Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Aerospaziale

Relazione per la prova finale «Design of a fixed-wing drone for cargo transportation»

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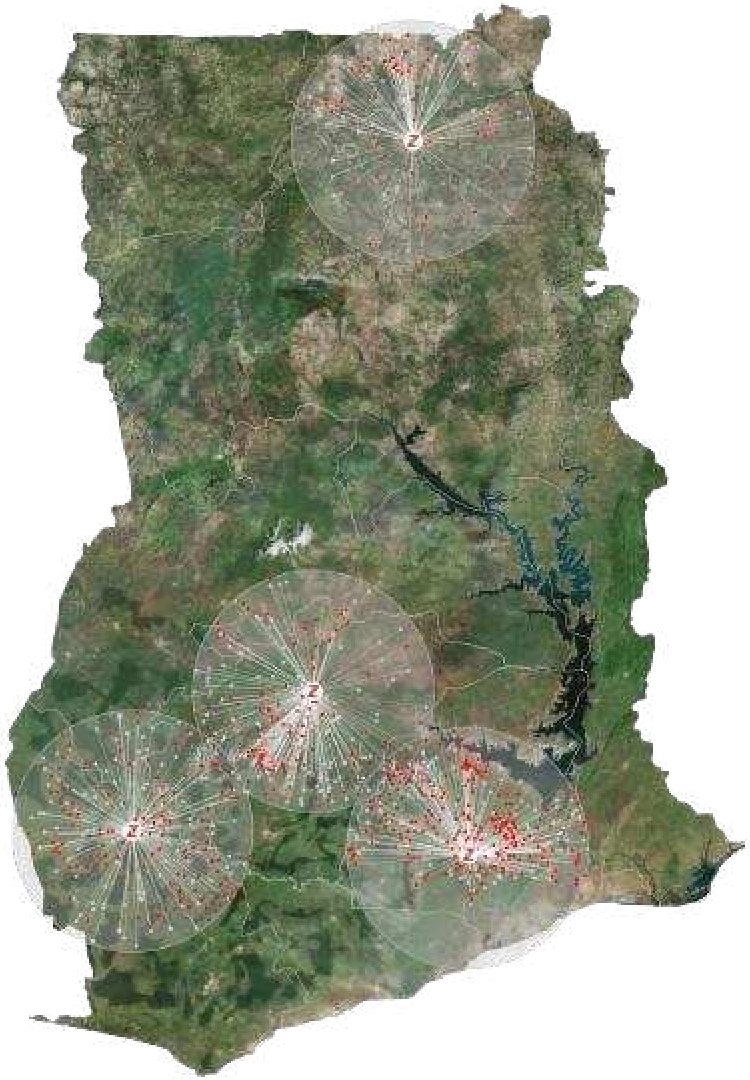
Motivations pushing the fixed-wing drone industry

***«Zipline International Inc.»*’s mission**

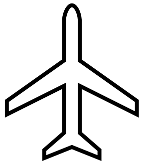
***«Zipline Inc.»*’s flight delivery model**

Fixed-wing drones in rural and urban areas

OBJECTIVES OF THE STUDY

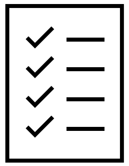


Main objective of the study



- General description
- Sizing
  - Wing assembly
  - Whole aircraft

Performance prerequisites



- Cruise altitude: 90m
- Cruise speed: 100kph
- Maximum operational delivery range: 100km
- Maximum transportable payload: 1.8kg

GENERAL DEFINITION OF THE AIRCRAFT

Propulsion

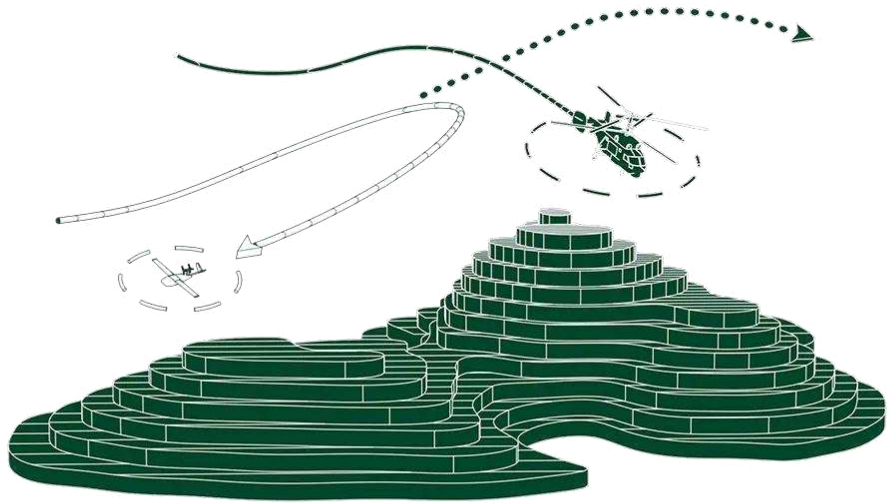
- Tractor Propeller
- Pusher Propeller
- Engine mount

Controls and piloting

- Remote piloting
- Automatic Flight
- Autonomous Flight

Construction

- CFRP
- Ribbed structure



Lift

- $L = \frac{1}{2} * p * Cl * S * V^2$
- If M<0.3: $C_{LW} = f(\alpha, R_e)$

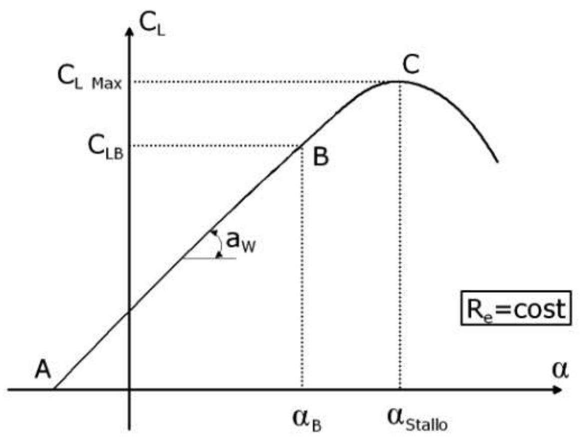


Fig.4.1 - Tipico andamento della funzione $C_{LW} = f(\alpha)$

Drag

- $D = \frac{1}{2} * p * Cd * S * V^2$
- If M<0.3: $C_{DW} = f(\alpha, R_e)$

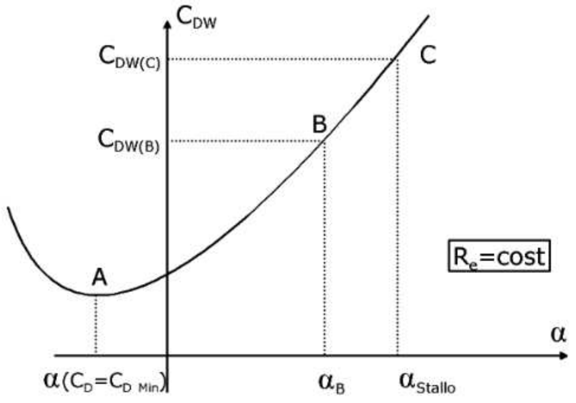


Fig.4.2 - Tipico andamento della funzione $C_{DW} = f(\alpha)$

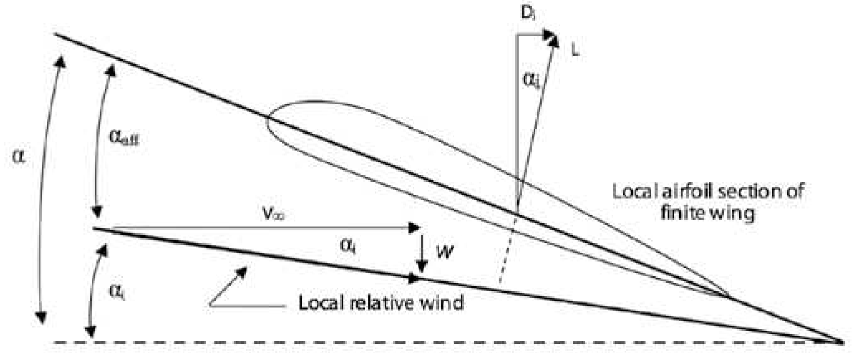
Drag formation

$$C_{DW} = C_{D0W} + K_1 C_{LW}^2 + C_{Di}$$

- C_{d0} : zero-lift drag coefficient
- $K_1 {C_l}^2$: viscous forces in the boundary layer drag coefficient
- C_{di} : coefficient of induced drag

$$C_{DW} = C_{D0W} + K C_{LW}^2$$

- C_{d0} : zero-lift drag coefficient
- $K = \frac{1}{A \pi e}$
- $e = 1.78(1 - 0.045 A^{0.68}) - 0.64$



AERODYNAMIC FORCES ACTING ON THE AIRCRAFT

Lift

- Main wing
  - Totality of lift
- Tail assembly
  - No added lift
- Fuselage
  - No added lift

Drag

- Main wing
  - $C_{d0w} + KCl^2$
- Tail assembly
  - C_{d0t}
- Fuselage
  - C_{d0f}

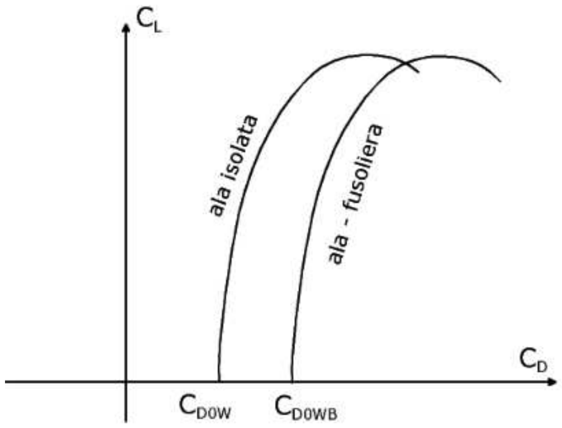


Fig. 4.7 - Polare della conbinazione ala+fusoliera

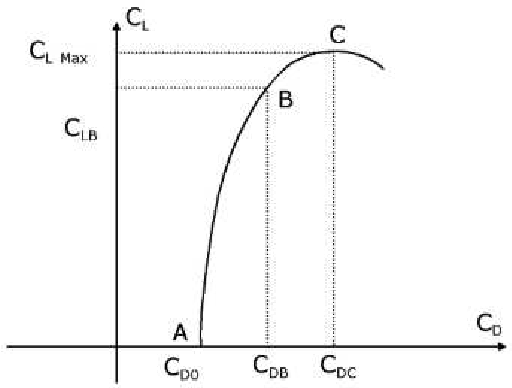


Fig.4.9 - Polare del velivolo completo - Configurazione simmetrica

ANALYSIS THROUGH XFLR5

Main wing dimensions

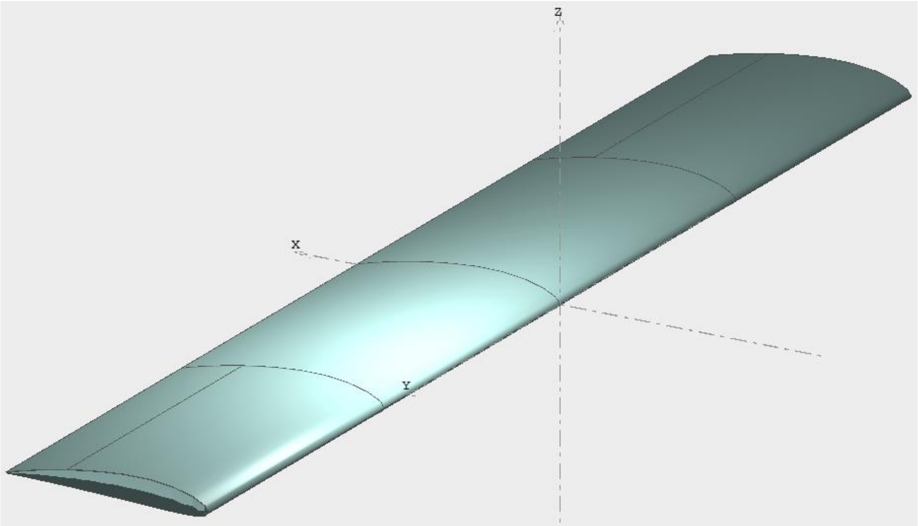
- Lenght: 3m
- Chord: 0.5m

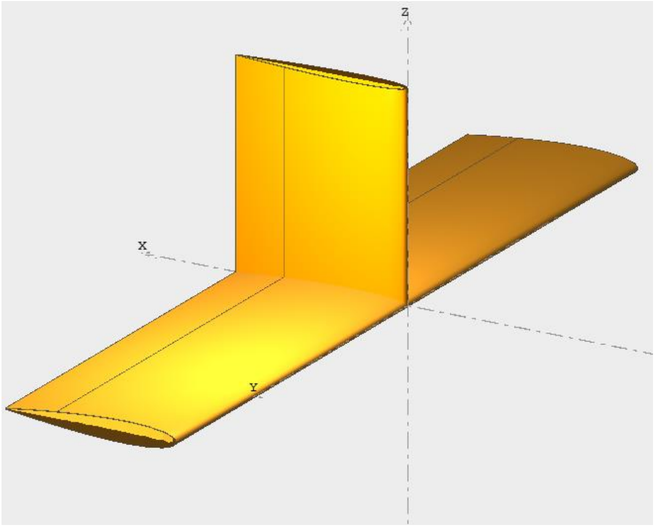
Stabilizer dimensions

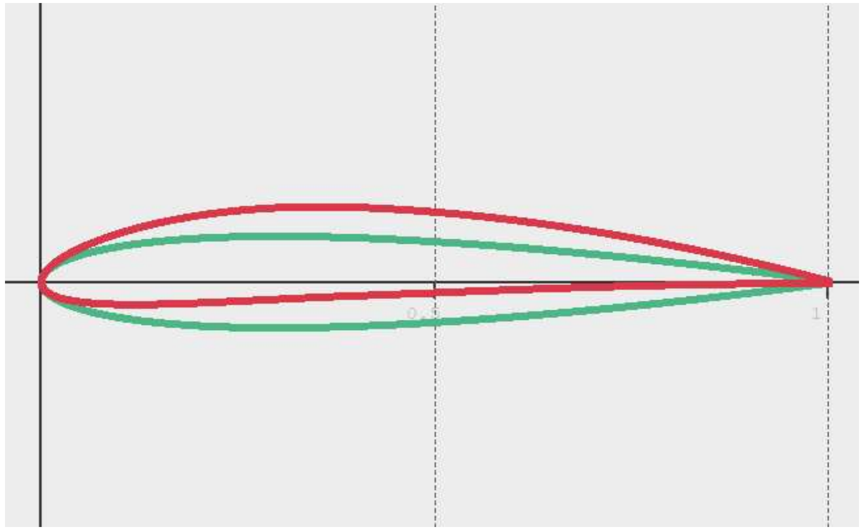
- Lenght: 0.7m
- Chord: 0.3m

NACA profiles

- Main wing: NACA 4412
- Tail assembly: NACA 0012







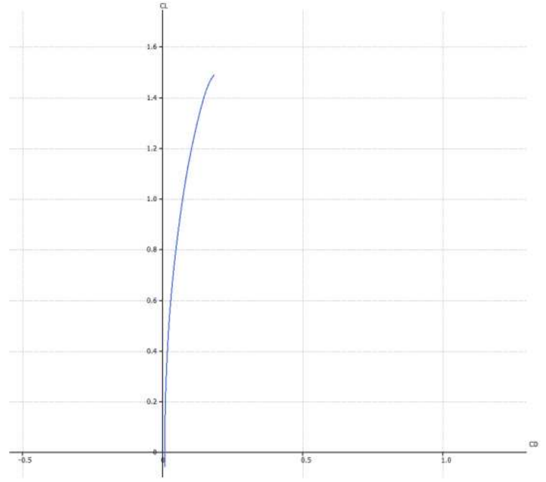
ANALYSIS THROUGH XFLR5

Phases of the analysis

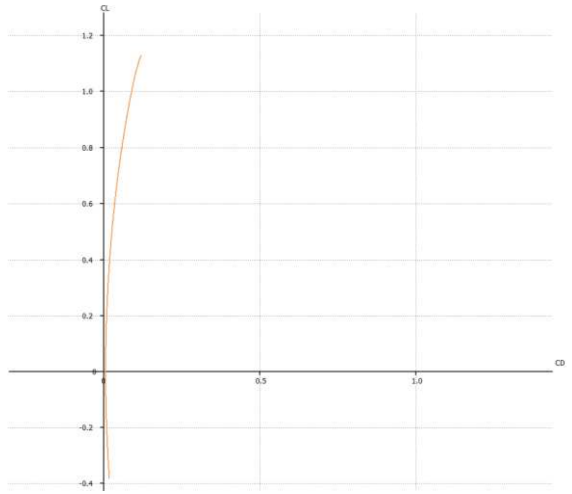
- Direct analysis of the NACA profiles ($10^5 < Re < 1.5 * 10^6$)
- Analysis of the C_l ($-5° < \alpha < 25°$) at 27.778 m/s
- Considered the C_l at α=0.5°, as C_l / C_d is max

Iterative process to find main wing dimensions

- Finding the surface area needed to support the drone's mass (23kg) at 27.778m/s, using C_l found at previous iteration
- Updating the wing's dimensions on Xflr5, then repeating the process
- Three iterations brought to a surface area that supports the drone's weight
- Final main wing dimensions: Lenght=2.602m, Chord=0.5m, S=1.301m^2



Main wing's polar



Tail assembly's polar

C_{d0} calculations ($C_{d0tot} = \mathbf{0.0274}$)

- Main wing: found through polar ($C_{d0w} = 0.0084$)
- Tail assembly: found through polar ($C_{d0w} = 0.006$)
- Fusolage: found using: $C_{d0f} = \frac{K_f * C_f * S_{wetf}}{S}$, considering a 2m*0.4m(D) cylinder ($C_{d0w} = 0.013$)

TOTAL DRAG, THRUST AND NEEDED POWER

Total drag

- $D = \frac{1}{2} * p * Cd * S * V^2 = \frac{1}{2} * p * (Cd0 + KCl^2) * S * V^2$
- $K = 0.0748$ (calculated)
- $C_d = 0.0375$ (calculated)
- $D = 23.08N$

Thrust needed for flight

- $T_n = 23.08N$

Power needed for flight

- $P_n = T_n * V$
- $P_n = 641.04W$

COMPONENTS

Engines

- Supposed yield for engine-propeller system: $\eta = 0.75$
- $P_{tot} = \frac{P_n}{\eta}$
- $P_{tot} = 854.71\text{W}$
- Supposed mean power requested by the engines (safety factor=1.2) $P_{tots} = 1000W$

Battery pack

- 100km max range, 200km total distance
- Time spent flying: $T = \frac{d}{v} = 2h$
- Energy needed in the battery: $E = P_{tots} * T = 2000Wh$
- Assuming a 48V operating engine: $E_A = \frac{E}{V} = 42Ah$

WEIGHTS

TOTAL WEIGHT	**23kg**
Maximum payload	1.8kg
Battery	9.8kg
Engine	3.6kg
Esc	0.7kg
Weight remaining for structure and other appliances	7.1kg

CONCLUSIONS

1. How has the cruising altitude been considered?

- Air density: ρ=1.225 kg/m^3
- Takeoff and landing at lower altitude

2. How has the crusing speed been considered?

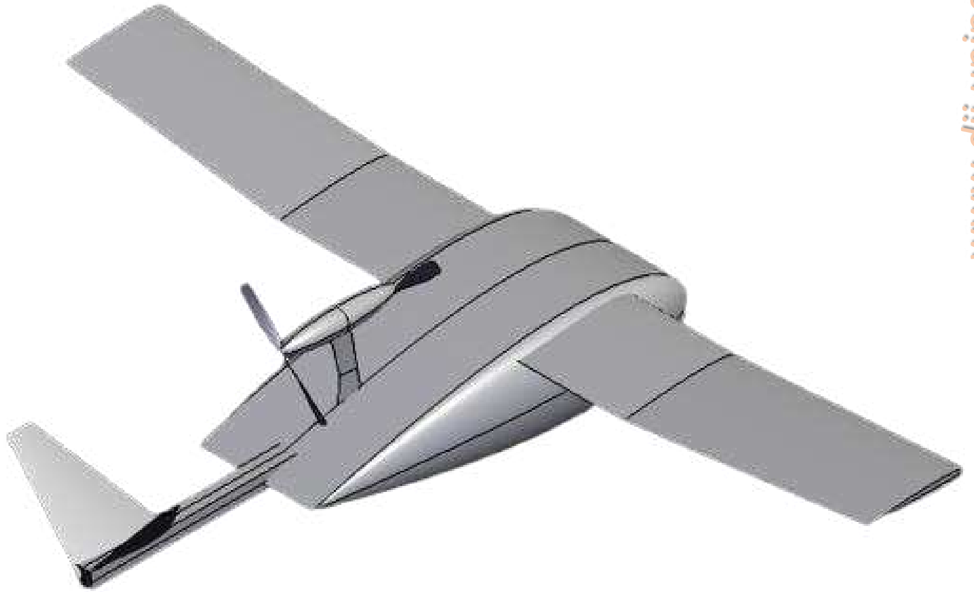
- Influenced lift and drag
- Influenced the sizing of the main wing

3. How has the max operational range been considered?

- Cruising happens at maximum efficiency
- Battery sized to ensure enough power

4. How has the max transportable payload been considered?

- Taken into account studying the masses on the aircraft
- Highen the operating voltage to reduce battery weight
- Distribution of the masses must be so that the baricenter lays under the main wing's center of pressure (0.195m behind the leading edge)



Information, graphs and pictures

1. Sito «*Zipline International Inc.*»: *https://www.flyzipline.com/technology*
2. FAA: https://www.faa.gov/sites/faa.gov/files/2022-06/EA_Zipline_Pea%20Ridge-and-Surrounding-Area.pdf
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4. Tesi Magistrale Adriano Bizzotto
5. «*Meccanica del Volo*» by Carlo Casarosa: Pisa University Press
6. «*Xflr5*» manuals and documentation: https://www.xflr5.tech/xflr5.htm
7. Amazon.com for components: https://www.amazon.it/