Editor's Technical Note

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Flight Stability and Control of Tailless Lambda Unmanned Aircraft

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Abstract: Marqués P. (2013). Flight stability and control of tailless lambda unmanned aircraft. *International Journal of Unmanned Systems Engineering*. ***1***(S2): 1-4. This paper illustrates the unique challenges with which Aerospace Engineers are presented in achieving dynamic stability and autonomous flight control in tailless lambda unmanned aircraft. The static margin in lambda configurations is short, making the aircraft unstable. To compensate for the short static margin, a priority in lambda UAV design is to obtain a small linear pitching moment. Negligible pitching moment is implemented using reflex camber airfoils that complement the longitudinal dihedral provided by combined wing sweep back and washout. The reflex airfoil permits a wider choice of wing planform and enhances control authority with minimum elevon deflection. Stability analysis shows that a lambda UCAV is longitudinally unstable in ground effect, in both the flaps extended and flaps retracted configurations. Vortical flow and asymmetrical vortex bursting unsteadiness in a rapidly maneuvering next generation near-lambda 1303 UCAV are responsible for unexpected changes in pitch, roll and yaw coefficients and illustrate the difficulty in maneuvering the UCAV beyond certain critical angles of attack. The primary mechanism of lateral-directional control in a *W*–shaped flying wing UAV is provided by drag rudders, however lateral-directional control in such aircraft requires a sophisticated on-board flight control system.

Keywords:
Flight control system
Dynamic stability
Lambda UAV
Reflex airfoil
Static margin
Vortical flow unsteadiness

1. INTRODUCTION

Tailless lambda configurations represent a next generation of unique autonomous aircraft. Typically, these vehicles have a fuselage that blends into a swept lambda wing and a low-profile dorsal intake near the front of the aircraft (Fig. 1).

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Lambda UAVs use no vertical control surfaces and no horizontal stabilizer. To make the aircraft stable in pitch, the aerodynamic center is moved backward. This is achieved by two means; sweepback of the wing leading edge and the use of reverse camber (reflex) airfoils[1]. This technical note illustrates the challenges that Aerospace Engineers face in achieving dynamic stability and autonomous flight control in tailless lambda unmanned aircraft. Flight conditions in ground effect and of steady and unsteady flows are explored.

Fig. 1: BAE Raven stealth UAV.
(Photo: Brigadier Lance Mans)

2. STABILITY IN PITCH

Tailless UAVs have a short *static margin*, defined as the distance between the center of gravity and the neutral point of the vehicle, making the aircraft unstable. Consequently, lambda UAVs are designed with minimum pitching moment to reduce the need for pitch control during flight. The angle of incidence of the swept wing of lambda UAVs is gradually reduced along the span in a washout configuration to achieve longitudinal dihedral, so that the wingtip region functions like a tailplane stabiliser[2]. In level flight, the aircraft is trimmed and the wingtips do not contribute any lift and may even produce downforce, therefore diminishing wing efficiency. Reflex camber airfoils have a strongly curved lower surface and a positive (pitch up) zero-lift pitching moment. The front of the airfoil is set at a high angle of attack (α) and the rear camberline remains horizontal and contributes no lift. According to Bernoulli's principle, the reflex camber tends to generate a small downforce. Therefore, the wing α must be increased to compensate. Although the higher α creates extra drag, a reflex airfoil permits a wider choice of wing planform compared to using wing sweepback and washout alone.

Tailless aircraft lack effective pitch control due to the missing horizontal stabiliser. Also, because the moment arm of the control surfaces is shorter compared to orthodox aft-tail layouts, control authority is lower[3]; Fig. 2. This problem is solved using large elevons capable of generating high control forces. Such high forces are necessary to compensate for the small moment arm. The larger control surfaces in lambda UAVs cause higher drag during manoeuvres than those in conventional airframe configurations. However, the use of reflex airfoils reduces the amount of deflection of the wing control surfaces to attain balanced flight[3]. A challenge in lambda UAV design is to achieve a *linear pitching moment* despite the short static margin. It is important to delay moment divergence to higher α.

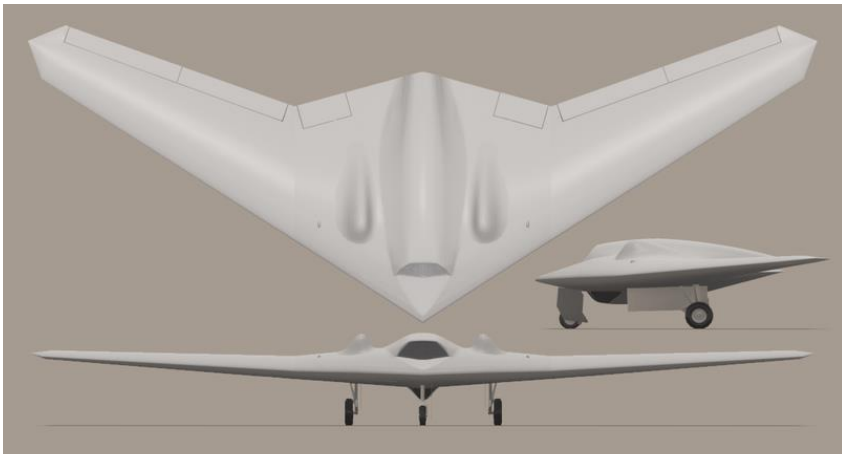

Fig. 2: RQ-170 Sentinel impression. **(Image: Truthdowser)**

3. LAMBDA UAV IN GROUND EFFECT

The aerodynamic behavior of a lambda unmanned combat air vehicle (UCAV) with deflected trailing edge split flaps *in ground effect* was studied by Mostaccio (2006)[2] using a 3' x 3' subsonic wind tunnel. The analysis involved symmetric and asymmetric flap deflections of +10° and +20°. Deployment of the flaps while flying in ground effect produces higher lift, less induced drag, greater total drag, and enhanced lift-to-drag ratio. In ground effect, the ground surface partially blocks the wingtip vortices and reduces downwash. This increases the effective α and, consequently, the wing generates more lift. Interestingly, flow visualization unveiled vortical flows over the upper wing surface at high α characteristic of delta wing aircraft configurations. Stability analysis conducted by Mostaccio (2006)[2] showed that a lambda UCAV is longitudinally unstable, in both the flaps extended and flaps retracted configurations.

4. FLIGHT IN STEADY AND UNSTEADY FLOWS

The study of steady and unsteady aerodynamics is imperative in a rapidly-maneuvering next-generation UCAV. The 1303 UCAV is a near-lambda delta wing design[1] developed by Boeing Phantom Works with a wing leading edge sweep back of 47°. The concave trailing edge crank at the mid and outboard sections combines increased aspect ratio and taper compared to a single-panel swept tapered wing. The 1303 UCAV exhibits aerodynamic properties typical of delta wing aircraft; that is, two leading edge vortices on the upper wing surface at high α. The pitching moment coefficient is negative (pitch down) at $\alpha = 0°$ and remains constant until vortical flow develops in the range $4° \leq \alpha \leq 6°$ causing a decrease in pitching moment coefficient. At higher α, vortical flow effects reduce the moment coefficient to a minimum value of -0.118 at $\alpha = 20°$.

The rolling and yawing moment coefficients stay very close to zero in the range $0° \leq \alpha \leq 18°$. As α increases above 20°, the side force coefficient, and rolling and yawing moment coefficients increase, which are indicative of a change in the flow field over the UCAV. In fact, the vehicle experiences asymmetrical vortex bursting, typical of delta-wing flows, and therefore vortex bursting unsteadiness. The effects of the vortical flow structure, typified by asymmetry and unsteady bursting, cause the unexpected side forces and rolling moments and illustrate the difficulty in maneuvering the UCAV 1303 beyond certain critical α.

5. AUTONOMOUS FLIGHT CONTROL

Longitudinal and lateral dynamic stability derivatives for a flying wing UAV of *W* panel shape that employs ten control surfaces (inner elevators, inner elevons, outer elevons and drag rudders) were determined by Xiaobo *et al*. (2013)[4] using CFX software. A symmetric airfoil is used at the body-wing junction and a reflex airfoil is employed in the outer wing to generate a positive pitching moment and improve longitudinal static stability. The lateral stability of the vehicle is neutral due to the absence of a conventional rudder. Lateral control is achieved using drag rudders positioned outboard near the wingtip to augment the moment arm. Asymmetric deflection of the drag rudders causes higher drag in one wing and therefore a yawing moment. The unconventional drag rudder control surfaces are effective in implementing heading changes of the UAV during flight. The drag rudders can also be used to control the speed of the UAV during the approach, landing, and air refuelling. In the Boeing X45-A shown in Fig. 3, aileron and rudder control is achieved using split drag rudders near each wingtip, which can function also as air brakes.

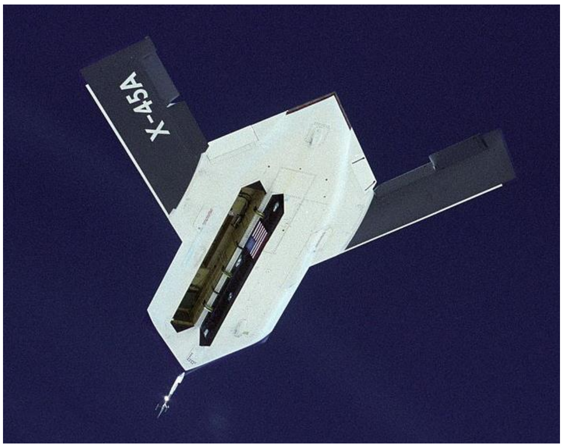

Fig. 3: Boeing X45-A lambda configuration. (Author: DARPA)

The tailless configuration of the *W*-shaped flying wing causes an unstable dutchroll mode[4]. It is the absence of a vertical tail that prevents the UAV from damping out yawing oscillation and wing sweepback alone is insufficient to damp out the dutchroll mode. Xiaobo *et al*. (2013)[4] designed an autopilot for longitudinal and lateral-directional motions of the *W*-shaped flying wing using a classical approach. The air speed and altitude hold controllers are contained in the longitudinal autopilot and integrated within the inner-loop controllers for pitch attitude stabilization. The lateral-directional autopilot controls the aircraft's heading using an inner-loop controller for roll and yaw stabilization. The on-board *flight control system* (FCS) consists of a high precision navigation unit, a powerful computer, and a digital communication modem.

6. CONCLUSIONS

Aerospace Engineers are presented with unique challenges in achieving dynamic stability and autonomous flight control in tailless lambda unmanned aircraft. The short static margin in lambda configurations makes the aircraft unstable. Thus, a priority in lambda UAV design is to achieve a small linear pitching moment to compensate for the short static margin. Aircraft design for minimum pitching moment utilises reflex camber airfoils that complement the longitudinal dihedral effect achieved using combined wing sweep back and washout. The reflex airfoil permits a wider choice of wing planform and reduces the amount of elevon deflection for control authority. Stability analysis has shown that a lambda UCAV is longitudinally unstable in ground effect, in both the flaps extended and flaps retracted configurations. The vortical flow and asymmetrical vortex bursting unsteadiness in a rapidly-maneuvering next-generation near-lambda 1303 UCAV cause sudden changes in pitch, roll and yaw coefficients and illustrate the difficulty in maneuvering the UCAV beyond certain critical α. Drag rudders are the primary mechanism of lateral-directional control in a *W*–shaped flying wing UAV and lateral-directional autopilot control in such aircraft requires a sophisticated on-board FCS.

7. REFERENCES

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