# E-Flap Design

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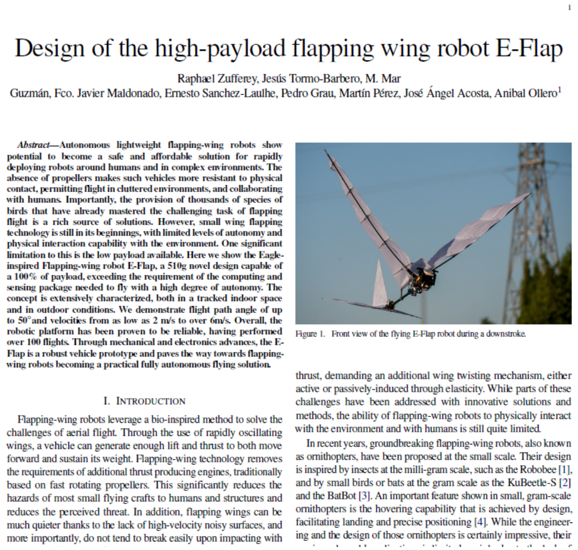
# E-Flap Design paper: *Design of the high-payload flapping wing robot E-Flap* review

- Main areas of improvement mentioned by the editor and the reviewers:

  - Comparison -> The state-of-the-art of large flapping-wing robots

  - Contribution -> the scientific contribution of the publication

  - Desing methodology section



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Design of the high-payload flapping wing robot E-Flap

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***Abstract*—Autonomous lightweight flapping-wing robots show potential to become a safe and affordable solution for rapidly deploying robots around humans and in complex environments. The absence of propellers makes such vehicles more resistant to physical contact, permitting flight in cluttered environments, and collaborating with humans. Importantly, the provision of thousands of species of birds that have already mastered the challenging task of flapping flight is a rich source of solutions. However, small wing flapping technology is still in its beginnings, with limited levels of autonomy and physical interaction capability with the environment. One significant limitation to this is the low payload available. Here we show the Eagle-inspired Flapping-wing robot E-Flap, a 510g novel design capable of a 100% of payload, exceeding the requirement of the computing and sensing package needed to fly with a high degree of autonomy. The concept is extensively characterized, both in a tracked indoor space and in outdoor conditions. We demonstrate flight path angle of up to 50°and velocities from as low as 2 m/s to over 6m/s. Overall, the robotic platform has been proven to be reliable, having performed over 100 flights. Through mechanical and electronics advances, the E-Flap is a robust vehicle prototype and paves the way towards flapping-wing robots becoming a practical fully autonomous flying solution.**

Figure 1. Front view of the flying E-Flap robot during a downstroke.

I. INTRODUCTION

Flapping-wing robots leverage a bio-inspired method to solve the challenges of aerial flight. Through the use of rapidly oscillating wings, a vehicle can generate enough lift and thrust to both move forward and sustain its weight. Flapping-wing technology removes the requirements of additional thrust producing engines, traditionally based on fast rotating propellers. This significantly reduces the hazards of most small flying crafts to humans and structures and reduces the perceived threat. In addition, flapping wings can be much quieter thanks to the lack of high-velocity noisy surfaces, and more importantly, do not tend to break easily upon impacting with

thrust, demanding an additional wing twisting mechanism, either active or passively-induced through elasticity. While parts of these challenges have been addressed with innovative solutions and methods, the ability of flapping-wing robots to physically interact with the environment and with humans is still quite limited.

In recent years, groundbreaking flapping-wing robots, also known as ornithopters, have been proposed at the small scale. Their design is inspired by insects at the milli-gram scale, such as the Robobee [1], and by small birds or bats at the gram scale as the KuBeetle-S [2] and the BatBot [3]. An important feature shown in small, gram-scale ornithopters is the hovering capability that is achieved by design, facilitating landing and precise positioning [4]. While the engineering and the design of those ornithopters is certainly impressive, their

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## Design Methodology

Payload=0.5kg
b=1.5m

- Payload : event camera, claws
- Wing span : 1.5m to fly in the testbed

m=100% Payload

- Dove 100% payload (Its custom electronics and a camera for one specific flight mision)

$S = 0.5\ m^2$

- Steady level powered flight equation : $\rho C_L v^2 S = 2Mg$ (v=target flight velocity= 5m/s)
- $C_L$ From CFD simluation , $C_L$ =1.3
- Planform : elliptical shape -> reduce wing tip losses, reduce wing inertia

AR = 5

- $AR = \frac{b^2}{S}$ -> Chord distribution selected to keep this aspect ratio

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## Design Methodology

f = 4Hz

- Teoretical, statistical and revised allomerical method for flapping wing micro air vehicles sizing : **Animal regresion + correction factor for ornithopter** ([A novel methodology for wing sizing of bio-inspired flapping wing micro air vehicles: theory and prototype])
- $f = \xi * m^{\frac{3}{8}} * g^{\frac{1}{2}} * b^{\frac{-23}{24}} * S^{\frac{-1}{3}} * \rho^{\frac{-3}{8}}$ ($\xi$=1.48 , Slowhawk -> closet wingspan to the E-Flap)

$\varphi = 32°$

- **Upstroke and Downstroke angles** ([A novel methodology for wing sizing of bio-inspired flapping wing micro air vehicles: theory and prototype])
- $\varphi_{up} = sin^{-1}\left(\frac{2h_a}{b}\right)$; $S_t = \frac{2fh_a}{v}$ ($S_t = 0.3(optimal)$ , $v = forward\ speed = 5m/s$)
- Proportions between the 4 bar mechanism determines the flapping angles: amplitude and mean dihedral -> The nominal desing provides 30-50º amplitude and 5º positive dihedral

$P = 130W$

- $M_{\mathrm{TR}}(\xi)$ = -$M_{aero} + I_{root}\ddot{\xi}$ ; ($\xi \in [-20, +30], I_{root} = I_{cm} + m_{wing}Y_{cm}^2$ $\rightarrow from\ Catia, M_{aero}\ from\ CFD\ simulation$) $\rightarrow$ $M_{\mathrm{TR}}\ maximum\ in\ the\ middle\ of\ downstroke = 6.5Nm$
- P =$2M_{\mathrm{TR}}\dot{\xi} = 130W$ -> 150W motor selected

Gear reducer = 42:1

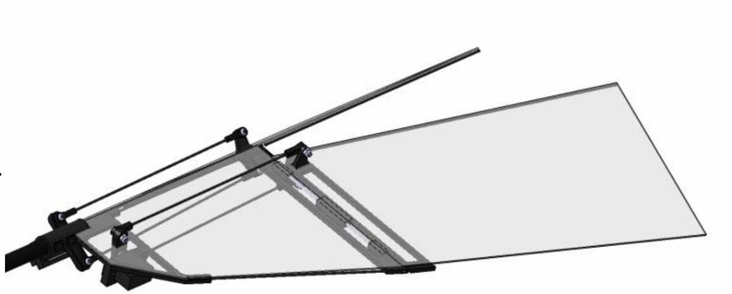
- Direct transmission to the wings = low Kv motor -> large and heavy
- We use smaller and faster motor with a reduction gearbox –> 2- stage gear reducer of 42:1

# E-Flap Tail

## Previous Designs:

1

2



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## New Design:

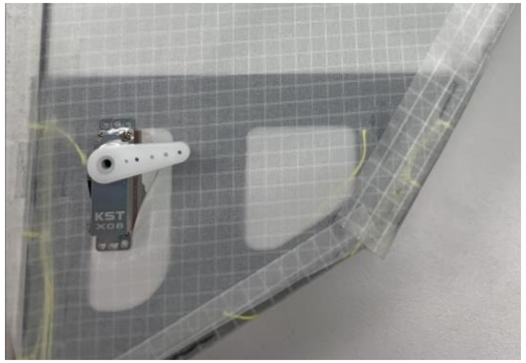
Paper Reading:

- Geometries changes -> relations between wing size, body lenght and tail shape and size
- Shorten the tail tube
- Changes in the materials and construction

# E-Flap Tail

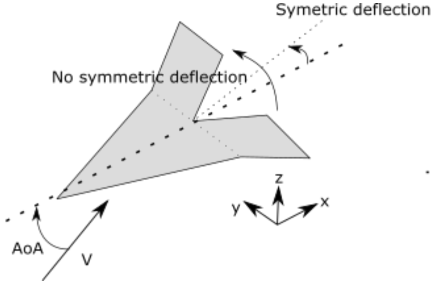
## New Design:

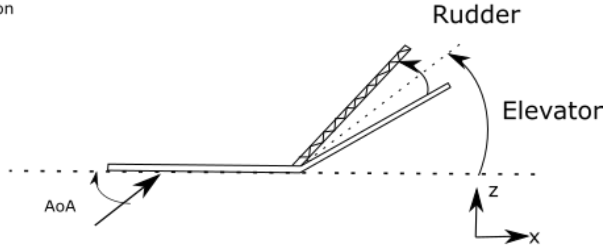
Carbon Fiber



# E-Flap Tail

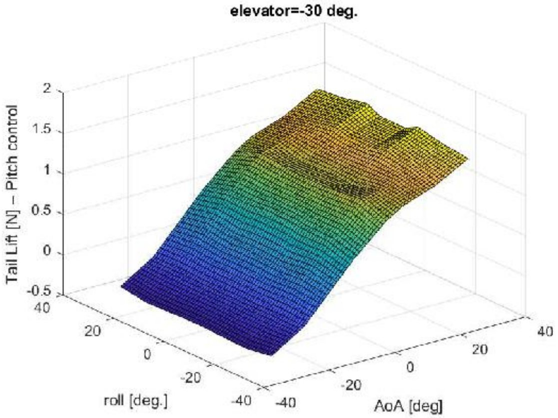
## Aerodynamic characterization by CFD

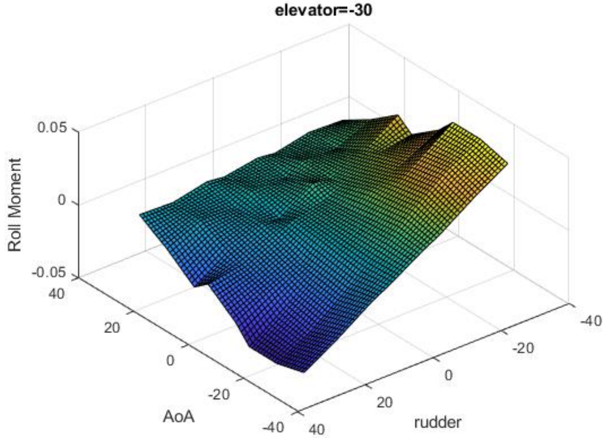


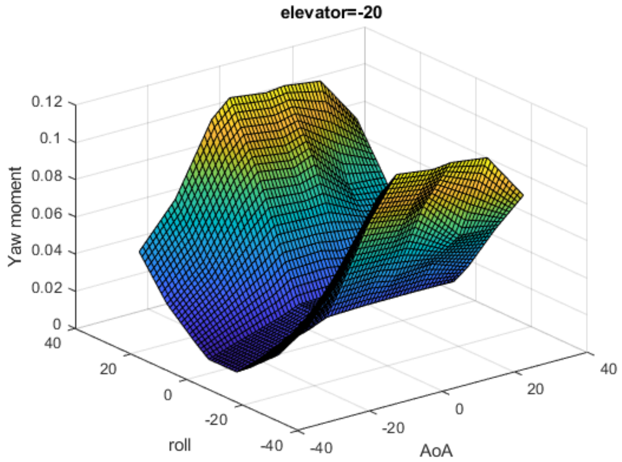




- 3 DoF: AoA, elevator, rudder
- Use of symmetry:  729 -> 225 cases
- 2-3 days of computation

Nonlinear Pitch-Roll-Yaw control



# QUESTIONS?¿