lift higher.

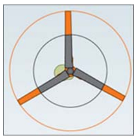


Fig. 10: Morphing at Rotary Wings

## 3. The proposed model

The method of transfer functions could be used for the analysis of dynamics of the flexible aircraft. In open-loop architecture (output not affecting the input), a controller is required to activate the process. Block diagram representation is also a suggestive way to deal with the closed-loop systems (output is the feedback to modify the input). The feedback loop measures the output using the sensors, multiplies this variable of the measurement in adjustable gain, and then provides this feedback signal to a comparator. Close-loop feedback could be used on flexible small-body aircraft to modify dynamic stability characteristics, and to implement autopilot functions.

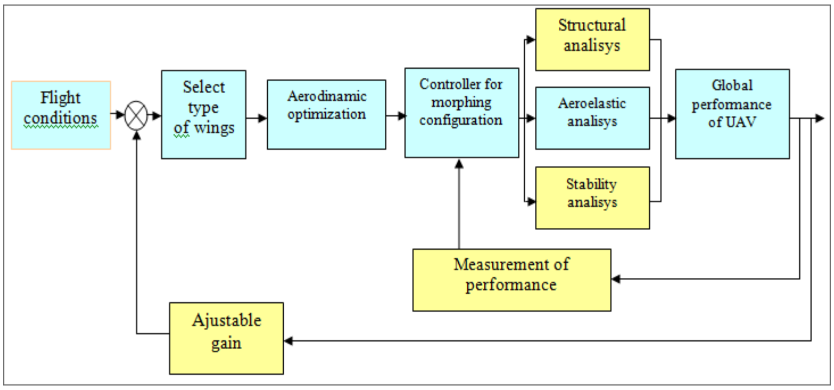


Fig. 11: Block diagram of the model

The block diagram (Fig. 11) represents one aircraft with a stabilizing system based on the variables of status. One could notice the existence of loops of parallel-opposed correction.

The considered structure does the control based on the variables of status, creating paramount dynamic performances in the linear case. The structure of a positioning system, angular / rectilinear tracking system or the same is shown in Fig. 12, where *v* is the size of the input data; *p* gives the random noise; operating system *(Ψ, Π)* developing a bloc based on the inner reaction speed with *(C1, C2)* as coefficients of reaction subsequent to transducer output *Γ*; *N* is the element representing a nonlinear amplifier with an output amplitude characteristic; *Ω* indicates an integrative-derivative correction; *x1, x2, x3* represent the variables of status.

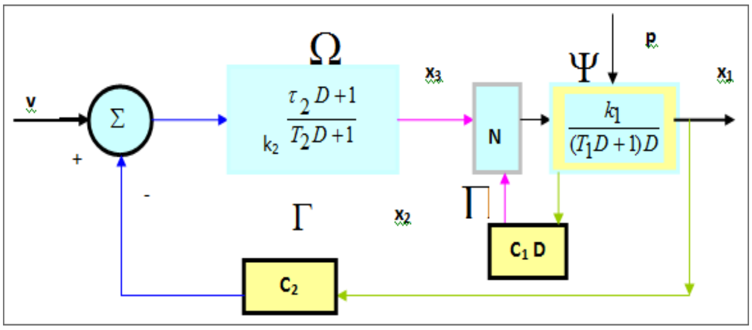


Fig. 12: Block diagram of the model

Below are presented the equations of the system:

$$\overset{\circ}{x}_1 = \frac{1}{C1}\left(x_2\right) \tag{1}$$

$$\overset{\circ}{x}_2 = -\frac{1}{T_1}\left(x_2\right) + \frac{C_1 k_2}{T_2} y \tag{2}$$

$$\overset{\circ}{x}_3 = \frac{1}{T_3}\left(x_3\right) + \left[\tau_3\left(\overset{\circ}{v} - C_2\overset{\circ}{x}_2\right) + \left(v - C_2 x_2\right)\right] \tag{3}$$

One should consider the Fig.13. if the considered system was reduced to a single buckle.

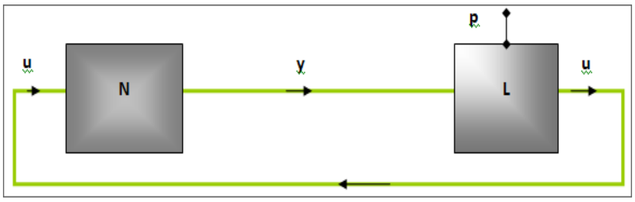


Fig.13: System with a single buckle

Considering $v = p = 0$ it results the differential equation for this part, and the static characteristic of the non-linear $N$ given by the following equation:

$$T1T3\,\ddot{u} + (T1+T3)\,\dot{u} + u = -k1\left[C1T3\,\ddot{y} + (C2k3\tau_3 + C1)\,\dot{y} + C1k3y\right] \tag{4}$$

$$y = g(u),\ u = x1 - x2 \tag{5}$$

The linear $L$ has the following operator for dynamic transfer:

$$H_L\,(D) = \left(-k_1\frac{k_2C_2 - C_1D}{D}\right) \bullet \frac{1}{DT_3 + 1} \tag{6}$$

One should notice that if $x1$ was taken as an independent value, than the equations (1, 2, 3) could be reduced to a system with two first grade differential equations in contrast with *(x2, x3)* that could be integrated in the tri-dimensional space *(x1, x2, x3)*.

$$\frac{dx_2}{dx_1} = -\frac{C_1}{T_2} + \frac{k_2 C_1^2}{T_2}\,\frac{g(x_3 - x_2)}{x_2} \tag{7}$$

$$\frac{dx_3}{dx_1} = -\frac{C_1}{T_3}\frac{x_3}{x_2} - \frac{C_2 k_3 \tau_3}{T_3} - \frac{C_1 C_2 k_3}{T_3}\frac{x_1}{x_2} \tag{8}$$

The stated model has also as input both the imposed flight parameters (speed, weight, flight level) and the random disturbances in the areas of flight, such as the atmospheric factors (pressure, temperature, humidity). UAV's overall performances are derived from dimensional, mass and motion, resulting from structural optimizations, analysis, and aero elastic stability.

## 4. Conclusions and future work

The main limitations come from the extreme miniaturization and the complexity or impossibility of downsizing. Additional, one should consider also the aerodynamic characteristics (lower lift coefficient, higher drag coefficient). More, for systems with un-conventional propulsion there are further limitations. The limitations of the morphing concept for optimized wing are imposed by compliance and enforcement mechanisms of the physical and chemical characteristics of the materials used in construction of the flying wing. The operating limits for UAVs with morphing could be the atmospheric conditions in the flying zones.

The special missions require the exceptional manoeuvrability capabilities of the MAV. Morphing solutions are analyzed and compared according to a global indicator focused on controllability and aggressive handling. Reduced manufacturing costs are further important in selecting a morphing strategy.

Static nonlinear characteristic *N* will fully affect the numerator and partial the denominator of the operator equivalent equation.

The concept of modularity is well adapted to the semi-flexibility concept proposed for flying wing with high elongation ratio. Inertial sensors used to measure the response characteristics of flight maneuvers together with qualitative analysis are leading to improved overall performance of the flying wing aerodynamics.

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