Aerodynamics of Insect Hovering Flight Methods

LABORATORY FOR UNDERGRADUATE COMBUSTION & HYPERSONICS LAFAYETTE

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Abstract

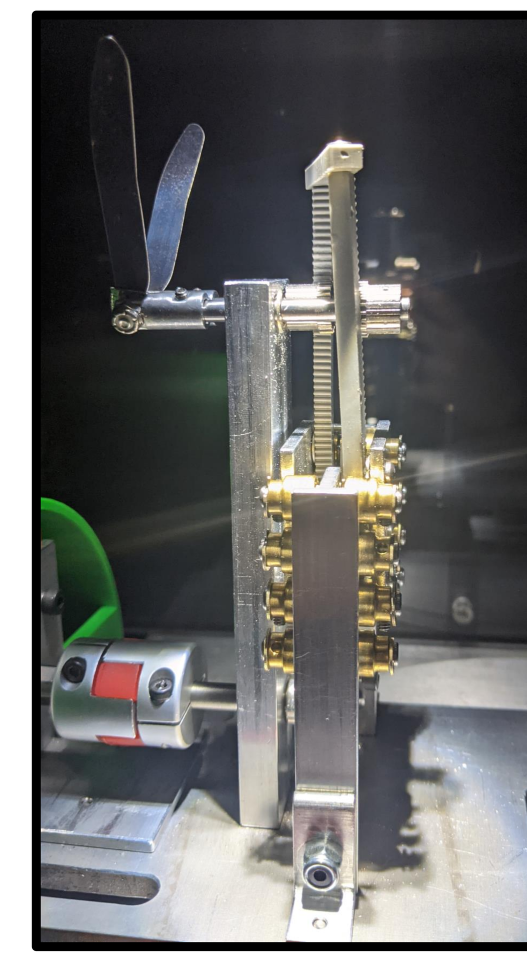
- Flapping hovering flight challenges traditional aerodynamics for small scale production of lift.
- Two main styles of insect flight; hovering flight and clap-and-fling hovering flight.
- The main source of lift generation is wing-vortex interaction
- Unsteady aerodynamics are necessary for calculating lift forces due to wing size


Background

- Insect flight falls outside of steady state aerodynamics due to oscillatory wing motion
- Lift is mostly generated by shed vortices and vortex interaction
- Both non-interference and clap-and-fling generate 60% of lift through wing-vortex interactions
- Clap-and-fling uses wing-wing interactions at the top of the upstroke to generate additional shed vortices, leading to more lift generation on the downstroke

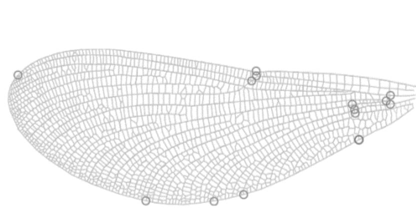
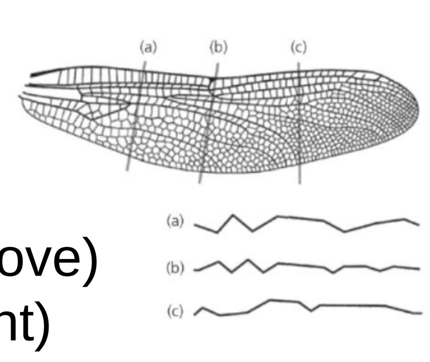
Mechanism Design

- Mechanism was built to simulate flapping flight in an experimental environment
- Sized to fit within the wind tunnel and be of comparable scale to the insects being studied
- Simplification of flapping dynamics to allow effective modeling for experimentation
- Motor runs under velocity PI control with live adjustable gains



Wing Design

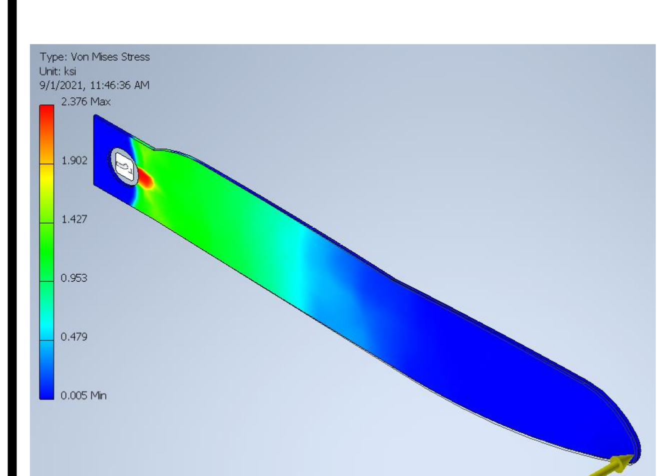
- The two sets of wings used are modeled after the wings of the specific species of dragonfly and damselfly being compared
- The smaller sets of wings are modeled to scale of the biological wings
- A second set of larger wings were manufactured for use in force measurement
- These larger wings allow for clearer visualization data and a larger surface for strain gages

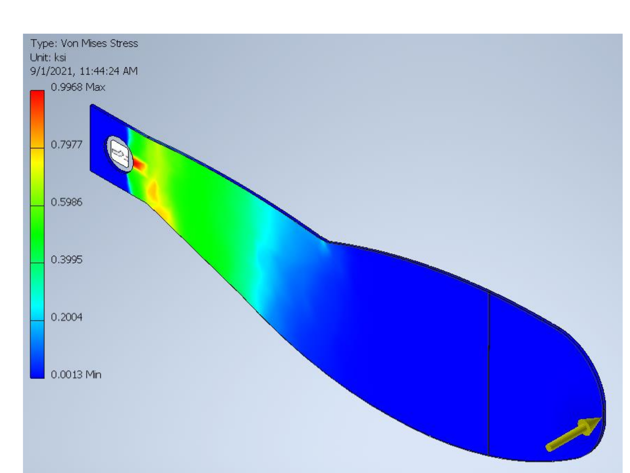
Damselfly wing (above)
Dragonfly wing (right)

Wing Analysis

- Wing material and thickness calculations were performed in MATLAB based on aerodynamic stresses
- Distributed loads simulated as point loads on the wingtip to determine maximum bending moment and wing factor of safety
- Wings needed to both be thin and strong enough to have comparable properties to insect wings, as well as be able to withstand multiple tests



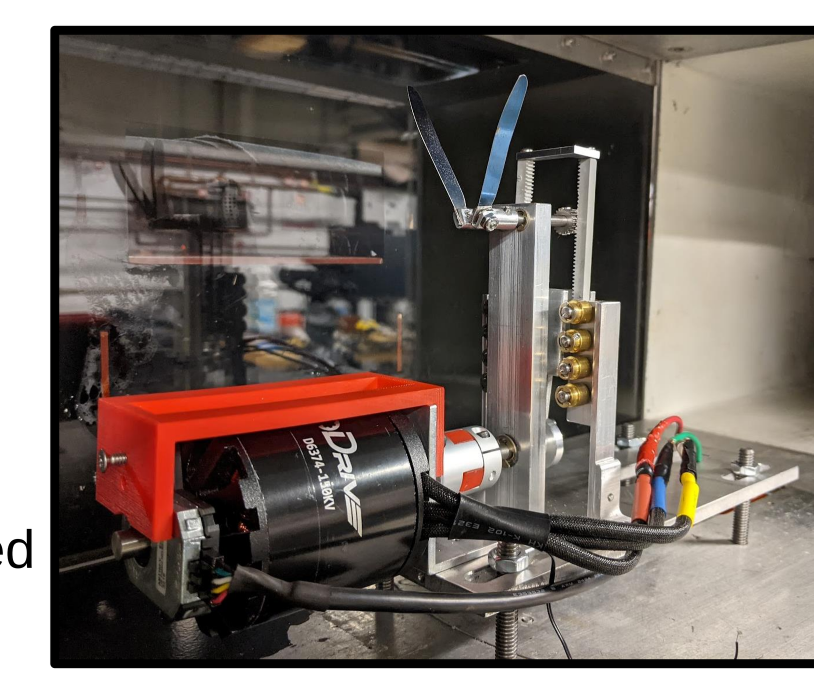
Dragonfly wing deflection analysis



Damselfly wing deflection analysis

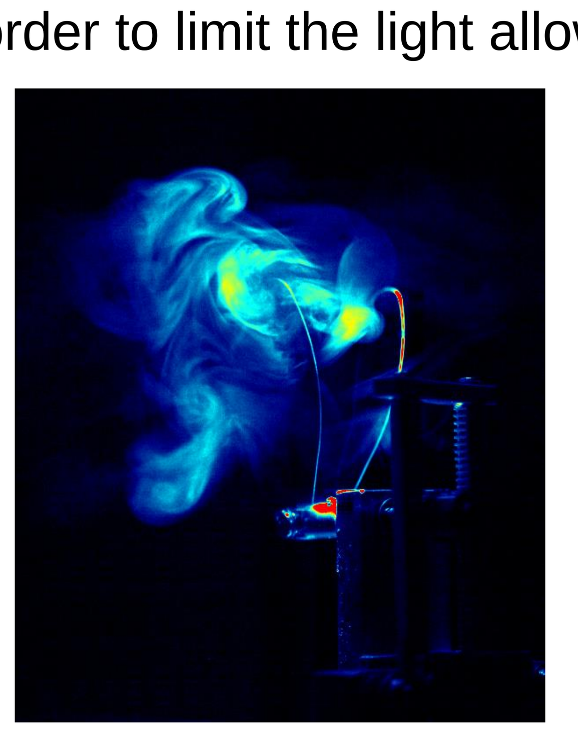
Experimental Procedure

- Flapping mechanism is leveled and installed in the wind tunnel test section
- High Speed Star camera used with DaVis imaging software to capture flow visualization data
- LED bank illumination was used for initial tests
- Fog machine using Rosco Fogger Fluid is used to seed the flow with an oil-based fluid to generate flow visualization data
- Dragonfly wings are run at 18Hz and damselfly wings at 9Hz due to Reynolds scaling resulting from a doubled wingspan correlating to a halved flapping frequency

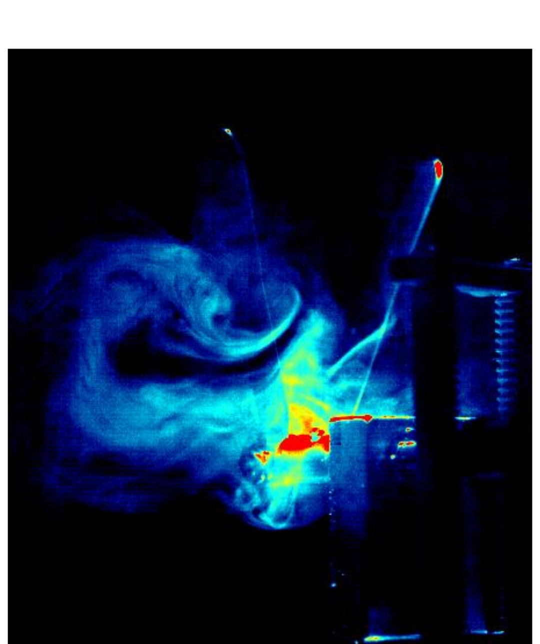
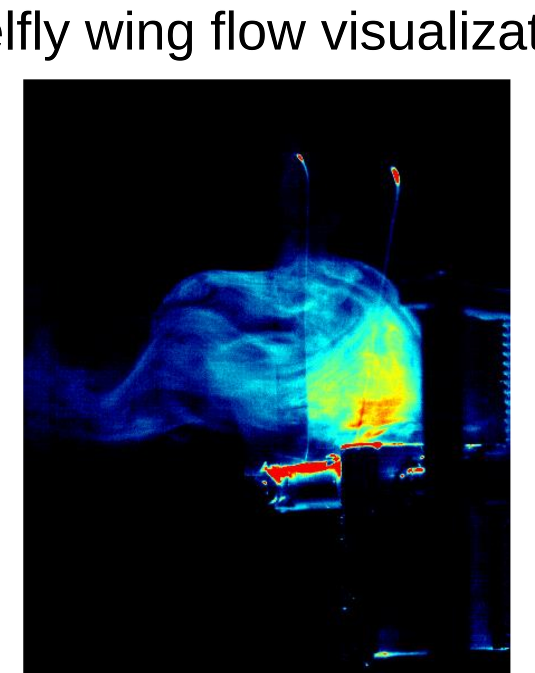
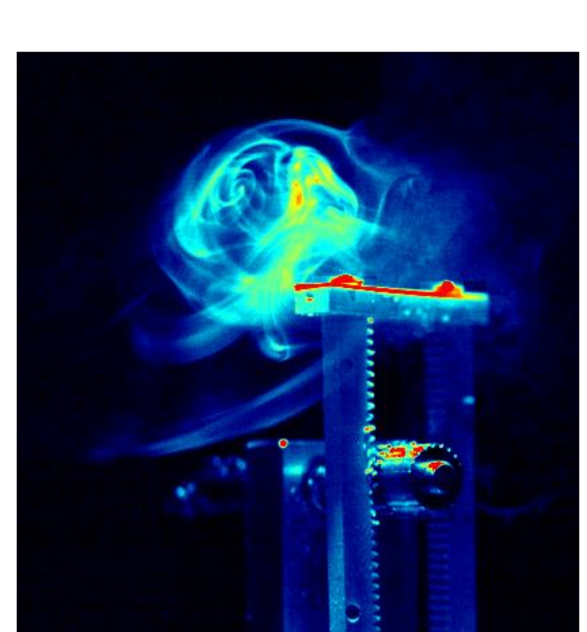


Flow Visualization

- To gather data describing the wing-shed vortex interactions high speed imaging was performed at a rate of 5kHz (5000 images/second), and shutter speed of 1/10000 in order to limit the light allowed into the camera to not damage the lens



Damselfly wing flow visualization

Dragonfly wing flow visualization

Flow Analysis

- The major differences between non-interference (dragonfly) flight and clap-and-fling (damselfly) flight is the presence of the wing impact vortices
- The mushrooming present in the third damselfly flow visualization figure is the result of vortex-vortex interaction, when created wing vortices collide in the flight wake
- The dragonfly wing flow visualization demonstrates vortex shedding and leading-edge vortex (LEV) roll off, as can be seen in the first dragonfly flow visualization
- The downward streak created by boundary layer shedding in the third dragonfly flow visualization demonstrates the trailing vortices responsible for gathering wake-shed lift forces for flight

Future Work

- Strain gages will be mounted at wing roots to gather wing force distributions to further quantify lift generation
- PIV (Particle Image Velocimetry) will be performed to provide mathematical data of flow behavior and development over time
- Further flow visualization data will be taken using laser illumination

Acknowledgments

- *David and Lorraine Freed Undergraduate Research Symposium, Lehigh University*