Flying Wing Description

A specific type of airplane that is especially useful for UAV's is the flying wing. This airplane does not include a fuselage or tail and, as the name suggests, consists only of a flying, swept wing. One of the most important aspects of the plane is the airfoil, which defines the cross section of the wing. An airfoil specially designed for flying wings will be used on this airplane. This airfoil has a maximum lift coefficient ($C_{L,\max}$) of 0.55.

To simplify the model for the airplane, the voltage of the motor is fixed at 11.1 V and a weight-to-power ratio of a motor is approximated as .0022 N/W. The energy density of the battery will also be assumed to be 47700 J/N. The airplane will be flown in standard atmospheric conditions at an altitude of 4000 feet.

To allow for sufficient structural wing area at the root, the taper ratio (λ) of this airplane will be fixed at 0.7 and the root chord (c_{root}) must be greater than 15 cm. For stability purposes the wing sweep at the quarter-chord ($\psi_{\frac{c}{4}}$) will be 0.4 and the aspect ratio (AR) must be between 4 and 12. Figure 1 shows a labeled drawing of a flying wing.

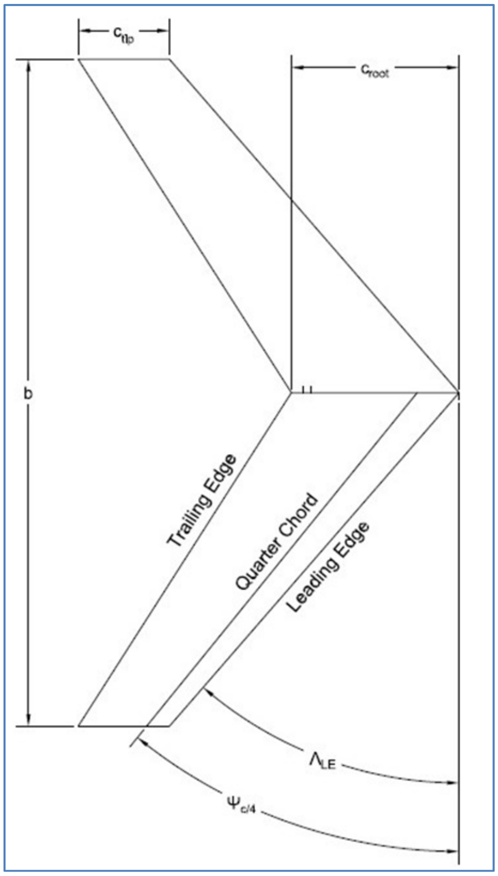

Figure 1 - Geometry of a Flying Wing

To design a flying wing, several parameters must be initially chosen and then the rest of the parameters will vary according to those chosen. In this case, the stall velocity (V_{min}), maximum velocity ($V_{\max}$), wing span (b), motor power (P_m), and battery capacity (C) will be chosen. The stall velocity must be between 9 and 12 m/s to facilitate espionage missions. The maximum velocity must be greater than 20 m/s to allow for the airplane to move to the desired target in a reasonable amount of time. The wing span must be between 50 and 100 cm to allow sufficient size for the plane while retaining a small radar cross-section. The battery capacity must be greater than 200mAhr and be a multiple of 100mAhr to ensure that replacement batteries will be readily available. The motor power must be greater than 10 V and be an integer number so that a standard motor may be used. The plane must be able to fly for at least 10 minutes at maximum velocity and 30 minutes at stall.

Because of the short range of small aircraft, this plane must be lightweight and portable so that it may be easily carried from one area to another. Therefore, the objective of this design is to minimize the weight of the airplane. The total weight of the airplane can be found by adding the weight of the battery, electronics, payload, and motor and accounting for the structural weight fraction (X):

$$W_0 = \frac{W_{batt} + W_{el} + W_{pl} + W_{motor}}{1 - X}$$

For this initial design, a camera will not be added to the airplane so the payload weight will be zero. It is also assumed that the weight of the electronics of the airplane (W_{el}) is equal to 0.5 N. The structural weight fraction depends on the wing span and is approximated as:

$$X = .5 + .05b$$

One of the first calculations necessary in the design of an airplane is to determine the planform area of the plane required to support the. Setting the lift at minimum velocity equal to the weight and solving for the planform area (S) yields:

$$S = \frac{2W_0}{\rho V_{min}^2 C_{L,\max}}$$

The aspect ratio (AR) can then be found from the span and the planform area:

$$AR = \frac{b^2}{S}$$

Using this information, the average wing chord ($\bar{c}$) can then be found:

$$\bar{c} = \frac{b}{AR} \quad or \quad \bar{c} = \frac{S}{b}$$

The root and tip chords are then found by using the taper ratio:

$$c_{root} = \frac{2\bar{c}}{\lambda + 1}$$

$$c_{tip} = c_{root}\lambda$$

The leading edge sweep angle is an important aerodynamic property and can be found using geometry. For simplicity, a mathematical representation of this geometrical calculation has been found to be:

$$\Lambda_{LE} = \frac{\operatorname{atan}\left(b * \tan\left(\psi_{\frac{c}{4}}\right) + \frac{c_{root} - c_{tip}}{4}\right)}{b}$$

Another important factor in aerodynamics is the Reynolds number (Re) which depends on the velocity of the airplane, the wing chord, and the properties of the air. To ensure that the equations used are applicable the Reynolds number must remain below 500000. Since this airplane varies in velocity, the Reynolds number at maximum velocity will be used in the calculations:

$$Re = \frac{\rho V_{\max} \bar{c}}{\mu}$$

The parasite drag coefficient ($C_{d,0}$) and wing span efficiency factor (e) are related to the drag on the wing and depend on the Reynolds number:

$$C_{D,0} = \frac{4.98}{\sqrt{Re}}$$

$$e = 4.61(1 - .045AR^{.68})$$

The induced drag coefficient, which relays how drag increases with velocity, is then calculated using the efficiency factor and the aspect ratio:

$$K = 1/(\pi eAR)$$

All of these are important parameters to determine because they factor into the power required (P_r) to propel the flying wing at a given velocity (V):

$$P_r = .5C_{D,0}\rho V^3 S + \frac{2KW_0}{\rho VS}$$

The power required is an essential parameter because the power available to the plane must exceed to power required to fly at a desired velocity. The power available (P_a) to the plane is found by multiplying the motor power by the motor (μ_m) and propeller (μ_p) efficiencies:

$$P_a = \mu_m \mu_p P_m$$

The endurance (E) of the airplane depends on the power required. The endurance (in seconds) at a given velocity if found from the following equation.

$$E = \frac{\Sigma}{P_r}$$

where Σ is the battery energy which can be found by multiplying the voltage (V) and the Capacity (C) of the battery with a conversion factor to make the energy in Joules:

$$\Sigma = \frac{3600VC}{1000}$$

The weight of the battery is found by dividing the battery energy by the battery energy density (ζ):

$$W_{batt} = \frac{\Sigma}{\zeta}$$

The range at a given velocity can also be calculated by using the velocity and the endurance:

$$R = EV$$