EXTREME BOLTING PROJECT

AUTOMATED SUBSEA BOLTING

Simon Linge
MFA Advanced Product Design Programme
Umeå Institute of Design, Umeå University
2017

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5ID096 Design Methodology

Supervisor:
Thomas Degn

Acknowledgements:
Christer Bülow
Ola Stray
Erik Borg
Dan Tore Olsen
the workshop personnel at UID
APD1 class of 2016

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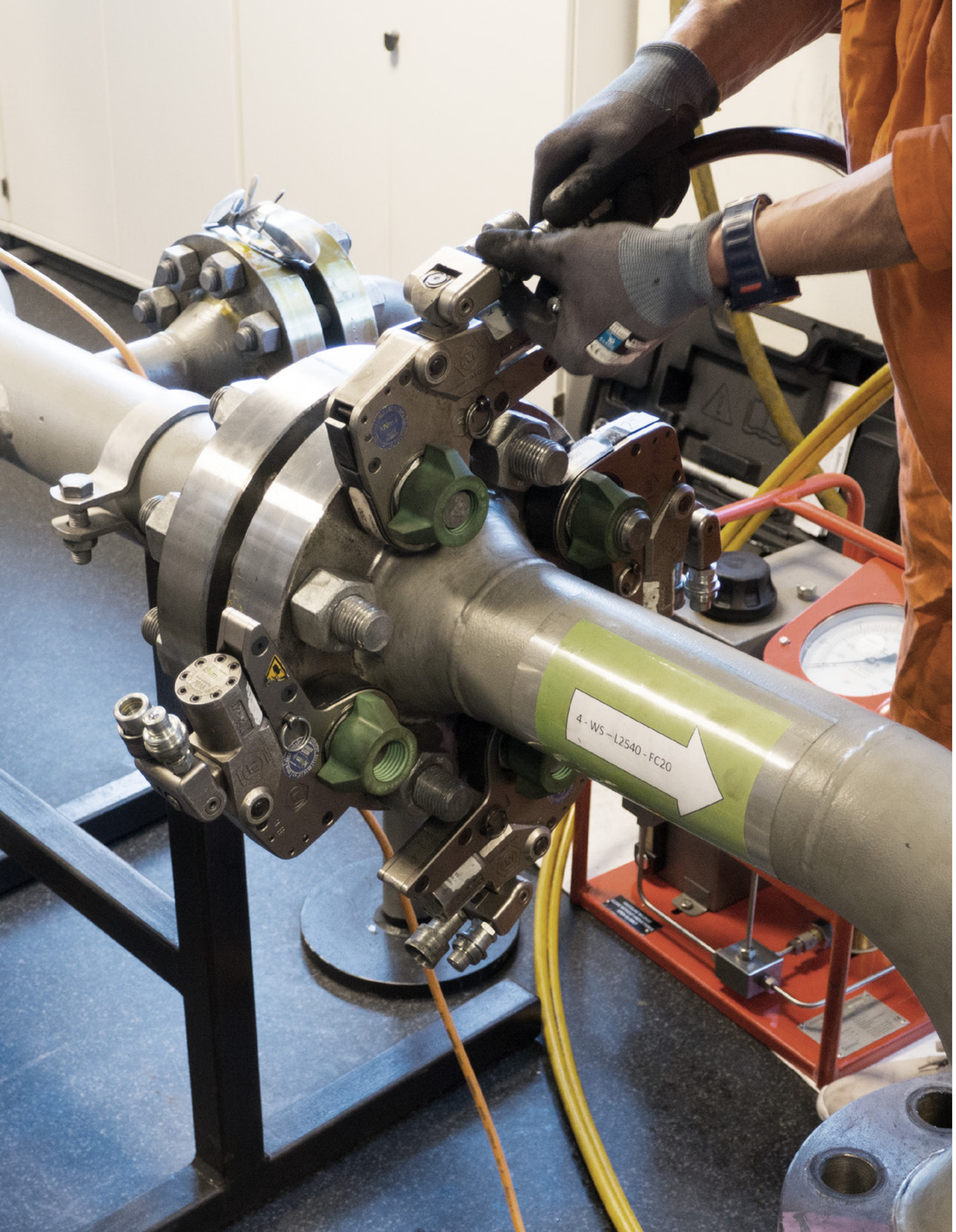


ABSTRACT

This project focuses on how the sub sea bolt tensioning procedure can be improved with the help of automation and robotics in the form of a remotely operated underwater vehicle (ROV). The resulting concept envisions a superior alternative to the current standard in sub sea bolting. The benefits are based on the fact that a human no longer need to be exposed to the dangers of deep diving, as well as crucial functions that are only possible in an automated system.

The work is based on a field trip that was conducted in cooperation with and sponsored by Atlas Copco with an end goal to explore new ways of developing hydraulic bolt tensioning tools. Atlas Copco has been available for feedback during various milestones during the project.

The final solution that is presented in this report is substantially faster and safer than the current diving methods and make the bolting solution more flexible, both in regards of time and actual bolting scenario. The lack of human intervention also reduces costs that may financially motivate the development and retail of this product.

INTRODUCTION

The principle of joining two parts with a nut and a bolt is prevalent in an enormous array of products, from minute electronics to vast bridges. The size of the nuts and bolts vary according to the load that they need to withstand. This project concerns the more extreme cases of bolt tightening that are applied in the assembly of wind turbines and oil platforms, to mention some applications.

Atlas Copco has been involved as a sponsor and advisor in this project. They recently acquired a series of companies that specialize in hydraulic tools and they currently offer a range of bolt tightening solutions, their more traditional electric and pneumatic solutions and their new line of hydraulic tools.

Atlas Copco is a Swedish industrial company that was founded in 1873. Atlas Copco companies develop, manufacture, service, and rent industrial tools, air compressors (of which it is the world's leading producer), construction and mining equipment such as rock drills, assembly systems. The Group operates in four areas: Compressor Technique, Mining and Rock Excavation Technique, Construction Technique and Industrial Technique. [1]

The main benefits of hydraulic tools is that they can apply greater force in a smaller package with superior precision compared to other systems. Atlas Copco's interest in this project lies in how their newly acquired tools can be improved, especially their usage scenarios.

A sub sea bolt tensioner (right) and a series of conventional bolt tensioners in various sizes (above) that Atlas Copco currently offer [2]

1. https://en.wikipedia.org/wiki/Atlas_Copco
2. The image are courtesy of Atlas Copco

The demonstration rig for hydraulic tools at Atlas Copco headquarters, Stockholm

METHOD

FIELD TRIP

A field trip was arranged in order to for the students to understand the tools Atlas Copco offers and to get acquainted with the users of said tools. The trip started with a visit at Atlas Copco headquarters in Stockholm, Sweden. The class was received by Christer Bülow, Business Development Manager, and Ashish Malhotra, Global Product Manager.

The visit at Atlas Copco's facilities in Stockholm provided a basic understanding of how the tools work as well as their benefits and issues. A seminar regarding ergonomics were also presented.

The Human Centered Design Toolkit developed by IDEO acted as a guide for the multiple interviews during the trip in order to gather as much user information and reflections as possible.

Human-Centered Design (HCD) is a process and a set of techniques used to create new solutions for the world. Solutions include products, services, environments, organizations, and modes of interaction. The reason this process is called "human-centered" is because it starts with the people we are designing for. The HCD process begins by examining the needs, dreams, and behaviors of the people we want to affect with our solutions. We seek to listen to and understand what they want. [1]

The field trip continued to Stavanger, Norway since one of Atlas Copco's suppliers of hydraulic tools are based there; kNm Hydraulikk. Christer Bülow and Erik Borg, an in-house industrial designer at Atlas Copco, joined for the rest of the trip since they, too, appreciated the chance to encounter the users of their tools. A visit at a manufacturer was arranged as well, Wepco, that use hydraulic bolting tools daily.

Hydraulikk is a knowledgeable and experienced provider of services and products within bolt tightening. They provide Atlas Copco bolting tools. This offer consists mainly of hydraulic torque tools and hydraulic tensioner tools. They provide rule-based training programs and courses in accordance to Norwegian Oil and Gas's guidelines. kNm Hydraulikk has people with extensive experience from field work both onshore and offshore. [2]

Wepco AS was established in 1986 and is today a modern and well-equipped service workshop with highly qualified personnel. Highly qualified employees and modern machinery makes us able to take on assignments that require a very high precision and quality level. Wepco serves customers with high demands for flexible production, short delivery and high quality. [3]

Since the people that we met at kNm and Wepco are veterans from the Norwegian oil and gas industry, they provided another perspective on the tools. They elaborated on some of the issues that they had found with the tools during their long-time usage of them, which always is interesting.

There was also and opportunity to visit an oil excavation museum in Stavanger, The Norwegian Oil Museum. This provided interesting information on the history of the Norwegian oil industry and it's impact on Norwegian society.

1. https://botfl.nd.edu/pdf/IDEO%20Human%20Centered%20Design%20Toolkit.pdf
2. http://www.knm-hydraulikk.no/om-knm-hydraulikk
3. http://www.wepco.no/en-moderne-verksted-maskinering-og-produksjonsbedrift/

PROBLEM ANALYSIS

Once back in Umeå after the trip, there followed a week of group work in order to digest and sort the information that was gathered during the study visits. Supervised by Thomas Degn, the class was divided into smaller groups at different stages during the week.

One of the main tasks was collecting, sharing and educate each other on what tools that had been encountered and how they work. Another was describing a believable persona in order to create a holistic view of the users featured in this project. A third one was acting out a scenario, again based on a persona, and one or more conceptual tools that would benefit that persona in some manner. There were also several sessions where quick product concepts were ideated, shared and discussed amongst the class.

These exercises served to produce ideas for how the bolt tensioning environment could be improved and some of those ideas served as underlay for some of the students' product concepts.

Visualizing the story about the persona (above) [1] and the collective ideation (below) [2]

1. Image courtesy of Melissa Mahmutovic
2. Image courtesy of Pontus Edman

Several issues were identified by the collective analysis. These ranged from minor usability problems with the current tools to more systematic issues.

The bolt tightening process may be divided into a set of steps in order to illustrate this. In this project they are referred to as logistics, setup and operation. Logistics concerns the carrying of the tools by the operator from the storage space to the location where the operation will take place, e.g. a flange on an oil rig. The next step is the setup of the tools required in order to carry out the operation. This involves connecting the pump and hoses to the tools and placing the tools correctly. The actual tightening, the operation, is then carried out. This step is usually the fastest, but the most important to get right. The setup and operation is repeated several times at different positions and bolt loads, e.g. moving along a flange in order to get a uniform tightening.

All of these steps currently require heavy manual labor, especially the logistics and setup of the tools. This is cause for injuries among the operators, such as joint pain in the wrists. This is worsened by the fact that the work is often carried out in unergonomic positions, depending on the shape of the pipe joints. The tools themselves also consists of several smaller parts that, beside adding to the labor, may create a dangerous or irritating situation if they are dropped.

"These tools are so heavy!"

- Dan Tore Olsen, kNm

Dan Olsen demonstrating the currently straining bolt tightening process at kNm Hydralikk

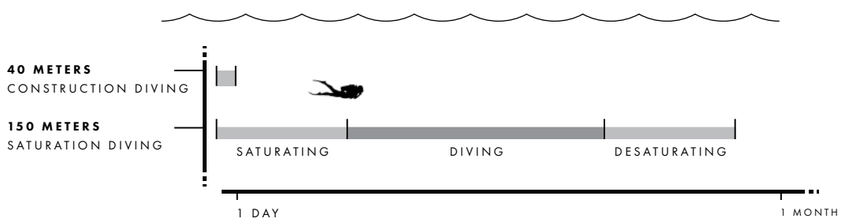
There is a specialized field within bolt tensioning which is called subsea bolting. This entails all of the procedures normally affiliated with bolt tensioning, with the addition of every step of the tensioning process being carried out under water several miles off-shore. It is reasonable that this result in an already complex procedure being even more straining for the operator. Fortunately, there are tools that, due to the increased difficulty, can assist the operating divers, to a point. One of these tools are the specialized sub sea bolt tensioner that was presented in the introduction.

The diving equipment used for offshore work is chosen to facilitate the work to be done while exposing the personnel involved to an acceptably low level of risk. When reasonably practicable, use of remotely operated underwater vehicles is preferred, as this avoids exposing the diver to underwater hazards. There is still a large amount of underwater work for which diver intervention is the only available alternative. [1]

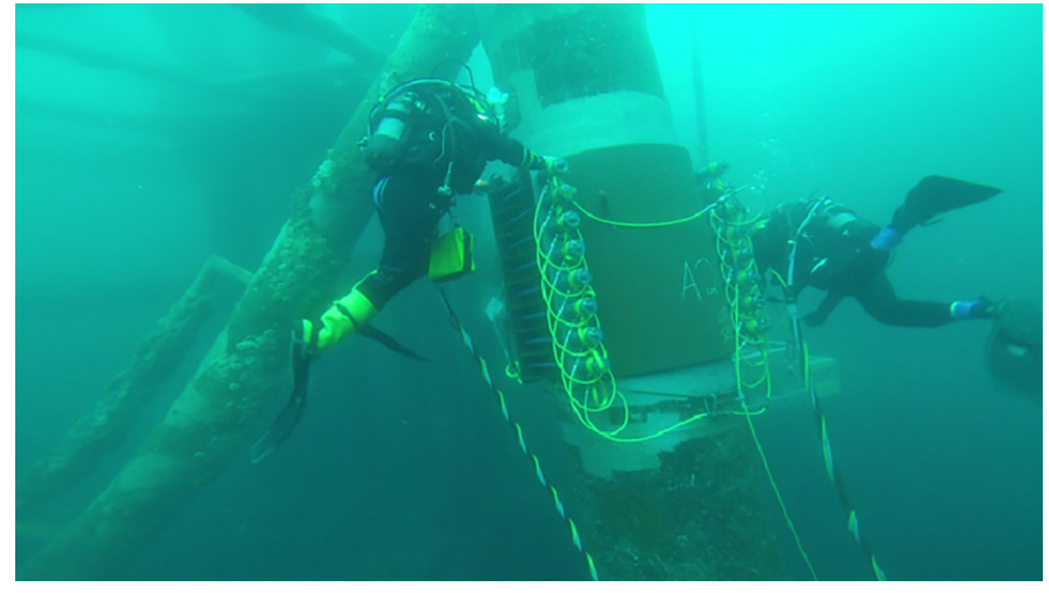
The divers that are referenced in this context are not ordinary diving professionals. Most professional divers are called construction divers and work at maximum depth of 40 meters. However, due to the nature of sub sea bolting, the divers that work within this field face much harsher conditions. They perform a sort of diving that is called saturation diving. This allows them to dive to depths of up to 150 meters.

Saturation diving is a diving technique that allows divers to reduce the risk of decompression sickness when they work at great depths for long periods of time. Decompression sickness occurs when a diver with a large amount of inert gas dissolved in the body tissues is decompressed to a pressure where the gas forms bubbles which may block blood vessels or physically damage surrounding cells. This is a risk on every decompression, and limiting the number of decompressions can reduce the risk. "Saturation" refers to the fact that the diver's tissues have absorbed the maximum partial pressure of gas possible for that depth due to the diver being exposed to breathing gas at that pressure for prolonged periods. This is significant because once the tissues become saturated, the time to ascend from depth, to decompress safely, will not increase with further exposure. In saturation diving, the divers live in a pressurized environment, which can be a saturation system or "saturation spread", a hyperbaric environment on the surface, or an ambient pressure underwater habitat. This may be maintained for up to several weeks, and they are decompressed to surface pressure only once, at the end of their tour of duty. By limiting the number of decompressions in this way, the risk of decompression sickness is significantly reduced. Increased use of underwater remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) for routine or planned tasks means that saturation dives are becoming less common, though complicated underwater tasks requiring complex manual actions remain the preserve of the deep-sea saturation diver. [2]

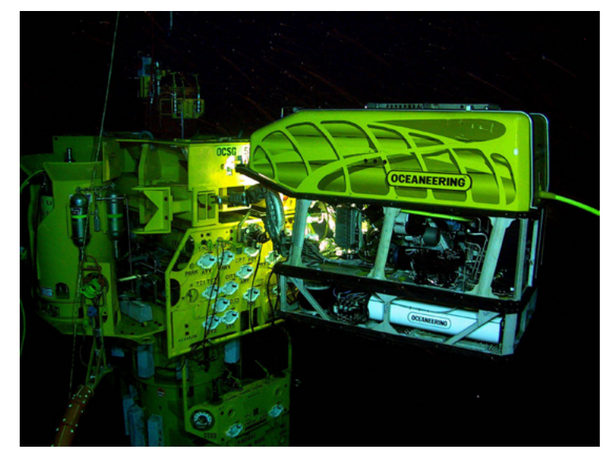
Due to the dangers involved and the long working shifts, saturation diving is also very expensive in order to compensate the divers adequately.



1. https://en.wikipedia.org/wiki/Commercial_offshore_diving
2. https://en.wikipedia.org/wiki/Saturation_diving

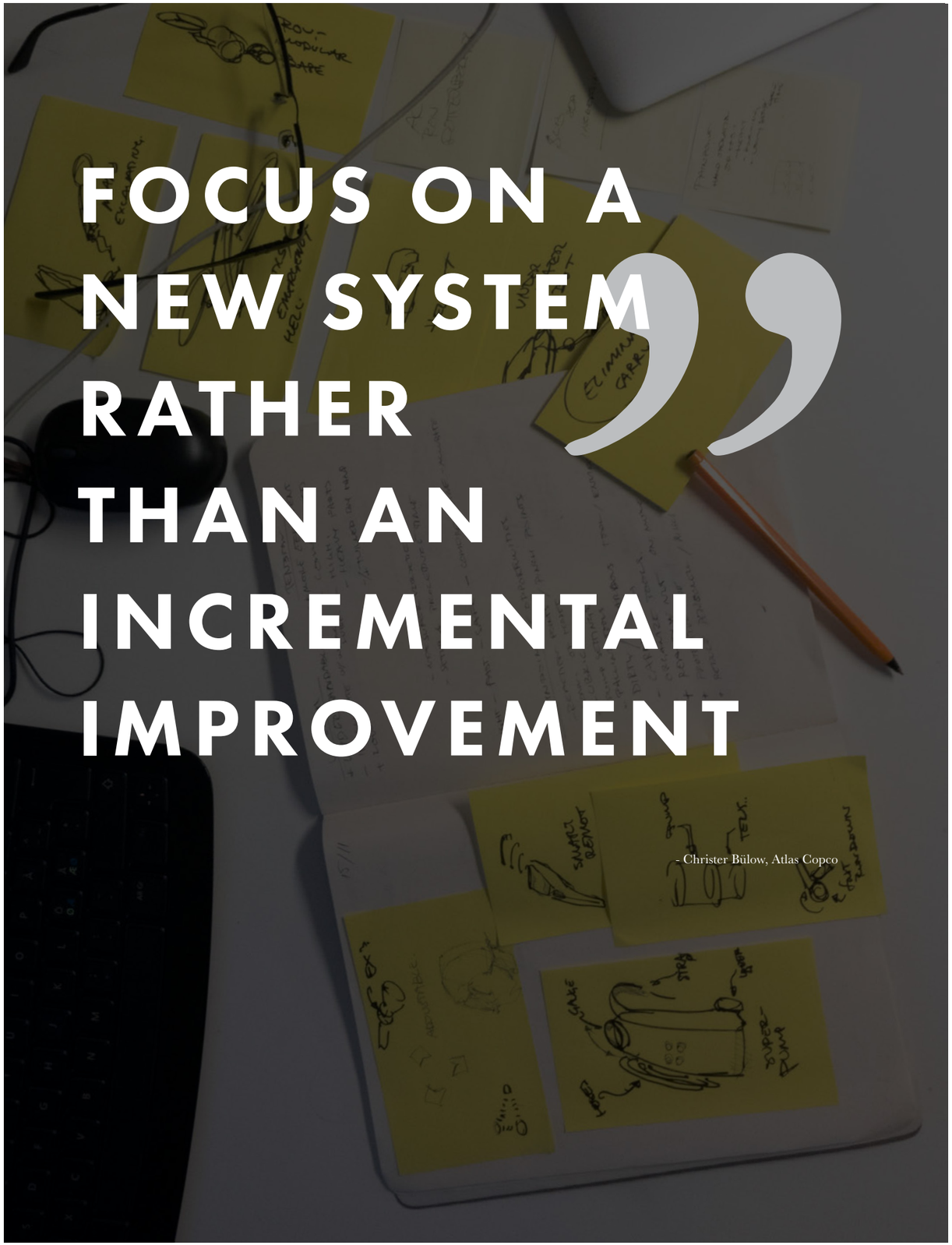


A team of off-shore divers using Atlas Copco's sub sea bolt tensioners. [1]



A ROV at work in an underwater oil and gas field. The ROV is operating a subsea torque tool (wrench) on a valve on the subsea structure. [2,3]

1. http://www.atlascopco.com/microsites/Images/Atlas_Copco_Bolt_Tightening_Solution_-_Subsea_tensioners_ac0072060_707.png
2. https://upload.wikimedia.org/wikipedia/commons/9/99/ROV_working_won_a_subsea_structure.jpg
3.https://en.wikipedia.org/wiki/Remotely_operated_underwater_vehicle



FOCUS ON A NEW SYSTEM RATHER THAN AN INCREMENTAL IMPROVEMENT

- Christer Bülow, Atlas Copco

DESIGN OPPORTUNITY

AUTOMATED SUBSEA BOLTING

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This project focuses on how the sub sea bolt tensioning procedure can be improved with the help of automation and robotics in the form of a remotely operated vehicle. The expansion of technology in this field could help sidestep several of the pain points that became apparent during the field trip and the collective and individual analyses.

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IDENTIFIED ISSUES WITH CURRENT SUB SEA BOLTING SCENARIO:

- **DANGEROUS**
- **SLOW TENSIONING PROCEDURE**
- **EXPENSIVE**
- **SLOW TO DEPLOY**

•

GOALS AND WISHES

DESIGN A PRODUCT THAT...

- IS A REMOTELY OPERATED VEHICLE
- OPERATES UNDER WATER
- CAN REPLACE THE DIVERS
- CAN PERFORM THE ENTIRE TENSIONING PROCEDURE
- MAKES SUBSEA BOLTING FASTER AND SAFER
- INCORPORATES ATLAS COPCO'S FORM LANGUAGE

THAT MAY ALSO...

- TAKE CURRENT SUBSEA WORKFLOW INTO CONSIDERATION
- ACT INDEPENDENTLY FROM CREW
- FEATURE VIRTUAL REALITY AS AN INTERFACE
- BE OPTIONALLY INTERACTIVE WITH DIVERS
- EXPLORE ADDITIONAL MARKET SEGMENTS FOR ATLAS COPCO
- REJUVENATE THE STAGNATED ROV MARKET

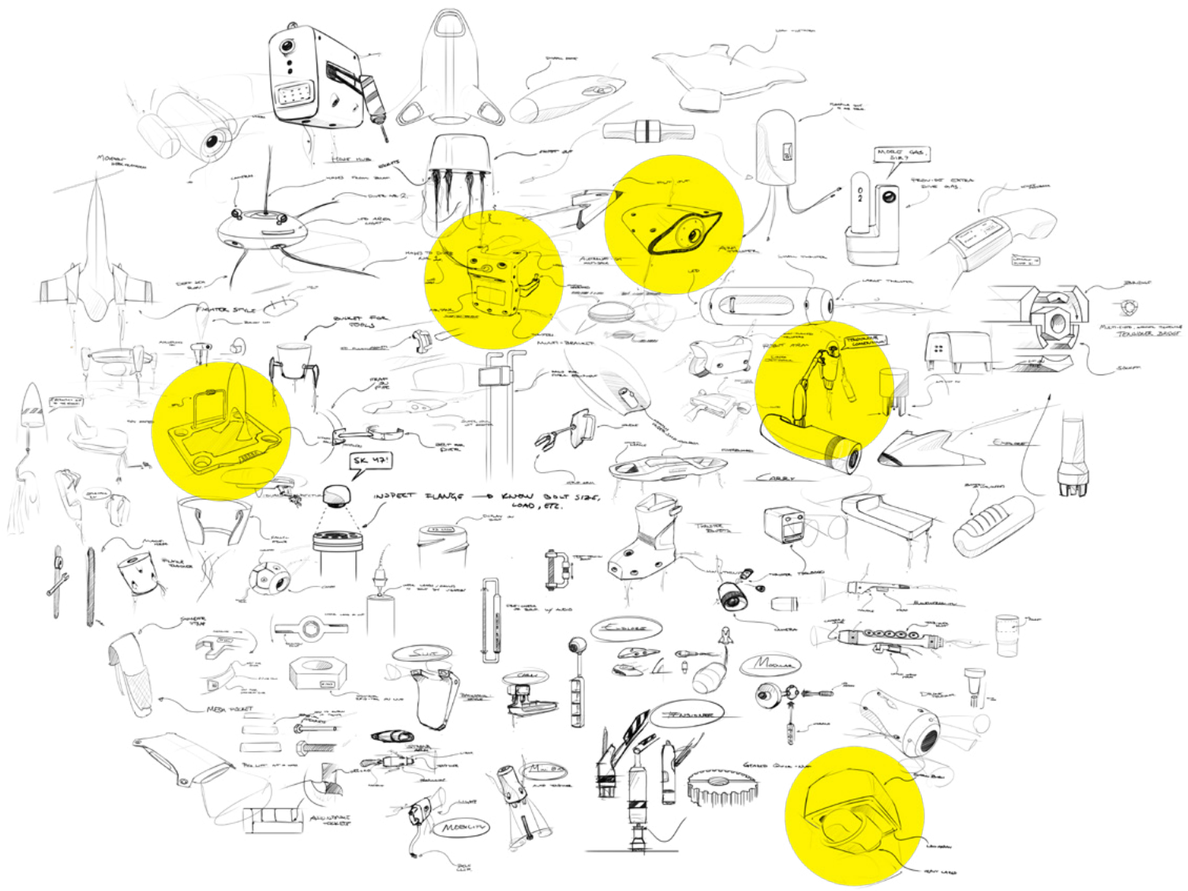
IDEATION

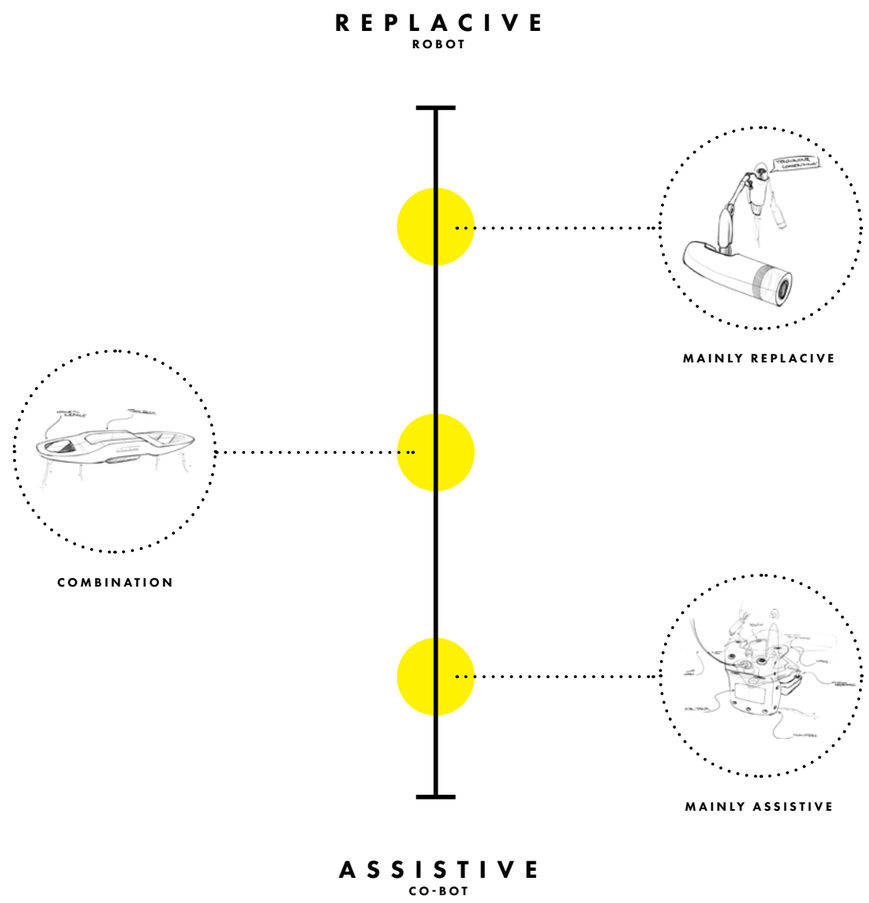
The ideation phase had a focus on sketching since there were a lot of factors that were open to the imagination to solve. The scenario, functionality and form of the design lacked a specific point of reference, which meant that these needed to be defined. In order to achieve that definition, a series of identified issues were specified. Their purpose was to get familiar with the project and explore different concepts and ideas.

A selection of the primary problem areas were:

- Heavy lifts required to handle the tools
- Reduced speed under water
- Storage and transport of equipment
- Lack of leverage for applying force

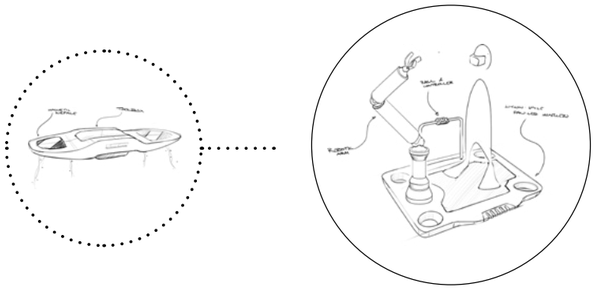
These subjects served as the origin for the first batch of ideation sketches.





The range of technologies that this product could incorporate soon proved to be the quite wide. One way of categorizing these technologies, and as a result the product it self, is wether they created a product that would be assistive to the divers or replace them entirely. Both direction had strong merit. There are some tasks that an autonomous robot probably never could do, at least in a cost effective way, like taking a crucial intuitive decision, thus divers will always be needed to some extent. The most efficient way of improving the bolting scenario may then be to help the divers perform their tasks in a more efficient way.

The replacive direction has the big advantage of speed to compensate for the lack of human insight since divers need to be pressurized slowly for a long period of time in order to handle deep diving. Still, divers normally only dive to depths of 150 meters while ROVs can without much difficulty exceed this and reach depths of so much as 6000 meters.

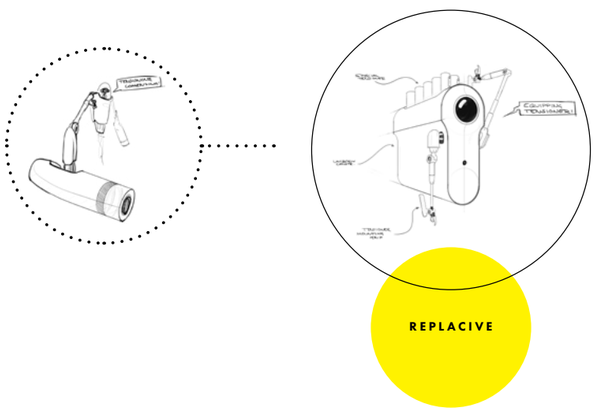


+ IMPROVE DIVER'S WORKFLOW
+ COULD WORK WITH AND WITHOUT DIVER

+/- MAY FACILITATE DRIVER

- COMPLEX
- LARGE
- ROBOTIC DEVELOPMENT STILL NEEDED
- LONGER TOTAL PROCESS TIME THAN REPLACIVE

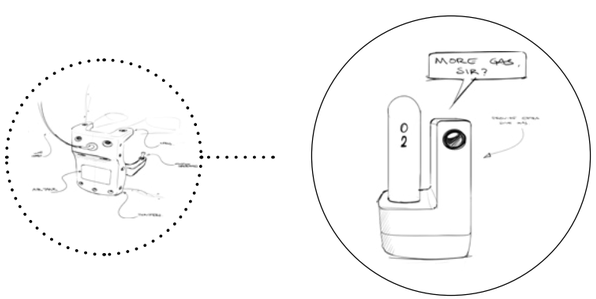
COMBO



+ NO DIVER REQUIRED
+ FASTER TO DEPLOY
+ SAFER
+ CHEAPER OVER TIME
+ SIMILAR PRODUCTS EXIST TODAY
+ CAN BE MADE COMPACT

- "SKYNET FACTOR"

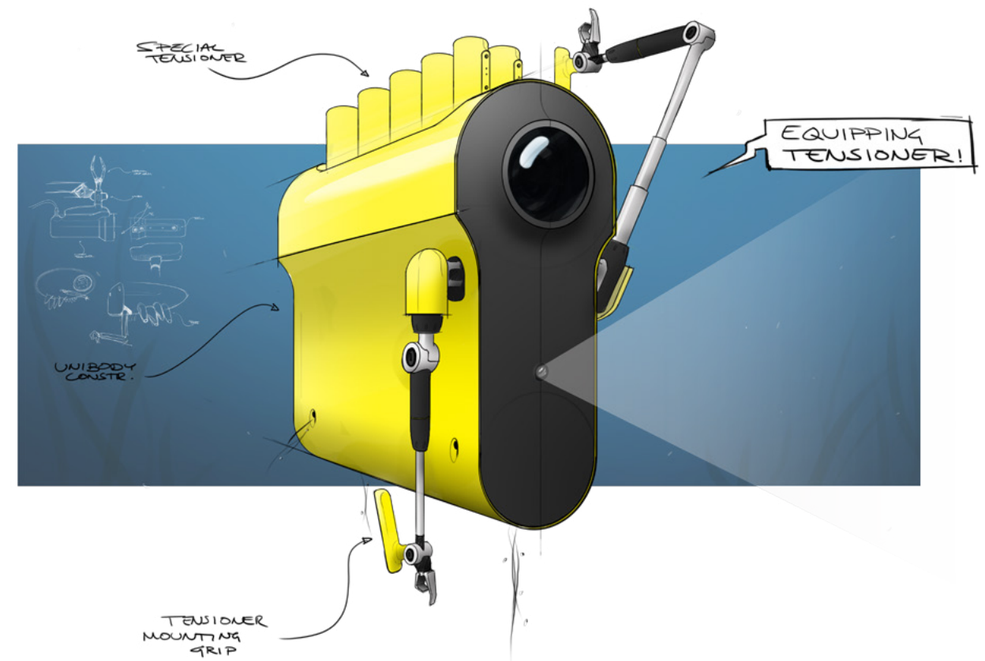
REPLACIVE



+ IMPROVE DIVER'S WORKFLOW

- STILL REQUIRE DIVER
- LONGER TOTAL PROCESS TIME THAN REPLACIVE
- SIMILAR TO MOST ROVS

ASSISTIVE



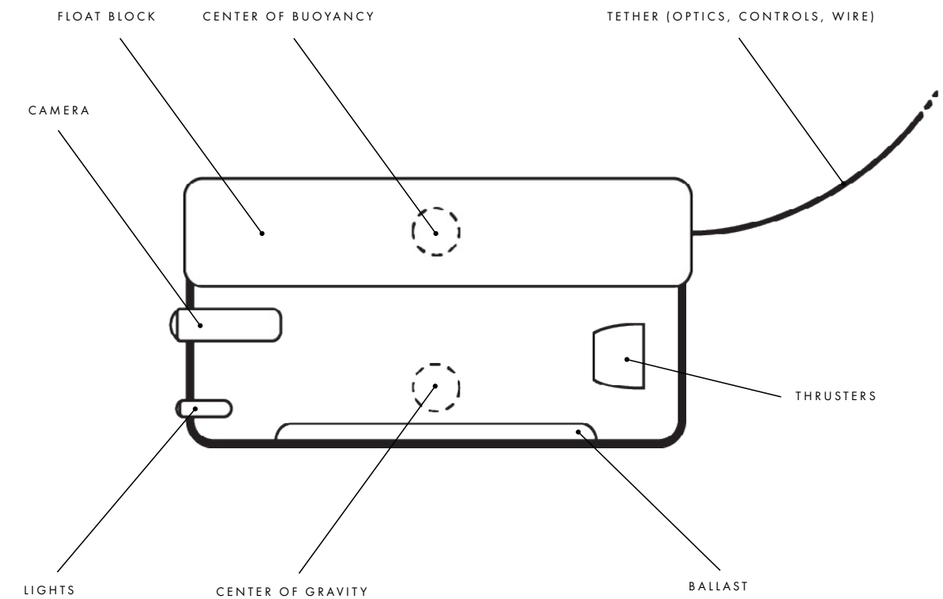
PRINCIPLE CONCEPT

The replacive concept was chosen as the direction that the project would continue along due to it's many benefits in comparison to the other directions. While the form only served as a placeholder, it served as a base to start to figure out how the final design would work and what kind of components that would be required in order to achieve that functionality.

REFINEMENT

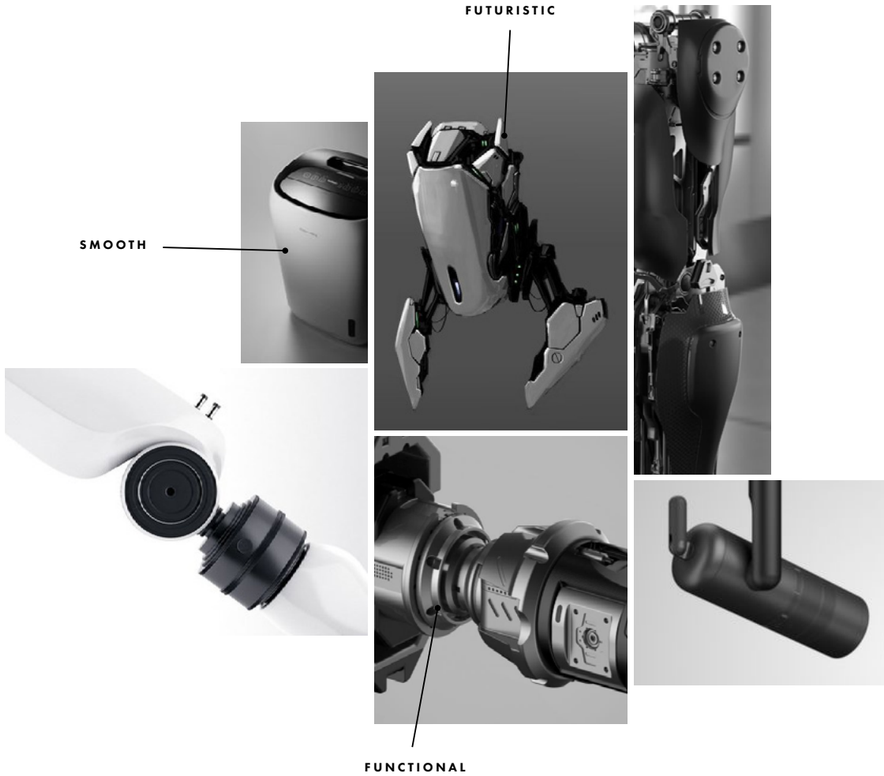
Due to the complexity of the proposed direction of the project there was a need for some technical reference. Current remotely operated underwater vehicles are based on the same principles as the very first ones that were introduced in the 1960's. Typically, there is a system for buoyancy, propulsion and one for the actual operation. the most basic ones serve to explore and thus are only equipped with cameras and light. More complex models have robotic arms as well. The buoyancy of the ROV is carefully balanced so that the propulsion system won't be strained.

GENERAL TECHNOLOGY LAYOUT



A typical ROV, manufactured by Saab Seaeye [1]

1. http://www.offshorewind.biz/wp-content/uploads/2015/06/Saab-Seaeye-Tiger.jpg



INSPIRATION BOARD

This inspiration board served as personal motivation in this project. The smooth, technical surfaces with the intricate details underneath convey an interesting blend of futurism and functionality.

http://lazymk.deviantart.com/art/Mech-359978476
http://www.g-mark.org/award/describe/40948?token=4z000RLtvk
http://hexeract.tumblr.com/
https://s-media-cache-ak0.pinimg.com/474x/89/9d/23/899d23d58c46607e8ba6f5cf04db3182.jpg
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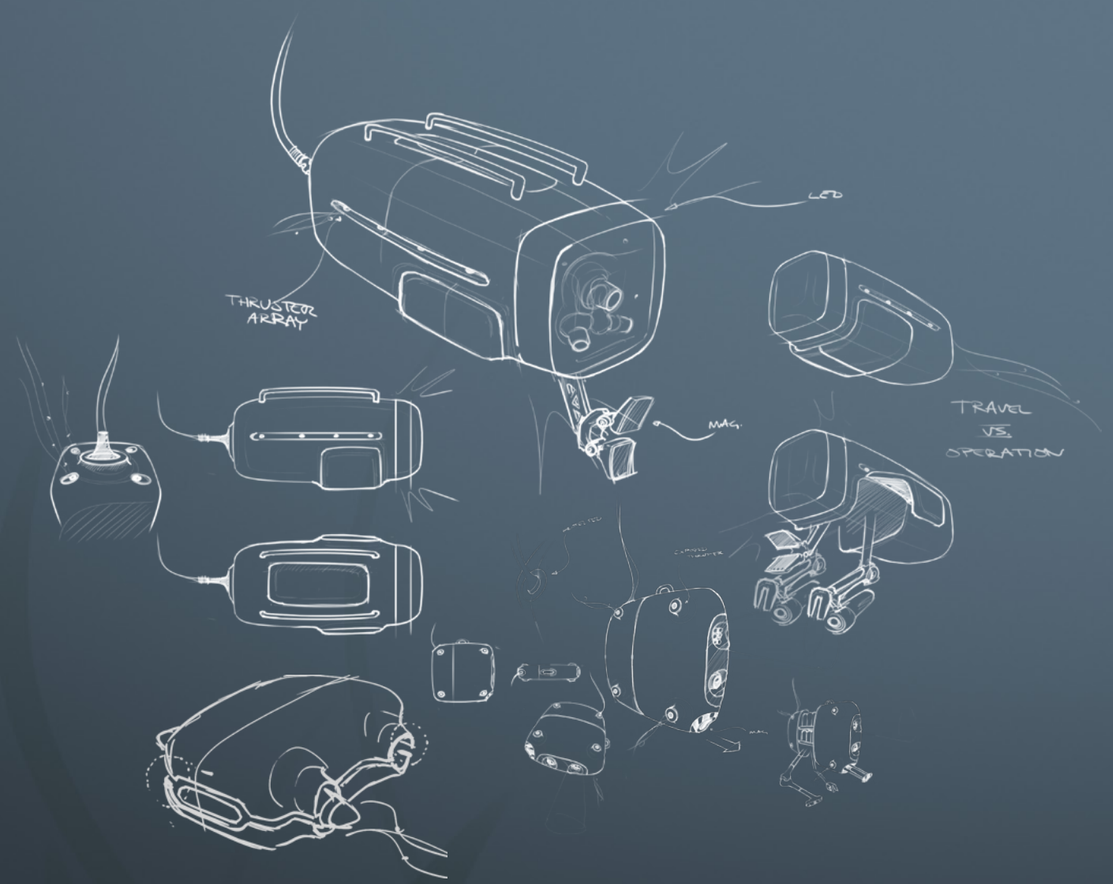
https://s-media-cache-ak0.pinimg.com/474x/3b/53/7d/3b537d97d22febef116b1c48d10b4a50.jpg

BRAND BOARD

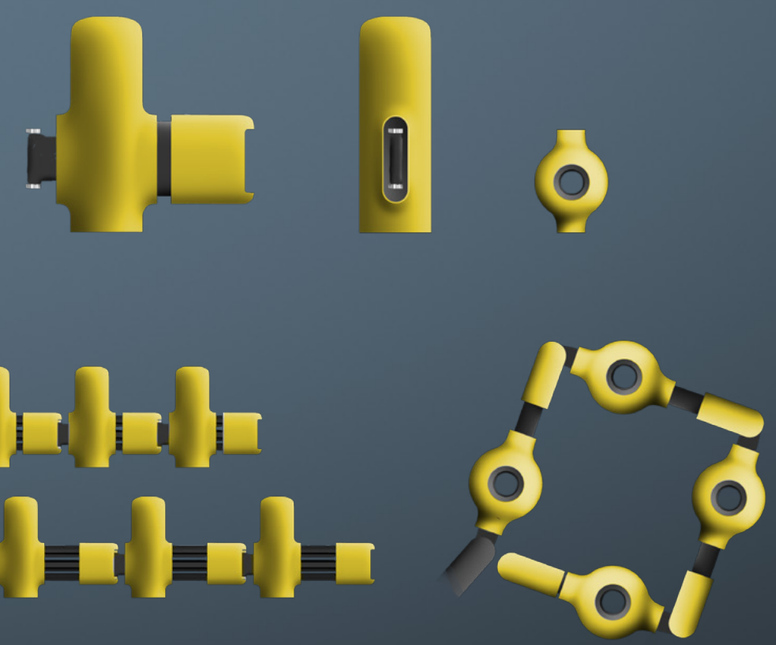
While Atlas Copco's form language varies between their different product segments, there are some common clues that are important to keep in mind in order for the final product to fit their brand, such as the use of color and the geometric shapes and the perceived ease of use.

https://s-media-cache-ak0.pinimg.com/564x/cb/49/fe/cb49febe95ac4eb0efa283375a5d8823.jpg
http://www.flexibleassembly.com/Atlas-Copco-LTV-Angle-Air-Screwdriver.jpg
http://drillingtoday.com/december-2014/atlas-copcos-minetruck-mt42-gets-major-upgrade.php
http://machinebuzz.blogspot.com/2012/11/atlas-copco-powerroc-t35.html
http://red-dot.de/pd/online-exhibition/work/?lang=en&code=25-05068-2015&y=2015&c=168&a=0



CONCEPT EXPLORATION

TENSIONER SOLUTION SKETCHES



EXTENDABLE

BENDABLE

The form development was restarted in order to adapt the shape to the various functions and needs that was discovered during the ideation. The shape needed to convey a certain message about the product. It needed to look advanced, but friendly in order to not intimidate the user and potential companion divers. robust and spacious, yet agile. Also, it would benefit the expression it looked like it belonged in the sea.

An opportunity to overhaul the tensioning procedure itself presented it self when it became apparent that the technology already present in the product. The idea is that instead of placing hoses and tools individually, they could be incorporated into a modular system. This would make the placement of the tools more efficient and could also remove the need of external cables since they would be integrated in the system. Hydraulic tensioners were chosen as the operating tool in this system due to the more controlled operation and lack of moveable parts.

SENTIENT - ADVANCED - DEPENDABLE
ICONIC - FRIENDLY

The concept features clues from both Atlas Copco industrial tools and from other Atlas Copco divisions, such as the mining vehicles. The reason for this is mainly the size of product. While it is roughly the same size as a human, it is much larger than a hand held tool. Therefore the design incorporates a layer strategy over a frame construction that lets the components work unhindered and remain accessible for maintenance. Extra attention was given to the areas that are central to the products function, such as the camera housing and the robotic arms.

RESULT

The Hydros concept envisions a superior alternative to saturation diving in sub sea bolting. The benefits are based on the fact that a human no longer need to be exposed to the dangers of deep diving, as well as other functions that are only possible in an automated system.

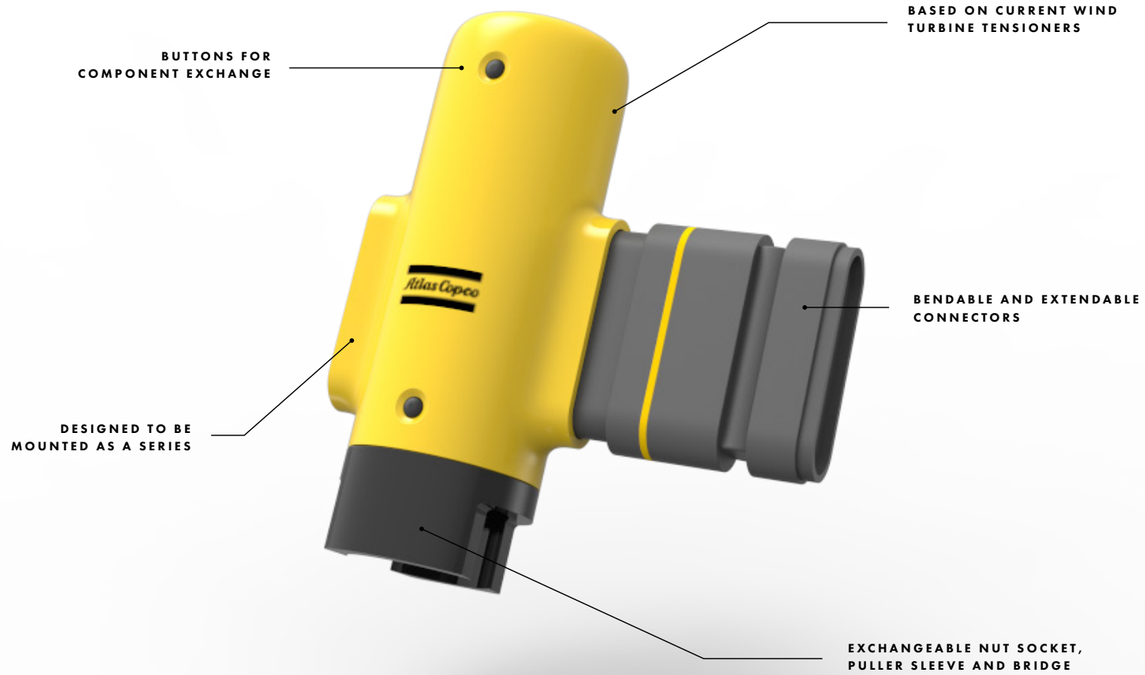
The solution is faster and safer than saturation diving and make the bolting solution more flexible, both in regards of time and function. The lack of human intervention also reduces costs that may financially motivate the development and retail of this product.

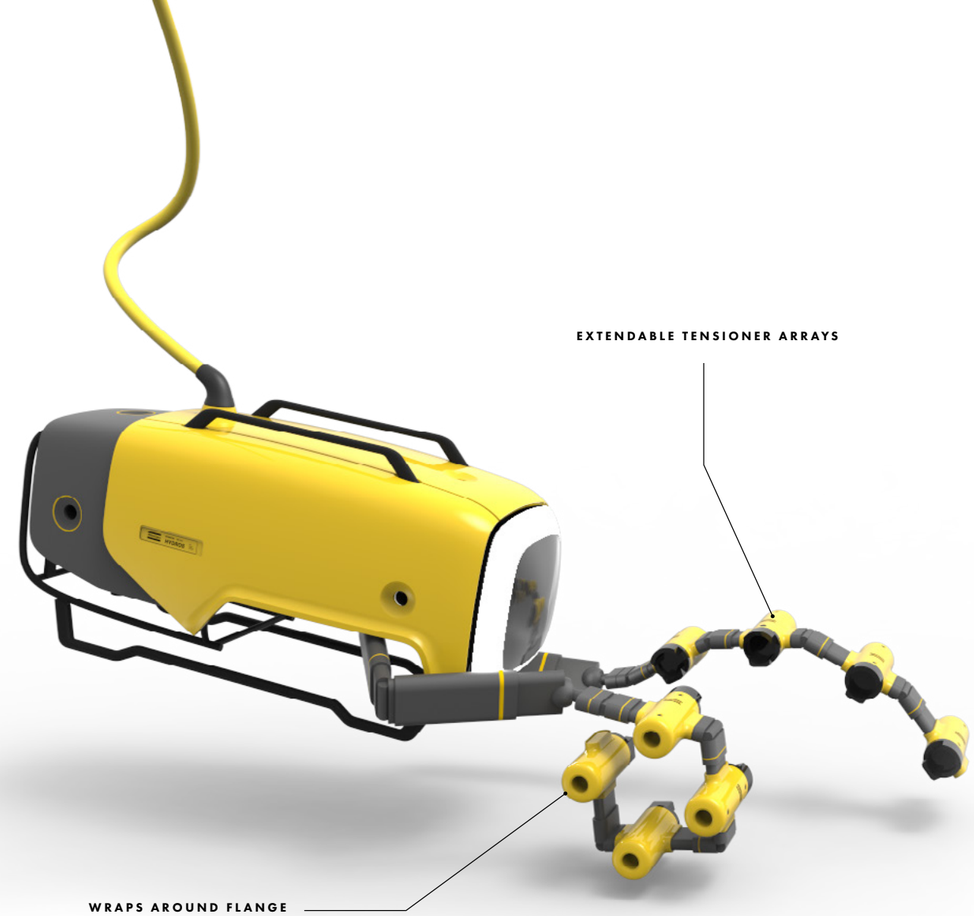
INTRODUCING

HYDROS

AN ATLAS COPCO HYDROTEC TENSIONING SOLUTION

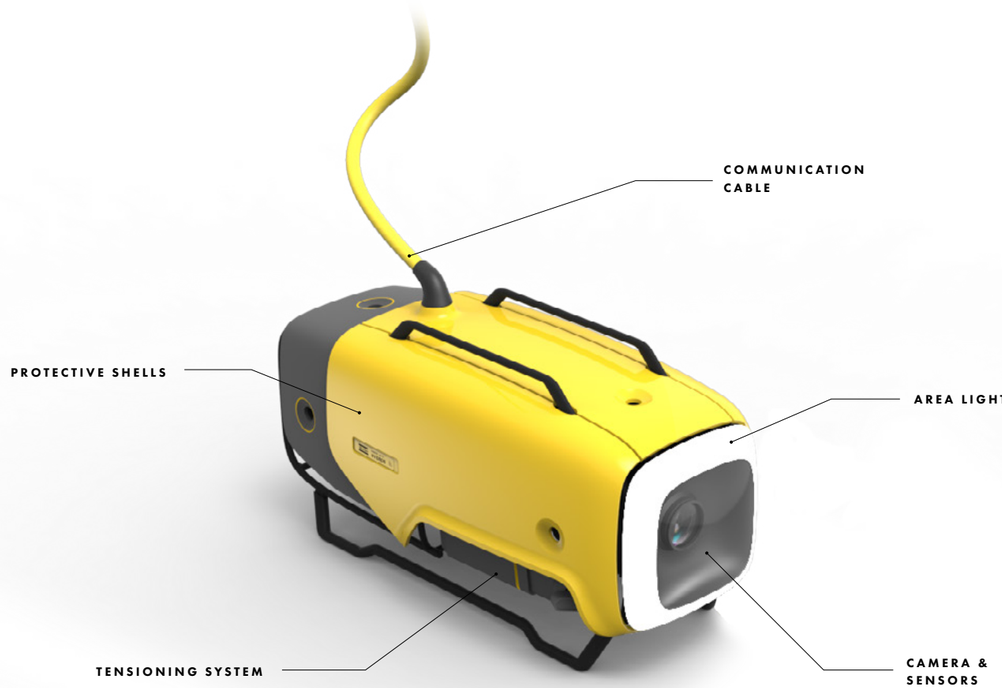
NEW TENSIONING SYSTEM



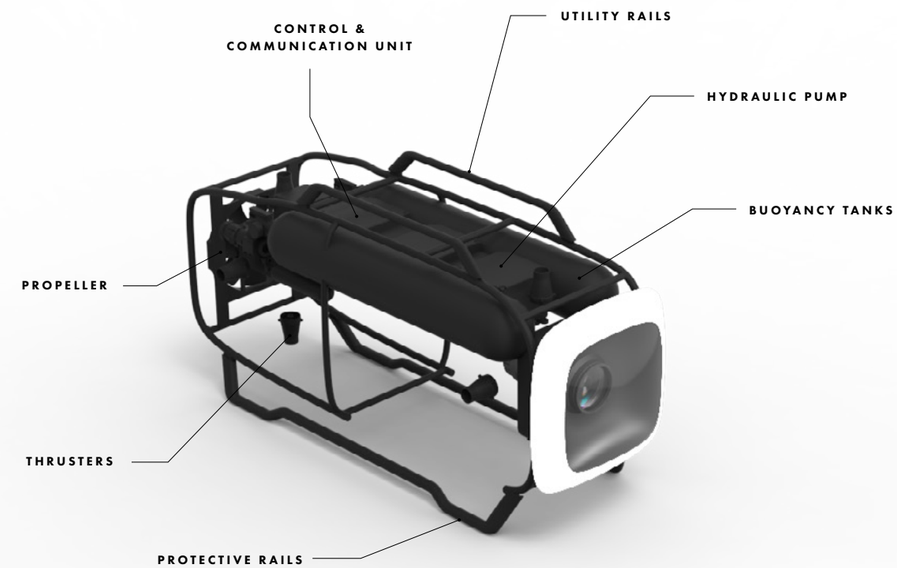


The new tensioning system consists of a tensioner that is based on current wind mill tensioners, which means that the nut runner socket and puller sleeve can be electrically fastened. Those two components, along with the bridge, may be easily exchanged in this model when corresponding button is pressed. The connectors between each tensioner can extend and bend at a joint in order to adapt to different flanges.

The system makes for a much faster tensioning procedure since it can mount all tensioners in a time frame that is not much longer than mounting individual tensioners in the conventional fashion. Also, the system would be able to align the tensioners prior to mounting them since it would know what sort of flange it would fasten, either via recognition or pre loaded data.



EXPLODED VIEW - EXTERIOR



EXPLODED VIEW - INTERIOR

The most attention in the exterior design have been given to the front of the design, where the main functionality of the product is located. In the very front is a wide-angle camera and other sensors that provide information to the operator back on the ship on the devices location. This information is transported via the cable which houses a steel wire and fiber optics along with power supply. There is a large area light around the camera that illuminates the environment that Hydros is operating in, providing more even light distribution due to the fact that it wraps around the camera housing.

The tensioning system is folded into the body in order to not get tangled or damaged during transport. The roof and the belly features rails that provide utility and protection.

The inside of the device features a central control unit that makes the system run as intended. It also features a pump for the hydraulic tensioning system. The hydraulic pump also powers the propeller and the thrusters, making them both powerful and operate smoothly.

Hydros features a buoyancy system that differs from conventional ROVs. Since the weight of the product may vary with the amount of tools it is equipped with, it regulates it's buoyancy with a set of air tanks, much like a submarine does, making the buoyancy system very flexible. This is also more material efficient than the conventional foam blocks found in other ROVs.

1

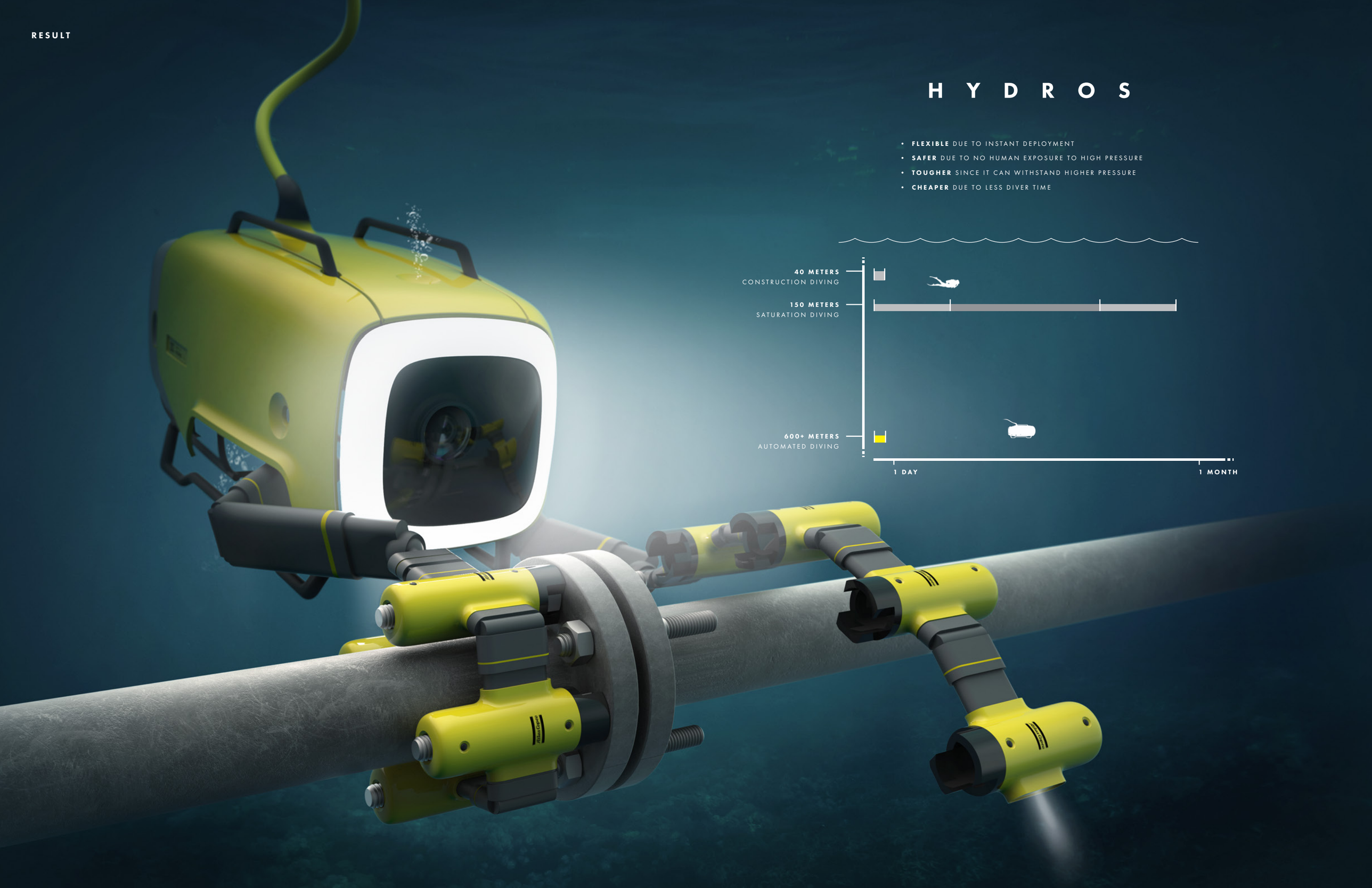
MODEL MAKING PROCESS

Due to the size of the product, the physical model had to be made in a scale of 1:8. The parts were individually 3D-printed in polymer or plaster that was bonded with resin, depending on the size of the component. The parts were then assembled according to the design.

1. Images courtesy of Pontus Edman

HYDROS

- **FLEXIBLE** DUE TO INSTANT DEPLOYMENT
- **SAFER** DUE TO NO HUMAN EXPOSURE TO HIGH PRESSURE
- **TOUGHER** SINCE IT CAN WITHSTAND HIGHER PRESSURE
- **CHEAPER** DUE TO LESS DIVER TIME



REFLECTION

I believe I succeeded with my goals for this project to a satisfactory level. Regarding the wishes, however, I had to do some demarcations in order to keep to the projects time frame. The feature that I miss the most in the project is how the operator would interact with Hydros. There was an idea formulated to deal with this in the form of an VR interface, which also motivated the exaggerated volume for the camera housing on the main body. This would have taken too long time to produce to a satisfactory level, which is why it was left out.

A personal goal for this project was to develop my sense of shape and digital rendering skills. I find both challenging and I would like to believe that I have improved in both aspects, but at the time of writing, that is too early too tell. Those goals, in part, explain why I choose to work with a larger design than the hand held size that is more reasonable for a hydraulic tool. The choice to work with an automated product opened up for some exiting new solutions, which I am happy about, so the choice to strive for my personal goals feels justified in the end, to me at least.

Had I done this project again, I would have put some more effort into my time plan in such a way that I would have made one that took the realistic time of every step into account so that I could follow it more precisely. But in the end, I am quite satisfied with the end result.

Umeå Institute of Design
Umeå University

Simon Linge
MFA Advanced Product Design Programme
Umeå Institute of Design, Umeå University
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