Vortical structures arising out of mutual interaction between wing and tip mounted propellers

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Why Electric-Powered Airplanes Are Headed for Takeoff

By Benedikt Kammel, Oliver Sachgau, and Tara Patel

Greener skies. PHOTOGRAPHER: JASPER JUINEN

Why aren't there electric airplanes yet?

November 27, 2018 10.41pm AEDT

Building an electric airplane is very different from building an electric car or truck.

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As electric cars and trucks appear increasingly on U.S. highways, it raises the question: When will commercially viable electric vehicles take to the skies? There are a number of ambitious efforts to build electric-powered airplanes, including regional jets and planes that can cover longer distances. Electrification is starting to enable a type of air travel that many have been hoping for, but haven't seen yet – a flying car.

A key challenge in building electric aircraft involves how much energy can be stored in a given amount of weight of the on-board energy source. Although best batteries store about 40 times less energy per unit of weight than jet fuel, greater share of their energy is available to drive motion. Ultimately, for a given weight, jet fuel contains about 14 times more usable energy than a state-of-the-ar lithium-ion battery.

That makes batteries relatively heavy for aviation. Airline companies are already worried about weight – imposing fees on luggage in part to limit how much planes have to carry. Road vehicles can handle heavier batteries, but there are similar concerns. Our research group has analyzed the weight-energy tradeoff in electric pickup trucks and tractor-trailer or semi-trucks.

SEPTEMBER 20, 2019

Why don't we have electric aircraft?

by Dries Verstraete, The Conversation

Research into low-carbon planes is underway, but we

Why the age of electri upon us

By Tim Bowler
BBC News, Le Bourget, Paris

3 July 2019

Climate change

EVIATION

ric aircraft, Alice, was a hit at the Paris Airshow

Ae rms are joining forces to tackle their industry's growing co on to greenhouse gas emissions, with electric engines seen as one solu n. But will this be enough to offset the growing demand for air travel?

This week's Paris Airshow saw the launch of the world's first commercial all-electric passenger aircraft - albeit in prototype form.

Israeli firm Eviation says the craft - called Alice - will carry nine passengers for up to 650 miles (1,040km) at 10,000ft (3,000m) at 276mph (440km/h). It is expected to enter service in 2022.

Alice is an unconventional-looking craft: powered by three rear-facing pusher-propellers, one in the tail and two counter-rotating props at the winglips to counter the effects of drag. It also has a flat lower fuselage to aid lift.

- **Firms team up on hybrid plane tech**
- **EasyJet backs plan for electric planes**
- **The Disruptors - Up, up and away**

"This plane looks like this not because we wanted to build a cool plane, but because it is electric," says Eviation's chief executive Omer Bar-Yohay.

"You build a craft around your propulsion system. Electric means we can have

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Electric aircraft – the future of aviation or just wishful thinking?

August 21, 2015 3.34pm AEST

A Review of Distributed Electric Propulsion Concepts for Air Vehicle Technology

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The emergence of distributed electric propulsion (DEP) concepts for aircraft systems has enabled new capabilities in the overall efficiency, capabilities, and robustness of future air vehicles. Distributed electric propulsion systems feature the novel approach of utilizing electrically-driven propulsors which are only connected electrically to energy sources or power-generating devices. As a result, propulsors can be placed, sized, and operated with greater flexibility to leverage the synergistic benefits of aero-propulsive coupling and provide improved performance over more traditional designs. A number of conventional aircraft concepts that utilize distributed electric propulsion have been developed, along with various short and vertical takeoff and landing platforms. Careful integration of electrically-driven propulsors for boundary-layer ingestion can allow for improved propulsive efficiency and wake-filling benefits. The placement and configuration of propulsors can also be used to mitigate the trailing vortex system of a lifting surface or leverage increases in dynamic pressure across blown surfaces for increased lift performance. Additionally, the thrust stream of distributed electric propulsors can be utilized to enable new capabilities in vehicle control, including reducing requirements for traditional control surfaces and increasing tolerance of the vehicle control system to engine-out or propulsor-out scenarios. If one or more turboelectric generators and multiple electric fans are used, the increased effective bypass ratio of the whole propulsion system can also enable lower community noise during takeoff and landing segments of flight and higher propulsive efficiency at all conditions. Furthermore, the small propulsors of a DEP system can be installed to leverage an acoustic shielding effect by the airframe, which can further reduce noise signatures. The rapid growth in flight-weight electrical systems and power architectures has provided new enabling technologies for future DEP concepts, which provide flexible operational capabilities far beyond those of current systems. While a number of integration challenges exist, DEP is a disruptive concept that can lead to unprecedented improvements in future aircraft designs.

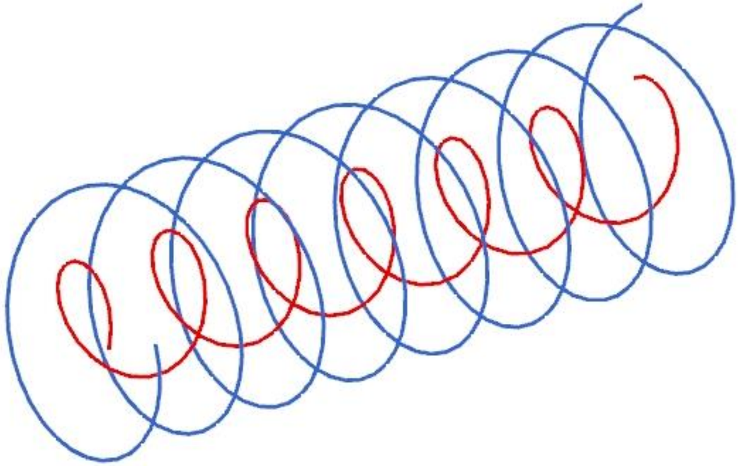
We have entered the age of electric aircraft!!

Some conceptual aircraft with wing tip propellers

Introduction:

Vortices are harder to generate, also once generated it is very hard to destroy. In this case we are not destroying the vorticity completely, but we talk about an attempt to attenuate the vortex especially trailing vortex from the wing. One such method is employing wing tip propellers.

In the present study, attenuation of a vortex of arbitrary strength by means of another vortex of opposite spin is investigated.



Representation of a pair of coaxial counter rotating vortices

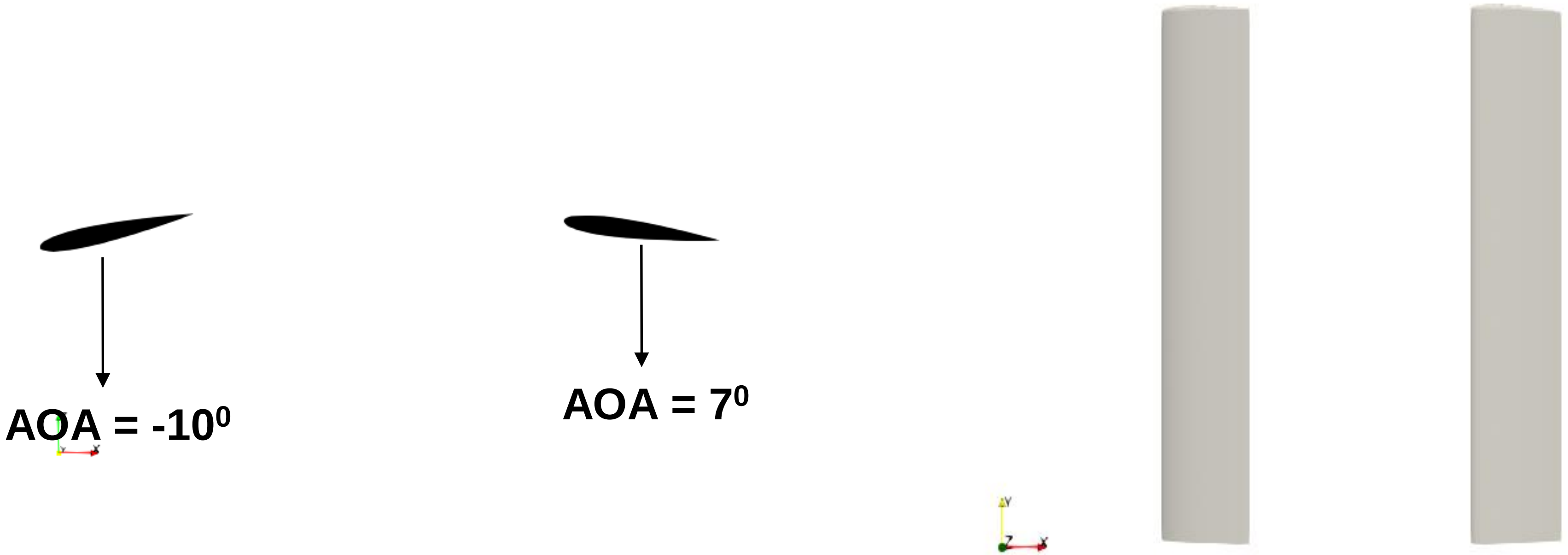
Benefits of employing wingtip propellers:

- Benefit of Reduced induced drag on counter vortex rotation of the propeller.
- Benefit of utilising the induced drag increase at the time of approach and landing on co vortex rotation of the propeller.
- Better roll control.

Note: All these can be achieved by not adding any extra weight to the aircraft, but by changing the placement of the propellers

A simple demonstration of vortex attenuation:

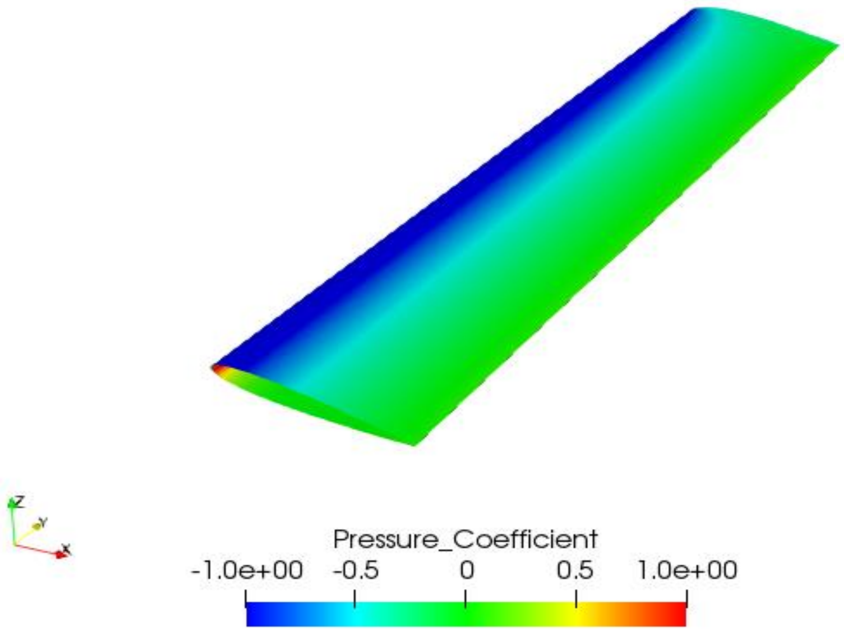
In this demonstration, two wings with NACA 0012 airfoil sections with 1.5 m span and 0.3m chord were placed as shown below. The upstream wing is at an AOA of -10^0 and the downstream wing is at an AOA of 7^0, such that the tip vortices from those wings have opposite spin. **RANS simulation with SA turbulence model** was carried out in SU2 open source CFD tool with symmetry wall boundary condition. For better comparison, simulation of only one wing at an AOA of 7^0 was also performed.



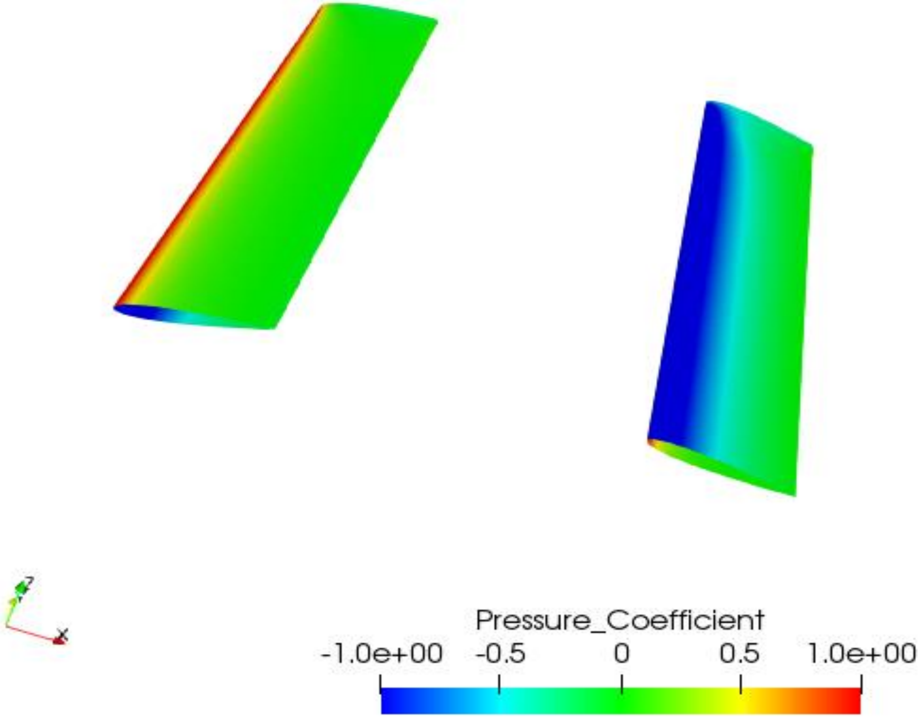
Computational layout for a simple demonstration of vortex attenuation

Coefficient of Pressure contours

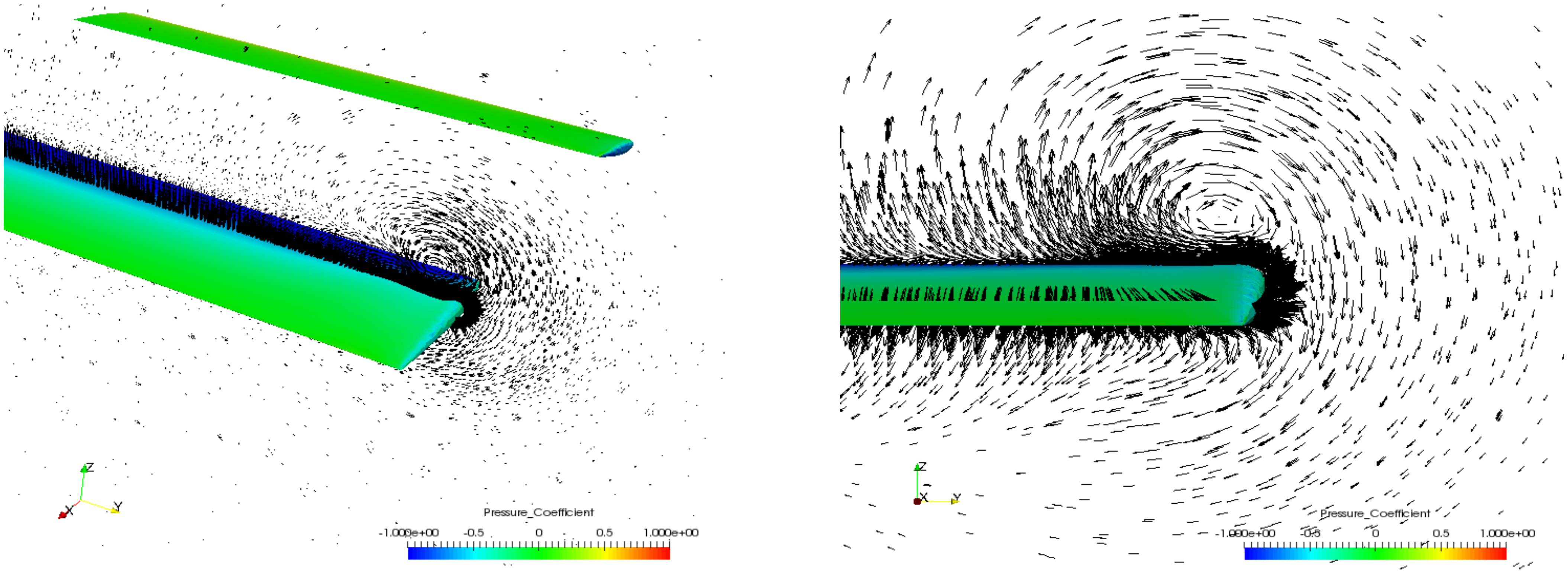
Wing at AOA 7^0



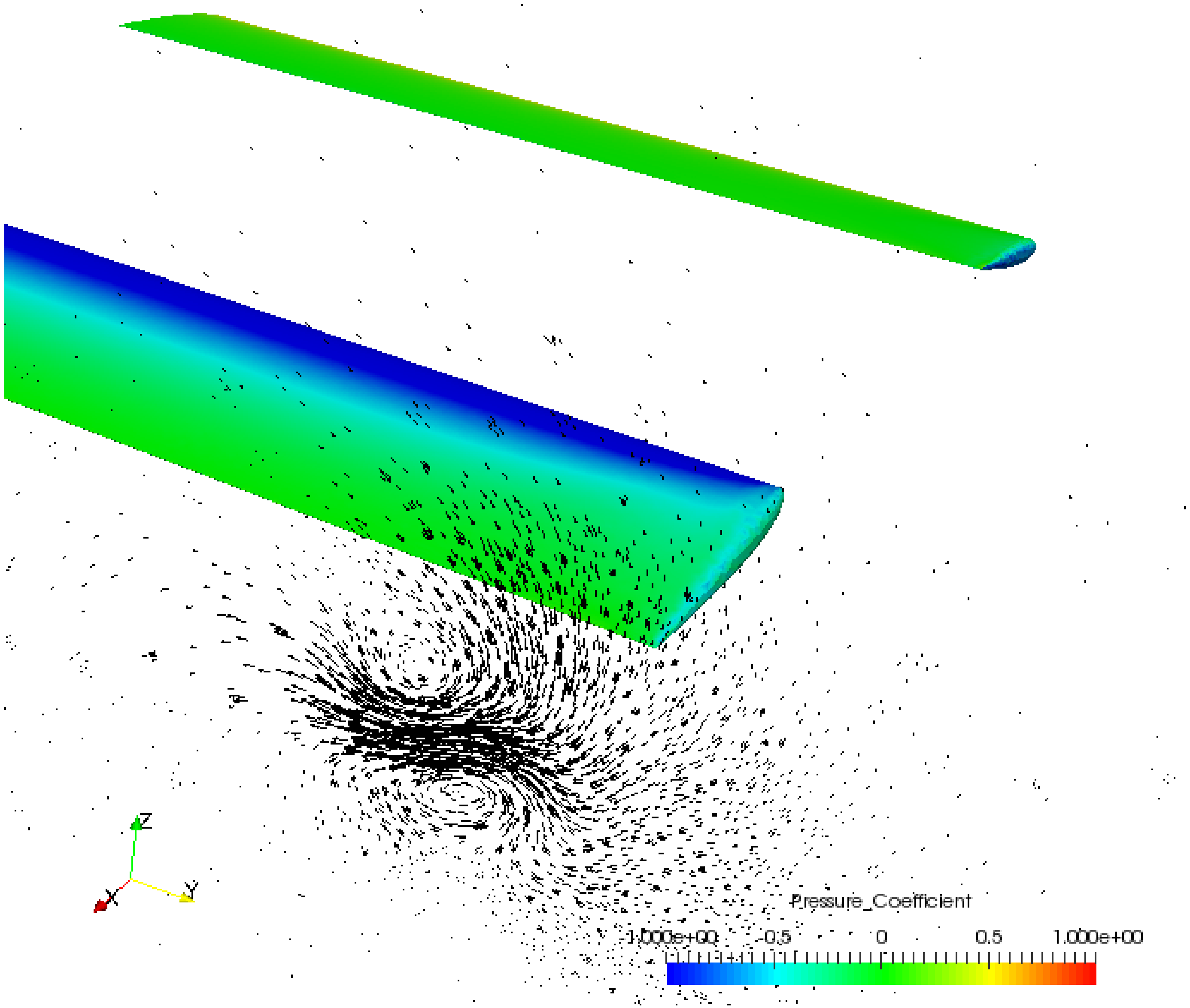
Upstream Wing at AOA -10^0 and Downstream Wing at AOA 7^0



Velocity vectors at the tip of downstream wing:

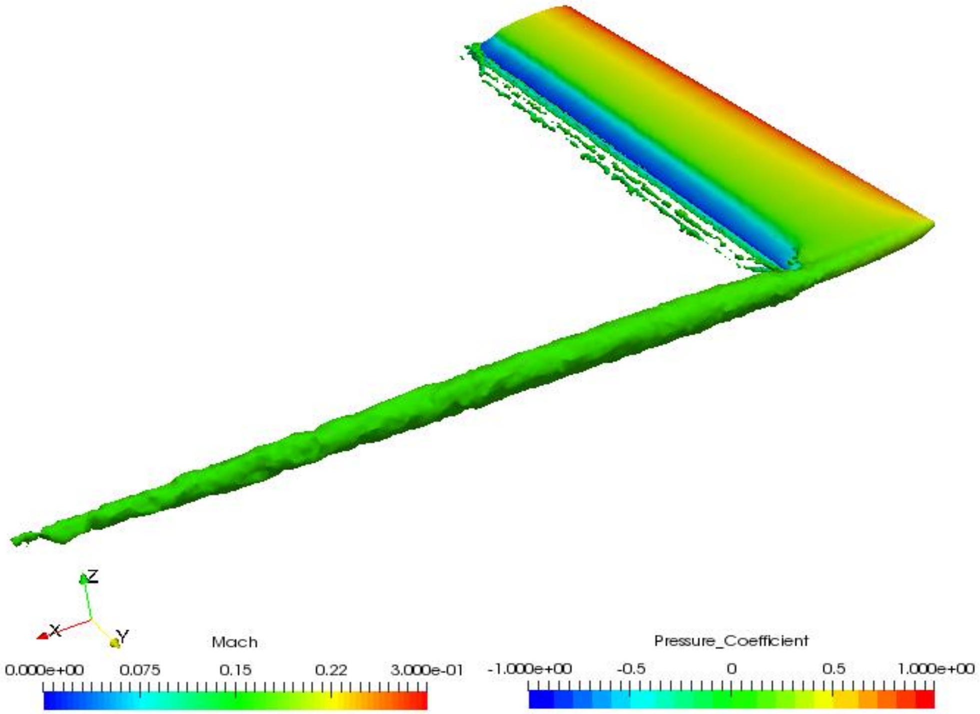


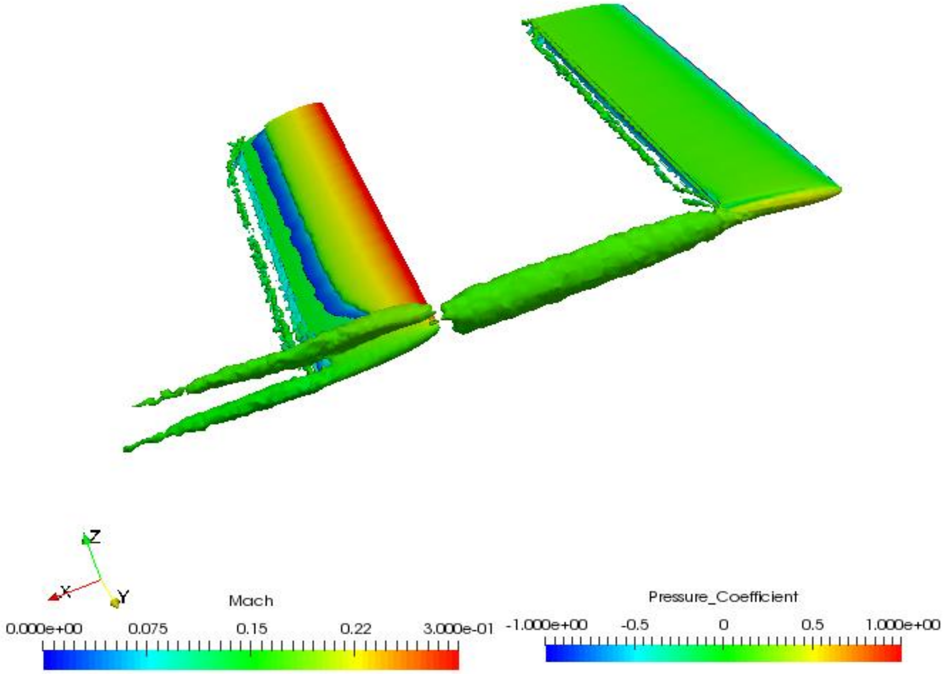
Formation of the secondary vortex on the suction surface of the wing



Secondary vortex convecting downstream along with the primary wing tip vortex of the second wing

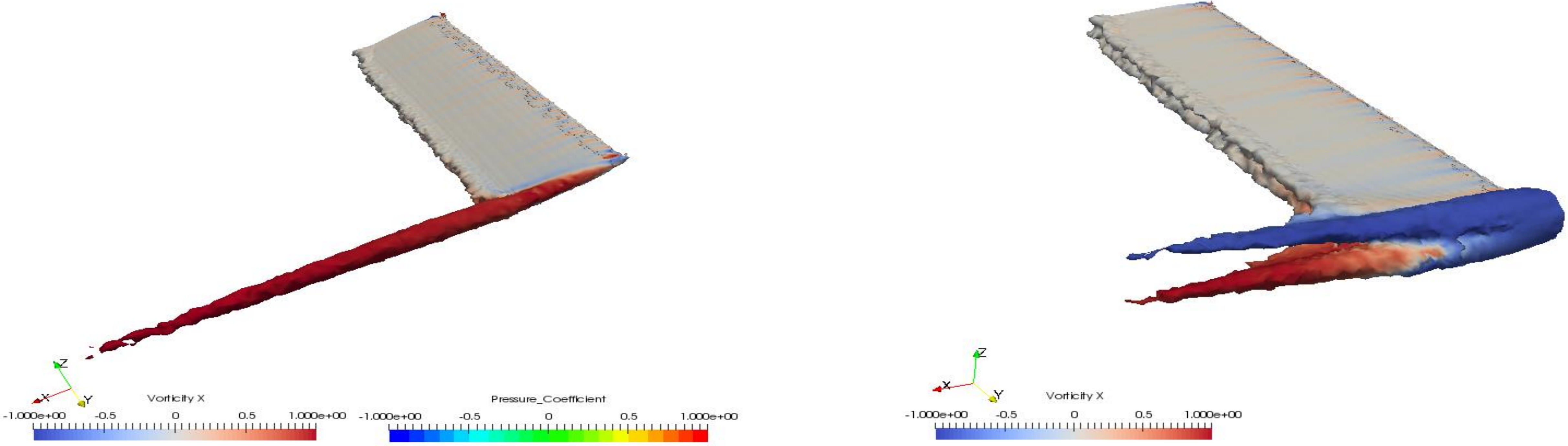
Iso contours of Q-criterion:


Wing at AOA 7^0


Upstream Wing at AOA -10^0 and Downstream Wing at AOA 7^0

Comparison of iso contours of Q-criterion of two wing vortex cancellation simulation and only one wing, shows the attenuation of tip vortex in the two wing configuration.

Iso contours of Vorticity magnitude:



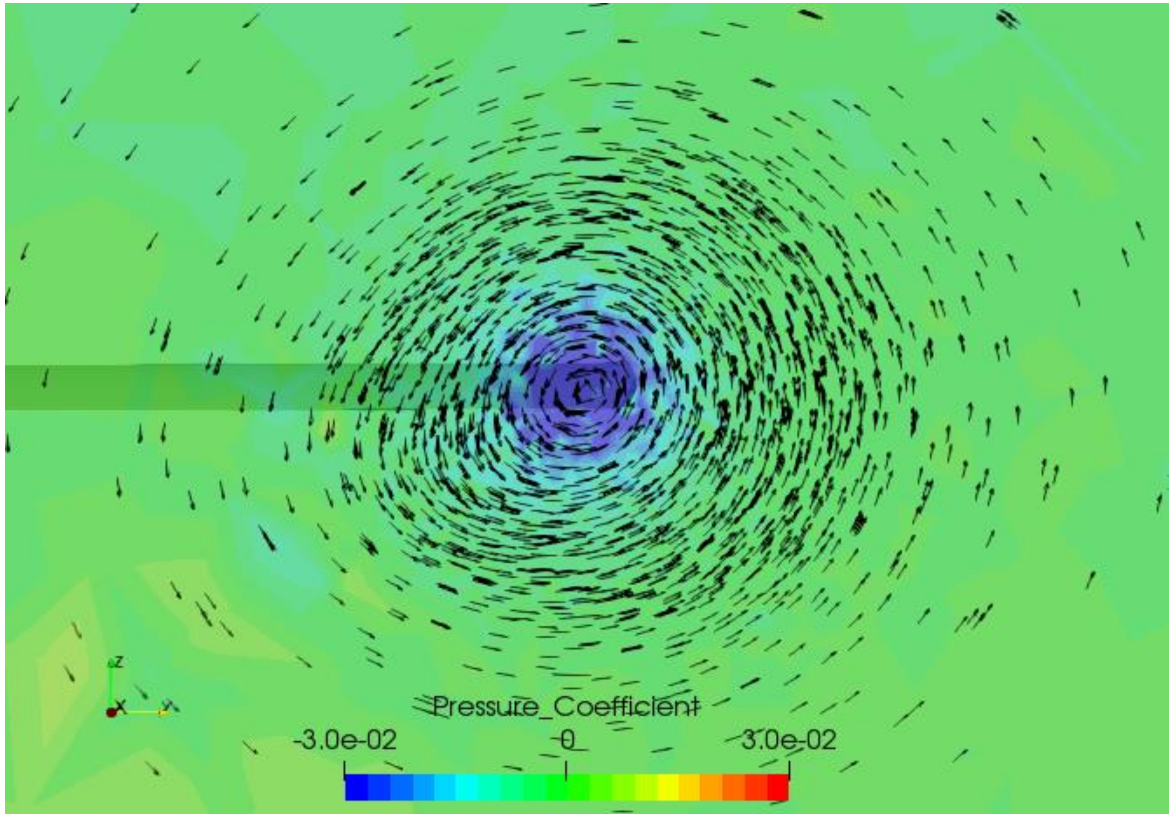
Wing at AOA 7^0

Downstream Wing at AOA 7^0 , in the presence of an upstream wing at AOA -10^0

Comparison of iso contours of vorticity magnitude of two wing vortex cancellation simulation and only one wing

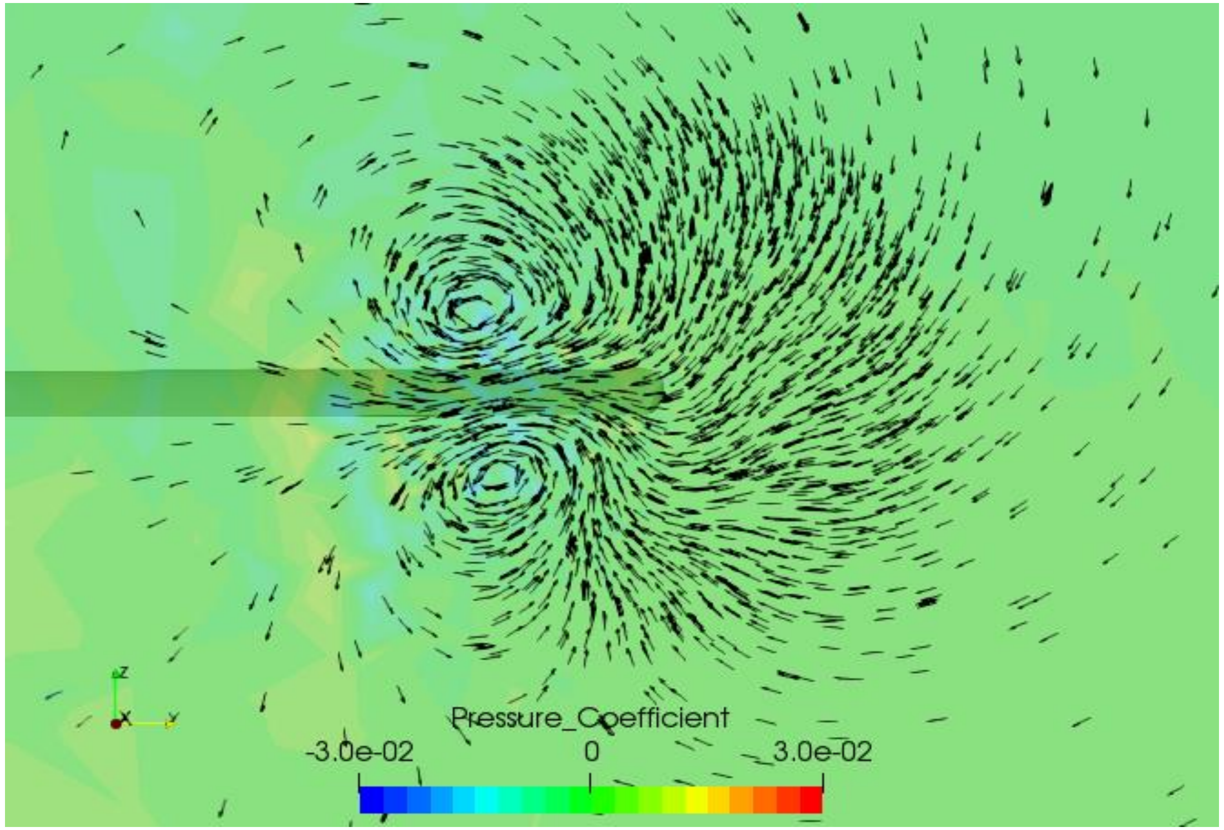
Pressure recovery downstream the wing (C_p contours) :

One wing simulation



Coefficient of pressure contours with velocity vectors one span downstream of the wing(one wing case)

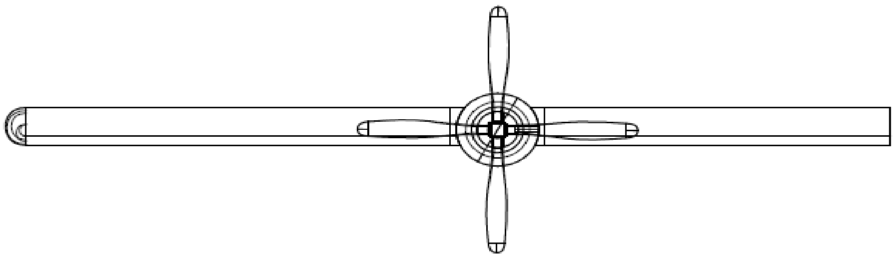
Two wing simulation

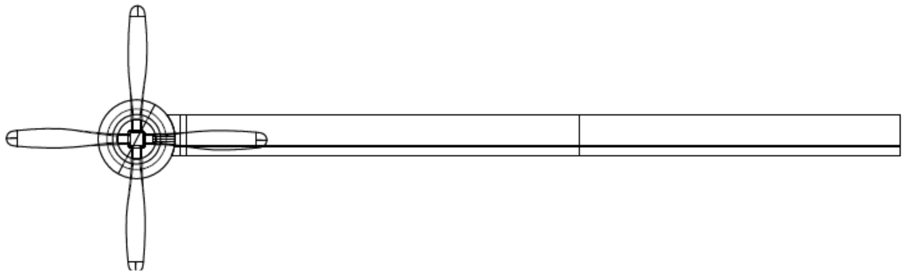


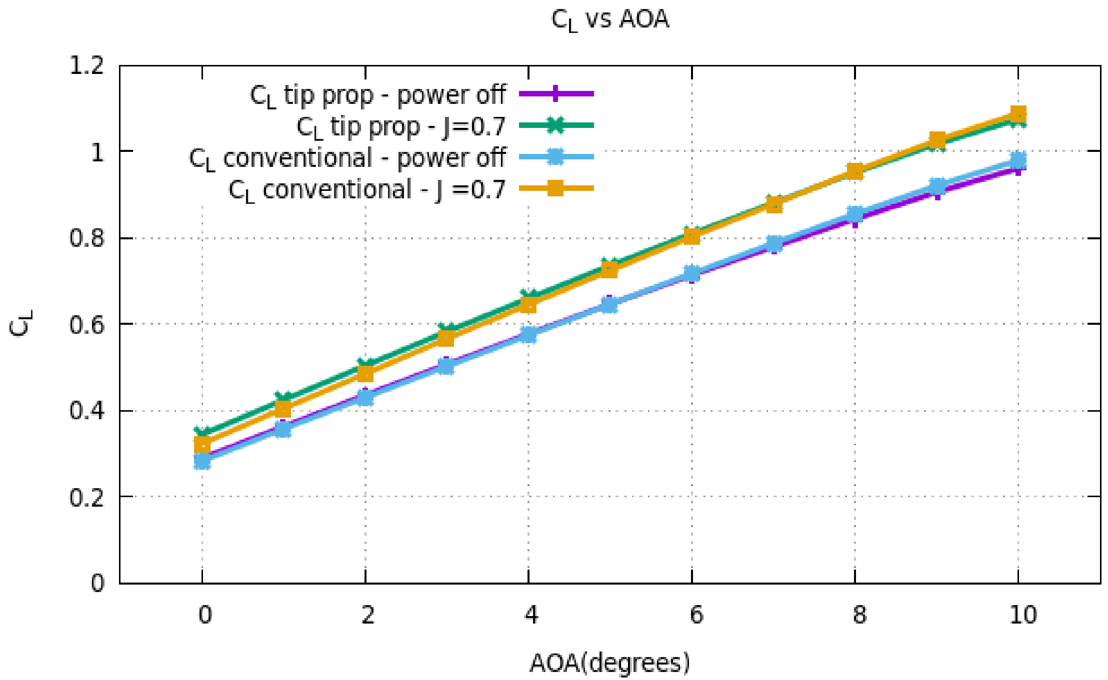
Coefficient of pressure contours with velocity vectors one span downstream of the second wing(two wing case)

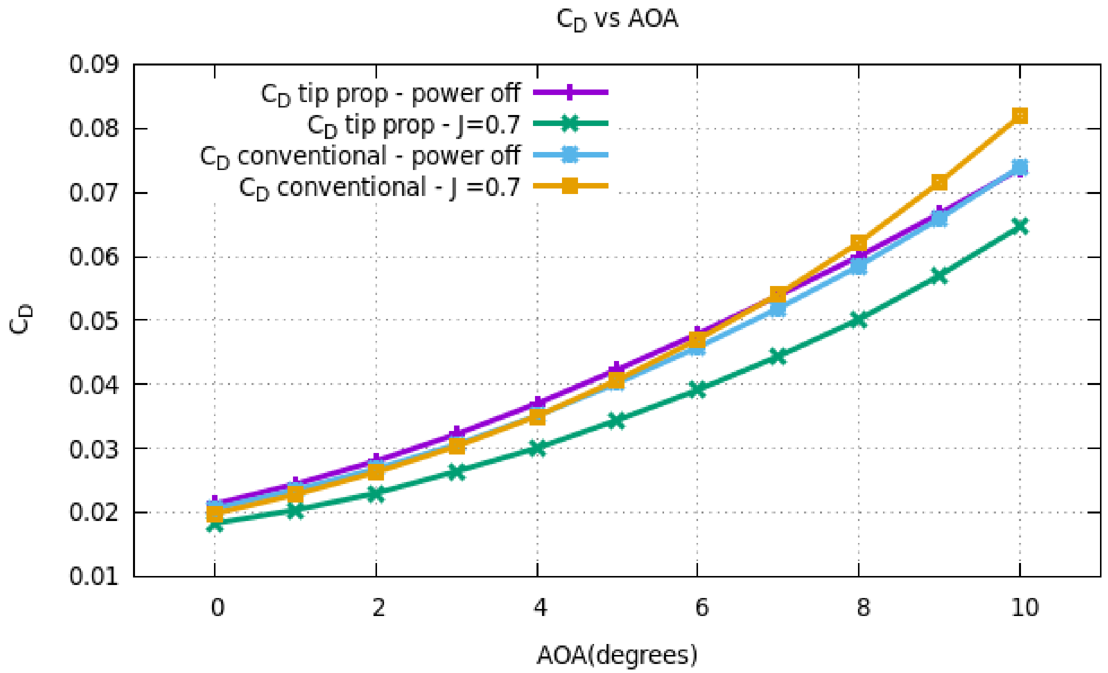
Wing – Propeller interaction studies

Studies in literature (Experiments):







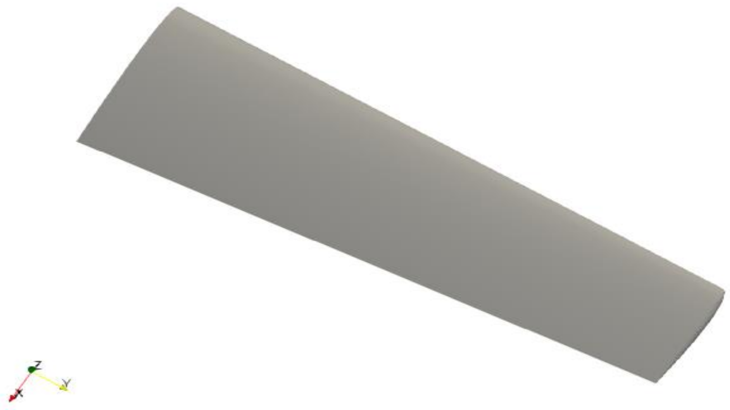


A drastic drag reduction around 5 – 20% is seen when wing tip propellers are used. Also, as the thrust increases, the drag reduction also increases.

Ref: *"Wingtip-Mounted Propellers: Aerodynamic Analysis of Interaction Effects and Comparison with Conventional Layout,"* Tomas Sinnige, Journal of Aircraft, Vol 56., No.1, Jan – Feb 2019.

Results (wing – propeller interaction):

For conducting studies on wing – propeller interaction, a wing with NACA 23018 section at root (0.3652m chord) and NACA 23015 section at the tip (0.24765m chord) and a span of 1.2225m was chosen. The propeller diameter chosen is 0.381m**. RANS simulation with S-A turbulence model** was carried out at a Reynolds number of 1.2 x 10^6 using SU2 open source CFD tool with symmetry wall boundary condition. The propeller was modelled with BEM where propeller geometry and airfoil characteristics at different sections has to be given a priori. **A coupled blade element method solver was used for carrying out the wing – propeller interaction studies.**

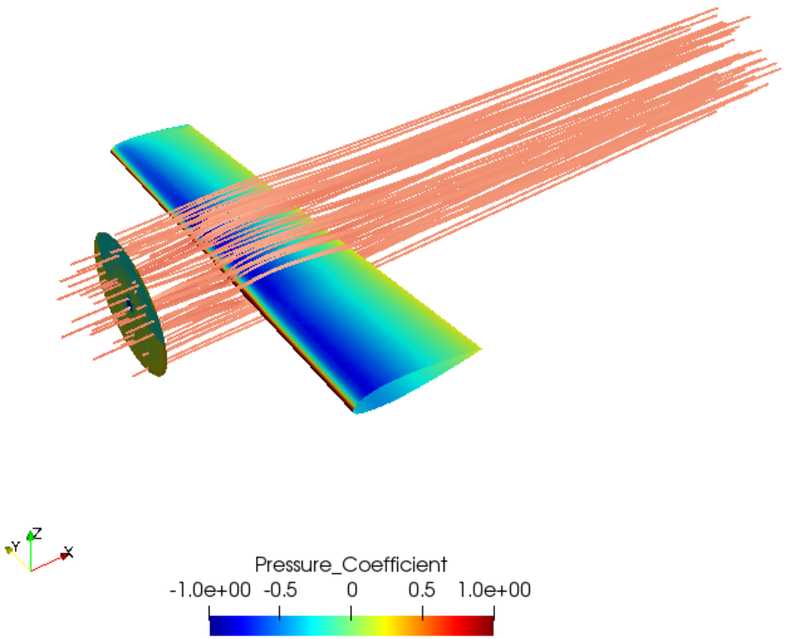


Basic Wing

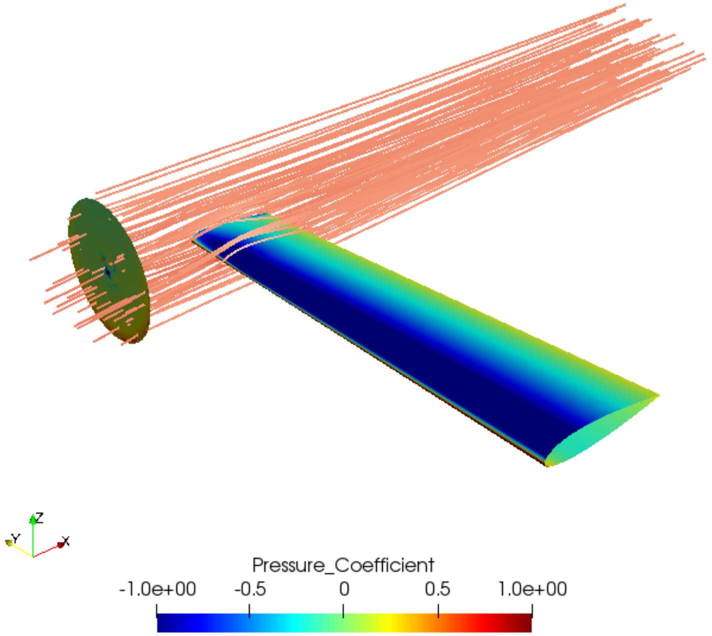
Results (wing – propeller interaction):

Configurations studied:

1. Wing, disk at 0.5 span rotating in the direction of wingtip vortex (co –vortex)
2. Wing, disk at 0.5 span rotating in the opposite direction of wingtip vortex (counter – vortex)
3. Wing, disk at tip rotating in the direction of wingtip vortex (co – vortex)
4. Wing, disk at tip rotating in the opposite direction of wingtip vortex (counter – vortex)



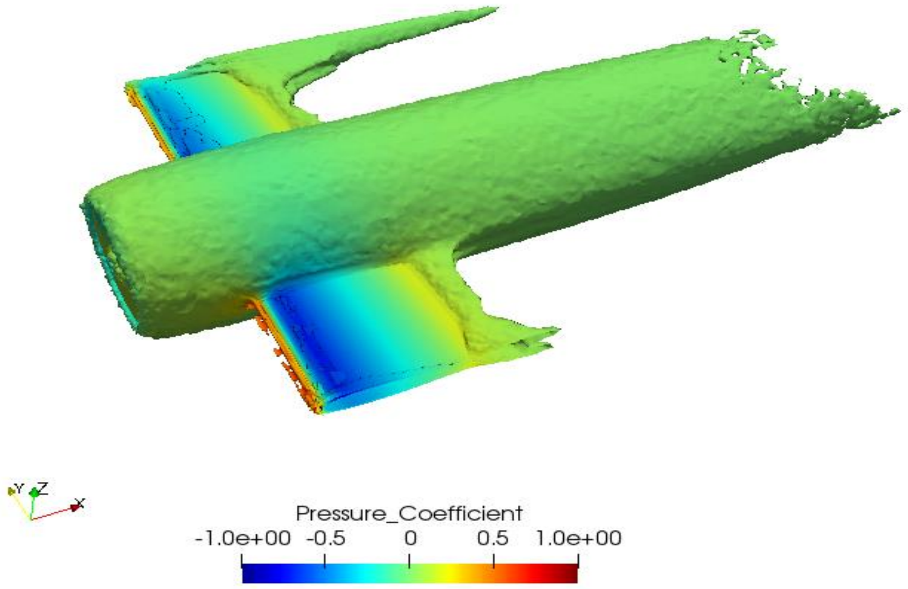
Wing with disk at 0.5 span, stream lines shown through the disk



Wing with disk at tip, stream lines shown through the disk

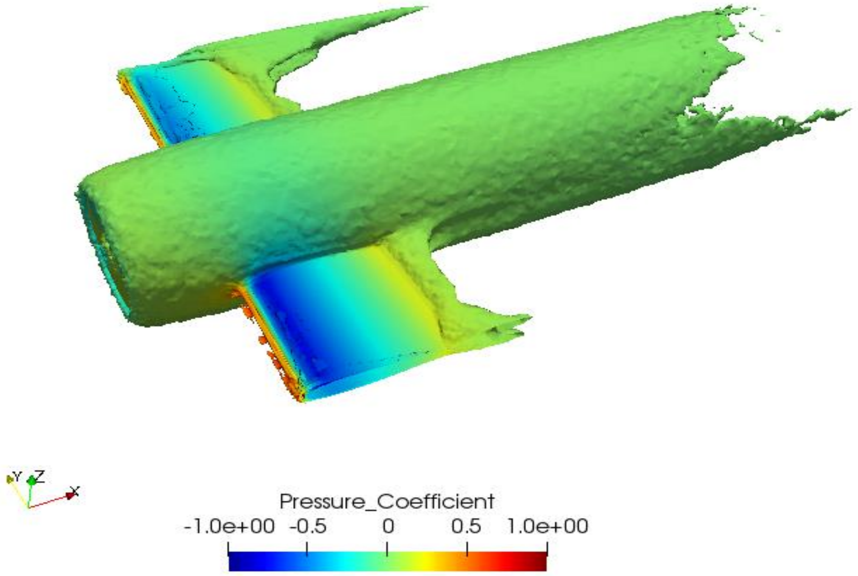
Disk at half span of the wing, AOA = 0 degrees– iso contours of vorticity magnitude

Co – vortex rotation



Iso contours of Magnitude of vorticity coloured with coefficient of pressure at 0^0 AOA.

Counter – vortex rotation

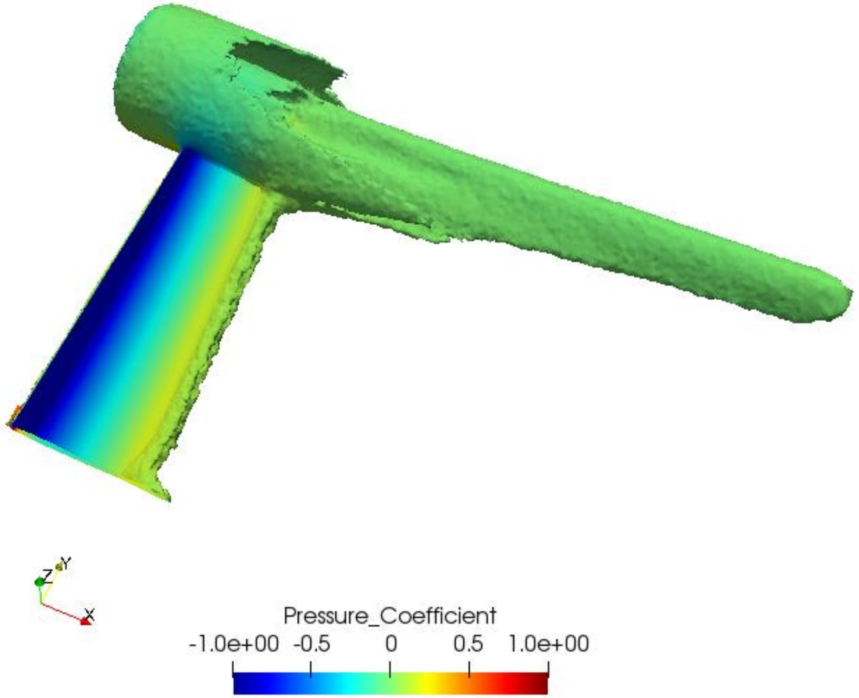


Iso contours of Magnitude of vorticity coloured with coefficient of pressure at 0^0 AOA

Configuration	Rotation Direction	CL(wing)	CD(wing)
Basic wing	-NA-	0.0915	0.0109
Wing + disk	Co-vortex	0.0881	0.0154
Wing + disk	Counter - vortex	0.0952	0.0149

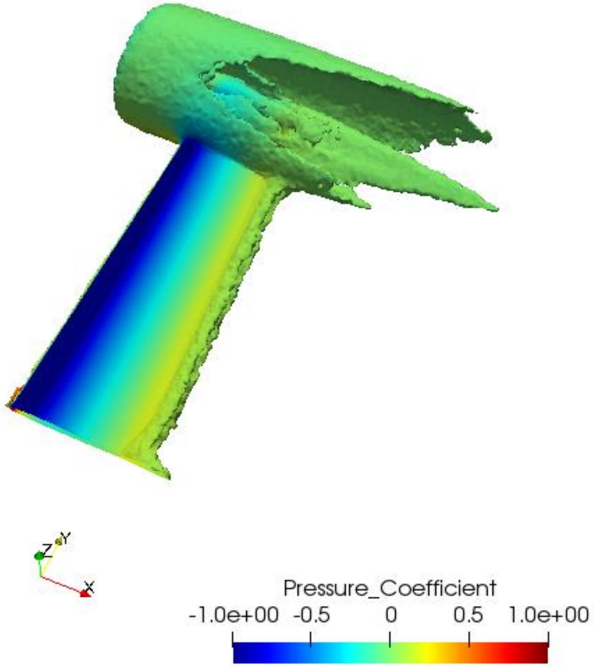
Disk at tip of the wing, AOA = 5 degrees– iso contours of vorticity magnitude

Co – vortex rotation



Iso contours of Magnitude of vorticity coloured with coefficient of pressure at 5^0 AOA.

Counter – vortex rotation

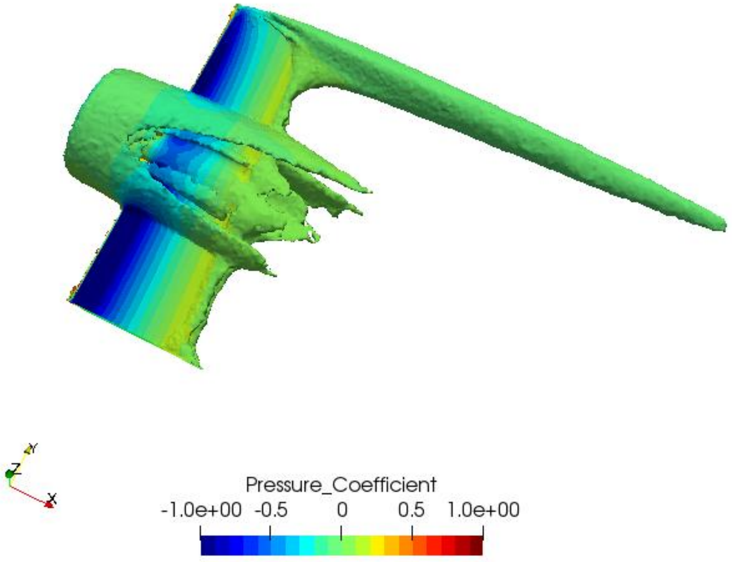


Iso contours of Magnitude of vorticity coloured with coefficient of pressure at 5^0 AOA.

Configuration	Rotation Direction	CL(wing)	CD(wing)
Basic wing	-NA-	0.4782	0.0221
Wing + disk	Co-vortex	0.4891	0.0263
Wing + disk	Counter - vortex	0.5301	0.0249

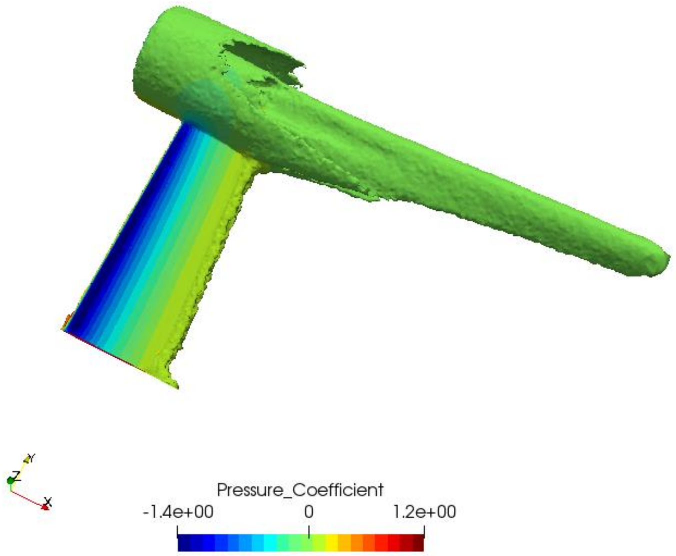
Comparison of different configurations at AOA = 5 degrees

Wing, Disk at 0.5 span, counter - vortex rotation



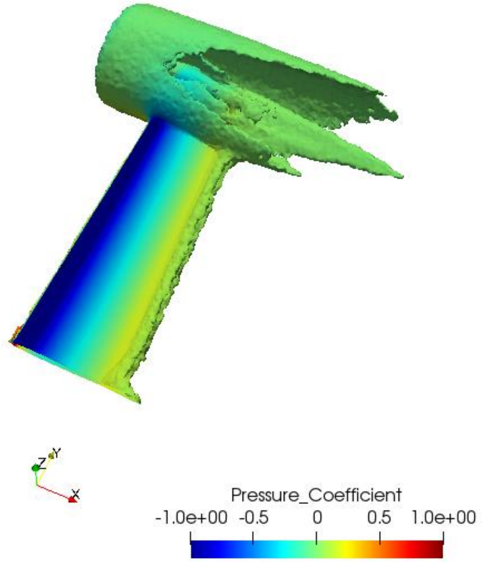
CL(wing)	CD(wing)
0.4681	0.02835

Wing, Disk at tip, co - vortex rotation



CL(wing)	CD(wing)
0.4891	0.0263

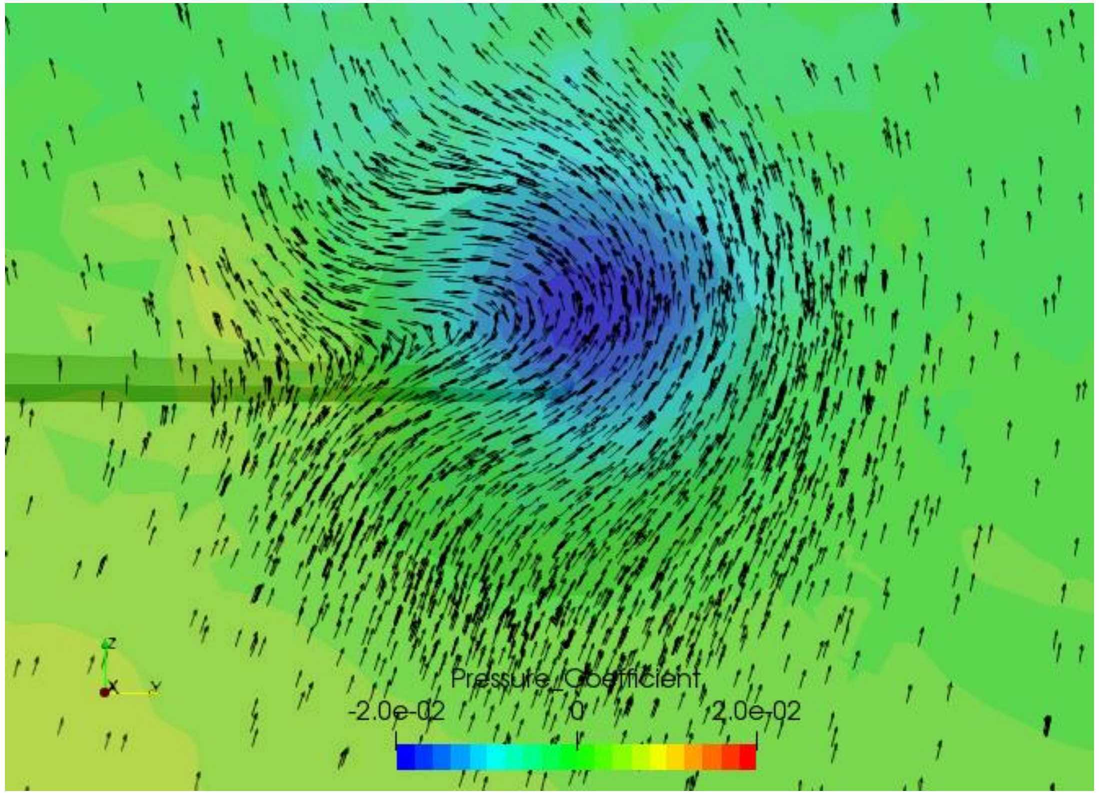
Wing, Disk at tip, counter - vortex rotation



CL(wing)	CD(wing)
0.5301	0.0249

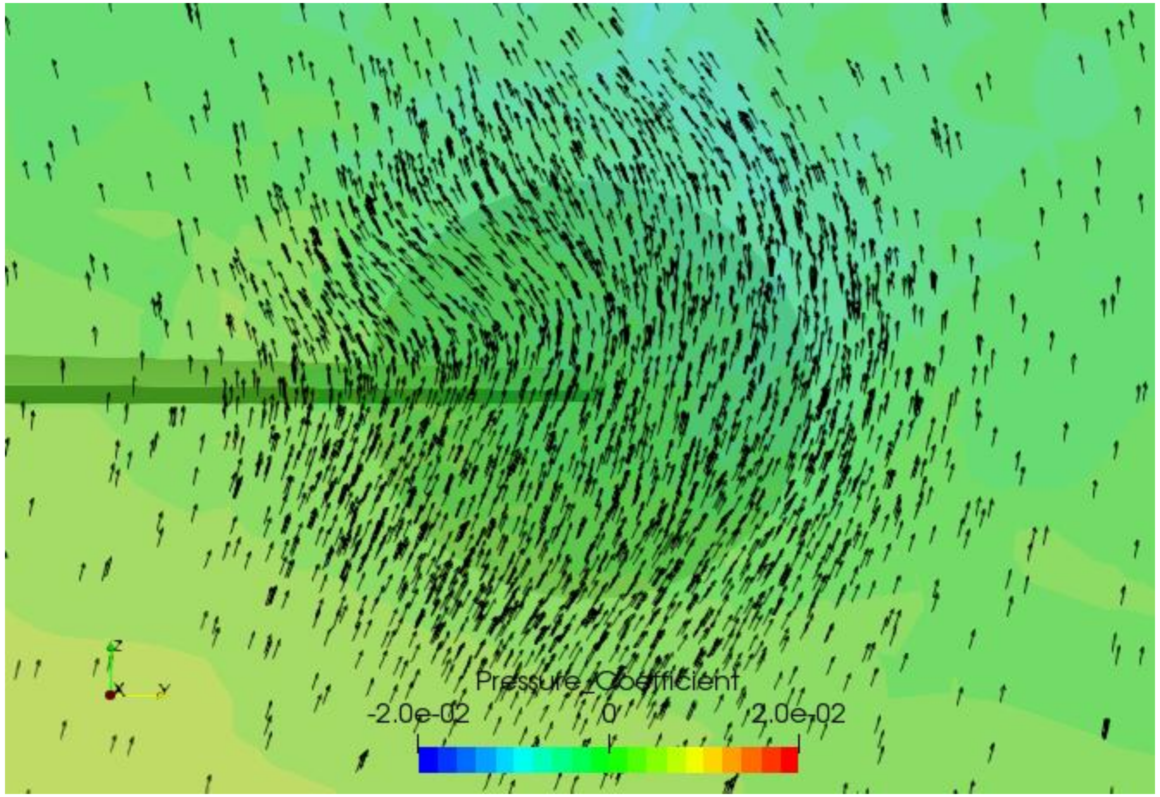
Pressure recovery downstream the wing (C_p contours):

Co – vortex rotation



Coefficient of pressure contours one span downstream from the leading edge, propeller rotating co – vortex direction.

Counter – vortex rotation



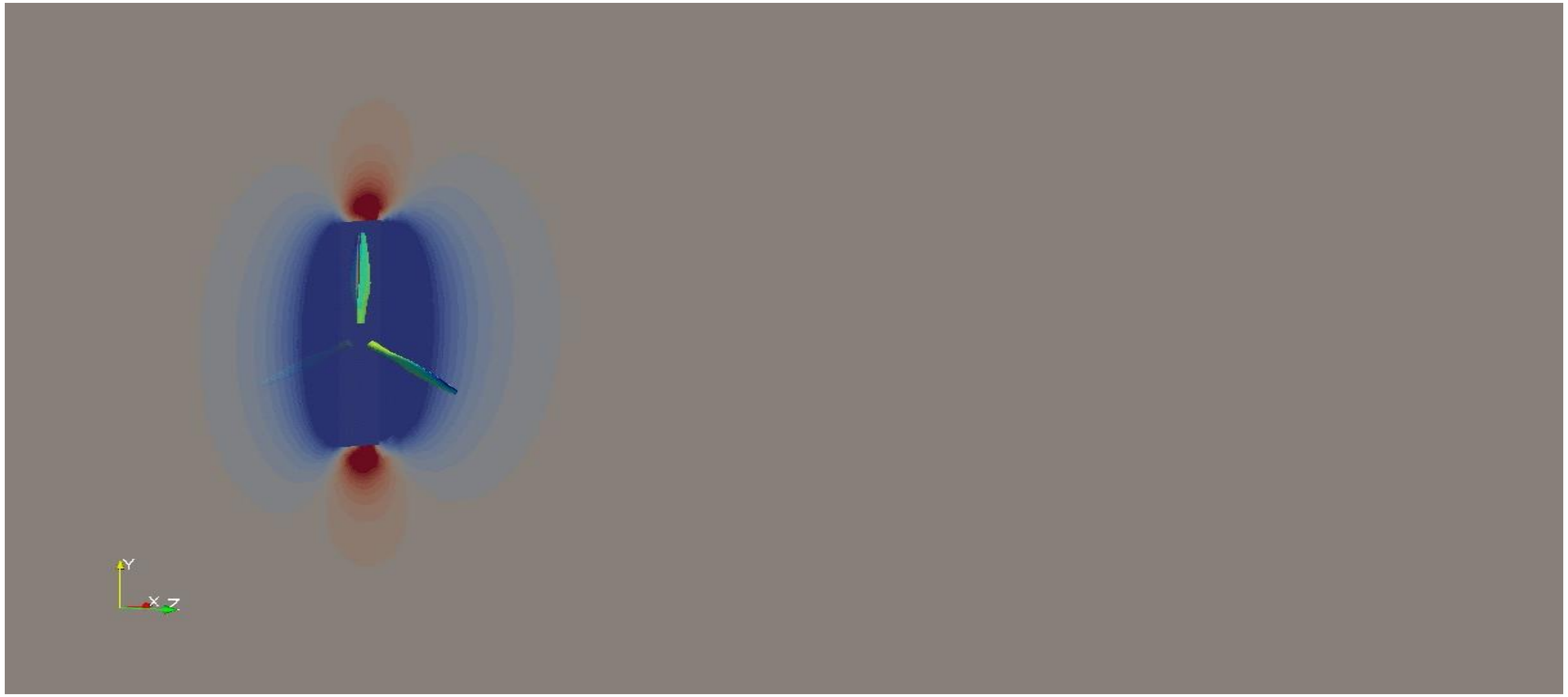
Coefficient of pressure contours one span downstream from the leading edge, propeller rotating counter – vortex direction.

Difficulties in numerical simulations of propeller flows:

- Rotating parts are involved. So, numerical simulations are complex.
- Vortex generation and vortex transport
- Simulations become more complex when multiple propellers are used.

Work in progress / future plans:

1. Actual propeller simulations using rotating frame and sliding mesh interface
2. Wing – propeller simulations using sliding mesh interface
3. Multiple propeller interactions using BEM



Trial unsteady simulation of a 3 bladed propeller without hub using sliding mesh interface technique. Mach contours are shown in the figure.

Conclusion:

- Attenuation of a vortex is possible by making use of the coaxial counter rotating vortex pair .
- This concept can be used in aircrafts to reduce the induced drag which is mainly because of the vortices from the wing tip.
- A small demonstration of vortex attenuation is performed to understand the concept, also some simulations were performed to know about the vortical structures arising out when wing tip propellers are used.
- The counter vortex rotation of the propeller is the most beneficial configuration at the wing tips. This reduces the wing drag by wing tip vortex attenuation.

Questions in mind:

- What effect does vortex(blade tip vortex) – vortex(wing tip vortex) interaction have?
- When multiple propellers are distributed along the span, what about wing loading?

Acknowledgments:

- I’m grateful to the CTFD division, CSIR-NAL for letting me use the BEM coupled solver developed by them.
- I thank the project assistants, grid generation group, CTFD division, CSIR-NAL for guiding me in grid generation.

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1. “*Wingtip-Mounted Propellers: Aerodynamic Analysis of Interaction Effects and Comparison with Conventional Layout,”* Tomas Sinnige, Journal of Aircraft, Vol 56., No.1, Jan – Feb 2019.
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8. *“Aerodynamic effects of wingtip-mounted propellers and turbines,”* L Miranda, J Brennan, AIAA Journal, 86-1802, 1986.

THANK YOU