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Aerodynamic, stability and flying quality evaluation on a small blended wing-body aircraft with canard foreplanes

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Abstract

Blended wing-body (BWB) concept promises up to 30 percent increase in aerodynamic efficiency and reduction in fuel cost by having planform geometry optimized to increase lift and to reduce drag. Many claimed to have achieved the target of increasing lift-to-drag ratio better than current conventionally-configured airplanes either large airliners or small unmanned airplane. However, achieving good balance of aerodynamic efficiency, stability and flying quality is harder than one might expect. Over years of studying small BWB aircrafts in Universiti Teknologi MARA (UiTM), it is found that unconventional behaviour of aerodynamic characteristics leads to limitations to BWB aircraft's flight envelope. In this paper, a short overview of aerodynamic, stability and flying quality of UiTM's BWB aircraft design is highlighted. Lessons learned from its unusual lift-angle of attack curves, stability reversals, the effect of canard to flight stability and poor longitudinal flying quality (short-period mode and phugoid mode) are discussed. A classical control solution to improve its flying quality has been proposed and simulated and the result shows that both short-period and phugoid modes are able to achieve damping ratios within 0.6 to 0.8 exceeding minimum Level 1 damping ratios of 0.35 and 0.04 respectively. Design flaws of this aircraft and recommendations to be implemented on the next evolution of aircraft design conclude this paper.

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1. Introduction

The challenge of improving flight performance, particularly range and endurance, had been undertaken since the early years of aviation. Flying wing is one of the solutions, introduced in Germany as a concept for long-range bombers [1], its use is limited to short years within the United States Air Force (USAF) in a form of B-49 [2]. Problems related to flight dynamics and control hampered the flying wing to serve in long years unlike its B-52 counterpart until advancement of digital fly-by-wire electronic control allowed the flying wing to be revived again in a form of B-2 stealth bomber [3]. It was also the time, in the late 1980s, when Blended Wing-Body (BWB) concept was introduced – a hybrid of flying wing and conventional tubular fuselage-wing-tail configuration [4].

Nomenclature

OFE	Operational Flight Envelope
P	Phugoid mode
SP	Short-period mode
c	Mean chord
C_D	Drag coefficient
C_L	Lift coefficient
C_M	Pitch moment coefficient
K_n	static margin, $K_n = h - h_n$
h	1. Centre of gravity location with respect to datum 2. altitude in feet
h_n	neutral point location with respect to datum
l_c	pitch moment arm for canard foreplane
η_c	canard incidence angle w.r.t. body x-axis
ω	Natural frequency
ζ	Damping ratio

The BWB concept promises up to 30% fuel consumption reduction by improving lift-to-drag ratio. It was found that the current airliners' conventional planform configuration had reach their limit of efficiency. Proposing flying wing airliners limits the passenger and cargo capacity thus a form of hybrid of the two different planform shape might be the answer. By carefully 'blending' the wing and body, removing tail and shaping the body like airfoil sections, one could reduce the wetted-surface area thus reducing skin friction drag, eliminate interference drag and increase lift [4]. This resulted in high lift-to-drag ratio, around 25 for some studies, compared with 18 for conventional configuration airliners while still carrying the same amount of passenger and payload [5, 6, 7, 8]. However, while BWB might poses the efficiency of a flying wing, it also inherit the latter's problems. Due to lack (or none) of horizontal tail and its relatively high pitch moment from its large lifting body, the BWB have serious problems with its longitudinal static stability and flying qualities [9, 10, 11]. Electronic controllers with advanced algorithm may provide stability augmentation but it may be forced to work all the time creating all sort of dynamically changing trim drag that reduces its aerodynamic efficiency (lift-to-drag ratio) [12].

BWB research team in Universiti Teknologi MARA was formed in 2005 with the first design, Baseline-I (HANTU), freezed and tested in wind tunnel within a year. The Baseline-I is a mere replica of Liebeck's planform with inspiration from the B-2 bomber albeit with intended use as a small two to four-metre span unmanned aircraft. It has the body span of 35 percent with body thickness-to-chord length ratio varies from 12 to 22 percent [13]. The study was extended to computational simulations to understand it aerodynamic behavior [14], implications to flight performance and flight stability and the effect of centre elevator to effectiveness of trim flight [15]. The second design took lessons learned from Baseline-I and used Inverse-Twist Method to design its planform and airfoil incidence [16]. The Baseline-II, introduced in 2009, had its body span reduced to just 19 percent, maximum body thickness reduced to 15 percent, larger wing area with high-wing location for lateral stability and smoother planform

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