DEVELOPMENT OF A MORPHING FLYING PLATFORM FOR ADAPTIVE CONTROL SYSTEM STUDY

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Abstract

To enhance control to an Unmanned Aerial Vehicle (UAV), an automatic control system is commonly used. The automatic control system may range from simple stability augmentation system to navigation and automatic mission definition. Further development of automatic control system might provide the ability to adapt to aircraft external configuration change triggered by damage or aircraft morphing mechanism. A morphing aircraft is an aircraft that has the ability to change its external shape substantially to adapt to a changing mission environment during flight and to obtain maximum performance for the entire flight mission phase. Substantial change in aircraft external geometry will result in a change in its flight characteristic. A morphing unmanned aerial vehicle will require the ability to adapt its flight control system in response to this change. Development of a Mini-Morphing Unmanned Aerial Vehicle (MiMo-UAV) is conducted to understand more about adaptive control system. The paper presents the design of the flying platform. The morphing design will implement variable sweep wing and variable extension tail configuration.

1 Introduction

To enhance the UAV flight characteristic, an automatic control system is commonly used. The automatic control system may range from simple stability augmentation system to navigation and automatic mission definition. Further development of automatic control system might be a control system that has the ability to adapt to aircraft external configuration change triggered by damage or aircraft morphing mechanism.

A possible control system is reconfigurable control scheme. Reconfigurable control scheme has been studied to deal with systems whose dynamics change drastically due to a certain change in the system, such as when failures occur during operation [1,2,3]. Since the dynamic characteristic of a morphing UAV changes as a consequence of the change in configuration, then the reconfigurable control approach may be adopted for this system.

The work presented in this paper is a preliminary design of a Mini Morphing-UAV (MiMo-UAV) that would be used as a flying platform for an adaptive automatic flight control development. The flying platform should have the ability to change significantly its external configuration during its flight [4].

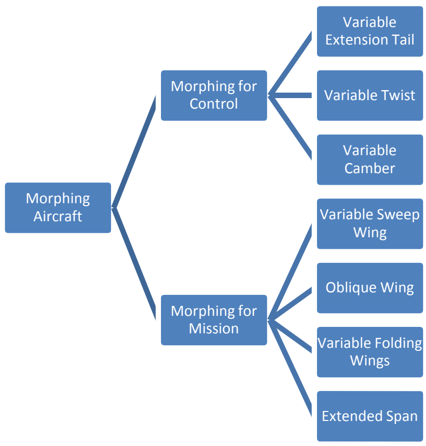


Fig. 1. Morphing classification

Aircraft morphing objective can be classified into two *i.e.* morphing for control and morphing for mission as illustrated in figure 1. The classification was adapted from Arrison [5] with some additions. Morphing for control aims to improve the change of moment coefficient in pitch, roll and yaw, whereas the morphing for mission aims to improve aircraft flight performance by expanding flight envelope significantly.

In this work, morphing mechanism is designed to permit an acceptable change of flight characteristic indicated mainly by static stability coefficient values. The selected morphing mechanism is a combination of variable sweep wing mechanism which is one of morphing for mission objective and variable extension tail mechanism which is one of morphing for control objective.

2 Design Process

Design Requirements and Objectives (DR&O) of MiMo-UAV are defined based on a survey of existing comparable aircraft [6,7,8,9,10,11,12] as follow:

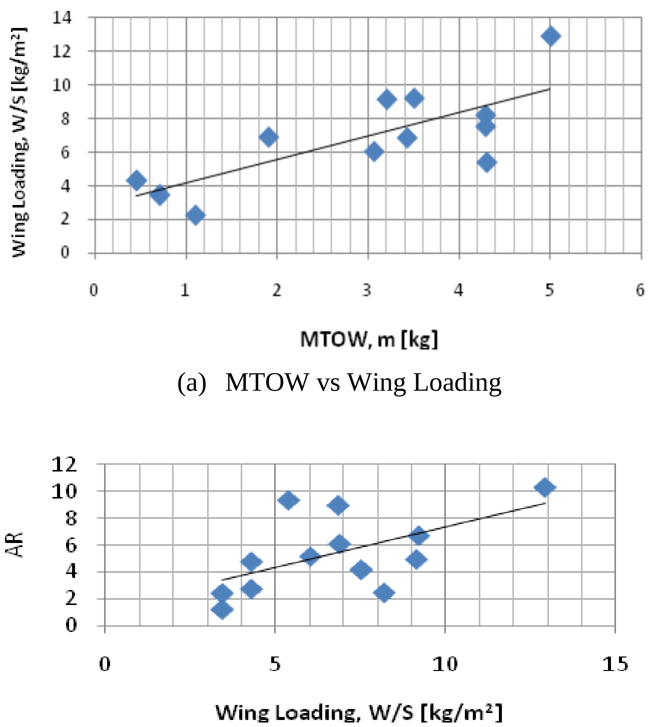
1. Maximum Take Off Weight (MTOW), including payload shall be four kilograms (4 kg) or less;
2. Payload shall be of not less than 500 gram;
3. Cruise speed shall be not less than 20 m/s at sea level;
4. Flight endurance shall be more than 10 minutes;
5. The morphing mechanisme shall include variable sweep wing and variable extension tail;
6. The morphing mechanism shall be able to be operated simultaneously during flight;
7. Type of material and component used shall be easily available in the market.

2.1 Configuration Design and Initial Sizing

The MiMo-UAV will be powered by an electric motor for ease of operation. There will be two morphing mechanism in MiMo-UAV: variable sweep wing and variable extension tail. Study conducted by Hayes [13] shows that the best mechanism for variable sweep wing is two outboard pivot points. Pivot rotation angle can range from 35^o to 40^o. The MiMo-UAV will have maximum sweep angle of 40^o. The morphing mechanism is driven by electric servo. A special attention on load concentration at the pivot mechanism and a synchronous swept angle between right and left wing should be taken into account in the detail design.

The variable extension tail will be operated by mini linear actuator that joined with special mechanism on fuselage. The actuator will drive a structure that supports both vertical and horizontal tail. The structure will carry bending, torsion and normal loads.

Figure 2 below shows relation between aircraft wing loading versus aircraft MTOW, wing aspect ratio and aircraft wing loading. For each relation, a linear trend line is generated based on existing aircraft data.



(a) MTOW vs Wing Loading

(b) Wing Loading vs AR

Fig. 2. Trend line of existing aircraft parameter

With estimated MTOW around 4 kilograms, the aircraft wing loading would be between 8 kg/m^2 to 10 kg/m^2. This will lead to an Aspect Ratio (AR) ranging from 6 to 7 and span ranging from 1.5 to 1.8 meters. From the data above and considering the acceptable size of the MiMo-UAV, the authors define that the aircraft wing span is 1.6 meter and Aspect Ratio of 6.

MiMo-UAV will have a rectangular planform and no dihedral angle to ease the morphing mechanism support structure. The aircraft will have a high-wing configuration.

Horizontal tail and vertical tail will be in conventional configuration which is integrated in one unit on rear fuselage. Initial sizing of tail plane is conducted by using tail volume coefficient method in which the coefficient values are determined by using data of existing Mini-UAV aircraft. From aircraft data comparison [8,12], it is determined that MiMo-UAV would have horizontal tail volume coefficient of 0.5 and vertical tail volume coefficient of 0.03. This leads to horizontal tail area of 0.1266 m^2 and vertical tail area of 0.0455 m^2.

2.2 General Configuration

Figure 3 shows system arrangement and Figure 4 shows a three view drawing of the MiMo-UAV in basic and morphing configurations.

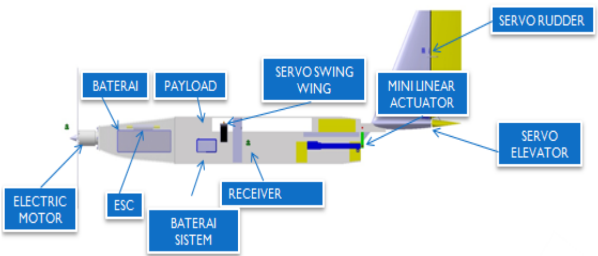
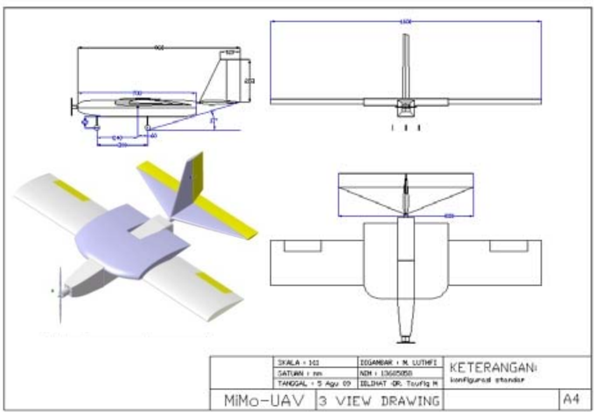
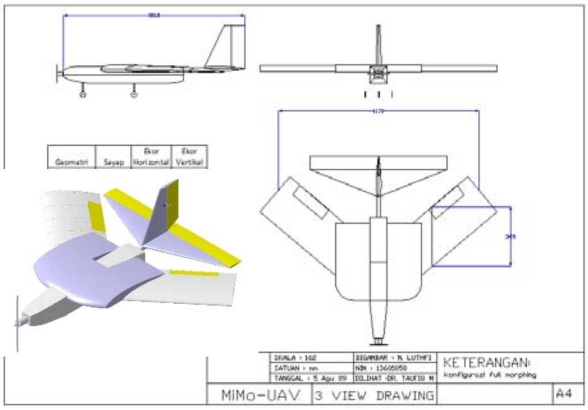


Fig. 3. System arrangement of MiMo-UAV



(a) Basic configuration of MiMo-UAV



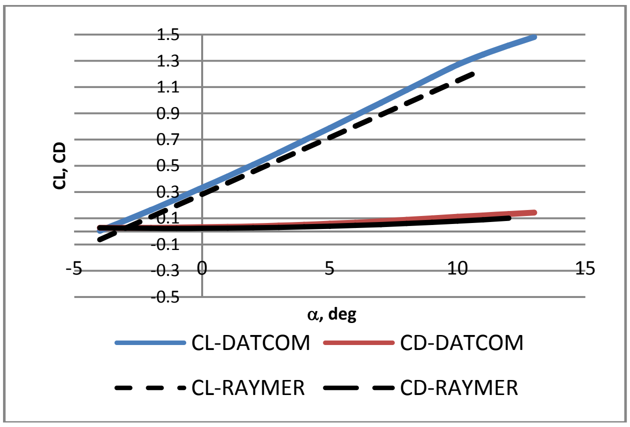
(b) Morphing configuration

Fig. 4. Three view drawing of MiMo-UAV

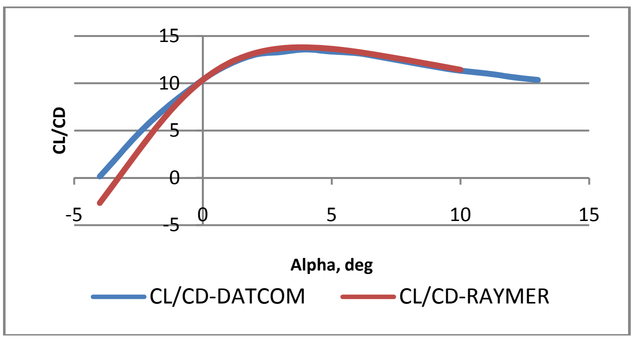
3 Analysis of Preliminary Design Result

3.1 Aerodynamic Analysis

Calculation of aerodynamic characteristics was done using DATCOM software and Raymer [14]. Figure 5 shows that both methods produce relatively the same results. Based on the calculation, the lift coefficient at cruise and at take off would be 0.37 and 0.96 respectively.



(a). CL,CD versus alpha of MiMo-UAV



(b). CL/CD versus alpha of MiMo-UAV

Fig. 5. Aerodynamics characteristic estimation

3.2 Stability Analysis

Level of stability will affect the overall flying characteristics of MiMo-UAV. Here, the analysis of static stability is carried out for the basic configuration.

Static Margin

By assuming the efficiency of the stabilizer of η_{HT}=0.65, and lifting surface aerodynamic center at 0.25% m.a.c, it can be obtained that neutral point is at 40.2% m.a.c. The center of gravity position is at 353 mm from the nose or 19.7% m.a.c. Hence the static margin would be 20.5% m.a.c.

Static Stability

Static stability parameters are longitudinal $C_{m_\alpha} < 0$ and lateral-directional stability $C_{l\beta} < 0$ and $C_{n\beta} > 0$. The values of static stability parameters are calculated by using Raymer method [14] and is shown in table 1. It is shown that MiMo-UAV is statically stable.

Table 1. Static stability of MiMO-UAV

Stability	Value (deg^{-1})
Longitudinal ($C_{m_\alpha} < 0$)	-0,01774
Lateral ($C_{l\beta} < 0$)	-0,00067
Directional ($C_{n\beta} > 0$)	0,001037

4 Preliminary Analysis of Morphing Mechanism

The consequence of variable swept was mainly to the wing mean aerodynamic chord length and location changes that have implications on the wing aerodynamic center and aircraft center of gravity location. The variable tail extension had implications on the aircraft static margin due to aircraft aerodynamic center shift. Both of them will cause significant changes to the aircraft static stability. Some preliminary analyses were conducted to check the consequences of morphing configuration to aircraft stability. The aerodynamic and stability calculation were done using DATCOM method.

4.1 Aerodynamic

Variable sweep wing configuration has a large effect on the changes in lift and drag. Changing the variable sweep wing mechanism will decrease lift and increase drag. While changing the tail extension position has no significant change compared to the standard configuration. This mechanism does not change the wing area of MiMo- UAV.

By using Datcom method, the relation between CL/CD versus alpha for wing sweep to 40^o is presented in figure 6.

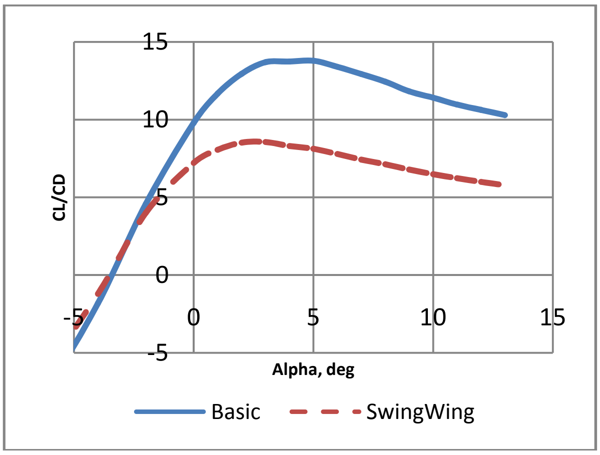


Fig. 6. CL/CD vs alpha curve for basic and 40^o sweep configuration

4.2 Stability

Changing the MiMo-UAV configuration will cause changing flight characteristics of MiMo-UAV in longitudinal, lateral and directional modus. However it is needed to ensure that the changes in flight characteristics are still within the stability region. Table 2 shows a static stability data of the MiMo-UAV using Raymer [14] method.

Table 2. Static stability data

Parameters	Basic (deg^{-1})	Sweep Wing at 40^o (deg^{-1})	Tail extd by 100 mm (deg^{-1})	Sweep Wing and Ext. Tail (deg^{-1})
$C_{m\alpha}$	-0,0177	-0,0333	-0,01759	-0,0333
$C_{l\beta}$	-0,0006	-0,0141	-0,00067	-0,0141
$C_{n\beta}$	0,00103	0,00149	0,001332	0,00150

5 Discussion and Future Works

Some of the MiMo-UAV's data are as follow:

- MTOW : 3.668 kg
- Basic wing span : 1.6 m
- Length: 0.96 (basic configuration) and 1.06 m (extended tail configuration)
- Endurance : 13.72 minutes
- Degree of sweep back : 40 degrees
- Extended Length: 100 mm
- Cruise Speed : 20 m/s

From table 2, it is shown that wing sweep to 40^o backward had changed significantly the static stability parameter, notably on lateral mode. The tail extension had changed slightly the lateral dan directional stability. However the MiMo-UAV is statically stable in all configuration. This condition will facilitate the flight testing.

For future works, a payload containing sensors and flight data logger will be installed into MiMo-UAV. The obtained data will be used to fine tune the mathematical model of the aircraft. A control system can later be built based on the mathematical model.

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