Numerical and experimental analysis of tandem wings

Thomas LAMBERT – G. Dimitriadis – T. Andrianne
Liège University

N. Warbecq – P. Hendrick
Université Libre de Bruxelles

R. Nudds
Manchester University
Introduction

• Studied since the very beginning of flight
• More or less abandoned during WW 2
• Renewed interest for micro and macro UAVs
Numerical and experimental investigation of tandem wing flyers

Introduction – Microraptor

- Oldest specimen of winged dinosaur
- Likely the common ancestor of today’s birds
- Feathers on hind limbs
- Glided from tree to tree
- No clear consensus among biologist about its aft wings posture

Main goal: Understand the effect of wing attitude in tandem systems.
Suggest the most probable positioning of wings for a four-winged animal, irrespectively of the wing size or profile.
Introduction – Microraptor

- Previous estimations based on empirical models for birds and biologically possible postures
- No real consensus on the methodology and results
- Wind tunnel tests conducted by biologists
  - Suggest that dihedral has no effect

Dyke et al., 2013
Overview

• Introduction
• Experimental model
• Numerical analysis
  ▫ UVLM
  ▫ Numerical model
• Results
  ▫ Horizontal and vertical positioning
  ▫ Angle of attack
  ▫ Dihedral angles
• Conclusion
• Future work
Models

Experimental model – Wind tunnel
Numerical model - UVLM
Experimental model

- Based on actual Microraptor dimensions: ~ 0.5 m total span
- 4 wings + large body

<table>
<thead>
<tr>
<th>Wing</th>
<th>Profile</th>
<th>NACA 0012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span</td>
<td>0.20 m</td>
<td></td>
</tr>
<tr>
<td>Chord</td>
<td>0.0625 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body</th>
<th>Profile</th>
<th>Nearly bluff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span</td>
<td>0.10 m</td>
<td></td>
</tr>
<tr>
<td>Chord</td>
<td>0.256 m</td>
<td></td>
</tr>
</tbody>
</table>
Experimental model

- Clamping mechanism with one single bolt to fix all DOFs
  - Easy to move and test a very wide range of configurations
  - Fiddly: when bolt is loosened, all DOFs may move
Parameters

- Horizontal \( (D_x) \) and vertical \( (D_z) \) separation
- Angle of attack \( (\alpha) \)
- Dihedral angle \( (\theta) \)
Wind tunnel

- Large subsonic wind tunnel @ ULiège
- Section of 2x1.5 m
- Reynolds sensitivity analysis
  - Final measurements realized at 20 m/s
  - $Re \approx 80 000$
Numerical analysis – UVLM

• Unsteady Vortex Lattice Method
  ▫ Potential flow theory
  ▫ Thin airfoil theory
  ▫ Free-wake model
• In-house code used for flapping wings analysis
Numerical analysis – Free wake model

- Usually induced velocity computed using Biot-Savart law
- Singularity when point of evaluation lies too close to the vortex segment
- **Solution:** Introducing a vortex core that reduces induced velocity
  - Common practice when wake interactions are expected
  - Add viscous dissipation in the vortex core
  - **Vatistas** second order

![Graph showing velocity profiles](image-url)
Numerical analysis – Model

- Model the entire system (4 wings + body)
- Same dimensions as experimental model
- Same number of panels on wings and body
  - 18 spanwise, 12 chordwise
  - Smaller panels at tips and for the body at leading edge as well
Numerical analysis – Body model

• Body’s impact too important to remove from total loads
  ▫ Body must be included in numerical model
  ▫ Results are presented for the entire system

• Experimental body is nearly bluff
  ▫ Modeled in the UVLM as a highly cambered plate
  ▫ The camber was adjusted in order to give the same lift as measured in the wind tunnel
  ▫ UVLM induced drag predictions were correct but an offset was added to represent viscous drag
Numerical analysis – Body model

- True body
- Mean camber
- UVLM
Numerical and experimental investigation of tandem wing flyers

Results

Horizontal and vertical positioning
Angle of attack
Dihedral angles
Results – Horizontal and vertical position

- 6° AOA, no dihedral
- Larger horizontal spacing lead to higher lift values
- Lift decreases when the aft wing is moved above the front wing
Results – AOA aft

- $D_x = 0.6 \, c$, $D_z = 0 \, c$, no dihedral
- AOA front fixed, only AOA aft changed
- System stalls at high AOA, thanks to downwash induced by front wings

![Graph showing lift and drag coefficients for different angles of attack](image)
Numerical and experimental investigation of tandem wing flyers

Results – AOA front

- $D_x = 0.6c$, $D_z = 0c$, no dihedral
- Increase in AOA front less beneficial than in AOA aft
  - Higher AOA at the front increases the downwash on the aft wing

![Graphs showing lift and drag coefficients vs. AOA front for different AOA angles]
Results – Dihedral

- $D_x = 0.4c$, $D_z = 0c$, $6^\circ$ AOA
- Some combinations lead to significant increase of performances
- Probably some errors due to setup inaccuracies
Conclusion

Conclusion
Future work and perspectives
Conclusions

- Horizontal and vertical spacing have a significant effect on the lift
  - Best lift is obtained when the horizontal distance is high and the aft wing is below the front wing
- Variations of the AOA are more efficient if applied on the aft wings
  - For best lift the aft wing AOA should be higher than that of the front wing
- Dihedral seems to play an important role in the lift force generated by the system
  - Best lift is obtained when the difference between the two dihedral angles is high
  - For the Microraptor, the best lift would be obtained with dihedral at the front and anhedral at the rear
- UVLM predictions are generally good
Future work

• Compare tandem wing results to an equivalent single wing
• Use of flow visualization techniques
  ▫ Better understanding of flow interference phenomena
• Repeat analysis with:
  ▫ Cambered wings
  ▫ Biologically accurate wings (goose)
• More accurate representation of an actual Microraptor
Thank you

Thomas LAMBERT – G. Dimitriadis – T. Andrianne
Liège University

N. Warbecq – P. Hendrick
Université Libre de Bruxelles

R. Nudds
Manchester University