Design of a easy to fly, low-cost generic unmanned aerial vehicle (UAV) for civilian aerial-imaging application

Conference Paper · October 2012

DOI: 10.1109/STUDENT.2012.6408420

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Design of a Easy to Fly, Low-Cost Generic Unmanned Aerial Vehicle (UAV) for Civilian Aerial-Imaging Application

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***Abstract*— This paper deals with the design of a generic UAV or commonly known as pilotless aircraft for civil application. Starting from market survey this paper will look into the existing civilian UAVs and designing of a new class of civilian UAV that can fill in the existing design gap that not readily available for commercial needs. The design goals have been previously established and the publication currently under peer review together with this paper [1]. This paper dealt with the preliminary design of a slow speed, easy to fly low-cost UAV known as the Alpha to fill in the gap that has been identified. A prototype has been built to demonstrate the capability of such craft completing the predefined mission typical of civilian usage.**

Keywords— UAV, Unmanned aerial vehicle, civilian UAV.

I. Introduction

Unmanned aerial vehicle (UAV) or commonly known as pilotless aircraft has been in the arena of air combat as early as 1915 when the concept was first introduced by Nicola Tesla [2]. Other known terms include unmanned aircraft system (UAS) or remotely piloted vehicle (RPV). While the capabilities of such craft open up new demands particularly in the commercial sector as it offer aerial solution that can be expensive to acquire via manned platform; most of these UAVs are designed with military mission in mind, thus ownership and maintenance cost for such category of UAVs are either beyond reach or not justifiable within the economic sense of most commercial and civil application.

II. Global UAV Demand

According to a report by an independent business information provider for defense industry, global spending in 2009 on unmanned aerial vehicles (UAV) reaches $5.1billion. Over the forecast period of 2010-2020, the cumulative UAV market will total nearly USD 71 billion [3]. Estimated revenues over the period of 2010 – 2015 are estimated to be USD 62 billion with calculated USD 5.5 billion spent globally in 2010 alone [4] [5]. In Australia, civil application of UAVs has been encouraging with AUS 2 million went to crop monitoring where only 10% of the 500’000 hectares agricultural land monitored are covered by manned aircraft [6]. With the steady demand of UAV across wide range of application, UAVs of different sizes and level of complexity has been developed, specifically designed according to the mission requirement and with cost consideration. It is therefore not uncommon to classify the UAVs into different types of categories. Some commonly known categories are: Micro UAV (MAV), generic UAV, tactical UAVs, unmanned combat aerial vehicles (UCAV), and civil UAV.

III. Civilian use UAV

The use of UAVs in the global civilian market is relatively low but yet UAV market surveys show that the growing trend of UAVs services in civilian market is happening right now. The use of civil UAVs has the strongest growth between the period of 2005 and 2011 [7]. There are growing research conducted for UAV designs towards civilian and commercial purposes [8] [9] as technology become more readily available in the civilian arena.

Cost and size are crucial elements in civil usages of UAV. Field surveys [10] [11] [12] are the main focus for civilian’s UAV and it has to be small, versatile, low in initial and maintenance cost [13] [14] and ease landing. This is important due to the nature of mission in civilian usage which may endanger properties and life forms which include human. Small size, low speed UAV has relatively small kinetic energy in the event of crashes. Payload compartment size and the ability to carry off-the-shelf imaging devices for photography field survey will be the focus. Small scale civilian UAVs are often having limited space for payload (Figure 2) and some require the payload to be hang beneath the wing (Figure 3) which expose the payload to outside element. In our experience in dealing with several commercial customers, mainly developer, plantation owner and researches, UAV capable of performing 20 to 30 minutes of flight with less than 1kg payload is more than sufficient. Typical 20 minutes of flight for a typical UAV (Figure 3) is capable of covering 1km^2 areas or with an

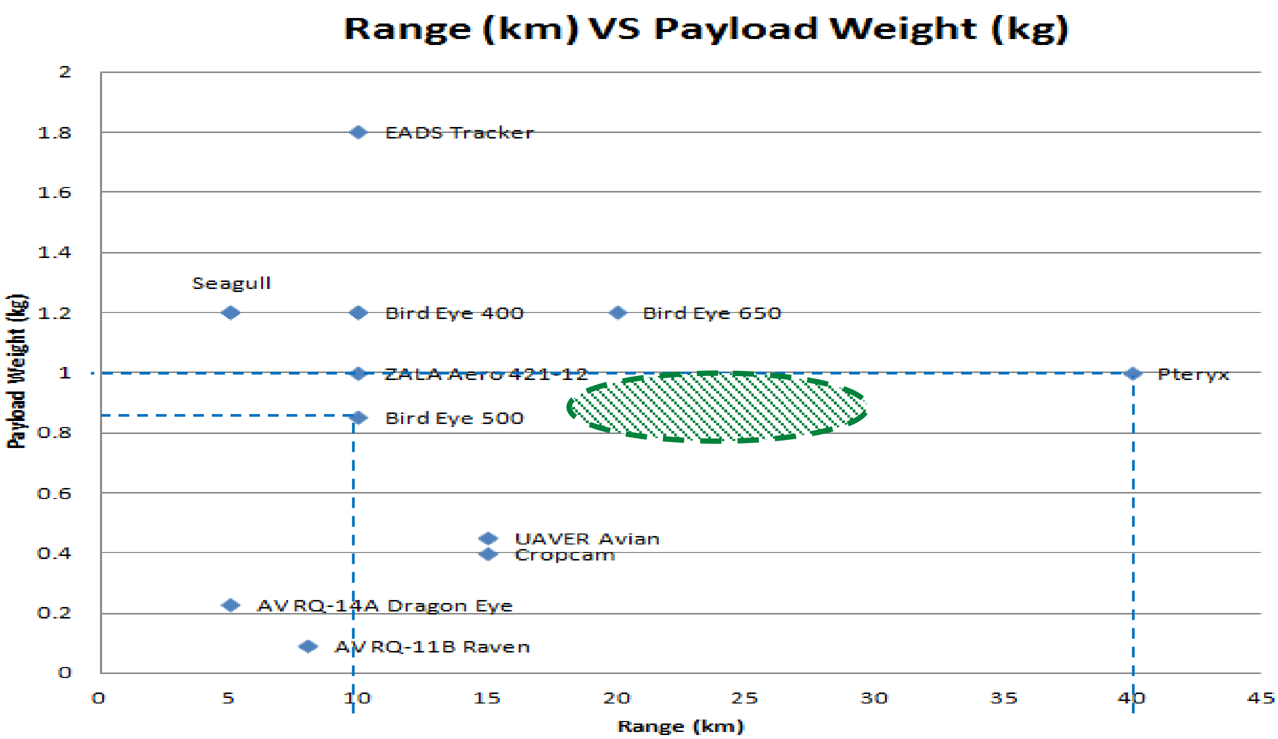

Figure 1: Green shaded region shows gap to be filled for current low cost civilian UAV demand.

equivalent range of 15 to 20km flying at an altitude of 1000 feet. Off-the-shelf compact camera, including supporting structure and electronic for airframe integration are around 400 grams (Figure 3) while a better off-the-shelf semi professional camera system such as the Canon G11 can add up to around 1kg.

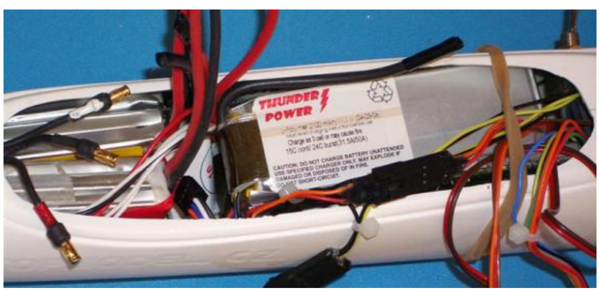

Figure 2: Cropcam UAV with small payload compartment. Source : www.topmodelcz.cz

Figure 3: Payload (camera mount) beneath the CropCam UAV's wing (circled). Source : www.Geosense.com.my

Study shown that CropCam UAV has been the most commonly used civilian UAV with the most affordable pricing. A complete ready-to-fly system estimated to cost around USD 15'000 [15] to USD 25'000 (according to Malaysia customer) as shown in Figure 3. Others can be around USD 60'000 and mostly dwell in the range of USD250'000 to millions as most are designed for military purposes. A typical small military UAV with wingspan of only 1.37 meter and estimated 90grams payload, the RQ-11B [16] can cost up to USD250'000 [17]. From Figure 1 (shaded region), looking at the demand for 20 to 30 km range and 20 to 30min endurance, a gap exist with no commercially available UAV readily available to fill in this gap. Since the acquisition cost of UAV increases proportionally with both weight and performance, it is therefore possible to reduce the cost by reducing the performance which in the Petryx case will be the range down to the 20 to 30 km range.

The design goals have been previously established [1] which were: 1) Capable of lifting 0.8 to 1kg payload that can be installed inside the UAV which double as protection in the event of unforeseen crashes; 2) flight endurance, at least 20 minutes; 3) wingspan not more than 2.5 meter for ease of transporting. 4) standard UAV design for good handling quality that can be flown by inexperienced pilot which will also contribute to 5) low cost production and lastly 6) Total take-off weight must be less than 6kg to comply with Department Civil Aviation (DCA) requirement for remotely piloted aircraft.

IV. Conceptual Design of the Alpha UAV

The conceptual flow chart for designing the Alpha UAV is presented in Figure 4. The mission profile is specifically design for commercial aerial photography: Take-Off > Climb to 1000ft > 20km Cruising range > Decent > Landing. Total estimated flight time to be 20-30 minutes. Software develops by Laminar Research known as X-Plane [18] is used to assist in the conceptual layout of the Alpha UAV, performing flight test and refining the design till the desire handling characteristic and flight performance. Computer Aided Design (CAD) software, Solid-Work (SW) is then used to assist in the prototype design.

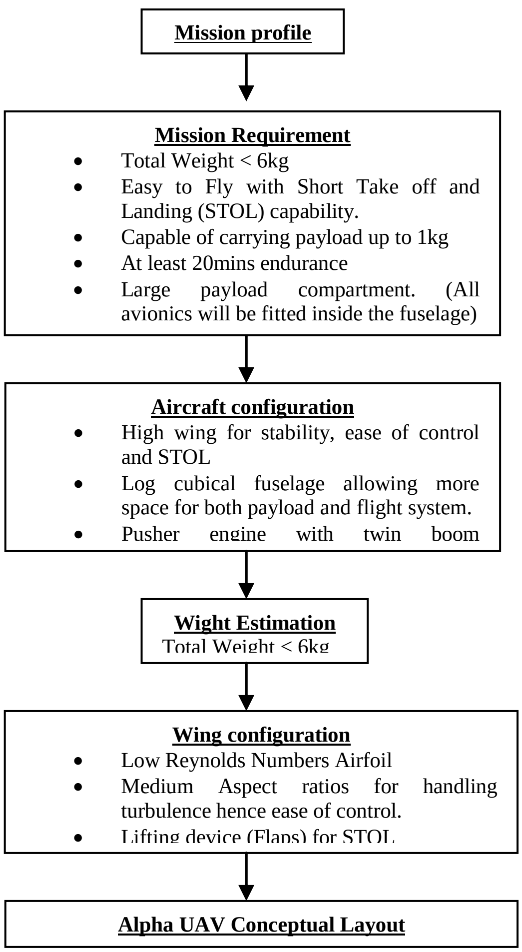

Figure 4: Conceptual design flow chart for Alpha UAV

X-Plane software has been used to develop several concept plane such as the Carter™ Copter, the famous MIT's Terrafugia™ and Cirrus™ Vision jet. Test flight done by NASA's UAV chief test pilot on the Verticopter™ remote control prototype verified the accuracy of the software in predicting the actual flight characteristic including some of its controls input value. Flight. Optimization on the structural design and some simple flow analysis on the Alpha's nose cone are done via SW to ensure the integrity of the structure and achieving desire flow characteristic over the nose cone. The process flow from conceptual design to actual prototyping is presented in Figure 5.

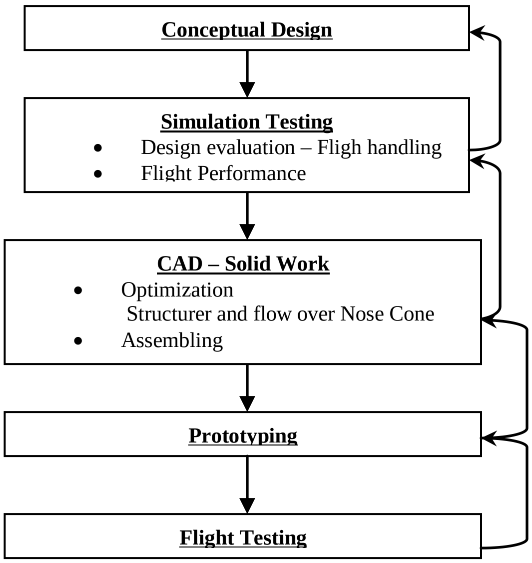

Figure 5 : Conceptual to Actual Prototyping Process Flow Chart

V. Numerical Analysis

By estimating the total weight of Alpha UAV based on general terbulation of simlar class UAV [1], it is possible to do some analysis on the Alpha's performance. With available off-the-shelf parts the wing span has been designed to be 2.05 meter in span and can be dismental into three parts for ease of transportation. The complete Alpha dimension can be seen in Figure 6. After actual flight testing, the length of the tail wing has been increased from 10.46cm to 11.0.cm to improve the control authority over pithing moment. Sizing of both main wing and tail wing areas are crucial for the aircraft dynamic stability. Sizing of wings is best upon general accepted coefficent value. The design is then tested in simulator environment for refinement. The main dimension,weights and caculated parameters (in blue) are tabulated in Table 1.

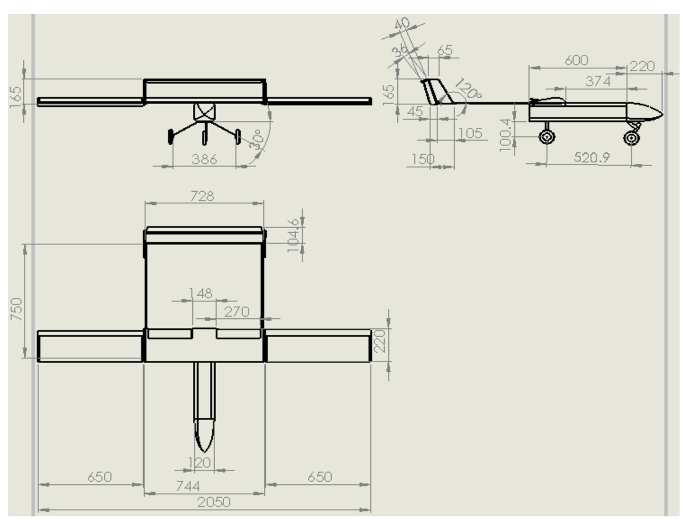

Figure 6: The Alpha UAV

A. Airfoil Selection and wing design

For low Reynolds number (Re) application, a modified SD7032 has been selected for its high lift characteristic. Based on experimental results [19] the airfoil having a maximum lift coefficient (C_{Lmax}) of around 1.3 at 6.0 x 10^4 Re. By incorporating high lift device such as flaps, it is possible to further increase the maximum lift coefficient to 2.3 [20] thus reducing its stall speed. With this we are able to calculate the minimum takeoff speed (1) during flap deployed. The maximum weight, *W* of 58.86N (6kg) was used. The result the Alpha able to take off at a very slow speed of 9.625 m/s or 34.65km/hr. Similar results also obtained in the simulation at around 20 knots (37km/hr). From Figure 7 the stall speed is the slowest air speed when the wing approaches its highest angle of attack (AoA). The drastic increase of air speed soon after as the result of the aircraft falling. At this stage the wing unable to generate enough lift to sustain flight. As expected, simulated stall speed is slightly higher as the aircraft performing the maneuver at higher altitude (3000ft) with lower air density.

$$V_{stall-flap} = \sqrt{\frac{w}{C_{L\max}\frac{1}{2}\rho S}} \qquad (1)$$

Table 1 : Alpha UAV's Main dimensions and weights

Main Wing		Tail Wing	
Area, S (m^2)	0.451	Area, S_h (m^2)	0.08008
Span, b (m)	2.05	Span, b_h (m)	0.728
Tip/Root Chord ,C (m)	0.22	Chord , C_h (m)	0.11
Vertical Tail (Rudder)			
Total Effective Area,two rudder combined,S (m^2)	0.0206		
Others			
Rudder Moment Arm, l_v (m)	0.7	Maximum Weight, *W* (N)	58.86
Vertical Tail Volume coeficient, V_v	0.03	Minimum take off Speed with flap, $V_{stall\text{-}flap}$ (m/s)	9.625
Tail Moment Arm, l_h (m)	0.63	Sea level Air Density, ρ (kg/m^3)	1.225
Horizontal Tail Volume coeficient, V_h	0.51		

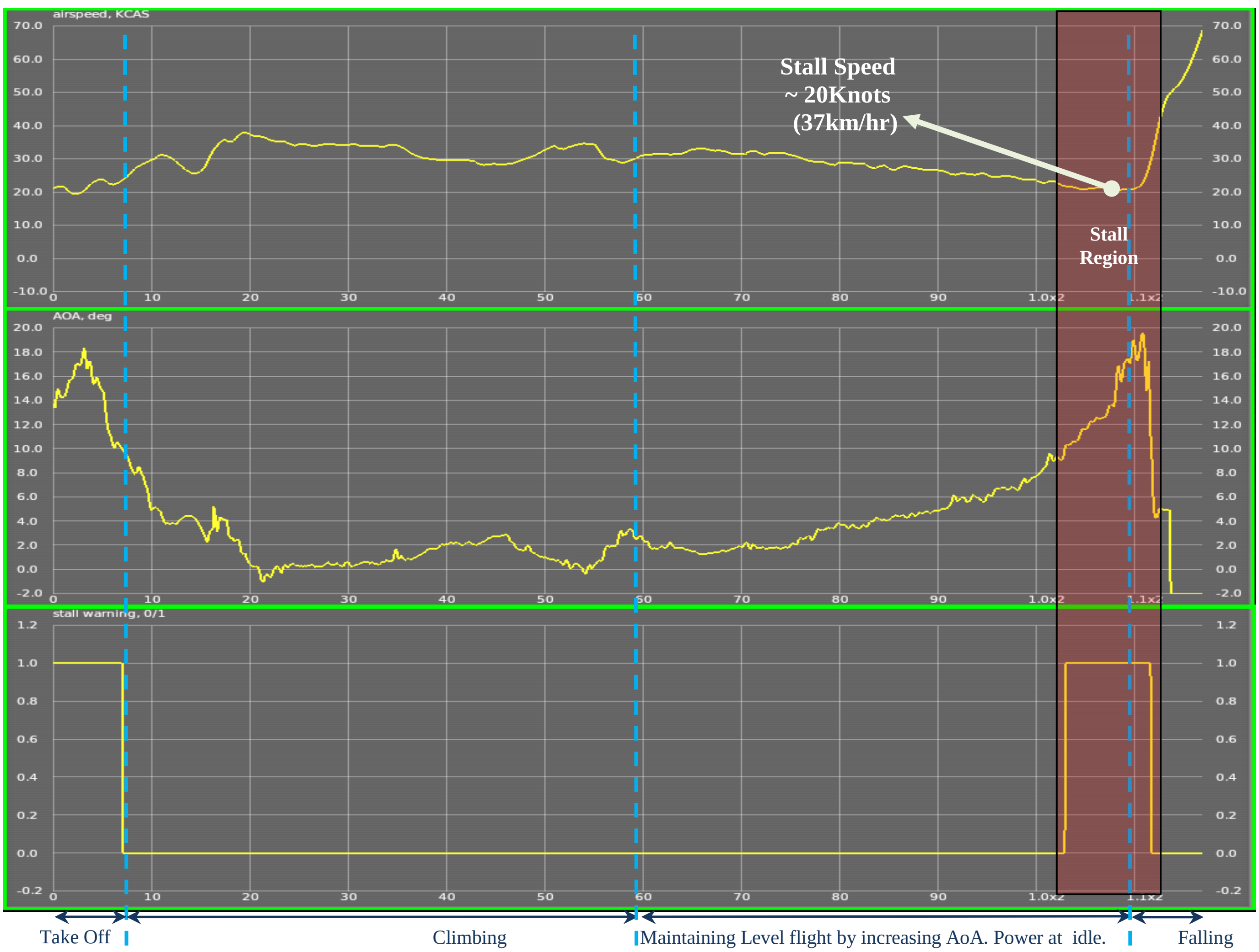

Figure 7: Flight test results in simulator at 3000 feet high altitude

B. *Horizontaland Vertical Tail Sizing*

Generally, a well behaved aircraft during flight is governed by Horizontal Tail Volume Coefficient, V_h (2) and Vertical Tail Volume Coefficient, V_v (3). Ideally, the aircraft should have the value of 0.30 to 0.60 and 0.02 to 0.05 respectively. The Alpha UAV having values within the accepted range (Table 1). Both simulation and actual test flight shows good handling quality of the UAV.

$$V_h \equiv \frac{S_h\ l_h}{SC} \tag{2}$$

$$\mathrm{V}_v \equiv \frac{S_v\, l_v}{SC} \tag{3}$$

C. *Finite Elemental Analysis (FEA) and Flow Simulation via Solid Work (SW)*

FEA has been done via SW to ensure the structural integrity of the Alpha UAV. The Alpha been simulated to 2g load (maximum allowable loading during flight) with a safety factor of 1.6 on its main structure. This subject the Alpha to a total of 3.2g loading or equavalent of 16kg (160N). A maximum mass of 5kg has been assumed as the payload and building material been identified. At this point of analysis the wings has been built and tested. The wing consist of few corbon rods which capable of handling the load. The results show a maximum of 8.3 mm displacement on the main structure which is within the accepted limit. Actual structure has higher strengh as thin layer of fiber glass is used. Flow sumulation via SW also demonstrated that the nose cone design able to induce some lift over the fuselarge as it manipulates the flow seperation point. This extra lift could be used to lower the stall speed on the prototype (Figure 8).

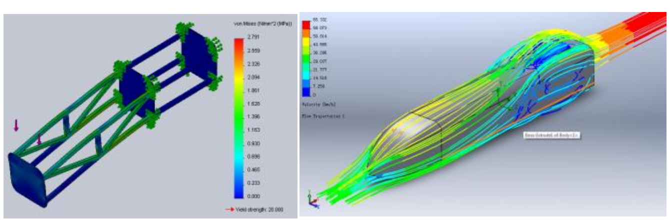

Figure 8: Sample picute of FEA and flow simulation over the nose cone.

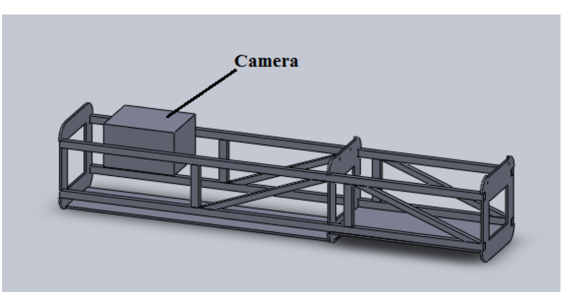

Figure 9: Alpha UAV with spaces compartment (12cm X 12cm X 60cm) for payload and flight system.

VI. FLIGHT SIMULATOR TESTING AND PROTOTYPING

With the numerically analysis and assembling design done according to plan, the Alpha been tested rigorously in the simulator to evaluate the flight handling quality. This is done with test pilot in the design loop, who gave feedback on the controls input and at the same time getting used to the flying characteristic of the aircraft prior the actual flight. The aircraft is then built according to the design and test flight been carrying out in phases (Figure 10). During the actual test flight, the Alpha demonstrated its capability in carrying its designated payload and perform short range aerial imaging mission. The payload is kept inside the UAV. This is possible with the spaces compartment available on the Alpha (Figure 9).

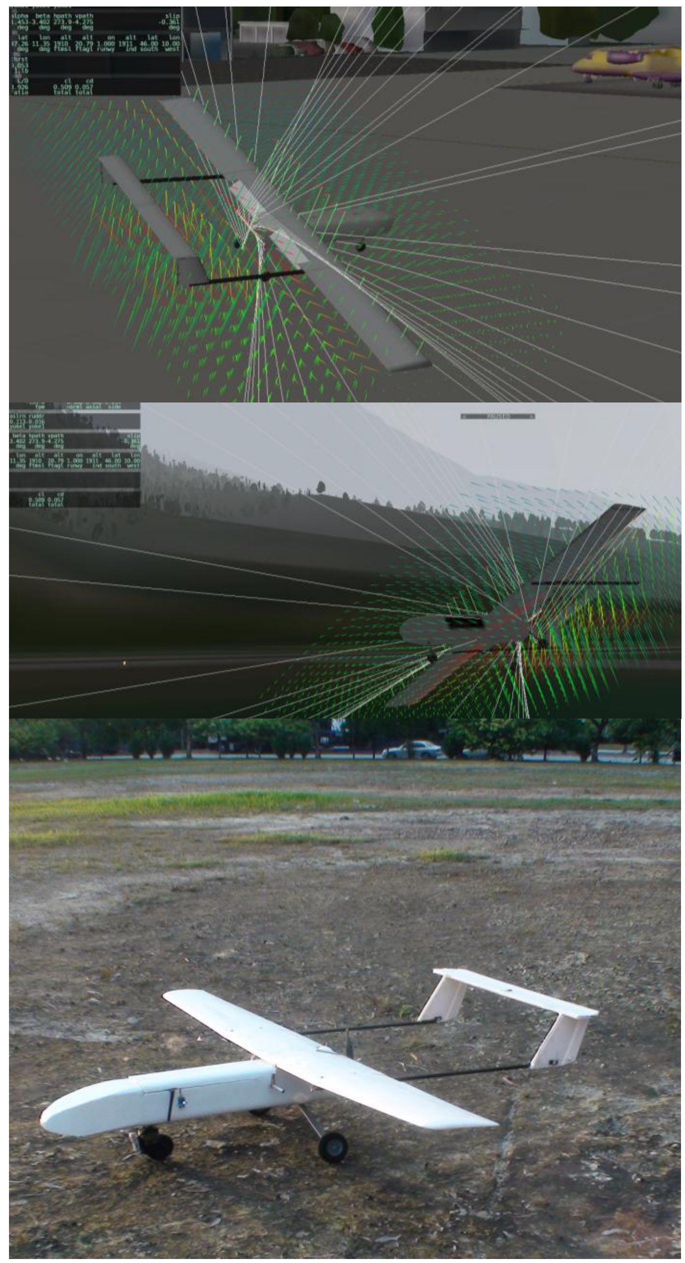

Figure 10: Alpha UAV during simulator testing (top, middle) and actual prototype ready for flight (bottom)

Figure 11: Alpha UAV successful Aerial Mission. Stiched image (top) and zoom in image show the pilot looking up at the UAV (bottom)

VII. CONCLUSION

The Alpha UAV has been built successfully according to the design goals. The aircraft flown continously for at least 20 minutes with 1 kg payload. During the flight the UAV demonstrated that it is capable of flying at slow speed with good handling quality. Hundreds of aerial images were taken at estimated 1000feet with great clarity. No UAV was lost during many of the test flight performed. With more funding available, the next step for this research is to incorporate autonomous flight in the Alpha airframe. The Alpha represents a feasible airframe to fill in the existing market gap for civilian UAV usage as outlined in author's another related publication [1].

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