Design of a Bioinspired Morphed Wing equipped with soft wing-tip devices

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Index

• Structure & Geometric features
• Final Structure Assembly
• Actuation based on Morphing of Primary feathers
• Test-Bench Experiments : Load cell Future Improvements
• $Lift_{\text{flap}}$ against frequency : $Lift_{\text{flap}}$ peak
• Parametric Analysis Results: $\mu$ and $\delta$ against $f$
• Ongoing Improvements
Design Features

Bioinspired Features
- Primary/Secondary remiges
- Aerodynamic profiles
- Coverts
- Reinforced Leading edge
- Double Stiffness Leading edge
- Tip actuation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>0.1 Kg</td>
</tr>
<tr>
<td>$S_{\text{max}}$</td>
<td>0.498 m²</td>
</tr>
<tr>
<td>$S_{\text{min}}$</td>
<td>0.420 m²</td>
</tr>
<tr>
<td>b</td>
<td>2 m</td>
</tr>
<tr>
<td>$c_p$</td>
<td>0.28 m</td>
</tr>
<tr>
<td>$p_m$</td>
<td>0.016 Kg</td>
</tr>
<tr>
<td>$P_t$</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

Secondary remiges
- Lift generation

1 N Stress analysis

1 N Displacement analysis
Final Structure Assembly

Wing bottom surface

Wing top surface

Additional Features:

Ø 2 mm Rods:
Prevent compression stress in the wingspan direction!

\[ m_{\text{rod}} = 0.6 \, \text{g} \]

Semi-folded surface:
Necessary to avoid turbulence due to non-homogeneous pressure field along the rod.

\[ S_{\text{folded}} \ll S_{\text{wing}} \]

The semi-folded surface also protects the nylon-guide during the actuation!
Actuation based on Morphing of **Primary feathers**: Dynamic Sweep-angle

- **Directional stability raises due to the presence of a sweep angle!**
- **Asymmetric Lift Distribution**
- **Roll Control**

**Pros**
- Light-weight: No needs to add more surfaces
- Modular implementation
- Proportional relation ~

**Cons**
- Not well-suited for the actual material
- The elasticity of the tip may cause an additional vortex field.

Test-Bench Experiments : Load cell

Reliable Approximation :

\[ \text{Lift}_{\text{flap}} \sim \text{LoadCell}_{\text{output}} \cdot g = \text{Vertical Force} \ [N] \]

Ongoing Tests:

<table>
<thead>
<tr>
<th>Lift(_{\text{flap}}) (f)</th>
<th>Lift(_{\text{flap}}) ((\mu),f)</th>
<th>Lift(_{\text{flap}}) ((\delta),f)</th>
</tr>
</thead>
</table>

Initial Test \(f=1.5\) Hz Slow Motion

Load Cell Main Force Reference

Data sampling = 90 Hz

Hardware Main Connection

**Lift\textsubscript{flap} against frequency : Lift\textsubscript{flap} peak**

$W_{\text{initial}} \sim 3.50 \text{ N}$

<table>
<thead>
<tr>
<th>$f$</th>
<th>Lift\textsubscript{flap}</th>
<th>$W_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>-1.04</td>
<td>7.82</td>
</tr>
<tr>
<td>2.5</td>
<td>-2.55</td>
<td>8.83</td>
</tr>
<tr>
<td>3.5</td>
<td>-0.65</td>
<td>7.22</td>
</tr>
</tbody>
</table>

The max and min values match the half-amplitude positions of the wing during up/down-strokes respectively!

Goal: decrease the maximum payload frequency to reduce battery consumptions!
## Parametric Analysis Results: $\mu$ and $\delta$ against $f$

<table>
<thead>
<tr>
<th>$\mu &gt; 0 \quad \delta = \text{max}$</th>
<th>$\mu &lt; 0 \quad \delta = \text{max}$</th>
<th>$\mu = 0 \quad \delta = \text{min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f = 1.5$</td>
<td>-1.174</td>
<td>7.624</td>
</tr>
<tr>
<td>$f = 1.7$</td>
<td>-2.112</td>
<td>8.505</td>
</tr>
<tr>
<td>$f = 2.0$</td>
<td>-2.581</td>
<td>8.892</td>
</tr>
<tr>
<td>$f_{\text{lift_max}} = 3.0$</td>
<td>-2.752</td>
<td>8.571</td>
</tr>
</tbody>
</table>

$Lift_{\text{flap}}(\mu, f)$

- Lift flap $N$
- $W_{\text{max}} N$
Ongoing Improvements
Ongoing Improvements

1) **Thrust\textsubscript{flap} analysis**: Load Cell, Negative Horizontal Force

2) Lift/Thrust Analysis *adding frontal wind gusts — outdoor tests*;

3) Improve structure strength: find out possible elastic coating solutions
   - Silicon Based material
   - Multi-Material wing: topic solutions

4) CFD simulation;

5) Enhance aerodynamic response of bio-inspired profiles;
Comparison among Bio-inspired profiles

<table>
<thead>
<tr>
<th>Bio-inspired Profile</th>
<th>Tip Max Deformation [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS6091 Low-Moment family</td>
<td>5,7</td>
</tr>
<tr>
<td>AS6096</td>
<td>2,7</td>
</tr>
<tr>
<td>AS6097</td>
<td>0,6</td>
</tr>
</tbody>
</table>


** http://heli-air.net/2016/03/23/the-low-drag-bucket/

Why thickness is important? (**) Drag bucket widens as Reynolds number increases!
Thanks for the kind attention!