

Development of an Aerial Air Quality Monitoring Platform Based on Vertical Takeoff and Landing (VTOL) Unmanned Aerial Vehicle (UAV)

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https://github.com/Athenachc/2021_FYP_ME_VTOL-UAV



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1. Project Background (Gantt chart)
2. Current progress
 1. Flight log analysis
 2. Reinforcement – composited wings
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3. Future plan
 1. Final report
 2. Final demonstration – video(s)

Project background

Introduction






- Background

- Referring to the Innovation and Technology Fund (ITF) project
- Air pollution monitoring in the Great Bay Area by a VTOL UAV
- Airframe selection of the VTOL UAV
- Reinforcement of the mechanical structure of a VTOL UAV

- Objectives

- Complete the flight task with the requirements
- Redesign the wings
- Manufacturing the wings with composited materials

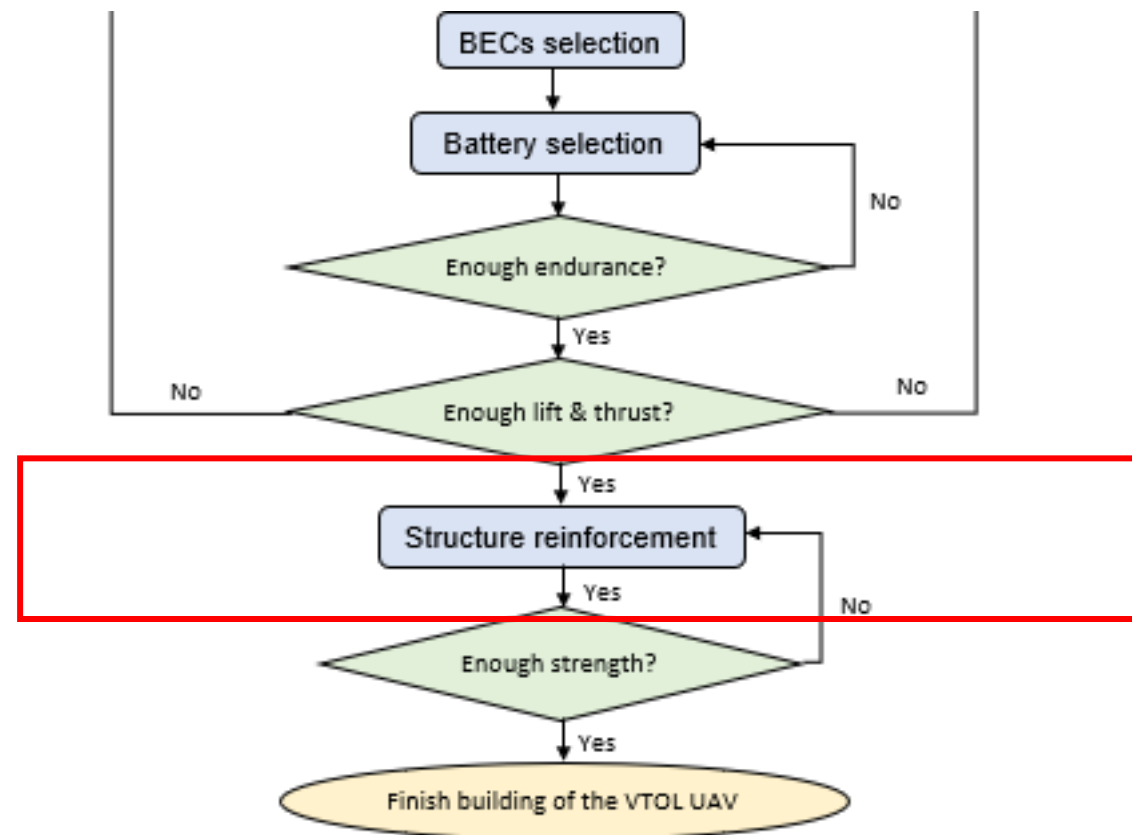
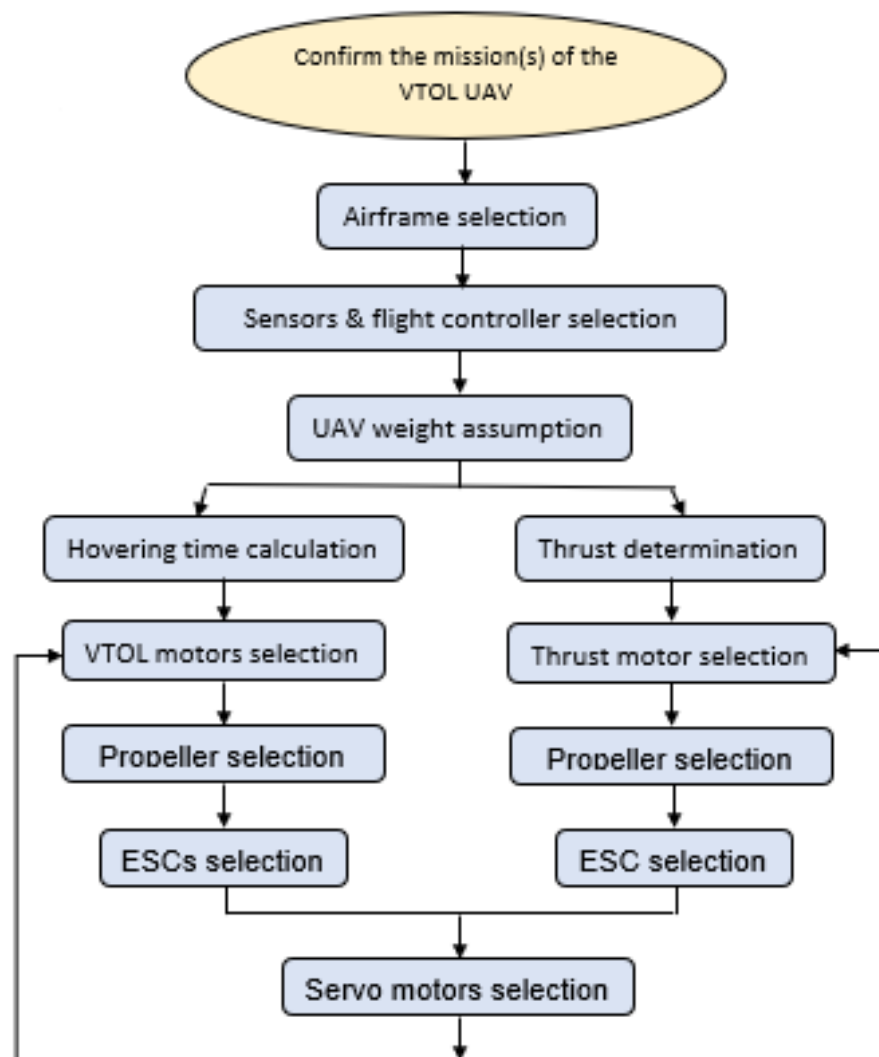
	Fixed Wing UAV	FWR-Hybrid UAV	Quadcopter
			
Flying Mechanism	Take-off and Landing, and Flying: A pair of wings & a pusher rotor	Take-off and Landing: Four rotors besides the fuselage Flying: A pair of wings, a pusher rotor & VTOL part	Take-off and Landing, and Flying: Four rotors as VTOL part
Shape	Streamlined shape	Hybrid of drone and fixed wing UAV	X shape or Plus shape
Type(s) of motors	DC brushless motors & servo motors	DC brushless motors & servo motors	DC brushless motors
Duration	Very High	High	Low
Speed	Very High	High	Low
Maneuverability	Low	High	Very High

Aseem Saini and Mukul Chhabra, “Hybrid VTOL-UAV for Air Delivery and Sampling Purposes”, B.Tech dissertation, Dept. Elect & Com. Eng., Indraprastha Institute of Information Technology, New Delhi, 2018.

Chika Yinka-Banjo and Olasupo Ajayi, “Sky-Farmers: Applications of Unmanned Aerial Vehicles (UAV) in Agriculture,” IntechOpen, 2019.

D. Baek, Y. Chen, A. Bocca, A. Macii, E. Macii, and M. Poncino, “Battery-Aware Energy Model of Drone Delivery Tasks,” in Proceedings of the International Symposium on low power electronics and design, 2018, pp. 1–6, doi: 10.1145/3218603.3218614.

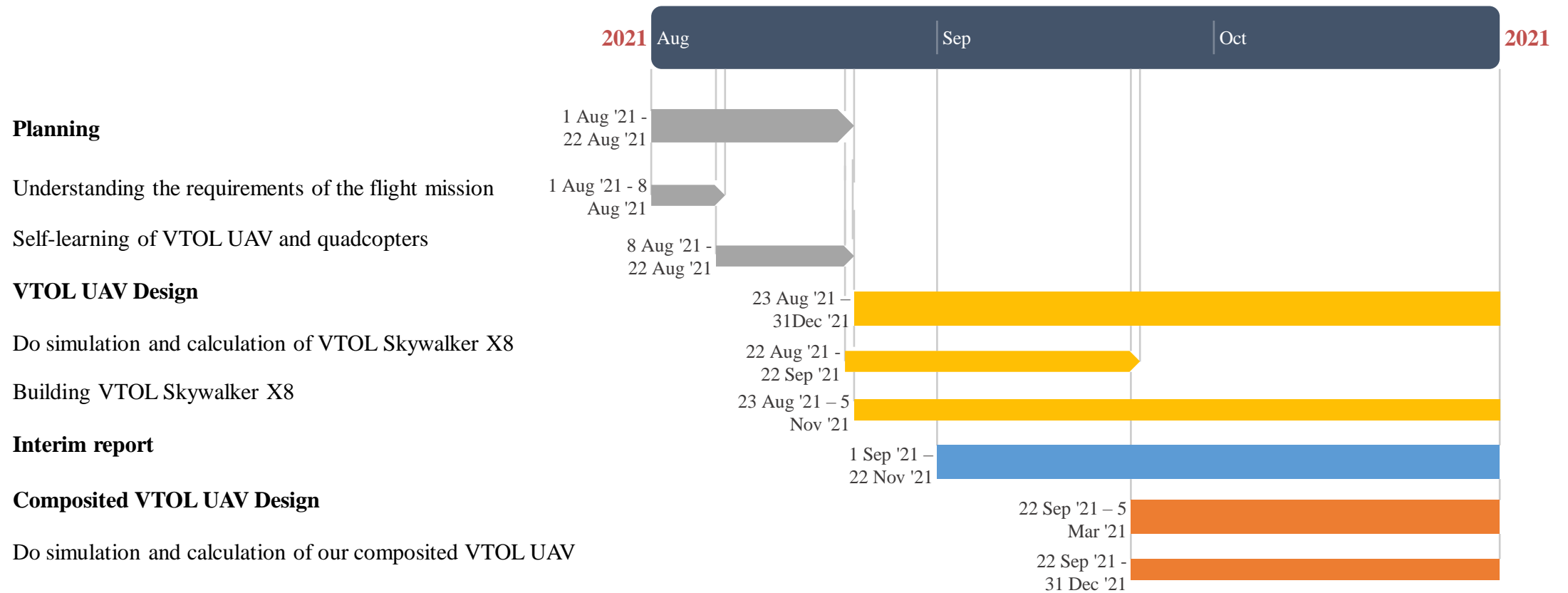
Methodology: Design flowchart of building a VTOL UAV



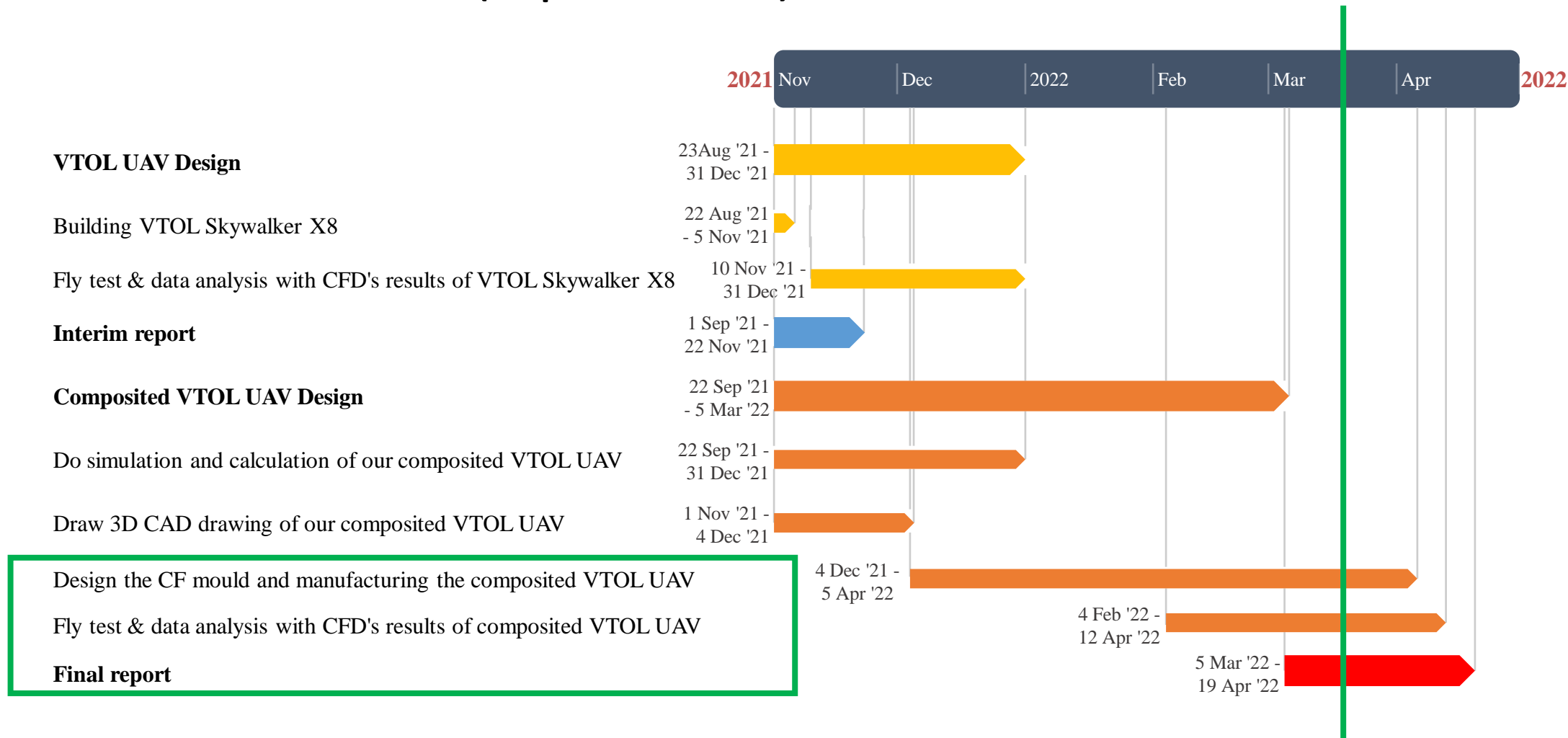
Project schedule (updated)

Description	Start date	End date	Duration (days)
Planning	01/08/2021	22/08/2021	22
Understanding the requirements of the flight mission	01/08/2021	01/08/2021	1
Self-learning of VTOL UAV and quadcopters	08/08/2021	22/08/2021	15
VTOL UAV Design	23/08/2021	31/12/2021	131
Do simulation and calculation of VTOL Skywalker X8	22/08/2021	22/09/2021	32
Building VTOL Skywalker X8	23/08/2021	05/11/2021	75
Fly test & data analysis with CFD's results of VTOL Skywalker X8	10/11/2021	31/12/2021	52
Interim report	01/09/2021	22/11/2021	83
Composited VTOL UAV Design	22/09/2021	05/03/2022	165
Do simulation and calculation of our composited VTOL UAV	22/09/2021	31/12/2021	101
Draw 3D CAD drawing of our composited VTOL UAV	01/11/2021	04/12/2021	34
Design the CF mold and manufacturing the composited VTOL UAV	04/12/2021	05/04/2022	123
Fly test & data analysis with CFD's results of composited VTOL UAV	04/02/2022	12/04/2022	68
Final report	05/03/2022	19/04/2022	46

Gantt chart (updated)



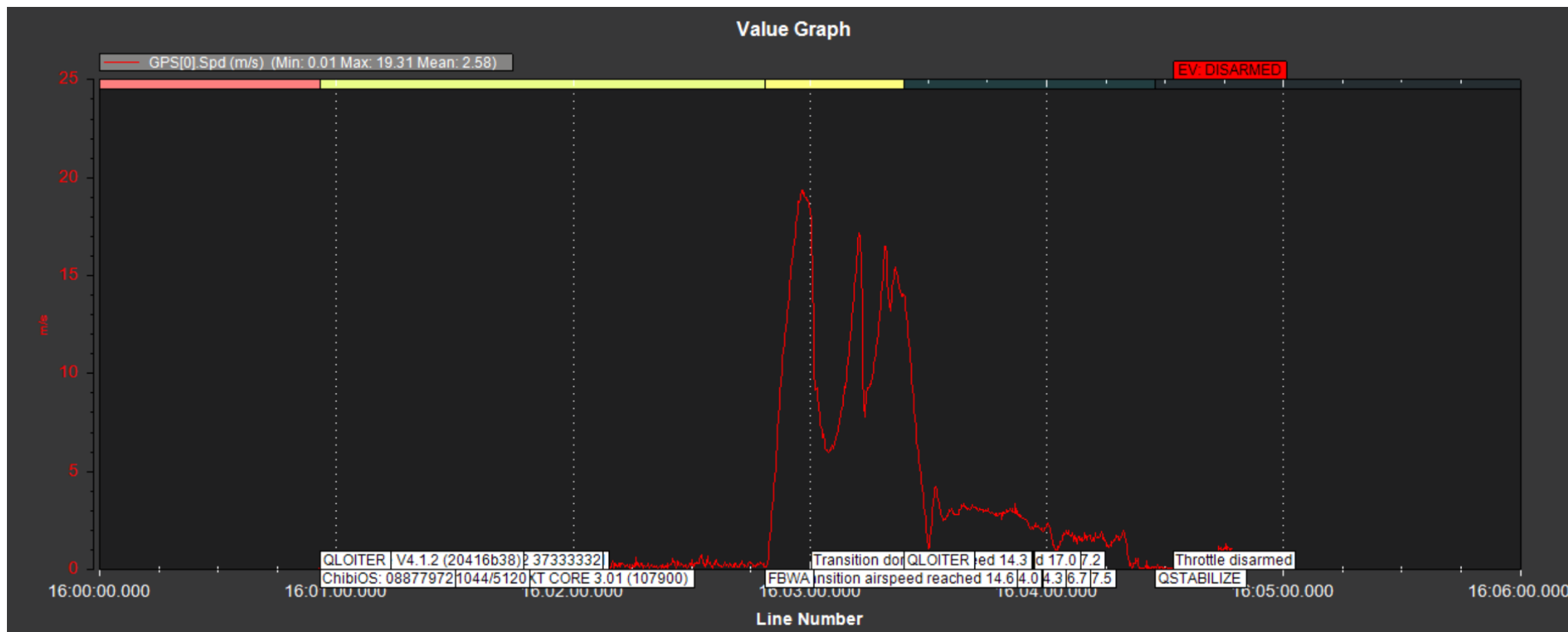
Gantt chart (updated)



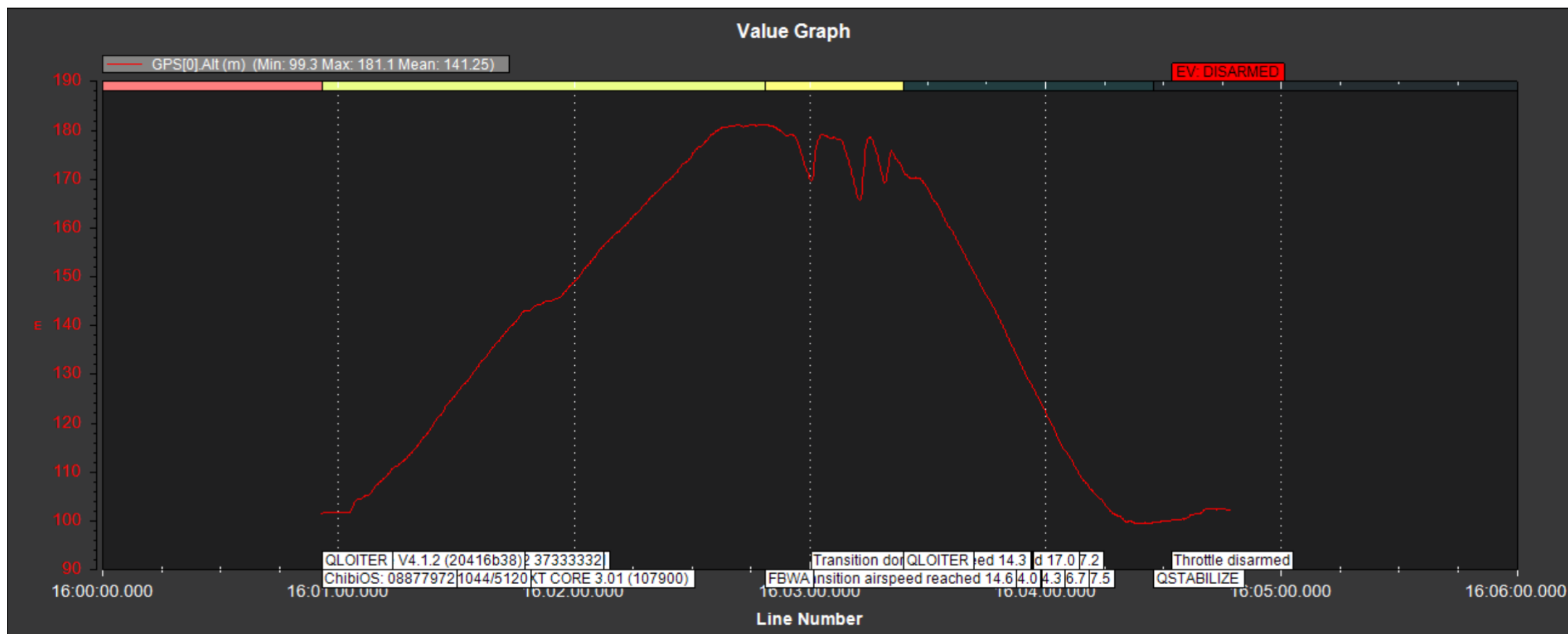
Current progress

Flight log analysis

The speed during the flight:

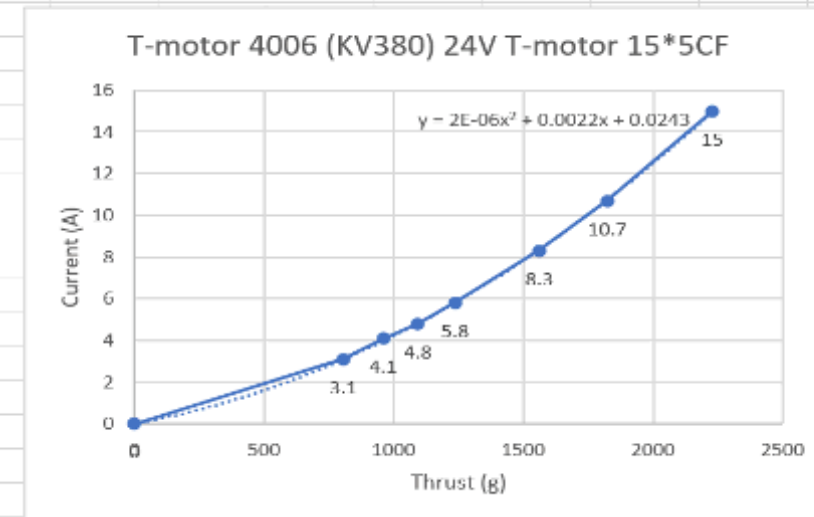


Altitude during the flight:

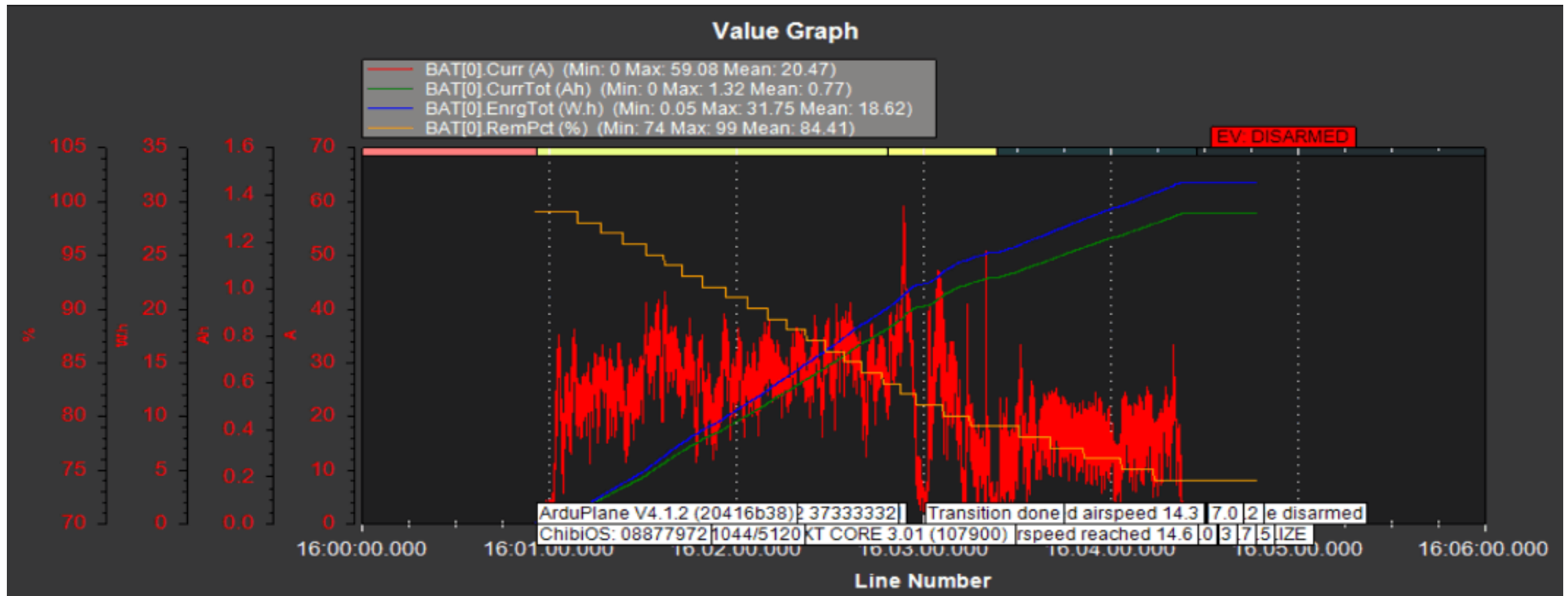


Estimation of the motor before flight

Motor	Propeller	Voltage (V)	Weight (g) (4 motors)	Weight (g) (4 propellers)
T-motor 4006 (KV380)	T-motor 15*5CF	24	272	106
			Thrust (g)	Current (A)
			0	0
			805	3.1
			959	4.1
			1093	4.8
			1236	5.8
			1561	8.3
			1823	10.7
			2228	15
Required equation: ax^2+bx+c				
a	b	c		
2.00E-06	0.0022	0.0243		
Assume total weight (g)	3567.9			
Assume total current (A)	14.31			
Assumed Depth of discharge (DOD)	0.70			
Required energy capacity (mAh)	20445.05029			
Hovering time (min)	64.56330413			
Weight/Thrust (%)	40.03478456			



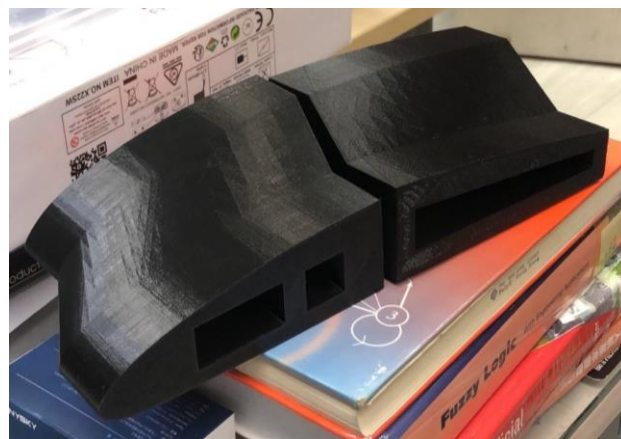
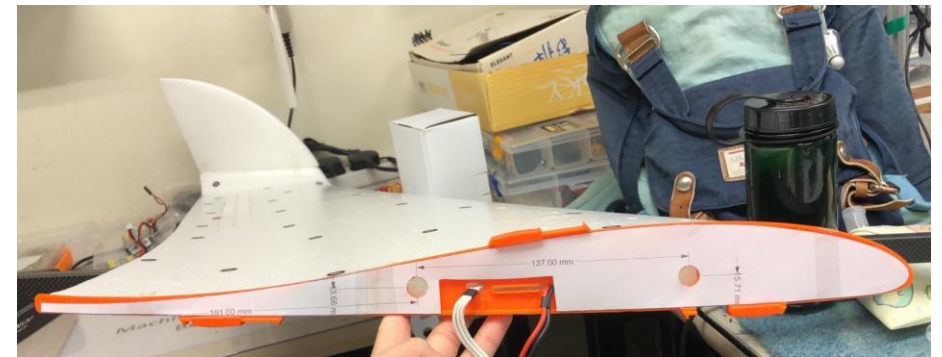
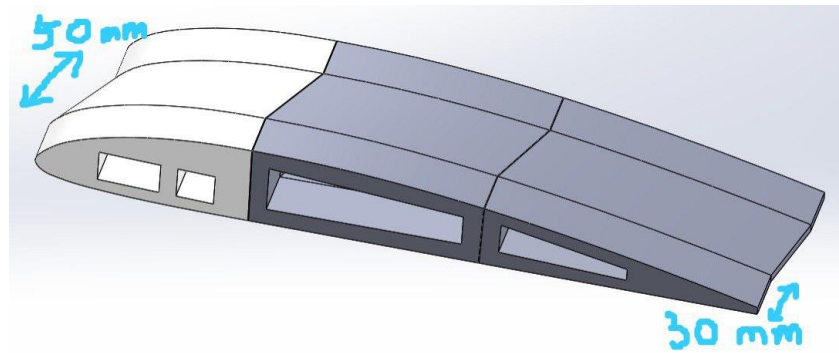
Battery log graph:



Current progress

Reinforcement – composited wing

Mold design for testing:



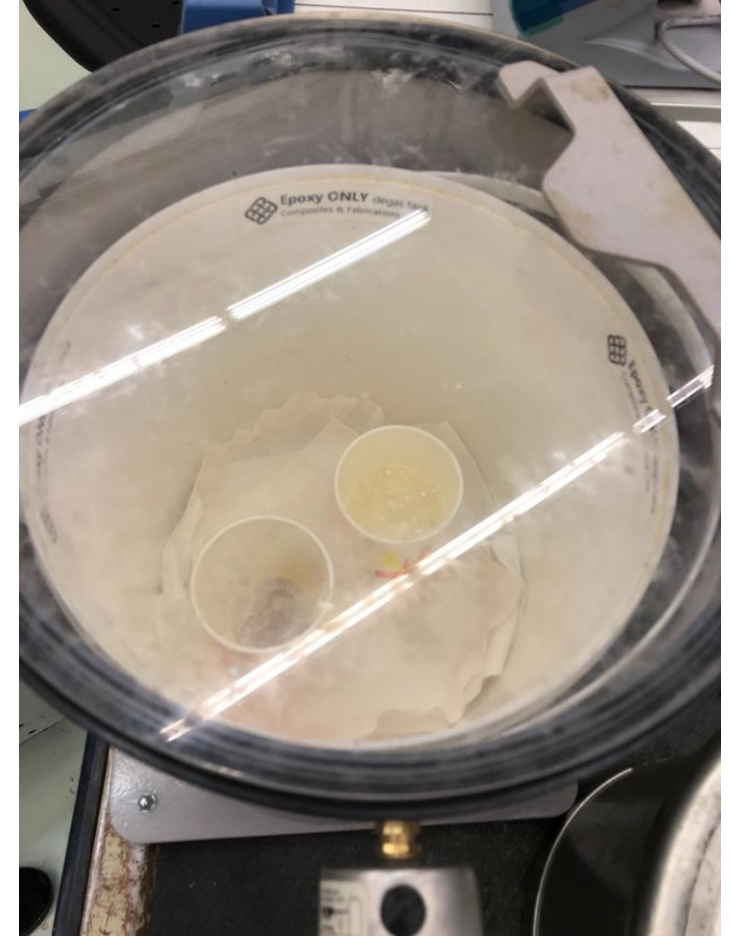
Manufacturing (test):



Adding releaser



Ply cutting



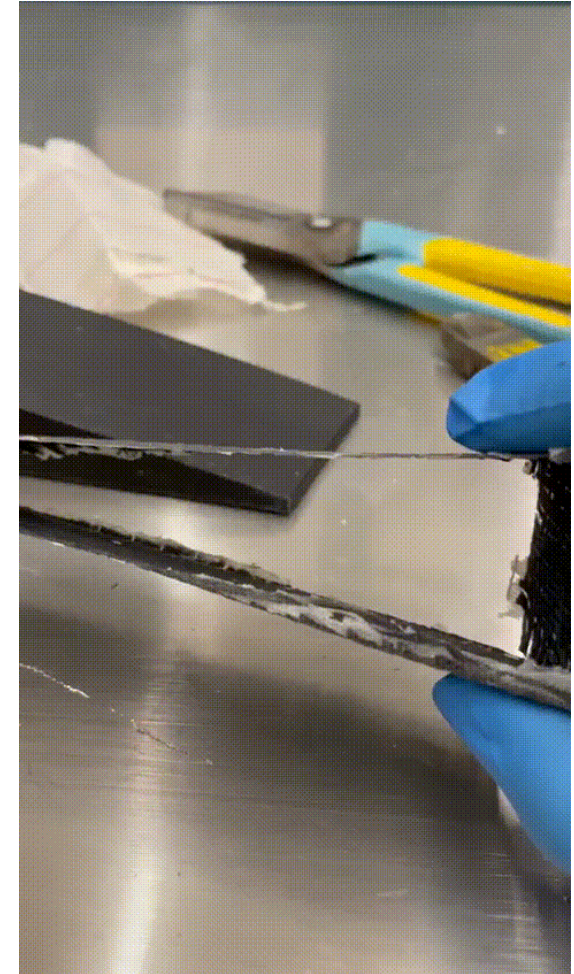
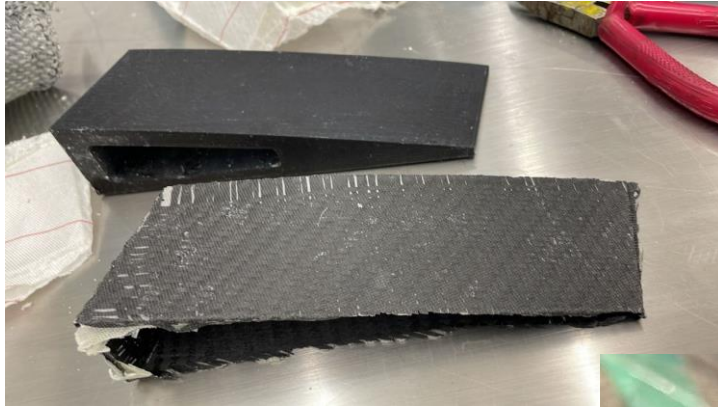
200g "WS 105" Resin + 54.35g "WS 209" hardener
(Referring to "Matrix Ratio Guide" in IC)



Vacuum bagging

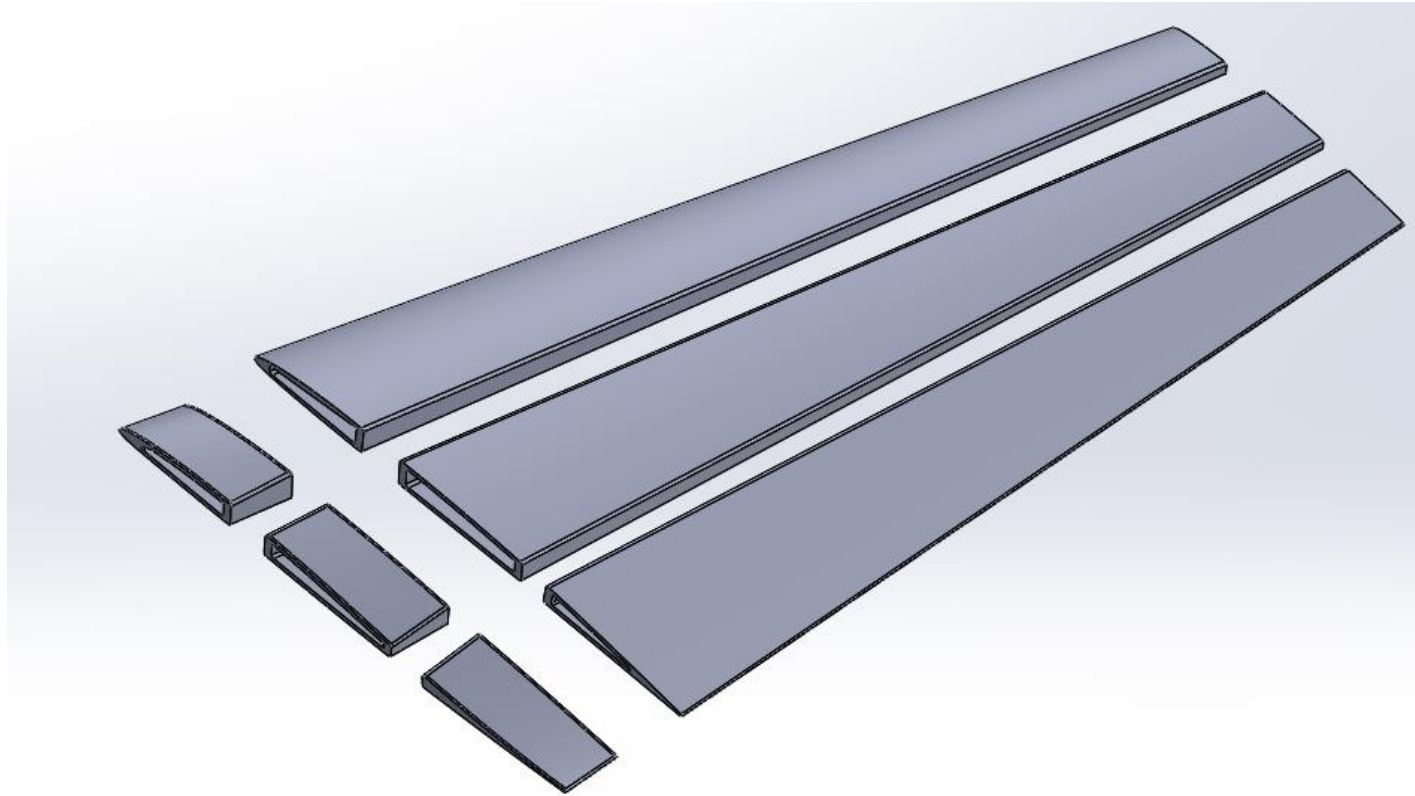


De-bagging



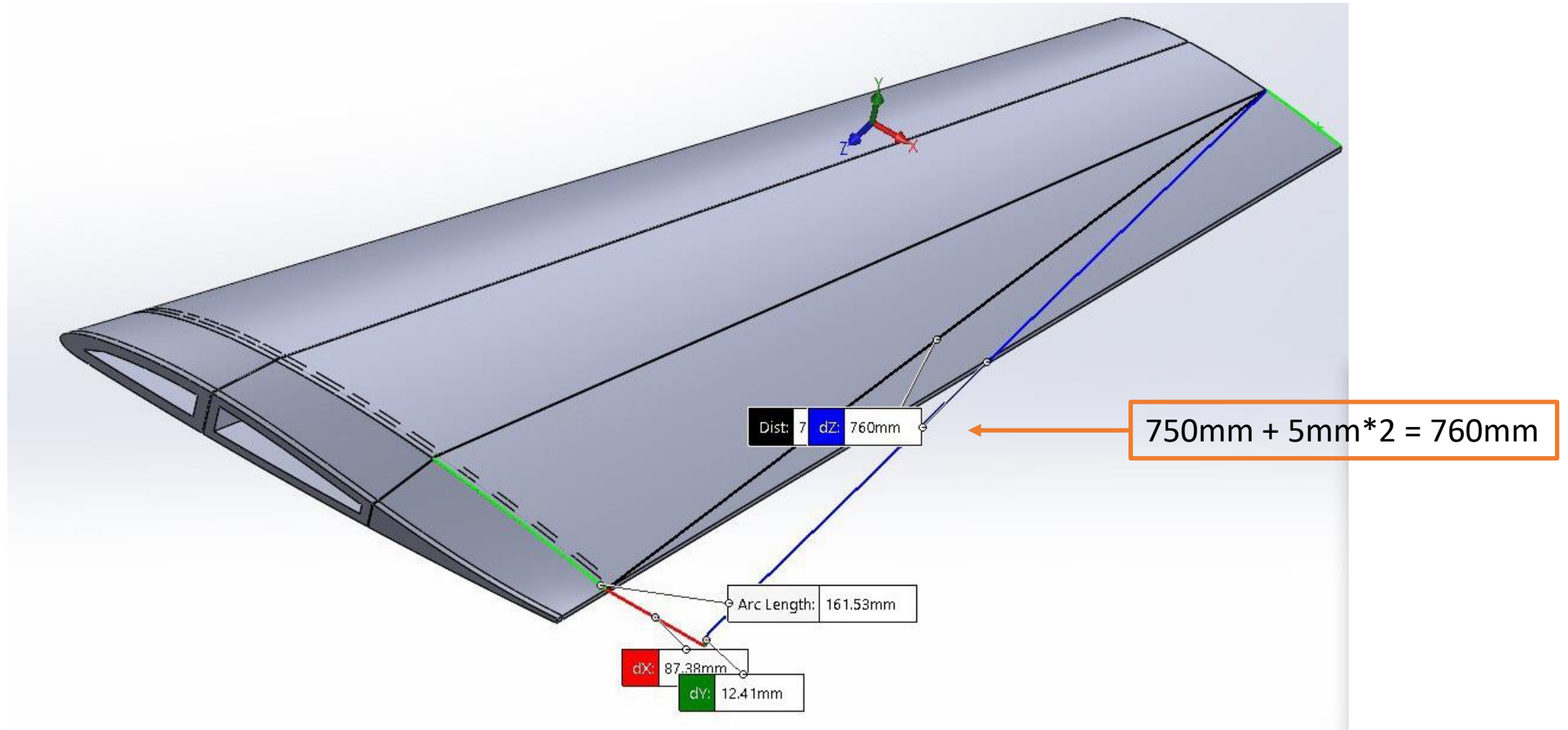
1 layer of 3K CF sheet

Modified mold design:

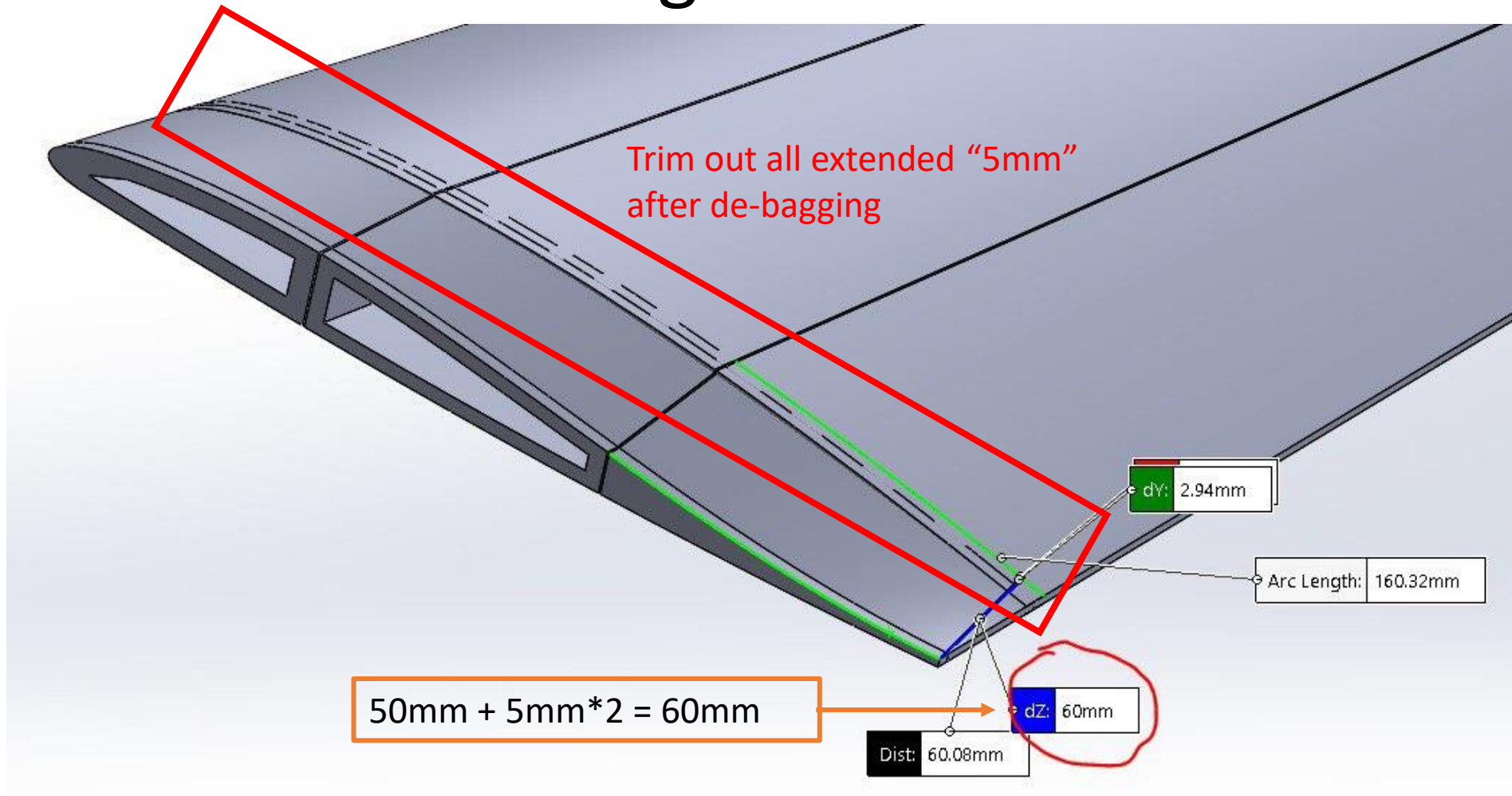


6 parts (PLA)

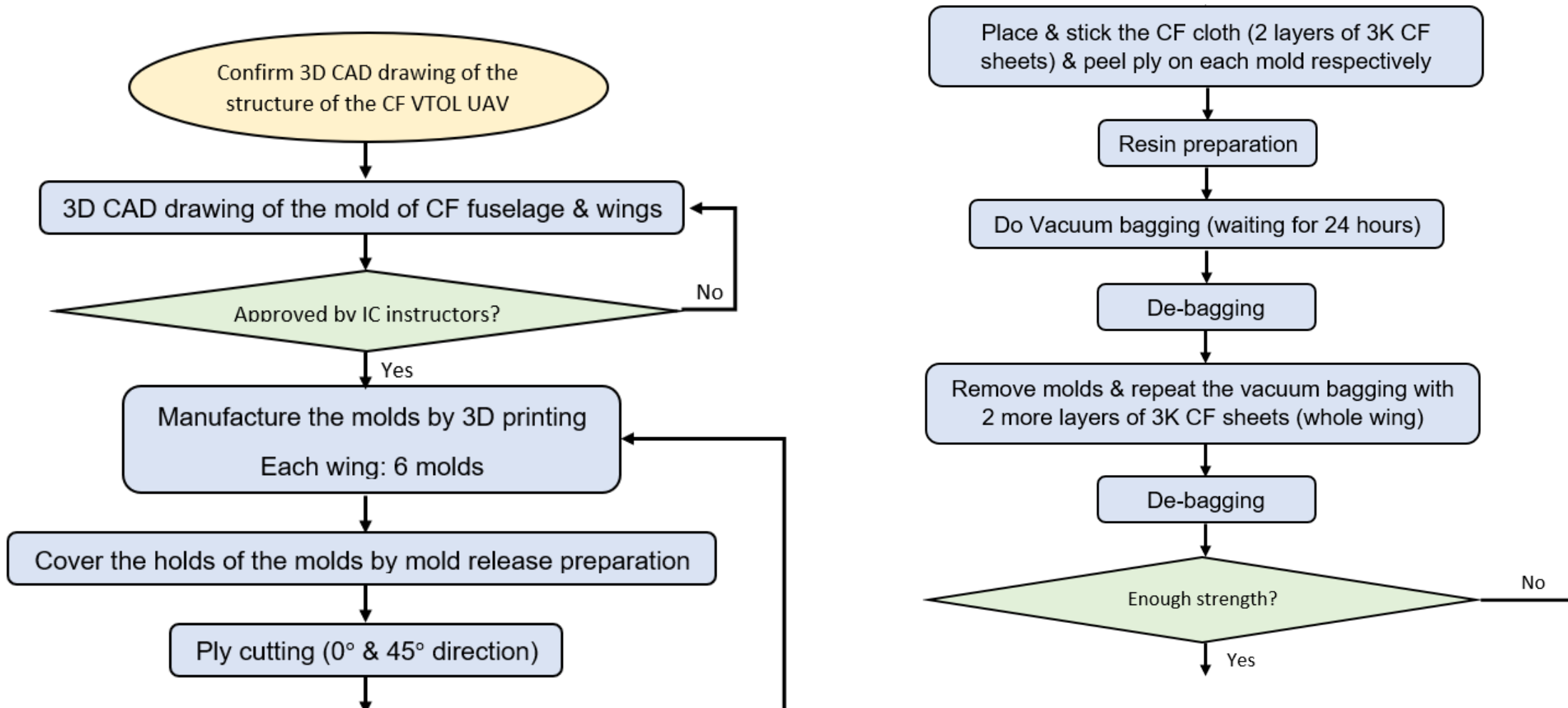
Modified mold design:



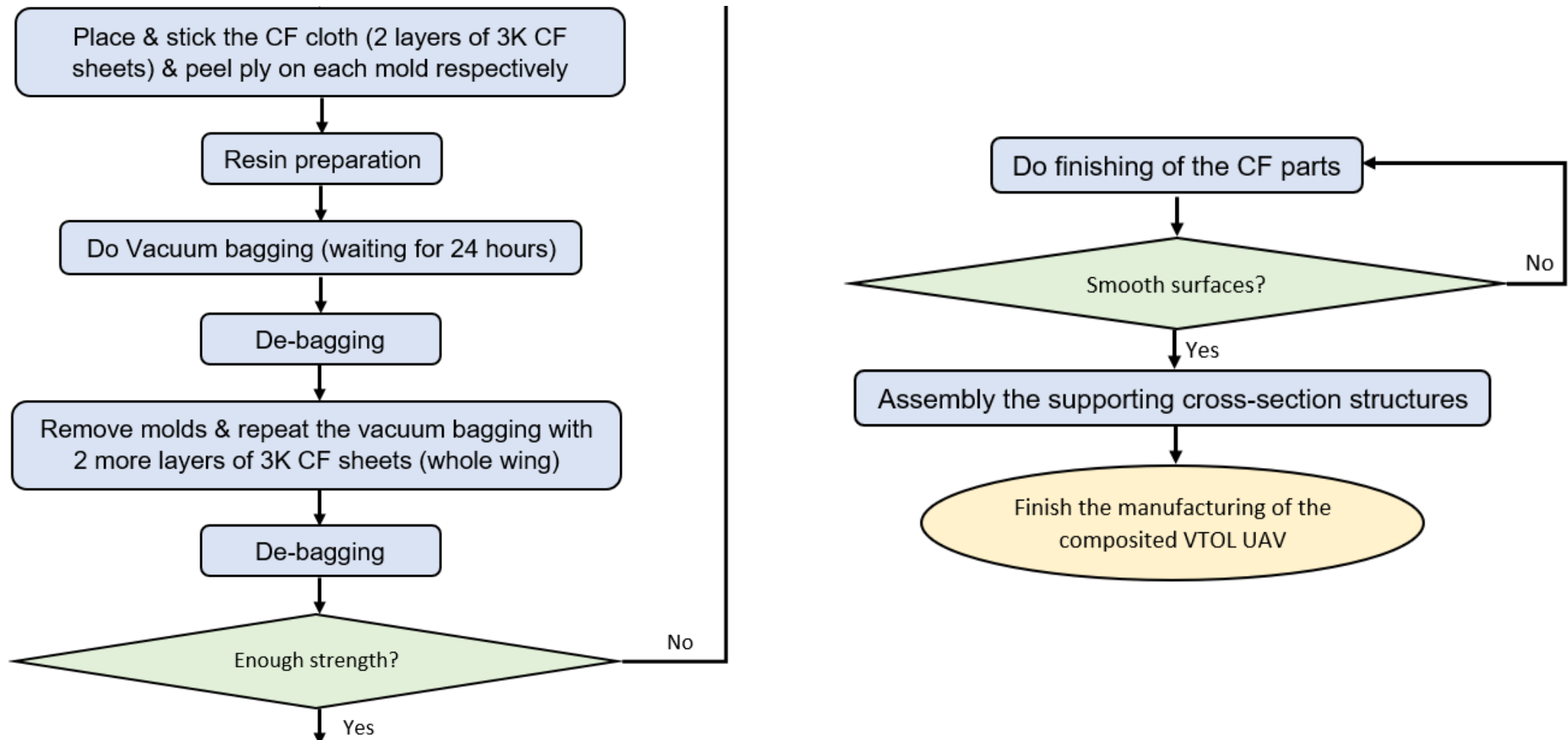
Modified mold design:



Design flowchart of structure reinforcement by manufacturing a composited VTOL UAV (updated)



Design flowchart of structure reinforcement by manufacturing a composited VTOL UAV (updated)



Current progress







Simulation – CFD

Ansys Fluent



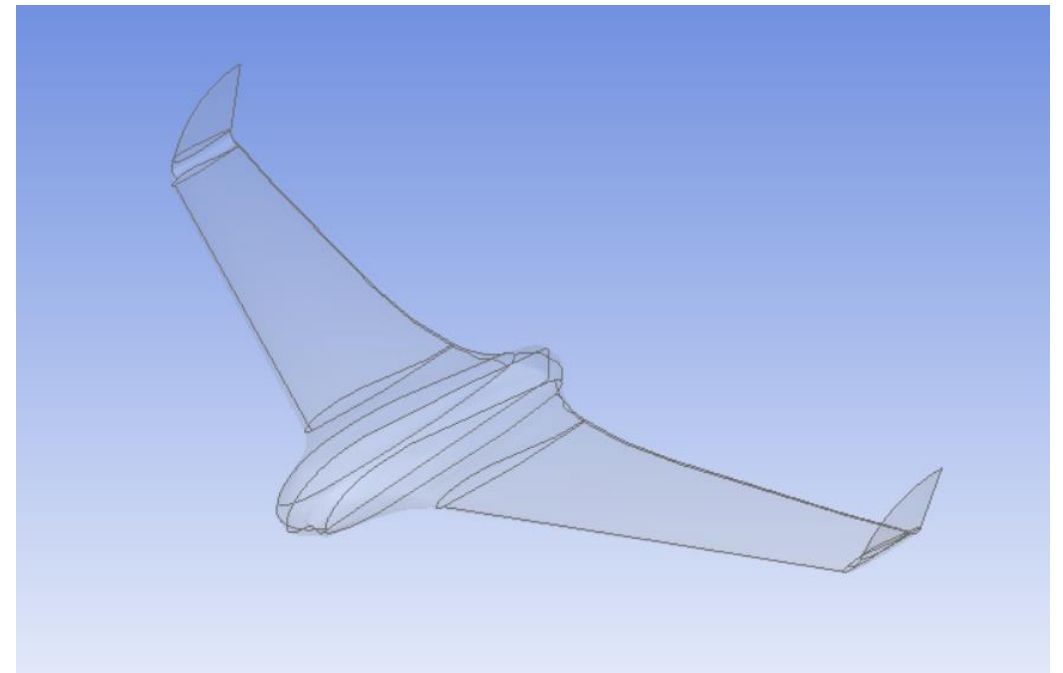
Steps:

1. Import CAD & draw wind tunnel (Geometry)
2. Create mesh (Mesh)
3. Launch FLUENT (Setup)

▼	A	
1		Fluid Flow (Fluent)
2		Geometry ? ▲
3		Mesh ? ▲
4		Setup ? ▲
5		Solution ? ▲
6		Results ? ▲

1. Import CAD & draw wind tunnel (Geometry)

- Import UAV from SolidWorks (.STEP) to “DesignModeler”
- Wind Tunnel created by "Enclosure" function
- Do subtraction by “Boolean” function



Import1 → Generate (right click)
MUST import 1 body ONLY (SW: combine all parts into 1 part by “Combine → Add” function)

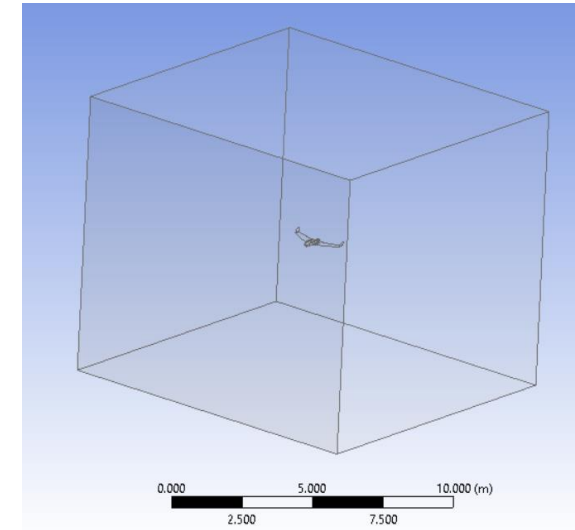
1. Import CAD & draw wind tunnel (Geometry)

- Import UAV from SolidWorks (.STEP)
- Wind Tunnel created by "Enclosure" function
- Do subtraction by "Boolean" function

Details View	
Details of Enclosure1	
Enclosure	Enclosure1
Shape	Box
Number of Planes	0
Cushion	Non-Uniform
<input type="checkbox"/> FD1, Cushion +X value (>0)	5 m
<input type="checkbox"/> FD2, Cushion +Y value (>0)	5 m
<input type="checkbox"/> FD3, Cushion +Z value (>0)	5 m
<input type="checkbox"/> FD4, Cushion -X value (>0)	5 m
<input type="checkbox"/> FD5, Cushion -Y value (>0)	5 m
<input type="checkbox"/> FD6, Cushion -Z value (>0)	5 m
Target Bodies	All Bodies
Export Enclosure	Yes

1. Import CAD & draw wind tunnel (Geometry)

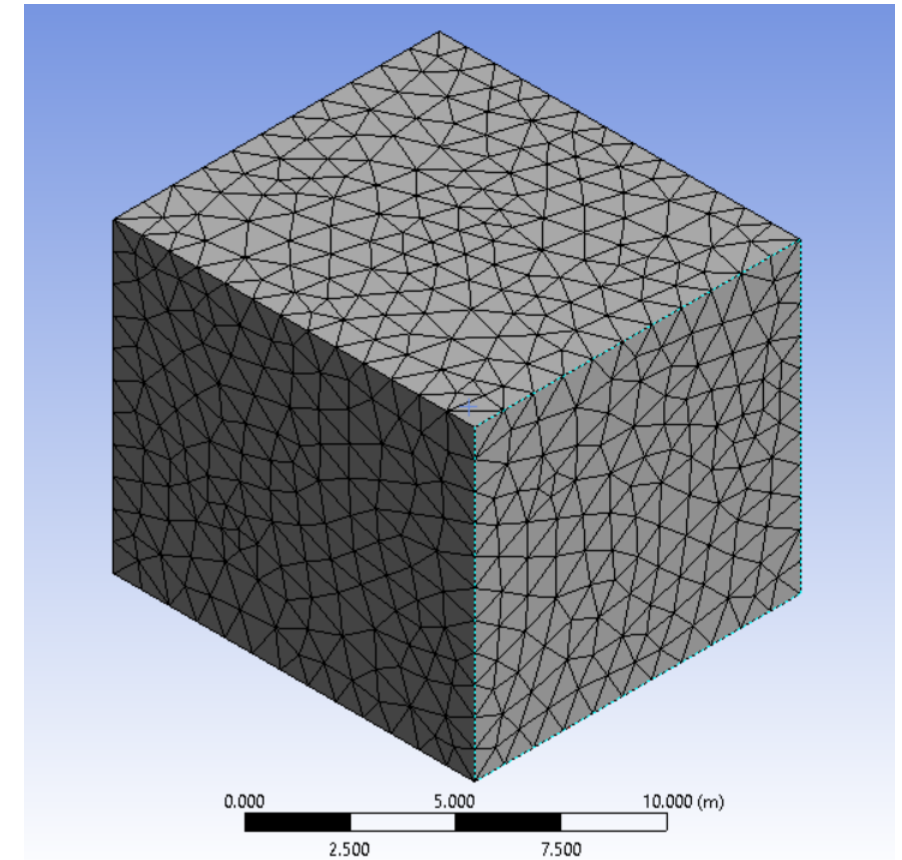
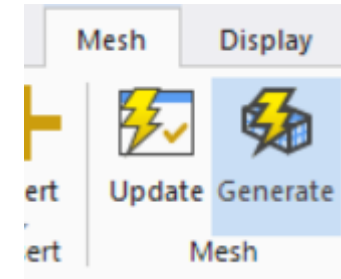
- Import UAV from SolidWorks (.STEP)
- Wind Tunnel created by "Enclosure" function
- Do subtraction by "Boolean" function



Details View	
Details of Boolean1	
Boolean	Boolean1
Operation	Subtract
Target Bodies	1 Body
Tool Bodies	1 Body
Preserve Tool Bodies?	No

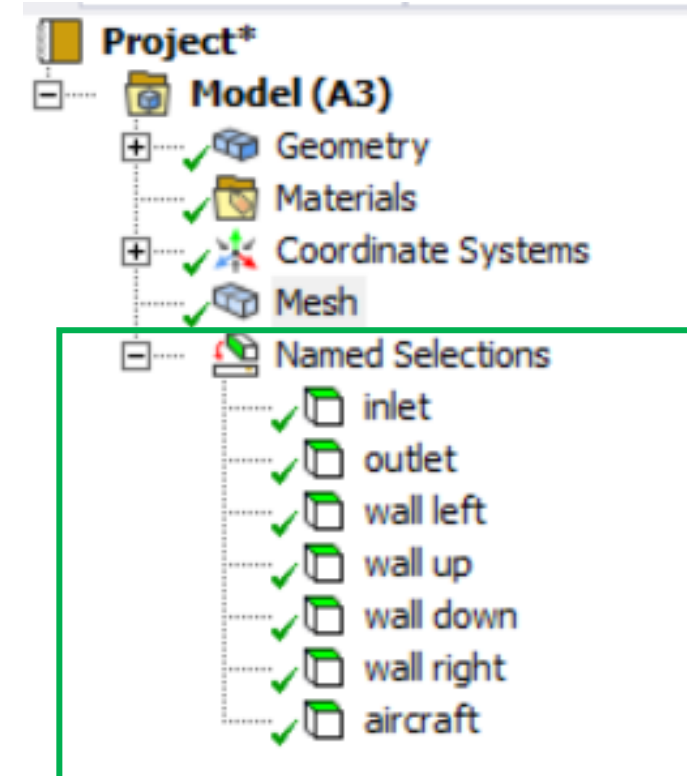
2. Create mesh (Mesh)

- Mesh creation
- Inlet, Outlet, Walls (wall left, wall right, wall up, wall down) and the aircraft are defined



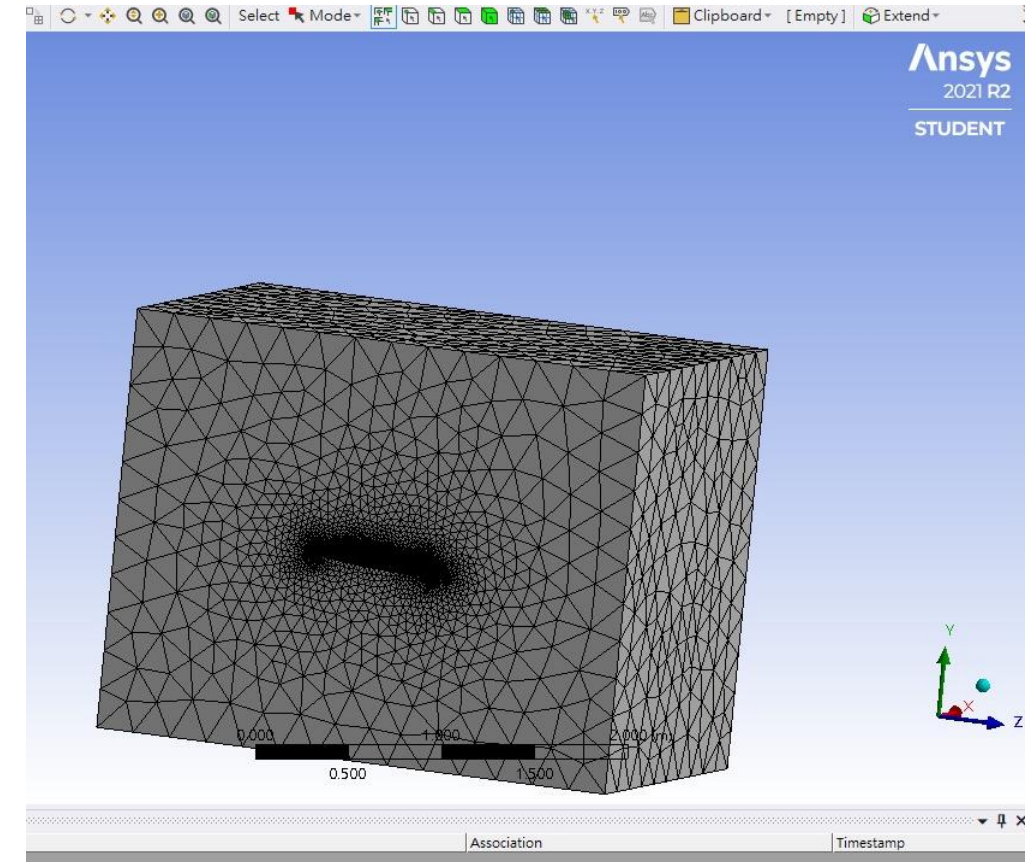
2. Create mesh (Mesh)

- Mesh creation
- Name Selections creation:
Inlet, Outlet, Walls (wall left, wall right, wall up, wall down) and the aircraft are defined



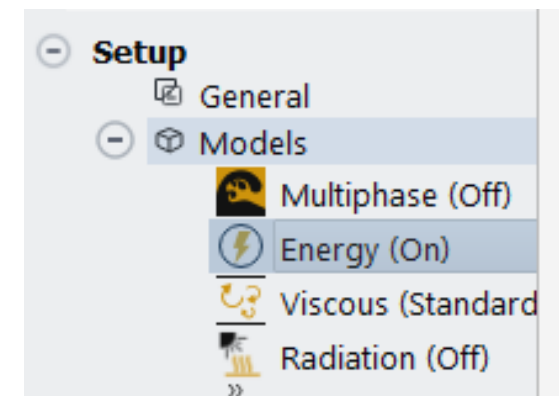
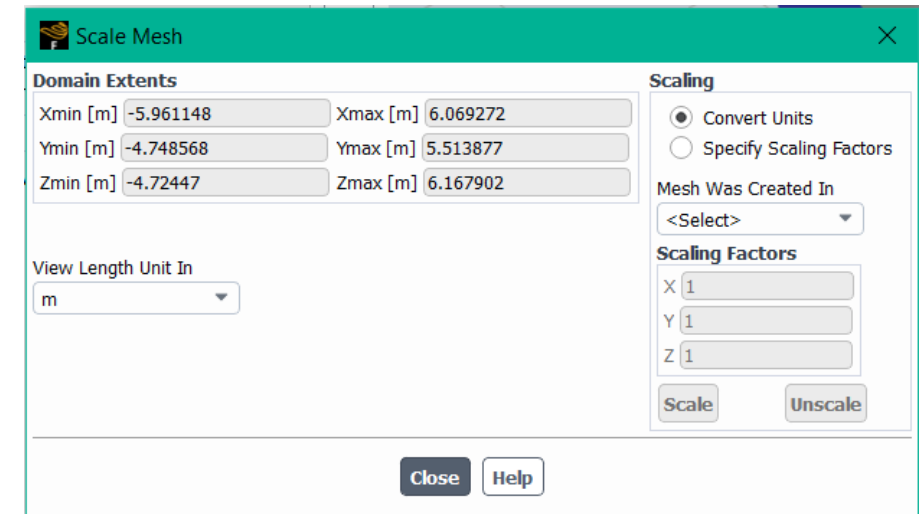
2. Create mesh (Mesh)

- Mesh creation
- Inlet, Outlet, Walls (wall left, wall right, wall up, wall down) and the aircraft are defined



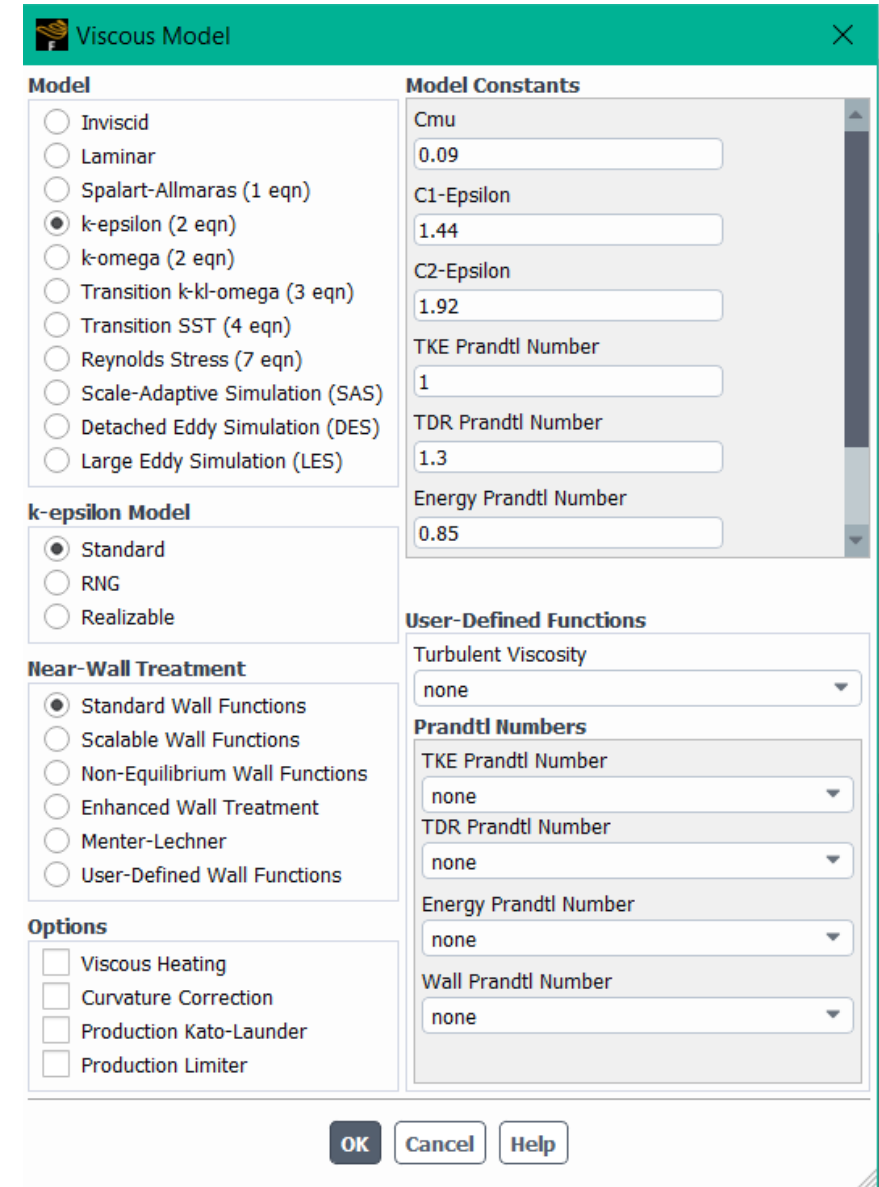
3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model (Common model for Turbulent flow ($Re \sim 4.3 \times 10^5$))
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



Viscous Model

Model

- ☐ Inviscid
- ☐ Laminar
- ☐ Spalart-Allmaras (1 eqn)
- ☒ k-epsilon (2 eqn)
- ☐ k-omega (2 eqn)
- ☐ Transition k-kl-omega (3 eqn)
- ☐ Transition SST (4 eqn)
- ☐ Reynolds Stress (7 eqn)
- ☐ Scale-Adaptive Simulation (SAS)
- ☐ Detached Eddy Simulation (DES)
- ☐ Large Eddy Simulation (LES)

k-epsilon Model

- ☒ Standard
- ☐ RNG
- ☐ Realizable

Near-Wall Treatment

- ☒ Standard Wall Functions
- ☐ Scalable Wall Functions
- ☐ Non-Equilibrium Wall Functions
- ☐ Enhanced Wall Treatment
- ☐ Menter-Lechner
- ☐ User-Defined Wall Functions

Options

- ☐ Viscous Heating
- ☐ Curvature Correction
- ☐ Production Kato-Launder
- ☐ Production Limiter

Model Constants

Cmu: 0.09

C1-Epsilon: 1.44

C2-Epsilon: 1.92

TKE Prandtl Number: 1

TDR Prandtl Number: 1.3

Energy Prandtl Number: 0.85

User-Defined Functions

Turbulent Viscosity: none

Prandtl Numbers

TKE Prandtl Number: none

TDR Prandtl Number: none

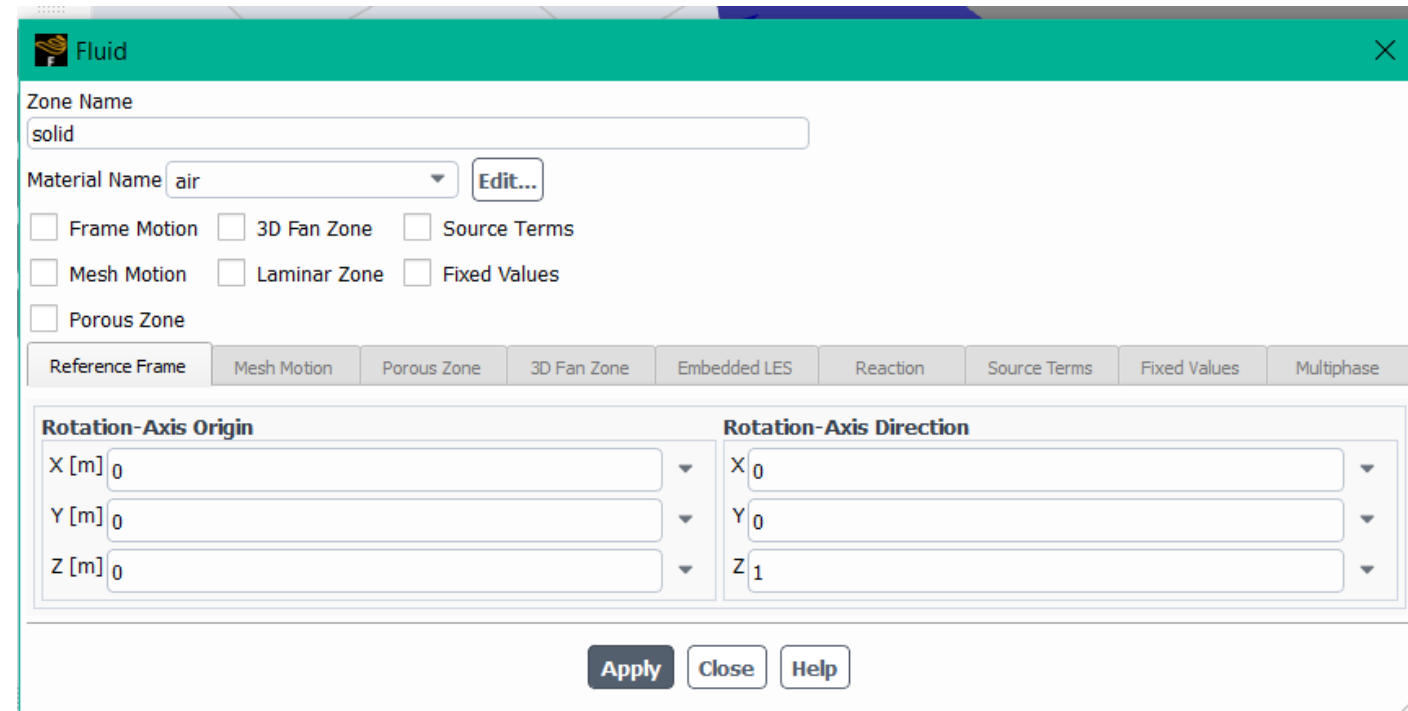
Energy Prandtl Number: none

Wall Prandtl Number: none

OK Cancel Help

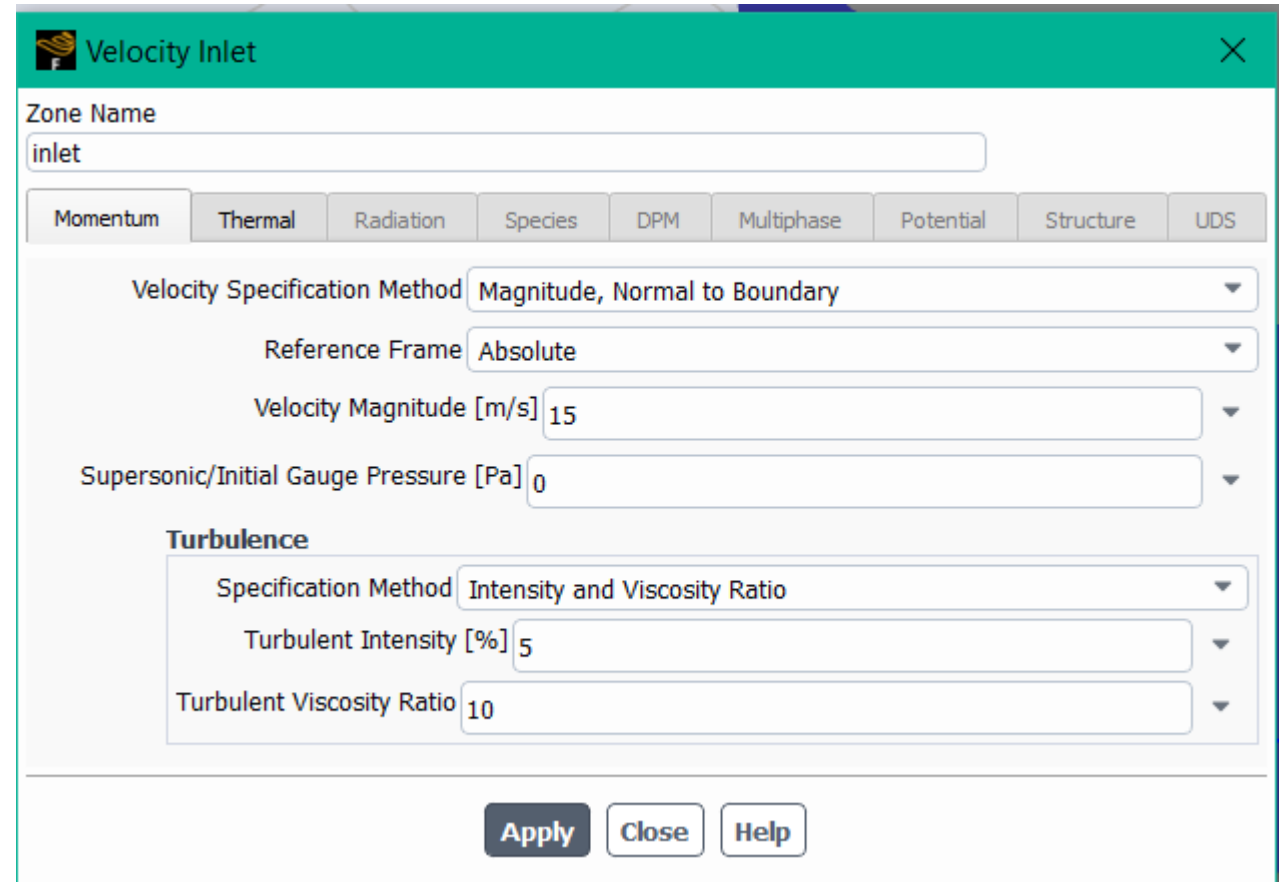
3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



The screenshot shows the 'Velocity Inlet' dialog box in ANSYS FLUENT. The 'Zone Name' is 'inlet'. The 'Momentum' tab is selected. The 'Velocity Specification Method' is 'Magnitude, Normal to Boundary'. The 'Reference Frame' is 'Absolute'. The 'Velocity Magnitude [m/s]' is set to 15. The 'Supersonic/Initial Gauge Pressure [Pa]' is set to 0. The 'Turbulence' section is expanded, showing 'Specification Method' as 'Intensity and Viscosity Ratio', 'Turbulent Intensity [%]' as 5, and 'Turbulent Viscosity Ratio' as 10. At the bottom are 'Apply', 'Close', and 'Help' buttons.

Velocity Inlet

Zone Name
inlet

Momentum Thermal Radiation Species DPM Multiphase Potential Structure UDS

Velocity Specification Method Magnitude, Normal to Boundary

Reference Frame Absolute

Velocity Magnitude [m/s] 15

Supersonic/Initial Gauge Pressure [Pa] 0

Turbulence

Specification Method Intensity and Viscosity Ratio

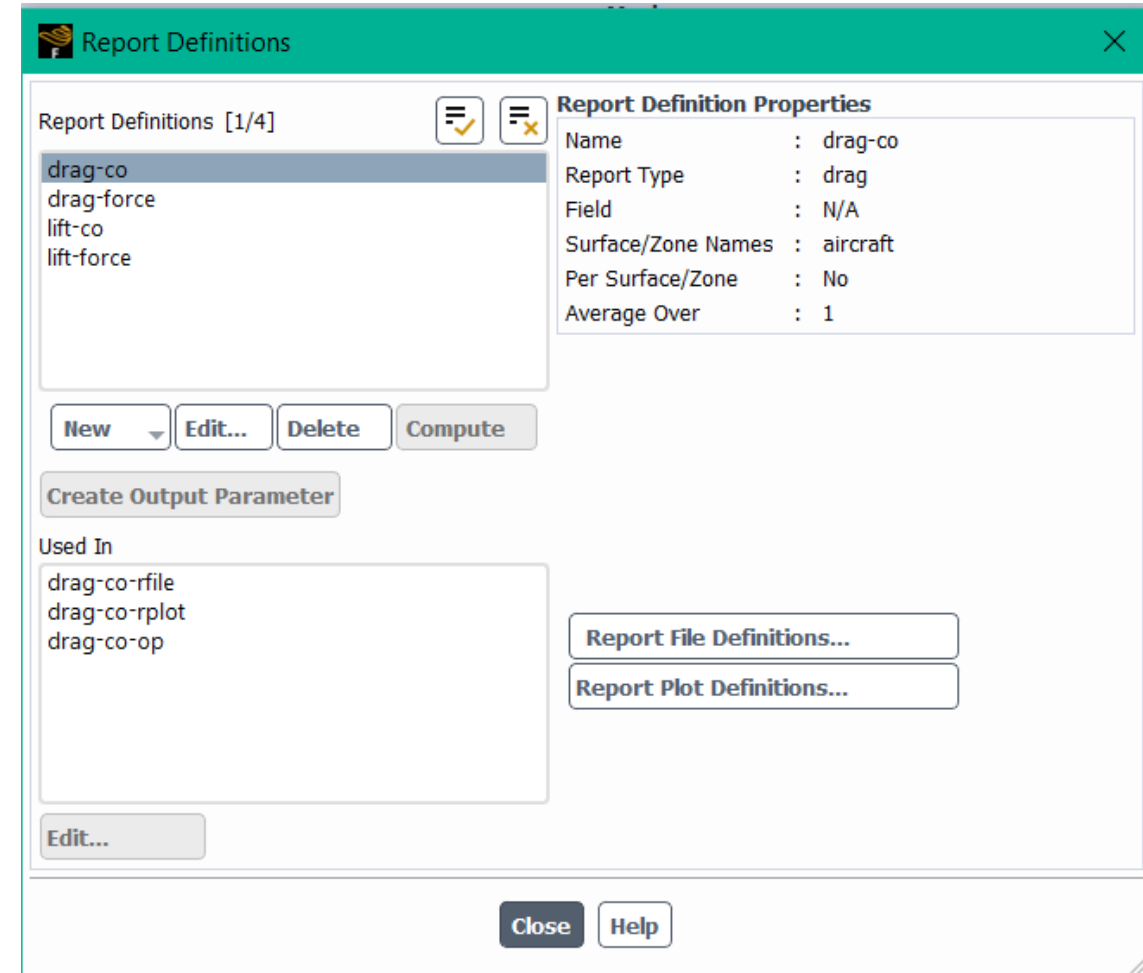
Turbulent Intensity [%] 5

Turbulent Viscosity Ratio 10

Apply Close Help

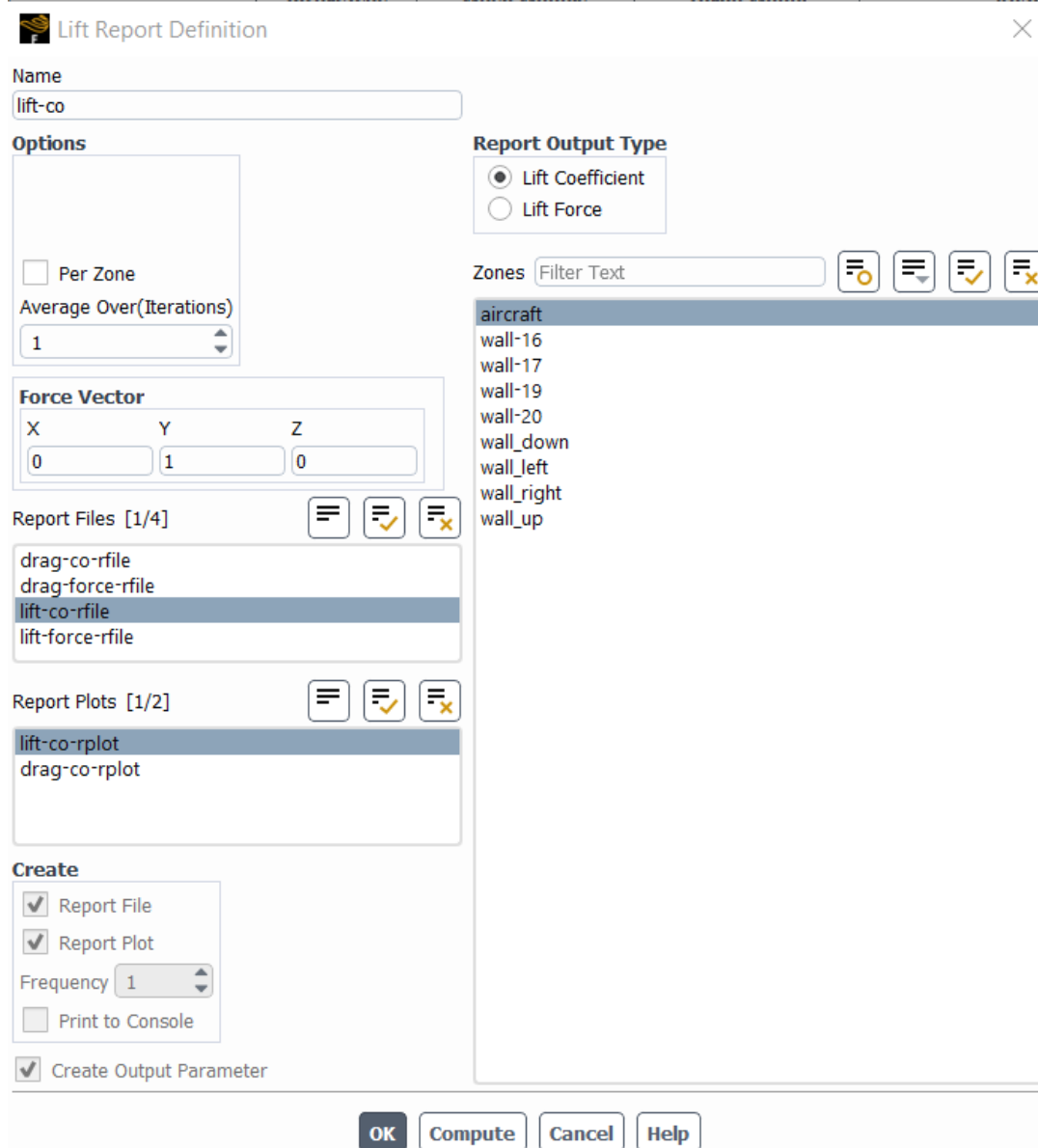
3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions (lift force, drag force, c_l , c_d)
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



3. Launch FLUENT (Setup)

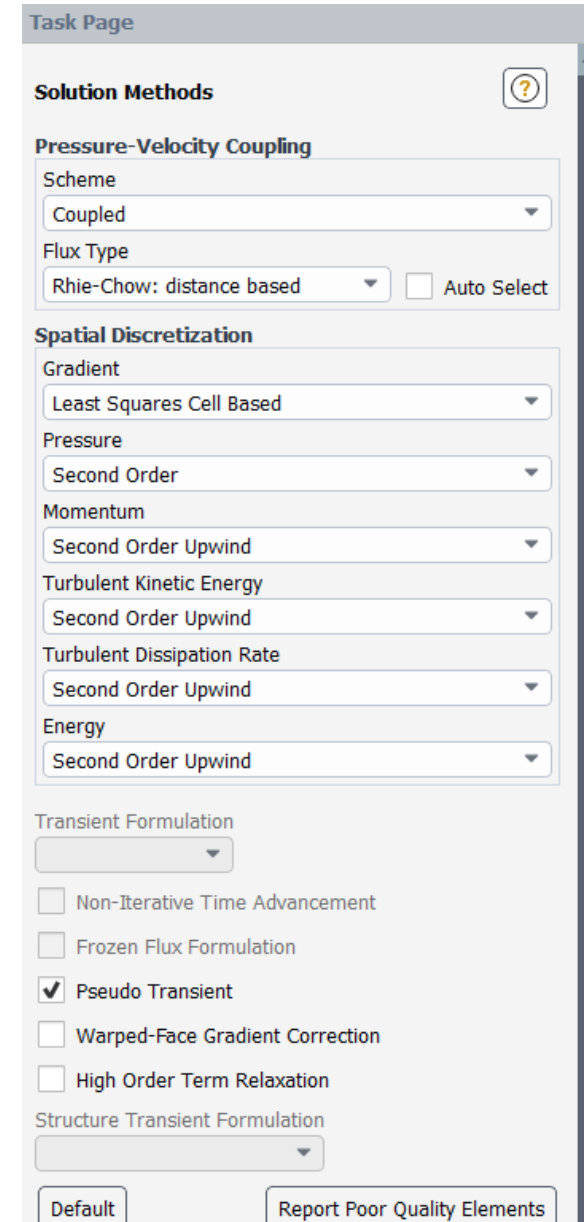
1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set report Definitions (lift force, drag force, c_l , c_d)
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



The screenshot shows the 'Lift Report Definition' dialog box in FLUENT. The 'Name' field is set to 'lift-co'. Under 'Options', 'Per Zone' is unchecked and 'Average Over (Iterations)' is set to 1. The 'Force Vector' section shows X=0, Y=1, and Z=0. In the 'Report Files' list, 'lift-co-rfile' is selected. In the 'Report Plots' list, 'lift-co-rplot' is selected. The 'Report Output Type' section has 'Lift Coefficient' selected. The 'Zones' list on the right includes 'aircraft', 'wall-16', 'wall-17', 'wall-19', 'wall-20', 'wall_down', 'wall_left', 'wall_right', and 'wall_up'. The 'Create' section at the bottom has 'Report File', 'Report Plot', and 'Create Output Parameter' checked, with 'Frequency' set to 1. 'Print to Console' is unchecked. At the bottom right are buttons for 'OK', 'Compute', 'Cancel', and 'Help'.

3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set Report Definitions
7. Set Solution Methods
Second Order → more accurate solution
8. Set Residual Monitors
9. Set Initialization (Compute from inlet)



The screenshot shows the 'Task Page' window in FLUENT. The 'Solution Methods' panel is active, displaying various settings for the simulation. The 'Pressure-Velocity Coupling' section shows 'Scheme' set to 'Coupled' and 'Flux Type' set to 'Rhie-Chow: distance based' with an 'Auto Select' checkbox. The 'Spatial Discretization' section shows 'Gradient' set to 'Least Squares Cell Based', 'Pressure' set to 'Second Order', 'Momentum' set to 'Second Order Upwind', 'Turbulent Kinetic Energy' set to 'Second Order Upwind', 'Turbulent Dissipation Rate' set to 'Second Order Upwind', and 'Energy' set to 'Second Order Upwind'. The 'Transient Formulation' section shows a dropdown menu and several checkboxes: 'Non-Iterative Time Advancement' (unchecked), 'Frozen Flux Formulation' (unchecked), 'Pseudo Transient' (checked), 'Warped-Face Gradient Correction' (unchecked), and 'High Order Term Relaxation' (unchecked). The 'Structure Transient Formulation' section shows a dropdown menu. At the bottom, there are buttons for 'Default' and 'Report Poor Quality Elements'.

Task Page

Solution Methods ⓘ

Pressure-Velocity Coupling

Scheme
Coupled

Flux Type
Rhie-Chow: distance based ☐ Auto Select

Spatial Discretization

Gradient
Least Squares Cell Based

Pressure
Second Order

Momentum
Second Order Upwind

Turbulent Kinetic Energy
Second Order Upwind

Turbulent Dissipation Rate
Second Order Upwind

Energy
Second Order Upwind

Transient Formulation
[Dropdown]

☐ Non-Iterative Time Advancement

☐ Frozen Flux Formulation

☒ Pseudo Transient

☐ Warped-Face Gradient Correction

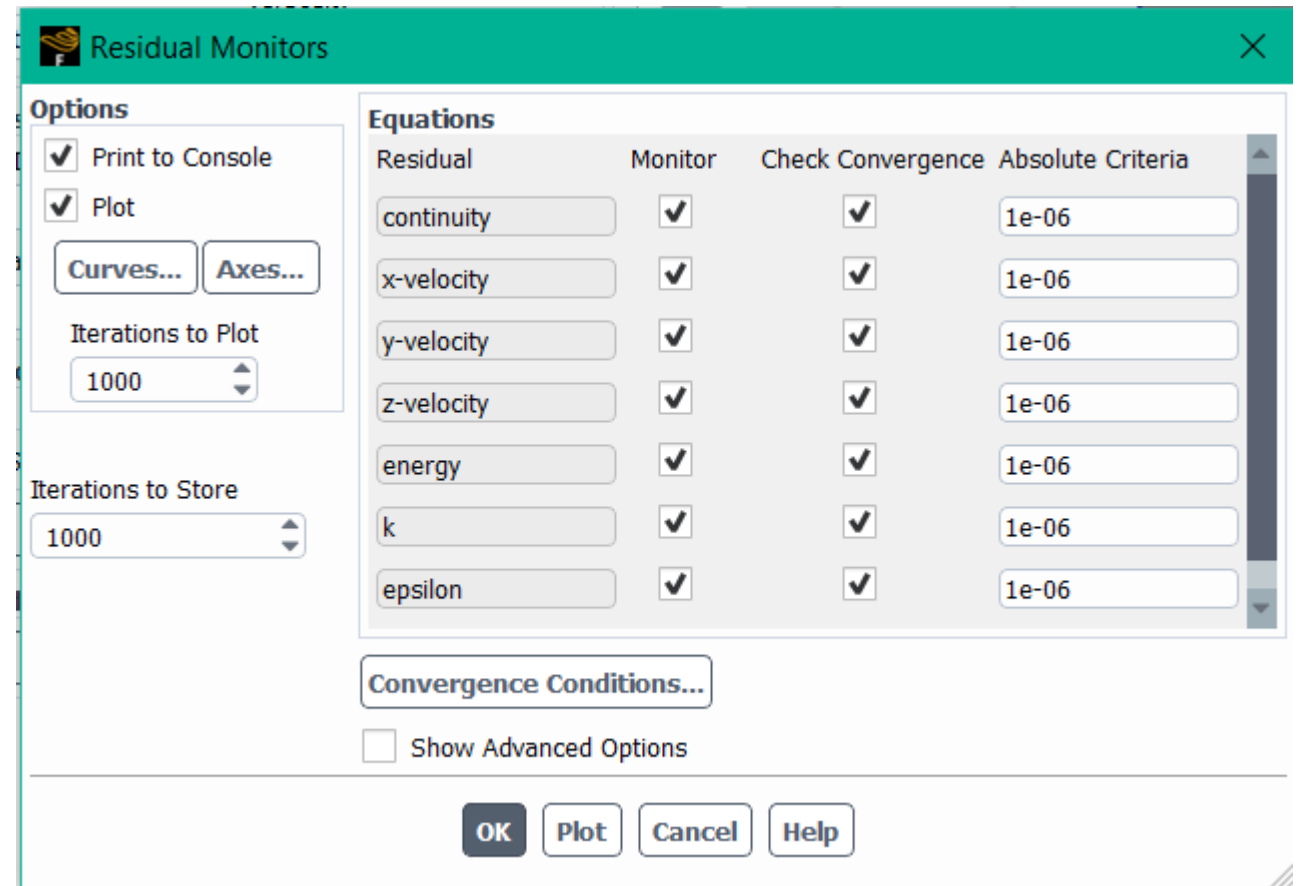
☐ High Order Term Relaxation

Structure Transient Formulation
[Dropdown]

Default Report Poor Quality Elements

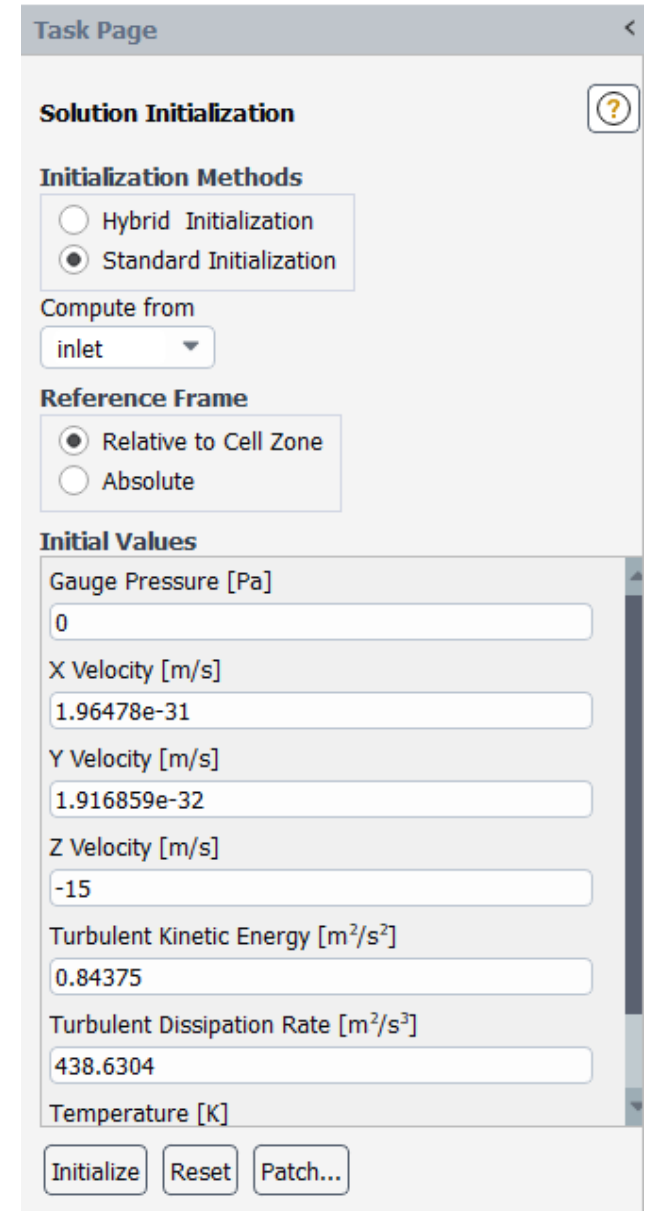
3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set Report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization



3. Launch FLUENT (Setup)

1. Scale Mesh: unit = m
2. Model: Energy On
3. Set K-epsilon model
4. Air as fluid
5. Inlet velocity: 15m/s
6. Set Report Definitions
7. Set Solution Methods
8. Set Residual Monitors
9. Set Initialization (Compute from inlet)



The screenshot displays the 'Task Page' window for FLUENT, specifically the 'Solution Initialization' section. The 'Initialization Methods' are set to 'Standard Initialization'. The 'Compute from' dropdown is set to 'inlet'. The 'Reference Frame' is set to 'Relative to Cell Zone'. The 'Initial Values' section shows the following settings:

Parameter	Value
Gauge Pressure [Pa]	0
X Velocity [m/s]	1.96478e-31
Y Velocity [m/s]	1.916859e-32
Z Velocity [m/s]	-15
Turbulent Kinetic Energy [m ² /s ²]	0.84375
Turbulent Dissipation Rate [m ² /s ³]	438.6304
Temperature [K]	

At the bottom of the window, there are three buttons: 'Initialize', 'Reset', and 'Patch...'.

Results

- Run Calculation
Number of iterations: 1000
- Generate Report

Task Page

Run Calculation ?

Check Case... Update Dynamic Mesh...

Pseudo Transient Settings

Fluid Time Scale

Time Step Method: Automatic Time Scale Factor: 1

Length Scale Method: Conservative Verbosity: 0

Parameters

Number of Iterations: 1000 Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☐ Data Sampling for Steady Statistics

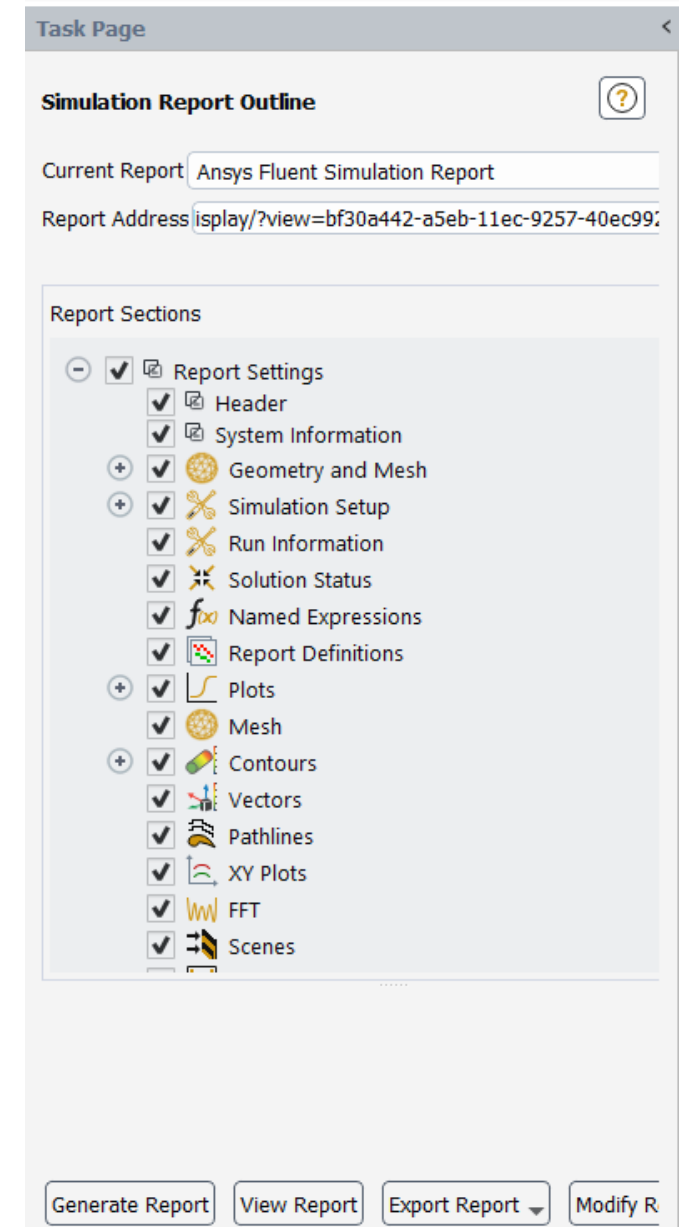
Data File Quantities...

Solution Advancement

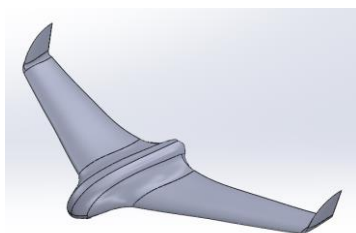
Calculate

Results

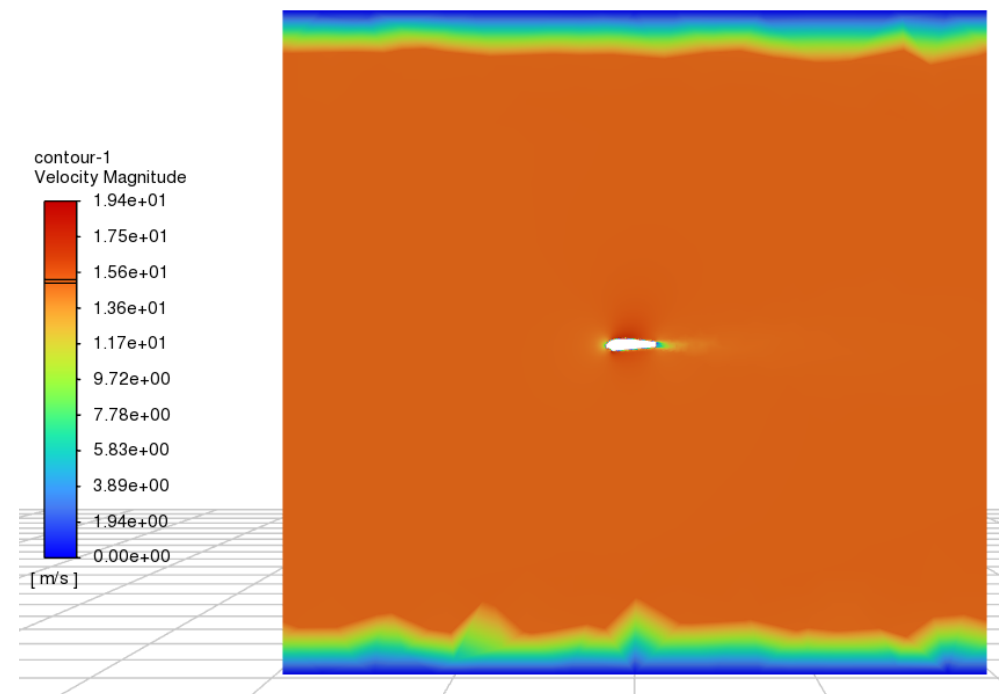
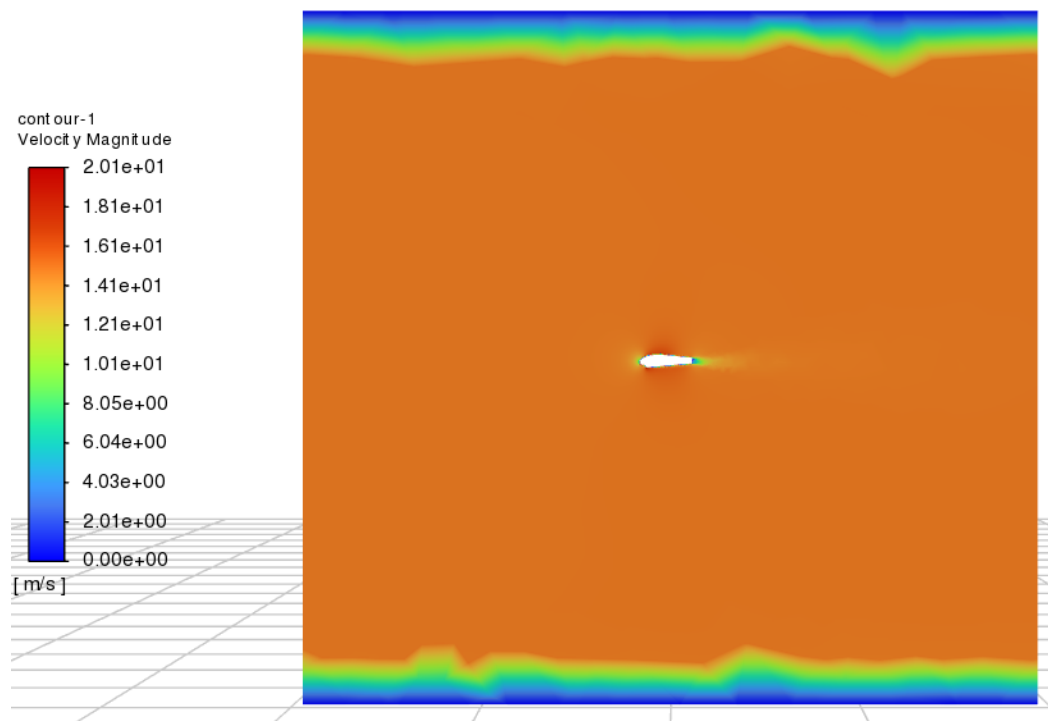
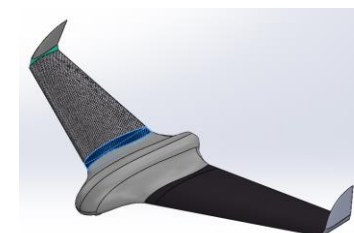
- Run Calculation
Number of iterations: 1000
- Generate Report → Export Report



Skywalker X8

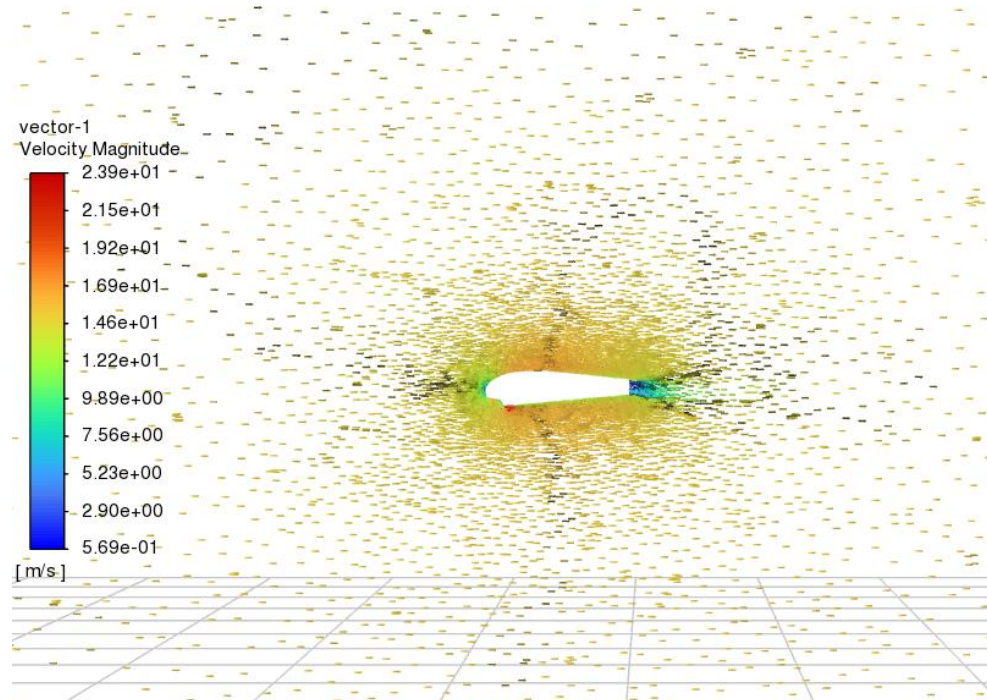
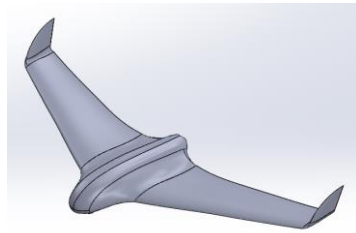


CF (Clark Y)

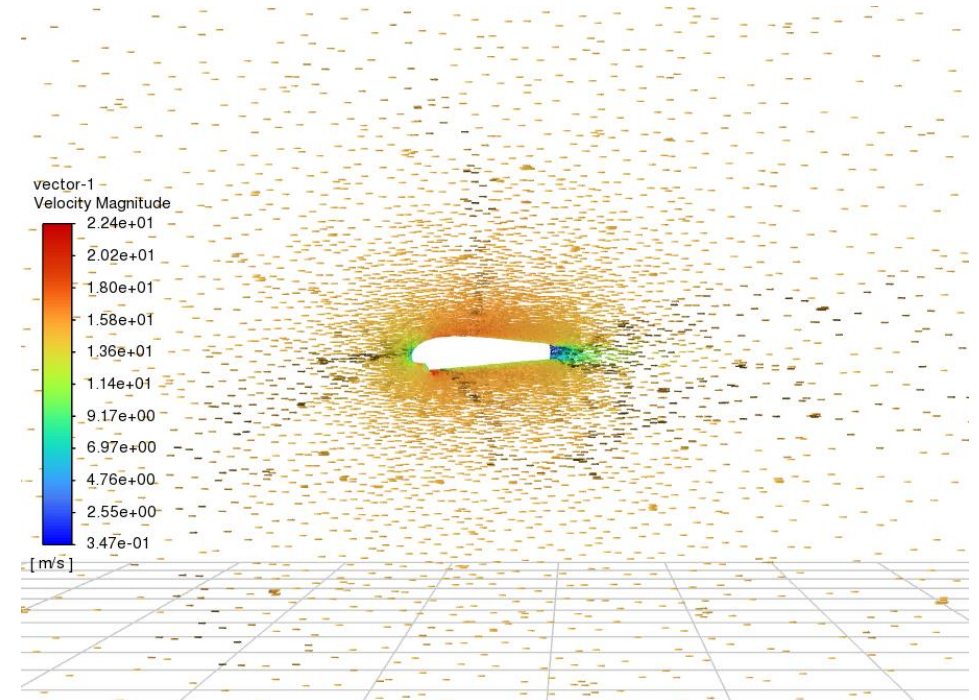


Contours of Velocity Magnitude (m/s)

Skywalker X8

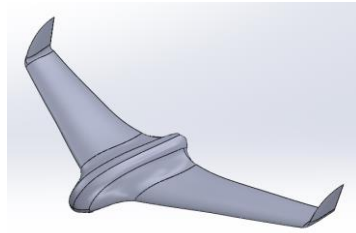


CF (Clark Y)

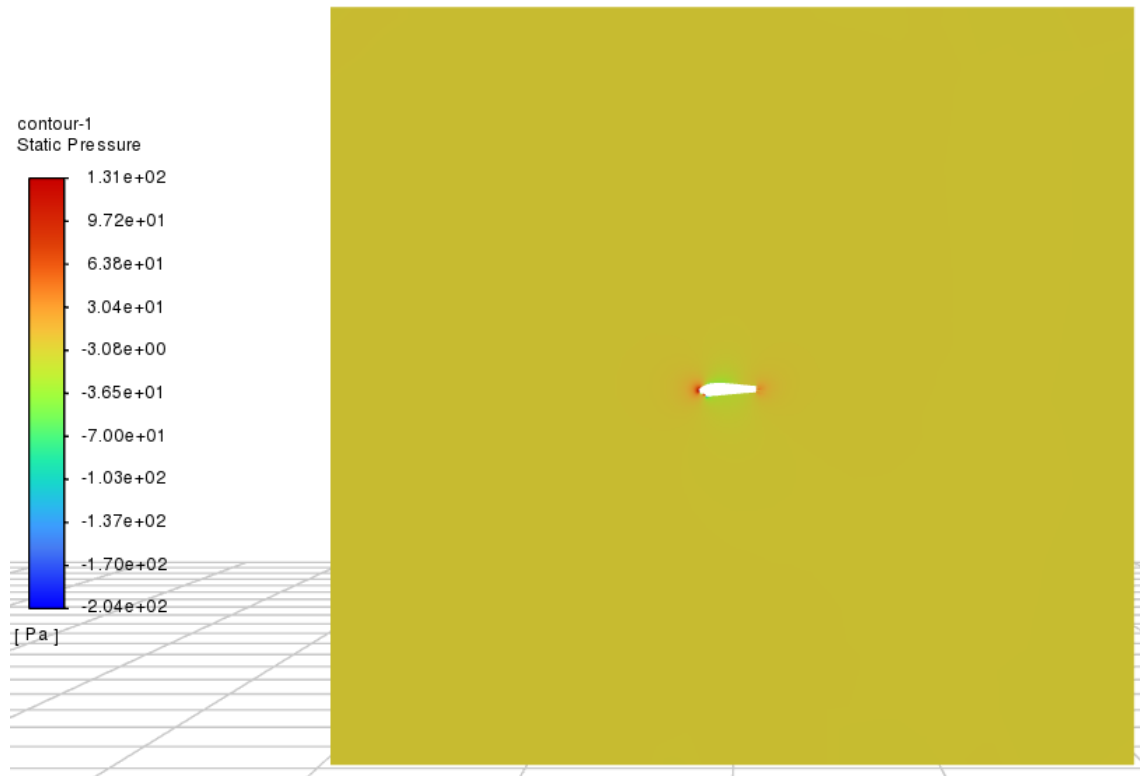
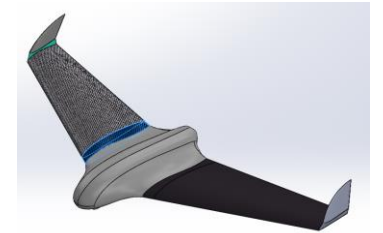


Vectors Colored by Velocity Magnitude (m/s)

Skywalker X8

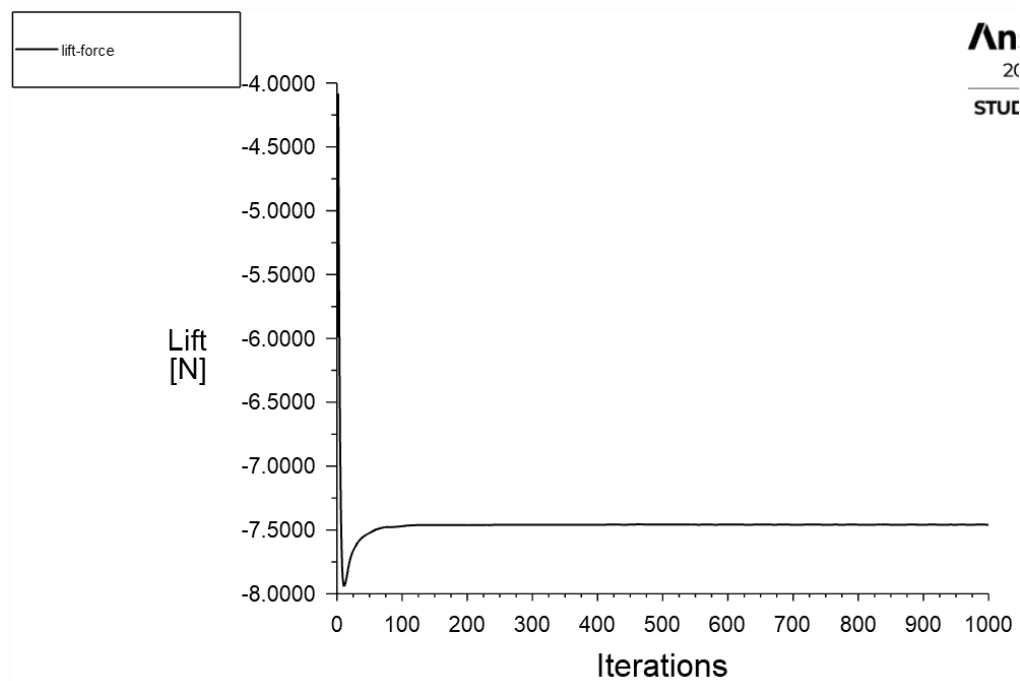
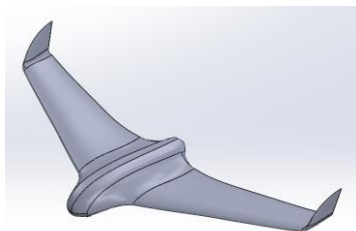


CF (Clark Y)

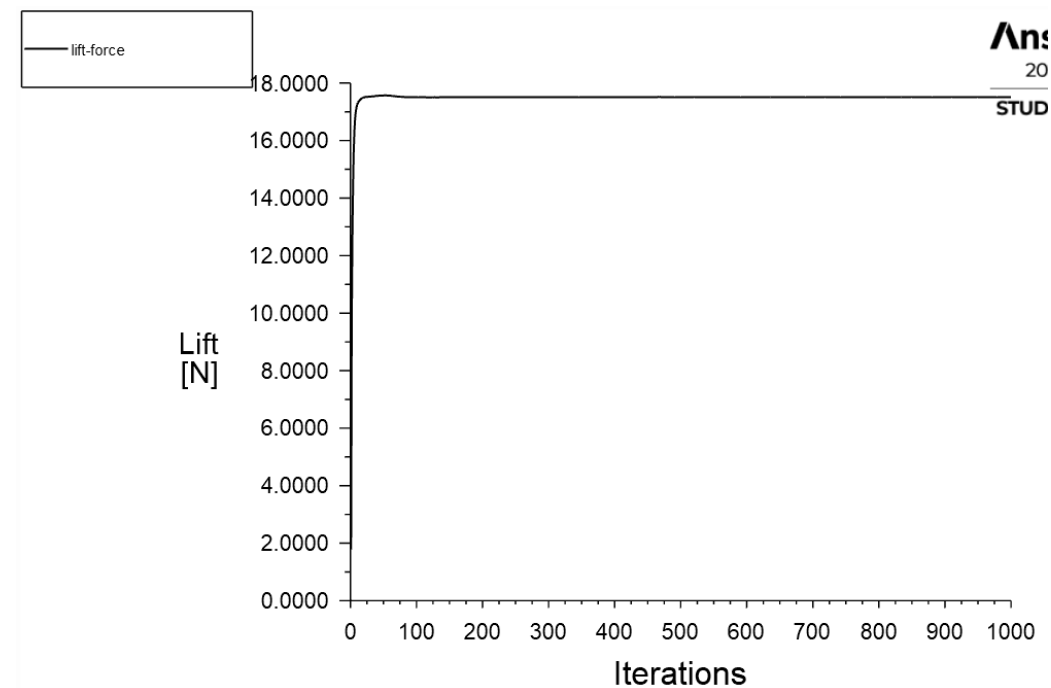
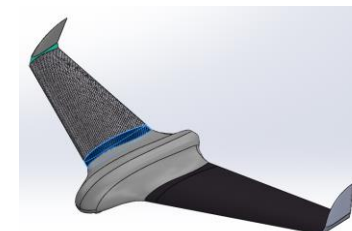


Contours of Static Pressure (Pa)

Skywalker X8

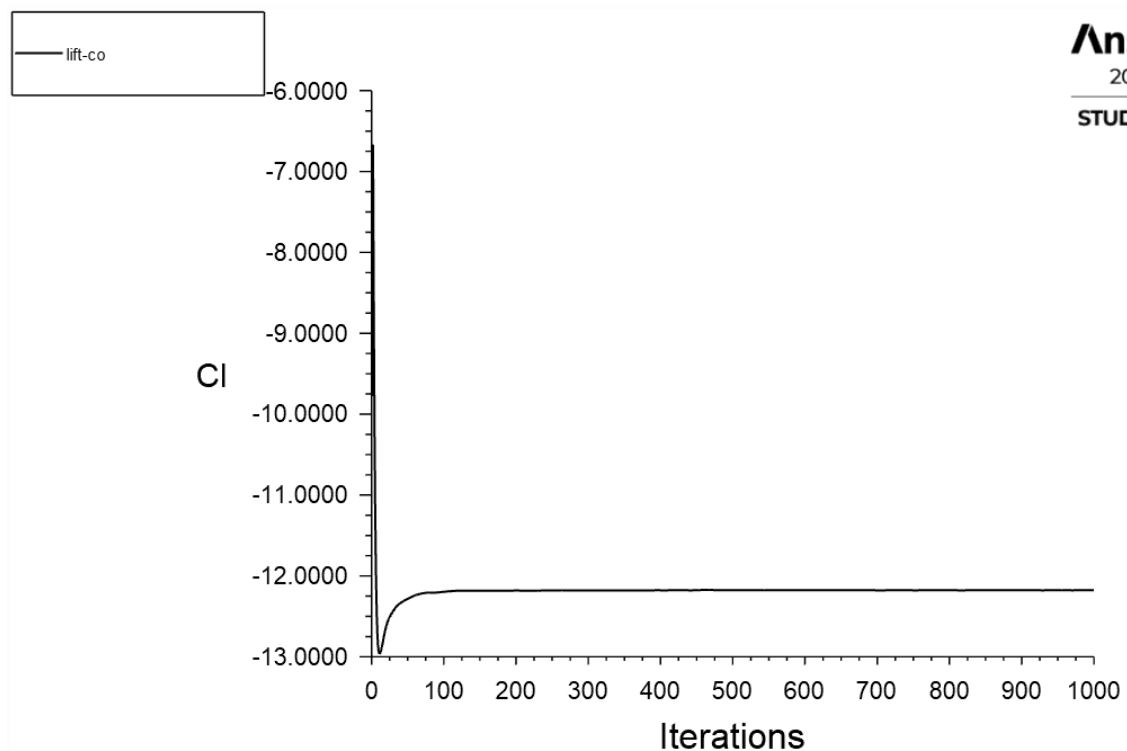
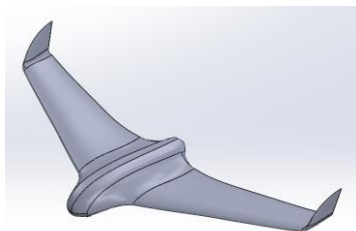


CF (Clark Y)

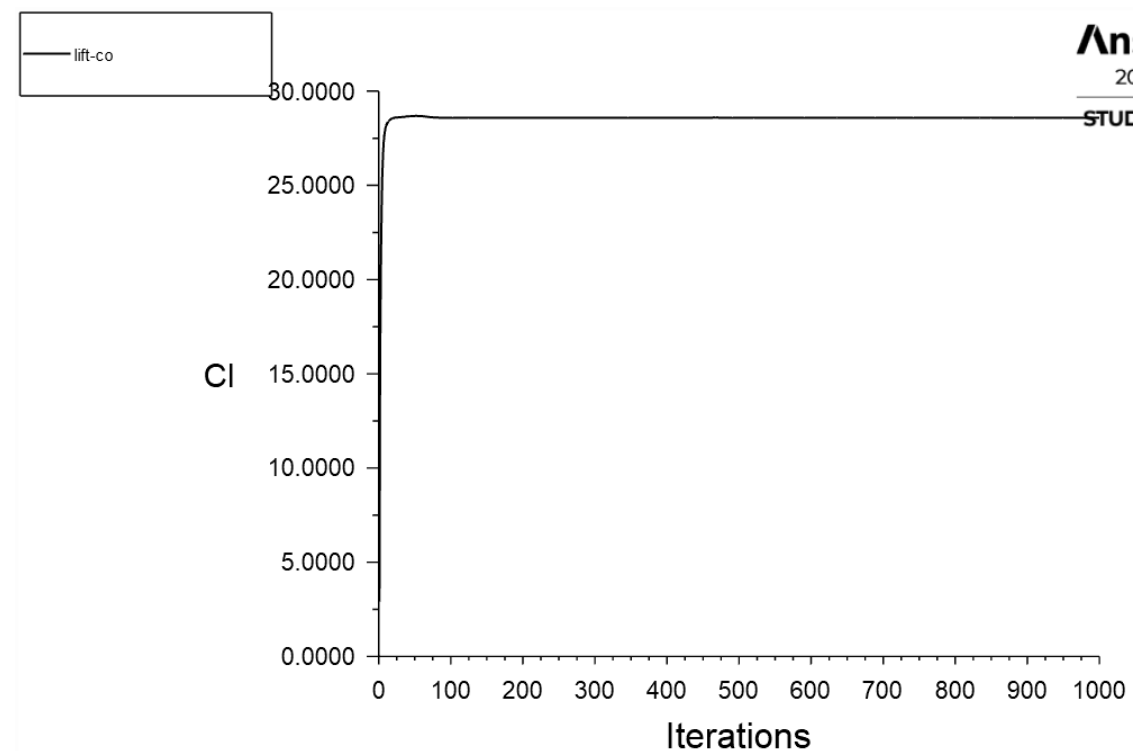
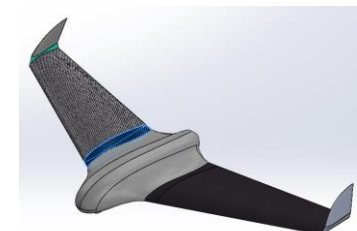


Lift force

Skywalker X8

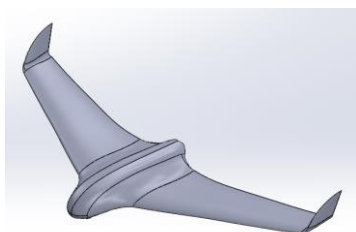


CF (Clark Y)

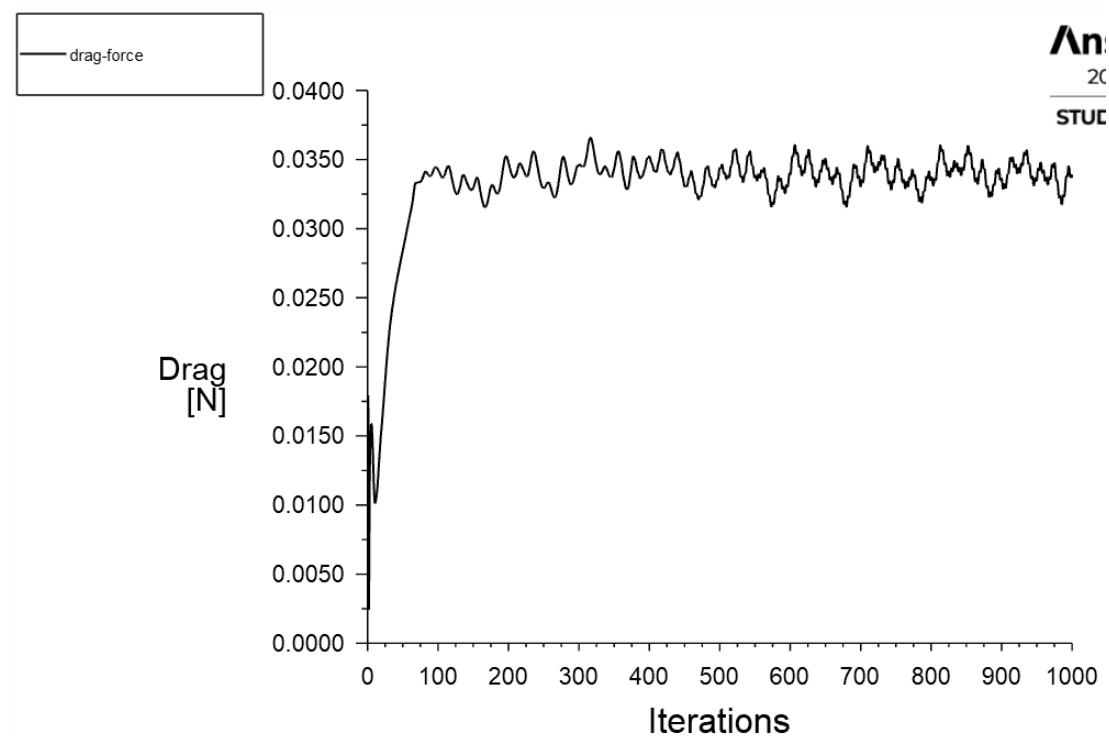
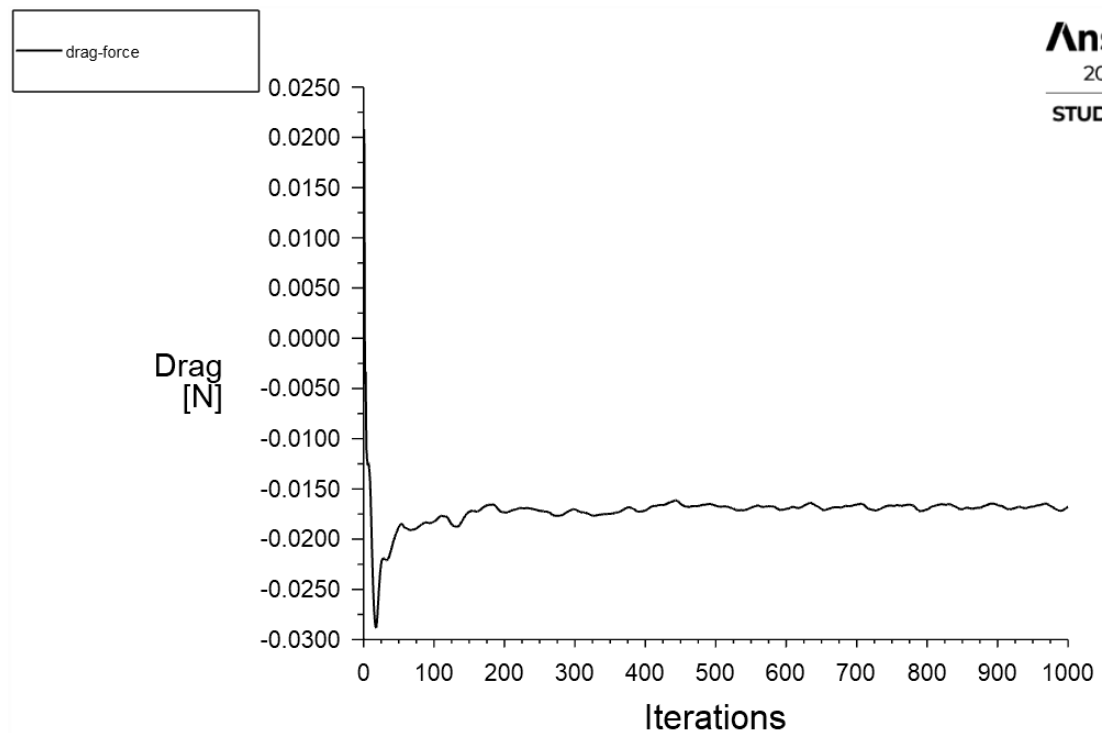
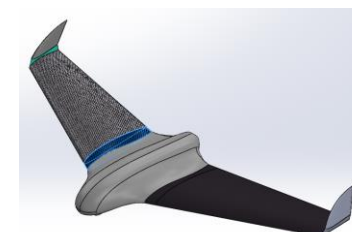


Lift coefficient

Skywalker X8

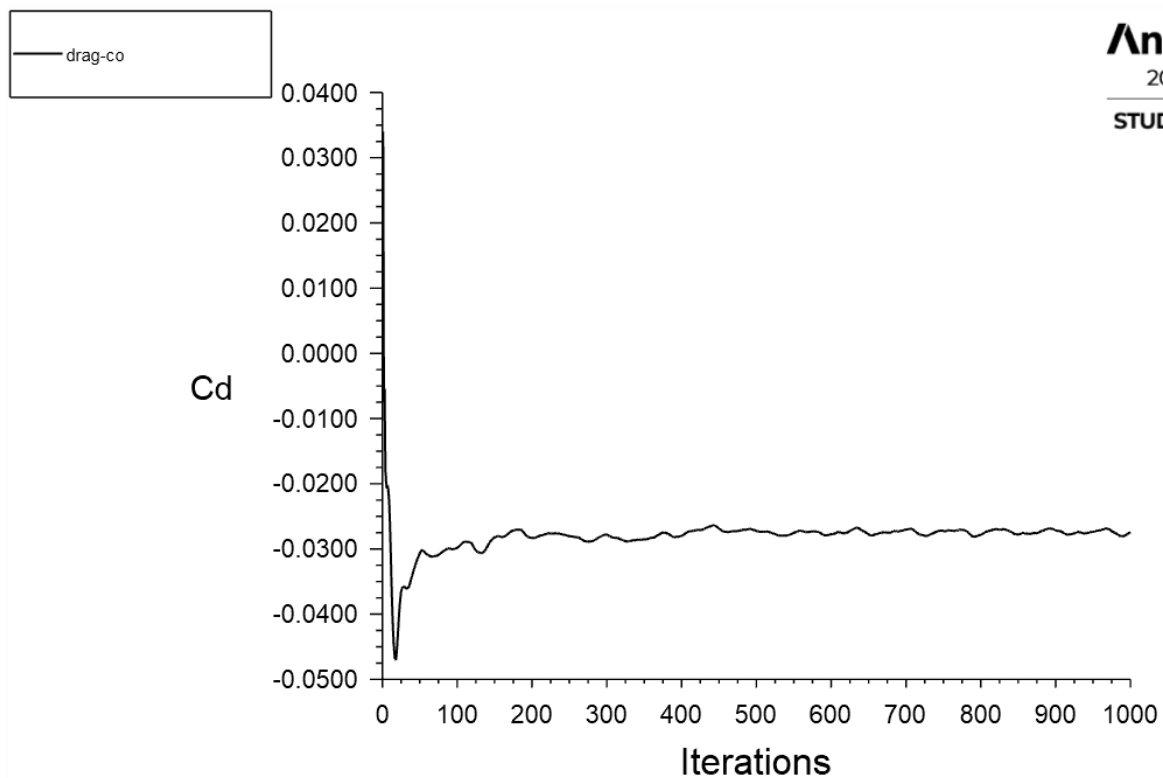
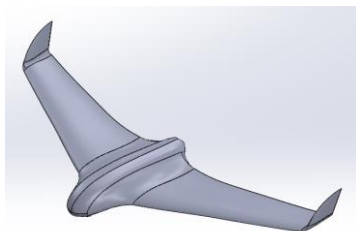


CF (Clark Y)

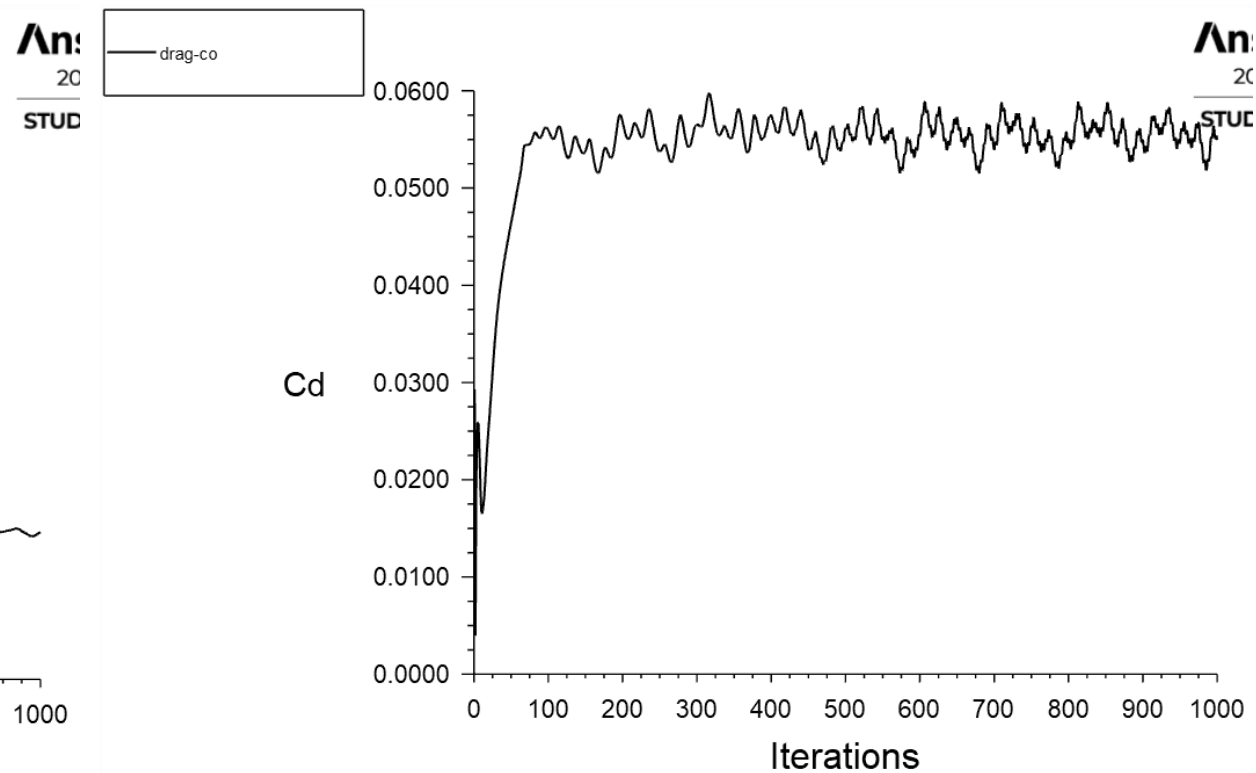
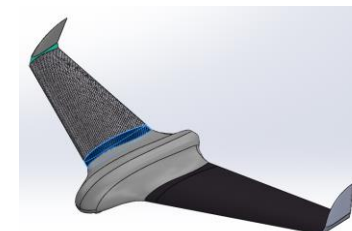


Drag force

Skywalker X8

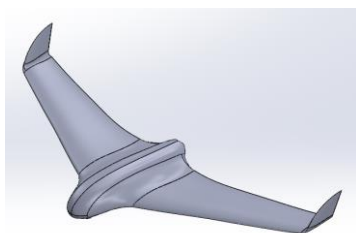


CF (Clark Y)



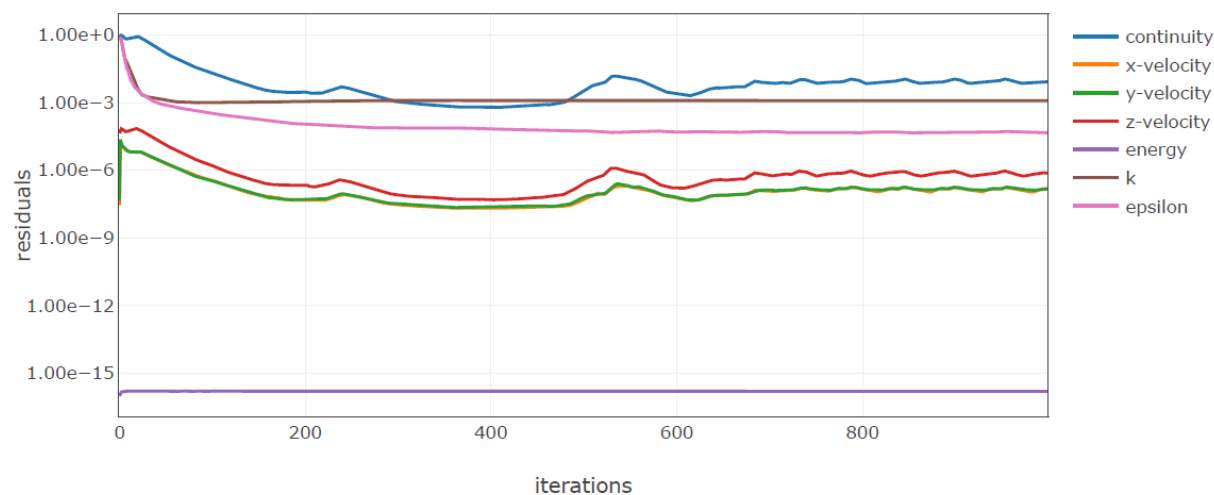
Drag coefficient

Skywalker X8

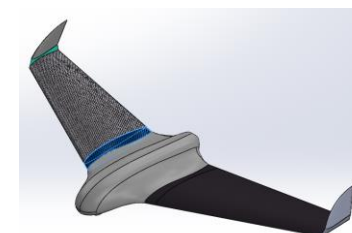


Residuals

Residuals

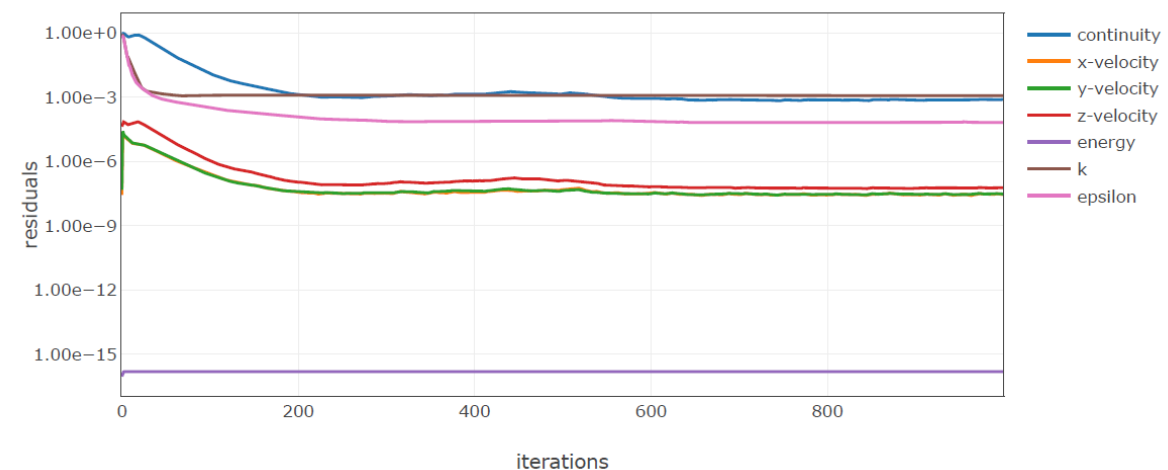


CF (Clark Y)

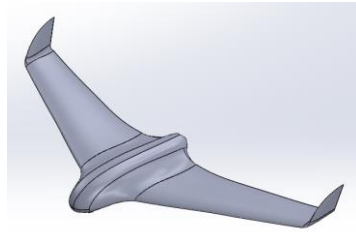


Residuals

Residuals



Skywalker X8



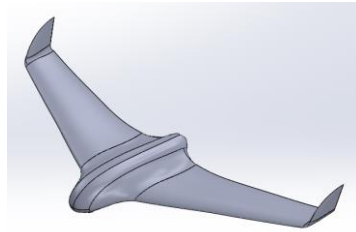
lift-force	-7.458751 N
lift-co	-12.17755
drag-force	-0.01678963 N
drag-co	-0.02741164

CF (Clark Y)



lift-force	17.51005 N
drag-force	0.03366275 N
lift-co	28.58784
drag-co	0.0549596

Skywalker X8



Iterations: 1000

	Value	Absolute Criteria	Convergence Status
continuity	0.008320905	1e-06	Not Converged
x-velocity	1.437123e-07	1e-06	Converged
y-velocity	1.486843e-07	1e-06	Converged
z-velocity	7.396273e-07	1e-06	Converged
energy	1.545174e-16	1e-06	Converged
k	0.001218344	1e-06	Not Converged
epsilon	4.562565e-05	1e-06	Not Converged

CF (Clark Y)



Iterations: 1000

	Value	Absolute Criteria	Convergence Status
continuity	0.0008046752	1e-06	Not Converged
x-velocity	2.879304e-08	1e-06	Converged
y-velocity	3.068185e-08	1e-06	Converged
z-velocity	5.979942e-08	1e-06	Converged
energy	1.564403e-16	1e-06	Converged
k	0.001199351	1e-06	Not Converged
epsilon	6.687712e-05	1e-06	Not Converged

Future plan

Final report

Things will be added in Final Report

- Acknowledgement:
 - Prof. Wen
 - Jeremy, Patrick, Bailun Jiang, Yurong Feng (UAV)
 - IC instructor, Dr Mabel Ho (Composites)
 - ME Senior Instructor, Ir Elsa Tang (CFD)
- Summary of Contribution
- Abstract
- Aerodynamics calculations
- Flight log analysis
- CFD
- Manufacturing of the composited wing(s)
- Possible recommendations for future work

Future plan

Final demonstration – video(s)

Brief ideas of the video(s) for online oral presentation

- C.G. test with payload & composited wings (if possible)
- Hovering test in CF005 (without payload)
- Flying test in Yuen Long in Dec 2021 (without payload)

Brief ideas of the video(s) for online oral presentation

- C.G. test with payload & composited wings (if possible)
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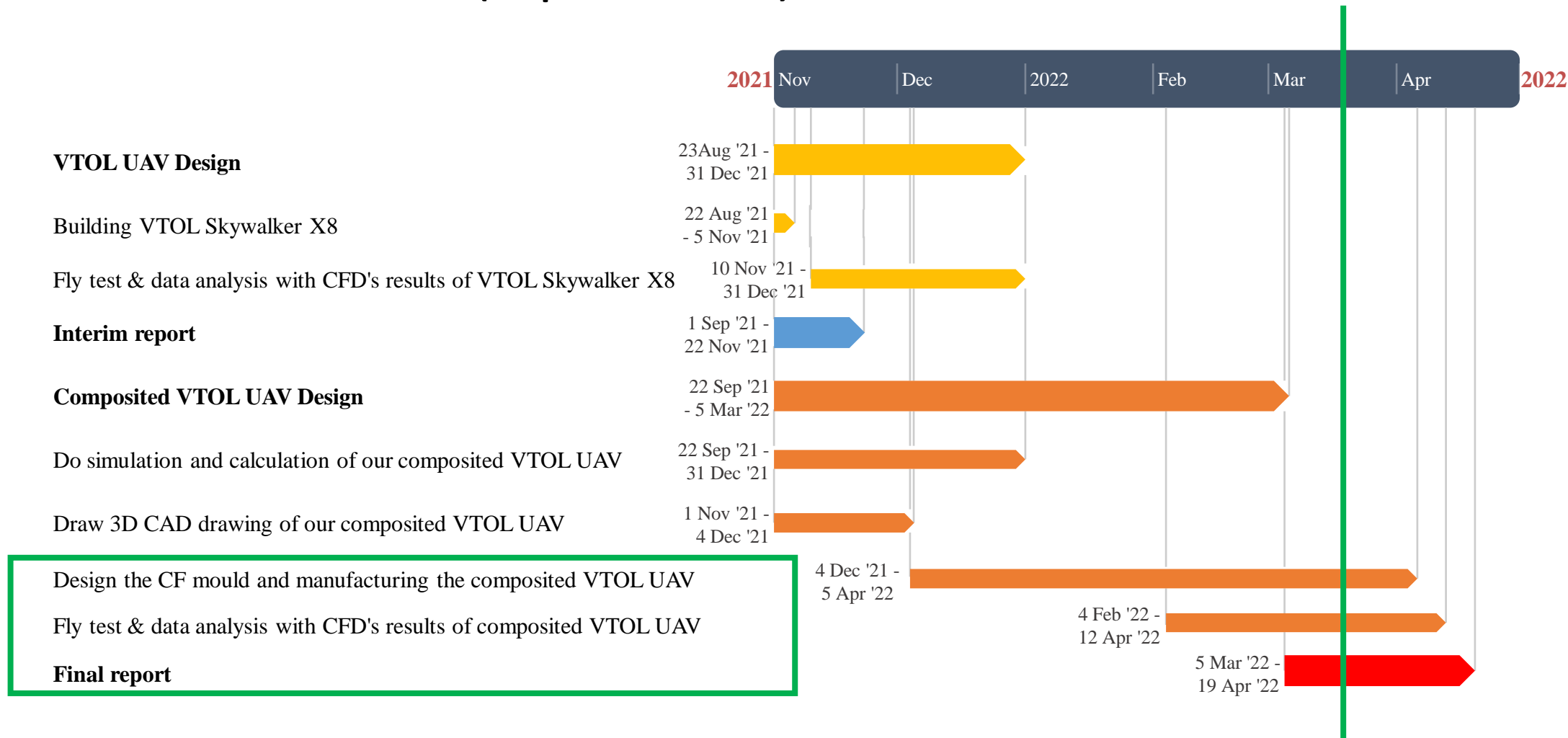


Brief ideas of the video(s) for online oral presentation

- C.G. test with payload & composited wings (if possible)
- Hovering test in CF005 (without payload)
- Flying test in Yuen Long in Dec 2021 (without payload)



Gantt chart (updated)



Thank you