Feasibility review of substitution a high-lift device by a telescopic wing with self-similarity of reynolds

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Abstract. This Paper describes results of the feasibility review of a telescopic wing application in unmanned aerial systems with self-similarity of Reynolds Re. Low Re is achieved through low-velocity flow of the lifting surface and small dimensions of an aircraft. Such combination is typical for a mini remotely piloted system according to UVS International classification. At low Reynolds the wing lift and high-lift device performance reduce. While in the high-lift mode, it is possible to adjust the wing area rather than the lift ratio. This can be achieved by a telescopic wing consisting of fixed and retractable sections. A telescopic wing is based on Morphing design with simultaneous wing geometry adapting to current flight parameters in one, two or three planes. The wing is simple by the design and can function as a high-lift device or aileron depending on whether the sections move out at the same time. The area of a telescopic wing with its sections moving out in the high-lift mode needs to be 2.0...2.18 times greater the initial area for Reynolds variation \((2.7...4)\cdot10^5\).

1. Introduction
Lifting surface lift of an aircraft depends on few factors. The main factors are the boundary layer flow (represented by Reynolds Re) and wing geometry. Ideally, the latter must give a non-separating flow across the surface with maximum static pressure drop per square. Only one effective wing geometry / incidence angle variant correspond to each combination of aerofoil parameters: velocity, temperature, viscosity, density, pressure, ram air non-uniformity. To improve the wing performance, the wing geometry must change according to the instant ram air. This requirement is met by Morphing Wing. “Morphing” means transformation. The morphing design utilizes a bird-like wing when the wing changes its shape to match the flying conditions \[1\]. Morphing wing of an aircraft can also change its geometry: area, proportion and coning angle or cross section \[2–5\]. A well-known example of Morphing Wing in today’s aviation is a wing with variable sweep. It consists of fixed and retractable parts and adapts to flight speeds. It is commonly used in military aircrafts.

2. Morphing Wing Types
In the past ten years, people are more focusing on Morphing Wing because of novel smart materials, effective drives and actuators, and design concepts allowing 3D transformations of a wing. Figure 1 and figure 2 show how the concept options can be implemented by changing the wing geometry in horizontal and vertical planes \[6\].
Morphing Wing design requires a non-standard approach. Let us see a telescopic wing where the linear surface geometry is changed by retractable sections, ref. to figure 1a. The wing consists of a main fixed section and one or more retractable sections. Retractable sections allow changing the wing span and chord which growth reduces the lift-induced drag from the non-maneuverable aircraft aerodynamics point of view [7, 8]. In addition, the retractable sections make the wing area greater and the lift eventually increases.

3. Aerodynamic Characteristics of Small-Size Aircrafts

Today, remotely piloted small-size aircrafts are more widely used [9]. A designer who determines a small-size aircraft design and parameters must know the difference between wing aerodynamic characteristics of a small-size aircraft and full-size aircraft. For example, the paper [10] shows that a smaller size and takeoff weight result in low Reynolds for the wing chord Reₘ that influences the lifting surface flow. When Reynolds drops to Reₘ ≤ 4-10⁵, the boundary layer flow becomes non-self-similar, laminar or transient laminar-turbulent [11, 12]. The layer loses its kinematic energy when the flow cannot overcome positive static pressure. The resulting laminar separation bubble effect on the lift surface affects the wing's ability to produce lift. The separation area can be over 5% of the wing chord [10] and proportionally reduce the lift. Thus, the aerodynamic specific is that a small-size aircraft wing’s
ability to generate lift per square represented by the lift ratio is less than for a full-size aircraft. This must always be considered when studying a small-size aircraft wing’s ability to generate the required lift in takeoff and landing regimes.

4. Evaluation of Telescopic Wing Applicability in Small-Size Aircrafts for Takeoff and Landing Regimes

The studied $Y_a$ lift control capabilities of an aircraft show that the lift varies under three factors and two of them directly or indirectly depend on the wing geometry. This appears from the lift empiric formula for the wing’s subsonic flow:

$$Y_a = c_{ya} \cdot q_{\infty} \cdot S_w$$  \hspace{1cm} (1)

- where $c_{ya}$ is wing’s lift ratio;
- $q_{\infty}$ is ram air, Pa;
- $S_w$ is wing area, m².

Coefficient $c_{ya}$ is the wing’s ability to transform ram air $q_{\infty}$ into static pressured drop per wing’s square. The better the wing shape, the higher coefficient $c_{ya}$ is and therefore the smaller wing area $S$ can be for a given aircraft weight.

For a constant wing geometry in plane i.e. $S_w$=const., it is possible to maintain the lift $Y_a$ equal to or exceeding the aircraft weight in stationary flight regime by changing: either the wing lift ratio or ram air $q_{\infty}$ (flying speed). The takeoff-landing regime causes $q_{\infty}$ to drop. It is possible to compensate it with $S_w$=const. by increasing the coefficient $c_{ya}$ accordingly using the wing incidence angle and airfoil transformation and high-lift devices i.e. wing chord extending slats and flaps. Such control of the lift $Y_a$ is power-consuming due to considerably increased drag yet it is common in full-size aircrafts in terms of the high coefficient $c_{ya}$ [13–15].

For a small-size aircraft, the aerodynamic specific is the flow regime under low $Re_b$ due to the small size and slow flying speed $v$. This causes the coefficient $c_{ya}$ drop comparing to a full-size aircraft. The conventional approach to controlling the lift in takeoff and landing regime by high-lift devices must be adjusted for small-size aircrafts because a small-size aircraft wing chord extension (which is minor in absolute terms) gives minor lift increase in a small-size aircraft. This suggests an alternative to be studied: controlling an aircraft’s $Y_a$ by changing the area $S_w$ of a telescopic wing with retractable sections. $S_w$ was evaluated for a telescopic wing model with plane geometry parameters illustrated in figure 3.

Figure 3. Telescopic Wing Geometry in Plane.
The evaluation applied the following parameters: \( L_0 \) – fixed section span, m; \( L_w \) – wing span with retracted sections, m; \( b_0 \) – root chord, m; \( b_{tf} \) – tip chord of fixed section, m; \( b_t \) – tip chord with retracted sections, m; \( b_{ch} \) – mean chord with retracted sections, m. The tapered wing area \( S_w \) is limited by the fixed and retractable sections and is the sum of the section areas:

\[
S_w = 2 \cdot \left( \frac{b_0+b_{tf}}{2} \cdot \frac{L_0}{2} \right) + \frac{b_{tf}+b_t}{2} \cdot \frac{L_w-L_0}{2}
\] (2)

A hypothetic small-size aircraft was studied for the following parameters [12]: the wing span \( L_0 = 1.5 \) m; chord \( b_{ch} = 0.21 \), wing area \( S_w = 0.315 \) m\(^2\), airfoil TsAGI 731, wing’s lift ratio in cruising regime \( c_{ya} = 1.2 \). With chord \( b_{ch} \) and speed \( v = 30 \) m/s Reynolds was \( R_e_b = 3.9 \times 10^5 \) and the aircraft weight was 18.35 kg.

For Reynolds \( R_e_b = 2.7 \times 10^5 \ldots 3.9 \times 10^5 \) typical for small-size aircraft takeoff-landing regime was applied to evaluate the compensation of the lift ratio \( c_{ya} \) drop 10% and 20% by increasing its area of the telescopic wing. The study results are illustrated in figure 4. Comparing to the initial variant, with non-retracted sections and given Reynolds \( R_e_b \) range the required wing area increase was \( \Delta S_w = 0 \ldots 1.00 \) for the lift ratio drop by 10% to \( 0.9 \cdot c_{ya} \) and \( \Delta S_w = 0 \ldots 1.18 \) for the lift ratio drop to \( 0.8 \cdot c_{ya} \).

![Figure 4. Relation between Wing Area Increase \( \Delta S_w \) and Reynolds \( R_e_b \).](image)

5. Conclusion

The evaluation results are theoretical prediction. Field studies are required to evaluate aerodynamic characteristics of a telescopic wing with self-similarity of Reynolds. This will allow obtaining objective and trusted data on effectiveness of lift control by changing the wing of a small-size aircraft.

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