University of the Ryukyus of
Global Science Campus Program

Research & Development of Multipurpose Autonomous Shallow Underwater Vehicle

Okinawa Catholic Junior & Senior High School
2nd grade Ryudo Kawano

Development Objective

Collectively collect data on coastal areas due to recent ocean expansion

High versatility

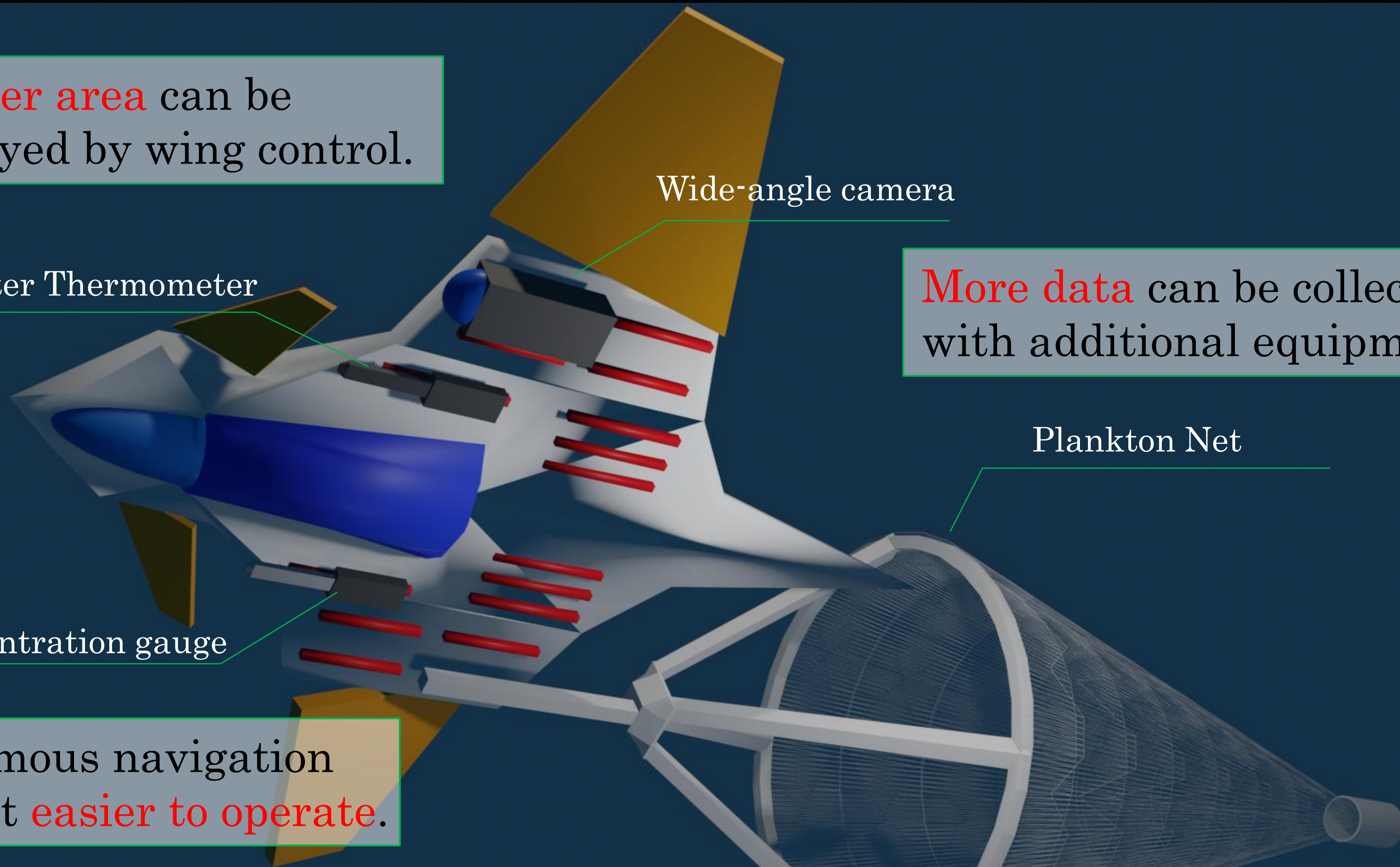
Wide radius of action

Ease of operation

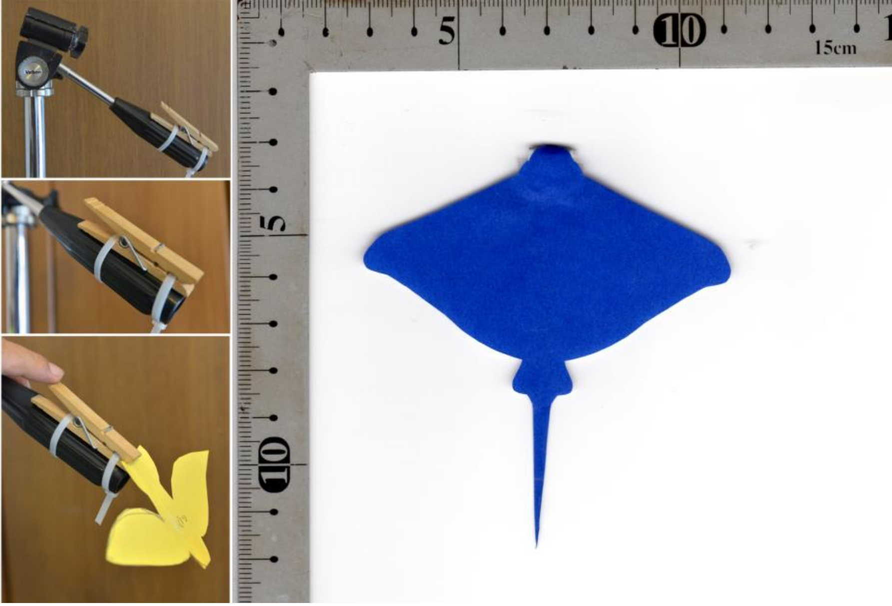
A wider area can be surveyed by wing control.

More data can be collected with additional equipment.

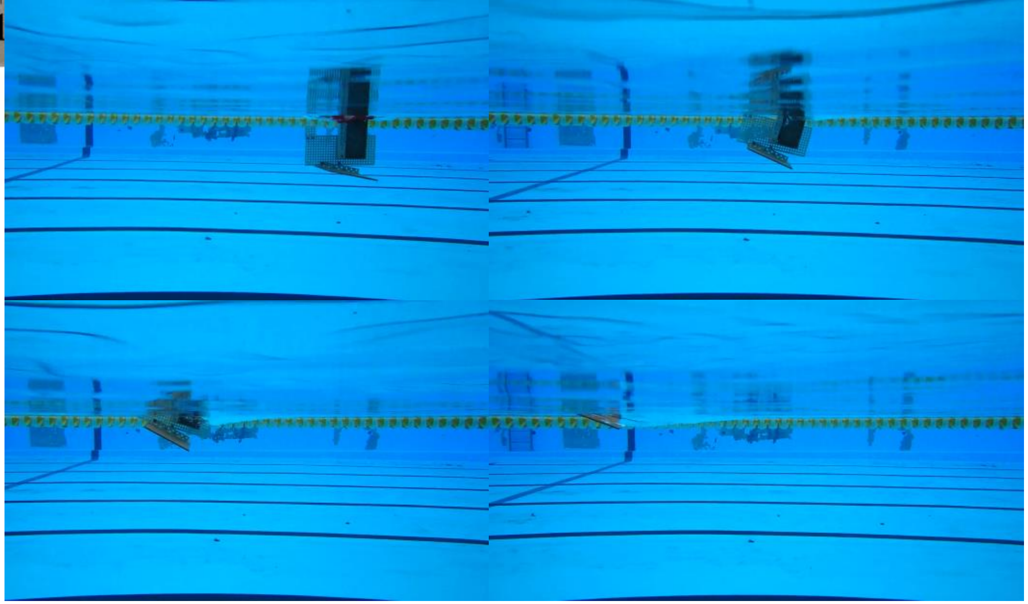
Autonomous navigation makes it easier to operate.



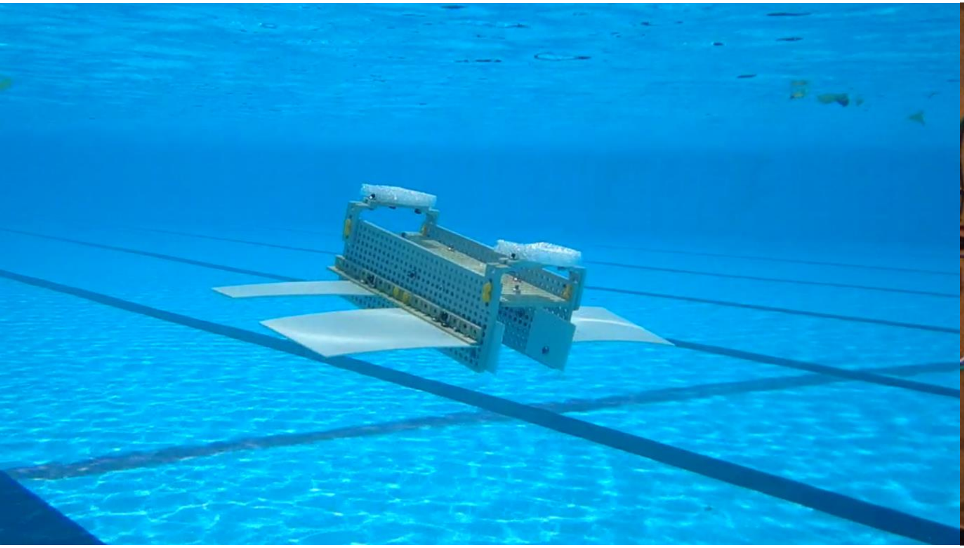
Multipurpose Autonomous Shallow Underwater Vehicle



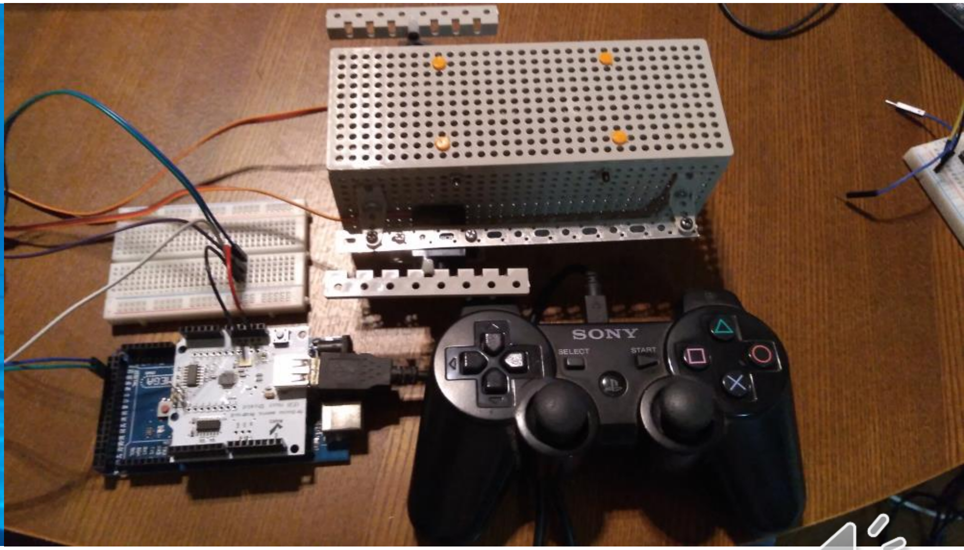
Glider research with biomimetics



An experiment using a hydrofoil to observe the behavior of a wing in water.



An experiment to observe behavior in water using a small experimental machine



Remote control experiment using a small experimental machine

Experiment (initial plan)

Waterproofing experiments: To manufacture actual machines and small experimental machines, using 3D printers, etc.

Wing control test: Performed by operating the wings in water using a small experimental machine.

Equipment loading test: Observing the behavior of a small experimental aircraft when it is loaded with a weight.

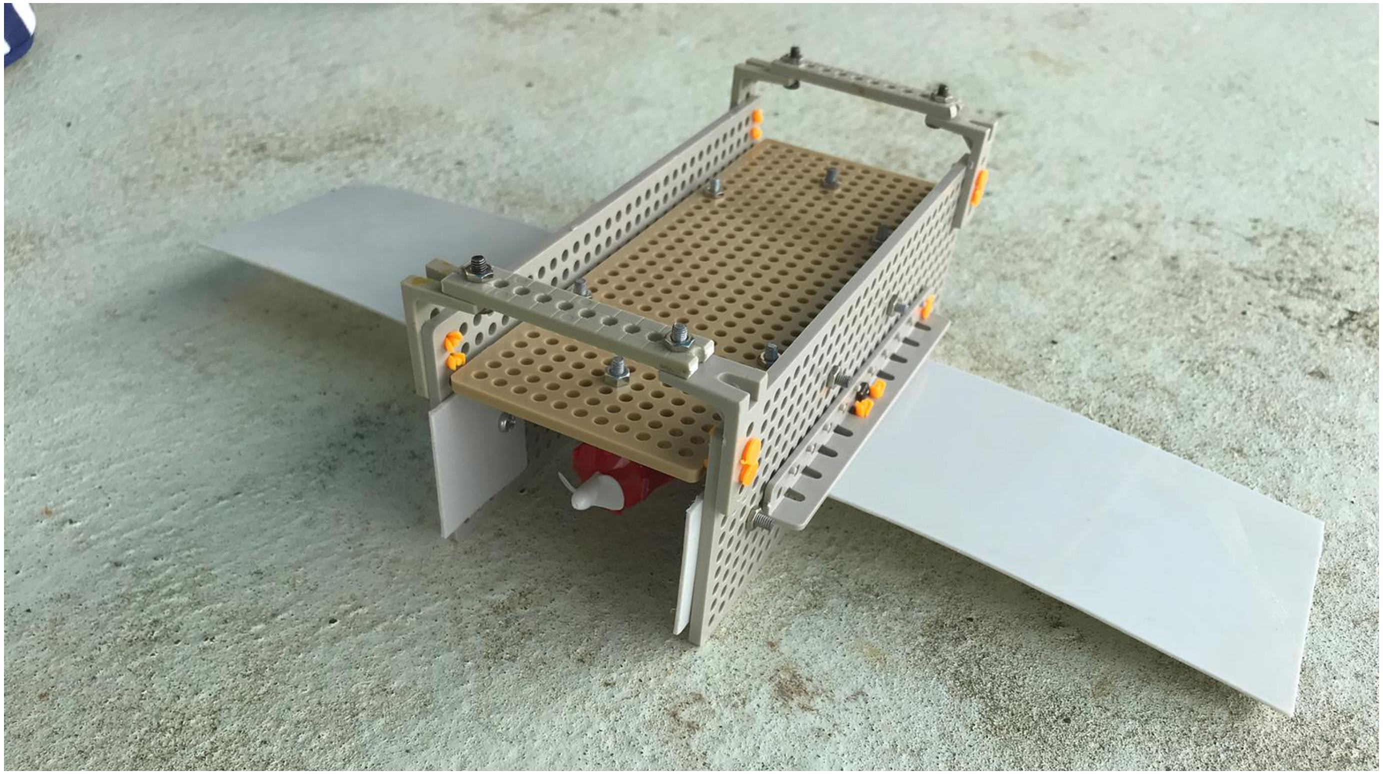
Data collection for autonomous control: Collecting behavior data for autonomous control.

impossible

Verification: Verify the behavior observed in the experiment but whose principle is unclear in the results so far.

Testing CFD: To what extent CFD can be used in determining and verifying the performance of hydrofoils.

Creation of autonomous control program: Under the supervision of Professor Wada of the University of the Ryukyus, the program will be created.



Small experimental model used in the experiment.

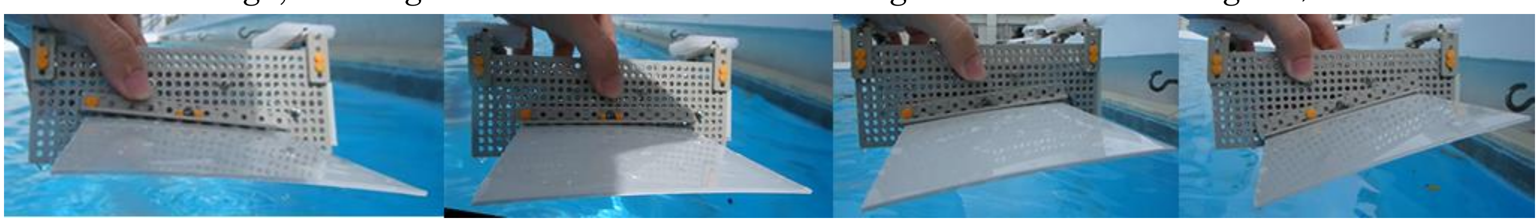
Length: 17cm
Overall width:31cm
Wing area: 240cm² total
Wing material: Daiso PP sheet 1.4mm
Motor:Tamiya Mini Underwater Motor (High Speed Type)

・The wing shape is drawn in orange to make it easier to see.
・Total area is equal.

Wing performing the experiment

One pair of wings | Two pairs of wings | Two pairs of wings with large front wing | Two pairs of wings with large rear wing

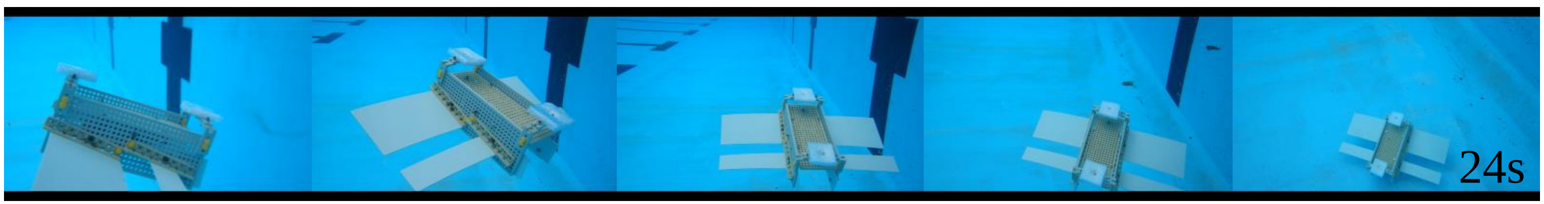
The angle of attack(AoA) at which the experiment is conducted (For the type with front and rear wings, the angles of the front and rear wings should also be aligned).



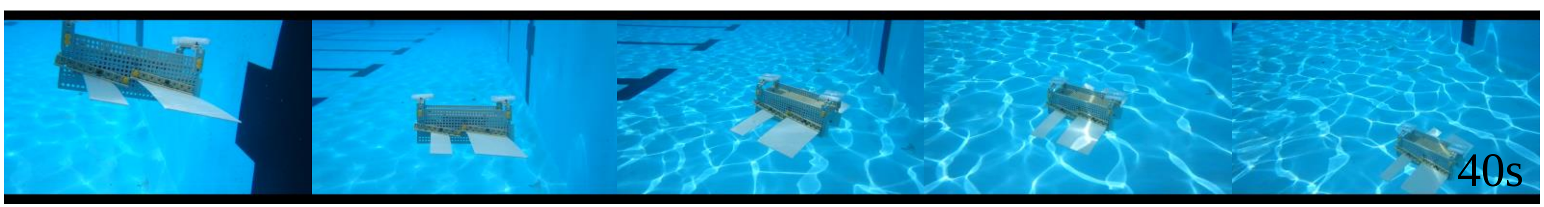
AoA + | AoA ±0 | AoA - | AoA --

For the type with two pairs of wings, the model did not rise, including both the type with large front wings and the type with large rear wings. The type with a large rear wing moved forward relatively more than the other two-pair type, but it could not rise.

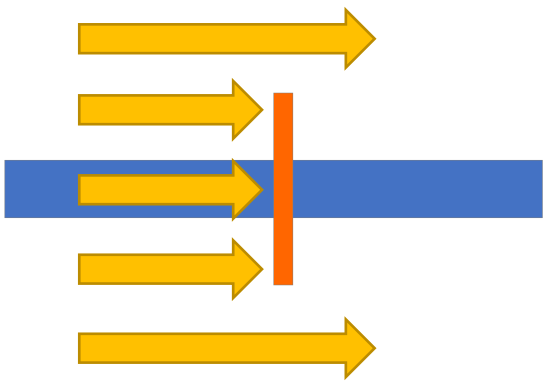
Large front wing



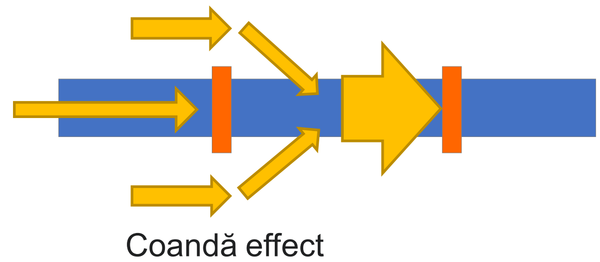
Large rear wing



For 1wing of 10cm



For 2wings of 5cm (total area is the same)

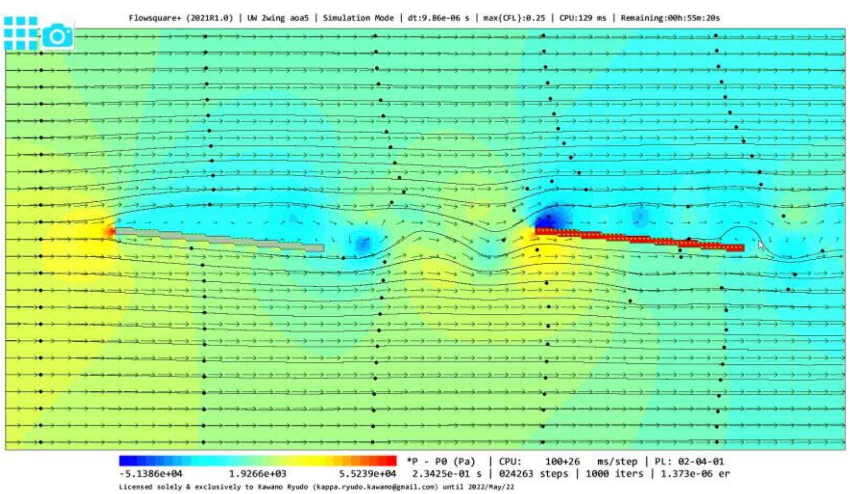


For the sake of clarity, we will assume that the wings are vertical.
Also, the drag force of the aircraft itself is ignored.

The total area of the wings is equal, but the drag on the entire aircraft is increased.

CFD(computational fluid dynamics)

- Initially, it was difficult to simulate underwater accurately, so I did not do it.
- I used this to make radio controlled airplanes in another research project.
- The software used was Flowsquare+ from Nora Scientific.
- Depending on the status of this experiment, we will decide whether to continue using CFD in the future.



Flowsquare+

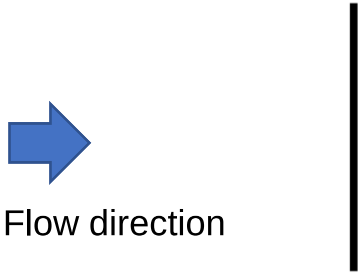
Resolution: 1st 200x100, 2nd and subsequent 400x200
Flow velocity: 10m/s
Fluid density: 997kg/m^3
Area length(x):0.2m
Wingspan: 0.1m(One pair), 0.05m(Two pair)
Number of steps: 50,000 (The first 10,000 steps are truncated to reduce the effect of the initial field.)
CPU: Ryzen5 2400G

Since the resolution is low and the accuracy of the simulation cannot be guaranteed, all the values in this experiment are for reference only.

Experimental Methods (Part 1)

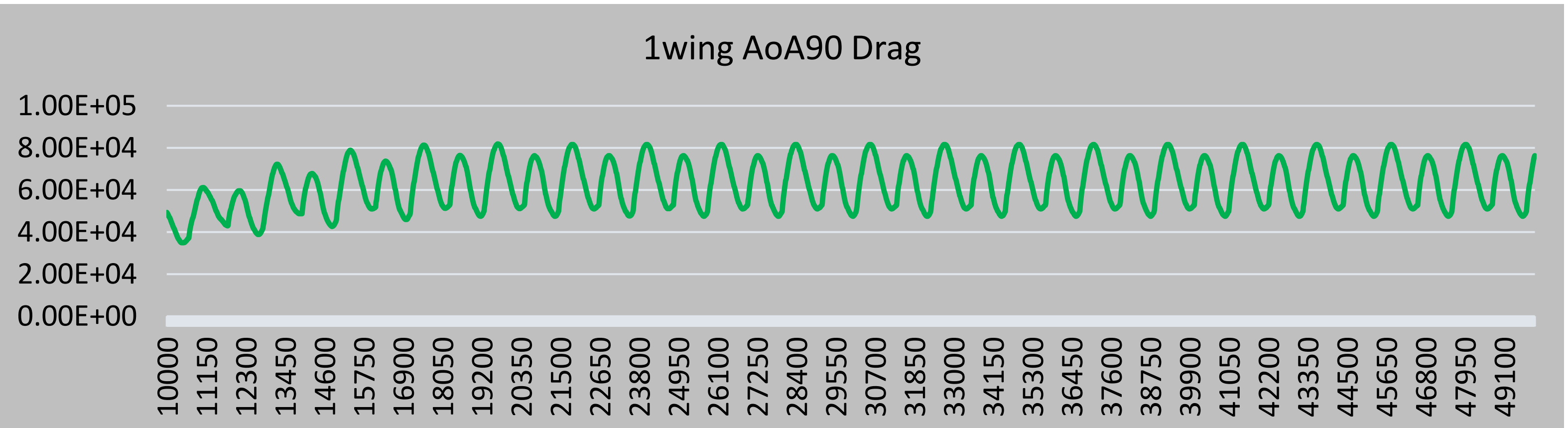
- I prepared two types of simulations, one with two pairs of wings and the other with one pair of wings (see the figure below), and conducted the experiments.
- For the wings, the angle of attack was set to 90° , considering only drag, to verify the above prediction.
- The total area of both types is equal.
- The rear wing of the two-pair type is red to output the front and rear drag separately (For Flowaquare+).

Two pair

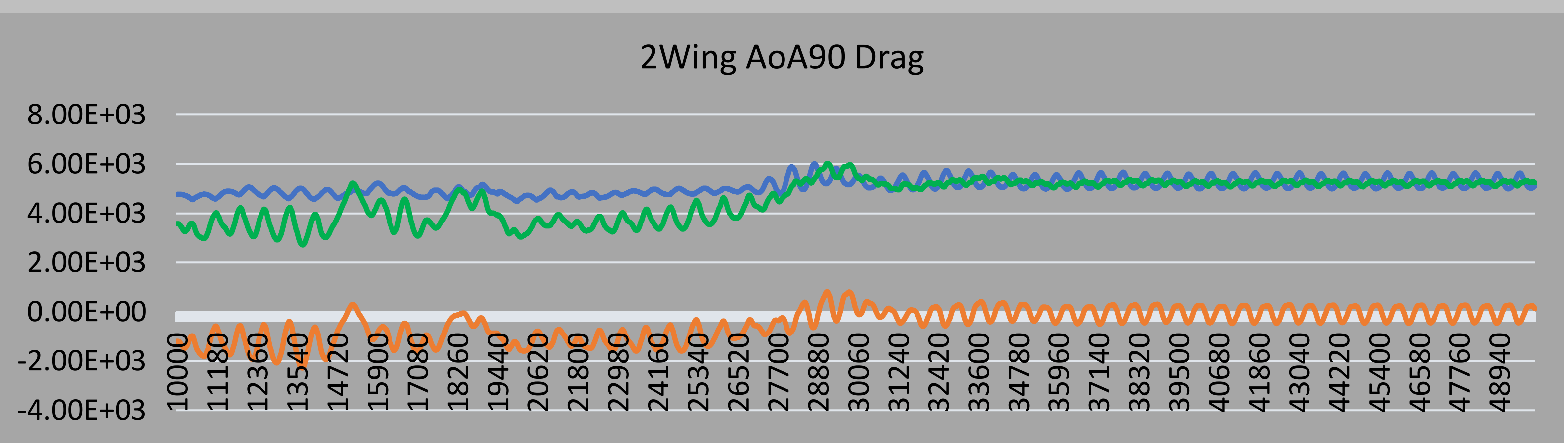


One pair

Result



Average :
6.27E+04N

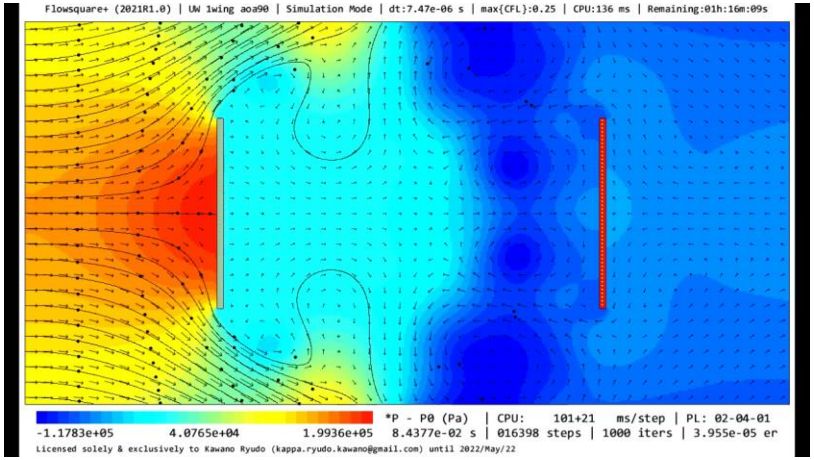


Average :
5.20E+03N

Front:5.09E+03N
Rear:-4.80E+02N

Consideration

- Unlike my expectation, the resistance of the two-pair type was not greater than that of the one-pair type, and the one-pair type was much greater. The reason for this is that in the two-pair type, the front wings blocked the flow to the rear, which reduced the drag of the rear wings, and the negative pressure generated between the wings also added forward force to the rear wings (see the figure below).

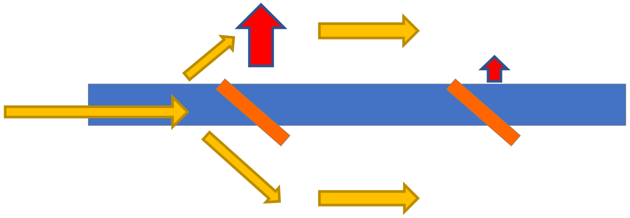


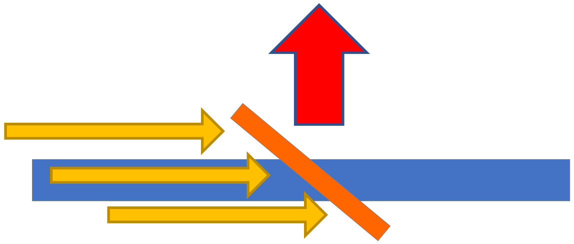
Experiment video

- Since the accuracy of the output figures has not been verified, they are low reliablity. Therefore, the numerical values should be considered as indicators within the simulation, and should be used only for comparison between experiments conducted under the same conditions (and also for reference only).

Forecast2

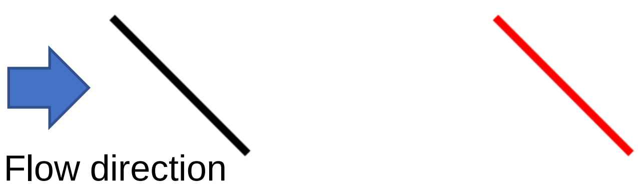
Low drag ≒ Weak water flow received
↓
Less force to float up?



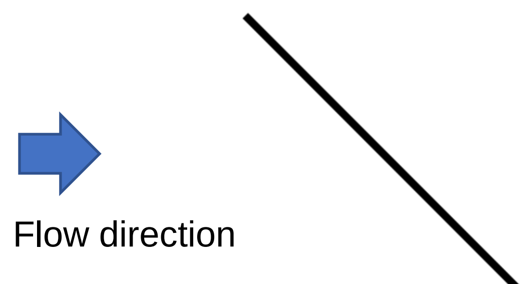


Experimental Methods (Part 2)

- We prepared a type of aircraft with two pairs of wings, and a simulation with one pair of wings (see figure below), and conducted experiments.
- We observe both drag and lift. Therefore, the wings were set at an angle this time. The angle of attack was 45°.
- The total area of both types is equal.
- The reason why the rear wing is red in the two-pair type is to output the front and rear drag separately (For Flowaquare+).

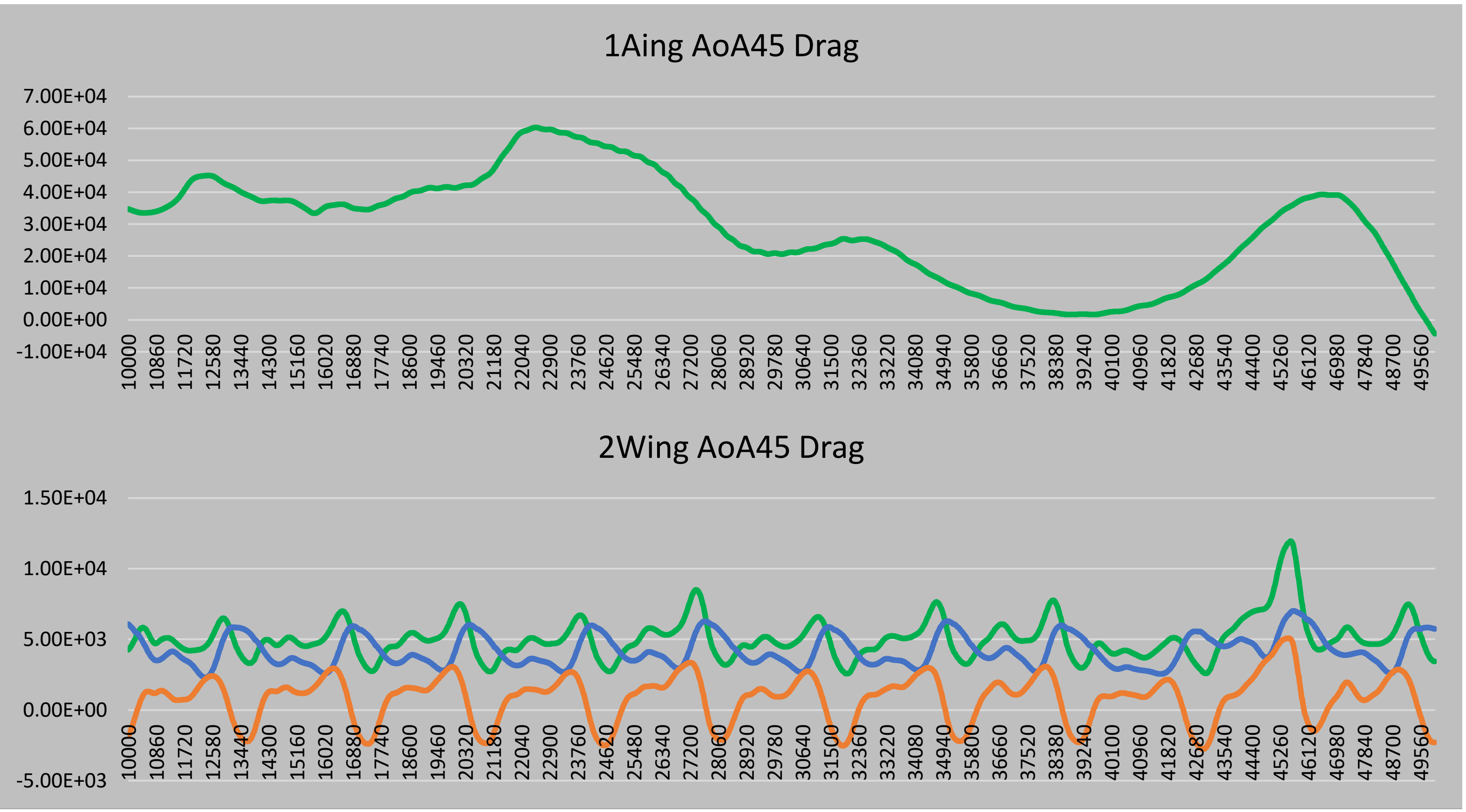


Two pair



One pair

Results (Drag)

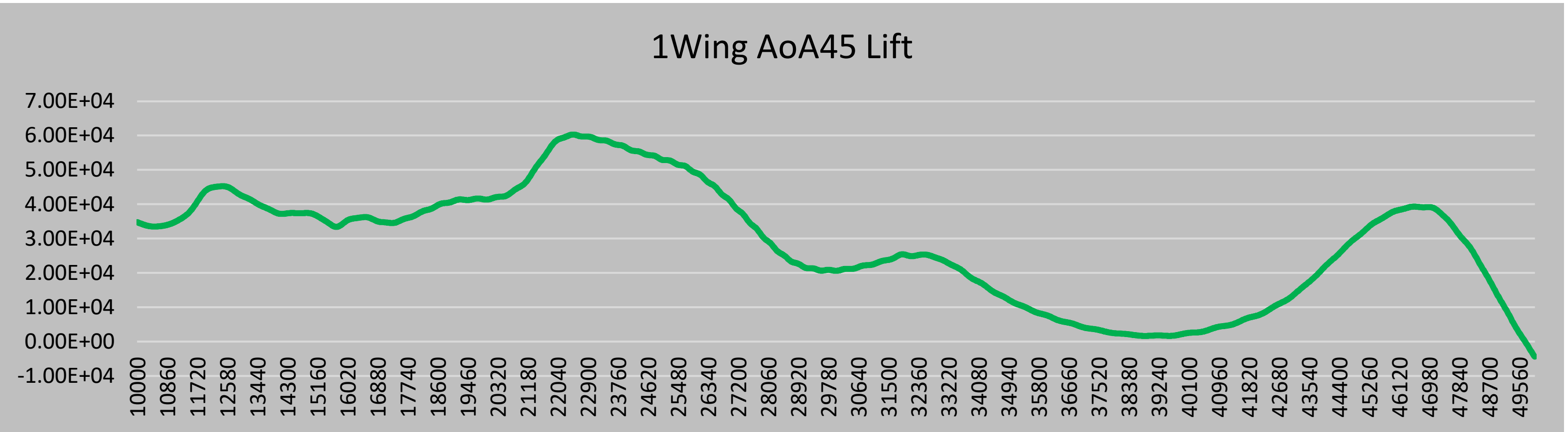


Average :
2.88E+04N

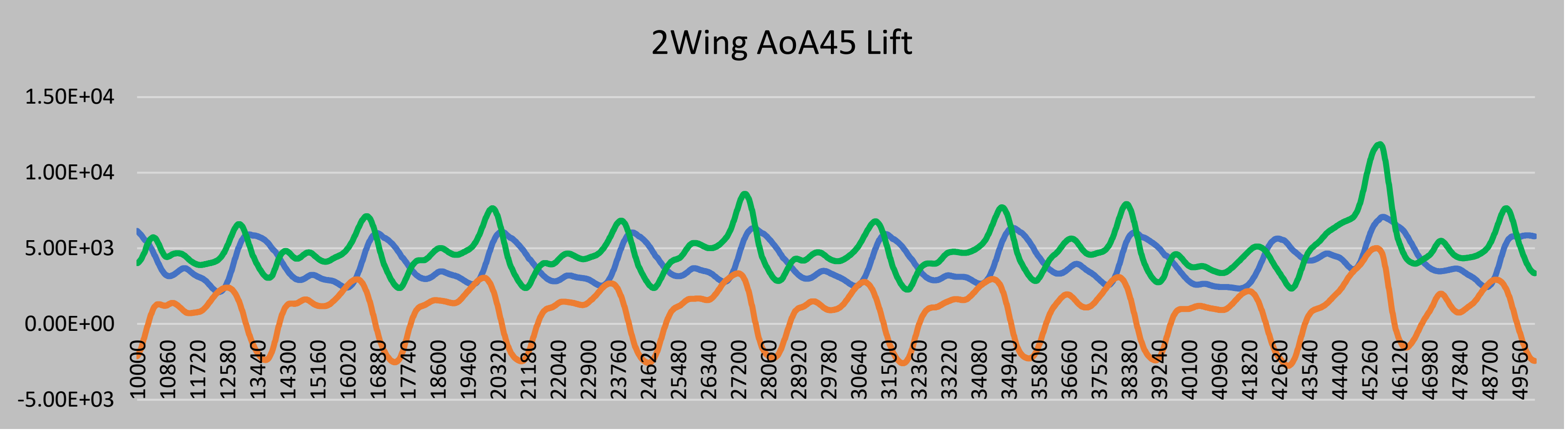
Average :
5.06E+03N

Front:4.22E+03N
Rear:8.39E+02N

Results(Lift)



Average :
2.97E+04N

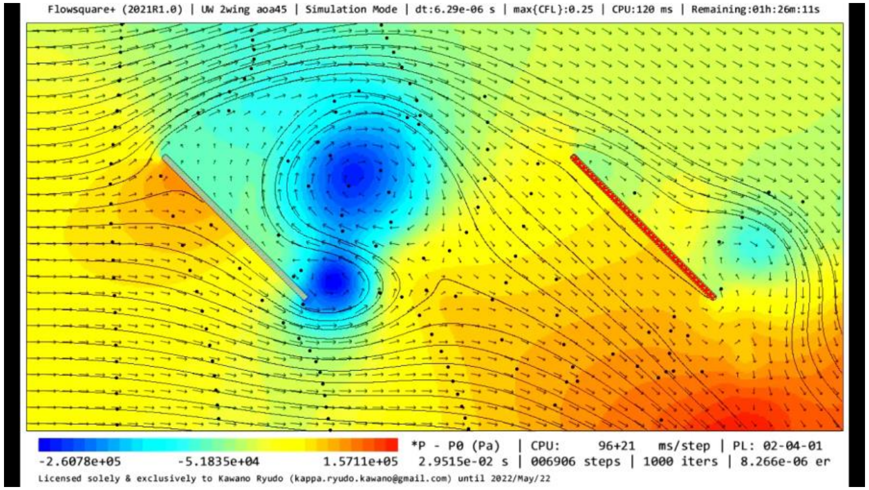


Average :
4.86E+03N

Front:4.05E+03N
Rear:8.17E+02N

Consideration

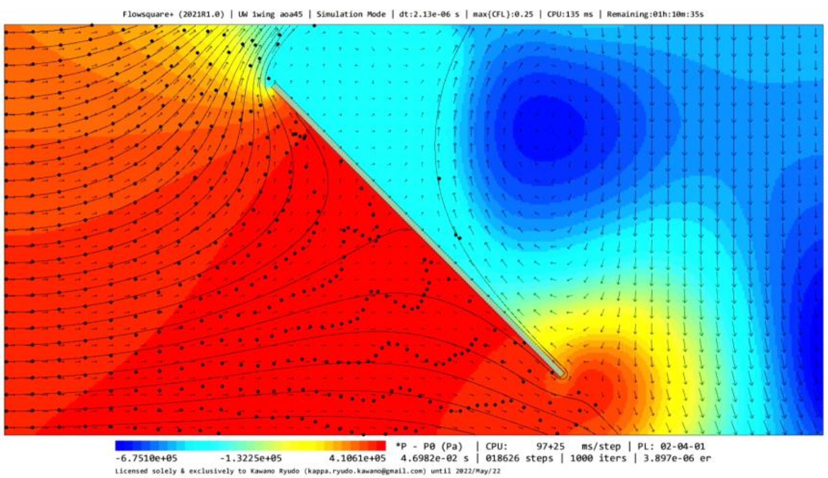
- The graph shows that both drag and lift of the two-pair type are smaller in the rear wing. The overall drag and lift were also smaller for the two pair type than for the one pair type, which was generally as expected. However, when we checked the video, we found that the rear wing was not blocked by the front wing, but the vortex separated from the front wing was affecting the rear wing.



Experiment video

Consideration

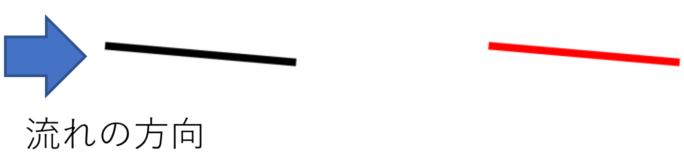
- It was found that the wing was "stalling" in both types, due to the circumstances of the delamination. In the case of an aircraft, the induced drag increases when the aircraft stalls, so it is likely that the same phenomenon caused the drag to increase.
- In the experiment using the small experimental model, there was an unavoidable angle discrepancy between the one-pair type and the two-pair type due to structural reasons, and there may have been a stall angle of attack in between.



Experiment picture

Experimental Methods (Part 3)

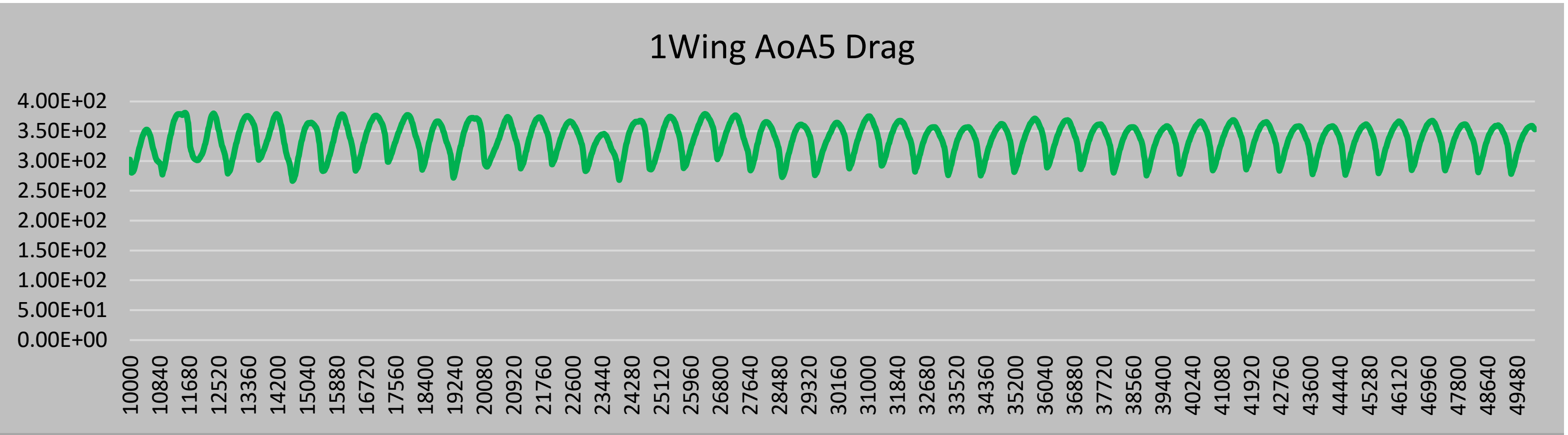
- We prepared two types of simulations, one with two pairs of wings and the other with one pair of wings (see the figure below), and conducted the experiments.
- In this experiment, the angle of attack was set to 5° in order to observe a stall-free state.
- The total area of both types is equal.
- The reason why the rear wing is red in the two-pair type is to output the front and rear drag separately (For Flowsquare+).



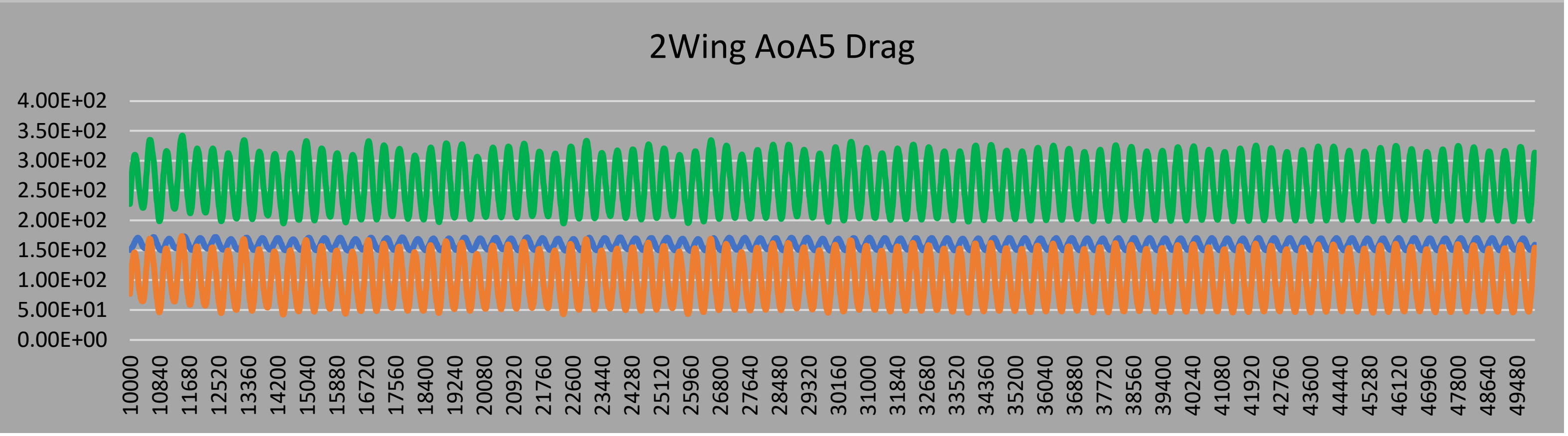
Two pair

One pair

Results(Drag)



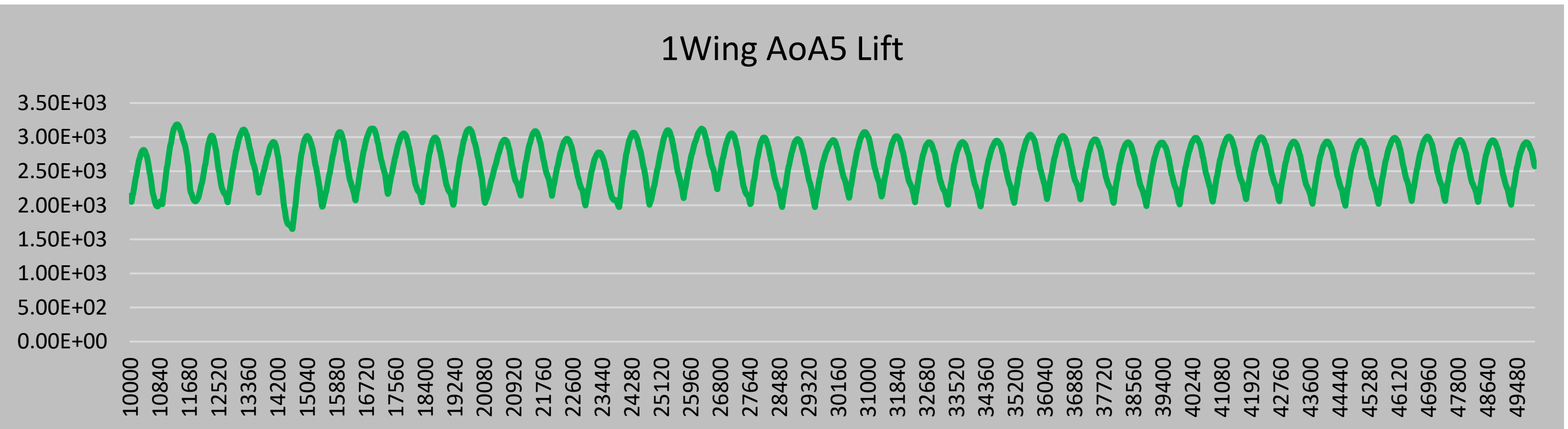
Average:
2.10E+02N



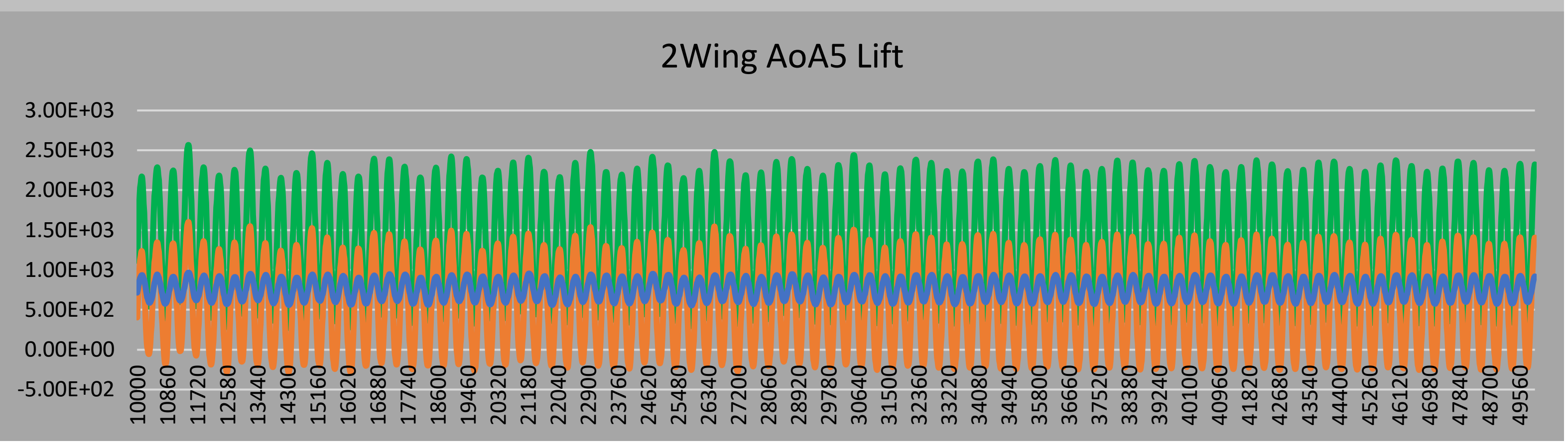
Average:
2.62E+02N

Front:1.60E+02N
Rear:1.02E+02N

Results(Lift)

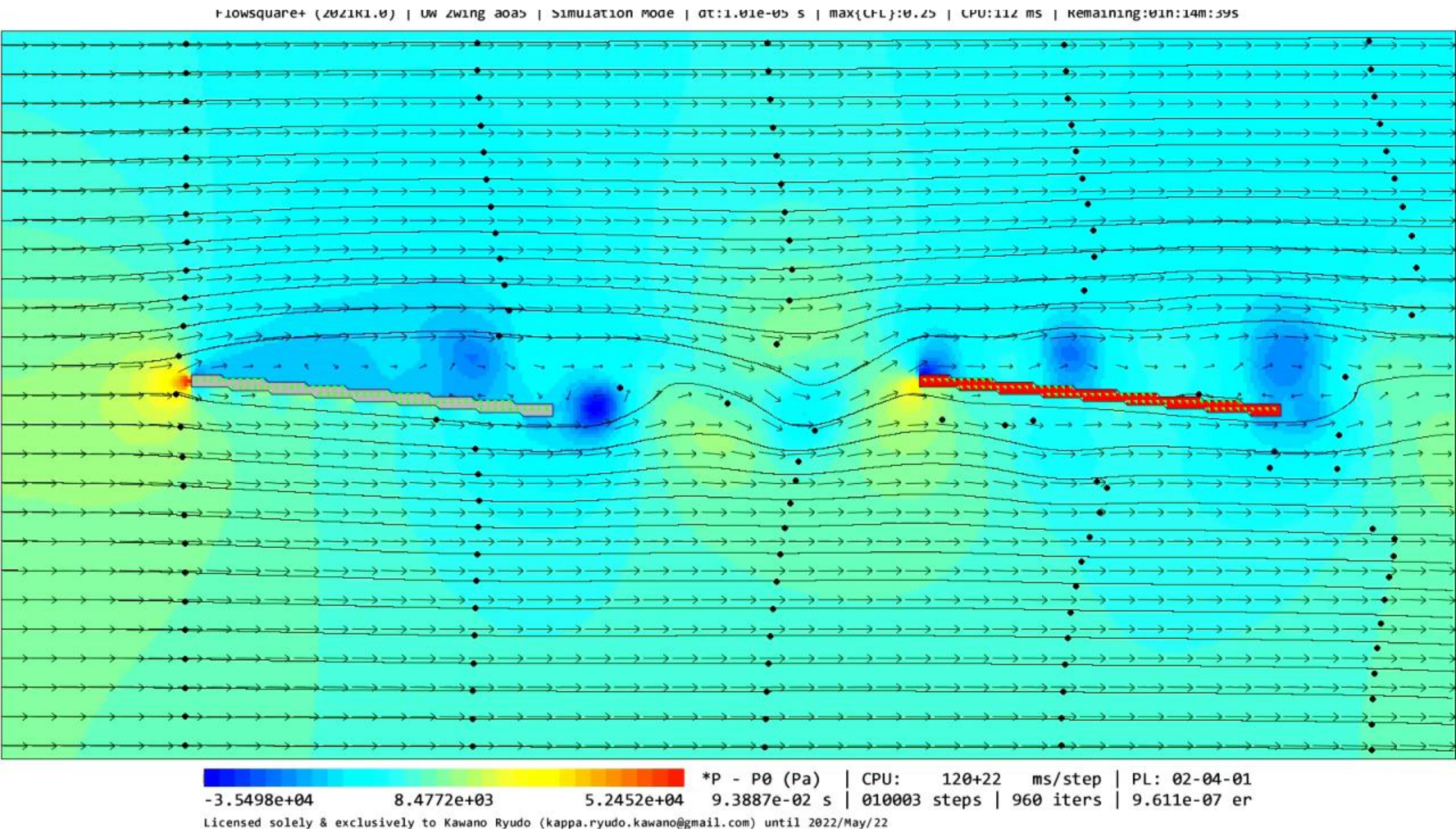


Average:
2.48E+03N



Average:
1.33E+03N

Front:7.56E+02N
Rear:5.79E+02N



Experiment video

Consideration

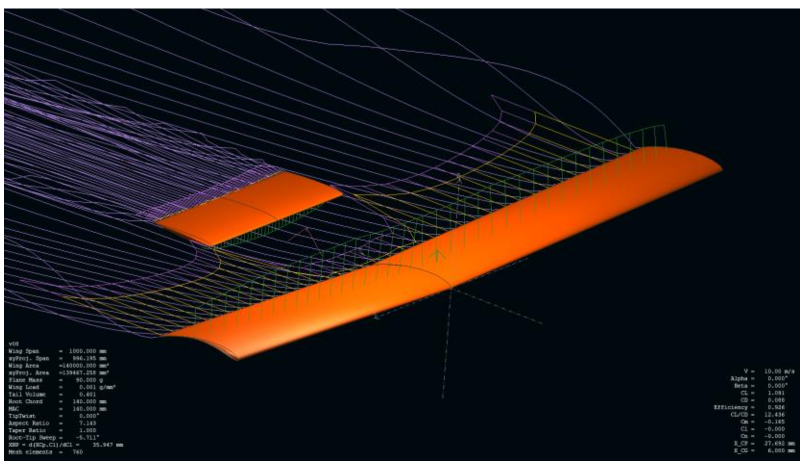
- The fact that the graph showing the values was stable indicates that it was stable without stalling under the present conditions.
- The reason for the much lower lift compared to a one pair is thought to be due to the lower Reynolds number caused by the shorter wing chords(Raynords Number of One pair = 9.96e+5, Two pair = 4.98e+5).
- As a result of reducing the induced drag by suppressing separate, the drag was significantly reduced compared to the lift (→ the lift-drag ratio increased).
- The lift-drag ratio has a great influence on the glide performance and fuel consumption of aircraft, but the drag force at stall is much greater in water than in air due to its high viscosity, and it is thought that this leads to a state of "no progress and no rise" as in the previous experiment.
- In this series of experiments, a large lift force was generated even at the time of stalling, but in this experiment, the flow speed was kept constant even at the time of stalling (high drag), but the flow actually decelerated, so it is thought that not much lift force was generated.

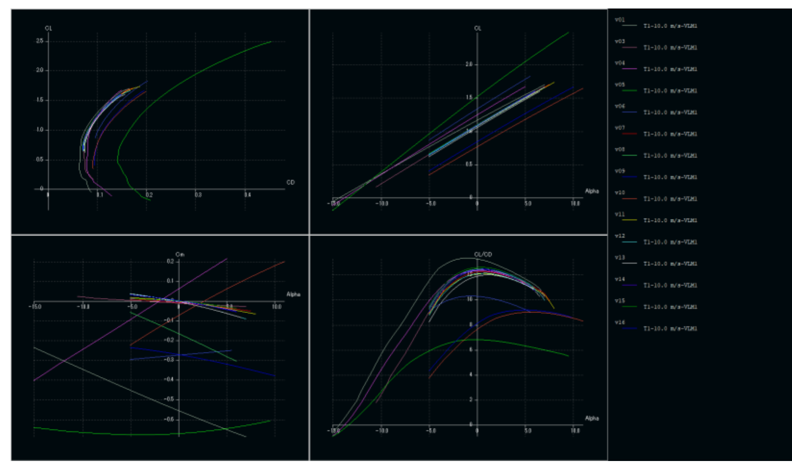
Future tasks

- It is expected that different results can be obtained depending on the distance between the wings, wing thickness, airfoil shape, etc.
- From the results of this study, we concluded that CFD is effective to some extent. We would like to continue the analysis using CFD in the future.
- In this experiment, the resolution was relatively low (400x200), but even so, we were only able to analyze one or two images per day. In the future, we will need to use a more powerful PC.
- In the future, I would like to use the university's facilities (computers, etc.) while watching the popularity of COVID-19.
- We would like to conduct an experiment using a small experimental machine to compare the results with CFD results.
- The accuracy of the CFD will be verified by comparing the results with those of existing research papers on hydrofoils(Now in progress).

Comparison with existing studies

- The results of several existing studies on hydrofoils (CL, CD, L/D, etc.) will be compared with the results obtained by CFD.
- In addition to Flowaquare+, XFLR5 will be used for CFD. XFLR5 is originally designed for aircraft design, but we would like to adapt it to underwater by adjusting parameters such as viscosity, density and Reynolds number.





XFLR5

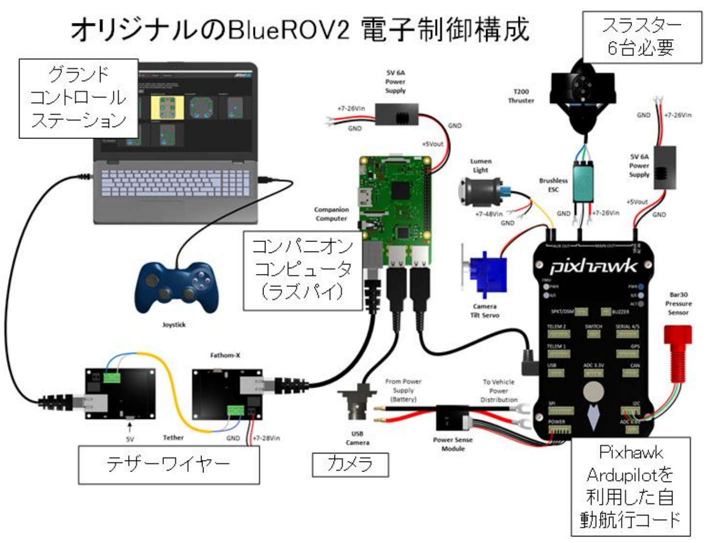
(The image shows a screenshot of XFLR5 being used in a model airplane fabrication project that is being conducted separately from this research.)

Autonomous Control Systems

- Under the guidance of Prof. Wada of Ryukyu University and mentor, Mr. Oshiro, we are learning about autonomous control of underwater probes.
- The control system will be developed using ArduPilot, an autonomous control software. In addition, since the spacecraft for this research is not yet completed, we plan to perform autonomous control of an existing underwater drone, BlueROV2 by BlueRobotics (the actual machine is currently being prepared).
- Since the hardware of BlueROV2 is not yet available, we used a simulator called SITL (Software in the Loop) on a PC to check the program operation.
- Although the control mechanism of the BlueROV2 is very different from that of the spacecraft in this study, we believe that there are many things that can be used in the BlueROV2, such as the position determination by GPS and the movement algorithm.

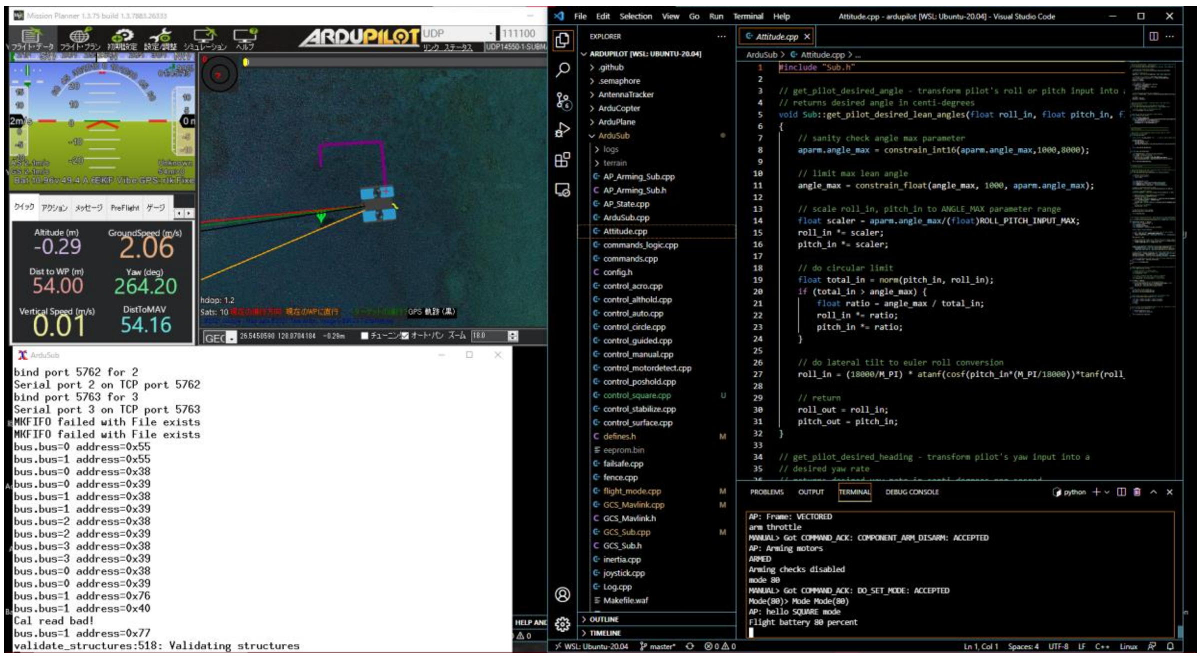
Autonomous Control Systems

- The figure below shows the electronic control configuration of the BlueROV2, which is the target of this project. In this figure, the drone is wired and controlled from a PC. The drone's operation is controlled by an automatic navigation system called Pixhawk, which runs ArduPilot software through a companion computer using a Raspberry Pi.



Autonomous Control Systems

- This time, we programmed C++ in ArduSub, the ArduPilot submersible drone software, to implement an automatic square navigation mode of operation.



ArduPilot

References

- 1) Flowaquare+HP　https://fsp.norasci.com/index.html#soft_intro
- 2) ArduPilot HP　https://ardupilot.org/
- 3) BlueRobotics HP　https://bluerobotics.com/store/rov/bluerov2/
- 江端重葉，安田孝宏，南川久人，宮本悠治，里深信行(2013)低レイノルズ数領域で用いる水中グライダーの翼断面形状に関する研究
- 西山哲男(1959)浅い深度に於ける翼型の特性
- Justin Winslow, Hikaru Otsuka, Bharath Govindarajan, and Inderjit Chopra(2018) Basic Understanding of Airfoil Characteristics at Low Reynolds Numbers (104–105)