THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Dynamics, Stability & Control of Flapping Wing Robots

Objectives

- Understand the nonlinear **dynamics**, **stability**, and **control** of various biomimetic flapping wing designs featuring
  - Analysis of wing flexibility
  - Consideration of wing mass
  - Non-naïve averaging methods
- Primary focus area: determine the **influence of wing flexibility** on the stability of flapping wing designs and **optimal stiffness**, **mass**, and **wing loading** for aerodynamic performance and stability
- Develop **robust nonlinear control** strategies for this nonlinear, time periodic system across the entire flight envelope

Researchers (http://compfluids.uah.edu)

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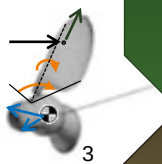
- Ph.D. Student: Major James E. Bluman, P.E.

Approach – Multi-fidelity Analysis

Wing Kinematics
- 2-DOF vs. 3-DOF rotation
- Split Cycle Manipulation
- Active vs. Passive Rotation

Aerodynamic Modeling
- Lift, Drag, and Moment Predictions
- Quasi-steady/Unsteady theory
- Surrogate Models
- Navier Stokes (DNS)
- Fully Coupled CFD/CSD Solutions[1]
- 2D vs. 3D Aerodynamics

Control Design
- Linear Control
- Nonlinear Control
-Model Free Control



3

Passive Stability Analysis
- Classical Linear Stability Methods
- Floquet Theory
- Limit Cycle Oscillations

Multi-Body Dynamics

Nonlinear Time Periodic System
- Multiple Averaging Methods
- Linearization vs. Nonlinear Simulation
- Rigid Body vs. Multi-body Analysis
- Rigid vs. Flexible Wings

Goal: Prediction of flight performance and determination of optimum design parameters and control methods

Motivation

Bombus hortorum (bumblebee)[2]

Significant chordwise wing flexibility[2]

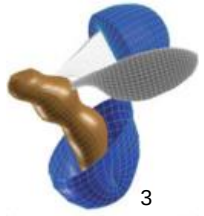
- Can hover or sustain forward flight at high advance ratios
- Maintains trajectory in unsteady wind conditions
- Exhibits rapid accelerations and decelerations
- Can carry loads exceeding their body weight

Achievements

- Developed full multi-body mathematical model for multiple winged insects/vehicles from first principles and verified the result against other models in the literature
- Developed aerodynamic pitching moment predictions based on both unsteady aerodynamic theory and full direct numerical simulation of the incompressible Navier Stokes equations
- Implemented a fully coupled open loop flight dynamic solver with multiple aerodynamic models

Future work

- Fully coupled CFD-CSD-EOM solver
- Stability analysis using advanced techniques
- Nonlinear control implementation
- Model free control development



3

Key References

1. Kang and Shyy, *Journal of Royal Society Interface*, 2013
2. Kang and Sridhar, *Journal of Bioinspiration and Biomimetics*, 2015
3. Liu, Nakata, et al., *Acta Mechanica Sinica*, 2010