DRAGONFLY BASELINE PERFORMANCE ANALYSIS

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1. DragonFly Baseline Analysis

1.1. Objective. The objective of this lecture is to give you a starting point to establish a performance baseline for the Dragonfly Design-Build-Fly Competition. First you need to establish a clear baseline for the expected performance of the *unmodified* aircraft, then you can start with redesign considerations, tradestudies and optimization.

2. Competition Scoring Algorithm

A critical analysis of the Dragonfly Competition Scoring Algorithm reveals that points can be gathered in three discrete phases of the competition.

3. R/C Model Aircraft Design Elements

The key elements of the aircraft that will contribute are the "propulsion system", the "wing" and the "fuselage".

3.1. Propulsion System.

4. Baseline Parameters

Before we can start with analysis we need to establish a set of Dragonfly baseline parameters. A set is given here, but some of these values are just estimates or guesses. You should verify the validity of the baseline parameters.

Table 1. Dragonfly Baseline Parameters

b	wing span	48	[in]
S	wing area	450	[in^2]
W	mass ("weight")	15	[oz]
	wing loading	4.8	[oz/sqft]
c	chord	10	[in]
l	overall length	35	[in]
	Motor	Graupner Speed 400 7.2	[V]
E	battery charge	350	[mAh]

5. Straight and Level Flight

The baseline velocity of Dragonfly is estimated as follows:

Key words and phrases. Baseline Performance.

5.1. **Velocity and Reynold's Number.**

$$v = 20[\text{ft/sec}] = 20 \cdot 0.6818[\text{ft/sec}][\text{mph/ft/sec}] \approx 13.64[\text{mph}] \approx 6.1[\text{m/sec}] \tag{5.1}$$

Based on this estimate and some baseline parameters we can estimate the Reynold's number regime at which the aircraft is operating.

$$Re = \frac{\rho v c}{\mu} \tag{5.2}$$

The Reynolds number, Re, is dimensionless, i.e. it is a ratio of two quantities with the same unit. v = the relative velocity of the fluid in [m/s]. c = The characteristic length, in this case the wing chord. μ = The viscosity of the fluid in [Ns/m^2]. The viscosity of air, also called the dynamic viscosity of air is μ=1.8 x $10^{-}5$ at 15C and atmospheric pressure at sea level. With $\rho = 1.23$ [kg/m^3] the density of the fluid in [kg/m^3]. Substituting in Equation (5.2), we obtain

$$Re = 13.64[\text{mph}] \cdot 10[\text{in}] \cdot 780[\ ] = 106,392 \tag{5.3}$$

Substituting the numbers in SI units yields:

$$Re = \frac{1.23 \cdot 6.1 \cdot 0.254}{1.8 \cdot 10^{-5}} = 105,876 \tag{5.4}$$

Thus we can say that the Reynolds number is roughly $Re \simeq 100$k. This regime features both pressure and friction drag. Most powered model R/C planes operate in the Re 200,000 to well over 1,000,000 range.

5.2. **Aspect Ratio.** The aspect ratio AR is going to have a large effect on the induced drag of the model aircraft. We estimate:

$$AR = \frac{b^2}{S} = \frac{\text{span [in}^2]}{\text{wing area [in}^2]} = \frac{48^2}{450} = 5.12 \tag{5.5}$$

We can put this aspect ratio in context with other types of aircraft:

TABLE 2. Typical Aspect Ratios

Application	wing loading [oz/sqft]	AR
High speed, highly maneuvrable	22-26	4-6
Moderate speed sport	16-22	6-8
Low speed trainer	12-16	8-10
Slope gliders	12-14	8-10
Soaring gliders	8-12	10-15

The corresponding wing loading during straight and level, unaccelerated flight is found as:

$$WL = \frac{W}{S} = \frac{15[\text{oz}]}{450/144[\text{sqft}]} = 4.8[\text{oz/sqft}] \tag{5.6}$$

5.3. **Lift Coefficient.** We need to obtain an estimate of the Dragonfly lift coefficient C_L. We know from the lift equation that:

$$L = \frac{1}{2}\rho v^2 C_L S \tag{5.7}$$

In straight, level, unaccelerated flight lift must equal weight , $L = W$, thus we can solve for C_L

$$C_L = \frac{2 \cdot W}{\rho v^2 S} \tag{5.8}$$

Substituting the values for the known quantities on the right hand side yields:

$$C_L = \frac{2 \cdot 15[\text{oz}] \cdot 0.030[\text{kg/oz}] \cdot 9.81[\text{m/s}^2]}{1.23 \cdot 6.1^2 \cdot 3.125 \cdot 0.093[\text{m}^2/\text{sqft}]} \approx 0.63 \tag{5.9}$$

Note that this lift coefficient is a rough estimate and only valid during cruise.

5.4. **Drag Coefficient.** The drag coefficient is given as:

$$C_D = C_{Do} + C_{Di} = C_{Do} + \frac{C_L^2}{\pi \cdot AR \cdot e} \tag{5.10}$$

If we are considering an aircraft, we can think of the drag coefficient as being composed of two main components; a basic drag coefficient which includes the effects of skin friction and shape (form), C_{Do} and an additional drag coefficient, C_{Di} related to the lift of the aircraft. This additional source of drag is called the induced drag and it is produced at the wing tips due to aircraft lift. The induced drag coefficient is equal to the square of the lift coefficient C_L divided by the quantity: pi (3.14159) times the aspect ratio AR times an efficiency factor e.

The aspect ratio is the square of the span divided by the wing area as computed above. Long, slender, high aspect ratio wings have lower induced drag than short, thick, low aspect ratio wings. Lifting line theory shows that the optimum (lowest) induced drag occurs for an elliptic distribution of lift from tip to tip. The efficiency factor (e) is equal to 1.0 for an elliptic distribution and is some value less than 1.0 for any other lift distribution. (Typical $e = .7$)

From experience we estimate $C_{Do} = 0.015$. Substituting the values we already know we obtain:

$$C_D = 0.015 + \frac{0.63^2}{3.14 \cdot 5.12 \cdot 1.0} = 0.015 + 0.025 \approx 0.040 \tag{5.11}$$

5.5. **Drag Force.** This allows us to compute the drag force that is acting on the Dragonfly. The drag equation is:

$$D = \frac{1}{2}\rho v^2 C_D S \tag{5.12}$$

We now have estimates for all quantities on the RHS and can substitute.

$$D = 0.5 \cdot 1.23 \cdot 6.1^2 \cdot 0.040 \cdot 3.125 \cdot 0.093 = 0.27[\text{N}] \approx 0.97[\text{oz}] \tag{5.13}$$

Now, we are equipped with estimates of lift and drag. How does this help us find the endurance for the design competition?

6. Competition Performance Estimate

We need to estimate the amount of power that is consumed by the Dragonfly during straight and level flight. We know that the thrust is generated by the propulsion system, i.e. the combination of battery-electrical D.C. motor-propeller. In straight, 1g, unaccelerated flight we have

$$T = D \tag{6.1}$$

i.e. thrust is qual to drag. Power is qual to force times velocity, i.e.

$$P = T \cdot v \tag{6.2}$$

$$P = D \cdot v \tag{6.3}$$

Where does the power come from? Right, it is produced by the electrical motor, unfortunately there are some losses and the efficiency, η, is smaller than one.

$$P = P_m \cdot \eta \tag{6.4}$$

We can now write the equation

$$P_m \cdot \eta = D \cdot v \ [\text{W}] \tag{6.5}$$

The efficiency of the motor must generally be determined experimentally. Some tests from previous years show that: $\eta_{max} \approx 0.66$. Solving for the power delivered by the elctrical motor we get:

$$P_m = \frac{D \cdot v}{\eta} = \frac{0.27 \cdot 6.1}{0.66} \approx 2.5[W] \tag{6.6}$$

6.1. **DC Motor Model.** In order to estimate the endurance, i.e. how long the battery charge will last, we have to get an estimate of the current drawn from the battery. The motor power equation is:

$$P_m = (E - Ri \cdot I_{..:})(I_m - I_o) \text{ [W]} \tag{6.7}$$

With $E = 8.4$ [W/A], $R_i = .357$ [Ω], $I_o = .72$ [A] and $P_m = 2.5$ [W] we can solve for the motor current, by solving a quadratic equation for I_m:

$$I_{..:} \approx 1.04[A] \tag{6.8}$$

This is the current drawn by the D.C. motor from the battery. Assuming that this current drawn is accurate and that the charge of the battery pack is .35 [Ah] as advertised we get:

$$\Delta T = \frac{.35}{1.04} = .33[h] \tag{6.9}$$

This corresponds to a flight time of 20 minutes. From experience we know that this is the right order of magnitude, but somewhat optimistic. It is the goal of the baseline assessment to verify this endurance during flight test.

6.2. **Competition Score.** We can obtain a rough estimate of the score at the design competition.

(1) Fly two laps. The distance between pylons is roughly 200 [ft]. Assume a radius of 60 [ft] around each pylon. Thus the total distance is $4 \cdot 200 + 4 \cdot \pi \cdot 60 \approx 1500$ [ft]. At 20 [ft/sec] this should take ca. 1:15, i.e. get the maximum of **30 points**.
(2) Crew Time. Assume that two people stop the aircraft after ground roll. One person loads the eggs. **Estimate ca. 15 [sec] crew time = - 15 points.**
(3) Flight for endurance: Assume that we have loaded one egg. With an endurance of 20 minutes we would get $20 \cdot 60 \cdot 1$ [pts/sec] = **1200 points**

This would result in a hypothetical competition score of $Points$ **= 30 -15 +1200=1215 points.**

However, this analysis is flawed. There are a number of assumptions that have to be corrected.

- In the drag and lift calculation we must consider not only the weight of the empty Dragonfly, but also the weight of the payload (eggs).
- The motor efficiency η is a crucial number and it depends on the current. It might not be valid to use the peak efficiency $\eta_m ax$.
- Note: Actual experience shows that flight times are more on the order of 5 [min] rather than 20 [min]. Verify this in Johnson. Discuss and discover additional sources of energy loss.
- Success in the competition is not only driven by efficient aircraft design, but also by efficient operations **and** robustness. There is no use designing an extremely high AR wing if it will crack during flight.

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