Madrid, 24-26 de abril de 2024

Hybrid aerial underwater vehicle: a new design for air and sea operations using low-cost, open-source technology

Mariano Marcos Pérez, Aurelio Muñoz Rubio, M. Victoria Redondo Neble, J. Rafael Rodríguez Galván, Andrés Yáñez Escolano.

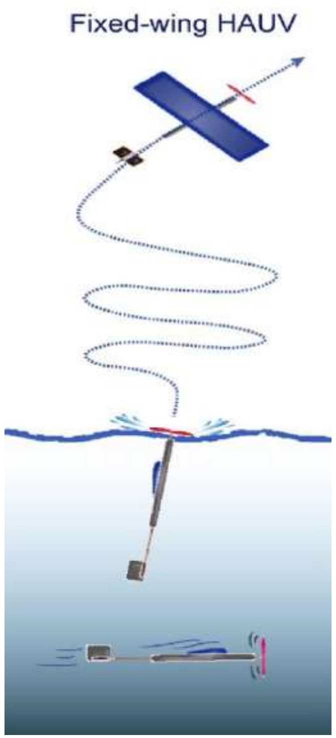
School of Naval Architecture and Ocean Engineering, Universidad de Cádiz. C.A.S.E.M., Polígono Río San Pedro S/N, 11510 Puerto Real, Cádiz.

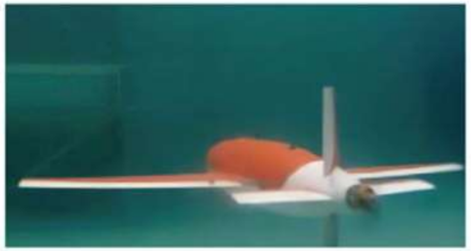
TRANSFORMANDO LOS OCÉANOS: INNOVACIÓN e ingeniería naval para un mundo CONECTADO y SOSTENIBLE

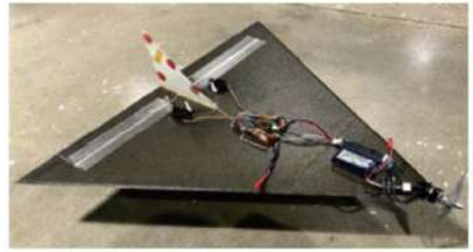
Introduction

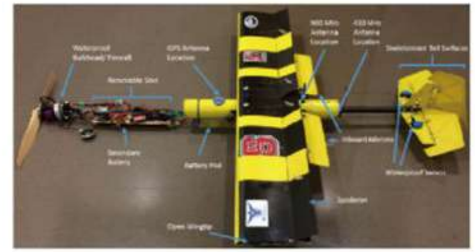
Existing forms of Hybrid Aerial Underwater Vehicles (HAUV) are grouped into three **dominant designs**:

Introduction

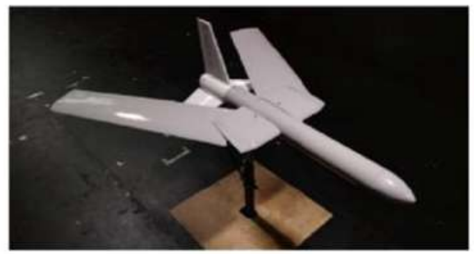



(a) Test Sub II


(b) Triangular plate-like HAUV


(c) EagleRay


(d) Improved EagleRay

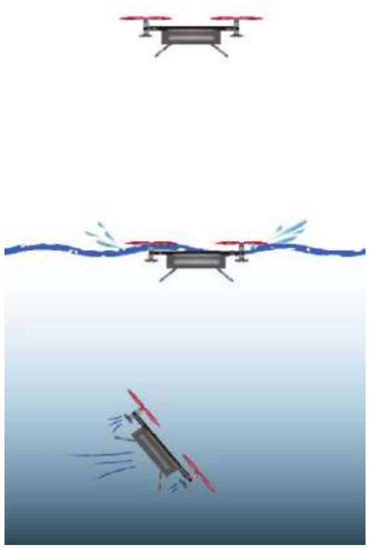

(e) HAUV with foldable wings


(f) AquaMAV

Adapted from (Zeng et al., 2022): Representative fixed-wing HAUVs. (a) Test Sub II (Edwards et al., 2017) (b) Triangular plate-like HAUV (Moore et al., 2018) (c) EagleRay (Weisler et al., 2018) (d) Improved EagleRay (Stewart et al., 2018) (e) HAUV with foldable wings (Guo, 2019) (f) AquaMAV (Siddall et al., 2017)

Introduction

Multi-rotor HAUV

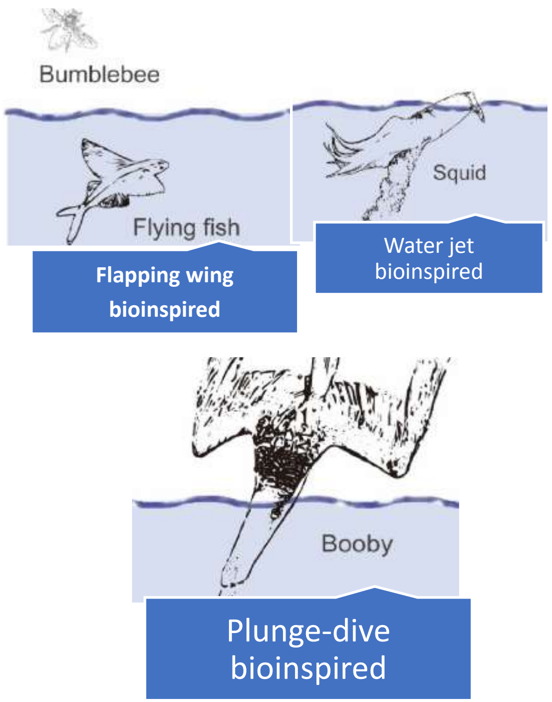


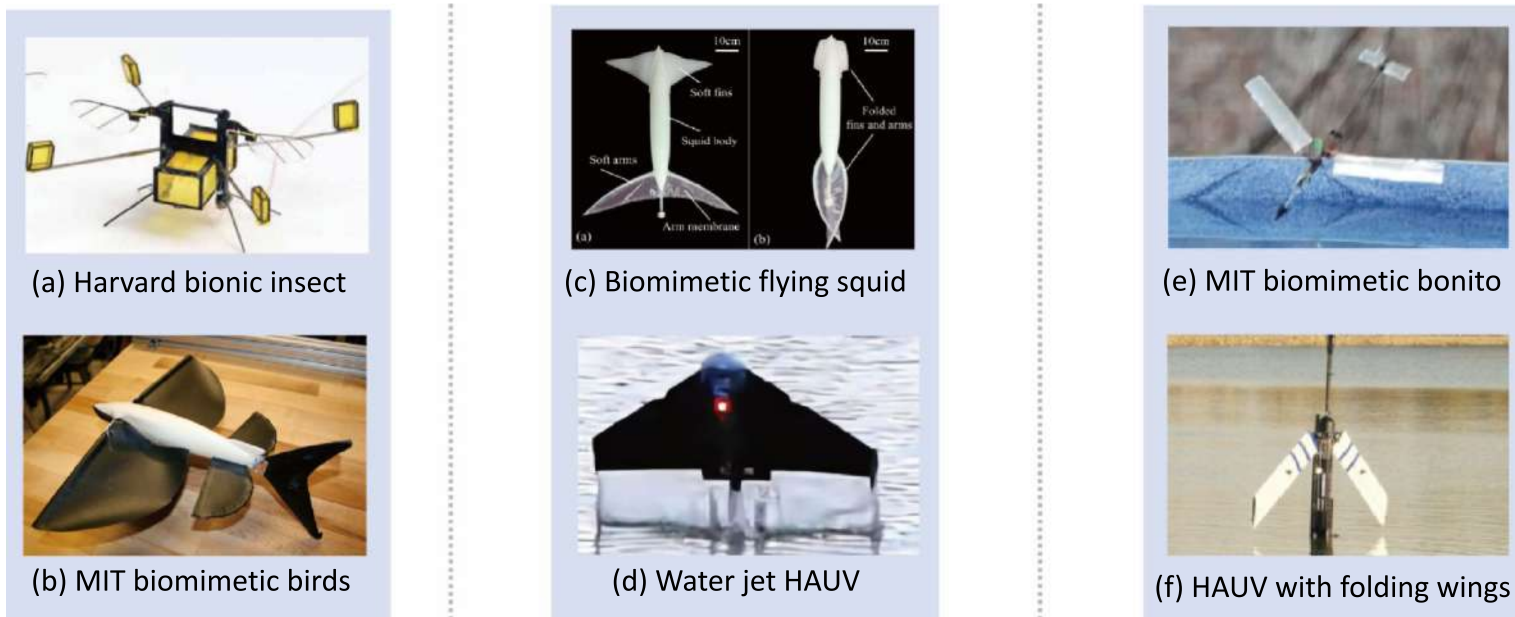
(a) Miniature quadrotor HUAV (b) Tilt-quadrotor HAUV (c) Dalian Maritime University (d) GTQ-Cormorant

(e) CRACUNS (f) Shanghai Maritime University (g) Loon Copter I (h) Loon Copter II

Adapted from (Zeng et al., 2022): (a) Miniature quadrotor HUAV (Zha et al., 2019) (b) Tilt-quadrotor HAUV (Tan and Chen, 2020) (c) Dalian Maritime University (Chen et al., 2019) (d) GTQ-Cormorant (Bershadsky et al., 2016) (e) CRACUNS (Staff, 2016) (f) Shanghai Maritime University (Chen et al., 2021) (g) Loon Copter I (Alzu'bi et al., 2015) (h) Loon Copter II (Alzu'bi et al., 2018).

Introduction

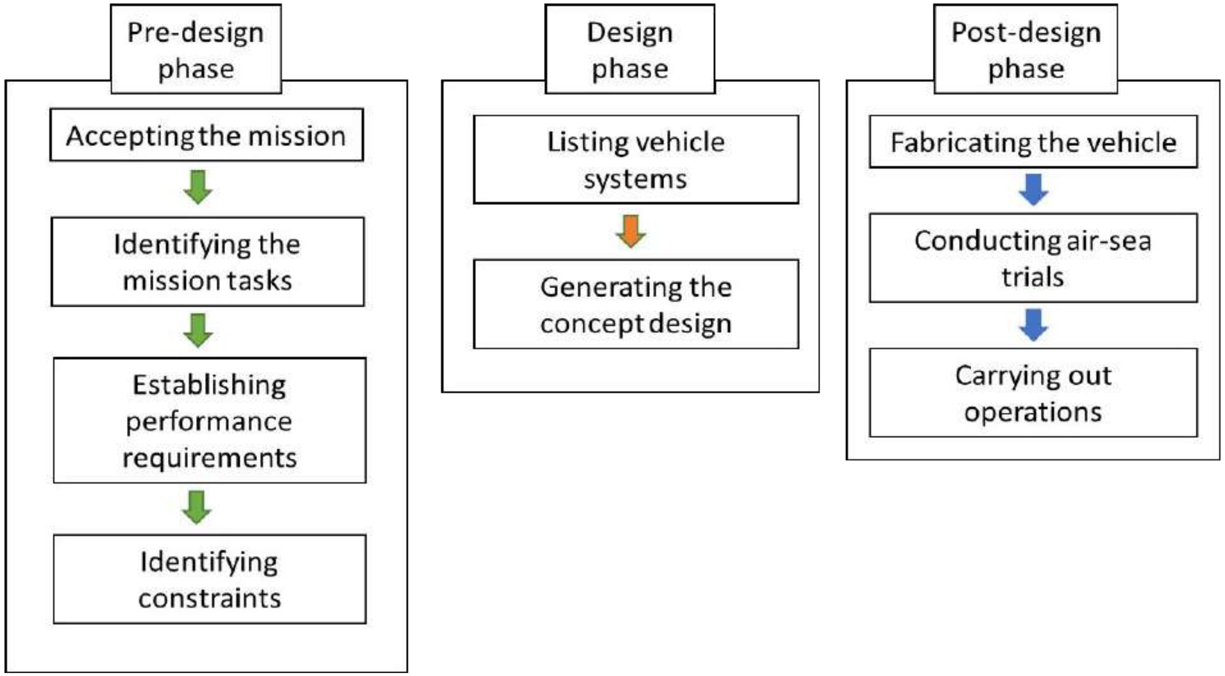




Adapted from (Zeng et al., 2022): Representative bioinspired HAUVs. (a) Harvard University bionic insect (Chen et al., 2017) (b) MIT biomimetic birds (Gao and Techet, 2011) (c) Biomimetic flying squid (Hou et al., 2019) (d) Chemical combustion HAUV (Zufferey et al., 2019) (e) MIT biomimetic bonito (Fabian et al., 2012) (f) HAUV with folding wings (Wang et al., 2013).

Design stages

Design stages



Design stages: Adapted from Moore et al., (2010).

Pre-design phase

Applications for UAVs. Adapted from Marques et al., 2021

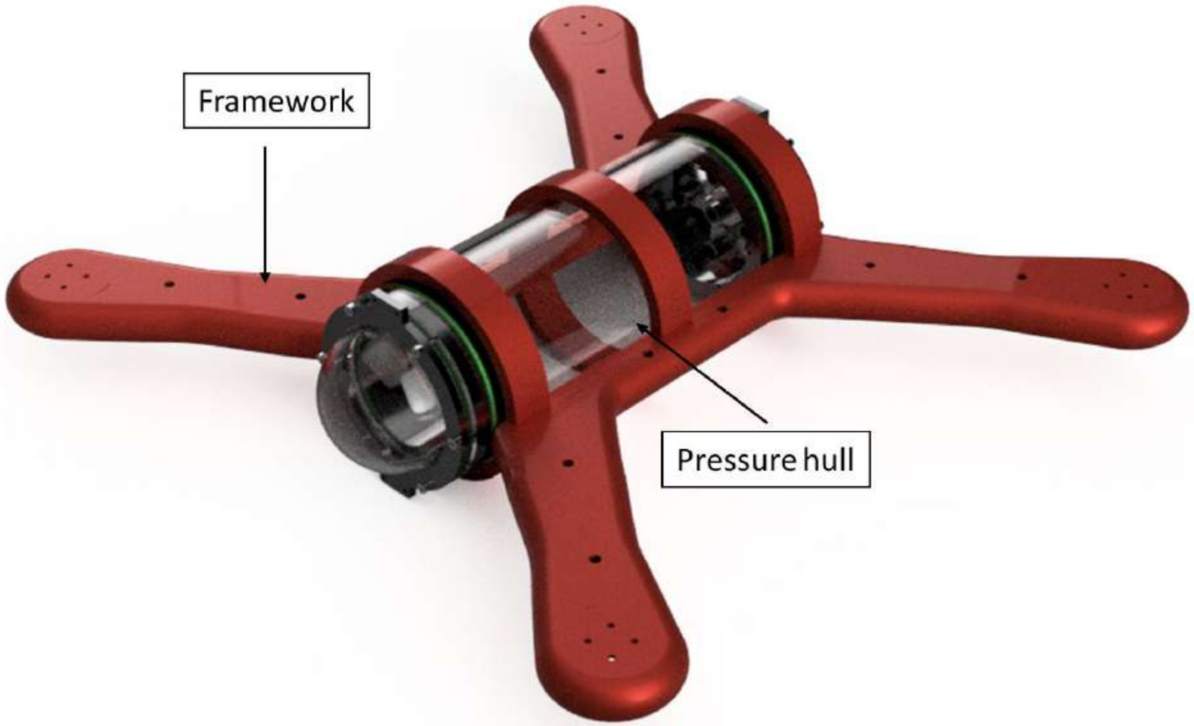
Aerial application	**Examples**
Intelligence/reconnaissance	Mapping, battle damage assessment, target acquisition & designation
Security missions	Search and rescue (SAR), drug interdiction
Coastal and oceanic missions	Coastal management, identification and tracking of marine species
Earth sciences missions	Cloud and aerosol measurements, Antarctic exploration surveyor
Civilian	Maritime patrol and assistance
Land Management	Wildfire / disaster: real-time comm

Applications for inspection-class ROVs. Extracted from Capocci et al., 2017

Underwater application	**Examples**
Environmental	Coastal monitoring, habitat monitoring, pollution assessments
Military	Mine hunting and disposal
Sciences	Seabed investigation, marine life studies, water and sediment sampling
Offshore oil and gas	Pipe and structure inspection, visual leak detection
Marine renewable energy	Structure inspection
Search and rescue	Search and recovery operations

Design phase: Structural system

Structural system

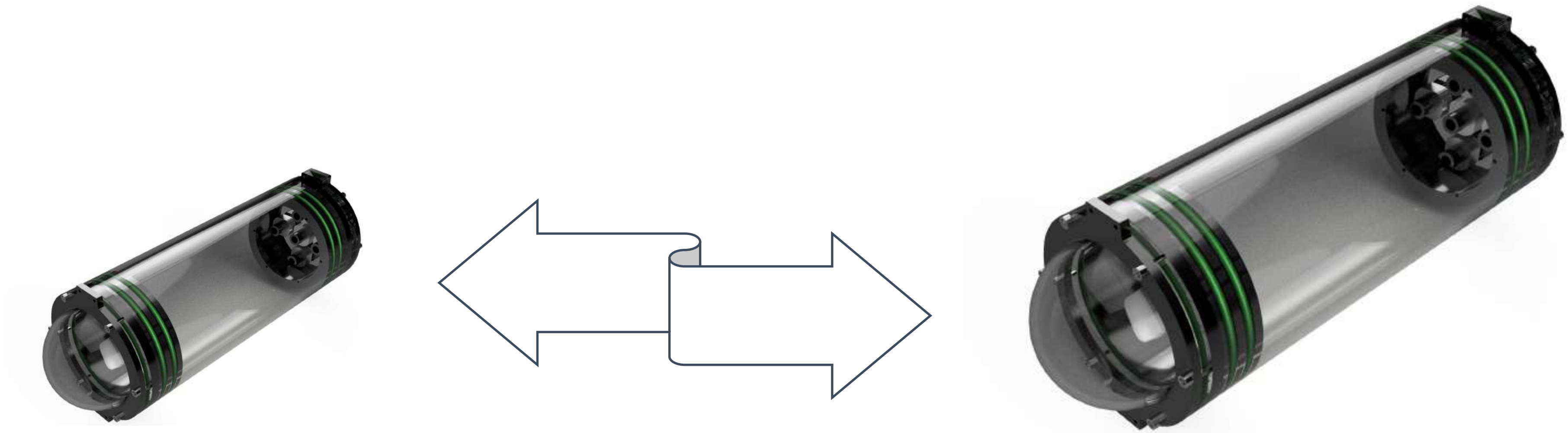


Structural system: Framework + pressure hull.

Design of submersible structures

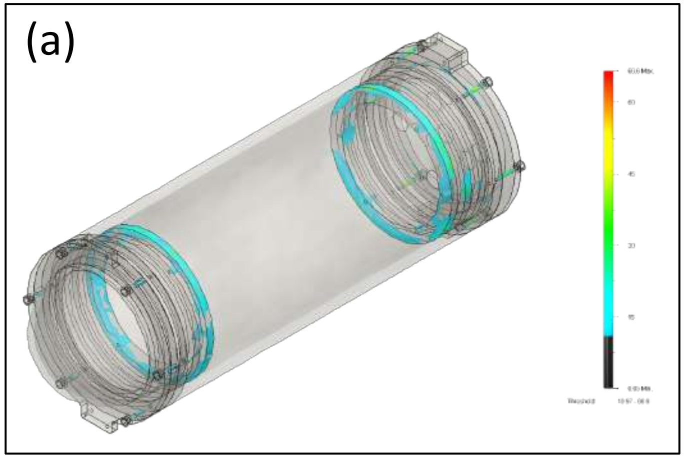
Shape

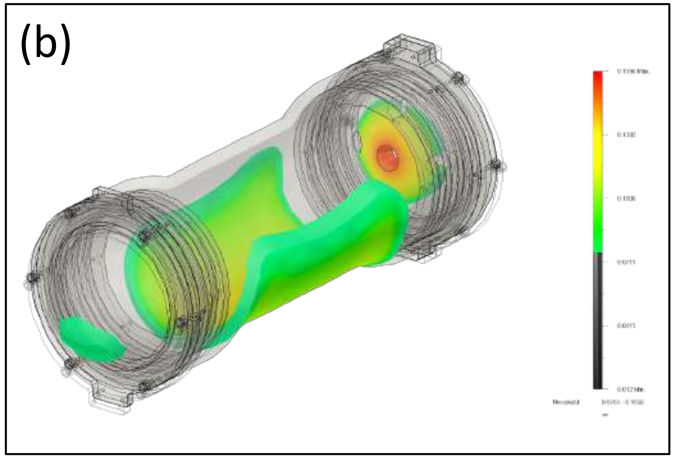
Design of submersible structures

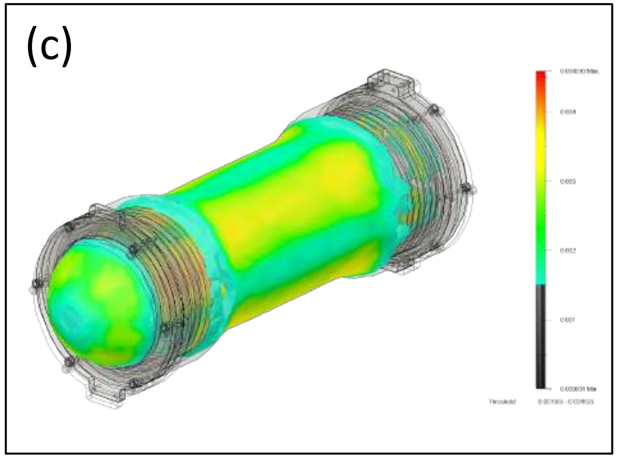


$$F[N] = \Delta pressure[Pa] \cdot exposed\ surface[m^2]$$

Structural system



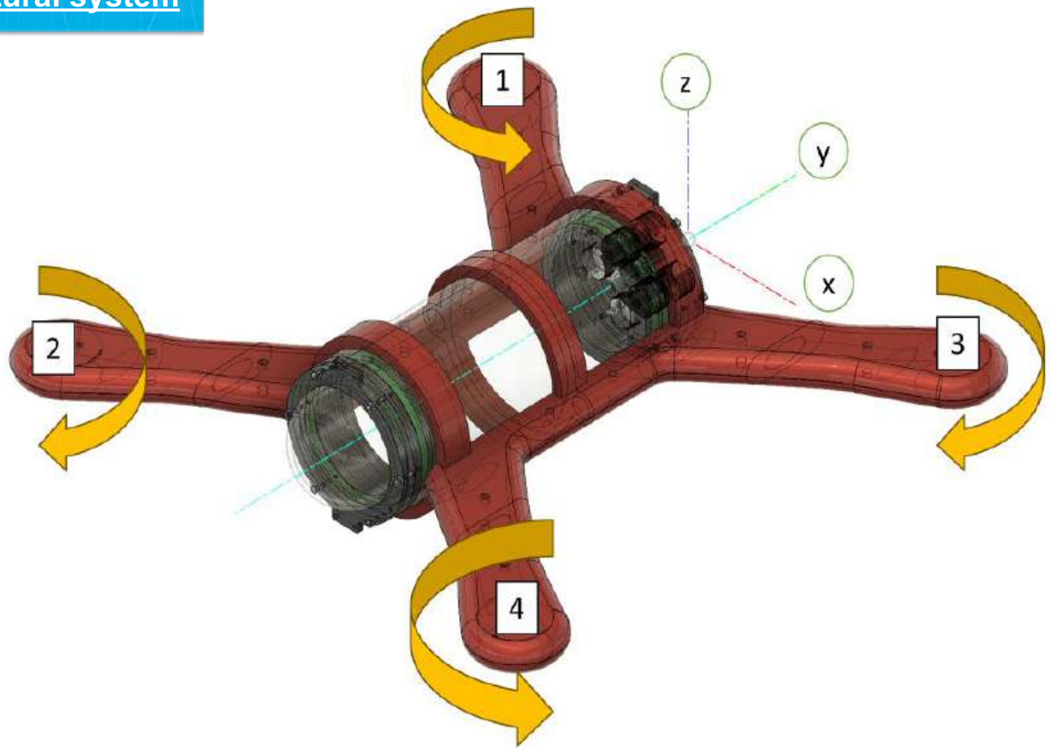


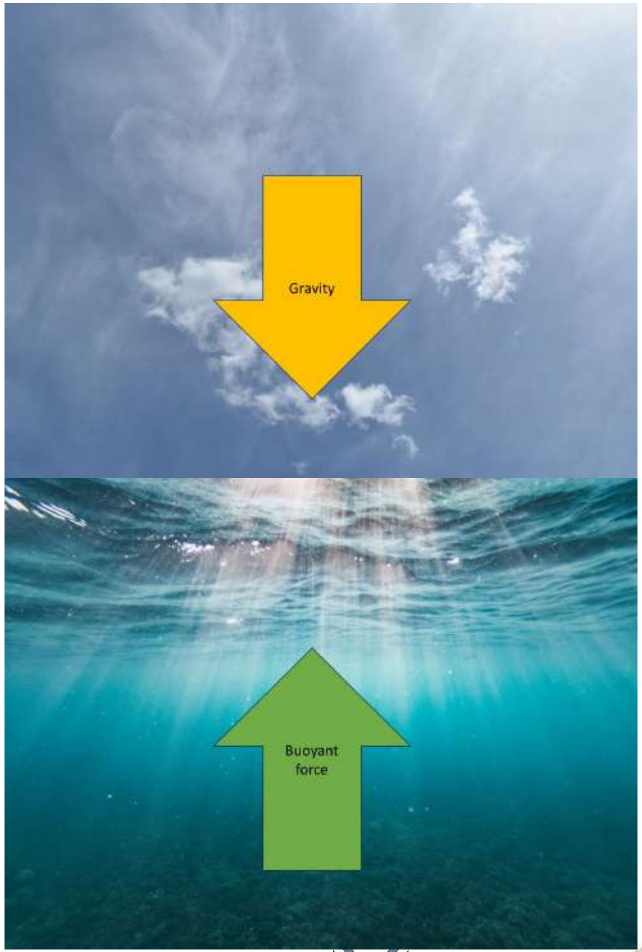


80m depth simulations: (a) Von Mises stress, (b) Displacement of the structure, (c)Deformations

Madrid, 24-26 de abril de 2024

Structural system





TRANSFORMANDO
LOS OCÉANOS:
INNOVACIÓN e ingeniería naval para
un mundo CONECTADO y SOSTENIBLE

Universidad de Cádiz

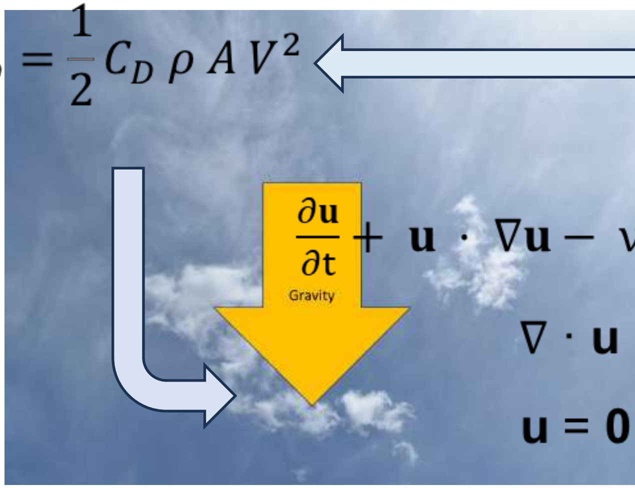
Design phase: Propulsion system

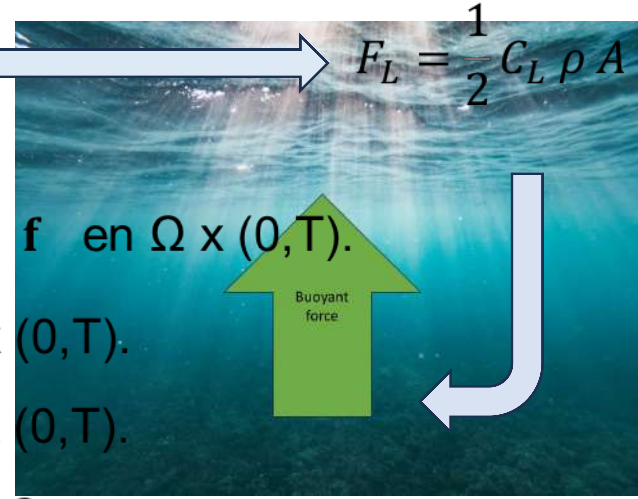
External flow

Power = total drag · vehicle speed

$$F_D = \frac{1}{2} C_D \, \rho \, A \, V^2$$

$$F_L = \frac{1}{2} C_L \, \rho \, A \, V^2$$





$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} - \nu \cdot \Delta \mathbf{u} + \nabla p = \mathbf{f} \quad \text{en } \Omega \times (0,T).$$

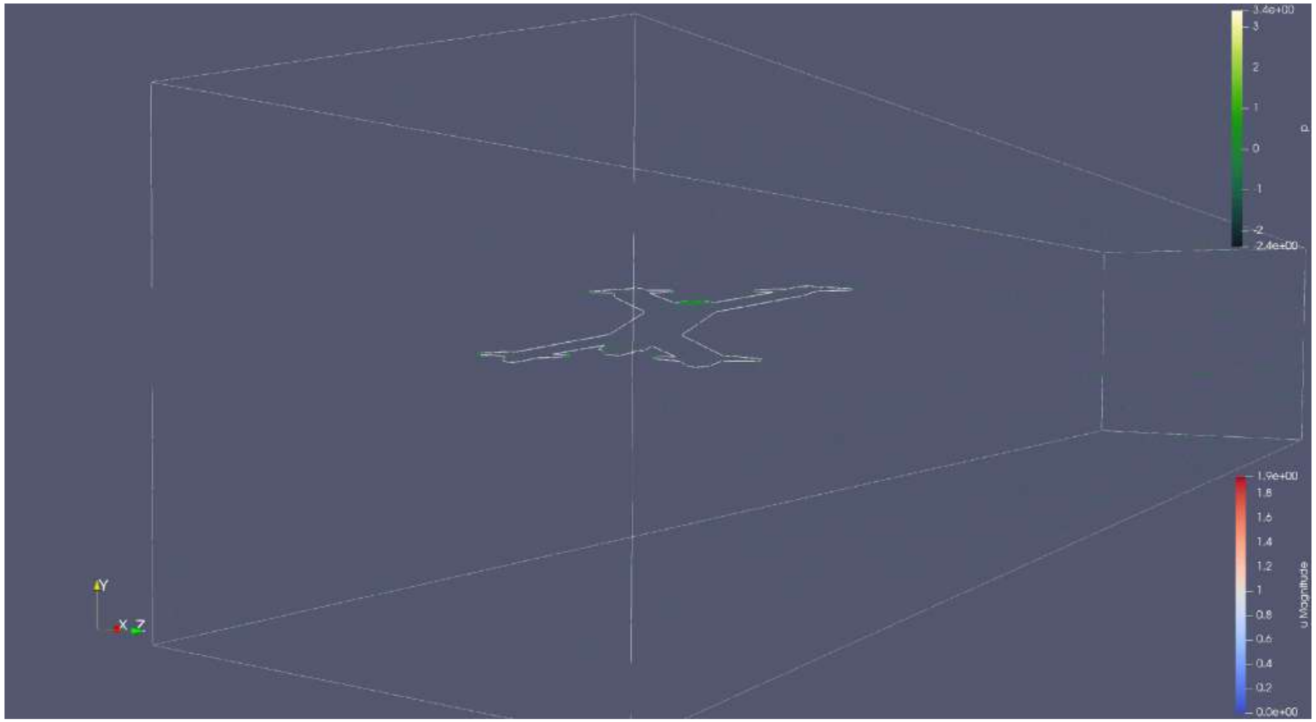
$$\nabla \cdot \mathbf{u} = 0 \quad \text{en } \Omega \times (0,T).$$

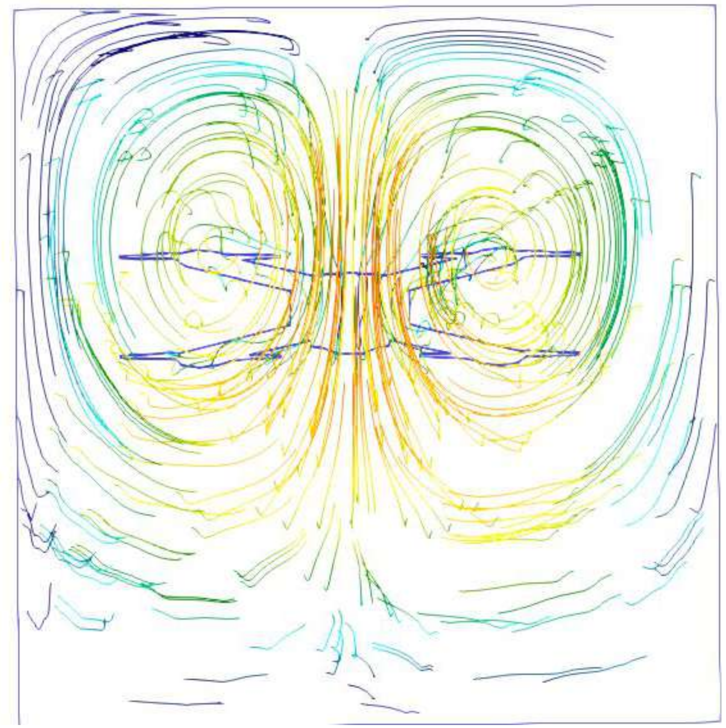
$$\mathbf{u} = \mathbf{0} \quad \text{sobre } \partial\Omega \times (0,T).$$

$$\mathbf{u}_{(t=0)} = \mathbf{u}_0 \quad \text{en } \Omega.$$

Propulsion system

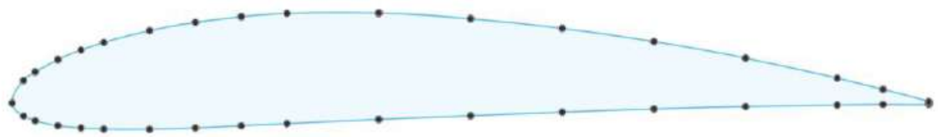
External flow



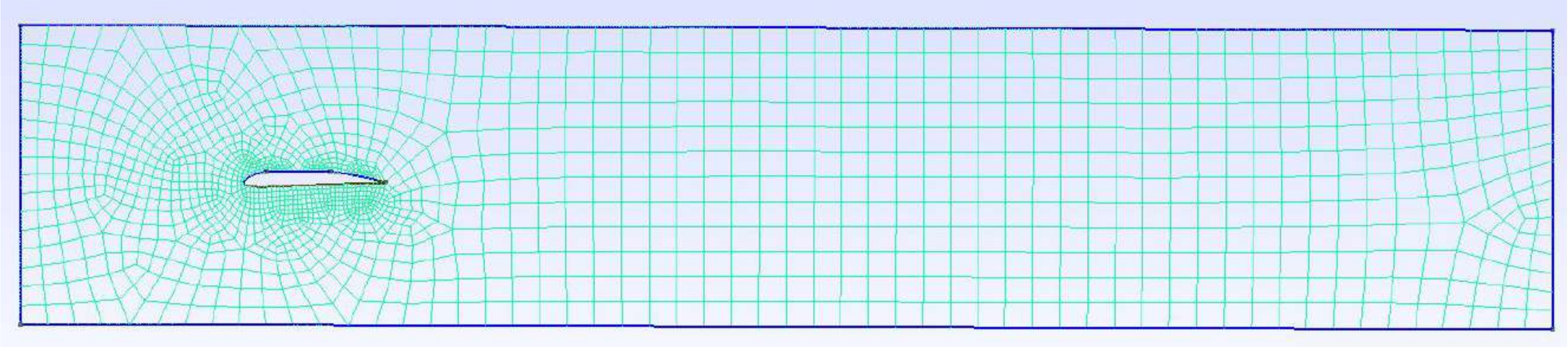


CFD simulations

Air and water thrust



NACA 4412 airfoil



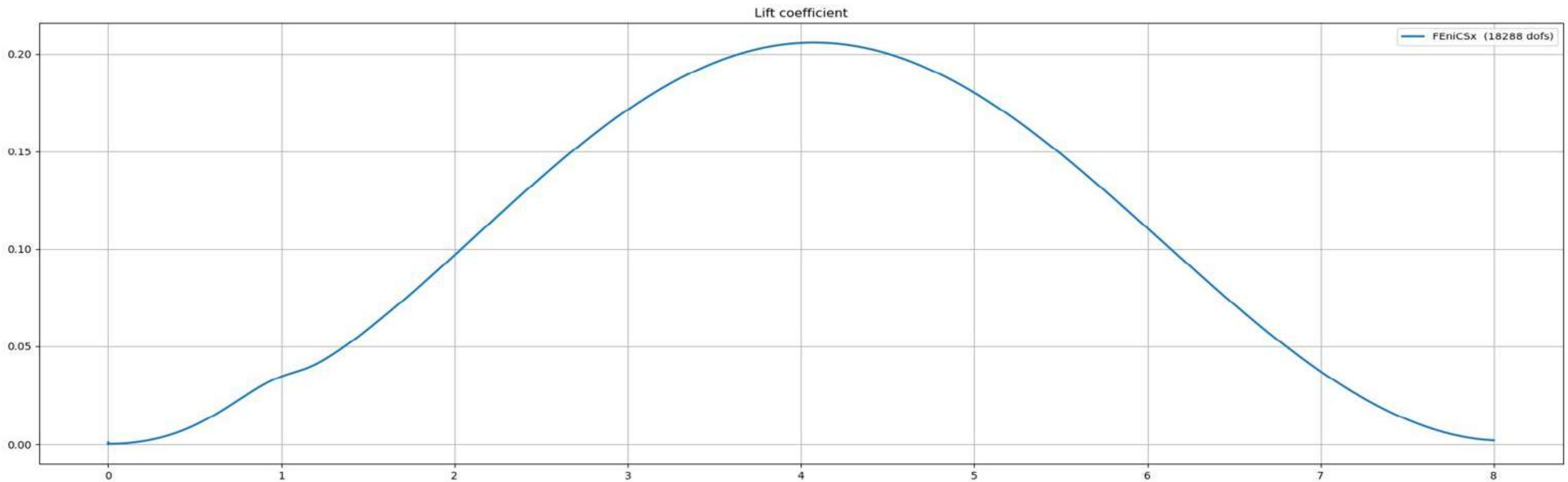
NACA 4412 airfoil mesh

Propulsion system

Air and water thrust

2D CFD simulations

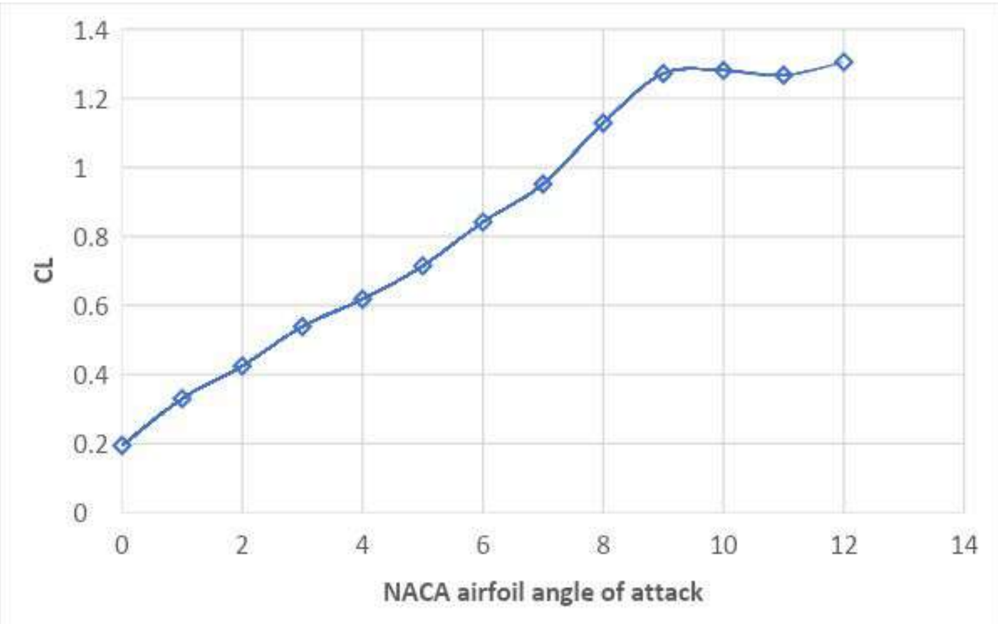
Air and water thrust



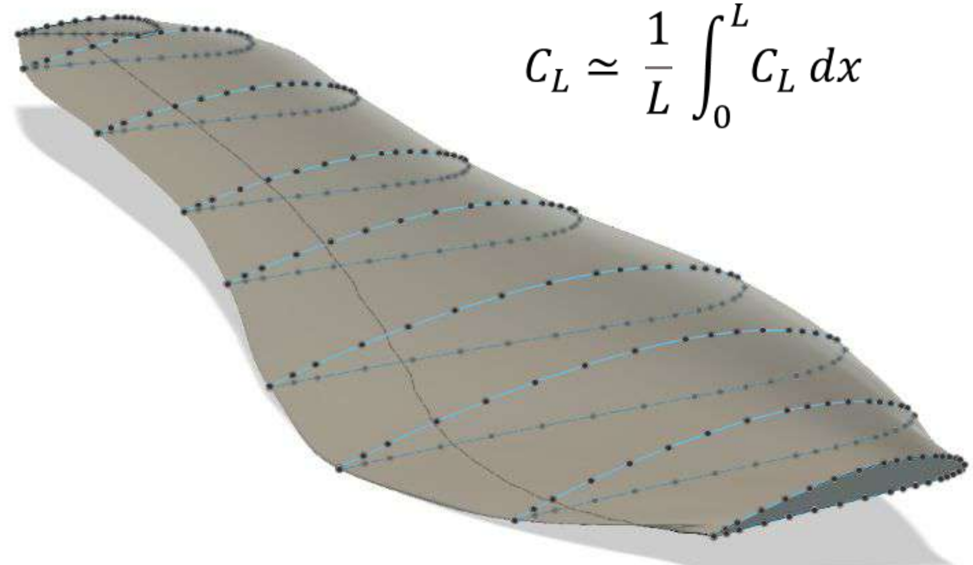
2D CFD simulation result

Propulsion system

Air and water thrust



C_L at 0° to 12° angle of attack



$$C_L \simeq \frac{1}{L}\int_0^L C_L\,dx$$

Propeller design

UCA Universidad de Cádiz

Propulsion system

Air and water thrust


Experimental verification of propeller thrust

Results from propeller thrust experiment

Device	Thrusters
Voltage (V)	12 – 24
Amperage (A)	17
Power (W)	100 – 300
Number of thrusters	4
Total power (W)	400 – 1200
Use per mission (min)	30
Total requirement (W·h)	200 – 600

Design phase: Power system

Power system

Results from propeller thrust experiment

Device	Thrusters
Voltage (V)	12 – 24
Amperage (A)	17
Power (W)	100 – 300
Number of thrusters	4
Total power (W)	400 – 1200
Use per mission (min)	30
Total requirement (W·h)	200 – 600

$$\text{Capacity } (A \cdot h) = \frac{Power\ (W \cdot h)}{Voltage\ (V)}$$

$$\text{Discharge rate } (C) = \frac{Max\ demand\ (A)}{\text{Capacity } (A \cdot h)}$$

Power requirements estimation

Battery	Voltage (V)	Total Requirement (W·h)	Capacity (A·h)	Max Discharge (A)
Required Power Supply	12-24	200 - 600	17 - 25	5C - 3C

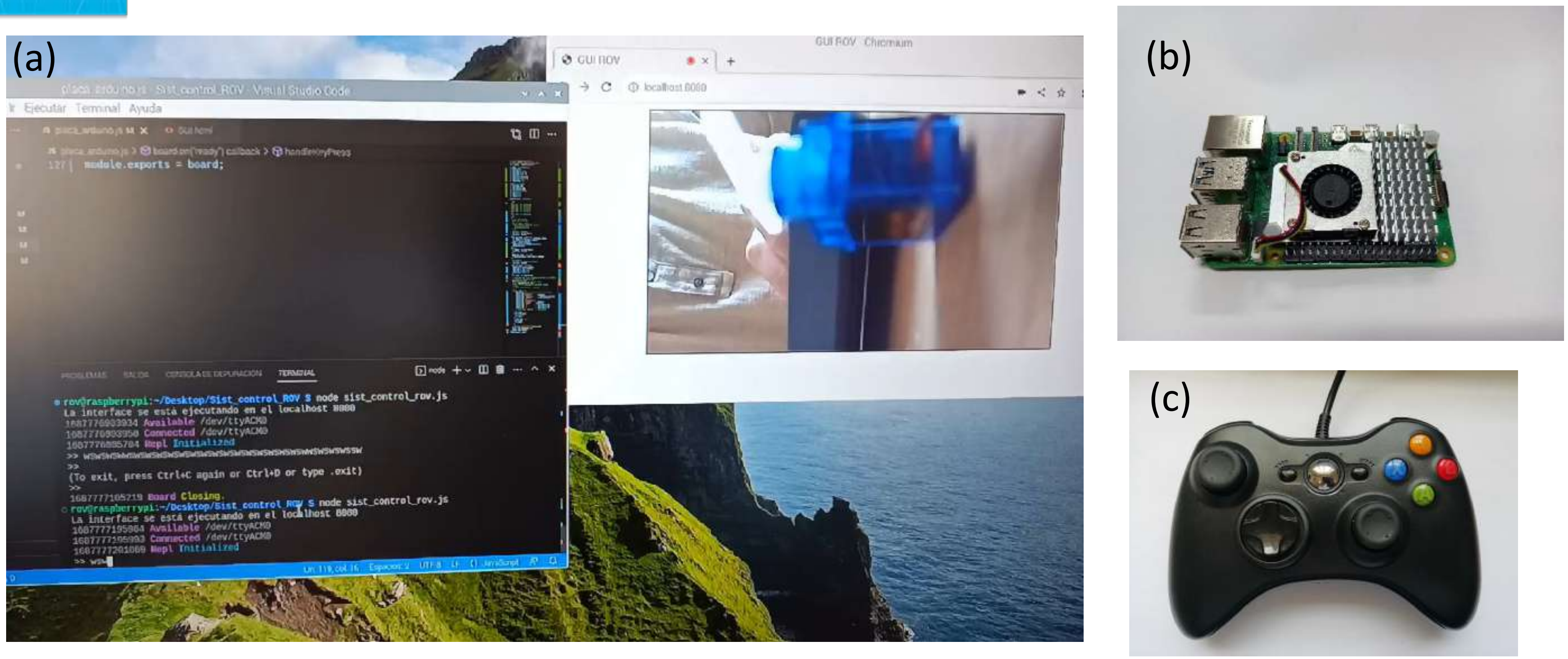
Battery example

Design phase: Control system

CIIN 2024
63° Congreso Internacional de Ingeniería Naval e Industria Marítima

Madrid, 24-26 de abril de 2024

Control system



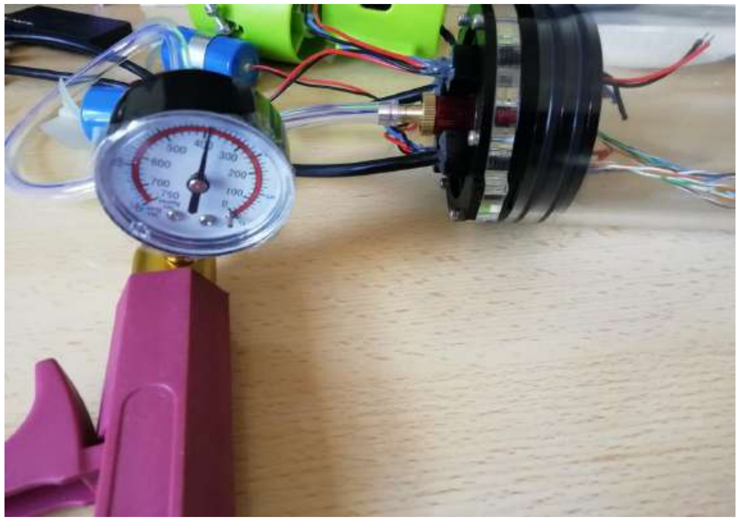
Control system: (a) First GUI, (b) Raspberry Pi5, (c) Gamepad

TRANSFORMANDO
LOS OCÉANOS:
INNOVACIÓN e ingeniería naval para
un mundo **CONECTADO** y **SOSTENIBLE**

UCA
Universidad de Cádiz

Post-design phase

Post-design phase



Tightness testing

Battery maintenance


Sealing

Conclusions

Madrid, 24-26 de abril de 2024

TRANSFORMANDO
LOS OCÉANOS:
INNOVACIÓN e ingeniería naval para
un mundo CONECTADO y SOSTENIBLE