atlantis The Atlantic Testing Platform for Maritime Robotics

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1. Introduction

This document was created as a guide for potential users of the ATLANTIS Test Centre in Viana do Castelo. Moreover, it can be used as material for preparing training sessions if needed. The main part of the deliverable is a set of presentations describing the location of the test site, the environmental conditions, and the available infrastructure, as well as specific use cases related to the experimental trials, conducted, by the partners, at the site. The presentations are summarised in the sections below and attached in the Appendix.

2. ATLANTIS Test Centre

The ATLANTIS test center is a proving ground for marine robots and related technological solutions. Installed in Viana do Castelo, the ATLANTIS Test Centre, it is composed of two test sites, the Coastal Testbed and the Offshore Testbed, as well as a Shore Control Centre.

The Coastal Testbed is located within the harbor of Viana do Castelo, in close proximity of the local sailing club. It is easily accessible by car or train, and as it is a public space, there are no restrictions in terms of access. It is composed by a decommissioned floating offshore structure, that replicates the challenges presented in floating offshore wind farms. Due to its proximity to the sailing club, the Coastal Testbed has access to all infrastructures required for easy deployment of robotic technologies. These include energy supply (directly on the structure or provided by power banks and generators, if needed), support vessels, large access roads for the transport of equipment, crane, internet access, toilets and a sheltered room (room of the control center).

The Offshore Testbed is composed by a real wind farm, the WindFloat Atlantic Wind park, located up to 20 kilometers from the coast of Viana do Castelo. It is composed be three floating wind turbines, and access is possible through the use of a support vessel at the disposal of the Test Centre users. During testing operations, users have access to 4G and a satellite link. Access to the testing area is restricted and subject to regulations defined by the owners of the wind park.

The Shore Control Centre (SCC) provides full communication with the robotic platforms on both testbeds; direct line of sight communication with the vehicles operating in the Coastal testbed, and with the vehicles on the Offshore testbed vehicles operating in the Offshore Testbed. The SCC is a private space, that allows easy monitoring of operations, with all of its infrastructures compatible with ROS (Robot Operating System), allowing easy transfer of data and remote monitoring of the operations.

For users performing tests in the ATLANTIS Test Centre, the process starts with coordinating with us the deployment and storage of the equipment to be used during the tests. Once the equipment is transported to (and stored in) the Test Centre, deployment will be dependent on the type and weight of the equipment. Easily transported equipment can be deployed manually, while for heavier and bulkier equipment support from the sailing club is required for deployment. Once the equipment is deployed, if *in loco* water support is required, a support vessel is deployed with the team member supporting the operation. Once the test is completed, the recovery process of the equipment occurs in a similar manner as the deployment. Manually for lighter and smaller equipment, and with support from the sailing club for heavier and bulkier equipment. Once back on shore, if further tests are required, the process is repeated. If the testing is concluded, arrangements need to be made for the transport of the equipment back to the origin point.

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While one of the aims of the ATLANTIS Test Centre is the de-risking of the technologies, performing work in a floating structure or offshore can pose some danger to human operators. Even though the Test Centre presents an ideal location to perform training programs and gather experience on the use of robotic technologies, risks still exist. As a result, there are a set of safety regulations in place for users of the Test Centre. These include the use of protective gear (life jacket and helmet) when on a vessel or on the floating structure, close inspection of the equipment to be used before deployment and the report of any potential hazards detected.

In addition to the safety regulations imposed by the ATLANTIS Test Centre, there are permission pertaining tests in the harbor and at sea that are required by external entities. These include the approval for all tests in the areas involving aerial vehicles by the Captaincy of Viana do Castelo and by the AAN (National Aeronautical Authority), registration of support vessels with DGRM (Directorate-General for Natural Resources, Safety and Maritime Services), and both Sea Survival Training and OEUK certificates for those going offshore. Depending on the tests to be performed, particularly offshore, additional training certificates might be required from the users.

To apply to test technologies in the ATLANTIS Test Centre, potential users are required to email atlantis.testcentre@inesctec.pt, indicating their interest and providing information on the test to be performed. The minimum information on the tests required includes the type of technologies to be tested, their intended application, which testbed would be used (testing on the Offshore testbed requires previous testing in the Coastal testbed), any supporting infrastructures required for the tests, the size of the team present at the Test Centre and the expected time-frame for the operations.

All data collected by ATLANTIS, either during the application or during the testing activities is subject to GPRD guidelines. This means that no personal information will be collected and all data collected during testing will be confidential and secure.

3. Use cases

3.1. INESC TEC

The INESC TEC team was involved the development of technologies that can be applied to 3 different scenarios: i) inspection of the floating structure, ii) support of operations with crewless vessels and iii) inspection of blades and tower. The technological developments related to these scenarios were centered on two different type of vehicles: an Autonomous Surface Vehicle (ASV), Nautilus, for the first two scenarios and an Unmanned Aerial Vehicle (UAV), RAVEN, for the last one. These developments involved the design of new sensor payloads to be integrated in the vehicles, as well as new navigation algorithms.

The development of Nautilus involved the design of a new mechanical structure and reconfirmation of the sensor payload and actuators. The objective was the development of a vehicle with increased robustness and stability. This will not only contribute to increased reliability in offshore environments, with its harsh conditions, but allow the ASV to pull tow vehicles transporting other robotic platforms.

For the scenario of inspection of the towers and blades, the developments were geared towards NDT inspection of the offshore infrastructures as well as achieving fully autonomous deployment and recovery of the vehicle. This was achieved through careful consideration of the sensor payload to be used by the RAVEN UAV, considering both the needs of inspection activities and the autonomous deployment of the vehicle. The payload consists of a 3D LiDAR, a visual camera and a thermographic camera. For the

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autonomous deployment, a small landing platform was designed and constructed to allow autonomous landing and take-off. This included the design of a marker that allows the UAV to detect the position of the platform.

During the trial performed in the ATLANTIS Test Centre, in July 2022, the INESC TEC team was able to successfully demonstrate the autonomous take-off and landing of the RAVEN UAV into the landing platform, both when the platform was attached to a fixed structure and when it was being pulled by the Nautilus ASV. Additionally, the inspection of the floating structure was also successfully validated.

The Nautius ASV was deployed through the use of the crane present in the facilities of the Coastal Testbed of the ATLANTIS Test Centre. The vehicle was transported to the crane using a boat trailer. From there it was attached to the crane carabiners through fixation points specifically implemented for the deployment. Once in the water, a support vessel was used to release the carabiners. The vehicle can then be either tele operated from shore or from the support vessel, or it can perform an autonomous operating, whist being monitored with a support vessel (with a kill switch).

The deployment of the landing platform for the UAV can be performed in the same manner as the ASV, or through water access ramps, as the platform has wheels. Once attached, either to fixed structures or to the ASV, the UAV takes-off manually from shore and is operated until it is positioned directly above the landing platform. From there it starts its landing operation autonomously. Once the UAV has safely landed, if the platform is attached to a fixed location, the drone takes off autonomously. If the landing platform is attached to the ASV, this one moves towards a different position, while carrying the UAV in the landing platform, with the AUV taking off autonomously upon arrival of the pre-determined goal point.

During the operations of the vehicles a ground station provides the RTK base information through WiFi to the vehicles in operation. The operations and data collected can be monitored and controlled through a mission controller deployed on shore. All of the telemetry data is shared from the robots with both the mission controller and the ATLANTIS SCC.

3.2.UdG

In the ATLANTIS project the UdG team has been developing technologies in two different directions: a) the permanent deployment of autonomous underwater vehicles for continuous monitoring of the wind farms and b) the autonomous IMR operations on the Windfloat structure, including cathodic protection testing with a contact probe, cleaning with a rotating brush, and laser scanning of anodes. Development of the first technology involved a complete design of a docking station for the Sparus II AUV as well as new control algorithms for autonomous docking. Development of the second technology included a new, dual-manipulator payload design for the Girona 1000 I-AUV, as well as implementation of control algorithms allowing for fully autonomous IMR operations.

The permanent deployment test was composed of a few parts: undocking of the Sparus II AUV, autonomous survey of the seabed, and autonomous docking manoeuvre. To monitor the operation of the robot during the test, it is connected to the control panel through a cabled buoy, floating on the surface and equipped with a WiFi antenna. This wireless connection is used only as a safety measure due to on-going evaluation of the system reliability and performance and in the final solution it would be removed.

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The IMR tests with the Girona 1000 I-AUV were focused on fully autonomous cathodic protection measurements with a contact probe. Each operation includes multiple stages: submerge action; identification of the location of the structure; approach to the surface of the structure and docking with a permanent magnet gripper, installed on one of the manipulators; unfolding of the second manipulator; touching multiple points on the surface of the structure, with a probe; folding the probing manipulator; undocking and surfacing.

During the trials performed in the ATLANTIS Test Centre in November 2022, the UdG team was able to successfully complete the permanent deployment tests, but failed to perform the IMR tests for various reasons explained below and in the related presentation.

The docking station was installed in the seabed, in the part of the port assigned to the ATLANTIS Test Centre, with the help of a crane and a group of divers. It was supported by wooden planks due to large amounts of sediment. The vehicle was deployed to the water from a floating pier of the sailing club, which is easily achieved be a single person, thanks to the design of the Sparus II AUV trolley and the low weight of the robot. The robot was then teleoperated in the surface, to the surroundings of the docking station. The autonomous docking algorithm was used to dock the robot, undock, and perform a survey of the bottom using a forward-looking sonar. Multiple sequences were completed successfully.

The IMR tests planned to perform using the Girona 1000 I-AUV were not possible to conduct. The main reason was the fact that the floating structure, being part of the ATLANTIS Test Centre, was not installed deep enough and its surface was covered with marine growth. This has pushed the UdG team to use an alternative structure, a test rig built for the trials in the CIRS test tank. The robot has successfully performed autonomous CP measurements in the lab environment, using this structure. However, two problems hindered the testing of the developed algorithms in the ATLANTIS Test Centre. The first problem was the difficulty in installing the test rig in the site. The location chosen for the installation was a pier which is constructed from concrete blocks with big holes, reducing the water resistance and allowing it to pass. When the test rig, which is a curved panel, was installed on the wall of the pier underwater, the forces exerted by the water has broken the lines and parts of the structure in a few hours. Therefore, the panel was not fixed and moving with the water, which has made it infeasible for performing any manipulation tests. The second problem was the very high turbidity of water in the site, which rendered impossible the testing of the laser scanning technology developed for anode inspection (see photos in the presentation). It is an important factor to consider if any vision based system is to be tested in the site.

3.3.IQUA Robotics

The main focus of Iqua in the ATLANTIS project is the development of algorithms for autonomous inspection of submerged sections of Windfloat structures. For this task, Iqua has chosen the Girona 1000 AUV, as it provides very stable roll and pitch DoFs, large and flexible payload area and connectivity, high processing power and accurate localization using GPS, DVL and INS. Iqua has also developed a payload specifically for this task which includes a multibeam sonar, two optical cameras and a pan/tilt device. The multibeam sonar and one of the optical cameras can be tilted using the pan/tilt device. The autonomous exploration algorithm developed at Iqua for the autonomous inspection of submerged structures is divided in two main stages: assessment and inspection. In the assessment stage, the robot navigates around the structure at a moderate distance, gathering occupancy information for path

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planning and obstacle avoidance. In the inspection stage, the robot performs a trajectory much closer to the structure, gathering not only occupancy information, but also optical data for the inspection of the asset. At all times, a path planner ensures the robot trajectories are safe. Prior to the testing in the ATLANTIS Test Centre in Portugal, Iqua tested the algorithm in two scenarios near Girona, a natural islet and a breakwater structure, with excellent results.

In the tests performed in the ATLANTIS Test Centre in November 2022, the Girona 1000 control station computers and the operators were located inside the provided containers. While a battery powered Wi-Fi antenna was used as an intermediate connection point between the control station and the robot. Deployment of the AUV was realized using the crane available in the operational area. In addition to the robot, a small cabled buoy was deployed to maintain communication when the robot is underwater. Several successful runs of the algorithm were performed in the ATLANTIS Test Centre, with the robot circumnavigating the floating structure from a close distance. However, the poor visibility during the test days impeded obtaining optical data of sufficient quality to perform a 3D reconstruction of the site. During the experiments in the ATLANTIS Test Centre, two payload configurations were tested. One of them with the tilting device sweeping the multibeam to scan vertically (forward), and the other sweeping the multibeam to scan horizontally (mainly sideways).

In the presentation, details are given regarding the integration with the SCC in the ATLANTIS Test Centre, developed in close coordination with the SPACEAPPS team. Mainly, the developments focused on transmitting telemetry from the vehicle to the web APP, mission integration and programming through the SCC and receiving basic commands from the web APP to the Girona 1000 AUV. Finally, the presentation concludes with a section describing problems and observations regarding the operation in the Test Centre.

3.4.RINA

The focus of Rina in the ATLANTIS project is the identification of new methodologies for O&M activities using robots, within the emerging set of technologies and to develop potential options that may be able to respond to industry's challenges.

This goal will be achieved through the development of methodologies and through the progressive increase of know-how acquired through testing campaigns carried out using robotic technologies (UAV, ROV, ASV) already available on the market.

Another crucial factor is the development of Risk assessment. Risk assessment and risk management of the structure will be also driven by data collected by the robots: therefore, the most relevant parameters to be monitored with/without robots will be early identified to constantly monitor the safety and the risk of the structure.

During the tests performed in the ATLANTIS Coastal Testbed in November 2022, Rina has performed following activities:

UAV

- **Equipment:** DJI MATRICE M 210 RTK V.2
- **Main Objectives** Calibration and Data collection Floating Structure capture of images and data.

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- **Planned Activity:** Inspection to verify the condition, construction, and integrity of the structure through thermographic and visual analysis.
- **Executed Activity**: Operational checks: (test of optics and thermographic sensors, wind resistance and stability during flight operations, electromagnetic fields interference). Test of Control signal (long distance ~7-8 km). Capture of details (components data of installed wind turbine is acquired). Verification of semi submergible structure (visual analysis)

ASV

- **Equipment:** Flytech model D16C-500 with sonar chirp plus deeper
- **Main Objectives** Calibration and Data collection: state of the seabed capture of images and data.
- **Planned Activity:** Analysis of the seabed of the area surrounding the floating structure conducted with the help of a drone that mounts a sonar chirp + and telescopic system with 360° camera. This sonar with a continuous flow of frequencies from bottom to top will allow the reading of the seabed and in association with bathymetric surveys allow to monitor the interference of the structure with the coastline. With the captured images it will be possible to monitor the development of benthic flora and fauna developed around the system to evaluate the possible impact/effect of the structure in the coastal environment.
- **Executed Activity:** Considering the adverse weather conditions and the poor visibility the activity has been limited to the use of the sonar for depth characterization.

ROV

- **Equipment:** FIFISH V6 EXPERT M20
- **Main Objectives** Calibration and Data collection Floating Structure (submerged section) capture of images and data.
- **Planned Activity:** The purpose of the activity is to determine the state of the art of the structure especially the erosive state to which the material is subjected.
- **Executed Activity:** Operational checks: (resistance and stability during operations). Capture of details (components data, mooring line). Verification of semi submergible structure (visual analysis). Considering the adverse weather conditions and the poor visibility the activity has been limited

The presentation provided by Rina is related to the use of drones in the coastal testbed. The objective is to provide useful information to possible users of this platform who intend to test drones or components of drones (sensors) in inspection operations.

Listed below the main topics analyzed for UAV inspection:

1. Briefing: preliminary checks to be carried out before to start the mission
    - Verification of insurance documentation of vehicles and pilot certificates
    - Weather forecast monitoring before and during the mission
    - Notify to Remote Surveillance Unit Start/End of the Inspection Works
    - Briefing Pre-flight With other Team Members
    - Check Installation Micro Sd Card
    - Check Battery Installation (Check Full Charge)
    - Check The Planned Route
    - Flight Mode Switch (On Desired Position)

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- Preflight-check: Before departure UAV shall be tested and checked according to supplier's guidelines
- Control of Possible External Interference
- Home Point Check (Take-off Point)

2. Identification of operational area within the Costal Test Center (Take-off Area)
3. Characterization of floating structure
4. Communications & SCC (*)

(*) Possibility to monitor all the mission with some parameters: state of vehicle, position, battery status, etc) to be evaluated and implemented in SCC.

Some videos and pictures are available to plan the activity (see pos.2&3).

3.5. ECA

ECA Team was present in the ATLANTIS Test Centre Coastal Testbed during one week from 7th to 11th of November for testing the ruggedized version of the Roving Bat (A remote controlled Hybrid ROV). The Roving Bat is involved into 2 different scenarios of the project: inspection of the floating structures and inspection of cable protection systems. For these trials the Roving Bat was equipped with 3 full HD TV cameras, a rotating sonar, a 7-axis manipulator fitted with a cleaning brush and a cathodic potential measurement probe and - as a payload - the MARESye 3D camera designed by INESC TEC.

These tests were the first sea trials of the Roving Bat and were mainly focused on navigation of the vehicle and its attachment on the floating structure. The purpose was to demonstrate the functionalities of the new technologies deployed and the future ability to operate in offshore conditions.

Both scenarios were tested with the inspection of the floating structure and of the mooring chains that keep it in position (replacing the cables protection system)

Firstly, we have demonstrated the functionality of the newly designed 8KW power converters installed on the Roving Bat and a dedicated umbilical cable. Some pictures and video were recorded by divers thus showing the Roving Bat in its real environment.

On the other hand, due to the slope and the lack of depth of the floating structure, there were difficulties in performing its landing on it. Some attempts were done but only attachment on the walls of the quay was performed. Some technical problems also made these operations even more difficult.

The manipulator, the cleaning brush and the CP probe were functional but not operational because the Roving Bat could not be placed correctly on a vertical structure (the arm must be operated while the Roving Bat is still)

Regarding the integration and the calibration the MARESye camera, the results were successful and we have performed realistic 3D images using some predefines object immersed near the ROV. This camera may be used on the structures of windfarm for 3D object reconstitution on the field during maintenance operations.

During the week we also have finalized the communication link between the Roving Bat system and the SCC in order to allow the remote reception of images and the future interoperability from the shore.

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These trials were also the opportunity to train our pilot for the future offshore trials. The Roving Bat was deployed by the mean of the crane present in the facilities of the Coastal Testbed of the ATLANTIS Test Centre. The launching and the recovery using the latch lock system installed on the ROV was successfully used and can be extended to its future use on a support vessel for the offshore deployments.

The Roving Bat was operated by a pilot by the mean of a control unit installed on a 20 feet container together with the power supply unit. A generator was used to delivered the necessary power for both 400Vac and 230Vac electrical supplies. The winch was installed outside. No particular problem to report for this installation except the management of the umbilical cable that was a little bit tricky. For these operations the umbilical cable needs to be supervised by an operator during all the navigation phases to avoid entrapping on the different floating structures present on the site. This monitoring is easy du to the fact of the umbilical cable is floating and visible even during bad meteorological conditions.

During all the trials HD videos and sonar images were recorded on a PC, but due to the water turbidity the cameras need to be close to the structure to take exploiting images. Only the sonar could be used for the navigation of the ROV. Automatic navigation like auto heading and auto depth functionalities are essentials to help the pilot to reach the floating structure from the launching point. As an axis of improvement we noted that a multibeam imaging sonar (Like *Oculus* from BluePrint or *Gemini* from Tritech model) would help during the approaching phase and the landing on the floating structure. The capabilities of Gigabit Ethernet transmission will allow the use of these sonars in real time.

4. Supporting technologies

4.1.SCC (SpaceApps)

In order to supervise the operations performed in the ATLANTIS context, Space Applications Services is in charge of the development of the Supervisory Control Centre, SCC, and of the integration between the robots involved and the SCC using the C++ interoperability library provided. The objective of the control centre is to monitor data coming from robots and to send commands to robots. Data coming from the robots are shown on the User interface of the SCC in real time and the operators can also navigate in the history of the data based on time constraints. Numerical data, Booleans, images, odometry, GPS and joint states of URDF models from all the robots can be received and visualized directly on the SCC.

An automated mission planning module is also integrated to the SCC to allow the operators to define missions by defining robots capabilities and assigning robots to geographical targets with associated actions to perform individually on each targets such as clean, inspect or asses.

Operators have the abilities to send direct commands to the robots connected to the SCC. Numerical commands, switches, target points and follow paths actions are handled. The operators can also set constraints to every commands in order to allow the commanding of the action only if the constraints are met. Robots can also be operated using the automated mission planning module that will output a coordinated list of actions for each robot involved in a mission. The operators can check and validate the mission plan before deploying it on the robots directly from the SCC. The control centre will then allow the operators to monitor and follow the execution of the mission plan on each robot simultaneously on the same view.

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To provide a better user experience the SCC was designed to be accessible on any web browser being connected to the ALTANTIS secured network. It can be accessible on laptops, tablets or even smartphones. The user also has the possibility to fully customize the view of the user interface to split it in different components and share it to other devices connected to SCC network.

4.2. Buoy sensor system (VTT)

VTT uses the ATLANTIS pilot site, and the Coastal Testbed in particular, for developing predictive maintenance analytics for offshore wind O&M needs. The Coastal Testbed is virtualized to bring together data from different sources: weather data, motions of the testbed structure, robot-based inspection data etc. VTT O&M module uses this data for predictive maintenance analytics and then provides analytics output to the SCC. A central part of the virtualization is a digital twin model of the Coastal Testbed floating structure that processes the motion data for the O&M module.

The Coastal Testbed was instrumented with three accelerometers, a motion sensor and two cameras to detect motions of the floating structure. Weather data was gathered with a wave buoy and an anemometer (wind sensor). Measurements are sampled simultaneously with the separate data acquisition modules connected to a local PC for data storage and measurement management. Wave buoy data and onsite video stream are synchronized with the rest of the data based on offline comparisons with data responses and time values.

Applied sampling frequency depends on the measurements, and at maximum, it will be about 100 Hz. The sampling is set to fulfill the requirements for promoting virtualization of the Coastal Testbed and structural O&M analytics requirements. The motion data is used as input to the digital twin seakeeping model that then provides (wave) loadings to the digital twin structural model. These together are used to provide short-term predictions for operations (e.g. motion limits) and long-term forecast for structural integrity.

The goals and first observations are reported in the training documentation (presentation).

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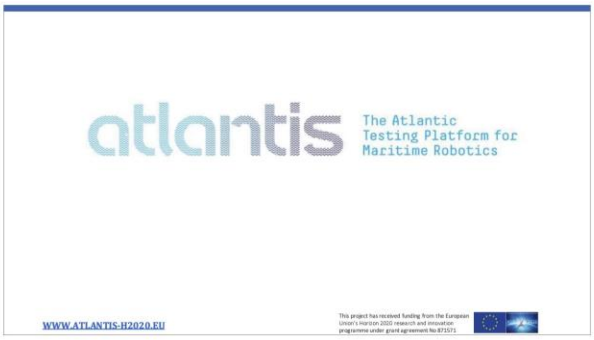
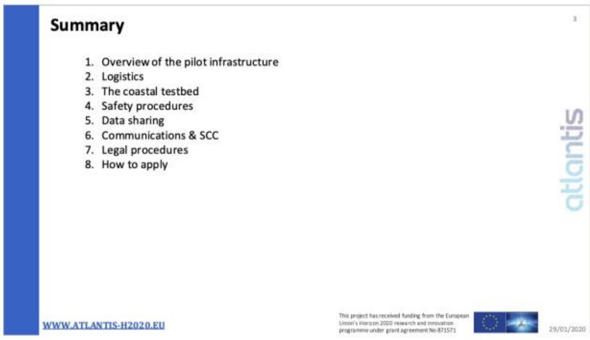
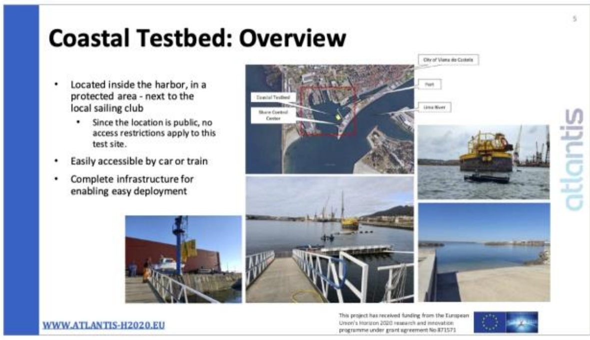
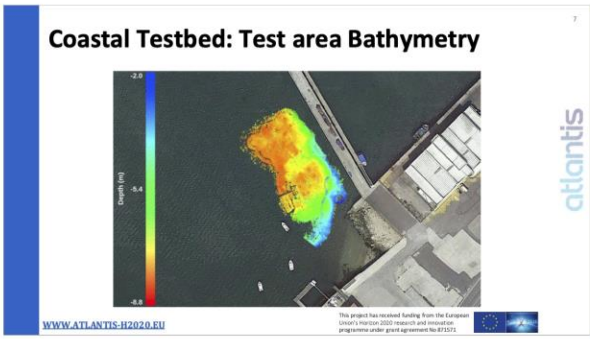
5. Appendix – presentations

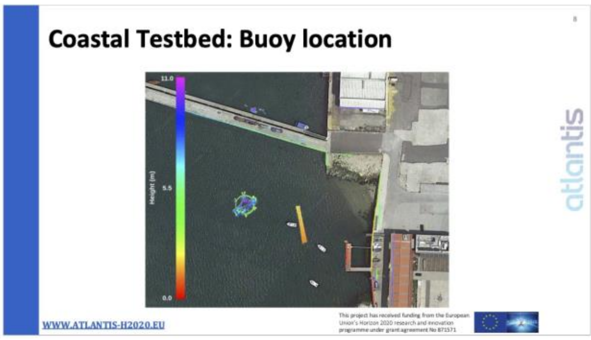
5.1. ATLANTIS Test Centre











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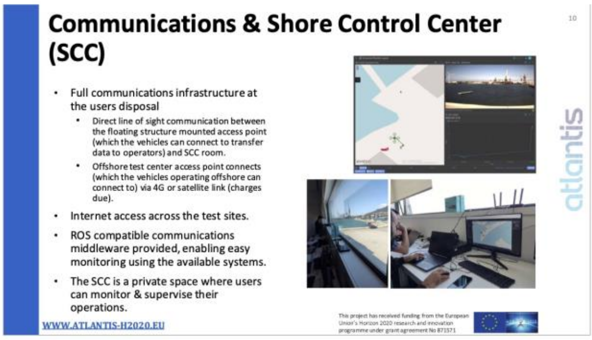

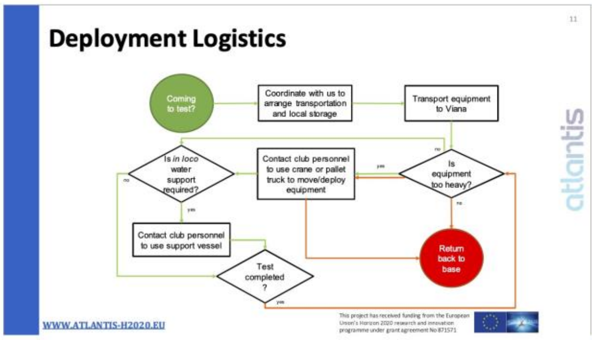

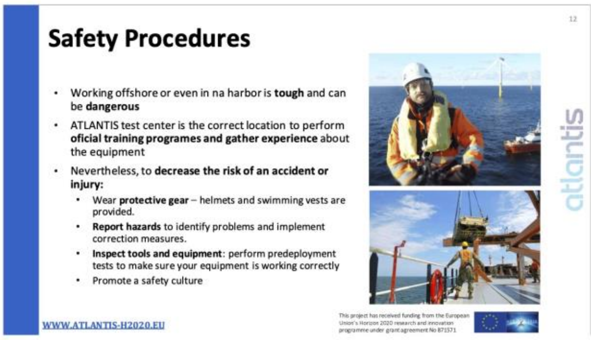

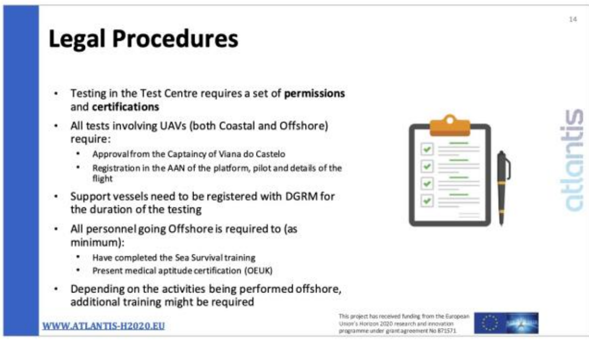

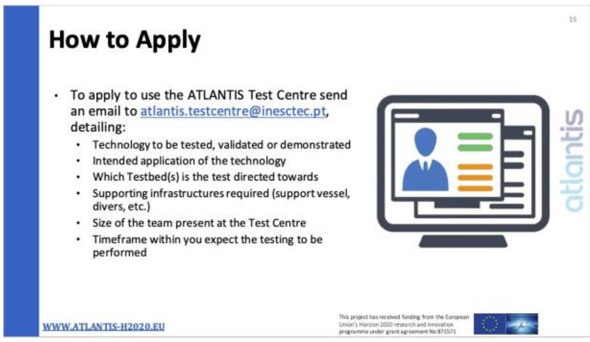

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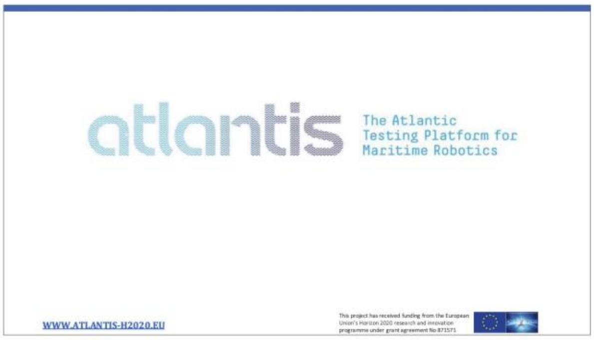
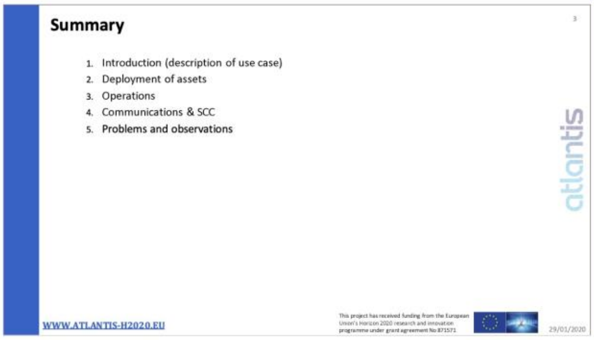
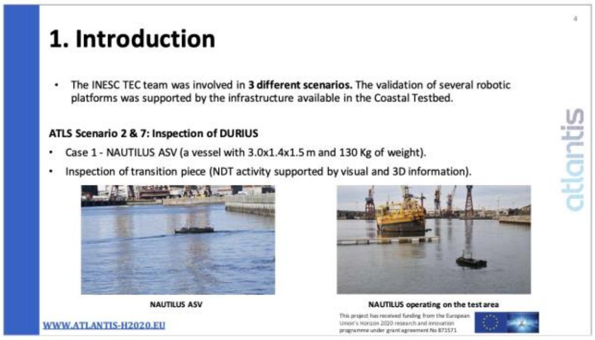
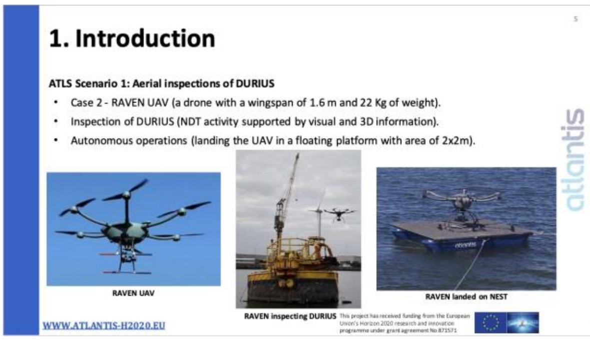
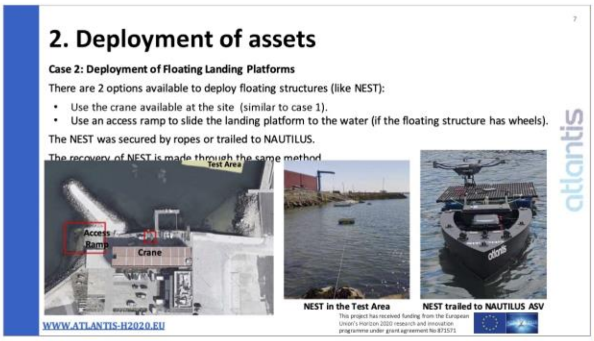
5.2. Use cases: INESC TEC











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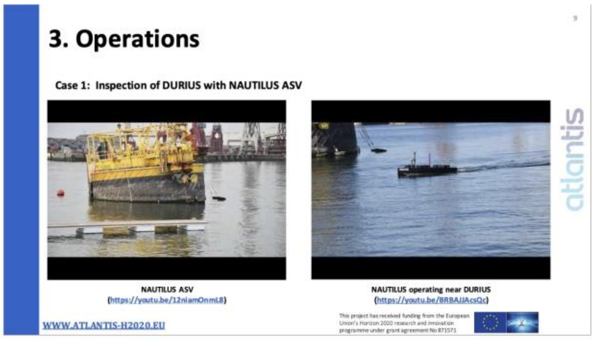

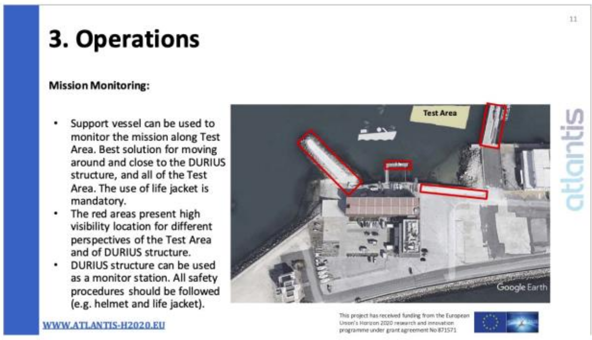

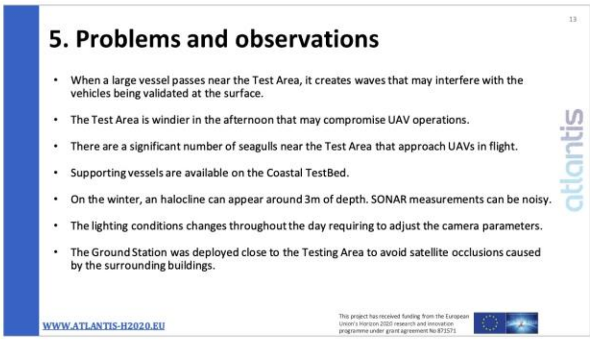

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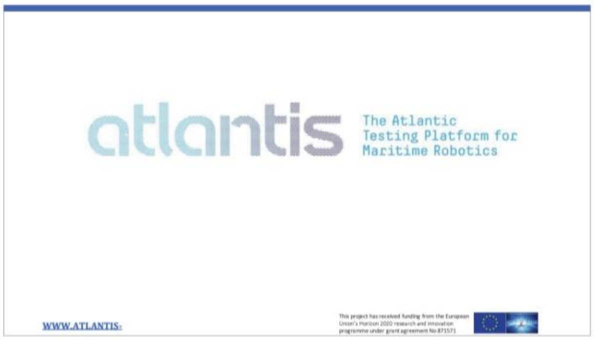
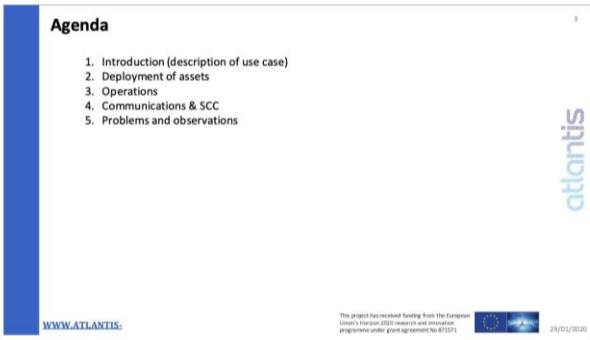
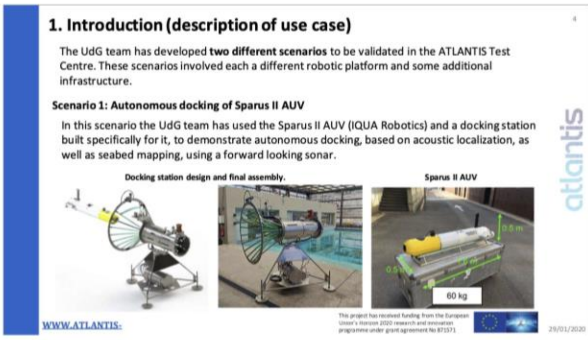
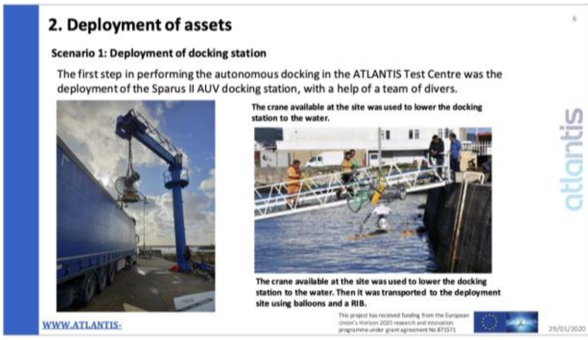
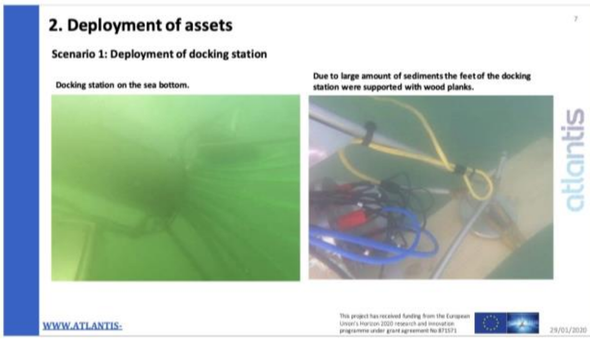
5.3. Use cases: UdG

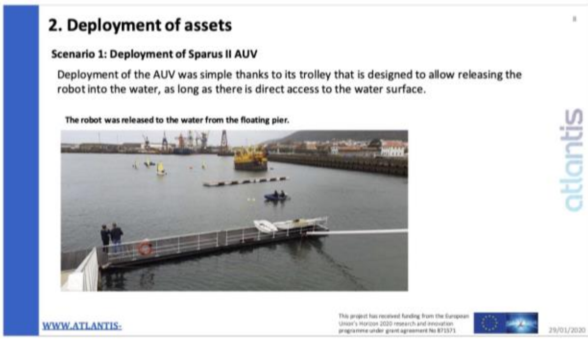












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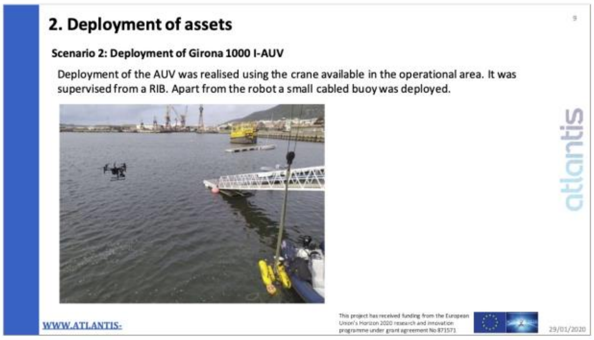

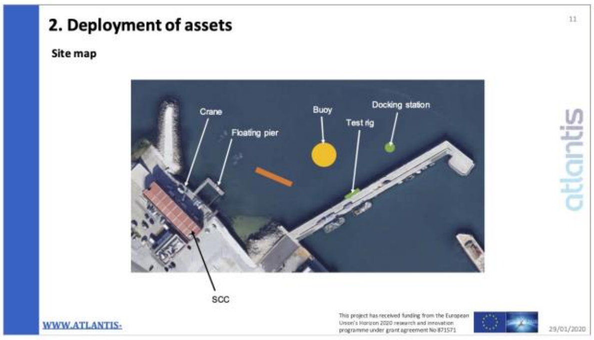

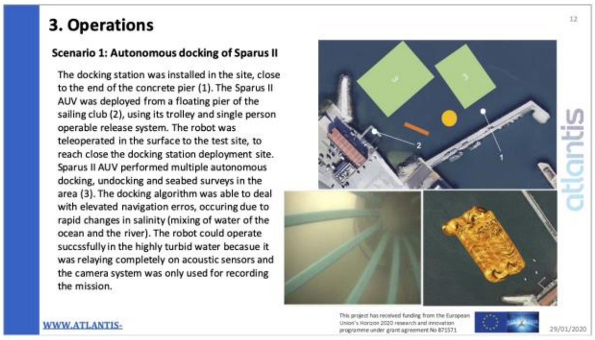

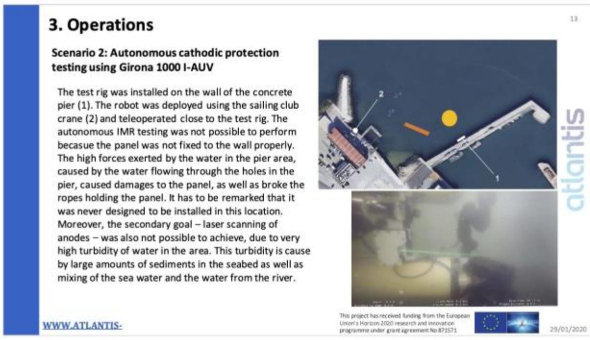

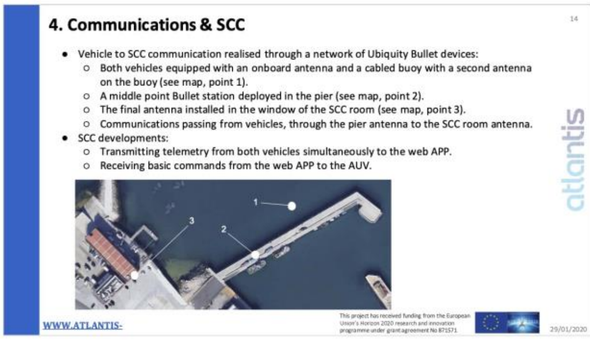

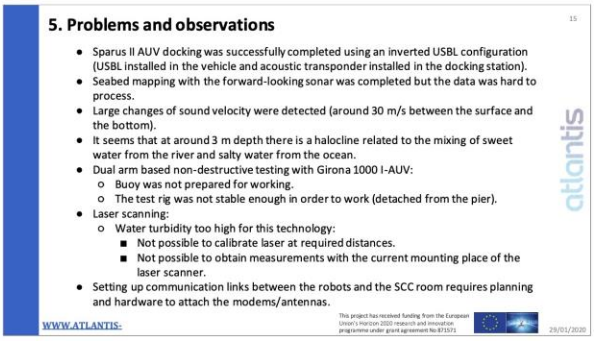

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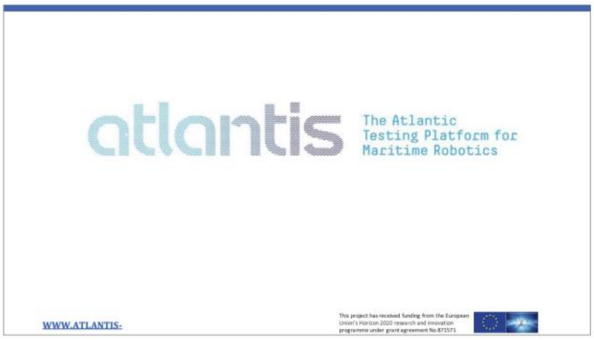
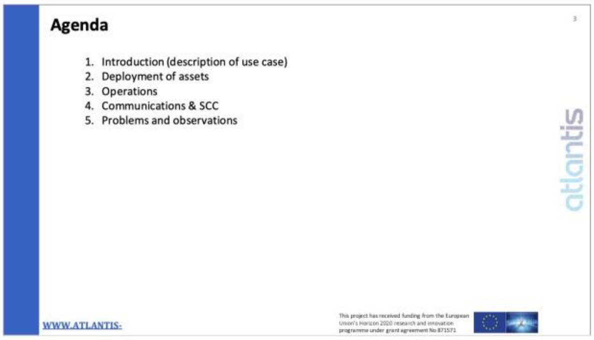
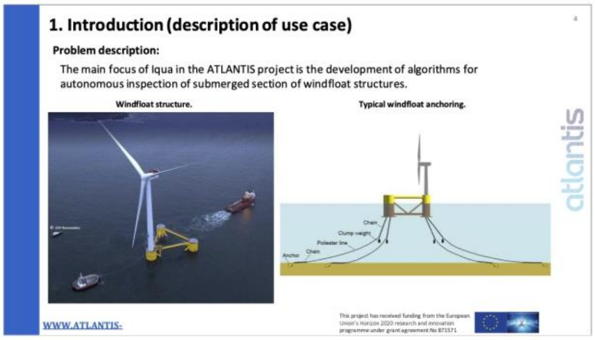
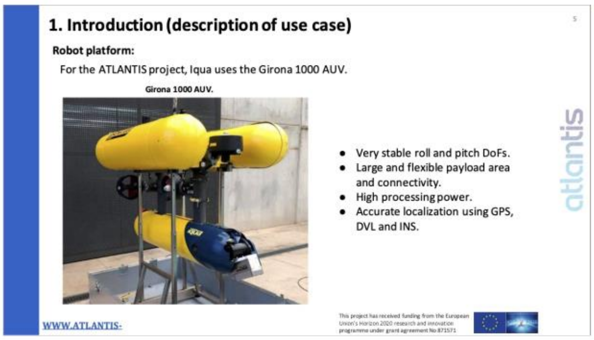
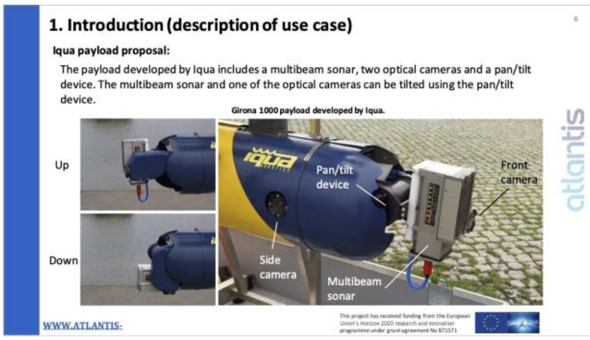
5.4. Use cases: IQUA Robotics

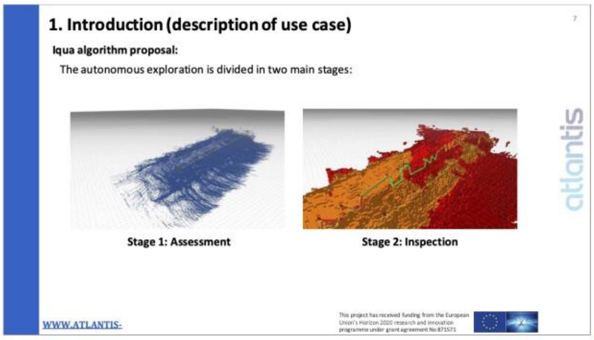


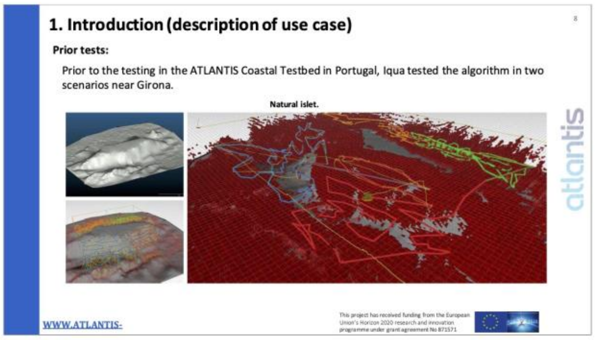












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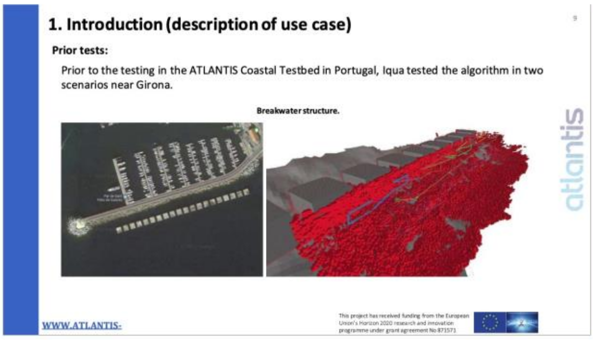

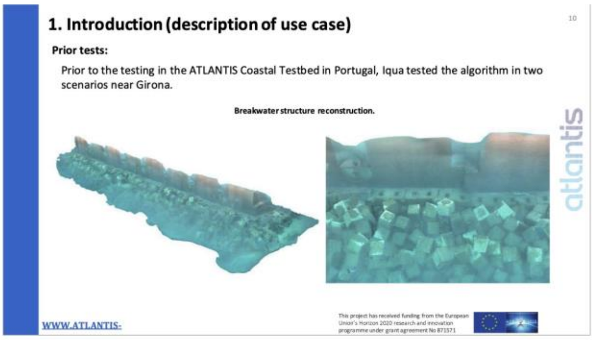

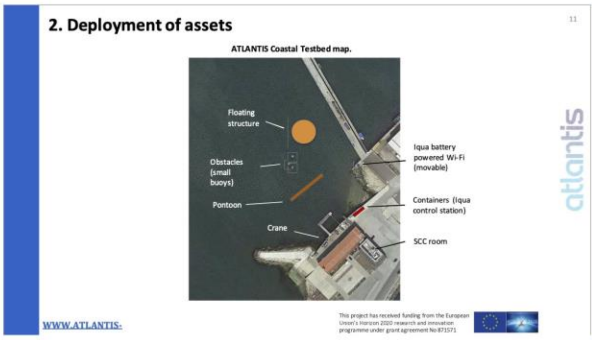

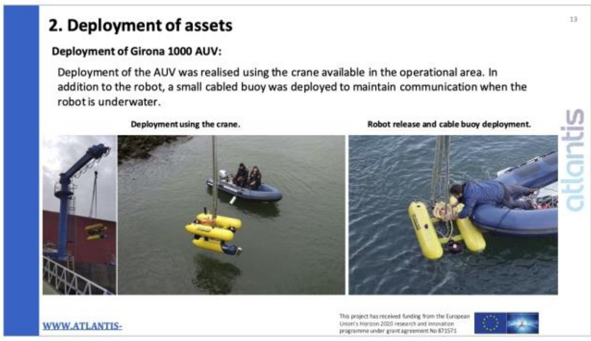

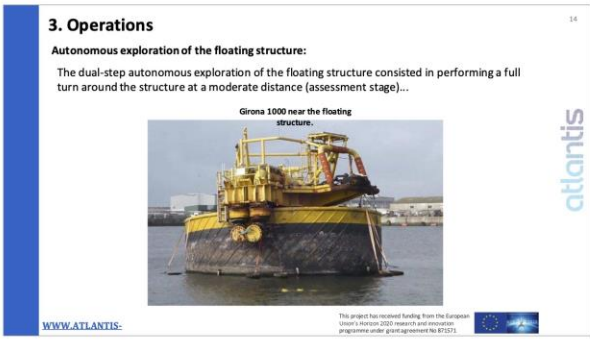

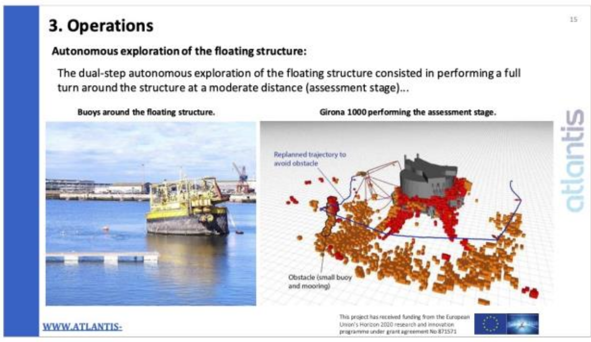

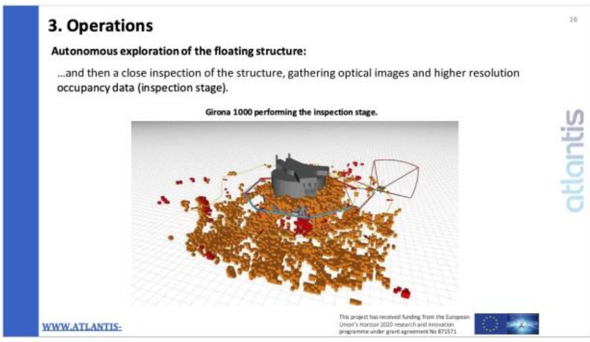

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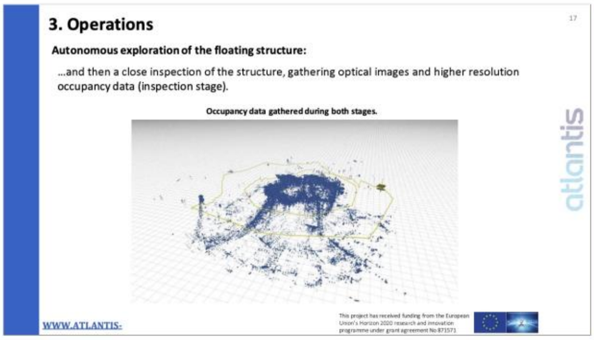

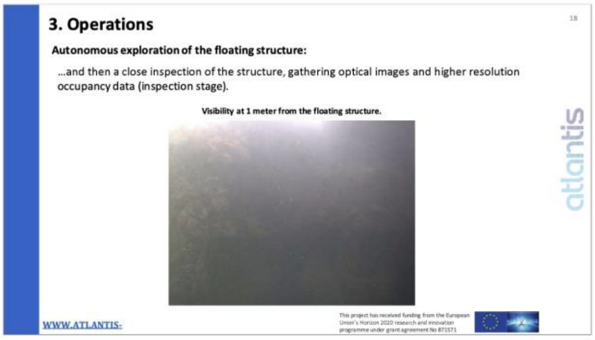

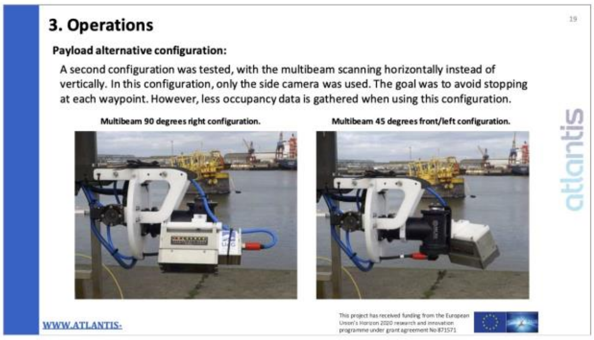

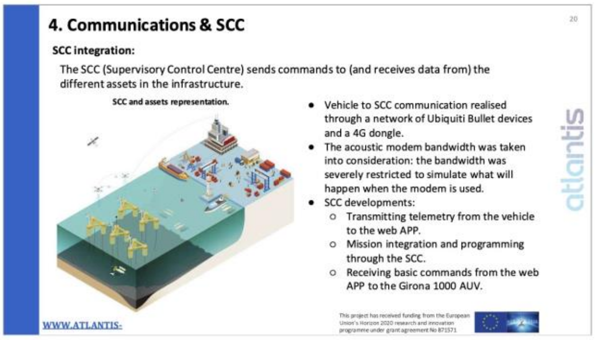

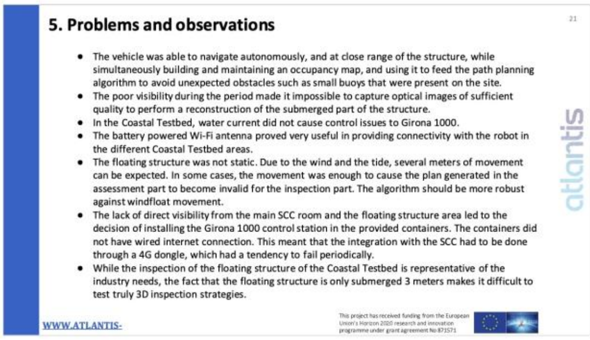

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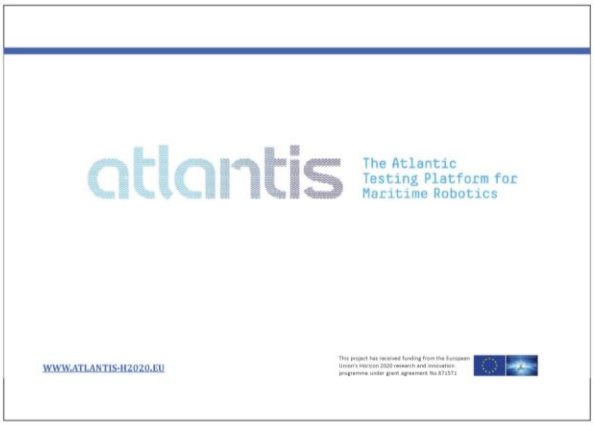
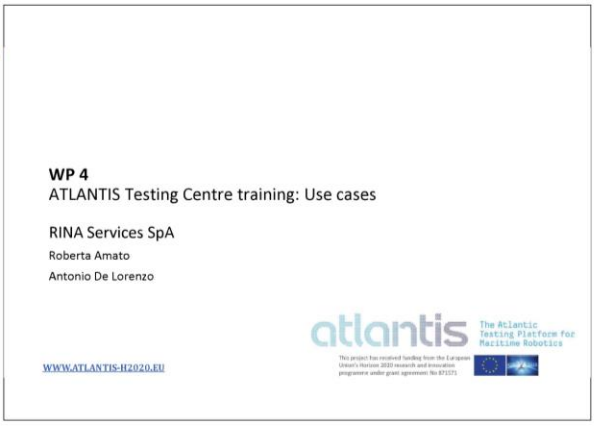
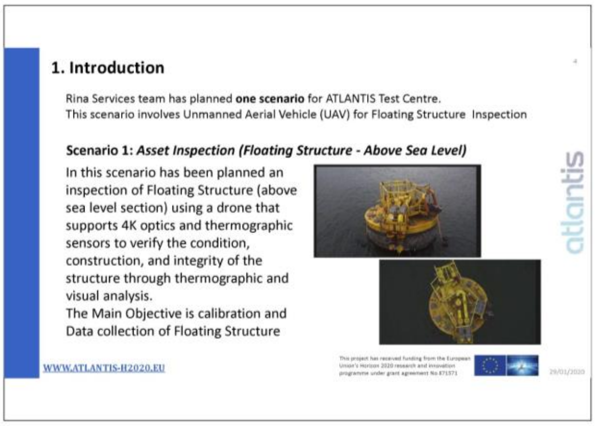
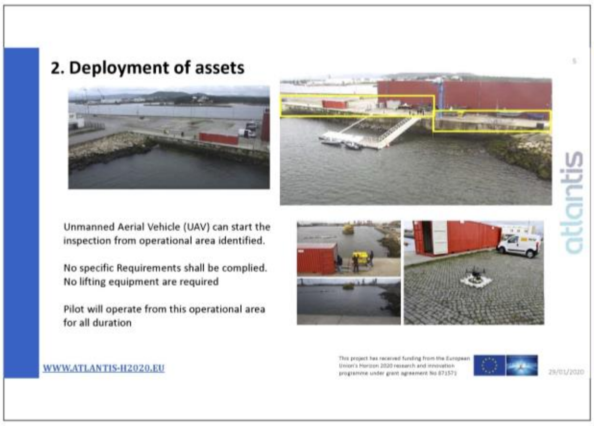
5.5. Use cases: RINA









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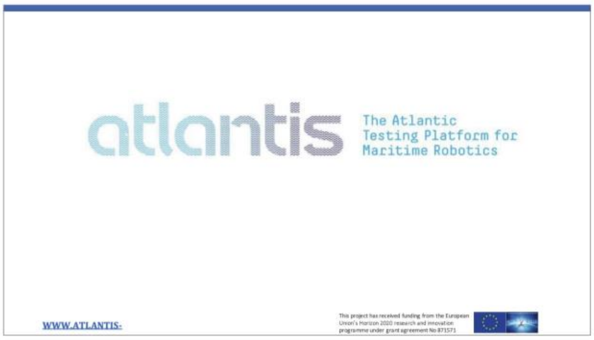
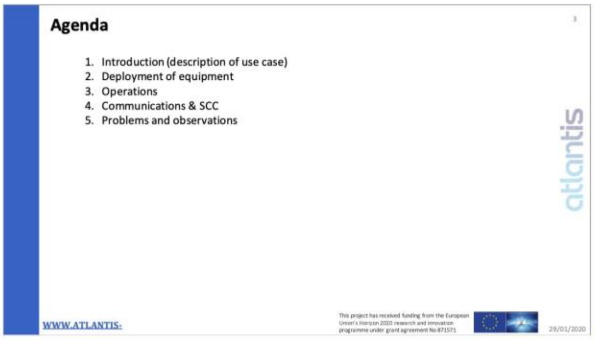
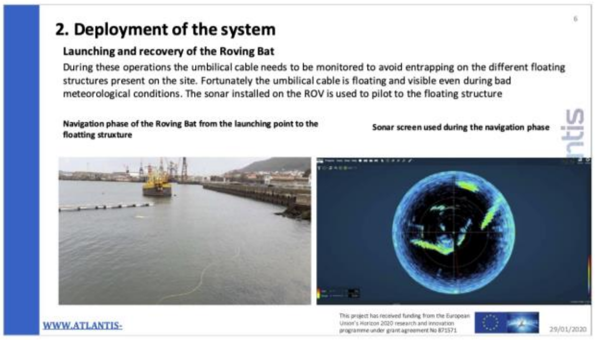
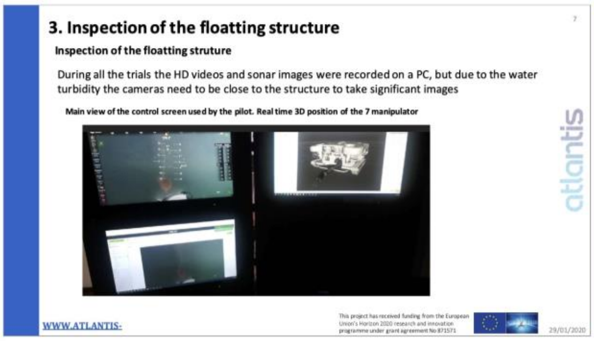
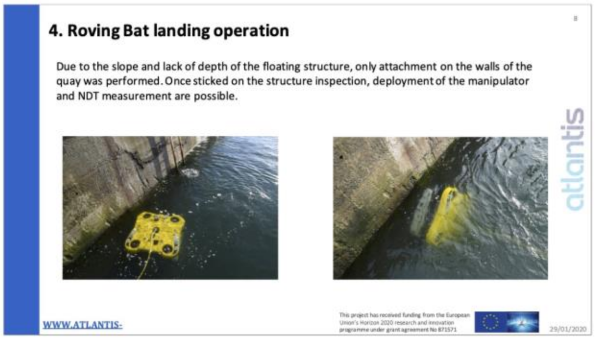
5.6. Use cases: ECA











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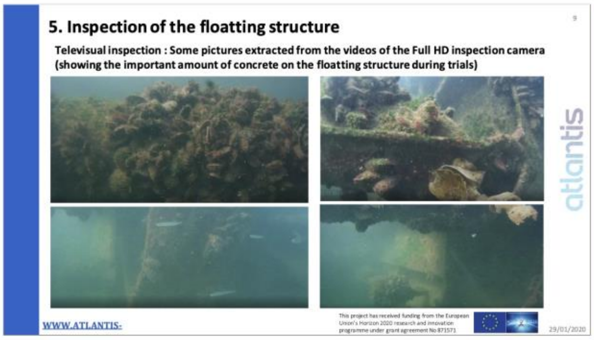

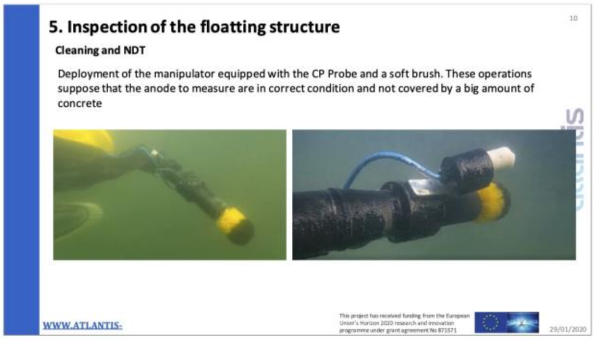

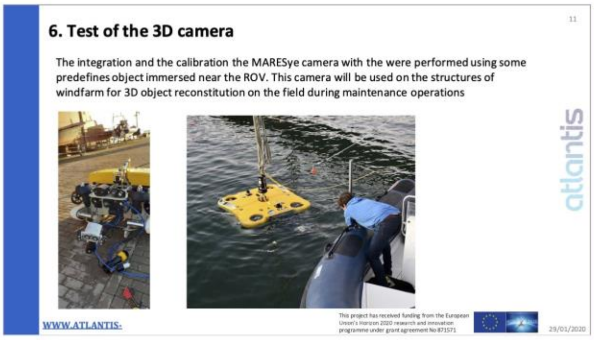

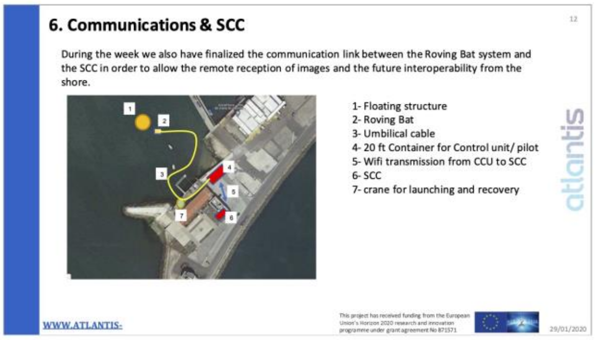

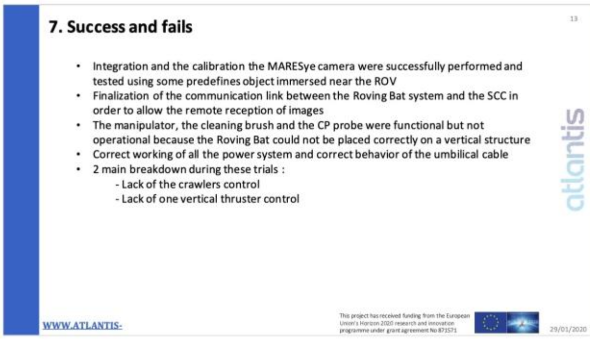

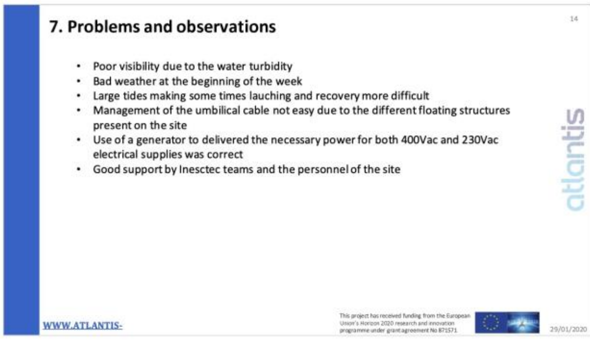

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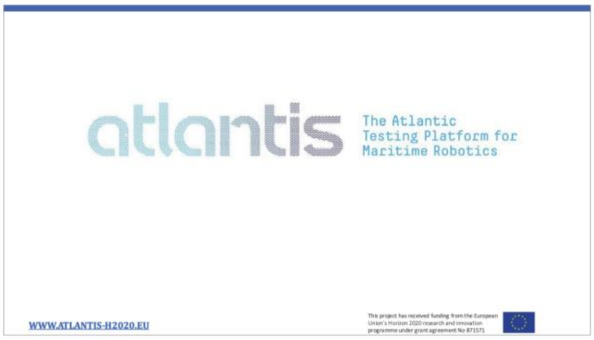
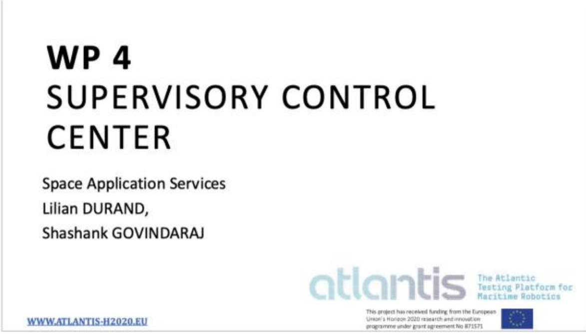
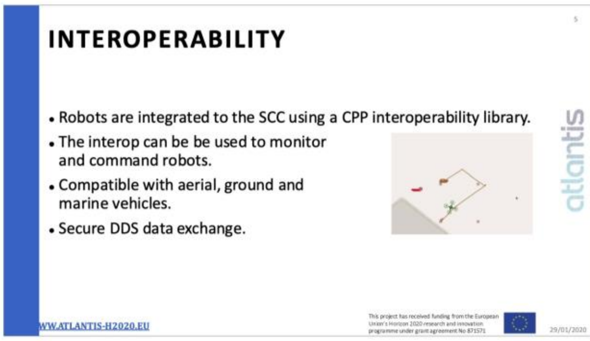
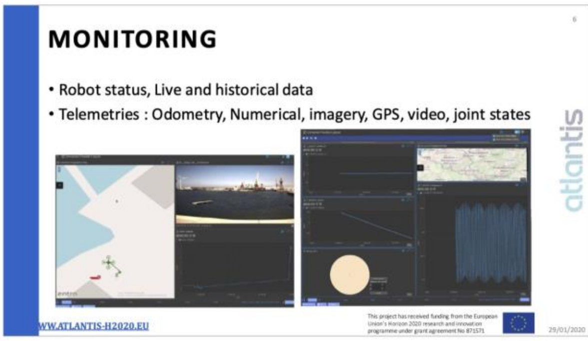
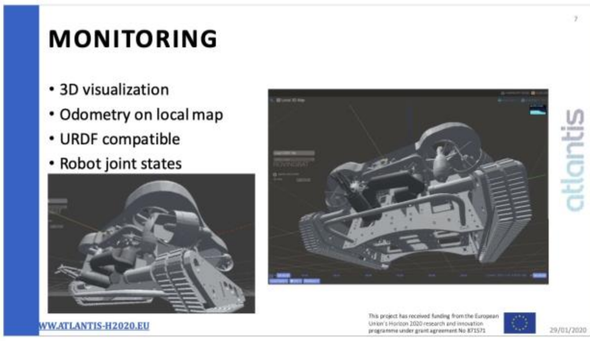
5.7. Supporting technologies: SCC (SpaceApps)

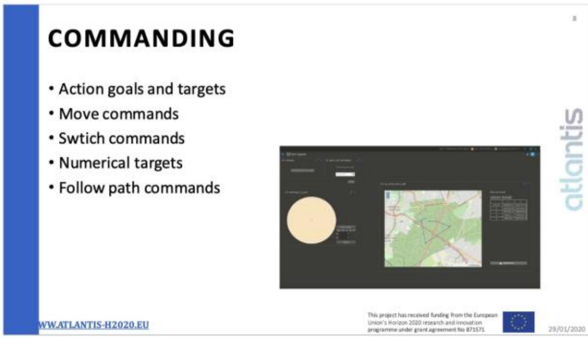












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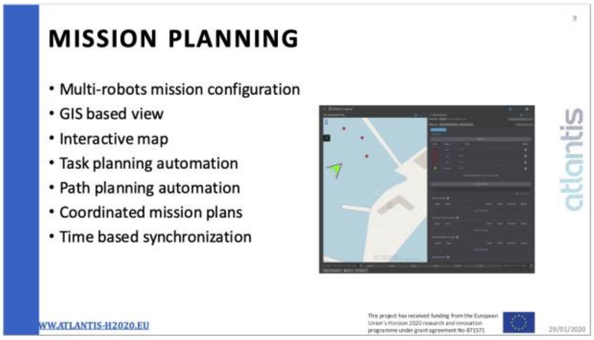

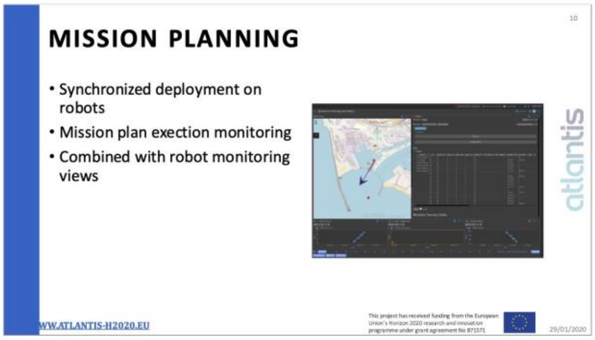

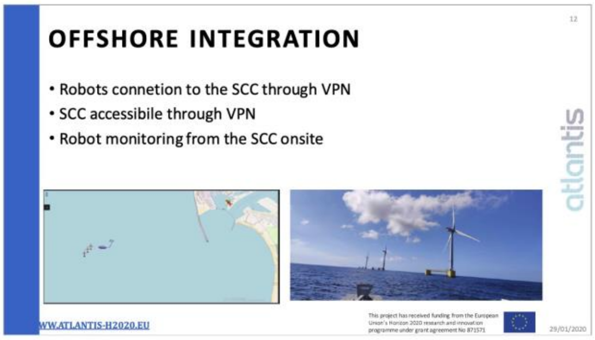

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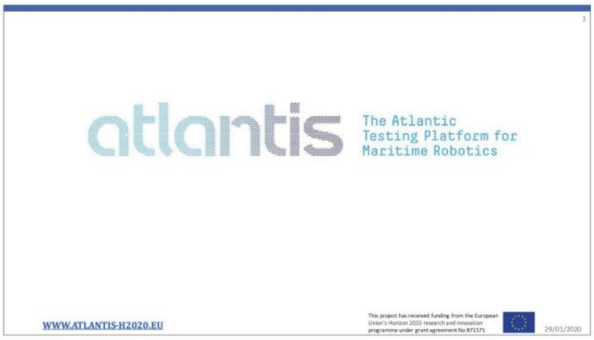
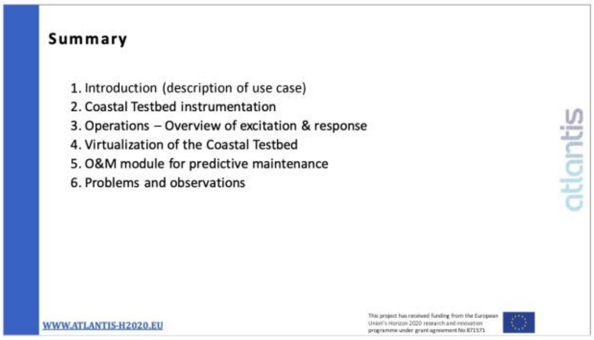
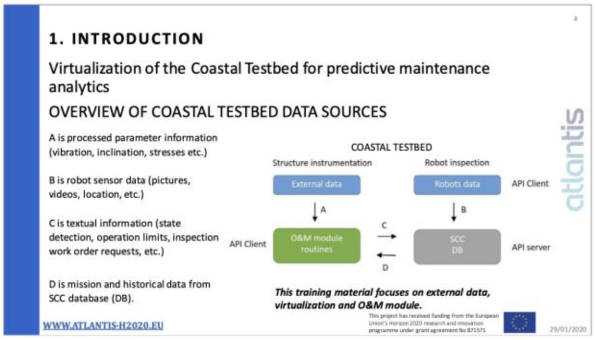
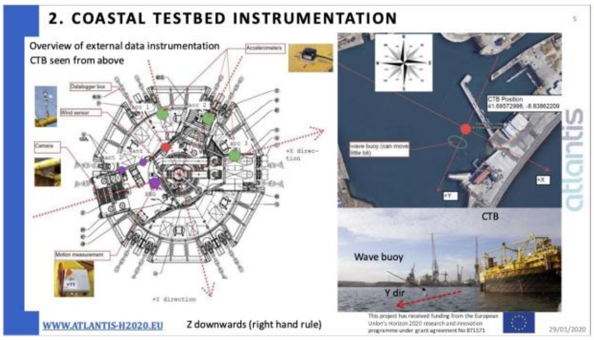
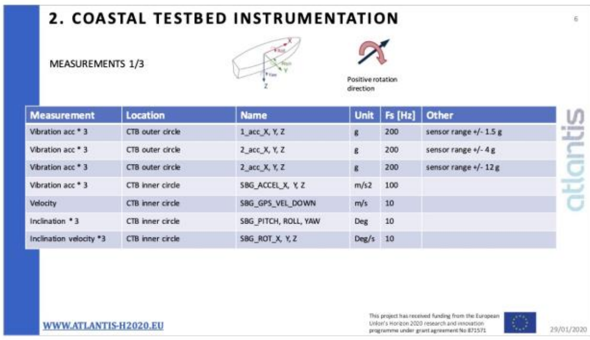
5.8. Supporting technologies: Buoy sensor system (VTT)



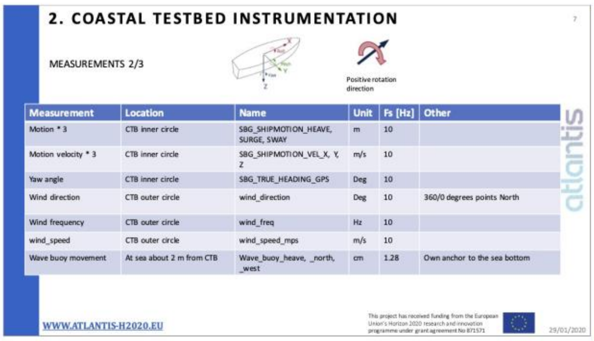




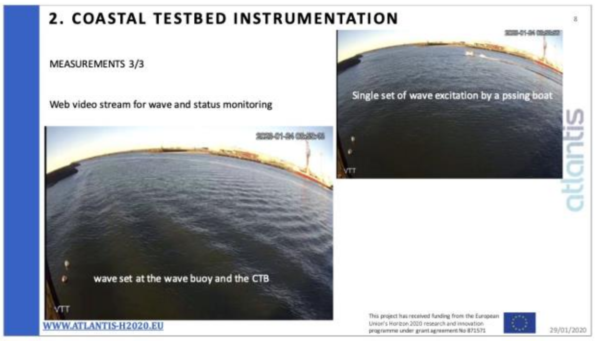




Measurement	Location	Name	Unit	Fs [Hz]	Other
Vibration acc * 3	CTB outer circle	1_acc_X, Y, Z	g	200	sensor range +/- 1.5 g
Vibration acc * 3	CTB outer circle	2_acc_X, Y, Z	g	200	sensor range +/- 4 g
Vibration acc * 3	CTB outer circle	2_acc_X, Y, Z	g	200	sensor range +/- 12 g
Vibration acc * 3	CTB inner circle	SBG_ACCEL_X, Y, Z	m/s2	100	
Velocity	CTB inner circle	SBG_GPS_VEL_DOWN	m/s	10	
Inclination * 3	CTB inner circle	SBG_PITCH, ROLL, YAW	Deg	10	
Inclination velocity *3	CTB inner circle	SBG_ROT_X, Y, Z	Deg/s	10	



Measurement	Location	Name	Unit	Fs [Hz]	Other
Motion * 3	CTB inner circle	SBG_SHIPMOTION_HEAVE, SURGE, SWAY	m	10	
Motion velocity * 3	CTB inner circle	SBG_SHIPMOTION_VEL_X, Y, Z	m/s	10	
Yaw angle	CTB inner circle	SBG_TRUE_HEADING_GPS	Deg	10	
Wind direction	CTB outer circle	wind_direction	Deg	10	360/0 degrees points North
Wind frequency	CTB outer circle	wind_freq	Hz	10	
wind_speed	CTB outer circle	wind_speed_mps	m/s	10	
Wave buoy movement	At sea about 2 m from CTB	Wave_buoy_heave, _north, _west	cm	1.28	Own anchor to the sea bottom



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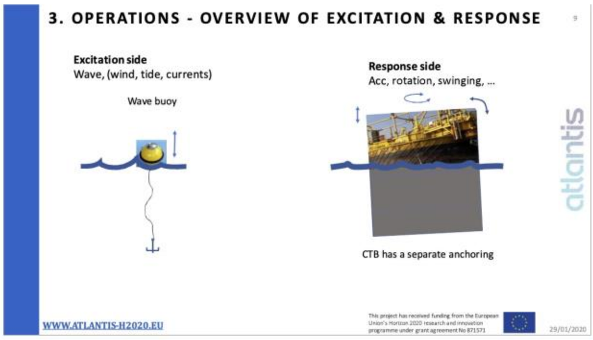

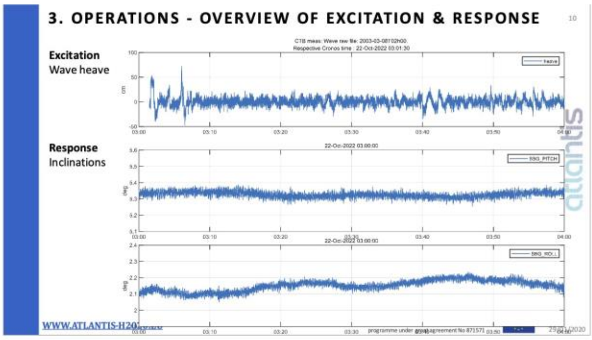

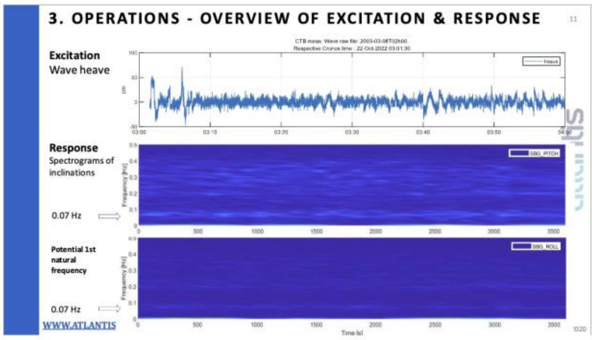

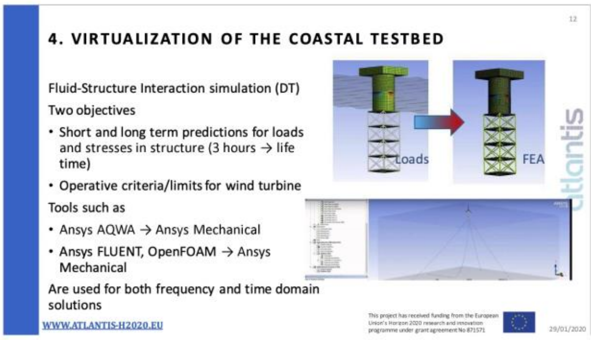

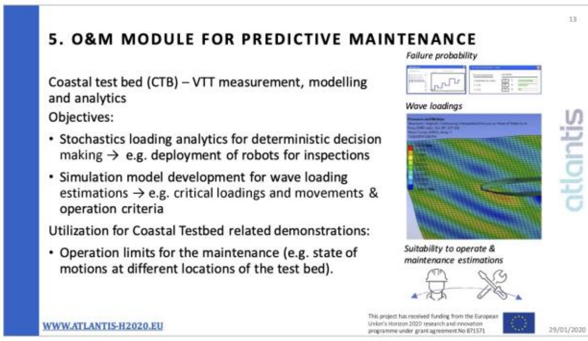

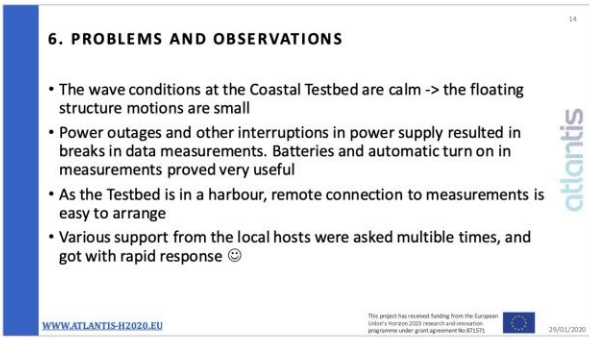

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