COMSOL CONFERENCE 2020 NORTH AMERICA

Bumblebee Aerodynamics

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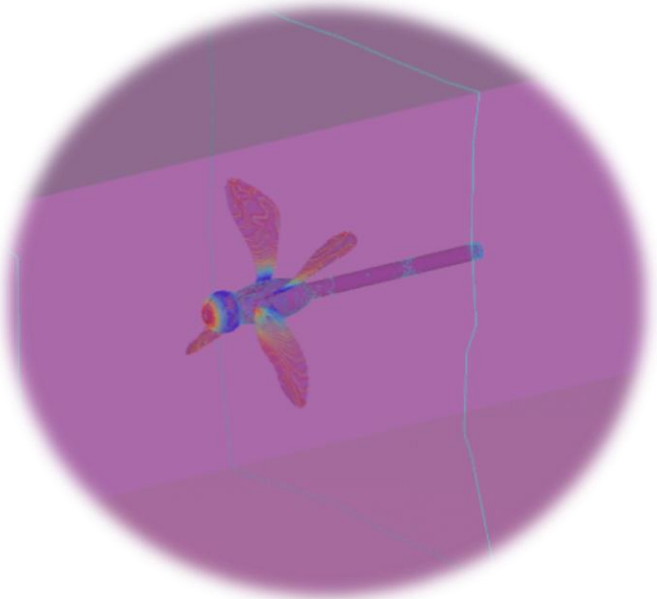
*Intern

Bumblebee & Dragonfly Aerodynamics in a Virtual Wind Tunnel

- Brief Review Insect Flight Mechanics
- Numerical Modelling of Insect Flight
- Virtual Wind Tunnel setup
- CFD models of Bumblebee and dragonfly
- Result and discussion of Flapping and Flight parameters
- Conclusion and future work.



Nature Inspired Flight

- Bird inspired flight helped us to develop intercontinental flying long range aircraft with efficiency as comparable to transcontinental migratory birds

- But, short range air travel, efficiency is much lower than short range flying birds and insects.

- Hence, in this paper, we investigate the flight behaviour of shorts range insects.

Insect Flight

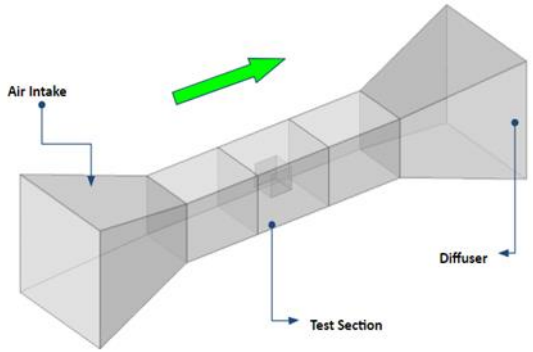
- Insects have evolved as efficient flyer

- They employ complex manoeuvring techniques
  - Take off and Landing
  - Forward flight
  - Hovering.
  - Flapping
  - Gliding
  - Rolling

- Bumblebee
- Dragonfly

Numerical Modelling of Insect Flight

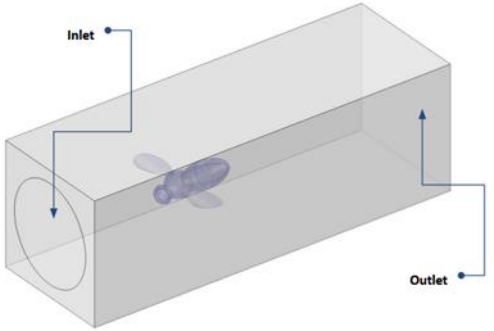
- Insect flight is a combination of physical mechanism and interacting systems that involves fluid dynamics, kinematics, morphology, and vortex dynamics, energy and power.
- Involves steady and unsteady aerodynamics
- Key aerodynamic mechanisms identified are; added mass, rotational circulation, clap and fling, wing wake interactions, and leading-edge vortex.
- Complex flight manoeuvres of insects are numerically modelled using Wing element, Actuator disc and Vortex theory.
- In this paper, we study the Insect's Aerodynamics in a Virtual Wind Tunnel.



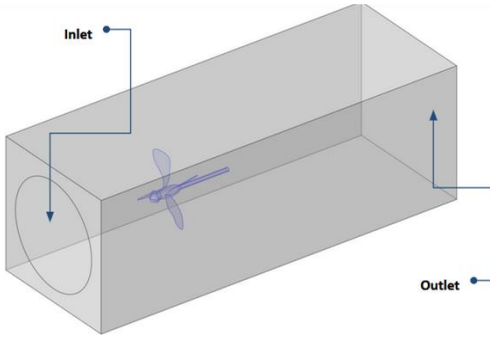
Parametric Virtual wind tunnel

Virtual Wind Tunnel

- A virtual parametric model a wind tunnel is designed in COMSOL to study the insect flight mechanics.
- The virtual wind tunnel is set up to simulate for various flow conditions using Reynolds-Averaged Navier-Stokes (RANS) formulations.
- Also, the virtual wind tunnel is equipped to use various Turbulence fluid flow models such as; L-VEL, k-ε, k-ω, SST, v2-f and Spalart-Allmaras models.
- Various insects and wing shapes with rigid, flexible and morphing configuration can also be modelled.
- The conventional flight parameters such as Lift Coefficient (Cl), Drag Coefficient (Cd) along with fluid velocity and pressure, and unsteady parameter can be probed.



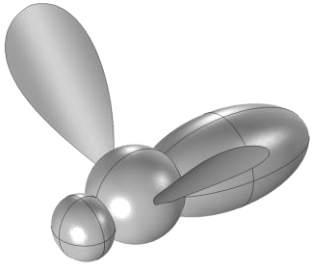
Bumblebee in a Virtual Wind Tunnel



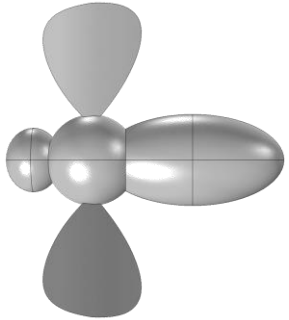
Dragonfly in a Virtual Wind Tunnel

Bumblebee CAD and CFD

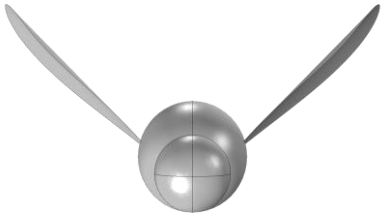
- Parametric CAD Model



Isometric View

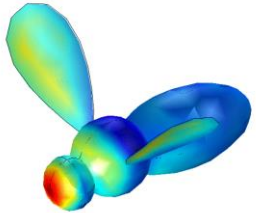


Top View

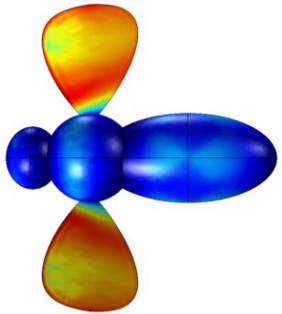


Front View

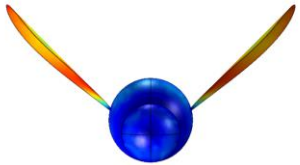
- Typical CFD results for various stroke angle.



Pressure



Velocity

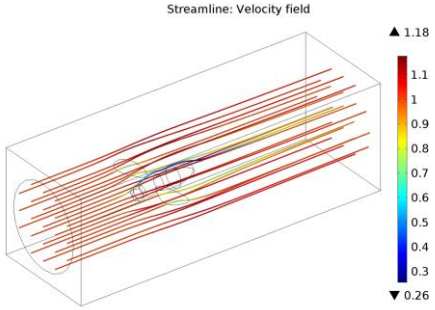


Velocity

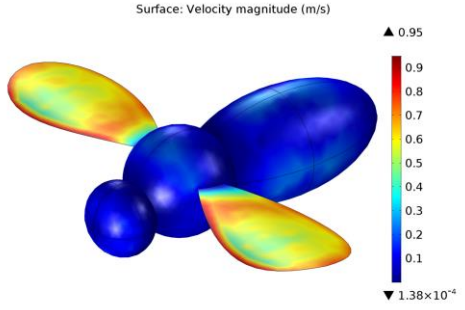
- The velocity and pressure contour plots of flying animation.

Bumblebee CFD Results V

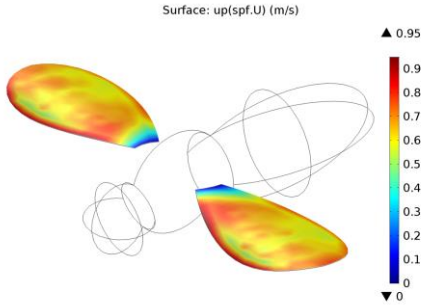
- Typical CFD results (V), Zero Degree Stroke Angle
- Velocity stream line of virtual wind tunnel with bumble bee.
- Velocity contour plots at 0^{o}.
- The velocity magnitudes around the bumblebee is derived and plotted graphically.



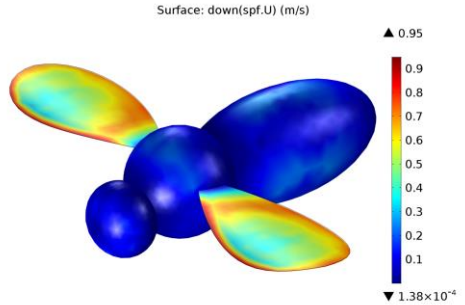
Streamline Velocity



Surface Velocity



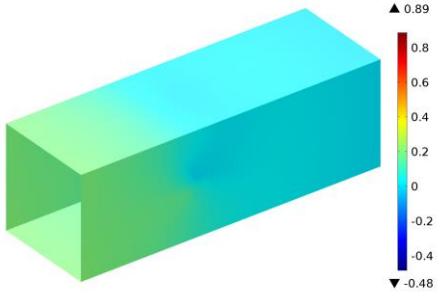
Upside Velocity



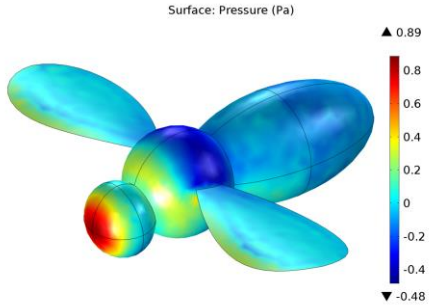
Downside Velocity

Bumblebee CFD Results P

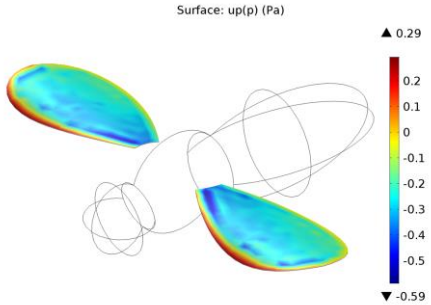
- Typical CFD results (P), Zero Degree Stroke Angle
- Pressure distribution of virtual wind tunnel with bumble bee.
- Pressure contour plots at 0^{o}.
- The pressure magnitudes around the bumblebee is derived and plotted graphically.



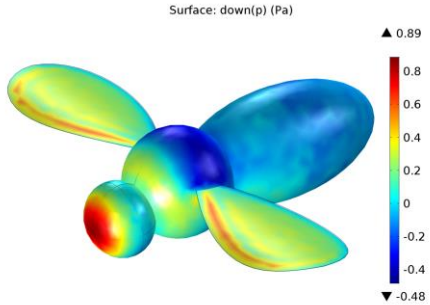
Chamber Pressure



Surface Pressure



Upside Pressure



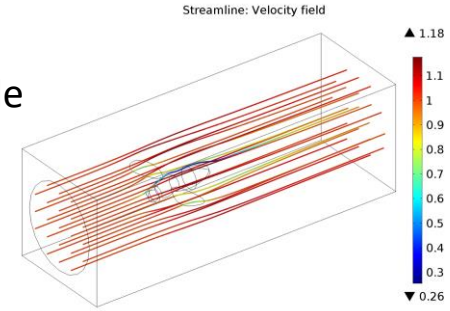
Downside Pressure

Bumblebee CFD Results PV

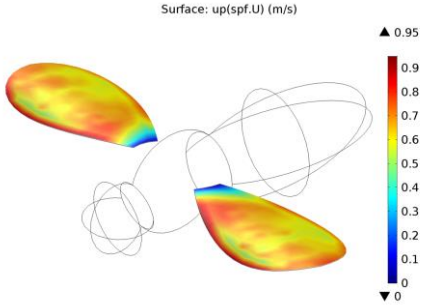
- Typical CFD results

Zero Degree Stroke Angle

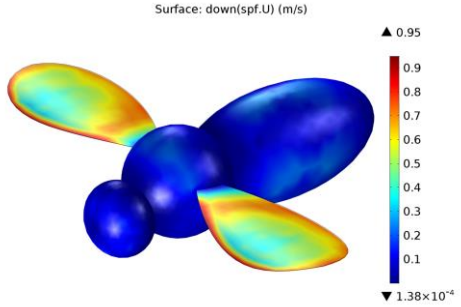
- Velocity stream line of virtual wind tunnel with bumble bee.



Streamline Velocity

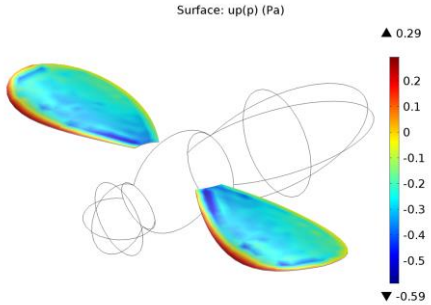


Upside Velocity

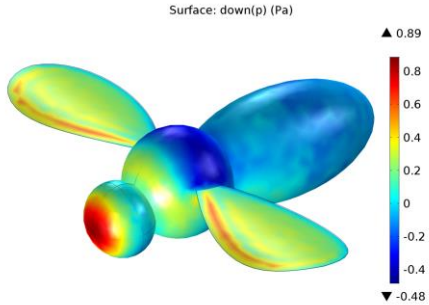


Downside Velocity

- The velocity and Pressure contour plot for upside and downside of Bumblebee at 0° Stroke Angle



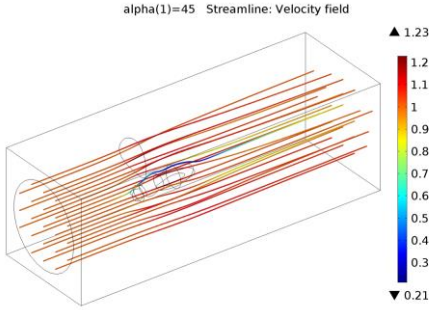
Upside Pressure



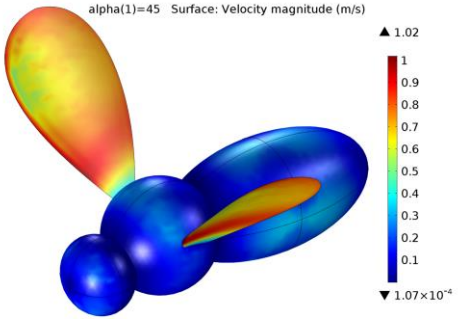
Downside Pressure

Bumblebee CFD Results Up Stroke

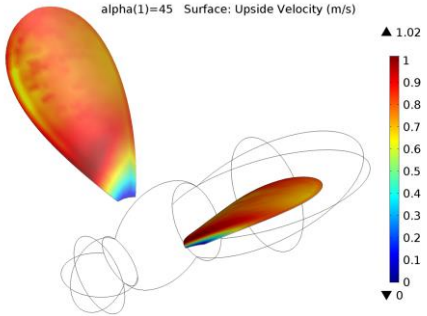
- Typical CFD results (V) for up stroke (45 Degree Stroke Angle)
- Velocity stream line of virtual wind tunnel with bumble bee.
- Velocity contour plots at 45°.
- The velocity magnitudes around the bumblebee is derived and plotted graphically.



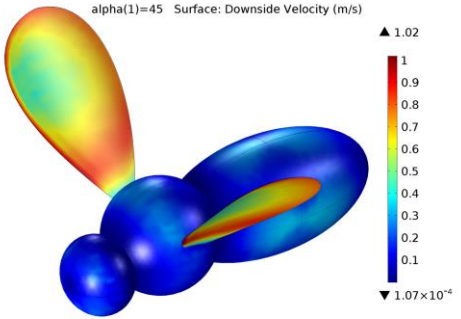
Streamline Velocity



Surface Velocity



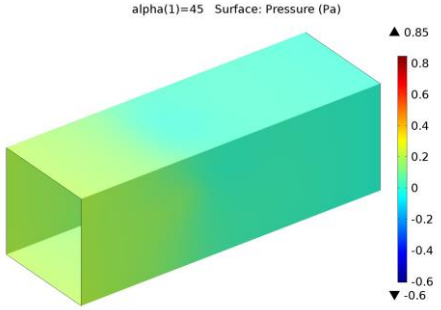
Upside Velocity



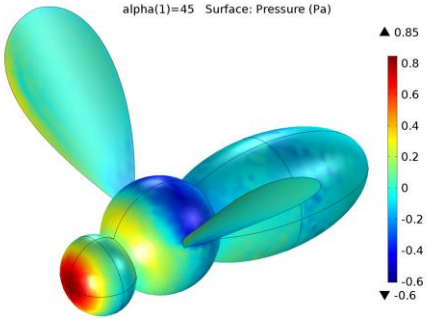
Downside Velocity

Bumblebee CFD Results Up Stroke

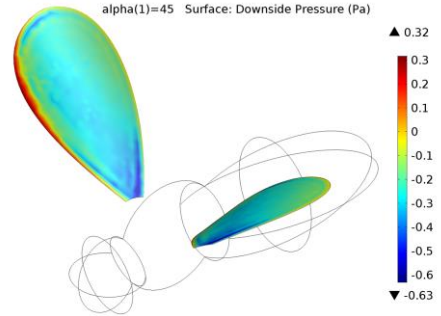
- Typical CFD results (P), up stroke (45 Degree Stroke Angle)
- Pressure distribution of virtual wind tunnel with bumble bee.
- Pressure contour plots at 45°.
- The pressure magnitudes around the bumblebee is derived and plotted graphically.



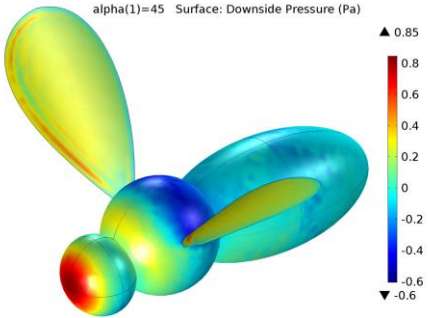
Chamber Pressure



Surface Pressure



Upside Pressure



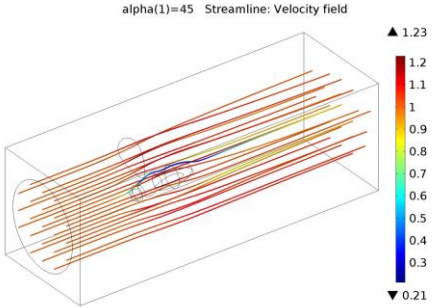
Downside Pressure

Bumblebee CFD Results PV Up Stroke

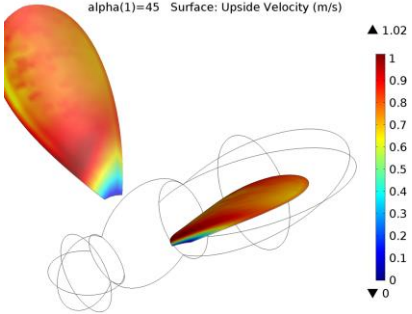
- Typical CFD results (PV) for up stroke (45 Degree Stroke Angle)

- Velocity stream line of virtual wind tunnel with bumble bee

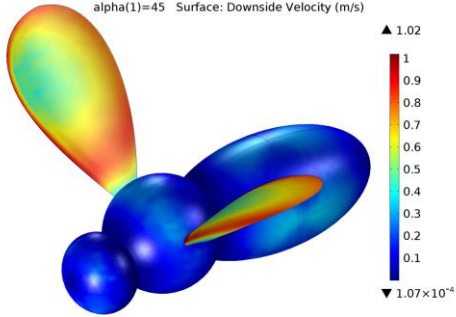
- The velocity and pressure contour plot for upside and downside of bumblebee for up stroke 45°



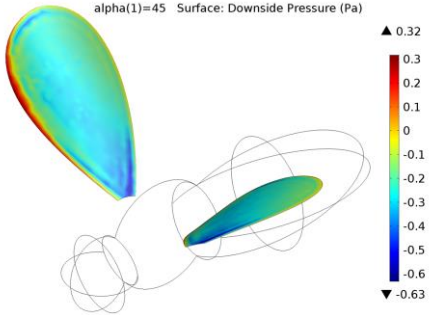
Streamline Velocity



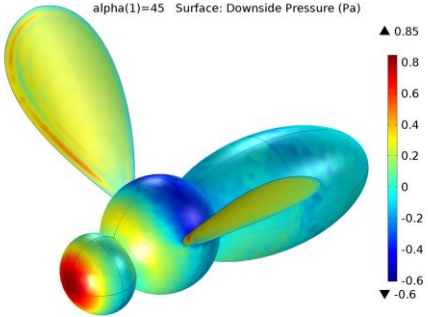
Upside Velocity



Downside Velocity



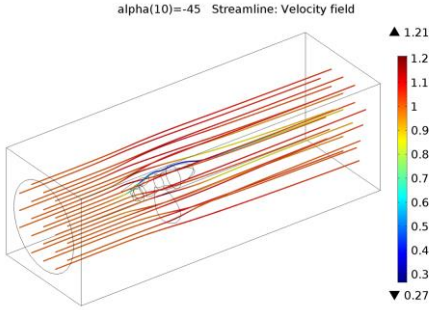
Upside Pressure



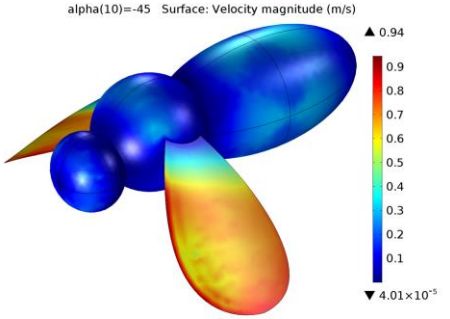
Downside Pressure

Bumblebee CFD Results Down Stroke

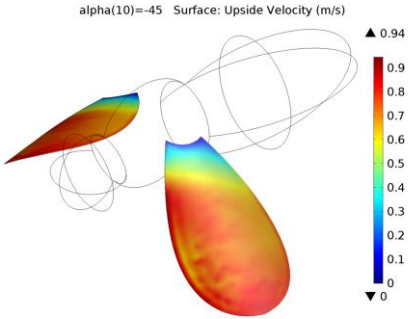
- Typical CFD results for Down stroke (-45 Degree Stroke Angle)
- Velocity stream line of virtual wind tunnel with bumble bee.
- Velocity contour plots at -45°.
- The velocity magnitudes around the bumblebee is derived and plotted graphically.



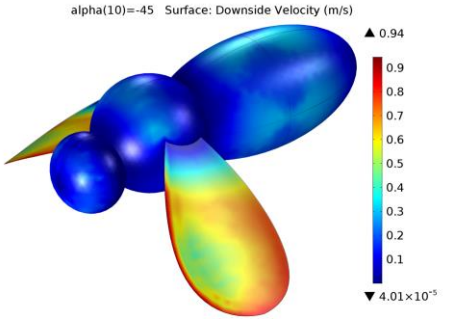
Streamline Velocity



Surface Velocity



Upside Velocity



Downside Velocity

Bumblebee CFD Results Down Stroke

- Typical CFD results (P), Down stroke (-45 Degree Stroke Angle)
- Pressure distribution of virtual wind tunnel with bumble bee.
- Pressure contour plots at -45°.
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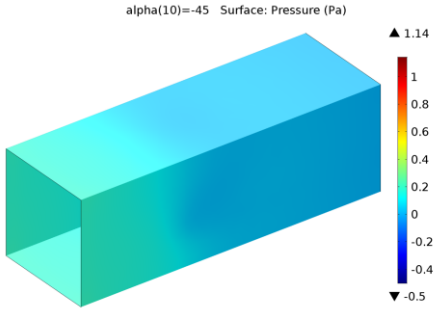
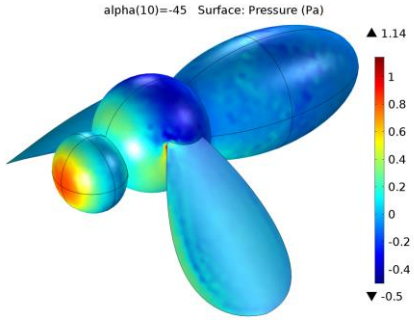
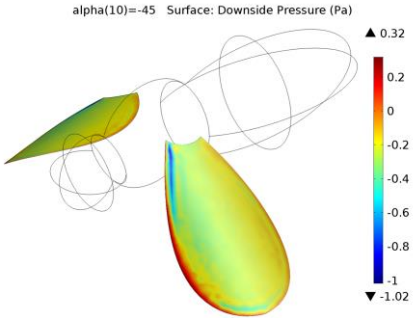


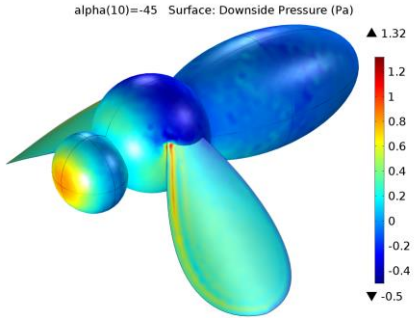
Chamber Pressure



Surface Pressure



Upside Pressure

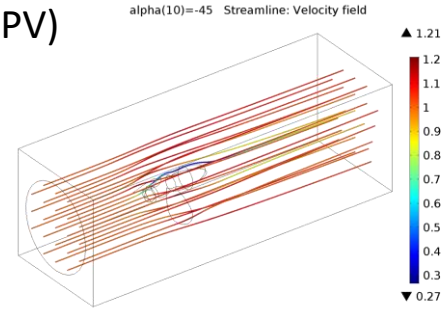


Downside Pressure

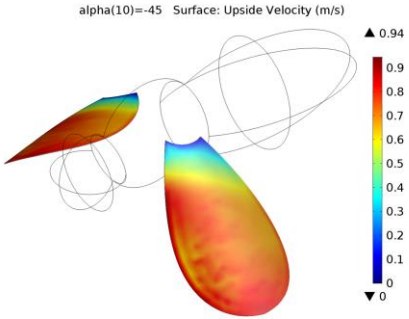
Bumblebee CFD Results PV D Stroke

- Typical CFD results (PV) for Down stroke (-45°)

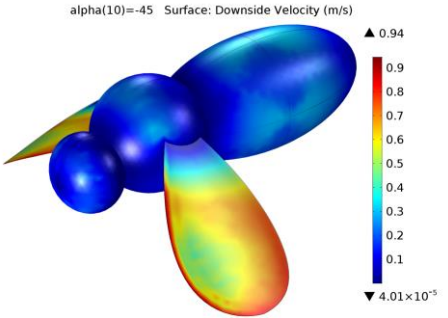
- Velocity stream line of virtual wind tunnel with bumble bee.



Streamline Velocity

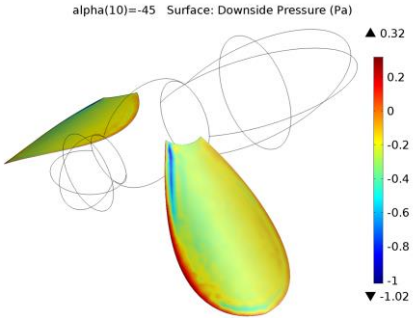


Upside Velocity

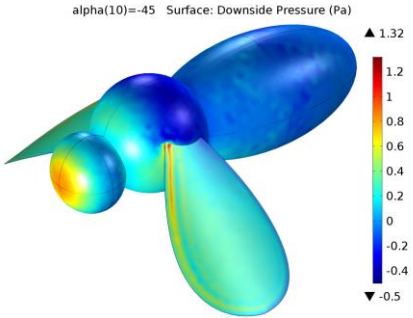


Downside Velocity

- The velocity and pressure contour plot for upside and downside of bumblebee for down stroke -45°



Upside Pressure



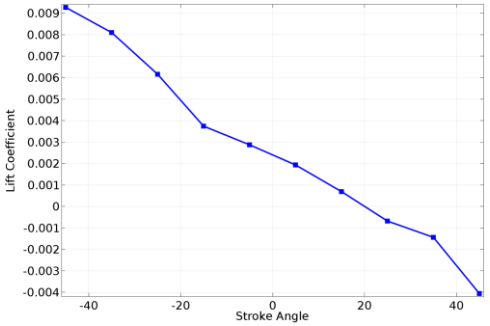
Downside Pressure

Bumblebee CFD Results Summary

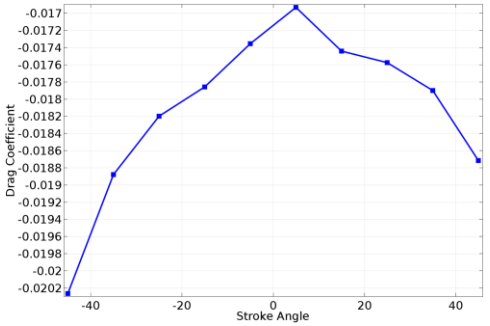
- Derived and plotted graphically from Stroke angle DoE.

- Lift Coefficient (Cl)
- Drag Coefficient(Cd)
- Cl, Cd vs Stroke angle
- Drag polar

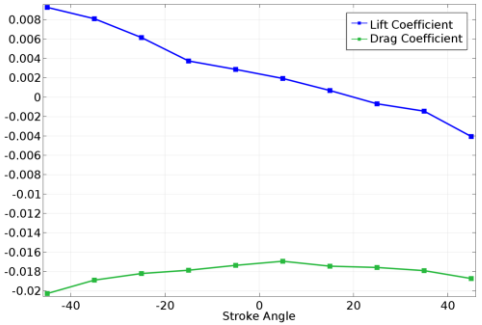
- To asses the flight performance



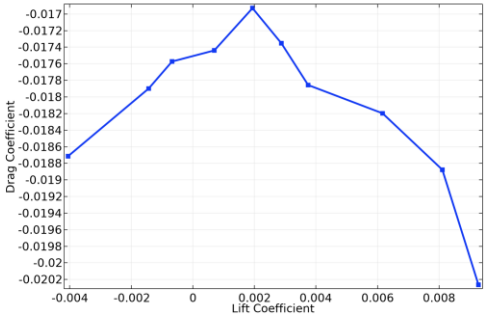
Lift Coefficient (Cl)



Drag Coefficient (Cd)



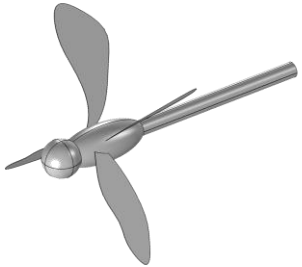
Cl, Cd vs Stroke Angle



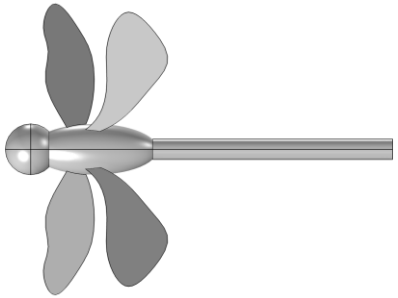
Cl vs Cd

Dragonfly CAD and CFD

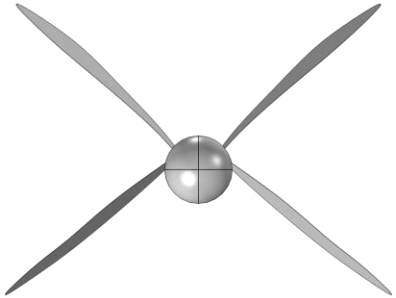
- Parametric CAD Model
- Typical CFD results for various counter rotating stroke angle.
- The velocity and pressure contour plots of flying animation.



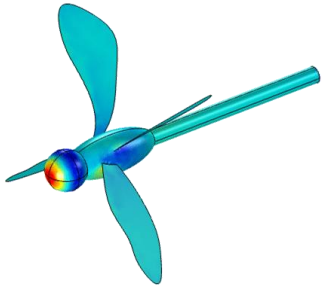
Isometric View



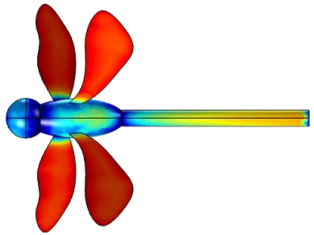
Top View



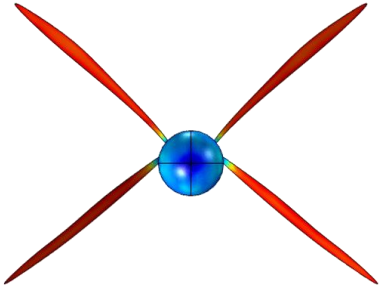
Front View



Pressure



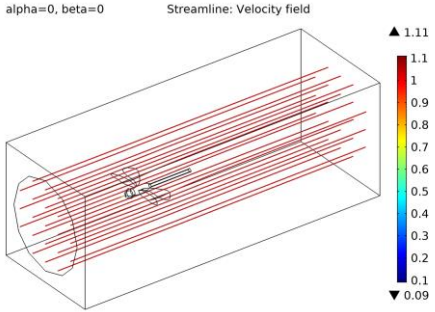
Velocity



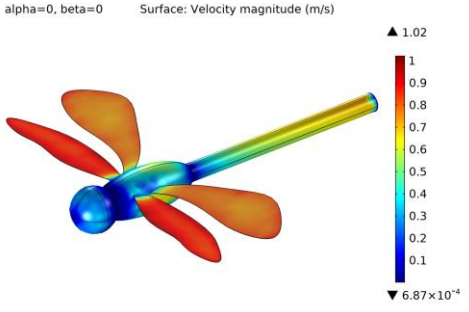
Velocity

Dragonfly CFD Results V

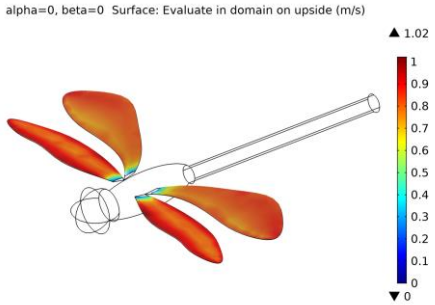
- Typical CFD results (V), Zero Degree Stroke Angle
- Velocity stream line of virtual wind tunnel with bumble bee.
- Velocity contour plots at 0^{o}.
- The velocity magnitudes around the bumblebee is derived and plotted graphically.



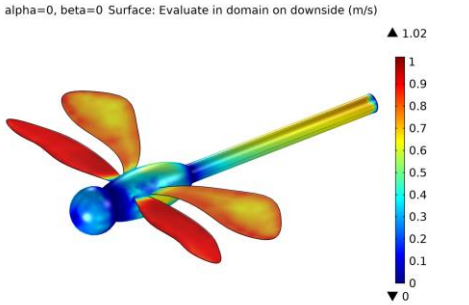
Streamline Velocity



Surface Velocity



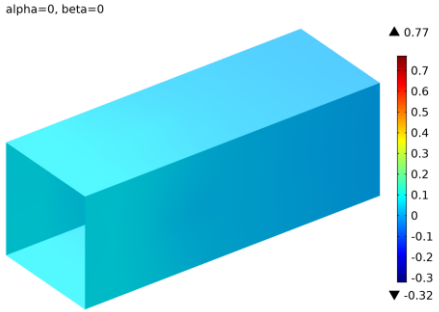
Upside Velocity



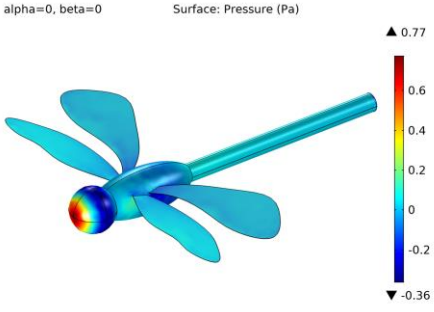
Downside Velocity

Dragonfly CFD Results P

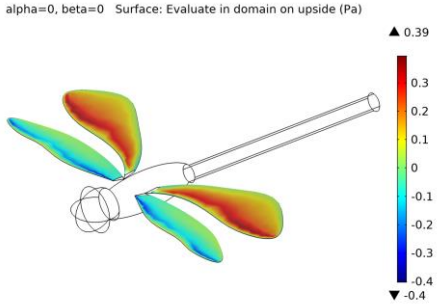
- Typical CFD results (P), Zero Degree Stroke Angle
- Pressure distribution of virtual wind tunnel with dragonfly
- Pressure contour plots at 0^{o}
- The pressure magnitudes around the dragonfly is derived and plotted graphically



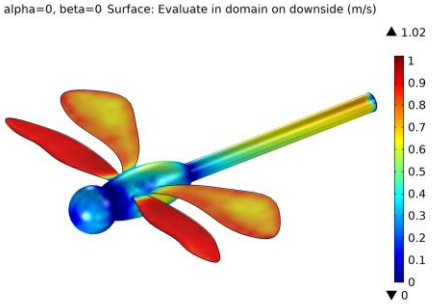
Chamber Pressure



Surface Pressure



Upside Pressure

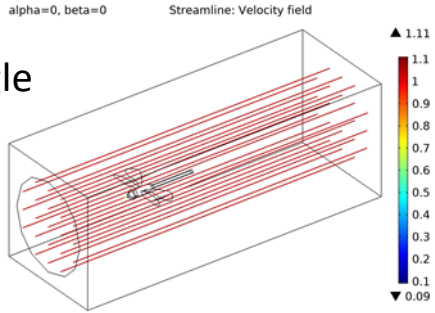


Downside Pressure

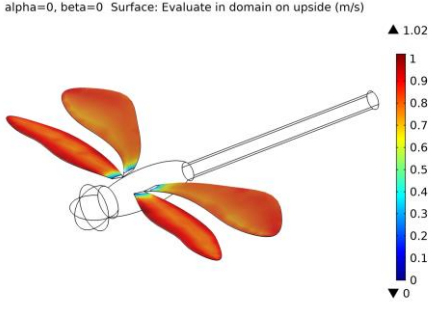
Dragonfly CFD Results PV

- Typical CFD results Zero Degree Stroke Angle

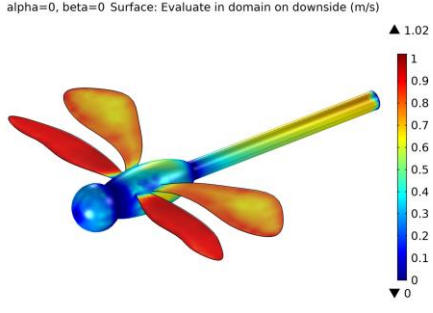
- Velocity stream line of virtual wind tunnel with dragonfly



Streamline Velocity

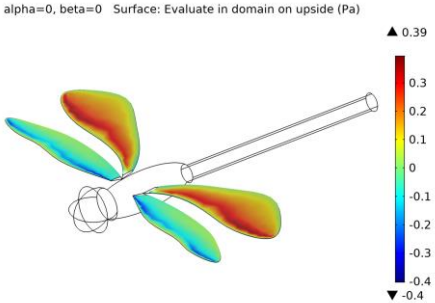


Upside Velocity

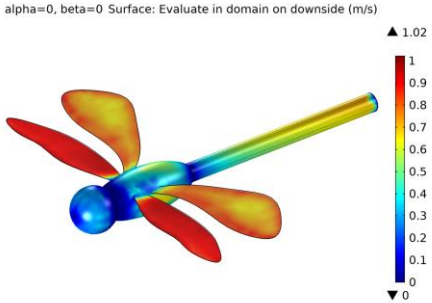


Downside Velocity

- The velocity and pressure contour plot for upside and downside of dragonfly at 0^{o} stroke angle



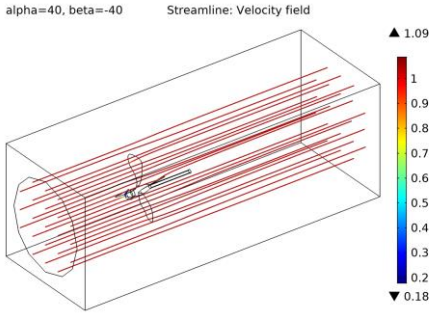
Upside Pressure



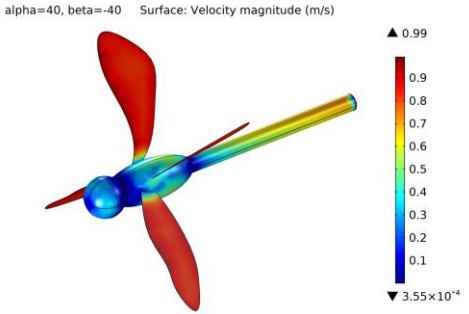
Downside Pressure

Dragonfly CFD Results V FWD Stroke

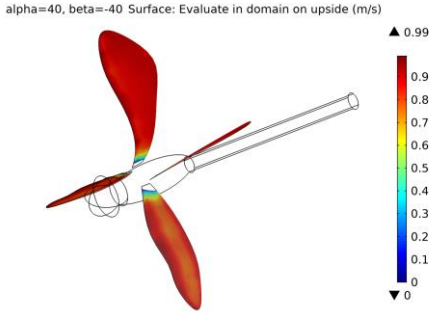
- Typical CFD results for foreword down stroke, back up stroke
- Velocity stream line of virtual wind tunnel with dragonfly
- Velocity contour plots at alpha 40^{o}, beta -40^{o}
- The velocity magnitudes around the dragonfly is derived and plotted graphically



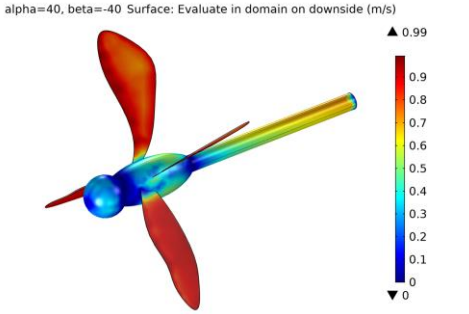
Streamline Velocity



Surface Velocity



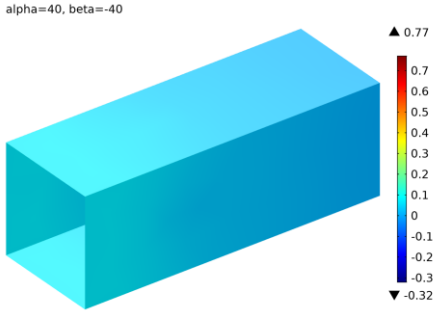
Upside Velocity



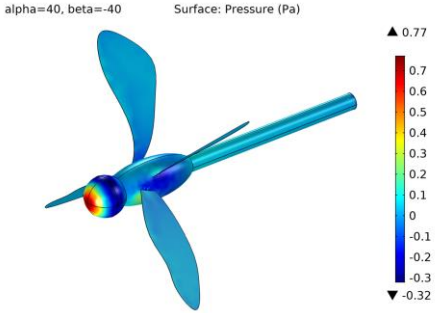
Downside Velocity

Dragonfly CFD Results P FWD Stroke

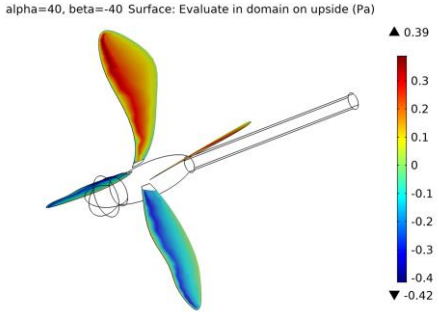
- Typical CFD results for foreword down stroke, back up stroke
- Pressure distribution of virtual wind tunnel with dragonfly
- Pressure contour plots at alpha 40°, beta -40°
- The pressure magnitudes around the dragonfly is derived and plotted graphically



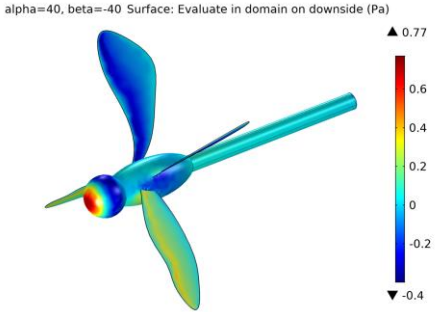
Chamber Pressure



Surface Pressure



Upside Pressure

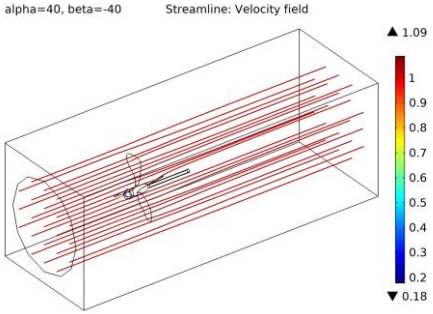


Downside Pressure

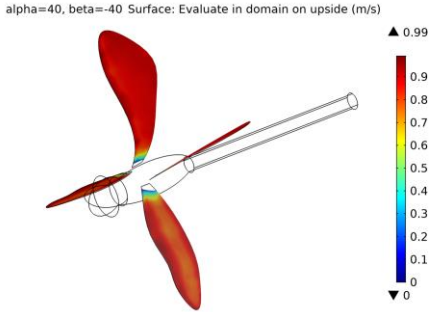
Dragonfly CFD Results PV FWD Stroke

- Typical CFD results (I for foreword down strok back up stroke

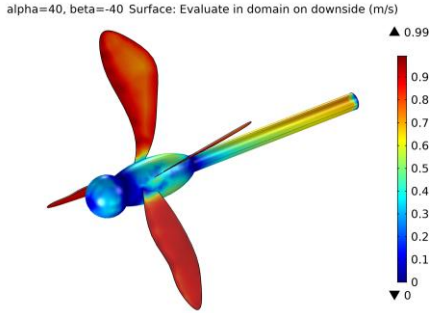
- Velocity stream line of virtual wind tunnel with dragonfly



Streamline Velocity

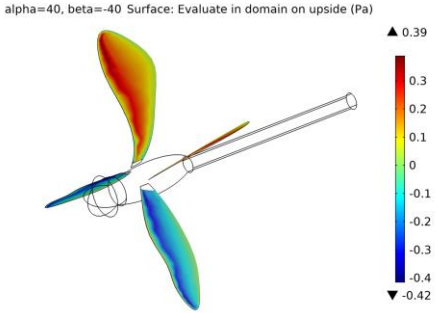


Upside Velocity

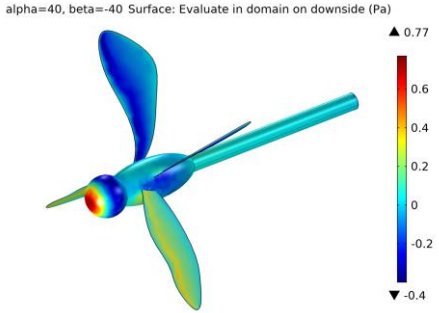


Downside Velocity

- The velocity and pressure contour plot for upside and downside of dragonfly for Forward down stroke (-40^{o})
- Backward up stroke (40^{o})



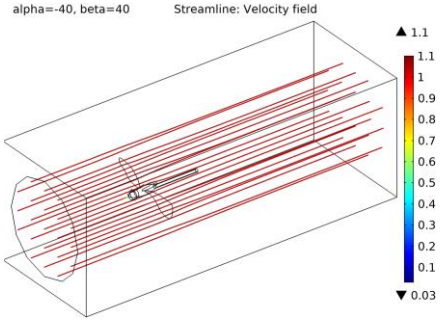
Upside Pressure



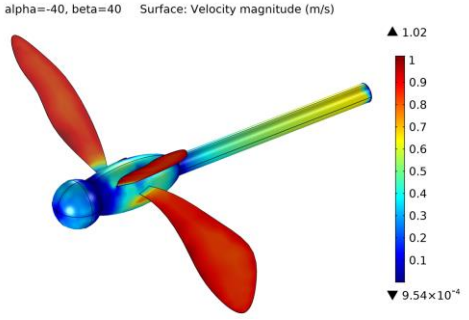
Downside Pressure

Dragonfly CFD Results V FUP Stroke

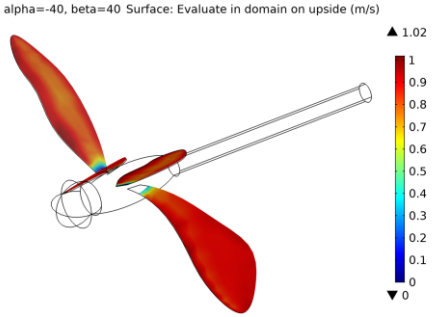
- Typical CFD results for foreword up stroke, back down stroke
- Velocity stream line of virtual wind tunnel with dragonfly
- Velocity contour plots at alpha -40^{o}, beta 40^{o}
- The velocity magnitudes around the dragonfly is derived and plotted graphically



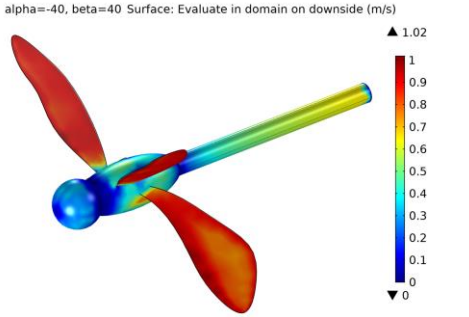
Streamline Velocity



Surface Velocity



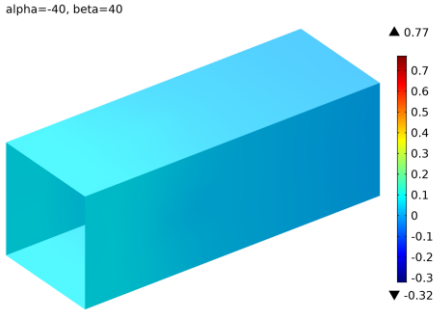
Upside Velocity



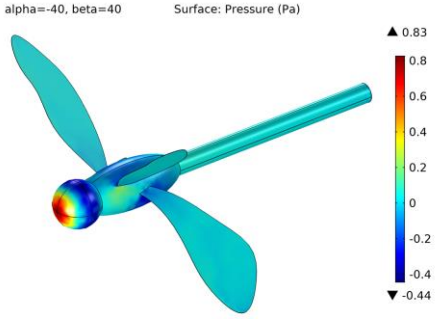
Downside Velocity

Dragonfly CFD Results P FUP Stroke

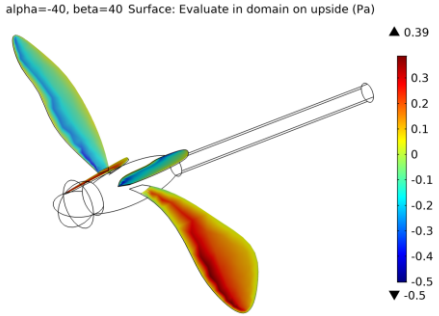
- Typical CFD results for foreword up stroke, back down stroke
- Pressure distribution of virtual wind tunnel with dragonfly.
- Pressure contour plots at alpha -40°, beta 40°
- The pressure magnitudes around the dragonfly is derived and plotted graphically.



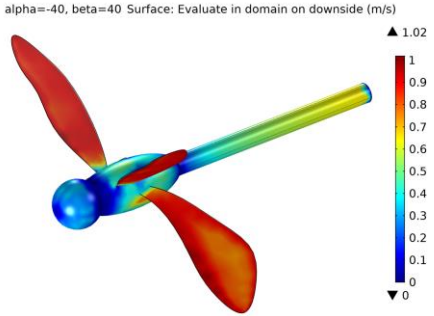
Chamber Pressure



Surface Pressure



Upside Pressure

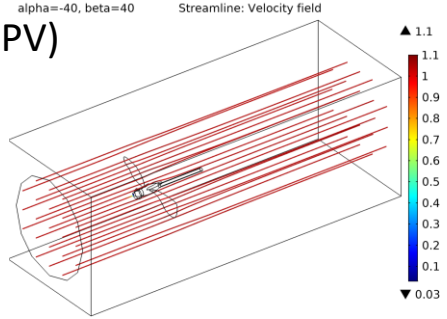


Downside Pressure

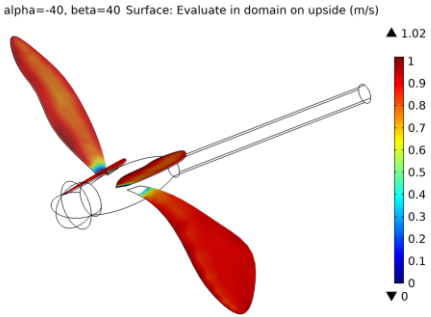
Dragonfly CFD Results PV FUP Stroke

- Typical CFD results (PV) for foreword up stroke back down stroke

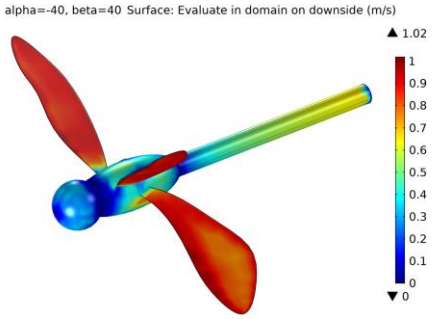
- Velocity stream line of virtual wind tunnel with dragonfly .



Streamline Velocity

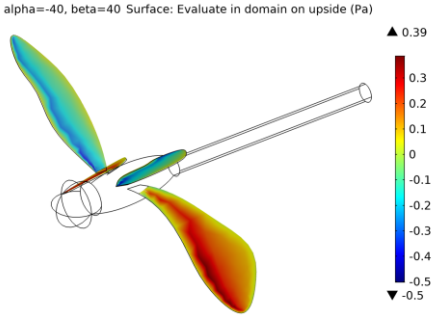


Upside Velocity

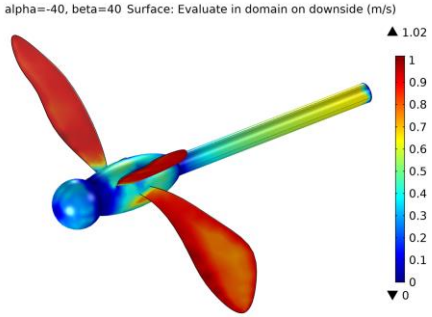


Downside Velocity

- The velocity and Pressure contour plot for upside and downside of Dragonfly for foreword up stroke (40^{o}) , Backward down stroke (-40^{o})



Upside Pressure



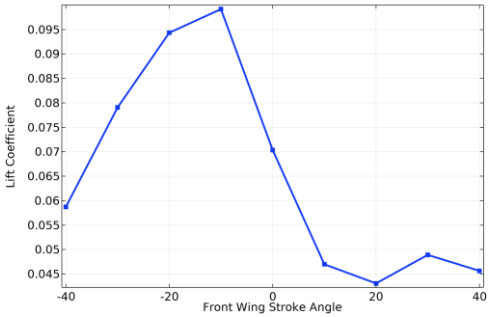
Downside Pressure

Dragonfly CFD Results SUMMARY

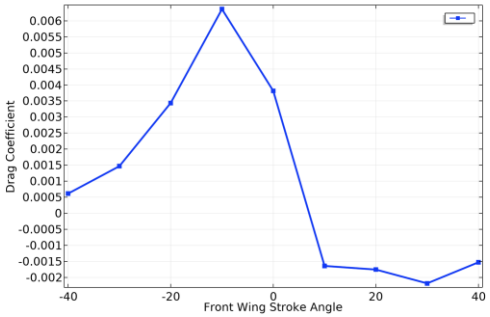
- Derived and plotted graphically from alpha, beta stroke angle DoE.

- Lift Coefficient (Cl)
- Drag Coefficient(Cd)
- Cl, Cd vs Stroke angle
- Drag polar

- To asses the flight performance

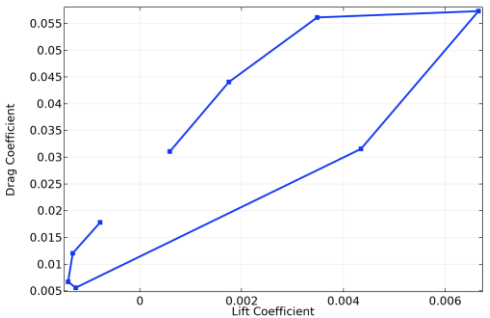


Lift Coefficient (Cl)



Drag Coefficient (Cd)

Cl, Cd vs Stroke Angle



Cl vs Cd

Conclusion and Future work

- Brief review of birds and insect flight was outlined with an overview of insect flight mechanics.
- The virtual wind tunnel setup to study the steady and unsteady aerodynamic behaviour were detailed.
- The aerodynamics parameters, the Lift Coefficient (Cl), Drag Coefficient (Cd) at different stroke angles helped us assess the flight performance of the insects at forward flight.
- Post-processed fluid velocity and pressure distribution contour plots and flight parameters at different flapping wing angles of the insect body and wings were used to study the flight performance.
- The insects model in the virtual wind tunnel can be scaled up to study biomimetic lightweight personal air transporters and also drones for general purpose short haul air cargo transportation.

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