COMMAND AND CONTROL OF THE FLYING WING IN THE MORPHING CONCEPT

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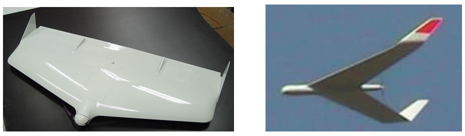
Abstract: *Flying wings in the morphing concept allow a growth to the aerodynamic performance for different flight conditions using 2D and 3D changes in the bearing surface geometry. The command and control architecture presents three operations levels: stability and control, navigation and autonomy. This article presents a solution regarding the equipment used for a UAV type flying wing together with some marks about the test activity of the aerial vector.*

Keywords: *flying wing, morphing, autopilot, command and control, flying test.*

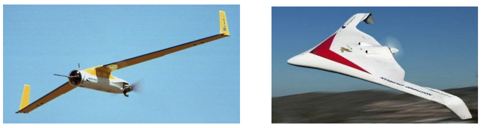
1. INTRODUCTION

UAV systems have become a military and civilian branch which develops continuously in an alert rhythm. The necessities and modern fight trends can be extracted from efficiency, speed and precision. The main purpose for any confrontation is to protect your own men without reducing the combat power and in the same time to increase the fighting skills.

Tailless aircraft are used almost in any category of operational UAV, starting from a small UAV till a UCAV, see figure 1 (Blyenburg, 2011).



Zala 421-08 Orbiter



Scan Eagle Killer Bee KB-4

Saab Filur X-45 C

Fig. 1 Flying wing UAV

A conventional flying wing is designed for a specific type of mission and will fly optimal with limits regarding the flight conditions for which was designed and the flight time. Flying wings in the morphing concept allow a growth to the aerodynamic performance for different flight conditions using 2D and 3D changes in the bearing surface geometry (Bowman, Sanders, 2007). The morphing concepts are inspired from biomimetics area, birds change their wing position with the purpose to make specific maneuvers or to adjust the aerodynamic profile so it can adapt to the flight conditions, (Mc Gowan, Cox, Lazos,2003), see figure 2.

a. loitering, b. strike

Fig. 2 Morphing

The 3D evolutions of the flying wing in morphing concept have been possible due to process information obtained from nature with the help of sensors and the execution through servo actuators, these two being a part of the command and control architecture.

2. THEORETICAL REFERENCES

2.1 Command and control architecture. They are three hierarchical levels that could be identified in autopilot modern system:

Level 1. Control and stability. At this level the system ensures only dynamic stability of the aircraft. The module contains three accelerometers on three axes, these calculating the angles between the afferent axes and the gravitational force vector and for the yaw angle the system contains a magnetic compass. The system also contains a speedometer and altimeter (barometric, sonar, laser) to record static and dynamic pressure.

Level 2. Navigation. At this level the autopilot can perform take-off/landing maneuvers, a flight on an established trajectory without any human intervention and in consequence in contains a GPS module. The UAV which are equipped at this level must have additional equipment at the ground base to program the missions (GCS – ground control system).

Level 3. Autonomy. Without any doubt it is the most complex level containing the interpretation functions that recognizes objects, risk, the capacity to take a decision in a mission and to reach the objective with minimal risks, aircraft identification in the flight zone, information exchange between UAV, detecting damage and future modification to save the aircraft (see figure 3).

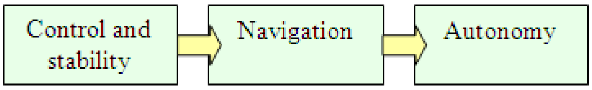


Fig. 3 Autopilot levels

2.2 The autopilot control theory. To obtain the desired maneuvers from the aircraft the autopilot system uses directly and indirectly control curls for the execution elements.

Lateral control (figure 4) can be obtained by changing the lateral inclination angle and flight direction angle. This could be realized through two direct curls and one indirect curl: aileron control depending on the flight rotation around the longitudinal axe (V_x); aileron control depending on the lateral inclination angle (φ); aileron control depending on the flight direction represents the indirect curl.

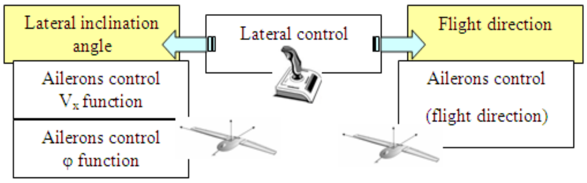


Fig. 4 The lateral control

The longitudinal control (figure 5) target is the pitch angle, speed and altitude. It is realized through three direct curls and two indirect ones. The direct curls control the depth and the motor rotation and the indirect curls command the direct curls. The direct curls are: the depth controller depending on rotation speed around the lateral axe (V_y); the depth controller depending on the pitch angle; speed control (*n*) depending on the flight. The indirect curls are: the depth controller depending on the altitude; depth controller depending on the flight speed (Deliu, 2001).

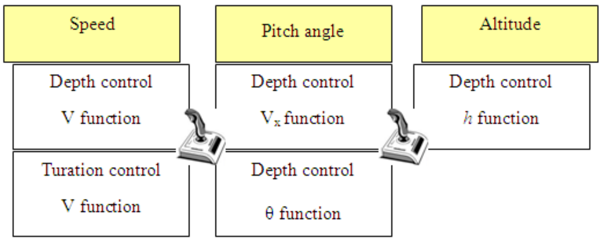


Fig. 5 The longitudinal control

Control calculation in turn attitude. To determine the conditions to execute a coordinated turn we use the state equation: First element (figure 6) is the UAV, the control regroup is done after ψ, ψ and δ command. The third element realizes serial connections, passive and active and ***N*** is the static characteristics of the execution element.

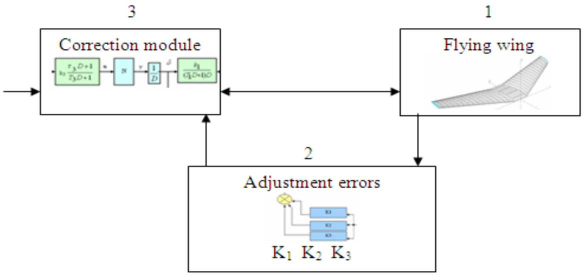


Fig. 6 Control in the turn

We have the following operators: the considered structure realizes the control after their state variables which imply characteristics and superior dynamic performances (Voicu, 2002). In this minimal architecture the state vector has the following components:

$$x1 \cong r = c1^{\psi} + c2^{\psi} + c3^{\psi}$$

$$x2 = \overset{\circ}{x1} - c3T1y \qquad (1)$$

$$x_3 = \overset{\circ}{x_2} + T_1 r - (k_1 c_2 + c_3) y$$

We have the following operators:

$$H1(D) = \frac{k_1}{(T_1+1)D^2}, \qquad (2)$$

$$H_2(D) = c_1 + \left(c_2 + \frac{c_3}{k_1}\right) D + \frac{c_3 T_1}{k_1} D^2, \qquad (3)$$

$$H_2(D) = k_3 \frac{\tau_3 D + 1}{T_3 D + 1}, \ \tau_3 \neq T_3. \qquad (4)$$

The state equations of the system

$$\overset{\circ}{x} = Ax + by + ep + fv, \ y = g(u) \qquad (5)$$

$$u = c^T x + dy + h^T p + d^{(3)} v$$

What does the control realizes after 3 state variables with elements:

$$A = \begin{bmatrix} -\frac{1}{T_1} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ -\frac{k_3 \tau_3}{T_3^2}(k_3 - 1) & 0 & 0 & \frac{-1}{T_3} \end{bmatrix}, \qquad (6)$$

$$b = \begin{bmatrix} c_3 \\ \frac{k_1 c_2 + c_3}{T_1} \\ \frac{c_1 k_1}{T_1} \\ 0 \end{bmatrix}, \qquad c = \begin{bmatrix} -\frac{k_3 \tau_3}{T_3} \\ 0 \\ 0 \\ 1 \end{bmatrix}, \qquad (7)$$

$$d = 0, \qquad f = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{k_3 \tau_3}{T_3} \end{bmatrix},$$

$$d^{(3)} = \frac{k_3 \tau_3}{T_3}, \qquad p = 0. \qquad (8)$$

For linear systems, the correction parallel-opposite through c_2 and c_3 from the second element resembles the series correction from the third level in the following form:

$$H_{3e} = k_{3e} \frac{b_2 D^2 + b_1 D + b_0}{a_2 D^2 + a_1 D + a_0} \qquad (9)$$

If the non-linearity **N** is replaced with a linear element that has no unitary path memory the equivalent operator has the following expression:

$$H_{3e}(D) = \frac{(T_1 D + 1) D}{T_1 D^2 + (1 + c_3 T_1) D + k_1 c_2} \qquad (10)$$

3. THE COMMAND AND CONTROL CONCEPT

The proposed concept envisages the realization of a simple aerial vector, modular and scalable that would be amenable to the low cost concept in the conditions imposed by the international aeronautic normative. The concept is based on a series of aerodynamic analysis which propose an implementation for the stabilization module on the main command chains (Prisacariu, Cîrciu, Boşcoianu, 2012).

This would be used for: gaining information about the aeromechanic behavior structures in laboratories and real flight conditions; obtaining information about the tactical situation in the interest zones; optimization and management of aerodynamic, mechanic components and a functional aerial vector. The result of the optimization and management process would be the improvement of maneuverability of the chosen configuration while maintaining the project designed characteristics.

3.1. Flying wing module

Upgrading the project fazes and manufactures from figure 6 we imposed a flying wing module in diagram conditions from figure 7. The wing is manufactured out of expanded polystyrene reinforced with tubular strut of duralumin.

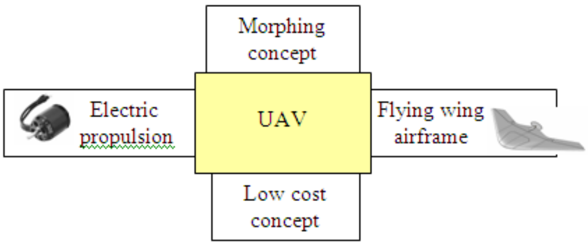


Fig. 6 Design conditions

The morphing command is based on the torsion of the bearing surface through the scale, the torsion moment being transmitted from the servomotor at the extreme nervure with the help of duralumin rods that get through the tubular strut of the wing.

The torsion angles are: $\tau_r = \tau_l = \pm 15^0$. The flying wing (from figure 7) is designed with the help of the aerodynamic analysis software in 2D/3D named XFLR5 v.6.07 (***, 2011).

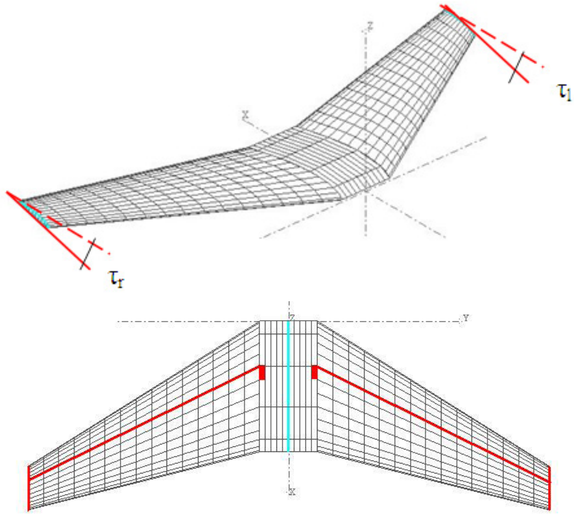


Fig. 7 Torque command

3.2. The command and control system

The command and control system contains necessary propulsion elements, control of the command surfaces and connections between the pilot and the airship (figure 8).

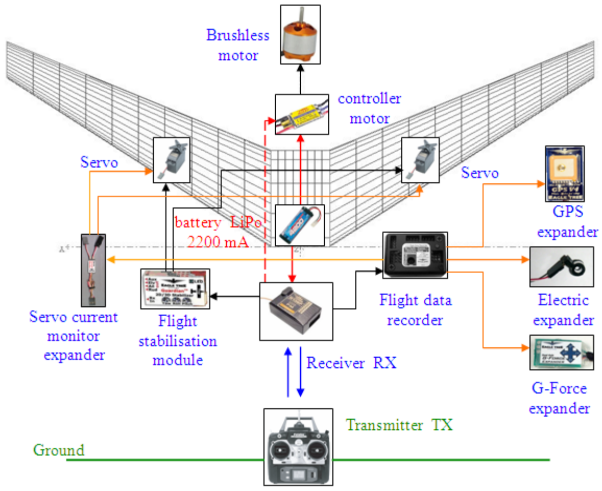


Fig.8 Command and control system

The propulsion is realized with the help of a brushless out runner motor controlled by an electronic speed variable of 50 A, (see figure 9).

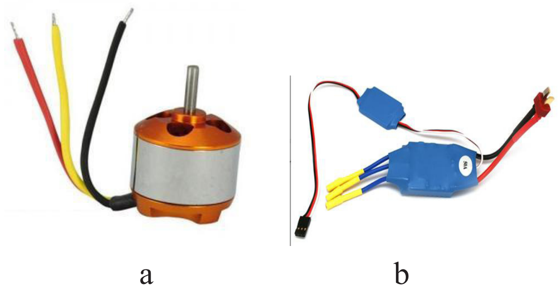

a b

Fig. 9 Propulsion system
(a. brushless motor, b. controller)

The FUTABA 6EAXP radio system to control the aerial vector on a frequency of 35MHz on 6 channels (see figure 10) and has 2 servo actuators FUTABA Standard 3003 as execution elements, (***, 2005) see table 1.

Table 1.Radio system features

TX/RX Futaba 6EAXP	
Channels	6
Current TX/RX	250 mA/ 9.5 mA
Distance	1000 m
Servo Futaba S3003 Standard	
Dimensions	40.4x19.8x36 mm
Mass	38 g
Power	4.8 – 6 V
Speed	0.23 s/60⁰ la 4.8 V
Torque	3.2kg-cm la 4.8 V

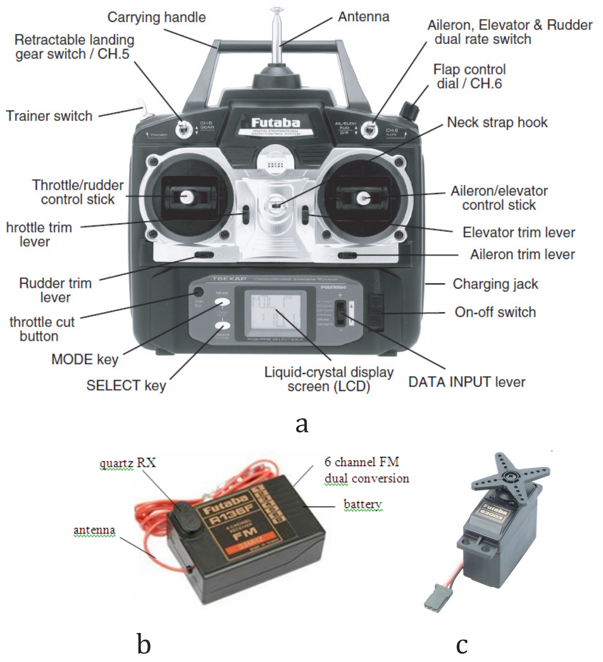


Fig. 10 Futaba 6EAXP radio system
(a. transmitter, b. receiver, c. servo S3003 Standard analogic)

Flight Data Recorder (data logger) realizes the data acquisition (figure 11, 12), it can monitor data regarding the atmosphere conditions with the help of sensors, flight parameters and the state of bearing surfaces, and are a few sensors:

GPS expander, G-Force expander, electric expander, servo current monitor expander (***, 2012).

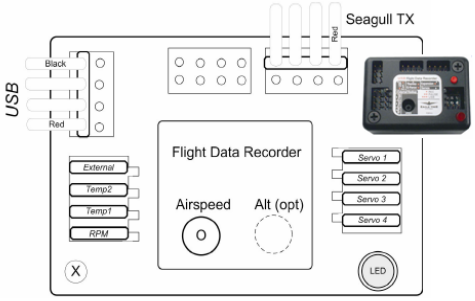


Fig. 11 Flight data recorder

Fig. 12 Flight Data Recorder system

Guardian stabilizer (figure 12) offers two functional modes: 2D back to horizontal flight and 3D for acrobatic flight (***, 2013), presents the characteristics from table 2.

Tabel 2. Guardian specification

Dimensions	41x22x11 mm
Current draw	31 mA
Input voltage range	4.5 – 16V
Weight	11 g
Max servo current	5A

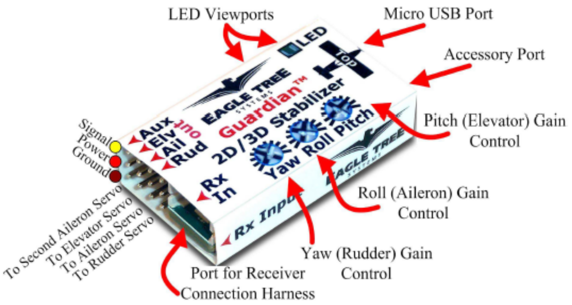
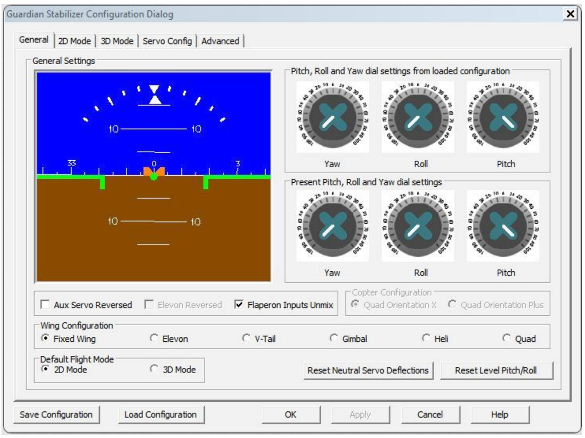


Fig. 13 Guardian 2D/3D module stabilization

The stabilization mode can be configured with a software interface (figure 13).



☐ Aux Servo Reversed ☐ Elevon Reversed ☑ Flaperon Inputs Unmix

Copter Configuration: ● Quad Orientation X ○ Quad Orientation Plus

Wing Configuration: ● Fixed Wing ○ Elevon ○ V-Tail ○ Gimbal ○ Heli ○ Quad

Default Flight Mode: ● 2D Mode ○ 3D Mode

Fig. 14 Guardian 2D/3D stabilization – configuration software

The systems used are power from a 2500 mA LiPo battery with characteristics from table 3.

Tabel 3. LiPo battery features

Tensiune	*11 V*
Capacitate	*800 mA*
Curent maxim de încărcare	*4000 mA*
Curent de încărcare	*800–2400 mA*
Curent maxim de descărcare	*20 A*
Dimensiuni	*57x30x23 mm*
Masa	*68 g*

4. FLIGHT TESTS

4.1. Balance and stability. The correct balance is realized when the position of the central fuselage of the LiPo battery has the gravity center in front of the pressure center. The longitudinal and lateral stability of the flying wing are in normal parameters, the command is precise and through the digital trimmer on the emission module the flying wing could be brought on horizontal flight.

4.2. Equipment and systems.

The radio system is configured in the flying wing version according to the exploration instructions (Prisacariu, Cîrciu, Boşcoianu, 2012), see figure 15.

The propulsion system. The test traction propulsion system generated data that was recorded in table 4.

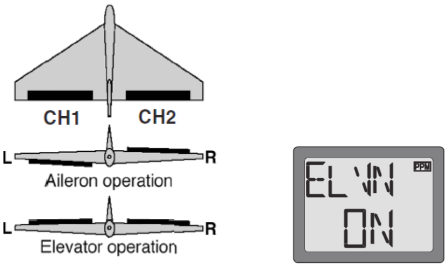


Fig. 15 Futaba system configuration for flying wing

Table 4. Brushless motor traction

Propeller	Battery	Curent	Traction
13 x 6.5	LiPo 7.4 V	30 A	1350 g
13 x 8	LiPo 7.4 V	33 A	1350 g
12 x 6	LiPo 11.1 V	39 A	1800 g
8 x 4	LiPo 14.8 V	25 A	1300 g
8 x 6	LiPo 14.8 V	34 A	1400 g
9 x 6	LiPo 14.8 V	41 A	1870 g

The flight tests of the flying wing have the purpose to check the integration mode of the system functions and equipment. The flight tests include the following stages: ground test and flight test in normal weather conditions.

Stability system. All the flight tests are executed with the help of the auto stabilization system in active and inactive mode to calibrate the command according to figure 16.

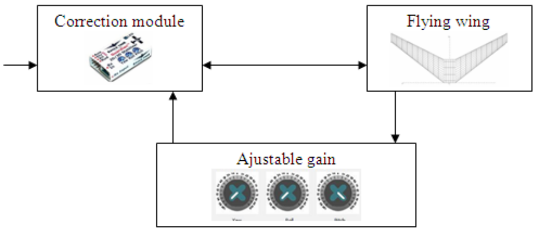


Fig. 16 Command calibration

The flight tests are analyzed based on the data taken from the board (figure 17).

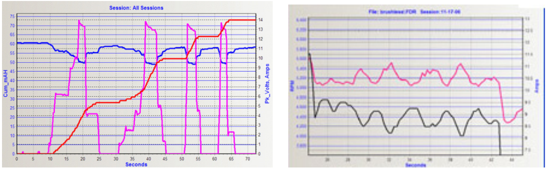


Fig. 17 Data onboard collection

CONCLUSIONS

A flying wing with morphing qualities will have better performances for a large variety of missions.

The stringency level of the test processes depend on the procedure used and the available equipment, the complexity of the installed system in the UAV and the funds for such activities.

The use of sensors and acquisition system in test together with software will raise the research activity standards in UAV.

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