BTP - I
Aerodynamic Analysis of Dragonfly Wings

Tarshit Sehgal
Under the guidance of
Prof. Abhijit Gogulapati
Department of Aerospace Engineering
IIT Bombay

April 24, 2025

Contents

1. Introduction

2. Methodology

3. Results

4. Conclusions

Introduction

Introduction

Biomimicry has been prevalent in engineering since long. Even the first aircafts were made flapping wings as an attempt to mimic birds

Some examples:

- Chevrons to reduce noise in B-737 - inspired from owls
- Honeycomb structure for increased strength - Beehive
- Lotus leaves repel dust and water - solar panels, glass etc.
- Octopus arms can bend and twist with high precision - soft robots for surgery

Why Dragonfly?

- Dragonflies are 300 million years old compared to 0.3 million years for humans! So more time for evolution and therefore highly optimized design
- Dragonflies are really good predators with a hit rate of about 95%

Table: Hunting Success Rates of Various Predators

Animal	**Hunting Success Rate**
Leopard	14–38%
Lion	27–34%
Tiger	5–50%
Great white shark	48%
Cheetah	40–50%

- Four wings, accurate predators, now wonder why dragonflies are considered as "**Kings of the air**"

Why Dragonfly?

But Gliding, Dragonflies??

- If looked carefully, dragonflies usually glide for 0.5-1 s while flapping (saves energy!)
- *Pantala flavescens* is migratory dragonfly known for crossing large water bodies like **Indian Ocean** recording about **18,000 km**
- Dragonfly *Aeshna Cyanea* can glide for 30 seconds, without significant altitude loss
- They have corrugated wing structure, increases bending stiffness (remember corrugated rooftop sheets?)

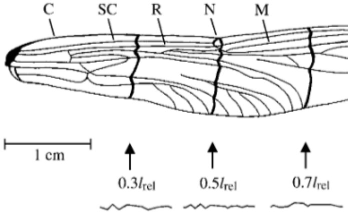


Figure: Forewing of *Aeshna Cyanea*

Figure: *Aeshna Cyanea*

Our Objective

- To study the aerodynamics of the corrugated wing structure
- To verify if dragonfly wings are optimized for aerodynamics/gliding
- Take inspiration from this structure for in engineering design
- Add control points to change the corrugation structure or wing morphing by changing properties like twist
- Potentially exploit the bistable/multi-stable materials to go from one corrugation pattern to other (left for BTP-II)

Potential Applications

- Wing morphing to get optimal mission specific performance like takeoff, cruise, glide etc.
- In flapping wing MAV, current TRL allows for around 10 min of max flight time Flapping - lot of energy!

Table: Power consumption for different activities

Activity	**Power consumed (in W)/ kg**
Dragonfly flapping	80-120
Dragonfly gliding	10–20
Human exercising	5–7
Human resting	1-1.2

- Incorporating phases of gliding in flapping can greatly improve endurance by approximately **3-6 times**

Methodology

Methodology

Dragonfly *Anax parthenope julius* was chosen for the study even though *Aeshna Cyanea* is a better known glider

Reason

- The profiles of both species had very close resemblance at similar spanwise locations
- Okamoto's team has done experimental studies on *Anax parthenope julius*, giving us real data to validate our results

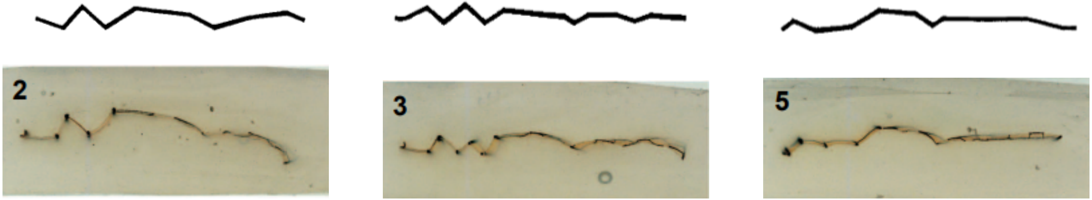


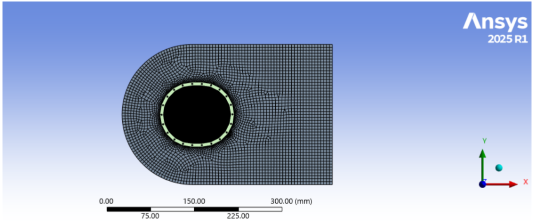
Figure: Profiles of *Aeshna Cyanea* (upper) vs.*Anax parthenope julius* (lower)

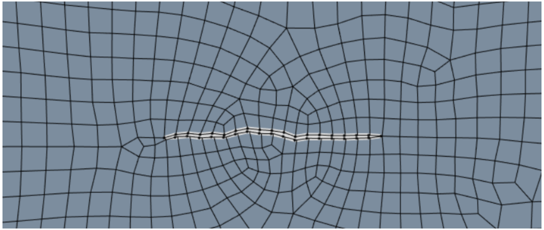
2-D Setup

- There are two parts in our study, 2-D and 3-D analysis
- We have profiles at 5 spanwise locations: 0.16, 0.3, 0.45, 0.6, 0.75 l_{rel}

Boundary Conditions

- **Inlet:** Curved surface
- **Outlet:** Flat surface opposite to curved surface
- **Symmetry:** Remaining faces on side





2-D Setup

A convergence study was attempted, but due to device limitation, had to restrict to element size of 0.5 mm

Fluid domain

Chord length is approximately 6mm, so a fluid domain with 10-20 times the chord length was made

- **Horizontal:** 240 mm
- **Vertical:** 240 mm

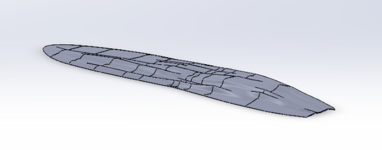
Mesh Statistics

- **Elements:** 50,099
- **Nodes:** 50,189

The pressure and temperature conditions were standard atmospheric at sea level, with a **freestream speed** of **3 m/s**, resulting in a **Reynolds number** of **1230**

3-D Setup

- The profiles at 5 spanwise location were used to create a 3-D wing using **Boundary Surface** feature in SolidWorks, which is kind of interpolation of the surface between two profiles
- A thickness of 0.05mm was chosen, **10 times** the actual thickness, due to software limitaions



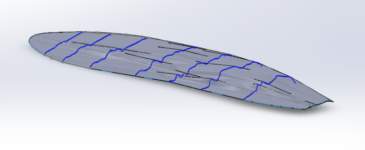


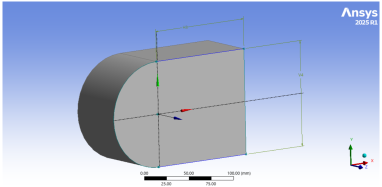
Figure: CAD of wing with -15° (left) and -15° (right) twist

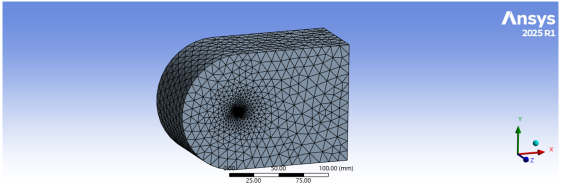
3-D Setup

Fluid domain

- **Horizontal:** 120 mm
- **Vertical:** 120 mm
- **Extrusion:** 70 mm

The pressure and the freestream conditions were same as 2-D





Mesh Statistics

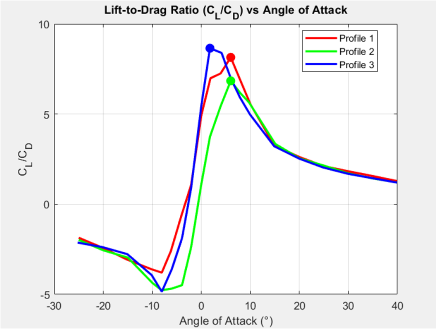
- **Elements:** 859,756
- **Nodes:** 157,327

But why test for negative twist?

- Kesel (2000) studied *Aeshna Cyanea* wing, C_l/C_d of which shows the trend in the figure
- The values of AoA for max C_l/C_d recorded in the table below, hints at negative twist

Table: AoA corresponding to maximum C_l/C_d for each profile of *Aeshna Cyanea*

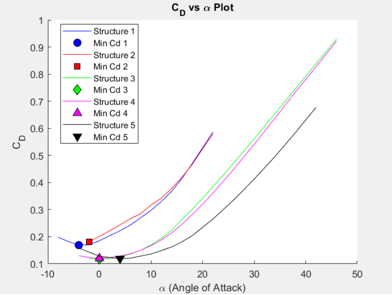
Profile	Spanwise loc (l_{rel})	AoA max C_l/C_d (degrees)
1	0.3	6.00
2	0.5	6.00
3	0.7	1.76

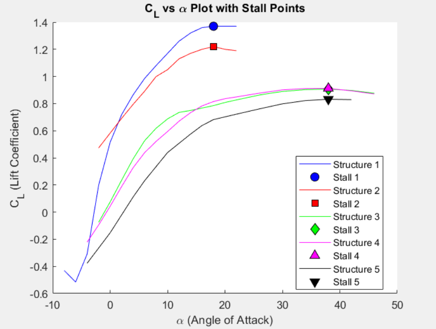


Results

2-D Simulation Plots

- Stall characteristics are gradual, mostly due to low reynolds number
- Minimum C_d is observed near 0^o angle of attack, probably due to minimum projected area (as seen from the direction of freestream)



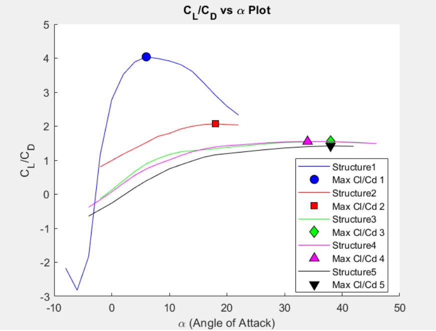


2-D Simulation Plots

- The C_l/C_d shows some interesting results, the curve is flattening out for profiles far from body
- A possible explanation to it is large deformation of the wing as we go outboard (Combes and Daniel (2003)), which can't be controlled by its muscles, unlike the part near the body

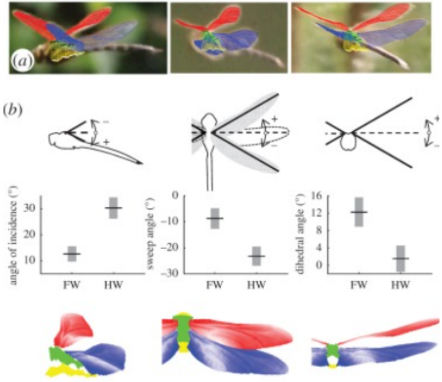
Table: AoA corresponding to maximum C_l/C_d for each profile of *Aeshna Cyanea*

Profile	AoA for max C_l/C_d
1	10.25
2	23.82
3	39.56
4	36.00
5	34.67



Wing Twist: Contradiction?

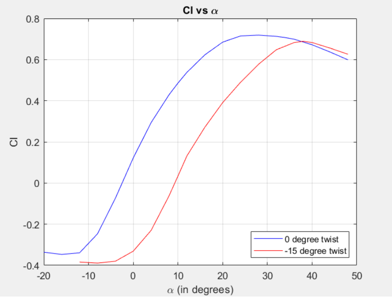
- The previous table shows a general increase in AoA with increasing relative spanwise location.
- This contradicts the previous assumption of a negative twist being beneficial
- So which one is correct?
  While there isn't much quantified data on the twist of dragonfly wings, a visual in the paper *"Flight of the dragonflies and damselflies"* by Richard J. Bomphrey shows a positive twist near the wingtip.
- Let's take a look at 3-D results find the truth

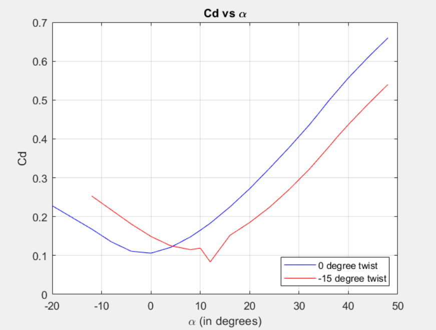


Wing twist illustration from Bomphrey (2006)

3-D Results

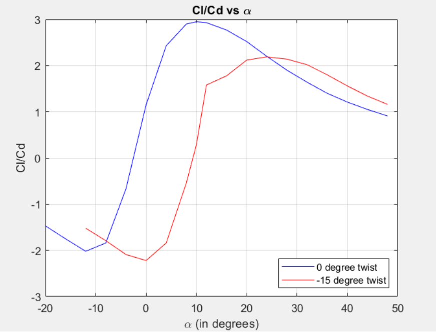
- Change of twist just shifts the curve laterally for both C_l and C_d
- There is a slight increase in C_L for 0^o twist, but that is not so significant





3-D Results

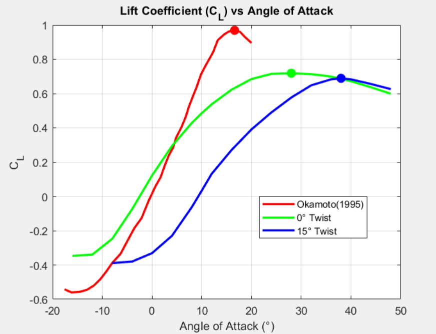
- The C_L/C_D curve shows a lateral shift like C_l and C_d curves
- There is an increase in maximum C_L/C_D as we go from -15^o to 0^o twist
- This results backs the data in the image from Bomphrey (2006)



Wing twist illustration from Bomphrey (2006)

Validation

- The 3-D wing results were compared with Okamoto (1995)
- This comparison just gives a rough estimate because:
-
    - We don't knowing the actual twist in wing used in the experiment
    - There is a slight difference in Reynolds number, 1230 vs. 1500



Comparison of the results with Okamoto(1995)

Conclusions

Final Thoughts

- Dragonfly wing aerodynamics was studied for both 2-D and 3-D
- Our attempt to generate actual dragonfly wing structure by place profiles at AoA of their max C_l/C_d seem to be going in the right direction
- There is a need of more 3-D simulations, for multiple twists, especially with the AoA given the table (on slide 18) to give a conclusive statement
- The flattening out of C_l/C_d curve for profiles father than bodies was an interesting find, and has a potential of being exploited

Acknowledgement

I would like to express my sincere gratitude to my project advisor, Prof. Abhijit Gogulapati, for their constant guidance, encouragement, and insightful feedback throughout the course of this work.

Thank you!

22b0077@iitb.ac.in

References

- Okamoto, *AERODYNAMIC CHARACTERISTICS OF THE WINGS AND BODY OF A DRAGONFLY*, 1995.
- Kesel, *Aerodynamic Characteristics of Dragonfly Wing Sections Compared with Technical Aerofoils*, 2000.
- Bomphrey, *Flight of the dragonflies and damselflies*.
- Vargas, *A computational study of the aerodynamic performance of a dragonfly wing section in gliding flight*.
- Y.H. Chen, *Gliding performance of 3-D corrugated dragonfly wing with spanwise variation*.
- Won-Kap Kim, *Effects of corrugation of the dragonfly wing on gliding performance*.
- Minghao Xu, *3D CFD model and aerodynamic analysis of dragonfly's corrugated wing during gliding*.
- Yuma Narita, *Aerodynamics on a faithful hindwing model of a migratory dragonfly based on 3D scan data*.