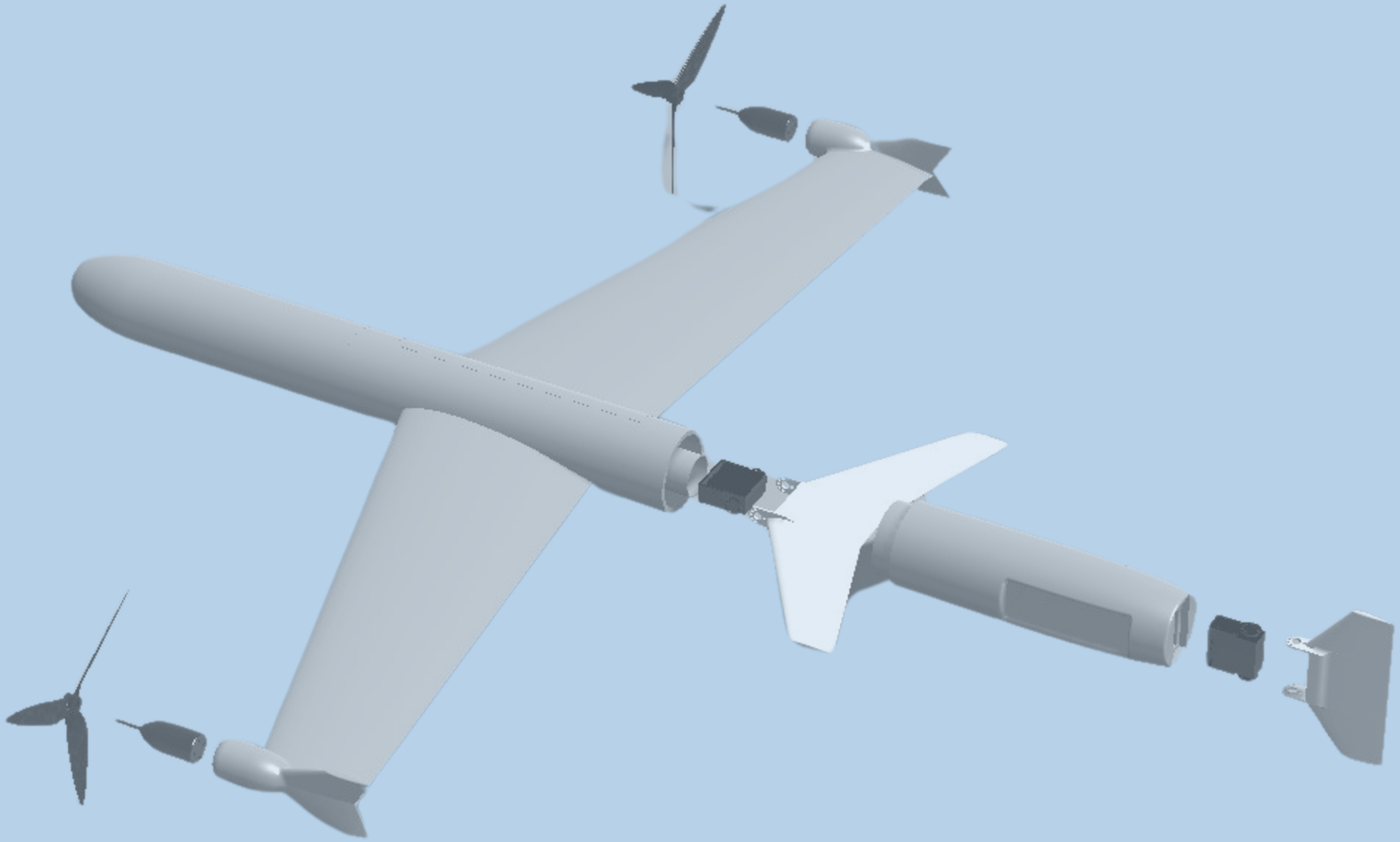
NEPTUNE | ENGINEERING
FOR A CLEAN AND QUIET OCEAN

NEPTUNE ENGINEERING PRODUCTS AND TECHNOLOGY

1870

- 1. This file is proprietary to the Neptune Engineering technological team. Any redistribution of this file or any parts of it must receive written consent from CEO or CTO of the team. Do not publicize this file under any circumstances as it contains sensitive design information.
- 2. This file is a handbook and demonstration for the product HV-5G and relevant technological articles produced by this team. The team does not bear any legal responsibilities for any data and design specifications revealed, and the team is not responsible for anything resulted from usage of data and design specifications disclosed by this file.
- 3. Airfoil and appearances are being patented as proprietary elements of the Neptune Engineering team. Replicating or referencing these works might result in legal consequences and Neptune Engineering will reserve all rights to pursue in protection of our technologies.

TABLE OF CONTENTS



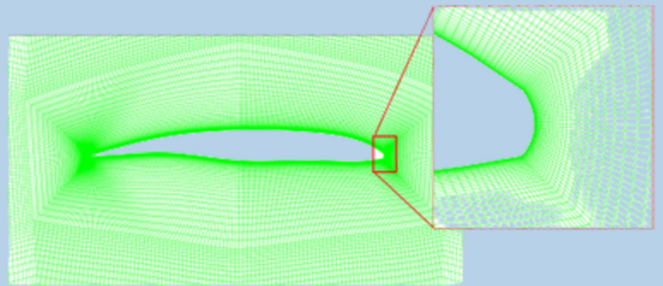
TEAM-TIMELINE

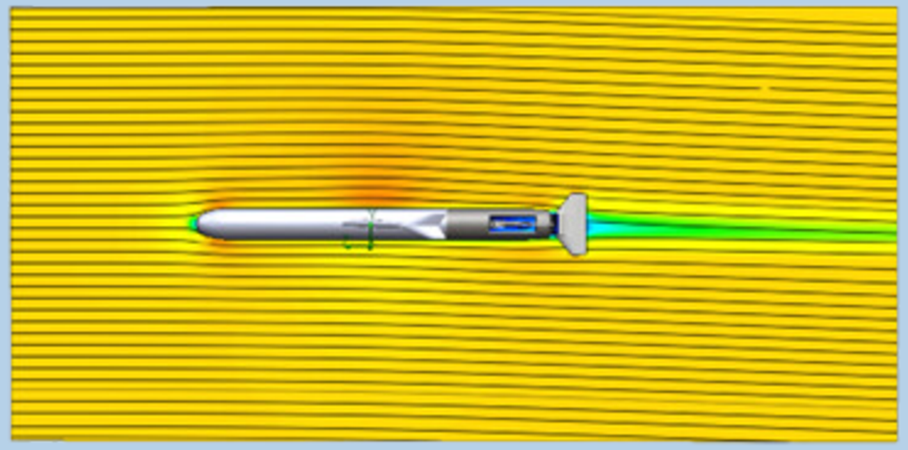
2024.3 Project Initiated

2024.4 HV-2 Prototyped

2024.8 Team formed as it is now

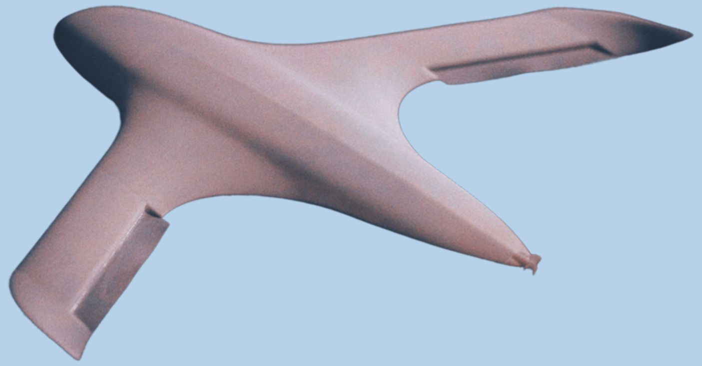
2024.10 Worked on bionic airfoil published





2024.11 HV-5G, HV-6A Published

2024.11 Active Flow Device research started



TEAM-HONORS

SCIENTIFIC SUMMITS

CERTIFICATE OF

PARTICIPATION

This certificate is presented to Prof./ Dr./ Mrs/ Ms.

HANYUE SHEN

Crimson Global Academy, China

in recognition of his/her Invited Virtual Presentation at World Summit and Expo on Applied Science and Engineering (WSEASE-2024) held during October 17, 2024 on the topic "The Potential of Water-Soluble Polymers In Cross Domain Flight"

PROF. EDUARD BABULAK
Panelist, National Science Foundation, USA
CONFERENCE CHAIR

KRZYSZTOF KAMIL ZUR, Bialystok University of Technology, Poland
CHUL PARK, University of Toronto, Canada
GORDON AGNEW, University of Waterloo, Canada

Notification of Acceptance for Publication and Presentation

Barcelona, Spain

November 24-26, 2024

www.maes.net

Dear Hanyue Shen,

Paper ID: M821

Paper Title: A Polyvinyl Alcohol Based Passive Wing Morphing Strategy

2024 2nd International Conference on Mechanical, Aerospace and Electronic Systems (MAES 2024) will take place on November 24-26, 2024 in Barcelona, Spain. Based on recommendation of Technical Committees, your paper is accepted for **Publication and Oral Presentation.**

Accepted and presented papers will be published into **IOP Conference Series: Journal of Physics: Conference Series (Online ISSN: 1742-6596; Print ISSN: 1742-6588)**, and will be submitted for Ei Compendex and Scopus.

Each paper is required making an presentation. For the presentation, 15 mins oral presentation including 2~3 mins Q&A is required , you may prepare .pdf or power point file beforehand. **Author that do not meet above requirements will be considered "no-shows."**

Please follow following procedures to finish your registration:

1. Revise your paper according to the review comments in the attachment carefully.	(See attachment)
2. Format your paper according to the template.	https://www.maes.net/Template.docx
3. Download and complete the registration Form.	(See attachment)
4. Finish payment of registration fee.	(See registration form)
5. Send all files to us via maes2022@163.com	Files include: 1. final paper (.doc & .pdf), it is required to updated the paper via submission system as well; 2. registration form (word format); 3. student ID (student ONLY); 4. payment proof

INTERNATIONAL RESEARCH CONFERENCE

ACCEPTANCE AND INVITATION LETTER

Mr. Hanyue Shen
X-Institute
China

September 23, 2024

Herewith, the international scientific committee is pleased to invite you for Oral presentation at ICAH 2024: XVIII. International Conference on Aerodynamics and Hydrodynamics to be held in Macau, China during December 16-17, 2024

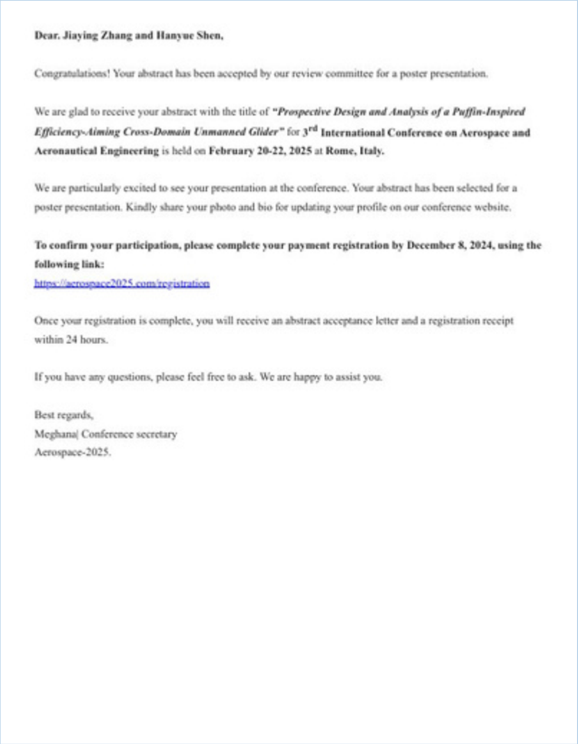
Visa Requirements:

Many delegates will require advance visa arrangements to enter the conference host country. You are kindly requested to submit a complete and accurate visa application to the consulate or embassy of the conference host country located in your country of residence. Please apply for your visa in due time and at your own responsibility.

We look forward to your participation in the ICAH 2024: XVIII. International Conference on Aerodynamics and Hydrodynamics.

Sincerely,

International Scientific Committee
ICAH 2024 Macau, China
https://waset.org/aerodynamics-and-hydrodynamics-conference-in-december-2024-in-macau



Dear. Jiaying Zhang and Hanyue Shen,

Congratulations! Your abstract has been accepted by our review committee for a poster presentation.

We are glad to receive your abstract with the title of ***"Prospective Design and Analysis of a Puffin-Inspired Efficiency-Aiming Cross-Domain Unmanned Glider"*** for **3rd International Conference on Aerospace and Aeronautical Engineering** is held on **February 20-22, 2025** at **Rome, Italy.**

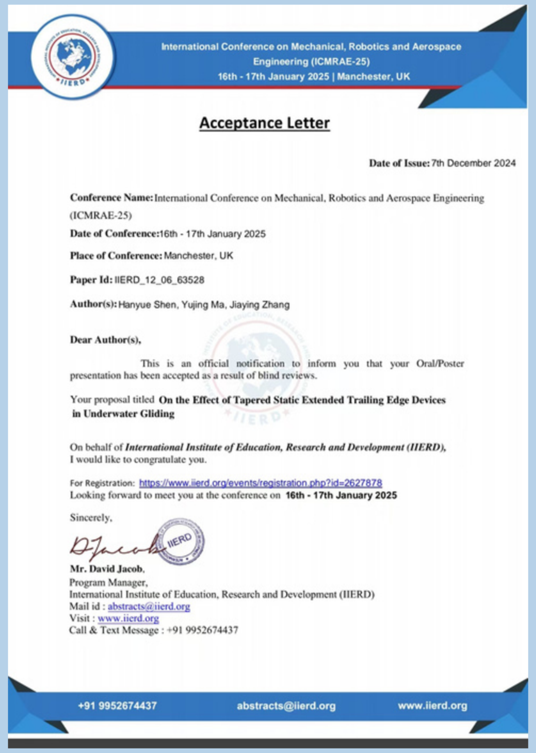
We are particularly excited to see your presentation at the conference. Your abstract has been selected for a poster presentation. Kindly share your photo and bio for updating your profile on our conference website.

To confirm your participation, please complete your payment registration by December 8, 2024, using the following link:
https://aerospace2025.com/registration

Once your registration is complete, you will receive an abstract acceptance letter and a registration receipt within 24 hours.

If you have any questions, please feel free to ask. We are happy to assist you.

Best regards,
Meghana| Conference secretary
Aerospace-2025.



International Conference on Mechanical, Robotics and Aerospace Engineering (ICMRAE-25)
16th - 17th January 2025 | Manchester, UK

Acceptance Letter

Date of Issue: 7th December 2024

Conference Name: International Conference on Mechanical, Robotics and Aerospace Engineering (ICMRAE-25)

Date of Conference: 16th - 17th January 2025

Place of Conference: Manchester, UK

Paper Id: IIERD_12_06_63528

Author(s): Hanyue Shen, Yujing Ma, Jiaying Zhang

Dear Author(s),

This is an official notification to inform you that your Oral/Poster presentation has been accepted as a result of blind reviews.

Your proposal titled **On the Effect of Tapered Static Extended Trailing Edge Devices in Underwater Gliding**

On behalf of ***International Institute of Education, Research and Development (IIERD),*** I would like to congratulate you.

For Registration: https://www.iierd.org/events/registration.php?id=2627878
Looking forward to meet you at the conference on **16th - 17th January 2025**

Sincerely,

Mr. David Jacob,
Program Manager,
International Institute of Education, Research and Development (IIERD)
Mail id : abstracts@iierd.org
Visit : www.iierd.org
Call & Text Message : +91 9952674437

+91 9952674437 abstracts@iierd.org www.iierd.org

丘成桐数学科学中心
YAU MATHEMATICAL SCIENCES CENTER

2024丘成桐中学科学奖（物理）

S.-T. Yau High School Science Award(Physics)

— 分赛区决赛二等奖 —

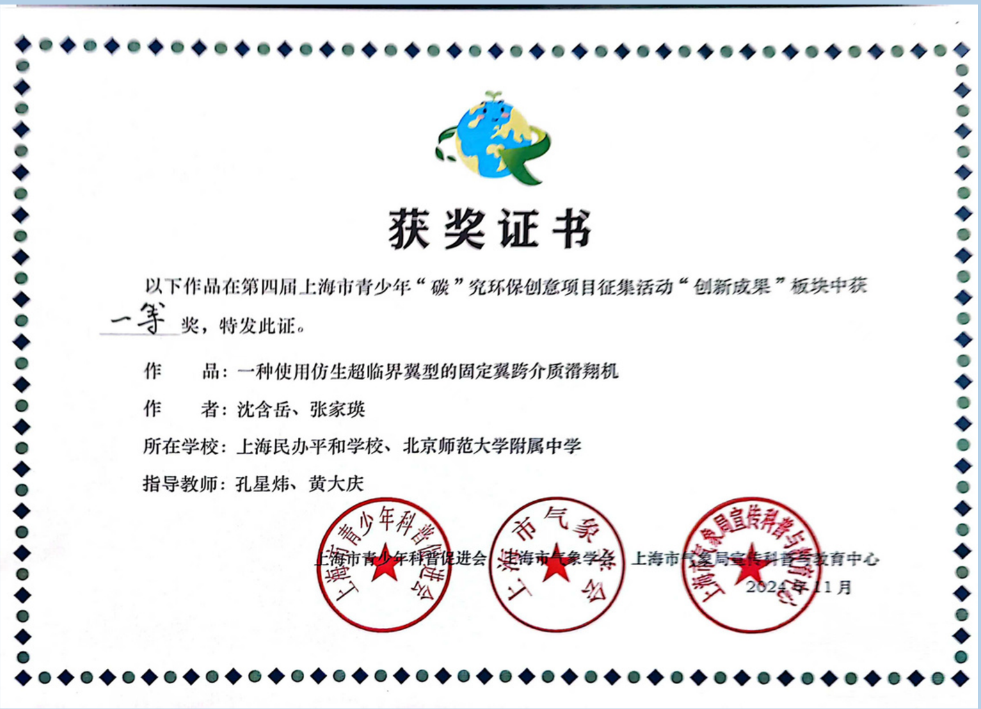
学生姓名：沈含岳 张家瑛
MEMBERS

指导教师：黄大庆 康文婷
TEACHER

论文题目：Towards a Biologically Inspired Supercritical Airfoil Adapted for Gliding Cross-Domain Vehicles
TOPIC

教监管厅函〔2022〕13号 不作为中小学招生入学依据

丘成桐中学科学奖组织委员会
The Organizing Committee of S.-T. Yau High School Science Award



获奖证书

以下作品在第四届上海市青少年“碳”究环保创意项目征集活动“创新成果”板块中获 一等 奖，特发此证。

作　　品：一种使用仿生超临界翼型的固定翼跨介质滑翔机

作　　者：沈含岳、张家瑛

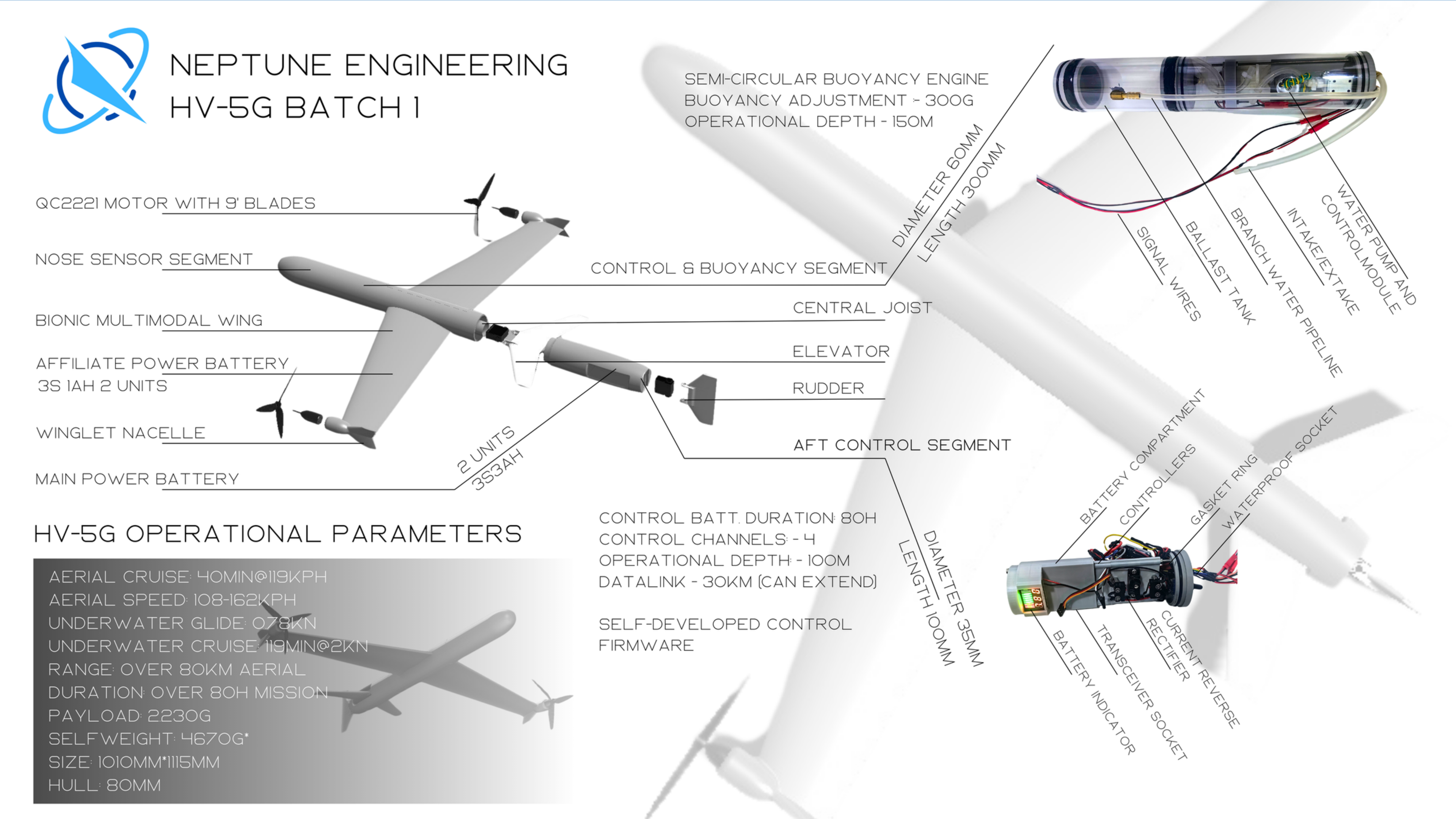
所在学校：上海民办平和学校、北京师范大学附属中学

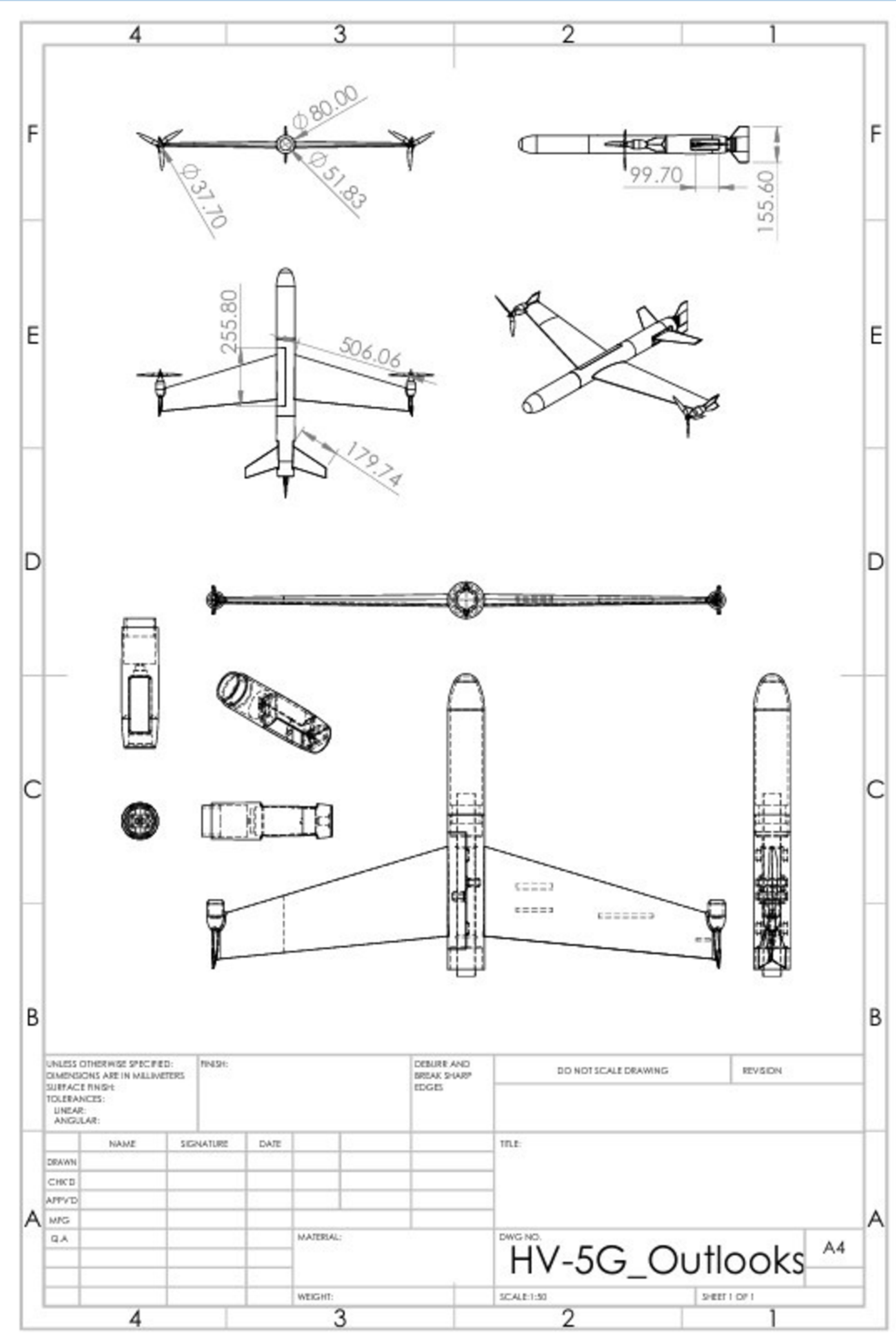
指导教师：孔星炜、黄大庆

上海市青少年科普促进会　上海市气象学会　上海市气象局宣传科普与教育中心

2024年11月

PRODUCTS-HV5G





PRODUCTS-HV5G

POWER SUPPLY

Default: 2*3S3Ah, 2*3S1Ah
Extension: 3S6Ah
Control Power: 3S2Ah

MOVEMENT

Flight: 108-162kph
Glide: 0.55-0.72kn
Cruise: 1.2-2.0kn
Range: >80km
Duration: >80hrs
Transition: Impact/Glideoff
Launch: Aerial/Catapult
Reliability: 96%*

SENSORS AND COMMS

Default: Camera, IR Camera (SIYI)
Comms: FM30 with Antenna +15dB
Datalink: I2C, RS232
Sensors: Depth, Temperature
Extension: 4*I2C Devices
Additional Datalink: 1

CONTROLS

Manual: SIYI-MK15
Automated: Serial Port
Algorithm: LQR / PID
Max. Glide Cycle: 30mins
Modes: Flight, Glide, Cruise

*As tested on HV-5C and HV-5G Scaled

PRODUCTS-HV6A

The HV-6A is a mini CDV glider designed for lightweight missions, educators, and enthusiasts.

While it spans ~750mm, we are unable to provide further structural information on this vehicle due to its classified developmental status.

Visit our product page at neptuneug.org on Jun 25, 2025 to obtain more information about this model.

PRODUCTS-HV6A

POWER SUPPLY

Default: 1*3S2Ah
Extension: 1*2S1Ah
Control Power: Shared

MOVEMENT

Flight: 96-126kph
Glide: 0.35-0.41kn
Cruise: N.A.
Range: >10km
Duration: >2hrs
Transition: Impact
Launch: Projectile/Catapult
Reliability: 90+%

SENSORS AND COMMS

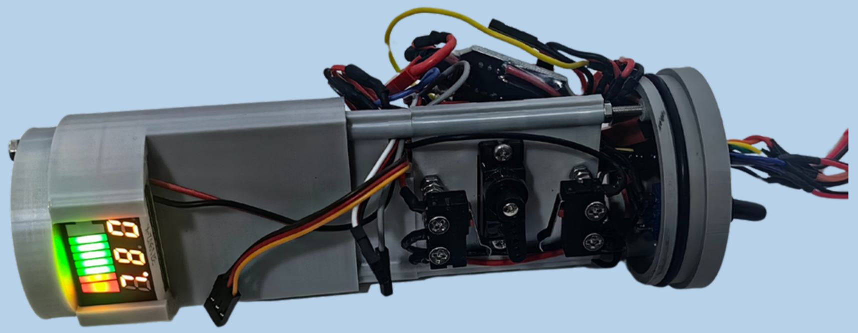
Default: Camera (SIYI)
Comms: LoRa with Antenna +5dB
Datalink: I2C
Sensors: Depth, Temperature
Extension: 2*I2C Devices
Additional Datalink: N.A.

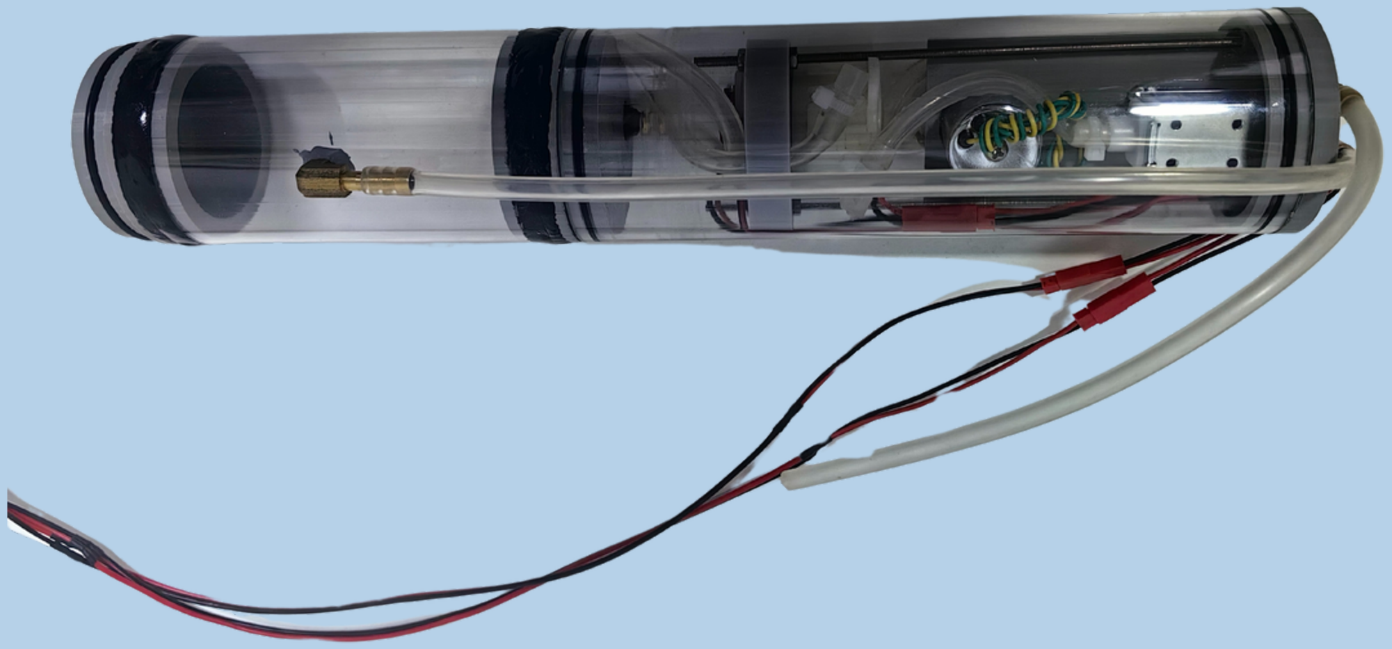
CONTROLS

Manual: MK15/RC Control
Automated: Serial Port
Algorithm: PID
Max. Glide Cycle: 5mins
Modes: Flight, Glide

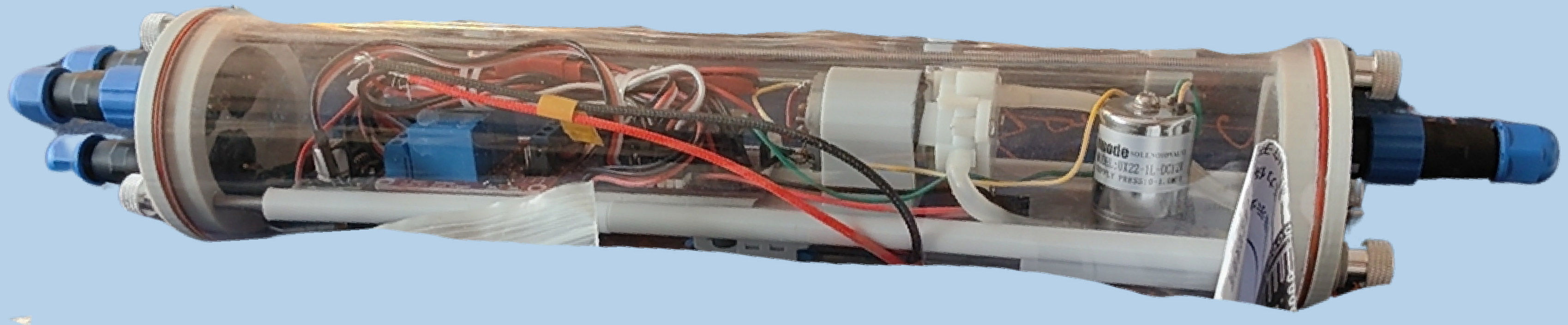
PRODUCTS-WATERTIGHT PODS

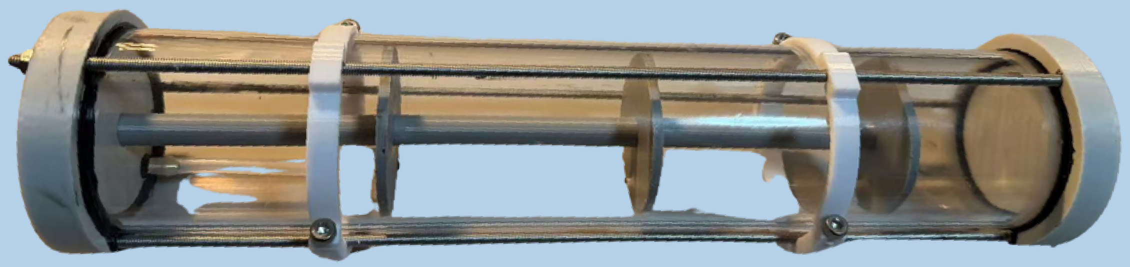
BASIC UNITS (5 SERIES)



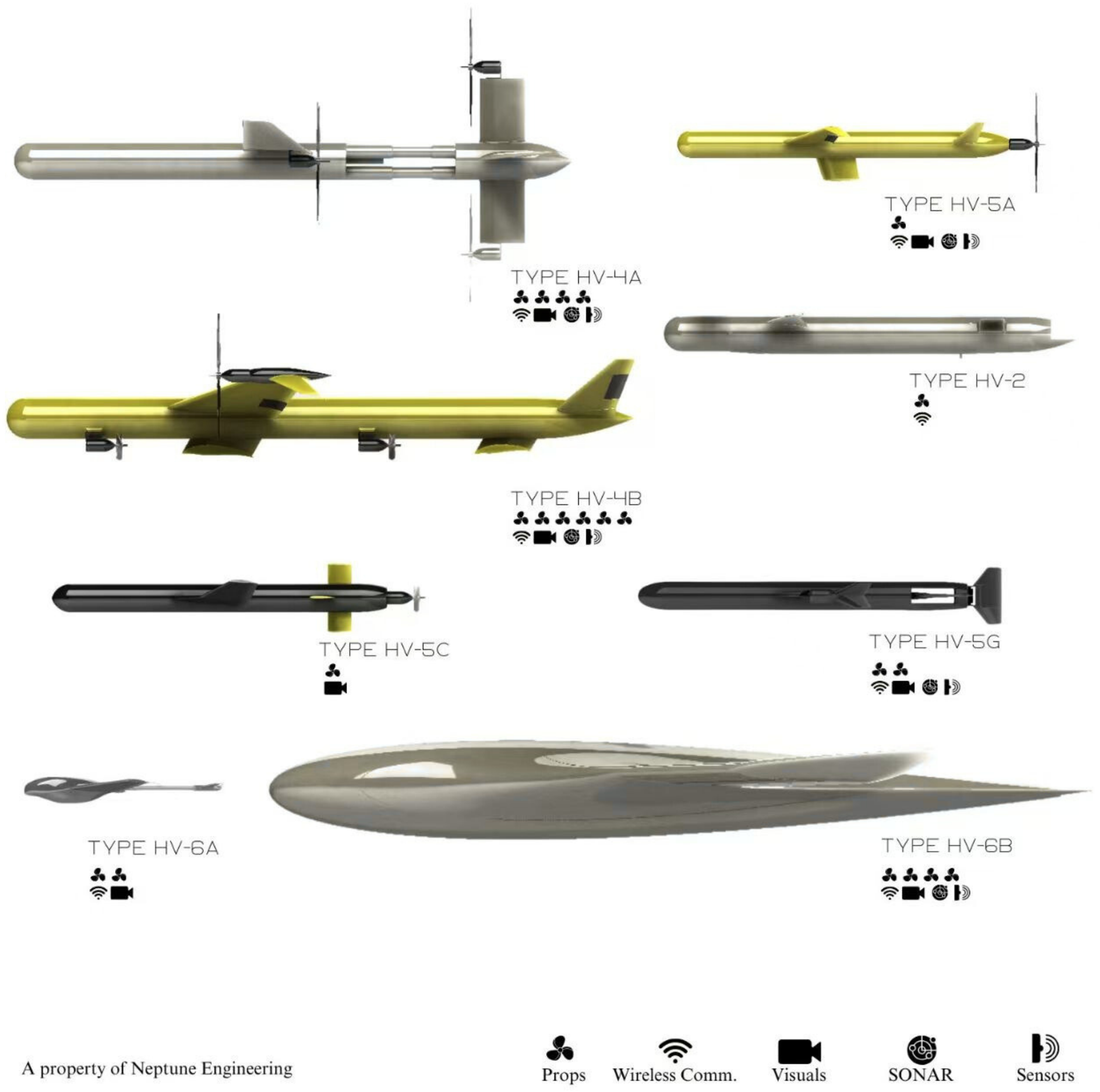


EXPERIMENTAL



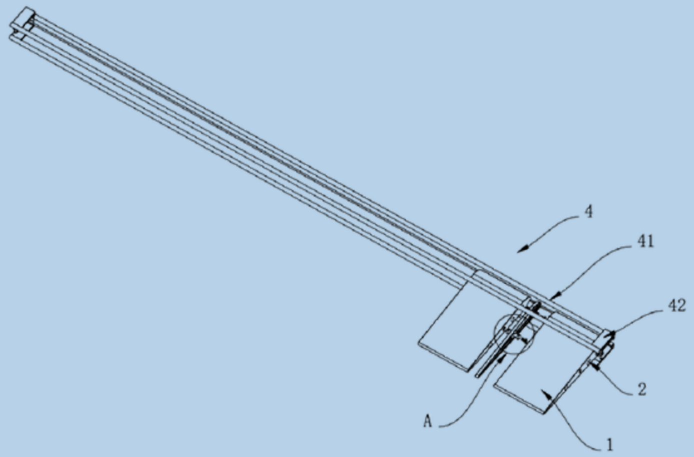


FUTURE FLEET

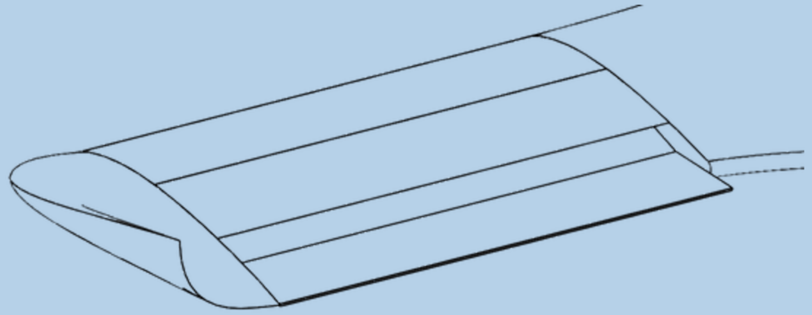


A property of Neptune Engineering

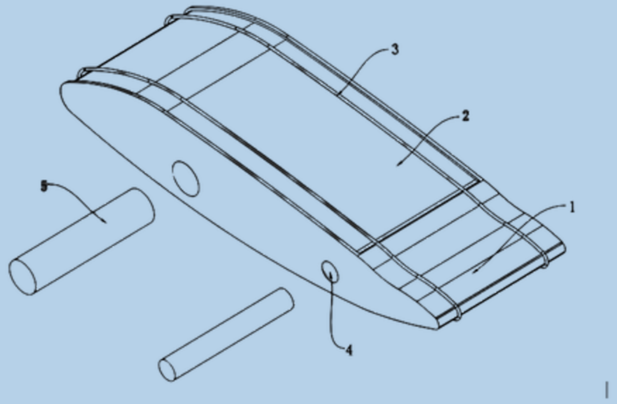
TECHNOLOGIES



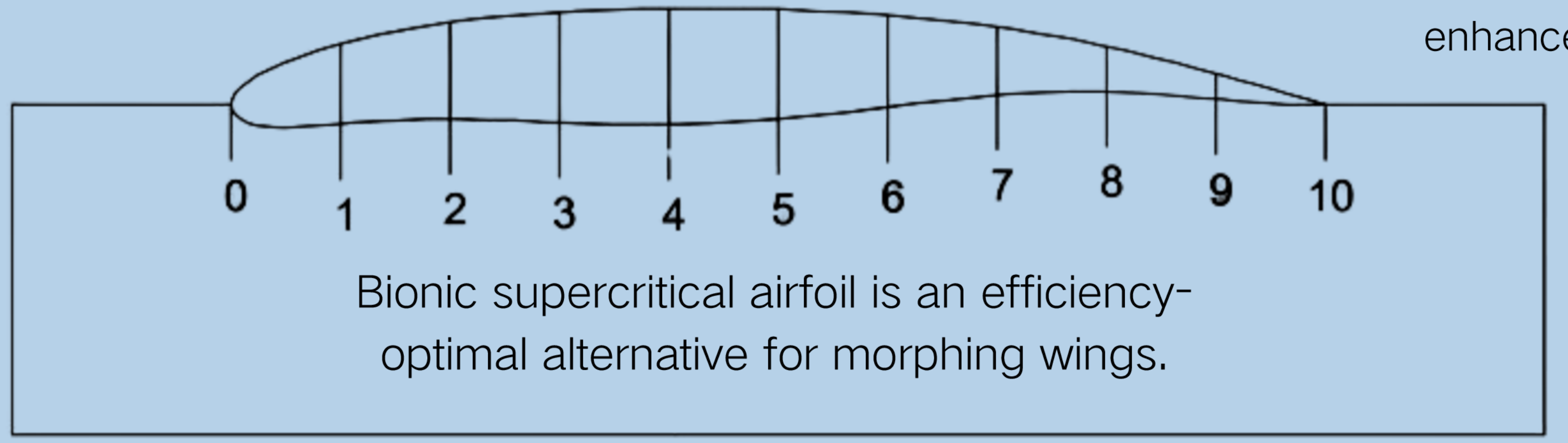
We’re patenting multiple advanced wing morephing techniques.



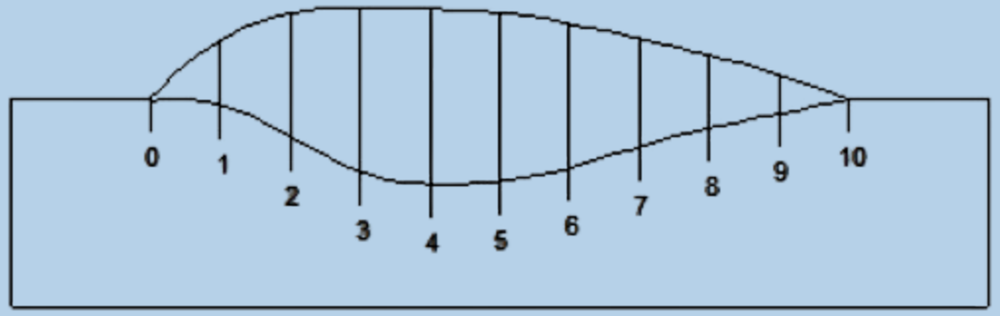
SETE-BTE Flap is a lift and efficiency augmentation device under development for high-speed hybrid gliders.



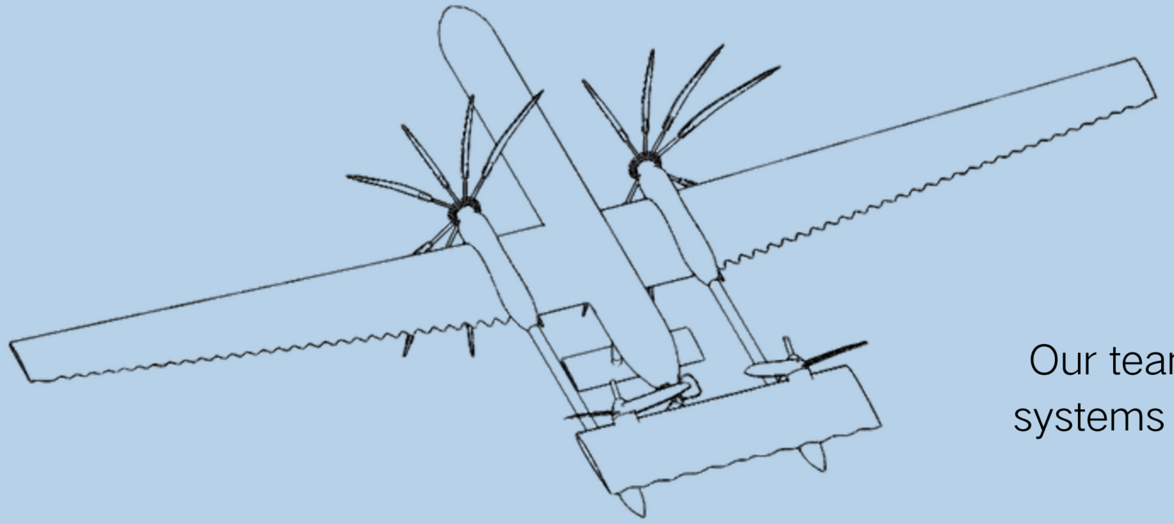
Chemically morphing wing uses PVA material as a powerful mechanism to enhance the range for single-return CDVs.



Bionic supercritical airfoil is an efficiency-optimal alternative for morphing wings.



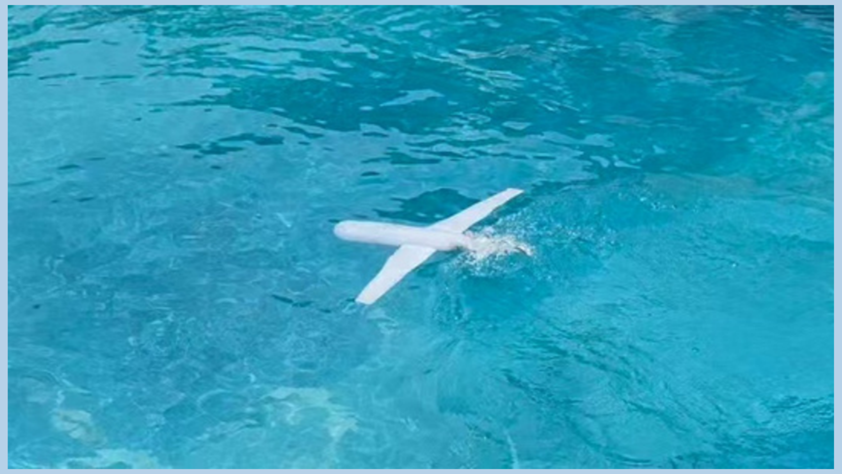
Bionicv fuselage further increases efficiency while allowing large internal spaces.



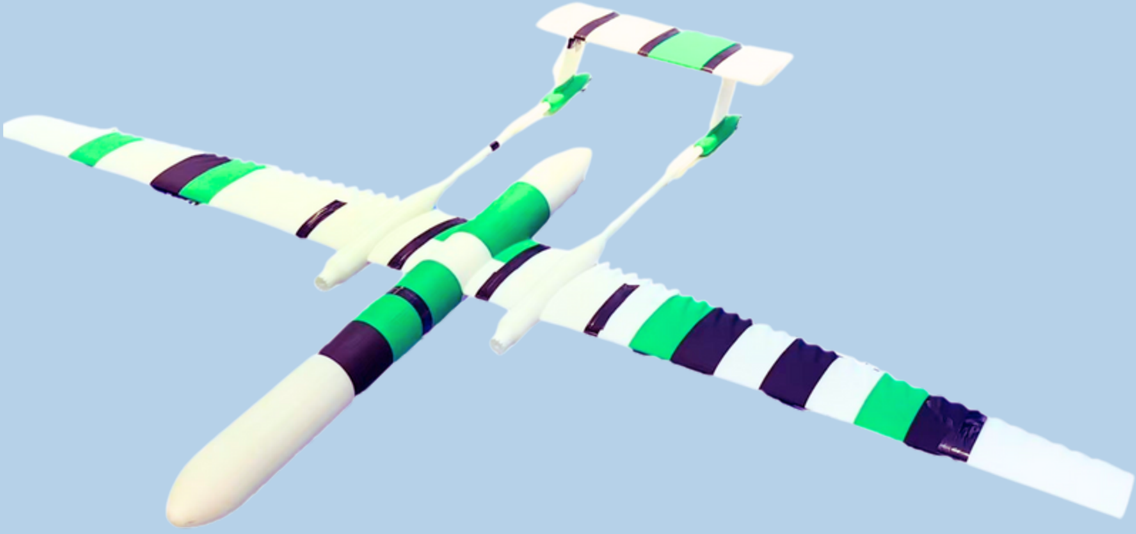
Our team is capable of developing full systems of solutions with varied modes.

TEST VEHICLES

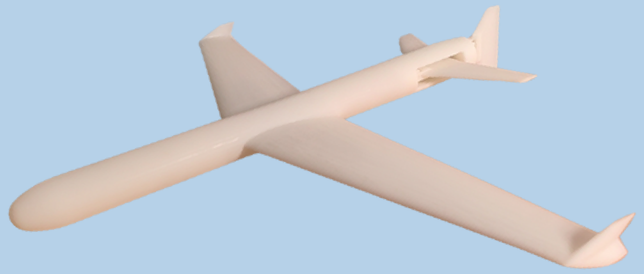
HV-2 Test Vehicle
Wingspan 790mm



HV-5C Test Vehicle
Wingspan 830mm

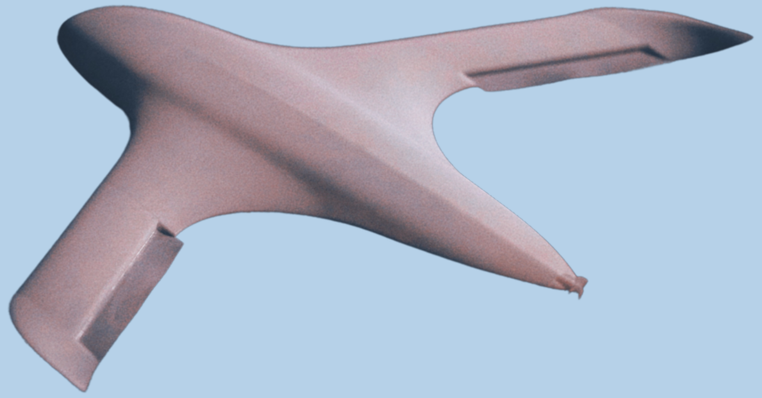


HV-3 Technology Validation Vehicle
Wingspan 1560mm



HV-5G Scaled Test Vehicle
Wingspan 740mm

HV-6A Test Vehicle
Wingspan 500mm



HV-6B Validation Vehicle
Wingspan 580mm

Towards a Biologically Inspired Supercritical Airfoil Adapted for Gliding Cross-Domain Vehicles

Hanyue SHEN[1*], Jiaying ZHANG[2], and Xingwei KONG[3]

Abstract—Growing research on Cross-Domain Vehicles (CDVs) has addressed the requirement to balance airfoil efficiency in air and water. No existing airfoil is specifically developed to adapt to the large Reynold's number range CDVs operate in. This research proposes a supercritical airfoil biologically inspired by Atlantic Puffins. The initial airfoil is parameterized with Composite Karman-Trefftz method, optimized with a series of multi-stage gradient descend procedures, and compared with other airfoils with Xfoil. Results from Xfoil are also validated via Fluent and experiment considering curvatures on the designed airfoil might affect the accuracy of Xfoil. The results indicate that while CFD and Xfoil results closely align, Xfoil produces results closest to the experimental value. The bionic airfoil demonstrates superior performance in the range $Re = 2 \cdot 10^4$ to $Re = 2 \cdot 10^5$ compared to other studied airfoils, satisfying design requirements. This airfoil and its future counterparts are probable solutions to be implemented on fixed-wing CDVs desiring to glide in the given working conditions, providing an efficient and structurally simple pathway.

Keywords—bionic airfoil; cross-domain vehicles; optimization; CFD.

I. Introduction

IN the spring of 2022, a research team from Shanghai Jiaotong University published their work on Nezha III, a cross-domain vehicle combining aircraft and underwater glider [1]. Fixed-wing CDVs developed over the past years are varied and take forms including glide-off [2], water jet assist [3], and VTOL [4]. With their development, it must be noted that the comparatively large lifting surfaces pose a natural challenge to efficiency.

The lift-drag ratio of the airfoil is crucial to the performance of such CDVs, directly affecting their cruise energy consumption and operation duration. However, no airfoils are currently specialized for increasing such flights' efficiency.

The densities of air and water vary by over 800 times, resulting in significant changes in Reynolds numbers as well as turbulence parameters.

In existing publications, CDV and hydrofoil profiles designed to function under submerged status (not specifically for super-cavitation) are known to take NACA symmetric airfoils (e.g., NACA 0009 [5]) and cambered airfoils (NACA 2412 [6], NACA 4412 [7], NACA 6-series [6] , or even Clark-Y [7]) as their final or baseline airfoil for hydrodynamic wings. However, these airfoils do not demonstrate high efficiency. Take the example of a CDV plan designed by a team from Beihang University [7]. It has a lift-drag ratio of 6.4 in air and 4.3 underwater - both are not considered efficient though it is comparatively balanced regarding the parameters of other designs. Aside from optimizing the layout (e.g., increasing the aspect ratio), another pathway is to operate on the airfoil.

A bionic alternative is proposed to aim for a higher peak efficiency by this research. Puffins are one of the few species that can glide in both water and air, making them a perfect source of biomimetic inspiration on CDVs requiring both submerged and airborne gliding. Relevant data [8] indicates that during underwater gliding, their wings operate at approximately $Re = 5 \times 10^4$ - slightly higher than that of the small underwater gliders [9] (UGs); under airborne conditions, they fly up to a speed corresponding to slightly over $Re = 10^5$. It can be hypothesized that the geometric properties of its wing profile will provide insights into balancing airfoil performance for a large Reynold's number interval. This research hence initiates from imitating the shape of a puffin's wing to produce a airfoil fitting specific design parameters.

H. Shen is with X-Institute, Shenzhen, Guangdong 518083, China, e-mail: shenhanyueshanghai@163.com

J. Zhang is with The Experimental High School Attached To Beijing Normal University, Beijing 100032, China

X. Kong is with Xi'an ASN Technology Group Co., Ltd, Sha'anxi 710065, China

II. Design Process and Methodology

The research begins the optimization by generating more specific design parameters and applying these constraints to the baseline airfoil. The resultant airfoil is then compared to other commonly used airfoils for evaluation. Meanwhile, the results generated with Xfoil are compared with Computational Fluid Dynamics (CFD) and underwater experimental results for validation.

A. Vehicle Design Constraints

The airfoil is optimized given a specific layout designed for cross-domain flight. The 3D model with coordinate axes is given below.

Fig. 1. The vehicle which the airfoil is optimized for.

A Polyvinyl Alcohol Based Passive Wing Morphing Strategy

H Shen[1]

1 Crimson Global Academy, Florida, USA.

Abstract. Cross-domain vehicles have been proposed as powerful tools for environment data collection. However, it is challenging to balance their efficiency in air and water, while using mechanical means of morphing will deplete energy and available space. This research proposes the usage of polyvinyl alcohol (PVA) material with biodegradable structure to fabricate an easily manufactured irreversibly morphing wing profile, demonstrating an example of morphing from a MH-78 airfoil to a symmetric foil closely resembling NACA-0009 upon entry to water. Existing data support that the proposed strategies are potentially useful for small air-water cross domain vehicles aiming for zero pollution and high efficiency due to its capability to boost the overall operation duration of the vehicle.

1. Introduction

Ocean has become an increasingly crucial part in sustainable development since recent years. However, as industrial development progresses, pollution to ocean has been severe. Plastic is found to be present at remote coral reefs [1], and the Pacific trash vortex [2] is endangering the water quality and biodiversity in the world's largest blue water region. In light of these, the need to monitor, as well as collecting visual data becomes crucial to repairing the environment.

Buoys have been used to these purposes as a cheap data collection method [3]. However, just like underwater robots, these buoys face the problem of deployment deep into the ocean, as well as the possibility of creating more pollution due to the failure of reclamation. Hence, this research proposes the utilization of cross domain vehicles.

Cross domain vehicles (CDVs) have been of interest in recent years due to their wide potentials in research contributed by their enhanced mobility. A research team from Imperial College London has formulated the AquaMAV project [4] to collect and return water samples from waters where conventional surface vehicles could not enter.

To maintain longer durations under water, however, it is more preferable that the vehicle could operate with buoyancy engines and glide with minimal consumption of energy in its cruising stage rather than folding aerodynamic wings as did by AquaMAV and other examples such as QiangXiang II [5]. Such measures not only take up the cabin space, but also consumes energy as well as reduces the reliability of the vehicle due to additional mechanical structure.

Nezha III [6] is an example of such type of vehicle that maintains its aerodynamic surfaces throughout its flight profile.

A Computational Study on Static Extended Trailing Edge and Blunt Trailing Edge as a Flap Device to Improve Gliding and Cruising Efficiency of Underwater Gliders

Hanyue Shen*
Shanghai Pinghe School, Shanghai 201203, China

Yujing Ma
Shanghai Xinzhuang Middle School, Shanghai 201199, China

Static Extended Trailing Edge (SETE) and blunt trailing edge (BTE) with splitters have been explored to improve airfoils efficiency. However, the possibility of merging the two concepts as one flap device to improve the performance of hybrid underwater gliders (HUGs) has yet to be discussed. In this research, a deployable structure - the SETE-BTE flap - based on NACA2412 airfoil with 100mm chord length was proposed, featuring a 25% decimation on the trailing edge extended by a plate with 0.4% thickness and 25% length when retracted, and alternatively, a 25% extension on the trailing edge with the thin plate when extended. The structure is studied fully rigid and simulated with SolidWorks Flow Analysis using Cartesian grids validated with grid independence test. Results indicated that by adopting the SETE-BTE flap, the projection area of the wing can be reduced by 3 times to achieve the same lift. During the propelled level cruising motion, extending the flap is more advantageous while the structure reduces over 60% of the drag when for a given typical scenario, while for a typical speed of 1.2m/s, the extended flap gives a 187.9% increase in efficiency compared to the raw foil. During buoyancy-driven gliding motion, retracting the SETE-BTE flap increases the speed by 12.1%, while extending the flap increases the range by 2.67 times with a slight 1.4% increase in speed in the same scenario. This demonstrates the effectiveness of the SETE-BTE flap in the speed increase in gliding mode and efficiency increase in level cruising mode, while the implementation of the flap automatically gains a significant efficiency increase. This points to the wide potentials of applying the SETE-BTE flap structure on HUGs and cross-domain vehicles.

I. Nomenclature

C_l	=	lift coefficient
C_d	=	drag coefficient
α	=	angle of attack
F_y	=	normal component of net aerodynamic force on airfoil
F_z	=	horizontal component of net aerodynamic force on airfoil
F_l	=	aerodynamic lift
F_d	=	aerodynamic drag
E	=	efficiency, which is the ratio of lift over drag
v	=	speed

II. Introduction

Underwater gliders (UGs) are autonomous underwater vehicles that use buoyancy changes and wings for efficient propulsion, primarily used in oceanography for data collection and research [1][2]. These vehicles can operate at depths up to 1000m with payloads typically under 25kg, although larger capacity gliders exist [1]. Gliders enable sustained observation at fine horizontal scales, connecting coastal and open ocean research, and are particularly useful

*Hanyue Shen is with Shanghai Pinghe School, shenhanyueshanghai@163.com.

On the Effect of Tapered Static Extended Trailing Edge Devices in Underwater Gliding

Hanyue Shen*
Virginia Polytechnic Institute and State University, VA 24601, U.S.A.

Yujing Ma†
Shanghai Xinzhuang High School, Shanghai 201199, China

Jiaying Zhang‡
The Experimental High School Attached To Beijing Normal University, Beijing 100032, China

Static Extended Trailing Edge (SETE) was first proposed by Liu et al. in 2007 as a lift-enhancement device that can outperform Gurney flaps in terms of efficiency. Though most discussions on this device and other trailing edge treatments have been on turbine noise reduction, their effects on the force components and relevant optimization are inevitably crucial in an attempt to adopt this technology for winged vehicles. In the context of hybrid underwater gliders, this research considers 0.5m/s and 1.5m/s as the typical speeds for buoyancy-driven gliding and motor-powered cruising and analyzed a rigid SETE device on a NACA-2412 airfoil deployed tangentially to the trailing edge of the upper surface. The root chord of the SETE device is 10% of the airfoil chord length, and taper ratio values in the range of 0.1 to 1 are discussed with SolidWorks Flow Analysis with Design of Experiments and Optimization module. Through CFD with Cartesian grids, while affirming the lift and efficiency increment resulting from the SETE device, it can be concluded that in the range considered, increasing the taper ratio slightly decreases the efficiency, but significantly increases the lift. Respectively, the percentage changes from a taper ratio of 0.1 to 1 are less than 4% and over 19%. This indicates the possibility of utilizing this device as an efficient and effective lift-regulation strategy in buoyancy-driven gliding and provides a flexible way of designing gliding wings given the targeted speed and payload.

I. Introduction

Due to flow complications at the trailing edge of airfoils, a continued effort has been made to improve airfoil performance through trailing edge designs. There are multiple methods for these treatments. The area of the trailing edge of the slat can potentially reduce noise by more than 20 dB by weakening Strouhal shedding [1]; porous treatments on blunt trailing edges have been found to delay vortex shedding, stabilize flow, and suppress velocity and pressure coherence[2]; 2D and 3D surface treatments such as finlets [3], sinusoidal trailing edge [4] and trailing edge with slits or serrations [5] have shown promising results in reducing surface pressure fluctuations and noise reduction However, while these treatment methods are discussed under limited conditions [6], their implementation also comes with significant costs due to their complexity and the need for alternative manufacturing methods.

In 2007, Liu et al. proposed the Static Extended Trailing Edge (SETE) concept and validated the results with experiments on the NACA-0021 airfoil [7]. Although this device shows an increase in lift and an improvement in efficiency, it is a flat plate installed tangentially behind the trailing edge, which is less complicated than other trailing edge devices. While this technology has been discussed as yet another method of aero-acoustic improvement on turbines [5][8], the drawback of deteriorated stalling performance of this device has also been addressed.

In this research, the discussion focuses on the efficiency improvements of SETE devices. Although calculations and experiments on these devices have been completed, the effect of the tapering of the trailing edge extension has not yet been concluded. Hence, this research calculates SETE with a taper ratio ranging from 0.1 to 1 with a 10% extension behind the NACA-2412 airfoil.

*Hanyue Shen is with Virginia Polytechnic Institute and State University, hanyueshen@vt.edu
†Yujing Ma is with Shanghai Xinzhaung High School, maryg006@dingtalk.com
‡Jiaying Zhang is with The Experimental High School Attached To Beijing Normal University, jiayingzhang0621@gmail.com

Prospective Design and Analysis of a Puffin-Inspired Efficiency-Aiming Cross-Domain Unmanned Glider

Jiaying Zhang*[1], and Qinghan Wang[2]

[1]The Experimental High School Attached to Beijing Normal University, Peking, PRC
[2]The High School That Affiliated Renmin University of China, Peking, PRC

zhangjiaying0621@gmail.com, wang.selina1@icloud.com

Abstract – Cross-domain vehicles (CDVs) are capable candidates in survey, rescues, and construction operations with their high hydrodynamic performances as well as agility brought by airborne capability. The researchers believe that fixed-wing cross domain vehicles, although not yet implemented widely, is a prospective development direction benefiting from their lightweight and simple mechanical and control structures. In this research, MATLAB-Xfoil-based panel method, CFD (Computational Fluid Dynamics) , wind tunnel experimentations, and composite algorithms are used to optimize and validate a bionic foil and resultant full vehicle layout solution inspired by Atlantic Puffins. The final solution is designed to gain a high submerged glide ratio of 7.2 and airborne glide ratio of 9.8, having a comparatively competitive efficiency that surpasses existing CDV solutions for similar scenarios. Its outstanding numbers indicate the wide application possibilities in cross-domain missions brought by this new proposal of bionic fix-winged hybrid unmanned vehicle.

Keywords: Bionic Airfoil, CFD, Cross Domain Vehicle, Fluid Dynamics, System Engineering.

1. Introduction

Cross-medium unmanned aerial vehicles (UAVs), as advanced vehicles capable of transitioning between air and water, are spearheading innovations in aerospace and marine exploration technologies. In recent years, with the growing demand for energy efficiency and environmental protection, the design of cross-medium UAVs has garnered widespread attention from various fields. Their unique design and functionality enable them to operate efficiently in two entirely different environments, with strong adaptability. Cross-medium UAVs have demonstrated tremendous potential in areas such as military reconnaissance [1-4], search and rescue missions [5,6], environmental monitoring, and resource exploration [7-12].

However, existing cross-medium aerial vehicles often suffer from low energy efficiency [27], limited range [13-14], and insufficient payload capacity [19-21] when operating in both air and water. Specifically, the power requirements for cross-medium aerial vehicles differ significantly between underwater and aerial environments. Current solutions often struggle to achieve efficient operation in both mediums simultaneously, which not only increases energy consumption but also greatly limits the range and mission capabilities of the vehicles.

2. Current Research

In 2010, Auburn University introduced the concept of a submersible aircraft [16], which combined the rapid deployment capabilities of an airplane with the stealth of a submarine, enabling wide-range aerial flight and covert underwater operations. However, the weight issue caused by maintaining a dry cabin added complexity to buoyancy control and increased energy consumption during underwater operations.

In 2014, the "Flying Fish" project by Beihang University was one of the earlier attempts [13]. This project combined the advantages of seaplanes and submarines. The "Flying Fish" exhibited low efficiency during mode transitions, and its slow underwater cruising speed affected its overall operational efficiency.

In 2017, North Carolina State University developed a fixed-wing cross-domain unmanned aerial vehicle (UAV) [17],

Opportunities in Active Hull Antifouling Technologies: A Review on Electric and Magnetic Methods

Hanyue Shen[a]

[a] *Virginia Polytechnic Institute and State University, 240 Mccomas Hall, Blacksburg, 24601, U.S.A.*

Abstract

Marine antifouling has long been a challenge to researchers. Due to limitations to mainstream chemical and polymer based methods, alternative attempts are being made. This review focuses on electromagnetic-related antifouling methods, acting in physical, chemical, or biological ways, and sheds light on the potential development of new methods based on existing biological research. The mechanism and effectiveness of each method are explained while addressing the imperfections due to energy, eco-friendliness, cost, duration, and scalability considerations. The review summarizes these innovative active antifouling methods and indicates their usage on emerging small unmanned aquatic systems, suggesting possible research and exploration pathways for future endeavors.

Keywords: Antifouling, Ecofriendly Antifouling, Active Antifouling, Electromagnetic Methods

1. Introduction

From historical wooden ships to modern marine platforms [1], biofouling impacts a significant number of marine systems. The organisms that attach to these surfaces not only increase drag, leading to economic losses, but they also facilitate the spread of invasive species to other regions of the world. This phenomenon presents a global economic and environmental challenge [2] that remains to be addressed.

In the fishing sector, biofouling accounts for 3 percent of intermediate consumption costs and 40 percent of ship maintenance expenses [3], as reported by a study involving a Cantabria fishing fleet. For marine heat exchangers, biofouling reduces efficiency, increasing fuel consumption and adverse environmental impacts [4]. In aquaculture, blue mussel biofouling on green-lipped mussel farms in New Zealand results in an estimated annual loss of 16.4 million USD, representing 10 percent of the regional industry value [5]. The economic impact is even more substantial for naval vessels. A study on Arleigh Burke-class destroyers found that hull fouling costs the U.S. Navy approximately 56 million USD annually per ship class, primarily due to increased fuel consumption resulting from heightened frictional drag [6]. These findings underscore the urgent need for effective biofouling prevention and mitigation strategies across maritime industries.

Biofouling results from the colonization of submerged surfaces by marine organisms, progressing from microfouling (which includes bacteria, microalgae, and protozoa) to macrofouling (which encompasses larger algae and invertebrates) [7]. Common fouling organisms include bacteria, diatoms, algae, barnacles, mussels, and ascidians [8]. In Table 1, three of these organisms are presented, along with their attachment methods and habitat dispersal.

Organism	Attachment	Habitat	Citations
Barnacles	Larval settlement.	Intertidal and sublittoral.	[9, 10]
Mussels	Byssal threads.	Varied waters.	[11, 12]
Green Algae	Acid-base interactions.	Water and soil.	[13,14]

Table 1: A brief overview of three common biofoulants.

It can be concluded that while attachment methods differ among species, the diverse habitats of biofouling organisms demonstrate their remarkable adaptability, which presents additional challenges to the prevention of biofouling.

Throughout the ongoing battle against biofouling, various methods have been developed to adapt manufacturing requirements, target specific species, and accommodate different operating conditions in contexts such as fixed structures, industrial sites, and maritime vehicles.

The development of antifouling solutions has been diverse. These solutions can be categorized into physical, chemical, and biological methods [15], with various intersections and combinations among them. Although effective solutions are available, they have not yet resulted in a universally applicable method due to several factors. Table 2 offers insights into some common antifouling strategies, along with their respective targets and drawbacks.

Method	Target	Problem	Citations
Bioactive	Molecular agents.	Toxic	[16,17]
Self-Polishing	Renew surface layer.	Toxic, durability, cost	[18,19]
Surface Wettability	Self-cleaning.	Performance	[20,21]
Biomimetic	Varied.	Cost	[22,23,24]
Photocatalytic	Deactive foulants.	Duration, cost, dependency	[25,26,27]
Acoustic	Inhibit biofouling.	Performance	[28,29,30]

Table 2: Targets and problems with some existing antifouling strategies.

In summary, although existing technologies are shifting from toxic to more environmentally friendly methods, no satisfactory solution currently exists due to factors such as effectiveness,