Marine robotics
Technology Overview and History

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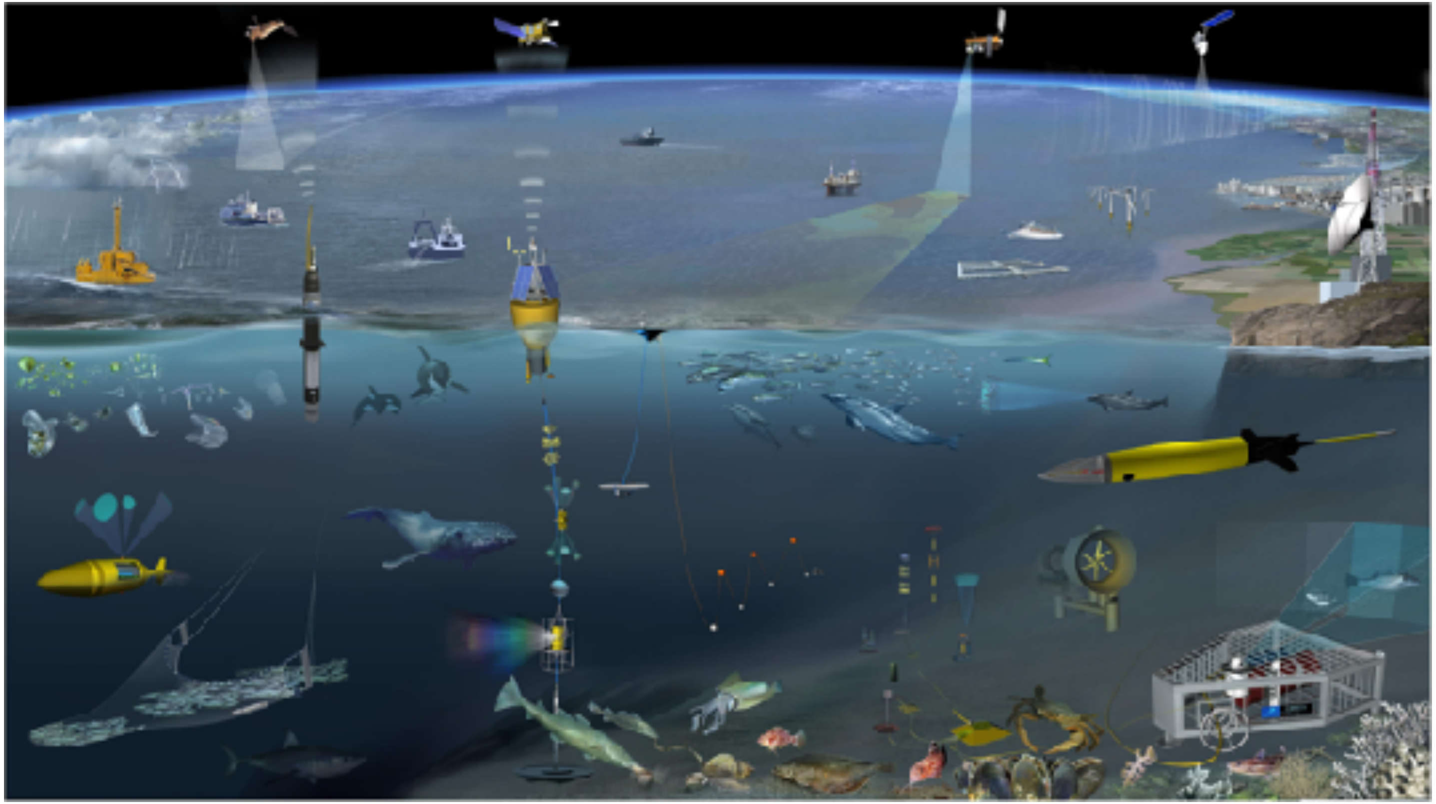
Future vision for autonomous ocean observation (2020)



frontiers in Marine Science | Ocean Observation

REVIEW ARTICLE

Front. Mar. Sci., 08 September 2020 | https://doi.org/10.3389/fmars.2020.00697

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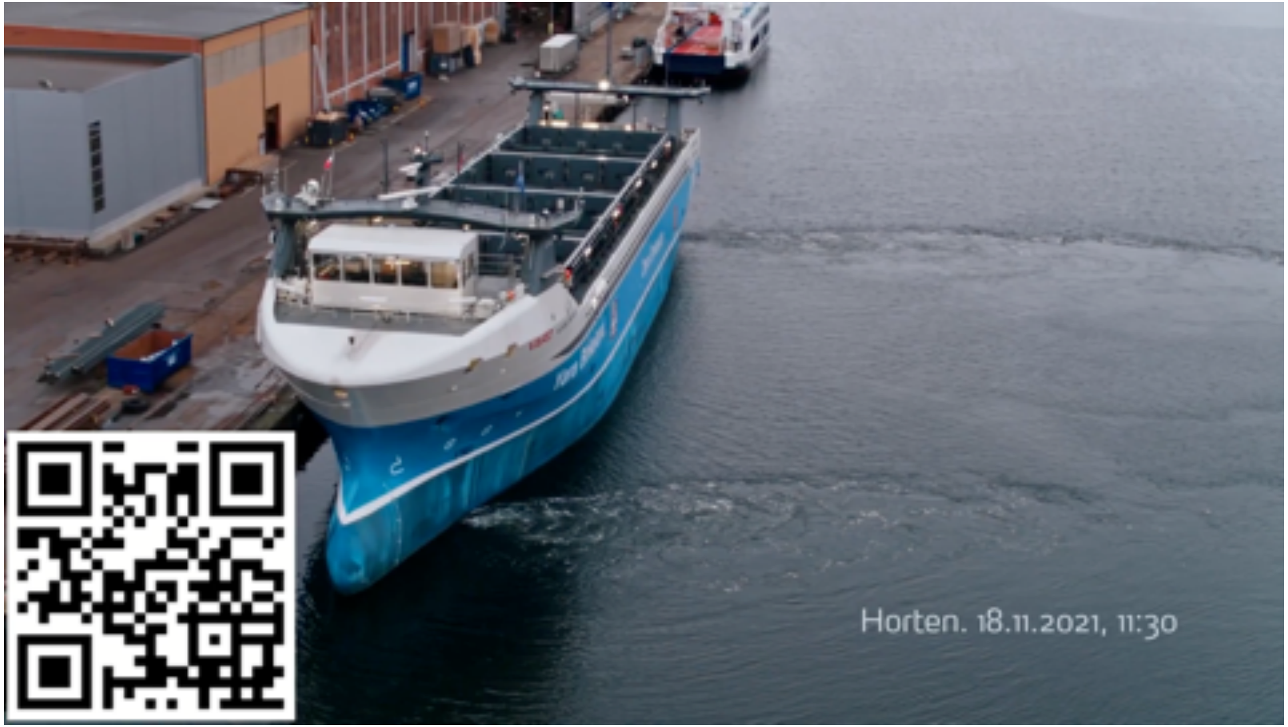
Autonomous ship: YARA Birkeland

- The world’s first electric, zero emission and autonomous container vessel (2021)

https://www.youtube.com/watch?v=TYnOyRvfM_U



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Ocean Infinity: Armada fleet

https://www.youtube.com/watch?v=XvRRJyNqlfE&ab_channel=MaritimeDigital

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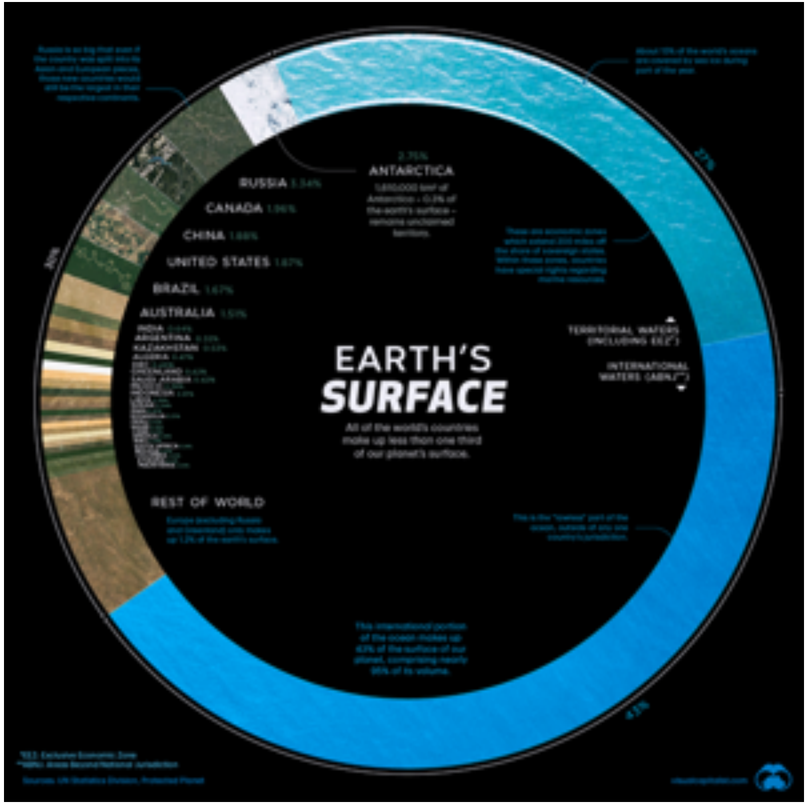
Why & How did we arrive to this vision?



By Unknown author - From [1] → http://www.photolib.noaa.gov/bigs/nur09514.jpgold src: en:Image:Submerge2.JPGText taken from the English language edition of the Wikipedia History of submarines, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3143350

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Humanity in the abyss

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Drebbel (1620-1624)

- Around 1620 Cornelius Drebbel developed a subsea vessel to dive 15 feet beneath the River Thames during a demonstration witnessed by King James. None of Drebbel's plans or engineering drawings has survived to today, so historians can only guess about the principle of operation of his diving boat.

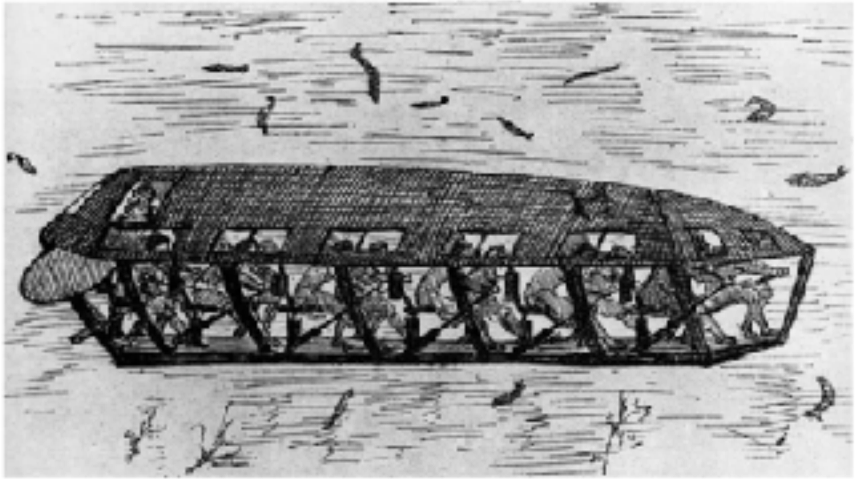
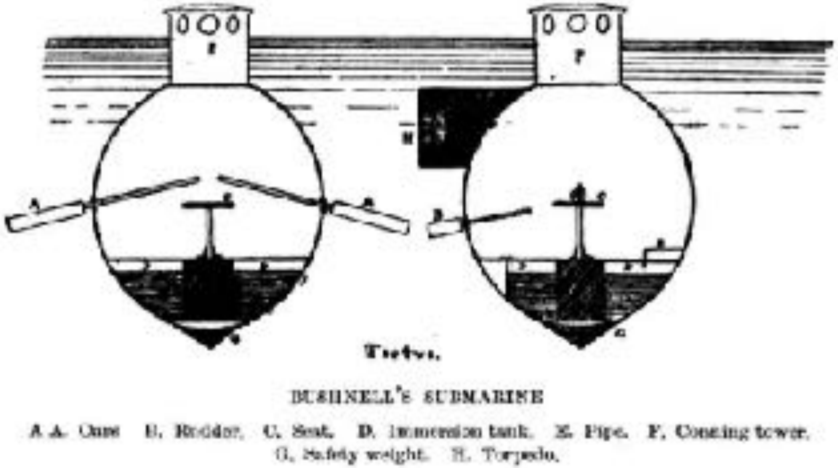


Illustration of a Drebbel. (Credit: ullstein bild/Getty Images)

Turtle (1775)

The first American submarine

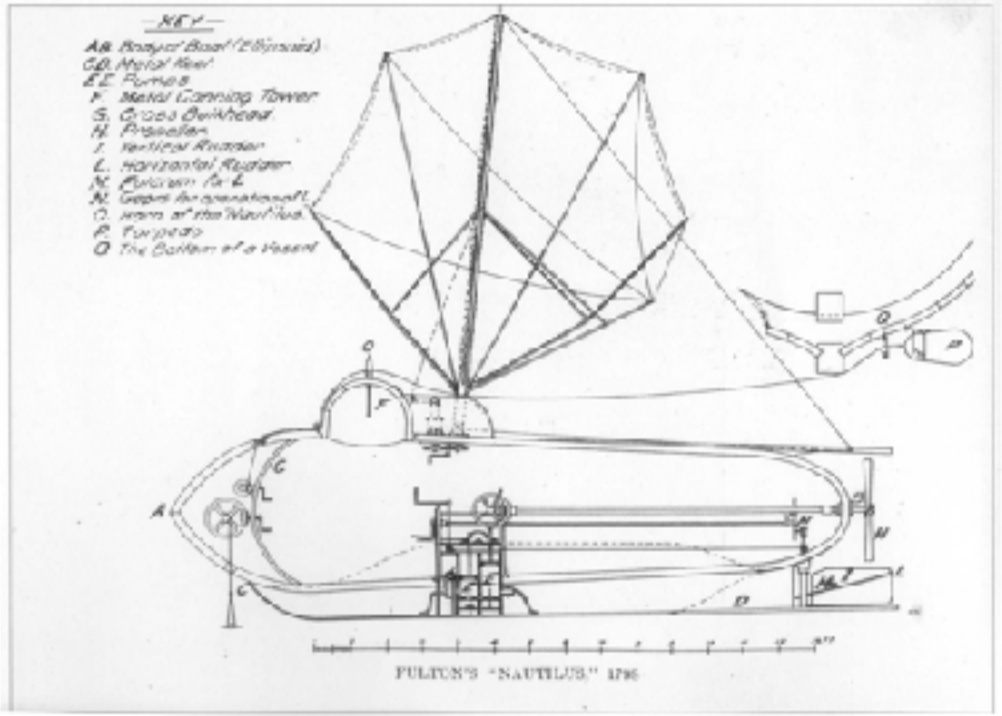
- built at Saybrook, Connecticut in 1775 by David Bushnell and his brother, Ezra
- one person could descend by operating a valve to admit water into the ballast tank and ascend with the use of pumps to eject the water
- the air supply lasted only 30 minutes
- in New York Harbor in 1776, there was the first naval battle in history involving a submarine: Turtle tried to affix explosives to the undersides of British warships, but all attempts failed



By Herbert C. Fyfe, John Leyland, Edward James Reed. Edition: 2 Published by E.G. Richards, 1907, pg. 174 [1]Originally uploaded to EN Wikipedia as en:File:Turtle submarine.jpg by en:User:Swampyank 20 February 2009, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6045528

Nautilus (1800)

- designed and built by American Robert Fulton, living in France
- copper sheets over iron ribs
- 6.48m (long) x 1.93m (beam)
- hand-cranked screw propeller



American civil war

Alligator

- the first operational submarine with the capability for a diver to leave and return to the vessel while both remained submerged

multi-agent marsupial platforms

CSS Hunley

- the first combat submarine to sink a warship (USS Housatonic), February 17, 1864
- sanked
  - August 29, 1863: 5 crew members died
  - October 15, 1863: 8 crew members, including H.L. Hunley, died
  - after attack was lost: 8 crew members died

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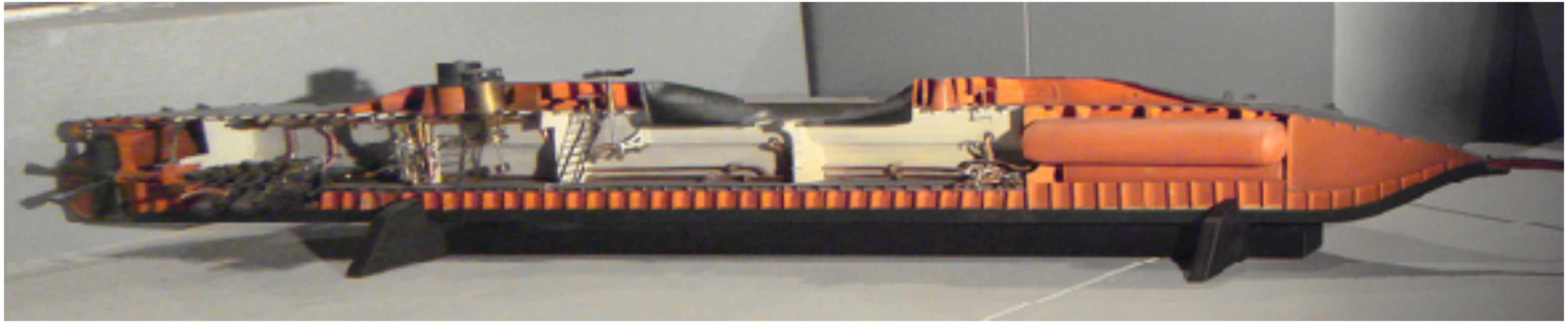
Mechanical powe submarines

- **Plongeur (1863)**
  - equipped with a reciprocating engine using compressed air from 23 tanks at 180 psi



- **Ictineo II (1865)**
  - Narcis Monturiol invented an air independent engine, based on a chemical reaction fueled by peroxide, that provided its own oxygen for combustion

Electrical, diesel-electrical & nuclear submarines

Drzewiecki (1884)

- the first battery powered submarine: 4 knots speed in Neva River

Diesel-electric submarines

- batteries used for running underwater and gasoline or diesel engines were used on the surface to recharge the batteries

diesel engines needed air → large and heavy batteries → snorkel

submarines needed to surface frequently → **Nuclear submarines**

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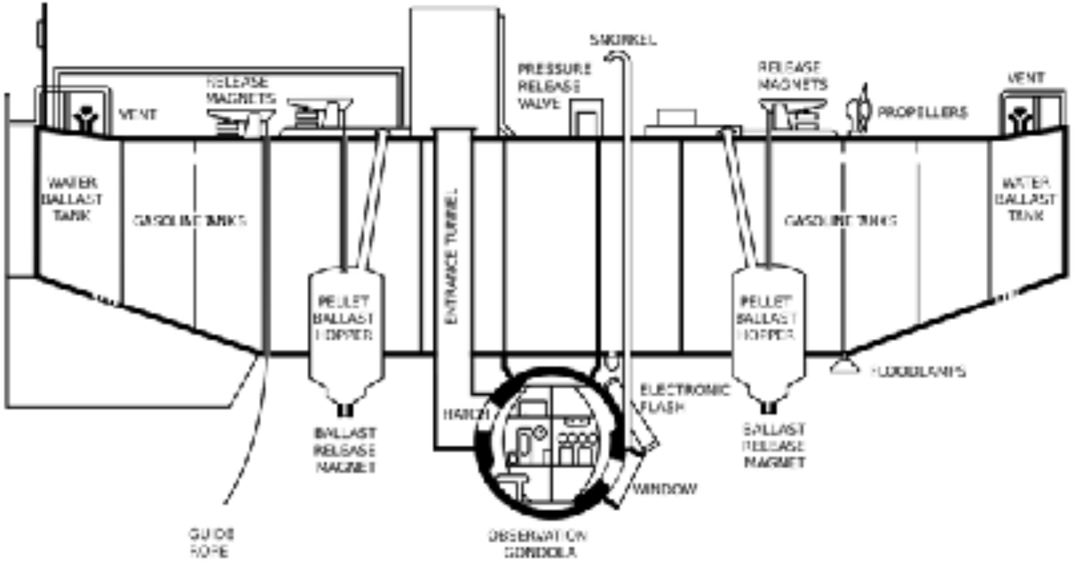
Batyscaphe

Trieste (1960)

- Dan Walsh & Frank Piccard, Marianna Trench (10911m)

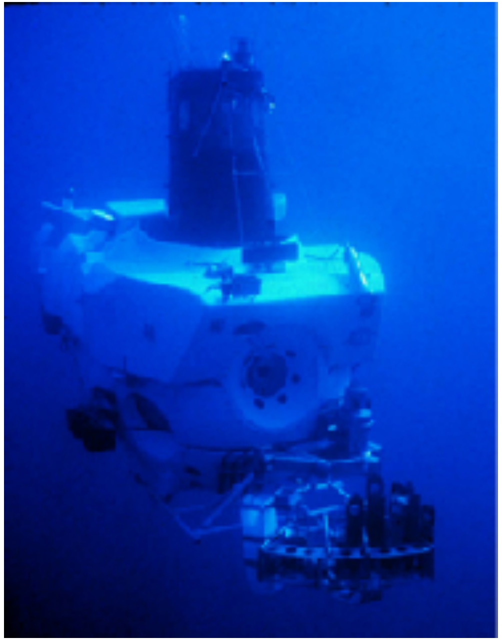


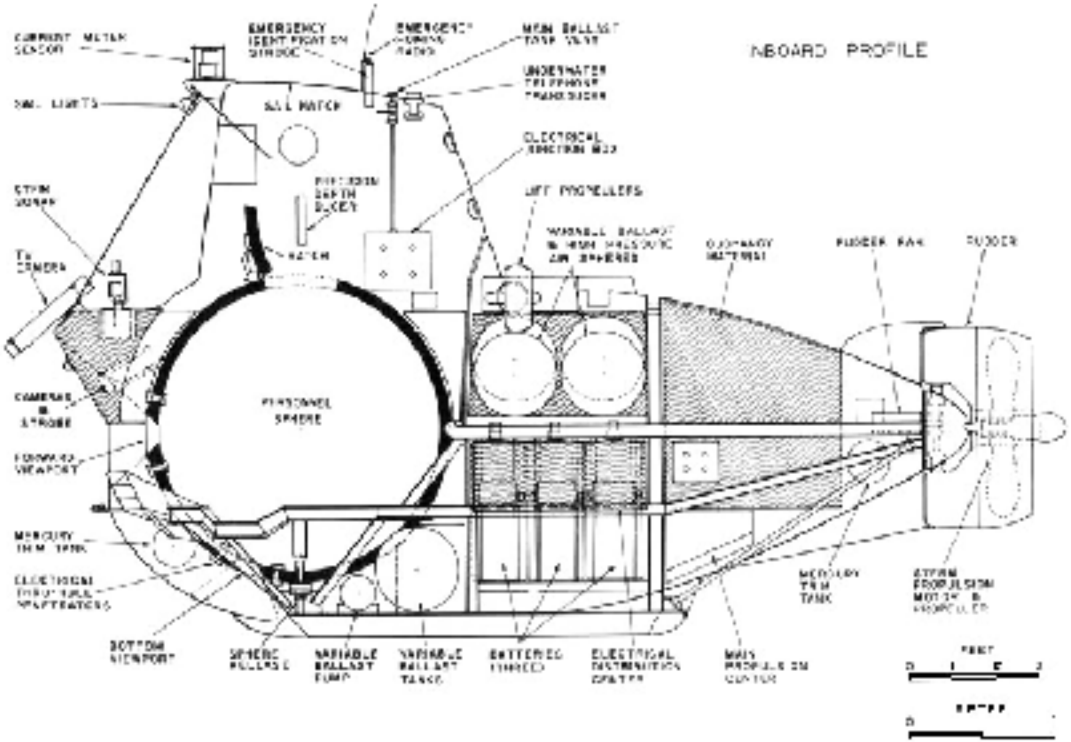
GENERAL ARRANGEMENT DRAWING OF TRIESTE, CA. 1959

Deep Submergence Vehicle

Alvin (1964)

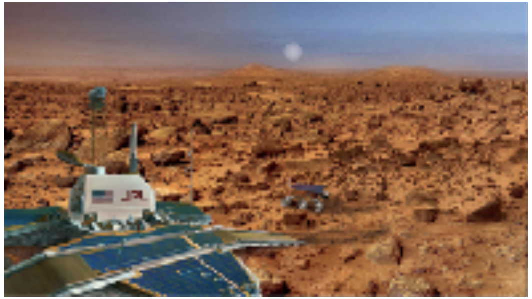
- 2 scientists and 1 pilot





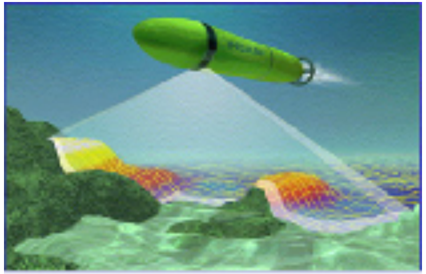
Exploration of the wreckage of RMS Titanic (1986), accompanied by Jason Jr

from mankind to robots…



Robot as an **extension** of the human being

- the robot can see and act for the human being
  - tele-operation & manipulation
  - live video



Robot as a **substitute** of the human being

- the robot can execute tasks instead of the human being
  - autonomous missions: data collection & survey

Robot as a **companion** of the human being

- the robot can support the human being in executing tasks
  - diver robot cooperative missions
  - diver health monitoring
  - interactive data collection

Physics-based technology challenge: pressure

- 1 atmosphere each 10 m depth
  - solution(s)
    - watertight containers
    - oil bath compensation

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Physics-based technology challenge: electromagnetic waves propagation

- strong attenuation makes e.m. waves useless for communication and localisation
  - solution(s)
    - acoustic waves
      - low channel capacity
      - slow rate position update
    - very short range e.m./optical comms
    - tether (for comms)

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Marine robots: what shape?

Why not fish-shaped robots?

- fin-based automatic propulsion is not able to guarantee the required performance in terms of reliability and precision **yet**
- bio-inspired snake-like robot is flexible and can manoeuvre in confined spaces, such as subsea installations on the seabed

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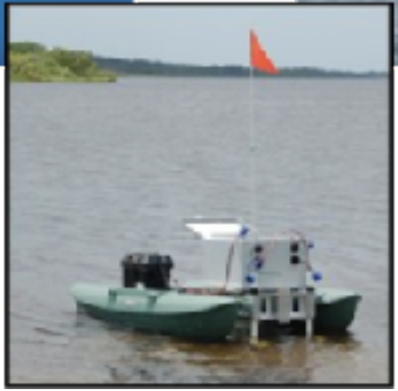
Marine robots: what shape?

The shape of marine robots id determined by their application

- open-frame
- torpedo
- glider
- vessel



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Marine robots: nomenclature

ROV: Remotely Operated Vehicle

- tele-operated unmanned underwater vehicle connected to the surface station through a cable for the transmission of data/images, and electric power

AUV: Autonomous Underwater Vehicle

- autonomous unmanned underwater vehicle (power and intelligence are on board); acoustic connection with the surface station

Glider

- AUV that uses his weight and wings to convert vertical motion to horizontal one

ASV: Autonomous Surface Vessel

- autonomous surface vessel (power and intelligence are on board); radio/wi-fi connection with the pilot station, remote supervision and/or tele-operation

ROV concept

Tether

- communication link
- power supply
- safety

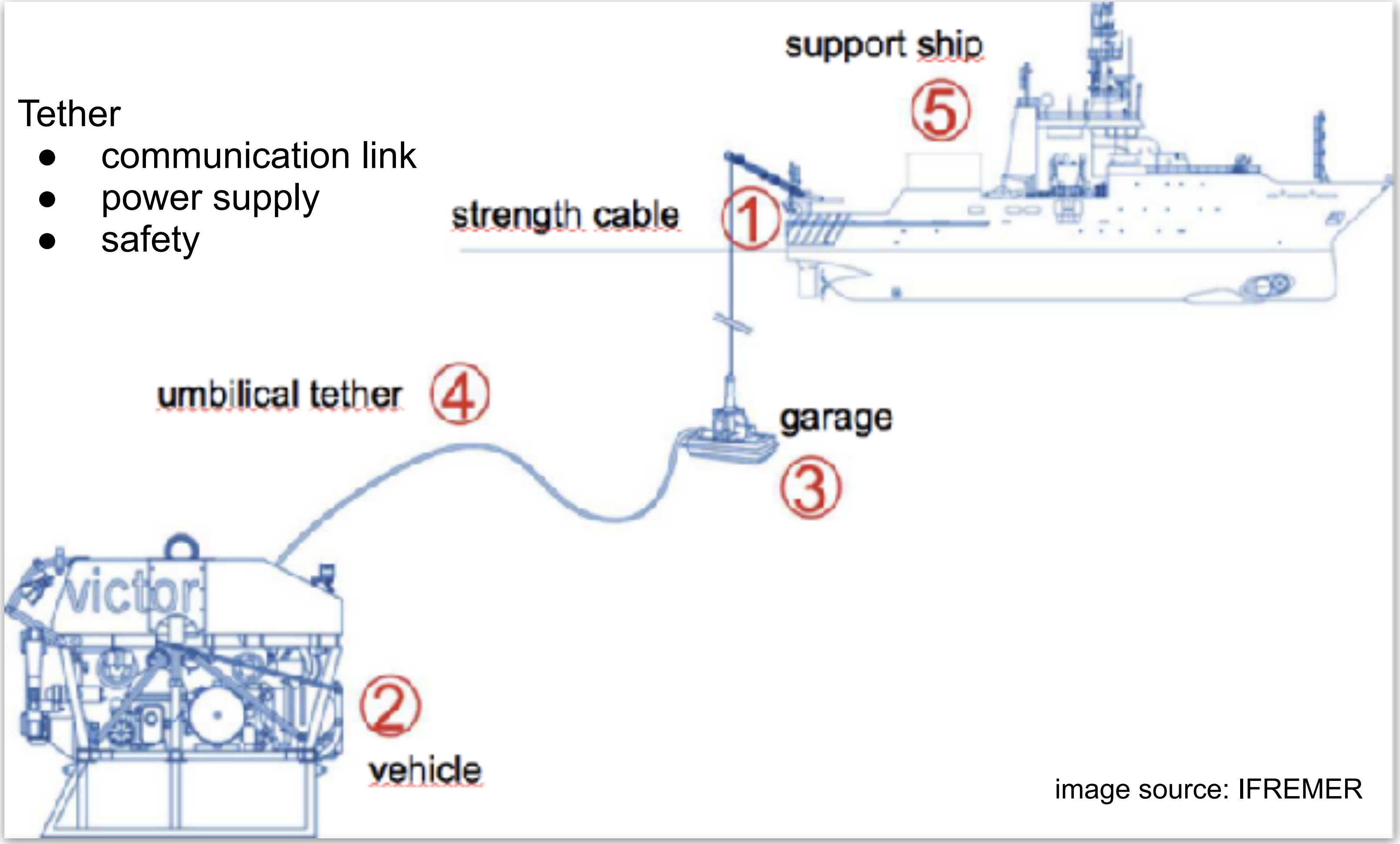

image source: IFREMER

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Working class ROVs

Saipem Innovator 2.0

- 210 Hp electric
- 1100 Kg in each direction
- max speed 3.5 knots
- pull 600 Kg
- 6600V power supply up to 7000m tether

Saipem's new Innovator 2.0 ROV (Photo: Saipem)

Oceaneering Millennium Plus

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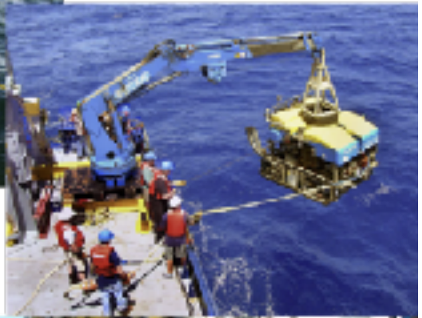
Research ROV: WHOI Jason

Applications

- wreck exploration
- archaeology
- geology



One main canister containing electronics → scientific instrumentation had to be integrated with the vehicle

Fyber-optic link →
→ control & data acquisition electronics was brought on surface

- **open source sw: GNU/Linux**

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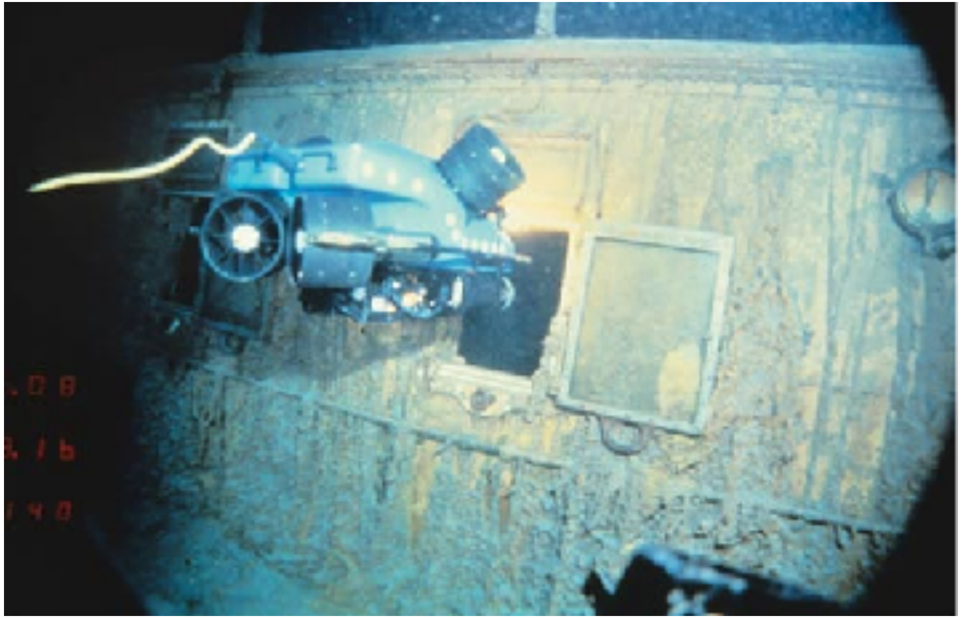
WHOI Jason Jr

operated by Alvin to explore Titanic wreck

- high quality video images through fyber optic link



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Networked research ROV with interchangeable toolsled

IFREMER Victor

- marine science down to 6000 m depth (Mediterranean Sea)

CNR Romeo

- down to 500 m depth, high manoeuvrability

- **multiple computers onboard**
- **onboard & surface network**
- **interchangeable toolsled to make the integration of scientific instrumentation standard.**
    - The ROV is seen as a carrier providing:
        - power supply
        - serial link
        - Ethernet link

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ARAMIS project

Advanced ROV package for Automatic Mobile Inspection of Sediments

ARAMIS

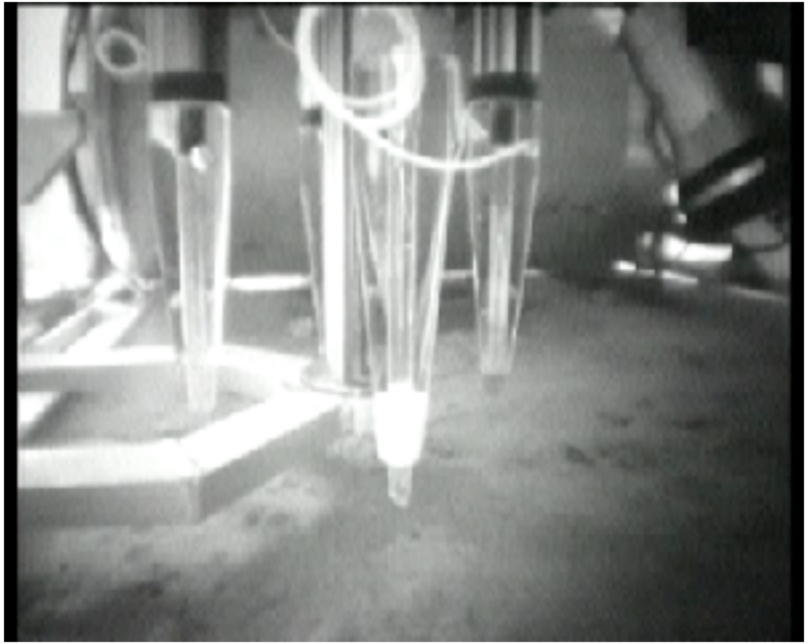
Grant agreement ID: MAS3970083

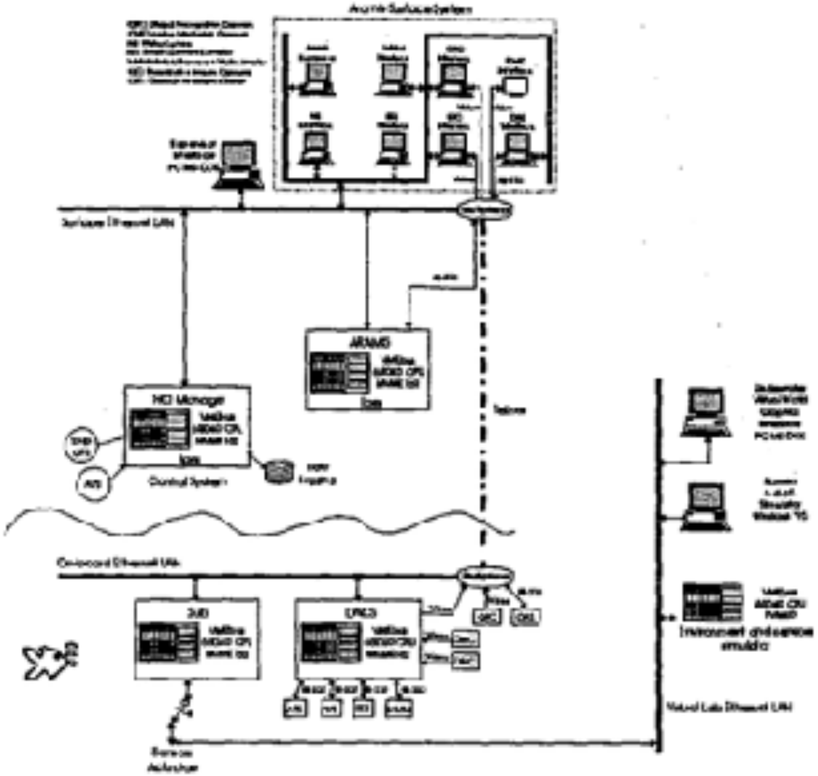
Start date: 1 December 1997

End date: 30 November 2000

Funded under

FP4-MAST 3





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micro-ROV

Videoray

- relatively low cost and very easy deployment and recovery
    - TV camera
    - 1 vertical and 2 horizontal thrusters

UARS Unmanned Arctic Research Submersible system

- Goal: exploring the keel of the Fletcher's Ice Island
  - University of Washington's Applied Physics Laboratory (Spring 1972)
    - AUV deployed from a hole in the packed ice
    - how to recover the AUV after a 17 miles traverse?
      - acoustic transmitter in the water through the hole
      - two directional acoustic receivers on the AUV bow
      - one omnidirectional acoustic receiver on the AUV stern
      - recovery through a net

Figure 2 Unmanned Arctic Research Submersible System (UARS) - University of Washington, Seattle

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Research AUV: IFREMER Epaulard

- manufactured in 1980, was the first unmanned underwater vehicle of the world diving to 6000m with an autonomy of several hour
- designed for photographic and bathymetric survey of seabed
- auto-altitude, remote-control by acoustic commands and tracked by an ultrashort baseline system

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Research AUV: MIT Odyssey class AUVs

created in the mid Nineties,
upgraded in 2000 and 2004

- length: 2.2 m
- weight in air: 300 Kg

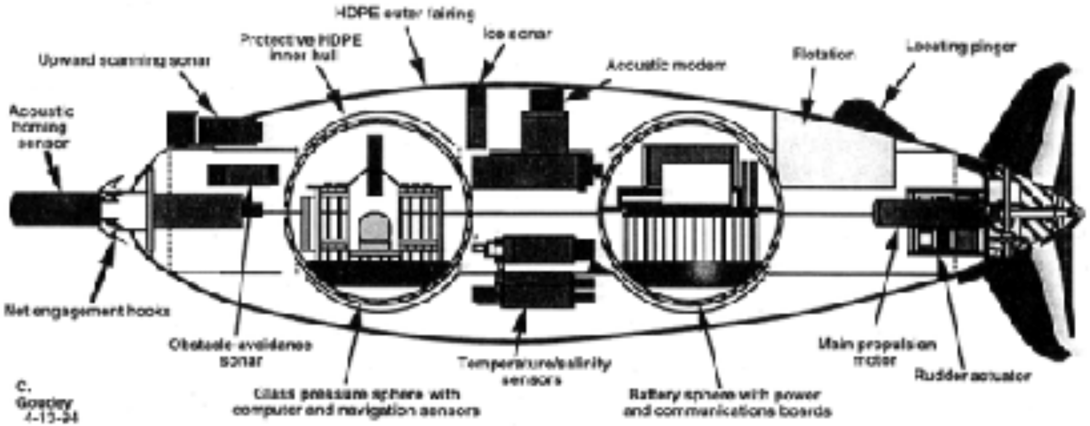
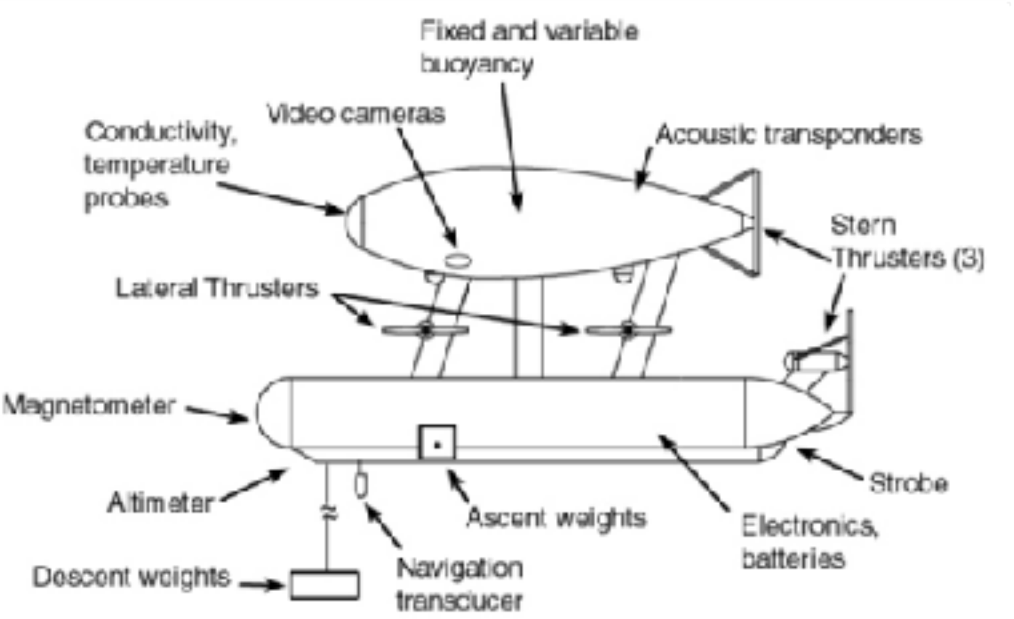


Figure 1: Arctic configuration of Odyssey II. Mission sensors are the scanning sonar at the nose, and the temperature and conductivity sensors located in the center of the vehicle.

Research AUV: WHOI ABE Autonomous Benthic Explorer

- max operating depth: 5000 m
- lost at sea on March 5, 2010 off Southern Chile, when about 16 years old



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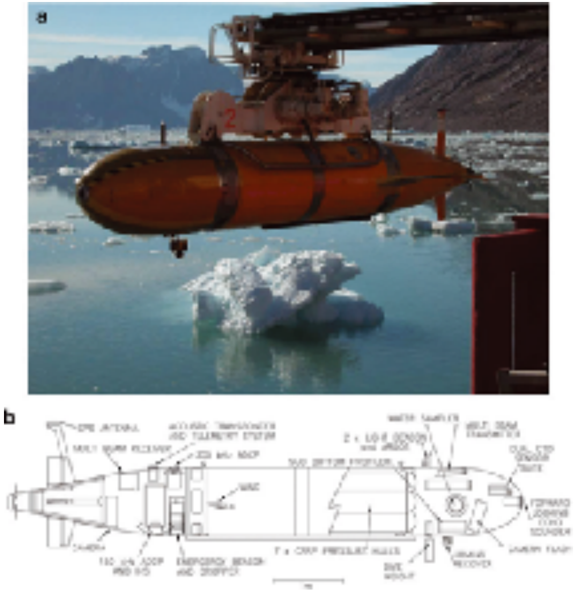
Other top AUV & ROV losses

JAMSTEK Kaiko ROV
- 2003, Shikoku island
    - breaking of the secondary cable

SOC/NOC Autosub
- 2005, February, Antarctica



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Commercial AUVs: Remus

Remote Environmental Monitoring UnitS

- developed @ WHOI Oceanographic Systems Laboratory
- since 2001, several models of REMUS have been built by Hydroid LLC in nearby Pocassett, Mass
- all the assets and business of Hydroid were acquired by Kongsberg in 2008

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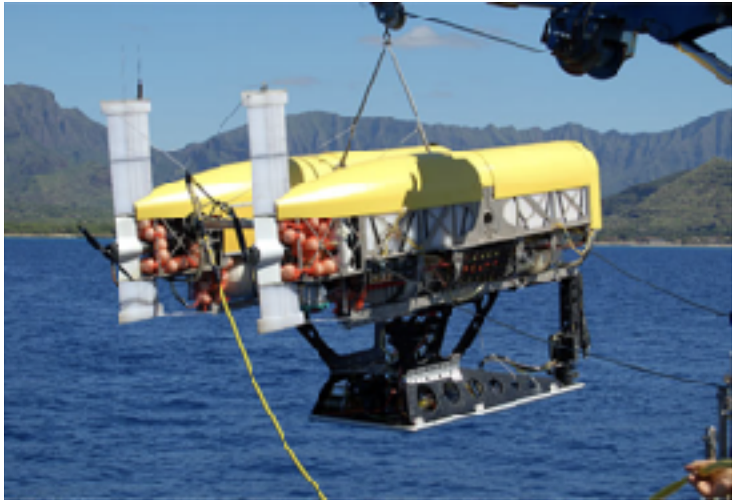
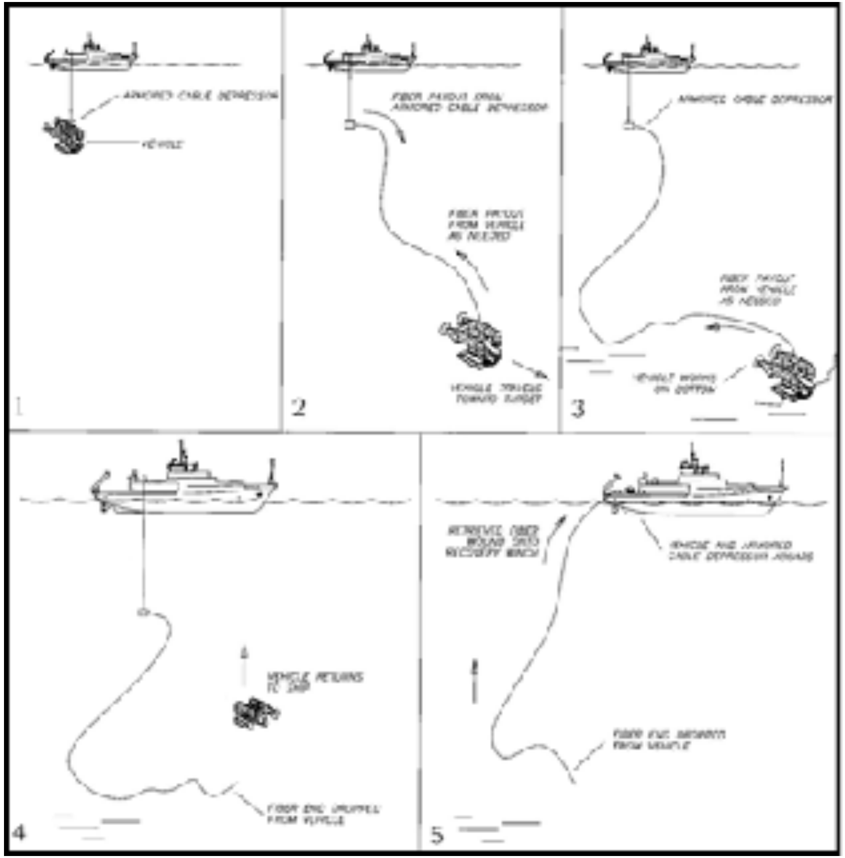
Shuttle AUV: IFREMER SIRENE

AUV for positioning a benthic station on the seabed in a default location

Hybrid ROV concept: WHOI Nereus

May 31, 2009
Mariana Trench
depth: 10902 m





IFREMER Ariane HROV

A. EXPLORATION AND SAMPLING CONFIGURATION

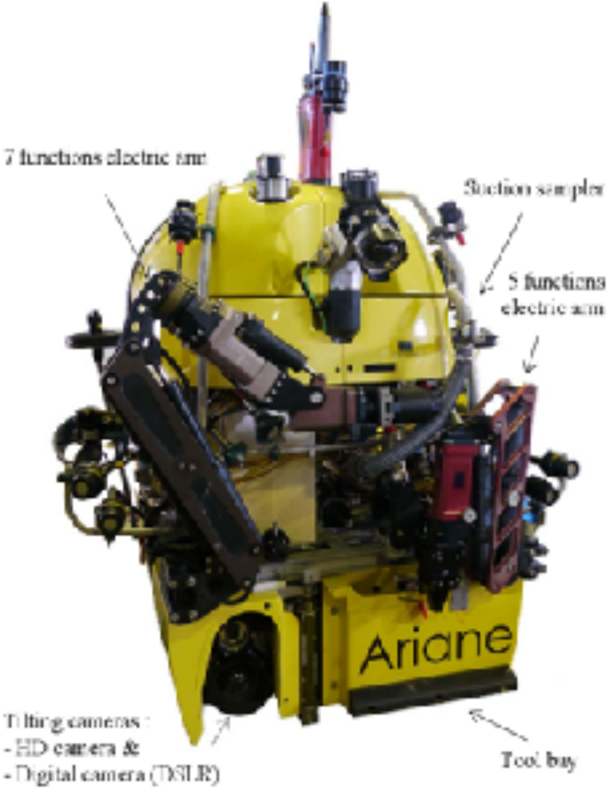
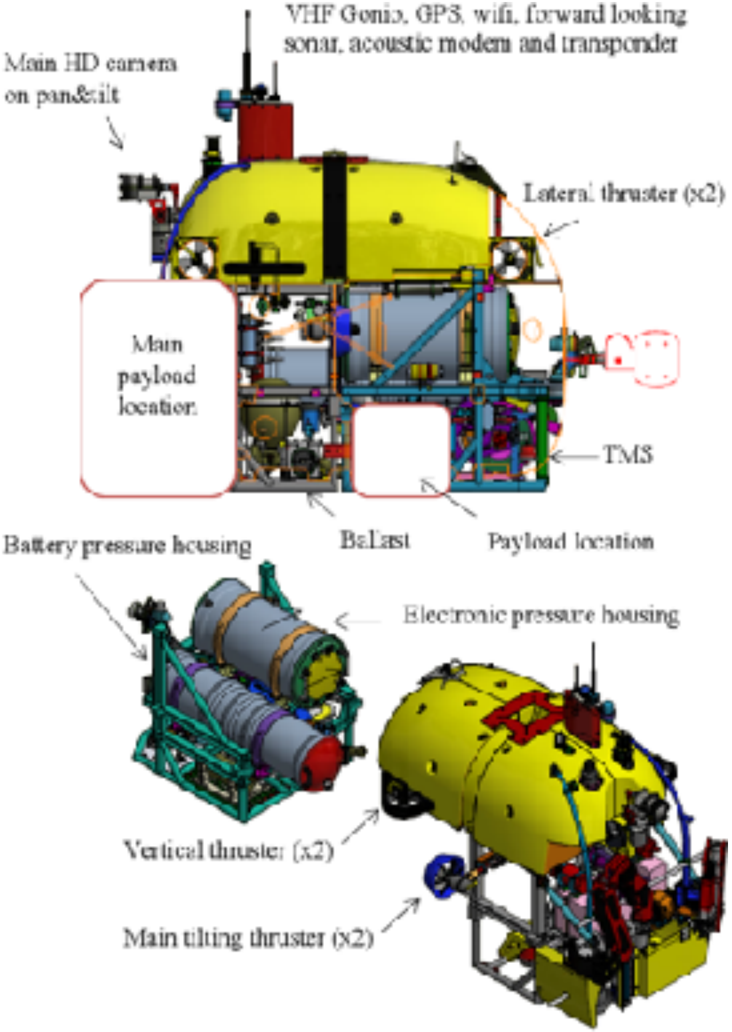


Fig. 7 : Ariane in "exploration and sampling" configuration



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Solar powered AUV - Blidbergh, Ageev (1998)

Solar Powered AUVs; Sampling Systems for the 21st Century

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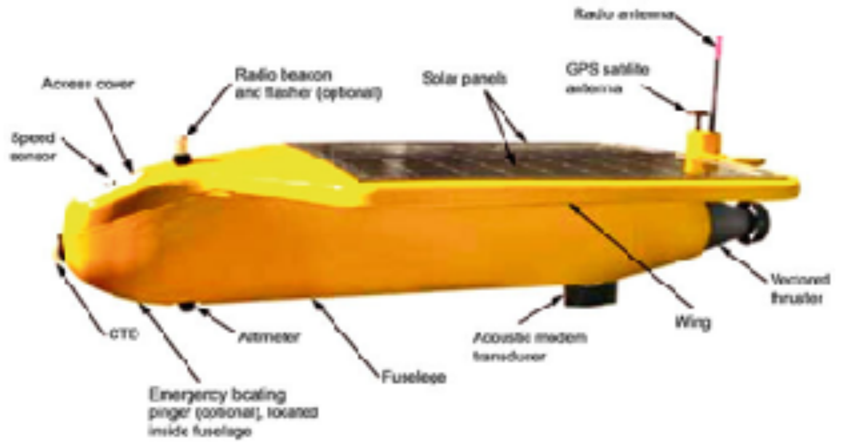
LONG TERM GOALS

The long-term goal of this program is to investigate those technologies that will enable the use of solar energy to power Autonomous Underwater Vehicles (AUVs). The program is focused on investigation of our ability to extract sufficient energy from the sun's radiation to power an AUV and our ability to efficiently manage the collection, storage, and utilization of that energy such that an AUV is able to perform tasks required during a mission. It is expected that, at the conclusion of this phase of the program, we will understand not only the relevant technologies, but also the advantages, methods of implementation, and limitations of their use on solar AUVs.



Underwater transformers: Aquanaut - Houston Mechatronics

AUV mode enables efficient long distance missions

When in AUV mode, Aquanaut can cover up to 200 km (108 nmi) in one mission while accomplishing typical AUV tasks like seabed mapping, and wide area structure inspection. We threw in a few cool features to set Aquanaut apart from other AUVs, like vertical thrust control, and a articulating bow.

Transformation

The Aquanaut transforms by actuating 4 in-house designed and built high-reliability linear actuators. The hull separates in one fluid motion, exposing two additional control thrusters, the vehicle arms, and adding another degree of freedom to the vehicle head mechanism.

Houston Mechatronics | Who We Are | Our Technology | What We Do | News & Updates | Careers | Contact Us

ROV Mode

Turn a valve. Use a subsea tool. Scan structures. Aquanaut can accomplish these advanced subsea operations with just a few mouse clicks. Our operators use mouse clicks, not joysticks, to operate Aquanaut. Our multi-mode machine vision system is comprised of acoustic, optical, and laser based tools that are processed into a dynamic point cloud using the computing power available onboard the vehicle. The point cloud is then compressed using our revolutionary new compression technology which offers compression ratios between 5,000:1 and 75,000:1 (depending on the scene quality). The operator maintains supervisory control over the vehicle whether onboard a support ship or from the comfort of our home office.

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THE SLOCUM MISSION

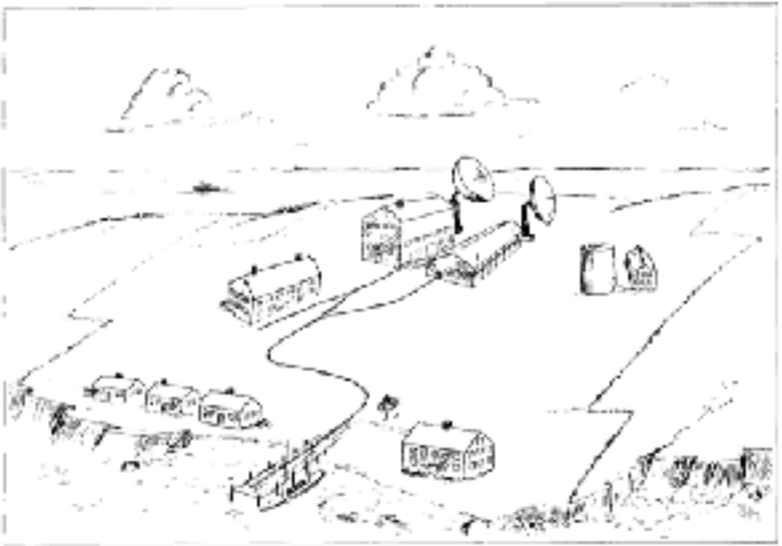
Narrative and Illustration
By Henry Stommel

OCEANOGRAPHY•APRIL•1989

the early nineteenth century. The government acquired Nonamesset to establish the World Ocean Observing System [WOOS], a facility capable of monitoring the global ocean, using a fleet of small neutrally-buoyant floats called Slocums that draw their power from the temperature stratification of the ocean. Nonamesset Island was chosen partly because

begin by saying what Slocums do.

They migrate vertically through the ocean by changing ballast, and they can be steered horizontally by gliding on wings at about a 35 degree angle. They generally broach the surface six times a day to contact Mission Control via satellite. During brief moments at the surface, they transmit their accumulated data and receive instructions telling them how to steer through the ocean while submerged. Their speed is generally about half a knot. There are mili-

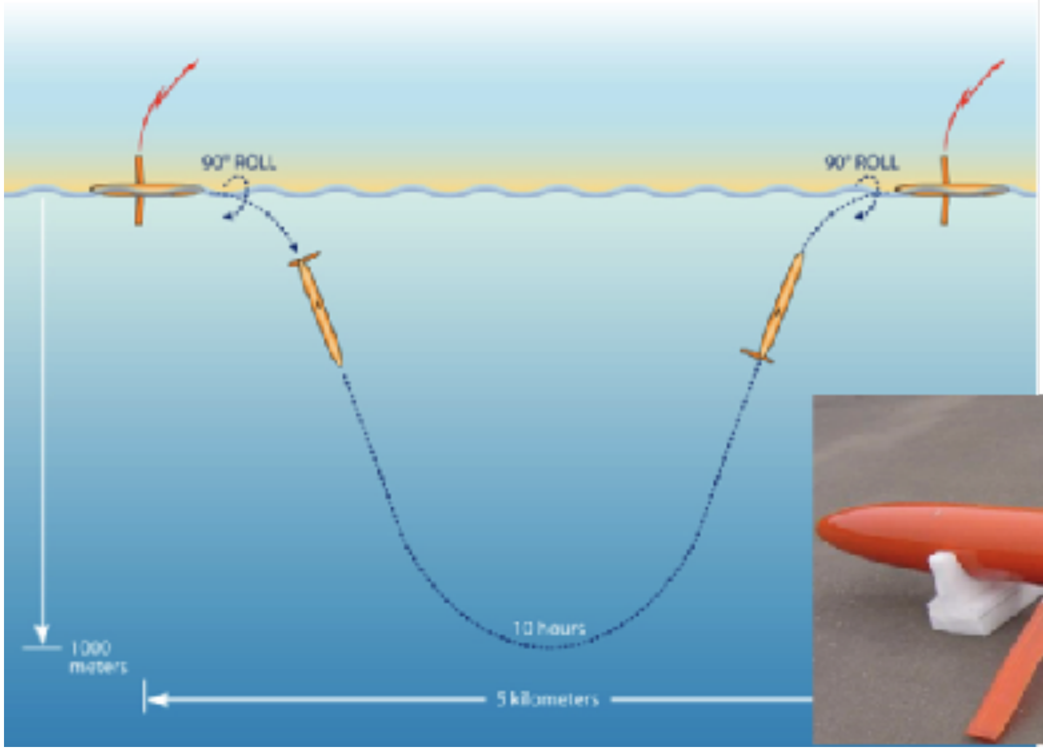


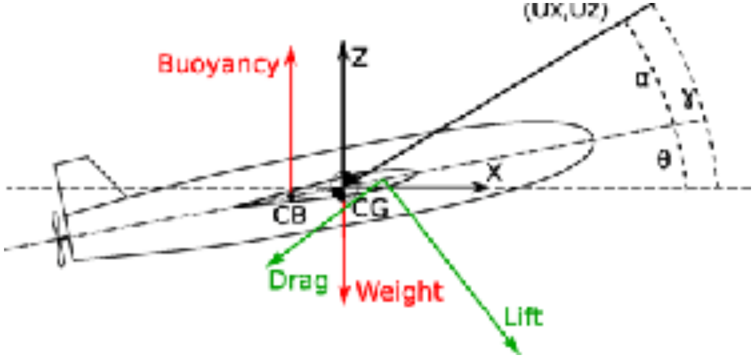
The Slocum Mission Control Center on Nonamesset Island.

Underwater gliders

Underwater gliders

Spray developed by Scripps and Whoods Hole on ONR funds





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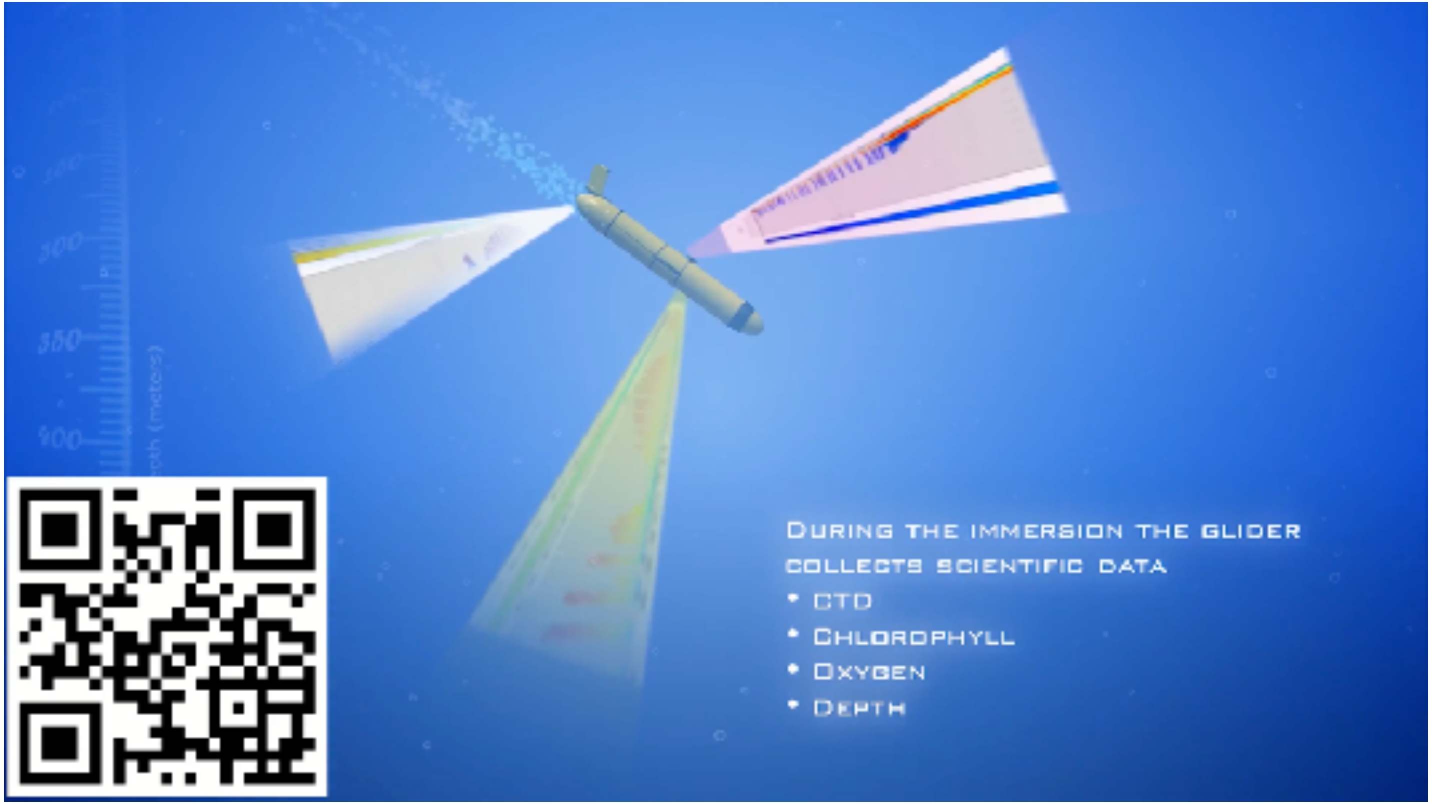
Underwater gliders



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Autonomous underwater glider circumnavigates the Atlantic Ocean

Silbo - Teledyne Marine Slocum G2 Glider (2016-2020)

- Cape Cod to Ireland, 6557 Km in 330 days
- Ireland to Canary Islands, 3695 Km in 178 days
- Canary Islands to St. Thomas, US Virgin Islands, 6256 Km in 418 days
- St. Thomas to Martha’s Vineyard, 6236 Km in 318 days

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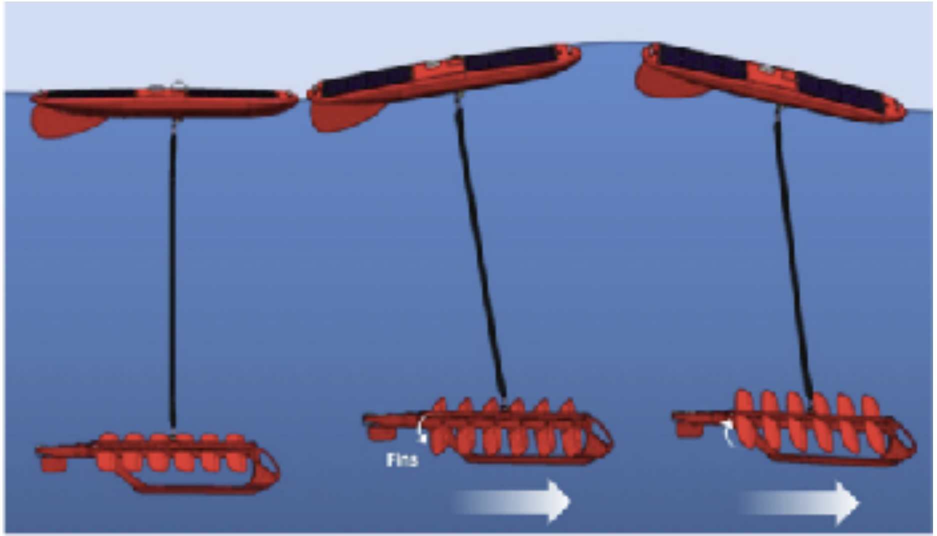
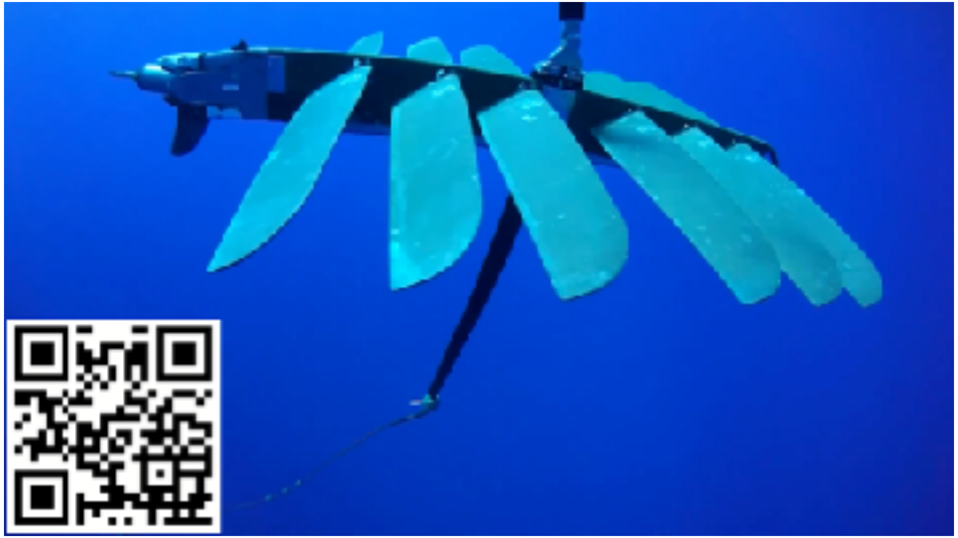
Wave glider - Liquid robotics

Working principle: vertical wave motion at the surface float is converted into forward thrust in the below surface sled





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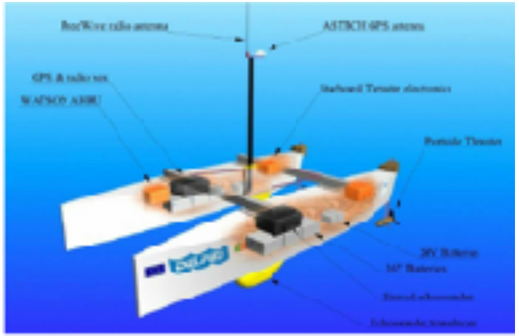
ASVs for research: the beginning

- 1993: MIT Sea Grant - ARTEMIS
  - scale replica of a fishing trawler
  - small size, limited endurance and sea keeping
- 1996-2000: MIT Sea Grant - ACES-AutoCAT
  - adaptation of a small catamaran hull
- 2000: IST-ISR - DELFIM
  - catamaran



catamaran-like shape
- stability
- payload capability
- differential steering

ASVs for research: the beginning

- 2004: CNR Charlie - the first ASV in Antarctica

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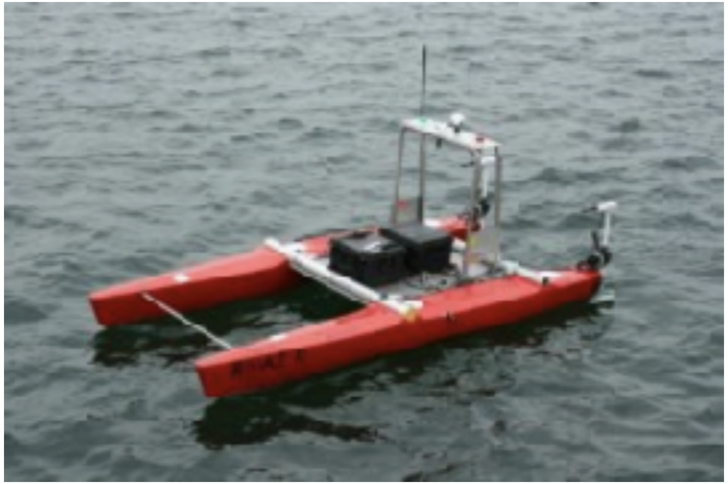
Research ASVs

- oceanography
- bathymetry
- security
- search & rescue



ROAZ - University of Oporto

Kongsberg Maritime

Charlie - CNR

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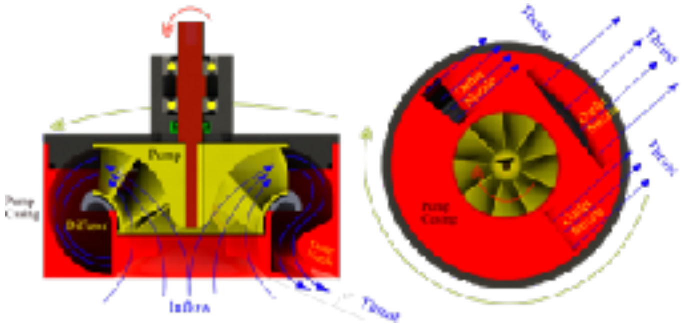
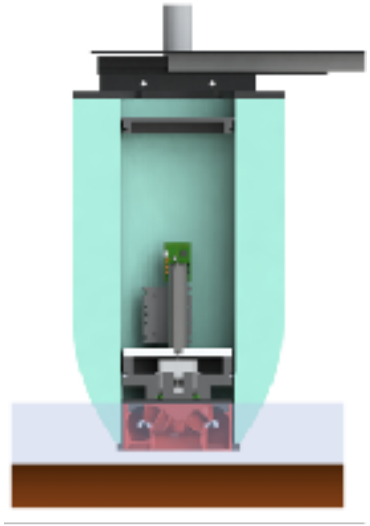
Portable Modular Reconfigurable distributed ASV

- very shallow water applications
  - azimuth pumpjets
  - foam hull





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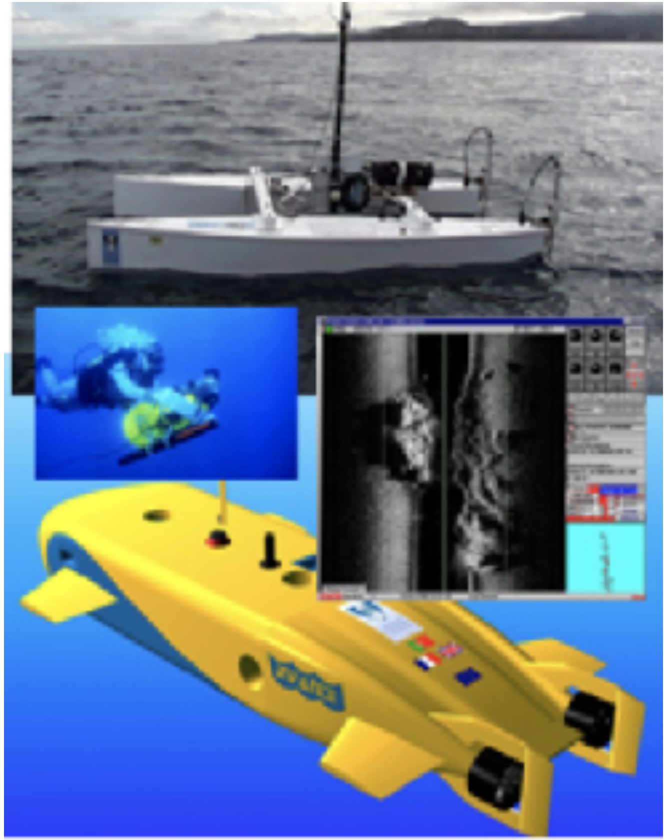
ASV & AUV joint operations

EC ASIMOV project (IST-ISR)

- ASV as an acoustic communication relay for a companion ASV
  - DELFIM ASV
  - Infante AUV

Cooperative guidance of Autonomous Marine Vehicles



ASVs & AUVs as force multipliers

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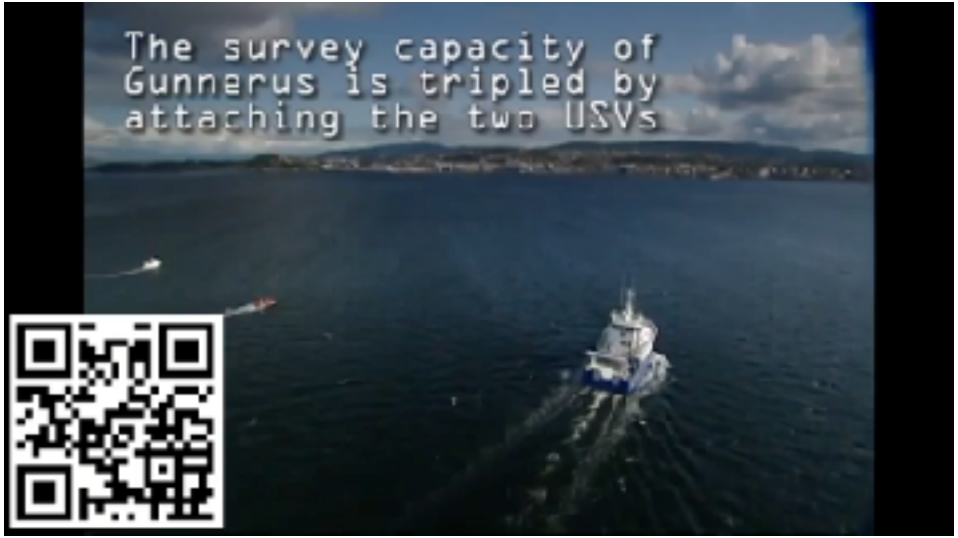
ASVs as force multipliers for manned vessels

NTNU & Maritime Robotics; Trondheim, Norway, August 18, 2009

- 2 USVs autonomously tracked the motion of a manned ship manoeuvring freely in Trondheimsfjord
    - to keep a fixed formation geometry with the manned leader vessel
    - plug-and-play functionality offered to a given vessel such that it can augment the basic survey capacity by attaching or detaching a number of USVs as needed



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ASVs as force multipliers for manned vessels

CNR; Genova, Italy, 2010

- 1 USVs autonomously tracked the motion of a hybrid manned-unmanned vessel in Genova Prà harbour

EC MORPH project

Marine robotics system of self-organizing logically linked physical nodes

- Underwater robotic system composed of a number of **spatially separated mobile robot modules**, carrying distinct and yet complementary resources.
- The **modules** are not physically coupled, they are **connected through virtual links** that rely on the flow of information among them.

MORPH
Grant agreement ID: 288704
Project website

Status
Closed project

Start date
1 February 2012

End date
31 January 2016

Funded under
FP7-ICT

Overall budget
€ 8 521 744

EU contribution
€ 6 284 371

Coordinated by
ATLAS ELEKTRONIK GMBH
Germany

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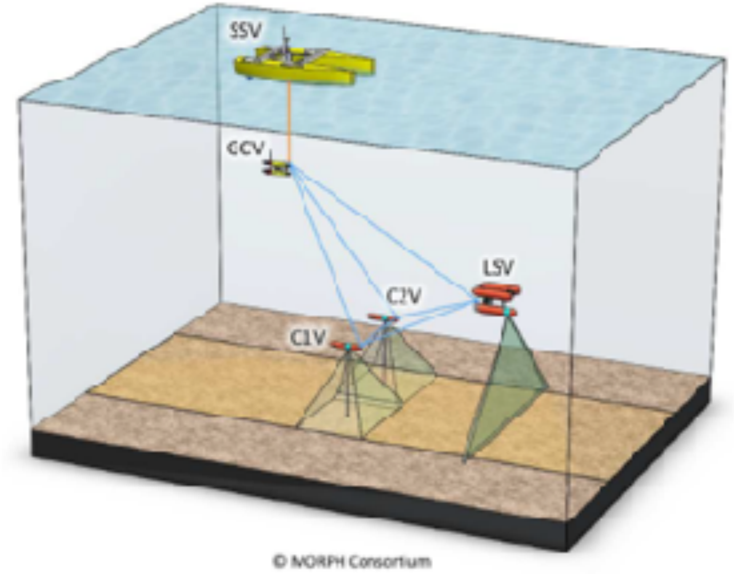
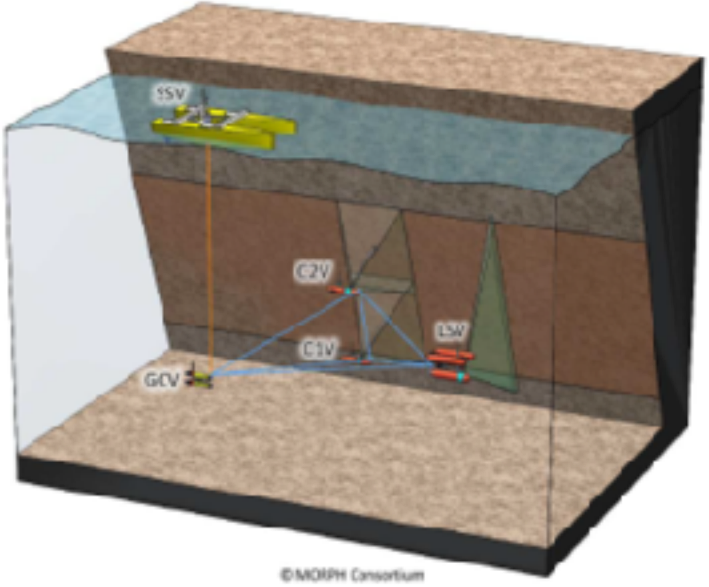
EC MORPH project

Without rigid link, the MORPH supra-vehicle can reconfigure itself and adapt in response to the shape of the terrain





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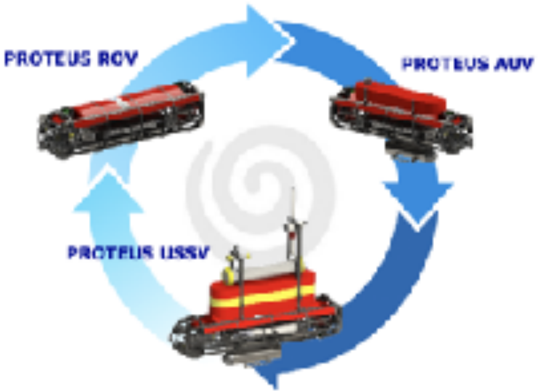
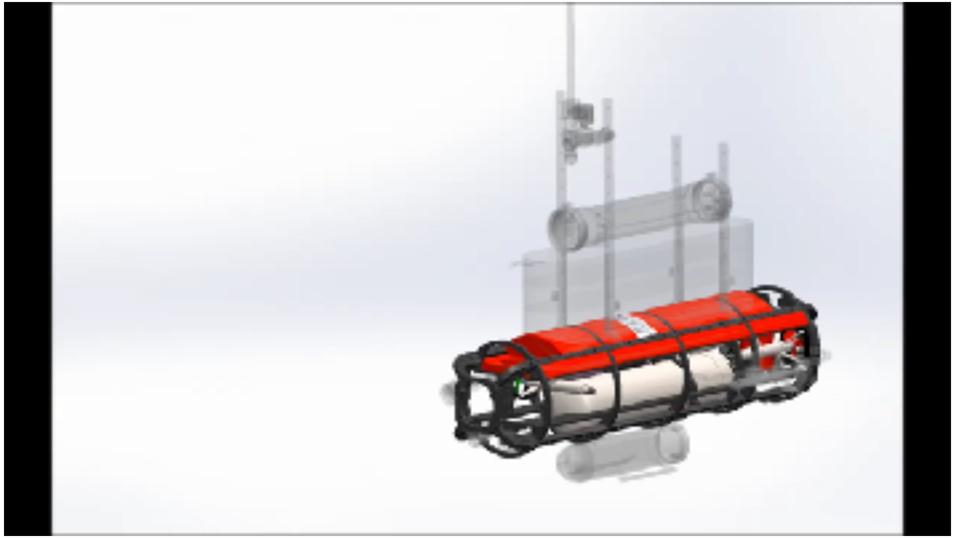
Surface and underwater transformers





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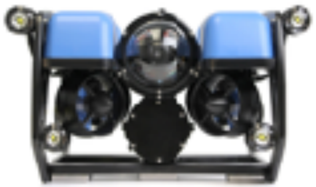
COTS marine drones: from UAV to UMV control systems

BlueBoat

BlueBoat Uncrewed Surface Vessel

BlueROV2



BlueROV2

ARDUPILOT

Versatile, Trusted, Open

Getting Started with Rover

To start with Rover, you will first need a rover with a ArduPilot compatible autopilot. You can either select from a list of ready-to-drive vehicles or assemble your own (See below).

ArduSub and the ArduPilot Project

The ArduSub project is a fully-featured open-source solution for remotely operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs). ArduSub is a part of the ArduPilot project, and was originally derived from the ArduCopter code. ArduSub has extensive capabilities out of the box including feedback stability control, depth and heading hold, and autonomous navigation.

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