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# From conventional to bioinspired: Evolution of tail surface designs in micro air vehicles

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ABSTRACT

The paper presents the evolution of the tail surface design of a micro air vehicle based on adaptive wing geometry. The initial prototype was conceived as a tailless aircraft geometry, waiting for future innovations and stability augmentations. An initial experimental test bench will be presented to characterize the variation of wing profile curvature as a function of the voltage, through MFC actuators. Once these results have been analyzed, the process of conceiving a conventional T-tail was initiated, ultimately evolving toward the proposal of a bioinspired tail based on the tail shape of various birds. The results obtained in wind tunnel tests using PIV techniques will be presented. The results validate the selected tail surface design as an appropriate geometry for a bioinspired micro air vehicle.

## 1. Introduction, methodology and results

Micro Aerial Vehicles (MAVs) have developed a great evolution in recent years due to their application in commercial and military scenarios [1]. The wing geometry is based on Low Aspect Ratio planform, and their operating flight regime is between a Re = $10^4$ - $10^5$ [2]. The aim of this article is to collect the works conducted by INTA and ETSIAE-UPM. Traditionally, most of the scientific research in this field has stated that the highest lift coefficients correspond to the Zimmerman and elliptical wing planforms [3]. In addition, it has Eppler 61 airfoils as they perform efficiently at low Reynolds [4].

The objective of the first prototype (tailless model) is to determine the viability of smart materials in morphing wings [4]. Trying to validate this morphing concept, this designed model is a micro-UAV (see Fig. 1a) that can modify its camber using Macro Fiber Composites (MFC) actuators. The wing camber was deformed by using this MFC actuator attached to the inner part of the lower surface of the wing. To modify the camber, a power source was attached to the power supply board; the higher the voltage applied, the greater the curvature and the lower the thickness it has; see hardware and mounting details in Ref. [4]. The experimental study using the wind tunnel was carried out with a speed of 10 m/s (Re = $6.5 \times 10^4$) and a turbulence intensity less than $I_U = 0.5$ %. Fig. 1b shows the flow field velocity comparison between the base configuration (Eppler 61, no deformation, no voltage) and one of the modified configurations (E61-MOD4, highest curvature, highest voltage), at 75 % of the wingspan, and angle of attack of 25°. According to this test campaign, it was seen that with the highest voltage the airfoil had a better stall (the E61-MOD4 configuration shows no detachment region) and turbulence performance (the E61-MOD4 configuration reduces the high turbulent region in the wake). This means that morphing is a promising path to increase performance.

After the previous experimental steps of the first tailless prototype, the second prototype was conceived. Due to geometrical characteristics and the relative location between aerodynamic centre with respect to the centre of mass, the drone is inherently statically unstable (in the longitudinal axis). Then, the design includes a conventional T-tail, to have an experimental estimation using the same wind tunnel (at Reynolds number of Re = $1.3 \times 10^5$) of the longitudinal stability properties of the vehicle [5]. The T-tail is formed by vertical and horizontal stabilizers (NACA 0012 airfoils) to control and stabilize the micro-UAV.

Finally, passing through the initial study of the tailless model and the analysis of the conventional T-tail, the third prototype has a clear final objective: developing an optimal entire biomimetic model inspired by nature using bird tails [6] (see Fig. 2). The experimental analysis consisted of measuring the forces using an external balance placed on the

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**Nomenclature**

| | |
|---|---|
| INTA | Instituto Nacional de Técnica Aeroespacial |
| ETSIAE-UPM | Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio (Universidad Politécnica de Madrid) |
| AoA ($\alpha$) | Angle of attack |
| CFD | Computational Fluid Dynamics |
| $C_D$ | Drag coefficient |
| $C_L$ | Lift coefficient |
| $C_M$ | Pitching moment coefficient |
| HSF-Tail | Horizontal-Squared-Fan-Shaped stabilizer |
| MAVs | Micro Air Vehicles |
| MFC | Macro Fiber Composites |
| Re | Reynolds number |
| b | aircraft wingspan |
| c | mean aerodynamic chord of the wing |

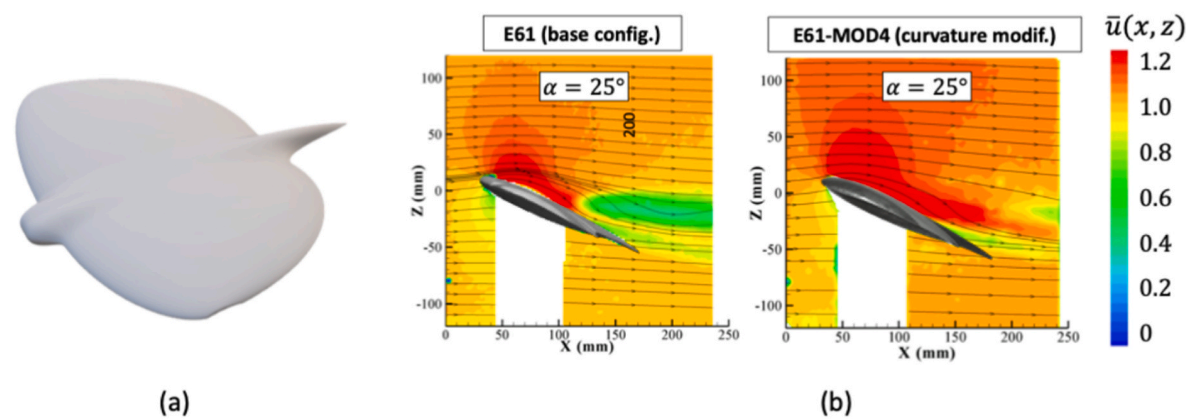


**Fig. 1.** First prototype designed based on morphing concept; (a) 3D view of the prototype; (b) Flow field comparison (in terms of non-dimensional velocity) between both configurations (E61 and E61-MOD4).

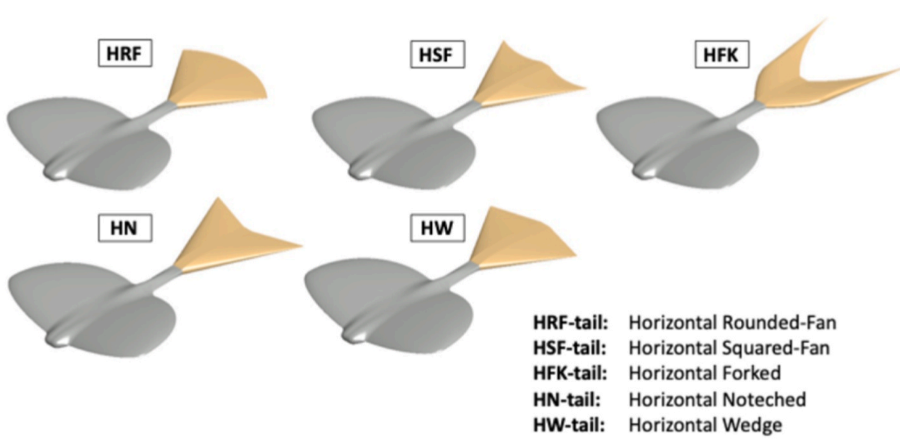


**Fig. 2.** Bioinspired horizontal stabilizers installed on the original prototype, for wind tunnel testing.

wind tunnel. According to this experimental procedure, the selection requirement was which bioinspired tail would provide the highest lift-to-drag ratio ($C_L/C_D$) on cruising conditions. Taking into account a complete analysis of these experimental results, the HSF-Tail was selected as the optimal configuration due to these previous aerodynamics criteria.

With this final selection, a wind tunnel test campaign was carried out based on PIV technique. Based on these results, a comparison was made between the second prototype (T-tail) and the biomimetic one HSF-Tail. Fig. 3 shows main differences between them. The T-tail (Fig. 3a) is immersed in the flow of the wing wake for high angles of attack, consequently, the effectiveness is reduced at 25° compared to the previous geometry without the tail. However, the biomimetic tail (HSF-Tail) maintains the flow attached (Fig. 3b) over the tail at high angles of attack ($\alpha \geq 25°$), in despite of the clearly detached flow over the wing. The objective has been achieved.

## 2. Conclusions

Throughout the article, an evolution of a tail surface in a micro air vehicle (MAV) has been presented, from a tailless design passing through conventional T-tails, and finally to bioinspired configurations. The initial MAV prototype featured a tailless configuration using smart materials (Macro Fiber Composites) that allow the MAV to modify its camber dynamically, enhancing aerodynamic performance during flight mission profile, particularly in stall conditions. The second prototype incorporated a conventional T-tail to address the inherent instability of the tailless design. Wind tunnel tests showed that while the T-tail improved longitudinal stability, its effectiveness was compromised at high angles of attack because of immersion in the wing's wake. The third stage of this research involved the development of bioinspired tails, conceived under bird tails, to optimize aerodynamic properties, such as

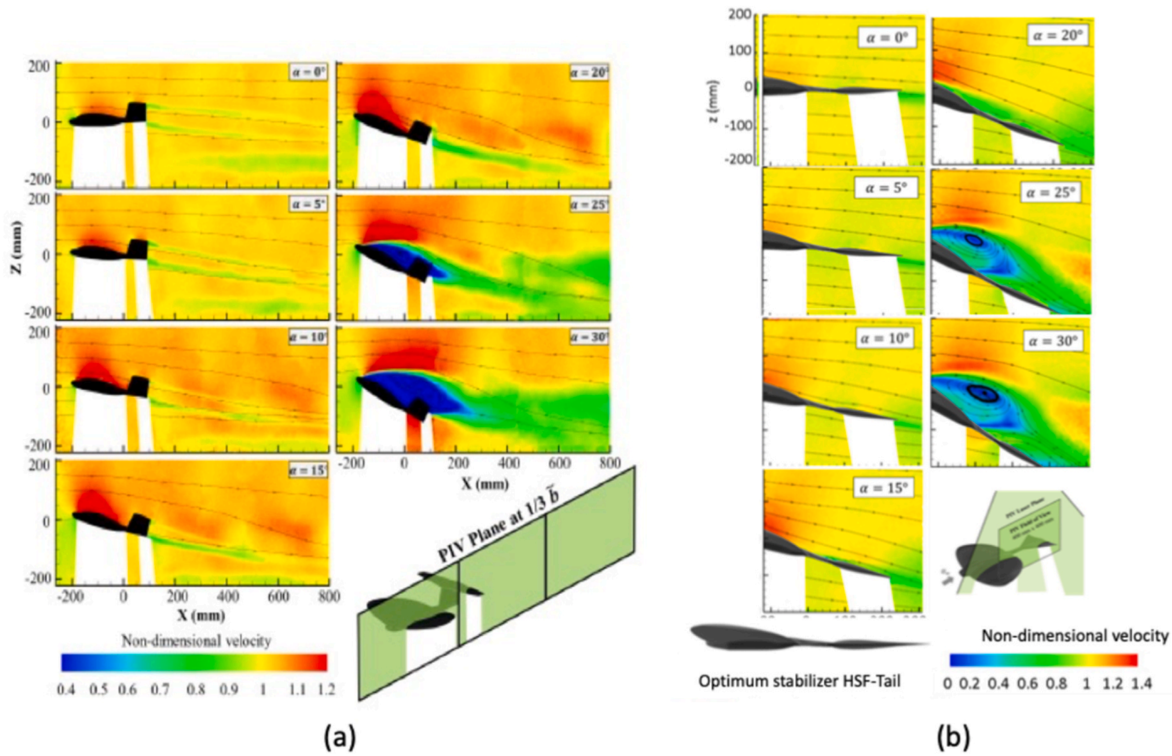


**Fig. 3.** PIV maps at angles of attack from α = 0–30°; (a) PIV maps of the T-Tail prototype; (b) PIV maps of the HSF-Tail prototype.

($C_L/C_D$). The studies have demonstrated that bioinspired designs can significantly enhance the performance of MAVs, offering advantages in terms of aerodynamic features. These findings suggest that further exploration into biomimicry could yield even more effective designs for future aeronautical new proposals, especially in the design of MAVs.

## CRediT authorship contribution statement

**Ángel Antonio Rodríguez-Sevillano:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Formal analysis, Conceptualization. **Rafael Bardera:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Estela Barroso-Barderas:** Writing – review & editing, Visualization, Validation, Software, Resources, Investigation, Data curation. **Juan Carlos Matías-García:** Writing – review & editing, Validation, Software, Resources, Methodology, Investigation, Data curation. **Alejandra López-Cuervo-Alcaraz:** Writing – original draft, Writing – review & editing, Visualization, Validation, Investigation

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

No data was used for the research described in the article.

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