AER1216: Fundamentals of UAS

Assignment # 3
Due: Nov. 4th

1. An unmanned aircraft has the following characteristics: $C_{L_{\max}} = 1.2$, $S = 20$ m^2, $W = 10,000$ N, with an installed jet engine, TFSC is 0.7 hr^{-1}. We also know that $C_{D_0} = 0.03$, $\varepsilon = 0.7$, $AR = 10$. **We also assume at sea level, the thrust available is 5,000N.** [**20 marks**]

   (a) Plot in a velocity-altitude envelope, the minimum flight speed $V_{\min}$ (corresponding to $C_{L_{\max}}$, and the optimum flying speed for minimum thrust required $V_{TR,\min}$, with respect to different altitudes (up to 15 km). One may refer to standard atmosphere model for the air density calculations.[1] [**5 marks**]

   (b) Draw the plot of maximum climbing rate with respect to altitude, and estimate the ceiling for this UAS to operate. [**5 marks**]

   (c) Let's assume the UAS is flying with constant angle of attack and a constant velocity of $M = 0.7$. Prove that range R of the UAS is given by

   $$R = \frac{V}{TFSC}\frac{C_L}{C_D}\ln\left(\frac{W_0}{W_1}\right)$$

   where $W_0 = W$, $W_1 = W - W_f$, W_f being the fuel weight. [**5 marks**]

   (d) Based on the assumption in (c), if we would like to give the UAS of range of 100 km, calculate the required fuel weight at sea level. [**5 marks**]

[1] There are many references for this subject, e.g. Anderson, Introduction to Flight

2. Consider a Quadrotor at sea-level with a total weight of 8 N and a frame C_D=0.7 based on the reference area $S = 0.01\text{m}^2$ that is powered by motors with a $K_v = 1050$ V/rpm, $i_0 = 0.4$ amps, $r_m = 0.12$ ohms, and $K_t = 1/K_v$. The quadrotor uses four APC 8x3.8 Slow Flyer propellers. The ESC internal resistance is $r_e = 0.05$ ohms. The battery is a 3 cell 1300mA-hr 30°C battery. The coefficients for the battery discharge curve are (for discharge in mA-hr):

$$\begin{aligned} a &= 12.3063 \\ b &= -0.000328 \\ c &= -0.008112 \\ d &= -4.7809 \times 10^{-7} \\ e &= -7.7835 \times 10^{-7} \\ f &= 1.4086 \times 10^{-10} \end{aligned}$$

[40 marks]

(a) What is the power required to hover from momentum theory, assuming no motor or ESC losses? **[5 marks]**

(b) What is the hover endurance from momentum theory assuming no motor and ESC losses and using the 0^{th} order model for the given battery? **[5 marks]**

(c) What is the hovering power considering the APC propellers measured characteristics (instead of momentum theory), assuming no motor or ESC losses? **[5 marks]**

(d) Using the same assumptions as part (c), what is the hover endurance using the 0th order battery model? **[5 marks]**

(e) Using the same assumptions as part (c), what is the hovering endurance if the motor is 85% efficient and the ESC is 95% efficient using the 0^{th} order battery model? **[5 marks]**

(f) Now considering the given propellers, motor, ESC and battery discharge characteristics (i.e. use the 1^{st} order battery model) what is the hover endurance? Assume the initial discharge state is at 1 mA-hr and use a $\Delta t = 0.1$ s. **[5 marks]**

(g) Using momentum theory for forward fight (steady-state, level flight at sea-level) calculate and plot the following for speeds from 0 to 20 m/s in increments of 0.5 m/s [**5 marks**]:

i. Thrust

ii. Induced Power

iii. Total Power Required

iv. Total Power/Velocity

(h) Using the 0^{th} order battery model and assuming the motor is 85% efficient and the ESC is 95% efficient, what is the maximum endurance and maximum range? What forward speed does the quadrotor need to fly to get these values? [**5 marks**]

3. Answer the following questions [**20 marks**]:

   (a) If a fixed-wing propeller aircraft loses power while cruising, what flight strategy should the pilot adopt to extend the flight time and how? Please use equation or diagram to illustrate. [**5 marks**]

   (b) Why does the thrust-required curve decrease first and then increase with respect to the velocity? [**5 marks**]

   (c) If you were a propulsion engineer for a single-prop fixed-wing UAS, please demonstrate how you will determine the best propeller for this UAS. First please clearly state your UAS requirements and assumptions (i.e weight, cruise speed, mission requirement). Then describe what is the trade off between different selections and what are the important factors on the propeller selection. Finally, please state which propeller do you choose and why do you choose this propeller. [**10 marks**]