

How to Build a Deep Sea Robot

II The steps of doing magic

- From a scientist's demand to a diving science machine

This document is a template / course guideline / brainstorm for the interactive part of the course “How to Build a Deep Sea Robot” within the 2021 APECS-ARICE Tech Training online series and was written beforehand. The author shares it with the training participants in order to supplement the topics that could not be addressed during the training because of time issues. No claim is made to completeness.

Material / ideas / supplement thoughts that were elaborated during the training will be available through [https://docs.google.com/document/d/1ddOzqdWzfHATDmiWxH4GH7qU1o3SMpSgmzEStne-](https://docs.google.com/document/d/1ddOzqdWzfHATDmiWxH4GH7qU1o3SMpSgmzEStne-Ac0/edit?skip_itp2_check=true&pli=1#)

[Ac0/edit?skip_itp2_check=true&pli=1#](https://docs.google.com/document/d/1ddOzqdWzfHATDmiWxH4GH7qU1o3SMpSgmzEStne-Ac0/edit?skip_itp2_check=true&pli=1#) (un-edited form) until link expires.

Speaker and author: Elena Schiller, Alfred Wegener Institute for Polar and Marine Research Bremerhaven.

1 How to find out what a scientist wants

Listen closely.

Learn to speak **their language** but don't expect them to learn yours. They will use the words “benthic” and “pelagic” like they're normal words but they will say “technical drawing” when they mean “3D model”, “strong” when they mean “tough” and “heavy” when they mean “dense”.

Understand their research! Go see some of the talks they give on conferences or in group seminars. Read some abstracts of their latest papers and (if you have a high frustration tolerance!) even the methods part. Always ask when they want to do or want you to do things you don't understand.

Use this understanding to **read between the lines and anticipate** their needs like “I assume the tubings for the calibration fluid should be oxygen-tight so they don't compromise the O₂ sampling?”

Use the word “**impossible**” wisely.

2 Where to start

Don't try reinventing the wheel! Check what has already been invented: Do robots that solve tasks similar to those your scientist wants already exist?

Check what components are already at hand. Clever engineering teams have over time accumulated a set of proven-to-work **modular system components** (cameras, motors, sensor mechanics, ...), like a big (and very expensive) LEGO box of robot elements that fit well together and that you can just use.

Directly **talk** to engineering colleagues who have solved similar tasks. Marine technology is a rather young field, so the people who built today's deep sea robots are mostly still alive. It's good to build up and maintain your across-institutes **network** so that you stay up-to-date with what is being developed and you always have someone to ask.

3 Principal decisions and outlines

3.a Payload - or the main attraction

Question: What science devices do we need down there?

- cameras: “normal”, time lapse, 3D, hyperspectral, ...
- sensors: pH, temperature, depth (pressure), salinity, chemical elements, turbidity
- sample takers: water (bottles, syringes, tubes, ...), sediment (cores, sink traps, ...), suspended particles (pump and filter, fine nets, ...), fauna traps (like mouse-traps with cheese), ...
- experiment setups: respiration chambers (O_2 / CO_2 concentration changes over time, tracer induction and tracking, ...)
- manipulator arm
- altimeter, sidescan sonar, bathymeter, ...
- ...

Follow-up question: What payload support do we need?


- lights in case we want to take photos (deep sea is dark!)
- lasers, e.g. line laser for 3D cam or parallel lasers for size estimation of object on footage
- storage device (tray, box, net) in case samples are being taken
- calibration fluid if needed for repetitive measurements; incl. application system
- experiment setup cleaning device (broom? squeegee? vacuum cleaner?) if needed for repetitive experiments
- ... anything else?

3.b Benthic or pelagic – or where we stay


Question: Where do we want to do our research?

- In or on the sea floor, we are a benthic system. 


→ We need parts to stand on, like feet or wheels or chain drives. We should also be a bit heavy so we keep standing upright when the current comes


- In mid-water (water column), without contact to the sea bed. We are a pelagic system. 

→ **follow-up question: How do we manage to stay at the right depth?**

- We dangle underneath the ship on a rope. 

→ We should be pretty heavy so we hang straight down and don't get blown around by the current too much (the rope has a 'sail' effect and gets us pulled a lot)


- We dangle over an anchor like a rainbow unicorn balloon on a fair. 
 - We need to be very light and have a heavy anchor on the sea ground to tether ourselves to! (Remember: this anchor line has a 'sail' effect too)


- We float by ourselves in mid-water without any rope. 
 - We always have to be the exact weight to not sink and also not move upward. This means we need a buoyancy system.

3.c Propulsion and drive systems - or how we move

Question to the audience: How do we move in our every-day life?

Question: Do we want to stay where we are and not move at all?

- Yes and we are a benthic system 
 - Easy! We just need feet and be a bit heavy on the ground to not get blown away by the current!
- Yes and we are a pelagic system [for sketches: see above]
 - We need to be tethered somewhere. It's practically impossible to stay where you are as a free-swimming pelagic system.
 - **Follow-up question: Do we want to stay there for long?**
 - Yes, for mid- or long-term
 - We need to be tethered to a ground anchor (and be very light) because we can't expect the ship to hang around with us for long (ship-time is expensive)
 - No, only short-term
 - We can be tethered to the ship (and be heavy)

- No, we will be moving and we are a benthic system 
 - **Follow-up question: What kind of terrain are we expecting?**
 - Maybe muddy, slippery or sandy
 - Let's go for chain drives, like a tank. Then we have a good grip on the ground and we don't risk getting stuck or sinking in. With chain drives, we are not very agile and precise, however: we can't go round corners so well.

- Probably solid ground, not too rough, maybe with gravel.
→ So no risk of getting stuck or sinking in! Let's go for wheels, like a car, then! It's a bit more complicated to engineer than chain drives, but much more agile and precise in driving.
- Dunno, but wouldn't it be fancy to be the first to have a crawler with legs and feet for walking?
→ No, please don't! That's too horribly complicated!



- No, we will be moving and we are a pelagic system

→ **Follow-up question: Who makes us move?**

- The ship will drag us through the water (OFO(B)S). We are passive.
→ Easy! Just hang on a cable and be heavy.
- We happily go with the flow (Drifter). We are passive.
→ We always need to be the exact right weight, so we need a buoyancy system



- We actively glide long distances energy-efficiently but not very precisely (Glider)
→ We make ourselves heavy (for sinking) and light (for going up) to create movement and we use fins to translate this vertical movement into a horizontal movement. So we need a buoyancy system and fins.



- We want to actively dive a precise pathway. (AUV)
→ We need a good buoyancy system, a really good navigation system, thrusters and a fin for steering. (Now we're talking complex and expensive!)

3.d Communication - or what we can share through water

Question to the audience: How do we talk to each other as humans?

Question: How do we talk to our robot deep down in the sea?

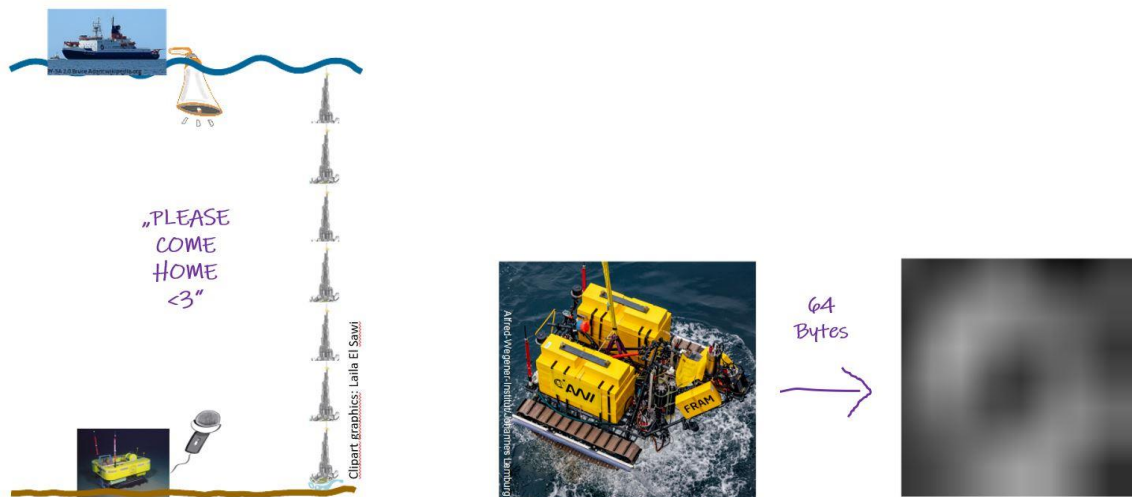
- Electromagnetic waves don't pass through sea water. So we can NOT use
 - WiFi
 - Phone network
 - Radio
 - Bluetooth

○ Cable to the ship

Pro	<ul style="list-style-type: none"> - high data transmission rates allow live imaging (see what robot sees) and live feedback (see what robot does, measures) - allows remote control (like video game: move around, use manipulator arm, ...) - allows targeted sampling, e.g. place time lapse camera at a particular angle to an individual coral and recover camera later / collect an individual sea cucumber
Con	<ul style="list-style-type: none"> - ship cannot go anywhere while robot is at work (ship time is expensive!) - cables can get entangled - cable needs to be stored somewhere (@ROV Kiel6000: own winch container!) - long cables (cable length \geq robot deployment depth!) are subject to water current ("sail" effect) -> robot needs to be very heavy or have strong thrusters to not be "blown" around

○ Acoustics: Ultrasound. Or shouting with whales.

Pro	<ul style="list-style-type: none"> - only way to communicate through water without cable at all
Con	<ul style="list-style-type: none"> - extremely low data transfer rate: 64 Bytes per message - expensive (€€.€€€€) - heavy and bulky



3.e Power supply - or how not to run out of battery

Question to the audience: What power supply options do you know?

Question: Where does our robot energy come from?

- Batteries
- Cable
- Rare, crazy options: pressurized air, exothermic chemical reaction, under-water-renewables!? ...

	Batteries	Cable
Pro	<ul style="list-style-type: none"> - robot can be autonomous / left alone (not bound to ship -> less ship time consumed) - handling on deck easier 	<ul style="list-style-type: none"> - endless energy! - more voltage options - if something goes wrong, robot can be recovered by cable - see above @Communication
Con	<ul style="list-style-type: none"> - very limited energy! - if batteries die, robot dies & is lost - super complicated paperwork: Dangerous Goods - can actually be really dangerous (fire, explosions ...)! - heavy 	<ul style="list-style-type: none"> - a lot of extra electric stuff (transformer) - see above @Communication - heavy

3.f Deployment and recovery - or how to get there and back

Deployment

Question: How do we get down there?

- Free Falling
- by Launcher
- by ROV (applies only to ROV modules)

	Free Falling	Launcher	ROV
Pro	<ul style="list-style-type: none"> - easy - cheap - quick 	<ul style="list-style-type: none"> - controlled deployment - you can see and choose where you drop your robot 	<ul style="list-style-type: none"> - highly controlled deployment (close-up HD inspection of area) - precise positioning possible - correction possible
Con	<ul style="list-style-type: none"> - robot needs to be sturdy - no control over where we land - no feedback if it landed well 	<ul style="list-style-type: none"> - needs time and space on deck - need to design a launcher or adapter and keep it updated - benefits only apply for good weather and current conditions 	<ul style="list-style-type: none"> - expensive (ROV time) - need a ROV - only works for small robots (ROV modules)

Recovery

Question: How do we come back up?

- send signal to drop weight
- autonomous, pre-programmed return dive to ship
- pick up by ROV (applies only to ROV modules)
- release by ROV (emergency option for anything but ROV modules!)

	Signal to drop weight	Autonomous return	Pick up by ROV	Release by ROV
Pro	- doesn't need ROV - can return on demand	- doesn't need communication	- robot doesn't need its own recovery system	- last resort!
Con	- needs Releaser with hydrophone (expensive, heavy) - needs drop-weight (heavy, mechanically complicated)	- if something goes wrong (your schedule changed and you can't be there to welcome it on time / an iceberg pushes itself over the robot while it's coming up / ...) your robot's lost	- expensive (ROV time) - need a ROV	- extremely expensive (spontaneous ROV time) - need a ROV

3.g Navigation - or how not to get lost

Question to the audience: How do we find our way in our daily life?

Question: How do we find our way through the deep sea as a robot?

- Just stay where you are
→ Your humans remember where they dropped you.
- Hang on a cable
→ Then at least you know you can't be far from the ship.
- Know the place
→ Deep sea robots don't know the place. They are usually the first ones to be there.
- GPS
→ doesn't work under water because GPS is an electromagnetic wave.
- Go by a map
→ What map!? Who do you think drew a map of the sea floor for you? Margin of error of normal satellite sea floor maps: several 100m! (Of course! Who's seriously interested in whether the water underneath their keel is 4318.5 or 4500 m deep?) -> usually no bottom profile information available.
- Know where you start and track where you go from there!
→ **Follow-up question: How do you track yourself?**
 - Tracking by velocity
idea: $v(t) = \frac{dx(t)}{dt}$ or rather $X(t) = \int_{start\ of\ dive}^{end\ of\ dive} v(t) dt$
Problem: How do you know your velocity v ?
Sensor: Doppler Velocity
You can measure and track your "speed in water", but that only gives you your velocity relative to the water around you, but the water around you is also moving because the

sea has currents – and you usually don't know the water current speed and direction! You can, instead (and if you're close to the ground), measure and track your "speed over ground"; as ground doesn't move, your velocity relative to the sea floor corresponds to your absolute velocity.

- Tracking by acceleration

idea: $a(t) = \frac{dv(t)}{dt} = \frac{d^2X(t)}{dt^2}$ or rather $X(t) = \int_{\text{start of dive}}^{\text{end of dive}} \left(\int_{\text{start of dive}}^{\text{end of dive}} a(t) dt \right) dt$

Precisely log what your extremely precise acceleration sensor is telling you, integrate twice over time and add these displacement vectors to your original position. The longer the dive goes, the more precision you lose.

Crazy technology!! Extremely expensive and extremely sensitive (never drop it on the floor or hit your robot against the ship's walls when the sea is rough!)

Used by military -> classified as Dual Use technology, but you're importing and exporting it by ship and plane across borders! So you have a lot of annoying paperwork to do and hassle with customs.

- Just don't care where you're going!

→ Be realistic. You don't know the place, you don't know what you will find going in any direction. Even if you find something really interesting, you won't be able to tell your humans anyway (because your communication is cut by the thousands of meters of water above you) – besides: you're not knowledgeable enough to know what is scientifically interesting and what's not, so you don't take decisions. You just do as you were told beforehand. Anyway – wherever you go, you can't go far because you're on limited batteries – unless you're meant to glide or go by the current. You don't need to know where you are or where you're going. Your humans remember where they dropped you, they know your maximum radius of motion and they know (roughly) the currents you are subjected to.

BUT: When you reach the surface, please send a satellite notice so your humans know you've arrived and where exactly to pick you up.

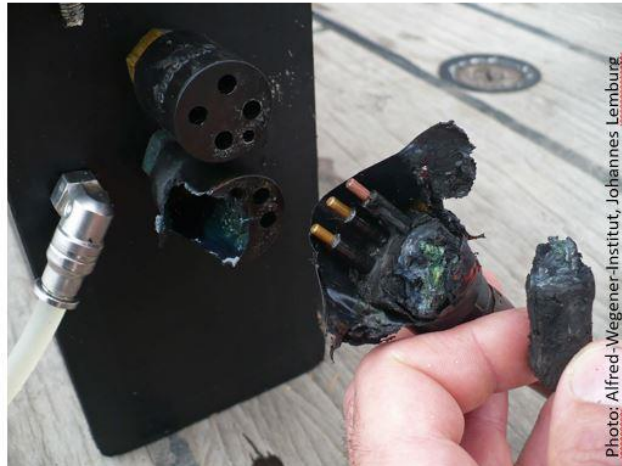
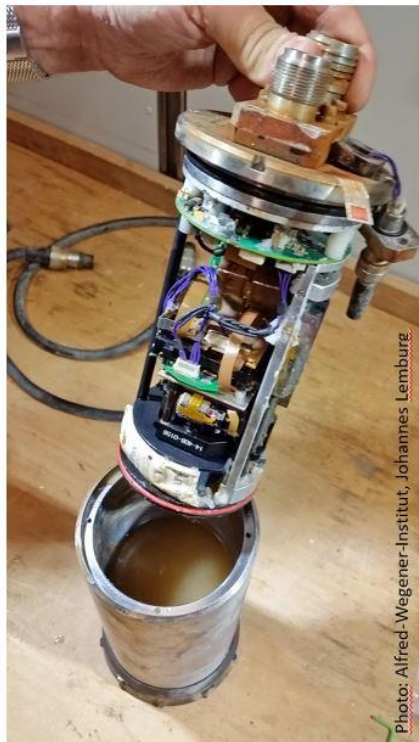
[3.h Q&A on principal decisions and outlines](#)

Need a WonderMe-break?

[Check time – maybe choose only some of the following chapters]

4 Construction design - or how to make it work

4.a Insulation - or how to waterproof electronics



Avoid this. Electronics don't like sea water.

Use O-Rings as seals and grease them well.

Use Subconn under-water electrical plugs by MacArtney! <https://www.macartney.com/what-we-offer/systems-and-products/connectors/subconn/subconn-circular-series/>

4.b Under pressure - or how to not get crushed

Gases are highly compressible. $pV = \text{const.}$

Liquids (water, oil, ...), are a bit compressible under deep sea pressure, but for the sake of simplification let's say they're not.

Solids (metals, plastics, glass, ...) are incompressible (at least let's consider them as such, also for the sake of simplification).

→ Solids and (to some extent) liquids don't care about pressure – So you don't have to worry about them.

Spaces filled with gas, however, will try to become smaller when pressure becomes higher.

(Deconstruct your concept of 'emptiness'! When you land-based humans say 'empty', you mean 'gas-filled') If your enclosure does not allow for this change of volume, the water pressure will exert very high forces on your enclosure and try to crush it.

→ Gas enclosures need to be protected against pressure by a pressure housing!

→ really sneaky work-around: pressure compensation!

Idea: You fill all “empty” space with oil! This way you don’t have gas enclosures, so nothing can get crushed.



Question: How do I protect my robot element from crushing?

- It’s just a solid (or a liquid)
→ no pressure protection needed
- Pressure compensation
- Pressure housing

	Pressure compensation	Pressure housing
Pro	<ul style="list-style-type: none"> - cheap - easy manufacturing - light - transparent housing (you can check if the inside is okay without opening it) 	<ul style="list-style-type: none"> - clean - you can put any standard electronic / optical device inside
Con	<ul style="list-style-type: none"> - liquid spills all over the place when you open it for maintenance - only works if your liquid doesn’t chemically interact with your device inside (some motors have a problem with oil here) - doesn’t work for optical devices (cameras, lights, ...) because they are built along the optical properties of air, not of your compensation liquid 	<ul style="list-style-type: none"> - expensive - heavy - be careful to not scratch O-ring contact surface!

4.c Corrosion - or how not to build a battery

The sea is a giant big pool of electrolyte!



Photo: Alfred-Wegener-Institut, Johannes Lemburg



Photo: Alfred-Wegener-Institut, Johannes Lemburg

Avoid this.

→ Check out Galvanic Series: https://www.google.com/search?q=galvanic+series&client=firefox-b-d&source=lnms&tbm=isch&sa=X&ved=2ahUKewjzv5GLutXvAhULtKQKHd7BDFEQ_AUoAXoECAEQAw&biw=1536&bih=722#imgsrc=xdxvFNTbwTa-JM

But why are they conflicting!? → difference: chemical and technical galvanic series. We need the technical one.

... You know what? Forget about Galvanic Series & tables & numbers! Just ask experienced deep sea robot engineers about their experience.

4.d Materials - or what it's made of

Question to the audience: What materials do you know?

Question: What materials can I use to build my deep sea robot?

material	resilient to sea water?	strong?	light?	other / comment
normal steel	--	++	--	used as ballast for drop-weight
stainless steel	-	++	--	easy to work with
aluminium	-	+	-	
eloxated aluminium	+	+	-	don't scratch!
titanium	++	++	-	expensive, difficult to work with: destroys tools, burns, ...
wood	-	-	+	swells in water, organic material
GfK	++	+	0	unhealthy to work with
CfK ('Carbon')	++	+(cond.)	+	expensive, unhealthy to work with, need to know how to use, otherwise unpredictable!!
POM	++	-	0	easy to work with
PE	++	--	++	
concrete	++	+(cond.)	--	

glass	++	++	-	used for pressure housings and buoyancy spheres
syntactic foam	++	-	++	expensive, unhealthy to work with, lightest deep-sea material → used for buoyancy

GfK ... glass-fibre reinforced plastics

CfK ... carbon-fibre reinforced plastics

POM ... Poly-Oxy-Methylene; a plastic

PE ... Poly-Ethylene; a plastic

Question to the audience: Do you know what 'fibre-reinforced compound materials' means?

fibre-reinforced compound materials: think paintbrush.



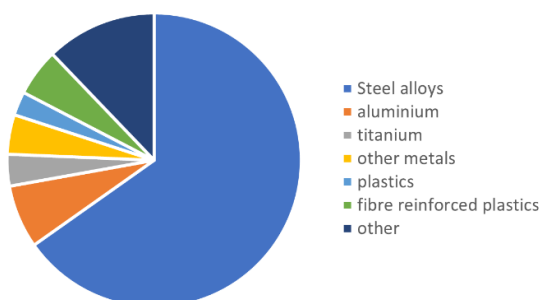
Beautifully soft
paintbrush fibres

paint

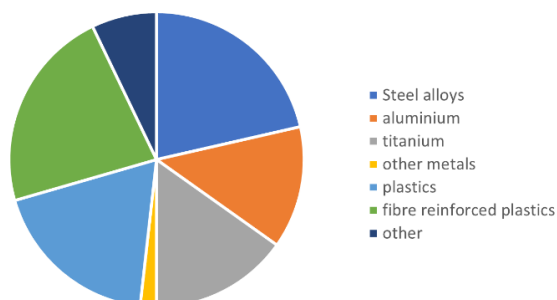
fibre-reinforced
composite

My problem (totally unscientific data, just visualisation of what I feel)

material studied at university



materials used for deep sea robots

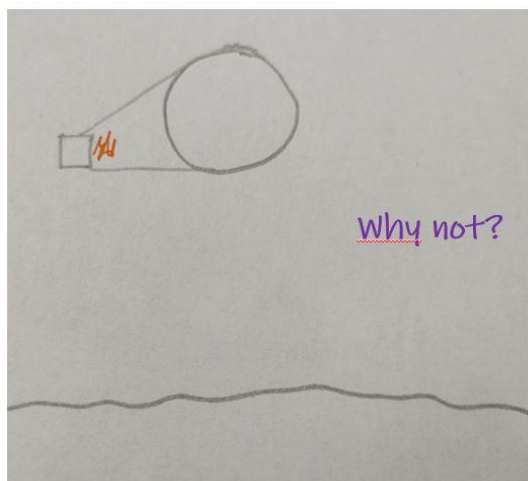
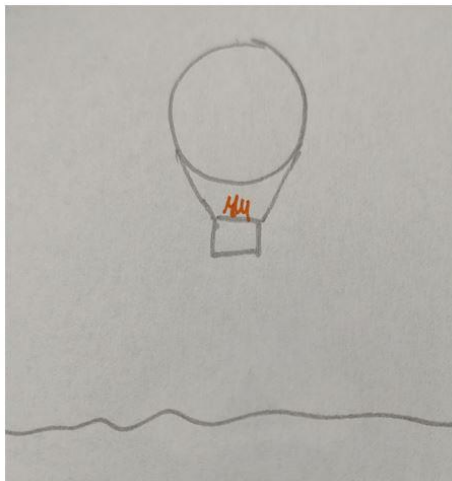


Knowledge mismatch ...

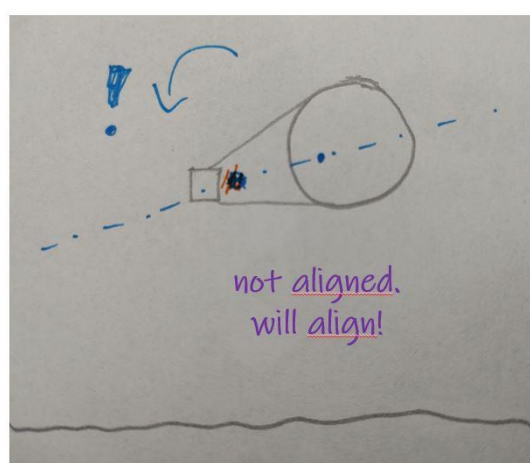
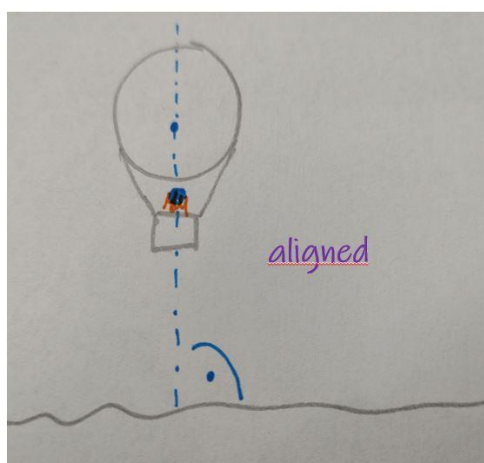
4.e Buoyancy - or what weight means under water

Mass pulls us down. Volume pulls us up.

Task for the audience: Please sketch a hot-air-balloon romantically carrying humans across the sky.



Center of mass and center of volume will always align.



Task: Build your robot in a way that it has the right density (mass per volume) and that it's in the right position when center of mass is directly under the center of volume.

→ arrange heavy (high-density) components where you define 'down' and light (low-density) components where you define 'up'!

→ arrange heavy (high-density) and light (low-density) components equally (left/right/front/back) around where you define 'center'

→ in total, you have to come out at a density of $\approx 1 \text{ g/cm}^3$ (if you want to float in mid-water: adjust exactly to density of surrounding sea water; if you're benthic or you want to move downward: be denser than that; if you want to move upward: be less dense), so you're not free to just add heavy things or buoyancy foam wherever you need it ...

This is actually the most tricky sudoku-like brains-consuming physical boundary condition!!!

4. f Q&A on Construction Design

Need a WonderMe-break?

[Check time]

5 3D modelling - or how to show a scientist what you intend to build

[open SolidWorks]

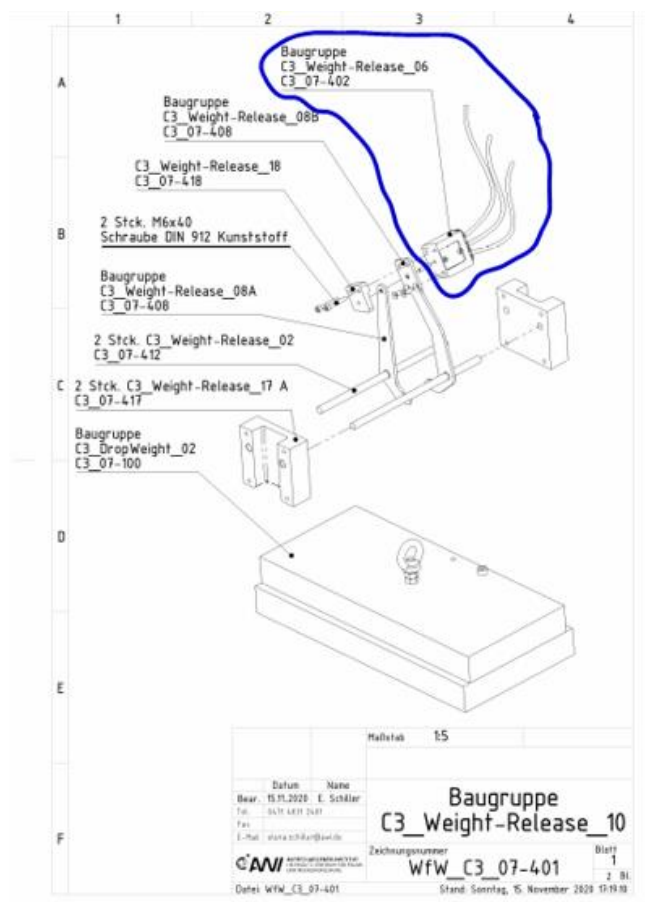
First time scientist gets to see what you have been working on all this time!

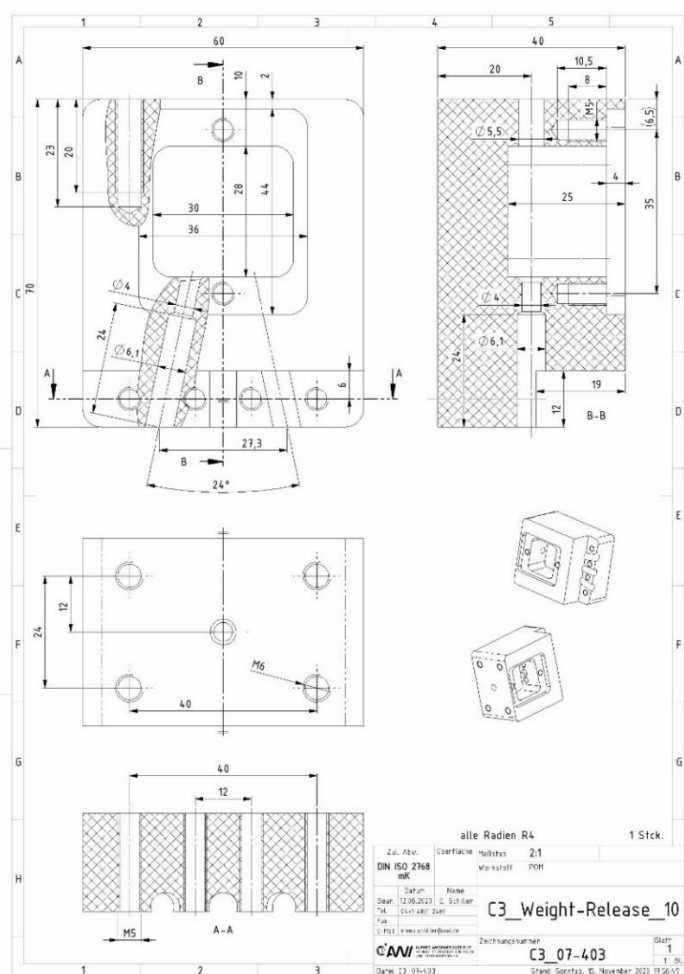
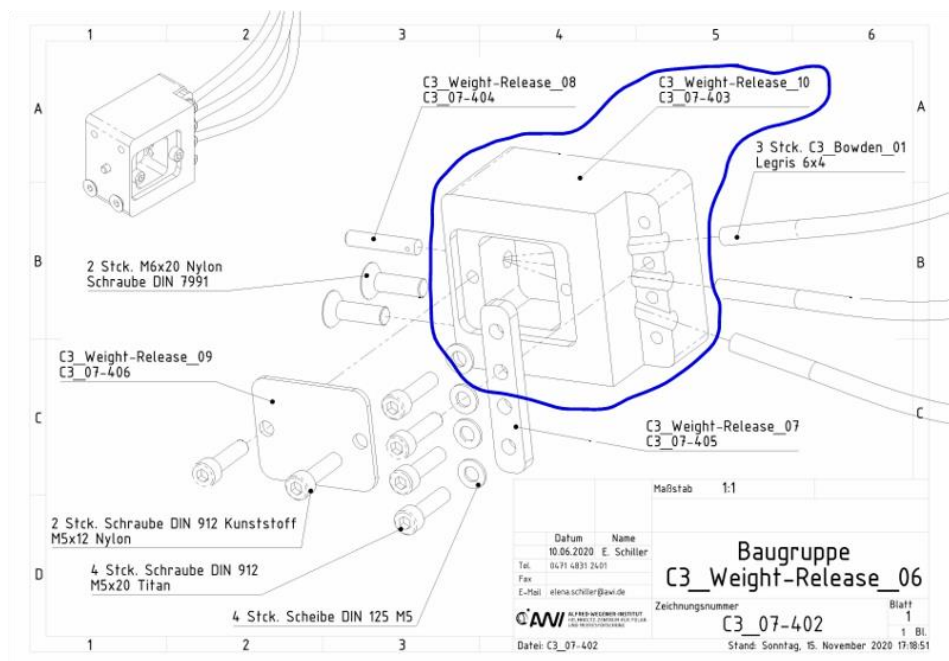
6 Technical drawings and manufacturing - or how to make it real

[show TechDrawings]

Repetitive diligence work!

Implies a lot of DIN norms, details that mean a lot ... technical drawings are like a language.





7 Assembly and tests - or how not to panic

[Video DropWeightMech]

[Video Crawler III in Water]

8 Deployment at sea - or how not to totally panic

[Video Nomad Drop]

Thank you for your attention 😊