MIT MECHE

MIT 2.S01 Introduction to Autonomous Underwater Vehicles

Lecture 2: Fundamentals of AUVs

Supun Randeni

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MIT Sea Grant AUV Lab

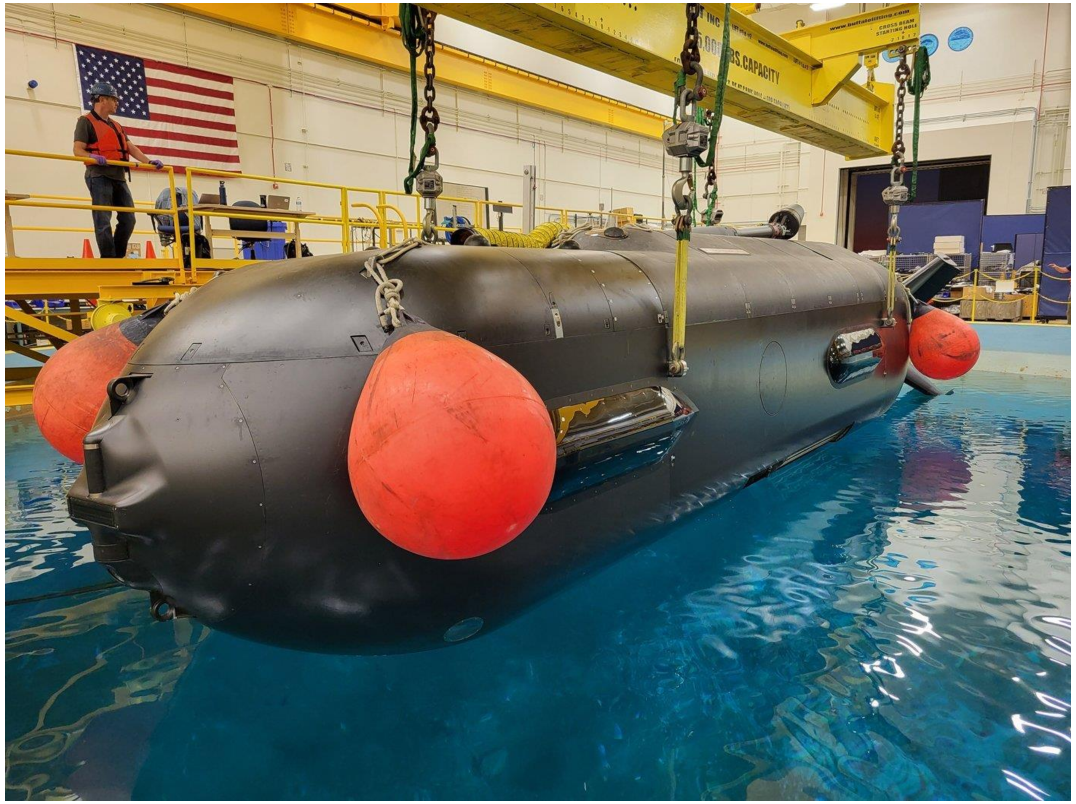
MIT Marine Autonomy Lab

Four main types of AUVs based on the size

Extra Large AUVs (XLUUVs)

- Primarily for defense related applications
- Longer endurance , larger payload capacity
- Cost: typically above $50 million

Scaled-down prototypes of DARPA Manta-Ray XL hybrid UUV



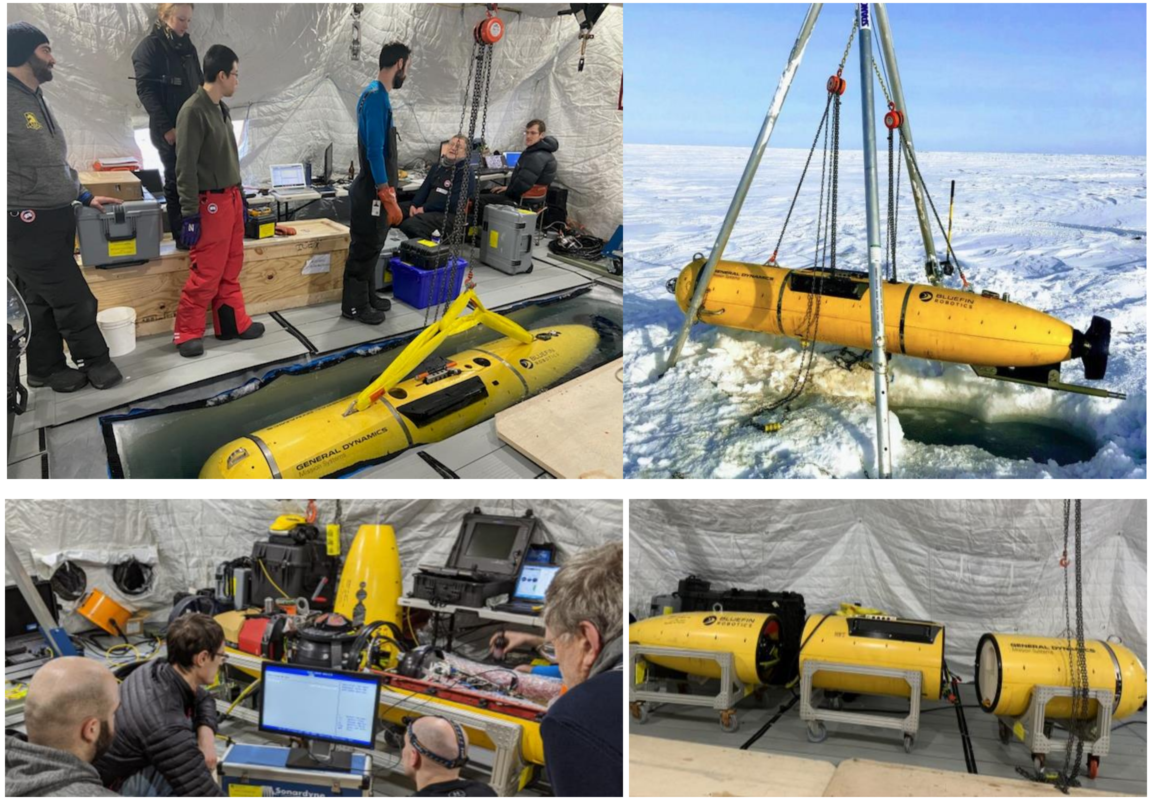
Boeing's Orca XLUUV

Four main types of AUVs based on the size

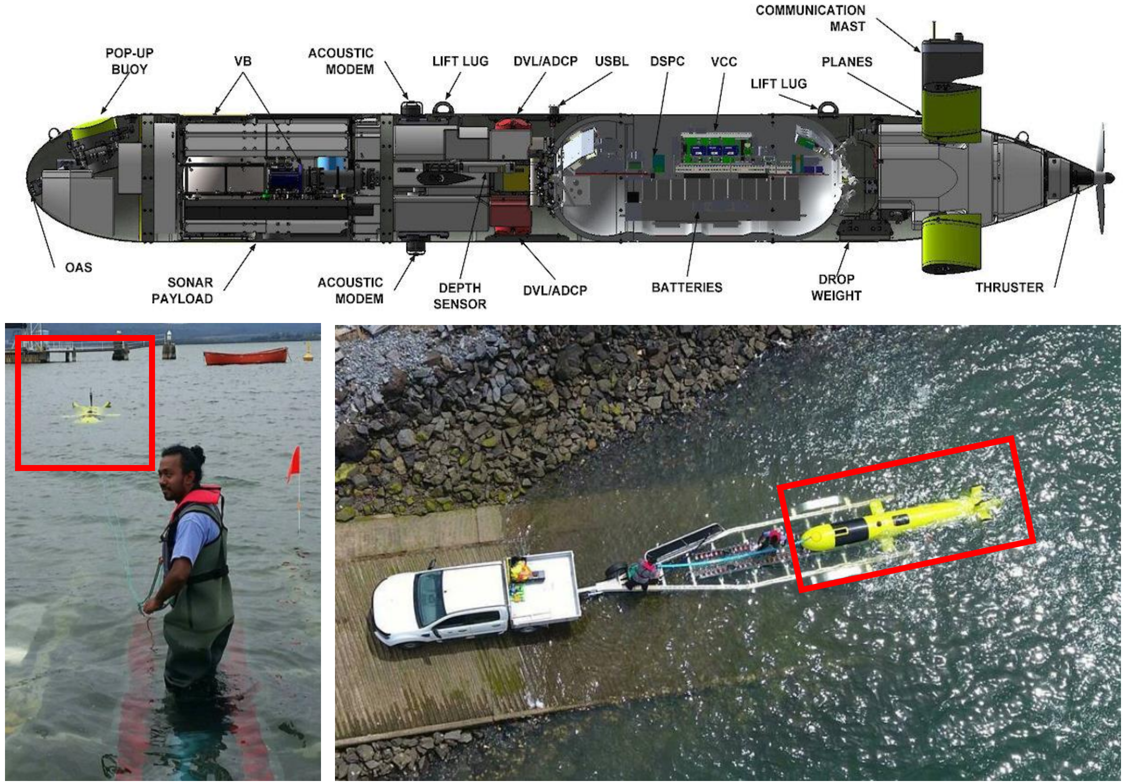
Large AUVs

- Defense, scientific and commercial applications
- Carries multiple different payload sensors
- Cost: typically, $2-10 million

Bluefin 21-inch AUV



International Submarine Engineering (ISE) Explorer AUV



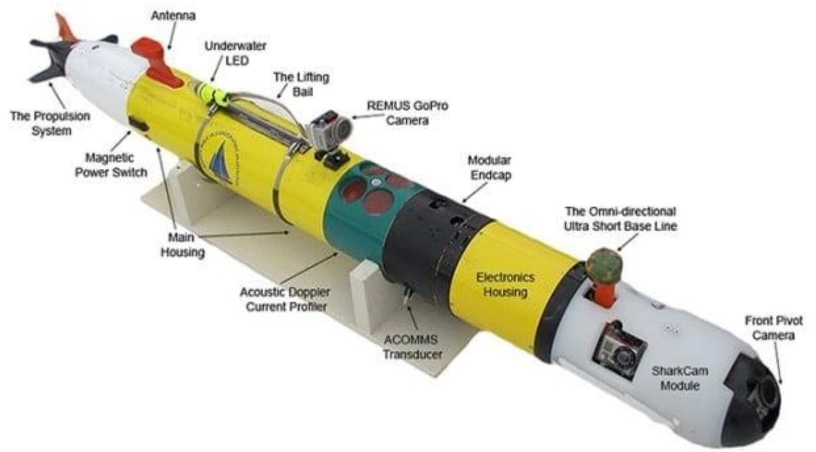
Four main types of AUVs based on the size

Medium-sized AUVs

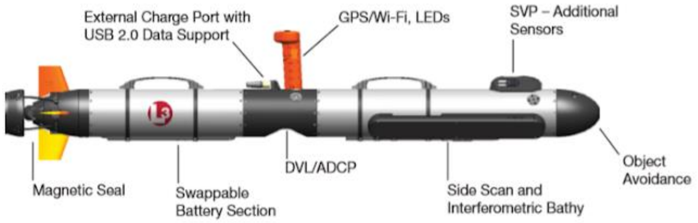
- Defense, scientific and commercial applications
- Endurance is typically 4-12 hours
- Cost: typically, $500K - $1.5M

Teledyne Gavia AUV

REMUS 100 AUV



Iver AUV



Four main types of AUVs based on the size

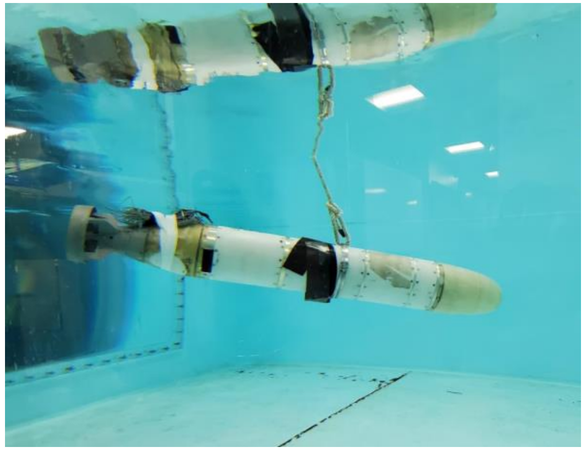
Micro AUVs

- Endurance is typically around 2-8 hours
- Cost: typically, $25K - $100K (except for EMATT)

Bluefin Sankshark AUVs

Riptide AUVs

EMATT *platform*

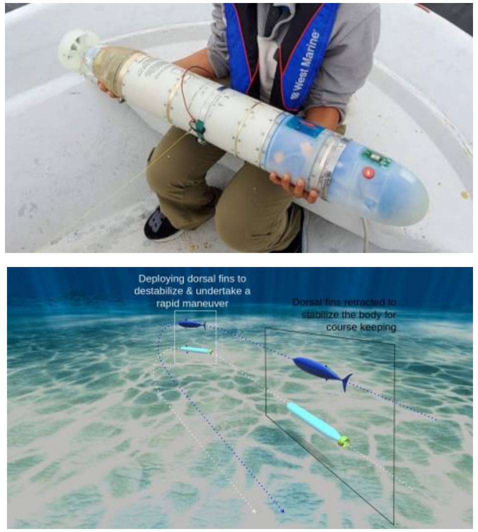


Seaber AUVs

AUVs that we developed

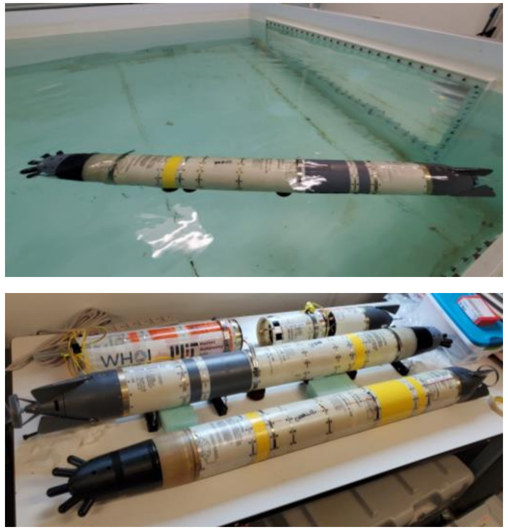
Silvertail (2019-2020)

MIT version of EMATT (2020)



Morpheus (2021-2022)

SeaBeaver I (2023)



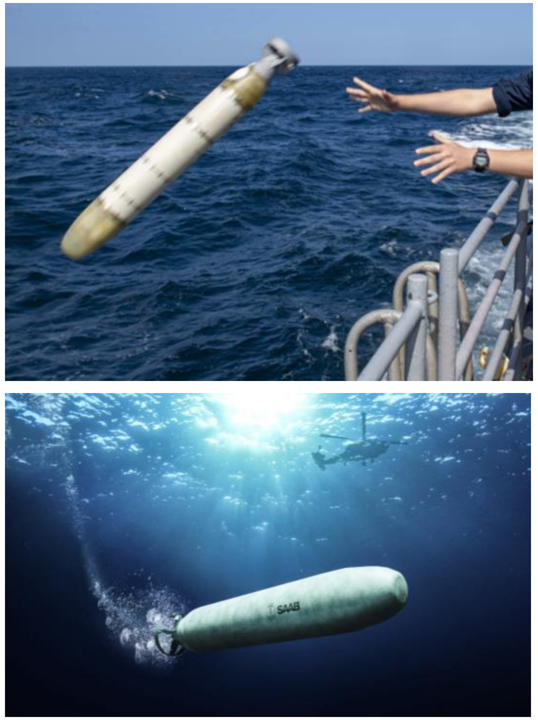
Sea Badger (2023)

SeaBeaver II (2024)

SeaBeaver III (2025-present)

Vehicles that we contributed with software

C-Ray Autonomous Amphibious Vehicle
https://www.pliantenergy.com/robotics

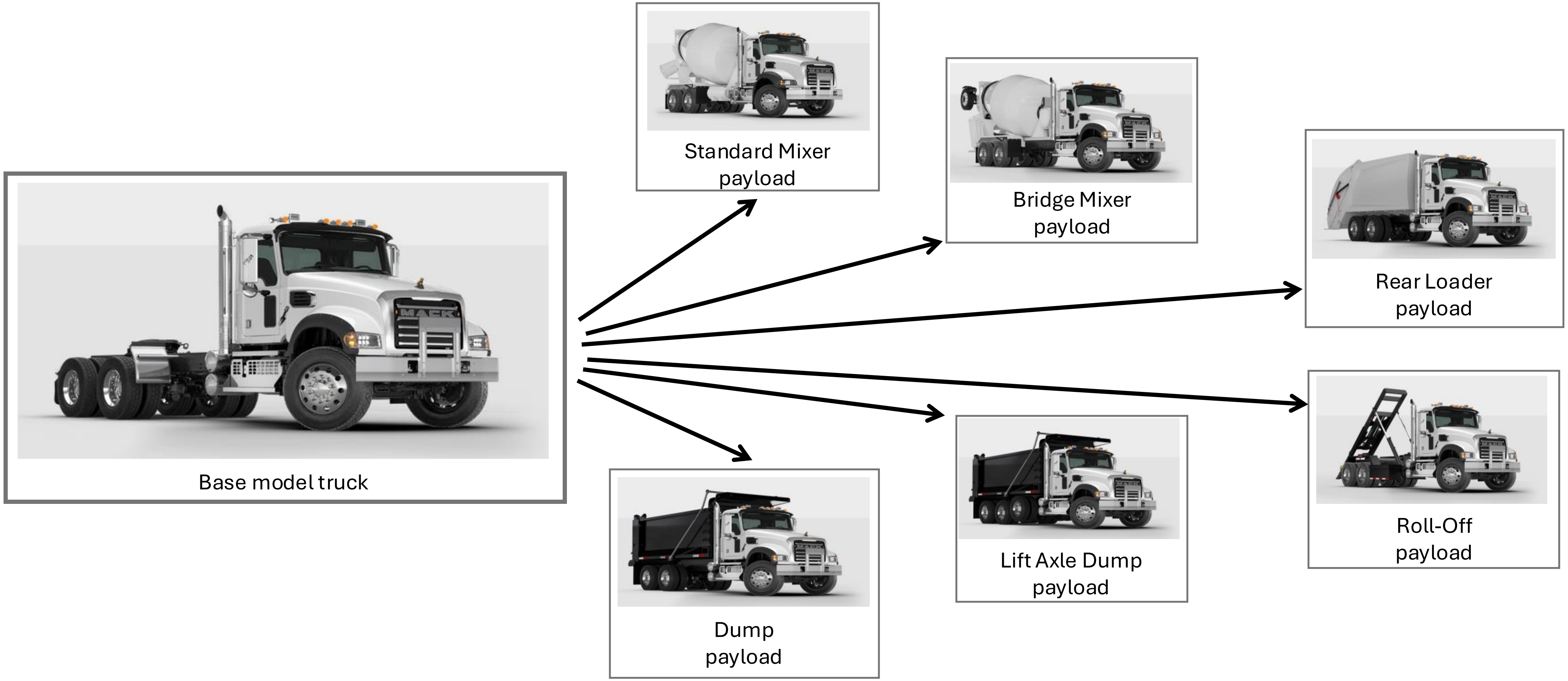


MK-39 EMATT
(Saab Inc. version)

DARPA Manta Ray

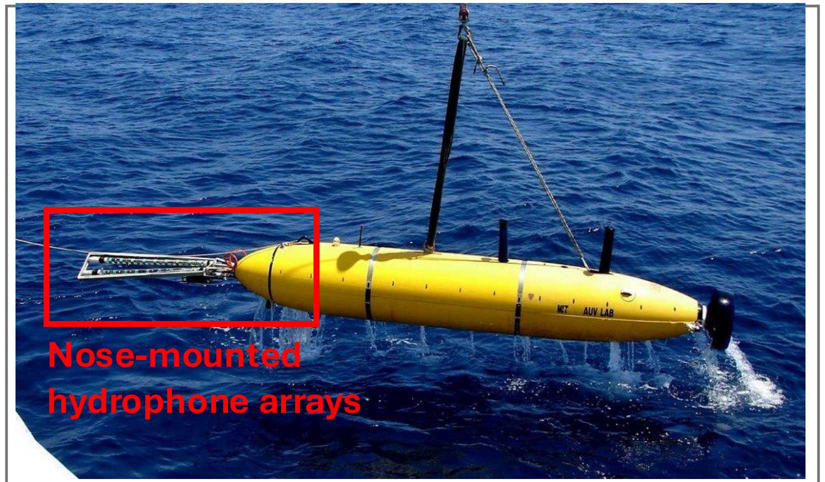
Triton DART

Base Mack Semi-truck + Payloads

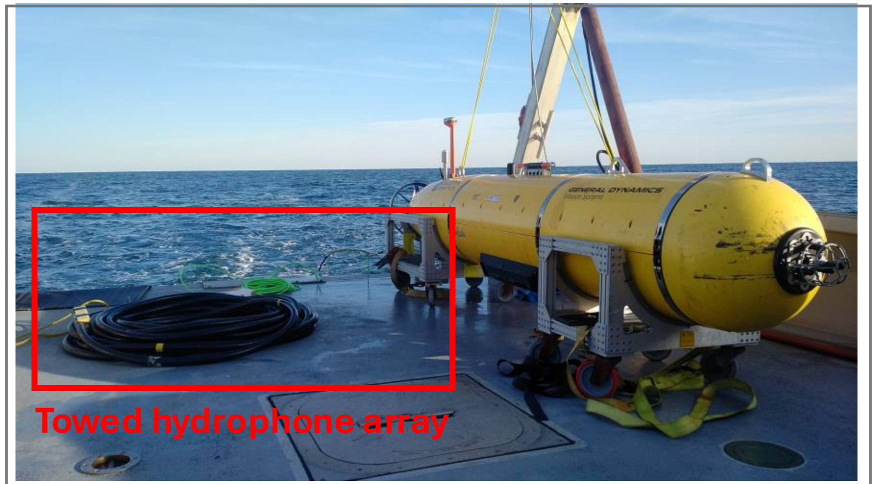


Base Bluefin 21-inch AUV + Payloads

Base vehicle



Base Bluefin 21 + nose-mounted acoustic payload

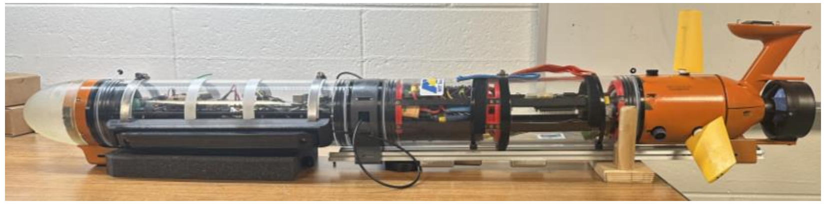


Base Bluefin 21 + towed acoustic payload

Base SeaBeaver AUV + Payloads

Base SeaBeaver vehicle

Base SeaBeaver + software defined acoustic modem payload



Base SeaBeaver + side scan sonar payload
By University of Delaware

Base SeaBeaver + DART gliding payload

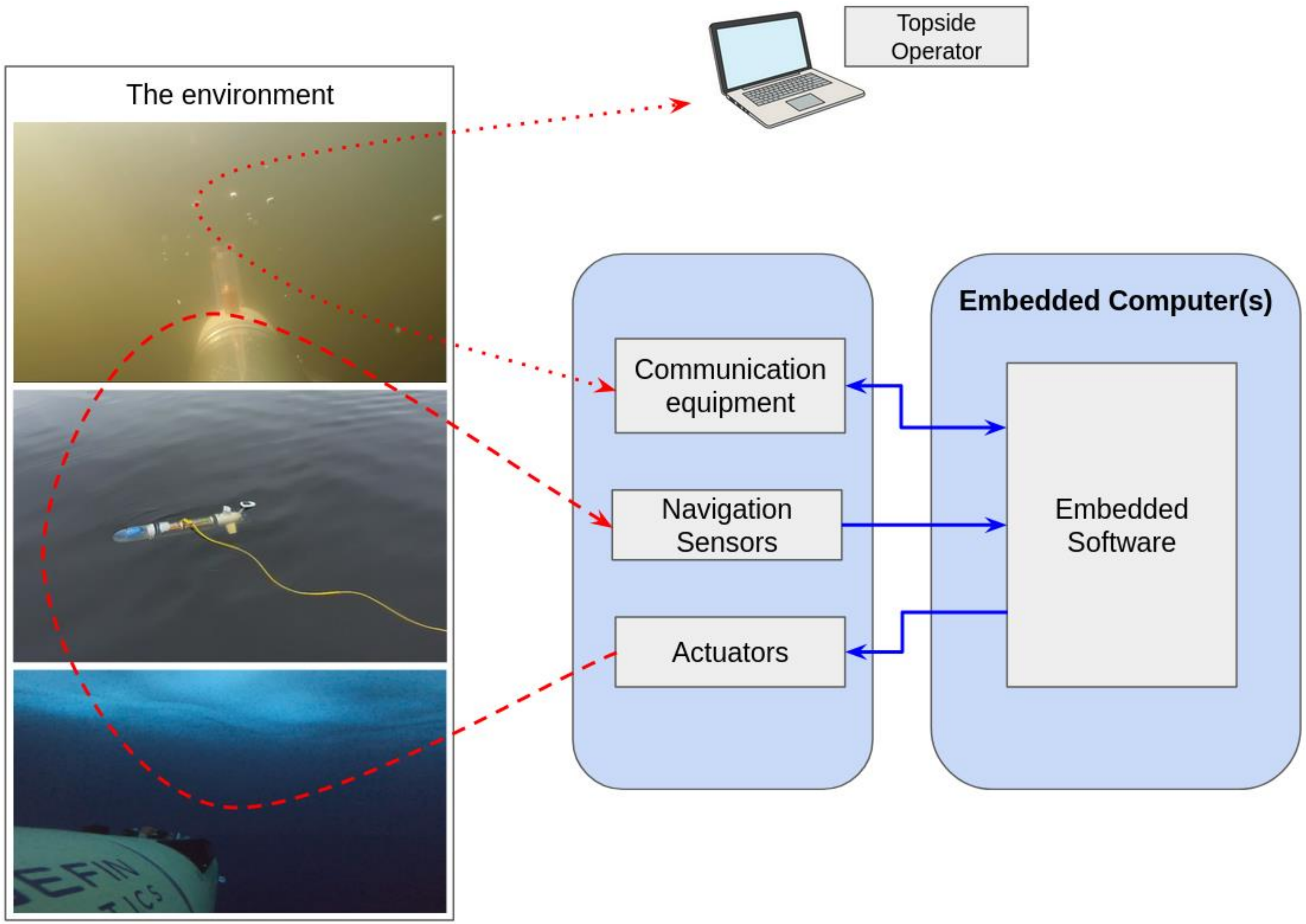
?

Base SeaBeaver + your payload

2.S01 Focuses on SeaBeaver Base Vehicle

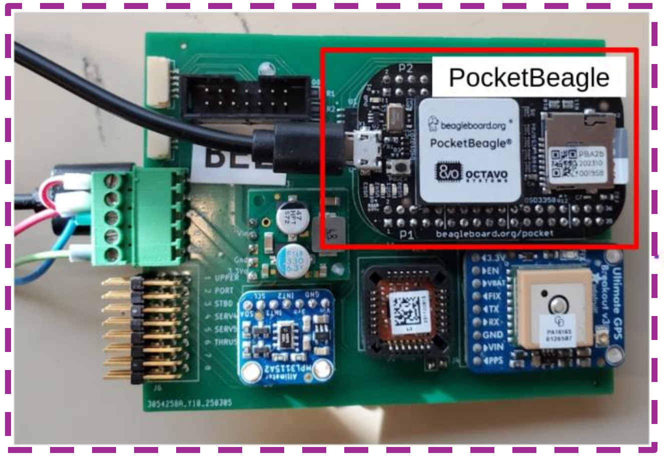
Essential components of a base vehicle:

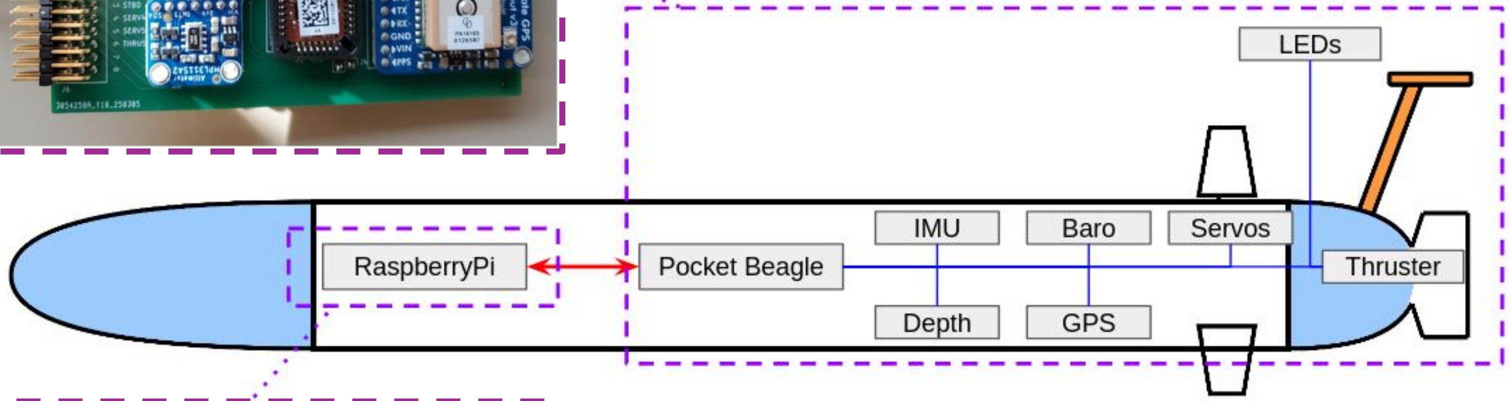
- Essential navigation sensors
- Embedded computer(s) and embedded software
- Actuators
- Communication equipment - SeaBeaver III base vehicle is limited to surface (i.e. above water) communication.

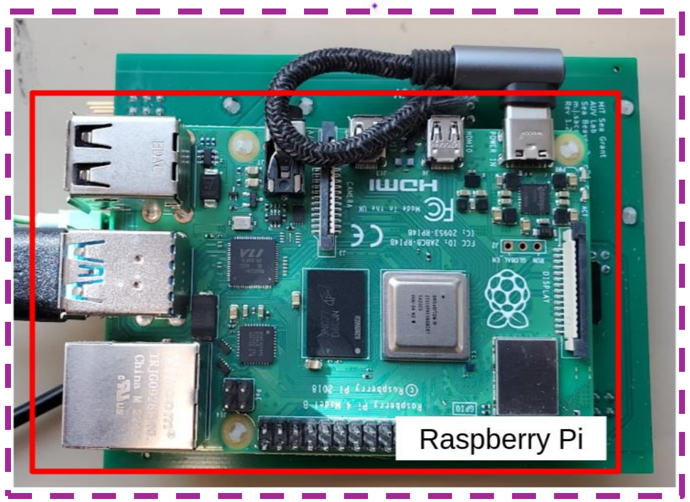


Embedded Single Board Computers

- SeaBeaver III has two embedded single board computers:
  - A BeagleBoard PocketBeagle
  - A Raspberry Pi 4
- The PocketBeagle and Raspberry Pi connects to each other via an Ethernet network.
- The PocketBeagle
  - Acts as a hub for base vehicle sensors and actuators.
  - Sensor and actuators are directly connected to PocketBeagle via interfaces such as Inter-Integrated Circuit (I2C), Universal Asynchronous Receiver/Transmitter (UART), General Purpose Input/Output (GPIO) and Programmable Real-time Unit (PRU) outputs.
- The Raspberry Pi
  - Dedicated for higher level software components (e.g. autonomy).
  - Handles wireless and wired communication with the operator via a local area network (the SeaBeaver II AUVs that we build during 2.S01 are limited to WiFi-based above water communication).

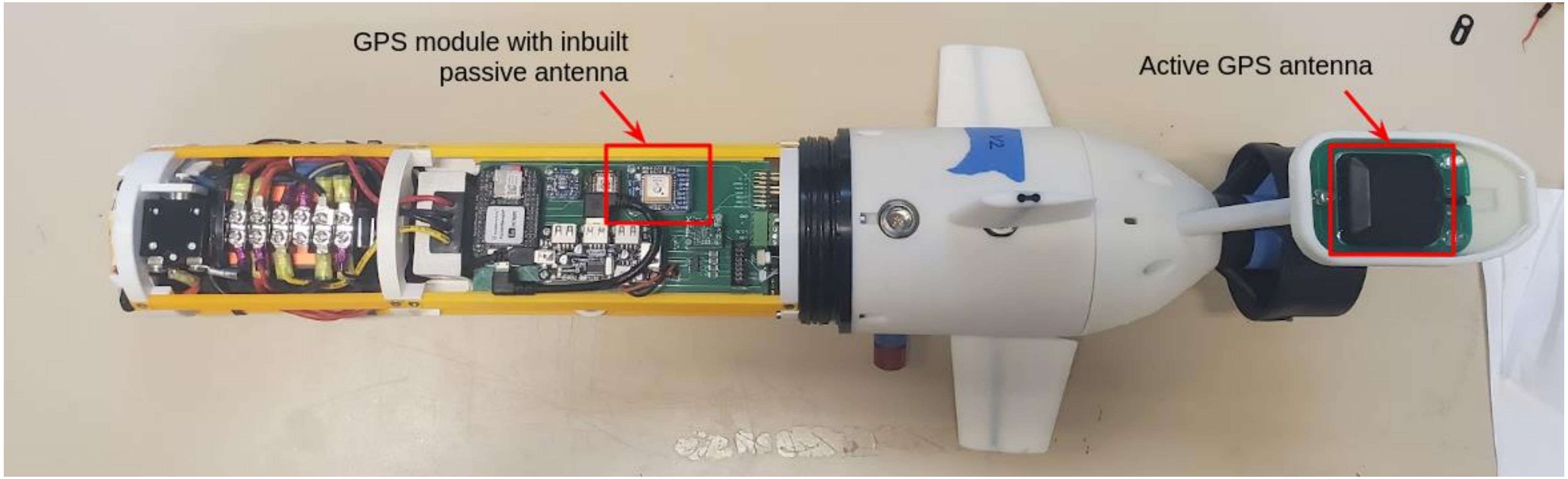






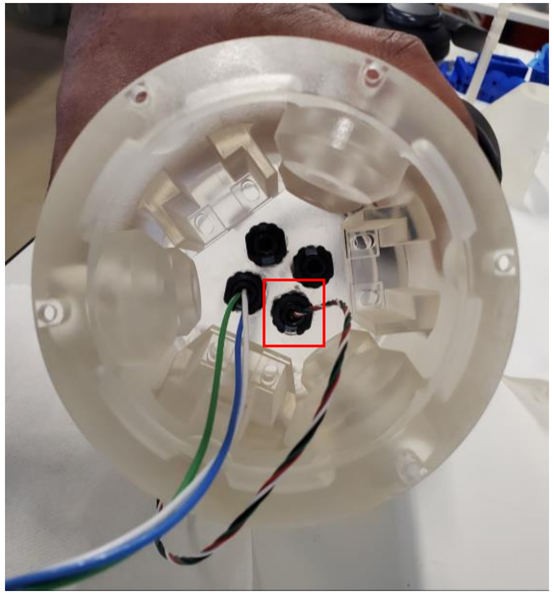
Global Positioning System (GPS)

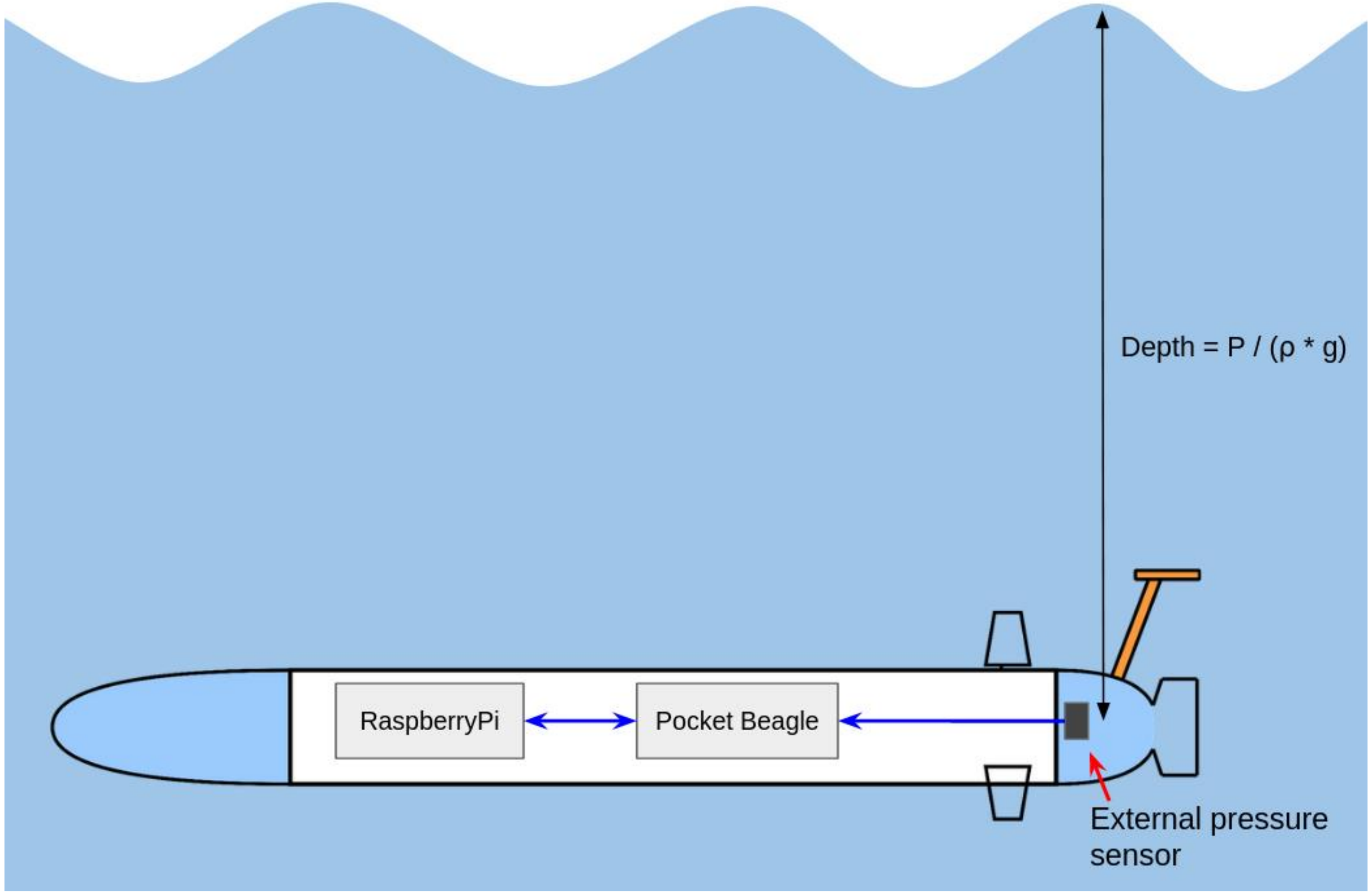
- Provides the absolute position (navigation solution) of the vehicle while at surface. Some parameters provided by GPS include:
  - UTC time
  - Latitude
  - Longitude
  - Altitude
  - Speed over ground
  - Course over ground
  - Number of satellites
  - Fix type
  - Pulse per second (PPS)
- Does not work underwater due to high attenuation of electromagnetic waves in the water



Depth Sensor

- Measures the external water pressure and water temperature
- The software converts the external water pressure to the vehicle depth





Attitude and Heading Reference System (AHRS)

- Provides the orientation and heading angle of the vehicle; i.e.
  - Roll angle
  - Pitch angle
  - Heading angle

Inertial Navigation System (INS)

Combines (fuses) AHRS data with external sensor data to compute the position of the vehicle

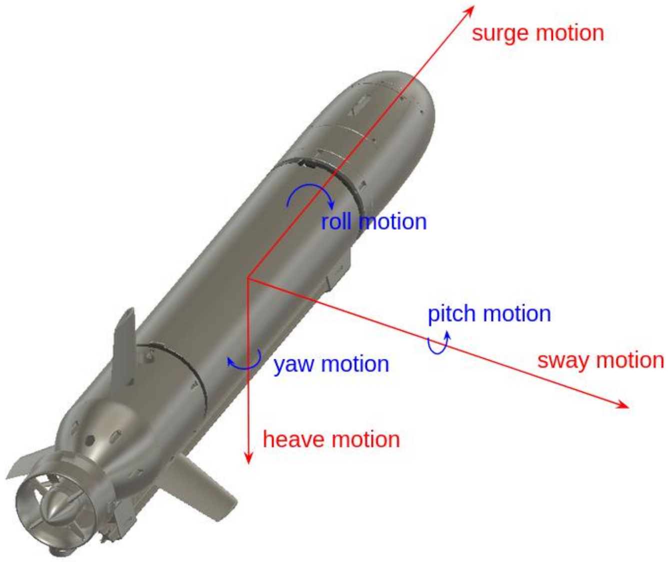
Attitude and heading reference system (AHRS)

Combines (fuses) IMU measurements to compute roll, pitch and heading angles

Inertial Measurement Unit (IMU)

- **Three accelerometers**: Measures accelerations along x-y-z axes
- **Three gyroscopes**: Measures rotational rates about x-y-z axes
- **Three magnetometers**: measures magnetic field along x-z-z axes

External sensor data



Attitude and Heading Reference System (AHRS)

- There are two types of Inertial Measurement Units (IMU):
  - Fiber Optic Gyro (FOG)
  - Micro-Electro-Mechanical systems (MEMS)
- Our AHRS has a MEMS IMU (Xsens MTi-3)
- FOG IMUs do not use magnetometers. They use fiber optic gyroscopes to measure the orientation. Therefore, magnetic interferences will not degrade the measurements

~ $5

~ $350

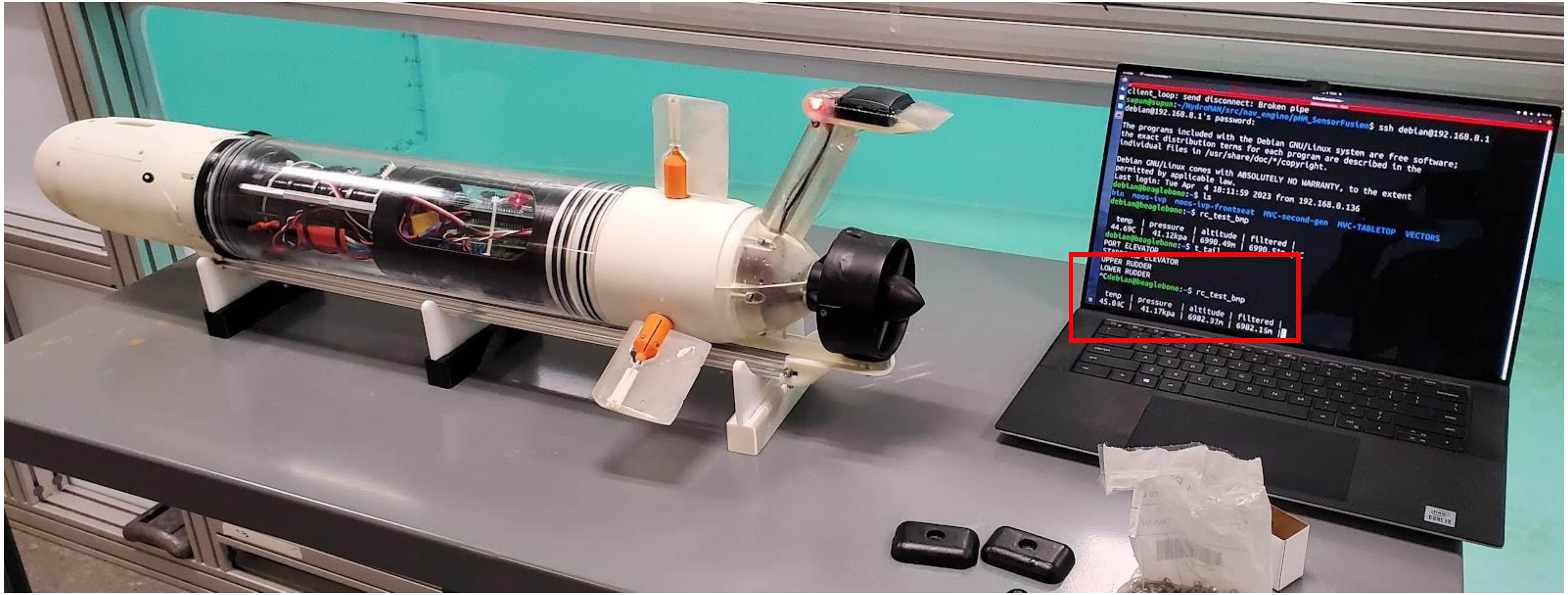
~ $1000

>$100K

>$1M

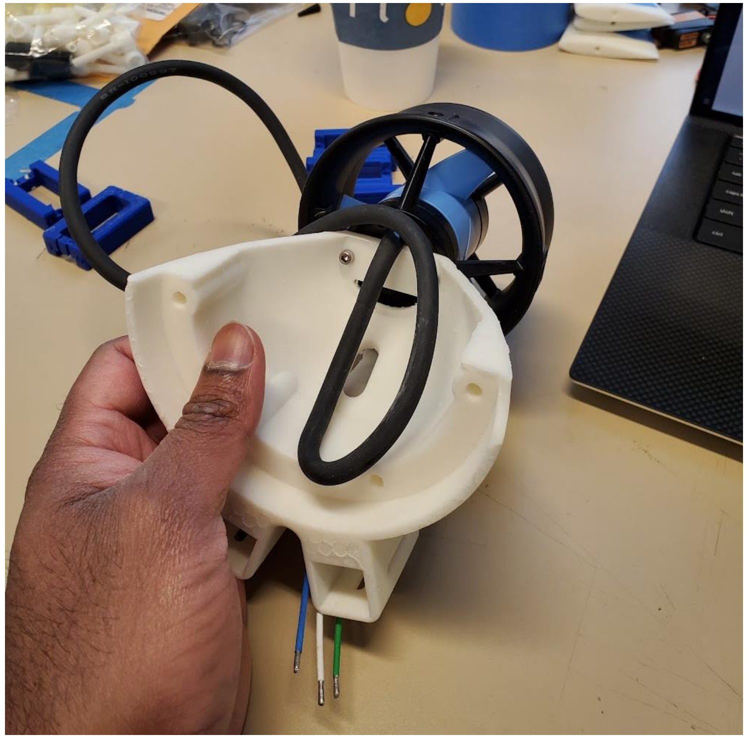
Internal Barometer

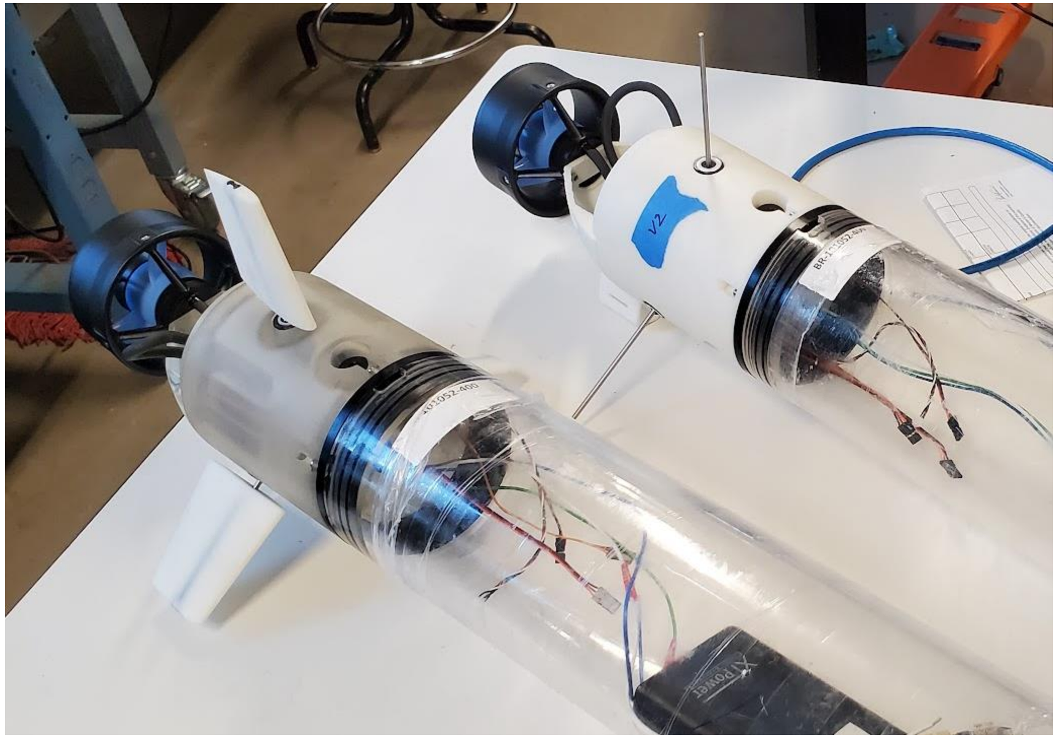
- Measures the internal pressure of the pressure hull
  - After assembling the AUV, the air will be sucked out to lower the pressure inside the hull
  - The internal pressure is monitored from the barometer
  - If there are no leaks, the lowered pressure will hold
  - If it raises beyond an acceptable rate, our pressure hull has a leak!



Main Propulsion Thruster

- Forward propulsion thrust force is provided by the main thruster.
- SeaBeaver III AUVs use an off-the-shelf, Blue Robotics T200 thruster.
- T200 consists of a fully-flooded brushless DC outrunner motor with encapsulated motor windings and stator as well as coated magnets and rotor.
- The thruster does not require its motor to be housed inside a pressure hull.
- The motor speed is controlled by a pulse-width modulation (PWM) signal provided by the PocketBeagle

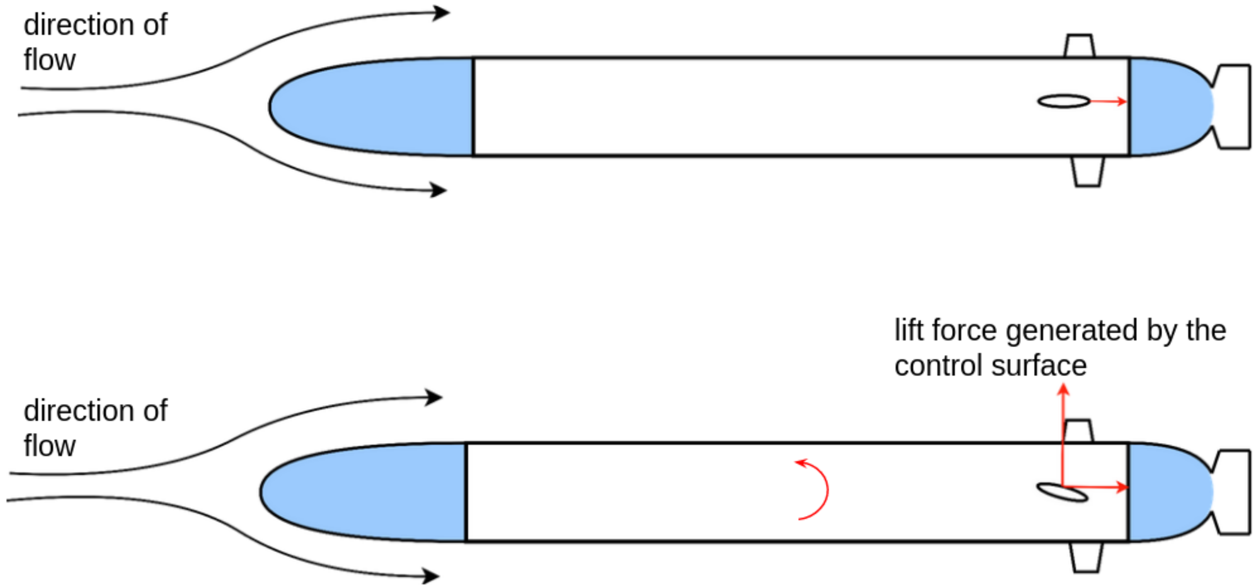




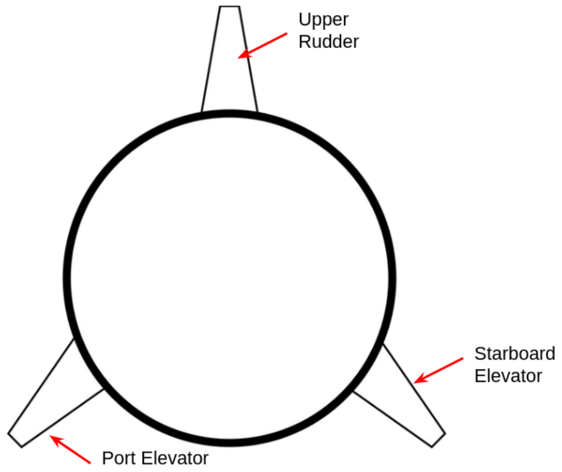
Control Surfaces

- When there is an angle of attack to the flow direction, the control surfaces generate a lift force
- This lift force will turn the vehicle
- SeaBeaver III has three control surfaces with a 120-degree spacing

Top-View

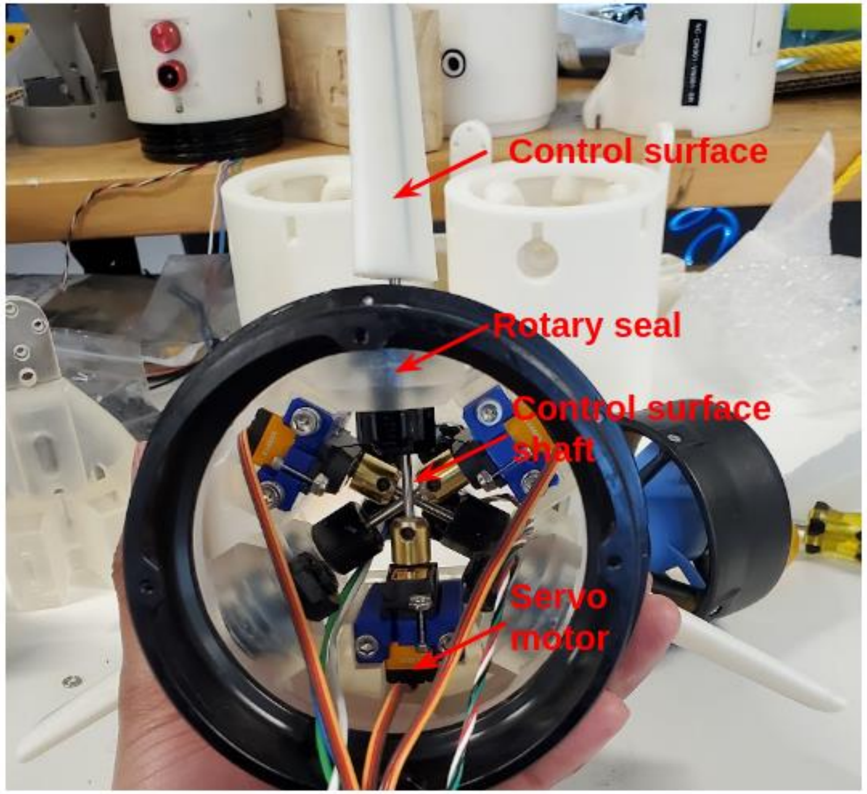


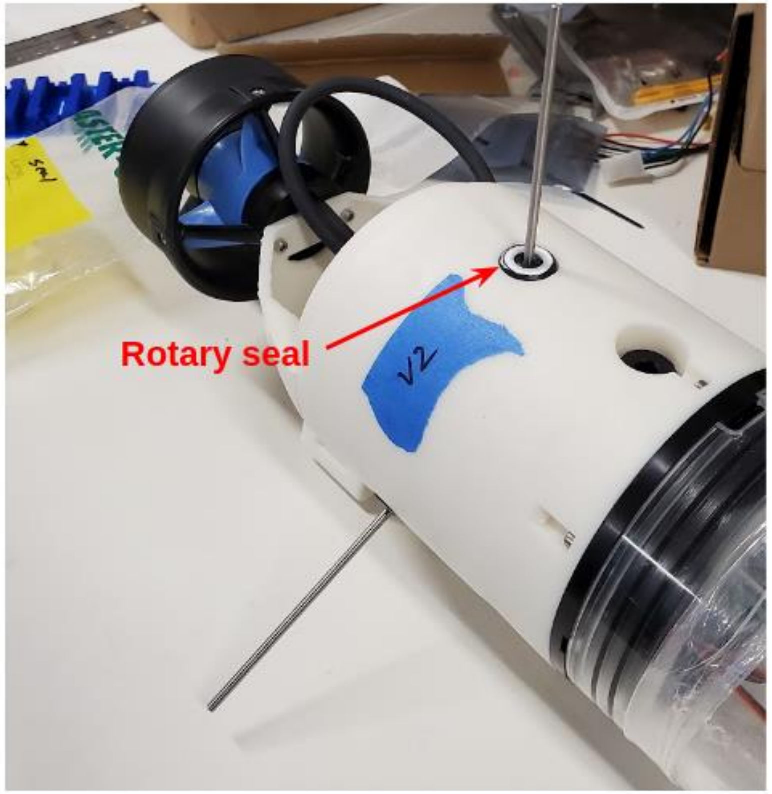
Rear-View



Control Surfaces

- Each control surface is driven by a servo motor, housed inside the tailcone pressure hull.
- The servo motors are driven by PWM signals provided by the PocketBeagle
- The shaft of the control surface is sealed by a rotary seal, preventing water from leaking inside





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