Experimental and Computational Analysis of Lift Generation by Wing Morphing Bird

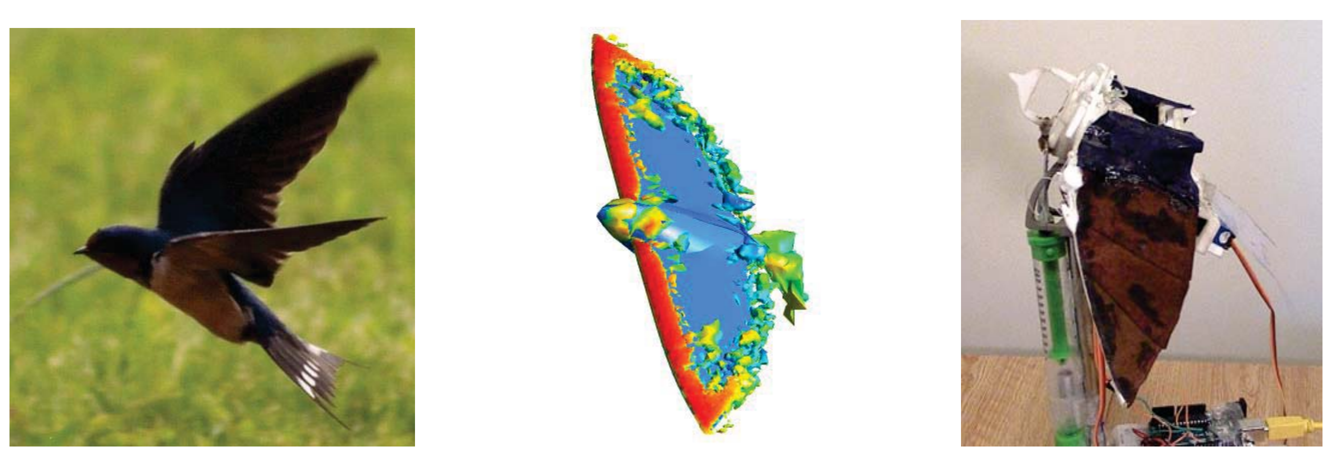
Theophilus Aluko
Dr. Meilin Yu, Assistant Professor, Mechanical Engineering;
Jamie Gurganus, Instructor, Mechanical Engineering

ABSTRACT

This research aims to study and mimic the lift of a barn swallow via computational and experimental analysis, by meeting finite dynamic constraints such as flapping amplitudes and frequency. This bird was selected because of its maneuverability, efficiency and conical morphing wing-flapping motion. An animation of a simplified lifting process was obtained by creating a three-dimensional scan of a representative bird from the Smithsonian National Museum of Natural History. In addition to the animation, we constructed a physical aerial robot prototype that mimicked the take-off process of the bird in its natural environment. Using the physical model, the generated lift force caused by the morphing flapping structure was measured and then compared with the force derived by a conventional flapping structure. To compare the experiment with the computation, coefficient of lift was obtained for each method. Our analysis and measurements support the hypothesis that the lift generation is highly affected by a characterization of changes in the bird's wing due to geometry. In particular we hypothesize that leading-edge vortices (LEVs) play an important role in lift generation and should be further parameterized for the making of safer, more efficient wing-morphing commercial aircraft.

INTRODUCTION AND HISTORY

The Leading Edge Vortices created by its hand wing make it, and similar species like swifts, very maneuverable even for low speeds by giving them the ratio of lift and drag they need for snatching prey in mid-air. It takes us to around 1500 AD before new contribution to knowledge to flight emerged. However, research on seamless wing-morphing aircrafts widely started in the 21st century.



(a) (b) (c)

Figure 1. Three stages of study: (a) Bird in natural take-off position, (b) Fluid Dynamics animation, and (c) Bio-mimicked robot assembly

METHODS

1. ANIMATION AND COMPUTATION
3D scanned from the Smithsonian Museum of Natural History, adjusted for animation, and computed lift coefficient.

2. EXPERIMENTATION (BIO-MIMICRY ROBOT)
Followed constraints below and assembled with 3D printed parts. Lift coefficient was calculated for comparison with computation.

Table 1. Geometry Constraints

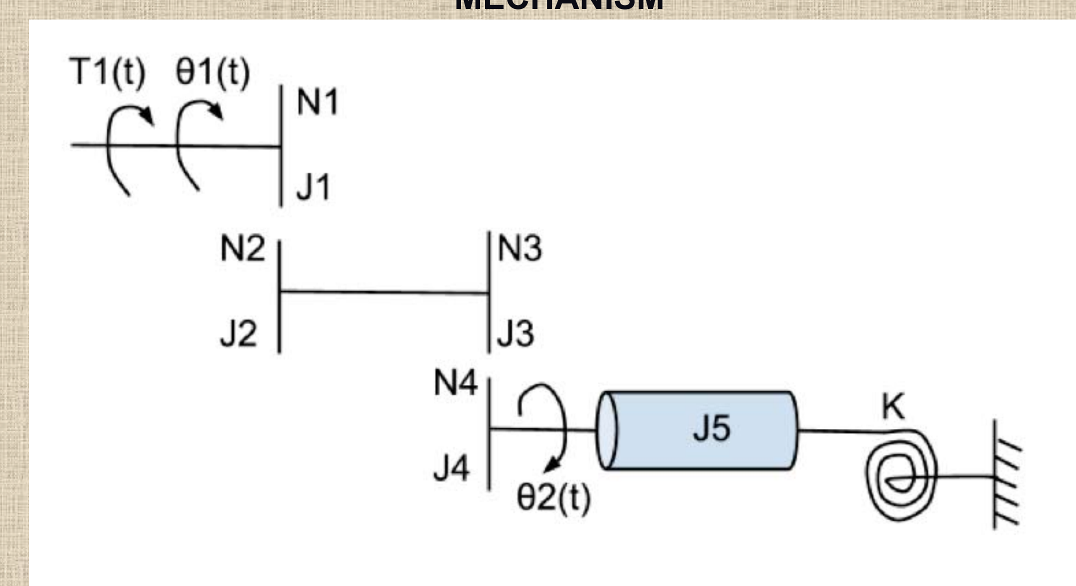
Geometry Constraints	
Wing span-wise length	6″
Wing angle of attack	10°
Body tilt angle	21°
Tail spread angle	45°
Dynamic Constraints	
Flapping amplitude	91°
Flapping frequency	8 Hertz
Max wing sweep (morphing) angle	60°
Environmental Condition	
Wind speed	4 m/s

ROBOT DESIGN

DESIRED WING MORPHING MECHANISM: SWEEP MOTION

Barn swallow, Angela Turner [1]

MECHANISM



Motion transfer function

$$G(s) = \frac{\theta 2(s)}{T1(s)} = \frac{\frac{(N2)(N4)}{(N1)(N3)}}{Je(s)^2+K}$$

Checking for Stability

Routh-Hurwith Criterion states a system is stable if there are no right poles. From the R-H table, there are no right poles. Hence, the system is inherently stable, for each individual wing motion.

EXPERIMENT OUTCOME

The Lift Coefficient for, now, minimal morphing (rigid) experiment with the bio-mimicked robot assembly is calculated by:

$$C_L = \frac{3(Lift)}{\pi^2 f^2 \phi^2 \varrho \, C o \, l}$$

EXPERIMENTAL SET-UP

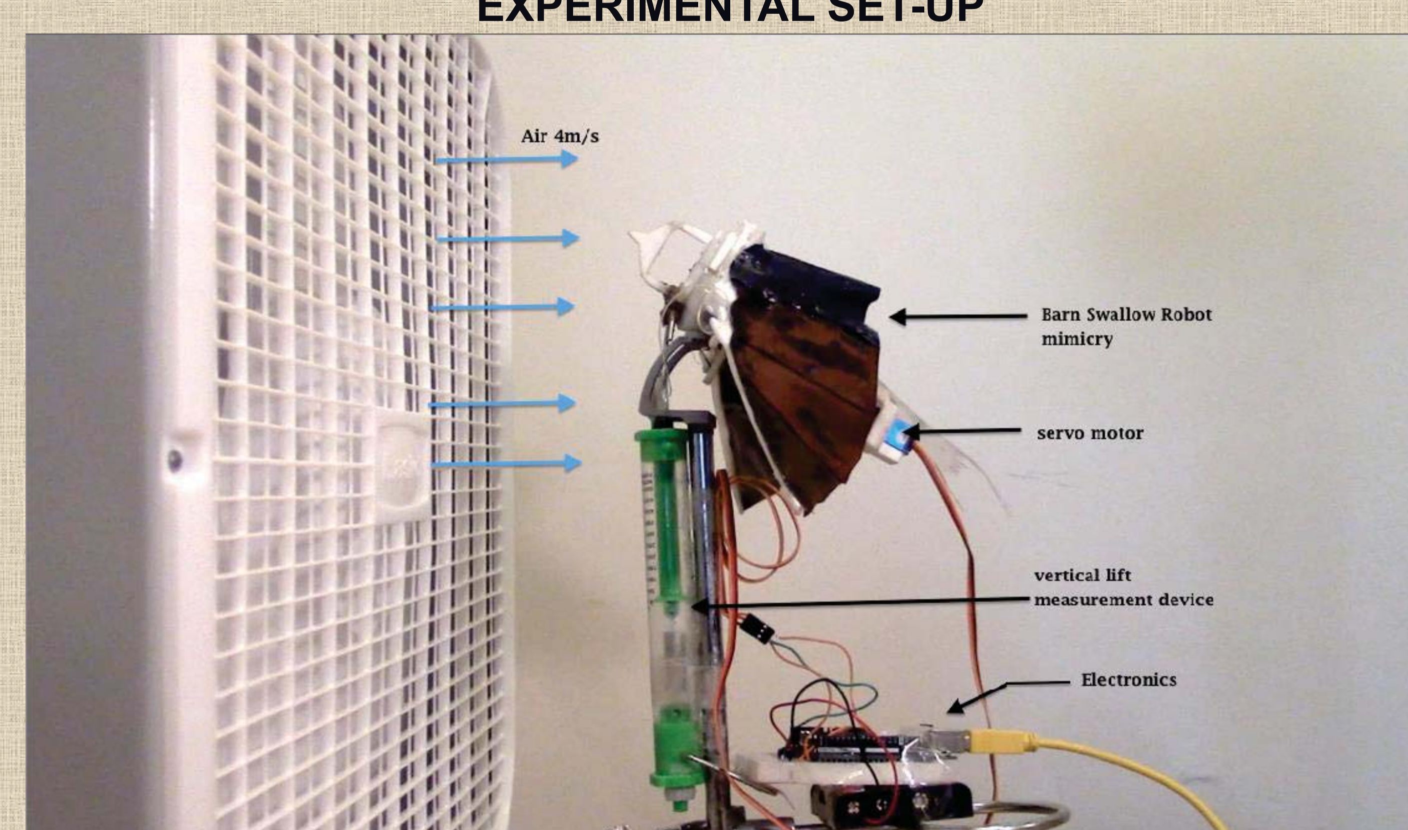


Figure 3. Schematic of experiment

RESULTS

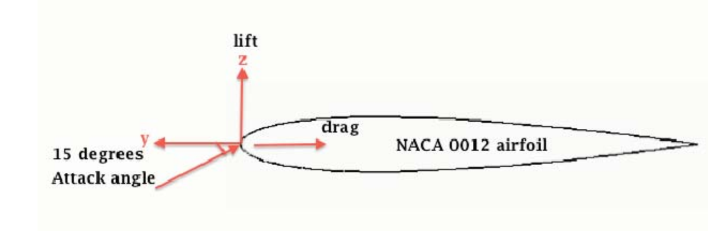


Figure 4. Schematic of CFD animation

CFD ANIMATION RESULTS

Lift Coefficient History

$$C_L = \frac{Lift}{\frac{1}{2}\varrho V^2 A}$$

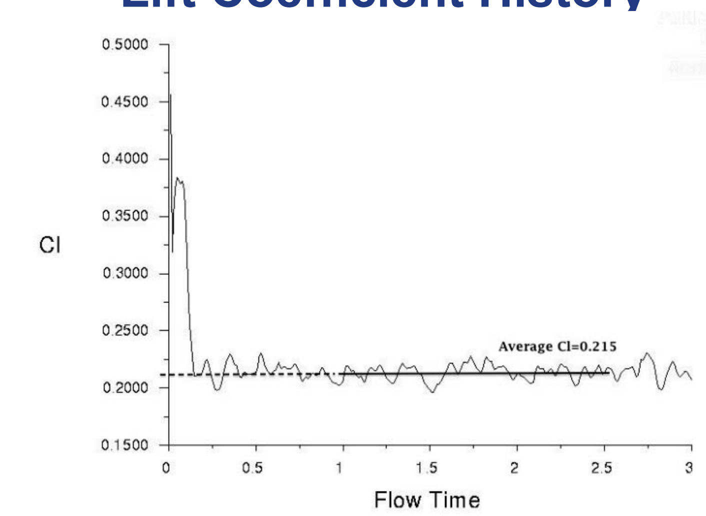
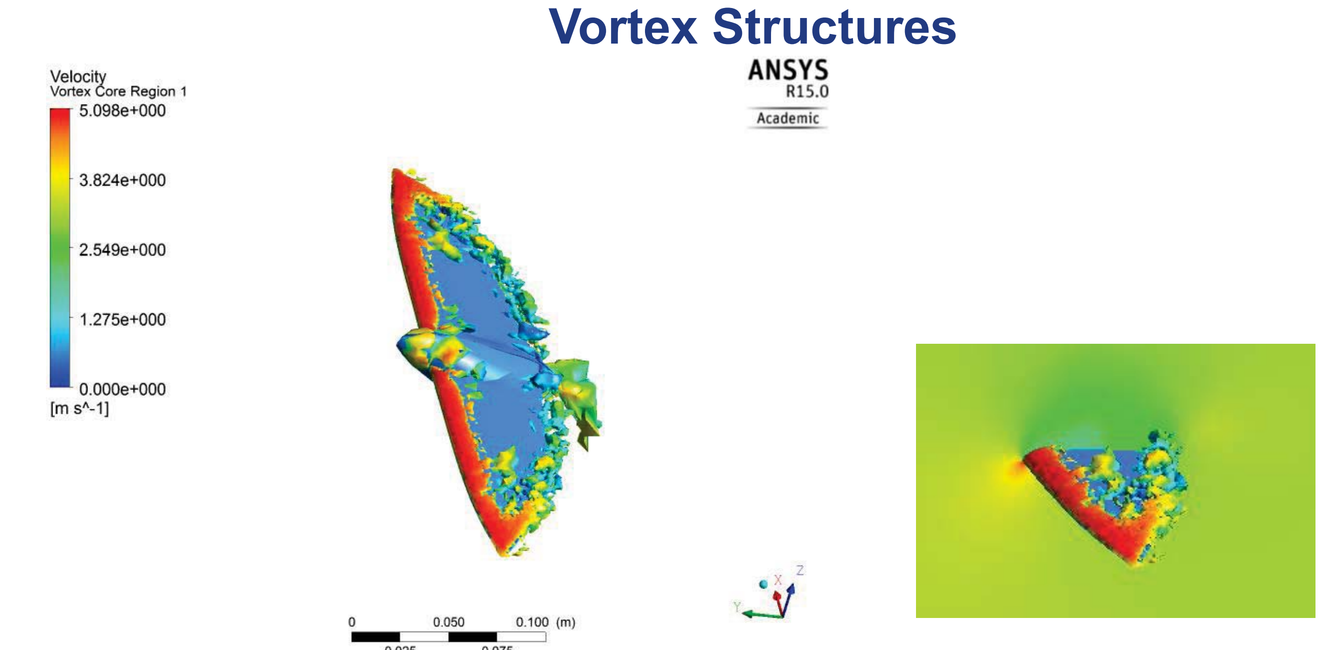


Figure 5. Lift Coefficient (Cl) History for, now-stationary scenario under similar experimental conditions

Vortex Structures



(a) (b)

Figure 6. (a) Vortex core region for velocity, and (b) A section view (iso-surface) through the velocity vortex, indicating the impact of leading edge vortices

COMPARISON

- **Average Lift coefficient for the computational animation was about** 0.215
- **Lift coefficient for the current experiment (for free flapping mechanism without morphing actuated) was calculated to be less than** 0.342. **This makes sense because one was flapping (varying shape dynamically).**
- **No conclusions can be made yet, until future work completed. Howbeit, our analysis and Measurements support the hypothesis that the lift generation is highly affected by the leading edge vortices, for which there would be a lot of destructive interference, where the flapping was up-and-down, rather than conical (with sideways morphing), thereby reducing the lift coefficient.**

FUTURE WORK

- **Dynamic CFD and animation using a dynamic User-defined function**
- **Robot Morphing Experiment: Actuate rigid connection string to allow wing morphing**

REFERENCES

[1] Turner, Angela K. The Barn Swallow. & C Black, 2006. Print.

This work was funded, in part, through an Undergraduate Research Award from the UMBC Office of Undergraduate Education.