



Flight performance of ABT 18 unmanned aerial vehicle

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General Note



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ABSTRACT

This Paper presents the analysis of flight performance of ABT-18 Unmanned Aerial Vehicle (UAV). This work was a subtask of a Group Design Project (GDP) where the overall aim was to modify the ABT-18 Standard version aircraft into a UAV which could be deployed for long endurance surveillance missions. To achieve this, some basic components and systems of the aircraft have been changed, modified or redesigned by individual designers. This change/modification of the aircraft components or systems results in change in the aircraft performance. Notable among these modifications are: Engine Selection, Surveillance gear attachment, Landing gears modification, incorporation of auxiliary fuel tank, removal of pilots and associated equipment from the aircraft etc. These modifications have resulted to change in the gross weight and overall parasite drag of the aircraft and this has direct effect on the performance of the aircraft. The gross mass reduced from 841kg to 789kg while the empty mass of the aircraft reduced significantly from 538kg to 471Kg. The gross mass reduction is not as significant as the empty mass reduction because the masses of pilots and associated equipment have been replaced by incorporating an auxiliary fuel tank to the UAV. The power plant (Lycoming Textron O-360 AIA) of the basic ABT-18 aircraft of Specific Fuel Consumption (SFC) and weight 0.30 l/hp/hr and 117kg was replaced with

UL350is of SFC 0.29l/hp/hr and 78kg respectively. Reduction in weight, Installation of auxiliary fuel tank and selection of engine with lower SFC has caused the range to increase from 567nm to 2400nm and endurance from 7hrs to 30hrs.

1. INTRODUCTION

The overall group design was based on modification of ABT-18 aircraft to ABT-18 UAV. This paper seeks to analyse the flight performance of the modified UAV. In doing this, the basic aerodynamic data and the propulsion system data of the aircraft must be known. The overall objective is aimed at designing a modified version of ABT-18 (UAV) with higher performance, such as: Improved fuel efficiency, light weight with sufficient stiffness and strength, modern avionics system, improved power to weight ratio, autonomous navigation, improved landing gear design, improved range and endurance etc. Students were organised in three major groups (namely: structures, systems and avionics) and several subgroups, based on their personal task in the GDP in order to achieve the ABT-18 UAV endpoints.

2. ANALYSIS

Aircraft performance is the result of aerodynamic, gravitational and propulsive forces acting on the aircraft¹. Certain simplifying assumptions would be discussed in this paper to represent these forces. Application of Newton's laws of motion to these forces yields the equations of motions that form a theoretical basis for analysing the flight performance for the Air-Beetle 18 (ABT-18) UAV.

2.1. Elements of Flight Performance

Typical Aircraft mission can be divided into six distinct elements. These are illustrated as shown:

1. Take-off
2. Climb
3. Cruise
4. Manoeuvre
5. Descent
6. Landing

Similar elements may be considered together to give the following four standard performance topics²:

1. Cruise
2. Climb and Descent
3. Take-off and Landing (Airfield)
4. Manoeuvre

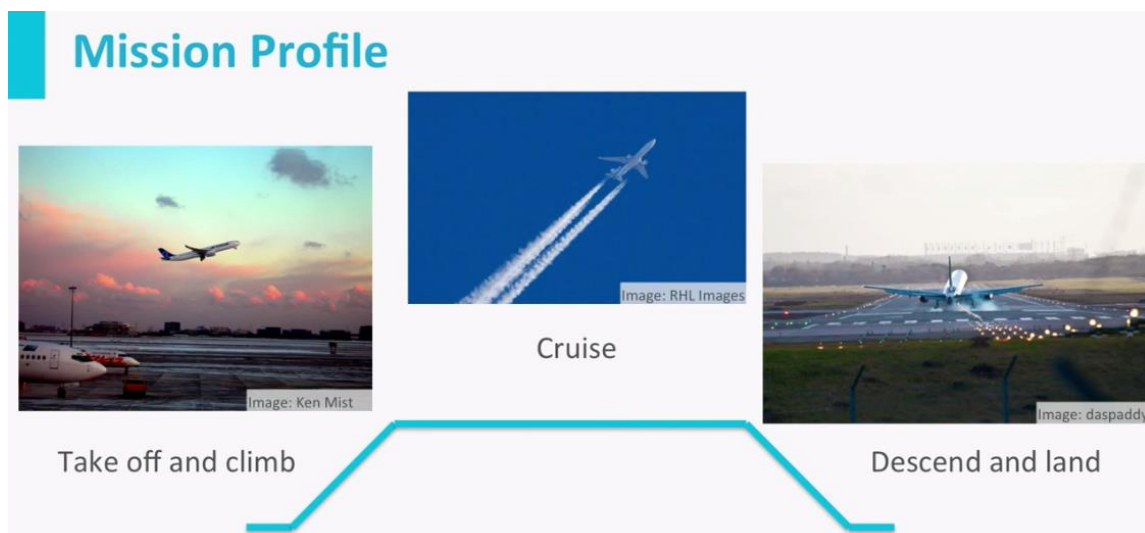


Figure 1 Typical Mission Profile of a typical Aircraft²

2.2. Cruise Performance

In cruise performance, the aircraft is considered in steady horizontal flight. As could be seen from the mission profile diagram in Figure 1, the largest part of the flight is the horizontal flight. There are four topics of relevance in cruise performance, which include²: minimum airspeed, maximum airspeed, maximum range and maximum endurance. The general equations of motion governing the translational motion of aircraft through air are defined in terms of forces and accelerations action on the aircraft. It is most convenient to express these forces parallel and perpendicular to the airspeed vector.

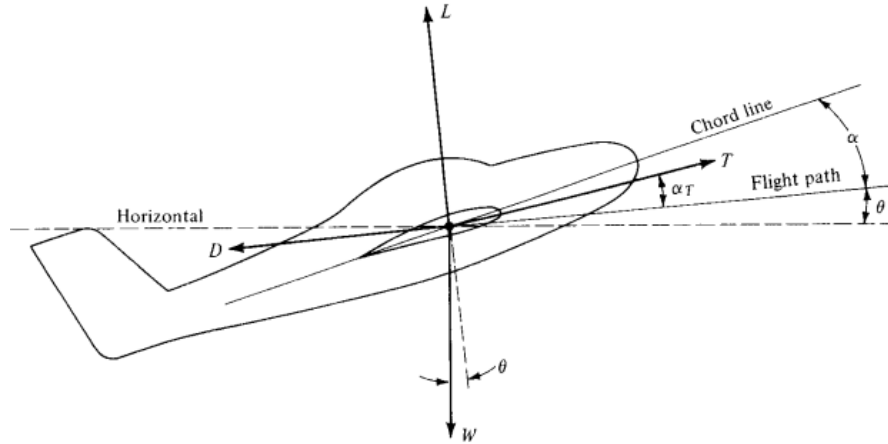


Figure 2 Forces acting on an aircraft in flight³

Based on the forces and accelerations, the point mass equations of motion can be written down as follows³:

$$T \cos \alpha_T - D - W \sin \theta = m \frac{dV}{dt} \text{ Eq. 1}$$

$$L + T \sin \alpha_T - W \cos \theta = m \frac{V^2}{r_c} \text{ Eq. 2}$$

In cruise, the aircraft is assumed to be flying in a level un-accelerated flight. Thus, accelerations $\frac{dV}{dt}$ and $\frac{V^2}{r_c}$ is zero. For most conventional airplanes, α_T is small enough that $\cos \alpha_T \approx 1$ and $\sin \alpha_T \approx 0$

Thus from equations 1 and 2,

$$T = D \text{ Eq. 3}$$

$$L = W \text{ Eq. 4}$$

These equations will form the basis of the cruise performance calculations.

2.2.1. Minimum Speed

The minimum speed is the Speed for maximum lift coefficient. The maximum lift coefficient (C_{Lmax}) for the aircraft is given in the project specification as 1.448. Thus the stall speed is defined by³:

$$V_{stall} = \sqrt{\frac{2W}{\rho_{\infty} S C_{Lmax}}} \text{ Eq. 5}$$

Then, the stall speed at sea level with clean configuration is given by:

$$V_{\text{stall}} = \sqrt{\frac{2 \times 789 \times 9.81}{1.225 \times 10.2 \times 1.448}} = 29.25 \text{ m/s} = 56.86 \text{ kts}$$

2.2.2. Maximum Speed

The maximum speed of the ABT-18 UAV has been calculated using two different approaches. The first approach was developed by Dr Ir Mark Voskuijl². He developed a mathematical model for the calculation of maximum speed for propeller driven aircraft. He expressed the maximum airspeed as a function of lift coefficient with depends on the maximum available power. The second approach was developed by Anderson⁴, where the maximum airspeed was determined graphically following the intersection between maximum power available and power required curves.

According to Voskuijl², the relationship between the optimum lift coefficient for maximum speed and maximum available power may be written as:

$$\frac{C_{D0} + KC_L^2}{C_L^3} = P_{\text{amax}}^2 \times \frac{S}{W^3} \times \frac{\rho_{\infty}}{2} \quad \text{Eq. 6}$$

Where the maximum power available was obtained from the selected engine (UL350is) specification as 130hp (96950 Watts) at sea level⁵. Substituting the values of the parameters and solving for C_L gives:

$$\frac{0.03842 + 0.088C_L^2}{C_L^3} = 96950^2 \times \frac{10.2}{8231^3} \times \frac{1.225}{2}$$

$$0.0384 + 0.088C_L^2 = 0.105C_L^3$$

Solving the cubic equation for C_L yields 0.237

Thus, substituting the value of C_L into Eqn 6.1 gives:

$$V_{\text{max}} = \sqrt{\frac{2 \times 789 \times 9.81}{0.736 \times 10.2 \times 0.237}} = 93.28 \text{ m/s} = 181.3 \text{ kts}$$

Anderson³ presented a graphical approach for estimation of maximum airspeed for a propeller driven aircraft. The maximum airspeed is a function of power required and maximum power available.

The power required by the aircraft is given by the equ 6.4 as:

$$P_R = T_R V_{\infty} \quad \text{Eq. 7}$$

Since it is a level flight,

$$T_R = D = 0.5 \rho_{\infty} V_{\infty}^2 C_D \quad \text{Eq. 8}$$

And

$$C_D = C_{D0} + KC_L^2 \quad \text{Eq. 9}$$

Again, for level flight,

$$W = L = 0.5 \rho_{\infty} V_{\infty}^2 SC_L \quad \text{Eq. 10}$$

Rearranging Eqn 6.8 yields

$$C_L = W / (0.5\rho_\infty V_\infty^2 S) \quad \text{Eq. 11}$$

The values of C_L was calculated for various airspeeds within the flight regime of the UAV (in this case from 15m/s to 140m/s). The calculated values for C_L was substituted into Eqn 6.7 and the C_D at different C_L values was obtained. The calculated values of C_D were used to obtain the thrust required at various airspeeds.

2.2.3. Range in Steady Horizontal Flight

The range and endurance of the ABT-18 UAV was estimated using the historical Breguet range and endurance equation. To obtain the maximum range of the aircraft, the maximum lift-drag ratio (L/D_{\max}) was evaluated. The value of the coefficient was also obtained at the cruise velocity to obtain a more practical value of the expected range of the aircraft.

Using the Breguet Range equation⁴:

$$R = \frac{\eta_{pr} L}{c D} \ln \frac{W_0}{W_1} \quad \text{Eq. 12}$$

Where c = specific fuel consumption⁴

$$c = \frac{\text{fuel flow}}{\text{power output}} \quad \text{Eq. 13}$$

Fuel flow for the engine (UL350is) at maximum RPM is 35L/hr

Thus Specific fuel consumption of the engine at maximum RPM, will be given as:

$$c = \frac{35}{130 \times 745.7 \times 3600 \times 1000} = 1.0029 \times 10^{-10} \text{ m}^3/\text{Ws}$$

The recommended fuel is Avgas 100LL with density of 720Kg/m³ [5]

Thus, SFC may be written as:

$$c = 1.0029 \times 10^{-10} \times 720 \times 9.81 = 7.84 \times 10^{-7} \text{ N/Ws}$$

Substituting the SFC value into the range equation, the maximum range of the UAV will be given as:

$$R = \frac{0.85 \times 13.22 \times \ln \left(\frac{7740}{5672} \right)}{7.84 \times 10^{-7}} = 4,450,000 \text{ m} \\ = 4450 \text{ km} = 2400 \text{ nm.}$$

2.2.4. Endurance of ABT-18 UAV

Maximum Endurance would be obtained for the ABT-18 UAV if the aircraft is flown at the speed for maximum $C_L^{3/2}/C_D$ [2]. From the graph (fig. 3.7), the maximum $C_L^{3/2}/C_D$ is 15.07 which corresponds to the airspeed of 41m/s (80 Knots).

Using the Breguet Endurance equation:

$$E = \frac{\eta C_L^{3/2}}{c C_D} (2\rho_\infty S)^{1/2} (W_1^{-1/2} - W_0^{-1/2}) \quad \text{Eq. 14}$$

Thus endurance at maximum $C_L^{3/2}/C_D$ at cruise altitude:

$$E = \frac{0.85 \times 15.07 \times \sqrt{2 \times 0.736 \times 10.2} \times (5672^{-\frac{1}{2}} - 7740^{-\frac{1}{2}})}{7.84 \times 10^{-7} \times 3600} = 31.5 \text{ hrs}$$

2.3. Climb and Descent Flight Performance

The topics of interest in climbing flight performance are rate of climb, time to climb, effects of air temperature and density on the climb performance. Similarly, in descending flight performance, power off gliding flight is the most critical condition for determining the descending flight performance. Thus, it is important to determine the minimum rate of descent (sink rate) in a gliding flight, endurance in gliding flight, range covered on ground in a gliding flight and effects of wind on the glide range.

2.3.1. Rate of Climb

Rate of Climb (ROC) is given by the following equation⁴:

$$\text{ROC} = \frac{P_a - P_r}{W} \quad \text{Eq. 15}$$

Where Power available (P_a) is given by the product of thrust available and airspeed, and Power required (P_r) is given by the product of aircraft drag and airspeed. Thus, rate of climb may also be written as²:

$$\text{ROC} = \frac{(T-D)V}{W} \quad \text{Eq. 16}$$

The difference between power available and power required is known as excess power and the rate of climb is maximum when excess power is maximum.

2.3.2. Climb Gradient

The difference between the thrust and drag determines the flight path angle γ . This flight path (climb angle) may be calculated using the following expression²:

$$\sin \gamma = \frac{T-D}{W} \quad \text{Eq. 17}$$

This expression may be written in terms of airspeed as²:

$$V \sin \gamma = \frac{P_a - P_r}{W} \quad \text{Eq. 18}$$

For a given aircraft weight, climb angle would be maximum when the difference between thrust and drag is maximum. This airspeed at which thrust and drag is maximum is the airspeed at which the lift coefficient, C_L is equal to $\sqrt{(C_{D0}/K)^{[2]}}$.

2.3.3. Rate of Descent in Glide

For a gliding flight, in case of engine failure, the power available (P_a) is zero. Thus, the rate of climb equation can be applied to calculate for rate of descent, with the P_a term being equal to zero.

Substituting $P_a = 0$, in Eq. 15, Glide Sink Rate becomes,

$$h_s = -\frac{P_r}{W} = -\frac{DV}{W} \quad \text{Eq. 19}$$

According to Pamadi⁶, this expression may also be written as:

$$h_s = \sqrt{\left(\frac{2W}{\rho S}\right)} \left(\frac{C_D}{C_L^{3/2}}\right) \quad \text{Eq. 20}$$

The maximum $C_L^{3/2}/C_D = 15.07$, thus, maximum $C_D/C_L^{3/2} = 1/15.07 = 0.066$

Thus, minimum sink rate,

$$h_s = \sqrt{\left(\frac{2 \times 7129.9}{1.225 \times 10.2}\right)} \times 0.066 = 2.23 \text{ m/s}$$

2.3.4. Minimum Glide Angle

According to Anderson⁴, minimum glide angle is given by:

$$\tan \theta_{min} = \frac{1}{(L/D)_{max}} \quad \text{Eq. 21}$$

Where $(L/D)_{max} = (C_L/C_D)_{max} = 13.22$

$$\tan \theta_{min} = \frac{1}{13.22} = 0.0756$$

$$\theta_{min} = \tan^{-1} 0.0756 = 4.33^\circ$$

Thus, minimum Glide angle of ABT-18 UAV is 4.33° .

2.3.5. Range Covered on Ground during Glide

The distance covered along the ground during glide from a certain altitude is given by Anderson⁴ as:

$$R_{glide} = \frac{h}{\tan \theta} = h \left(\frac{L}{D}\right)_{max} \quad \text{Eq. 22}$$

Where h is the altitude at the start of the glide. Assuming a glide from the ceiling of 15,000 ft, the range covered becomes:

$$R_{glide} = 15,000(13.22) = 198,300 \text{ ft} = 32.63 \text{ nm}$$

2.3.6. Maximum Endurance during Glide

The conditions for maximum endurance during cruise also hold for gliding flight. A procedure for estimating glide endurance was presented by Pamadi⁶ as follows:

$$t_{max} = \sqrt{\frac{\rho S}{2W}}^4 \sqrt{\frac{27}{k^3 C_{D0}}} \left(\frac{h_i - h_f}{4}\right) \quad \text{Eq. 23}$$

Thus, glide endurance from a ceiling of 15,000ft to the earth is given by:

$$t_{max} = \sqrt{\frac{1.225 \times 10.2}{2 \times 7130}}^4 \sqrt{\frac{27}{0.10201^3 \times 0.03842}} \left(\frac{4572 - 0}{4}\right) = 965 \text{ secs} = 16.1 \text{ minutes}$$

Comparing equations 20 and 23, it could be seen that the endurance is maximum when the sink rate is minimum.

2.4. Takeoff and Landing Performance

In the analysis of takeoff and landing performance, the objective is to determine the length of runway required for takeoff and landing of the aircraft at various conditions. The conditions considered in the takeoff analysis are as follows:

- Flaps deployment (clean configuration and flaps down)
- Atmospheric conditions

- c. Altitude of the runway
- d. Runway Surface condition (considered only during landing)

2.4.1. Takeoff Analysis

Stall Velocity⁴

$$V_{stall} = \sqrt{\frac{2Wn}{\rho_{\infty}SC_{Lmax}}} \quad \text{Eq. 24}$$

$$V_{stall} = \sqrt{\frac{2 \times 841}{1.225 \times 10.1 \times 1.448}} = 30.2m/s$$

Flight path Radius⁴

$$R = \frac{6.96V_{stall}^2}{g} \quad \text{Eq. 25}$$

$$R = \frac{6.96 \times 30.2^2}{9.81} = 646.92m$$

Flight Path angle (θ_{OB})^[4]

$$\theta_{OB} = \cos^{-1}\left(1 - \frac{h_{OB}}{R}\right) \quad \text{Eq. 26}$$

$$\theta_{OB} = \cos^{-1}\left(1 - \frac{25}{646.92}\right) = 0.279rads = 16^{\circ}$$

Airborne Distance (S_a)^[4]

$$S_a = R \sin \theta_{OB} \quad \text{Eq. 27}$$

$$S_a = 646.92 \sin 16^{\circ} = 178m$$

Ground Roll (S_g)^[4]

According to Anderson⁸ the ground roll is given by the following equation

$$S_g \approx \frac{1.21(W/S)}{g\rho_{\infty}C_{Lmax}(T/W)} \quad \text{Eq. 28}$$

$$S_g \approx \frac{1.21(808.84)}{9.81 \times 1.225 \times 1.448 \times 0.54} = 150m$$

$$\text{Total Takeoff distance at sea level} = S_g + S_a \quad \text{Eq. 29}$$

$$\text{Total Takeoff distance, } S_{TO} = 150 + 178 = 328m = 1076ft$$

2.4.2. Landing Analysis

In the analysis of landing performance of ABT-18 UAV. The approach distance was first calculated by obtaining the flare height and the flight path radius. The conventional 3^0 approach angle was used in the approach distance calculation⁷.

The procedure for the landing distance calculation was presented by Anderson⁴ as follows:

Flare Velocity, V_f

$$V_f = 1.23V_{stall} \quad \text{Eq. 30}$$

$$V_f = 1.23 \times 30.2 = 37.146m/s$$

Touchdown Velocity, V_{TD}

$$V_{TD} = 1.15V_{stall} \quad \text{Eq. 31}$$

$$V_{TD} = 1.15 \times 30.2 = 34.73m/s$$

Flight path Radius, R

$$R = \frac{V_f^2}{0.2g} \quad \text{Eq. 32}$$

$$R = \frac{37.146^2}{0.2 \times 9.81} = 703.27m$$

Flare height, h_f

$$h_f = R(1 - \cos \theta_a) \quad \text{Eq. 33}$$

$$h_f = 703.27(1 - \cos 3^0) = 0.964m$$

Approach distance, S_a

$$S_a(ft) = \frac{50 - h_f}{\tan \theta_a} \quad \text{Eq. 34}$$

$$S_a(m) = \frac{15.24 - 0.964}{\tan 3^0} = 267.82m$$

Flare Distance, S_f

$$S_f = R \sin \theta_a \quad \text{Eq. 35}$$

$$S_f = 703.27 \sin 3^0 = 36.8m$$

Ground roll, S_g

In the analysis of ground roll, the engine power is assumed to be reduced to idle (essentially zero). Thus $P = 0$ and $T = 0$

Therefore the thrust loading (T/W) is assumed to be zero for landing.

J_T is a factor that depends on thrust loading (T_{rev}/W) and rolling friction coefficient (μ_r)

$$J_T = \frac{T_{rev}}{W} + \mu_r \quad \text{Eq. 36}$$

Typical values of (μ_r) are given in Table 8-1 below for various runway conditions and brakes consideration.

Table 1 Typical values rolling friction coefficient⁴

μ_r (Typical Values)		
SURFACE	BRAKES OFF	BRAKES ON
Dry Concrete/asphalt	0.03-0.05	0.3-0.5
Wet Concrete/asphalt	0.05	0.15-0.3
Icy Concrete/asphalt	0.02	0.06-0.10
Hard Turf	0.05	0.4
Firm Dirt	0.04	0.3
Soft Turf	0.07	0.2
Wet Grass	0.08	0.2

J_T was estimated for a dry concrete/asphalt with $\mu_r \approx 0.4$ (brakes on).

$$J_T = \frac{T_{rev}}{W} + \mu_r = 0 + 0.4 = 0.4$$

J_A is another constant coefficient which depends on several factors like air density, wing loading, drag polar, ground effect and rolling friction coefficient.

J_A is defined as:

$$J_A = \frac{\rho_{\infty}}{2(W/S)} \left[C_{D0} + \Delta C_{D0} + \left(K_1 + \frac{G}{\pi e AR} \right) C_L^2 - \mu_r C_L \right] \quad \text{Eq. 37}$$

Where G is the ratio between in-ground effect and out-of-ground effect and is given by:

$$G = \left\{ \frac{(16h/b)^2}{1 + (16h/b)^2} \right\} \quad \text{Eq. 38}$$

Where h = height of the wing above the ground (0.9m)

b = wing span (7.01m)

$$G = \left\{ \frac{(16 \times 0.9/7.01)^2}{1 + (16 \times 0.9/7.01)^2} \right\} = 0.809$$

Thus, J_A becomes;

$$J_A = \frac{1.225}{2(808.84)} \left[0.03272 + \left(0.10201 + \frac{0.809}{\pi \times 0.65 \times 4.8} \right) 0.1^2 - 0.4 \times 0.1 \right] = 6.0 \times 10^{-8}$$

Ground Roll, S_g

$$S_g = NV_{TD} + \frac{1}{2gJ_A} \ln \left(1 + \frac{J_A}{J_r} V_{TD}^2 \right) \quad \text{Eq. 39}$$

According to Raymer⁷, time increment for free roll (N) may be assumed to be 3seconds. Thus, the ground roll becomes;

$$S_g = 3 \times 34.73 + \frac{1}{2 \times 9.81 \times 6.0 \times 10^{-8}} \ln \left(1 + \frac{6.0 \times 10^{-8}}{0.4} 34.73^2 \right) = 257.82m$$

Finally,

$$\text{Total Landing Distance} = S_a + S_f + S_g$$

$$\text{Total Landing Distance} = 267.82 + 36.8 + 257.82 = 562.44m = 1845ft$$

2.5. Mission Analysis

The mission profile for the ABT-18 UAV is the same as for the basic configuration except that the UAV is designed to be a surveillance aircraft hence it will spend more time loitering in the cruise phase of the mission profile.

Table 2 Setup for mission Analysis

Maximum Takeoff mass	789 Kg
Maximum Zero Fuel mass	578.2Kg
Operating Empty mass	471Kg
Overall Fuel weight	210.8Kg

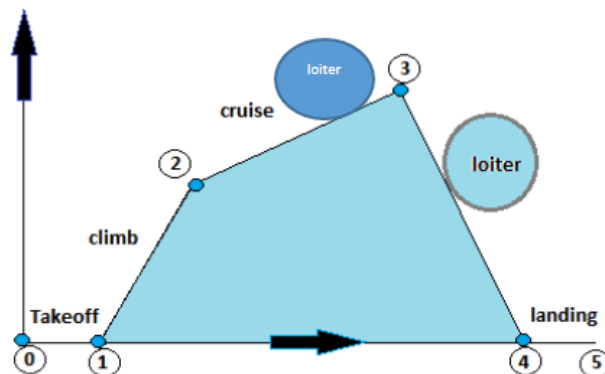


Figure 3 Mission Profile

The segment 0 – 1 is the takeoff, 1 - 2 the climb phase, 2 - 3 the cruise phase which comprises most of the flight of the aircraft including most of its surveillance loitering. Segment 3 - 4 defined the decent to the landing, 4 - 5 phase with allowance made for loiter in an aerodrome.

The segment weight fractions were obtained from statistical data given by Roskam⁸, as well as typical values of expected weight reductions in the appropriate segments.

Table 3 Mission Profile segment weight fractions

Weight Fractions	Ratios
W_e/W_0	0.560
W_1/W_0	0.970
W_2/W_1	0.985
W_3/W_2	0.81
W_4/W_3	0.972
W_5/W_4	0.995

2.5.1. Mission fuel

Mission fuel could be estimated using Breguet Range Equation, and applying the range and the various weight fractions as follows:

$$R = \frac{\eta_{pr} L}{c D} \ln \frac{W_2}{W_3}$$

$$\ln \frac{W_2}{W_3} = \frac{c R}{\eta_{pr} L/D}$$

Where,

$$c = 0.29 \frac{l}{hphr} = 7.68 \times 10^{-8} \frac{N}{W_s}$$

(Where density of Avgas 100LL = 720kg/m³)

Thus,

$$\ln \frac{W_2}{W_3} = \frac{7.68 \times 10^{-7} \times 3704000}{0.85 \times 15.89} = 0.2106$$

$$\therefore \frac{W_2}{W_3} = e^{0.2106} = 1.234$$

$$\text{or } \frac{W_3}{W_2} = 0.81$$

$$\text{then, } \frac{W_5}{W_0} = \frac{W_1}{W_0} \frac{W_2}{W_1} \frac{W_3}{W_2} \frac{W_4}{W_3} \frac{W_5}{W_4} = 0.970 \times 0.985 \times 0.81 \times 0.972 \times 0.995 = 0.748$$

Allowing a 6% fuel reserve for unusable fuel, it follows:

$$\frac{W_f}{W_0} (W_0) = 1.06 \left(1 - \frac{W_5}{W_0} \right) = 1.06(1 - 0.748) = 0.267$$

Hence, fuel weight fraction for the mission $\frac{W_f}{W_0} = 0.267$ and fuel weight required for the mission is given as follows:

$$W_f = \frac{W_f}{W_0} (W_0) = 0.267 \times 789 = 210.7 \text{ kg}$$

2.6. Payload Analysis

The payload considered in the design of the ABT-18 UAV is only the surveillance camera of 20kg and some avionics equipment like the autopilot, etc., whose weight is not to exceed 15kg. Therefore, the maximum payload carried by the UAV for a standard mission is 35kg. However, the maximum allowable payload capacity of 45kg has been allocated to the aircraft, this allows the UAV to be installed with higher performance cameras (of higher weight) depending on the mission. Positioning of these payloads may have may result to stability issues if the CG moves out of limit. Thus, the payloads must be strategically placed and the CG position must be recalculated if a new payload is being introduced.

This payload capacity was estimated using Anderson's approach which is given as follows:

$$W_0 = W_{\text{payload}} + W_{\text{fuel}} + W_{\text{empty}} \quad \text{Eq. 40}$$

$$W_0 = W_{\text{payload}} + W_f + W_e$$

$$W_0 = W_{\text{payload}} + \frac{W_f}{W_0} (W_0) + \frac{W_e}{W_0} (W_0) \quad \text{Eq. 41}$$

$$W_{\text{payload}} = W_0 \left(1 - \frac{W_f}{W_0} - \frac{W_e}{W_0} \right) \quad \text{Eq. 42}$$

$$W_{\text{payload}} = 789(1 - 0.267 - 0.560) = 136.5 \text{ Kg (301lb)}$$

This shows that for a fuel load of 210kg, a payload of 136.5kg could be carried by the UAV. However, additional payload of 100kg has been traded-off for fuel for increased endurance and range. Figure 8-2 shows the relationship between the aircraft range and payload.

3. RESULTS AND DISCUSSION

The analysis has shown that by converting ABT-18 (standard version) aircraft into ABT-18 unmanned aerial vehicle, a considerable amount of weight has been saved, thus lift induced drag has reduced and power required to lift the aircraft has also been reduced as a result, a lighter engine (78kg) with less power (130hp) has been selected. However, the parasite drag has increased, this is as a result of modified landing gears, surveillance gear attachment. The basic configuration of the aircraft did not change, thus the key performance parameters that need to be recalculated include weight, drag polar, wing loading and thrust to weight ratio.

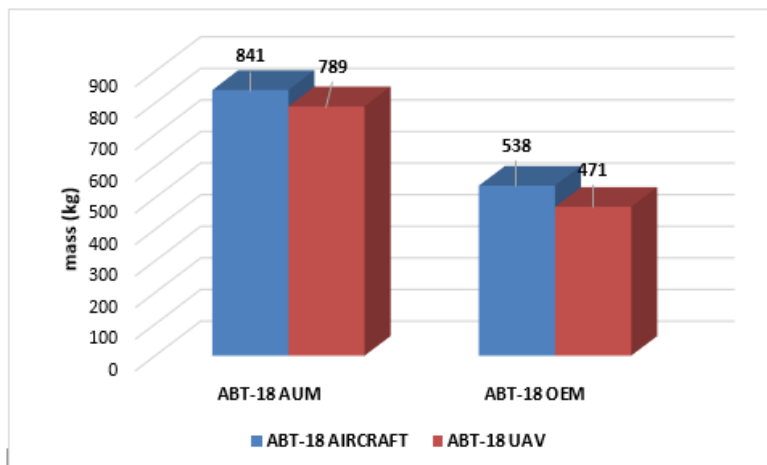


Figure 4 Weight comparison between the baseline ABT-18 aircraft and ABT-18 UAV

Figure 4 shows the weight comparison between ABT-18 aircraft and ABT-18 UAV. The various weights of components to be removed from the aircraft in converting it to unmanned vehicle (including pilots, instrument panel, control sticks, seats etc.) was calculated to be 240kg. Weight of two pilots estimated at 80kg each contributed to 67% of this weight. The weight of the components (including antennas, camera, auxiliary fuel tank, servos etc.) which is required for the UAV operation was found to be 226.2Kg. Bulk of this mass (about 58%) was contributed by the auxiliary fuel tank (and fuel) which has been designed for the UAV. This auxiliary fuel is required for long endurance surveillance mission of the UAV. However the total mass of components incorporated into the UAV will be 96kg without the auxiliary fuel tank. Some components (such as landing gears, power plant, engine mount, firewalls etc.) have been modified or changed to suit the UAV operation. The overall mass of components before modification was estimated to be 233.9kg while the total mass after modification was 195.7kg. Bulk of the mass saved was from the power plant selected. The baseline ABT-18 aircraft has a power plant (Textron Lycoming 0-360A1A) of dry mass 117kg, while the selected power plant (UL power 350iS) has a dry mass of 78kg. The operating empty mass (OEM) of the aircraft changed from 538kg to 471kg, while the gross mass (AUM) changed from 841Kg to 789Kg. This implies 12.5% and 6.2% reductions in the OEM and AUM respectively.

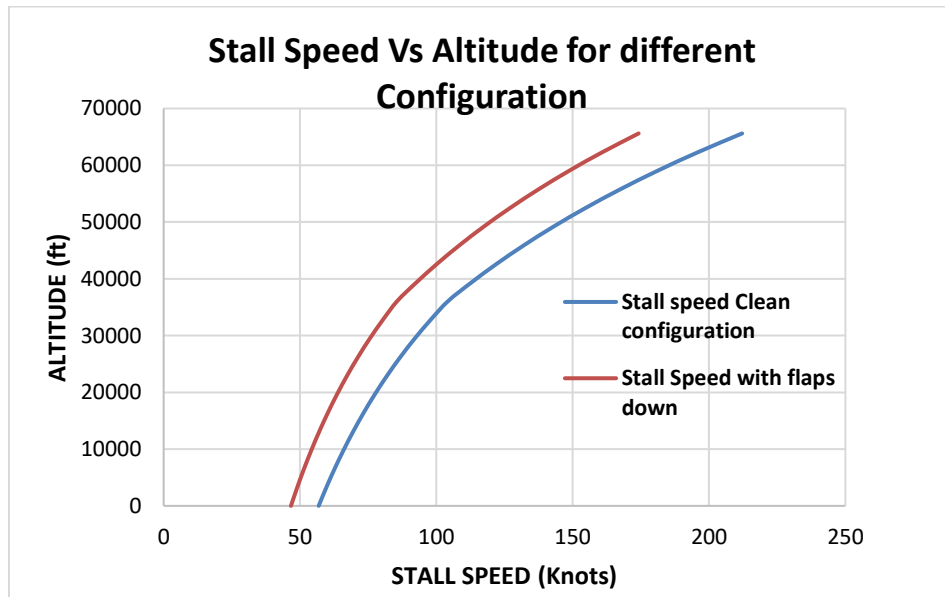


Figure 5 Stall speed against altitude for different configurations

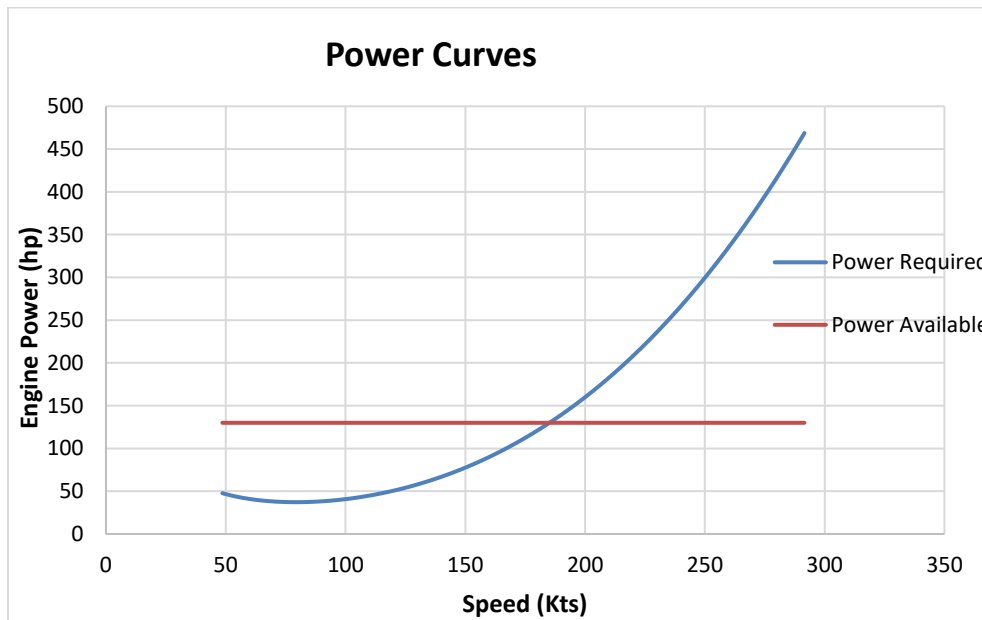


Figure 6 Power Curves against Airspeed

Figure 5 shows the stall speed for the ABT-18 UAV. Minimum stall speed of 58.63 knots is obtained at sea level where the air density is maximum. The stall speed could further be reduced by application of flap to 48.13 Knots. From figure 3.2, it could be seen that stall speed increases with increase in altitude.

From Figure 6, The maximum airspeed is the airspeed at which the power required is equal to power available, for the ABT-18 UAV, this value corresponds to 153Kts (78.71m/s). This value agrees with the analytical value of 74.56m/s (145kts) obtained using Voskuijl's⁶ method.

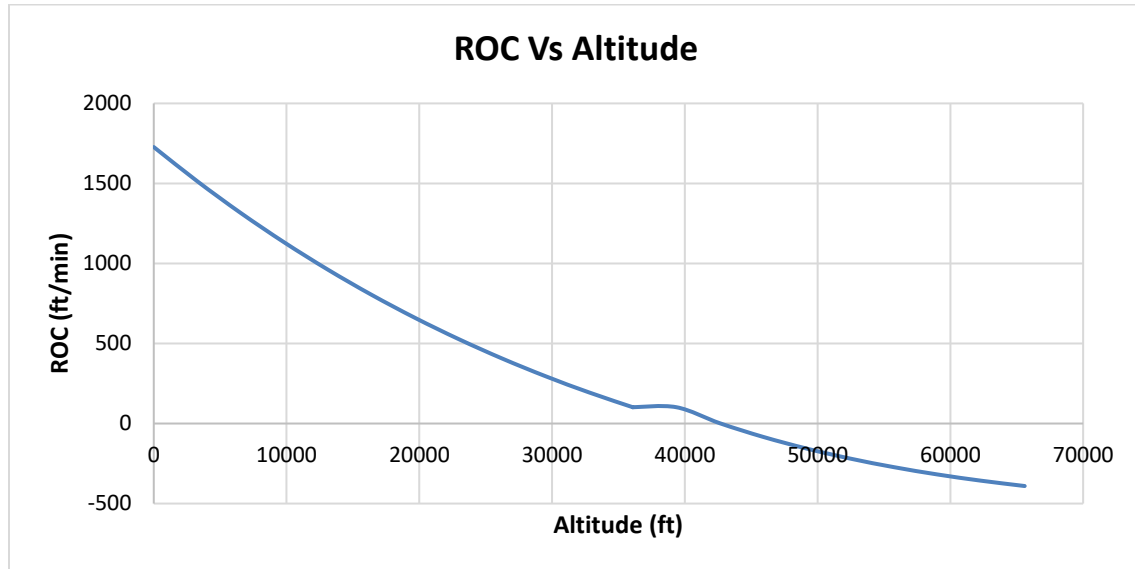


Figure 7 Rate of Climb against Altitude

From Figure 7, the maximum rate of climb of the ABT-18 UAV was found to be 1650ft/min at sea level. Thus, the rate of climb of the UAV reduced by 520ft/min. since the rate of climb of the ABT-18 standard version was found to be 2170ft/min. Reduction in rate of climb is due to selection of engine with lower power.

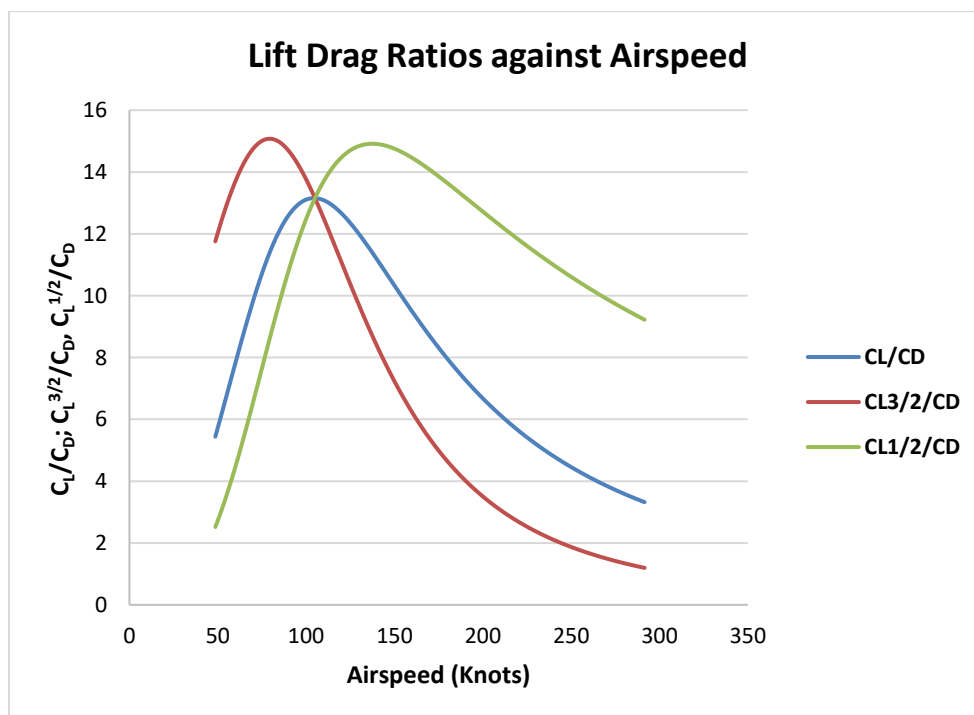


Figure 8 Lift Drag ratios against Airspeed

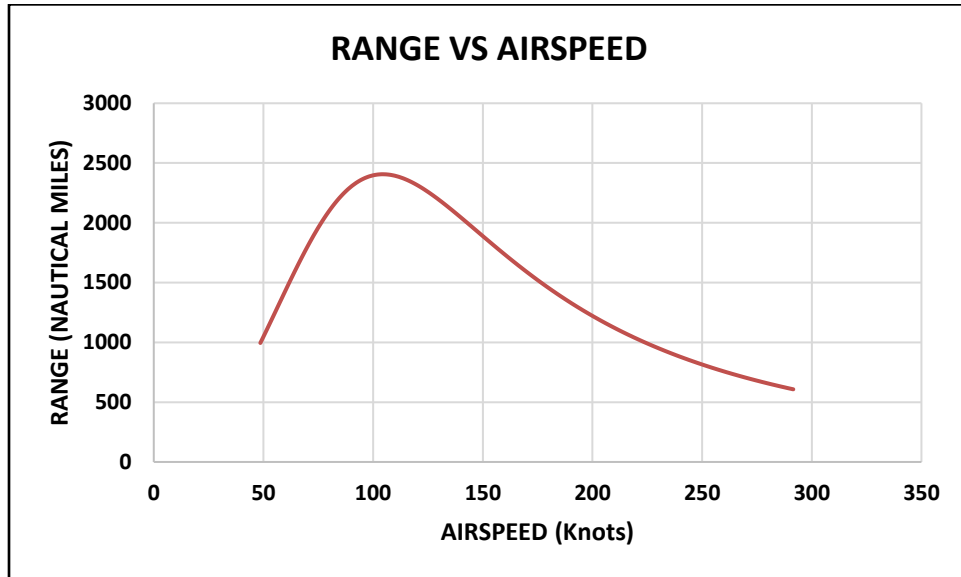


Figure 9 Range against Airspeed

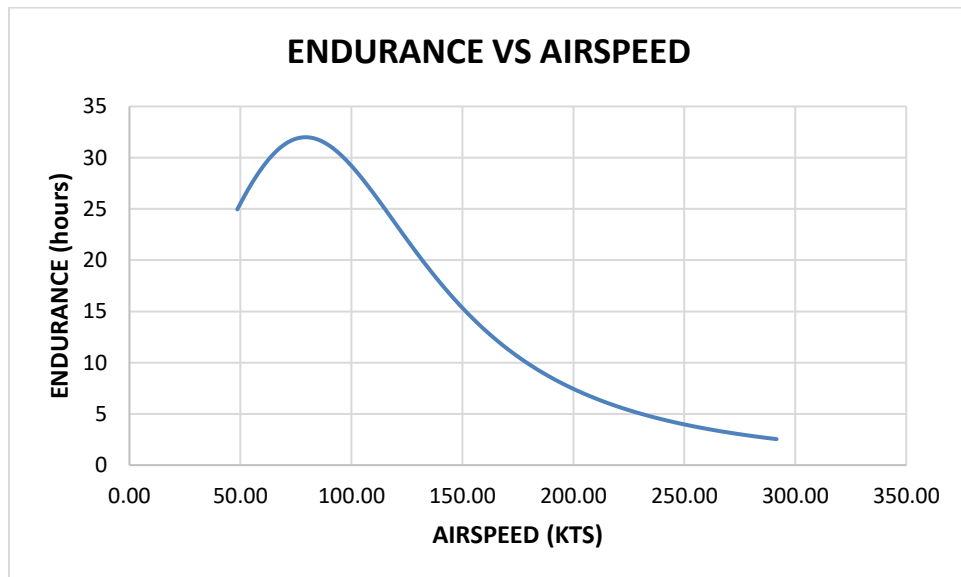


Figure 10 Endurance against Airspeed

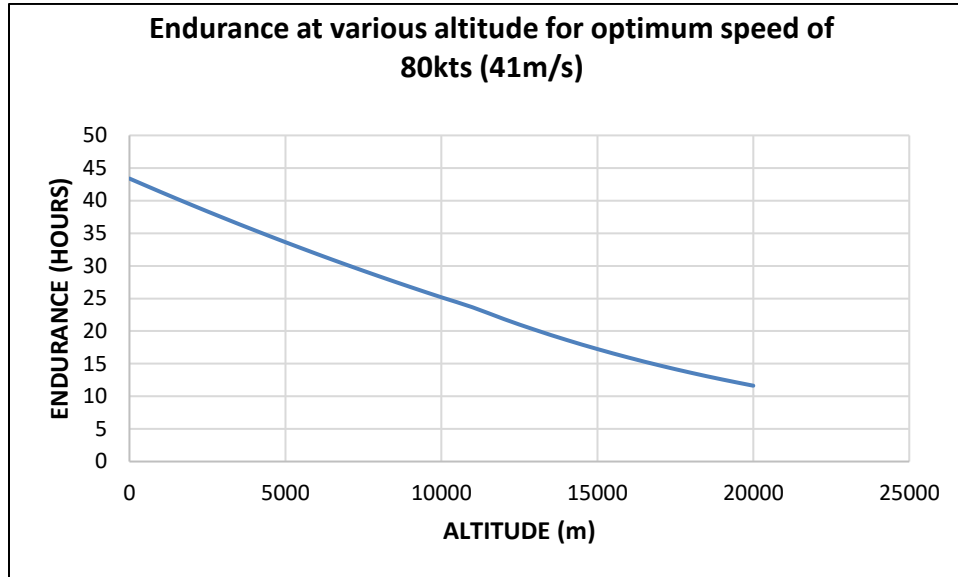


Figure 11 Endurance against Altitude

The results of range and endurance analysis are shown in Figures 8 to 11. The range and endurance of ABT-18 UAV was greatly improved by incorporation of auxiliary fuel tank with additional fuel of 160liters. With specific fuel consumption of 0.305L/hp-hr, the maximum range of the UAV was found to be 2400nm and the maximum endurance was found to be 31.5hours. The values of range and endurance of the standard version ABT-18 aircraft was calculated to be 1053nm and 14.5hours respectively at best operating conditions. This implies about 228% increase in range and 221% increase in endurance. However, these calculated values varies from what was given in the ABT-18 aircraft specification, since all several operating conditions, including worst cases has been put into consideration in generating the specifications.

Takeoff analysis shows that ABT-18 UAV can takeoff and clears an obstacle of 25m within a distance of 328m (1076ft) without flaps, or 132.68m (435.4ft). This satisfies CS-23 requirements. Landing analysis shows that ABT-18 UAV can land, clearing an obstacle of 50ft (15.24m) within a distance of 1854ft (562.44m) and 1615ft (492.33m) in clean configuration and with landing flap setting respectively. This also satisfies the CS-23 requirement. Table 11-1 shows the overall summary of ABT-18 UAV performance calculation and it's comparison with the baseline ABT-18 aircraft.

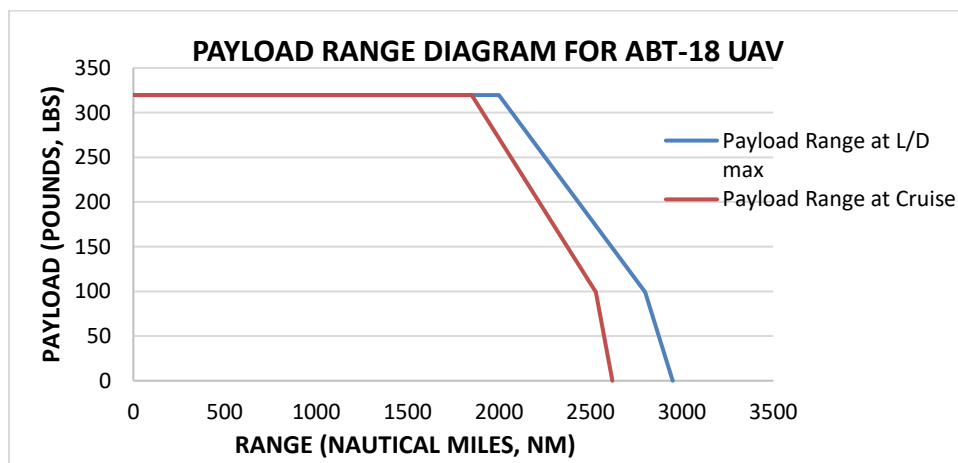


Figure 12 Payload Range Diagram for ABT-18 UAV

4. CONCLUSION

This report analysed the flight performance of the conceptual ABT-18 UAV. To achieve this, the components of the aircraft have been modified, some components removed, and some introduced to ensure successful operation of the aircraft as a UAV. Flight performance analysis seek to determine the performance of this modified aircraft, and how it varies from the baseline aircraft. Therefore, the weight and drag of the modified aircraft is expected to vary from the standard version aircraft.

The overall weight saving 227Kg. 130Kg has been budgeted for auxiliary fuel which is required for long endurance missions. The remaining 97kg is for payload. At the moment, the payloads carried by the aircraft are the surveillance camera and avionics equipment which has 20kg and 25kg respectively. The remaining 52kg is still vacant. Thus, the UAV has the capability of carrying additional payloads such as advanced avionics equipment, advanced surveillance gears for very high altitude surveillance, and armaments. Typical armaments could include under wing javelin missiles and anti-armour weapons which could weigh over 60kg^[9,pg42]. To achieve this, part of the mission fuel might be traded for the armament payload.

The endurance was calculated to be 31.5hrs if the aircraft is flown at maximum at maximum $C_L^{3/2}/C_D$, which was calculated to be 15.07. To maintain this value of $C_L^{3/2}/C_D$, the pilot need to maintain the speed for maximum endurance which is the speed for maximum $C_L^{3/2}/C_D$. This speed, however, is not constant, since maximum $C_L^{3/2}/C_D$ depends on weight of the aircraft. Since weight of the aircraft gradually decreases from beginning of the flight to the end, due to fuel burn, the speed should also gradually be reduced to maintain maximum $C_L^{3/2}/C_D$. Factor such as variations in ambient air temperature and inability of the pilot to maintain a speed for maximum $C_L^{3/2}/C_D$ are major reasons while the calculated maximum endurance are not always obtained.

Finally, the aim of the ABT-18 UAV to show improved performance on the ABT-18 (standard version) aircraft has shown promise in terms of the flight performance as shown in this paper.

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REFERENCE

- Ojha, S. K., (1995) Flight Performance of Aircraft. Washington DC: American Institute of Aeronautics and Astronautics (AIAA).
- Voskuijl, M., (2014) Introduction to Aeronautical Engineering. Lecture Video by AE1110X EDX team. Delft University of technology, Netherlands.
- Anderson, D., (2012) Introduction to Flight, 7th Edition; McGraw-Hill Companies Inc, New York.
- Anderson, J., (1999) Aircraft Performance and design. USA: McGraw-Hill
- UL350iS Manual, Available at: <http://www.ulpower.com>; accessed on 15th June, 2015*
- Pamadi, B. N., (2004). Performance, Stability, Dynamics and Control of Airplanes, Second Edition. American Institute of Aeronautics and Astronautics, Inc., Reston, Virginia.
- Raymer, D. P. (2006), Aircraft Design: A conceptual Approach.
- Roskam, J. (1990), Airplane Design; Roskam Aviation and Engineering erringration, Ottawa, Kansas.
- Kenneth Munson (2004). Jane's Unmanned Aerial Vehicles and Targets. Jane's Information Group, UK.
- Uguzo, S., Yusuf, G., Udu, A., Sadiq, T., Samuel, I., Marcus, A., (2014). ABT-18 project specifications and requirements. Air Force Institute of technology, Kaduna.
- Kweitsu, O., (2013) Flight Performance of AFIT LTA. Air Force Institute of Technology (AFIT), Kaduna.
- Air beetle (ABT-18) Aircraft Maintenance Manual (1994). Published by AIEP Limited, General Aviation Service Center, Kaduna Nigeria.
- Torenbeek, E. (1976), Synthesis of Subsonic airplane Design, Delft University Press, Netherlands.
- Air beetle (ABT-18) Aircraft Maintenance Manual (1994). Published by AIEP Limited, General Aviation Service Center, Kaduna Nigeria.