Autonomous Flight Control System Design for a Blended Wing Body

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Abstract: A Blended Wing Body (BWB) UAV has several aerodynamic advantages of lower wetted area to volume ratio and lower interference drag as compared to conventional type UAV. This paper is focused on the design of the autonomous flight control system for a BWB UAV. An onboard control system is developed by using a powerful computer, navigation sensors and communication modem. The autopilot of the BWB UAV is constructed based on the stability analysis using the linearized model at trim condition. We propose a simple control allocation scheme and evaluate its performance through nonlinear simulation. Furthermore, flight test is performed using the designed autopilot and satisfactory performance is obtained in autonomous flight.

Keywords: Blended Wing Body UAV, Autopilot, Nonlinear simulation, Control allocation, Stability analysis

1. INTRODUCTION

A BWB type aircraft is a revolutionary conceptual change from the conventional aircraft and sometimes referred to a ‘flying wing’ due to its configuration of the integrated wing and fuselage. Actually, the BWB configuration has been proposed to improve the economic efficiency of future air transportation [1, 2]. The BWB configuration increases the maximum lift-to-drag ratio to about 20% and shows lower stall speed without flap over conventional one. Nevertheless, these significant benefits, stability and control problem are still remained as the main drawback of BWB configuration [5]. In the aspect of stability, aerodynamic center is very closely located to center of gravity(CG) or is located ahead of the CG. Also, BWB UAV has low directional stability and adverse yaw characteristics during rolling maneuver [2]. Moreover, since the two control surfaces simultaneously generate the longitudinal and the lateral-directional motions, control allocation scheme is necessarily implied to flight control system of BWB UAV.

In this paper, a detailed dynamic model of the BWB UAV is constructed and then the flight performance and stability are analyzed. After designing the autopilot with the dynamic model applying a simple control allocation scheme, we evaluate its control performance through nonlinear simulation.

Consequently, we integrate the BWB UAV platform with onboard computer, navigation sensors, and communication modem and perform the real flight test.

2. SYSTEM OVERVIEW

To demonstrate the autonomous flight, it is needed to integrate the BWB UAV platform with the suitable hardware and software so that the vehicle can perform the desired autonomous maneuvers. Since the limit of the mass budget and mounting space, lighter instruments should be selected. The flight control computer (FCC) acquires its attitude data from the sensors attached to the vehicle such as GPS, attitude heading reference system (AHRS). By using common personal computer, GCS is constructed. Real time kernel is selected to operate the FCC.

2.1 BWB Model

To demonstrate the real flight test, a reliable vehicle platform is significant. In this paper, a small BWB model aircraft had been adopted for the ease of maintenance. The onboard computer is equipped on the center of the body. The detailed specification of this model is shown in the Fig. 1 and Table 1.

Fig. 1 BWB model

<table>
<thead>
<tr>
<th>Table 1 Physical parameters of the BWB UAV.</th>
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</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>total</td>
</tr>
<tr>
<td>$I_{xx}$</td>
</tr>
<tr>
<td>$I_{yy}$</td>
</tr>
<tr>
<td>$I_{zz}$</td>
</tr>
</tbody>
</table>
deflected in the opposite direction for roll control. In Fig.
3, we can find the fact that the effect of pitching
moment is about 10 times larger than the effect of roll
moment by deflection of the control surface. This
phenomenon is related with the configuration that has
the reduced kinematic damping in the pitching motion.

3.3 Control Derivatives

\[
\begin{align*}
\dot{\alpha} &= -0.239 + 1.513 + 9.810 & \dot{\alpha} &= 0.000 + 0.000 + 0.000 \\
\dot{\theta} &= -0.133 - 5.940 - 0.000 & \dot{\theta} &= 0.000 + 0.000 + 0.000 \\
\dot{\psi} &= 0.017 -170.612 - 7.853 & \dot{\psi} &= 0.000 + 0.000 + 0.000 \\
\dot{\beta} &= 0.000 -12.000 -12.000 & \dot{\beta} &= 0.000 + 0.000 + 0.000 \\
\end{align*}
\]

\[
\begin{align*}
\dot{\alpha} &= -0.090 -0.008 -0.008 & \dot{\alpha} &= 0.000 + 0.000 + 0.000 \\
\dot{\theta} &= 0.000 + 0.000 + 0.000 & \dot{\theta} &= 0.000 + 1.328 +1.328 \\
\dot{\psi} &= 0.000 + 0.000 + 0.000 & \dot{\psi} &= 0.000 + 0.000 + 0.000 \\
\end{align*}
\]

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Table 2 Trim condition of the BWB UAV

<table>
<thead>
<tr>
<th>Flight Condition</th>
<th>Trim State Value</th>
<th>Control Input for Trim Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (m/s)</td>
<td>12</td>
<td>9.14</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>100</td>
<td>0.00</td>
</tr>
</tbody>
</table>

In these linearized dynamic models, short period mode is fast and the damping ratio is comparatively small. Unfortunately, also it has an unstable dutch-roll mode, which may be caused by the fact that there is no appropriate control surface such as rudder in order to damp out yawing oscillation even though it has a sweep-back wing.

The autopilot for longitudinal and lateral-directional motions is designed by applying the classical approach referred to Ref. [7]. As shown in Fig. 4, longitudinal autopilot consists of speed controller and altitude hold controller that are integrated with the inner-loop controllers for pitch attitude stabilization and orientation.

Since the motions of the BWB UAV are controlled by only one elevon control surface, control allocation technique is need to generate control signal to each control surface effectively in order to merge the longitudinal and lateral-directional autopilot. Although there are several researches related to applying control allocation scheme to control of BWB aircraft [5, 9], we distribute the control signals into right and left elevon using a simple distributor as shown in Fig. 6.

The gains in the dotted-line box of Fig. 4 and Fig. 5 are for determining the direction of deflection of each elevon that describe the control allocation scheme. The designed controllers for autopilot of BWB UAV are summarized in Table 3. The bode diagrams of altitude hold and heading control loop represent that the designed autopilot system assures a sufficient gain margin and phase margin.

Table 3 Autopilot of the BWB UAV

<table>
<thead>
<tr>
<th>Speed Control Loop</th>
<th>Altitude Hold Loop</th>
<th>Heading Orientation Loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{tr}(s) = \frac{0.4s + 0.12}{s}$</td>
<td>$G_{ar}(s) = \frac{5.0s + 2.5}{s}$</td>
<td>$G_{ar}(s) = \frac{5.0s + 1.2}{s}$</td>
</tr>
<tr>
<td>$G_{r}(s) = \frac{0.05s + 0.01}{s}$</td>
<td>$G_{r}(s) = \frac{0.05s + 0.01}{s}$</td>
<td>$G_{r}(s) = 2.5$</td>
</tr>
</tbody>
</table>

Fig. 6 Control distributor for autopilot of BWB UAV

Fig. 7 represents the control performance of the designed autopilot when the step input command of altitude and heading angle is simultaneously imposed. From the results, we can observe that the performance of heading orientation loop is poor compared to altitude hold loop. In fact, in order to improve this control performance, optimal control allocation should be designed and integrated into autopilot. The right and left elevons are actuated asymmetrically during the initial transient period to achieve the control objective.

Fig. 7 Control performance of the autopilot
4. FLIGHT TEST
A series of flight tests have been performed using the developed BWB UAV. Fig. 9 shows the flight data on altitude channel during the vehicle is commanded to perform level flight at 100m above the ground. Fig. 10 shows the flight result of heading orientation during the vehicle is commanded to hold -100 deg from the north. From the flight data, we can observe that the designed autopilot control the BWB UAV satisfactory.

Fig. 9 Flight test result of altitude channel

Fig. 10 Flight test result of heading channel

Fig. 11 represents the trajectory of vehicle during the waypoint navigation. Since the scale of the waypoint is relatively small, the overshoot may be occurred.

Fig. 11 2D trajectory of the BWB UAV

5. CONCLUSION
The BWB model platform is integrated with onboard computer and sensors to implement autonomous flight. The autopilot is designed with the linear model obtained from the nonlinear BWB model using the software of ‘Digital DATCOM’. The linearized model provided the specific flying characteristics of BWB UAV, such as unstable dutch-roll mode. The autopilot for speed, altitude, heading control was evaluated through the nonlinear simulation. Furthermore, we performed real flight tests to verify the control performance of the developed autopilot system. Consequently, we obtained satisfactory flight data and applied the autopilot to waypoint navigation.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge for financial support by Korea Ministry of Knowledge Economy.

REFERENCES

