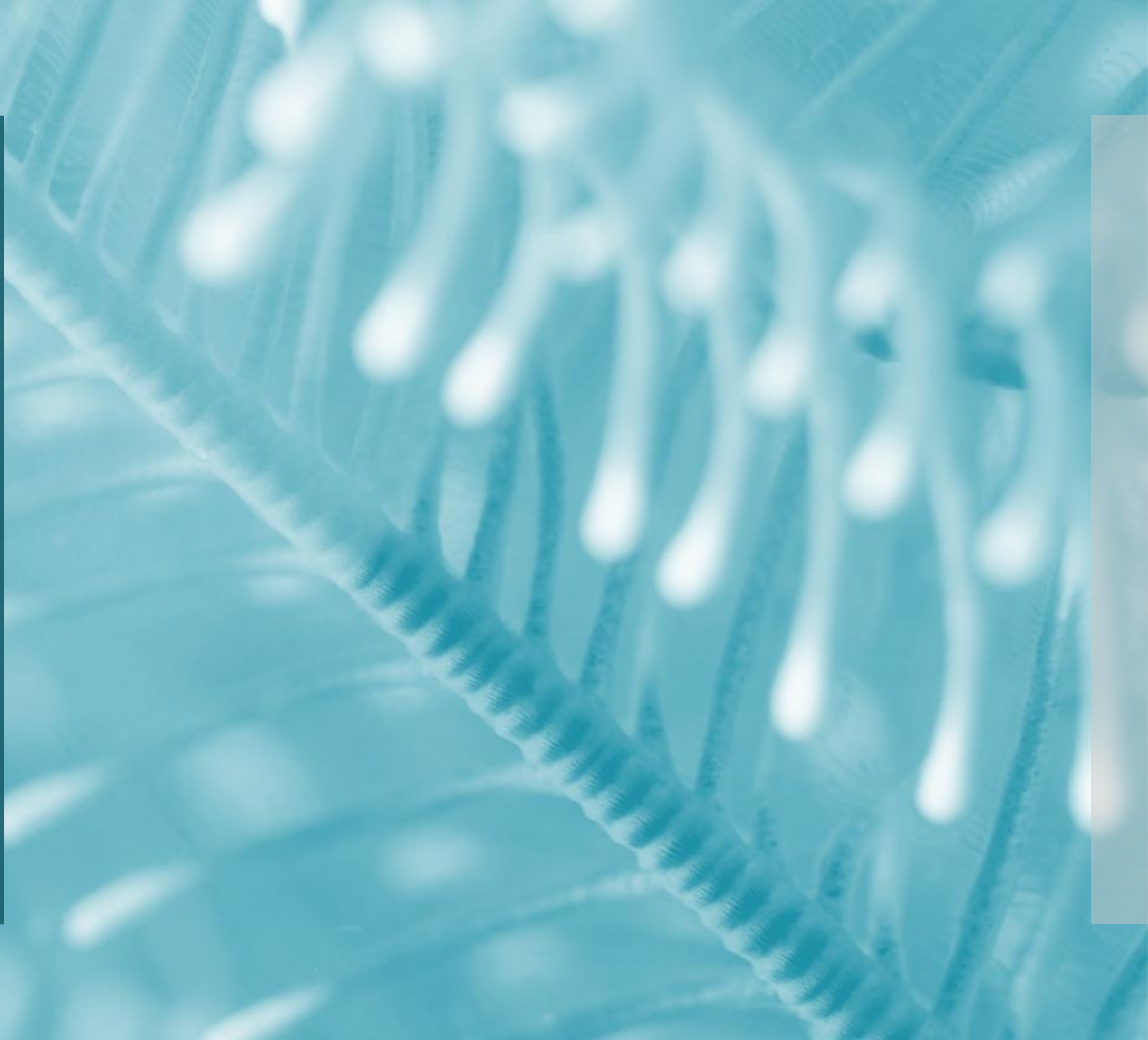
R. O. V. s

Dive, dive dive…. An introductory outlook to human made underwater dwelling critters…

An introduction to underwater critters….

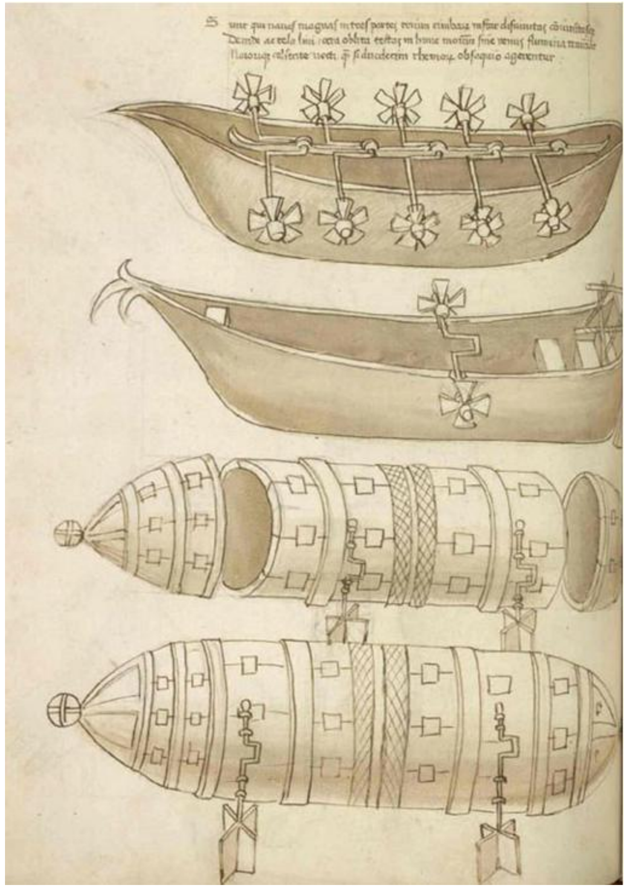


In the beginning….

- First concise drawings for an underwater vehicle:

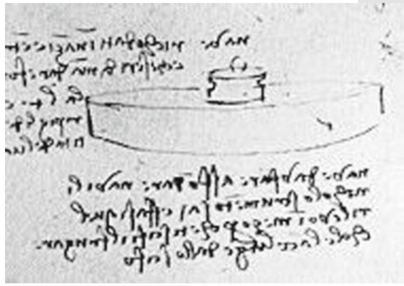
- No not Leonardo

- Roberto Valturio (1405-1475)



Well…

- Leonardo DaVinci is present in almost every possible mechanical apparatus known to man
- A draw has been found in the *Codice Atlantico*(Codex Atlanticus), written between 1480 and 1518, together with the development of some diver's devices
- Legends say that Leonardo worked on the idea of an underwater military machine and that he further destroyed by himself the results judged too dangerous



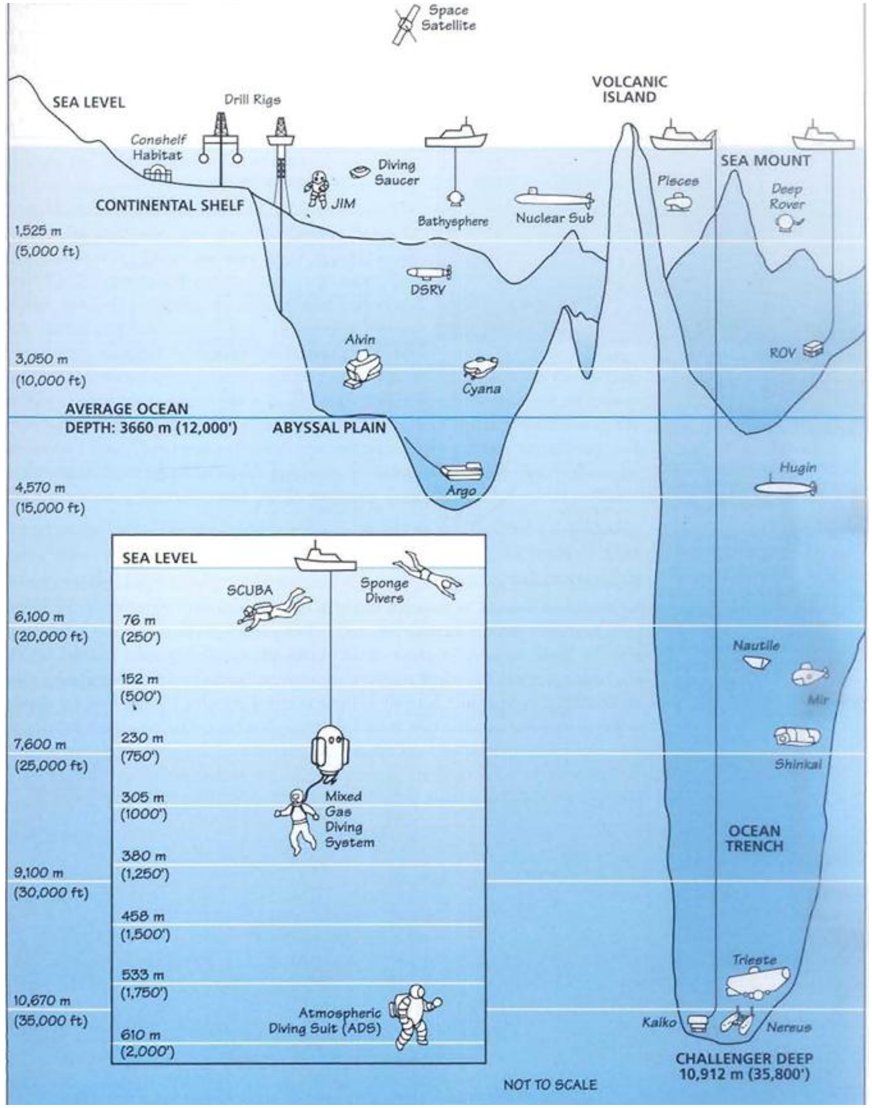
However…

- Maybe the first idea of an underwater machine is from Aristotle
- following the legend he built a machine: *skaphe andros* (boat-man) that allowed Alexander the Great (Alexander III of Macedon, 356–323 b.C.) to stay in deep for at least half a day during the war of Tiro in 325 b.C.
- However, this is deemed unrealistic, of course, also considering that the Archimedes's law was still to become a reality (around 250 b.C.)

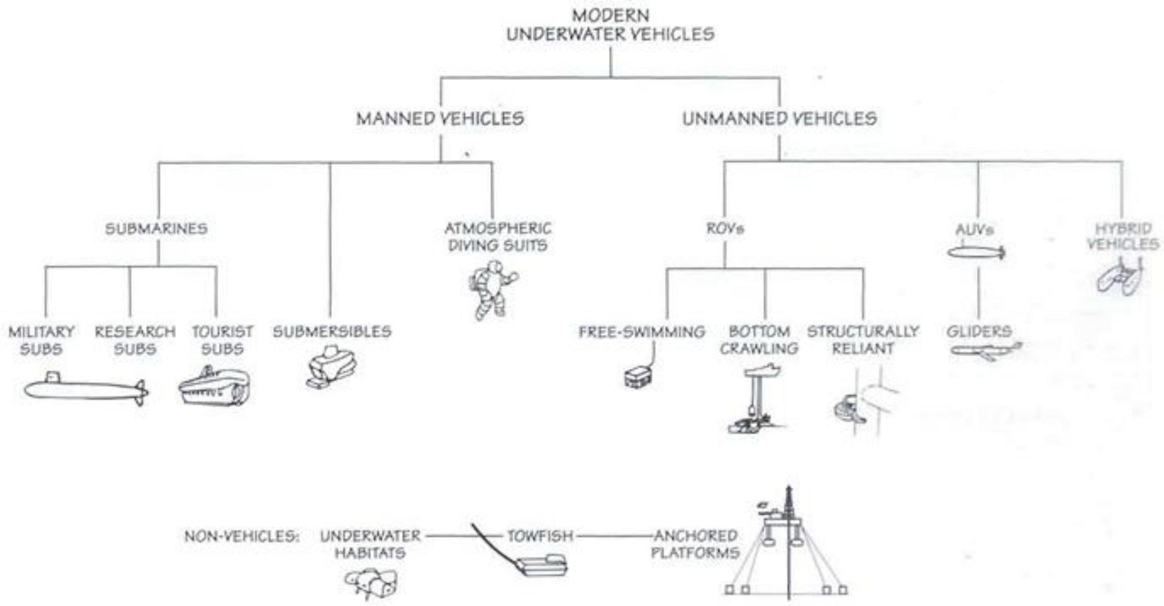
Fast Forward

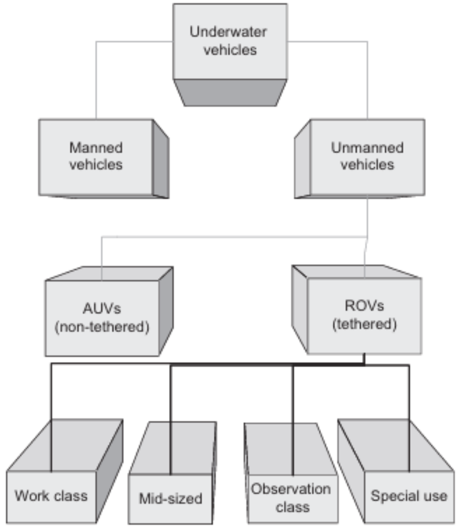
- In August, the 4th, 2005, in the Pacific sea, in front of the Kamchatka, at a depth of 200meters, a Russian manned submarine, the AS-28, got stacked into the cables of an underwater radar
- At that moment, seven men were in the vehicle.
- One day later a British Remotely Operated Vehicle (ROV), Scorpio, was in place and, after another day of operations, it was possible to cut the cables thus allowing the submarine to surface safely.

So… how deep is deep?

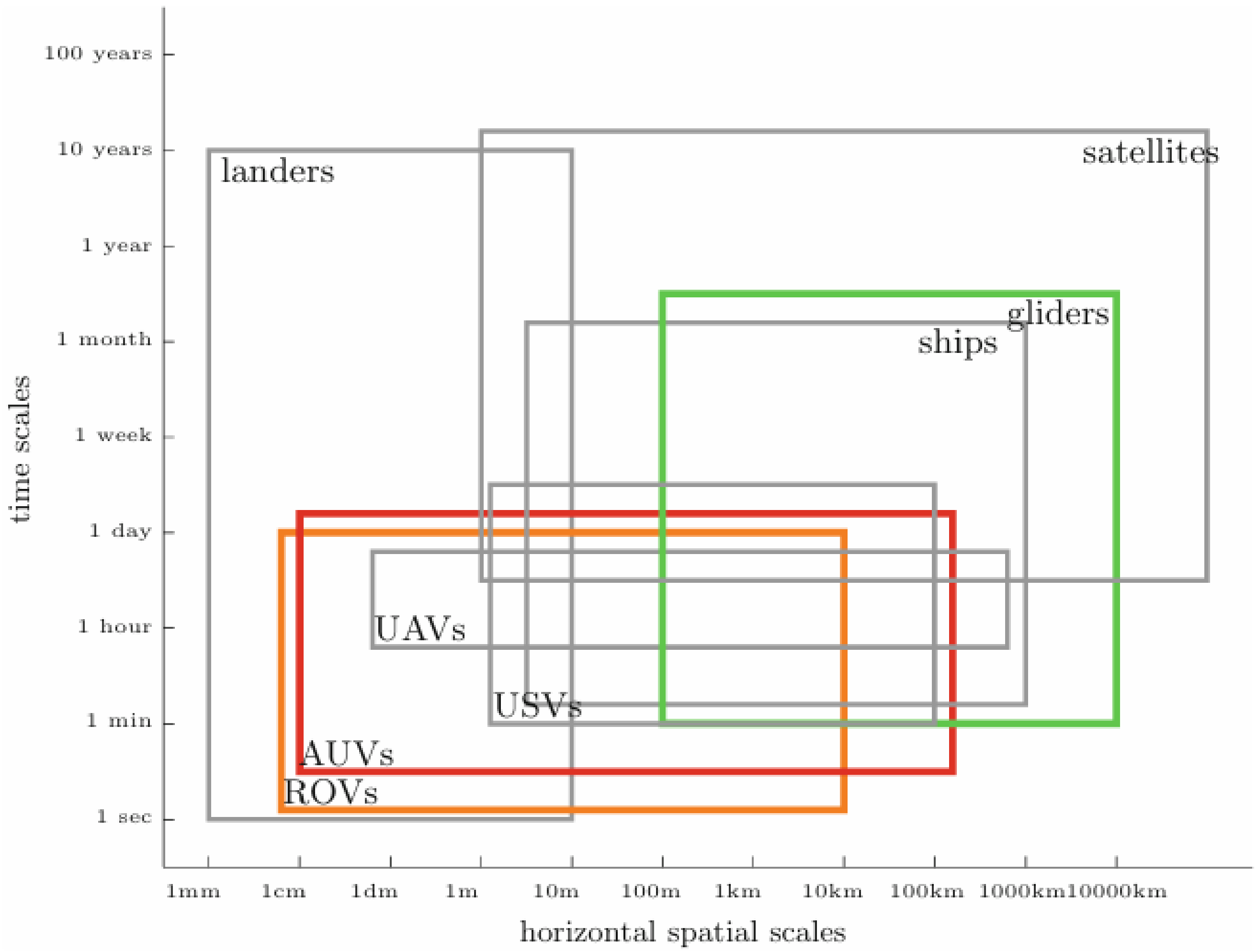


Categorization

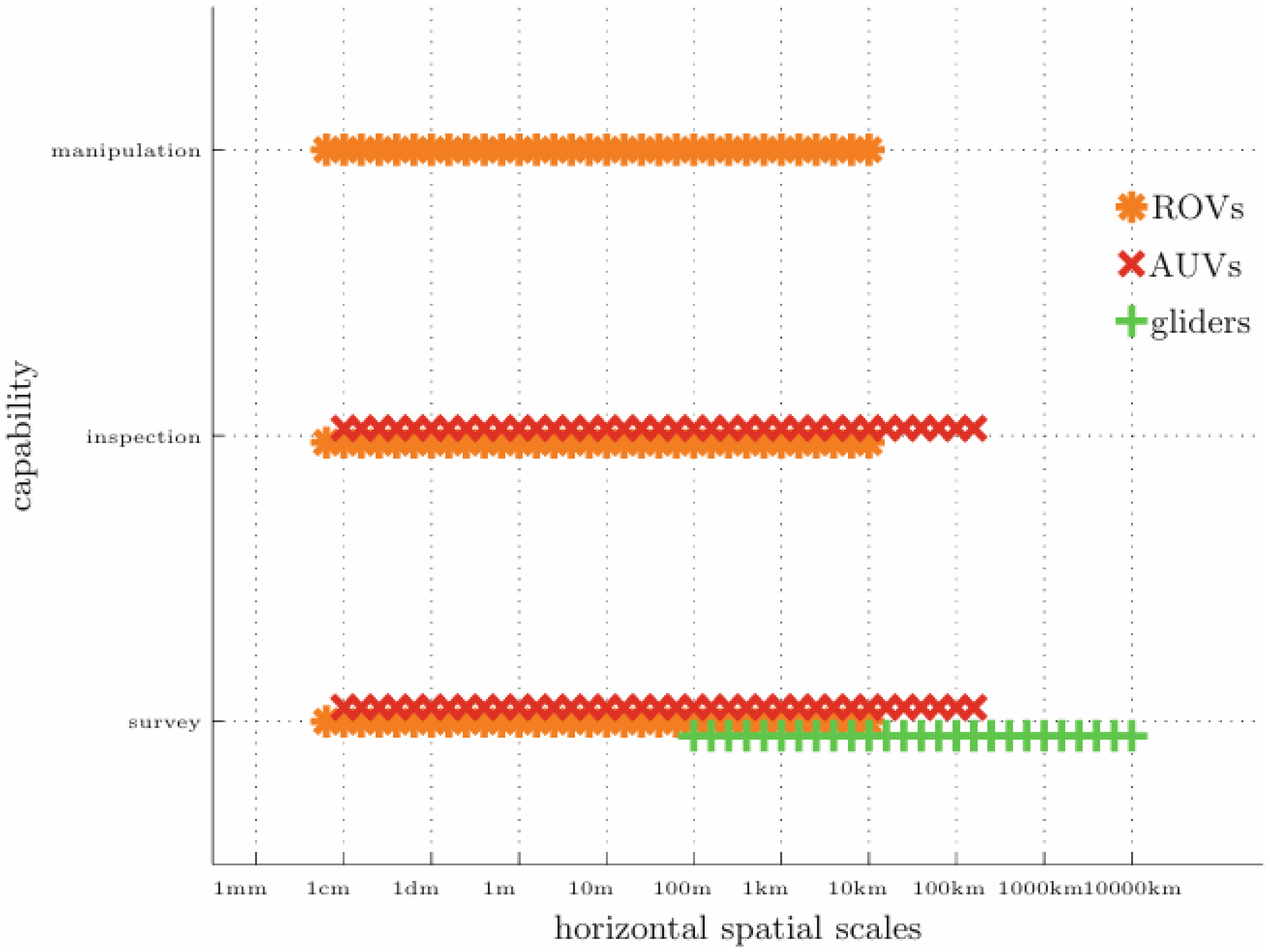




Lets talk about scale



What about capabilities?



So… underwater robots?

- The term Remotely Operated Vehicle (ROV) denotes an underwater vehicle physically linked, via the tether, to an operator that can be on a submarine or on a surface ship.
- The tether is in charge of giving power to the vehicle as well as closing the manned control loop.
- Autonomous Underwater Vehicles (AUVs), on the other side, are supposed to be completely autonomous, thus relying to on-board power system and intelligence.
- These two types of underwater vehicles share some control problems, in this case one has to refer to them as Unmanned Underwater Vehicles(UUVs).
- In case of missions that require interaction with the environment, the vehicle can be equipped with one or more manipulators; in this case the system is usually called Underwater Vehicle-Manipulator System (UVMS)

Sensing the environment

- The AUVs and ROVs need to operate in an unstructured hazardous environment
- One of the major problems with underwater robotics is in the localization task due to the absence of a single, proprioceptive sensor that measures the vehicle position and the impossibility to use the GNSS under the water.
- The use of redundant multi-sensor system, thus, is common in order to perform sensor fusion tasks and give fault detection and tolerance capabilities to the vehicle

Powerrrrrr

- Surface-powered vehicles must be tethered, since the power source is from the surface to the vehicle.
- Vehicle-powered vehicles store all of their power-producing capacity on the vehicle in the form of a battery, fuel cell, or some other means of power storage needed for vehicle propulsion and operation.
- A hybrid system involves a mixture of surface and submersible supplied power.
  - A battery-powered submersible with a surface-supplied charger (through a tether) for recharging during times of less-than-maximum power draw
  - a surface-powered vehicle with an onboard power source for a transition from ROV to AUV

So how many sensors?

- Compass: Provides an estimate of geodetic north.
- Gyroscope
- Inertial measurement unit (IMU):
  - Three accelerometers
  - three gyroscopes
  - three magnetometers
  - Provides information about the vehicle's linear acceleration and angular velocity
- Attitude and Heading Reference System (AHRS): Provides 3D orientation information.
- Depth sensor
- Altitude and forward-looking sonar
- Doppler velocity log (DVL): estimates of vehicle velocity relative to the sea floor and relative water motion can be obtained
- Global Navigation Satellite System (GNSS)
- Acoustic positioning
- Inertial Navigation System (INS)
- Vision systems

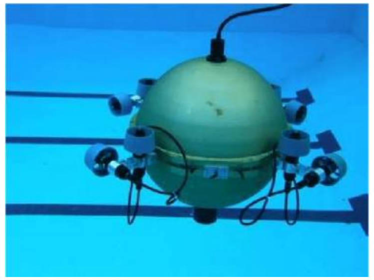
Two examples

JHUROV instrumentations

Measured variable	Sensor	Precision	Update rate (Hz)
3DOF-vehicle position	SHARP acoustic transponder	0.5 cm	10
Depth	Foxboro/ICT model n. 15	2.5 cm	20
Heading	Litton LN200 IMU Gyro	0.01°	20
Roll and pitch	KVH ADGC	0.1°	10
Heading	KVH ADGC	1°	10

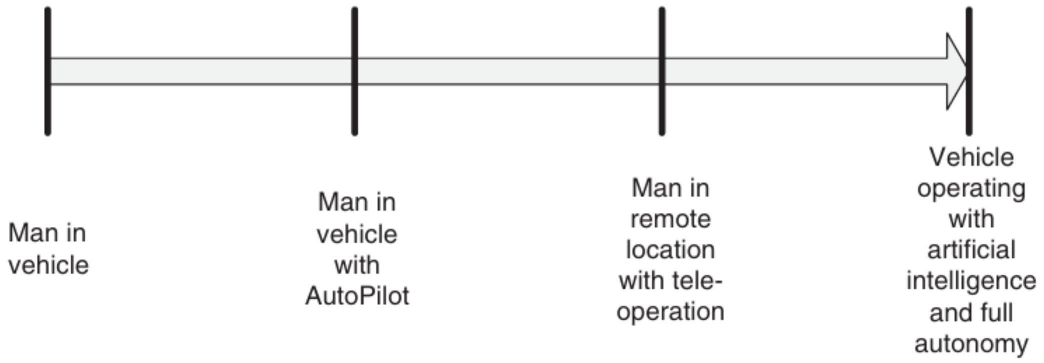
ODIN III sensors update

Measured variable	Sensor	Update rate (Hz)
xy vehicle position	8 sonars	3
Depth	pressure sensor	30
Roll, pitch and yaw	IMU	30



Autonomy plus: An aircraft analogy

- Man in vehicle: Pilot sitting aboard the aircraft in seat manning controls.
- Man in vehicle with AutoPilot: Pilot sitting aboard aircraft in seat with AutoPilot controlling the aircraft's navigation
- Man in remote location with teleoperation: Technician sitting in front of control console on the ground with RF link to the unmanned aircraft while the technician is manipulating the controls remotely.
- Vehicle operating with artificial intelligence and full autonomy: No human supervisor directly controlling the vehicle. The vehicle controls are preprogrammed with the vehicle making objective decisions as to the conduct of that flight from inception to termination based upon the "Sense/Plan/Act" paradigm.



Ok, back to underwater vehicles

- Man in vehicle: Manned submersible pilot sitting aboard the vehicle underwater in the pilot's seat manning the controls and directly commanding the vehicle.
- Man in vehicle with AutoPilot: Same situation with AutoPilot controlling the submersible's navigation (pilot supervising the systems).
- Man in remote location with teleoperation: Technician sitting in front of control console on the surface (or other submerged platform) with tether or other data link to the submersible while the technician is manipulating the controls remotely.
- Vehicle operating with artificial intelligence and full autonomy: No human supervisor directly controlling the vehicle. The vehicle controls of the AUV are preprogrammed, with the vehicle making objective decisions as to the conduct of that dive from inception to termination.

So… why the tether?

- RF waves penetrate only a few wavelengths into water due to water's high attenuation of its energy.
- If the RF is of a low frequency, the waves will penetrate farther into water due to longer wavelengths.
- But with decreasing RF frequencies, data transmission rates suffer. In order to perform remote inspection tasks, live video is needed at the surface so that decisions by humans can be made on navigating the vehicle and inspecting the target.
- Full teleoperation (under current technology) is possible only through a high-bandwidth data link.
- A hard-wire link to the operating platform is needed to have a full teleoperational in-water link to the vehicle.
- Thus, the need exists for a hard-wire link of some type, for the foreseeable future, for real-time underwater inspection tasks.

An attempt to a taxonomy

- **Automated robot, automatic system**. The robot executes a deterministic sequence of tasks without human intervention and without adaptation on the environment
- **Remote-controlled robot**. The operator provides input to the robot in a nearly continuous way acting, e.g., directly at the motor level to drive the robot
- **Tele-operated robot, management by consensus**. The operator provides input to the robot which are of higher level with respect to the remote-controlled level. The robot perform several operations autonomously such as, e.g., handling of time-delay;
- **Semi-autonomous robot, human-supervisory control**. The robot is able to plan and execute a task. Different level of interaction between operator and robot are possible. Decision-making is needed also by the machine
- **Fully-autonomous robot, highly-autonomous robot**. The operator is out of the loop. The robot accomplish its task/mission without human intervention and with the capability to sense and adapt to the environment. A robot monitored by an operator who might eventually activate an emergency procedure still can be considered as fully autonomous.

Classes of critters

- The International Maritime Contractors Association lists its own classification of ROVs as follows:
- Class I—observation ROVs (small vehicles fitted with camera/lights and sonar only)
- Class II—observation ROVs with Payload Option (vehicles fitted with two simultaneously viewable cameras/sonar as standard and capable of handling additional sensors as well as a basic manipulative capability)
- Class III—work-class vehicles (vehicles large enough to carry additional sensors and/or manipulators)
- Class IV—towed and bottom-crawling vehicles (vehicles pulled through the water by a surface craft or winch, and bottom-crawling vehicles using a wheel or track system to move across the seafloor)
- Class V—prototype or development vehicles (those still being developed and those regarded as prototypes).

Size matters: A classification by sizes

- OCROV—from the smallest vehicles to submersible weights up to 200 lb (91 kg)
  - Micro (or small) OCROVs—basic weight of less than 10 lb (4.5 kg)
  - Mini (or medium) OCROVs—submersible weight between 10 lb (4.5 kg) and 70 lb (32 kg)
  - Large OCROV—weights between 70 lb (32 kg) and 200 lb (90 kg)
- MSROV—submersible weights from 200 lb (91 kg) to 2000 lb (907 kg)
  - Shallow MSROV: typically low-power vehicles with copper (or fiber) telemetry and ,3300 ft (1000 m) depth capability
  - Deepwater MSROV: typically deepwater versions of the shallow vehicles and may run single or dual light manipulator systems along with high-voltage power, light-duty electric and hydraulic manipulator systems (Hydro-Lek or similar), and fiber-optic telemetry
  - Heavy MSROV: often named “light work class” and typically have electric thrusters, dual medium-duty hydraulic manipulator systems (Schilling Orion or similar), and a hydraulic power unit for operation of medium-duty hydraulic tooling

Size matters: A classification by sizes (cont.)

- WCROV—submersible weights in excess of 2000 lb (907 kg)
  - Standard work class: These are in the 100-200 hp range typically used in drill support or light construction.
  - b. Heavy work class: These are very large and heavy work vehicles of 200 hp or greater for heavy construction work

How and where do underwater critters make a living?

Science

- *Typical mission*: ROV equipment is typically used in this application to take physical in situ samples and to deliver sensors for gathering data from the operational environment.
- *Typical vehicle type and configuration*: As no significant heavy work is performed during science missions (other than geological sampling), minimal intervention is needed requiring small electric actuators, manipulators, and end effectors.
- Typical vehicles for this mission are the OCROV and/or MSROV with high data-throughput capabilities and small electrical manipulators/ end effectors.

Fisheries and aquaculture

- *Typical mission*: The typical service provided by ROVs in this industry is the inspection of fish cages within a fish farm and for various usages including checking nets for holes, assuring the integrity of moorings for the farm, and the retrieving of “morts” (dead fish) from the cage for health/sanitation purposes.
- *Typical vehicle type and configuration*: As the intervention needs of this mission are minimal and the operational environment is predominantly shallow water, the “flying eyeball” OCROV with a simple video camera and a small manipulator is the vehicle/configuration of choice.

Military

- *Typical mission*:
  - MCM mission: the ROV is sent to a location of targets identified through other sensors or means.
  - Once the mine is located some form of end effector is required to neutralize the mine for final disposition.
  - Object retrieval function: much heavier vehicles are needed to rig heavy-lifting gear for retrieval to the surface.
  - Inspection/security function: a simple video camera along with basic sensors is needed.
- *Typical vehicle type and configuration*:
  - MCM mission: predominant vehicle is a special-use explosives delivery platform typically an MSROV with a dexterous electric manipulator capability
  - single-shot MCM vehicle is clearly an OCROV (hopefully of minimal cost)
  - object retrieval ROV, a heavy-duty WCROV is needed along with hydraulic manipulators and deepwater capabilities.
  - The inspection/security vehicle is clearly an OCROV with minimal sensor and tooling requirements.

Homeland security

- *Typical mission*: ROVs are typically used in this application for periodic ship hull and pier security inspections and sweeps.
- *Typical vehicle type and configuration*: This function is clearly the realm of the OCROV with minimal sensor and tooling capabilities.
- The cheaper the per inspection cost the more likely and often the inspection will take place

Public safety

- *Typical mission*: Many public safety diving (PSD) teams are attached to various municipalities and/or regional governmental authorities.
- In many cases, the PSD team has an ROV capability assigned to a team member to augment the team's capability.
- By the time the ROV is typically called in, however, the team is in full recovery mode (as opposed to rescue mode).
- The typical mission of a PSD team is search and gathering/recovery of crime scene evidence or recovery of inaccessible items (e.g., drowning victim).
- *Typical vehicle type and configuration*: The budgets of most municipalities obviate the funding for anything other than OCROVs with minimal tooling and sensor capabilities

O&G drill support

- *Typical mission*: ROVs for drill support are used from the first spud-in through to well completion.
- Missions include observation of the seafloor environment, mounting of well casing seals and guides, guiding of tooling and drill equipment into the well along with various other operations.
- *Typical vehicle type and configuration*: The typical ROV size and configuration for drill support are a larger MSROV or a light WCROV.
- A drill support operation typically requires a drill-rig-located ROV with a 7-function hydraulic manipulator along with a second 5-function manipulator/grabber for steadying the vehicle during work.
- As the heavy-lifting functions are mostly handled from the surface, the vehicle does not require the muscle of a construction project, thus allowing the vehicle to be in the 50 100 hp range.

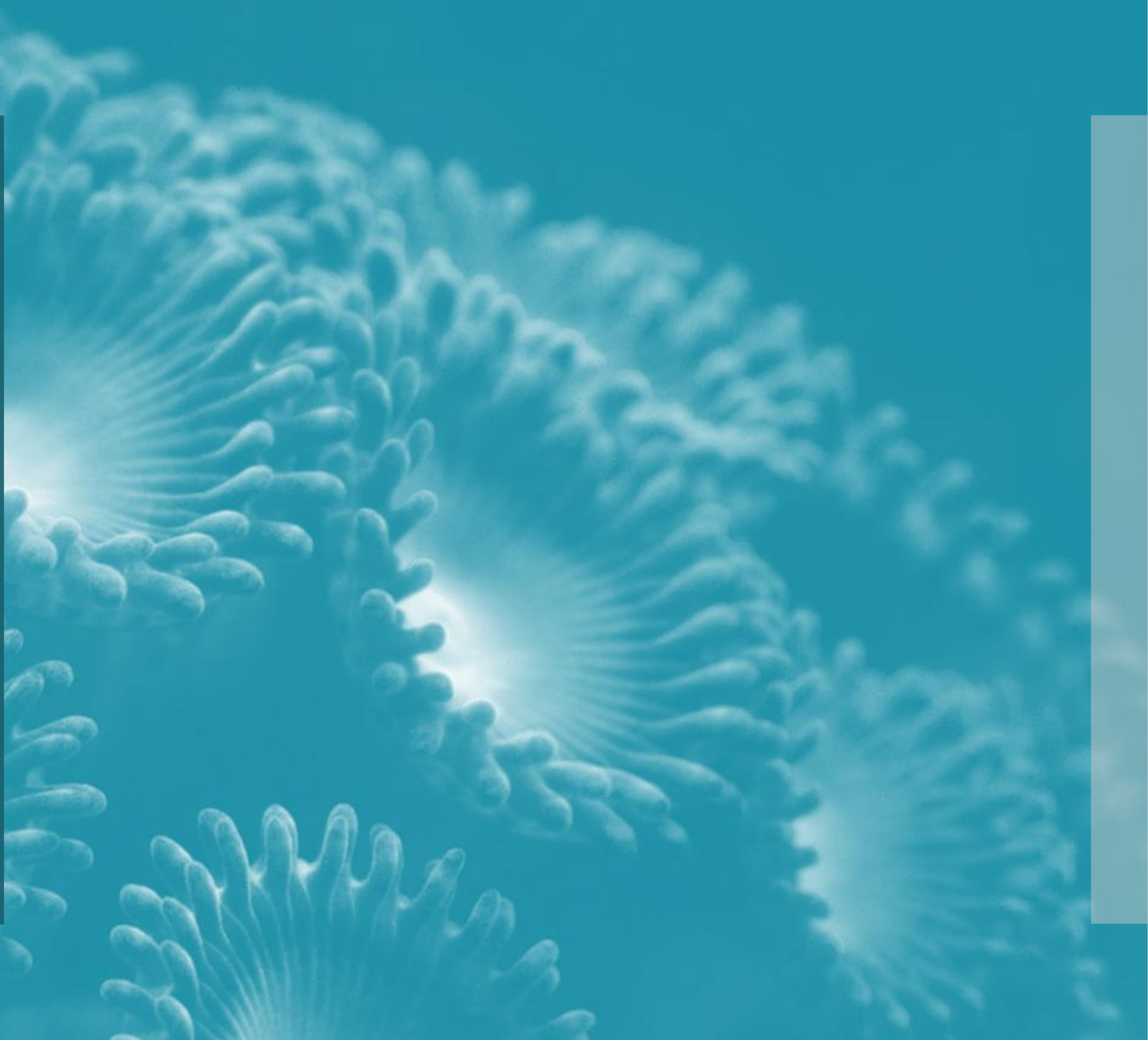
Inspection, repair, and maintenance

- *Typical mission*: The typical mission for inspection of subsea structures involves the visual and nondestructive testing/evaluation of various man-made items for safety, security, structural integrity, and functionality of the fixture as well as primary and supporting systems.
- The repair and maintenance functions are carried out during the asset's life through various techniques for supporting the life of the project.
- *Typical vehicle type and configuration*: The ROV need during the inspection phase varies depending upon the operating environment and the type of inspection being conducted.
- For basic visual shallow water inspections, a small OCROV will be sufficient, but for higher-bandwidth sensor delivery and/or deepwater operations in harsh conditions, an MSROV will be required.
- For the repair and maintenance functions, most operations can be accomplished with an MSROV with light intervention and tooling capabilities.
- As the need for further mechanical tasks becomes heavier, the project may have periodic need for a WCROV, but in most cases the MSROV will suffice

Construction (O&G as well as civil)

- *Typical mission:* ROVs for use in this mission typically are tasked with setting and pulling rigging, guiding large construction pieces into place, moving heavy pieces from location to location, laying and burying cables and pipelines and setting mattresses
- *Typical vehicle type and configuration*: Vehicles in use for the subsea construction tasking are typically higher powered (.150 hydraulic hp) and specification WCROVs with dual 7-function manipulators and high pressure/flow remote tooling delivery capabilities.

So, how to design an underwater critter?



Design objectives

Who does it better?

Stationary Vehicle (ROV)	Rapidly Moving Vehicle (AUV)
Close visual inspection	Wide area sensor deployment
Localized NDT or NDE sensor deployment	General visual inspection
Physical manipulation or intervention of stationary structures	High-speed weapons delivery
Localized sensor deployment	

So, what is considered “pretty” in design?

Stationary Efficiency (ROV)	Moving Efficiency (AUV)
Low vehicle aspect ratio (length to width)	Optimized for travel over one axis only
Similar drag profiles about all axes of sway	Closed frame for drag minimization
Easy thrust and movement about all planes of motion	Lowest possible frontal profile
Open frame design	Onboard power
Drag as secondary design consideration	Tetherless for drag minimization
Typically offboard power through hard-wired umbilical/tether	

Talking about drag…

- The function of an ROV is to act as a delivery platform (for sensors and tooling) to a remote work site.
- All items and subsystems of the vehicle support this function.
- The vehicle must have some type of locomotion to take it to the work site and perform the work.
- In order to achieve the locomotion objective, the vehicle must power itself and overcome the fluid drag of the vehicle/ tether combination to travel to and remain at the work site.
- This sounds simple, but the devil is in the details

Drag in reality

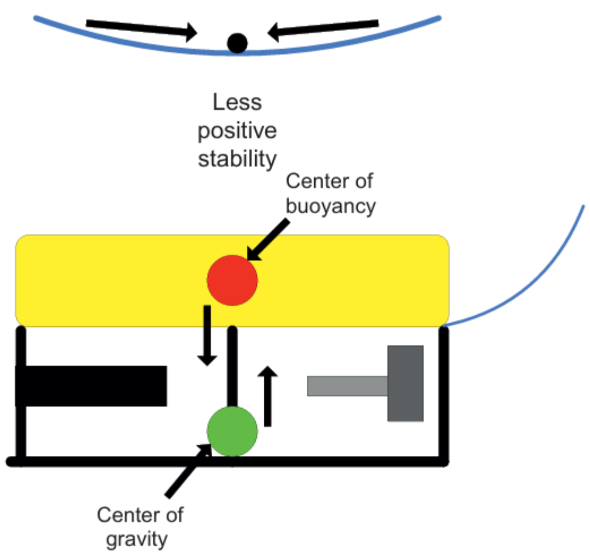
- Imagine a closed-circuit water tunnel for inducing all of the characteristics for identifying a theoretical fluid flow equation, namely:
  - 1. a fully enclosed fluid
  - 2. a blunt form factor
  - 3. a large enough Reynolds number to induce turbulence downstream from the item
- Now think of an object stationary in the tunnel with no water flow.
- Turn on the pump and make the water flow.
- As the water flow through the tunnel is slowly increased, the drag will increase in an amount proportional to the density of the fluid as well as the square of the object’s speed relative to the fluid.
- Also, with a constant object volume, the shape of the object will directly affect its drag force—this factor is referred to as the “coefficient of drag” (Cd).

Some established Cds

Shape		C_d
Sphere		0.47
Halfsphere		0.42
Cone		0.50
Cube		1.05
Angled Cube		0.80
Long Cylinder		0.82
Short Cylinder		1.15
Streamlined Body		0.04
Streamlined Halfbody		0.09

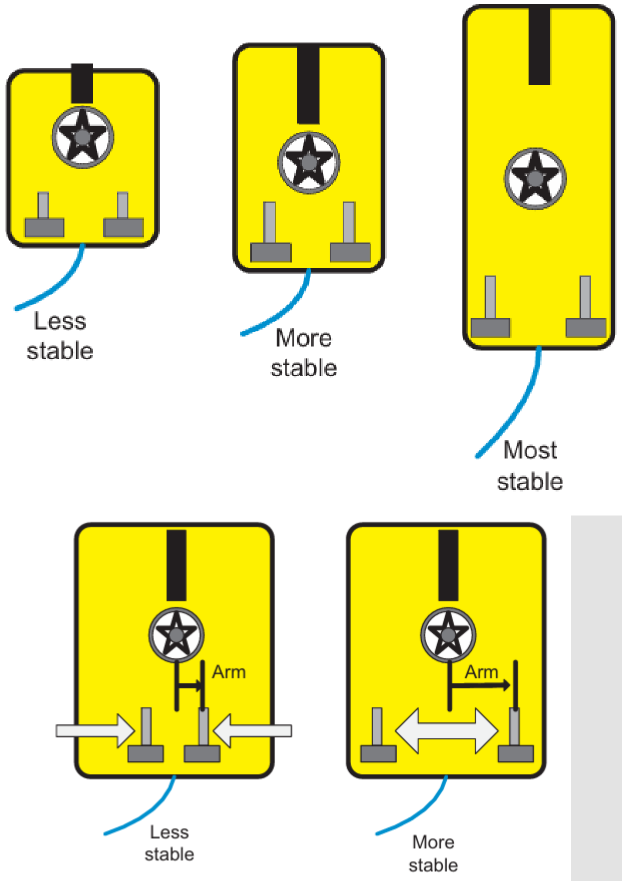
Sta.Bi.Li.Ty

- As with a child's seesaw, the further a weight is placed from the fulcrum point, the higher the mechanical force, or moment, needed to "upset" that weight.
- It is called "positive stability" when an upset object inherently rights itself to a steady state.
- When adapting this to a submersible, positive longitudinal and lateral stability can be readily achieved by having weight low and buoyancy high on the vehicle.
- This technique produces an intrinsically stable vehicle on the pitch and roll axis.
- In most observation-class ROV systems, the higher the stability the easier it is to control the vehicle.
- With lower static stability, expect control problems



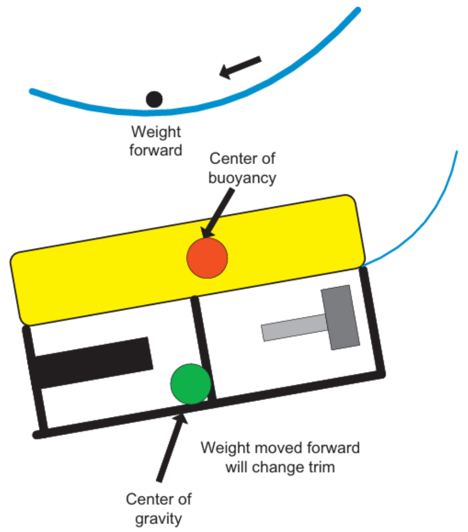
Sta.Bi.Li.Ty (2.0)

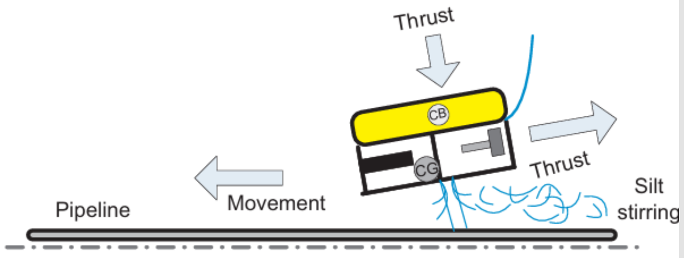
- External forces, however, do act upon the vehicle when it is in the water, which can produce apparent reductions in stability.
- For example, the force of the vertical thruster when thrusting down appears to the vehicle as an added weight high on the vehicle and, in turn, makes the center of gravity appear to rise, which destabilizes the vehicle in pitch and roll.
- The center of buoyancy and center of gravity can be calculated by taking moments about some arbitrarily selected point.
- Other design characteristics also affect the stability of the vehicle along the varying axes. The
- so-called aspect ratio (total mean length of the vehicle versus total mean width of the vehicle) will determine the vehicle's hull stability, as will thruster placement



Trim(ing) based on mission

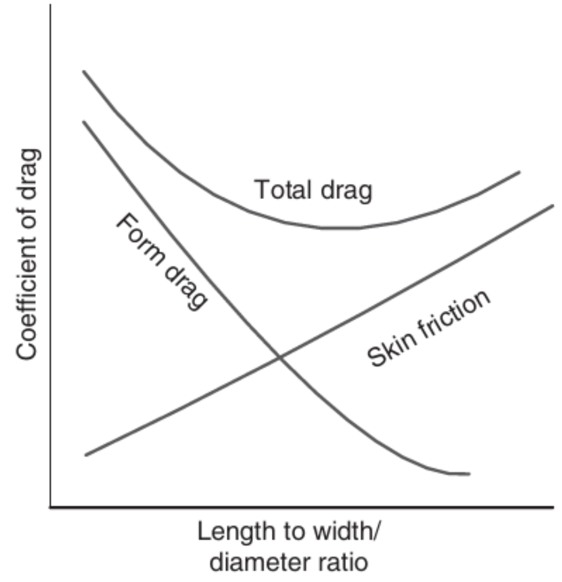
- Two examples of operational situations where ROV trim could be adjusted to assist in the completion of the mission are as follows:
- If an ROV pilot requires the vertical viewing of a standpipe with a camera tilt that will not rotate through 90 , the vehicle may be trimmed to counter the lack in camera mobility
- If the vehicle is trimmed in a bow-low condition while performing a transect or a pipeline survey, when the thrusters are operated to move forward, the vehicle will tend to drive into the bottom, requiring vertical thrust.
- The vehicle ballast could be moved aft to counter this condition





Talking about drag (again…)

- Another critical variable in the vehicle control equation is the joint effect of both the point of net thrust (about the various axes) and the point of effective total drag
- Skin friction drag: Friction drag is created by the frictional forces acting between the skin and the water.
- Form drag: A second effect of the viscous action of the vehicle's hull is to reduce the pressure recovery associated with nonviscous flow over a body in motion.
- There is an optimum aspect ratio whereby the total drag formed from both form drag and skin friction is minimized



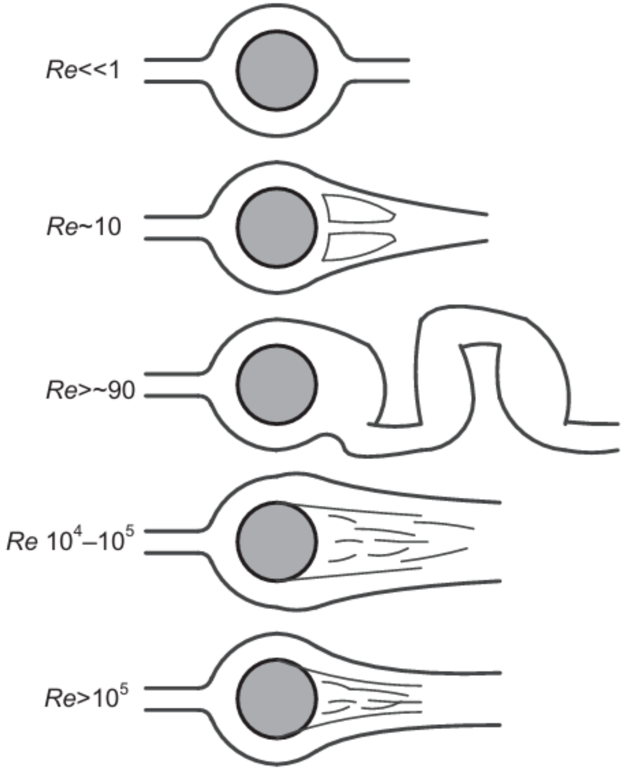
Skin Friction….Nope, Reynold’s number first…

- The Reynolds number is a dynamic factor for fluid flow and comes into place for determining the flow characteristics around the vehicle (which directly affects the drag equation).
- The three modes of flow around a body are as follows:
- 1. laminar—smooth flow over the body
- 2. transient—approaching the critical Reynolds number where laminar transitions to turbulent
- 3. turbulent—disorganized flow over the body

More on Reynold's

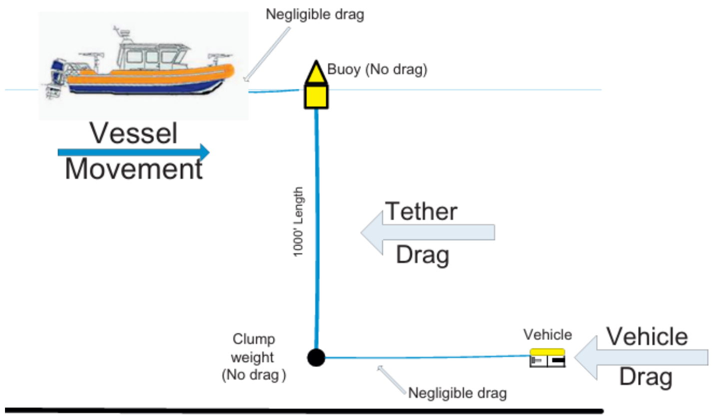
$$Re = pVl/m = Vl/v$$

- where:
- p=density of fluid,
- V=velocity of flow,
- m=coefficient of viscosity,
- v=m/p=kinematic viscosity,
- l =a characteristic length of the body



Form drag

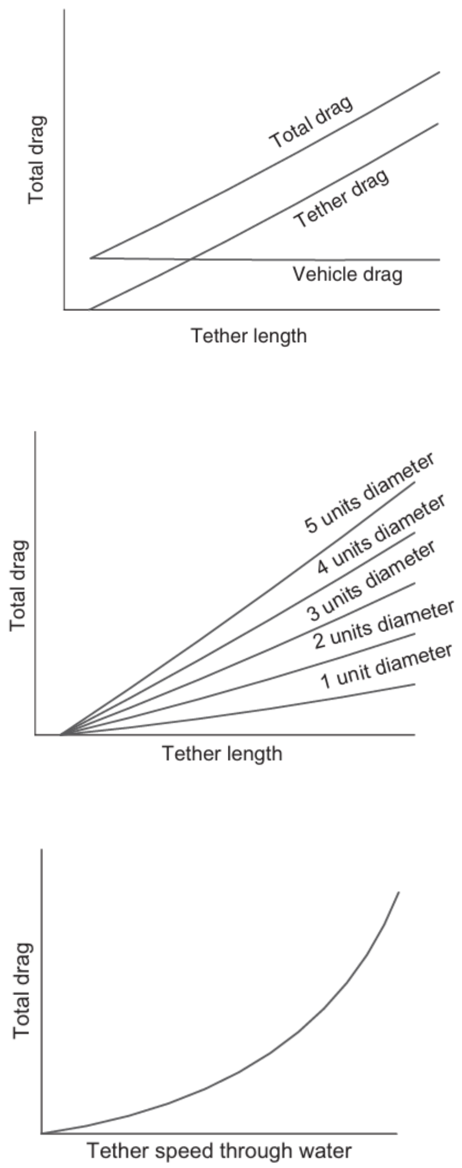
- With an ROV, the two components causing typical drag to counter the vehicle's thruster output are the tether drag and the vehicle drag
- The function of an ROV submersible is to push its hull and pull its tether to the work site
- The only significant metric that matters is the net thrust to net drag ratio.
- If that ratio is positive (i.e., net thrust exceeds net drag), the vehicle will make headway to the work site.
- If that ratio is negative, the vehicle becomes a very high-tech and very expensive boat anchor



Form drag (in mathematical terms)

$$\text{Vehicle drag} = 1/2 \times \sigma A V^2 C_{\mathrm{d}}$$

- σ=density of seawater/gravitational acceleration
- A=characteristic area on which Cd is non-dimensionalized. For an ROV, A is defined as the cross-sectional area of the front or the vehicle. In some cases, the ROV volume raised to the 2/3 power is used
- V=velocity
- Cd=nondimensional drag coefficient.
- Total drag of the system is equal to the vehicle drag plus the tether drag



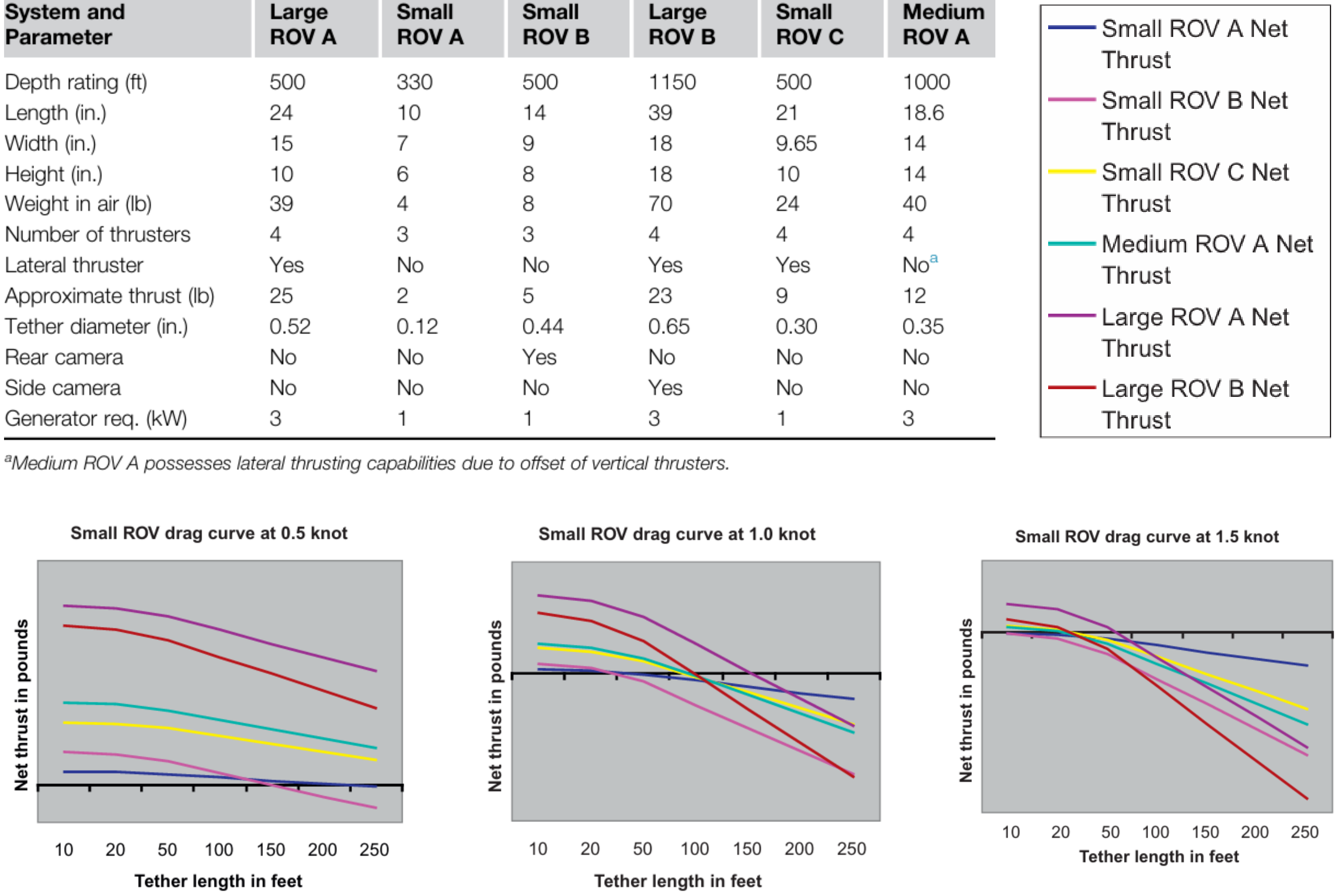
Drag and Powerrrrrr

- The power required to propel an ROV is calculated by multiplying the drag and the velocity as follows
- Power=Drag x V/C
- Where C is a constant changing velocity units to horsepower
- The drag of a vehicle is proportional to the velocity of the vehicle squared
- Accordingly, the propulsion power used is proportional to the velocity cubed
- To increase the forward velocity by 50%, for example, from 2 knots to 3 knots, the power increases by $(3/2)^3$, or $(1.5)^3$, which is 3.4 times more power.
- To double the speed, the power increases by $(2)^3$ or eight times.
- Increased speed requirements have a severe impact on vehicle design.

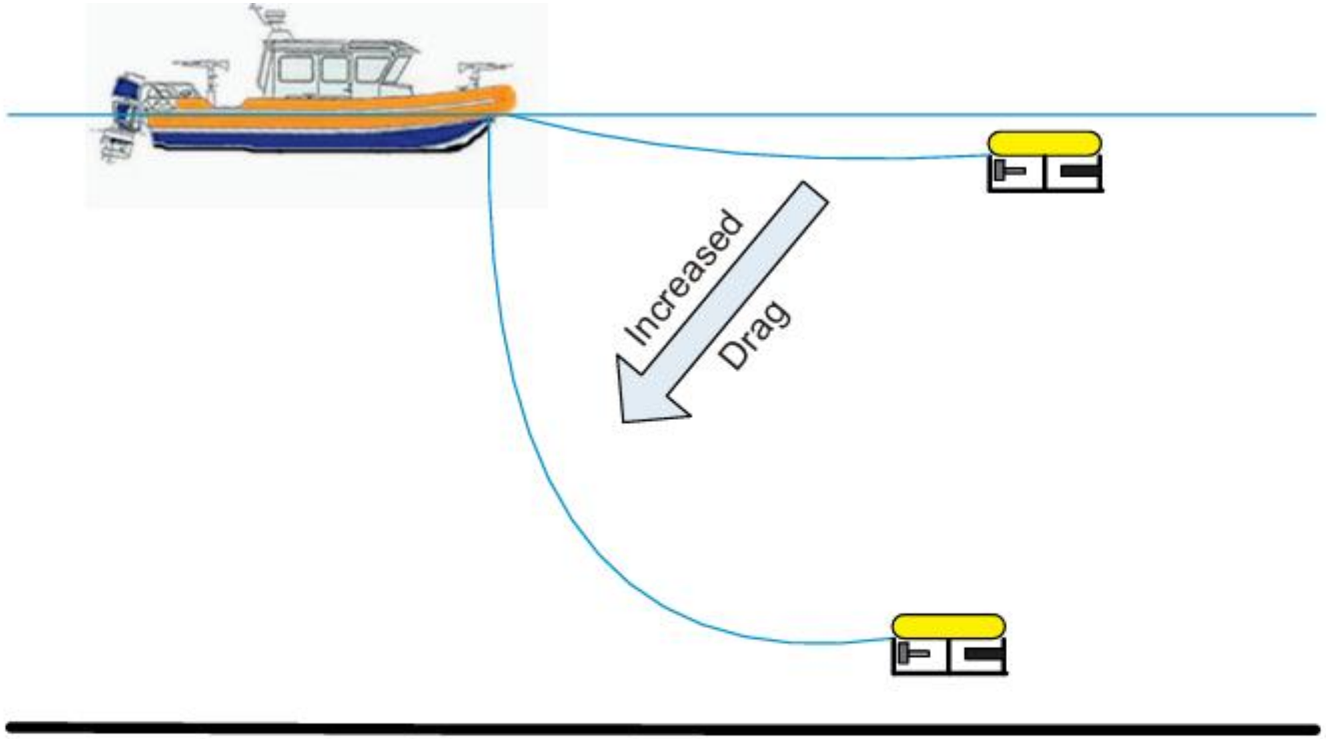
Some data to visualize…. (US coastguard to the rescue)

System and Parameter	Large ROV A	Small ROV A	Small ROV B	Large ROV B	Small ROV C	Medium ROV A
Depth rating (ft)	500	330	500	1150	500	1000
Length (in.)	24	10	14	39	21	18.6
Width (in.)	15	7	9	18	9.65	14
Height (in.)	10	6	8	18	10	14
Weight in air (lb)	39	4	8	70	24	40
Number of thrusters	4	3	3	4	4	4
Lateral thruster	Yes	No	No	Yes	Yes	No[a]
Approximate thrust (lb)	25	2	5	23	9	12
Tether diameter (in.)	0.52	0.12	0.44	0.65	0.30	0.35
Rear camera	No	No	Yes	No	No	No
Side camera	No	No	No	Yes	No	No
Generator req. (kW)	3	1	1	3	1	3

[a]*Medium ROV A possesses lateral thrusting capabilities due to offset of vertical thrusters.*



Tether drag and depth



Underwater critter control

Mr Nasty….

- Direct control:"I am driving my manned submersible in the harbor looking for sea mines when I spot Mr. Nasty protruding from the bottom within the sea lane. I directly operate the fire control button. RIP Mr. Nasty [and hopefully not yourself!]."
- Remote control (RC): "I am standing on a hill overlooking the sea lanes while operating the joystick linked to the thrusters of my ROV. I sense and control vehicle movement through line of sight as I spot Mr. Nasty floating near the surface. I direct my ROV to collide directly into the mine. RIP Mr. Nasty [and vehicle]."
- Teleoperation: "I am sitting in my air-conditioned control room in some remote location sipping a soda while operating a joystick linked to the thrusters of my ROV. I am viewing the undersea world through a camera on the ROV's nose. I see a sea mine and operate the vehicle's fire control system to shoot a projectile into the mine. RIP Mr. Nasty."
- Logic driven: "I am sitting in that same control room observing the ROV automatically navigating a series of waypoints while running a search pattern when I observe Mr. Nasty anchored to the bottom. The ROV automatically operates the fire control system. RIP Mr. Nasty."
- Logic driven with goal orientation: "I upload goal instructions (i.e., Find and neutralize Mr. Nasty.) for layering on top of the basic thruster controls, then launch my ROV [or AUV] into the morning waters of the harbor. I am at the pub in the evening sipping a beer when I receive a text from the ROV/AUV saying, RIP Mr. Nasty."

Basic thruster control

- Basic ROV mobility is achieved through control of thrusters to reactively vector fluid for vehicle movement
- For direct human control of thrusters, a joystick is normally used
- The joystick control matrix can significantly affect the ease of control over the smaller vehicle
- As the size of the vehicle increases, fine thruster control becomes less critical due to the amount of mass requiring movement
- Most ROV submersibles are designed for speeds no greater than 3 knots.
- In fact, somewhere in the speed range of 6 8 knots for underwater vehicles, interesting hydrodynamic forces act upon the system, which require strong design and engineering considerations that address drag and control issues.
- At higher speeds, small imperfections in vehicle ballasting and trim propagate to larger forces that simple thruster input may not overcome.

Auto stabilization

- With sensor feedback fed into the vehicle control module, any number of parameters may be used in vehicle control through a system of closed-loop control routines
- ROVs can use sensor input for positive navigation

Dynamic posistioning

- The basis for an ROV DP system involves the data fusion between various navigational sensors to hold position as well as move along some user-specified track
- For instance, a Doppler Velocity Log is able to sense movement across the bottom once bottom lock is gained.
- Fuse this data with a motion reference unit (basically, an inertial navigation system combined with inclinometers to sense motion relative to absolute coordinates), a gyro, North seeking compass, and acoustic positioning, and the operator is then able to precisely track the vehicle.
- Once the vehicle is in a known position, any variation from that position can be sensed, thus determining what thrust vector is required to maintain the desired orientation
- The latest developments in this field have also seen the introduction of DP systems that use a multibeam imaging sonar to keep station relative to objects within the environment

Lets get logical

- Utilizing a layer of high-level control (e.g., waypoint navigation fused with some other operational task for sensing or physical intervention) over the DP system → voila!: high-level logic driven circuit and ROV → AUV
- Utilizing another overlay layer of a goal-oriented mission planning instruction set → fully autonomous control system able to make onboard decisions toward some assigned goal
- This is the ultimate goal of roboticists worldwide, whereby machines will eventually be able to emulate man (or woman) toward a fully compliant robotic system.
- As inventor, author, and futurist Ray Kurzweil puts it, "The Singularity Is Near."

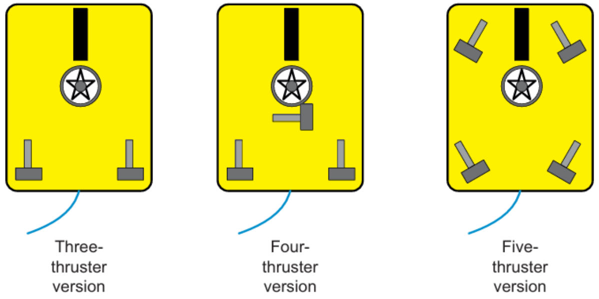
Thrusting for underwater critters

Propulsion

- ROV propulsion systems come in three different types:
  - electrically driven propeller,
  - hydraulically driven propeller,
  - (rarely) ducted jet propulsion
- The main goal for the design of ROV propulsion systems is to have high thrust-to-physical size/ drag and power-input ratios
- The more powerful the propulsion of
- the ROV, the stronger the sea current in which the vehicle can operate.
- Consequently, this extends the system’s performance envelope.
- The propulsion system has to be a trade-off between what the ROV requires for the performance of a work task and the practical dimensions of the ROV

Thruster basics

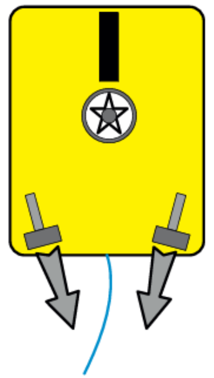
- Thrusters must be positioned on the vehicle so that the moment arm of their thrust force, relative to the central mass of the vehicle, allows a proper amount of maneuverability and controllability.
- Thrust vectoring is the only means of locomotion for an ROV.
- There are numerous placement options for thrusters to allow varying degrees of maneuverability.
- Maneuvering is achieved through asymmetrical thrusting based upon thruster placement as well as varying thruster output



Thruster basics (cont.)

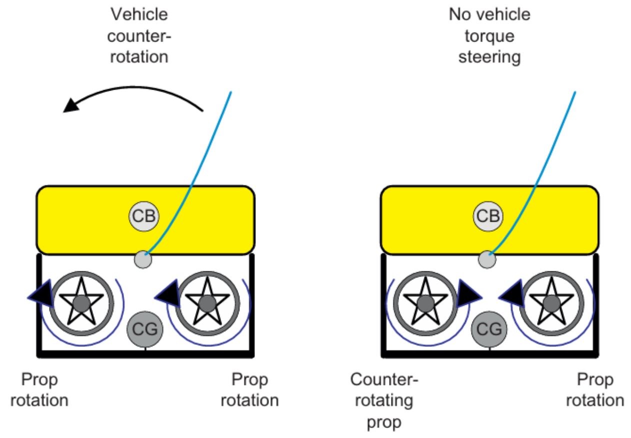
- Placing the thruster off alignment from the longitudinal axis of the vehicle will allow a better turning moment, while still providing the vehicle with strong longitudinal stability

Thruster aligned off the longitudinal axis



Torque steer

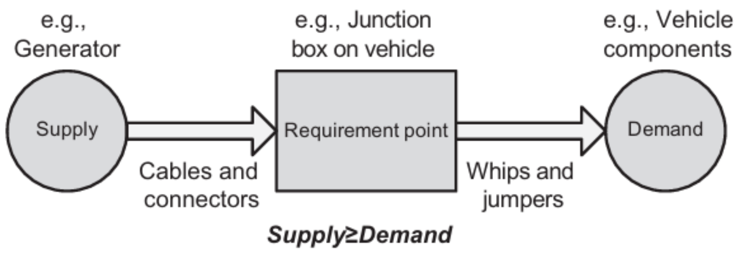
- One problem with multiple horizontal thrusters along the same axis, without counter-rotating propellers, is the "torque steer" issue
- With two or more thrusters operating on the same plane of motion, a counter-reaction to this turning moment will result
- If this roll does occur, the resulting asymmetrical thrust and drag loading could give rise to course deviations

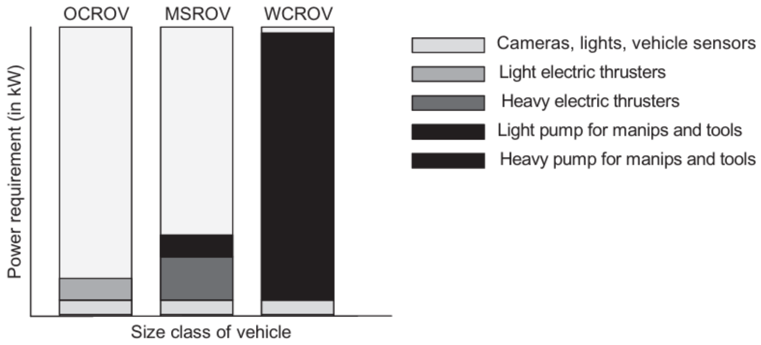


Underwater Critters have the powerrrrr

Power systems (general)

- An ROV power system is requirements driven.
- The general rule of thumb is to start with the end requirement, and then build back toward the generator to size the power source.
- Supply must be greater than or equal to the demand for the system to function as designed.
- The power requirements progression, from the smallest of vehicles to the largest, emulates a logarithmic curve





Underwater critters can manipulate

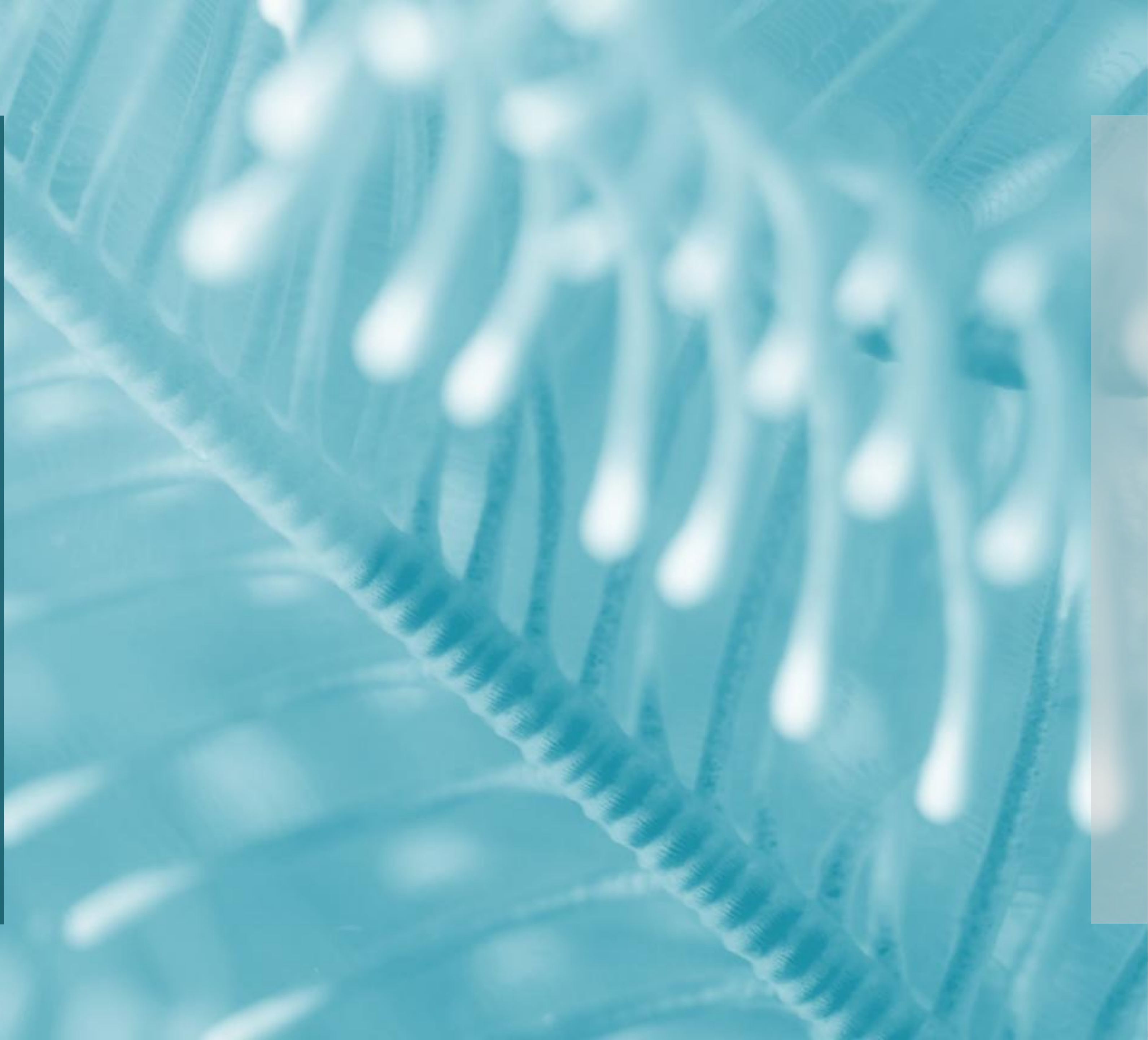
Types of manipulators: Grabbers

- Grabbers are the simplest of the manipulators available
- They usually have fewer DoF, relying on the vehicle to position them
- Since they are often required to hold the vehicle in position, often in a dynamic environment, they are usually more robust in design

Types of manipulators: Dexterous arms

- The dexterity of the arm, that is, more DoF, essentially increases its capability from that of a grabber to the more sophisticated status, that of a "manipulator."
- Dexterous manipulators generally have at least six DoF plus the end effector, which could be a tool or gripper
- Most work tasks are on the seafloor or on a vertical plane in front of the ROV.
- Therefore, the industry standard manipulator design is the backhoe or elbow-up configuration

Our Underwater critter: BlueROV presentation



Thank you very much for your attention