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Design and implementation of electrical system morphing wing flight control on prototype light aircraft

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ABSTRACT

This journal discusses the implementation and testing of the electrical morphing wing system on light aircraft prototypes, namely technology on the wing to increase the value of aerodynamic efficiency on the wing surface with experimental methods based on knowledge obtained from various literature sources. Using a configuration of eight servo actuators arranged in parallel for the aileron and flap functions as well as setting and control with a six-channel Flysky-FSi6 remote to control the movement of the master and slave aileron actuators as well as the flap function on the morphing wing. The design includes the layout of the actuator, setting commands on the remote and wiring system electrical components. Other aspects such as rib design, mechanism and material selection affect the overall distribution of motion produced by the servo actuator. Through the design of the electrical system morphing wing design on the prototype aircraft, it is proven to be able to support the needs of the morphing wing motion mechanism with the concept of an arrangement of eight actuators in parallel on the rib morphing wing. It is hoped that the concept of the morphing wing can be implemented and further developed so that it can be used on full-scale aircraft.

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1. INTRODUCTION

Transportation has been developed and will continue to be perfected, given the need for high mobility, comfort, and shorter travelling times [1]–[4]. Today, airplanes are still one of the choices of transportation modes that are considered fast, comfortable, and safe. All these advantages are followed by one drawback, namely the expensive ticket prices due to the large operational costs. This can be suppressed by developing a new technology which can reduce operational costs such as the use of more efficient fuel. One way to improve the efficiency of fuel usage is to modify the shape of the aircraft. By modified the shape of the aircraft especially the wings, by doing this the amount of drag on the aircraft can be reduced so that it flies more aerodynamically and more efficiently [5].

The drag is one of four forces that determine whether aircraft can fly or not. The other three forces are trust, weight and lift. Drag force is a problem in the world of aviation. Because higher drag will reduce flight efficiency, from an aerodynamic point of view, drag will affect fuel consumption in flight operations which requires propulsion to work harder so that fuel requirements increase [6]–[8], this will also lead to emission pollution problems [9] and noise caused by aerodynamic noise [10]. The part of the aircraft that is used to process the force generated by the aerodynamic shape is the wing of the aircraft, so it is very important to pay attention to aerodynamic efficiency in this section [11]. This statement shows that the shape of wings can improve the efficiency and aerodynamic of the aircraft.

There are many previous study and research have been done to improve the aerodynamic efficiency of the wing by increasing the flexibility of the geometry and shape of the surface which is also known as the morphing wing, its ability to change the structural geometry adaptively can increase the aerodynamic efficiency of the aircraft [12]–[16]. Several previous studies conducted experiments and research to improve this morphing technology so that it can be implemented on full-scale aircraft wings [17]. Development and research are developed from various aspects such as the use of appropriate materials, structural design, mechanisms, and controls [18]–[21].

The flexible morphing movement and different movement positions with conventional wings [22] are a challenge for researchers to design the electrical morphing wing system. Previous researchers conducted various tests and methods in the control morphing wing, such as shape memory alloys (SMA), piezoelectric actuators (PZT), and shape memory polymers (SMP) [23], developing a two degree-of-freedom (DOF) mechanism [24]. placement of the actuator position to perform the desired mechanism movement [25], so that the morphing wing movement can also meet the aircraft movement on the longitudinal axis which is to meet the needs of rolling motion and flap function which serves to optimize the aerodynamic performance of the wing [26]–[28]. Through the design of the electrical morphing wing system design on this prototype aircraft, it can support the needs of the morphing wing motion mechanism with the concept of the arrangement of eight actuators in parallel on the morphing rib. It is hoped that the concept of the morphing wing can be implemented and henceforth it can continue to be developed not only on prototype aircraft but also on larger-scale aircraft.

2. METHOD

The method used is an experiment based on methods obtained from various literature sources. Tests and experiments were carried out on a prototype light aircraft depicted in Figure 1. In designing this aircraft, a definite concept was needed in order to obtain the appropriate results for the purpose. The selection of hardware and software which is the implementation of the mechanical system and control system on the aircraft greatly affects the design of the aircraft, so that the aircraft becomes more accurate in maneuvering according to the orders given. The basic concept is a guideline for planning something in doing the electrical system design, where this concept contains steps and instructions to determine what support is needed in designing such as the movement mechanism that will be produced by rib morphing [29]–[31]. Figure 2 shows the rib design that will be researched and tested in this paper.

Figure 1. Design of prototype light aircraft

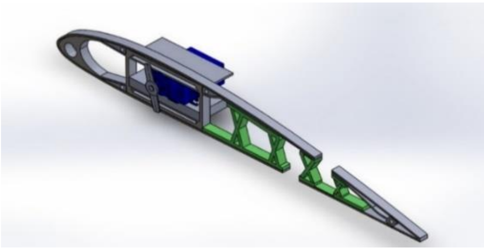
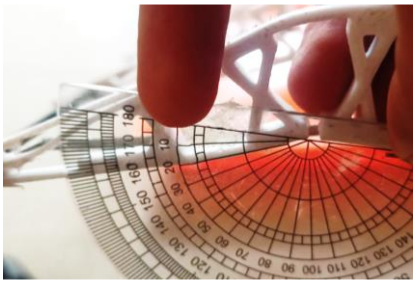
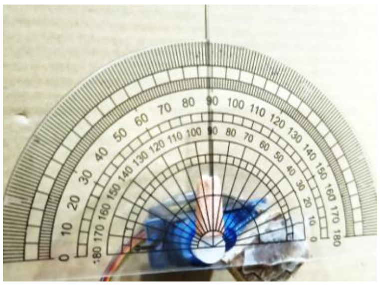


Figure 2. Design of rib morphing wing

The research stages include previous research study, aircraft design preliminary concept, aircraft body manufacture, morphing wing manufacture, rib morphing testing, electrical assembly, control program settings, overall aircraft design implementation, testing to prove the electrical and control system design is able to accommodate the morphing wing mechanism. The process of taking functional data from the rib deflection test using the 120% end points parameter on the Flysky-FSi6 remote. By placing the control stick position at the maximum position for channel 2 movement of the aileron control plane and the VrA channel 5 position at the maximum position. This test is intended to see the ability the rib morphing wing deflection produced in this design. The data collection process for the deflection value can be seen in Figure 3(a). The data collection process for the actuator servo functionality used, namely the Servo Motor SG90 Micro Servo, is carried out by setting the end points in multiples of 10% from 10-120%. The deflection angle data is documented and presented with changes in control from the remote, with VrA channel 5 control on the flysky remote-fsi6, can be seen in Figure 3(b) the data collection process. The electrical and material type component morphing wing in Table 1. The materials and structures applied to the design of the morphing wing will of course also affect the mechanism and distribution of motion that will be produced. The type of material used in the design of the morphing wing on this light aircraft prototype, considering the changing chamber positions and reducing the energy required to drive the morphing requires flexible materials and structures [32].



(a)



(b)

Figure 3. Data collection method (a) rib station functionality test and (b) servo actuator functionality test

Table 1. Electrical and material type component morphing wing

No.	Electrical component	No.	Electrical component
1.	Motor brushless Turnigy D3536/8 1000 KV brushless outrunner motor	8.	Link bar wing mechanism (aluminum)
2.	Electronic speed control predator ESC 100 A	9.	Rib morphing wing (PETG)
3.	Motor servo SG90 micro servo	10.	Tip morphing wing (ABS filament)
4.	Motor servo MG996R	11.	Root morphing wing (ABS filament)
5.	Battery TATTU 2300 mAh 4 cells	12.	Spar morphing wing (aluminum)
6.	Remote flysky FS-i6 (6 channels)	13.	Stringers morphing wing (aluminum)
7.	Skin morphing wing (mica plastic 0.3 mm)		

3. RESULTS AND DISCUSSION

Based on the processes and design methods previously mentioned, to determine the performance, results, and reliability of the flight control system, a testing process was carried out. Tests are carried out in stages starting from design testing, aircraft design analysis, testing of rib movement mechanism, material testing, component testing to function properly. Wing motion test using an electrical system that has previously been designed.

3.1. Wiring diagram morphing wing prototype light aircraft

The full wiring diagram of the Flysky-FSi6 remote control is shown in Figure 4. This remote has 6 channels, the operator can give six commands from the remote to be channeled and received by the receiver. Then from the receiver with a cable connector, it is connected to each electrical component to carry out its duties according to the commands sent by the remote control. The power supply comes from a battery mounted on the ESC to drive the brushless motor, through the cable connector ESC to the receiver module, the supply power is also distributed to the receiver module and to each servo actuator. In the morphing wing, the servo actuator for the flap is connected to channel 6 where there are four servo actuators connected to three Y cables, so the command is only from one switch on the remote control. For the inboard aileron there are two servo actuators, one on the left wing and one on the right wing connected to channel 5 with a Y cable. For the outboard aileron there are two servo actuators, one on the left wing and one on the right wing connected to channel 6 with a Y cable. Then the combination of motion of the inboard aileron and outboard aileron will be programmed via the remote, so that it can be moved simultaneously or separately.

3.2. Morphing wing actuator servo configuration

Based on the need to basic requirement of aircraft to perform a rolling motion on the longitudinal axis of rotation and downward bending of the flap to increase lift. Researchers conducted a literature study and discussion with the manufacturing and design divisions, and found the results of the configuration of the movement and placement of the servo actuator in parallel which is placed on the rib with force distribution through the link bar to move the trailing edge [33], in order to meet the needs of the mechanical motion of the morphing wing. The aileron movement is deflected between the right wing and left wing, the outboard aileron right wing is in the opposite direction of movement from the outboard aileron left wing, the inboard aileron right wing is in the opposite direction of movement to the inboard aileron left wing. The difference in the direction of motion or deflection of the inboard and outboard ailerons because the servo installation position is opposite from one servo to another, the position of the white lever facing the wing tip, can be seen in Figure 5. The servo aileron on the same wing side must be in the same direction because the resulting movement is also in the direction. If the right-wing aileron goes down, the left-wing aileron will go up, so the plane will roll left. If the right-wing aileron goes up, the left-wing aileron will go down, so the plane will roll right.

The flap movement moves downward from the normal position. Flap serves to increase lift during take-off and increase lift and drag during landing. The installation of the four servo actuators faces the same direction, so that the direction of movement is the same as can be seen in Figure 5. What distinguishes it from conventional wings is that the angle of each station wing from tip to root is different considering its elastic and flexible structure. If the conventional wing flight control surface is separated from the main body wing, then the morphing wing flight control surface becomes a single unit with the main body wing and the same skin layer, which is expected to overcome and reduce drag to make it more aerodynamic and efficient.

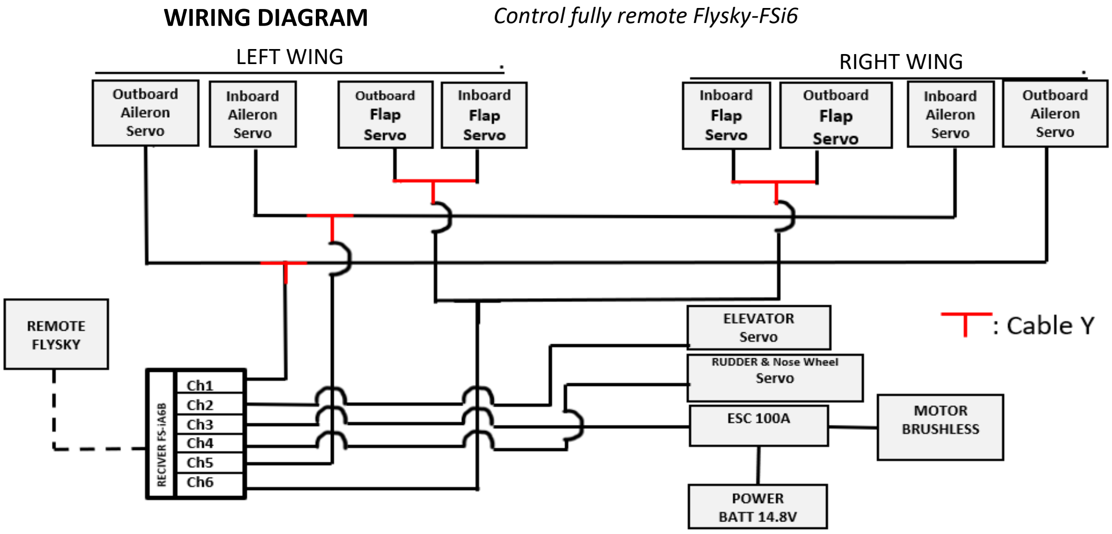
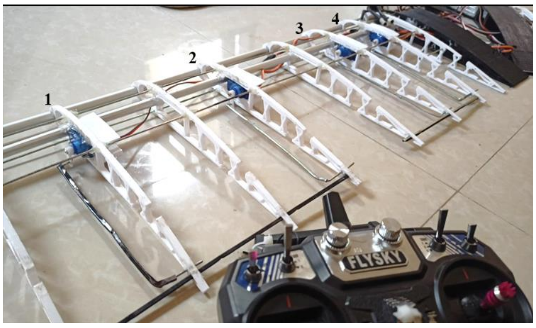


Figure 4. Wiring diagram morphing wing prototype light aircraft



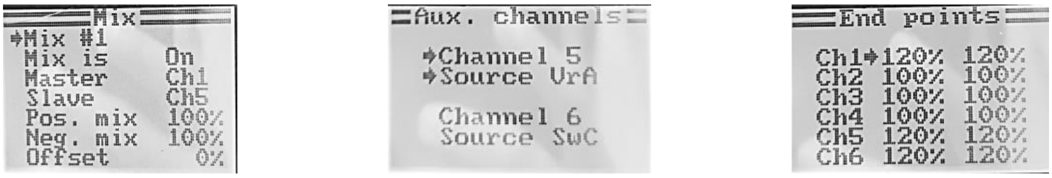
Description:
1. Outboard aileron actuator
2. Inboard aileron actuator
3. Outboard flap actuator
4. Inboard flap actuator

Figure 5. Servo actuator mounting configuration on rib morphing wing

3.3. Flight control program

To produce a combination of movements of eight servo motors on the wing with two types of commands, namely rolling motion by outboard and inboard ailerons, outboard movement, and inboard flap actuator on the inside of the wing to increase lift by flap movement, it is necessary to program the remote so that the movement of each servo can move with a certain configuration. For the aileron movement, the movement of the right-wing aileron and left-wing aileron deflects in opposite directions. As explained earlier, the configuration of the servo placement affects the movement. However, to perform right or left rolling, the inboard ailerons and outboard ailerons must move together.

To set this combination of movements, it can be set on the mixing menu on the Flysky-FSi6 Remote, where the results of this design are as follows; channel 1 acts as Master and channel 5 acts as Slave see Figure 6(a), where channel 1 is the outboard aileron and channel 5 is the inboard aileron. Then the movement of the inboard aileron will follow the movement of the outboard aileron. In this case channel 5 with source VrA see Figure 6(b) on the remote can be moved independently, while if you move channel 1 with source stick control, the slave will follow the movement of the master. For flap movement as described previously in the wiring diagram, the flap with cable connector is connected to channel 6. Where channel 6 with SwC source on the remote has three positions, namely off, middle, and fully down. Then the flap movement is moved by 4 servos connected by a Y cable in parallel and the position of the servo is in the same direction so that the resulting movement will be the same and in the same direction. The selection of inboard ailerons and outboard ailerons on different channels and using the program mixing feature on the remote is to make it easier for the operator to adjust the end points of the servo actuator as can be seen in Figure 6(c). This is very concerned by researchers to improve flight efficiency and control stability while flying, because the configuration of the angle size on the outboard side and inboard side will affect the sensitivity of rolling motion. It also makes it easy for the operator to control the sensitivity of the aileron's movement via the remote.



(a) (b) (c)

Figure 6. Program on remote Flysky-FSi6: (a) mixing, (b) auxiliary channels, and (c) end points

3.4. Flight control actuator test results

Based on the electrical system circuit as described in sub-chapter 3.1. It is important for us to ensure that the servo motion can meet the motion requirements. This test is done by testing the value of the servo actuator output angle with remote control. The test is done manually by using tools such as protractor and needle which is connected to the servo actuator lever. Then test the rib angle before and after skin installation, this aims to get the actual value of the influence of the servo actuator movement on the rib mechanism. From the test, the results of the rib movement are influenced by other variables such as the selection of materials, installation parts, manufacture, or the selection of electrical components.

3.4.1. Actuator servo movement angle measurement results

The test is carried out by connecting the servo to channel 1 and changing the end points sequentially from 10% to 120% and then decreasing in multiples of 10%. The results are as shown in Figure 7. The test results show that the change in the end points on the remote control linearly affects the change in the angle of the servo motor. With end points 120%: 104° servo movement, this result is enough to prove that the remote control can work well with servo movement.

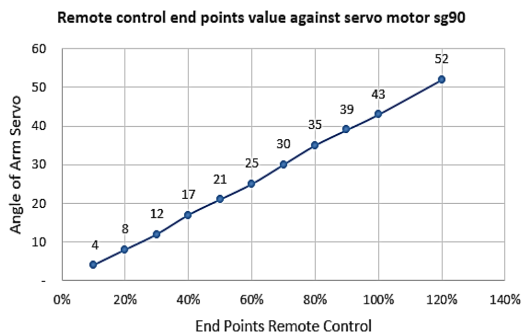


Figure 7. Remote control end points value against servo motor sg90

3.4.2. Rib angle measurement results after actuator installation

The results of the measurement of the rib angle after the servo actuator installation is important to determine how much movement change is obtained after the morphing mechanism is driven by the servo actuator. Before testing, the researcher determined the station based on the order of ribs from tip to root, which can be seen in the numbering of the ribs in Figure 8. Ribs 1-4 are the aileron control plane and ribs 5-7 is the flap control plane, where the movement of the aileron control plane ribs can move up and down. while the control plane of the flap only moves middle down and fully down, that's why in Figure 9 ribs 5-7 it remains 0 because it has no up movement, as is the case with the flap function.

The tests were carried out to determine the maximum rib angle at maximum UP and maximum down. The result of these tests shows that the angle of each rib morphing was not homogeneous, it can be seen in Figures 9(a) and 9(b). This is influenced by the shape and installation of the link bar servo rib mechanism which is not the same either. In Figure 9, the deflection values generated at each station are presented, then a line is also presented to be able to see the deflection comparison between each station. The blue line on the graph shows the deflection on the right wing while the red line shows the deflection on the left wing.

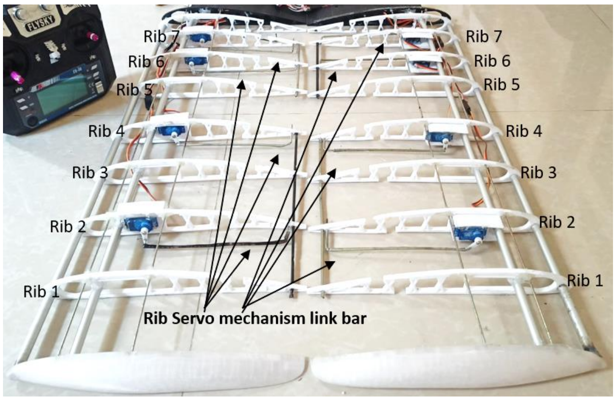
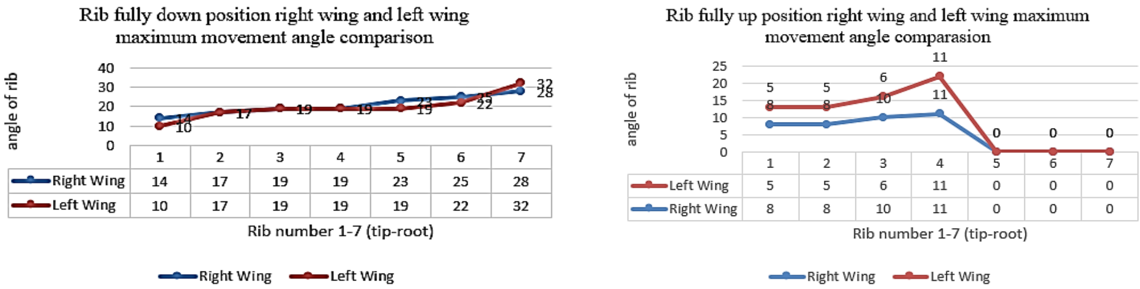


Figure 8. Rib numbering



(a) (b)

Figure 9. Rib deflection test right wing and left wing (a) rib fully down position and (b) rib fully up position

4. CONCLUSION

The design of the electrical system flight control morphing wing technology circuit with the characteristics of using a large number of actuators to produce varied movements on the wing. The solution for a large number of servo movements can be completed with the right wiring to perform the same movement and program mixing on the remote as well as other parameters such as end points control for variations in the servo motion angle. The selection of the flight control electrical system circuit configuration must consider the mechanical movement of the morphing wing and the material used in order to adjust the motion requirements for the morphing wing mechanism. Configuration of servo positioning and wiring is a solution to produce servo actuator movement according to flight control needs on prototype morphing wing aircraft. A good installation and manufacturing of a series really supports the performance and homogeneous rib angle movement between the left wing and right wing on the morphing wing, so that the servo motor actuator movement can be well distributed.

The results of the measurement of the angle of motion of the servo actuator against commands from the remote control can function properly and are considered capable of meeting the motion needs for the morphing wing mechanism. The servo movement against the rib mechanism can function well. The problem is the shape of the link bar which is not homogeneous, and the installation is not good so that the movement also becomes inhomogeneous. The morphing motion becomes increasingly limited. When the skin is installed, the structure of the mechanism becomes less flexible so that the load for the servo motor becomes heavier. If forced to overload the servo will heat up and lose its function and then be damaged.

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